auto-carto II

proceedings
of the
international symposium on computer-assisted cartography

September 21-25, 1975

INTERNATIONAL SYMPOSIUM
On
COMPUTER-ASSISTED CARTOGRAPHY
(AUTO-CARTO II)

This second conference on automation in cartography was sponsored by the American Congress on Surveying and Mapping in cooperation with the U.S. Bureau of the Census. WILLIAM B. OVERSTREET, President of the American Congress on Surveying and Mapping, and VINCENT P. BARABBA, Director of the Bureau of the Census, had official responsibility for the conference and coordinated activities between the two organizations. Chairman of the Conference was ROBERT T. AANGEENBRUG, former visiting scholar at the Bureau of the Census from the Department of Geography of the University of Kansas. Executive Secretary for the conference was JOHN C. KAVALIUNAS of the Center for Census Use Studies, U.S. Bureau of the Census. Special appreciation is given to the following Census Bureau staff for their assistance during the Symposium: ANN CASEY (Data User Services Division), MARIE DOOMS (Center for Census Use Studies), MICHAEL GLASCOE (Center for Census Use Studies), and SHARON GONGWER JOHNS (Center for Census Use Studies).

The Symposium Proceedings were compiled and edited by JOHN KAVALIUNAS. FREDERICK BROOME of the Geography Division of the Bureau of the Census served as technical reviewer.

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U.S. Department of Commerce
BUREAU OF THE CENSUS

American Congress on Survey and Mapping
Cartography Division

FOREWORD

This is the second conference on automation in cartography sponsored by the American Congress on Surveying and Mapping. Auto-Carto I, held in Reston, Virginia, December 9-12, 1974, set the precedent for the international discussions continued at this symposium.

In the spring of 1974 Vincent Barabba, Director of the Bureau of the Census, and I attended professional meetings where great interest was expressed in the Urban Atlas map series produced by the Bureau. Discussion focused on the quality of these maps as well as their impact on the various users. Mr. Barabba believed that further discussions and an exchange of information about basic methodology, applications problems, and software and hardware in the field of computer-assisted cartography would be useful. He provided me with excellent staff and support from the Bureau of the Census which enabled me to organize a symposium to meet these objectives.

Dean Edson, Auto-Carto I Conference Chairman, lent enthusiastic support as well as useful guidance for the symposium. Warren Schmidt assisted by directing me to numerous programs and individuals involved in the week's activities. Bernard Schechter, Chairman of the Cartography Division of ACSM, provided program advice and practical suggestions on the numerous details one often overlooks in putting a final program together. Robert Herndon, ACSM's Executive Director, was invaluable as the man behind, as well as in front of, the logistic scenes. The entire symposium staff benefitted from his exceptional patience and extensive experience.

Thomas Peucker deserves much credit for encouraging a rather ambitious program. Both he and Arthur Robinson offered more suggestions than I could accommodate and together with Bernard Schechter, Waldo Tobler, George Jenks, Fred Broome, and the numerous speakers and chairpersons they deserve credit for the final program format and the resulting symposium message.

The extensive support services provided by the Bureau of the Census cannot be properly credited in a brief foreword. A list of the Census Bureau staff that assisted in pre-conference planning, registration, making local arrangements, and compiling the conference proceedings is found in the appendix. A list of acknowledgements, however, does not reflect due credit for the work of the conference Executive Secretary, who, in addition to providing logistic support, assembled and edited our proceedings. Let us hope that another John Kavaliunas will be available for Auto-Carto III.

A further note of appreciation is extended to the United States Geological Survey, the Defense Mapping Agency, and the University of Kansas for their invaluable help and cooperation.

Any compliments concerning this conference should be directed to those I have named here, and any criticisms should be directed to me so that future meetings of this type may benefit.

ROBERT T. AANGEENBRUG
Conference Chairman

PREFACE

The technical articles contained in these proceedings were assembled from papers submitted by the authors. Editorial changes were kept to a minimum. In some cases, complete papers and/or illustrations or other displays used by the speakers were not furnished; therefore, these proceedings should not be considered a complete record of the symposium.

A summary of each seminar, including abstracts of the papers, is provided at the beginning of each section. An author index and participants' list are included in the appendix.

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OPENING REMARKS

Robert T. Aangeenbrug
Conference Chairman

Good morning. This symposium's purpose is to promote an exchange of information about basic methodology, application problems, and software and hardware in the field of computer-assisted cartography. Our last conference (Auto-Carto I) provided extensive discussions which highlighted technical progress in this area. At this conference we will add presentations which explore the impact of automation on the map reader. The capacity of cartography to keep up with technical-mechanical production of maps, often by non-cartographers, raises many issues for producers and readers alike. Vincent Barabba and Arthur Robinson represent two important approaches to serving our society's needs for information, a Federal agency's need to communicate to the public and a scholar's concern with a process of decisionmaking practiced by cartographers.

Our staff and this facility provide the setting. Our speakers, panelists and you, the participants, will make this a successful symposium. Thank you for coming. Let us get started.

The American Congress on Surveying and Mapping, our sponsor, provides us with our first speaker. This distinguished gentleman needs no further introduction. Ladies and gentlemen, Mr. William B. Overstreet, President of the American Congress on Surveying and Mapping.

CHARGE TO THE CONFERENCE

William B. Overstreet
President, American Congress on Surveying and Mapping

It is with pleasure that I greet you at this the opening of the Second Conference on Automation in Cartography, co-sponsored by the Bureau of the Census and the American Congress on Surveying and Mapping. Those of us associated with the first conference were pleased with the results -- both from a technical and an attendance standpoint. Certainly on the basis of your program content and speakers, Auto-Carto II should exceed the success of the December 1974 meeting. I believe that it is most appropriate that this meeting be co-hosted by the Bureau of the Census and ACSM. As a collector of such an enormous amount of data, it is important that we translate this digital data into a graphic medium as clearly and timely as possible if it is to be of value to the users of the type of information serviced by the Bureau of the Census.

I can think of the following more specific reasons for automation:

- To speed up the process of map making.
- To improve the economics of mapping.
- To generate digital data for direct dissemination, and for rapid manipulation to produce, with a minimum of effort, maps at different scales and with selected contents.
- To facilitate revision and updating of maps.
- To reduce the incidence of errors.

It seems to me that any one of the cited reasons, if valid, is sufficient to justify automation, but when combined, the case becomes overwhelming. The relative importance of these reasons will vary among map makers and users, but the order in which I have given them is my particular priority.

TO IMPROVE THE ECONOMICS OF MAPPING

In these days of spiraling costs, economy of operation is an attribute dear to everyone's heart, and a real prime mover toward implementing automated techniques. Not too many years ago, when people presented papers on the subject of automation, they avoided the cost effectiveness factor like the plague. Today, it is a different scene -- equipment effectiveness is rising with speeds ever increasing to the point where, in spite of inflation in hardware and software costs, new techniques are truly competitive. Despite continued higher costs of equipment and manpower, due largely to inflation, overall mapping costs have not risen because of increased efficiency.

A major advantage of cartographic data in digital form is the convenient interface with other geographically related information and management systems. Such interfaces provide a means for numerical data in machine-readable form to be utilized in complex modeling and problem analysis. Examples of the type of data required for various systems include: positions and elevations of manmade or natural features, transportation routes, lakes, streams, shorelines, slopes of terrain, land use, cadastral and political boundaries, population distribution, soils, geology, hydrology, and flood-prone areas. When these data are digitized, the end product can be in a variety of forms and at any scale.

It is reasonable to assume that nearly everything that is constructed by man is known at some level of government. We, therefore, must strive harder to seek ways of accessing local government data in an effort to achieve the goal of "best information for the least possible cost."

Another advantage of digital data is that it can be rapidly manipulated to produce, with a minimum of effort, maps at different scales and with selected contents. In the past, cartographers have mapped specific areas of interest at a scale commensurate with the unit in use that best satisfied the average map user requirements. As such, the level of content was, of necessity, limited by the scale selected. Past technology has also condemned the end product to be a hard copy at a single scale with limited and generalized content.

Far too often users have found it necessary to produce their own maps because of their need for specific content or particular scale. Often the scale of the general maps can be changed by use of a copy camera to the desired scale, but the content must be treated separately and manually. These analog processes are sometimes expensive and limited by optical or mechanical constraints. Today, automated techniques in cartography can be applied to develop new and different forms of presentation.

TO REDUCE THE INCIDENCE OF ERRORS

To produce an absolutely perfect map or chart must surely be every cartographer's dream. We have always accepted this dream or goal as being unattainable. Additionally, the degree of perfection or tolerable amount of error is tied closely to economics.

Automated cartographic techniques may help us on both ends -- providing a more reliable and complete product at lower cost.

While accuracy is normally limited by the inherent capability of the various machines utilized, reliability and completeness are a function of costs and human judgment.

Each phase of mapping that can be removed from the frailties of human judgment and be automated is likely to become more error free.

CONCLUSION

Summing up, the introduction of automated procedures to map making and map maintenance presents a whole array of opportunities to improve the cartographer's art. It can eliminate vast amounts of tedious work, and cut years off the time presently required to produce new maps. It can be the means for timely updating of existing maps. It can permit the cartographer to be much more responsive to the demands of map users for special content or particular scales. It can be the means for obtaining access to large amounts of existing data which are not now effectively used because under present methods of data gathering and accession, they cannot economically be assimilated in the map maker's data base. And it can do all these things faster, better, and with less cost and less chance for error than they are now being done. The use of automated techniques in cartography can be likened to "letting the genie out of the cartographic bottle" -- releasing a giant slave whose services may be utilized almost at will.

Automation in cartography is a real challenge to our creativity. The results of our creativity reflect on all fields -- social, economic, communications, planning, decision-making, and organizing our activities. These are but a few examples of the challenge to the cartographer and we can multiply these challenges many times if we were to include the full spectrum related to the need to develop energy, minerals, and food supplies for the future and to maintain the quality of our environment.

If we accept uncertainty as a part of our future, then we must pursue vigorously imaginative action in those directions in which there appears to be promising solutions. Obviously, automation in cartography is one area that we need to pursue vigorously with our creative minds. We have only touched the surface in the conversion of statistical data to map form. It is my sincere hope that we will return from this meeting with a better understanding and application of this dynamic process in cartography.

On behalf of ACSM and the U. S. Geological Survey, I hope that you have a most productive meeting, and if there is anything that I can do for you, please let me know -- I will let the Bureau of the Census speak for themselves. Thank you, and the very best to you in your meetings this week.

WELCOMING REMARKS

Vincent P. Barabba
Director, U.S. Bureau of the Census

On behalf of the Bureau of the Census, I would like to welcome you to this International Symposium on Computer-Assisted Cartography. We are pleased to cooperate with the American Congress on Surveying and Mapping in cosponsoring this second conference on automation in cartography. Hopefully, it is the beginning of a long and fruitful association.

A real problem at the Bureau of the Census is how to communicate the large volume of information that we gather, not just every ten years, but every month. How can we make these data more meaningful, more useful, more easily understandable to you -- the data user? It is my strong belief that we must develop graphic techniques which complement our existing data formats by summarizing data efficiently and accurately.

We at the Bureau are excited about our cartographic programs and activities. The Urban Atlas series, presenting information from the 1970 census for major metropolitan areas, is the latest in a long line of developments in the field of data display. I encourage you to view the displays in the Census Bureau exhibit room and give us the benefit of your experiences. Your comments will help us improve the geographic and cartographic support of census operations.

We hope to have a frank and open interchange of ideas and information during the week. We believe that we have something to contribute to this Symposium, and we know that you have much to contribute from your varied experiences in the university, in private enterprise, and at the Federal, State, and local levels of government. We welcome your active participation in the plenary sessions and at the seminars, and we look forward to a continuing dialogue with you following the conference.

Editor's Note: Morton A. Meyer, Chief of the Census Bureau's Geography Division, delivered the welcoming remarks on behalf of Mr. Barabba.

MAP DESIGN

Arthur H. Robinson
University of Wisconsin

INTRODUCTION

The basic philosophy toward map design derives from the fact that designing is a decision making process. The cartographer is essentially an engineer attempting to construct a visual device which will effectively communicate geographical information to a percipient. The perception of a graphic display is a total reaction quite unlike sequential oral and written language. The construction materials for a map are the visual variables and he must know the perceptual consequences of their variation. The cartographer must analyse the purpose and the audience of a map with care, make his presentation as simple or possible, and be entirely concerned with the percipient.

MAP DESIGN

I shall begin by reminiscing, and I have a reason for being personal. Last spring, when I was asked to talk to you on the subject of map design, the combination of autumn in Washington, D.C. and a paper on map design seemed vaguely familiar. Long after I had prepared my remarks for this morning, I dug around in some old files, and what had lurked in the back of my mind turned out to be a paper delivered to the then newly formed Washington Geographers Club 33 years ago next Monday night. The title of that paper was "Design as a Technical Problem in Map Making."[1] Some of it is rather apt even now. Quoting from one's self is usually an indication of an inflexible attitude, an unhealthy state for a scholar, but on this subject I have not changed my opinion.

> "The designing of maps has received little or no ordered examination, yet I know of no phase of cartography which is in greater need of study. In this emergency of wartime many directives are being presented pleading for

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EDITOR'S NOTE: Professor Robinson served as honarary co-chairman of the Auto-Carto II Symposium. Currently president of the International Cartographic Association, the author received the Ph.D. from Ohio State University in 1947. During World War II he directed the Map Division, OSS. At the University of Wisconsin since 1946, he is past director of the Cartographic Laboratory and is Lawrence Martin Professor of Cartography. He is the author of The Look of Maps, co-author of Elements of Cartography, and has published numerous scholarly papers. A former president of the Association of American Geographers, he is a life member of ACSM. Former chairman, Cartography Division, he is currently editor of The American Cartographer.

> brief, clear, concise reports. Speed is of vital importance. Unfortunately, in the field of cartography speed has been analyzed primarily from the production viewpoint. However, speed of consumption is just as important in the presentation of intelligence data. No busy intellegence officer, strategic adviser, or economic analyst appreciates a product requiring more consumption time than is warranted in relation to the value of the information. The depiction of economic-geographic data becomes therefore a problem of visual design. Speed of consumption is dependent upon good design, and when the final word is said concerning any map, it has served its purpose only if it has been well presented and well designed. The cartographer should think of himself as a kind of salesman of a visual product, the virtues of which should be quickly comprehended and easily retained."

Now let me jump ahead 33 years. Just a week ago I attended an International Symposium on Communication in Cartography held in London to which a variety of specialists contributed. Sometimes it helps to see ourselves as others see us. (When one does, -- and I can't resist the pun, sometimes one gets Burned!) The following is a case in point. A psychologist opened his paper on the legibility of relief maps with some observations on the competence of cartographers in communication.2/ He began with an analogy.

He asked his listeners to picture a man who had the job of designing an automobile, but for some reason he had no technical data available to him. The designer knew what an automobile was, of course, but he had no data on how the car worked with particular engines, or the adaptability of the car, its aerodynamics, etc. The psychologist further observed that the unhappy engineer had no idea who might purchase the car or the kind of individual who would drive the car or on what kinds of roads the car would be driven. He suggested that, although this might seem to be a "ludicrous picture," it seemed to him to be almost the norm for designing a map. He asserted that most cartographers seem to design their maps without any understanding of who the users will be, where, when and how the users will read the map and without much technical information about the way the map design may affect the users efficiency.

My reaction was that the psychologist was overly harsh. We cartographers have learned a good deal in the past 30 years, but perhaps we haven't spread the gospel as well as we could. It might help if we had among us a kind of cartographic Billy Graham, or if we were to open each technical meeting with a rousing rendition of some cartographic spiritual. Two appropriate titles come to mind!

"Nobody Knows the Trouble We've Got with Double Color Coding"
"From Out of the Ground the Figure will Rise"

There is no way, of course, that we can cover completely the complex subject of map design in the short time available this morning. Instead, I propose to present what appear to me to be the basic elements of an essential philosophy toward map design. Some 20 minutes ordinarily would not be enough to develop and justify a philosophical point of view. Fortunately, however, there is, I think, general agreement on a good many matters having to do with map design, which in itself is a mark of progress, and I need not waste much space on them. It is also necessary to narrow the scope since the general term 'design' is very broad and 'map' now seems to include everything from the tactile maps of John Sherman to the perspective views of a statistical surface available through a plotter or a CRT. Although my general remarks will refer to all kinds of design activity, I will stress the graphic component. Furthermore, I will focus primarily on design in thematic cartography.

Because it will help to emphasize an important point about map design I would like to face the question of what it is about a map that makes it a thematic map. Thematic maps are usually contrasted with general maps, and there is no question that general maps, such a topographic and atlas reference maps, are quite different things than thematic maps. Barbara Petchenik and I have considered the theoretical foundations of this at some length, and we are prepared to argue the position that fundamentally, a general map attempts to present simultaneously a set of diverse phenomena about some area, while a thematic maps tries to portray the *structural characteristics* of some particular geographical distribution, such as population density, freight rates, or bedrock geology.[3] These are fundamentally very different objectives. Because a map is concerned primarily with one topic, such as soils or vegetation, does not make it a thematic map. There are a great many such maps which fall in the general class. The pure general map and the pure thematic map lie at the ends of a theoretical continuum. Of course, many maps combine some of the characteristics of each class. Often this is intentional and appropriate. But very often it happens because the cartographer was fuzzy about his objective and was designing intuitively. Map design is fundamentally a decision making process, and decisions are more likely to be good if they are rational rather than intuitive.

Since I am already sounding like a preacher it is appropriate that I have a text. Since the subject is map design, it is also appropriate that the text be cartographic. As a text, then, I would like to show you three maps, partly because they illustrate a basic theme in my remarks and partly because I think this audience will find them intrinsically interesting.

The first map, so far as we now know, is the first printed choropleth map. It was made by Baron Charles Dupin and appeared in 1827.[4] He employed a manuscript version in an address to the *Conservatoire des arts et metiers* in Paris in November 1826 on the general subject of popular education and its relation to the prosperity of France. The map has many points of historic and cartographic interest; although that is not our concern here, let me point out a few. The statistic in each *departement* is masculine chauvinistic and curious. It is derived by dividing the total population of the *departement* by the number of male children in school. The smaller the figure presumably the more enlightened the population and the lighter the tone. The tones, which were obtained by lithographic engraving, were intended to correspond exactly with the statistics, that is, they were not grouped or classed. As you can readily see, the cartographer made a poor choice of technique because the engraver did not have control of this medium. Today, choropleth maps without class intervals can be produced by automation, as Waldo Tobler has shown.[5] Whether it is a good thing to do is an appropriate question.

The second map is one on the very same subject published in 1832 by Adolph Quetelet, the great Belgian statistician.[6] Quetelet specifically did not like the choropleth technique Dupin had used (devised?), and he conceived this alternative method which he hoped would more effectively show the structure of the distribution. Although it has the appearance of being a shaded relief map of a statistical surface, it is not that at all. The best way to characterize it in terms of present techniques is that it is a sort of continuous tone dot map. Again, the lithographer did not have control over his medium, crayon shading, and the map came out much too dark. A more successful attempt using the same technique on another subject, incidence of crimes against persons, is another of Quetelet's maps published a year earlier in 1831.[7] These are just two of many possible ways of mapping these kinds of data.

The cartographic text to be derived from these early statistical thematic maps may be summarized in two assertions:

1. The map designer is in charge and he must control his media. If a map is a disaster it is not the technician's fault; it is the designer's.
2. In most instances the designer has a great variety of options, not only on the symbolic system to use but on a whole host of subsidiary graphic elements.

Now that we have put the responsibility for all the decision making squarely on the cartographer, let us look more in detail at the various aspects of map design.

It is helpful to define design, and I like the definition by J.F. Blumrich.8/ Shortened and paraphrased a bit it is:

> "Design develops solutions to and structures for problems not solved before or new solutions to problems which have previously been solved a different way."

There are two key elements in that definition. One is the implication that it is likely that there is more than one solution. It is imperative that a designer keep his imagination active. The second, and the most important point, is that the designer, in the sense we are using the term, is faced with solving a problem. In that sense the cartographer is clearly an engineer. Just as no engineer can erect a proper structure or solve any other problem unless he knows what the function of the structure or the nature of the problem is, the map designer cannot possibly solve his design problem unless he has carefully settled on the purpose of the map he is going to design. Careful attention to the communicative aspects of the map, including an assessment of its audience, and appraisal of all the technical capabilities available for its production are primary components of the cartographic problem. When these are clearly defined, only then can the cartographer make decisions rationally.

It is difficult to focus specifically on some of the more general aspects of map design because they are all interwoven. To consider objective without considering the audience is to leave out an important element, but in order to examine the process we must stand off and look at various parts. Let us look at a number of these components in a little more detail, and in the manner of a good preacher I will offer a few comments and perhaps a few precepts.

Settling on a purpose requires considerable analysis of the functional context of the map. Is the map to be studied in a textbook for various reasons or is it simply to make clear to a selected audience the basic structural character of a geographical distribution that would not be apparent if the data were only made available in tabular form? Is the map to show the detailed complexities of the configuration of a distribution (thematic) or is it to provide only a suggestion of form along with geographically located numerical information (general)? All the pros and cons of all the possibilities must be assembled; it is not easy, but it is absolutely essential to good design. If one doesn't know exactly what one is trying to do, it will only be by chance that a particular purpose will be accomplished.

The primary objective of any map is, of course, to communicate. To be sure, even today there are maps which are mainly aesthetic in that their decorative character is a paramount. This aspect of cartography was more important in past time than today, but in any case, things aesthetic lie largely in the domain of intuition and in most instances cannot be approached rationally. Since most cartographers have had little familiarity with the graphic arts, I think it is safe to say that most mapmakers are better advised to approach map design rationally rather than intuitively.

The main idea behind the communication objective is to evoke in the mind of the percipient or map viewer an understanding of the geographical relationships attending the distribution being mapped.9/ Just how this can be done is a very complex question to which we are just beginning to learn the answers. Even though we do not know in detail the nature of the perceptual processes involved in communicating about the geographical milieu, some things are clear.

The perception of a graphic display in two or three dimensions is entirely different from the communication accomplished verbally or by the written word. Unlike oral or written communications which come to us in a given sequence, a graphic display appears to us as a unified structure with a total meaning rather than as a summation of its different parts. This means the cartographer must go about much of his graphic designing in a way that is likely to be rather foreign to him. Some aspects are not unfamiliar. For example, there is a good deal of analytical thinking involved in settling on the purpose of a map and in choosing the particular symbolic system to be used. Most cartographers are comfortable with this aspect because they come to mapmaking from scholarly backgrounds where systematic analysis and synthesis are normal patterns of thinking. On the other hand; in the graphic arts the totality of impression is the primary objective, and most cartographers have not been trained to cogitate in this manner. Perhaps, this is why some of the maps made by artists in slick magazines look so different and are often so much more interesting than many of ours.

For communication to occur we need to be able to predict the perceptual consequences of the way we use the marks we put on a map. I refer to the "visual variables," a term introduced by Jacques Bertin. Basically, the mapmaker has available to him a set of marks which can be varied in graphically distinct fashion. Bertin lists six in addition to the two dimensions of the map space: shape, size, value (tone), pattern, color, direction, location.10/ Psychologists for a long time, and cartographers more recently, have been investigating the psychophysical dimensions of these visual variables. In some instances we can come quite close to predicting responses to the varying stimuli, as for example, in the tones of equal value scale, the equating of some symbol shapes, responses to circle size, and so on. There are a great many more, especially in the area of color, which are less well known. We do know a surprising amount, however, and as more studies in perception are made, in other fields as well as cartography, we will be more and more able to manipulate skillfully the visual variables in order to attain the communication objective.

One problem in settling on the purpose and audience is the question of how much variation in use to allow for. Some mapmakers appear to be overly concerned that someone may use a map in ways other than for the specific purpose it was made. In consequence a variety of things are often added to provide for the possible desires of what we can call a secondary audience. I refer to such things as geographical detail, additional place names, boundaries, transportation routes, graticule, etc. Generally speaking I think this is a mistake; a thematic map is best when it is straightforward and to the point. Singleness of purpose in thematic cartography seems to correspond to simplicity in art. As pointed out by Arnheim 11/ simplicity seems generally to be a virtue in artistic design, and Blumrich assumes it to be desirable in engineering.

It is fitting to bring these remarks on map design to a close with an observation which at first seems not at all creative. In his esthetic analysis of works of art, Helmholz pointed out that although beauty is subject to laws and rules, the laws and rules are not consciously present either in the mind of the artist or the observer.12/ He goes on to say that a work of art ought to have the appearance of being undesigned. Similarly, if a percipient looks at a map and exclaims on its graphic design, it is obvious that he is straying from the geographical objective of the mapmaker.

It is not normally good practice to conclude on a negative note, either pedagogically--or spiritually. But it is not really negative to assert that the design of a map should not be apparent. What that really means is that the map designer should be like a truly humble samaritan. He should make his decisions, and do his designing, not to please himself; instead he should give all his attention to the other guy.

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A CHALLENGE TO CARTOGRAPHERS

Vincent P. Barabba
U.S. Bureau of the Census

INTRODUCTION

I am especially pleased to speak here today -- not only because it gives me a chance to meet once again with some of the leaders of the international statistical and cartographic community, but because the subject is of great interest to me.

All of us here today are concerned with finding meaningful methods by which to communicate information. In many ways we are working against time. It has been predicted that by the end of the next decade new information will be generated and circulated at six times the present rate and 20 to 25 times the volume of a mere 15 years ago.

Even if such a forecast is exaggerated, there is little doubt the amount of data is increasing rapidly, and that new and effective ways of communicating the information these data contain must be developed.

It is my strong belief that the answer lies in developing graphic methods which complement existing data formats by summarizing data accurately and efficiently. Because of the wide variety of users, the methods of display must be standardized in a manner which allows decision-makers in various fields to easily understand what they are viewing. And finally, the methods should be as fully automated as existing technology permits.

What we are talking about is a fully automated and standardized graphic presentation system.

I think we are at a point where the scope of the problem has been adequately defined -- and now we can focus on the challenge it presents.

Unfortunately, one of the major challenges is the machinery of adoption. Developing such a system is not as difficult as getting it known and into use.

EDITOR'S NOTE: Vincent P. Barabba has been Director of the Bureau of the Census since 1973. In this capacity he has encouraged Bureau responsiveness to the needs of data users. He has taught at several universities and has made presentations at numerous national and international conferences, as well as professional society meetings. Prior to coming to the Census Bureau, he served with several data consulting firms, where he pioneered the advanced technical application of computers to analyze population data in marketing and other types of surveys. Mr. Barabba served as honorary co-chairman of Auto-Carto II.

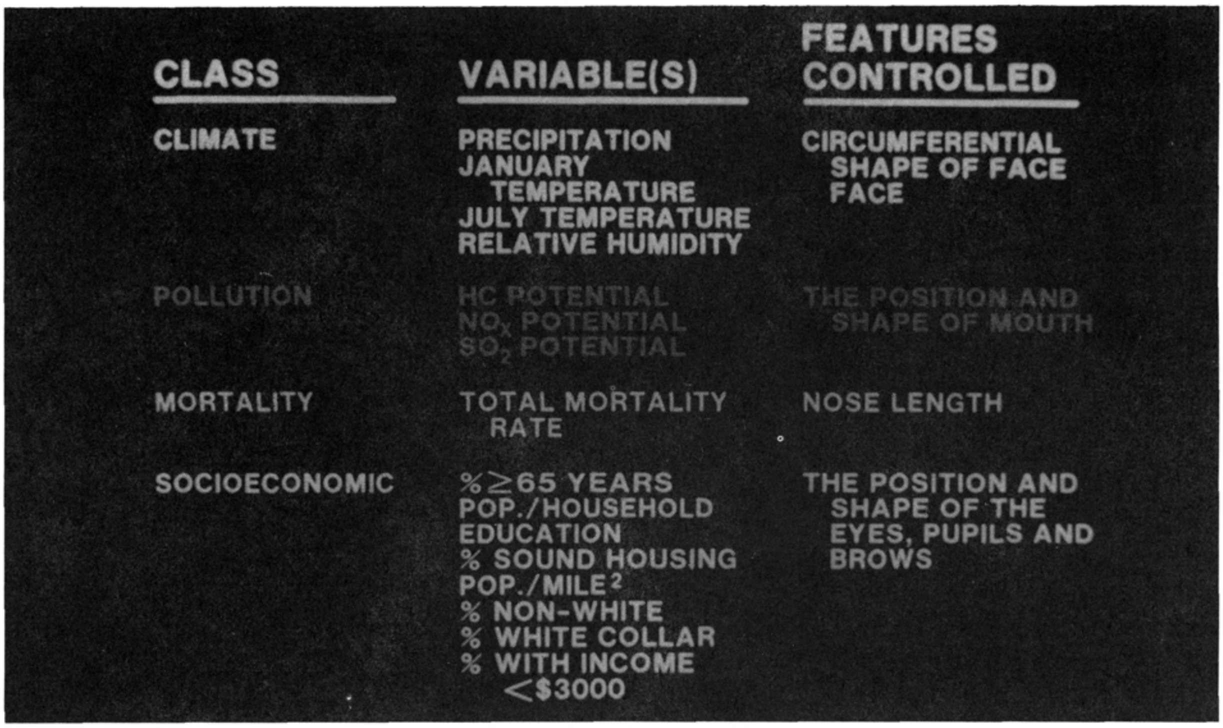
To underline the situation, let me offer the following quotation:

> The graphic method of statistics, though inferior to the numerical in accuracy of representation, has the advantage of enabling the eye to take in at once a long series of facts.... Its defects are such that many statisticians seldom use it except for the purpose of popular exposition, and for this purpose I must confess it has great dangers. I would however venture to suggest the inquiry whether the method has had a fair chance. It seems to me that so long as it is used in a desultory and unsystematic manner its faults produce their full effect, but its virtues do not.

Does anyone care to guess when that was written? The style of the language may give you a clue. It comes from a paper entitled "On the Graphic Method of Statistics," written by the famous economist Professor Alfred Marshall, and appeared in the Jubilee Volume of the Statistical Society of London -- in 1885.

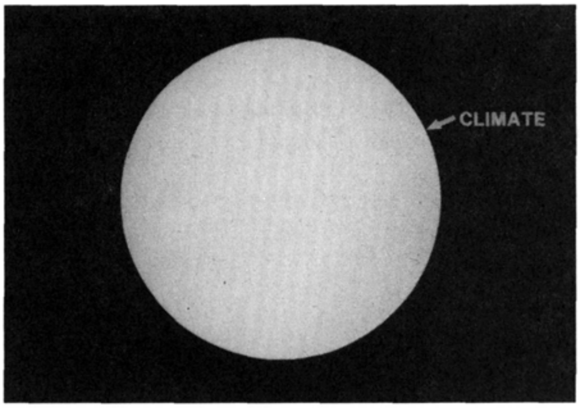
In the 91 years since that was written, graphic presentation still has not had its "fair chance." However, there is activity on a number of fronts. Let's look at one example of a way to enable "the eye to take in at once a long series of facts."

In the June 1973 Journal of the American Statistical Association, Herman Chernoff presented the concept of using the components of cartoon faces to map multivariate data. His purpose was to find a helpful tool to communicate information to the analyst in a form that was easier to use than the many complex tables found in the traditional computer output. A year later, McDonald and Ayers applied the Chernoff faces in the analysis of a community mortality and pollution study. In this study sixty faces represent portraits of sixty different standard metropolitan statistical areas. They are drawn so that each face represents the relationship in a metropolitan area of sixteen different variables organized into four classes of data.

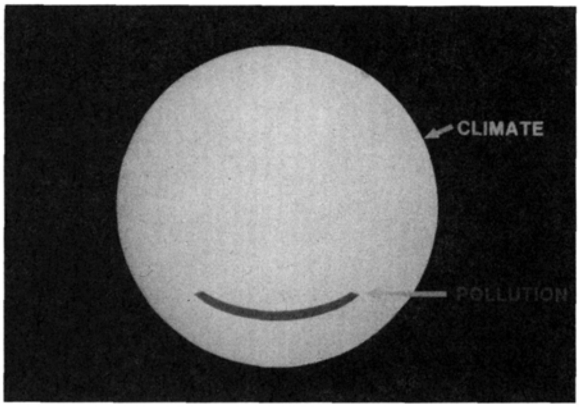


CLASS	VARIABLE(S)	FEATURES CONTROLLED
CLIMATE	PRECIPITATION JANUARY TEMPERATURE JULY TEMPERATURE RELATIVE HUMIDITY	CIRCUMFERENTIAL SHAPE OF FACE FACE
POLLUTION	HC POTENTIAL NO$_x$ POTENTIAL SO$_2$ POTENTIAL	THE POSITION AND SHAPE OF MOUTH
MORTALITY	TOTAL MORTALITY RATE	NOSE LENGTH
SOCIOECONOMIC	%≥65 YEARS POP./HOUSEHOLD EDUCATION % SOUND HOUSING POP./MILE^2 % NON-WHITE % WHITE COLLAR % WITH INCOME <$3000	THE POSITION AND SHAPE OF THE EYES, PUPILS AND BROWS

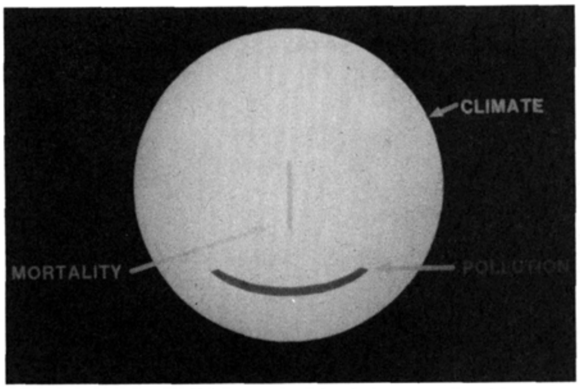
The authors have attempted to present their data graphically in the following manner:



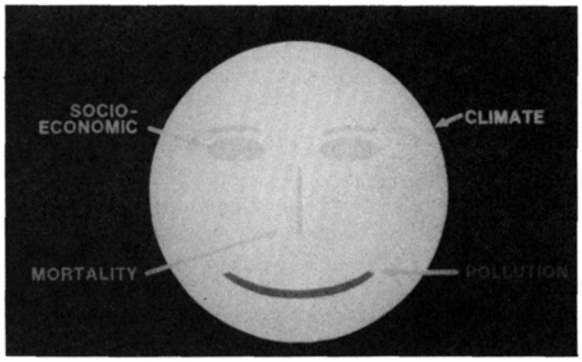
The four climate variables control the circumferential shape of the face.



The three pollution variables control the position and shape of the mouth.

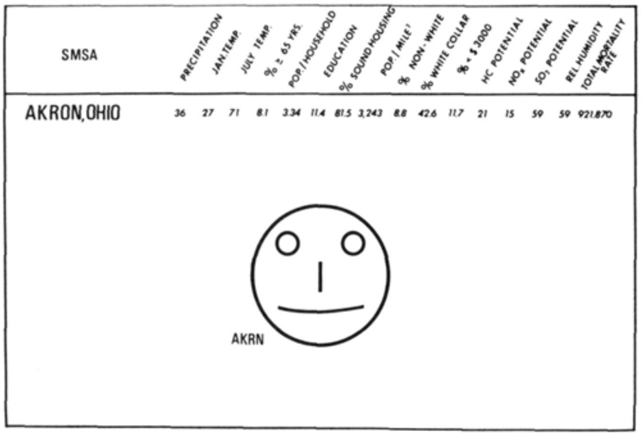


The one mortality statistic controls the nose length.

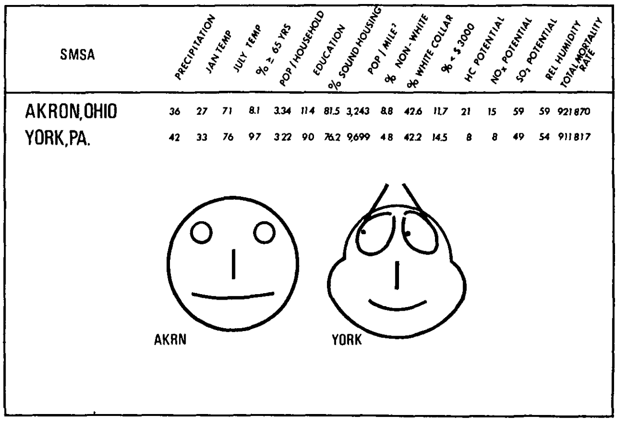


And finally, the eight socioeconomic variables control the position and shape of the eyes, pupils and brows.

This is a face representing the Akron, Ohio, SMSA. The 16 variables appear across the top. Of the 60 metropolitan areas in the study, Akron is a middle-of-the-road example. The facial features appear neutral, undistorted.



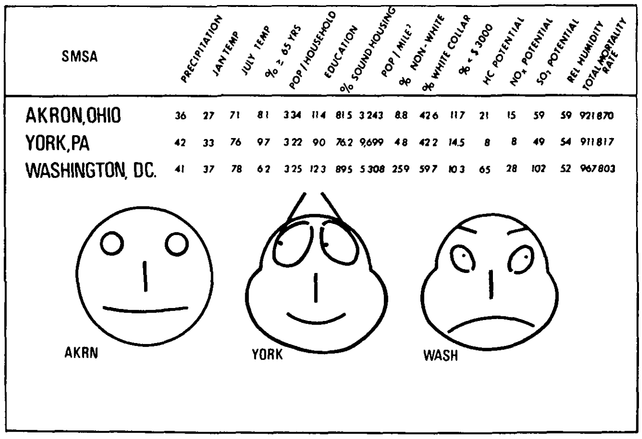
SMSA	PRECIPITATION	JAN.TEMP.	JULY TEMP.	% ≥ 65 YRS.	POP./HOUSEHOLD	EDUCATION	% SOUND HOUSING	POP./MILE²	% NON-WHITE	% WHITE COLLAR	% < $3000	HC POTENTIAL	NO_x POTENTIAL	SO_2 POTENTIAL	REL. HUMIDITY	TOTAL MORTALITY RATE
AKRON,OHIO	36	27	71	8.1	3.34	11.4	81.5	3,243	8.8	42.6	11.7	21	15	59	59	921.870



SMSA	PRECIPITATION	JAN TEMP	JULY TEMP	% ≥ 65 YRS	POP / HOUSEHOLD	EDUCATION	% SOUND HOUSING	POP / MILE²	% NON-WHITE	% WHITE COLLAR	% < $ 3000	HC POTENTIAL	NO_x POTENTIAL	SO_2 POTENTIAL	REL HUMIDITY	TOTAL MORTALITY RATE
AKRON, OHIO	36	27	71	8.1	3.34	11.4	81.5	3,243	8.8	42.6	11.7	21	15	59	59	921870
YORK, PA.	42	33	76	9.7	3.22	9.0	76.2	9,699	4.8	42.2	14.5	8	8	49	54	911817

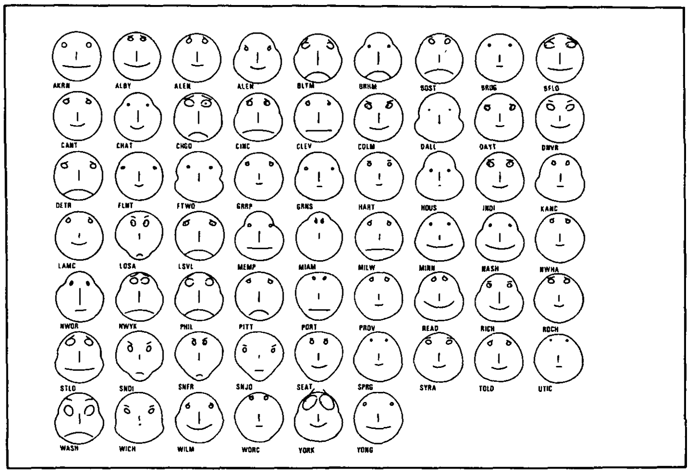
Next is York, Pennsylvania. A considerable difference is evident--especially in the larger population density, as reflected in the size of the eyes, the lower pollution potential, reflected in the shape of the mouth, and the climate, which affects the general shape of the face.

Finally, Washington, D.C. This is not an editorial comment, by the way. Immediately apparent is the high potential for all forms of pollution, and a fairly high population density. You can see also that the climate is not too different in York and Washington.



SMSA	PRECIPITATION	JAN TEMP	JULY TEMP	% ≥ 65 YRS	POP / HOUSEHOLD	EDUCATION	% SOUND HOUSING	POP / MILE²	% NON-WHITE	% WHITE COLLAR	% < $ 3000	HC POTENTIAL	NO_x POTENTIAL	SO_2 POTENTIAL	REL HUMIDITY	TOTAL MORTALITY RATE
AKRON, OHIO	36	27	71	8.1	3.34	11.4	81.5	3243	8.8	42.6	11.7	21	15	59	59	921870
YORK, PA	42	33	76	9.7	3.22	9.0	76.2	9,699	4.8	42.2	14.5	8	8	49	54	911817
WASHINGTON, DC.	41	37	78	6.2	3.25	12.3	89.5	5308	25.9	59.7	10.3	65	28	102	52	967803

With a little training, an analyst can glance at the sixty faces and pick out metropolitan areas with characteristics and relationships in which he is interested. Instead of facing a page of 960 data items, he sees this presentation of faces -- a visual catalog of 16 variables for 60 SMSA's.

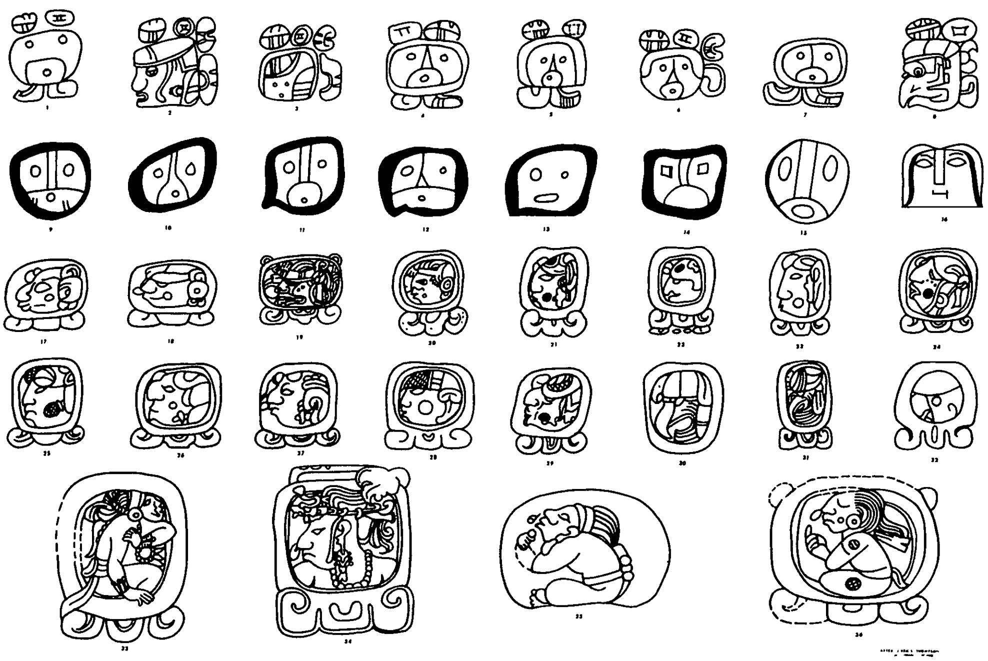


But just how new is the concept of presenting information through the medium of facial components?

The ancient Mayan Indians had a highly developed written language based almost entirely on glyphs of either whole persons or faces. These symbols were also intended to convey given facts -- information independent of other glyphs.

The Mayan symbols were not an alphabet in the sense we use the word. Nor were they pictography as in the Egyptian hieroglyphics. What the Mayan written language has in common with Chernoff's faces is that both employ abstract representation of known forms to transmit information expressed by the size, length or curvature of the lines making up the given symbol.

Although Chernoff's general concept may appear new to many of us, there certainly is an historical parallel in the Mayan faces of some 700 years ago.

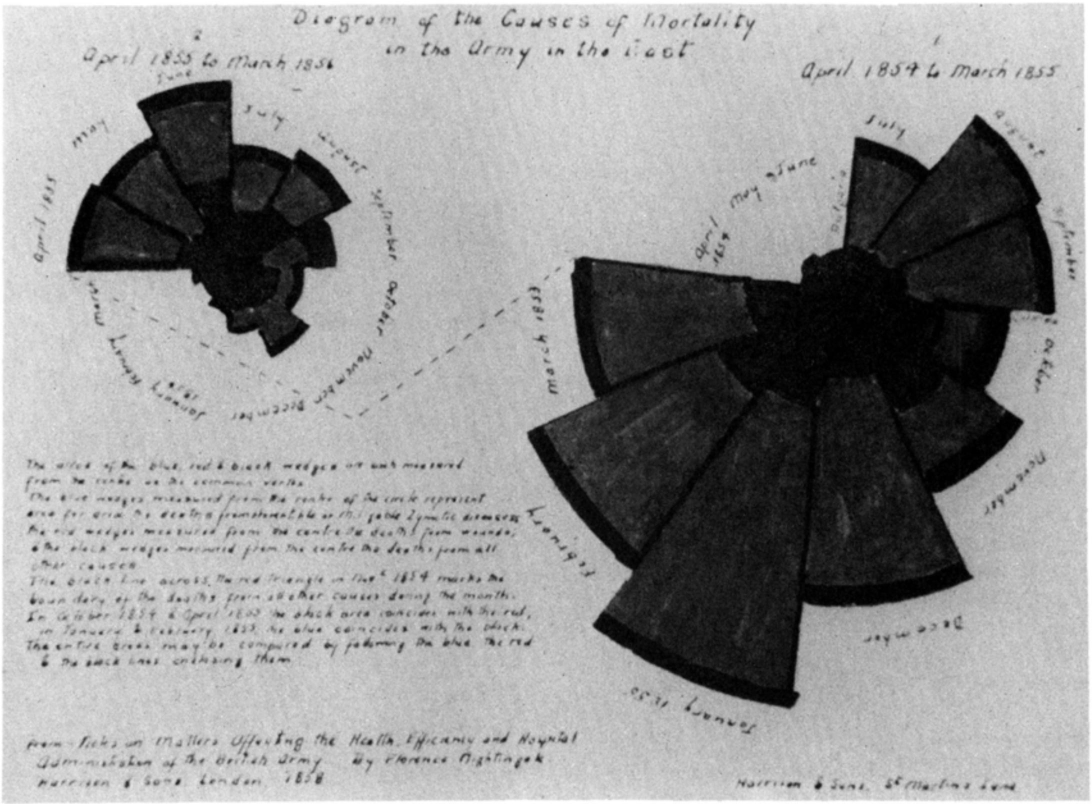


In a recent Census Bureau seminar, Dr. Roberto Bachi of Hebrew University presented an alternative graphic alphabet. He stressed the need to understand such a new alphabet <u>before</u> attempting to evaluate the graphic system's effectiveness.

Let's look at another example.

In a recent discussion the Bureau had with another U.S. Government agency, the development of polar aerial graphs -- such as the one shown here -- was discussed.

We found that many people considered this form of graphic presentation to date from the late 1960's. However, this graph represents casualties during the Crimean War as illustrated in the 1850's by Florence Nightingale, the noted British nurse.



The areas of the blue, red & black wedges are each measured from the centre as the common vertex
The blue wedges measured from the centre of the circle represent area for area the deaths from Preventable or Mitigable Zymotic diseases the red wedges measured from the centre the deaths from wounds, & the black wedges measured from the centre the deaths from all other causes
The black line across the red triangle in Nov. 1854 marks the boundary of the deaths from all other causes during the month.
In October 1854 & April 1855 the black area coincides with the red, in January & February 1855 the blue coincides with the black.
The entire areas may be compared by following the blue the red & the black lines enclosing them

From Notes on Matters Affecting the Health, Efficiency and Hospital Administration of the British Army By Florence Nightingale
Harrison & Sons London 1858

Clearly the ability and the desire to present information in a graphic way is not new. The phrase "one picture is worth a thousand words" has been with us a long time. Using poetic license, I would say "one statistical map is worth a thousand pictures." In this case the map on page 251 presents two variables and imparts a large amount of information. Figures 2 and 3 (pp. 252, 253) show the individual maps that went into preparing the cross-map.

STANDARDS

Another component of our goal is standardization.

Again, we have yet to break new ground. Not only is the concept of graphical standards not new, but difficulty in establishing them has been with us for a long time as well.

In 1872, over 100 years ago, the Eighth Congress of the ISI had a lively debate on the subject culminating in the following declaration: "As for uniformity of diagrams, properly called, the Congress declares that the time has not yet come to propose uniform rules." In fact, the first tangible efforts related to standards did not come about in the United States until 1936, in a report prepared by the Committee on Standards of Graphic Presentation, entitled *Suggested Symbols for Plans, Maps and Charts*.

One of the key reasons for having standards was pointed up in a recent article in *The Cartographic Journal* by Ronald Carswell and Haze Wescott of the University of Calgary. They noted that illustrative material is not automatically more informative than straight text--that a person must be taught how to use pictures and graphic illustrations in order to extract the information they contain.

My point here is that such teaching is not being accomplished because there are no standards on which to base teaching.

Before leaving the subject of standards, I want to make sure I am not creating a wrong impression. The standards I am calling for are not a set of rigid rules and regulations, but guidelines--perhaps conventions would be a better word.

AUTOMATION

The final component of our goal is fully automated.

Once more we find the idea is not new. However, in this regard most development has occurred within the lifetime of the people in this room. In fact, it was not until the late 1960's that computer-driven pen plotters came to be widely employed. The interactive graphics systems such as Ivan Sutherland's "Sketchpad" and the "Magic System" of the U.S. National Bureau of Standards are as recent as 1963 and 1964.

What then about the development of a fully automated and standardized graphical presentation system. Is it in fact an innovation? The answer is both yes and no.

Here I would like to refer to the work of Everett Rogers, a Professor of Communications at Stanford University in California. Rogers defines an innovation this way:

> An idea, practice, or object perceived as new by an individual. It matters little, so far as human behavior is concerned, whether or not an idea is "objectively" new as measured by the lapse of time since its first use or discovery. It is the perceived or subjective newness of the idea for the individual that determines his reaction to it. If the idea seems new to the individual, it is an innovation.

The important point here is that an innovation need not be truly new, in the sense that it has never existed before, in order for it to be perceived as new.

Keeping Rogers' definition in mind, let's ask the question once again--what is innovative about a fully automated and standardized graphic presentation system? The answer is the attempt to put all three elements together. Graphic Presentation--Standards--Automation.

For discussion purposes, let us accept the concept of such a system as not only an innovation but one whose time has come. Where then do we start? We must convince the decisionmakers of our society that not only do they need this system, but, that in the initial stages of development they are going to have to divert scarce resources from other projects so that we can produce the system in a form that will effectively and efficiently meet their requirements. How can we systematically go about developing and presenting an innovation that will be adopted and used by those responsible for making decisions based on information?

I find a sense of direction in the work of Rogers as he outlines the complexity of the innovation-decision process. In this model Rogers depicts four stages.

First is the KNOWLEDGE stage where the individual is exposed to the innovation's existence and gains some understanding of how it functions.

I think most people accept the statement that we generally tend to come into contact with ideas or concepts which are in general accord with our interests, needs or existing attitudes. Rogers identifies the central point of the knowledge stage as follows:

> Consideration of a new idea does not pass beyond the knowledge function if the individual does not define the information as relevant to him or if he does not seek sufficient knowledge to become adequately informed so that persuasion can take place.

Which leads us to the second stage: PERSUASION.

During this stage the individual forms a favorable or unfavorable opinion about the concept. He becomes more psychologically involved as his knowledge of the innovation increases. Rogers stresses the key point that both the knowledge and persuasion stages move only as rapidly and effectively as the channels of communication allow. If an innovation has possible meaning to many individuals the only way this may be realized is by bringing the potential user into contact with it.

The third step is the DECISION stage, and here the individual engages in activities which lead to a choice to adopt or reject the innovation.

Although the two earlier stages implied that choices were being called for, in the decision phase the type of choice is different, because it reflects a commitment to adopt or reject a new idea. An important finding Rogers has made in studying this area is that innovations which are amenable for a trial or test are generally adopted more rapidly.

Following a decision to adopt an innovation, even on a limited basis, comes the CONFIRMATION stage.

Here the individual seeks reinforcement for the decision he has made--although the possibility of a reversal remains. There seems little doubt that meaningful standardization would assist in this process.

What is it about an innovation that determines its rate of adoption? What kinds of innovations are fully adopted in months or years as distinguished from our subject today, portions of which were being discussed over 100 years ago and are not yet fully adopted? What can we do to "package" the innovation to hasten its adoption?

Rogers points to five attributes of an innovation which tend to determine its adoption rate. It is important to remember that it is the perception of the decisionmakers we are dealing with at this point, not the attributes of the innovation as seen by those who are seeking to have it adopted. The five attributes are relative advantage, compatibility, complexity, trialability, and observability.

Relative advantage is the degree to which an innovation is perceived as being better than the idea it supersedes. The degree of relative advantage is often expressed in economic profitability, but may be measured in other ways as well.

Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of the receivers. An idea that is not compatible with the salient characteristics of a social system will not be adopted as rapidly as an idea that is compatible. Compatibility ensures greater security and less risk to the receiver and makes the new idea more meaningful to him.

Complexity is the degree to which an innovation is perceived as relatively difficult to understand and use. Any new idea may be classified on the complexity-simplicity continuum. Some innovations are clear in their meaning to potential adopters, others are not.

Trialability is the degree to which an innovation may be experimented with on a limited basis. New ideas that can be tried on the installment plan will generally be adopted more rapidly than innovations that are not divisible. An innovation that may be used on a trial basis is less risky for the adopter.

The impact of a fully automated system should be noted here, since it would allow many more trials of new ideas before adoption, and at greatly reduced cost.

Observability is the degree to which the results of an innovation are visible to others. The results of some ideas are easily observed and communicated to others, while some innovations are difficult to describe to others.

After more fully describing these attributes, Rogers goes on to observe how they relate to the rate of adoption: In the left side of the chart we identify the five attributes perceived by potential adopters, on the right hand side we identify whether the attribute increases or slows down the rate of adoption.

PERCEIVED	Effects the rate of adoption	
	by increasing it	by slowing it
RELATIVE ADVANTAGE	X	
COMPATIBILITY	X	
COMPLEXITY		X
TRIALABILITY	X	
OBSERVABILITY	X	

I think that most of us would agree with the observations presented by Rogers. In fact, we might very well ask: Why was it necessary for him to state the obvious? But he goes a step further by listing the number of empirical studies that support and do not support each of the five generalizations he makes regarding attributes of the innovation and its rate of adoption.

PERCEIVED	Effects		Empirical Evidence		
	Increases	Slows	Agree	Disagree	Total
RELATIVE ADVANTAGE	X		29	14	43
COMPATIBILITY	X		18	9	27
COMPLEXITY		X	9	7	16
TRIALABILITY	X		9	4	13
OBSERVABILITY	X		7	2	9

Not all of Rogers' findings and particularly those related to <u>complexity</u> have been fully substantiated by empirical evidence. That, of course does not mean they are incorrect. It simply means they are hypotheses not yet fully tested.

This review of Rogers' work brings two benefits. First, his findings provide us a sense of direction in finding the most effective ways of understanding the diffusion process so that we can see that our ideas are not only developed but adopted as well. Secondly, we can see from reviewing his approach the need and the importance of empirical evidence to demonstrate the utility of our ideas as we attempt to have them adopted.

Applying Rogers' work in a specific sense, I think one of the key obstacles to be overcome lies within the statistical graphics community itself. Professor Arthur Robinson referred to it in his Presidential Address to the International Cartographic Association in Ottawa in 1972. He said:

> When one looks at the history of cartography, one cannot but be impressed by the persistence of techniques, and the strength of the urge to maintain the status quo. This is true in many areas, perhaps most obviously in the graphic.

He went on to call for the creation of a climate which fosters change and which demonstrates that rapid change is normal.

Keeping in mind the stagnation of the last century regarding graphic presentation, along with the work of Everett Rogers and the words of Arthur Robinson, let me ask a series of questions to the statistical graphics community at large. These are questions we each must deal with if we are to overcome inertia and see the rapid adoption and effective use of a fully automated standardized graphic presentation system.

-- What, if anything, will the system replace?

-- What tools and techniques are likely to be modified as a result of <u>introducing</u> the system?

-- Which would have to be modified if the system is <u>accepted</u>?

-- Who will benefit immediately and who will suffer immediately from a fully automated standardized graphic presentation system?

-- Who in the statistical community will have to abandon or change their occupations as a result of the system?

-- Is there a possibility that the system will open up new forms of cooperation, or perhaps of conflict? If so, will this be within the statistical community, or between that community and the users of data?

-- Do individuals and group leaders -- statisticians, cartographers, demographers, economists, and others who will be affected really understand the nature and purpose of the system?

-- Who will take part in planning a fully automated standardized graphic presentation system, and who will not?

-- What is the history of introducing new ideas within the statistical graphics community?

-- Other than technology, what traditional way of doing things are likely to be affected by the system? Relationships between program specialists and computer programmers? Between the statistical graphics community and data users?

These are tough questions -- and they are only a sample of the many that must be answered before a graphic presentation system such as we have been discussing will be a reality. However, I am confident satisfactory answers can be found, and that the immense pool of talent within the statistical graphics community can be brought to bear, not only on finding the answers, but doing so in a relatively short time.

The Bureau of the Census would like to begin a dialogue with both producers and users of graphic presentations. We hope this dialogue would lead to the development of a graphic presentation center which would assist in developing prototype techniques that can be systematically evaluated "in the field." Additionally the Bureau can serve as a clearing house or depository of empirical evidence which demonstrates the utility of different forms of automated graphic presentations.

In essence, I foresee a situation where the Bureau of the Census, with its available resources of people and machines, could help implement ideas of others, through the use of our existing automated technology and the availability of extensive and timely data sets. This does not mean, I hasten to add, that the Bureau has unlimited resources to contribute to this endeavor. It does mean, however, that we do have some resources and we are willing to open discussions to find how we can most effectively use these limited resources to accomplish the most good.

That's the heart of the challenge I bring with me today. Let us do more in the next ten years toward developing a graphic presentation system than was accomplished in the last 100 years. Let us approach the task not as we would an unknown -- but in the manner of a medical researcher who has isolated the cause of a disease, and is now perfecting a vaccine. Let us systematically collect empirical evidence as we proceed, so that when the time comes to convince others outside the statistical graphics community, we can speak from a basis of fact rather than our own personal desires.

This is a challenge which must be met if we are to help society as a whole meet the larger challenges we have alluded to this morning:

- The forecast of increased information flow, coming at us at an accelerated rate; and
- The dilemma of a society facing difficulty in making good decisions as well as being more realistic about the consequences of making bad ones.
- We need to develop and insure the adoption of a fully automated and standardized graphic presentation system. If we do, we will have contributed greatly to reducing the number of casualties which will occur in a world which is already beginning to face "future shock."

VISIONS OF MAPS AND GRAPHS

William Kruskal
University of Chicago

Cartography and statistics have much in common and many bonds beyond the presence of a statistician as speaker at your excellent banquet. In general terms, cartography and statistics both deal with the compression or distillation of complex quantitative data sets into packages comprehensible to human eyes and minds. Another general similarity is that both statistics and cartography are much concerned with the efficient design of investigations.

The two disciplines have long historical links. Let me read you a short quotation from G. N. Clark's 1948 book, Science and Social Welfare in the Age of Newton. Under discussion are the advances in cartography in England during the late sixteenth century; Professor Clark says that

> "This new cartography was used in the service of the state, for instance by the great Cecil in Elizabethan England, who employed more than one map-maker. In all its aspects it was closely allied to statistics. The estate maps often had in the corners tables of the amounts of land held by different owners, or the numbers of beasts they had a right to pasture. The county maps of Saxton, the most notable of Cecil's cartographers, were accompanied by descriptions which gave figures. This was no accident but arose from the nature of the two methods. A map is an abstract statement based on measurement; statistics are abstract statements based on measurement, counting, and calculation. If this appears to be a farfetched identification, let it be remembered that two of the pioneers of statistical science, Petty and Gregory King, were surveyors before they were statisticians. Neither of them ... got very far away from the geographical point of view."

Editor's Note: Dr. William H. Kruskal, Ernest DeWitt Burton Distinguished Service Professor of Statistics, and Dean of the Division of the Social Sciences at the University of Chicago, delivered the address at the closing banquet of Auto-Carto II. A professor of statistics at the University of Chicago since 1950, Dr. Kruskal has received numerous awards and fellowships in this field. He was President of the Institute of Mathematical Statistics (1970-71) and Vice President of the American Statistical Association (1972-74). He is a member of the American Academy of Arts and Sciences, the International Statistical Institute, the Royal Statistical Society, the American Mathematical Society, the Mathematical Association of America and the Biometric Society, just to name a few of his many affiliations. In his address, Dr. Kruskal explored the relationship between cartography and statistics. Preparation of his paper was partly facilitated by the National Science Foundation, Grant Number SOC 72-05228 A03.

Modern connections between the two fields are superbly discussed by Brian J. L. Berry in his 1968 article on "Statistical Geography" in the International Encyclopedia of the Social Sciences. I mentioned three specific connections that have had special interest for me.

First, there is in geography a literature on the many possible ways of describing centers—centers of land mass, of population distribution, or whatever—with lengthy discussion of the merits of various proposals. This literature is much like the statistical literature on what used to be called "measures of central tendency," indexes to give some sensible idea of where the middle of a distribution might be. In the case of a two-dimensional distribution, perhaps on the surface of a sphere, we are essentially in the geographer's position.

The utility of such summary measures presumably comes from the facilitation of comparisons that flows from them; we have all, I expect, seen maps of how the center of gravity of the U. S. population has moved westward with the years.

Any one measure, like the center of gravity, may have disadvantages in particular contexts. A problem that has interested me—and also some geographers—is whether there is a sensible analogue to the median for bivariate distributions; "sensible" includes the requirement that rotating the coordinate system leaves the median-like point unchanged. So, in particular, taking the ordinary univariate medians along two conventional axes does not satisfy that condition.

Second, the development of least squares methods, including nonlinear regression, owes a great deal to the motivation and energies of nineteenth century cartographers, geodesists, and surveyors. From the very start, least squares theory was intertwined with difficult calculations in astronomy, terrestrial magnetism, and map-making. The issues discussed were both practical and theoretical.

Charles Sanders Peirce, perhaps best known for his philosophical thought, was, I believe, exposed to statistical-cartographic problems at the Coast and Geodetic Survey; he was an early, thoughtful, and inadequately appreciated American statistician.

I am told that continuing needs for handling redundant, not fully consistent, data hold today even with the most up-to-date technologies, especially if one includes whatever cartography is called as it travels out to space along with rockets and satellites.

Third, there are contexts in which cartography and statistics are so intertwined that separation is impossible. A recent article by Robert Hoover and others (1975), for example, uses U.S.A. maps by counties, with specific cancer mortality rates shown by shading or color. From these, clusters of counties are chosen for comparison with patterns of industrial concentration.

After this brief description of some links between statistics and cartography, I turn to another that leads to a main theme of these comments. That theme is the importance of empirical experiments dealing with what gets communicated by maps on the one hand, and by statistical graphics on the other.

I cannot speak for cartography with special authority, but for statistical graphics I may safely say that we are at a primitive state: in choosing, constructing, comparing, and criticizing graphical methods we have little to go on but intution, rule of thumb, and a kind of master-to-apprentice passing along of information. You need only look at a good text on statistical graphics. Much of its advice will be excellent, no doubt, but it will also be dogmatic or arbitrary, in the sense that there is neither general theory nor systematic body of experiment as a guide. What we have instead are accumulated experiences, social conventions, and prescriptions. Actual practice in statistical graphics often does not rise to the level expounded by good texts: witness, for example, graphs in otherwise excellent scientific journals that show curves faired through observed data points, but not the data points themselves; or again, graphs of economic statistics in the daily press--even in the Reports of the Council of Economic Advisors--in which choices of origin and scale appear to have been made so as to magnify or diminish, in a self-serving way, some behavior of the data. I must immediately qualify that statement, for it is always dangerous, and perhaps ultimately evil, to ascribe motivation when one sees error. Even, with all good will, honesty, and candor humanly possible, however, can one hope to present graphical material without distortion? What's more, how do we know when distortion occurs? Even if we knew, it would doubtless vary from viewer to viewer: a graphical display honestly presenting material to those of us at this conference might be quite misleading to a conference of lawyers, of automobile salesmen, or of musicians.

My initial theme then is to deplore the paucity of empirical experiments on statistical graphics. Yet there have, of course, been such experiments ... there is a literature. Together with Ian Eggleton, a doctoral candidate at the Graduate School of Business of the University of Chicago, I have been exploring the literature of empirical work in statistical graphics, and also in cartography, for the boundary between the two is fuzzy and work in one may well inform the other.

Our review to date suggests a number of serious shortcomings in the literature of empirical investigations on statistical graphics and cartography. I must apologize in advance of the shortcomings listed really reflect the inadequacy of our search.*

First, the literature appears sketchy in a number of senses. There is relatively little systematic, cumulative research in specific topics. For example, the early work by F. E. Croxton and others in the 20's and 30's on the comparative perception of different shapes for symbols in statistical graphics has apparently received little further attention. Yet these early results were inconclusive and the problem is of continuing importance.

Exceptions to my critical remark are the 1953 paper by J. R. MacKay on cubic symbols and the 1959 paper by John I. Clarke on statistical map reading. On the whole, however, we sense a tendency to introduce new sorts of symbols, perhaps highly imaginative and interesting, but without systematic empirical investigation. Examples are the superimposed symbols of H. R. Wilkinson (1967), the six pointed stars of D. R. MacGregor (1967), and Roberto Bachi's graphic rational patterns (1968). Professor Bachi's book calls for careful experimentation, but I do not think that it reports any; I hope that he will tell me of great work done since or planned soon.

Sustained attention has, it appears, been given to graded series of shadings for maps, and we took special interest in the 1961 paper by G. F. Jenks and D. S. Knos.

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*Further search has brought us in touch with a few more careful empirical studies; in particular, I cite with admiration the 1969 monograph by Henry W. Castner and Arthur H. Robinson.

Second, we sense generally inadequate attention to the psychological aspects of empirical trials and their reporting. Many papers are remarkably silent about the population of subjects, the experimental instructions and conditions, the exact nature of the stimuli and instructions, etc., all those kinds of information necessary for peer criticism, replication, and extension.

To illustrate the importance of full reporting, I cite a recent paper by Judy Olson (1975) on the subject of map complexity. To its credit, this paper is relatively detailed; in particular, it is reported there that two similar instructions to subjects gave rise to different results, a puzzling and possibly valuable finding.

Third, the papers we have found show relatively little evidence of close cooperation with experimental psychologists concerned with perception and cognition. A few papers show awareness of the psychological literature, but we have found little towards the construction of a psychologically informed theory or of specific hypotheses for future testing.

Fourth, serious questions come to mind about the external validity, so-called, of much of the experimental work to date. I.e., how broadly do the results apply? Subjects seem to be narrowly drawn, often traditionally from student populations, and the effect of training is often neglected. (When training is taken into account it may be important, as was shown by MacKay in 1953.) Stimuli may be stylized or schematic, as in the recent work by Olson with checker-board-like patterns, and she raises herself the question of generalizability.

I must say that statisticians doing this sort of experiment on, for example, visual fitting of lines to data, or numbers of intervals for histograms, are subject to similar criticisms, so I come as a fellow sinner. Surely part of the problem is that of arousing the interest of psychologists, to whom our concerns may appear special and technological. On the other hand, one might hope to elicit their concern, since they themselves use, or should use, statistical graphics in their own research and teaching.

Now surely putting procedures and practices to empirical check is pragmatic and scientific. Let me mention three examples to illustrate this next theme. The first is from an unrelated area in which I have a personal interest: swimming. When I first learned to do the crawl, as a small boy, I was told how important it was to keep the fingers together. Dutifully I accepted that dictum and by now the habit is ingrained; it would be distinctly uncomfortable for me to separate my fingers while swimming.

James Counsilman (1968; pp. 9-12), swimming coach at the University of Indiana, decided to put this established wisdom to empirical test--along with other swimming traditions--by means of special apparatus. It turns out that there is hardly any difference between fingers together and fingers apart! What is the world coming to? Next thing you know, someone will announce that peppermint ice cream is healthier than spinach.

My second example is medical; it is one of many similar examples described and analyzed by Dr. Thomas Chalmers, head of Mt. Sinai Medical School in New York. There is a surgical operation called the portocaval shunt that is traditionally carried out on cirrhotic alcoholics on the basis of plausible arguments about prolongation of life. Yet no proper experiment--with control group and randomization--had been carried out until a few years ago. When the experiment was done, lo and behold, it did not at all prolong life for alcoholics--quite the contrary, it had a shortening effect on average. See Chalmers (1970) and Grace et al.(1966).

(Of course it might be that some categories of patients would benefit from the operation. It is, as we all know, in the discovery of such relevant strata that much scientific advance resides.)

My third example is closer to the statistical tone of this talk; I draw it from the valuable writings of Amos Tversky and Daniel Kahneman (1974). Tversky and Kahneman have been concerned with many aspects of how people actually deal with probabilistic concepts, as opposed to how they might ideally deal with them. In particular, they were curious about the extent to which increasing sample size is perceived as tending to bring a sample average closer to the population average. Among a number of imaginative experimental procedures, they presented subjects with a carefully worded description of two hospitals, one of which has about 15 births a day and the other about 45. Then they asked, for example, about the fraction of days one would expect the percentage of boy babies to be greater than 60%. It turned out that there was hardly any difference in reported fractions greater than 60% despite the considerable difference in sample size, and hence in tightness of distribution of the newborn sex ratio in the two hospitals.

In fact, over half the respondents said that the two hospitals would have the same fraction of days with more than 60% boy babies. Yet it seems clear to us that the smaller hospital, with its higher variability, is bound to have more days with boy babies in excess of 60%.

Reading the Tversky-Kahneman article is a chastening experience for me; what is the point in research and teaching of advanced statistical theory and practice when the general public exhibits such complete ignorance? A discussion of that question would inevitably lead to issues like those that arise in discussing statistical graphics and maps, especially for distribution to wide audiences. I suppose that issues like this are a recurrent topic within government statistical agencies.

To summarize the theme to date then: empirical testing of graphic and cartographic methods is important. That testing should bring in the competences of good psychologists, and it should be based on proper experiment designs. I might add the hope that such activity would lead to usable perceptual theory for the future. After all, it is impossible to test everything empirically; and it is impossible to draw subjects from all groups. Thus ultimately we rely on a combination of experiment and intuition cum experience cum theory. As someone said--I wish I know who it was--, "There is nothing so practical as a good theory."

Next I'd like to discuss briefly the role of statistical graphics within statistics generally. That role has had tremendous ups and downs: at one time, graphical methods were near the core of statistics--Karl Pearson devoted considerable attention to graphics and he was following the emphasis of his hero, Francis Galton. Later on, statistical graphics became neglected and even scorned in comparison with the blossoming of the mathematical side of statistics. In recent years, however, there has been a renaissance of concern with graphics and some of our best statistical minds have suggested new graphical approaches of great interest.

For example, John Tukey (1976) has made highly imaginative suggestions to improve some of the simplest graphical devices: I think in particular of his so-called stem and leaf way of tallying observations and simultaneously producing a rough histogram; I think too of his hanging histogram suggestion, in which the histogram bars hang from an approximating curve rather than poke up towards it.

Several recent suggestions deal with the fundamental problem of exhibiting graphically more than two or three numerical variables at once. Here in the Bureau of the Census, for example, there is current work with color to gain new ground in this direction. A completely different approach has been taken by Edgar Anderson (1957) with his so-called metroglyphs: circles to represent points on a chart or map, each with four or five lines sticking out to represent other variates.

George Barnard, an eminent British statistician, suggests (1969) starting out with a two-dimensional perspective drawing of a surface of y as a function of x_1 and x_2; then, by showing that drawing on a moving picture or television screen and letting it move, one can introduce a third independent variable x_3. Indeed he suggests adding another variable x_4 by shifting x_3 in a relatively slow cycle and x_4 in a relatively fast one, thus presenting the viewer with a pictured surface that heaves (for x_3) and quivers (for x_4). Whether this has been tried, and how practicable it is, I do not know.

Perhaps less limited in dimensionality is an idea discussed by David Andrews (1972): one lets each numerical coordinate determine a coefficient of a finite Fourier series, and then looks at the resulting graphs with their bumps and wavinesses.

One of the most dramatic suggestions is that of Herman Chernoff (1973), who starts from the fact that human beings are remarkably good at recognizing, remembering and discriminating among the faces of other human beings. So Chernoff suggests using schematic faces: the first coordinate might provide degree of ovalness of the face, the second, interocular distance, etc. I have seen computer drawn faces of this kind for some 10 or 12 variates, and they are fascinating to work with. The cartoon-like faces make one laugh at first, and then one takes them seriously.

Note that most of these suggestions depend, for their practical effectiveness, on high speed computers or on television and motion picture technology. So be it, although I fear the decrease in objectivity that may result from the growth of technological graphics.

Ordinary graphics and traditional cartography carry along their own opportunities for distortion, whether conscious or not. We all know the standard cases, for example, misleading scales that make statistical graphs dishonest; in cartography, purposive choice of a projection or of a color can make the red threat look bigger or smaller. Vision is notoriously subject to emotion and predisposition. Just consider the famous, or infamous, canals of Mars.

Yet the addition of motion to graphic or cartographic displays may permit far more extensive distortion and departures from objectivity. Let me read you a passage written by Pauline Kael, motion picture critic for The New Yorker magazine,

> ". . . it is perhaps the most spectacular example of agitprop moviemaking so far, and it demonstrates in a classic way the problems that seem to be inherent in propaganda movies. It is painfully affecting, since it shows the diseases and miseries of the poor, but it is also upsetting and maddening, since it throws facts and figures at us that we cannot evaluate while we're watching it, and calls for revolution as if the case for it had been made on plain, objective grounds." The New Yorker, 6 March 1971.

I note also that — to my knowledge — there has been little serious psychological experimentation on the characteristics of any of the above suggestions.

How stable, for example, are the results of intuitive clustering with Chernoff-like faces under permutation of the coordinates? How much do any of these methods depend on practice and experience?

Chernoff (1975) himself, together with M. Haseeb Rizvi, have carried out just such an experiment. I should also again cite Castner and Robinson (1969).

I would like to push these themes, with your indulgence, in a direction orthogonal to the main thrust of this conference, and yet not one that is absolutely irrelevant.

Earlier I suggested that statistical graphics was in a primitive state, that it was far more an art or a craft than a science. That is even more true for the making of statistical tables. Yet tabulation is the traditional communication mode for the Census and other government statistical agencies. Some agencies, like the Census, are — it seems to me — very good at statistical tabulations and with long experience. Some other agencies, with much less experience, have published tables that are dreadful . . . unreadable, too many figures, poor or missing legends, lots of broken numerals, poor use of white space, and so on.

Yet when I say that Census tables are very good — and I say that with the contented thought that absolute honesty and common courtesy here go hand in hand — when I say that Census tables are very good, I neither know exactly what I mean nor can I point to a body of extensive, careful empirical work to document the assertion. There are publications that give conventional rules for good table making, but these tend to be dogmatic and conventional. There are other books, for example, Hans Zeisel's Say it with Figures, that go much deeper, yet not to first principles as regards tables themselves. There is, to my knowledge, at most a handful of pilot experiments. For example, Andrew Ehrenberg in London has carried out some empirical trials, including comparisons between tables and graphs. (He comes out in favor of tables, to my surprise, but I am not sure how widely his results can be generalized.)

All the problems one has with graphical materials are there for tables: What are the criteria of honesty, clarity, cost, insightfulness? How can one think about variability of readership or of use? The table that a Census demographer will take in almost at a glance would take my youngest son two hours to understand — if then. To what extent can one generalize from results on one or two kinds of table, with one or two kinds of reader or viewer?

Now let us move a little further along this road to the text, the ordinary prose text, of a statistical — or a cartographic — report. Some authors seem to be much better at writing clear, communicative, interesting prose than others. Surely those are desirable characteristics, at least so long as clarity and interest are not used in the service of meretricious propaganda.

I recently ran across a relevant quotation from Tom Margerison (1965); he says "Report writing, like motor-car driving and love-making, is one of those activities which almost every Englishman thinks he can do well without instruction. The results are of course usually abominable." That's a funny, but perhaps an arrogant remark.

How do we really know what gets communicated, and what prose devices are superior to others? Who does careful empirical work on scientific prose — much less careful theory?

Here there are, I believe, starts towards the building of an empirical base: psychologists, linguists, and others have, I understand, been hard at work to develop empirical knowledge and some relevant theory about language. Presumably we have a long way to go, and I doubt that we will ever be able to put some tables in a computer, push a button, and have a finished standardized report come tumbling out.

Research into all these modes of display, exposition, and communication is enormously difficult. As Vincent Barabba says in a recent Census publication, no one knows how decision makers actually use or fail to use a graphic display . . . and I might add a numerical table or a prose exposition. Nor does anyone seem to know how scientists use graphs, tables, etc. for insight. One can safely venture the generalization that people use materials differently. Harold Lasswell said that

> ". . . a trained imagination is necessary before one can perceive with full vividness the significant events referred to in a table of figures, a map, or a chart. Our perceptions of current and past events are facilitated by the context provided by the concreteness of news stories, anecdotes, and personal observations. By contrast the charts, graphs, and tables that refer to the future lack support. This is a problem especially for nonspecialists, since, if laymen are to grasp the meaning of a technical communication, they must relay upon equivalencies with common experience." Lasswell (1959), p. 105.

I began with the title "Visions of maps and graphs" and I intended that in a double sense. First, I look ahead to great improvements in statistical graphics, cartography, tabulations, and other modes of quantitative communication. So that is one sense of vision. And second I think that such improvements must be founded in better knowledge of human perception and cognition, that is to say, if you will forgive the metonymy, a better knowledge of vision.

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General Session Papers

GENERAL SESSIONS

General sessions were held each morning to discuss general interest topics such as map models, map design and map generalization, as well as specialized cartographic applications.

MORTON A. MEYER, chief of the Census Bureau's Geography Division, discussed "A Geographic and Cartographic Program for the 1980 Census." To assign correct geographic identifications to the data provided from the major demographic and economic censuses is no small task. It requires accurate boundary information, up-to-date maps and effective data handling techniques. These requirements are met in part by the Bureau's Annual Boundary and Annexation Survey, the Metropolitan Map Series, and the GBF/DIME System. The Census Bureau is also exploring new techniques to facilitate the massive production requirements of the 1980 census and new mapping techniques to graphically illustrate the highlights of census statistical products.

GEORGE JENKS, of the Department of Geography of the University of Kansas, examined the deficiencies of contemporary map making. These deficiencies stem from several sources. Many cartographers often confuse the function of a statistical map with that of a statistical table. Secondly, many map makers do not adhere to the conventional symbology of thematic mapping -- the graphic language which has developed through centuries of cartographic experience. Thirdly, some statistical map makers do not sense the relationship between data processing and the fidelity with which their map portrays the information they wish to convey. And finally, too many map makers are either not trained in, or appreciative of, the subtleties of graphic communication; the subject matter should be presented with simple and clear graphic statements. Several examples were presented and contrasted; corrective procedures were suggested and some opportunities for improving statistical maps were proposed. Professor Jenks' paper, an abbreviated version of his presentation in Reston, also appears in The American Cartographer, volume 3, number 1, April 1976.

JAMES CORBETT, formerly with the Statistical Research Division of the Bureau of the Census, is responsible for the development of the theory underlying dual independent map encoding (DIME). In his paper "Topological Principles in Cartography" he set forth the mathematical foundation for modern automated cartography, based on relevant parts of topology and graph theory. The generality and future value of this theory were also discussed.

WALDO TOBLER has been with the Geography Department of the University of Michigan since 1961. His primary specialty is cartography and the development of computer methods, while his related interests are in the mathematical modeling of the geographical aspects of social processes. In his paper "Mathematical Map Models" he used examples to illustrate the mathematical model underlying only three classes of geographical map. The first model, a geometrical one, has a long history and is well known to cartographers. Some novel interpretations were demonstrated. The second model dealt with operations on a scalar function. Realizations of this model occur in the field of picture processing, and these can be applied to aerial photographs, to maps of topography, or to maps of population density. Illustrations were presented, using these topics, of the value of enhancement and degradation. A mathematical interpretation of these processes was given, and the roles of resolution and quantization were examined. The last example considered the case in which the cartographer is presented vector valued data, and a novel approach was again demonstrated.

ROBERTO BACHI was a professor of statistics in several Italian universities before organizing the Department of Statistics at the Hebrew University in Jerusalem, where he is currently professor of statistics and demography. He is the author of many books and papers on various topics of statistical methodology, general demography, social statistics, etc. He urged a reappraisal of the entire graphical field to insure that graphs and maps -- whose use is increasing due to growing demand and improved automatic production techniques -- meet proper scientific standards. The consequences of limitations of usual graphical methods should be evaluated and, as far as possible, eliminated or corrected. New methods should be developed to fill existing gaps. In his paper, "Graphical Methods for Presenting Statistical Data: Progress and Problems," he gave examples of proposals in this direction and discussed the possibilities of international cooperation in this area.

JOHN C. SHERMAN is a professor of geography at the University of Washington, Seattle. He has received various research grants and research contracts in the fields of cartography and geographic applications of remote sensing. His paper was entitled "Maps for the Visually Handicapped." There are two groups of persons for whom few maps are available. There are the partially-seeing and the legally or totally blind. He described the creation of two prototype maps and a new photo-mechanical system for creating tactual maps which is applicable to almost any graphic device and which preserves the opportunity to fully utilize automated procedures in their creation. Particular attention was given to dual use maps for those with restricted or no sight, as well as for those with normal sight.

JOEL MORRISON is an associate professor of geography at the University of Wisconsin-Madison, and Director of the University of Wisconsin Cartographic Laboratory. His primary responsibility and research field is thematic cartography. Dr. Morrison discussed the theory of map generalization with particular reference to the processes of simplification and classification. He suggested that a nonrigorous definition of generalization is of little use for making a map with computer assistance. He offered a more rigorous definition for the purpose of classifying the processes involved in map generalization. He attempted to show how these processes have been and/or may be implemented in practice, and to provide some insight into the economics of generalization algorithms relative to the total map preparation costs.

A GEOGRAPHIC AND CARTOGRAPHIC PROGRAM FOR THE 1980 CENSUS

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INTRODUCTION

Within the Census Bureau, the Geography Division has responsibility for the development and implementation of all geographic activities necessary to meet the requirements of Census Bureau programs. This includes the preparation of maps--more than a quarter of a million in total--needed by census enumerators during the conduct of the decennial census of population and housing; the development of geographic classification schemes, and geoprocessing and geocoding systems covering both economic and demographic census activities; the delineation of statistical areas for which the Bureau publishes survey and census data such as census tracts, census county divisions, "unincorporated places" and urbanized areas; the development and implementation of the GBF/DIME System (i.e., the Geographic Base (DIME) Files and the Metropolitan Map Series) to include all SMSA's designated by the Office of Management and Budget, and the extension of the system to provide for the geographic classification of decennial and economic census data; and the preparation of publication maps identifying statistical and political boundaries as well as maps displaying (in color) in thematic form data collected in the censuses.

The value of census data is directly related to the ability of the Census Bureau to classify data geographically. The total population of the U.S. (203,211,926 as of the time of the 1970 census) is an interesting number -- but not really useful. For the user, the important questions are where is the population located (What is its distribution?), how does a particular area relate to adjoining areas, to itself at an earlier time, and what are the characteristics of the population for the specific geographic area involved?

It is the job of the Geography Division to assign correct geographic identifications to the data provided from the major economic and demographic censuses conducted periodically by the Bureau of the Census. It is no small task. For example, between July 1, 1975 and June 30, 1980, the many geographic programs of the Bureau will probably entail the expenditure of more than 50 million dollars for cartographic operations, computer processes (including geoprocessing and geocoding) photographic and reproduction requirements, field surveys, development and maintenance of the GBF/DIME System and other Address Coding Guides, and, of course, the necessary accompanying administrative, professional and technical direction and clerical operations.

BACKGROUND

Thirty-five years ago the functions of the Geography Division of the Census Bureau were primarily those of map collection and map annotation. One description of the Division's activities in 1940 referred to its map holdings as being equivalent to 7 railroad box cars full of maps. These maps were used to delineate the approximately 250,000 administrative areas (enumeration districts) required for a door-to-door nationwide enumeration. The maps, as always, not only had to be up to date and accurate if the results of the census were to be correct, but since very few maps depict all of the political, statistical, and administrative boundaries that must be observed in a decennial census, the basic set of maps had to be manually enhanced by trained cartographers.

The mapping for these areas required that accurate boundary information be obtained for 3,070 counties, more than 48,000 minor civil divisions, more than 16,000 incorporated places, 435 congressional districts, and wards in cities of 10,000 population or larger. In addition, since census data were published for the several types of statistical areas delineated by the Geography Division, maps showing these boundaries had to be prepared also. And, of course, in addition to "input" maps (i.e., enumeration maps) there also had to be "output" maps, and a series of thematic and planimetric maps were prepared to accompany the published results of the census.

The basic elements of the mapping requirement still exist. The major difference is that since the 1940's much has happened to increase the importance of geography in respect to census data. One of the most important was the series of U.S. Supreme Court rulings commonly referred to as the "one man, one vote" decisions. The Court held that each congressional district and later each State legislative district, within a State must have substantially the same population-with the official population being determined to be that reported in a national census. The implementation of these decisions had the effect of requiring the census to report population counts for more and smaller areas than ever before specifically for use by State legislatures (or the courts) as the fundamental building blocks for defining legislative or congressional districts.

The "one man, one vote" dictum was not the only change which occurred during the 1960's and early 1970's that mandated the use of census data. The various laws which provided for "Revenue Sharing" establish Census Bureau data and Census Bureau geography as one of the basics upon which the funding entitlements of State and local governments are to be calculated. Although the specific requirements of these laws are not relevant to this paper, a listing of some (there are many others) of the legislation which requires use of Census Geography is of interest.

(1) The Federal-Aid Highway Act of 1973 (Public Law 93-87)

(2) The Housing and Community Development Act of 1974 (Public Law 93-383)

(3) The State and Local Fiscal Assistance Act of 1972 (Public Law 92-512)

(4) The Disaster Relief Act of 1974 (Public Law 93-288)

(5) Comprehensive Employment and Training Act of 1973 (Public Law 92-203)

(6) The National Mass Transportation Assistance Act of 1974 (Public Law 93-503)

In addition, numerous administrative guidelines refer to census defined geography because it offers an easy means of establishing the areal basis for the program at hand. These include environmental impact statements which use census tracts as a surrogate for neighborhoods and the use of census tracts as reporting units for welfare data. And most recently, local government economic and resource allocation programs and planning activities have brought a demand for census data for "locally defined areas" not heretofore considered a part of census geography. Thus, the Geography Division's program for 1980 is designed not only to meet the enumeration and tabulation needs of the Census Bureau, but is geared also to respond to the requirement of "outside" users. And this is as it should be if census products are to serve the statistical needs of the Nation.

MAP ACQUISITION

One of the basic activities of the geography division is the acquisition of accurate geographic information. We obtain from the major public map making agencies such as the United State Geological Survey, Defense Mapping Agency, Bureau of Land Management, and the State Highway Departments a continuous flow of up-to-date mappings. We also receive current maps from regional planning agencies, councils of government, and local agencies of government. In addition, we are now undertaking a comprehensive review of our complete file of map holdings to identify areas where better quality and more up-to-date maps are required and will seek new sources of maps for these areas.

But, as you know, no mapping program, no matter how comprehensive, can keep pace with the dynamics of growth and change. In the past we attempted to solve this problem by waiting until near the end of the decade to acquire the maps for the census and thus obtain the most recent maps available. This "end-of-decade" system met its end with the 1960 census as it was unable to meet current program needs. Useful Address Coding Guides and GBF/DIME-Files (more about these later) demand current maps. And, obviously, revenue sharing allocations cannot be tied to the mapping needs of census programs which occur once every 10 years.

To help meet Bureau needs in this area, the Geography Division has developed two major programs. These are the Metropolitan Map Series and the Boundary and Annexation Survey programs.

THE METROPOLITAN MAP SERIES (MMS)

Prior to 1960, major problems were encountered in the mapping of metropolitan areas as the only maps available consisted of a melange of place and county maps of varying scales and widely varying quality. Often place boundaries appearing on separate maps would not agree and the location of conjoint corporate boundaries would vary depending upon the particular place map being used. Streets continuing between communities would not match. The need for a standardized series of census maps could no longer be denied and the development of the Metropolitan Map Series (MMS) began.

MMS maps, which use a basic scale of 1" = 1600', are derived from the USGS quadrangle maps. The quads are divided in half along their east-west axis and from each half-quad a final map sheet 18x24 inches (45x60 centimeters) in size is produced which covers an area approximately five by seven miles (8.0 by 12.9 kilometers). (For areas of little urban density, multiples of the USGS quads are used to produce maps at scales of 1"=3200' and 1"=6400'.)

Over 3,500 MMS maps covering some 110,000 square miles (285,300 square kilometers) were prepared for 1970. As of today 500 additional MMS map sheets have been completed and 2,500 more are in various stages of preparation. The eventual goal of the program calls for preparation and maintenance of a total of some 14,000 MMS maps.

THE BOUNDARY AND ANNEXATION SURVEY

The need for maintaining an up-to-date file of municipal boundaries on a continuing basis resulted in the Bureau's inaugurating on January 1, 1971, the first of its now annual Boundary and Annexation Surveys. This Survey is designed to monitor changes in boundaries for all incorporated places of 2,500 or more population as well as identifying all new incorporations, mergers and disincorporations, regardless of the size of the place involved.

In addition to serving the needs of Census Bureau programs, one of the purposes served by the Boundary and Annexation Survey is the measuring of changes in population which take place as a result of annexation activity as such changes may affect the revenue sharing funding entitlements for the place concerned. Similarly, information on new incorporations, disincorporations, mergers and/or consolidations of political entities, and municipalities annexing into adjoining counties, impacts not only upon the General Revenue Sharing Program but other Federally funded and state funded programs as well.

At the time of the 1970 census, there were nearly 5,300 incorporated places of 2,500 or more inhabitants in the United States with a total population of more than 121.7 million. In the last 4 years, these places have reported over 23,600 annexations; 329 detachments and 61 other types of boundary changes.

Based on estimates provided to us by the local governments concerned, these annexation actions indicate that over 3,500 square miles of land and over 1,500,000 persons have been added to cities of 2,500 or more inhabitants since 1970. During this same period, 321 new municipalities have come into being, 61 municipalities have dissolved and 23 mergers or consolidations of cities have taken place. Extrapolated to 1980, these represent changes of considerable significance and magnitude.

Many more communities exist with populations under 2,500 persons than over - and all of these must be enumerated in a census. Therefore, in January 1977, a major expension of the Boundary and Annexation Survey will take place in preparation for the 1980 census. All incorporated places, regardless of size, will be included in the program so that accurate and current boundary maps can be obtained for all places. In total, approximately 12,000 places will be added resulting in more than 18,000 places being surveyed annually.

DELINEATION OF STATISTICAL AREAS

Supplementing "legally" defined areas are the statistical areas for which the Bureau also provides data. As defined by the Geography Division, they are the following:

(1) Census Tracts: Census tracts, which were first used in the 1910 census, are the most numerous of the statistical areas. (Approximately 37,000 have been delineated to date.) They are established by local committees (whose memberships embrace a wide spectrum of data users) following Census Bureau specifications. On the average, tracts are designed to contain about 4,000 persons so that small geographic area analysis can be provided. Basic to the tract program is the relative permanence of tract boundaries so as to make possible measurement of changes taking place over time for identifiable subcity level geographic areas. Some tract changes must and do occur to keep pace with changes in a city's growth and spatial organization, but insofar as possible this is accomplished by splitting existing tracts into two or more parts rather than changing their boundaries.

The census tract program centers on metropolitan areas and it is our goal to completely tract all new SMSA's, new areas added to existing SMSA's, plus as many of the potential 1980 SMSA's as possible, by late 1976. In addition, we will conduct a review of the existing tracts for their continued utility as statistical units. All of this work is being carried out with the wholehearted (and welcomed) cooperation of the Census Statistical Areas Committees (formerly the Census Tract Committees.) The work involved is considerable; we anticipate that 40,000 or more tracts will be defined and mapped for the 1980 census.

Further, as part of the Bureau's continuing effort to provide users with more and better information, we have recently requested the Census Statistical Areas Committees to supplement their historic role of establishing and maintaining census tracts also assisting the Bureau in meeting the demands being placed on it for more comprehensive delineations of small area geography. Among these is the development of standardized groupings of tracts for which aggregate statistical data not now available for sub-city areas--such as data from the 1977 Economic Censuses--could be tabulated by the Bureau. Such standardized tract groupings may meet a variety of local needs not now served by census statistics.

(2) Census County Division (CCD's): In 21 states where the minor civil divisions (usually townships) had proved to be unsatisfactory data reporting units either because of frequent (sometimes yearly) boundary changes or because they were neither used nor recognized locally, census county divisions have been established. In many ways these serve as the rural equivalents of census tracts and are based upon market or service areas, delineated around identifiable centers of population within each county. CCD's are established with local cooperation and formal approval of the Governor's Office for the State concerned.

To date, 7,068 CCD's have been defined. More are anticipated for 1980 and work is, in fact, now underway to establish CCD's in the States of Maryland, Virginia, North Carolina and South Dakota which have recently expressed an interest in the Bureau's CCD program. CCD's are defined in conjunction with the tract program and (where possible) in SMSA's and other counties with tracts, CCD's are composed of groups of whole tracts. To some extent the functions of CCD's and tracts are overlapping and the CCD program is being reviewed with the thought of possibly utilizing in tracted areas aggregated tract information, as described above, instead of defining CCD's. Consideration is also being given to providing more statistical data for CCD's, particularly, for those of substantial population.

(3) Unincorporated Places: In many areas of the Nation, relatively large groups of people reside in communities which are identifiable by name and recognized locally even though they do not have any legal status. Locally, they represent important centers of population which have much the same characteristics as municipalities of similar size. As a means of identifying the populations of these areas, and publishing statistical data for them, the Bureau early developed the concept of "unincorporated" places. The communities so designated are those with a population of 1,000 or more (5,000 or more within urbanized areas) and a population density generally in excess of 1,000 persons per square mile.

The "statistical" boundaries for these places are delimited by State Highway Departments, by the Census Statistical Areas Committees, and by local agencies of government in accordance with Bureau developed specifications. It is not always easy to identify these population clusters and in the hope that improvements in their detection will result, research is currently underway to determine whether they can be successfully identified by satellite imagery. If so, this would provide, for the first time, a uniform method of locating all "unincorporated" places, nationwide.

Once unincorporated areas have been delimited and named, no distinctions exist between them and legally defined places as regards either the enumeration of the census or the tabulation of the collected statistics. As with incorporated communities, unincorporated places with populations of 2,500 or more are classified as urban, those below 2,500 as rural. Unincorporated places also meet the test of being "census defined places" as called for in various pieces of Federal legislation and are also places of record for the purposes of defining SMSA's and urbanized areas.

Interest has also been expressed in the possibility of defining unincorporated places down to populations of 500 rather than 1,000 and the Bureau is looking into this possibility. Costs, rather than technical considerations may be the deciding factor.

(4) Urbanized Areas: The fourth statistical area defined by the Bureau is the urbanized area. In general terms, an urbanized area consists of the central city of an SMSA and surrounding contiguous territory which has a population density in excess of 1,000 persons per square mile. The original purpose for this concept was to provide a means for more accurately and realistically defining the urban populations

which exist around the central cities of the SMSA's, as well as to obtain more accurate measures of the extent of urbanization for individual areas. Since that time, the urbanized area concept and the populations of urbanized areas have been recognized in Federal legislation as a means of determining funding eligibility, identifying the source of the funding, and for calculating the amount of the funding entitlement.

Although the specifications for defining an urbanized area are too lengthy to be included here, they involve dividing the territory surrounding central cities into very small geographic areas and examining each one to determine whether it meets the criteria for inclusion in an urbanized area. In 1970, more than 30,000 such reviews were undertaken and unless improvements in technology can be made, even more areas will need to be defined for review in 1980.

To improve the methodology for defining urbanized areas, research is being undertaken by the Bureau and NASA jointly to explore the use of LANDSAT multispectral data for this purpose. Briefly discribed, we are attempting to define the approximate limits of an urbanized area from remotely sensed reflectance characteristics of the urban landscape and thus limit, substantially, the number of small geographic areas that would otherwise need to be mapped and reviewed - with considerable gains in efficiency, economy, and timeliness.

LOCAL GEOGRAPHIC NEEDS

The traditional geographic classifications provided by the Census Bureau, State, county, place, SMSA, census tract, urbanized area, unincorporated place, etc., may not be sufficient to meet the needs of State and local governments in the 1980's. For example, bills have been introduced in the Congress which would require the Census Bureau to provide data by election district (provided that States delineate election districts 3 years in advance of the 1980 census and follow Census Bureau specifications requiring the boundaries to observe visible physical features).

Similar interests have been expressed as regards data for school districts, planning districts, health areas, and other locally defined areas, each of which, by and large, demands a unique set of boundaries. The extent to which all of these needs can be met is as yet unknown. But it seems fairly certain that showing all the boundaries on a single map produces a clutter of overlapping polygons which cannot be followed by an enumerator and makes the map impossible to use as an enumeration control. We believe we have solved the problem in urbanized areas through the use of the Geographic Base (DIME) Files (GBF/DIME). We are examining the possibility of utilizing radio navigation techniques (LORAN-C) as a possible solution to the problem in rural areas.

THE GBF/DIME SYSTEM

As I have noted earlier, the geographic accuracy of any census is a function of the accuracy of the mapping and geographic classification (geocoding) operations. In door-to-door enumeration areas, the operation is relatively straightforward. Give the enumerator an accurate map, check to make sure the limits shown on the map are being followed on the ground by the enumerator, and establish procedures to guarantee that all questionnaires obtained by that enumerator are geocoded to the correct geography. But what do you do when there are no enumerators? When the enumeration of a substantial portion of the Nation's population is carried out by mail? The answers led to the development of entirely new geoprocessing techniques. Mail enumeration (which covered some 60 percent of the U.S. population in 1970) was utilized in those areas wherein each housing unit could be uniquely identified through its address (i.e., street name and house number) as all such addresses can be precisely located geographically. The tool which made possible the precise location and thus the geographic classification of street addresses was the GBF/DIME-File.

Essentially, a GBF/DIME-File is a computerized description of the street and non-street features of the Metropolitan Maps supplemented by (1) an inventory of the address ranges between the street intersections, and (2) a set of geocodes which describe the geographic location (state, county, congressional district, municipality, census tract, census block, etc.) of each address range. Once every address range was identified geographically, the next step was the development of computer techniques which could match the address of each of the individual housing units included in the decennial census mail enumeration areas to the corresponding address ranges of the GBF/DIME-Files. Thus, for every mail address, a complete set of geographic classification codes could be accurately determined.

The GBF/DIME-File can be described very simply. However, because extreme accuracy was called for (errors in either the address range or geographic code assignments could create major errors of geographic classification) the preparation of the file was an extremely laborious undertaking. To help guarantee the accuracy of the file, local agencies of government were called upon by the Census Bureau to review, correct, and update the information content of the GBF/DIME-File as it applied to their particular geographic area.

It need not be said, of course, that the Metropolitan Maps and GBF/DIME-Files as they were prepared for the 1970 census, if left unchanged, would be completely out-of-date and unuseable by 1980. The dynamics of city growth and socio-economic change rapidly modify street patterns and political and statistical boundaries. To avoid this obsolescence, local agencies of government (primarily councils of government and regional planning agencies) are once again participating with the Census Bureau in a program designed to Correct, Update, and Extend (the CUE Program) the coverage of both the Metropolitan Maps and the GBF/DIME-Files. At the present time, the CUE program is ongoing in approximately 180 SMSA's. The eventual goal of the program is to establish an up-to-date GBF/DIME System in all SMSA's (currently numbering 276) throughout the Nation.

Beyond Census Bureau requirements, local agencies have their own interest in the CUE Program. The Geographic Base (DIME) File provides a "framework" through which address relatable data which have been too voluminous or geographically complex to analyze, can now be organized and mapped and thus made usable and understandable to those in decision and policy making positions. Current local uses being made of the GBF/DIME System capabilities include analysis of the spatial distribution of criminal activity, transit planning, distribution of building permits, car pool planning, and distribution of school children by school of attendance, among others. Future uses of the GBF/DIME System are limited only by the imagination of the user.

I am pleased to note at this point that the Census Bureau is now able to assist local agencies of government financially as they participate with the Bureau in the development and update of the GBF/DIME System. Through the use of Joint Statistical Agreements approximately $900,000 will be available during this fiscal year to help local agencies meet the costs of Bureau mandated GBF/DIME/CUE activities. More will be available in succeeding years.

PUBLICATION MAPPINGS

One of the important outputs of the Census Bureau are the thematic maps which illustrate the highlights of the census' statistical product. Some of these maps accompany the published census reports. Others, such as the GE-50 series, are large, wall-size maps, printed in color and suitable for classroom instruction and display purposes.

We have not, in the past, produced as many publication maps as we wished simply because the time and cost restraints were prohibitive. The future, however, looks brighter because we now believe that these restraints have been largely overcome through new mapping techniques which the Geography Division has pioneered. Basically, the system employs micrographics with the map outputs being produced under computer control. We use micrographic techniques to produce 35mm open window negatives from which, after enlargement, full color or black and white maps can be produced. Essentially, our system combines the rapid and accurate manipulations of a computer with the traditional photo processing techniques common to most cartographic work. This capability has allowed us to quickly meet requests for specific maps to illustrate the spatial relationships of complex data. Some of the maps we have been producing show the relationships between two variables on the same map through the use of a 16 color matrix. The 1969 Census of Agriculture Graphics Summary, and the new series of 1970 Census Urban Atlases are current examples of our product. The 1980 census will see the first full use of this capability.

I would be remiss not to add that many local governments are also automating their mapping outputs and by utilizing the network (coordinate) features of the GBF/DIME-File are able to display the spatial relationships of local data distributions.

NEW HORIZONS

A geographic processing concept that is now being researched by the Geography Division involves the arrangement of the basic census data files in geographic coordinate sequence. Such an arrangement would, in effect, permit the individual census records to be embedded in a geographically unrestricted data base from which data for any defined geographic area (whether defined by the Census Bureau or by a local agency of government) could be aggregated. The entry key into the data base would be longitude-latitude coordinates and (within the constraints required to guarantee the confidentiality of individual census data) tabulations could be provided for any area which could be described in a longitude-latitude coordinate system.

In metropolitan areas, the GBF/DIME-File -- since it includes coordinates for every street intersection -- provides the basis for an automated and accurate means of defining any desired geographic area. Outside the area of GBF/DIME coverage we are, as noted earlier, testing the utility and practicality of the Coast Guard LORAN-C system to provide geographic coordinates for each block in rural towns and for each housing unit in the rural countryside.

We have demonstrated that we can locate the position of a housing unit in a rural setting through the use of LORAN to within 120 feet of its actual location with only a 1% chance that the unit is actually located further away. I should, of course, quickly add that coordinate identification is only part of the answer. A LORAN system would also require the development of digitized boundary files for the smallest geographic area for which census data is tabulated. Not the easiest of undertakings. But the Geography Division has just acquired a large scale interactive digitizing and coordinate editing system for its GBF/DIME program. This same equipment can also be used to develop the more extensive digitized inputs needed for geographically ordered files.

It is not likely that LORAN-C techniques will become operational in time to meet the massive production requirements of the 1980 census. But we do expect, as a part of the census, to be able to test the system in real time and in a real environment. Coordinate identification systems may in the long run prove to be the only feasible technique for meeting data requirements for areas not identified through the standard hierarchical arrangements of census geography, such as school districts, neighborhoods, watersheds, proposed legislative districts, planning areas and the others referred to earlier.

SUMMARY

I have attempted to provide a brief overview of the increasingly complex world of census geography. We now routinely provide services and capabilities that were neither required nor asked for in the past. But in reality, our work has just begun. We look forward to being able to provide better census geography and we would like you to help us. Your ideas, comments, and suggestions as to how we can best meet our goals are more than welcome and will be of benefit to all.

CONTEMPORARY STATISTICAL MAPS
EVIDENCE OF SPATIAL AND GRAPHIC IGNORANCE

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INTRODUCTION

Maps are windows into the minds of their creators and, if one peeks into these inner recesses, evidences of spatial and graphic ignorance become readily apparent. An inspection of a jumble of statistical maps taken from magazines, newspapers, professional journals and governmental reports gives rise to the following semantic range of contemporary map qualities: 1/

communicative/secretive
clear/indistinct
directed/haphazard
decorative/useful
simplistic/complex
pleasing/ugly
accurate/erroneous

What do these polar adjectives imply about modern statistical maps? 2/ First, there is a confusion in the minds of many cartographers as to the function of a statistical map. Second, the graphic language, or the conventional symbology of thematic mapping, which has been developed through centuries of cartographic experience, is not part of the vocabulary of many map makers. Third, some statistical map makers do not seem to sense the relationship between data processing and the fidelity with which their map portrays the information they wish to convey. Last, too many map makers are either not trained in, or appreciative of, the subtleties of graphic communication. In this paper these deficiencies of contemporary statistical map making are examined, corrective procedures are suggested, and some opportunities for improving statistical maps are proposed.

WHY MAKE STATISTICAL MAPS?

If one raises the question, Why make statistical maps?, he poses the query because he assumes that there is a logical need behind each cartographic display. Additionally, since statistical maps are often included in a larger work, one can also assume that there is something about a map which makes it more useful than words, tables or graphs in the transfer of certain types of information. The enormous utility of a statistical map can easily be demonstrated if the reader will refer to Table 1, a typical censual map of enumerated data. 3/ Attempt to describe the spatial information contained in these tables. Most readers, even if provided with a base map (Figure 1) are unable to integrate areally the twenty-nine cropland acreage values given in the table. Furthermore, if the reader is provided with an "areal table" (Figure 2), he will still find it difficult to perceive "in his mind's eye" the distributional characteristics of cropland acreage in Utah.

Table 1

Cropland Acreage, by Counties, Utah, 1969

Beaver	29,917	Piute	15,302
Box Elder	360,571	Rich	66,550
Cache	176,926	Salt Lake	69,415
Carbon	14,692	San Juan	91,299
Daggett	8,106	Sanpete	98,029
Davis	40,946	Sevier	52,320
Duchesne	96,035	Summit	38,218
Emery	48,344	Tooele	39,643
Garfield	23,714	Uintah	93,023
Grand	3,132	Utah	139,987
Iron	65,973	Wasatch	20,116
Juab	77,275	Washington	33,650
Kane	11,215	Wayne	17,642
Millard	151,319	Weber	44,690
Morgan	16,527		

What then is the function of a map and particularly a statistical map? Simply, it is to provide the reader with a graphic display of information in such format that it promotes a conceptual relationship with spatial arrangements on the surface of the earth. The information communicated by a map may be the distance or directional relationships among things, the pattern of objects in space, or the shape and location of a region such as the Corn Belt. Very few readers of the information presented in Table 1 are able to perceive the geographical patterns and spa-

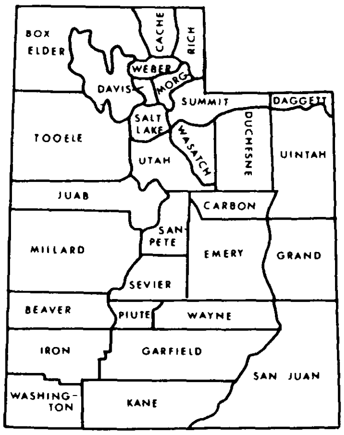

Figure 1: This base map of Utah provides the geographic network upon which a variety of statistical maps of the State can be formulated.

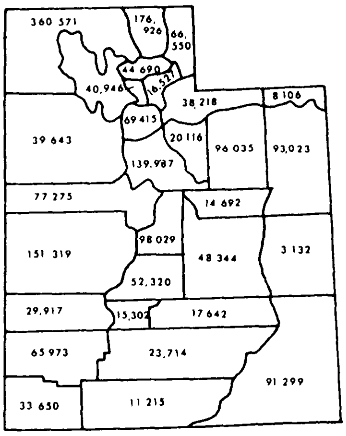

Figure 2: An areal table differs from a map in that it does not provide the reader with a graphic visualization of a distribution. Most readers are unable to integrate the numerical values on this table into a meaningful spatial pattern.

tial relationships of cropland acreages which are so clearly set forth on the map in Figure 3.

Contemporary map makers often confuse the primary purpose of a statistical map with that of a table. As a result they attempt to provide the reader with specific facts about specific places. Usually these attempts are no more successful than those achieved by inventors who have tried to create a hybrid between the automobile and the aircraft. There are two dominant reasons why authors ought not to confuse cartographic and tabular utility. The first, and most obvious, is that statistical maps are symbolized generalizations of the information contained in a table. Statistical maps tend, therefore, to be inefficient and inaccurate sources of data. For example, it is not easy to count the dots on Figure 3. Furthermore, each dot on Figure 3 represents five thousand acres, and in processing the data into symbols the map maker was obliged to round off the specific values given in the table. This procedure may create errors of as much as two thousand and forty-nine acres in some parts of the map.

A second, and geographically more sinister error is involved in attempting to provide the dual function in a statistical map and is illustrated in Figure 4. Most readers are thought to be unfamiliar with the geographic base information of an area and thus the cartographer feels that he must provide boundaries and names to assist his reader in obtaining data from the map. Thus, a portion of the map surface is occupied with lines and words prior to symbolization. This generally results in spatial patterns of symbols which are not properly related to earth position. What you really see on the map in Figure 4 is a combination of the patterns created by past historical-political decisions and a spatially erroneous display of cropland acreage.

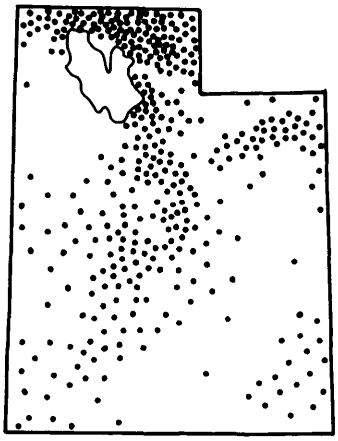

Figure 3: A dot map of the enumerated data presented in Figures 1 and 2. Each dot represents 5,000 acres of cropland and is placed in the approximate position of where that amount of cropland exists in the State of Utah.

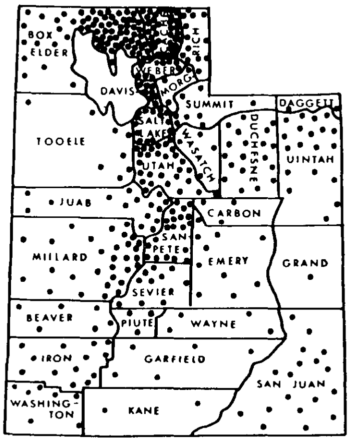

Figure 4: A dual purpose dot map of cropland acreage in Utah. This map provides the reader with rough acreage figures if he elects to count the dots but the spatial pattern of the distribution is confusing because the county names and boundaries interfere with the more accurate areal patterns shown on Figure 3.

Statistical maps have also been used for purposes other than those just described. If one reads the textual material associated with statistical maps, it becomes apparent that some authors use maps only for decorative purposes since no reference is made to the significance of the map message either in the caption or the exposition. Other authors seem to use maps as badges of membership in the fraternity of scientists and these individuals also ignore the map as a communicative device. If an author or a map maker is not primarily concerned with those unique spatial relationships which can best be illustrated in map format, some device other than a map ought to be utilized to communicate his concerns to his reader.4/

THE SYMBOLIC LANGUAGE OF MAPPING

The statistical maps found in contemporary literature are the products of a heterogeneous lot of individuals who are grouped together because of the function that they perform rather than because of the training that they have received. In one way, this diversity of academic experience and methodological outlook is advantageous because new informational concepts and types of statistical maps are produced. In another way it is disadvantageous, however, since many of these cartographers do not know the symbolic language of their trade. A review of the accepted practices in the use of map symbols and a common error in presentation are discussed in the following paragraphs.

In general, there are five types of symbols which are used to present information on statistical maps and each symbolic form has been assigned a particular function in thematic convention. Point symbols, e.g. dots, are used to represent phenomena which occur singly at points on the surface of the earth. Typically one finds population, either human or animal, and crop acreages represented by point symbols. Proportional symbols, e.g. circles, are used to present clusters of things which occur in very limited areas. The population of cities or the value added by manufacturing may be symbolized in this way. Area symbols are used to represent spatial phenomena which may be considered to be evenly distributed over the area. Due to this assumption, it is common practice to represent ratios with shading patterns. Lastly, we find certain phenomenon which occur ubiquitously on, above, or below the surface of the earth. Air pressure or elevation are distributions of this type and their configurations are represented by isarithms of which the contour is most common. Each of these symbolic types can be varied in color, size, shape and texture so that a very diversified array of marks is available to the cartographer. 5/

While there are no absolute rules for symbolic conventions, the statistical cartographer is well advised to practice recommended usage. Each mappable phenomenon has distinctive geographical characteristics and an understanding of these is the basis upon which symbolic conventions were established. It is also clear that many map users expect certain types of phenomenon to be depicted in a certain manner and if the symbolic language of the map coincides with the expectations of the reader the impact of the map message occurs more rapidly and with fewer aberrations than would be the case otherwise.

The two contrasting maps shown in Figure 5 illustrate the significance of failure to follow symbolic convention. The two maps communicate very different spatial messages but both were derived from the same cropland data used for the dot maps of

Figures 3 and 4. At least part of what is seen on map A results from the simple fact that large enumeration districts tend to have large numbers of things and small districts tend to have small numbers of things. If one flew over the State of Utah and observed cropland patterns he would perceive regions with a large proportion of cropland as distinct from regions with widely dispersed field patterns. His impression of the distribution of cropland would, therefore, be more like that shown on map B than on map A of Figure 5. It then follows that acreage and similar types of data should be areally standardized by the cartographer in order to present a truthful visual statement on his choropleth map about those distributions, the enumerations of which are directly related to the size of the enumeration units. 7/

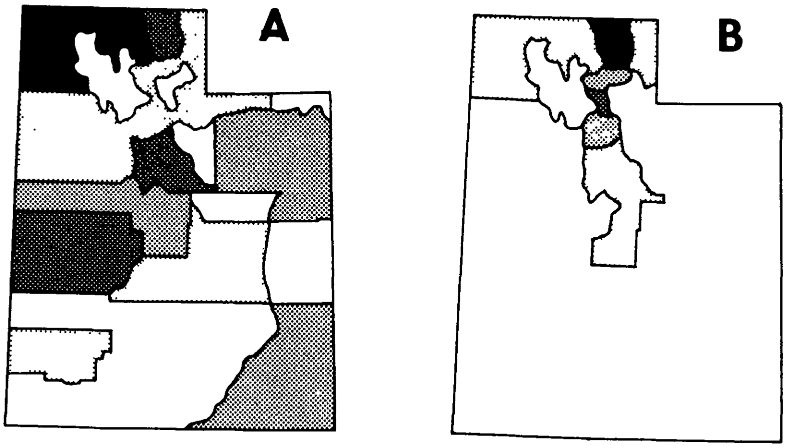

Figure 5: These two very different maps were created from the same data set, Table 1. Map A is a five-class representation of the raw enumerated data. The dark gray county in the middle of the western side appears to be more important, because of its size, than the dark gray county along the northern border. In Map B data were areally standardized before they were symbolized, and the visual importance of the two counties mentioned above has been reversed. The patterns on Map B more closely represent reality than those on Map A.

MAP ACCURACY AND DATA PROCESSING

Cartographers in survey mapping establishments take great pride in the high level of accuracy that they incorporate into their maps. Anyone who has visited a topographic mapping organization has no doubt been made aware of the care with which the contour and cultural data were measured, symbolized and plotted on the topographic sheets. This is as it should be, but this concern for positional and elevational accuracy has caused some thematic map makers (as well as the general public) to believe that their maps are equally accurate. This is an unfortunate circumstance because some statistical map makers, having taken great care in the arithmetic manipulation of their data, fail to realize that other types of significant error may creep into their map products.

In 1971 Joel Morrison introduced the term, "method produced error". 8/ This term was used to distinguish decision-making errors from arithmetic errors in the cartographic process. The two maps presented in Figure 6, although both arithmetically accurate and symbolically correct are quite different in appearance. This difference in map message is not related to the number, orientation or values (tones) of the symbols on the map nor is it related to the scale at which the maps were prepared. Instead, the difference in message is the direct result of the method used to subdivide the twenty-nine values (percent of land in cropland) into four classes. Quartile classes were used on map A while the classes on map B were derived by an optimizing technique. How can two arithmetically and computationally accurate maps produce such different distributional patterns?

Cartographers often face a choice like that posed by the two maps in Figure 6, and of necessity, they must select one to place before their readers. Too often the selection is made intuitively, but if one turns to traditional statistics, the problem can be resolved more rationally. Ideally, the cartographer should select the representation which minimizes the differences within classes and maximizes the differences between classes on his map, and this can be measured by analysis of variance. Application of this measure to the maps in question reveals that the within-class variance of map A is 2,524 while that of map B is 940. These values, when compared with the total variance of the data set, indicate that map B is ninety-four percent accurate while map A is only eighty-three percent accurate. With this information there is no problem in deciding which map should be used.

Statistical maps are considered to be poor data retrieval sources but many census map makers believe that the average map reader will use a map as a data bank. If their assumption is correct, and it has not been proven otherwise, the choice of classification procedure becomes critical. The standard error of the estimates for the maps in Figure 6 indicate that on the average a value obtained from map A will be in error 9.3 percent while a value obtained from map B will be in error 5.7 percent.

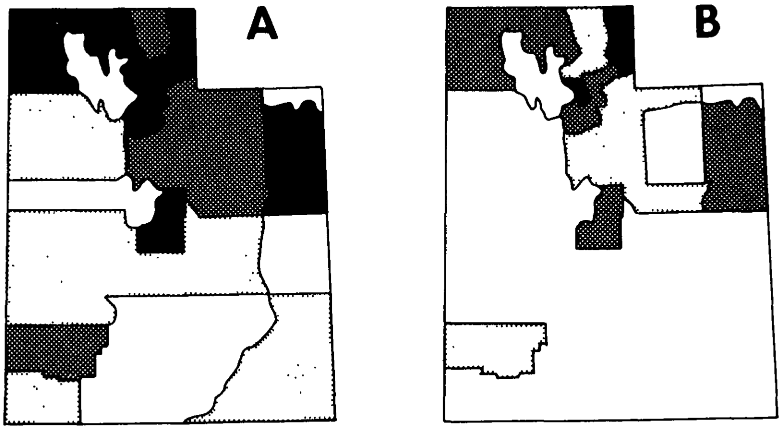

Figure 6: Two maps are different versions of one distribution, the percent of area in cropland in Utah. The classes for Map A are quartiles while those for Map B were created by an optimization technique. Eighty-three percent of the total variance is accounted for by the classes in Map A and ninety-four percent by those in Map B. Thus, Map B is the more accurate map.

AESTHETICS AND MAP COMMUNICATION

The message of a map is communicated to the reader by a process of visual integration in which the characteristics of individual symbols are subjugated to the perceived patterns of sets of symbols. Recognition of this map reading procedure is essential in cartographic design because size, color, texture of symbols must be considered on two bases. In the first instance each symbol must be identifiable. In addition, each symbol must be compatible with all other symbols since they must work together to create a visual whole. Failure to recognize symbolic identifiability and compatibility results in map messages which are complex and "noisy" rather than simple and clear.

Several graphic principles are of concern to the cartographic designer. Figure and ground must be separated clearly so that the major symbols which present the distribution can be seen as distinctly different from those lesser symbols which may be necessary to the purpose of the map. Poor figure-ground relationships are demonstrated on the map presented in Figure 4 where, in addition to areal misplacement, the dots become visually confused with the boundary lines and the county names. A second aspect of figure-ground relationships is shown in Figure 7 where lack of contrast on map A subdues the map message which becomes clear and distinct on map B.

Many of the most confusing and displeasing maps to be found in contemporary literature are those which are symbolized with self-adhesive shading patterns. These patterns are available in a variety of styles, textures and values and they can be applied in all of the orientations of the compass. The patterns used on map A of Figure 8 are so coarsely textured that they are visually unstable. Compare this map with those shown in Figure 6 and there is little doubt as to which are easier to read and more pleasant to look at.

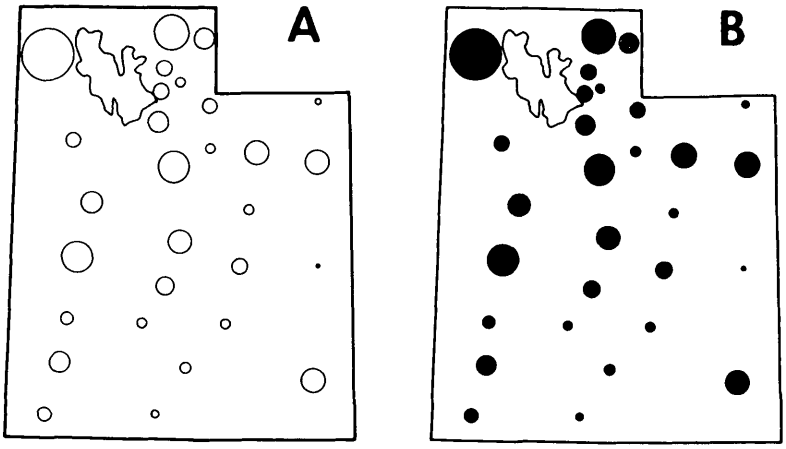

Figure 7: Minimal (Map A) and maximal (Map B) contrast between figure and ground. Map B is a clearer and more forceful visual statement than Map A.

At first glance, the reader of map B in Figure 8 might conclude that he is looking at a two-class map but in reality it is a four-class map. A single pattern is used for classes one and two and another for classes three and four and the only visual difference between these pairs of classes results from pattern orientation. This makes the task of the map reader more difficult than would be the case were the patterns also separated by visual differences in value. The intersection of the lines in these rather coarse patterns with the boundary lines of the regions causes a degree of noise on this map that could be reduced by decreasing texture.

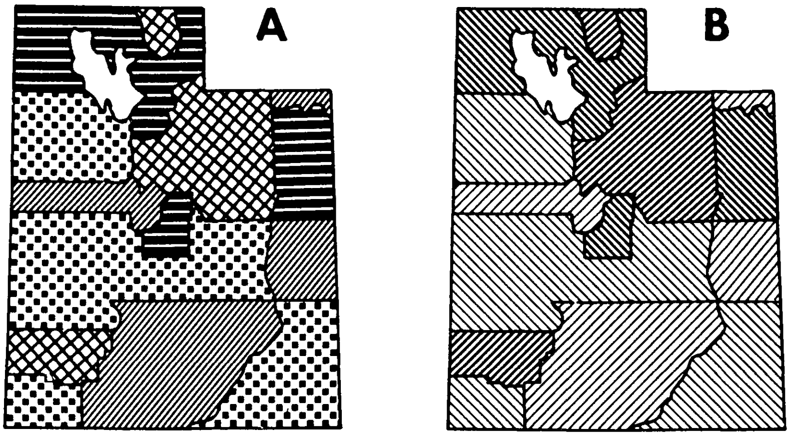

Figure 8: Two aesthetically unpleasant and visually unstable choropleth maps. The pattern is so coarse that they "dance" before the reader's eyes.

To paraphrase a current television commercial, statistical cartographers should prepare maps which are in "good taste." Great works of art like the Mona Lisa or Venus de Milo are appreciated because their creators presented their subject matter with simple and clear graphic statements. Statistical map makers would do well to remember and emulate these artists when they design their maps.

A LOOK INTO THE FUTURE

Rudolph Arnheim in his book, Art and Visual Perception, states that gestalt psychologists believe that "any stimulus pattern tends to be seen in such a way that the resulting structure is as simple as the given conditions permit." 9/ If this concept is applied to the perception of maps, one can assume that complex patterns of symbols are perceived as simplified or generalized patterns. Carrying the idea further, the simplified patterns that are perceived must be those that are remembered and later utilized when the reader wishes to recall the informational content of the map. These notions raise a very important question about map communication. Do all (or a majority of) map readers visually simplify a pattern of symbols in the same way and thus obtain and remember the same map message?

Current research in map communication seems to indicate that messages obtained from maps may have an individualistic and highly personalized informational content.

As a case in point, study the three maps presented in Figure 9. 10/ The center map (B) was shown to a group of individuals who a short time later reconstructed what they had seen and remembered. The response maps on the left and right (A and C) indicate that the readers obtained both an aberrant and a different spatial message. Research cartographers are unable to explain why these response maps are different, nor are they sure whether these responses represent extreme cases of map reader diversity. This example makes one wonder whether research cartographers can depend upon map reader generalization. Perhaps the map designer should take the initiative and create the simplifications he wishes to communicate.

Traditional map makers may think that such manipulation of the map message is an abhorrent misuse of cartographic prerogatives and akin to preparing propaganda. Upon further contemplation, however, we realize that speakers and authors select words, create phrases, and structure paragraphs to suit the message that they are attempting to communicate. Should cartographers be denied the same privilege?

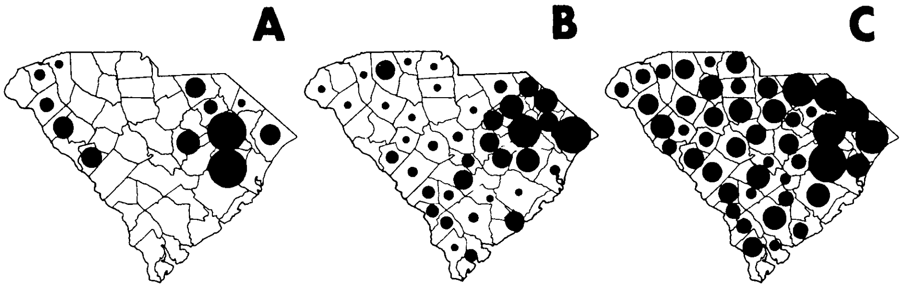

Figure 9: Map B was shown to a group of freshman college students and later these students were asked to reconstruct from memory what they had seen. Maps A and C are two of these memory reconstructions and they are both very different from the original (Map B) and from each other. This experiment raises serious questions about the efficiency of maps as tools for the communication of spatial information.

RESUME

A number of rather pernicious impressions about statistical maps and the cartographers who create them have crept into the minds of the public. It has been the objective of this paper to help dispel these notions and to provide alternative ways of looking at maps and their creators. The following statements summarize these attempts.

- Statistical maps are not good sources of specific information about specific places.
- Maps are created to provide information about spatial relationships. No other medium communicates distance, directional and areal pattern relationships as well.
- There is a symbolic language of mapping and good maps can be created only by those who understand it.
- Accuracy in cartography involves conceptual as well as arithmetic

precision in data handling.

- Maps are graphic communicators and clear and concise map messages result from easily read, clear rather than noisy maps.
- Communication via the map is not perfectly understood and there is need for continued research if we are to create more effective maps.

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2. Statistical maps are not necessarily products of statistical inference; rather many statistical maps are two-dimensional graphic representations of enumerated data obtained by censual procedures.

   This paper is an abbreviated version of an oral paper presented at the International Symposium on Computer-Assisted Cartography (Auto-Carto II), sponsored by the American Congress on Surveying and Mapping in cooperation with the Bureau of the Census.

3. The data presented in Table 1 and that used for other maps of Utah were taken from Utah Agricultural Statistics 1975, Salt Lake City:Utah State Department of Agriculture, pp. 86-7. Map makers frequently array these types of data in sequential order as a preliminary to processing the figures into categories for symbolization.

4. For a more sophisticated analysis of maps as communicative devices see: Robinson, Arthur H., and Barbara B. Petchenik, "The Map as a Communicative System," The Cartographic Journal, vol. 12, No.1 (June 1975), pp. 7-15.

5. Also see Robinson, Arthur H., and Randall D. Sale, Elements of Cartography, 3rd edition, New York: John Wiley and Sons, 1969.

6. Dobson, Michael W., "Symbol-Subject Matter Relationships in Thematic Cartography," The Canadian Cartographer, vol. 12, No. 1 (June 1975), pp. 52-67.

7. Areal standardization of data for choropleth maps is achieved by converting simple enumerated data to ratios. In the case of map B in Figure 5, the cropland area of each county was divided by its total land area to derive the ratio, cropland as a percentage of total area.

8. Morrison, Joel, Method Produced Error in Isarithmic Mapping, Cartography Division Technical Monograph No. CA-5, Washington, D.C. : American Congress on Surveying and Mapping, 1971.

9. Arnheim, Rudolph, Art and Visual Perception, Berkeley: University of California Press, 1971, p. 44.

10. These maps are taken from the unpublished Ph.D. dissertation research of Theodore Steinke at the University of Kansas.

TOPOLOGICAL PRINCIPLES IN CARTOGRAPHY

James P. Corbett

ABSTRACT CHARACTER OF A MAP

A map may be described as a linear graph embedded in a orientable, two-dimensional manifold. A manifold, aside from being a two-dimensional continuum, is locally flat, that is, each point of the manifold is contained in a neighborhood homeomorphic to a disk.

A linear graph so embedded will, if it contains l-circuits, delineate a number of simply connected domains. The collection of 0-cells and 1-cells of the graph, together with the 2-cells so delineated forms a two-dimensional complex, having the special property of local flatness.

The structure of this two-dimensional complex is completely specified by a pair of relations among the cells. These are the oriented incidence relations between 0-cells and 1-cells, and those between 1-cells and 2-cells. The local flatness condition implies that there is a form of symmetry, known as duality, between these two relations. A widely used model of this relational system, the DIME encoding, illustrates this symmetry in a perspicuous manner. This representation consists of a quadruple, or pair of ordered pairs of cell identifiers,

$$a, b; c, d$$

one such quadruple for each segment of the graph generating the map. The geometric interpretation of this model is as follows: a and b are interpreted as identifiers of the ordered pair of 0-cells, the initial and terminal points of the directed segment; c and d are interpreted as identifiers of an ordered pair of 2-cells, the right and left 2-cells separated by the segment. This latter interpretation is permissible only because of the local flatness condition of the manifold.

The natural dualism is apparent from the DIME representation. Exchanging the first and second pair provides a representation of a dual segment which can be drawn in a canonical way on the same manifold. The dual elements and relation pairs are indicated below:

0-cells	2-cells
1-cells	1-cells
boundaries	coboundaries*

The order relations on the oriented manifold are also expressed by the DIME representation. If we exchange the elements of the first pair, we obtain a representation of a segment oppositely directed on the oppositely oriented manifold, and

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*The converse of the relation bounds is known as <u>cobounds</u>.

if we exchange the elements of both pair, we obtain a representation of the oppositely directed segment on the manifold with orientation unchanged. Since this is to all intents and purposes the identical segment as originally given, we see that the segment is invariant to an exchange of the elements within each pair. This fact allows us to establish a unique segment representation within a set of such quadruples. This uniqueness is established by ordering the first pair of identifiers in lex order, exchanging, if necessary, both elements of each pair. In case the elements of the first pair are identical, the ordering is established by the second pair. If both pair of identifiers are identical, the segment is not orientable.

Given a map abstractly defined in this manner, the description of the geometrical properties of the map are completed by a metrical representation of the manifold and the embedded graph. In practice, such a description is carried out to some specified degree of approximation. The fundamental encoding of the distinguished points of the manifold and the arcs establishes the degree of fidelity of the representation from the beginning.

It is customary to provide the basic data describing both the manifold and the embedded arcs as parametric arcs or data strings

$$x(s),y(s),z(s)$$

for a discrete parameter, $\underline{s}$. This description covers such structures as contours, profiles, street segments, and any other one-dimensional structures required for the representation of the relevant map data.

FINITE NEIGHBORHOOD SYSTEMS

Although the basic manifold has the usual complete set of neighborhoods of a two dimensional manifold, the finite representation represented by the map data must be regarded as a finite approximation to the complete structure. However, for a given base encoding, no finer description is available. The finest neighborhood system definable by the coded elements will be referred to as a set of fundamental neighborhoods.

The relational system represented by a DIME segment defines implicitly a set of four operators, which relate boundaries and coboundaries to individual cells. The designations of these operators are given in the table below.

E^1_0	from 1-cells to 0-cells
E^1_2	from 1-cells to 2-cells
E^0_1	from 0-cells to 1-cells
E^2_1	from 2-cells to 1-cells

The importance of these operators will be indicated by the following formulae for the retrieval of the fundamental neighborhoods.

The formula $E^1_2 \, E^0_1 \quad (\quad c_0 \quad)$

represents the operator composition which acting on a given 0-cell retrieves both the 1-dimensional and 2-dimensional elements abutting the cell.

The formula $E_2^1 \, E_1^0 \, E_0^1 \quad (c_1)$

represents the operator composition which retrieves the cells abutting a given 1-cell.

The formula $E_2^1 \, E_1^0 \, E_0^1 \, E_1^2 \; (c_2)$

represents the operator composition which retrieves the cells abutting a given 2-cell.

THE CONNECTION BETWEEN NEIGHBORHOODS AND GRAPHS

Since each fundamental neighborhood of a subgraph of the complex is a set of cells, we can represent such a neighborhood as a dual graph, and the boundary of such a neighborhood as a primal graph. We can therefore employ the theory of linear graphs in the analysis of neighborhoods.

For this purpose, ARITHMICON, is furnished with a graph analyzer consisting of a pair of routines, CHAINS, and KIRCHOFF. The first of these routines reduces a graph by eliminating vertices of index two. The resulting graph will be referred to as the reduced graph.

Segments within a graph can be classified as cyclic or acyclic. A segment is cyclic if it belongs to some proper 1-circuit of the graph. If a segment is acyclic, its removal will separate a connected component into two pieces.

Segments can also be retracted. This is not a classifying property of a segment, but of a graph. By retraction, a graph can be reduced to a set of loops.

The routine KIRCHOFF provides all the information necessary to classify segments, count loops, and to retract segments within loops where this is possible. The resulting graph is a Hsumi tree or a cactus.

It has not been found necessary to utilize all the information provided by KIRCHOFF. A curtailed graph code consisting of a quadruple of integers is returned by the system ARITHMICON graph analyzer,

$$n_1, n_2, n_3, n_4$$

The interpretation of these numbers is as follows

n_1 denotes the number of independent loops of the graph

n_2 denotes the number of segments of the reduced graph

n_3 represents the number of acyclic segments of the reduced graph

n_4 represents the number of vertices of the reduced graph

Some of the codes will be given for the fundamental neighborhoods and their more commonly encountered anomalies. For a fundamental open neighborhood of a

0-cell, the admissible graph codes are

n+1,n+1,0,1	for points on the boundary of an elementary 2-cell
n, n, 0, 1	for points interior to an elementary 2-cell

a code representing a graph consisting of a set of loops having a common point.

In cases in which a graph falls into pieces, KIRCHOFF returns a code for each individual component.

In the foregoing example, n represents the number of singular segments abutting the node, that is segments embedded in an abutting 2-cell.

Any other code indicates some anomaly due to a coding error. For example

0,1,1,2

is a common anomaly representing a graph consisting of a single 1-cell with two distinguished endpoints.

Another frequently occurring anomaly is

1,2,1,2

which represents a graph consisting of a loop with a tail, and two distinguished vertices.

The occurrence of components invariably indicates the inadvertent replication of a 0-cell identifier.

APPLICATIONS OF THE PRINCIPLE OF HOMOTOPY

The analysis of graphs outlined in the preceeding section relates to homeomorphic classes of graphs. These classes represent graphs that can be thought of as abstractly identifiable under a relabeling. However the requirements of homotopy relate to the continuous deformation of one figure into another within the confines of the manifold. The homotopy classes therefore distinguish between the interior and exterior areas of bounded domains.

There are two important applications of this principle. First, the fundamental neighborhood of a point must contain that point within its interior. If a point in polygon test is made between a given point and the cyclic boundary of its fundamental neighborhood, any homotopic inconsistency of the metric description can be detected. This is one of the most fruitful tests for uncovering errors in coordinates.

The second application is somewhat more complex. Consider a system of contours describing the shape of a two-dimensional manifold. Some observers have pointed out that such a system of contours can be ordered by set inclusion. A more general ordering principle is available. If we consider the set of contours to be generated by the intersections of the manifold with a one-parameter family of parallel surfaces, we can regard the contours in the neighborhood of a given contour as homotopic images.

Thus a contour lies between two of its neighbors if it is an intermediate contour encountered as the parameter varies between two of its values. There is therefore a mapping between open intervals of the parameter and the contours themselves. The end points of these intervals correspond to the singular curves of the system of contours. This observation implies that the system of contours can be mapped onto a linear graph. Such a mapping provides a useful organizing principle for the storage and retrieval of contour data.

There is some tendency to prefer storage and retrieval of such descriptive data from files representing systems of profiles. The identical mapping described above pertains to a data file of this kind. The mapping is characteristic of the abstract nature of the data, and not of the particular form of representation.

DIMENSIONALITY IN COMPUTERIZED CARTOGRAPHY

This presentation will close with a brief mention of the subject of dimensionality. To begin with, practically all feasible applications of cartography as it exists today are concerned with the description of two-dimensional manifolds. Although these manifolds are imbedded in three or higher dimensional spaces, they remain two-dimensional objects.

In order to find common examples of practical applications of the geometry of three-space one would have to leave the domain proper of cartography and enter that of engineering constructions.

When the need to consider legitimate three-dimensional structures becomes established, it will be found that the theory just outlined, which pretains to the two-dimensional manifold, will fit exactly without change into the more inclusive theory. The more inclusive theory will differ only in the introduction of a broader relational system, essentially the system obtained when the local flatness condition is dispensed with. However, the theory will apply unchanged to those subsystems which are representable as two-dimensional manifolds within the more comprehensive system. It would be too great an excursion to enter into greater detail about this matter here. However it is important to realize that the system just described will not have to be discarded in order to accommodate the needs of the coming era in which higher dimensional representations will be required.

MATHEMATICAL MAP MODELS

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University of Michigan

Since earliest times the cartographer has used mathematical models to deal with the geometrical content of maps. Most of what one learns in surveying courses bears on this aspect of cartography. The mathematical nature of the model becomes very explicit in analytical photogrammetry, or in the hypotheses about nature which are invoked for computer interpolation in a digital terrain model. Similarly, one has only to consider the reductions which take place after distances or directions have been measured. We can assume that plane Euclidean geometry holds, or that the earth is a sphere, or an ellipsoid; or we can invoke the more recent model proposed by Hotine.2/

A single example suffices to illustrate some of these points. Figure 1 shows an outline map of the United States. Its construction adheres to the following algorithm, all done using a computer/plotter combination:

(1) Using spherical formulae compute a table of distances between places of known latitude and longitude.

Figure 1: An Empirical Map Projection of the United States.

(2) From this table compute plane coordinates such that separations subsequently computed from these coordinates (by plane formulae) agree, as nearly as possible, with the distances in the original table.

(3) Use the resulting table of latitude/longitude to x/y coordinate correspondences and interpolate detail to complete the final map.

That this algorithm results in a reasonable drawing is clear from the figure; greater mathematical detail is available elsewhere. 9/

Now go to a road atlas and look up the latitude and longitude of all of the places cited in the table of road distances. Operate on this table of road distances with steps (2) and (3) of the foregoing algorithm. The resulting map might appear as in Figure 2. The same algorithm will work with travel times, or travel costs, etc. It comes as somewhat of a shock to the cartographer to observe that the model also works if one knows only ordinal distances (far, farther, farthest), or even only adjacencies, but this simply illustrates the power of topology.4/ In these strange maps we are adopting an alternate geometrical model. Consider the set of all places which you could reach within one hour of travel. Think of this as a geographical circle of one hour radius. Shade it on a map. Is πr^2 the formula for the area? Does your circle have holes in it? Disjoint pieces? The geometry of geography is more complicated than the cartographers might have us believe. Cartograms

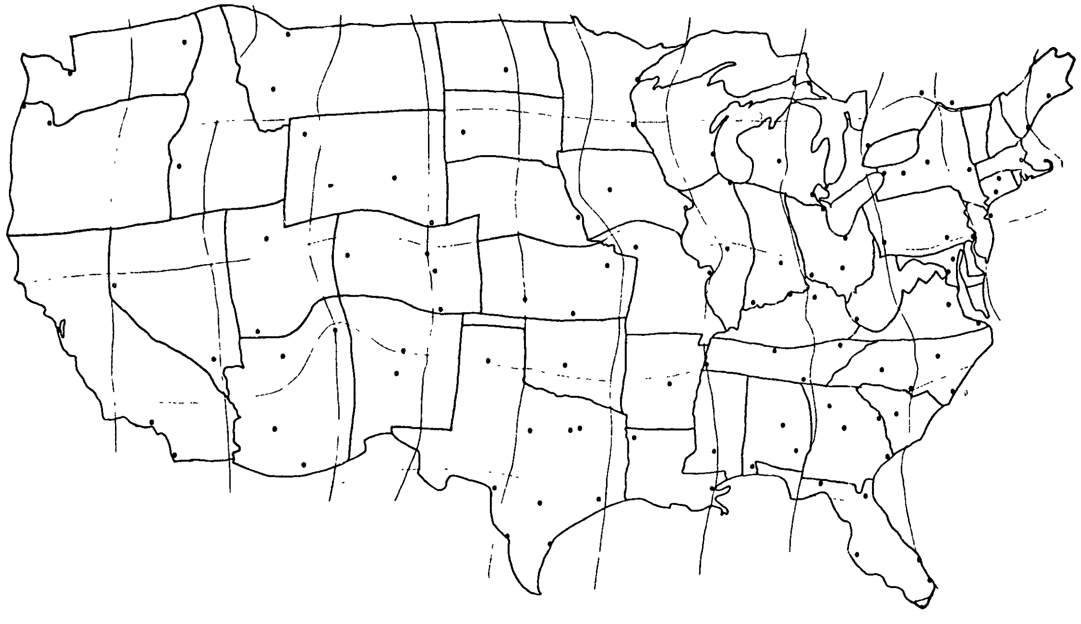

Figure 2: A Road Distance Projection of the United States. By J. Cwirko.

illustrate this from another point of view.10/ Figure 3 tries to show a New Yorker's map of the United States assuming that the usual mean-information-field measures the amount of detail available to a person living in that city. 11/

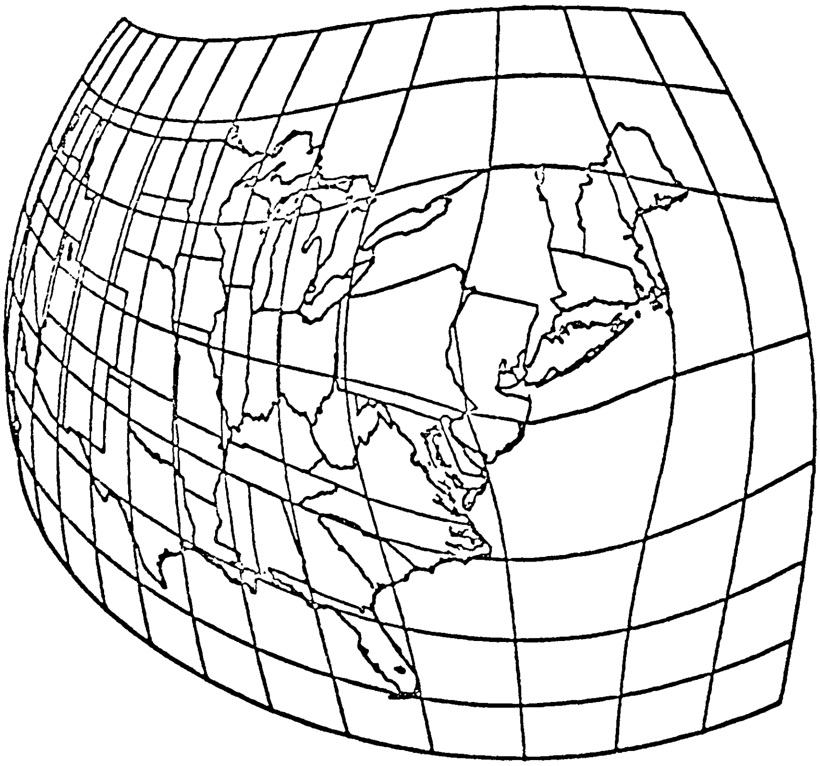

Figure 3: The New Yorker's Mean-Information Field

The substantive content of maps is much less well understood than the geometric content. Frequently the symbols are classified as denoting points, lines, or areas. More recently the measurement level of the data depicted has been cited. This yields the nominal-, ordinal-, interval-, or ratio-data classification. For some purposes I find it useful to consider how many observations apply to each point on the map, further broken down as to whether these are numerical or categorical observations. A presence-or-absence map for one class of phenomena can be thought of as a binary map. A land use map of N exclusive and exhaustive categories is an N-ary map with one observation at each location. A scalar map consists of one real number at each location. This number might represent elevation (as on a topographic map), or population density, etc. On a map of winds one has two real numbers at each location, the components of the wind. A colored map can be thought of as a representation of three distinct positive numbers, the tristimulus values. A map of wind roses really tries to represent an infinite number of numbers at every single point, obviously a difficult task.

The scalar field is clearly one of the simplest things imaginable. I concentrate on it for my second example of a mathematical map model. Scalar fields are often written in the cartographic literature as z=f(x,y); are shown by contour maps, or by computer block diagrams, as in Figures 4, 5, and 6.

Figure 6 is perhaps the most important, for the present purpose, of the three illustrations. It is an unconventional view of an aerial photograph, with the darkness of the grey tones shown as "elevations." The rough topography is a residential subdivision; the irregular trough is a freeway; and the flat area is an empty field. The basic point is now very simple. We can apply to the data of Figures 4 and 5 -- a piece of topography and a statistical "surface" -- the same

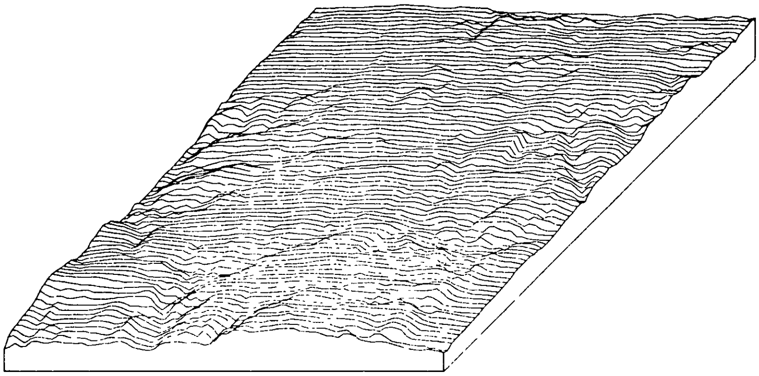

Figure 4: A Topographic Surface, $z=f(x,y)$

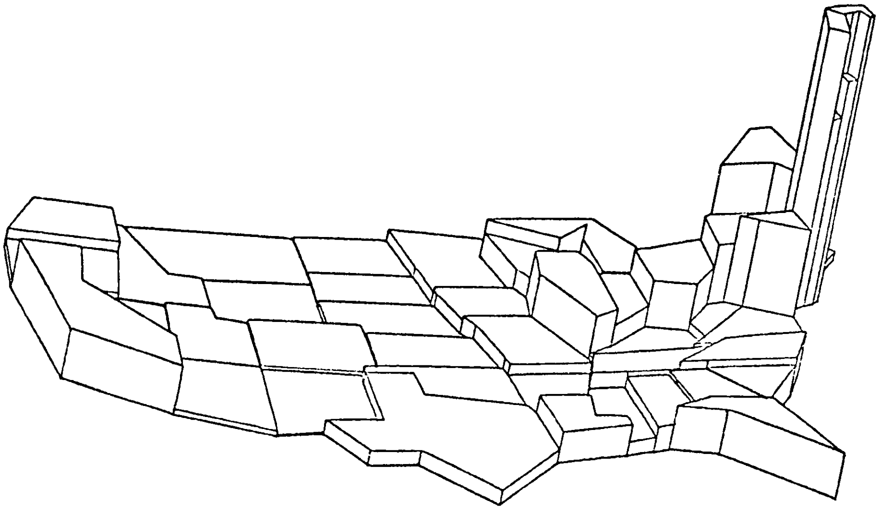

Figure 5: A Statistical Surface, $z=f(x,y)$

types of mathematical operation as are applied to photographs. 1/ 7/ The idea is not new 12/, but the applications to date have been rare. For example, one of the common operations on pictures has edge detection as its objective. Mathematically,

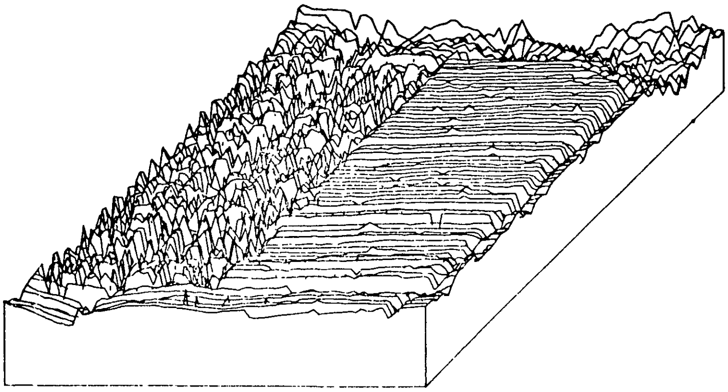

Figure 6: An Aerial Photograph, $z=f(x,y)$

this consists of taking the second spatial derivative or LaPlacian. Could not this be used to detect the edges of geographical clusters of people, when the input data are population densities? 6/ Another common application in picture processing is noise removal or image enhancement. 3/ There is a nearly one-to-one correspondence between these ideas and map generalization, and attempts to make maps more legible.8/ A basic mathematical idea behind much of this work is that any picture can be considered as the weighted sum of several simpler pictures. Depending on the purpose one may wish to emphasize certain of these basic pictures at the expense of others. 13/

One of the fundamental concerns in the interpretation of aerial photographs is the spatial resolution. This should also be of concern when making statistical maps. Figure 7 shows Holland at five different levels of spatial resolutions. One knows, from the sampling theorem, that phenomena of a size less than twice the sampling interval can generally not be detected. Thus it is very important to choose the spatial resolution on the basis of the problem one is trying to solve.5/ A

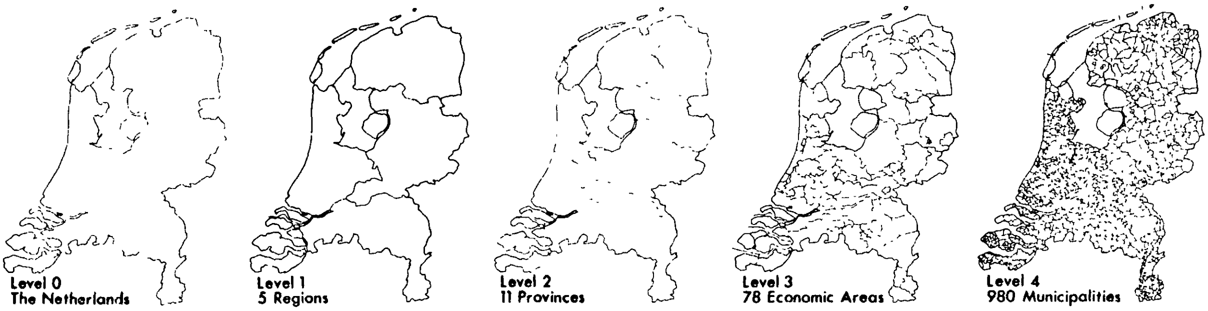

Figure 7: Spatial Resolutions of 200 km, 90 km, 60 km, 23 km, and 6.5 kilometers.

county map of the United States has a resolution of approximately 50 kilometers; phenomena with a magnitude of less than 100 kilometers cannot be detected. State data has a mean resolution of 430 kilometers; features larger than 860 kilometers on a side can be detected.

Digital pictures are also quantized into discrete grey levels, usually measured in bits. A two-bit map would contain four levels of shading. The choropleth map of the cartographer can be viewed as the process of converting the data of Figure 6 back into an image of greys using zip-a-tone or some other shading technique. The fineness of detail in the resulting image is dependent on this quantization process. 14/

As a final example of a mathematical map model consider the case in which there are N numbers at each of N locations; we may refer to this as a vector valued data set. A simple example is a migration table in which both the row headings and the column headings represent the places, and the entries in the body of the table detail the movement of the population during some period of time. The cartographer is faced with the problem of representing all of these data on a map. One solution is to sum across the rows and columns, then take their difference, obtaining the net movement with some places having net immigration, others emigration. The effect is to reduce the N^2 numbers to N, and these can then be shown as a scalar function. But the data could also be considered as arrows flowing from each

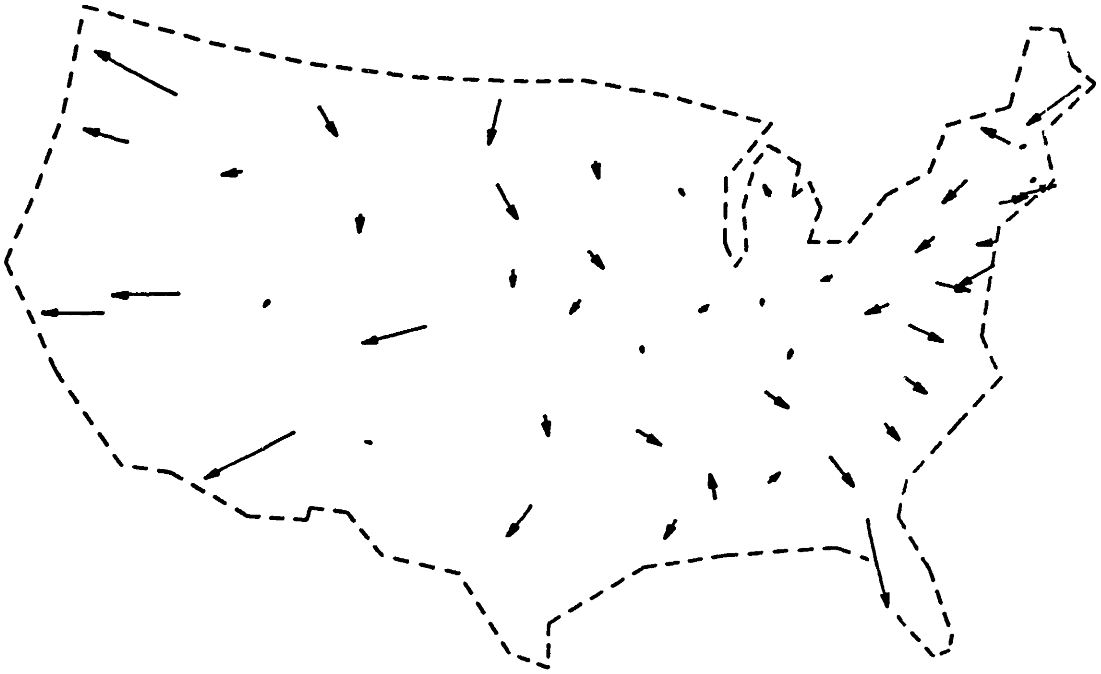

Figure 8: Winds of Change: U.S. Interstate Migration, 1965-1970

location to every other point, somewhat like a diagram of winds. If one takes a particular resultant of these arrows, one obtains a field of vectors which in fact quite adequately portrays aspects of the original data; see Figure 8. Such a vector field can be further analyzed mathematically to obtain the corresponding potential field; Figure 9. The technique is described in greater detail elsewhere.[15] As before it can only be justified if it is based on a clear mathematical model which bears some resemblence to the process being examined. No advance in cartography can be achieved without such a model.

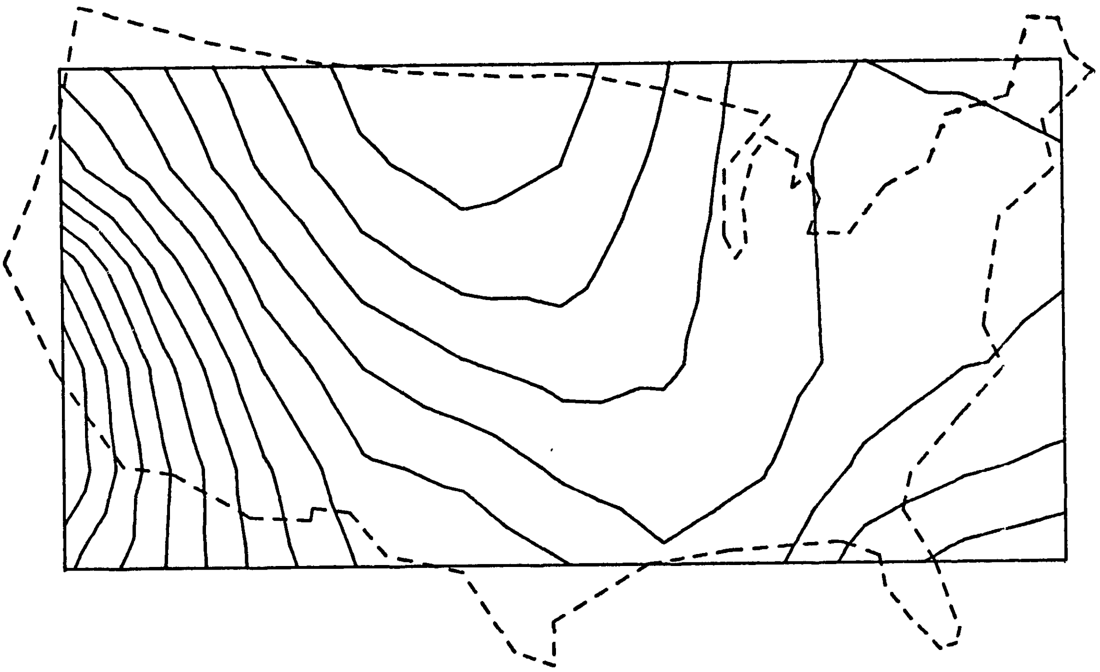

Figure 9: Interstate Migration, 1965-1970; the Forcing Function

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GRAPHICAL METHODS FOR PRESENTING STATISTICAL DATA: PROGRESS AND PROBLEMS

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THE PROGRESS ACCOMPLISHED IN AUTOMATION OF GRAPHS AND ITS IMPLICATIONS

Statistical maps are of great interest both to cartographers and to statisticians. Cartographers and geographers consider such maps as a very important category of thematic maps. Statisticians view them as applications of the graphical-statistical method to the special case in which the data to be graphed are detailed geographically. Professor Jenks and Professor Robinson have discussed statistical maps from the first viewpoint. I shall discuss them from the second. In so doing I shall draw largely from the conclusions of a meeting on geographical statistical methods held recently at the 40th session of the International Statistical Institute in Warsaw 1/ and from the experience gained from an exhibition of automated statistical graphs and of new graphical symbols held at that session.

The most impressive and encouraging development that has occurred in statistical graphics in the past two decades or so is the tremendous increase in technical facilities for the automated production of statistical graphs of many types (diagrams, bar and pie charts, stereograms, statistical maps, etc.). There is no need in this symposium on computer-assisted cartography to discuss such facilities or even to list them because they are well known to all participants.

However, it may not be superfluous to perhaps stress some of the consequences of this development. The most obvious of these is the enormous growth in the mass production of graphs resulting from the use of cheap and quick methods. Additionally, important shifts in the uses of graphs, resulting from applications to new fields beyond the traditional ones (illustration of findings, spreading knowledge among the general public, and teaching), should be noted. For instance:

1. Graphs are beginning to be applied as tools which may assist in solving the difficult problem confronting many statisticians today -- that of mastering the enormous quantity of data produced by the computer.
2. The automated graph has great potential as a research tool. Bringing onto the computer's screen parallel sets of data in graphical form and graphically comparing actual data to fitted models can help to obtain an overview of the data, to explore their meaning, to discover regularities and irregularities, to suggest, test or discard scientific hypotheses.
3. Animation of graphs may constitute an additional tool of research, mainly in regard to dynamic phenomena.
4. Graphs may be of help in communicating to politicians and to business and administrative executives the statistical information needed to make decisions.

By the way, graphs used for the various purposes may require different properties. For example, while graphs for executives should be easily understandable, graphs for internal use by statisticians or scientists may be more sophisticated and may not require the same degree of aesthetic properties. On the other hand, pleasant and attractive graphs, such as those obtained today by the automatic use of color, may have important applications as illustrative, educational and mnemonic tools.

However, all graphs should be produced in a way which guarantees objectivity and honesty in the transmission of information, and which gives a trustful representation of the data, apt to be interpreted quickly and in a more or less similar way by their readers, To reach this aim they should stand up to acceptable scientific standards.

DANGERS IN THE CURRENT DEVELOPMENTS OF GRAPH PRODUCTION

Unfortunately this is not true of a considerable part of the graphs produced today. From this viewpoint, it appears that we are not yet fully prepared to meet the challenge of mass production of graphs and of their use for very responsible purposes, such as those mentioned above. Actually in many cases no clear rules for the production of graphs seem to exist and, if they exist, they are largely neglected by producers of graphs. Widespread production of bad graphs may have, among other consequences, executives using such graphs making the wrong decisions and this may, in the long run, bring discredit upon the whole graphical method.

The situation seems to be partly related to insufficient education on the part of graph makers and partly to insufficient development of scientific research and thinking in the graphical field.

If we try to summarize today the "state of art" of statistical graphics, it appears that the common graphical methods enable us to represent in a satisfactory way only a rather limited part of the many types of statistical data currently produced.

EXAMPLES OF LIMITATIONS OF COMMON GRAPHICAL METHODS

To appreciate some of the limitations of common graphical methods it is sufficient to consider a few examples:

(1) Consider first the common diagrammatic method, which is considered the best from a scientific point of view and which renders invaluable services to statistics. This method is severely limited due to two well-known reasons: (a) the diagram employs two coordinates (x,y) to represent respectively the values of the characteristic according to which the data are ordered, and the statistical data. Therefore, while one linear series covers only one line or column (one dimension) in a table, its graphical presentation requires two dimensions in the plane. This creates serious difficulties when we try to represent graphically in the same graph many parallel lines or a composite series. The use of a logarithmic scale can help to find a practical solution to this problem, but it is warranted for only certain types of data. (b) The lack of generally accepted criteria for linking the scale of

x and y is a problem which has intrigued statisticians for a very long time. Every graph maker knows this problem and is aware of the fact that by stretching and compressing the scales, he can completely change the aspect of the graph. The consequences of this have been put in evidence by the impertinent and yet so pertinent remarks by Huff on "how to lie with statistics." 2/

(2) If it is desired to represent a function of two variables, $z=f(x,y)$, the best solution -- in theory at least -- is given by stereograms. Stereograms can be plastically built and may be very useful; however, their construction and use is not simple. Preparation of two-dimensional graphs, showing in perspective the stereogram, can be performed with the help of the computer. However, their interpretation is not easy because not all readers are really able to follow from such graphs how z changes in function of both variables; moreover, the aspect of the graph may change according to the perspective used. Use of contour lines to represent the stereogram avoids difficulty. However, here also considerable skill is required of the reader to interpret the graph, mainly when "depressions" and "elevations" are found in the same graph and if they can be distinguished only by reading the numbers indicating the levels of each line.

In consequence of that we lack a commonly accepted and simple device for graphically representing sets of statistics of great importance such as grouped correlation tables or contingency tables.

(3) Many of the choropleth maps actually produced today are far from being satisfactory for the reasons mentioned by Professor Jenks in Monday's plenary session. Another defect of choropleth maps is explained below.

It is generally accepted today that any series of average values ($\bar{X}i$), referring to the regions i in which a territory is divided, can be presented graphically by covering the area (Ai) of each region i on the map with an appropriate pattern, shading or color.

This method is correct whenever the $\bar{X}i$ is an average value referring to the area of region i and whenever the conditions of the areas of the regions are the object of our research. Consider, for instance, Graph 1, which shows the average value of agricultural production per hectare (=10,000 square meters) in each of the provinces of Italy. Here

$$\bar{X}i = \frac{Xi}{Ai}$$

where Xi is the total value of the agricultural production in i.

In order to simplify our discussion let us suppose that the pattern used to represent $\bar{X}i$ has a blackness proportional to $\bar{X}i$, and let us forget the inability of the human eye to judge correctly the degree of blackness.

Under such hypotheses our map has some very useful and simple properties:

a. The visual impression received by considering the territory of i on the map is proportional to the product of the blackness per unit of area of i and of the area of i, viz., to

$$\bar{X}iAi = Xi$$

which is the total value of the agricultural production in i.

b. The visual impression received by considering the entire map is proportional to

$$\Sigma \bar{X}iAi = \Sigma Xi = X$$

viz. to the total value of the agricultural production in Italy.

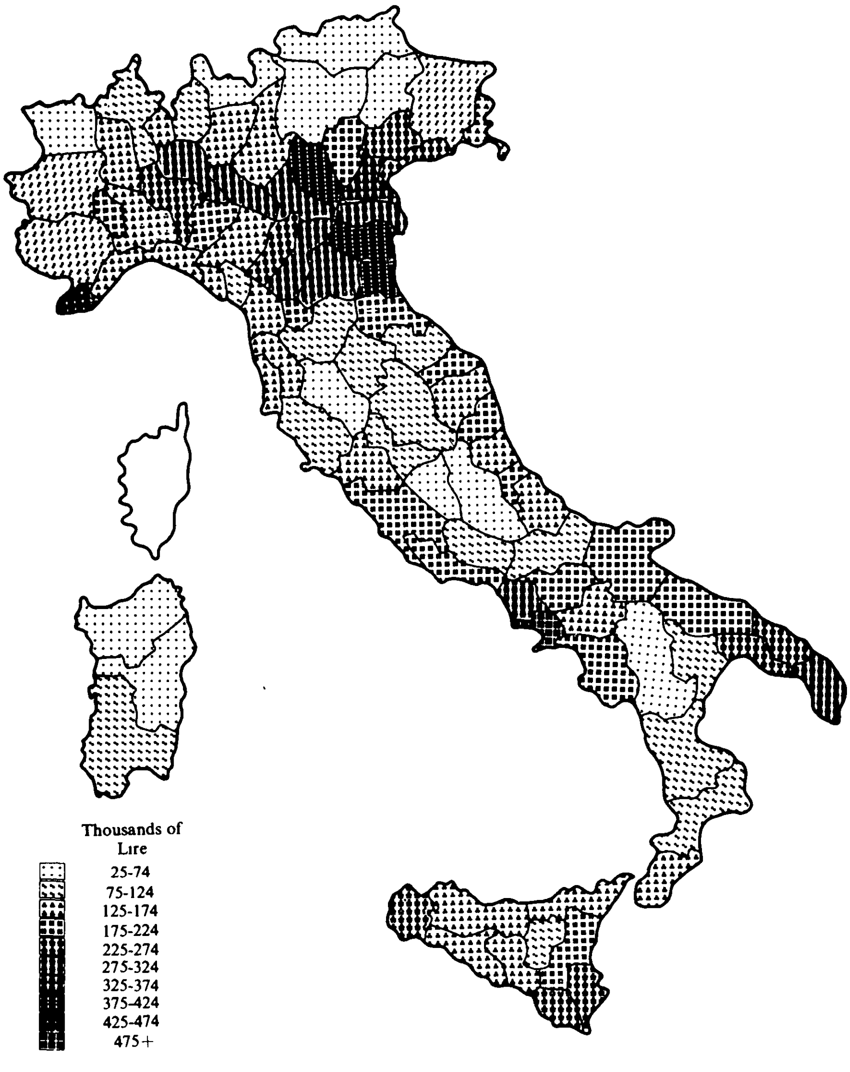
c. Suppose that maps are constructed in the same way and with the same scale for the value of agricultural production in Italy for different years. The comparison between such maps will convey correctly not only information on the changes occurred in the course of time in the average value of agricultural production in each province, but also on the total changes of the value in each province and in the entire country.

However, let us consider now the very frequent case in which the regional averages $\bar{X}i$ do not refer to the area of i but to its population, whose conditions we wish to investigate. For instance, let us suppose we wish to study: (1) the average income of the population in each region i, (2) the birth rate per 1,000 inhabitants of i, or (3) the proportion of people aged 65 or over among the population of i. If we write

$$Xi = \frac{Xi}{Pi}$$

where Pi is the size of the population of i, Xi represents in the above examples: (1) the total income produced in i; (2) the total number of births in i; and, (3) the number of people aged 65 and over in i.

Adopting the usual method of graphical presentation has in this case the following consequence. The visual impression received by considering the territory of i on the map is again proportional to $\bar{X}iAi$. However, as $\bar{X}i = \frac{Xi}{Pi}$, $\bar{X}iAi = \frac{Xi}{Pi}Ai$, which does not correspond to the object of our research, and is often of little or no meaning. Properties a, b, and c listed above are lost, and the map may give very misleading impressions. In order to appreciate the dangers of this graphical presentation let us consider a few common examples:



Graph 1 Italy (1965). Value of gross production from agriculture and forestry per hectare of territory
Source of data "Moneta e Credito", September 1966 *Scale* 5000 Lires = 1 GRP unit

- Graph 2 represents the median income of families in each of the States of the United States as published in the Report of the U.S.A. Census of 1950. As the number of patterns is too small, and the patterns used are arbitrary, the map has been redrawn in Graph 3 by using Graphical Rational Patterns (See the section entitled "NEW GRAPHICAL SYMBOLS. GRAPHICAL RATIONAL PATTERNS," for an explanation of such patterns), proportional to the average 3/ income $\bar{X}i$ and repeated (according to the method generally followed) over the entire territory of each State. To understand the implication of this method compare in Graph 3 Utah and New Jersey, which have a very similar median income per family. Utah is by far more impressive than New Jersey in the map as it has a territory almost 11 times larger. However, as New Jersey has a population almost 8 times that of Utah, its importance (in regard to the economic conditions of the people) is much larger.

- Consider the beautiful maps of the Urban Atlas produced by the Bureau of the Census for presenting the data of the census of 1970. (See Figures 5 to 8, pp. 256-259.) In such maps many census tracts can roughly be considered to have a population with the same order of magnitude. In the maps which describe the conditions of the population (such as percentage of population in each age group, average income, educational conditions, etc.) each tract i should contribute to the creation of the general visual impression in a way roughly proportional to $\bar{X}i$. Actually it contributes in a way proportional to $\bar{X}iAi$.

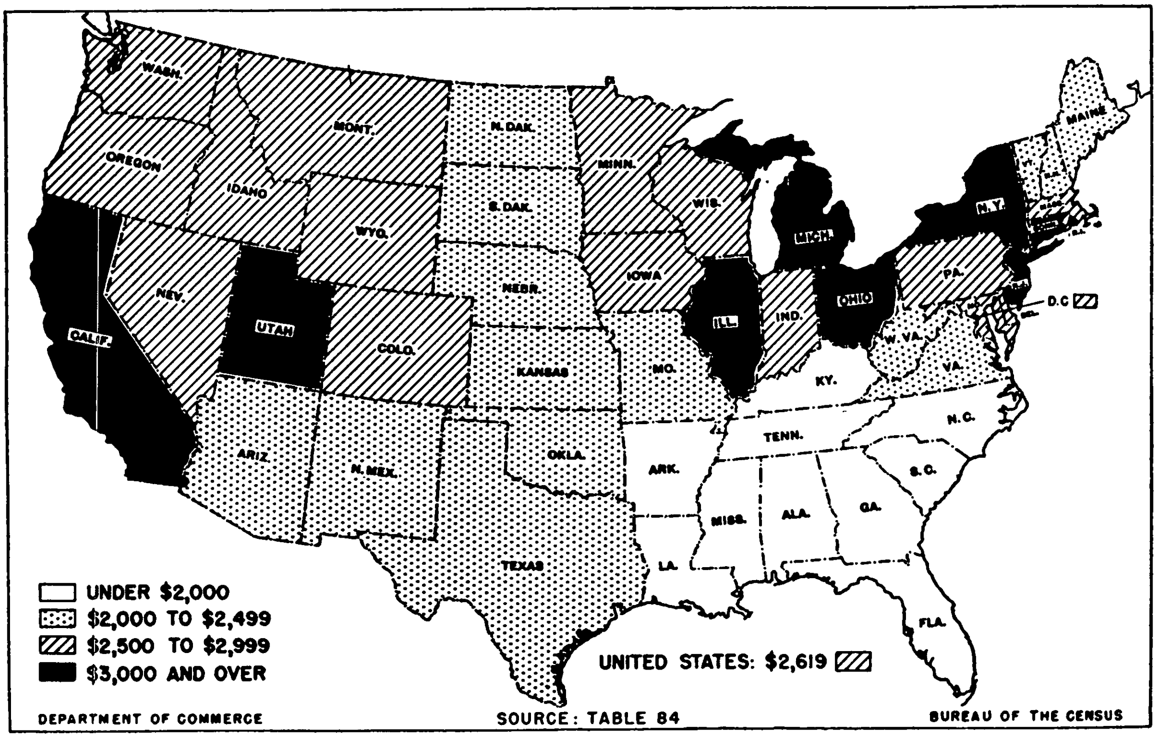
  Generally speaking, this implies that wide suburban tracts have a disproportionately large importance in catching the eye of the reader in comparison with the small central tracts. It may happen that in a town only a few large suburban tracts dominate the entire map, while tens of central tracts have an almost negligible visual importance. As a consequence, the average visual impression that we receive from the entire map may be very different from the average $\frac{\Sigma Xi}{\Sigma Pi}$ which is given in the legend of the map.

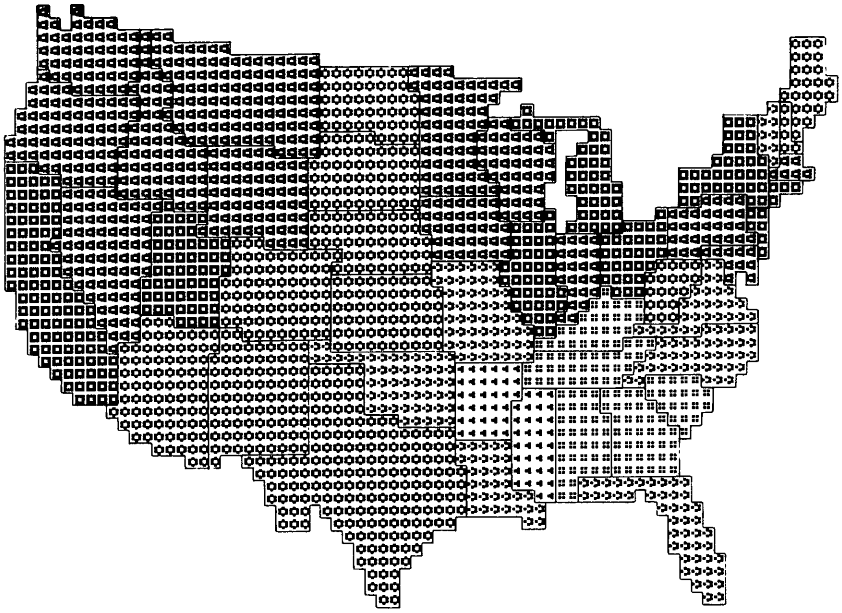
- A similar situation is found whenever the population is very unevenly distributed (which is very often true). Then the eye of the reader is caught by the $\bar{X}i$ in the wider regions, which are often those with low population density (being desert or semidesert or mountainous, etc.). By contrast, the reader may neglect to consider the areas, generally small, where the majority of the population is concentrated and which have decisive importance in determining the average $\bar{X} = \frac{\Sigma Xi}{\Sigma Pi}$ for the entire population.

POSSIBLE ELIMINATION OF PRESENT LIMITATIONS OF GRAPHICAL METHOD

The above criticisms of the usual graphical methods should not bring us to the negative conclusion that most graphs cannot be based on good scientific criteria. The contrary is probably true. Many of the existing limitations can probably be eliminated, if we are ready to make efforts to seek solutions. In the following a few examples are given of work in that direction. The proposals given are to be considered as provisional and may still need study, discussion, and improvements in the technical implementation of some of the tools introduced. However, they seem to show that attempts at improvement are feasible.

Graph 2: MEDIAN INCOME IN 1949 OF FAMILIES AND UNRELATED INDIVIDUALS, BY STATES: 1950





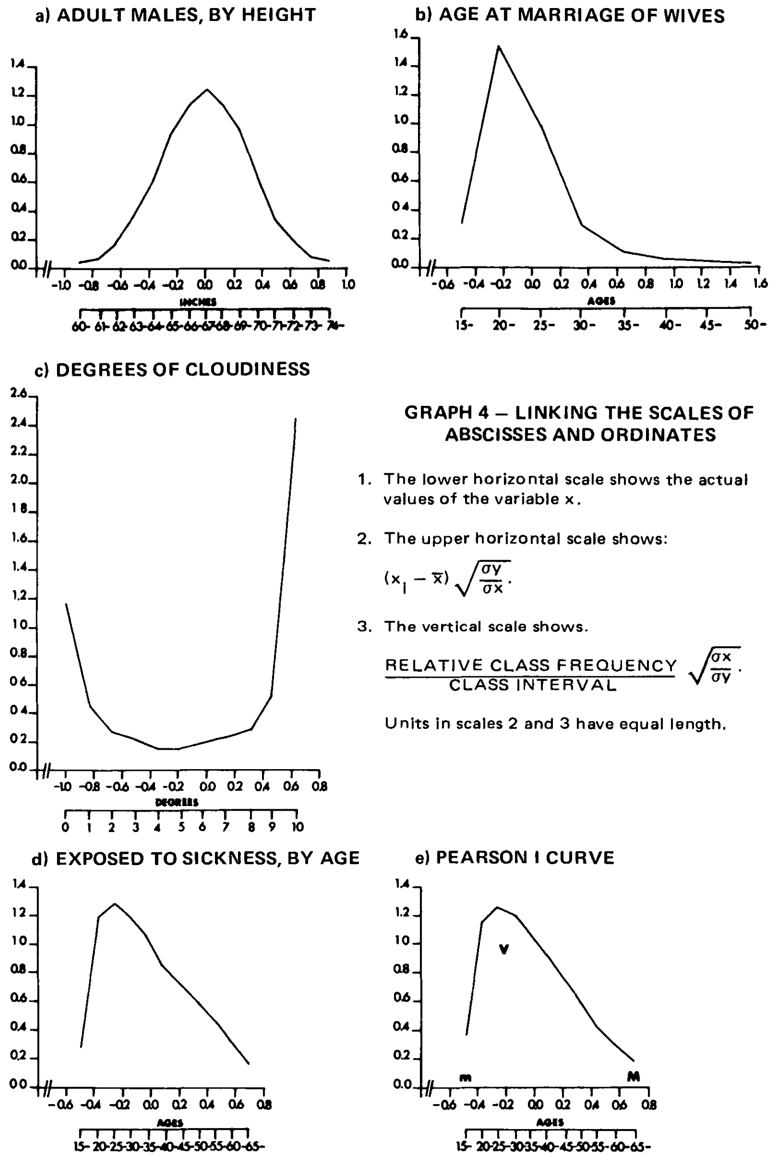
Graph 3: USA (1950) Median income per family

Patterns (X_1) 1200-1600 1600-2000 2000-2400

2400-2800 2800-3200 3200-3600

LINKING x- AND y-SCALES IN DIAGRAMS

In the following an attempt (taken from an article -- in preparation -- by Bachi and Samuel) will be presented in regard to possible linking of x- and y-scales in graphical presentation of one-dimensional statistical distributions (probability density functions, empirical frequency distributions, or histograms). Let us limit ourselves here, for the sake of simplicity, to the case in which the main aim of graphical presentation is that of enabling us to compare quickly the shape of distributions irrespective of their location and dimensions. In the (x,y) plane consider a density function f(x) as shown by Graph 4e which determines a figure V defined between x = m and x = M and between y = 0 and y = f(x). Let σ_x and σ_y denote the standard deviations of the elements of V along the x and y axes respectively.



GRAPH 4 – LINKING THE SCALES OF ABSCISSES AND ORDINATES

1. The lower horizontal scale shows the actual values of the variable x.
2. The upper horizontal scale shows: $(x_i - \bar{x})\sqrt{\frac{\sigma y}{\sigma x}}$.
3. The vertical scale shows. $\frac{\text{RELATIVE CLASS FREQUENCY}}{\text{CLASS INTERVAL}}\sqrt{\frac{\sigma x}{\sigma y}}$.

Units in scales 2 and 3 have equal length.

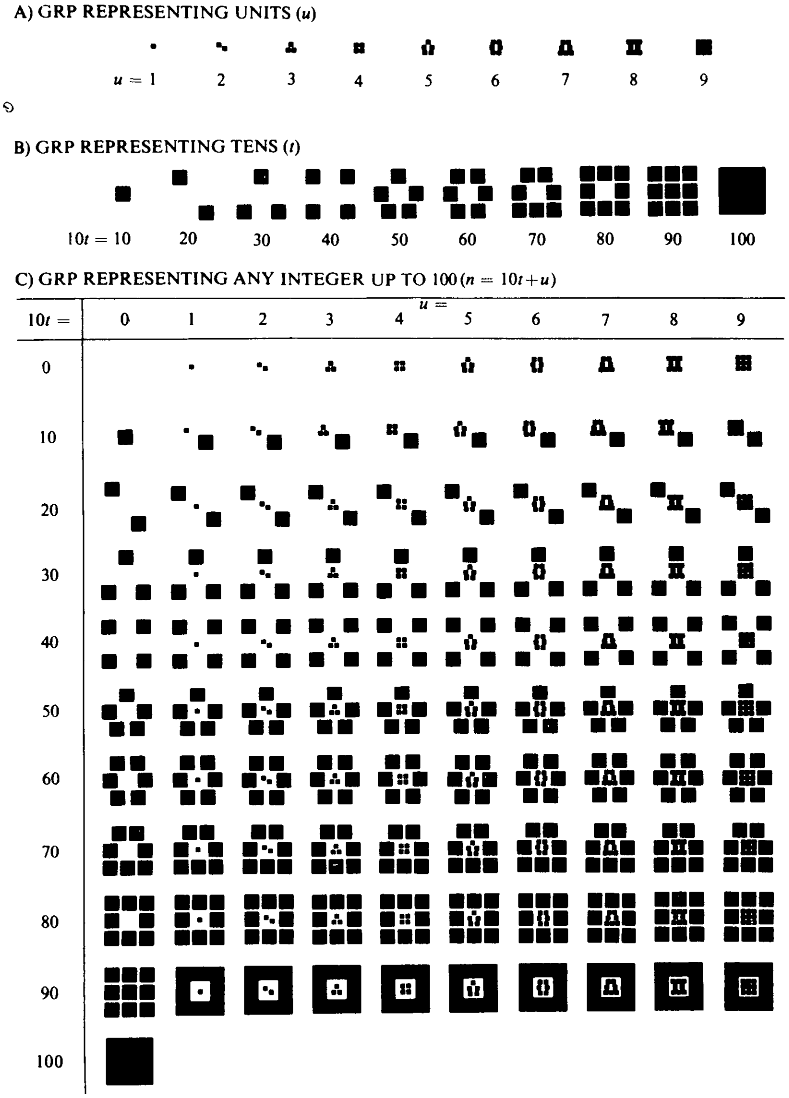
In order to standardize graphical presentation, it is proposed that x- and y-scales be based on the simple criterion of giving the same length to represent σ_x and σ_y. This means that in any of the usual diagrams the original x-scale is to be corrected by a factor (σ_x/σ_y), and the original y-scale should be corrected by a factor (σ_x/σ_y). This correction can easily be performed also in regard to any empirical frequency distributions by applying appropriate formulas. The illustrations in Graph 4 show examples of empirical and theoretical distributions drawn according to the above rules and indicating respectively: (a) the height of 8,585 British male adults (see Yule and Kendall, 1950, p. 82); (b) the ages at marriage of 315,300 English wives (ibid., p. 201); (c) the degree of cloudiness in 1,715 observations at Greenwich (ibid., p. 96); (d) the distribution of age of 2,995,724 persons exposed to risk of sickness (Elderton, 1953, p. 7); (e) Pearson I curve fitted to (d) (ibid., p. 62). The method proposed may be connected with the use of certain parameters of shape of the distributions, which cannot be discussed here. The method enables us to discover quickly similarities of shape between empirical distributions and between them and theoretical models. For instance, all empirical distributions similar to a normal curve will have an appearance near to that of 4a; the empirical distribution 4d appears to be very similar to the theoretical distribution 4e, etc.

NEW GRAPHICAL SYMBOLS. GRAPHICAL RATIONAL PATTERNS

In the past decade or so various proposals of new graphical symbols have been put forward to fill the gap in the current graphical methodology. Some of them, such as Chernoff faces 4/ have been discussed in other papers at this symposium. Others, such as Bertin's distinguishable circles, 5/ have been mentioned. Here we will describe a system called Graphical Rational Patterns (GRP) 6/ which may help in seeking solutions to some of the problems mentioned above.

In its simplest form, the GRP is a pattern representing any integer $n = 10t + u$ by u unitary square marks of an area a (which indicate the units) and t square marks of area 10a (which indicate the tens). Correspondence between n and the pattern representing it is ensured in two ways: (1) the blackness of the pattern is n times that of the pattern representing 1; (2) the marks forming each pattern are clustered in a way which enables us to easily read the value of the pattern whenever the need arises. The patterns are drawn in such a way as to require very little space and, as a matter of convenience, they may be enclosed within a small square frame (see Graph 5). Besides the single patterns described above, repeated patterns can be used, in which the symbol is repeated many times either (a) in a line to show that a value n is to be attached to a given line (such as a traffic line or an isoline) (see Graph 6); or (b) over an area to show that a value n is to be attached to a given region in a map or a given portion of a diagram (see Graph 7). The scale of the patterns can be extended to $n > 100$ (for instance up to $n = 1{,}000$).

The scale can be adapted to represent any value $0 \leq nk \leq 100k$ by attributing any arbitrary value k to the elementary unit square of area a and multiplying by k the values of the patterns. By printing the GRP in color (or in black over a colored field) or by enclosing it by frames of various types, it becomes possible to add qualitative information indicated by colors or type of frame to quantitive information given by the GRP. Proper methods can be used to adapt GRP to show negative versus positive data. Various attempts have been made to automate GRP: (a) A scale of n = 1,.......,10 has been built by combining dot, line, and other symbols of the high speed line printer into a form more or less similar to that of the

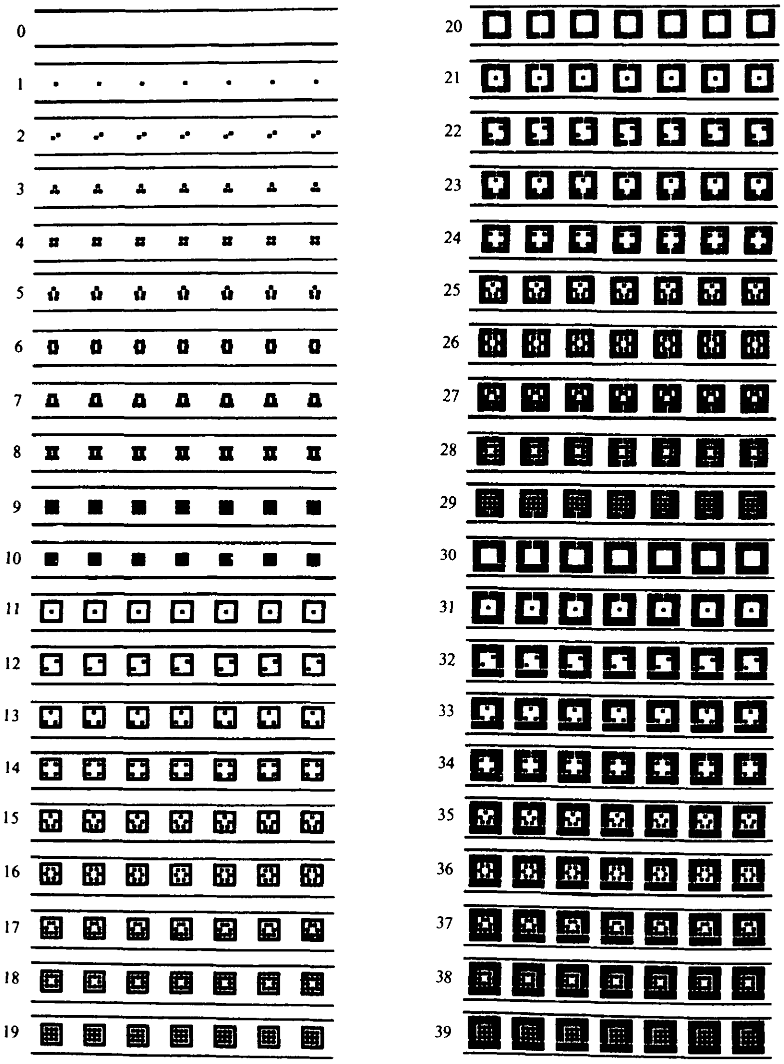


Graph 5

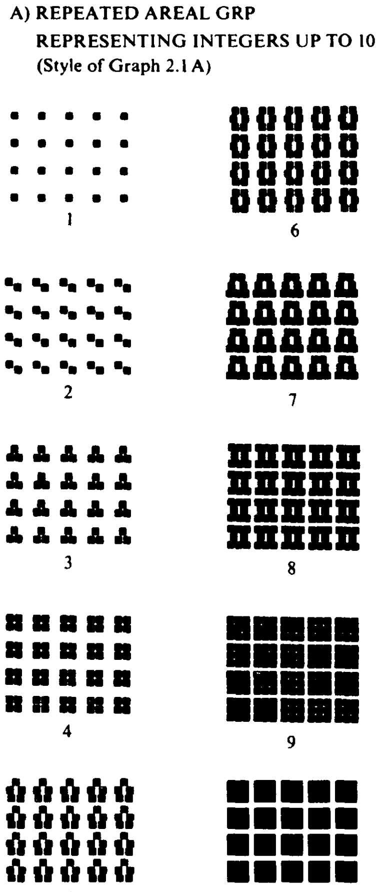
Basic scale of single GRP showing integer numbers up to 100 original GRP, and a scale of tens has been prepared by repeating in a convenient number and way the symbol for 10; (b) A scale of GRP has been built by the plotter. However, as (a) was not entirely satisfactory from a scientific viewpoint, and as production of (b) was too slow, the GRP are now produced (c) on a photo-electric typesetter which enables us to obtain the GRP in the desired form and size on any desired spot on a film. Moreover, (d) GRP are being put at present on CRT.

The properties of the GRP system, as compared to those of the common diagrammatic system can be seen from Graph 8, where a few selected numbers n are represented by the two methods. It is seen that (a) both methods enable us to represent

A) REPEATED LINEAR GRP OF VARIABLE SIZE REPRESENTING INTEGERS UP TO 39
(STYLE OF GRAPHS 2 1A and 2 3A)

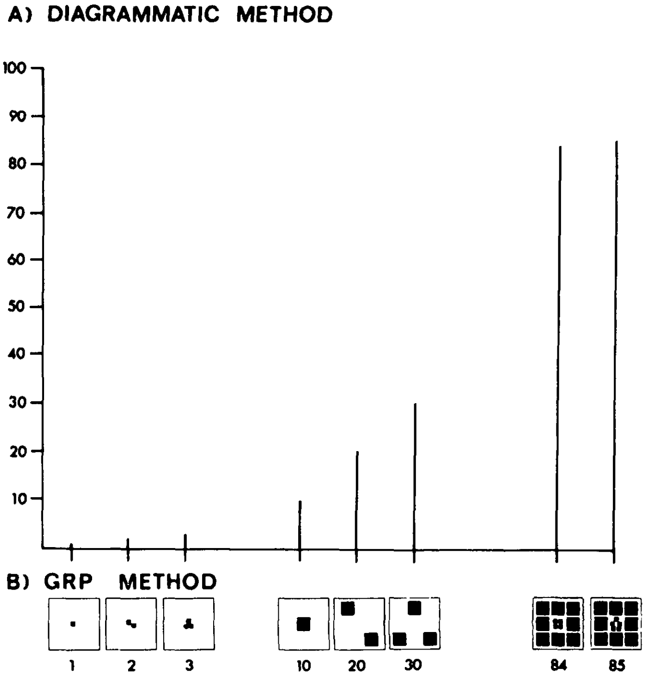


Graph 6 Scales of repeated linear GRP



Graph 7
Scales of repeated areal GRP.

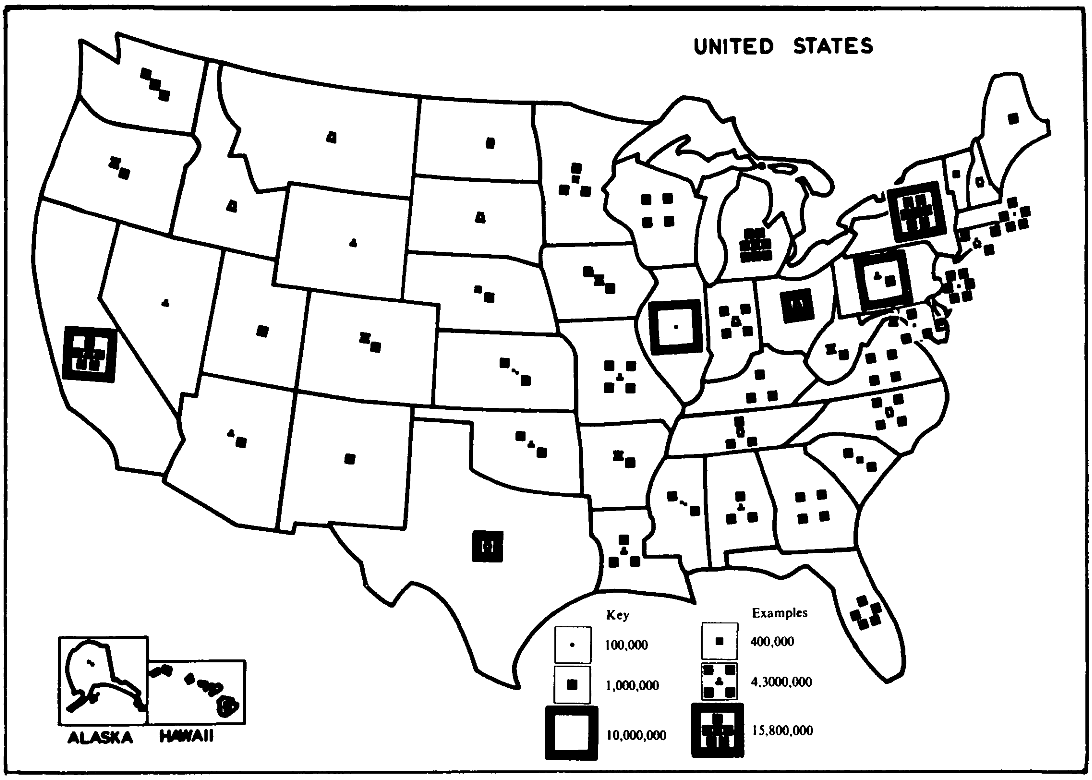
in an accurate way the numbers n. In the diagrammatic method correspondence is between n and the length of the ordinate: reading requires comparison with the scale. In the GRP system correspondence is between n and the blackness of the pattern. After a little practice, it is possible to read n directly from the pattern. (b) While the diagrammatic method demands two dimensions for representing a series of n, the GRP method demands one dimension only. Therefore, many series of data can be represented in one GRP graph, although this is not possible in common diagrams. (c) After the reader has mastered the rules of formation of GRP, he can appreciate even small differences between patterns. Thus in Graph 8 the differences between n = 84 and n = 85 is clearer in the GRP than in the ordinate. (d) While the diagrammatic method does not show equality of ratios such as 2/1 = 20/10, 3/2 = 30/20, the GRP do (as do semi-logarithmic charts). (e) On the other hand, the GRP are clearly at a disadvantage in comparison with the usual diagrammatic method in the following respect. In the usual diagrams it is often legitimate to join ordinates of consecutive data and to judge differences between



Graph 8 : Comparison of GRP Method and Diagrammatic Method them (or in semi-logarithmic charts, ratios) on the basis of inclination of the diagrammatic line. This additional powerful tool of information is not available in the GRP system. However, as GRP and diagrammatic methods can be integrated and used together, it may become possible to utilize in a proper way the advantages of both systems.

In the following a few examples of applications of GRP to statistical maps are shown.

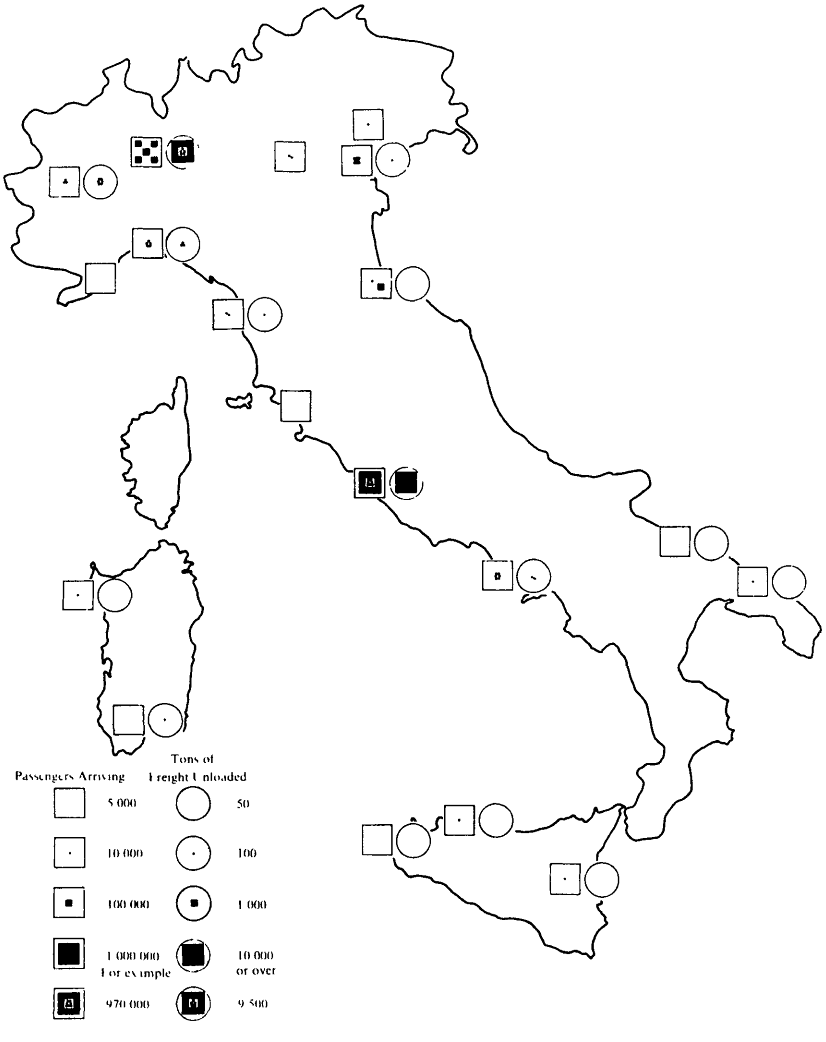
Graph 9 presents a map of the absolute size of the population in each of the States of the U.S.A.; this map is built only for readers to whom the internal divisions of the U.S.A. are known and meaningful. As the population symbol is put at the center of each State, and as the States have different areas, the map is not intended to show variations in densities over the areas of the U.S.A. Despite this, it gives some broad information on prevailing patterns of population distribution. Maps of population densities can be built with repeated GRP by a method similar to that illustrated in Graph 1.



Graph 9 U.S.A. (1960). Population in each state. *Source of data:* Statistical Abstract of the United States, 1962. Washington, Bureau of the Census, p. 10. *Scale:* 100,000 inhabitants = 1 GRP unit.

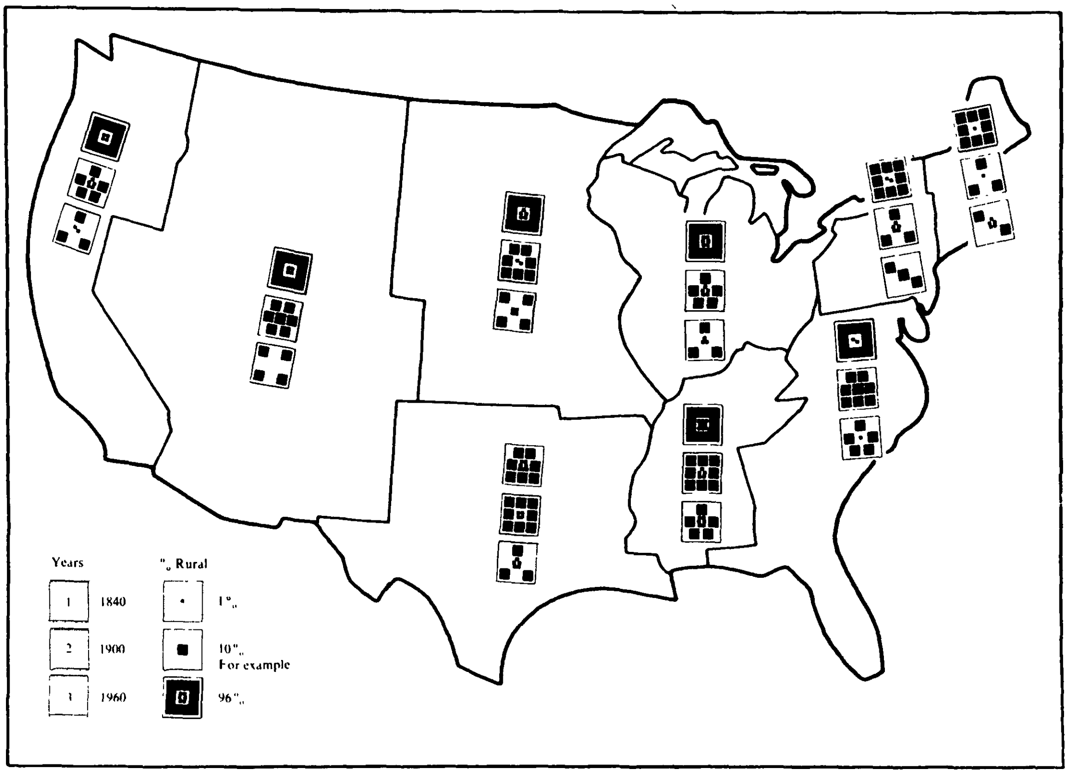
Graph 10 gives an example of presentation of two geographical series in the same map: traffic of passengers in Italian airports is given within a square pattern; traffic of merchandise is given within a circle. If instead of these different frames, colors are used to distinguish each series, far better results can be obtained.

Graph 11 illustrates an application to a series in which the data (indicating percentage rural in each of the divisions of the U.S.A.) are classified both by geographic regions and by time (censuses of 1840, 1900, 1960). Here too the use of colors would greatly improve the presentation by faciliting the association-dissociation processes.

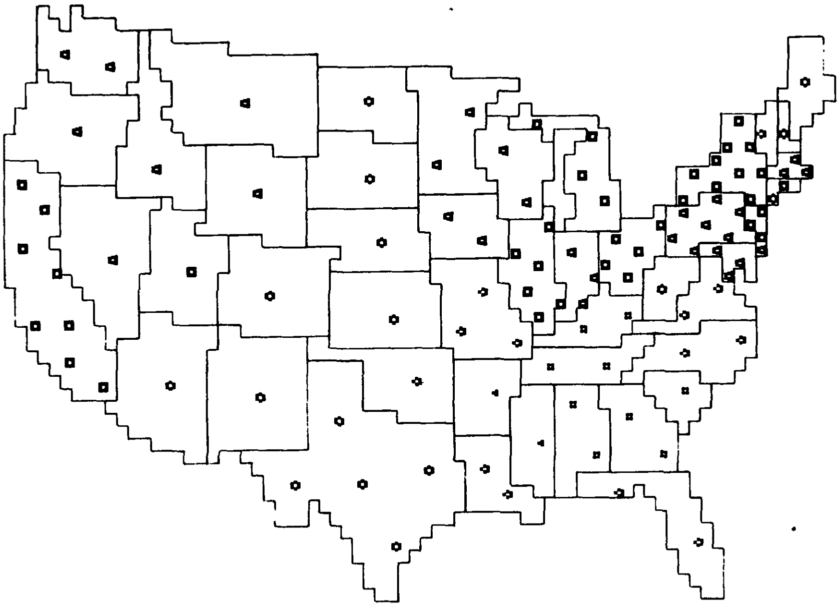


Graph 10 Italy (1964) Traffic in main airports *Source of data* Annuario statistico italiano, 1965 Roma, Istituto Centrale di Statistica, p 296 *Scale* 10.000 passengers arriving = 1 unit in square GRP 100 tons of freight unloaded = 1 unit in circular GRP

In Graph 12 a map is shown representing the same data as Graphs 2 and 3. Here median income in each State i is given by a pattern proportional to it. The number of patterns in each i is proportional to its population of families Pi. In order to keep in line with symbols previously used, let us forget that the map shows median income and suppose it indicates arithmetic average of income per family. Then averages can be indicated by $\bar{Xi} = \frac{Xi}{Pi}$, where Xi is total income. The visual impression given by each State is proportional to the product



Graph 11
U S A (1840, 1900, 1960) Percent rural population.



Graph 12: USA (1950) Median income per family

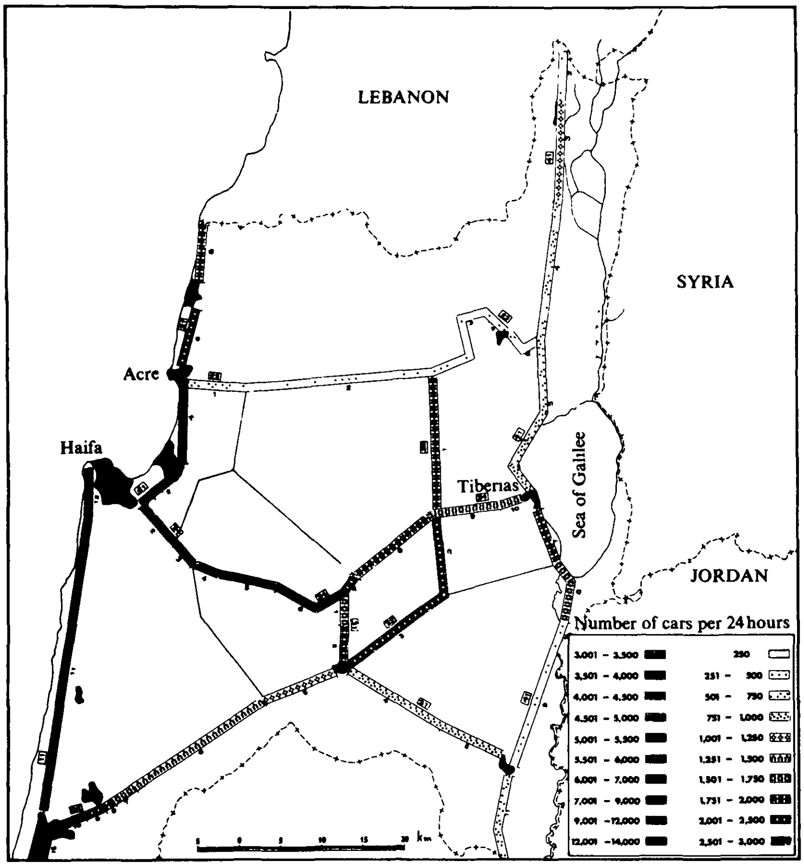
Patterns (X_1) ▪ 1200-1600 ■ 1600-2000 ▪ 2000-2400

▪ 2400-2800 ▪ 2800-3200 ■ 3200-3600

between $\bar{X}i$ and the size of population Pi, viz., to $\bar{X}iPi$ and thus is solved into XiPi = Xi. Then properties similar to those indicated under (a), (b), (c) for Graph 1 are found.

While all other graphs presented before are hand-drawn, Graphs 12 and 3 are computerized.

Graphs 13 and 14 show applications of repeated GRP to represent intensity of traffic; they show respectively intensity of traffic on part of a country (Northern Israel) and part of a town (Jerusalem). Graph 14 is computerized. GRP presentation seems advantageous over the usual presentation of intensity of traffic by bands of differing width which are not always easy to be interpreted (see an example in Graph 15).



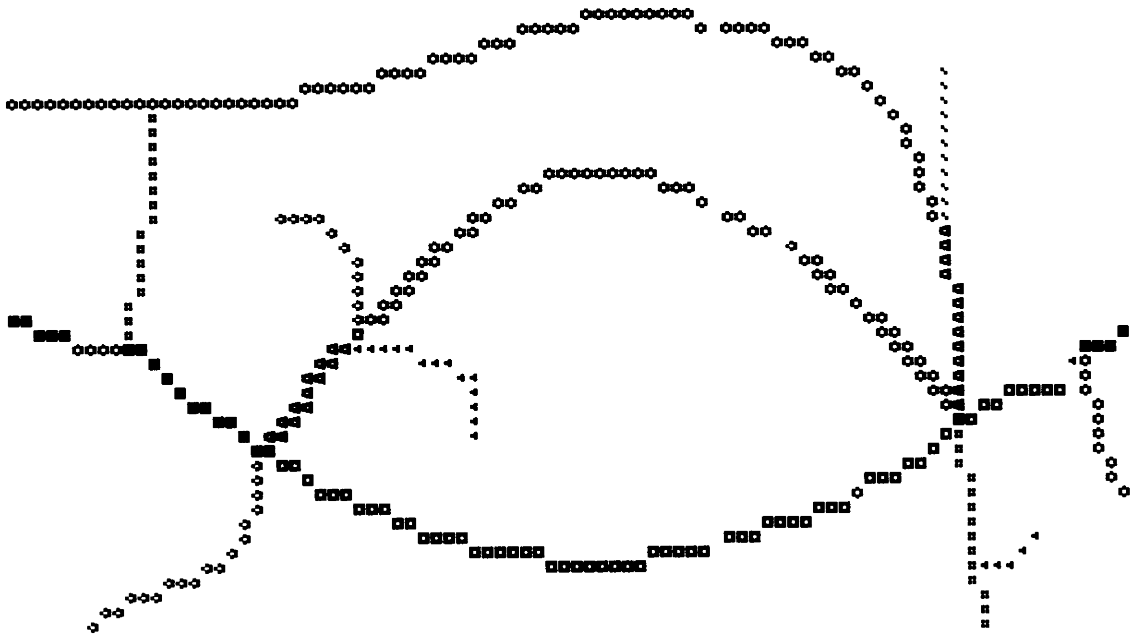
Graph 13

Israel: Northern part of the country (April 1962–March 1963). Traffic density on non-urban roads.
Source of data Sample traffic counts performed by the Central Bureau of Statistics.

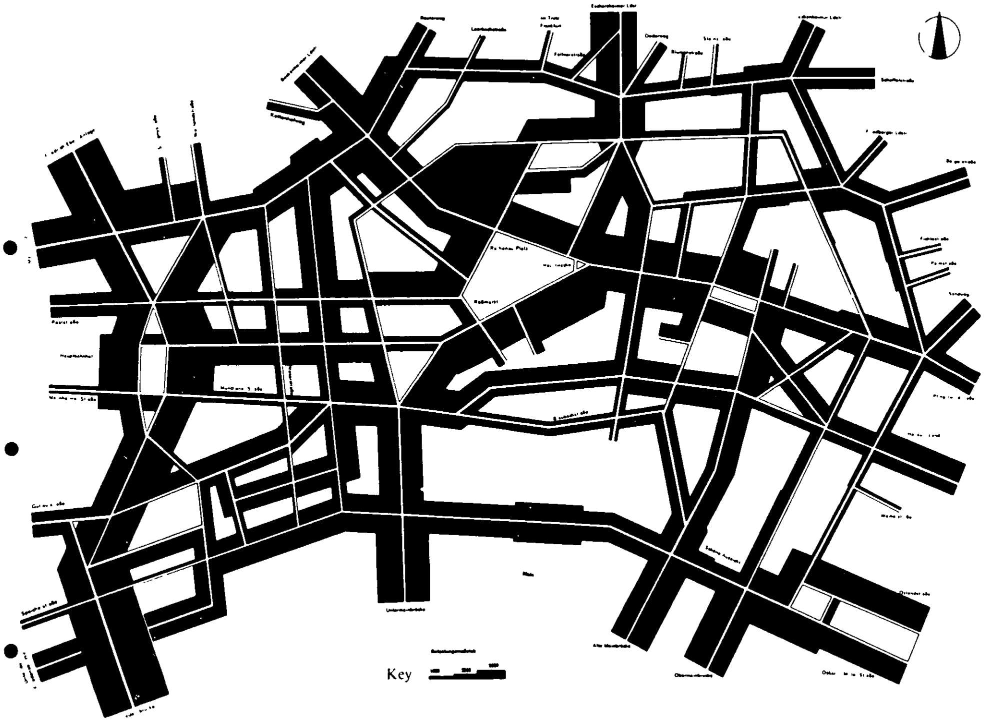
The above examples seem to suggest some cautious optimism with regard to the feasibility of improvement of graphical methods and indicate that further research work in this direction may be worthwhile.

NEED FOR ORGANIZED EFFORTS FOR IMPROVING GRAPHICAL METHODS

Another reason for cautious optimism for the future can be found in the fact that some awareness for the need of systematic efforts in the graphical statistical field seems to be felt today by various national and international institutions.



Graph 14



Graph 15

Frankfurt am Main (1961) Traffic in part of the town
Graph reproduced by permission of the Municipality of Frankfurt from Gesamt Verkehrs Planung Frankfurt am Main, 1961 (Magistrat der Stadt Frankfurt am Main 1961).

A very clear and encouraging example of this is given by the stand taken recently in this field by the U.S. Bureau of the Census.

Therefore, it is perhaps not utopic to think that in the course of time the challenge put on graphical statistical methodology by the developments due to automation may be successfully met. It is to be hoped that in the years to come the entire field may be reappraised.

In such reappraisal, the following aims seem to be of particular importance:

(a) Criteria to which scientifically dependable graphs are to conform must be investigated and restated clearly. (b) Properties, limitations, and pitfalls of each of the existing graphical systems should be thoroughly reinvestigated. (c) Also the problem of building rational scales for the graph, apt to ensure good correspondence between the data represented and the graphical symbols used, needs deep rethinking and finding of general solutions valid for all types of graphs. (d) Systematic exploration of future needs should be performed in order to encourage development of new graphical methods capable of standing up to scientific requirements.

This reappraisal is a major enterprise in which statisticians, geographers, cartographers, psychologists, and people dealing with information theory and methods should cooperate. To reach it, better communication should be established too between theoreticians, technicians, and builders of hardware and software, and between producers and users of statistics and graphs.

REFERENCES

1. Provisional copies of the opening paper of this meeting (R. Bachi, "Graphical Methods: Achievements and Challenges for the Future") were distributed at the International Symposium on Computer-Assisted Cartography. The final report on the meeting will appear in the Bulletin of the International Statistical Institute.

2. See: D. Huff, How to Lie With Statistics. New York: Norton and Co., 1954.

3. To simplify the discussion, we disregard here the fact that the data refer to the median income and not to the arithmetic average of incomes.

4. See: Journal of the American Statistical Association, Vol. 68, No. 342, p. 361.

5. J. Bertin, Semiologie graphique. Paris: Mouton & Gauthier Villars, 1967.

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THE CHALLENGE OF MAPS FOR THE VISUALLY HANDICAPPED

John C. Sherman
University of Washington

INTRODUCTION

It is a pleasure for me to participate in and hopefully make some contribution to this Symposium on Computer-Assisted Cartography. While I am interested in and involved in various ways with the broad spectrum of subjects with which all of you are concerned I should like to confine my remarks to two special groups of potential users of the graphic communication products in which we are all interested. Those two groups include: 1) persons who have very low levels of visual ability, sometimes referred to as partially seeing; and 2) persons who are legally or totally blind, including both adventitiously and congenitally blind individuals.

I do this for two reasons: 1) the functions of maps and graphics for these two groups is, in essence, exactly the same as for all human beings. These functions relate primarily to the process of learning and understanding the static and dynamic characteristics of spatial data sets distributed above, upon and beneath the terrestrial surface as well as, increasingly, those related to extra-terrestrial phenomena; and 2) the philosophy, methodology and technology of cartography, with some special modifications, is directly applicable to the creation of graphic products to serve the needs of these two groups.

The range and variety of activities in which those who must adjust to severe visual malfunctions or blindness are participating is steadily increasing. Whether these activities involve sports, such as skiing, hiking, fishing and, whether they are related to employment in industry or the professions, or involve the daily problems of learning to operate in and gain understanding about an unseen or dimly seen environment, maps could serve as useful communicative devices. As one blind person commented, "I have acquired various tactual maps and atlases, and am astounded by their uselessness. They are merely base maps." And further, "...disturb me because of the lack of thematic maps."1/ Despite the fact that the need has existed for many years the cartographic profession, with a few exceptions, has not recognized it and has not contributed very significantly to the knowledge and techniques needed to create effective maps for these people. I am sure that you all recognize the fact that the graphic mode of data presentation is not necessarily the most effective device for conveying information to all sighted individuals, neither can it be assumed to be best for those with severely restricted or no sight. Furthermore, the lack of a variety of easily available maps designed for different learning tasks has been so severe that many visually handicapped people have never seen a map designed for their use and thus have never acquired any training or experience in reading and interpreting them. Thus the increasing range of activities in which they participate has not generated an increase in demand for maps that could be useful tools in those new learning situations. We thus face an historical vicious circle--the visually handicapped do not use maps therefore there is no reason to create maps. The circle must be broken, but as is apparent to all of you this entails solutions to many psycho-physical, design and technical problems as well as an educational program for teaching the visually handicapped to read and interpret maps and to convey ideas of the possible multiple functions which maps could serve for them.

RESEARCH NEEDS

In my view there are three broad, closely interrelated areas or stages which require research and experimentation if we are ever to become competent in providing for the map needs of the visually handicapped. The first relate to a technology for creating tactual graphics which is flexible, inexpensive and as compatible as possible with current systems for production of maps for the sighted. A production system must be available or other phases of research will be sharply constrained. The second area relates to the host of problems which are largely psycho-physical in character. These include the question of tactual perception and discriminable symbol design as well as fundamental knowledge about spatial orientation and environmental data needs for independent mobility of the blind. For those with severely impaired sight we need to broaden our research on visual parameters to yield better data on figure to background contrasts achievable in black and white as well as in color.

Studies related to optimal symbol (data) loading or complexity are badly needed in the applied design of graphics for both groups. We very much need to know more about the potential for and the parameters of symbol scaling particularly in an ordinal and possibly an interval sense for both groups. The third area has to do with the application of knowledge, gained through the first two stages of research, in developing a methodology for communicating or transmitting information and especially spatial concept understanding to the visually handicapped. I am curious as to how I could get across Ullman's concept of spatial interaction, intervening opportunity, etc. to a blind student through use of audio and tactual methods. Would map-like tactual diagrams be effective and how should they be structured and used? I have never seen a tactually readable map of population distribution even though hundreds have been produced and are used in teaching sighted students. What about the enormous variety of special purpose thematic maps which have been prepared for the sighted--are any of them (assuming they could successfully be transformed to a tactually readable version) useful in teaching the blind. I believe that progress in all three of these areas might eventually put use in the position of creating and using maps as one type of aid for imparting the same range of knowledge to the blind and partially seeing as we now attempt to do for those with no significant visual impairment. In my view this is a very legitimate objective.

RECENTLY COMPLETED AND ON-GOING RESEARCH

During the last year we have undertaken anew a literature search and correspondence with agencies and individuals around the world to assess the state of current research which has been completed or is underway, on maps for the visually handicapped.2/ To date I have not identified any significant studies having to do with the design and production of maps for those with severe visual impairment, the partially seeing. Only Greenberg's study3/and a joint paper by Greenberg and Sherman4/ are directly related to these problems. For the blind, some very significant progress has been accomplished chiefly in England, Sweden and the United States. Space and time do not allow for a full description here but certainly the recent work of Gill, James and Armstrong in England, Jansson in Sweden, Morris, Nolan and Berla from the American Printing House for the Blind and Wiedel and Groves as well as

Gilligan and Amendola here in the United States all have contributed significantly to the body of knowledge needed in creating maps for the blind. There are many others who have or are undertaking significant work but in many cases it is not as directly related to map design problems as those cited.

The work of Gill and James has pertained to all three areas of research already identified. Gill[5] has developed a computer-assisted method of routing, in negative form, combined with a computer program for transposing to braille with which he has produced a number of effective mobility maps. Gill and James[6] have performed controlled testing which has both confirmed and expanded our knowledge of symbols and their discriminability. Armstrong[7] has written thoughtfully about results of research at the University of Nottingham. While most of this activity is related to large-scale mobility map function and design, it has contributed knowledge and experience pertinent to the broader frames of reference discussed in this paper. Nolan and Morris[8] of the American Printing House for the Blind have been major contributors to our knowledge of tactual symbols and their discriminability. Franks[9] and Berla[10] have and are working with problems associated with the third area of research related to strategies and uses of maps for communication of concept understanding to children. Wiedel and Groves[11] have also been major contributors to our knowledge in all three areas of research. I wish time permitted a more complete review and a further range of citations, but it is obvious that within the last five years or so many have contributed to a substantial amount of knowledge upon which others (hopefully including cartographers) can build. There is of course a moral obligation to do our best in providing for the needs of the visually handicapped; increasingly there is a growing legal obligation as Federal and State laws relating to equal access to information develop and are enforced.

RESEARCH PROGRESS AT THE UNIVERSITY OF WASHINGTON

Under a research contract funded by the U.S. Geological Survey we are exploring the rationale and methods of converting standard USGS map products into forms useable by both the partially seeing and the blind. As the range of activities of the visually handicapped expands, it seems probable that a selected range of map types, published by this agency, could and should be published as special editions. We have begun with the objective of creating two experimental maps as part of the Bicentennial program. The first is of Metropolitan Washington, D.C., all the area within the Beltway, at a scale of 1:24 000 or one inch to two thousand feet. Basically this involves conversion of all or portions of twelve seven-and-a-half minute quadrangles into a visual image designed for those with very restricted vision as well as one which is tactually readable. This map for wall display will be published in two dual-use editions in molded plastic; one with the multi-color normal visual image with tactual symbols in relief and the other with a large type reverse image combined with tactual symbols. The pre-printing on plastic and the vacuum forming of the final products will be carried out by the Defense Mapping Agency Topographic Center, which is cooperating on this project. The second map will be of the Mall in Washington to function as a personal mobility map at a scale of one inch to three hundred feet. One dual-use edition will be produced combining a large print visual image and raised tactual symbols. Entirely new data are required for this map which have only now been acquired, thus completion will be delayed until the end of the year.

The metropolitan map will be unique for I cannot identify a single map of a whole major city that has been produced anywhere in the world for use by the visually handicapped. In fact the support and encouragement of USGS is unique, the first case in the world in which a national mapping agency has ever attempted to produce maps for the visually handicapped. The map scale eliminates its use as a mobility map; its function will be as a tool to learn about the gross morphology of the city and the major transportation linkages within it.

As for any map, our first concern was analysis of the functions the map should be designed to serve. We knew from our own and others work and experience that the physical restrictions on possible symbology (size, spacing and general discriminability) reduce the permissible information load to about 25% of that for a normal vision map of comparable scale. I questioned many blind and partially sighted about function and content of such a map in hopes they would be able to help. Unfortunately I met with the statement, "I have never seen such a map, never thought about such a map even of my home city--I don't know the purpose for which I would use it and thus I am not sure of what information it should contain," over and over. We produced three versions of a test sample of downtown Washington, had blind individuals examine it and then discussed content. We reviewed the content of the only other nearly comparable map, that of Central London first published by the Royal National Institute for the Blind in England in 1961 at a scale of four and a quarter inches to the mile. The review of existing literature gave us very little more enlightenment. Thus we have selected and symbolized information on this map to the best of our ability; we have eliminated far more content from the original quadrangle source maps than we have preserved. The validity of our decisions will have to be determined by user reactions once the map is available for their use. We plan an evaluative study at a later date.

We know that the larger percentage of blind in the United States does not read braille. For this reason the map will be restricted to use by those who can read braille or large print. At a later date we shall try to structure and create an audio-tape cassette to go with the map although this will be more difficult than Blasch's[12] specific route descriptions recorded on tape. These problems also relate to the dual-use (visual-tactual) character of the final products with which a normally sighted or partially seeing person could help a non-braille reading blind individual use the map. In fact our experience indicates that unless it is absolutely impossible a tactual map for the blind should never be produced without at least a large print visual image combined with it.

Almost simultaneously with our investigations of functional design problems was our development of a photomechanical system of transforming a two dimensional image into a three dimensional one. I will not detail all the products we have experimented with, in the end and for the moment we have found the Dyna Flex[13] printing plate system least expensive and as effective as any other. These polymer plates[14] are exposed through a high contrast line negative and when processed an image is formed whose height is .025[15] of an inch. Completed plates cost approximately eight dollars per square foot, but are tough and durable such that they can be used directly as tactual graphics or as masters for vacuum-forming additional copies in plastic. Our experiments also indicate that the plates may be used in blind embossing of paper copies at much lower unit prices. This photomechanical process makes possible pre-separated manuscript copy in hand drawn, scribed or plotter output form and the use of conventional contact techniques for producing composite negatives from which the plates can be made. Separation made feasible could allow several subject-specific maps to be produced on the same base at relatively low cost. This last capability is of utmost importance for tactual and low vision maps since the information load is so much lower than on maps for those with unimpaired sight. As a result the visually handicapped will be better served by several isolated subject maps than one composite which is so complex that it cannot be read or requires so much effort that it is not used.

The polymer plates which are quite satisfactory for many tactual communicative products suffer from one major limitation. They are manufactured for printing, thus requiring all image elements to be on the same plane. We are aware of the tactual functional values of more than one height for all symbols. Variation in symbol z values increases the discriminability of categories of symbols. Greater relief for certain symbols seems to also give them greater tactual emphasis much as thicker line weights, color allocations or varying of figure to ground contrasts create in maps for those with normal sight. Therefore, as part of our continuing research Carl Youngmann is undertaking work with a numerically-controlled router system, similar to that of Gill's and we are also looking into a new experimental digitally controlled twin-laser system which is being developed by Formigraphics Engineering in California. Using either, we may be able to control the vertical heights of each type of symbol at will, thus making it feasible, through testing, to establish the desirable ranges of relief for symbols which should be used for tactual maps.

Design and production of the Metro map, which is virtually complete, has involved the creation of braille in black and white form (not raised) to be compatible with our photomechanical conversion system. Thanks to information obtained from Mr. Gilligan we have used Chartpak transfer braille sheets[16/] for this composition. To accurately set up braille for map labelling, legend and key, one must have the editorial help and advice of a sighted person who is expert with braille and its use. Lack of an existing automated system with output in visual, not embossed, form to transpose names, descriptive phrases and text to braille equivalents makes this process very time consuming and increases the likelihood of human error. The bulk of braille, as a general rule, makes it impossible to incorporate full names on a map at any scale. We are using abbreviations of names rather than abstract alpha or numeric braille symbols to reduce as much as possible the necessity for referring to the key. We have also departed from standard braille placement procedure in aligning it close to symbols dictated by the alignment of the symbol. As a consequence the legend content must be more redundant than for a sighted map to incorporate samples explaining the symbol to braille relationships and particularly the orientation rules that have been developed for the map. The key giving full identity to the abbreviations on the map has to be prepared in two cross-referenced forms. The first gives full names by categories for each abbreviation and a locational description. The second is organized by abbreviations in alphabetical order independent of the category each identifies. We hope this will facilitate quicker and more accurate reference from the map to the key and reduce confusion in reading the braille.

Type for the partially seeing image is in 18 point Helevetica in capitals and lower case letters. Very minimal data on type specifications for large type, for those with highly restricted vision, are available. We had, consequently, to establish our own rules for photo-type setting. We hope our decisions will retain a high level of legibility and readability for this image.

I wish I could say, "Here is the final product, please help us in any way you can to evaluate its characteristics and functional effectiveness." This I cannot do for final stages of reproduction will not take place until late this autumn. What I have said must be regarded as an interim report of our research progress. I hope by spring, during the ACSM meetings, to be able to make a more complete report accompanied by samples of the completed maps. At that time we should also have completed the map of the Mall which in itself poses a number of special problems. I have ordered the new Map Making Kit and Map Makers Handbook[17/] which is being marketed in England. Among other objectives, this unit is intended to stimulate and help develop use of standard tested symbols for mobility maps. I am very sympathetic to this objective and after analysis we may attempt to utilize the same symbols for the Mall map. Very few attempts have been made, anywhere in the world, to standardize tactual symbols for such maps, those that presently exist vary greatly in their design and symbol use. This diversity severely constrains training programs for the blind intended to train them in the use of such maps.

CONCLUSION

I believe, at this point in time, it is reasonable to conclude with the following statements.

1. The map resources designed in an effective manner and form for those with visual handicaps, the blind and partially seeing, is extremely limited and in many respects non-existent.

2. We cannot, however, assume a large pent-up demand for maps from these two groups. Most, never having had a variety of maps easily accessible to them, do not think of them as a useful device and, often, would not know how to use them for gaining access to knowledge.

3. Demand will grow slowly and then only after the resources are expanded and made available at modest cost.

4. The real hope for demonstrating the utility of maps as a communicative device for the visually handicapped and teaching them how and for what purposes they could and should be used lies in educational programs of our schools.

5. There is a substantial body of research findings and general knowledge which can be applied by the cartographic profession in creating new and useful map products for these persons.

6. New technology and materials make it possible to incorporate an expanded range of cartographic methods including computer-assisted methods, to significantly decrease the cost and increase the flexibility with which we can create maps for the visually handicapped.

7. If, finally, we can aid in the utilization of such products as communication devices to help convey concept and process understanding to those with severe visual handicaps we will have at least partially closed the loop in the cartographic process. We will then be able to apply user and experiential feedback to create a still broader range of functional maps for the two groups of people identified at the beginning of this paper.

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12. Blasch, B.B., R.L. Welsh and T. Davidson, "Auditory Maps: An Orientation Aid for Visually Handicapped Persons, The New Outlook, 67 (1973), pp. 145-158.

13. Manufactured as a letter-press and dry-offset printing plate by Dyna-Flex Corporation, Salt Lake City, Utah.

14. There are several other similar plates manufactured, of which the Nyloprint plate manufactured by BASF in Wyandotte, Michigan, is fully as effective for this purpose and only slightly more expensive.

15. Standard braille calls for a height of from .017 to .022 of an inch.

16. While we have made the Chartpak V.T. 736 transfer sheets work, the present product should not be used for it has serious inadequacies in alignment, cell size and spacing and dot size. We will shortly have produced a new version which should become available in a few months.

17. Both produced by and available from the Blind Mobility Research Unit, University of Nottingham. Price is $5.50, prepaid. Address orders to Dr. G. A. James, Blind Mobility Research Unit, University of Nottingham NG7 2RD.

MAP GENERALIZATION:
THEORY, PRACTICE AND ECONOMICS

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INTRODUCTION

The theory of map generalization is discussed with particular reference to the processes of simplification and classification. Both of these processes are used extensively in computer-assisted cartography; however, a comprehensive, flexible software package has not yet been organized from the myriad of algorithms available. Further, systematic use of algorithms, based on the reasons for generalizing in cartography, is not common practice. When viewed in respect to the reasons for generalization, the costs of using a theoretically based algorithm can easily be absorbed in most computer-assisted cartographic situations.

Robinson and Sale in the third edition of Elements of Cartography define cartographic generalization as being composed of four elements. These elements or processes are simplication, classification, symbolization, and induction. They do not claim that these four processes are independent of one another, only that they represent facets of the total process of cartographic generalization which cartographers can conveniently isolate and discuss. The definitions of these four processes by Robinson and Sale are not rigorous, but they are the best available.

Non-rigorous definitions are usually ignored when the cartographer interacts with automated systems to produce a map. Therefore, it is not out-of-line to suggest that a non-rigorous definition of generalization and its elements is of little or no use for the purpose of making a map with computer assistance. One can use non-rigorous definitions only to discuss the map after a software manipulation sequence has been selected and/or the map plotted. What is basically needed is to define generalization so that the reason or purpose for making the map can aid the cartographer in selecting the most appropriate software sequence for map production given the structure of stored data files and the available software manipulation sequences. To date, this luxury is not available.

The intent of this paper is to offer more rigorous definitions for the purpose of classifying the processes involved in map generalization, to show how these processes have been and/or may be implemented in practice, and hopefully to give some insight into the economics of generalization algorithms relative to the total map preparation costs.

EDITOR'S NOTE: *All graphics in this presentation have been reduced from the original scale for publication purposes.*

THEORY

It is possible to redefine and categorize the four processes of generalization mentioned above as transformations possessing or not possessing certain properties. The transformational properties considered are two: the property of being one-to-one and the property of onto. A function $f: A \rightarrow B$ is said to be one-to-one if distinct elements in A have distinct images, (i.e., if $f(a) = f(a') \Rightarrow a = a'$). A function $f: A \rightarrow B$ is said to be onto if every $b \varepsilon B$ is the image of some $a \varepsilon A$, (i.e., if $b \varepsilon B \Rightarrow a \varepsilon A$ for which $f(a) = b$). 2/ The property of one-to-one is the easier to understand. If there exists a data file A and a derivative data file B resulting from a transformation of file A, so long as each single entry selected from file A results in a single entry in file B, the property of one-to-one is preserved. The onto property is a little harder to illustrate. It requires that every entry in file B have a referent entry in file A. In other words, file B has no element that has no referent in file A.

The possession or lack thereof of these two properties gives four possible categories of transformations: 1) transformations that are both one-to-one and onto (bijective), 2) transformations that are neither one-to-one nor onto, 3) transformations that are one-to-one and not onto, and finally 4) transformations that are onto but not one-to-one.

If one examines closely how a cartographer generalizes, it appears reasonable to refer to a transformation that is one-to-one and onto as approximating the process of simplification, a transformation that possesses neither property as induction, a transformation that is one-to-one but not onto as symbolization and finally a transformation that is onto but not one-to-one approximates classification. If cartographers then use these transformation properties to refer to the four processes of generalization, any algorithm can be classified as to which generalization process or combination of processes it approximates. Thereafter discussion can follow based on the knowledge that everyone involved understands what each other means by a simplification process or a classification process.

To use these more rigorous definitions of the processes of generalization can help the cartographer. But before this can be illustrated, the term "map" must also be defined. Simply stated, a map is a communication channel. Its primary function is to serve as a vehicle to communicate information from one cognitive realm to another cognitive realm. To start the mapping process, an idea about what the cartographer wishes to communicate initiates a selection from his cognitive realm of information to be communicated. (See Figure 1.) This initial selection is both one-to-one and onto and is not part of map generalization. Only after this selection process can map generalization take place, and furthermore, the processes of map generalization can only take place under certain additional constraints.

Ideally all of the following constraints are present: purpose of map, map format, scale, intended audience, data quality, and graphic limitations. Practically, of course, there is an economic constraint; and in fact, all of the above constraints are usually based in economic terms.

After the selection process, generalization of the selected information can take place to form the cartographer's conception of the map (illustrated as set A" in Figure 1). The processes of simplification and classification may be performed sequentially several times and in any order until the cartographer has arrived at a conception of the map, $A'' = C'' \cup D$. Once the cartographer has a conception of the map, symbols can be assigned and thus the third generalization process, symbolization, becomes operative.

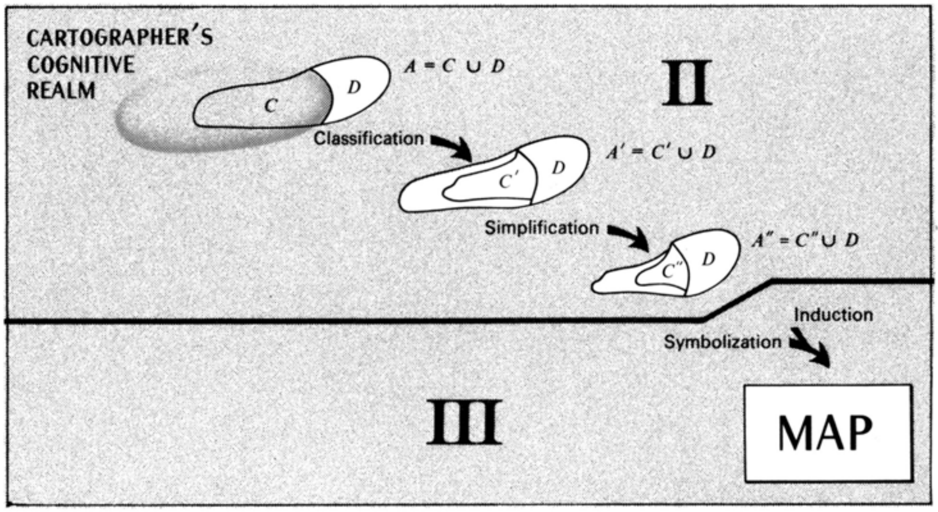


Figure 1. The mapping process

The cartographer may reiterate back to more simplification and/or classification transformations if a given symbolism appears inappropriate, but in automated cartography such reiteration may become costly. In fact, the automated case of map production is only efficient where the cartographer has so specified the conception of the map that each generalization process need be performed only once. The final process of inductive generalization accompanies symbolization and the cartographer has little or no control over it. But if the three processes of simplification, classification and symbolization are done well, induction will probably not hinder the communicative effectiveness of the map. Rather inductive generalization usually enhances a map's effectiveness.

According to this line of reasoning then, in theory, map generalization is a series of processes defined by the properties of their transformations applied to a selected set of information with the explicit purpose of efficiently conveying that information via a communication channel called a map to a map reader or a map-reading audience. How is this instituted into cartographic practice and, more specifically, into computer-assisted cartographic practice?

PRACTICE

In computer-assisted cartography, two types of computer-readable data storage currently predominate: 1) data stored as strings of coordinates (mostly the result of digitizing), and 2) data stored as picture elements (remotely sensed or scanned). While all four generalization processes can operate on both types of stored data, this paper will concentrate solely on the processes of simplification and classification while ignoring symbolization and induction.

SIMPLIFICATION

Two cases can be identified in the simplification of data stored as strings of coordinates: 1) point simplification and 2) feature simplification. Point simplification refers to the simplification of a string of coordinate points defining a line or the outline of an area. Such simplification takes place by eliminating all points but a chosen few that are deemed more important for phenomonological character retention. The feature case of simplification occurs when many small items of the same class are present in an area. Certain of the items are retained while others are omitted. The essential character is retained while detail is eliminated. In addition to these two cases of simplification, the simplification of data stored as picture elements can consist of smoothing techniques including surface fitting, and/or enhancement procedures.

Phenomena exist in reality as points, lines, areas or volume. It has been shown that by rigorous definition the cartographer conceives of these for mapping purposes as really only three categories: point, line and area/volume. 3/ The cartographer must conceive of all data as existing for mapping purposes in one of these three categories. Theoretically, when discussing data stored as strings of coordinates, each of these three categories can occur in each of the two cases, point and feature simplification; however, if the features themselves are points, there need be no difference in the simplification algorithm between the two cases.

Figures 2 and 3 illustrate the point case for line data and the feature case for area/volume data respectively. In Figure 2, the map of Portugal illustrates

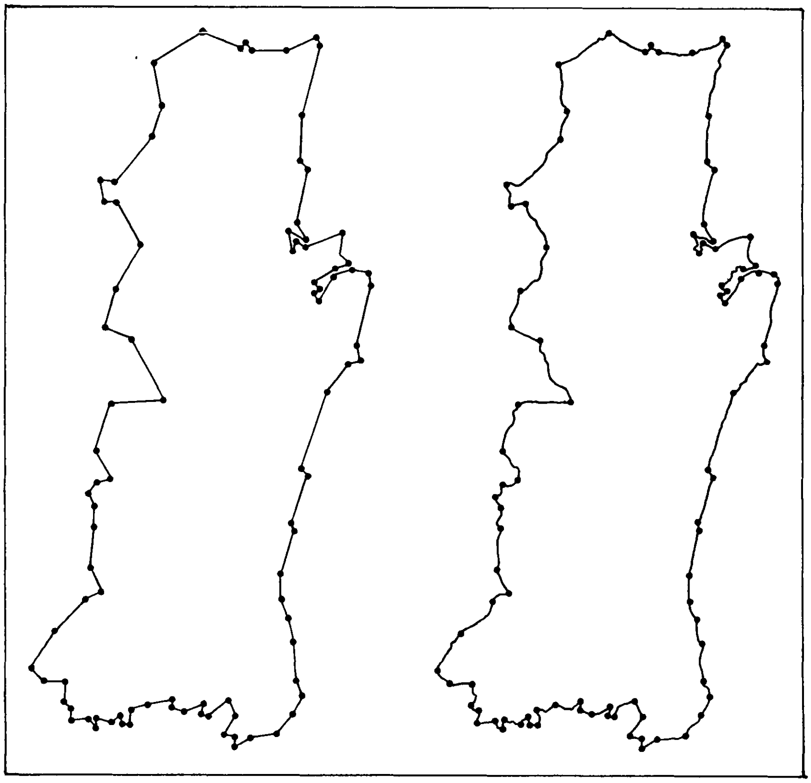


Figure 2. Simplification of lines from selected points

that simplification of lines results from the one-to-one transformation of selected points onto a new map. The points denoted on both sides of Figure 2 are exactly the same. These selected and transferred points from the left map are connected by straight line segments and are shown on the right map.

Simplification by feature elimination is illustrated in Figure 3, which shows forest cover areas of Sheboygan County in Wisconsin. In feature elimination simplification, either a feature is shown in its entirety or it is omitted. In Figure 3, the smaller areas present on the map on the left are eliminated on the map on the right. Obviously it is possible to combine point and feature elimination simplification by eliminating features and by point simplifying the outlines of the uneliminated features.

Figure 3. Simplification by feature elimination

For data stored as picture elements, simplification using a smoothing operator is illustrated in Figure 4. The picture elements are evaluated one at a time and retained as is or modified; thus the transformation retains its properties of one-to-one and onto.

Simplification can be applied along either of two dimensions. Either a reduction in the scale dimension (see Figures 7 and 8), i.e., reduction from an original scale to a smaller scale representation, or a simplification along some constant scale dimension (see Figures 5 and 6), i.e., a detailed representation versus a simplified representation at the same scale. Figures 2, 3, and 4 are all illustrations of this latter type. Along either of these two dimensions, the process of simplification can be applied to each data category in both point and feature elimination cases and/or using smoothing operators. Usually generalization in practice calls for an application of the simplification process primarily along the dimension of scale reduction and secondarily along the dimension of constant scale. It also usually involves, for stored data strings, both the simplification of points and feature elimination.

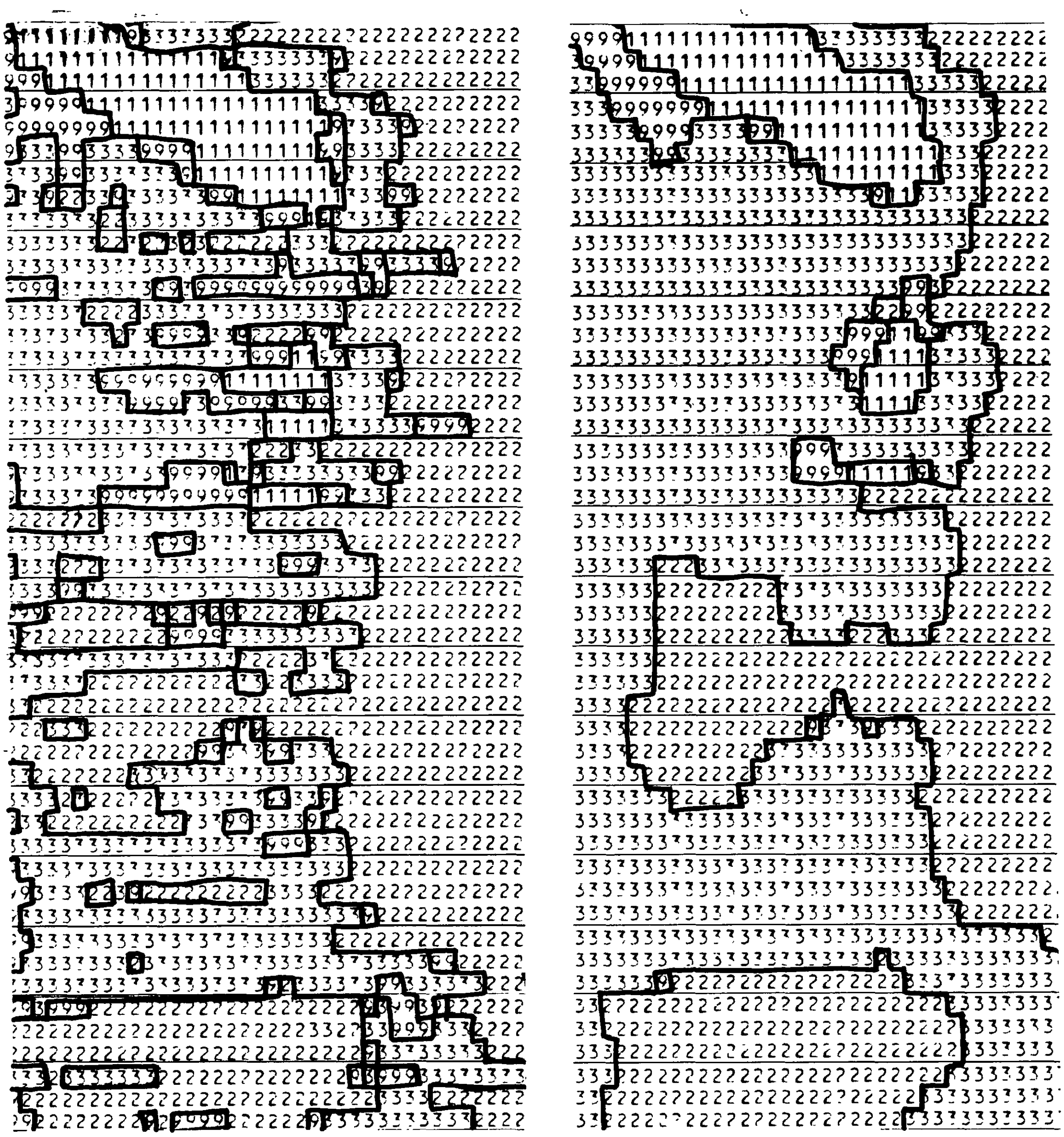
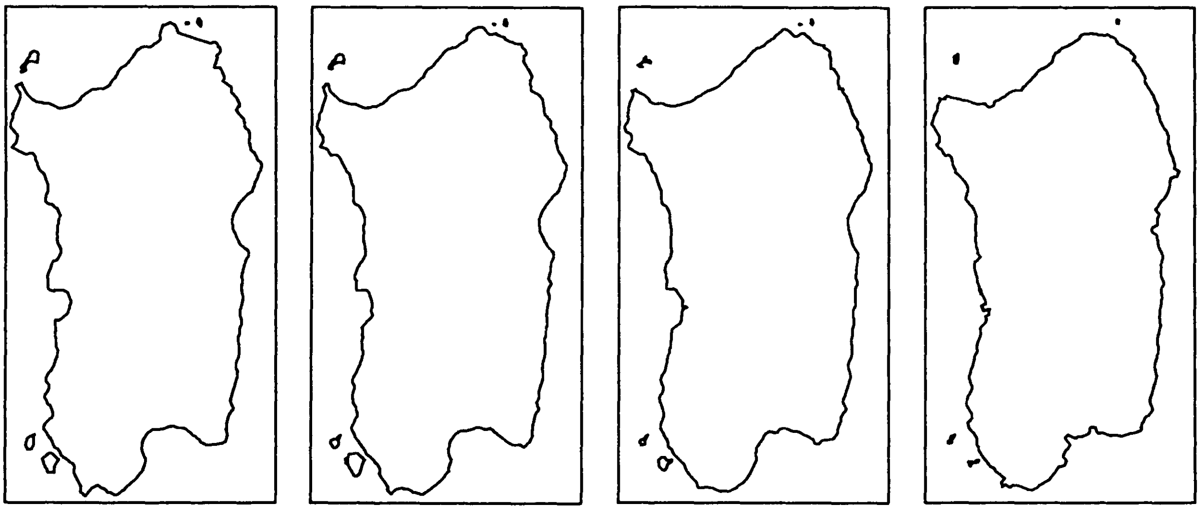


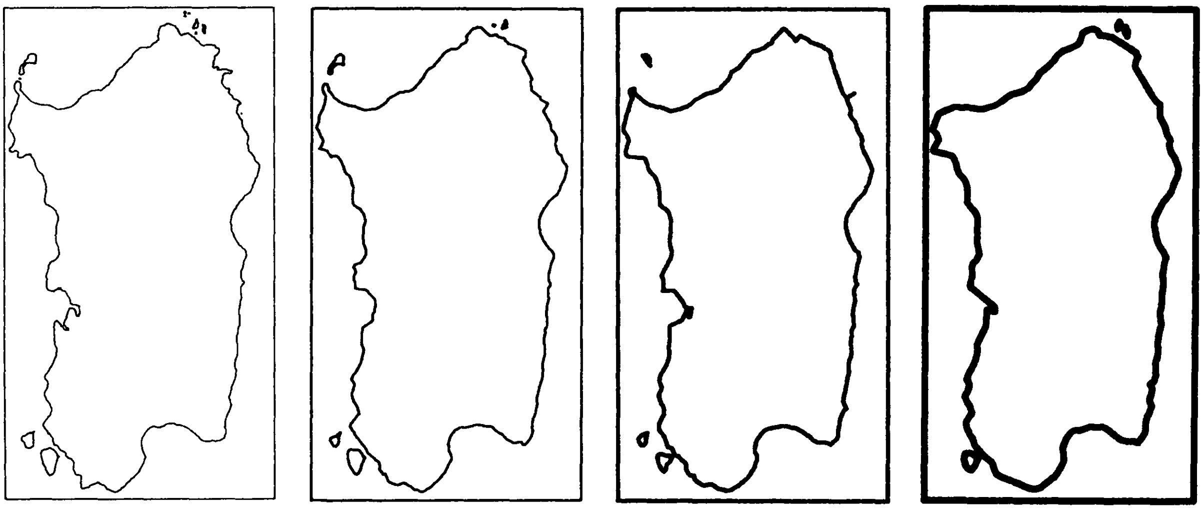
Figure 4. Simplification using a smoothing operator

Many algorithms currently exist to aid the cartographer in computer-assisted simplification. Currently in computer-assisted cartography data reduction is sometimes referred to as a separate process in constructing and editing files from the generalization process. Data reduction is not different from the simplification process and, therefore, should be considered part of cartographic generalization, not just data preparation. As long ago as 1964, Tobler outlined several possibilities for the simplification of lines composed of a series of points. 4/ For 1964, Tobler's work was a very useful contribution, and his conclusion at that time was that none of his tested methods resulted in generalizations that were appreciably better than a generalization done by allowing the output hardware to eliminate all points that were closer together than its plotting resolution. Since 1964, however, common plotter resolutions have become smaller, so that the efficiency of allowing the output hardware resolution to determine which points are plotted can again be questioned.



Map 3a. .01 Map 3b. .30 Map 3c. .60 Map 3d. .90

Figure 5. EFFECTS OF GENERALIZATION LEVEL
(*from Brophy*, 1973)



Map 4a. .012" Map 4b. .020" Map 4c. .032" Map 4d. .047"

Figure 6. EFFECTS OF LINE WEIGHT
(*from Brophy*, 1973)

Later during the 1960's, several other point or feature elimination simplification methods were proposed. 5/ Likewise, smoothing operators which can be applied to picture elements during a simplification algorithm have been proposed for spatial smoothing and filtering. 6/ The computer application of these algorithms to data matrices is straightforward.

Two methods of simplification applicable to data strings were readily available at the University of Wisconsin to run a comparison, and the results are illustrative and should be of interest to cartographers. The methods were programmed by Brophy and Douglas respectively. 7/ Brophy's algorithm appears to have a firmer base in cartographic theory.

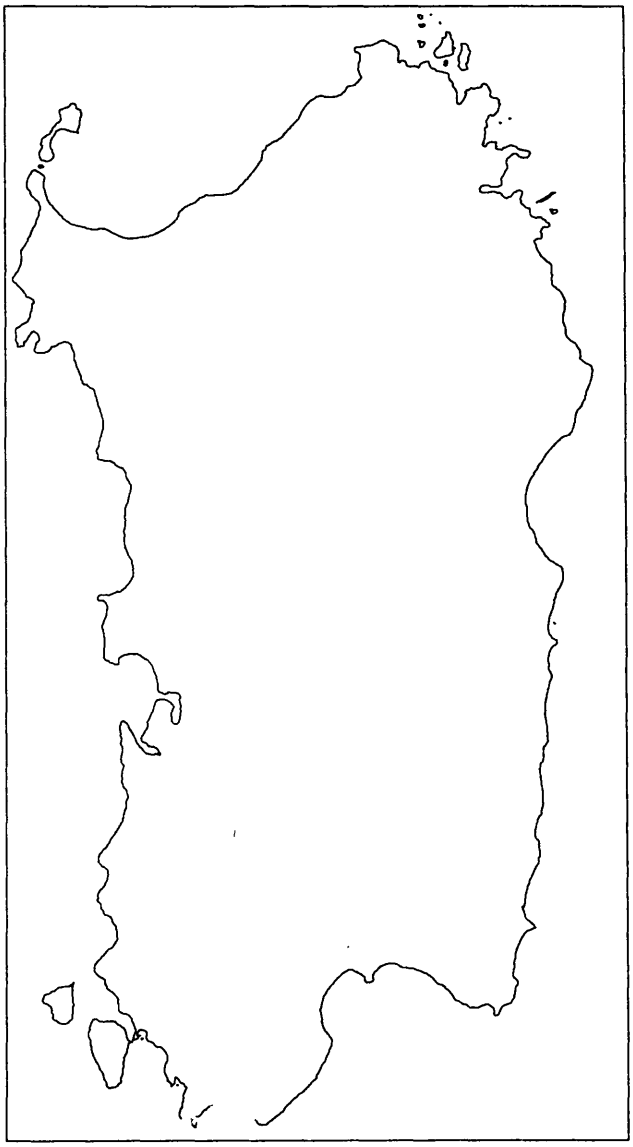


Figure 7. 1:125M Generalization .20 Feature Elimination (from Brophy, 1973)

Brophy programmed a simplification routine for the point case of lines that requires classification first. The method consists of five components and a detailed explanation is readily available in the literature. 8/ Although this algorithm sounds complex, it runs rather efficiently and gives reasonable results. Figure 5 is taken from Brophy's work and shows from left to right increased generalization levels at a constant scale and line width. Figure 6 illustrates increased line widths at a constant level of generalization and scale. Figures 7 and 8 show constant levels of generalization and line width at increased scale reduction. The total algorithmic package allows the cartographer to specify: a) the amount of generalization, defined on a 0<x<1 scale, b) the line width (assuming more detail can be presented at a constant scale with a finer line width), and c) the amount of scale reduction.

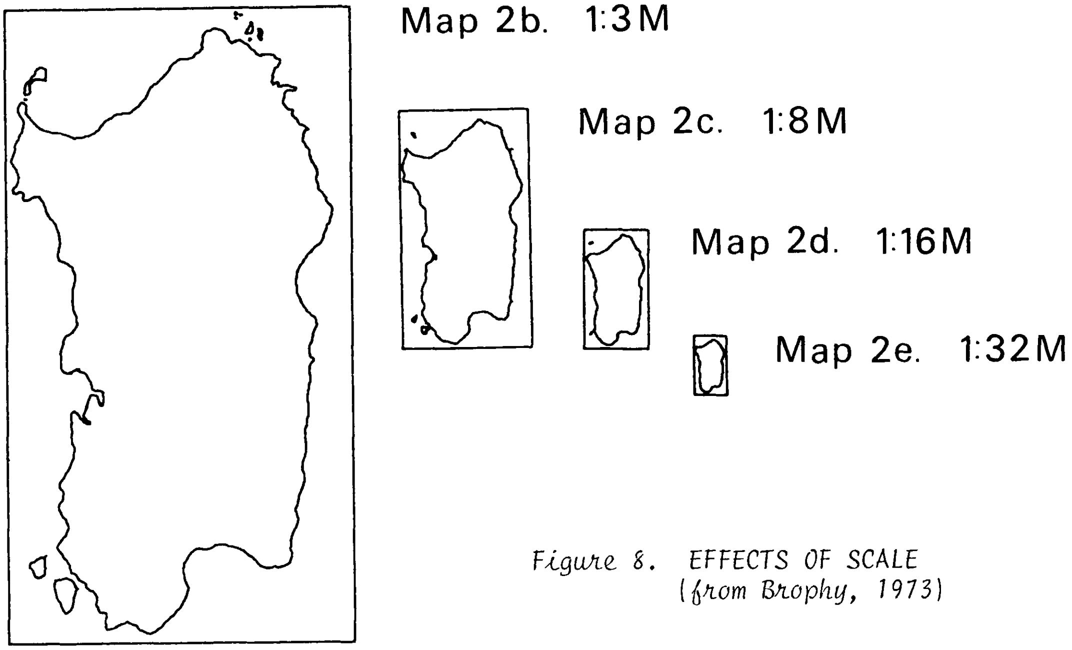


Figure 8. EFFECTS OF SCALE
(from Brophy, 1973)

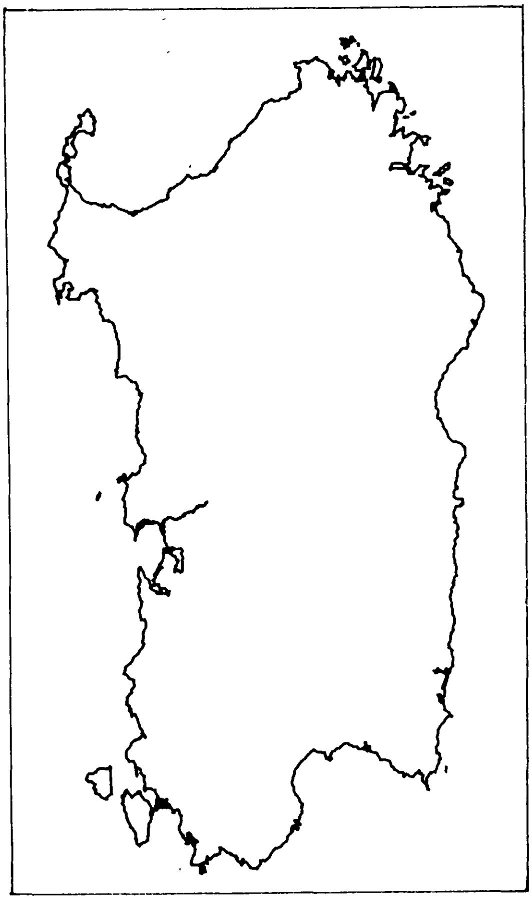


Figure 9. A plot of the original file, 15,000 points scale 1:2,125,000

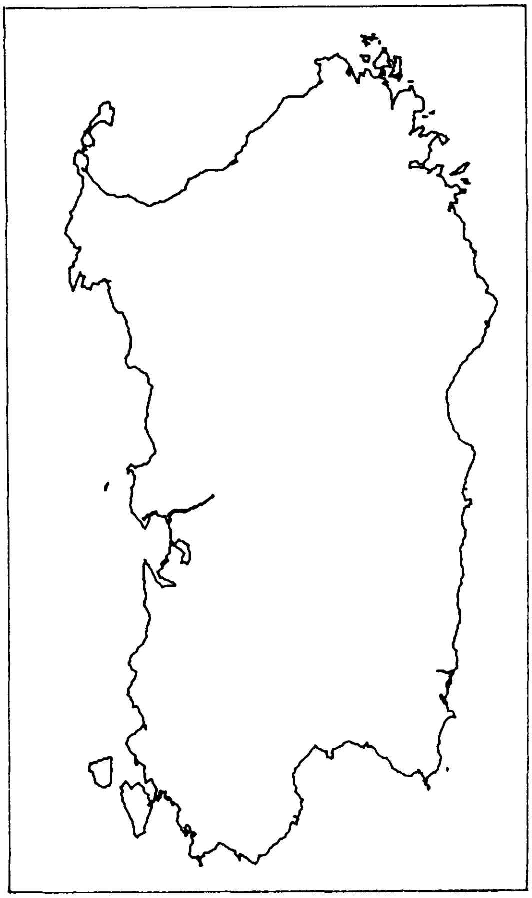


Figure 10. A plot of a reduced file, 1000 points scale 1:2,125,000

The second algorithm, included in a software package developed by Peucker with the particular subroutine of interest written by Douglas in 1972, offers a simplification routine that considers the elimination of points based on the degree of offsetting of these points from lines connecting separated points along the curve.[9] A case study comparing those algorithms can be seen by observing Figures 9, 10 and 11.

Figure 9 shows a plot of the original Brophy data file of Sardinia, 15,000 points in all (plotter resolution generalized). Figure 10 shows a plot of every 15th point of Brophy's data file (1,000 points in all). Figure 11 shows the results of Douglas's generalization of these files. These are comparable to Brophy's plot shown as Map 2c in Figure 8. Brophy's system would appear to offer more options to the cartographer for the point case of simplification, however, economics will probably dictate which algorithm will be used. Douglas's algorithm has no provision for feature elimination, thus the reduced line work on the west side of Sardinia closes on itself and results in heavy dark lines. Brophy's algorithm removes such features altogether.

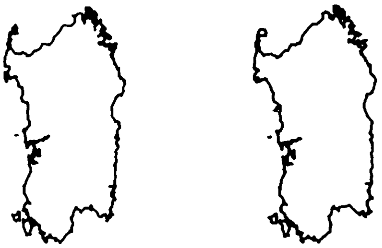
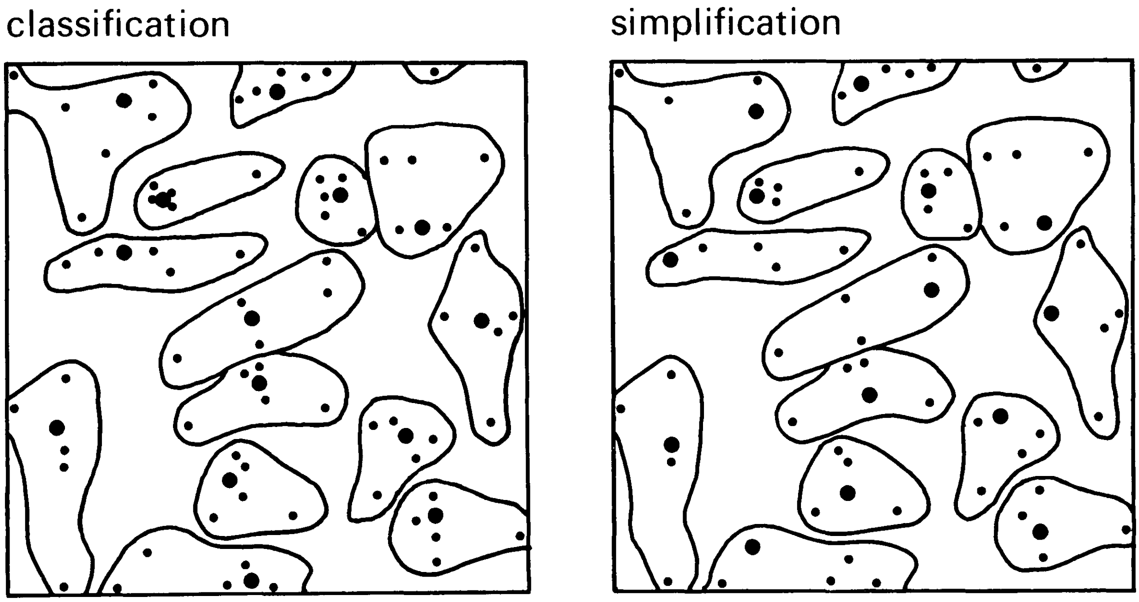


Figure 11. Figures 9 and 10 reduced to a scale of 1:8,000,000 using the Douglas algorithm

The rather unique case of feature elimination of points, however, can be treated just like the point elimination in lines as discussed above. For example, consider a dot map where one dot represents 50 people. Using simplification, a map where one dot represents 250 people would be as shown on the right in Figure 12. Simply eliminating four out of every five dots, allowing one of the original dots to remain, is an example of simplification.



classification

simplification

Figure 12. Examples of classification and simplification of a dot pattern

As mentioned earlier, most surface fitting and smoothing routines are simplification techniques. Moving averages represent one such class. The number of automated algorithms available to accomplish this are legion. Surface approximations by mathematical equation are simplification routines, provided the region approximated is exactly coincident with the region to be mapped. If extrapolation takes place using a surface approximating equation, the process has become one of induction for the area of extrapolation.

Finally, feature elimination routines can only be done easily in simplification if rankings have been recorded in the header information. Simplification is then accomplished merely by calling for all streams of rank 5 or above, or all roads of rank 2 or above, etc. Without rank assignation, there are no simple feature elimination schemes available. All available schemes would require operator intervention or size calculation for elimination.

What commonly seems to be lacking in most of these simplification algorithms is a convenient means for determining the correct input parameters. For example, smoothing is often applied iteratively, but at the end of what iteration does one stop? Statistical criteria can be established but a visual subjective decision, efficient only in the interactive mode, is usually relied upon. Brophy gives us flexibility in terms of specifying these parameters, but where are the guidelines for using the parameters? Cartographers to date have rarely relied on a theory to specify the weights that one might wish to apply to a smoothing algorithm. These are areas in need of research. The same arguments can be raised about surface approximation techniques. Is 95% explanation sufficient? The point is: Given our map purpose, what can we deduce from cartographic theory about answers to these questions? Answers to these questions should be our goal.

CLASSIFICATION

If one clustered 5 dots in Figure 12 and assigned a dot to the centroid of the dot cluster, the process would be classification. (See the left side of Figure 12). Two cases of classification routines are important for cartographers. (A) the agglomeration of units, and (B) the selection of class limits. Again, the categories of point, line and area/volume data can occur in both cases. Ancillary problems include the allocation of unit areas to a type or class, e.g., if an area is 40% cropland, 30% forest and 30% water covered, is it classed as cropland or as mixed since no category covers over 50% of the area? A similar problem is the categorization of picture elements.

The agglomeration of like units takes place most often by point clustering techniques from tables of locations of data points in storage. The agglomeration of lines is rare and the agglomeration of areas is part of one type of dasymetric mapping as well as applicable to data stored as picture elements. The automation of point clustering techniques is possible and at least one software system can purportedly agglomerate irregular areas as in dasymetric mapping.10/

The second case of classification, namely, class interval selection, has perhaps received more than its fair share of space in the cartographic literature. These routines obviously work only on ordinally or higher-scaled data. In general, in class interval selection, the cartographer has a theoretical base from which to work.

Since the cartographic goal is the communication of information via a map, at least three theoretical bases can be justified in class interval classification schemes: 1) the use of critical values, 2) the satisfaction of a set of statistical criteria, and 3) standardized schemes which purportedly enhance map comparisons. The first basis, critical values, is externally imposed on the cartographer. For example, if the Department of Health, Education and Welfare desires that all families with annual incomes under $10,000 qualify for a given Federal program and those with incomes $7,500 - $10,000 qualify for 25% benefits, those from $5,000 - $7,500 for 50% benefits and those under $5,000 for full benefits, the cartographer's class limit classification scheme presents no problem.

Examples of the second theoretical basis, the satisfaction of a set of statistical criteria, have also been outlined and programmed. When no outside criteria are imposed, cartographic theory could dictate that the aim of class interval classification is to define a set of class limits such that a member classified into any one class is more like the members of that class than the members of any other class. In other words, the theoretical goal of classification is a maximization of the homogeneity within the classes and a maximization of the heteogeneity between classes. These are statistical criteria, and Jenks has proposed iterative algorithms to solve this problem. In 1967 he proposed the equal average deviation scheme and the relative equal average deviation scheme.11/ Both satisfy a theoretical goal that can be deduced from cartographic theory.

Finally, when considering the comparison of maps the appropriate class interval scheme is less certain. Muehrcke and Muller 12/ have studied the problem. Armstrong suggests the use of the mean and standard deviations for class interval selection when comparisons will be necessary both between maps and over time.13/ Much work remains to be done in this area, however. Olson and Monmonier 14/ have separately studied map complexity as it relates to class interval determination. Standard routines have not been agreed upon. In any event, computer assistance will be both necessary and relatively easy.

In concluding this section the problem with simplification and classification schemes, i.e., the problems in automating cartographic generalization, would appear to be solved for the majority of the cases encountered. The need is to have a flexible efficient software package that has all of these routines available and to have cartographers sufficiently educated to allow them to make a judicious choice for their mapping requirements. A few areas still demand software development, however, and cartographers need to be more thoroughly educated before they can fully utilize computer-assisted generalization as it should be used from a theoretical point of view; that is, objective generalization before the making of the map.

ECONOMICS

The final part of this paper quickly touches on the subject of the economics of computer-assisted cartography.

What are the economics of computer-assisted generalization? Some algorithms vary directly with the number of input data points, others vary exponentially. Simplification which is one-to-one is often assumed to vary linearly with the number of points. This tends to be true except for some applications of surface approximations. Classification schemes are often not linear, rather they tend to vary exponentially with the number of points, and most hybrid algorithms, i.e., those algorithms having both classification and simplification components, are therefore exponential.

Returning to the examples of the point generalization of Sardinia discussed above, a cost breakdown for the 1:8 000 000 plots utilizing both software routines is as follows:

	Brophy		Douglas
Reading original data file (15,000 pts)	14.23		14.23
Reducing to 1:8 000 000 (15,000 pts)	3.22		5.67
Reducing to 1:8 000 000 (1,000 pts)	N/A		0.88
Reduction of 15,000 pts to 1,000 pts		5.47	
Reading reduced file (1,000 pts)		1.09	

All data in seconds of CPU time

Does this have important economic considerations for cartographers? In any generalization scheme there is the fixed cost of reading the original data. Obviously the above data support the hypothesis that the costs here can be overly large due to the storage of too much data. In fact, it may be possible to more than absorb the cost of a theoretically-based generalization scheme by reducing to reasonable size the amount of stored data. Experience at the University of Wisconsin Cartographic Laboratory has been that our digitizers capture far too much data for our intended uses. Therefore, a one-time reduction of the data in storage to eliminate unneeded and unuseable detail often allows long run savings in excess of the cost of adding objective generalization schemes, as the above illustration demonstrates.

Cartographers need theoretically-based generalization algorithms that are of use at the planning stage of map preparation not only in the analysis of the map after it is made. The additional cost of utilizing such algorithms in computer-assisted cartography may well be less than the cost of current operating expenses due to the fact that presently in computer-assisted cartography, cartographers are commonly storing and processing too much data, allowing hardware resolution to determine output, and in so doing relinquishing direct control over map generalization.

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Panel Discussion on Experiences in Federal Automated Cartography

PANEL DISCUSSION ON EXPERIENCES IN FEDERAL AUTOMATED CARTOGRAPHY

Representatives of major Federal agencies involved in computerized cartography discussed their experiences in the field and described the broad spectrum of Federal activity in this area. The panelists included representatives of the U.S. Geological Survey, the Soil Conservation Service of the Department of Agriculture, the National Ocean Survey of the National Oceanic and Atmospheric Administration, the Defense Mapping Agency and the Bureau of the Census.

BERNARD SCHECHTER, chairman of the Cartography Division of the American Congress on Surveying and Mapping, presided over the session and introduced the various speakers. His introductory remarks pointed out the increasingly widespread use of computer-assisted cartography and stressed the need for standardization.

WARREN SCHMIDT, chief of the Cartographic Research Team in the Topographic Division of the U.S. Geological Survey, drew upon his cartographic experiences, which include service with the Army and the Central Intelligence Agency. In a paper entitled "Decision Day for Automating," he gave eight reasons for automating: economy, speed, original data in machine form, volume, accuracy, graphic precision, computation and data manipulability. He examined the rationale of four selected mapping agencies that had decided to automate. The emphasis in most cases was on manipulability and speed and the paper suggested that these can be combined into a single significant term -- "responsiveness."

FRED BROOME is chief of the Computer Graphics Staff, Geography Division, U.S. Bureau of the Census. He discussed automated cartography at Census as it pertains to two basic needs -- operational requirements and data presentation. The GBF/DIME Project is an example of the first; the Urban Atlas Series an example of the second. Quality control of existing data, speed and costs are reasons for automating cartography at the Bureau of the Census. A summary of his remarks is included in this section.

C. GENE JOHNSON is chief of the Map Construction Branch in the Cartographic Unit of the Soil Conservation Service, U.S. Department of Agriculture. He discussed the Advanced Mapping System (AMS) which was developed for the Soil Conservation Service. AMS was designed to meet the need for a fast and efficient way of converting soil information into computer readable form. The AMS uses both automatic and semiautomatic methods to produce a data base for soils information.

DONALD H. HUNT is director of Chart Automation Projects, National Ocean Survey, National Oceanic and Atmospheric Administration (NOAA). In his presentation he discussed the use of automated cartography in several areas at NOAA -- the National Environmental Satellite Service, the National Weather Service, the Environmental Data System and the National Ocean Survey. Automated cartographic systems being developed at the National Ocean Survey include the U.S. Nautical Charts, the U.S. Aeronautical Charts, and the U.S. Horizontal and Vertical Geodetic Control Maps. A synopsis of Mr. Hunt's remarks are included in this section.

DAVID HOLLAND, chief of the Systems Engineering Branch of the Defense Mapping Agency's Topographic Center, discussed the semi-automated cartographic system at the agency and described the hardware used in the system.

INTRODUCTORY REMARKS

Panel Discussion on Experiences in Federal Automated Cartography

Bernard Schechter
Cartography Division
American Congress on Surveying and Mapping

I want to add my welcome to you on behalf of the Cartography Division of the American Congress on Surveying and Mapping. This symposium is another effort by our organization, this time together with the Census Bureau, to further the knowledge of those who are interested in cartography and its broad applications. It is made possible through the membership and we invite all to join us as we continue to make your participation more meaningful and rewarding.

Eleven years ago this same week, in September 1964, at the Fall meeting of the ACSM in Kansas City, I was privileged to present a paper entitled "A Look at Mapping in the 1970's." I attempted then to forecast certain aspects of mapping in the period 1974-76. Several thoughts expressed at that time may help give perspective to what we hear and see in this gathering and to our efforts in the near future. Let me quote for a few moments:

> "In our own country, I sense that the continuing growth of urban areas will require increased efforts in different types of mapping. The obvious pressures on real property values, on water and other public utility and service needs, such as transportation and recreation, which we are beginning to feel already, will create demands for very accurate large-scale maps of these urban regions. The scope of the urban area problem is magnifying rapidly, but very little new is being done today" -- (that was 1964) -- "in the mapping field to help bring the areas under examination in a logical way for efficient planning. The essence of the requirement revolves around a mass of detail and intensive land use. The newly mushrooming urban area data banks, on a trial basis as yet for several areas around the country, may well be departures from conventional mapping that could profitably employ some of the newer forms of information acquisition and data reduction being used in modern mapping systems. The fields of cadastral mapping and property assessment loom ever more important as tax revenues are increasingly required for increased services. New photogrammetric systems could readily serve to help modernize and simplify what currently are often archaic, complex, and costly existing land and real property records. One of the newer concepts does away with the finished map, per se, and uses instead digital data, taken from maps or photos, and stored on magnetic tapes for use in computer programs which provide desired information on terrain characteristics and positions. The degree of sophistication of future equipment and systems would seem to be limited only by investment of funds for research and development."

And in talking about the possibilities for integration of Federal Government mapping I said:

> "If this does materialize one could envision a base cartographic data center and management entity directing and servicing field production centers located around the country and tied to it be electronic data links. Government departments requiring information or products would levy their needs on the national center and be serviced from the center or appropriate field component."

Well, that was September 1964 and a good bit of research and development and initial production has taken place since then. We have seen major advances in hardware and impressive progress in systems and software. Our speakers in this panel will give testimony to that as do the exhibits and the work of other agencies and people around the United States and in other countries. We are, literally speaking, seeing the beginning of a major explosion in the application of computer-assisted cartography and the widespread use of the data bases which are developed in the process. As we enter this epoch, I suggest consideration of a few pertinent thoughts.

Digital-record cartography has certain inherent characteristics which distinguish it from the antecedant classical mapping and give concern for pause and consideration. In hard-copy mapping we have the benefit of direct hands-on contact with the product through a sort of universal language expressed by lines and symbols which are readily understood and used, essentially on an international basis. And we have evolved standards of accuracy by which we evaluate the quality of the map information shown and these too assist the user in his application of the contents.

In what I now sense is the rush to go digital we are beginning to see the creation of what will become hundreds of thousands of records, developed by many different agencies -- and very likely not in a universalistic manner. The condition is roughly analagous to the chaos resulting from the early uncoordinated hardware, languages and formats when computers in general first were being applied. There is a certain element of good in this competitive-type situation and we plunge ahead in faith that the better systems survive and become the standards.

I, for one, hope however we can learn from the past and try to preclude some of the difficulties. Warren Schmidt, one of our speakers today will allude to the international scene and to what his agency is undertaking which relates to this concern. The problems of data structures, of access to and dissemination of the computerized information, of establishing qualitative standards are complex and we can perhaps only aim at reducing anticipated technical turmoil. Unlike the minor concerns with relatively homogeneous classical national map series, we face the proliferation of digital cartographic data bases encompassing, in the beginning at least, accurate maps from the regular series along with a mixture from heterogeneous maps and graphics lacking standardized formats or qualifying identifications as to quality of map position or content or time-date reference of the information. A major concern relates to the obvious area of data base maintenance where computer-assisted cartography appears to have singular advantages commending early application. As in almost every computerized data base situation, but especially applicable to the digital cartography area, we must early on establish the mechanics for integrity of data along with ready access and update.

I hope that Bob Aangeenbrug, the Director of this symposium may include in his summary remarks suggestions on cooperation which may help us avoid a digital-type

Tower of Babel situation as we progress rapidly in our endeavors which John Wolter has so aptly described as: Cartography - An Emerging Discipline.

And now on to our panelists who have all had major experience and involvement in computer-assisted cartography. The work they describe by no means illustrates the broad spectrum of Federal activity in this field. The presentations during Auto-Carto I last December touched on several of the major systems involved. These papers add to the compendium.

DECISION DAY FOR AUTOMATING

Warren E. Schmidt
U.S. Geological Survey

INTRODUCTION

Decisions are not made in a vacuum. To give direction, management must have both the facts and expert predictions on the outcome of each alternative. Automation is a particularly thorny decision for management. There are a few route markers. The equipment is frighteningly expensive. Personnel must be retrained or recruited. Finally, the production flow must be altered. So it is not hard to see why those who decide are often hesitant.

When first asked to serve on this panel, I reflected on the decision points in various governmental cartographic units. When these were listed, the exact chronology of events seemed unimportant. In each case, the "why" seemed more critical than the "when". Therefore, this discussion will focus on the rationale for automation rather than on the timing.

In developing this topic, I will first give eight reasons for automating and then relate four case histories. Despite the reference to Federal Government in the session title, one British and one Canadian and two U.S. agencies have been chosen as examples. This diversion was made because of the significance (and success) of their efforts and because this is an international meeting.

WHY AUTOMATE IN THE FIRST PLACE?

There are many arguments for automation and they can undoubtedly be divided in many different ways. I have observed eight good reasons and offer them as the basis of the rationale in each example. The eight are as follows:

1. Economy

   In such a labor-intensive field as cartography, management must be constantly alert to new methods to offset rising wages as well as increasing materials costs.

2. Speed

   In applications where data are highly perishable, such as weather and intelligence, automation significantly reduces reporting time. Even where the production cycle is less hurried, the elapsed production time can be markedly reduced.

3. Original Data in Machine Form

   Substantial bodies of scientific, engineering, and business data are initially captured in machine-readable form. Continued automation in the process of data reduction to map or chart form is desirable and the only possible way cartographers can keep pace with increasing data collection and graphic demands.

4. Volume

   Spatially organized data in some information systems is so voluminous that only the most sophisticated automated techniques can handle the load. Census, telemetry, and hydrologic data are examples of products from large information systems that employ computers, automatic plotters, and other display devices to reduce raw input to meaningful lists, graphs, charts, and maps.

5. Accuracy

   Map data can be handled by the computer with a fraction of the errors generated by manual systems, thereby eliminating most of the current editing procedures. Format, balance, and procedure checks placed in the computer programs can, in themselves, virtually eliminate processing errors.

6. Graphic Precision

   Improvements in positional accuracy and graphic quality are among the benefits of the new technology over manual methods. The computer and high-precision automatic plotters now give operational results equal or superior to manual techniques in most areas. Even typography and hill-shading are now being tackled successfully.

7. Computation

   When highly complex and repetitive computations are required, the computer or programmable calculator becomes a necessity. These are currently employed for map projection and control work by many mapping units.

8. Data Manipulability

   If the same data are presented in differing ways, automated techniques are indicated. Varying scale, format, and center are common graphic payoffs. In the nongraphic area there is a growing list of applications. Examples include area and volume calculation, network analysis, correlation of overlaying features, and line-of-sight computations.

FOUR DECISIONS

The four agencies chosen as representative examples are the Ordnance Survey at Southampton, England; the Ontario Ministry of Transportation and Communication in Toronto, Canada; the Central Intelligence Agency and the U.S. Geological Survey, both in the Washington, D. C. metropolitan area.

THE ORDNANCE SURVEY

This organization has almost one-quarter of a million large-scale maps to maintain with an annual revision rate of 11,000. Further, these maps represent the legal description of the land for ownership purposes. They have to be correct! The decision to automate was made in 1970 but only after exhaustive studies. The route chosen was point digitizing and menu coding on a Ferranti Digitizer, mainframe processing and verification plotting on a Xynetics, digitizer corrections and final photo scribing on a Ferranti Master Plotter.

The result was a series of high-quality maps that cost slightly more to produce, at least the first time. The payoff, though, is the beginning of a cartographic data base that can satisfy not only future revisions and smaller-scale needs but also the increasing demands of planners and managers for digital spatial data. Returning to the eight reasons, the Ordnance Survey made its decision primarily on the basis of data manipulation and to a lesser extent on requirements for accuracy and graphic precision.

ONTARIO MINISTRY OF TRANSPORTATION AND COMMUNICATION

The photogrammetric unit of this organization is responsible for preparation of large-scale engineering drawings for highway rights-of-way. A means was sought to replace the lengthy conventional procedure that began with a stereomodel and then went to a pencil manuscript and next to an inked or scribed fair drawing. A proposal was made in 1969 to record the output from the Zeiss Planimat directly onto digital tape via a Wang or Instronics digitizer. This would then be processed on the Hewlett-Packard 2116B computer, which also served as the controller for the Gerber 1232 plotter, which in turn was used to photoscribe the final drawings. Since installation in 1970, the cost per drawing has been reduced 50%. The primary impetus in this case was economy, but speed and data manipulability from the resulting data base were also considered.

CENTRAL INTELLIGENCE AGENCY

The CIA began planning for cartographic automation in 1965 and initiated a pilot system two years later. A producer of small-scale thematic maps, it needed the capability of quickly varying all map parameters. The resulting system, called AUTOMAP, used a Bendix digitizer, IBM 2250 CRT for correction, and IBM 360 computers for manipulation to input data into a cartographic data bank of the world. The same main frame is used to generate plots on CRT and a wide variety of vector or raster plotting devices. The main reason for AUTOMAP was data manipulability with speed and computation following closely behind.

U.S. GEOLOGICAL SURVEY

The USGS was in some respects a latecomer to automation. While there was substantial employment of automated photogrammetric devices, cartographic advancement was limited to photomechanical slope mapping, projection computation, and the plotting of grids and grid values. What was lacking was commitment to an overall goal. This gap has been filled since we last met in December. The Topographic Division management designed a new National Mapping Program with a pledge to produce maps in both analog and digital form. You will hear more of this effort elsewhere on the conference program. This discussion, however, will only deal with the reasons behind the decision. The prime motive behind a Digital Cartographic Data Bank, a major feature of the National Mapping Program, is data manipulability.

Secondary reasons are speed and the fact that significant bodies of the original data are already in machine form.

DECISIONS FOR AUTOMATION IN FOUR ORGANIZATIONS

REASONS	ORDNANCE SURVEY	ONTARIO MTC	CIA	USGS
1. Economy	-	1	-	-
2. Speed	-	2	2	2
3. Machine form	-	-	-	3
4. Volume	-	-	-	-
5. Accuracy	2	-	-	-
6. Graphic precision	3	-	-	-
7. Computation	-	-	3	-
8. Manipulation	1	3	1	1

CONCLUSION

Here in four examples from three countries, we have spanned ten years between times of decision. What is noteworthy among the reasons offered for automation is the emphasis on data manipulability and speed. While cost consciousness is a mandatory goal for those employing public funds, the need to present the same data in different ways (such as smaller scales and format variations) and to reduce the elapsed time for production is paramount. Manipulability and speed can be combined into one and called responsiveness. And responsiveness to the map user is what cartography is all about in 1975.

AUTOMATED CARTOGRAPHY AT THE U. S. BUREAU OF THE CENSUS

Frederick R. Broome
U. S. Bureau of the Census

The U. S. Bureau of the Census prepares maps for two basic purposes -- internal operational needs and the presentation of published data. Generally the difference is that maps prepared for operational needs are planimetric while those for publication are statistical. Some portion of both types of mapping has been automated at the Bureau. I shall spend the time alloted giving you a brief overview of our automation efforts -- including, if time allows, our problems and successes.

The reasons for automating cartographic activity at the Bureau varied with the type of map. These in turn determined which portion of the operation to automate. The first automation effort was the GBF/DIME (Geographic Base File/Dual Independent Map Encoding) Project. This project entailed the production of thousands of map sheets, the transcription and punching of millions of geographic records, and the digitizing of more millions of points along streets, political boundaries, and other features within most of the urban areas of the United States. Figure 1 is a close-up view of a metropolitan map. The dots along the streets are the points that were

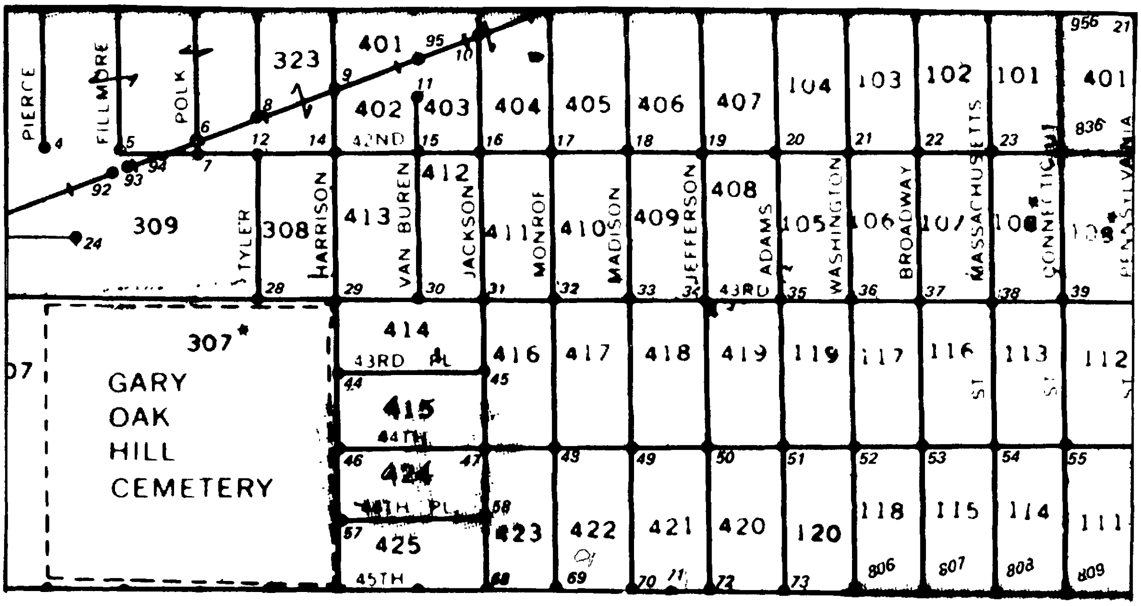

Figure 1. Example of a Metropolitan Map

digitized. Figure 2 shows one of our present digitizers. It is a card output device capable of taking the largest of our maps. The machine readings for each node point dot are outputted directly to cards. The cards are then read into our large Univac computers where the machine readings are converted to latitude-longitude, State plane, and a coordinate system we call map set miles. After conversion, the coordinates are merged with the other encoded geographic information. The result is a digital map of the metropolitan area.

Digitizing is only one part of the automation process. The system used to produce the GBF/DIME-Files is prone to error -- both human and mechanical. Automated plotting of the file is used to check the quality of the coordinates in the file. We currently create a paper plot at the same scale as the original map used in the digitizing operation. The plot is placed over the original map and a check is made for positional differences. Errors are corrected by redigitizing and merging new coordinates into the file.

The system may be complex by today's standards, but it has served us well. We have a national standard file which serves our needs and those of many other Federal and local agencies. We are currently upgrading our digitizing system through the acquisition of new equipment. The new digitizing system will include an interactive record retrieval and change station for correction of errors before sending the coordinates to be merged with the master files.

The other mapping effort is in automating maps for data presentation. All of you, I hope, have visited the Bureau of the Census display area. There you saw an excellent sample of our mapping for data display. We have applied automation to some operations in thematic mapping -- both dot and choropleth. I shall restrict my remarks to choropleth mapping because of time constraints.

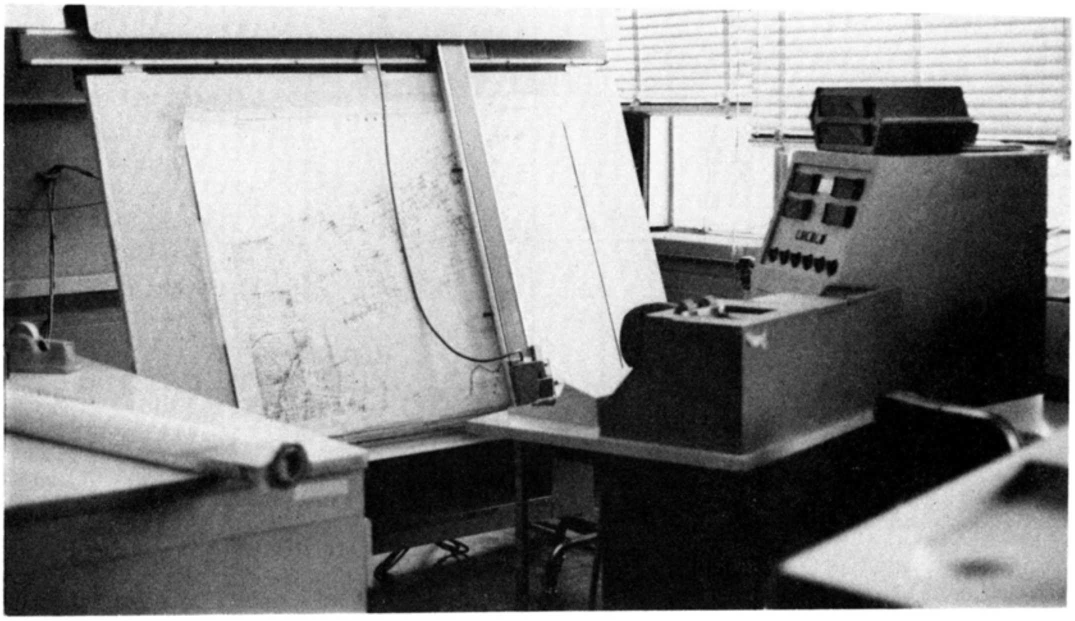

Figure 2. Digitizer at the Bureau of the Census

Two steps of choropleth mapping have been automated: data coding and open window negative production. Figure 4 on pp. 254-255 depicts the total system. Starting with a digital data base, we extract the items to be mapped and the geographic codes. The items are classed and held in an intermediate file. The other input is a digital description of the area to be mapped -- in this case, the counties of the United States. The digital county description for each county is processed into an image at the scale and in the coordinate position that it will appear on the microfilm. The images are merged with the data classes, the record sorted by class, and the images outputted to the microfilm plotter. The plotter produces one frame of microfilm per class plus one frame for the geographic area outline. The microfilm is sent to the cartographic staff where it follows a more or less conventional process into the final map.

The system produces maps of acceptable quality in a shorter time and at a lower cost than a completely manual system. The savings varies from product to product, but is generally about 80% or 90% of the manual cost.

In summary, the Bureau of the Census has applied computers to assist the cartographic effort for three reasons: 1) quality control of existing data, 2) speed, and 3) cost.

In the case of quality control, automation was the only reasonable way to go. Where speed of map production was the requirement, the time between request to final map has been reduced significantly. The cost of producing a single map has been reduced, but this has resulted in an apparent contradiction. For data display -- automation has resulted in no savings. Rather it has created more work because instead of a sponsor getting one map for $1,000, he is asking for and receiving four or more.

AN ADVANCED MAPPING SYSTEM FOR THE SOIL CONSERVATION SERVICE

C. Gene Johnson
U.S. Department of Agriculture

AMS is an automated cartographic application that will produce base, topographic, soil and interpretive maps ready for black and white or multicolor lithographic processing. Map data will be digitized and stored, together with associated tabular data, in computer format and then processed, analyzed, and retrieved as desired.

Data for producing interpretive maps will be obtained from published soil surveys. The automatic scanner will digitize the soil information. The features will be identified both automatically and manually. The data will then be edited for accuracy and stored for later interpretive use. In addition, base and topographic maps will be manually digitized using a coordinatograph table or stereoplotter. The maps will be edited and photographically plotted at the desired scale.

The system is designed around four minicomputer subsystems to be located at the Hyattsville, Maryland, Cartographic Unit. These subsystems are for scanning, identification, editing, and automatic drafting. Each subsystem will independently perform one or more operations. One remote system for digitizing base and topographic maps will be located at each of three field cartographic units. The cost for software and hardware, excluding the automatic drafting subsystem, is $1,400,000. The contract was awarded February 28, 1975. Delivery is scheduled for February 28, 1976, and the equipment is to be in full production in May 1976.

The scanning subsystem will automatically scan, at the rate of 4 square inches per second, each individual sheet of a published soil survey. An average soil survey area has 70 map sheets. A map sheet will consist of one, two, or three overlays containing alphanumeric, cultural, and soil information. The overlays will be film positives and be in one of three formats:

- All soil and planimetric information on one overlay,
- Soil lines and soil symbols on one overlay and planimetric detail and place names on a second overlay,
- Soil lines on one overlay, planimetric detail on a second overlay, and all alphanumeric information on a third overlay.

Scanning of the alphanumerics in the AMS requires manual preparation and Recognition. Because of the state of the art at the time the system was ordered, only semiautomated techniques were available. Software for recognizing characters is being developed, and we will eventually automate the character recognition to reduce time and manpower requirements. Before the alphanumerics can be scanned into AMS, a red line must be drawn under each name to determine the angle and location of the character string for positioning on the final map. As the map sheet is scanned, the alphanumerics are stored on disks in raster format, processed into vector format, and stored on magnetic tape for use in the identification subsystem.

The identification subsystem will use the magnetic tape created in the scanning subsystem as input data. Once the soil maps of an area or county are stored on disks, the data are ready for identification. For data on one overlay, significant manual identification must take place. For data on two and three overlays, software features will be used to automatically identify soil lines, roads and drains. Discrepancies occurring in automatic identification will be stored and displayed for manual identification. Character strings are displayed sequentially on a 19-inch cathrode ray tube (CRT). An operator will use the keyboard to enter the character string that is displayed. The characters will then be displayed on the CRT at the correct location and angle. When this step is completed, the next character string will appear on the CRT for identification. The identification subsystem will also do the processing required to produce interpretive maps. A list of the soil mapping symbols and interpretations will be entered for processing. The processing will then produce a magnetic tape for the edit subsystem to edit the automatic drafting subsystem to photographically plot.

The edit subsystem will correct errors in the data base or digitized data, produce a plot of the overlay or map, and prepare megnetic tapes for photographic plotting of base and topographic maps. A plotted map will be given to an editor who will check it manually against the original map. Errors will be noted on the plot, and the plot will then be sent back to the edit subsystem for corrections. These corrections are made on a 19-inch CRT or a coordinatograph table, depending on the accuracy required. Magnetic tapes from the remote systems also will be read in, plotted, edited, and a magnetic tape produced for the automatic drafting machine.

The automatic drafting subsystem, which we have, consists of a Gerber Model 1275 automatic drafting table controlled by a Hewlett-Packard Model 2114 mini-computer. The 5' X 8' drafting table is capable of drawing with a pen on paper or a beam of light on photographic film. The resolution of this subsystem is ± 0.002 inches (± 0.05mm) and accuracy is ± 0.005 inches (± 0.127mm). This subsystem will produce all the alphanumerics and line work for base, topographic, soil and interpretive maps. The output will be film positives or negatives ready for lithographic processing.

The primary software features of AMS follow. The scanner software will record coordinate data for lines, symbols, and alphanumerics for each sheet of a published soil survey. It will recognize whether a line is solid or broken and classify it. It will recognize the placement and orientation of character strings so that these can be displayed for identification. The identification software will tag all alphanumerics, cultural, and line information in the data base and store it on different layers for ease of extraction at a later time. It will link soil symbols to line segments. Line segments will be linked together to form polygons to calculate area and to classify soils according to a list. Four different styles of characters are available in upper and lower case. Up to 64 special line types will be available. The area of closed polygons will be calculated and listed. The scale of the output can be changed as required. Color separations will be produced for color maps.

Editing software will provide the ability to add, delete, or move a feature, correct alphanumeric data, change the endpoint of a line, connect a line to another line, eliminate a crossover, change the line type, add or delete symbols, join feature parts that come from two different sections of a drawing, extract a section of a map by defining as many as 100 coordinate points, eliminate common lines between adjacent soil types that are the same, and automatically join data that come from two different sources.

AMS will digitize 70 soil surveys and 1,000 base and topographic maps per year. The daily throughput of the entire system is 24 soil survey publication sheets, four base maps and four topographic maps per 8-hour day. The system will be able to produce graphic displays and engineering drawings from sketches. In addition, it will be used as a computer for processing other computer programs. The system will require nine people to maintain the required work flow.

To conclude, AMS is an integral part in automating the soil survey program. Its intent is to automate the cartographic phase for producing interpretive maps from a completed soil survey publication. AMS will be integrated with ADP files on soil survey interpretations to automate completely the preparation of interpretive soil maps. Digitized information from the AMS system will be combined with digitized cartographic data from local and state planning agencies to produce plans in which soils are only one of many considerations for decision makers.

AUTOMATED CARTOGRAPHY IN THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Donald H. Hunt
National Ocean Survey
National Oceanic and Atmospheric Administration

Automated cartography is currently in operational use in four areas and under development in three additional areas in the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce. These are briefly outlined below.

NATIONAL ENVIRONMENTAL SATELLITE SERVICE

Two types of environmental monitoring satellites are flown by NOAA: the polar orbiting satellite, which scans a swath of the earth's surface from pole-to-pole during each orbit until the entire earth is viewed; and the geostationary satellite, which by orbiting synchronously with the rotation rate of the earth maintains a nearly fixed earth position, from which it views the entire earth's disk. One widely distributed product is the T.V. Weather Report's U. S. Daily Cloud Cover satellite pictures with basic map overlay.

POLAR ORBITING SATELLITES

Approximately 500 to 1000 maps are produced each day. Automated mapping of geographic and political boundaries and latitude and longitude grids are computed for each satellite frame of the earth's surface and inserted in real-time in the processed data stream between the Down-link and Up-link communications with the satellite. Thus, the second Down-link transmission contains an accurate earth mapping overlay together with the vidicon pictures.

GEOSTATIONARY SATELLITE

About 90 maps per day are produced. As each of the two NOAA geostationary satellites orbits synchronously with the earth, differences between the earth rotation and the satellite orbit result in the satellite sub-point circumscribing approximately a figure-eight. Predicted positions of the sub-point are calculated for each earth disk time frame, and appropriate adjustments to the automated mapping program for each picture frame are calculated and transmitted by landline from Suitland, Maryland, to the Synchronizer Data Buffer at the Wallops Island receiving station. Output consists of geographic and political boundaries and latitude and longitude grids superimposed electronically on each earth frame (45 per satellite per day). Time-lapse movies are prepared for analysis of daily atmospheric changes.

NATIONAL WEATHER SERVICE

Nearly 1000 maps are produced daily. Automated output (about 400/day) of weather maps is in either Mercator or Polar Sterographic projection, with meteorological data plotted and isopleth contours drawn. About 300 maps per day are produced for local use at the National Meteorological Center on an electrostatic plotter, continuous feed paper 20" wide. Output generation software has the capability to split the map into northern and southern halves, 20"x72", for combination as a single map, 40"x72".

ENVIRONMENTAL DATA SERVICE

Many types of environmental data are stored in digitally mapped form and output on request. These include data on climate, sea surface temperatures, and snow cover for flood prediction.

NATIONAL OCEAN SURVEY

There are three automated cartographic systems under development in the National Ocean Survey (NOS): U.S. Nautical Charts; U. S. Aeronautical Charts; and U. S. Horizontal and Vertical Geodetic Control Maps.

NAUTICAL CHARTS

The NOS conducts hydrographic surveys, sterophotogrammetric aerial surveys and tidal measurements from which the 960 U. S. nautical charts are compiled and updated periodically.

Automated hydroplot survey systems have been developed and placed aboard all NOAA ships and surveys launched. Automated data processors and plotters for survey sheets have been installed at the Atlantic and Pacific Marine Centers at Norfolk, Virginia, and Seattle, Washington.

A nautical charting automated compilation system, currently under procurement, will provide the capacity for interactive compilation and update by the professional cartographers. High speed vector plotters and a laser raster plotter have been procured and are in operation. The output of the automated compilation system will be separation and/or color overlays ready for the reproduction process.

AERONAUTICAL CHARTS

NOS produces over 5000 different charts required for the safe and efficient use of the Federal Aviation Administration's National Aviation System by commercial airline, business, military and private pilots. Availability of appropriate current charts is mandatory for all flights under instrument flight rules. These charts are currently updated on 56 day cycles, and distributed to FAA controllers and pilots throughout the country. NOS is undertaking the development of an automated cartographic system for aeronautical charts with completion planned for 1982.

GEODETIC CONTROL MAPS

The National Geodetic Survey (NGS) has under development a master data base for horizontal and vertical geodetic control throughout the U. S. The data base will support the NGS field parties through remote data terminals, and also provide data on request to State and local surveyors.

Development of an automated cartographic system for production of geodetic control maps for the U. S., based on the current data in the National Geodetic Data Base, is planned for completion in 1981.

Seminar on Statistical Mapping

SEMINAR ON STATISTICAL MAPPING

This seminar, held in two sessions on Monday and Wednesday afternoons, dealt with statistical mapping, map generalization and classification. Papers were presented by JEAN-CLAUDE MULLER, RICHARD SCHWEITZER and RONALD ABLER. Critiques of the papers were made by the other seminar participants who included ROBERTO BACHI, WALDO TOBLER and GEORGE JENKS, chairman of the seminar.

At the Monday session JEAN-CLAUDE MULLER of the Department of Geography at the University of Georgia presented a paper on "Statistical Accuracy and Map Enhancement in Choroplethic Mapping." Many cartographers have been concerned with the contradictory relationship between statistical accuracy and map readability in choroplethic mapping. Map readability is not the only limiting factor in choropleth map accuracy. As the number of classes of a choropleth map decreases, the generalization process makes the map more informative by deleting details (noise) that do not belong to the ideal picture (signal) of the distribution presented. This recovery process of the underlying meaningful pattern on a map by generalization is called map enhancement. Study of the contrast within and between various choroplethic map patterns shows that 1) patterns are significantly affected by the number of classes, and 2) the smaller the number of classes, the sharper the contrast in the cartographic pattern, and the more amplified the differences between the maps. Solutions for conciliating statistical accuracy and map enhancement were also described.

The paper, "Undergeneralization and Figure-Ground Relationships in Statistical Mapping," summarizes the remarks of GEORGE JENKS of the University of Kansas. He stressed the clarity of the map message as the overriding factor in statistical mapping. The map designer should retain only that information which is essential to the map message. Map clarity, therefore, demands the development of suitable visual figure-ground relationships.

In the second session, the *Comparative Atlas*, a project of the American Association of Geographers, and the *Urban Atlas*, produced by the Bureau of the Census, were described and discussed. Both projects were compared in terms of the type of maps, method of production, and the underlying rationale.

"The Urban Atlas Project: Historical and Cartographic Review" is the title of the paper presented by RICHARD SCHWEITZER of the Bureau of the Census. He reviewed the development of the Urban Atlas Project from the viewpoint of the cartographic techniques used. He discussed alternative approaches and the type of decisions that were made in producing the final atlases. Impetus for the atlas stemmed from the need to supplement voluminous statistical tables of 1970 census tract data with a companion graphic summary. A dozen variables for sixty-five of the Nation's largest standard metropolitan statistical areas (SMSA's) are being plotted in color through automated mapping techniques. The inherent nature and requirements of census work requires adhering to choropleth map presentations. Given the heavy use of maps by the Bureau of the Census, the innovativeness of the FR-80 Computer Output Microfilm Recorder and of the micrographic negative contributes significantly to meeting this demand.

RONALD ABLER of the Pennsylvania State University's Geography Department discussed the second atlas project in his paper entitled "The Comparative Atlas of America's Twenty Largest Metropolitan Regions." The purpose of the project was to provide Federal, State, and local officials with information on the occurence and intensity of problems in large American cities. The comparison and analysis of geographic patterns is facilitated by this standardized presentation directed towards the lay map reader. Several questions were raised in the preparation of the atlas, as for example, which cities to map, what topics to map, map scales and cartographic techniques, and the organization of the atlas. At the time of conception, however, automated cartography had not reached the level of development and refinement necessary for such an undertaking.

Following the presentations two questions were raised by the seminar chairman: 1) Is the selection of a choropleth or isopleth map a function of an individual's perception or is it a policy decision; and 2) does the use of a 4x4 color-cross map, which yields 16 color variations, really facilitate understanding for the map reader. These questions were discussed from the viewpoint of both papers.

STATISTICAL ACCURACY AND MAP ENHANCEMENT IN CHOROPLETHIC MAPPING

Jean-Claude Muller
University of Georgia

INTRODUCTION

Many cartographers have been concerned with the difficult problem of conciliating map accuracy and legibility in portraying spatial distributions. Geographic distributions are seldom simple enough to be readily perceived and understood. For the sake of cartographic communication, a certain amount of generalization is usually required. The original complicated distribution is converted into a simpler form. The new cartographic image, however, contains less information than the original data set; and there is no guarantee that the information lost is irrelevant. This last observation has led Waldo Tobler to challenge the idea of class generalization in choroplethic mapping. 1/ Class generalization is accomplished by partitioning the range of the data set values into intervals, and by representing all map points with values in a given interval by a same gray tone. This type of choropleth generalization was traditionally motivated by 1) the difficulty of finding shaded screens whose visual intensity was exactly proportional to the original data intensity, and 2) the reader's inability to distinguish and visually separate more than a limited number of different shades. 2/ The first obstacle can now be technically overcome by programming an automatic line plotter to create a continuum of gray tones with virtually any light intensity. 3/ The gray tone values simulate the statistical values of the enumeration units. Thus, choropleth maps can be used to portray accurately every value of a given spatial distribution. Tobler's solution, however, has been strongly criticised on the ground of map legibility. 4/ It was argued that the resulting increase of information displayed by choropleth maps without class intervals may obliterate the reader's ability to perceive the map distribution. Aside from the complexity problem, the poor enhancement of unquantized choropleth patterns presents a major drawback. The purpose of this paper was to investigate the effect of quantization on one particular aspect of map enhancement -- map contrast. Contrast in blackness was computed within and between a series of quantized and unquantized choropleth patterns. Finally, the contradictory relationship between statistical accuracy and pattern enhancement was discussed and solutions conciliating both variables were described.

DEFINITION OF CONTRAST

Choropleth maps usually show subsets of regions that appear light or dark. The lightness or darkness of each region can be described by a picture function $Z(x,y)$ proportional to the light intensity impinging the map at the points (x,y) of the region. Contrast within a choropleth map was measured by the variation of darkness between adjacent regions, whereas contrast between different maps was measured by the variation of the overall darkness of the map bodies.

CONTRAST WITHIN MAP

The outline of choropleth regions are the common boundary of enumeration units whose Z values are different. Thus the contrast between adjacent regions can be found by measuring the absolute difference of darkness between the corresponding enumeration units:

$$c_{12} = |Z(x_1, y_1) - Z(x_2, y_2)| \qquad (1)$$

where (x_1, y_1) and (x_2, y_2) are map points on two adjacent regions. The overall contrast within maps was computed by the formula:

$$C_w = \sum_{i}^{n} \sum_{i}^{n} c_{ij} \qquad (2)$$

where n = number of enumeration units.

$c_{ij} = |Z_i - Z_j|$, absolute difference of Z values between units i and j if units i and j are adjacent, and $c_{ij} = 0$ when otherwise. In this study, the above formula was standardized by defining the measure of contrast as a ratio between the observed contrast within a map and the maximum contrast if the absolute difference $|Z_i - Z_j|$ was maximum for every i and j.

CONTRAST BETWEEN MAPS

In a multimap comparison situation, some maps may appear visually darker than others. In this study, contrast between two maps, say k and l, was defined as a function of the absolute difference of blackness between the corresponding map bodies:

$$C_b = |B_k - B_l| \qquad (3)$$

where blackness of map k (B_k) is the average percentage of the paper in the map body that is covered with ink. Map blackness was computed as follows:

$$B = \sum_{i}^{n} s_i b_i / \sum_{i}^{n} s_i \qquad (4)$$

where n = number of enumeration units; s_i = area of unit i; and b_i = blackness of unit i (in percentage).

THE EXPERIMENT

Seventeen geographic variables depicting various aspects of the geography of France were mapped on an automatic line plotter using Tobler's Calcomp Choropleth Mapping Program. 5/ Area, number of enumeration units (22), scale, and symbolization were held constant.

Symbolization in itself is a complex problem. Shaded patterns can vary in color, style, texture, orientation and value. In this study, shaded patterns were held constant except for value. The assignment of value intensity to the choropleth classes was purposely conventional. The lowest and highest classes were represented by solid white and black color, respectively. The other classes were symbolized by shaded patterns whose visual intensity was exactly proportional to the class ranks. Although this type of symbolization does not appear statistically very sound, it is the most traditionally used. 6/ The purpose of this experiment was precisely to study the effect of quantization on pattern contrast in the context of conventional choropleth mapping.

Each geographic variable was represented by a series of quantized and unquantized choropleth maps. The number of classes on the quantized maps varied from two to ten. The class interval system for quantizing the data was derived from Jenks and Caspall. 7/ Several maps with and without class generalization were shown in Figures 1 and 2. Considerable variations of contrast within or between the maps could be observed depending on the geographical variables represented and the level of generalization. Study was made of these variations to show the relationship between map contrast and choropleth generalization. Map contrast was related to the broader concept of map enhancement, and solutions were proposed trading off statistical accuracy and map simplification.

CHOROPLETH GENERALIZATION AND CONTRAST WITHIN MAPS

Contrast within map (formula 2) was measured on every quantized and unquantized map. The mean contrast was then computed for each set of seventeen maps (Table I). Results showed the following:

1. Quantized maps were usually more contrasted than unquantized ones. Visual examination of the choropleth patterns confirmed this result(Figures 1 and 2). The grouping of the data into classes emphasized the regions containing abrupt dark-light transitions, and de-emphasized regions of close homogeneous density. This combined smoothing and sharpening process had important implications. Sharp contrast at the edges of choropleth regions produced a figure-ground effect. This was especially true for the maps with few classes. Distributional characteristics that were concealed in the original data set, such as tight regions or contrasted areas were emerging by compression of the interval scaled data into ordinal scaled map values.
2. Contrast increased slowly as the number of classes decreased. The slow increase may be explained by the counter effect smoothing has on contrast. This fact was illustrated by the two-class maps, which in some instances were much less contrasted than the three- or four-class ones (map number 16). In this case, the smoothing effect of pattern simplification and regionalization was more important than the sharpening of the remaining region edges.

CHOROPLETH GENERALIZATION AND CONTRAST BETWEEN MAPS

Contrast between maps was defined as a function of the difference of blackness (formula 3 and 4). Within a given map set, contrast can be measured by computing the deviation of blackness of each individual with respect to the mean blackness of

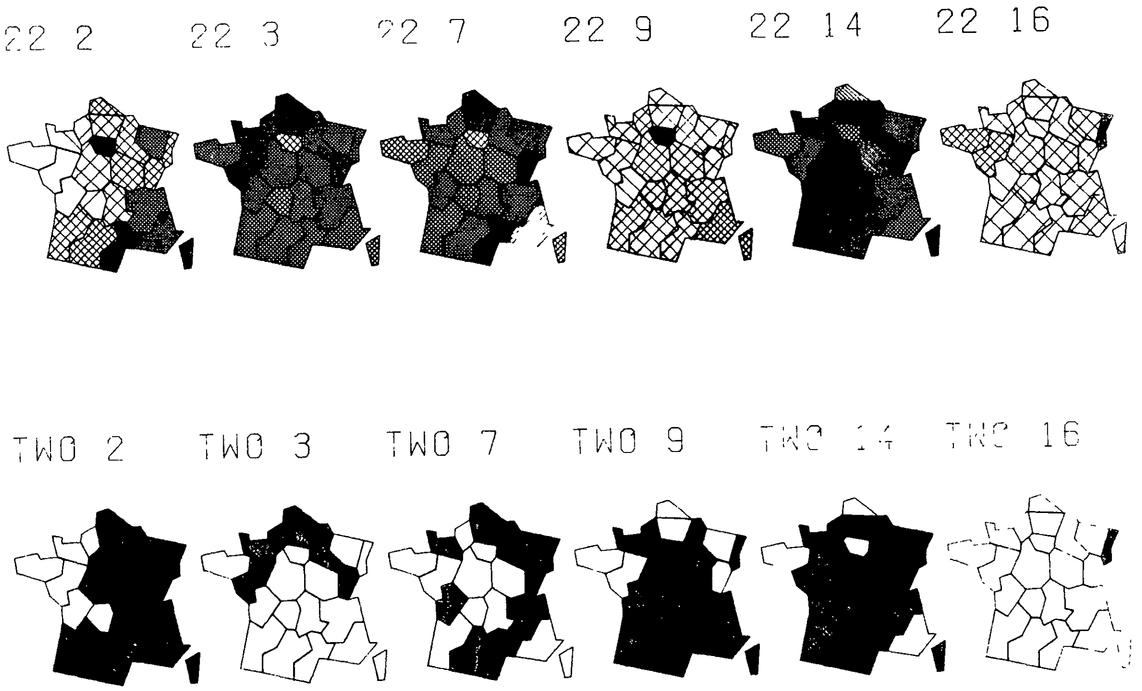

Figure 1. A Sample of Unquantized Maps and Two-Class Maps. The visual intensity of the shaded patterns on the unquantized maps are exactly proportional to the data intensity.

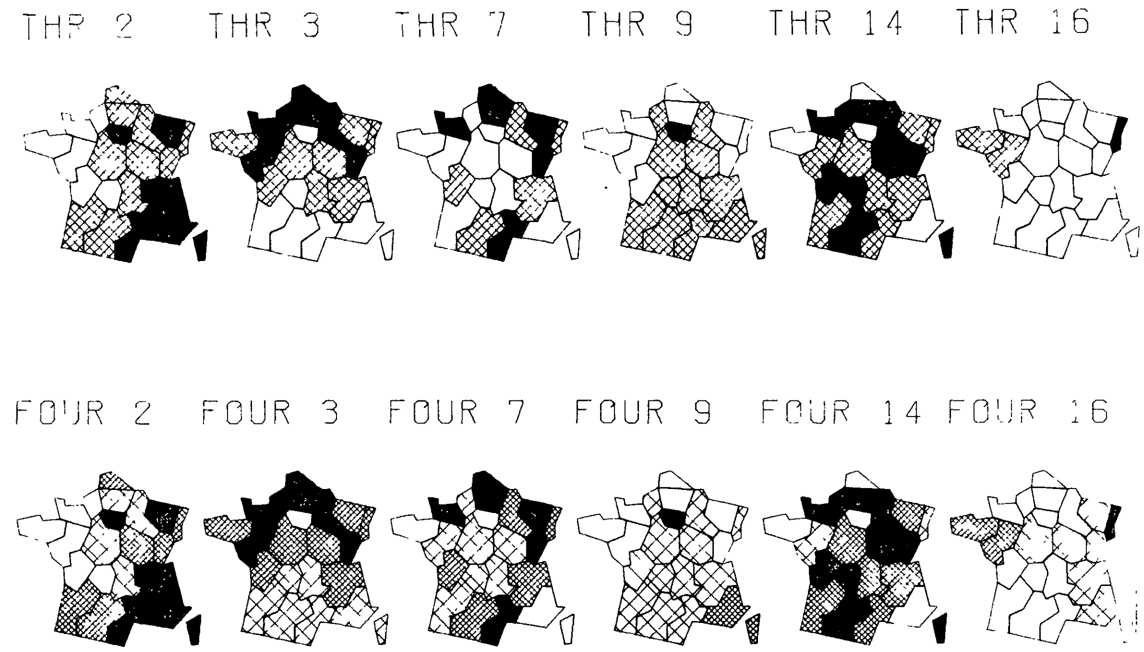

Figure 1. (continuation) A Sample of Three- and Four-Class Maps. The visual intensity of the shaded patterns are exactly proportional to the class ranks.

Figure 2. A Sample of Five- and Seven-Class Maps. The visual intensity of the shaded patterns are exactly proportional to the class ranks.

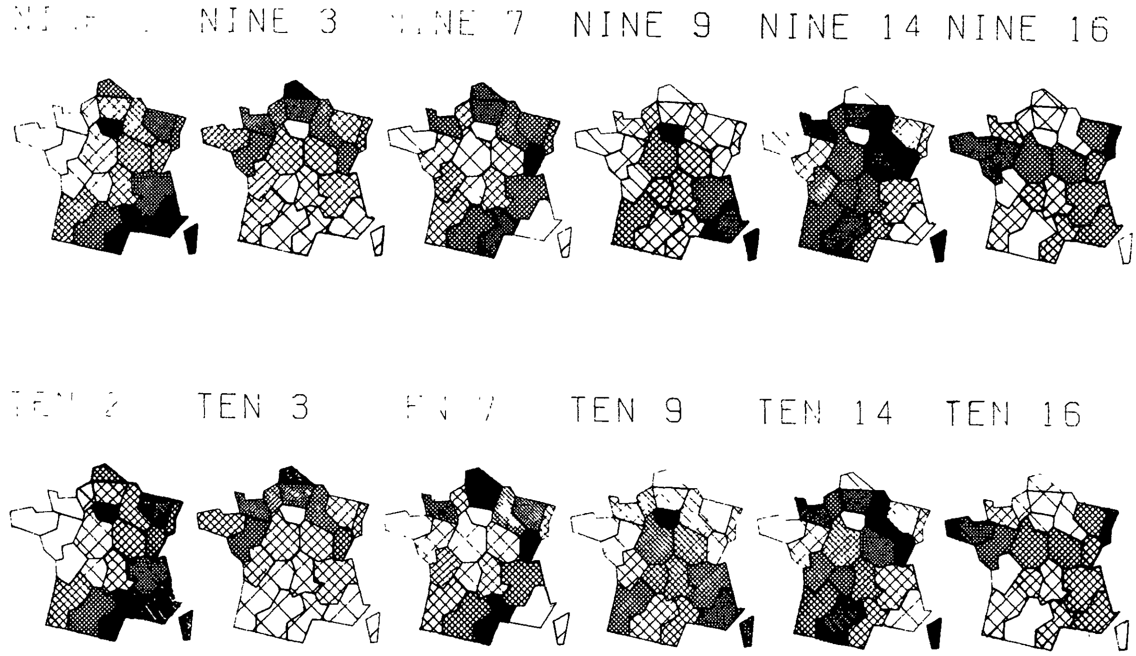

Figure 2. (continuation) A Sample of Nine- and Ten-Class Maps. The visual intensity of the shaded patterns are exactly proportional.

TABLE I. CONTRAST WITHIN MAPS FOR THE QUANTIZED AND UNQUANTIZED CHOROPLETH PATTERNS

Number of Classes:	Quantized Maps									Unquantized Maps
	2	3	4	5	6	7	8	9	10	
Map Number										
1	0.34	0.25	0.26	0.31	0.28	0.27	0.24	0.27	0.28	0.29
2	0.25	0.35	0.37	0.37	0.36	0.32	0.32	0.33	0.23	0.36
3	0.21	0.30	0.23	0.23	0.18	0.17	0.22	0.20	0.20	0.08
4	0.33	0.34	0.35	0.29	0.25	0.26	0.25	0.27	0.28	0.14
5	0.25	0.25	0.24	0.23	0.25	0.22	0.23	0.21	0.20	0.29
6	0.47	0.45	0.38	0.28	0.25	0.27	0.30	0.29	0.27	0.15
7	0.49	0.42	0.34	0.27	0.30	0.25	0.27	0.29	0.33	0.13
8	0.28	0.34	0.32	0.27	0.25	0.26	0.27	0.24	0.25	0.19
9	0.25	0.15	0.16	0.22	0.18	0.23	0.23	0.21	0.23	0.10
10	0.39	0.37	0.30	0.31	0.32	0.34	0.33	0.31	0.28	0.08
11	0.19	0.33	0.23	0.26	0.26	0.26	0.23	0.26	0.25	0.18
12	0.33	0.25	0.26	0.21	0.26	0.24	0.25	0.26	0.24	0.17
13	0.11	0.23	0.27	0.27	0.28	0.24	0.25	0.22	0.22	0.05
14	0.22	0.40	0.37	0.29	0.32	0.31	0.28	0.26	0.30	0.06
15	0.31	0.33	0.27	0.30	0.27	0.25	0.26	0.29	0.25	0.15
16	0.02	0.07	0.19	0.24	0.27	0.23	0.24	0.26	0.24	0.14
17	0.38	0.22	0.23	0.17	0.23	0.24	0.22	0.23	0.23	0.08
Mean Contrast	0.28	0.30	0.31	0.29	0.27	0.26	0.26	0.25	0.25	0.15

the set. Blackness, mean blackness, and standard deviation of blackness were computed for the maps with and without quantization (Table II). Results were as follows:

1. Quantized maps were often lighter than unquantized ones. In other words, the overall data intensity tended to be underestimated in the generalized maps.
2. Difference of blackness between quantized maps decreased as the number of classes increased. Except for the two-class maps, these differences did not appear as sharp as those existing between the unquantized maps. Thus, the effect of quantization on contrast between the maps was mixed. First, the grouping of the data into numerous

classes tended to smooth out the blackness differences between the maps. Second, these differences were recovered as the number of classes decreased.

3. Contrast was not always consistent. For instance, in the set of two-class maps, map number 9 was darker than number 3; whereas this situation was reversed in the set of three-class maps.

TABLE II. BLACKNESS, MEAN BLACKNESS AND STANDARD DEVIATION OF BLACKNESS FOR THE QUANTIZED AND UNQUANTIZED CHOROPLETH PATTERNS

Number of Classes:	Quantized Maps									Unquantized Maps
	2	3	4	5	6	7	8	9	10	
Blackness (%) of Map Number										
1	0.59	0.72	0.53	0.52	0.56	0.48	0.54	0.53	0.53	0.70
2	0.79	0.53	0.53	0.61	0.53	0.59	0.58	0.59	0.59	0.50
3	0.38	0.57	0.68	0.74	0.60	0.52	0.58	0.55	0.52	0.86
4	0.24	0.51	0.50	0.59	0.48	0.54	0.48	0.48	0.45	0.71
5	0.42	0.28	0.28	0.39	0.42	0.50	0.47	0.42	0.47	0.60
6	0.61	0.50	0.36	0.52	0.57	0.51	0.51	0.47	0.50	0.70
7	0.61	0.49	0.61	0.69	0.71	0.59	0.57	0.59	0.60	0.82
8	0.36	0.35	0.45	0.37	0.33	0.33	0.41	0.36	0.47	0.27
9	0.68	0.27	0.26	0.31	0.44	0.41	0.38	0.44	0.50	0.41
10	0.28	0.40	0.55	0.45	0.46	0.43	0.48	0.52	0.56	0.91
11	0.25	0.52	0.38	0.47	0.53	0.52	0.58	0.59	0.59	0.68
12	0.41	0.26	0.47	0.36	0.44	0.51	0.47	0.46	0.51	0.63
13	0.89	0.74	0.56	0.45	0.51	0.59	0.60	0.53	0.49	0.93
14	0.82	0.63	0.66	0.73	0.68	0.69	0.72	0.65	0.62	0.94
15	0.66	0.64	0.71	0.63	0.53	0.59	0.61	0.59	0.64	0.75
16	0.02	0.09	0.22	0.32	0.32	0.42	0.49	0.51	0.46	0.32
17	0.33	0.58	0.47	0.34	0.36	0.40	0.36	0.35	0.38	0.69
Mean Blackness	0.49	0.48	0.48	0.50	0.50	0.51	0.52	0.51	0.52	0.67
Standard Deviation of Blackness	0.24	0.18	0.15	0.15	0.11	0.09	0.01	0.08	0.07	0.20

Inconsistency in darkness can be explained by the distribution of the data sets. Quantization of distributions statistically close to uniformity usually provides a misleading image of the data intensity. This is especially true in the case of a distribution of large values and small range. In the mapping process, the relative differences between individual observations are exaggerated and the map does not appear as dark as it should be. Map number 3 provided an example of this case (Figure 3). Another source of darkness inconsistency is the presence of an erratic value isolated from the core of a distribution otherwise uniform. Map number 9 illustrated this situation (Figure 4).

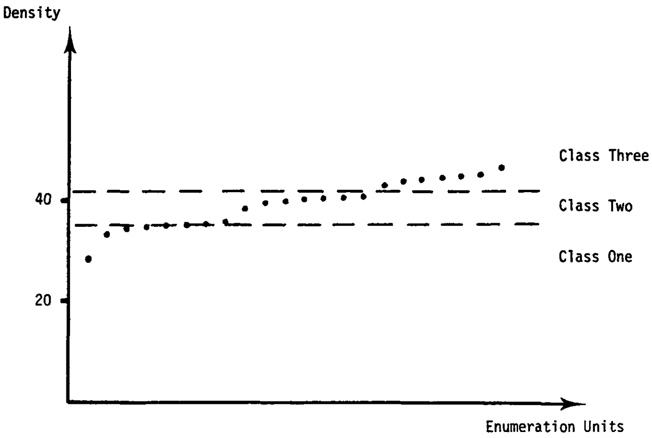

Figure 3. Data Set of Map Number 3. In a three-class partition, fifteen enumeration units were represented in white or medium gray (class one and two). This representation did not simulate accurately the overall data intensity. Whereas the visual intensity of the shaded patterns ranged from white (0%) to black (100%), the corresponding data intensity ranged from 63% (smallest value of the data set) to 100% (largest value of the data set).

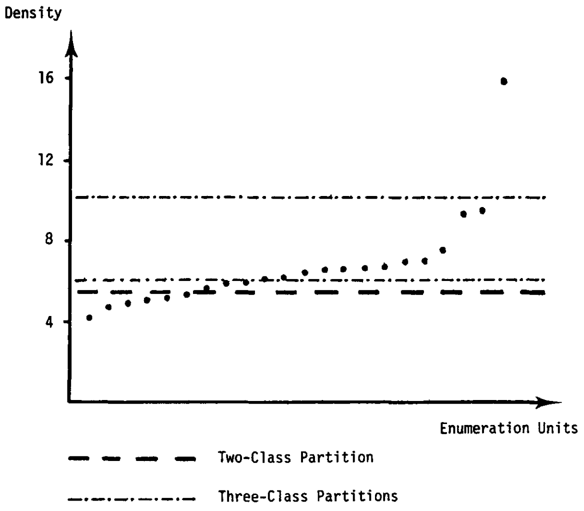

Figure 4. Data Set of Map Number 9. Except for one value, most of the observations were uniformly distributed. Such erratic value had strong unstabilizing effects on the apparent blackness of the map. In the two-class map, sixteen enumeration units belonged to the higher class and were represented in black. Only one enumeration unit remained in the higher class from the three-class partition, which caused the three-class map to appear much lighter.

CHOROPLETH GENERALIZATION AND STATISTICAL ACCURACY

It was observed that map contrast was strongly affected by quantization. Quantization created sharp contrast within the maps; and as the number of classes decreased the contrast in blackness between the maps was amplified. As the number of classes decreases, however, the maps became increasingly less accurate (Table III). 8/ This fact was demonstrated by the curvilinear relationship

TABLE III. OVERALL ACCURACY OF THE QUANTIZED MAPS

Number of Classes:	2	3	4	5	6	7	8	9	10
Map Number									
1	0.50	0.67	0.79	0.83	0.86	0.89	0.91	0.94	0.96
2	0.37	0.79	0.85	0.89	0.92	0.93	0.95	0.96	0.96
3	0.33	0.65	0.79	0.88	0.90	0.92	0.94	0.96	0.97
4	0.70	0.73	0.83	0.88	0.91	0.94	0.96	0.97	0.99
5	0.57	0.74	0.80	0.84	0.88	0.92	0.94	0.95	0.96
6	0.51	0.67	0.76	0.82	0.88	0.93	0.95	0.96	0.96
7	0.52	0.70	0.81	0.87	0.90	0.92	0.94	0.96	0.96
8	0.55	0.72	0.80	0.87	0.92	0.94	0.95	0.96	0.97
9	0.28	0.54	0.70	0.80	0.86	0.89	0.92	0.94	0.96
10	0.51	0.67	0.80	0.85	0.89	0.91	0.94	0.96	0.97
11	0.35	0.56	0.67	0.76	0.83	0.89	0.92	0.94	0.95
12	0.54	0.69	0.81	0.85	0.89	0.91	0.92	0.94	0.96
13	0.46	0.59	0.74	0.79	0.84	0.88	0.91	0.94	0.95
14	0.45	0.70	0.79	0.86	0.88	0.90	0.93	0.95	0.96
15	0.49	0.65	0.73	0.79	0.85	0.89	0.93	0.94	0.96
16	0.33	0.63	0.83	0.88	0.91	0.95	0.96	0.98	0.99
17	0.42	0.62	0.73	0.84	0.88	0.92	0.94	0.96	0.97
Mean Accuracy	0.46	0.66	0.78	0.84	0.88	0.91	0.93	0.95	0.96

Note: The overall accuracy varies between 0 and 1.

between the average accuracy of the seventeen maps and the number of classes (Figure 5). The problem, of course, was to find the level of generalization which best conciliated map enhancement and map accuracy. A few criteria for answering this difficult question may be suggested.

Since one purpose of quantization was to increase map contrast, it seems logical to select the generalized maps that most accurately replicate the contrast between the maps without class intervals. Correlation between the overall blackness of maps with and without quantization showed that the four-class maps most closely reproduce the data intensity (Table IV).

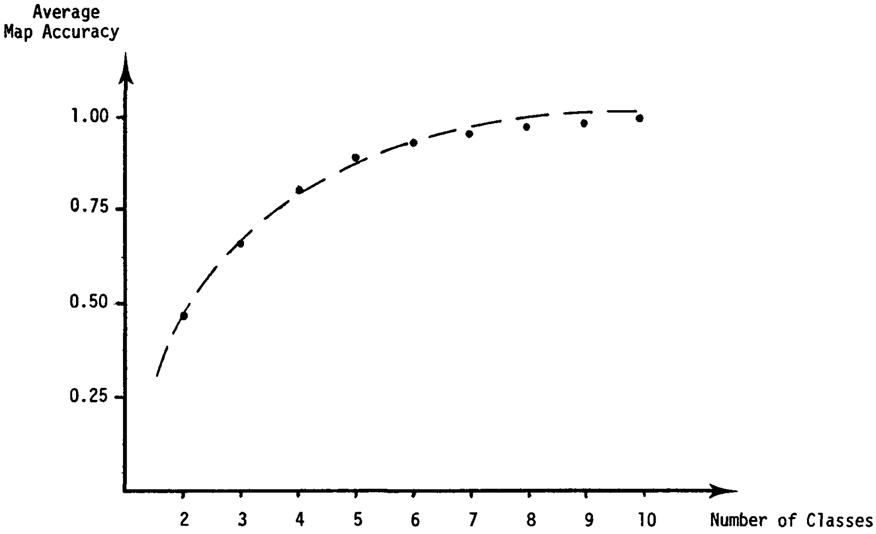

Figure 5. Relationship Between Average Statistical Accuracy and Number of Classes of the Maps.

TABLE IV. CORRELATION BETWEEN THE OVERALL DARKNESS OF THE QUANTIZED AND UNQUANTIZED MAPS

Number of Classes of the Quantized Maps	Correlation (r) with the Unquantized Maps
2	0.34
3	0.67
4	0.69
5	0.57
6	0.68
7	0.63
8	0.58
9	0.51
10	0.37

Another criterion may be provided by the overall accuracy of the maps. One acceptable solution would be to examine the relationship between accuracy and generalization and choose the number of classes which appears to be at a suitable elbow of the resulting curve. For instance, five classes seemed to be the most acceptable solution for map number 3 (Figure 6).

Finally, in the case of multimap comparison, one may be more particularly interested in the representation of statistical relationship between geographic variables. The representation is accurate if the statistical correlation between the maps duplicates the statistical correlation between the variables. This is seldom the case. By compressing the data into classes, some information is lost that usually distorts the relationships between the data sets. The fact that map correlation takes different values on the same mappable set of data would be relatively unimportant, however, if all the correlation coefficients were jointly monotonic. In other words, if all correlation values for pairs of maps on one number of classes were ordered so that they form a monotonic series, the correlation values taken by the corresponding pairs of data sets would also be monotonic. Correlation values were computed between all pairs of variables and all pairs of maps. They showed to be not jointly monotonic, although the relationship between the series became increasingly monotonic as the number of classes increased (Table V).

Two minor elbows were found in the improved relationships of the series, located at four and ten classes which represented the best mapping solutions in this case.

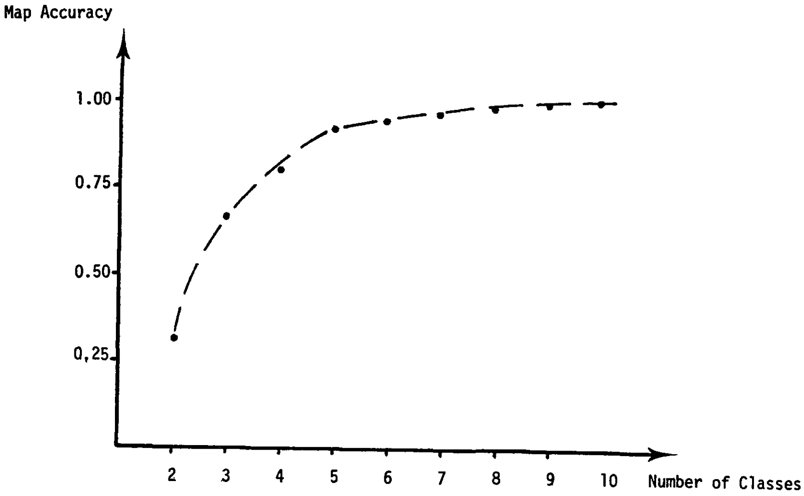

Figure 6. Relationship Between Statistical Accuracy and Number of Classes of Map 3. The optimum mapping solution is indicated by the elbow of the resulting curve which appears at the five-class mark.

TABLE V. CORRELATION (r) BETWEEN DATA SET RELATIONSHIPS AND MAP RELATIONSHIPS

Number of Classes of the Quantized Maps	Correlation (r)
2	0.75
3	0.77
4	0.81
5	0.82
6	0.82
7	0.83
8	0.84
9	0.84
10	0.93

Note: Data-set and map relationships were measured by areally weighted Pearsonian coefficient and areally weighted rank correlation respectively.

CONCLUSION

This study has shown some important aspects of choropleth generalization. Quantization had obvious effects on contrast within map and edge enhancement between regions. Furthermore, experiments have already shown that map readers concentrate most of their attention on the borders between more or less homogeneous regions. 9/ Under these circumstances, data classification becomes a necessity and a key element in the theory of choropleth mapping. It leads to the characterization of well contrasted subsets which can be visually recognized and whose components can be easily assembled into a geographic pattern.

Quantization presents serious statistical drawbacks, however. Map accuracy decreases rapidly as the number of classes decreases. Depending on the distribution of the data, the partition process may lead to a wrong representation of the data intensity. In this experiment, contrast between the generalized maps was not always consistent. Finally the statistical relationship between generalized choropleth maps seldom replicates the statistical relationship of the data sets.

Although a general choroplethic mapping solution, conciliating the contradictory trend of map accuracy and map enhancement does not seem feasible, individual answers to the quantization problem can be found. In this essay, analysis of contrast within and between maps and statistical accuracy suggested that the four or five class maps may represent the optimum mapping solution.

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3. Tobler, op. cit.

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6. Statistically, it would seem more logical to symbolize the choropleth classes by shading patterns whose visual intensity would be proportional to the data mean of each class.

7. G. Jenks and F. Caspall, "Error on Choroplethic Maps: Definition, Measurement, Reduction," *Annals of the Association of American Geographers*, Vol. 60, No.2 (1971), pp. 217-244. Jenks and Caspall's solution has the advantage of minimizing the information loss or discrepancy between the numerical values displayed by the map classes and the corresponding numerical values given by the raw data.

8. Map accuracy is measured by the absolute deviation of the map values from the corresponding values of the data set. See G. Jenks and F. Caspall, *op. cit.*

9. Richard O. Duda and Peter E. Hart, *Pattern Classification and Scene Analysis*, (New York: John Wiley and Sons, Inc., 1973), p. 268.

UNDERGENERALIZATION AND FIGURE-GROUND RELATIONSHIPS IN STATISTICAL MAPPING

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INTRODUCTION

Every statistical map is a device by which the author (cartographer) attempts to communicate spatial information to mapreaders. The cartographer translates his understanding of the subject matter into a graphic statement by controlling such design elements as content, contrast, symbology, scale, etc. If these concepts are transferred to the mapreader with little or no distortion, the map can be judged to be a success, but if for some reason the reader obtains a highly distorted version of the spatial information, there is a breakdown in communication.

Breakdowns in graphic communication which are related to the psychological, physiological or environmental state of the mapreader tend to be beyond the control of the mapmaker. The cartographer cannot know who will read his map or when it will be read, nor can he control the conditions under which it is read. Since these are the realities of the map user situation, it then seems reasonable to assume that the greatest improvements in cartographic communication will come about by increasing the capabilities of the mapmaker and by broadening his knowledge of the psychophysical characteristics of the "average mapreader."

Spatial information on a statistical map can be broken down into two quite different classes: specific facts about selected places or agglomerative facts which become apparent when specific knowledge is suppressed so that areal patterns become visually dominant. 1/ This dichotomy of spatial information gives rise to three different mapmaking objectives. The cartographer may elect to 1) facilitate data retrieval, 2) maximize perception of spatial features, or 3) attempt to combine both data retrieval and pattern perception. Many cartographers select the third objective, and some create maps which are rather successful in communicating both types of information. Many others fail, however, and the failure can often be linked to undergeneralization and a misunderstanding of the figure-ground relationships on statistical maps. 2/

UNDERGENERALIZATIONS

In the process of creating a statistical map the cartographer normally uses two sources of information: a base map and a statistical table. Information on the base map may include point, line, or areal places and their identification. The section of the Bureau of the Census base map shown in Figure 1 is a good example of the nature and content of a base map source. 3/ Tabular sources of information are

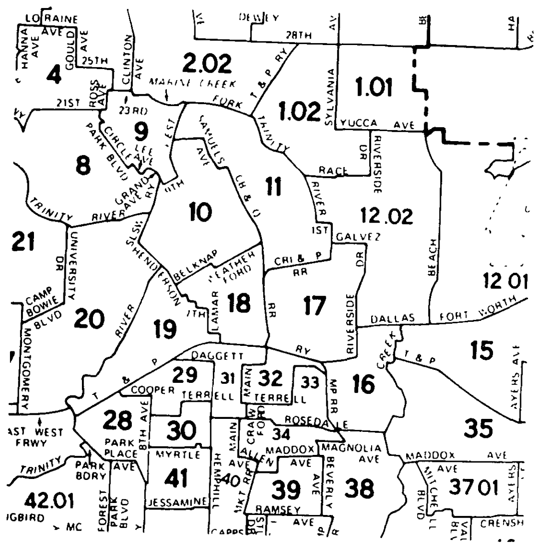

Figure 1. A section of the United States Bureau of the Census base map for the Fort Worth portion of the Dallas-Fort Worth Standard Metropolitan Statistical Area. Census tract tabular data for this area are keyed to the bold identification numbers.

composed of enumerated or measured facts which pertain to an area of concern. Obviously, to be useful in map construction the base map and the tabular data must be for the same area and the data and the base map identification must be keyed to each other.

Statistical maps are normally small-scale representations which are designed to communicate information about a single phenomenon. Even though the subject matter is limited, the amount of information available from the source materials is greater than can be accommodated. Because space is limited and because suitable cartographic symbols cover relatively larger areas on the map than the phenomena they represent occupy on the earth, the data must be reduced in amount and kind. This data transformation process is known as cartographic generalization and it includes selection or omission of information, and simplification or classification of information. The objective of the generalization process should be to retain only that information which is deemed to be essential to the map message, but unfortunately human nature, being what it is, causes us to hesitate to throw "good data" away. The significance of this undergeneralization becomes clear when the nature of the relationships between figure and ground on statistical maps is reviewed.

FIGURE-GROUND RELATIONSHIPS IN STATISTICAL MAPPING

In psychological terms the figure of a statistical map is composed of the myriad of symbols which represent the distribution being mapped. 4/ The ground is the field upon which the figure is displayed and it must contain the locational information necessary to put the symbolized data into a spatial framework. The interrelationships between figure and ground determine the quality of a map design because two different graphic elements are superposed within the same spatial domain or body of the map. Even though the figure and ground are separate elements of a statistical map they must work together so that the eye can organize and the mind understand the nature of the distribution.

Undergeneralization can inhibit the transfer of certain spatial information because the eye may be unable to differentiate the symbols or the complexity of map detail may obscure the patterns. In the latter case "we cannot see the forest for the trees" because individual symbolic features refuse to be visually blended into regional unity. In other instances, the eye does not differentiate and, thus, the content of the symbology fails to reach the mind of the mapreader. The two maps shown in Figure 2 are illustrative of this situation. Many mapreaders think that

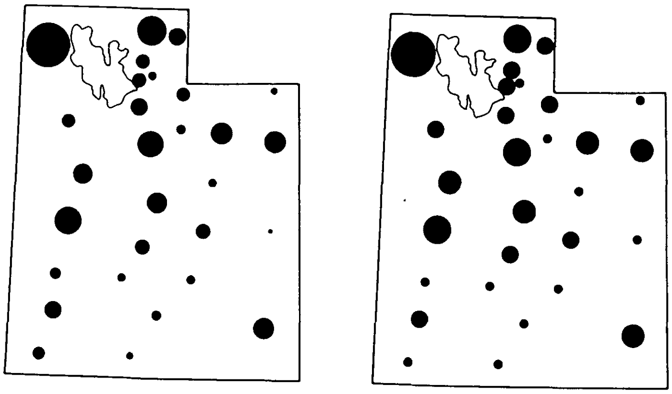

Figure 2. At first glance these simple proportional circle maps of Utah appear to be identical. There are 20 different sizes of circles on the left-hand map while only 5 different sizes are used on the right-hand map. Many think that these two maps communicate identical spatial messages.

these two maps communicate the same information and, insofar as these readers are concerned, the maps are identical. From a technical point of view, however, the maps are quite different since there are 20 different-sized circles on the left-hand map and only 5 different sizes of circles on the right-hand map.

The figure-ground relationships of the maps in Figure 2 are simple and easily understood because the ground has been kept simple and there is a high degree of contrast between figure and ground. If the reader will look at the dot maps shown in Figure 3 of the article entitled "Contemporary Statistical Maps--Evidence of Spatial and Graphic Igorance" (see p. 53), a similar figure-ground relationship can be seen. Compare the distributional patterns on this map with those evidenced in Figure 4 of the same article. Notice the fuzziness in the spatial pattern which has resulted from the increased informational load of the ground on this map. The design of the map in Figure 3 was developed to emphasize pattern while the objective of the map in Figure 4 was to provide for both information retrieval and pattern information.

Figure-ground relationships are particularly important in choropleth mapping as can be seen on the pairs of maps shown in Figures 3 and 4 (this article). The ground of the left-hand map satisfies the design objective of spatial pattern emphasis, while that of the right-hand map is for dual purpose information transfer. In the case of the left-hand map only those census tract boundaries which separate tones on the final map are retained while all tract boundaries were kept on the right-hand map. When the same shading patterns (figure) are combined with the grounds of the two maps very different impressions are created. Pattern information is clearly and easily perceived on the left-hand map, while a muddier and less definite pattern emerges on the right-hand map.

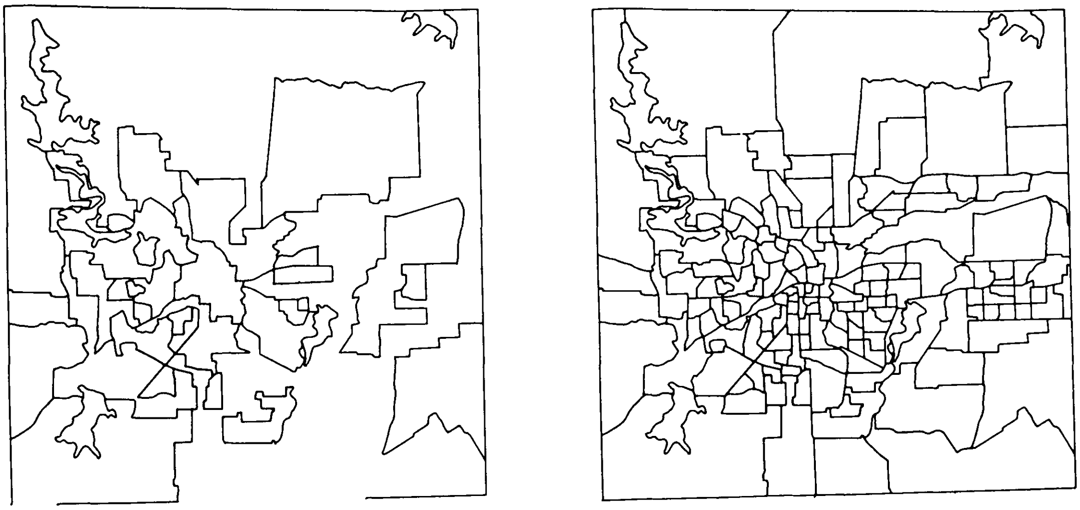

Figure 3. Two base maps prepared for part of the Fort Worth area. Only the census tract boundaries needed to separate classes have been retained on the left-hand map while all of the tract boundaries are shown on the other map. In terms of numbers of separate areal units, total length of line, or the amount of area covered with ink, the right-hand map must be considered to be much more complex than the left-hand map.

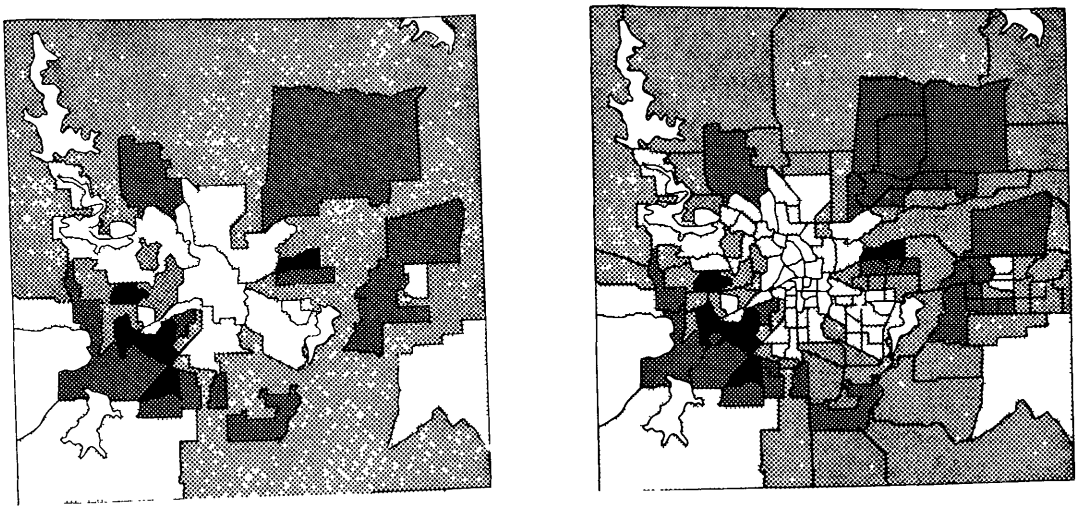

Figure 4. The figures (shading patterns) on these maps are identical. The maps look very different because of the ground (base map) complexity. Spatial patterns are more clearly seen on the left-hand map because there is less visual noise in the ground.

The proportional circle, dot and choropleth maps that have been used to illustrate the importance of the ground in the transfer of spatial information indicate why dual-purpose map designs are difficult to render, particularly when the graphic media available are limited. The visual separation of figure and ground becomes increasingly more difficult as the complexity and amount of information in the ground is increased. Furthermore, increased symbolic usage in the ground decreases the contrast and further inhibits figure and ground separation. It is clear that the designer of statistical maps should be particularly parsimonious when symbolizing ground and under no circumstances should he keep any details which are not vitally important for the transmission of the map message. In other words, err on the side of overgeneralization rather than retain more detail than is needed.

The ten maps of Louisiana shown in Figure 5 illustrate another aspect of undergeneralization which ought to be studied so that better statistical maps may be constructed. The four maps on the top row and the four maps on the bottom row of

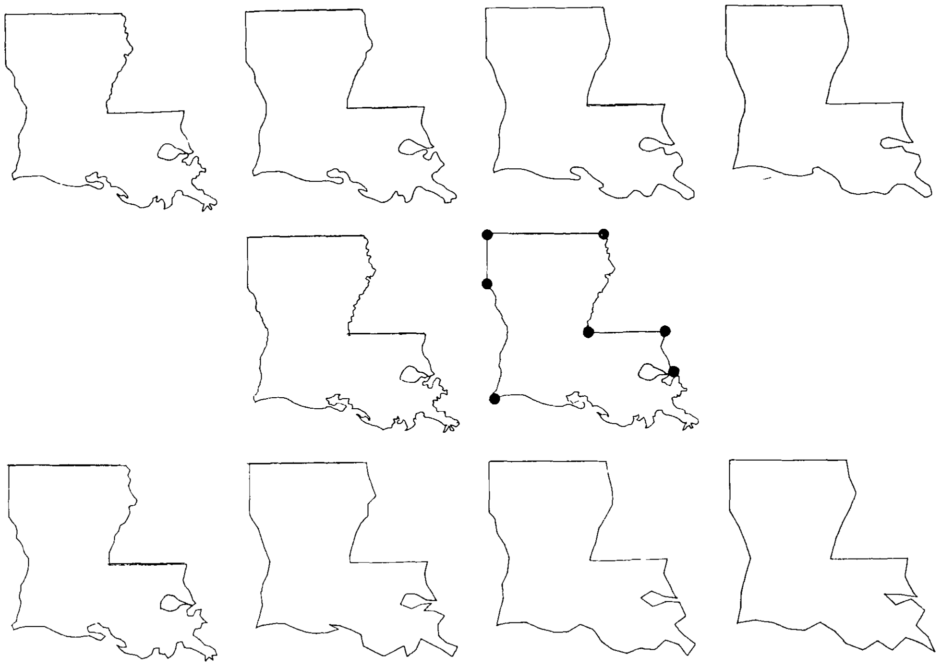

Figure 5. The maps in the top row are three point moving average simplifications and the four maps on the bottom row are polygonal simplifications of the left-hand map in the middle row. The black dots on the right-hand map of the middle row are essential topological points and these points are held constant on all maps. If statistical maps were created with more generalized outlines than is the usual case, spatial pattern perception might be enhanced.

Figure 5 are generalizations of the two maps on the middle row. Normally cartographers designing choroplethic maps of the United States use a base map with detail similar to that found on the maps in the middle row. As can be seen these maps contain a wealth of information along the coastline. Might it not be better to use a more generalized base map, especially when the subject matter has no relationship to the geomorphology of the coast?

Visualize if you can, the base maps shown in Figure 3 after a linear simplification similar to that shown on the upper right hand of Figure 5. Such a generalization would probably have enhanced the spatial patterns of both maps presented in Figure 4. Most of the base maps used in statistical mapping are undergeneralized and improved communication might well result from some linear simplification.

SUMMARY

Statistical mapmakers face numerous problems in designing the single subject small-scale representations that they create. Scale and symbolic limitations are formidable design obstacles and, as a result, careful analysis of map objective and map content are imperative. In this evaluation the clarity of the map message must be the overriding factor because this means the development of suitable visual figure-ground relationships. From a personal point of view the map designer must put his "pack rat" tendencies on the back burner lest he become an undergeneralizer and the producer of illegible and distorted map messages.

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THE COMPARATIVE ATLAS OF AMERICA'S TWENTY LARGEST METROPOLITAN REGIONS

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The Comparative Atlas of America's twenty largest metropolitan regions will summarize the insights of the Comparative Metropolitan Atlas Project of the Association of American Geographers. 1/ The Project's overriding objective was to provide an accurate comparative assessment of the progress being made toward meeting basic human needs in America's largest cities. Research focused especially on variations in the occurrence and intensity of problems among the twenty places. Given these purposes, designing the Atlas raised questions concerning: 1) which cities to map, 2) what topics to map, 3) map scales and cartographic techniques, and 4) the organization of the Atlas. The normal production processes of data gathering, compilation, editing, scribing, and proofing were also governed by the objectives of the Atlas and by the technology available to achieve its cartographic goals.

DESIGN

Intended Audience--The Comparative Atlas will provide Federal, State, and local officials with a useful tool for comparing similarities and differences among the cities mapped. The basic processes of urbanization and metropolitan evolution are common to all cities, but regional and temporal variations among American cities have caused urban processes to work themselves out in different ways, producing cities as dissimilar as Baltimore and Los Angeles within the same nation. No city's problems are exactly the same as any other city's. At the same time neither are they wholly dissimilar. The same principle holds regarding workable solutions for urban problems. Whereas the policies that would solve Washington, D.C.'s housing problems have elements in common with those that would work in Minneapolis-St. Paul, they must also take on local character that is responsive to the individuality of the Minneapolis-St. Paul region. Programs and policies that fail to recognize and accommodate the individuality and the underlying similarities among the Nation's metropolitan regions will certainly fail to yield maximum benefits.

The notion of putting maps of the same variables for different places together and examining them may sound rudimentary, but with one unsatisfactory exception, 2/ it has not heretofore been done for American cities. Combining maps of different variables in the same city with maps of the same variable for different cities in the same volume will help politicians, bureaucrats, and scholars make the comparisons among places that are prerequisite to formulating intelligent policies that respond effectively to America's metropolitan problems.

City Selection--The twenty largest metropolitan systems were selected for mapping in the Atlas after other alternatives were rejected. The Project's directors and steering committee weighed the advantages of choosing a stratified sample of urban places of different sizes versus the benefits of analyzing a manageable number of the largest metropolitan regions. They found it impossible to establish clear and consistent criteria for a stratified sample, and were simultaneously impressed with the aggregate size and economic importance of the twenty largest places (Figure 1). In 1970, 81 million people, or 40 percent of the Nation's population, lived within the Daily Urban Systems (commuting hinterlands) of the twenty largest places. The twenty commuting regions mapped in Figure 1 contain 24 standard metropolitan statistical areas, with an aggregate 1970 population of 68 million people, or 61 percent of the Nation's 1970 metropolitan population. Economic activities are equally or even more concentrated in these places, which are small in area but which loom large in the Nation's daily affairs. In 1967, for example, almost 60 percent of the Nation's wholesale trade was conducted within the twenty regions, and in 1970, 370 (75 percent) of the top 500, and 81 of the largest 100 industrial corporations in the Nation were headquartered in one of the twenty largest regions. The proportion of the Nation's metropolitan population living in the twenty places and the share of the Nation's productive capacity that is controlled from the twenty places made it quite clear that focusing on the twenty largest metropolitan regions would yield greater benefits than the alternatives.

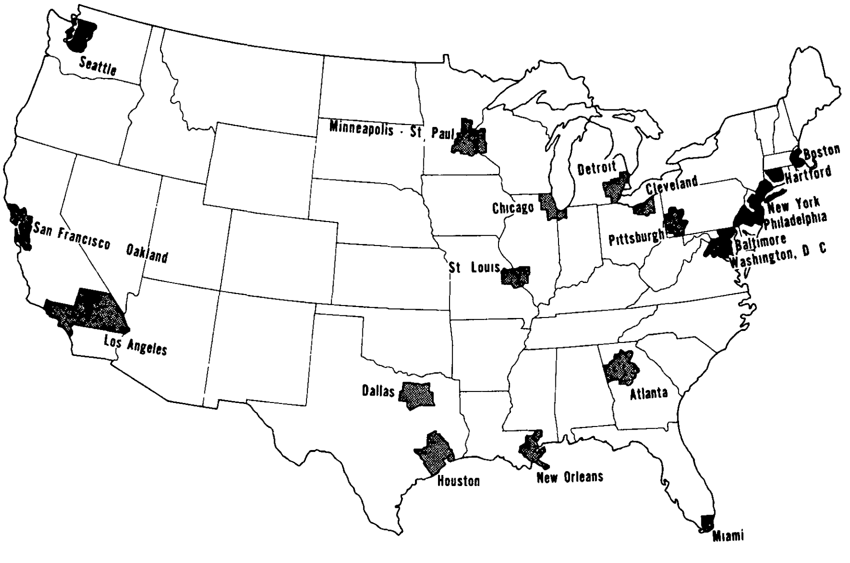

Figure 1: America's twenty largest Daily Urban Systems. Each Daily Urban System consists of one or more standard metropolitan statistical areas and the surrounding counties that have 5 percent or more of their labor force working in its employment.

Variables--Selecting topics to map was more complicated than choosing the cities. Making it possible for Atlas users to compare geographical patterns among the twenty cities dictated almost exclusively reliance on statistics from the 1970 Censuses of Housing and Population. The numerous data developed by local and State agencies usually differ in definition, scope, and format to the degree that they cannot be used for direct comparisons among places. Indeed, our few attempts to use data from local sources were only partially successful because of such problems. Census data do have many limitations of their own, but their outstanding value for our purposes was that they are produced by identical inquiries made in a uniform manner throughout the Nation.

Tens of thousands of cross-tabulations are available on the Fourth Count Census Tapes that were our major data source. We selected 44 standard variables for mapping in the Atlas based on: 1) the degree to which they were commonly accepted indicators of socioeconomic conditions, and 2) the extent to which they would measure the progress being made toward providing human needs in American cities. Because of the biases inherent in the census, the Atlas is perhaps overrich in some topics and inadequate in others. It contains many maps of basic demographic characteristics, housing conditions, employment, and income variables. On the other hand, it is deficient in standard series on topics such as the physical environment and environment degradation, health care and disease, recreational resources and activities, and crime.

Most of the Atlas maps are based on tract level data, with a few map series based on minor civil division statistics. For most purposes, block data would have provided too much detail and summaries for units larger than tracts did not provide enough detail for our purposes.

Scales and Cartographic Techniques--Proper selection of scales and retention of the same scales throughout the Atlas were especially important because of the comparative uses foreseen for the Atlas. Valid comparisons among places require common scales throughout. The large size of the central city of Chicago and the small size of Washington, D.C., for example, are basic elements of the geography of both cities that would be obscured if both central cities were not mapped at the same scale. Metropolitan regions and their components are therefore mapped at three scales. Topics mapped for the Daily Urban Systems will appear at a scale of 1:2 000 000. standard metropolitan statistical areas have been mapped at 1:1 000,000, and each central city will be mapped at 1:250 000. These scales will be maintained for all cities, regardless of size. At these scales, the largest maps fit within the Atlas's 13 x 11 inch trim size.

A scale and its corresponding region was chosen for each variable in accordance with the portions of the metropolitan system in which values of interest occurred. Predominantly black neighborhoods, for example, are conspicuous for their concentration in central cities and for their absence in suburban and urban fringe areas. Thus, mapping black population at the DUS or SMSA scale, while it might be a good way to illustrate where blacks aren't, produces few insights beyond those evident on a central city map. Problems caused by onsite sewage disposal, on the other hand, are serious in suburban and urban fringe areas whereas they are usually negligible in central cities.

Maps presented at any of the selected scales will necessarily be highly generalized. It is our intention to present the basic patterns rather than the fine details of the topics mapped, and the readers for whom the Atlas is intended are in most cases not skilled map readers. We therefore converted absolute values to percentages whenever possible, and smoothed individual tract values by portraying them as a statistical surface. Most maps are shaded isopleth maps. Interpolation was generally linear, but strict linear interpolation was modified often enough to make some parts of many maps quasidasymetric. This usually occurs where linear interpolation of extreme values for small areas might give an erroneous impression, as in the case of the effect a home for the elderly that occupies an entire census tract would have on a map of median age. Most isopleth maps are accompanied by a small histogram that makes it possible for Atlas users to see the statistical shape of the geographical pattern they are examining.

Dot distribution maps are used for items that occur erratically or in small numbers. Percentage maps for ethnic groups or abandoned houses, for example, would be low and would vary widely from tract to tract; dot maps provide more accurate impressions of such distributions.

The Atlas will be printed in two colors, black and orange. We had hoped to print in four colors, but the costs of doing so became prohibitive. Base information and isopleths will print solid black and the shading between isopleths will be different values of the orange hue selected. Water bodies will be shown with a light black screen. Because of the emphasis on comparing general patterns from place to place, base information is minimal; only major highways, water bodies, and political boundaries appear as location cues.

Atlas Organization--We foresee that some Atlas users will be interested in specific cities and the full array of their interacting problems and processes, whereas others will be more concerned with individual problems and differences in their occurrence and intensity from place to place. Thus the 1,050 maps in the Atlas proper are arranged in a way that facilitates the study of individual cities as well as comparisons among them. The first half of the Atlas will consist of one chapter for each of the twenty cities. Within each city's chapter an opening series of maps describing topography, land use, and housing characteristics is to be followed by a second section that concentrates on population density, age-sex structure, and racial and ethnic characteristics. A third part of each city's chapter will deal with social topics, occupations, and income, and the concluding section will contain six maps that highlight special problems in that city. Most maps in each city's chapter will be at the SMSA (1:1 000 000) scale, although central city and DUS maps will be used when necessary.

The second half of the Atlas is organized topically. Each chapter will consist of one map of the same variable in each of the twenty cities included in the study. Topics roughly parallel those mapped in the city chapters. Three items on the physical environment are followed by a larger number comparing housing, transportation, and land use patterns among the twenty regions. Education and health care are also briefly examined. A set of maps on minority segregation, employment, and poverty follows, and the Atlas will conclude with an essay on public policy requisites for American metropolitan areas. The twenty chapters on individual cities are to be preceded by five chapters that introduce the reader to the national metropolitan network, data sources, and Atlas cartographic conventions. The concluding essay on policy requisites will be followed by an appendix on cartographic methods and data reliability.

The Atlas will contain, in addition to the maps and their accompanying histograms, an extensive commentary that places individual maps in the broader context of the regional and national dimensions of the problem under discussion. The commentary averages about 150 words per map, or almost 200,000 words when introductory material and appendices are included.

PRODUCTION

Compilation--Variables selected for mapping were extracted from DUALabs tapes and converted to hard copy by the Institute of Urban and Regional Research at the University of Iowa. Clerical employees of the Cartographic Laboratory at the University of Minnesota, where the Atlas was produced, then transferred the data to base maps. The Atlas uses 60 base maps, one for each of the three scales for each of the twenty cities. Data compilation bases were derived from the metropolitan area tract maps that accompany the PC(1) printed tract reports and from the State minor civil division maps published by the census. In addition, 60 separate political boundary bases and another 60 overlays showing water features and major highways were prepared. All bases were first drafted at four times final production scale, and all data compilation and interpolation was performed at the same scale. The histograms were compiled and drafted at five times production scale.

Isopleth and dot distribution overlays were interpolated by the chief cartographer and his assistants. Standard isopleth values and standard dot values were used throughout because of the comparative nature of the Atlas. For most topics mapped with shaded isopleths, the extreme values are of greatest interest, and since such topics have been mapped in percentages, (for example, percentage Negro), isopleths were interpolated at 10, 30, 70, and 90 percent. Dot values of one dot for 50 people on ethnic group maps and one dot for 10 dwelling units on housing condition maps were established after some experimentation. Standardized data intervals of this kind are less than optimal for most individual city maps, but using different class intervals for different cities, however much it might be justified locally, would destroy the comparative value of the work. The judgement that most potential readers would be unskilled at reading thematic maps led us to adopt the standard 10, 30, 70, 90 percent breakdown for all maps that could be presented in percentage terms.

The Atlas editor generalized each data map, suppressing erratic and isolated values that complicated general patterns. A dummy of the Atlas had been prepared that grouped related topics on the same page or on facing pages in the individual city chapters, and that grouped cities with similar growth histories on the same or facing pages in the topical section. The edited overlays were photographically reduced to final production size and arranged for scribing according to the layout established in the dummy.

Scribing and Color Separation--Atlas pages were scribed as single units, with the number of maps and histograms on a given page varying between one and six of each. Isopleths were scribed on one overlay, and the photographically reduced histograms were then stripped into the same overlay. The political boundary and location cue bases had also been photographically reduced, and they were scribed also. Because the political boundaries and location cues for a given city at a given scale were invariant from map to map, page negatives for those features were composed photographically from a single scribed version at a considerable saving in cartographic time.

Color separations were produced by the triple exposure of photosensitive strippable film through the isopleth/histogram, political boundary, and location cue overlays. Five color separation negatives were made for the five orange values (10, 20, 40, 60 and 100 percent), and one separation negative was made for water features (20 percent black). A separate positive lettering overlay was prepared using stick-up typography, from which a contact negative was then produced.

The negative for the 100 percent black areas was compiled by multiple contact exposure of the lettering negative, the scribed data/histogram film, the political boundary negative, and the location cue negative to duplicating film. The normal products delivered to the printer will thus consist of seven negatives, five for exposure on the orange plate and two for exposure on the black plate. Pages containing one or more dot maps are to be produced in much the same way, except that a separate dot negative has been prepared for direct exposure onto the appropriate plate. Pages with isopleth maps and dot maps in both colors thus require nine exposures on the two plates, whereas pages with black dots only and no isopleth maps will require but three exposures. Figure 2 summarizes the production scheme.

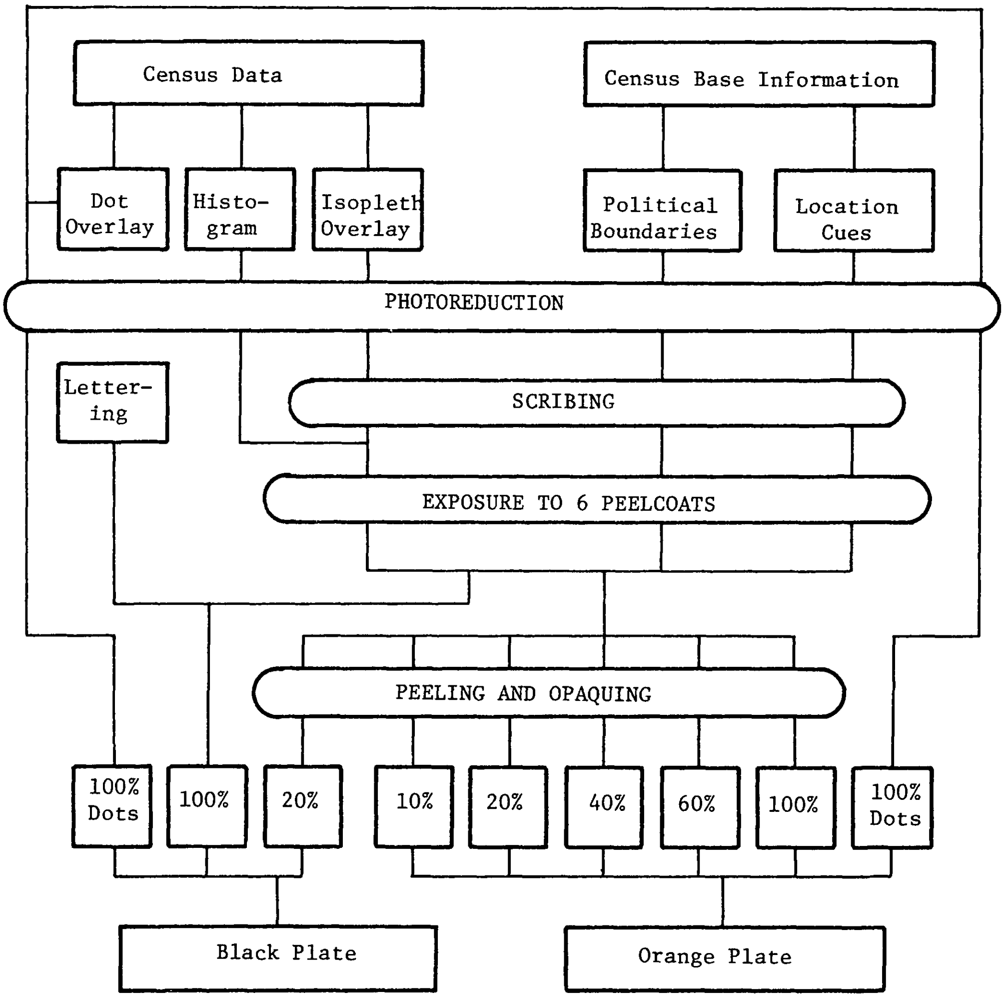

Figure 2: Production Scheme

The printer will prepare color proofs for each page to provide a final check for errors before the plates are exposed. All scribing materials photographic films, and strippable films used in production are 0.0075 inches thick, and pin registration was used at all stages after photoreduction of the overlays. Thus the negatives supplied to the printer should be in almost perfect register.

The Atlas will contain over 1,800 maps and graphs, all of which were compiled, interpolated, and scribed by hand. Many production economies were realized because only the data overlays and histograms varied over the 60 standard bases. Thus although the comparative nature of the work imposed certain constraints on layout and symbolization, such limitations were offset by the benefits of frequent repetition of bases and standardization of symbols. Computer cartography was much more in its infancy in 1970 and 1971 when the Atlas was conceived than it is today. Given the relatively primitive state of the art then, the decision to perform all compilation, interpolation, and production by hand was appropriate. Were the same project being conceived now, more intensive use of computer technology would doubtless be incorporated.

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THE URBAN ATLAS PROJECT:
HISTORICAL AND CARTOGRAPHIC REVIEW

Richard H. Schweitzer, Jr.
U.S. Bureau of the Census

The presentation of high quality graphics, particularly maps, has in the last 60 years been a major feature of census publications. Periodically the Census Bureau has published a series of maps showing the spatial patterns of various demographic, social, agricultural, or economic data. These maps, sometimes presented in an atlas format, have occasionally been issued separately; however, most of the time the maps have been included directly as part of the United States summary reports. The graphics, whether they entailed the creation of choropleth maps, dot maps, or cartograms, had always, until 1972, been the products of manual cartography. Consequently, the number of maps which have been included in the various census reports has always been, of necessity, limited compared to the number of maps which could have been included or were desired.

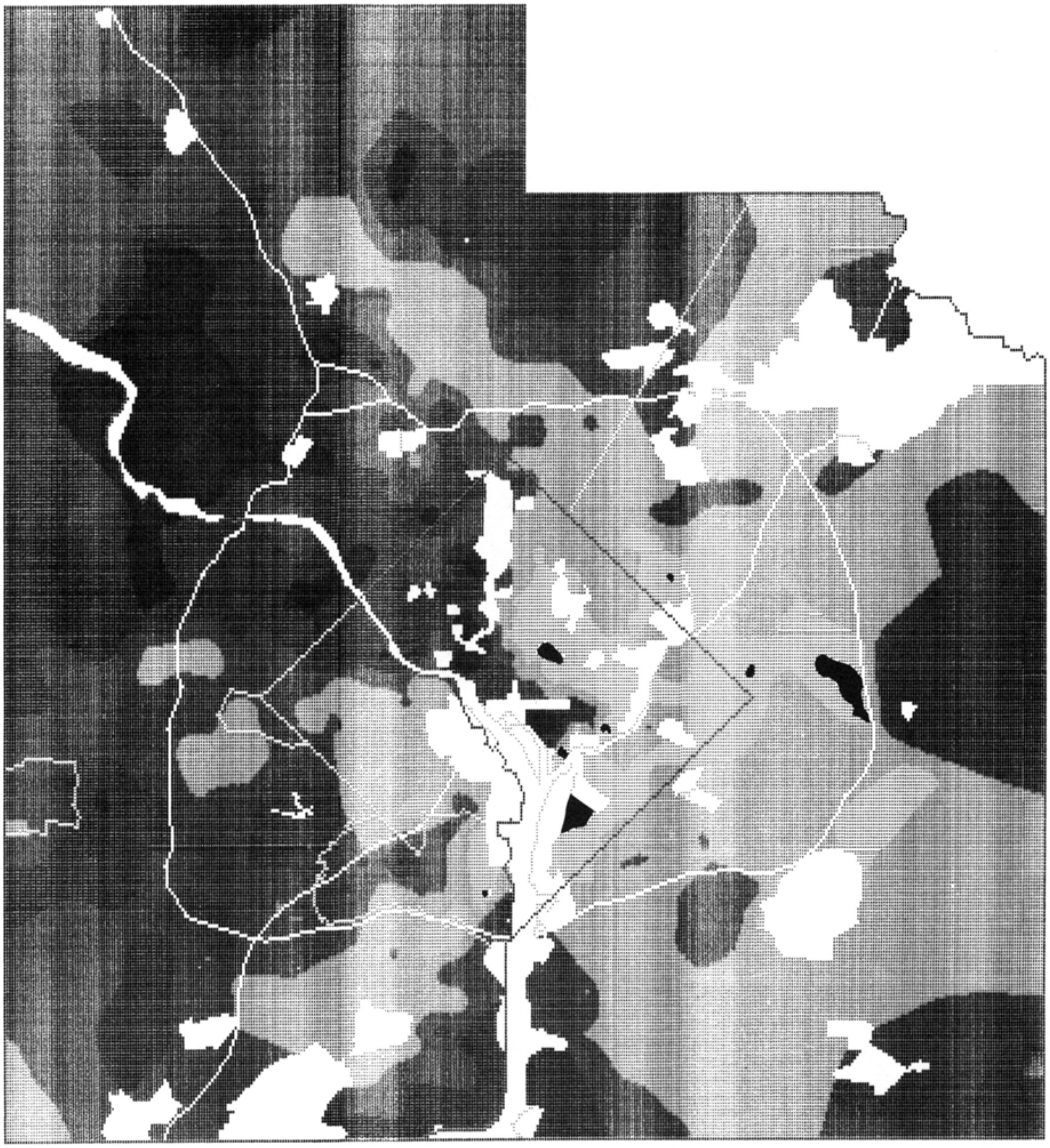
Early in the planning of the publications for the 1970 Censuses of Population and Housing, considerable thought was given to the creation of an urban atlas or the preparation of maps showing the spatial patterns of selected demographic characteristics within the major metropolitan areas of the nation. However, it was felt that as of 1970 the state of the art, insofar as computer cartography was concerned, had not advanced enough to support the large-scale effort that would be necessary to prepare a comprehensive series of maps of urban America. Likewise, the cost, both in fiscal and human terms, required to prepare choropleth maps of the major metropolitan areas by the standard manual cartographic techniques was too expensive and time-consuming to permit the maps to be produced in this manner. As a result of the suspected inability of automated cartography to economically mass produce the number of the map sheets that would be required and the high costs of traditional cartographic methods, the idea of producing an urban atlas or individual maps of urban America was dropped.

Even at that point of time it was acknowledged, nevertheless, that computer mapping offered a tremendous potential for presenting census data in its spatial setting at a reasonable cost. This capability had been demonstrated in several of the reports which were produced as a part of the 1967 Census Use Study in New Haven, Connecticut. However, the experimental, custom-made maps included in these reports did not reflect the problems that would be encountered in the production of a series of urban atlases for the nation's largest metropolitan areas.

Throughout the early 1970's computer graphics technology progressed far more rapidly than many of its most ardent proponents had hoped was possible. During 1972, the Census Bureau acquired considerable experience in producing computer maps of various metropolitan areas. Figure 1 is an example of an early SYMAP covering the Washington, D.C. urban area. This experience, plus other research and development work, demonstrated that it was now possible to produce a national series of urban atlases.

AVERAGE HOUSING VALUE OF OWNER OCCUPIED UNITS

Washington, D.C. - Md. - Va. SMSA (part)



VALUE

■ under $15,000
░ $15,000 - 19,999
▒ $20,000 - 29,999
▓ $30,000 - 39,999
▓ $40,000 - 49,999
■ over $50,000

U.S. DEPARTMENT OF COMMERCE
BUREAU OF THE CENSUS

SYMAP MAPPING PROGRAM

The feasibility of such a project, both from the technological and economic perspectives, had been tested by the publication of the Graphics Summary, 1969 Census of Agriculture in 1972. This Atlas contained a total of 219 computer-generated dot and choropleth maps representing all facets of American agriculture. This publication demonstrated that the automated cartography technology had advanced from line printer images to graphics arts quality maps produced by micrographics. This technological breakthrough, which is described in more detail elsewhere, allows the rapid production of either black or white or color maps. Even though the technology had been demonstrated, it had never been used to produce maps as large as the atlas sheets (15 x 19 inches) or in such volume -- over 1,000 maps.

The entire Atlas project was tempered by the basic purpose of the reports. The Atlases were intended and designed to provide a descriptive graphical presentation of several of the basic statistical indicators that were included in the Census Tract Reports. They provide a basic overview of the spatial patterns of 12 major indicators of urban life. The data items that are included are:

1. Population density: population per square mile.
2. Percent of the population under 18 years of age.
3. Percent of the population over the age of 65.
4. Black population as a percentage of the total population.
5. Percentage of persons over 25 years of age who are high school graduates.
6. Median family income.
7. Interrelationship of family income and educational attainment.
8. Percentage of the labor force employed in blue collar occupations.
9. Median housing value.
10. Median contract rent.
11. Percentage of housing units which are owner occupied.
12. Percentage of occupied units constructed after 1960.

The only attempt to provide any analysis of the data is Map 7 which presents family income and educational attainment on a single map. This was intended to graphically illustrate the sociologist's classic contention that educational attainment and income have a high positive correlation.

Because of budgetary considerations, the publication program was limited to the presentation of 12 data characteristics for the largest 65 Standard Metropolitan Statistical Areas of the nation. The larger metropolitan areas are shown either with insets or in sections in order to provide the reader with the ability to clearly identify individual census tracts. Four reduced examples of sample urban atlas pages are shown in Figures 5 through 8 on pages 256-259.

OPERATIONAL CONSTRAINTS

The overall format of the Atlases was a subject of extensive discussions. For instance, many hours of discussions were devoted to evaluating the various viewpoints on the size of the Atlases. In the end it was decided to use a large Atlas format rather than the standard census publication ($8\frac{1}{2}$ x 11 inch) size for two reasons: (1) the ability to show an entire SMSA on one sheet, and (2) the desire not to artificially subdivide the larger SMSA's into many sections in order to show the detail necessary to clearly show an individual census tract.

Similarly, because of the very positive reactions to the color maps in the Census of Agriculture's Graphics Supplement, it was decided that the Atlases would be printed in color if funds were available. At the time the printing was commissioned, the funds were available. An additional reason for the use of color was the inclusion of a cross-map which had been developed as the result of a suggestion of Vincent P. Barabba, Director of the Bureau of the Census. This mapping technique, which has been described elsewhere,requires the use of at least three colors in order to be effective.

Another major constraint was that the maps had to be choropleth maps and show census tract boundary lines. This was required because of the nature of the census data. Many of the data items included in the Urban Atlases are based on sample statistics. That is, the final figures for most census data items are determined by the responses from only a fraction of the inhabitants of the census tract. Because of the problems of confidentiality and also the limitations imposed by sample size and sampling theory, inferences could not accurately be made within a census tract. Therefore, the characteristics had to be displayed as if they were distributed uniformly within the census tract boundaries. Proximal or contour mapping techniques could not be used because they would distort the data and imply patterns within the tracts which could not be supported by the data.

CARTOGRAPHIC CONSIDERATIONS

Even though several unique techniques were used to produce the Atlases, most of the fundamental, traditional cartographic judgements still had to be answered. However, some of the traditional aesthetic judgements were, in effect, preempted by the use of automated techniques. The discussions that were undertaken are illustrative of the types of constraints that automated techniques impose upon traditional cartographic standards.

SCALE

Since the primary purpose of the Atlases was to provide a means of comprehending the spatial patterns of the data, the map scale was varied between different standard metropolitan statistical areas (SMSA's). The scale of the maps for any area was strictly a function of the size of the smaller tracts and the overall size of the entire SMSA. A rough rule of thumb was that the smallest tracts should be no smaller than a tenth of a square inch. Whenever this required that the SMSA be shown on two (or more) pages, one (or more) insets were shown on additional pages so that each tract could be easily identified.

Since the maps were strictly statistical maps with no planemetric data, it was felt that the legibility of the statistical areas was more important than holding to a set of fixed map scales. Individual census tract outline maps were included in the rear of each Atlas to assist the reader in relating the statistics to local landmarks and specific locations. A bar scale is included on each map so that relative distances can easily be determined.

SUBJECTS

Early in the planning of the program, a set of potential subjects were extracted from the published 1970 Census Tract Reports. These tentative items were submitted to the Bureau's Population and Housing Divisions for review. They were asked to provide a list of specific data items that could be used to display the desired subjects. In addition they were asked to place the subjects and specific data items into a rank order of their preference.

In addition, the members of the Bureau's Small Area Data Advisory Committee were briefed on the program and asked to submit suggested items which might be mapped.

A total of 25 specific items was suggested for inclusion. Several, particularly in the income and poverty areas, appeared to reference the same basic data area with a different emphasis. When the overlapping subjects were eliminated, only 21 unique subjects remained. These were ordered on a consolidated list pending the determination of how many maps could be prepared.

Budgetary constraints limited the number of maps to twelve for each area. As a result, the original list of proposed map subjects was again reviewed. Three of the proposed subjects in the demographic area which had been originally ranked in the top twelve subjects were dropped because of data comparability problems (Spanish ancestry), or because of maps already available in other Bureau publications (poverty), or because of the age of the data (unemployment). The Bureau's executive staff then approved the inclusion of the twelve data items that were previously noted.

The population density map was included to provide the reader with a means of evaluating in his own mind the relative importance of the physical size of the tract in respect to the number of persons residing in the tract. These maps also provide a useful means of relating the effects of urban expansion on the surrounding land area.

CLASS INTERVALS

In a similar manner to the choice of the subjects, the determination of the class intervals was made by subject matter specialists within the Bureau's Population and Housing Divisions. They were asked to examine the data for the particular items for the metropolitan areas of 500,000 population and larger. Six classes, not including "Data not Available," were to be selected so that they were representative of the candidate metropolitan areas as a whole. The only exception occurred with the population density map. The population density of all tracts ranged from 0 to 257,000 persons per square mile. However, only 3.7 percent of the tracts had densities over 50,000 persons per square mile. Therefore, six classes were designed to cover tracts under 50,000 persons per square mile and an additional four classes were created to display the tracts with extremely high population densities. These four "extra" classes were needed in only 14 metropolitan areas. The same class intervals were used on corresponding maps in every Atlas so that cross-area analysis could be made.

In some cases special data tabulations were prepared for the use of the subject matter specialists to assist in the choice of appropriate and reasonable breaks. Even so, some of the maps in a particular Atlas reveal almost no internal divisions because the data for that SMSA were so highly skewed in comparison to the national norms. A table showing the comparison of the data for the Nation, States, the component counties, and the larger places within the SMSA was included in each Atlas.

COLOR CHOICES

In order to avoid having all of the maps look the same, a wide variety of color sets were used. Most of the color sets had been used previously in the Bureau's GE-50 map series. In all but one of the maps, the lower data values are shown with lighter colors.

The map displaying the percentage of owner occupied housing units uses a dark blue color to represent the class interval where most housing units are owner occupied. A dark red color is used where very few residences are owner occupied (i.e., highest proportion of rental units).

INSETS

As mentioned earlier, the use of insets was kept to a minimum because of the large image area provided by the use of the atlas format. However, when it was necessary to provide additional detail to clearly represent individual census tracts, the fewest number of insets were used. Whenever possible the boundaries of the insets were chosen to respect recognized political boundaries, or physical features, or major cultural boundaries. An example of the latter situation was the use of circumvential highways or beltways in Washington, D.C. and Atlanta, Georgia to enclose the inset area.

LINE-WEIGHT

The line-weight of the census tract boundaries was directly a function of the spot size of the computer output to microfilm (COM) unit that was used to prepare the window negatives. As a result, the actual width of the printed lines does vary in respect to the degree of enlargement that was required for each set of film. Most of the differences are so slight that they are not noticeable. In a few cases the base map and inset are shown on the same page, and the difference in line-weight is noticeable.

The Urban Atlas Project clearly represents a major new advance in automated cartography. The size of the undertaking and the number of statistical units mapped precluded the use of traditional techniques. However the utilization of automated techniques did necessitate the revision of some of the standards that have traditionally been used to judge fine cartographic efforts. However, we believe that the results speak for themselves and do illustrate that automated cartography is capable of producing graphics art quality at a lower unit cost.

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Seminar on Map Reading and Perception

Editor's Note: A 16-page color signature (pp. 251-266) illustrating various presentations follows this section.

SEMINAR ON MAP READING AND PERCEPTION

The seminar on Map Reading and Perception was held in two sessions. The first session on Monday afternoon was chaired by BARBARA PETCHENIK of the Newberry Library, Chicago, Illinois. Entitled "An Interdisciplinary Forum," it was designed to bring together individuals from various disciplines which are, depending on one's point of view, either peripheral to cartography or at the very heart of it. At the second session, held Wednesday afternoon and chaired by GEORGE MC CLEARY of the University of Kansas, practicing cartographers discussed current research products and methodology.

At the Monday session experts in various disciplines including psychology, urban planning, and cartography, looked at the visual processes involved in extracting information from maps.

The psychologist of art, RUDOLF ARNHEIM, formerly of Harvard University, focused on various problems shared by art and cartography in his paper entitled "The Perception of Maps." These problems include simplification and generalization. Geographic shapes, like other visual shapes, are always seen in context and are the carriers of dynamic expression. The dynamic qualities are essential in impressing students with experiences that give life to intellectual information. Other perceptual aspects, such as orientation in space and the representation of three-dimensional relief, can be studied with the help of psychological principles and techniques developed by artists. Remarks on "generalization" of visual form concluded the paper. Dr. Arnheim's paper is not reproduced in these Proceedings but can be found in The American Cartographer, volume 3, number 1, April, 1976.

DAVID STEA of the University of California at Los Angeles is well versed in the fields of psychology, engineering, planning and geography and brought a wide range of experience to the seminar. In his paper, "Children as Cartographers," he related the results of research conducted over a number of years at the Place Perception Project. He summarized a series of studies which were carried out among children aged 3 to 7 in the United States and other countries. His findings indicate that children appear to have map and air photo reading and mapping capacities at very early ages, prior to formal school experience. The results of this research have been published in several journals including the Annals of the Association of American Geographers ("Studies of Geographic Learning," with J.M. Blaut, 1971, volume 61, pages 387-393) and the Journal of Geography ("Mapping at the Age of Three," 1974, volume 23, number 7, pages 5-9). Dr. Stea has also written (with Roger Downs) Image and Environment (Chicago: Aldine, 1973).

WILLIAM CHASE, a psychologist at Carnegie Mellon University, described psychological experiments in visual imagery and current theories of image representation. His paper described the cognitive aspects of visual information processing, especially the problem of determining the nature of the skills (spatial and otherwise) related to expert chess playing. His research appears to have rather direct relevance for map use analysis. The topic of his presentation, "Psychological Investigation of Visual Imagery," is discussed in detail in the following two articles: William Chase and Herbert Simon, "The Mind's Eye in Chess," in Visual Image Processing, edited by William Chase, New York: Academic Press, 1973; and William Chase and Herbert Simon, "Skill in Chess," The American Scientist, volume 61 (1973), pages 394-403.

ROBERT C. KLOVE reported on problems in statistical mapping at the Bureau of the Census, concentrating on user definitions and map design. Statistical mapping at the Census Bureau has many problems that are related to map reading and perception. He grouped these under three major headings: 1) statistical map perception problems within the Census Bureau; 2) the nature of the users and the kind of map they need; and 3) statistical map planning and design problems or do the maps tell the story they should. The emphasis was on the United States Map Series (GE-50) developed over the last ten years at the Census Bureau. Dr. Klove also noted the methods used and gave indications of their success, as well as problems that remain to be solved.

BARBARA PETCHENIK of the Newberry Library's Atlas of Early American History Project chaired the first session and presented a paper on "Cognition in Cartography." For more than a decade cartographers have been conducting research in map reading and perception using the basic assumptions and tools of the field of behavioral psychology. Now, however, there has been an important shift among experimental psychologists toward the field of cognitive psychology. Dr. Petchenik examined the nature of this shift and its implications for cartographic research. She attempted to establish a broad theoretical framework that could encompass the results of research in disciplines other than cartography and proposes a shift in cartographic research from reductionistic points of view to more wholistic approaches.

The second session brought out several of the problems which confront cartographers who embark on a program of research in map reading and perception. The major question to be addressed is: who is the map reader and how will the map affect his behavior and his activities in the environment?

JOHN E. DORNBACH of the National Aeronautics and Space Administration's Johnson Space Center in Houston, Texas, reviewed the background and history of map and chart design investigations prior to the 1950's and touched upon the relationship of the psychological approach to map design. Citing the development of cockpit instrument displays as an example, he stressed the need for integrated graphic design so that information is presented as quickly and as unequivocably as possible. He suggested several areas where research would be of value. The needs of the map user and his ability to effectively extract the information he requires from the map should be foremost in the mind of the map designer. His paper was entitled "An Analysis of Approaches in Map Design."

CHARLES OGROSKY of Rutgers University (New Brunswick, New Jersey) described current research in the field of tactual cartography. Identification of more efficient forms and codes for representing geographic data is an essential part of extending the usefulness of maps to the visually handicapped. Past research has shown that differences of shape, size, texture and relative levels of relief may be used to create qualitative point and linear symbols and area textures. Recently, the use of photomechanical processes and numerically controlled milling devices has made investigation of more complex symbol scaling relationships possible. Current research includes the evaluation of active tactual sensitivity to changes in the planimetric dimensions of four point and linear symbols. The results of this research will make possible the production of ordinally scaled symbols for use on more meaningful quantitative thematic maps for the blind.

THEODORE STEINKE of the University of South Carolina presented his research on "The Optimal Thematic Map Reading Procedure: Some Clues Provided by Eye Movement Recordings." Cartographers, geographers, and other frequent users of maps commonly allude to the map reading process. Just what that process is has never really been determined despite the existence of numerous technical manuals and college courses dealing with the subject. Eye movement recordings provide a mechanism by which the map reading process can be defined. From these recordings it can be determined where a person looks on a map, how much time is spent looking at the map and its various parts, and the sequence in which these parts are looked at. In this study, eye movement recordings were made of 20 college students while they looked at a typical thematic map. Each was then asked to reconstruct the pattern of graduated circles that made up the body of the map. The reconstruction was used as a measure of how well they understood the map and how much information passed from the map to the reader. Analysis of the eye movement recordings in conjunction with the map reconstructions revealed considerable variation in the map reading procedure used by the subjects but also indicated which attributes of the map reading process are associated with most efficient information flow and thereby provides some insight into the optimal thematic map reading process.

MICHAEL DOBSON of the State University of New York at Albany provided some contributions to an understanding of the role of the eyes during visual search. During map reading, the goals of the reader and the cartographer intermix to produce a specific search behavior. Subject-evoked variability and map-induced constancy are defined as critical components determining the sequence of looking. His paper was entitled "The Map -- In the Mind's Eye."

CARLETON W. COX of Illinois State University applied frame-of-reference psychophysics to adaption level theory in an attempt to reach a realistic modification of S. Smith Stevens' "power law." He discussed cognitive influences on visual perception and called for the application of frame-of-reference psychophysics to map design in order to develop a "new cartography" which is more responsive to map users both in the classroom and in the environment.

In his paper, "In Pursuit of the Map User," GEORGE MC CLEARY of the University of Kansas and chairman of this second session stated that while many maps are created each year, there has been too little evaluation of their use and effectiveness. Many maps seem to have been developed without real understanding of their use and effectiveness and without real understanding or concern for the map user. He suggested several areas of research which might help the cartographer understand the map user better. Cartographers need to know what and how well map users read; then they will be able to produce, and educate, accordingly.

CENSUS STATISTICAL MAPPING AND THE USERS

Robert C. Klove
U.S. Bureau of the Census

INTRODUCTION

Cartography at the Census Bureau is concerned with three types of map work, mapping for enumeration, the preparation of statistical area identification maps, and what is generally known as statistical mapping. It is with the third type of mapping that this paper deals and the focus is on our experience in planning and designing census statistical maps rather than on methods and techniques of production. These planning and design problems are closely related to the map reading and perception problems of the users.

My presentation is organized under three general headings: (1) Statistical mapping by the Census Bureau, (2) Who are the users and what kind of maps do they need? and (3) Statistical map design problems and the users, or do the maps tell the story they should?

STATISTICAL MAPPING BY THE CENSUS BUREAU

Census statistical cartography goes back over one hundred years to the first Statistical Atlas produced by Francis Walker after the 1870 census. It reached a peak in 1890 under Henry Gannett and then gradually declined to a low level in the twenties and thirties. It began to recover in the forties and fifties, burst into color again in the sixties, and in the seventies is becoming computer generated and user oriented. This capsule history of statistical mapping at the Census Bureau is covered in more detail in an earlier paper by the author.*

The revival of statistical mapping at the Census Bureau was probably due to many factors. One of these undoubtedly was an increasing awareness of user needs. Another was the strengthening of the professional staff and particularly the geographic staff. This was accompanied by a revival of interest in area measurement and resulted in the publication of a large two-sheet color map showing population density by minor civil divisions in the United States after the 1940 census. With the 1945

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*R.C. Klove, "Statistical Cartography at the Bureau of the Census", International Yearbook of Cartography, VII, 1967, pp. 191-199 (Gutersloh, C. Bertelsmann Verlag).

Census of Agriculture, the Census Bureau assumed responsibility for preparing and publishing agricultural statistical maps for census reports, a task earlier undertaken by the Department of Agriculture. For the 1950 Census of Population a number of black and white statistical maps were prepared for the summary volume and a large single-sheet population distribution map of the United States in color was published. Some statistical maps were introduced into the reports of the economic censuses in the fifties, particularly the 1958 Census of Manufactures. With 1960, statistical maps in color were introduced in the summary volume of the Census of Population. Then in 1963 came the initiation of the large separate United States maps in color, familiarly known as the GE-50 series. These maps were developed to illustrate some of the more important statistical distributions found in each of the various censuses, both demographic and economic. We, who originated this map series, felt that there was a public need for maps of this type, and we sought to make them as useful and attractive as possible. Much of the remainder of this paper is concerned with our experiences in developing this particular set of maps while I was associated with the Geography Division.

WHO ARE THE USERS?

We know something about our statistical map users, but we need to know a great deal more. Some we have talked with; others have written to us. Most of the separate maps as well as those in publications have been sold by the Government Printing Office. We do know that in the early years of issuance of the GE-50 map series several thousand copies of most of the maps were sold. Many have also been distributed to depository libraries.

The users are distributed in about five groups: (1) the academic world, including teachers and students, (2) Federal, State, and local governments (3) economic activities, especially marketing but also production, (4) nonprofit institutions for research, and (5) others. We also know that the maps are used for at least three purposes: (1) as a reference, or to understand quickly the geographic distribution of the statistics, (2) for research, or to relate other distributions to the one in hand, and (3) as a tool in teaching.

During the last decade a concerted and greatly increased effort has been made by the Bureau of the Census to find out more about the users of census statistics and their data needs. Since the mid-sixties the Bureau has had a Data User Services Division which acts to assist users and to determine their needs. This division has publicized the maps and exhibited them but has not been in a position to determine how statistical maps are used and how they could be improved. The Geography Division has provided and manned exhibits of its maps at annual meetings of academic associations with increasing frequency in recent years. Through such activities only small segments of the users and potential users are reached. It is frequently discovered that there are conflicting uses and that it is difficult to determine how statistical mapping can be improved to satisfy most users.

The Geography Division conducted a small survey in 1973 primarily to find out how users of the GE-50 United States map series might react to a reduction in the scale of these maps from 1:5,000,000 to 1:7,500,000 with comparable reduction in sheet size. Printed samples of maps at both scales were submitted and the letter indicated that the Geography Division preferred the smaller size. Letters were sent to 53 persons. Included were editors of publications which have given publicity to these maps in the past, selected Federal government officials, and officials of other organizations with map interests, but the major group consisted of university professors of geography with a known interest in cartography. Of the 31 who replied, 18 were for reduction, 11 favored the present scale, and 2 gave no preference. Those for reduction noted that the smaller scale still provided the same information and that the smaller sheet sizes were easier to examine and work with and also easier to file. Several mentioned as an advantage that they were the same scale as the National Atlas maps of the U. S. Geological Survey. Those favoring holding the present scale of 1:5,000,000 generally expressed themselves in a strong manner, perhaps to make their views clear in opposition to the preference expressed for the reduction by the Geography Division letter. Their argument was clear and unanimous that the larger map was needed for classroom instruction. There was indication that some would prefer even larger scale maps comparable in size with the average wall maps. There was also criticism of the 1:7,500,000 scale map - doubt that it could ever show all county names legibly and also, that without county names it would be better for most purposes at page size.

A further mini-survey was made at the annual meeting of the National Council for Geographic Education in Washington, D.C. in 1974. Visitors to the Census Bureau exhibit were asked to register their opinions concerning the two differently scaled maps exhibited. Of 66 polled, 56 were for the 1:5,000,000 scale, 6 for the 1:7,500,000 scale, and 4 for both scales. Many of these had used the maps in teaching geography at the elementary, junior high, and senior high school levels.

As yet, the Geography Division has made no change in the publication scale of this map series. The samples were very small and certainly not unbiased, but more important, the two results were contradictory. In that case it is usually better to stay with what you have until more definite information is available. There could be another solution, as some have suggested, and that is publication of the maps also in 2 x 2 inch color slides, but that has not been investigated.

Size of map sheet and map scale for a particular map series are only two characteristics out of countless numbers that could be investigated in order to learn more about the effectiveness of these statistical maps. I believe the Bureau of the Census should develop controlled surveys of map users to gain information for statistical map improvement, although I know this approach will be difficult.

The Bureau of the Census has a great interest in getting more people to use its statistics and to use them in the most intelligent way. If good statistical maps and also graphs help people to understand statistics better, and, therefore, a greater demand for them is developed, more will be produced.

STATISTICAL MAP DESIGN PROBLEMS AND THE USERS

Better solutions to many design problems in statistical mapping could be achieved if we, the cartographers, knew more about how the users draw information from the maps. Research cartographers have made progress in recent years in learning some of the answers, but the results are still fragmentary and the production cartographers have to rely on their best empirical judgment for a great many decisions made in preparing statistical maps. Therefore, I thought it would be useful to present some of the experience gained in four of the more critical planning and design phases of statistical mapping at the Census Bureau.

SUBJECT MATTER SELECTION

In selecting subjects for statistical mapping for a census one must examine the statistics that were collected to determine what data are suitable for mapping. Absolute figures should only be presented in distribution maps using dots or graduated circles, or the like. For choropleth maps we need density figures, averages, percentages, or ratios of one statistic to another. In both cases we need a geographic breakdown by States, counties, SMSA's, cities, or smaller areas. For most censuses we know the conventional subjects that have been mapped in the past and the more important of these distributions bear repeating with every new census, but trying to improve the format. We must seek out types of data which have never been mapped and also the data elements which are being collected for the first time. This is the kind of cartographic planning that should be done for each census. Usually it has been done at the Census Bureau by Geography Division.

Far more data could be presented in statistical map form than are. Some of these maps would be useful, but others would present patterns very similar to related subjects already mapped. For example, we could make dot and circle maps of male and female population separately, but their patterns probably could not be distinguished from each other and would be very similar to total population. On the other hand, a sex ratio map could be useful.

Some census subjects lend themselves to statistical mapping much better than others. Agriculture is one. It has many subjects such as different crops, livestock, equipment, and practices, and these are spread widely as every region has some form of agriculture. Population is also widely spread, but its depiction on small-scale statistical maps is hampered because so much of the population is urban and concentrated on a very small proportion of the land (1.5 percent in the United States in 1970). Economic activities also are concentrated in small areas, but the uses of their statistics are subject to a further difficulty, that of disclosure of confidential information. The census laws prevent release of information which might reveal the magnitude of activity of individual establishments or companies. The same law applies to population and agricultural data, but because the numbers in these fields are greater, the effect is minimal.

TYPES OF STATISTICAL MAPS

Users have their preferences and prejudices about statistical maps. Some express a dislike for maps with graduated circles, because they say it is difficult to measure the value of any given circle. While there is some truth to this, it misses the purpose of a statistical distribution map which, in my mind, is to give an overall correct view of distribution in terms of geographic concentrations and patterns. If you want precise figures, you go to the statistical table, but a table won't tell you much about the distribution of small areas even though you know the areas and try to form a mental map of them. Normally, reading of the map gives the answer quickly, but in general rather than precise terms, because the data are expressed in number of points (dots) or in interval shadings (choropleths or isopleths). Statistical maps do not replace statistical tables. They are complimentary rather than competitive. Also, the comparison of statistical maps of the same subject made for different years enables one to understand where changes in distribution have occurred over time.

The selection of the type of statistical map to use for a particular distribution is not too difficult, because there are basically only four types of statistical maps: (1) maps with point symbols (usually dots and graduated circles) to show the distribution of absolute numbers; (2) choropleth maps (with data areas shaded) to show densities, averages, and rations; (3) isopleth maps (with contour lines) also to show densities, averages, and ratios; and (4) flow maps (with proportioned lines and arrows) to show movements from one area to another. Of course, there are countless variations in these maps and many combinations and these are the ways in which cartographic ingenuity can contribute much to making more informative maps. The Census Bureau's statistical mapping programs have used all of these types except the isopleth map. It would seem that the isopleth map has been neglected for at least four reasons: (1) its use for economic and social statistics is less familiar to the public; (2) its use would make the value identification of individual geographic areas such as States or counties, more difficult to obtain from the map; (3) its construction has been somewhat more difficult; and (4) in the mapping of census data the interest is not so much in the slope of the statistical surface which isopleth maps show so well, but rather in how the statistical areas are grouped in regions and their relative values.

Before leaving the subject of types of statistical maps let me illustrate what happens when the choropleth type of map is selected to show absolute numbers. On Map No. 47, "Number of Negro Persons: 1970" (Figure 9, p. 260) a large county like Los Angeles is much more prominent than the five counties of New York or Chicago area which are relatively small in area but have much larger Black population. Also, compare Map No. 49, (Figure 10, p. 261) "American Indians: 1970," with Map No. 14, "American Indians: 1960," (Figure 11, p. 262) which used graduated circles and see how the latter gives a more accurate picture not emphasizing some large counties with low densities of population as in Nevada and Oregon.

CLASS INTERVALS

A statistical map uses symbolization to show data distribution, because ordinarily it is impossible to provide details for each statistical area. Accordingly, the data must be generalized into classes. It is important that these classes or class intervals be well selected so as to reveal an accurate picture of the statistical surface of the map.

In developing class intervals for choropleth maps at the Census Bureau we have found that five classes are about ideal and rarely ever have used more than eight.

Five shades in black and white or color are easily distinguished, but there is increasing difficulty with more shades.

Different kinds of class intervals may be developed for different sets of data. The sizes of the intervals may be equal, or vary in some regular or irregular manner. The purpose is to divide the areas into only five or six classes, which will show the regional variations accurately. While recognizing that there are various ways to select intervals, our usual method involved developing a frequency distribution of the data or of a random sample of the data if we were dealing for instance, with over 3,000 counties. Then, we determined the mean average or the median, the highest and lowest values, and where there were breaks in the distribution with few areas or none. Within this range and with this information we set up tentative class intervals. We also considered it desirable for general public use and easier understanding that the interval breaks come at whole numbers or preferably numbers ending in 0 or 5. The mean and medians ordinarily should be in one of the middle classes and each class should have enough representatives so that it would show up clearly on the final map. If the distribution were skewed or otherwise abnormal, the class intervals reflected this. Also, if a map was repeated from one census to another, we considered it desirable for comparative purposes to maintain the same class intervals.

USE OF COLOR

We have had two problems with color on statistical maps. One is selecting the right colors to make the maps most effective for the users and that usually is the Geography Division's responsibility. The other is getting the printers always to use the colors as instructed, and sometimes this has been difficult for the separate U.S. map series (GE-50) where each printing order is separately contracted out by the Government Printing Office. Almost every order has been done by a different printing plant and they have been scattered across the United States. It is a tribute to the quality of the American color printing industry that specifications are followed as well as they are. Nevertheless, once in awhile, the work is not as good as one would like to see it.

What I have to say about the selection of color for statistical maps concerns our experience with the United States maps, GE-50 series, during the time that I was directing their development and ends not long before map numbers 40 though 45 were printed. I feel that I can freely criticize these maps and tell you what I like and don't like about them and what I believe we learned from making them.

Cartographers as well as others recognize that color and its use are a subjective matter and that people see colors differently. When we started to use color, we had no definite color plan. We knew we had to distinguish high values from low values and that the intervals next to each other on the graded scale should be enough different to be distinguished easily. We experimented and while we certainly never achieved the perfect color scheme, I believe we learned by trial and error some rules or principles which may be worthwhile to pass on for the considerations of others who face similar problems with color on choropleth maps. Some if not all of these conclusions have been reached by others, I will concede.

COLOR GRADATION RULES

1. Reject a full color spectrum or even a modified full spectrum, because the spectrum colors (red-orange-yellow-green-blue-violet) range in value from dark to light and back to dark and therefore are misleading for showing statistical value gradients from high to low.

With the first two choropleth maps in the GE-50 series we experimented with a color gradation that might be called a modified full spectrum. Map No. 6, "Families with Income Under $3,000 in 1959," has six percentage classes from high to low with the colors of red-brown-orange-yellow-green-blue. The color values go from dark to light to dark. The reader has to go to the legend to learn that red is high and blue is low and he might be bothered by the considerable jump in color value between yellow and green. Map No. 7, "Older Americans: 1960," with only five classes drops the red and brown and substitutes a pink that is rather weak for the highest value. After these two maps we gave up on using the full spectrum.

2. Ordinarily reject a single primary color in different values from dark to light, because it fails to show sufficient differentation between classes if there are five or more.

We found it works well with three or four, but five is doubtful. Map No. 39, "Percent of Population Urban: 1970," uses five shades of violet or purple, but it also has some pink. I think it is fairly effective but some people don't like purple.

3. Favor a shortened modified spectrum with two basic schemes ranging from dark to light values:

a. From violet through blue and green to yellow

b. From red through orange to yellow

These may be modified in countless ways by various mixing of adjacent colors and by varying the amounts of gray or white. They should always have value shadings from dark to light. See Map No. 8, "Per Capita Money Income for 1959," and Nos. 9 and 10 on education. Each has seven class intervals from purple through blue, green, and yellow to a cream. On Map Nos. 12 and 13 on employment, purple was dropped and a lighter color added in the green-yellow level. Map No. 16, "Negro Population as Percent of Total Population," uses seven color values from dark brown through yellow to cream. On Map Nos. 29, 31, and 33 on agriculture, color values from dark green through yellow to cream were used. Green and yellow are appropriate for suggesting the subject of agriculture.

4. For percent change maps which show gains and losses we have favored blue values for increases and red values for decreases.

We selected this scheme for use in 1960 for maps in the summary volume of the Census of Population. There was precedent for this in part. Red was being used for decrease dots on increase-decrease dot maps for showing crop and livestock changes for the censuses of agriculture. We were only allowed two colors other than black on the population maps so we chose blue as the other color. Once in Amsterdam when I was showing these maps, someone asked why we didn't use red for gain and blue for loss. They were probably thinking red is the dominant color and is used for high mountains and blue for the seas. We could have made that selection, but I suspect that whoever first used red for loss on maps was thinking of being in debt or losing or "in the red" as the American expression goes. In any event, this practice has become a convention on census maps and to change it now could introduce confusion. See Map No. 42, "Population Trends" which illustrates this color scheme rather well. Nevertheless, we did depart from this rigid convention for three agriculture maps of percent change where we used shades of green and yellow for increases and a light brown for all decreases. See Map Nos. 30, 32, and 34.

Selecting colors for choropleth maps is difficult and takes a great deal of time and patience. Also, what looks good in small patches looks quite different sometimes when spread all over the map. Someone has also asked why we haven't taken one color scheme and stayed with it. My answer to that is that I don't believe we have found a perfect color gradation scheme and I have some doubts that we ever will, because I believe people see the same colors differently. Also, I believe varied color schemes heighten people's interest in such maps as these. However, some of the recent maps in this series have failed to follow closely the rules of color gradation design which we used earlier, but I shall leave their effectiveness to your judgement. Note particularly some of the ethnic and income maps.

Before ending this discussion I wish to make two comments about possible improvements in color on dot and graduated circle maps as used in this same series of maps. The first is to suggest the use of even brighter colors of high intensity or chroma for dots and circles, because they occupy relatively little space on the maps and need to be emphasized. The second comment concerns the development of some means of making the land area with the dot and circle symbols stand out, perhaps by a contrasting tint on the land area or a stronger blue on the oceans. I make these comments because in studying the maps and particularly the slides while preparing this paper, I found that choropleth maps with greater expanses of color catch one's attention much better than some of the dot and circle maps.

COGNITION IN CARTOGRAPHY

Barbara Petchenik
Newberry Library

The essence of what I have to say today is well summed up in these words from Rudolf Arnheim's book, <u>Art and Visual Perception</u>:

> All perceiving is also thinking,
> all reasoning is also intuition,
> all observation is also invention.

These ideas are related to certain fundamental issues in map reading and map perception that I should like to consider under the broad title, Cognition in Cartography.

A considerable amount of perceptual research within the general framework of behavioral psychology has been conducted by cartographers during the last ten or fifteen years. However, as one reviews the findings of this research in connection with problems encountered during the normal process of making maps, it doesn't seem to add up to much. No whole theory or set of principles, greater than the sum of the small component parts, has emerged. Similarly, analytical attempts to deal with the notion of map reading have not led to any theoretical structures from which principles that would assist in the details of map design can be deduced. Clearly, map reading is more than just the cumulation of a number of simple perceptual comparisons of symbol size or value. Perhaps it is time, in recognition of this fact, to shift our thinking from the details of empirical research, from psychophysical studies, etc., to a concern with the broader assumptions that underlie the conduct of such research, and to the possibility that certain shifts in those basic assumptions might be of some value to cartography. Whitehead has characterized science as, "the union of passionate interest in the detailed facts with equal devotion to abstract generalization." We need to be concerned always with both levels of research activity.

During the last few years, a number of significant theoretical shifts have occurred in disciplines influencing cartography, especially in the field of psychology. As I see it, these shifts bear on cartographic research in a number of important ways. The assumptions underlying the work of experimental psychologists for the past 40 years or so have been essentially reductionistic rather than wholeistic, and behavioral rather than dealing with mental processes. In reductionistic-behavioral research the only legitimate means for developing theory is by using inductive techniques. But in psychology, as in cartography, the experiments accumulated and the specific details proliferated, while no coherent and comprehensive whole theories emerged. In addition, some researchers were personally uncomfortable about the explicit omission of any reference to the internal thought processes that form such an important part of any individual's experienced reality.

The important shift that has occurred in psychology is away from an emphasis on strict behaviorism, and toward an emphasis on thought processes, toward what has come to be called cognitive psychology. Intellectual processes are now a legitimate topic of concern and are receiving considerable attention from both theoretical and empirical points of view. Evidence for this shift is contained in books such as that edited by William Chase, Visual Information Processing, where he says in the introduction: "If there is a single organizing theme in this book, it is the mind's eye, or the contents of the mind's eye -- images." The terminology employed attracts the cartographer's attention, for the notion of "cognitive mapping" appears frequently in the psychological literature. The term suggests that there might be something in it for us, and indeed, I believe there is.

While cartographic researchers have concentrated on the perception of individual map symbols or on limited comparisons among symbols, the problem of map reading extends far beyond such concerns. But the notion of map reading itself has not yet received as much attention as it should have. The real problem is this: How does a map user develop internal, personal knowledge of relations among things in space on the basis of viewing a sheet of paper covered with ink marks? How, in common language, does one read a map?

This question takes us far beyond the simple symbol size comparisons that were appropriate at an earlier, more limited level. It is a question that in a broader sense is of interest to many other disciplines -- to the communication theorist, the perceptual psychologist, the reading specialist, the anthropologist, and the artist. Ultimately, it is the problem of the epistemologist, interested in the nature of all knowledge and in the knower.

Cartographers have often analyzed the map reading process with concepts and terminology developed originally for other purposes. We are all familiar, for example, with the information theory metaphor and its vocabulary of "channels" and "redundancy" and "noise." Such concepts were developed by electrical engineers concerned with the transmission of electrical impulses along wires. From it the conception of knowledge being transmitted as some sort of sealed packet, carried unaltered from transmitter to receiver, emerged. Fortunately, this concept is being discarded in favor of another, quite different conception.

This new approach conceives of communication as the process wherein thought originating in one human mind is converted by that mind into physical forms according to rules developed by the culture in which he lives. These symbols are then apprehended through eye or ear by the person for whom the message was intended, and from them he constructs in his own mind the meaning originally formulated in the message sender's mind. In this view, the physical means of communication such as language and maps, do not carry meaning, but rather, they trigger or release it. The psychologist Weimer puts it this way:

> The strong claim of the constructive cognitive theorists ... is that there is no meaning or knowledge in language per se. Stated another way, the claim is that language does not carry meaning in sentences, but rather triggers or releases meaning (i.e., occasions understanding)

> that is already in the head. Unless a hearer can generate a context which renders a sentence interpretable, the sentence has no meaning at all.

In other words, for there to be successful communication the receiver of a message must be able to construct meaning from the physical stimulus in essentially the same way that the originator of the meaning constructed it. It is unlikely that the thoughts in the two minds will be exactly the same in form, although both are necessarily related to the physical form of the message.

It is useful to view this interactive process with terms developed by Piaget to characterize all organism-environment transactions, that is, the words "assimilation" and "accommodation." Piaget likens the process of acquiring knowledge from the environment to that of the ingestion of food by the organism, where there is a transformation from something external to something which becomes an intrinsic part of the organism. The food which the organism ingests must be assimilated to the nature of the organism -- it must be made smaller by mechanical means, it must then be acted upon by digestive chemicals, etc. The action which takes place on the object is called assimilation, and in the process of interaction the object itself is changed. On the other hand, certain changes must also take place in the organism, for not only does he change the assimilated object, but the object changes him as well. He may have to open his mouth wider to ingest, his stomach must expand to take in new food, he must produce digestive juices, etc. This process whereby the organism changes as a result of the transaction is called accommodation. The metaphor is a convenient one for analyzing the interaction between knowledge and the knower. It makes rather obvious the over-simplification inherent in the concept of communication as the transmission of information along a one-directional linear path.

As a result of these new assumptions about the active and interactive nature of communication, we can conclude several things. We must be concerned with meaning in cartography to an extent far greater than that to which we have been in the past. If the function of a map is to trigger meaning, then meaning becomes all-important. We must determine what the meaning of a map is, and how research could take account of such meaning.

These are difficult questions, with which other disciplines are also concerned. Quoting the psychologist Weimer again, he says:

> No matter where one goes in psychology there comes a point at which one runs straight into an insurmountable wall that is, conceptually speaking, infinitely high and wide. All we can do is look up and see that written on the wall are all the problems of the manifestations of meaning.

It is useful to compare the problems associated with map meaning to the problems involved in spoken and written language. Considerably more has been written about the latter topics, and there would seem to be some application of this material to maps.

For a good many years, researchers in the field of reading and linguistics approached the problem of the acquisition of knowledge from printed symbols with the idea that meaning was assembled on a unit-by-unit basis in linear sequence. One began with small units, such as letters and words, and then built up to the larger units of sentences and paragraphs. But while this view has been essentially discarded, a replacement has not yet been completely worked out. A new view does see the eye-brain interaction as not necessarily linear, but rather complex, and utilizing processes that allow the apprehension of the visual stimuli of printed text at several levels simultaneously. Meaning seems to come from an all-at-once grasp of the relation of the stimulus to the reader's previous knowledge structures, rather than from a bit-by-bit build up. We have all had the experience of glancing at a paragraph or page in order to quickly derive meaning, with no recollection whatever of individual letters, words, or sentences. Meaning goes beyond particular forms.

Yet there is an interesting and important contrast of text with maps in this regard. While the sounds and images of normal language are of no consequence in themselves and do not usually affect the meaning, this is not the case in mapping. The marks that make up the map have character and implicit meaning of their own, quite apart from their earth-surface referents. This character-of-their-own is what has received the most attention in cartographic research dealing with map perception and reading. In the terminology of some current cognitive research, there has been a concern with the characteristics of map marks or symbols as "brute things." This is defined by Bransford and McCarrell in the book, Cognition and the Symbolic Processes, thusly:

> ... knowledge of entities arises from information about their relations to other knowledge, and that knowledge of relations distinguishes a meaningful object from a 'brute thing.'

This "other knowledge" must, of course, be brought to the map by the map reader in order that the spatial symbols he sees take on spatial meaning. There is little the cartographer can do to control this, but there are things he can do to facilitate the development of such relations, if we think about the matter at all. For example, we all know how much easier it is to tell "where something is" on a map if we can see shapes that we recognize -- and we also know how quickly such familiar shapes can be lost with larger and larger scales, or with tighter and tighter cropping of the map area. Perhaps it would be well for us to have some idea of "most recognized shapes" at particular scales. Or perhaps there are ways in which map information can be given more meaning through linkage with verbal language -- through titles, legends and captions that relate what is seen to other things already known. These are just some of the ways I can think of to help the map reader move from the level of sensing brute objects to that of spatially meaningful symbols.

The meaning of maps is consequential spatial arrangement; it is the fact that objects isolated in real perceptual experience are put into relation with one another on the surface of the map. Cartographers are not concerned fundamentally with the nature of objects per se, but rather with a particular set of relations among those objects. The reader must reconstruct these relations in his mind for the map to have meaning.

Piaget has shown quite clearly that the knowledge of relations in space is not a given, but is rather constructed gradually with experience over a long period of time. He is not the only one with this point of view, of course. Bertrand Russell has written:

> People who never read any psychology seldom realize how much mental labour has gone into the construction of the one all-embracing space into which all sensible objects are supposed to fit. Kant, who was unusually ignorant of psychology, described space as "an infinite given whole," whereas a moment's psychological reflection shows that a space which is infinite is not given, while a space which can be called given is not infinite.

This seems an appropriate point to stress a major emphasis of this presentation: cartographers interested in fundamental research, the outcomes of which are intended to increase map utility, cannot feel that they are sufficiently well grounded to conduct such research unless they are familiar with the more basic cognitive research now being conducted by psychologists. Cartographic research should be more than superficial manipulation of questionnaires and correlation coefficients; those cartographers pursuing it must clarify certain basic issues having to do with the very nature of knowledge itself. In this view epistemological cartography is not a peripheral concern -- it is the heart of the matter.

One interesting point has been made recently in cognitive psychology, having to do with the question of the form in which knowledge exists in the mind. In the past, some have argued for verbal encoding, others for imagery, still others for a combination of the two. It is now being proposed that ultimate knowledge, Michael Polanyi's concept of "tacit knowledge," has neither form, and in fact, may have no form at all. Knowledge appears to be pure structure, pure relation, and at the most basic level we all know a great deal more than we can tell, that is, than we are able to convert from tacit to explicit form. It seems that we can convert portions of our vast stores of tacit knowledge to various explicit forms, upon demand. Sometimes there is a preference for imagery, at other times a need to express our thoughts in words. Knowledge seems to take on form for the purposes of communication, rather than for internal thought processes.

It is difficult to "picture" knowledge if it indeed lacks form as this conception suggests. Yet a simple cartographic illustration of how knowledge exists without specific form should clarify the situation. We may know where certain places are, or how certain areas are arranged, even though we have not actually seen them and have only derived such knowledge from maps. Yet if we were asked to describe the graphic characteristics of the maps from which we derived the knowledge, it is unlikely that we would be able to recall line weights, type styles, or colors. Yet we know the relations that were depicted, regardless of the form of the original marks. Once we assimilated those marks and converted them into tacit knowledge, they lost their form. However, we can retain the relations of interest to us, that is, the structures of the maps from which they were obtained.

So far cartographic research in map reading has not penetrated at all deeply into matters of this sort. In fact, comparing what has been done in map reading with what has been done in text reading, it seems fair to say that what has been done with maps in the way of symbol perception, is to total map reading, as typeface perceptibility studies are to reading comprehension research. We really lack a word that describes the apprehension of spatial knowledge from maps, a word that would compare to "comprehension" for text.

It is scarcely encouraging to find, however, that in the matter of textual comprehension reading experts are far from agreeing about the ways in which comprehension can be defined or measured in empirical terms, or even exactly what the nature of comprehension is. It may be that with increased emphasis on meaning, we are moving toward a realm where not everything can be defined and observed and measured in completely objective fashion. But it would surely profit us to know something of the nature of such limitations, and assuredly, this is something we do not yet know enough about.

It might be well to consider another basic matter at this point, and that is, the definition of the word "perception." It may be that for this new view of communication the word "perception" needs to be newly defined, or perhaps even eliminated. Part of the problem in using the word at all is that in the past it has been used without adequate definition or constraint. David Stea writes:

> Unfortunately, perception and cognition have been employed in a confusing variety of contexts by psychologists and other social scientists ... To many geographers, perception is an all-encompassing term for the sum total of perceptions, memories, attitudes, preferences, and other psychological factors which contribute to the formation of what might better be called environmental *cognition*.

He continues:

> Thus, we reserve the term *perception* for the process that occurs because of the presence of an object, and that results in the immediate apprehension of that object by one or more of the senses ... Cognition need not be linked with immediate behavior and, therefore, need not be directly related to anything occurring in the proximate environment.

Yi-Fu Tuan says something similar and makes an important point:

> A percept is sustained by the information in the environment; we see what is before us. An image, on the other hand, is something we see when the environmental stimuli do not appear to justify it ... When percept and image are examined closely, however, they can be shown to differ in degree rather than in kind.

In these two views, which are consistent and complementary, perception no longer forms a separate class of human activity, isolated from thinking or feeling or judgment. Rather, it is a portion of a continuum along which human responses to stimulation can be ranged, from the simplest apprehension of raw sensation to the intermediate level of perceptual processing to the most complex of the higher cognitive operations. Percepts differ from thought and ultimate meaning only in the level of complexity of cognitive processing that is taking place.

Although the fact is largely ignored in cartographic research, the spatial knowledge that is acquired in the course of ordinary life is multi-sensory in nature. The map, of course, is one part of the input that is visual, so if a map user is to relate knowledge encoded in his total store with that acquired from the map, he may be relating two quite different things. Kinesthetic sensation, for example, must be equated with visual sensation aroused by the map. As Stea says:

> A cognitive spatial representation (or image) depends upon more than visual input -- it is an integrated, multimodal representation.

Or Bertrand Russell puts it this way:

> The first thing to notice is that different senses have different spaces. The space of sight is quite different from the space of touch; it is only by experience in infancy that we learn to correlate them ... The one space into which both kinds of sensations fit is an intellectual construction, not a datum.

In short, the map produces visual sensations that must interact with previously stored knowledge that resulted from multi-sensory cognition, which may not be stored in either spoken or imaged form.

If the cartographer hearing this review of recent approaches to cognitive processes as they relate to map use feels that there may be some truth or utility in them, he might consider what they mean in two ways: one, as they affect the ways he makes and improves maps, and two, as he devises research to provide information to be used in making and improving maps. Several directions are implied in these concepts.

First, if we assume that a map is not lifted intact from the paper by the eye and carried unchanged into the brain, and if the map becomes meaningful only in relation to previous knowledge of the user, then we should probably know something about that knowledge which is brought to bear on the map. Certainly when we communicate with words we have a preconception of what our hearer knows and how that knowledge will interact with and make meaningful what we are saying. We are betting that the words we speak will trigger a shared meaning in our listener's mind. Similarly with maps; we must interest ourselves not only in clarifying the spatial message we intend to convey with a map, but also in assessing the cognitive resources the map user brings to bear on the problem of reconstructing space from this image.

This will be a difficult order, even though some research has been conducted in recent years that might seem to bear on this situation. The words "mapping" and "map" appear in both the psychological and geographic literature, with the usual prefixes being "cognitive" with mapping and "mental" with map. When examined carefully, however, these concepts are disappointing in the cartographic sense. "Cognitive mapping" is a metaphor that refers to the mental process whereby unorganized external stimuli are converted to organized knowledge structures, in a manner that resembles the way a cartographer selects, abstracts, and organizes information from a complex, unstructured milieu and arranges it in coherent fashion on the map surface. The use of this metaphor in psychology serves to point up the very basic nature of mapping -- so basic that it is convenient to use it as a metaphor for all knowing.

The term "mental maps" would seem to offer us much more -- it sounds as if it should refer to the sum total of all spatial knowledge that any individual carries about with him in the form of tacit knowledge and potential spatial images. Unfortunately, this is not at all what the term has come to mean in geographic literature, though few besides the perceptive Yi-Fu Tuan have bothered to make the careful distinction he does in this quote:

> Under the influence of Peter Gould and Thomas Saarinen, among others, geographers tend to see mental maps primarily as 1) cartographic representations of how people differ in their evaluation of places, and 2) freehand maps that people can draw -- outlines of city streets and continents.

In an article in which he reviews the Gould and White book, Mental Maps, Tuan also says:

> So far as I can tell, the mental maps of this book are opinion and information surveys represented in cartographic form.

He adds, in telling fashion,

> I don't think enviro-preferential maps throw much light on the psychology of perception and cognition ...

and I thoroughly agree with him.

Another person who has penetrated the superficiality of the way the term "mental map" is used in geography is Stea, and he writes in Image and Environment:

> Another area of research ... is that of environmental dispositions and preferences. Unfortunately, this latter area was entitled at one time 'mental maps' thus causing others to believe it a part of spatial cognition.

In this same book, Stea also clarifies the relationship between spatial knowledge and all other knowledge in this way:

> The structure underlying the spatial map of the world that people carry around in

> their heads is not different from the structure that underlies all cognitive processes ... In this framework a spatial cognitive map might be viewed as a special case of cognitive maps in general. It is more likely, however, that spatial maps are not neatly separated from other sorts of cognitive structures.

It would be a mistake to imagine that human spatial knowledge is carried around in the head in the form of a stack of map-like images, for, as stressed before, much of it is not even visual to begin with.

We find, then, that there is practically no research that is relevant to the question of the nature of the map user's personal spatial knowledge. Perhaps this is an impossible task. If it begins to appear likely that each person is unique in the mental baggage he brings to the task of map reading, what is the poor cartographer to do with a map that is to be circulated among thousands of viewers?

What he should probably do is forget for the moment the research that emphasizes idiosyncratic spatial knowledge and recall the fact that explicit knowledge comes in a variety of forms, and that some of these forms are arbitrary and prescribed for anyone who wishes to function successfully in the cultural forms of a particular society. When dealing with formal means for communication, such as words or maps or mathematical symbols, we assume that most viewers are familiar enough with them so as to constrain the meaning each one can have to a greater or lesser degree. Only in Alice in Wonderland can words mean whatever the speaker wants them to mean. If people know nothing at all of maps, the map maker no longer has any responsibility for the possible failure of any one map to communicate adequately. But even if this does free the cartographer from the impossible task of making self-explanatory symbol systems, there are many ways in which he can facilitate the transfer of information via the map. It is important to clarify, partly through intellectual analysis and partly through empirical research, which aspects of the map are part of a societal agreement or contract, and which are truly subject to the cartographer's control.

In the concern with testing individuals to determine what they see or think about particular map symbols, the fact that certain aspects of mapping are totally arbitrary has been too often ignored. If there is no reason at all to expect that some aspect of the map can be interpreted in any way other than by the rules of the mapping game, then there is no need to find out how various subjects think it should be interpreted. I recall, for example, some of the research that has been done in testing various color schemes that show elevation changes. The assumptions on which it was done were not logically clarified to the point where it should have become apparent that, for the most part, readers' responses to certain questions are of no consequence. It is analogous to conducting a survey to find out whether or not the letters C-A-T look like what they mean. It has simply been agreed that they will mean what they mean in our culture, and there's an end to it.

This is equally true of many aspects of mapping. A Canadian artist, Joe Bodolai, wrote perceptively in a special issue of artscanada that dealt with maps and mapping:

> A map can also be said to be somewhat like a contract in that it is a document of agreement about the nature and distribution of phenomena in space. Mapping is an effort not to eliminate point of view but to socialize it, even to conventionalize it ... When a map is used a reversal of the map-making process takes place. Reason informs perception and makes the field of vision meaningful.

In summary, we do need to know how map users see particular things and how the meaning assigned to these things varies among individuals. But it is important to distinguish between those aspects of research that are related to variations about which the cartographer has the potential for doing something, and those about which he can do nothing because they are pre-determined by the rules of the formalized communication system. Much of the research in the Stea and Downs book, Image and Environment, for example, is interesting as it shows how individuals vary in their conceptions of space. But there seems no way to make such information directly relevant to map making. Insofar as mapping is a scientific activity, a comment made by Bertrand Russell is relevant:

> Scientific knowledge aims at being wholly impersonal and tries to state what has been discovered by the collective intellect of mankind.

It is important for cartographers to understand this distinction between individual and collective intellect.

In concluding, I turn for the first time to the theme of this conference, that is, to the matter of computer-assisted cartography. How, you may be wondering, can this theoretical and wide-ranging exposition of recent trends in cognitive psychology have any relation to computers? In quite an obvious way, I think. When the computer is utilized in one way or another to produce a map, the human cartographer must tell it exactly what to do. Therefore, he must know exactly what *he* does to make a map, and then be able to code these procedures in explicit, step-wise forms for the obedient machine to replicate. The difficulty in this seemingly simple process is that much of what goes on in cartography is not explicitly understood, particularly at the level of the nature of the human knowledge transfer that is involved. The relation between computers and the topics I've discussed should thus be clear; if we are to instruct machines to do rapidly what we can only do slowly by other means, then we must have clear insights into the nature of the tasks we are undertaking and speeding up. These insights must be based on a knowledge of the perceptual-cognitive characteristics of the human being, and on a firm understanding of the meaning of maps. A human being can operate successfully himself, in the domain of mapping or elsewhere, on the basis of poorly understood tacit knowledge. But for the computer all tacit knowledge must be clothed in explicit forms. If, as mentioned earlier, we know a great deal more than we can tell, then there may be absolute limits on what we can know in a form that can be conveyed to the computer.

What the implications of this approach for specific research topics are, I don't yet know. I simply have this initial, mildly disturbing sensation that the notions introduced here _are_ important, and will become more so in the years ahead. In her novel _The Years_, Virginia Woolf wrote:

> The steps from brain to brain must be cut
> very shallow ... if thought is to mount
> them.

The structure of those steps, as they are used to communicate spatial information from one brain to another is important to us; for the sake of all of our map users, we'd like to know if we could make them shallower and easier to climb.

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AN ANALYSIS OF APPROACHES IN MAP DESIGN

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Although I missed the Monday afternoon session, due to my witnessing of a serious automobile accident near the Dulles Air Terminal, I was fortunate in being able to read George McCleary's comprehensive notes taken during that session. What I hope to discuss today is, first, the general area of the background and history of map and chart design investigations prior to the fifties and then, some few words on the relationship of the psychological approach to map design. Then I plan to follow with a discussion on the modern focus on information management systems which use map information. In addition, I prepared for the purposes of this meeting, some visual aids as a sort of "strawman" to explain what might be termed the psychological research and design problem in relation to subsystems which are parts of larger information management systems. I think that this ties in with things that Arthur Robinson said this morning and several speakers said yesterday.

I first encountered this whole realm back in the late forties and early fifties. After I finished my academic training, I immediately went to the Aeronautical Chart and Information Center in St. Louis, and pretty soon got involved in map and chart design. The first thing I tried was literature research and I looked around to see what kind of information there was in the cartographic literature to learn how to improve the design of maps and aeronautical charts. Ultimately, I got back to such noteworthy authors as Max Eckert, Karl Peucker, and others, much of which was in German and had not been translated into English, so that a bit of translating was necessary to find out what they were talking about. In the 1940-50 period, of course, was Arthur Robinson and his noteworthy Look of Maps, but unfortunately, it didn't deal directly with the design of aeronautical charts.

Additional research led quite readily to what was then called "human factors" and "human engineering" research, in which people were concerned with man-machine interaction, display problems and the design of displays for use by pilots, in the control of aircraft for orientation and navigation purposes. In this late forties and early fifties time period, you might remember that jet aircraft were coming into wide use and the speed and complexity of the aircraft was increasing. The human being's capabilities as part of this man-machine system were being overburdened by being forced to use displays and equipment that had been designed prior to World War II.

The literature available was generally related to display design through either a physics, physiological, or psychological approach. In almost all cases, I found that there was considerable misunderstanding by cartographers as to how laws of the physics of light applied to map design, especially if the human factors and human engineering concepts were followed. I believe that even today there is little evidence of a connection between the laws of physics and what people learn when they read a display. Obviously, they see color, but learning or making "course of action" decisions requires more than a response to specific wavelengths. For example, when going back to the work done in Germany and Switzerland and elsewhere, I found out that some of those noteworthy authors believed that short wavelengths were obviously useful in showing lower elevations because all human beings associate short wave lengths (blues and greens) with lower elevations, while higher elevations are associated with the longer wave lengths toward the red end of the visible spectrum.

In looking into the physiological and psychological research — there was a lot of it -- I found again that what was reputed to be psychological was somewhere on the borderline between what psychologists call psycho-physiological and psycho-physical -- I was not sure at the time of the difference. Such physiological factors as advancing and receding colors had been used by cartographers as map design parameters. It became obvious later, that although there is a physiological relationship of the eyes accommodating to warm and cool colors, in-so-far as advancing and receding space is concerned, once the colors become part of a display such as a map or instrument, the eye-brain combination no longer perceives a focal length difference.

Then, in the case of some of the so-called psychological parameters, there is such a thing in cartographic literature called atmospheric perspective, such as the haze when we look at some distant mountain. Whether or not there is a carry-over of clues for distance that the eye sees and a map design parameter is unproven. This, of course, is seen in the literature in relation to the use of greyish, hazy color for lower elevations (farther from the eyes of the map reader) and the bright, sunny colors to show higher elevations (closer to the eyes of map users). People also talked about a pleasing appearance as a necessity in map design -- somehow or another a pleasing appearance was supposed to imbue a user with some kind of confidence. It didn't take too long to find that some of this type research was inappropriate in terms of a human factors approach. Also, the work of John Sherman and Willis Heath and others in making maps for the blind indicated that if the logic that maps had to be pleasing in appearance for sighted individuals to gain confidence was valid, then obviously they should feel pleasant to the fingertips of blind individuals. That didn't exactly make sense. What John Sherman said this morning about most of the design and information systems parameters being directly applicable whether a person is sightless or sighted, I think makes a lot of sense. My research has indicated this also.

People such as James Gibson, George Hoover, Alphonse Chapanis and others were instrumental in a lot of the psychological research in the 1940-50 time period that dealt with products, devices, and graphic displays for use in specific use situations. It is necessary to emphasize the specific use situations, since that's where the user gets needed information from the map or graphic display. Gibson, in approaching what he called the psycholphysics of problems in visual perception, developed a case for something called the "visual world" and the "visual field." The visual world, as he defined it, is a stable world that we see when we move our head and move our eyes -- everything stays in place -- even if we stand on our head the world is still there and doesn't fall apart. This is what he called the world of everyday experience: the world we live in -- it has color, it has motion, it has all these things, but it remains stable and up-right.

Then there is something that he calls the visual field -- something that you see if you hold your head still and you introspect about what your eyes are seeing at any one moment of time. We all navigate the same in the visual world, since if there is a chair in our way when we walk across the room, we miss it because we are reacting to a perception of the visual world. We don't really introspect on the chair being there, in order to walk around the chair. However, Gibson points out that if you are going to design something, make something for someone to approximate the clues that you get in the visual world, you've got to understand the kind of clues that you would expect to see if you were in this boundless, stable visual world. In the visual world we know that railroad tracks do not come together, but if we paint a picture of railroad tracks, in the visual field they do come together. We know that one clue for distance in the visual field is that distant mountains appear hazy. If you paint a picture, you paint them to appear as they appear in the visual world. However, that same rule doesn't apply to the appearance of anything other than distant objects or mountains that you are trying to give someone a clue that they are a considerable distance from the viewer. There are many other clues in between the viewer and the mountains that also tell him the mountains are far away. Perspective itself, e.g., converging railroad tracks and size of objects tell him the mountains are far away. On the map, use of that same atmospheric perspective where there are no other clues for distance, does not provide the human in the visual world with information (or clues) that the lower elevations are further away from the eye than higher elevations. From Gibson's standpoint, that kind of design logic is very questionable.

Another interesting point in relation to daily functioning in the visual world and graphic design problems is that, unless a psychophysical approach to human factors analysis is followed, the designers (cartographers in this case) make their own approximations of logic. Or, as someone said this morning, they appear to use intuition if they have not been trained in a particular field such as psychology or graphic design. But, there is even a serious problem in knowing precisely what psychological concepts have been found valid in graphic design. Gibson attempted to develop a "Proposal for a Theory of Pictorial Perception," but his work never got beyond the proposal stage.

There is an excellent lesson which can be learned from the pre-World War II U. S. Army Air Corps' visual testing of depth perception by potential pilots being asked to line up two sticks, ten or twenty feet away. This was to test depth perception which was assumed to be a valuable clue for landing an airplane. During World War II, psychologists such as Gibson said that since depth perception is only one clue for distance, and it is only good in humans up to fifty or a hundred feet in front of the eyes, why use this test? He also pointed out that so many other clues are available, such as convergence, rate of speed objects move past, size of objects, etc., that one-eyed pilots experience little difficulty in landing an aircraft. There was what appeared to be a well-founded concept, which was proven unsound by "visual world" research. I believe many of our cartographic conventions would suffer the same fate, if examined with a similar approach. At this meeting there have been references to use of warm and cool colors for such things as maximum and minimum temperatures. These same individuals used warm colors for incidence of thunderstorms and hence, their logic escapes me.

During and after World War II there was much research into the design of cockpit instrument displays used for monitoring and guiding the functioning of aircraft systems. The cockpit design at the time people started to train on pre-World War II aircraft instruments followed little logic. Pilots were told they had to construct a picture of the airplane and its attitude by reading about thirty or forty different dials, and in their brain, concoct the present attitude of the aircraft (See Figure 1). Now it wasn't long after that the people got busy, i.e., the human factors people, and they said "look, that doesn't make sense." We're not unburdening the visual task of the pilot — we're making his job more difficult. So they fed this information into, what I call here, an integrator or a small computer system — and out of the computer system comes an integrated picture, if you will, of the present attitude of this aircraft in relation to the earth's surface. (See Figure 2). This little aircraft on this display was simply an intergration of what the instruments would have told the pilot and the pilot could

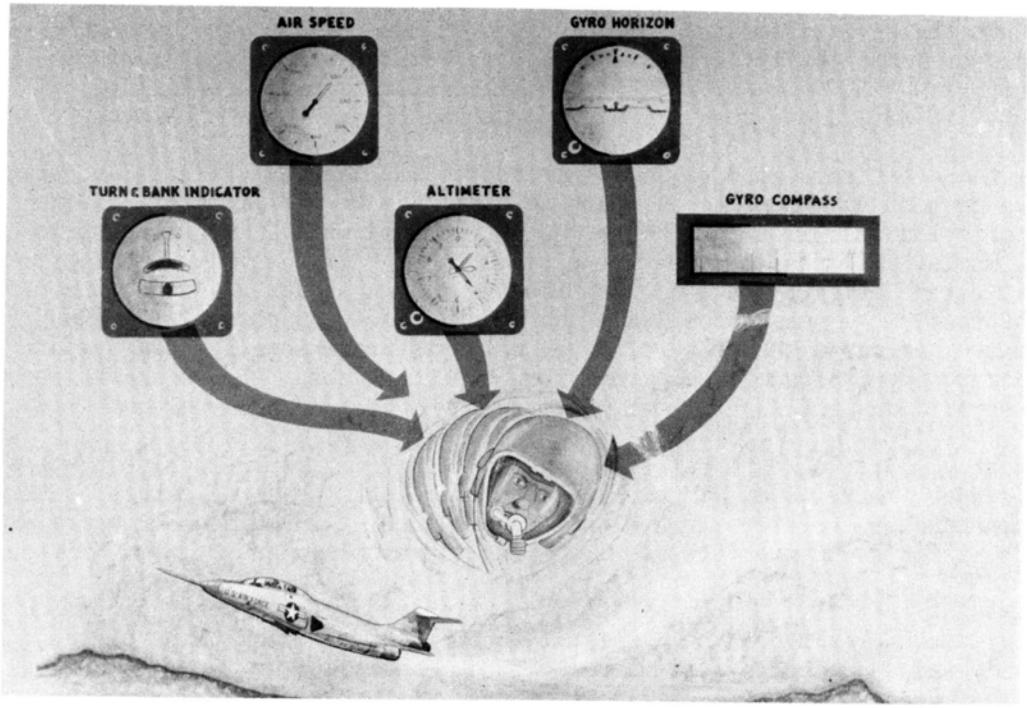

Figure 1

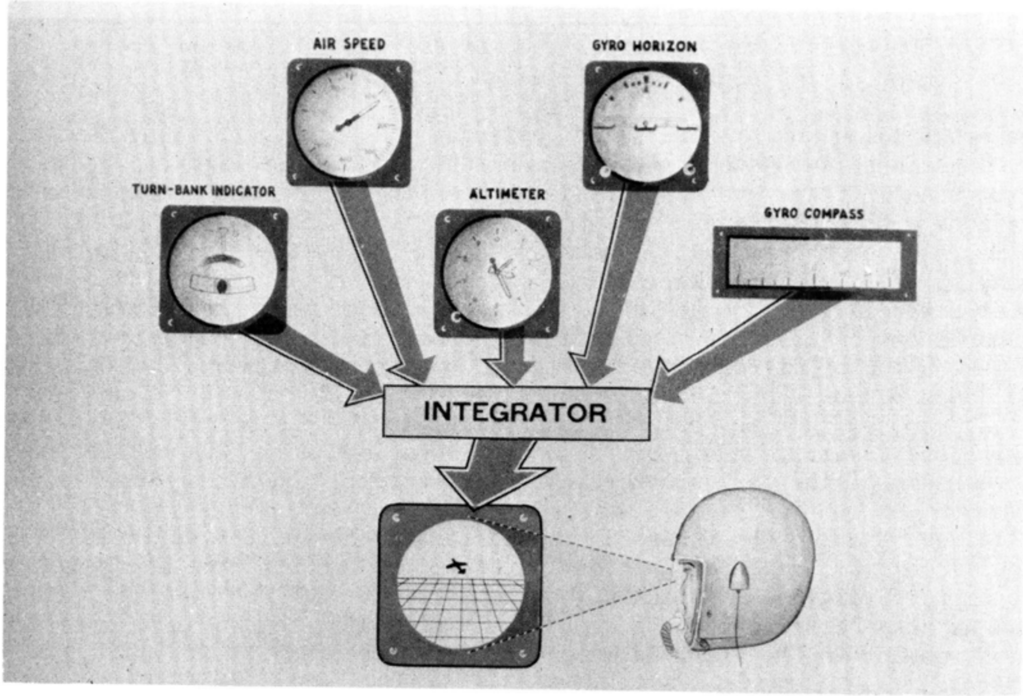

Figure 2

take immediate action to correct the attitude of the aircraft. It made things so easy that training was made easier and it took less time to train pilots. It made the task of actually flying the faster, more complex aircraft easier than those aircraft flown in World War II. Since I flew from carriers in World War II and I know that it was no easy task, I can appreciate the improved displays.

I think the same kind of logic applies to map design. Figure 3 shows this when we present an aeronautical chart to a pilot. In the light of different kinds of information the pilot requires, he must somehow mentally integrate map information into a whole. All that I am saying here is that it is possible to have what I call an integrated design (Figure 4) in which the map is so designed that the pilot gets the information he needs as quickly and unequivocally as possible, without having to compare various sizes of type, etc., which is traditionally used by cartographers to indicate population of a city and things of that sort. So, again by thinking of an integrated design, we are leading to improved design parameters.

Lastly, I am going to be talking about closed loop, man-machine systems, i.e., systems where there is man involved, where he gets information, where he takes action, and where he stays in a closed-loop-system. If you don't require action with the information from the display, then the problems are somewhat different.

I think that in the case of an aeronautical chart or something that is actually used by someone, it's not too difficult to find out the conditions of use, how it was used, and user-design parameters. The difficulty of designing classroom maps and atlas maps is made more difficult in that use and user situations are not closed-loop-systems or operations.

In any case, where a decision or an action is required, there is no reason why we can't find fundamental design parameters, that is, those related to the use and the use situation. Obviously, the optimum design may not necessarily be what the cartographer thinks the user requires, especially if the cartographer follows fallacious physical and physiological design parameters.

We are finding now, in the talks yesterday and today, that many maps are being developed and used in systems in which man interacts. (See Figure 5). Map information used in these systems includes conventional data and remote sensing observations with these being fed into a total information system. It is assumed that some resource manager has to make a decision. Now the question is -- can this man, as the decision maker, use a bunch of maps and charts piled on a table, no matter how well they are designed. It is now clear that the information from those charts can be more efficiently used in some kind of computer system. Does it really make a lot of difference what kind of cognitive realm the cartographer was in? He doesn't know what kind of information this fellow needs to make his decisions. I propose, such as Joel Morrison talked about this morning, that I would start with the cognitive realm of the cartographer and work back and try to fit the cognitive realm of the cartographer into this system, rather than vice versa.

I believe that in the future increased demands for better decisions on the use of the environment and better information to be used in resource management will require improved digital information management systems. Notice that I did not say that we need better maps. We must have improved systems to integrate map and other information in the user, decision-making environment.

The next three slides are the "strawmen" I referred to earlier. In these, I have tried to discuss maps in terms of information systems. I have tried to categorize the maps and charts and graphics that we make into one of these three

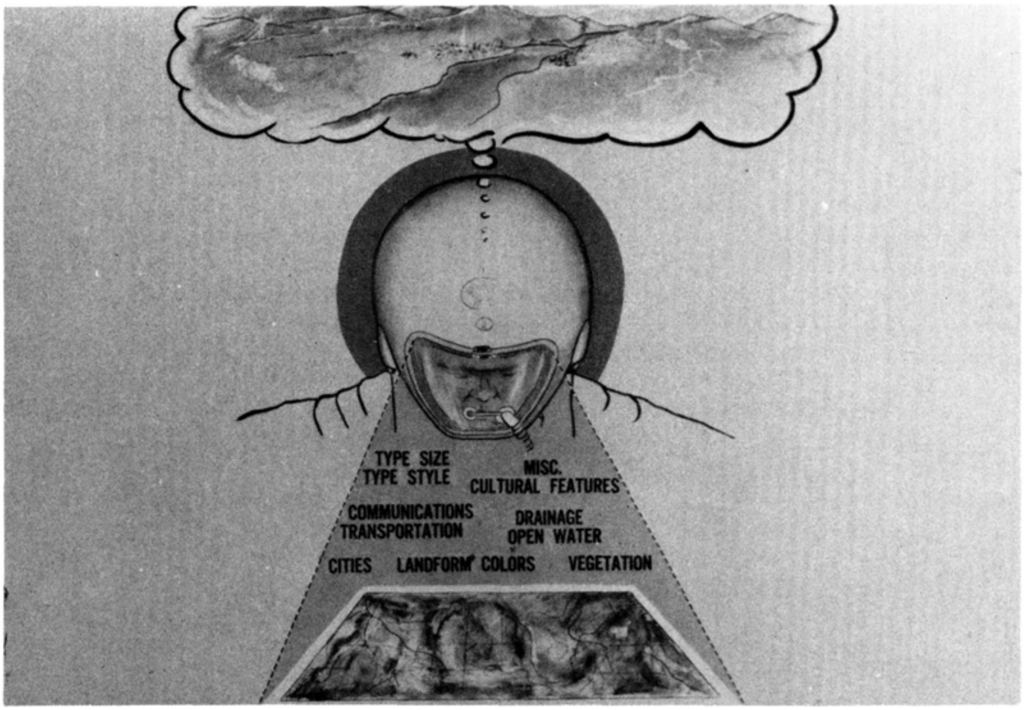

Figure 3

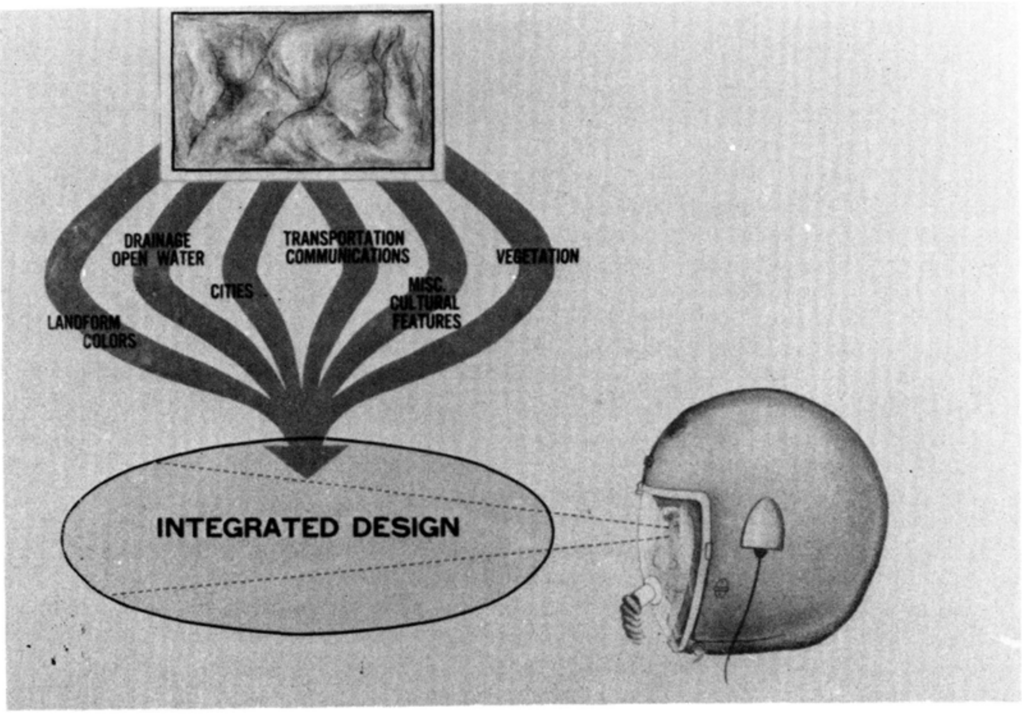

Figure 4

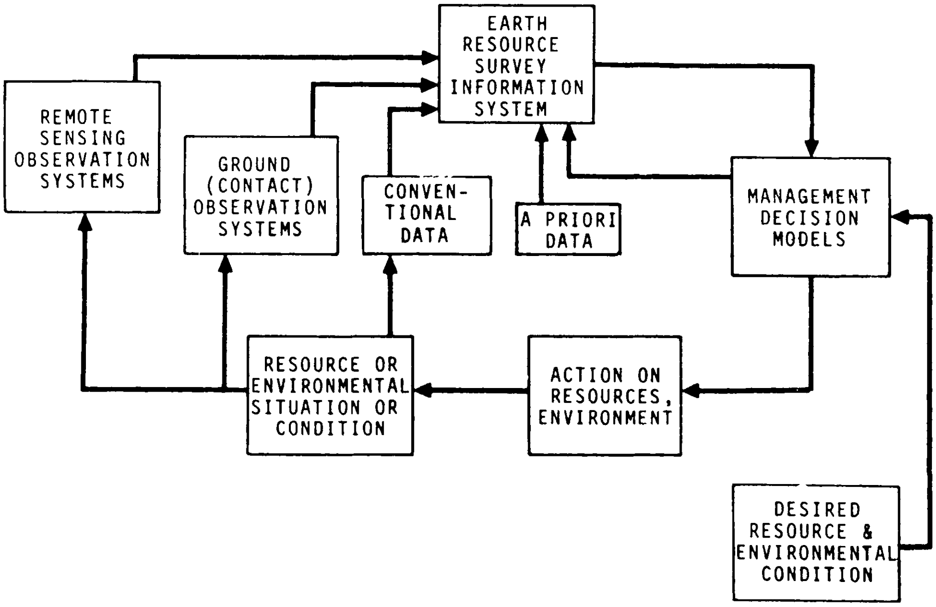

Figure 5

CLASSES OF CARTOGRAPHIC (MAP, CHART, AND GRAPHICAL) DISPLAYS
IN TERMS OF INFORMATION SYSTEM FUNCTIONS

STORAGE

- BASE MAPS
  - PLANIMETRIC
  - TOPOGRAPHIC
  - ORTHOPHOTO MAPS
  - ORTHOPHOTO IMAGES
- GEOGRAPHIC (PLACE AND LOCATION) REFERENCE MAPS
  - ATLASES
  - GAZETTEERS

INFORMATION EXTRACTION

- THEMATIC MAPS (INCLUDING OVERLAYS TO BASE MAPS)
- GENERAL AND SPECIAL PURPOSE WALL MAPS
  - EDUCATIONAL
  - RESOURCE INFORMATION
  - STATUS INFORMATION
- SPECIAL PURPOSE REFERENCE MAPS AND GRAPHICAL DISPLAYS
  - SURVEYS
  - STATUSES
  - INVENTORIES
  - ATLASES
  - RELIEF MODELS
- RAILROAD TIMETABLE MAPS

DECISION-MAKING

- ORIENTATION AND NAVIGATIONAL
  - ROAD MAPS
  - AERONAUTICAL CHARTS
  - HARBOR AND COASTAL CHARTS
  - SPACE FLIGHT CHARTS AND MODELS (SIMULATIONS AND OPERATIONS)
  - MAPS FOR THE BLIND
- TACTICAL USE
  - MAPS
  - MODELS
  - GRAPHICS
- RESOURCE MANAGEMENT
  - MANAGEMENT OBJECTIVES
  - ALTERNATIVE COURSES OF ACTION
  - EVALUATION OF ALTERNATE PLANS
  - PLAN SELECTION
  - RESOURCE UTILIZATION
  - MONITORING OF USE
  - MODIFICATION OF MANAGEMENT PLAN

Figure 6

systems (Figure 6). On the left there is the case of maps being simply storage systems. These include U.S.G.S. topoquads, Soil Conservation Service soil maps, etc. Also place name atlases and gazetteers fall in this category. The user simply searches for information in this group.

In the middle section, "INFORMATION EXTRACTION," we have all of our thematic maps, census maps, wall maps, etc., and those such as railroad timetable maps. As in the storage case, the user does not make decisions with these maps (except perhaps when he arrives at his station).

Lastly, on the right as far as decision-making is concerned, I haven't presented an exhaustive list. Here are just three examples for the purpose of illustration. The first heading is orientation, and please note that it includes maps for the blind. Remember that this blind fellow has to make decisions and he has to be right — otherwise he will not end up at his intended location. It is very important that he get correct information from his fingertips. The tactical category of use is obvious and, lastly, I have included resource management. Shown here are the steps the resource manager goes through. I don't know whether these managers want maps or will even use map information. In any case, on the right of this chart is decision-making. The analysis uses are in the middle. The analyst and the manager may not be the same individual, and in fact, in most cases they aren't.

On the previous illustration I categorized the cartographic products which are produced. On the next chart (Figure 7) I'm going to use the same three categories, but now I am going to use those kinds of products in terms of the time and attention that the user must expend in attempting to use those products. In case of

CLASSES OF DISPLAYS IN TERMS OF

USER COMMUNICATION TIME AND ATTENTION

STORAGE	INFORMATION EXTRACTION	DECISION-MAKING
● VIRTUALLY UNLIMITED TIME FOR STUDY, SCALING, AND MEASURING FROM PRECISION PRODUCTS.	● TIME SIGNIFICANT, BUT NOT A MAJOR FACTOR IN STUDY, SCALING, AND MEASURING. PRODUCTS MAY OR MAY NOT MEET NMAS.	● TIME CRITICAL SINCE IN MANY CASES COURSE-OF-ACTION DECISIONS MUST BE MADE QUICKLY AND IN RAPID SEQUENCE. STUDY, SCALING, AND MEASURING WHICH MUST BE DONE VISUALLY PRECLUDE NEED FOR PRECISION PRODUCTS.
● ATTENTION TIME FOR STUDY AND VISUAL COMPARISON ALMOST UNLIMITED.	● ATTENTION TIME FOR STUDY AND VISUAL COMPARISON ONLY SLIGHTLY RESTRICTIVE.	● ATTENTION TIME (VISUAL COMMUNICATION) MUST BE, IN MANY CASES, VIRTUALLY INSTANTANEOUS WITH AS LITTLE ATTENTION TIME AS POSSIBLE SPENT IN STUDY AND COMPARISON.
● ENVIRONMENT OF USE OF LITTLE CONSEQUENCE, OTHER THAN ADEQUATE SPACE AND ILLUMINATION.	● ENVIRONMENT OF USE OF SOME CONSEQUENCE, E.G., CLASSROOM, OFFICE, FIELD, ETC.	● ENVIRONMENT OF USE OF MAJOR IMPORTANCE, E.G., COCKPIT, COMPUTER DISPLAY TERMINAL, ETC.

Figure 7

the information storage product he can take all the time he wants to study scale and conventions. Obviously, they need to be precise, i.e., he needs to know where places are and how high they are above sea level. He can take all the time and use any kind of tools that he wants to. So visual design for momentary communication is not important, or is relatively unimportant. So, poor design doesn't necessarily overtax the fellow who simply wants storage information. The time duration for studying visual comparisons again is almost unlimited. The environment of use just requires a large table and good illumination. In the middle group, time again is not a major factor, neither in studying nor in scaling or measuring. Products may or may not need national map accuracy standards. In most cases they don't have to, because the user of an extractive product (that is usually a generalized and smaller scale product) doesn't need the national map accuracy standards. If he does, he had better go back to the original data and not use the generalized smaller scale map. Attention time for study and visual comparision will be slightly restricting, but, in any event, decisions and actions are not required.

Lastly, environment of use is of some consequence, that is, if it's a classroom, obviously the student in the back of the room has to get the same information as the one in the front of the room. On the right is the decision-making process and this is where the cartographer runs into the problem. Time is critical since, in many instances, course-of-action decisions must be made quickly and in rapid sequence. Studying, scaling, and measuring, which must be done visually, precludes the need for a precision product. If the user must get the information fast, then extreme accuracy is probably not required. Attention time, that is the time for visual communication, must be in many cases virtually instantaneous. As little attention time as possible must be spent in study and comparison. Lastly the environment of use is of major importance — it could be the cockpit of an aircraft, a computer display terminal, or other. If a television display is used, scale and degree of generalization becomes simply a matter of storage capacity, since complex or generalized maps can be generated almost instantaneously.

On the last chart (Figure 8) I have used the same three classes again, but I have tried now to summarize in terms of map, chart, and display design. It is hoped that this figure will indicate where we should spend our time in research. In the first column it should be obvious that if the Department of Defense or other mapping agencies standardize these products, all they are affecting is the storage function. As long as all users are merely interested in stored information, there is no problem in use.

CLASSES OF DISPLAYS IN TERMS OF
MAP, CHART, AND DISPLAY DESIGN

STORAGE	INFORMATION EXTRACTION	DECISION-MAKING
● FEW PROBLEMS ARE ENCOUNTERED IN USE OF CARTOGRAPHIC CONVENTIONS WHICH MUST BE LEARNED AND REMEMBERED BEFORE THEY CAN BE USED, SINCE TIME IS AVAILABLE TO CONSULT LEGEND.	● SOME PROBLEMS ENCOUNTERED IF CONVENTIONS ARE ADHERED TO. TOO MUCH INFORMATION IN ABSTRACT FORM CONFUSES USERS WHO CANNOT CONSULT A LEGEND, E.G. WALL MAPS.	● DESIGN IS CRITICAL, SINCE VISUAL COMMUNICATION MUST BE VIRTUALLY INSTANTANEOUS. ONLY IMMEDIATELY RECOGNIZABLE SYMBOLS ARE USED.
● OPTIMUM DESIGN FOR RAPID COMMUNICATION OF NEEDED INFORMATION OF MINOR IMPORTANCE, SINCE FEW VISUAL COMPARISONS ARE REQUIRED.	● DESIGN IMPORTANT FOR INTENDED PURPOSE BUT VISUAL COMPARISON AND COMMUNICATION DO NOT RESULT IN A DECISION OR ACTION BEING TAKEN.	● DESIGN MUST PROVIDE FOR A MINIMUM AMOUNT OF TIME SPENT IN STUDY AND VISUAL COMPARISON. DISPLAY SHOULD UNBURDEN USER AND NOT BURDEN HIM WITH MORE INFORMATION THAN HE NEEDS.
● MEASUREMENTS AND SCALING ARE ACCOMPLISHED USING PRECISION INSTRUMENTS AS REQUIRED IN ANY ADEQUATE WORK SPACE.	● MEASUREMENTS AND SCALING NOT AS IMPORTANT SINCE ENVIRONMENT OR USE PRECLUDES THE NEED.. VISUAL COMPARISONS IMPORTANT BUT AGAIN, NO DECISION OR ACTION WILL RESULT.	● PRECISE (IN TERMS OF USE) INFORMATION MUST BE COMMUNICATED VISUALLY. DISPLAY EFFECTIVENESS CRITICAL IN TERMS OF USE ENVIRONMENT.

Figure 8

In the second column, in what I have called information extraction, if you adhere to too many conventions, people will have trouble using these products. Wall maps are a good example. If the student in front can see the legend and if the student in back cannot, they may not receive the same information. You have to be careful, since in this group design is important, but it is not critical. Lastly measurements and scaling are somewhat important, since visual comparison is required; but again, no decision or action will result from this category of products. These are products that end up after analysis, but haven't been used as yet in a management or action context. Over in the right column are the decision makers. Here design is critical, visual communication must be unequivocal and virtually instantaneous. Only immediately recognizable symbols should possibly be used to communicate information in a minimum amount of time, since, in many cases, there is little time for study and comparision. The display should unburden the user and should not burden him with more information than he needs. I saw a bunch of people at this meeting spending ten to fifteen minutes trying to understand the color code on one of the new maps in the census room. The logic behind the color code may have been arrived at systematically, but I can see what is going to happen to the average citizen who attempts to relate color to quantities of something. If people here at this meeting don't understand, or it takes fifteen minutes to a half hour to understand the code, what will happen to the average man?

Lastly, products in this category must be precise. And I say precise in terms of the user, not precise in terms of the cartographer. Precise information must be communicated visually and the display effectiveness is critical in terms of the use environment. If the designer doesn't consider the use environment, or, if he doesn't consider precision in terms of the use of the information to be communicated, then the cognitive realm is left out in left field. If the cartographer doesn't start with the user and a use situation before he plans the design, there is a question as to whether he ever approaches a real "cognitive" realm in which the user thinks in terms of a mental map.

CURRENT RESEARCH IN TACTUAL CARTOGRAPHY

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INTRODUCTION

Estimates of the importance to humans of vision as a source of information about their surroundings vary, but there is little doubt that visual imagery often dominates inputs from the other senses. Geographers have relied heavily on visual imagery for data collection and for the communication of information about spatial relationships. However, much geographical information is not readily available to a significant minority of persons in the United States and worldwide, the visually handicapped. 1/ Persons who are severely handicapped -- the blind -- are very limited in the ease and efficiency with which they may perceive patterns and processes in their environments.

Compared to visual acuity, the other human senses are quite crude. For example, the visual two point threshold, an indication of the ability to correctly report one stimulus as one and two closely spaced stimuli presented simultaneously as two, is about .1 mm for a person with "normal" (20/20) vision at a reading distance of 30 cm. The tactual two point threshold for active exploration of a three dimensional surface is approximately 2.5 mm.2/ By this standard, the human visual sense is at least 25 times more acute than is the tactual sense. Furthermore, tactual information acquisition is strictly a linear process; multidimensional relationships must be reconstructed mentally from a series of serially acquired percepts. The blind can not "stand back" and view, tactually, the general relationships of a set of mapped phenomena without first becoming fully aware of the details of the distribution. Because the blind must rely primarily on touch for active acquisition of information, they must directly experience either their immediate surroundings or three-dimensional representations of their surroundings.3/ Therefore, most blind persons are slow to gather information about their environments and many have demonstrated generally poorly developed levels of understanding of basic geographic concepts.4/

MAPS AND THE EDUCATION OF THE BLIND

Tactually legible surrogates for many phenomena play an important role in the education of the blind. Tactually legible maps are known to be effective for transmitting information about the relationships of geographical phenomena.5/ Knowledge of such relationships is useful both for practical purposes such as unassisted mobility (travel) as well as for the development of an understanding of abstract relationships. Although alternative "map" forms, such as tape recorded directions are being explored,6/ most tactual maps are of the conventional, raised relief variety.

Of the three classes of tactual maps (mobility, orientation and thematic-reference), by far the greatest emphasis has been placed on the development and production of large-scale mobility maps. Maps such as neighborhood plans (Figure 1) are used to encourage independent mobility and exploration. These graphics are usually small, about 30 cm square, and lightweight to insure their portability. Image content must, therefore, be restricted to only the most essential phenomena. Relatively less attention has been devoted to the production of maps of the second type -- regional orientation maps. Particularly lacking are medium-scale map resources for urban areas, even though many blind persons live in cities. The map of central London (Figure 2) is typical of the limited number of such maps which are available.7/ The distribution of major points of interest and of primary transportation routes such as roads, bus lines and railroads is stressed. Regional orientation maps are not usually designed for portability, but are intended to be used for regional mobility planning. Moreover, such products are useful for helping the blind to develop an understanding of the complex spatial relationships of urban environments. Finally, only a very few small-scale thematic and general reference maps are available in tactual form. The general reference map of the United States (Figure 3) is part of a braille reference atlas. Because of the greater tactual two point threshold, data density has been drastically limited and a nonuniform degree of image generalization has been applied to various parts of the map. Production of more meaningful tactual reference and thematic maps is particularly important. Increasing numbers of blind persons are being educated with their sighted counterparts and growing numbers of State and Federal regulations mandate equal access to information for all persons.8/

RESEARCH IN TACTUAL CARTOGRAPHY

Opportunities for both graphic design research and the actual production of more effective tactual maps have been restricted by the relative lack of knowledge of tactual perceptual processes and by the inability to produce high quality, original, three-dimensional images at reasonable costs. Because of the relatively low demand for, and decentralized production of most tactual maps, images most often have been created manually by embossing figures in aluminum sheets or similar materials.9/ The result is often an image which lacks the uniformity necessary for optimal legibility. Better images have been produced by standard photoengraving methods, but costs have been prohibitive. Very recently, research involving the use of existing computer hardware and adaptable software has shown promise for helping to cut the costs of image preparation while simultaneously helping to increase the objectivity of tactual graphic design.10/ Programs are being developed to aid in the conversion of geographic data sets to graphic data structures and in the analysis of these structures for tactual legibility, based on objectively defined symbology and design criteria. Numerically controlled routing machines have been used to prepare three-dimensional map images directly. Laser systems may also be adapted to the production of three-dimensional surfaces with variable relief. Plotted output has been converted to raised form using recently developed, low cost photomechanical materials.11/ Full use of these technological advances will result in the availability of more maps of the types now produced and in the production of maps not currently available, including more thematic maps. In addition, by making possible the production of numerous alternative map displays, automation of some or all of the tactual cartographic process will increase the possibilities for experimentation aimed at expanding our understanding of tactual graphic design principles.

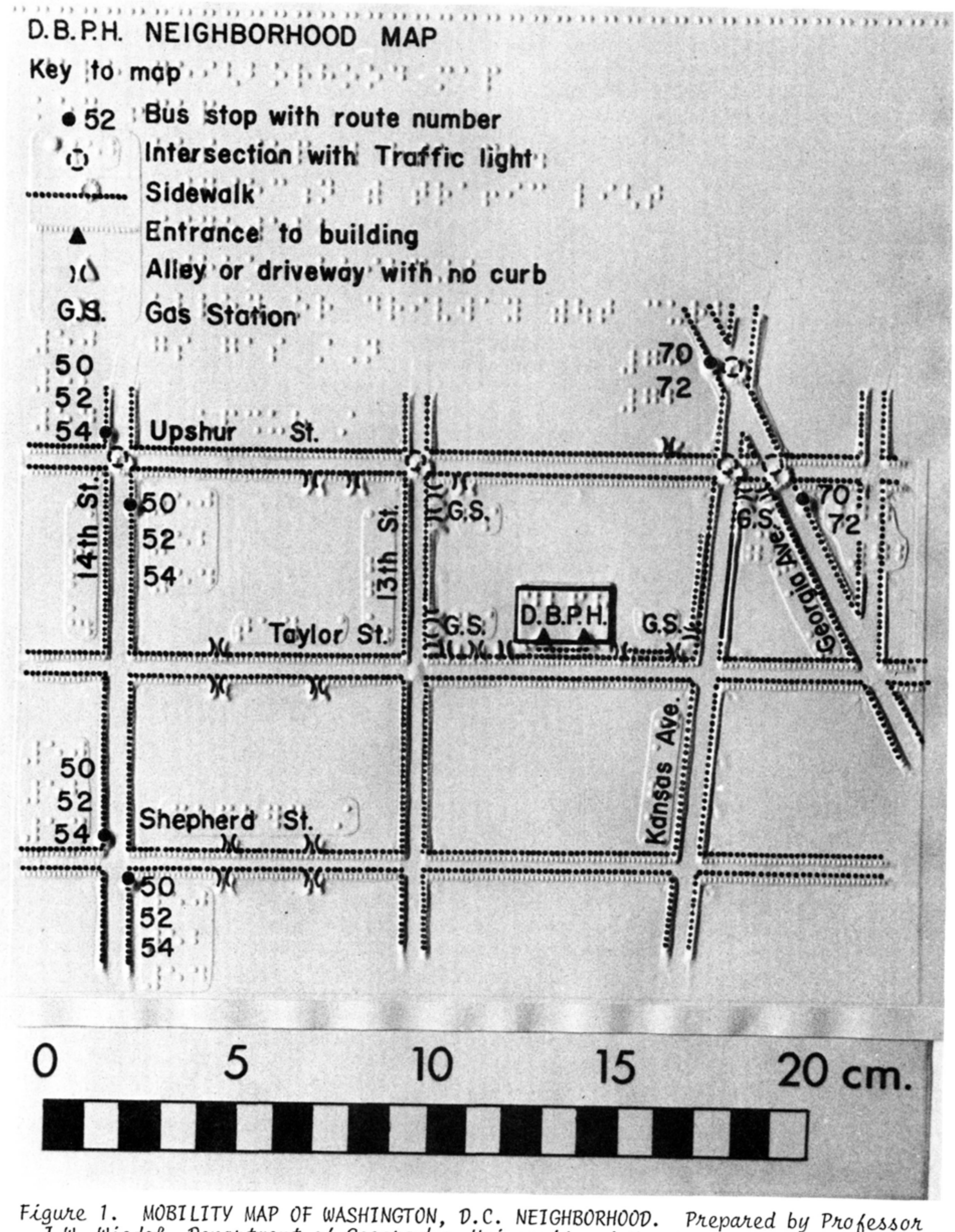


Figure 1. MOBILITY MAP OF WASHINGTON, D.C. NEIGHBORHOOD. Prepared by Professor J.W. Wiedel, Department of Geography, University of Maryland, College Park, Maryland. The plastic was preprinted and the three dimensional image was reproduced by vacuum forming. The dimensions of the original image are about 25 by 25 cm.

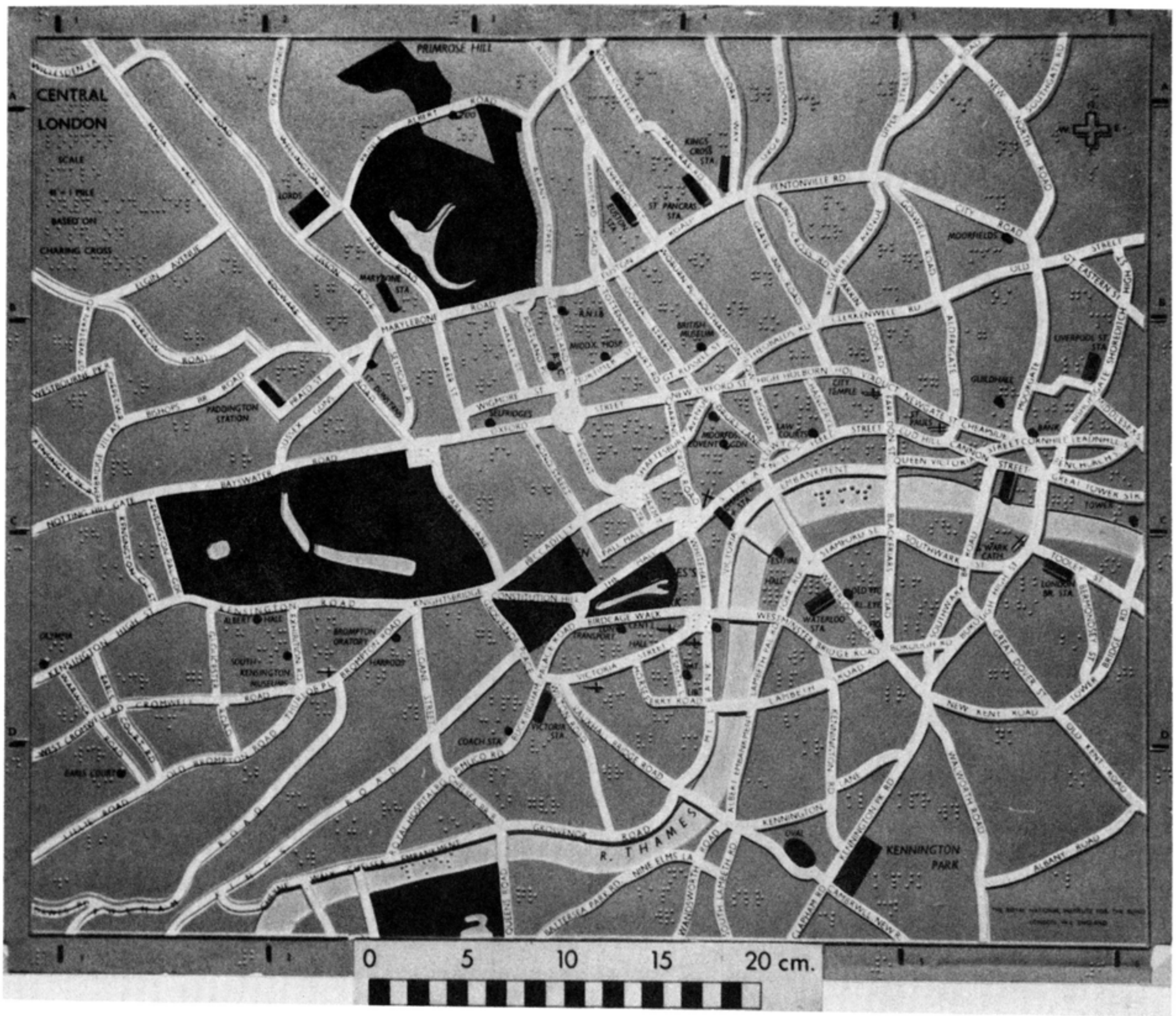


Figure 2. ORIENTATION MAP OF CENTRAL LONDON. Scale of original about 1:14,000. Prepared by the Royal National Institute for the Blind, the map is reproduced in plastic with a preprinted, multicolor image. The map is too large to be easily transported and used during travel, but it is well suited to mobility planning and general orientation. A braille legend is reproduced separately.

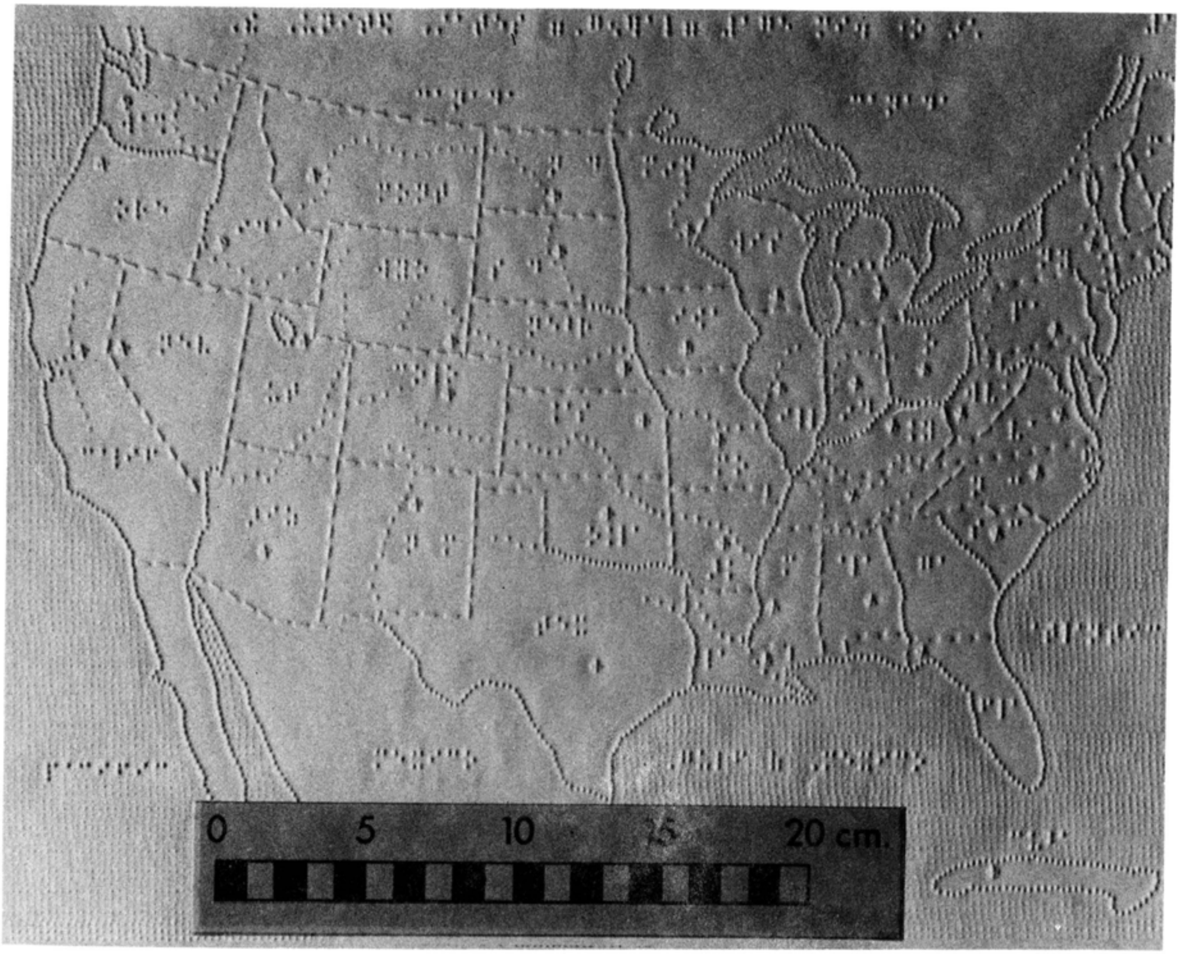
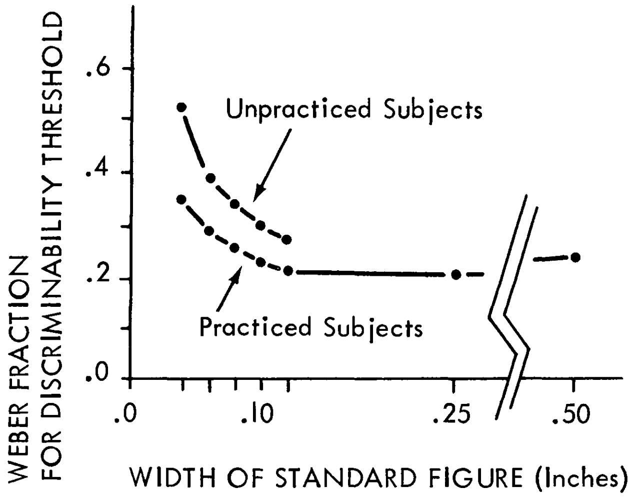


Figure 3. GENERAL REFERENCE MAP OF THE UNITED STATES. Size of original about 13 by 40 cm. The map is embossed in paper. The relative insensitivity of the human tactual sense dictates a high degree of generalization. In particular, note the lack of State identifiers in the northeast portion of the Nation.

Much of the existing research in tactual graphic communication has been directed toward the identification of tactual design variables and the isolation of sets of legible symbols.12/ As opposed to conventional cartography, in which differences in shape, size, color, tone, pattern, etc., may be used to create maps, tactual variables are less numerous and differences must be more coarse. Changes of shape -- for point symbols -- and texture -- for linear symbols -- have been shown to be important design parameters. 13/ Other tactual variables include size, orientation and height of the figure above the map base. The symbol sets which have been shown to be discriminable have meaning primarily in situations requiring nominal differentiation of map elements. Thus, mobility maps have been produced on which squares or rectangles represent buildings, triangles show the location of building entrances, single lines represent streets and dotted lines represent sidewalks. Although mobility maps serve a useful and well-defined purpose, production of maps showing higher level relationships, including all quantitative thematic maps, has not been possible. Production of such maps must be based on an improved understanding of certain aspects of active tactual perception including discrimination of changes in symbol characteristics which imply a change in the rank or value of phenomena (ordinal, interval or ratio relationships) rather than a change in the class of phenomena (nominal differentiation).

ORDINAL SCALING OF THREE-DIMENSIONAL FIGURES

Little attention has been given to the study of ordinal, interval and ratio scaling of tactually discriminable figures. Of the studies which have been completed, most have involved either passive touch, in which stimuli are applied to the skin of a subject, or forms of active touch, such as thumb-finger span, which are not directly applicable to the dynamic perception of three dimensional maps. In a recent study, Berla and Murr14/ investigated the tactual perception of single line widths by active touch to find discriminability thresholds for judging differences of line width. The discriminability threshold was defined as the minimum difference in the width of two linear stimuli necessary for a group of observers to correctly pick the wider stimulus in 90 percent of a series of trials. The Weber fraction, the ratio of the change in the dimension of a stimulus to the comparable dimension of the original figure, was computed for the 90 percent threshold for the range of stimuli used (Figure 4). High frac-



Source: E. P. Berlá and M. J. Murr, "Psychophysical Functions for Active Tactual Discrimination of Line Width by Blind Children," Typed manuscript submitted for publication, 1974, Table 7.

Figure 4. WEBER FRACTIONS FOR SIMPLE LINEAR FIGURES

tions were noted for both practiced and unpracticed subjects, although those persons who were tested repeatedly over a period of eight weeks showed improved discriminatory abilities. Although Berla and Murr's research provides deeper insights into certain aspects of dynamic touch, immediate implementation of the results in the design of ordinally scalled figures for maps may not be possible. The study was executed using milled steel lines mounted on wooden blocks and the tactual scan pattern of the subjects was restricted.15/

	POINT SYMBOLS		LINE SYMBOLS	
FIGURE	●	■	—	═
VARIABLE DIMENSION	Diameter	Side	Width	Interline Spacing
SIZES OF STANDARD FIGURES	5 to 25 mm in increments of 5 mm		2.5 to 12.5 mm in increments of 2.5 mm	

Figure 5. POINT AND LINE SYMBOLS CHOSEN FOR PAIR COMPARISON TESTING

To extend the understanding of ordinal tactual symbol scaling to other commonly used figures and to investigate active tactual exploration in a more realistic graphic reading situation, two linear and two point symbols were chosen for pair comparison testing (Figure 5). A variety of line widths, interline spacings and point symbol sizes are being evaluated to find discriminability thresholds for the standard figures. The raised standard and variable stimuli were created by (1) using a Calcomp plotter to plot two-dimensional figures on paper, (2) converting the figures to .7 mm high raised images using photomechanical methods 16/ and, (3) reproducing the raised symbols in vacuum-formed plastic, a medium in common use for the production of three-dimensional maps. Subjects are being allowed to scan the figures using any finger (usually the index or middle finger) of the preferred hand in a manner similar to that which would be used for reading an actual graphic. At this time, September 1975, the testing program is about 60 percent completed and certain well-defined trends are evident. In general, few persons seem to be extremely accurate in judging size differences, but subjects have made very large errors.

FIGURE	●	■		—	═
STD. SIZE			STD. SIZE		
5 mm	.15	.10	2.5 mm	.20	.10
10 mm	.08	.10	5.0 mm	.15	.10
15 mm	.12	.10	7.5 mm	.07	.07
20 mm	.08	.10	10.0 mm	.15	.10
25 mm	.08	.10	12.5 mm	.12	.12

Figure 6. PRELIMINARY WEBER FRACTIONS FOR THE DISCRIMINABILITY THRESHOLD

Weber fractions (Figure 6) have been computed for the standard figures being used in the current testing program. (It must be emphasized that these fractions are based only on partial results.) Comparison of the fractions for the single line stimuli with those obtained by Berla and Murr (Figure 7) show that, under more typical graphic reading conditions, smaller differences in line widths have been recognized more consistently in the present testing program. In no case is the Weber fraction more than .20 and, for the mid-range of the line widths, the fraction is only about .15. The group of unpracticed subjects in Berla

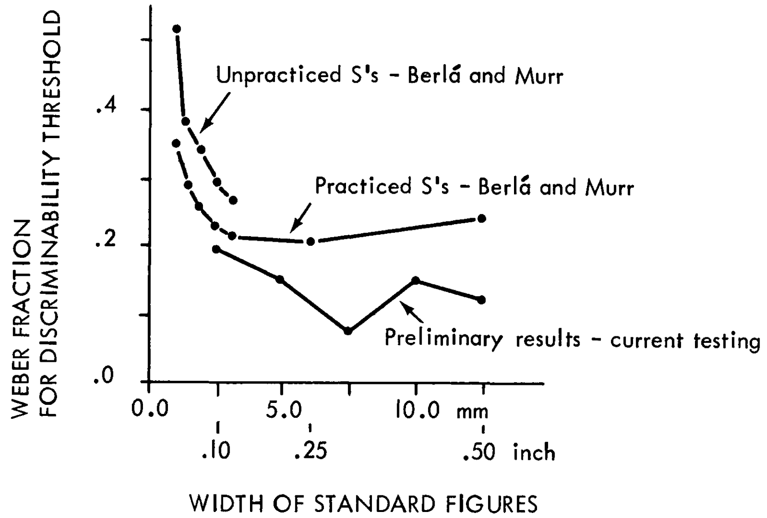


Figure 7. COMPARISON OF WEBER FRACTIONS FOR THE DISCRIMINABILITY THRESHOLD FOR SINGLE LINES

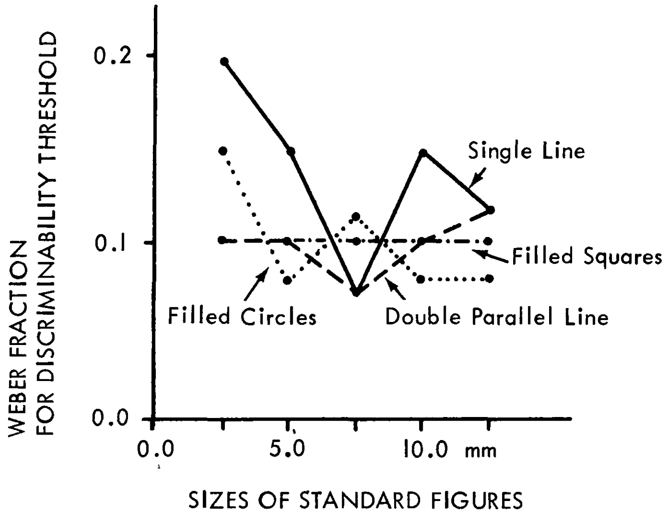


Figure 8. COMPARISON OF PRELIMINARY WEBER FRACTIONS FOR THE DISCRIMINABILITY THRESHOLD - CURRENT TESTING PROGRAM

and Murr's study achieved higher fractions, ranging from a low of .27 to a high of .52 for very fine lines. Even the group of subjects who were tested repeatedly for a period of eight weeks attained fractions ranging from a low of .21 to a high of .35. A similar function is evident in the Weber fractions for the double line symbol (Figure 8), but the 90 percent threshold is somewhat lower and more stable than for the single lines, ranging from about .07 to .12. Finally, preliminary indications are that subjects are able to perceive relatively fine differences in the dimensions of filled circles and squares. For these stimuli, Weber fractions for the 90 percent threshold range from .08 to .15. No previous results are available for comparison.

CONCLUSION

Although the foregoing preliminary results must be confirmed by more extensive testing, it seems unlikely that any significant deviations from the apparent trends will be found. Following the completion of the pair comparison testing stage of the project, the symbols will be tested in a map context. It is anticipated that the Weber fractions established on the basis of pair comparison testing in isolation will increase when the symbols are imbedded in a more complex graphic environment. However, the preliminary results are encouraging. The results for the single line symbols confirm previous work -- subjects are able to differentiate consistently between lines on the basis of size differences. Confirmation of the existence of this ability makes possible the design of more meaningful tactual maps. Simple line symbols scaled on an ordinal basis may be used to represent relatively complex linear geographic relationships. Furthermore, subjects engaged in tactual reading in a more realistic map reading situation, using commonly available materials, seem to be more adept at perceiving size differences for squares, circles and double linear symbols than had been assumed.

If the ability to judge size differences is confirmed in additional testing, it will mean that ordinally scaled symbols can be used on tactual maps with assurance that they may be read accurately. By basing design decisions on the results of this and related research, cartographers will be able to create uniform symbols which will occupy less of the very limited map image area than previously was thought possible. More information, within limits, may be placed on three-dimensional, quantitative thematic maps without a loss of image legibility. The ultimate increase in the availability of high quality, more easily read tactual maps will play an important part in extending the influence of map form to the visually handicapped, helping them to understand spatial patterns and processes in their unseen environment.

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6. Leonard and Newman, "Three Types of'Maps'."

7. Only a few other urban area maps have been produced. Work, under the supervision of Dr. John Sherman, is currently in progress on preparation of a metropolitan area orientation map for Washington, D.C. This project is being sponsored by the U.S. Geological Survey and also involves preparation of a large-scale mobility map of the Mall in central Washington.

8. Typical of laws which mandate equal opportunities for the blind, as well as for other handicapped persons, are Sections 28A.13.005 and 28A.13.010 of the 1974 Revised Code of Washington (State). Included in the sections is the provision that "each school district . . . (must) ensure an appropriate educational opportunity for all handicapped children of common school age."

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13. Nolan and Morris, "Improvement of Tactual Symbols," p.9.

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15. "The stimuli were...oriented perpendicularly to the body so that when the subject moved his fingertip across the length of the line he had to judge the width of the line. Consequently, the extent of arm or finger movement provided little if any information about the size of the line." Berla and Murr, "Psychophysical Functions," p. 2.

16. For a full description of the process, see footnote 11.

THE OPTIMAL THEMATIC MAP READING PROCEDURE: SOME CLUES PROVIDED BY EYE MOVEMENT RECORDINGS

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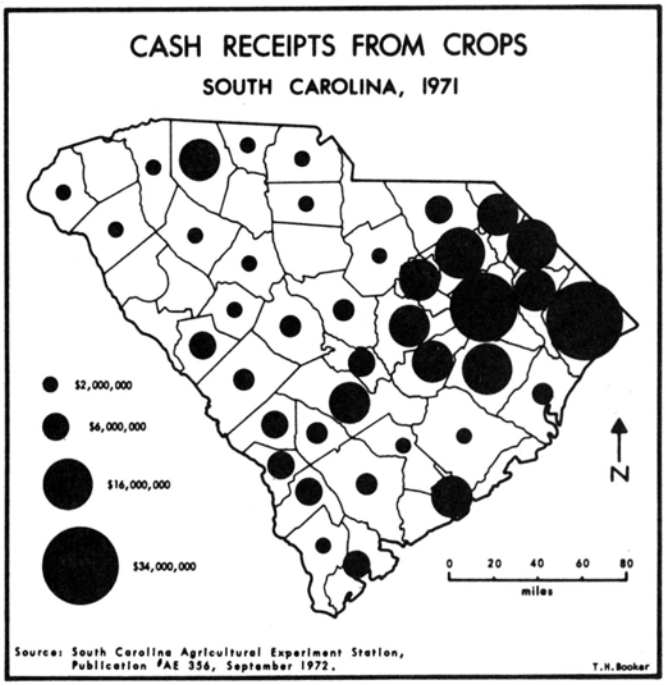
INTRODUCTION

A thematic map is an assemblage of different kinds of information on a white piece of paper. These bits of information are commonly referred to by cartographers as map elements or map components. Some of these elements include the title, body, legend and source statement. Each of these elements, as well as others, provides the map reader with information that can help him understand or evaluate the message the map author is trying to communicate. Hopefully, as the cartographer proceeds with the creative process of map construction, he structures each of the elements, and then the entire collection of elements, in a way that enhances the flow of information from map to map reader. Most map elements can be placed in an information hierarchy. This hierarchy is commonly reflected in the design of the map where more important pieces of information are visually emphasized by large or bold type or by prominent location near the top-center of the map frame. The features are made large, bold, or prominent to not only order their importance for the reader but also to attract his attention. Thus, the process of map design provides the cartographer with the means to orchestrate the map reading process -- first directing the reader to the most important information and then leading him to other less important map elements in some systematic fashion that he hopes will aid communication. This leads to the question of whether there is an optimal way to read a thematic map of given design. Most cartographers would admit that there are a large number of possible ways to read a map and it would seem likely that some map reading strategies are more productive than others from a communication point of view.

This study has attempted to answer the question of whether there is an optimal map reading process. To do this a typical thematic map was constructed and is shown in Figure 1. This map was prepared as a monochrome and contains a title, body, legend, source, scale, north arrow, author, and neatline. An attempt was made to make this map typical in all respects of the maps that commonly appear in professional geographic publications. The map was shown to twenty college students enrolled in introductory geography courses. While each subject looked at the map his eye movements were recorded on 8mm movie film by means of the corneal reflection technique. In this technique a light is directed at a person's eye. As the person shifts his gaze to look at different parts of the map the reflection of the light off the front surface of the eye also moves. The systematic movement of this reflection can be used to determine the map reading process used by a map reader. The test set-up used to make the eye movement recordings is shown in Figure 2. The subject was seated in front of the back-projected map. His head was held firmly in a head and chin rest to minimize the unwanted movements of the light reflection caused by shifts of the head. The recording camera was located below the screen on which the map was shown and was aimed at the subject's right eye. Through the use of the eye movement recordings made in this way the map reading process can be defined in terms of where on the map the subject looked, how much time he spent looking at the whole map and its elements, and what sequence he followed in reading the map.



Source: South Carolina Agricultural Experiment Station, Publication #AE 356, September 1972.

Figure 1. This thematic map is typical of many maps which commonly appear in geographical publications. While 20 subjects looked at this map their eye movements were recorded on film and later analyzed in an attempt to define the map reading process.

Human vision is a complicated process. As the human eye scans a map, or any other visual scene for that matter, it does so by shifting from one location to the next. However, little information is taken in during these rapid shifts known as saccades. Only when the

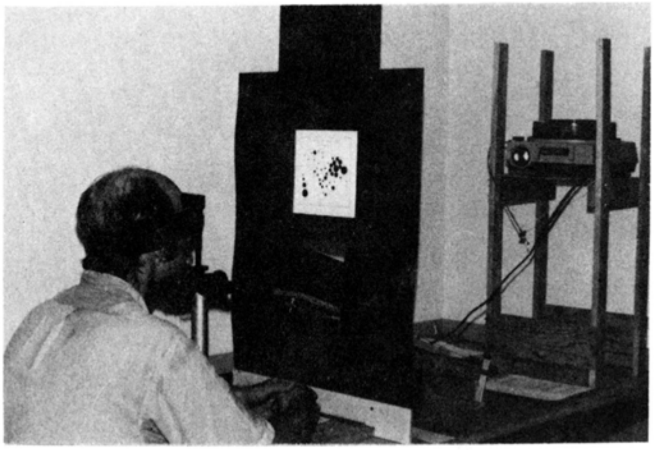
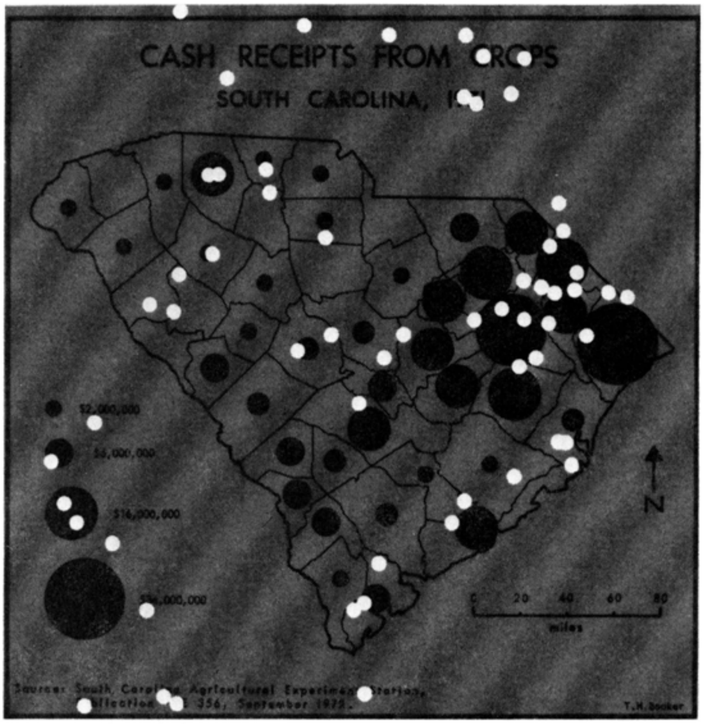


Figure 2. This subject is in position ready to look at the map projected on the screen before him. The eye movement recording camera, located below the screen, is aimed at the subject's right eye.

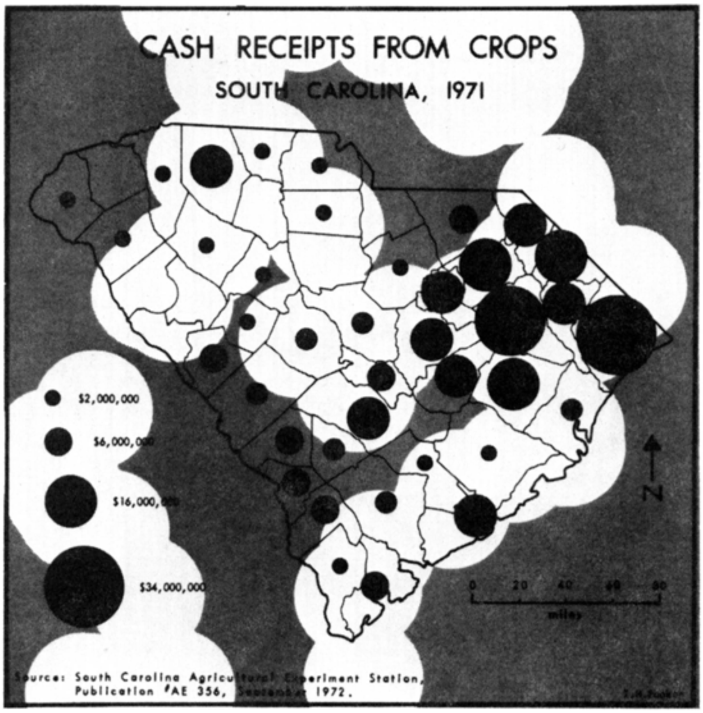
eye comes to rest for at least 2/10 of a second can visual information be processed. These periods of rest known as fixations average 1/3 of a second in duration but may last two seconds or more. The photographic records of the eye used in this experiment were made at the rate of nine frames per second and therefore, if two successive frames showed the eye to be looking at the same place a fixation was identified. Figure 3 shows the location of the fixations for a single subject. Just what a person sees during one of these fixations is difficult to say. It is known that the sharpness of vision drops off rapidly away from the point of fixation so that it is likely that little detailed information is taken in beyond 1/2 inch from the point of fixation at a reading distance of 18 inches. While peripheral vision plays an important role in map reading, helping the reader to direct his gaze from one area to another, little detailed information is received in this way. Figure 4 shows that portion of the map that was most likely seen clearly by the subject whose fixations were shown in Figure 3. Each of these white circles, about the size of a quarter at a reading distance of 18 inches, reveals that part of the map probably seen clearly by the subject.

Since the eye movement recordings were made on film, the duration of each fixation could easily be determined. After the duration of each fixation was known it was possible to determine the amount of time spent



Source: South Carolina Agricultural Experiment Station, Publication AE 356, September 1972.

Figure 3. Each white dot represents the location of a fixation of the eye as a subject looked at the map. During these fixations, which average 1/3 of a second, the subject takes in information from the map. Note which parts of the map are and are not looked at.



Source: South Carolina Agricultural Experiment Station, Publication AE 356, September 1972.

Figure 4. These open circles show that portion of the map that was most likely seen clearly by the subject. Observe that most of the informative parts of the map were covered by his map reading activity.

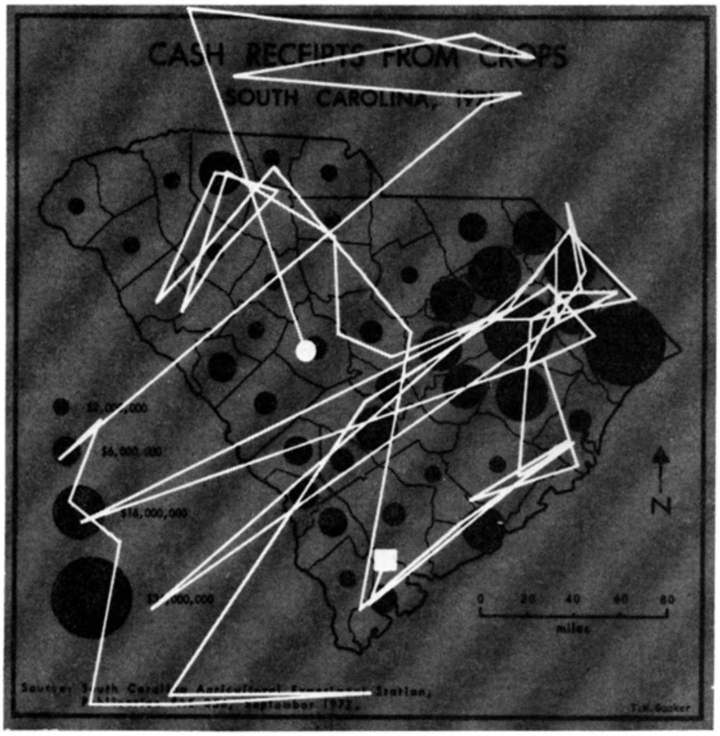


Figure 5. The eye movement film allowed each of the fixations to be linked along the map reading time-line to produce this record of the subject's scan path as he looked at the map. The scan begins at the circle and concludes at the square.

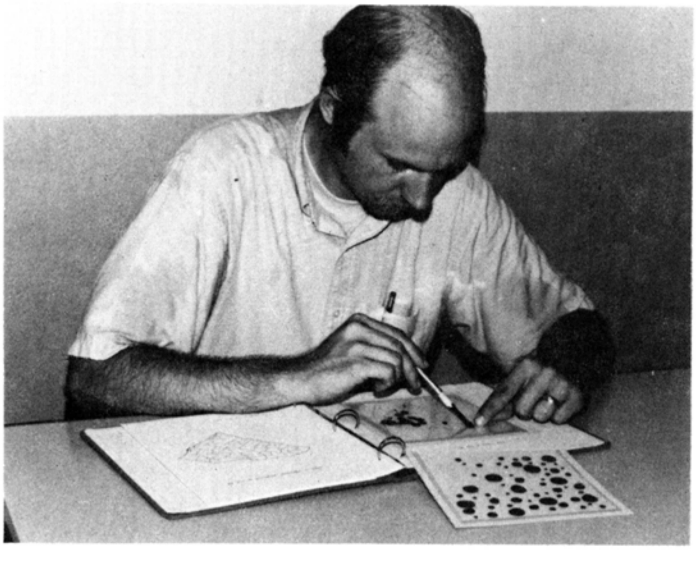


Figure 6. This subject is reconstructing his memory of the pattern of circles on the original map by transferring adhesive backed circles to a blank outline map.

looking at the entire map as well as the time devoted to each of the map elements.

The recording of the fixations on film also made it possible to link the fixations along a map reading time-line. Figure 5 shows the path connecting the fixations that was followed by a subject as he read the map. The circle indicates where he began reading and the square where he stopped reading.

These three characteristics, the location of the fixations, the duration of the fixations, and the sequence of the fixations, were used in this study to define the map reading process. Through the use of the eye movement recordings the map reading process used by each subject was determined.

In order to say which subject did the best job of reading the map, or in other words which map reading process resulted in the best transfer of information, it was necessary to obtain a measure of information flow from map to reader. This was done by means of a map reconstruction test. After each subject finished looking at the map and having his eye movements recorded, he was asked to prepare, to the best of his abilities, a replication of the pattern of circles making up the body of the map. In order to reconstruct the map body each subject was given a black outline map of the State of South Carolina and a supply of adhesive back circles of the same sizes as those used on the original map. In Figure 6 a subject is seen transferring one of the circles to the base map as he "builds" his reconstruction. Subjects were free to use as many circles as they desired and they could adjust location and add or delete circles as they proceeded with reconstruction.

The 20 reconstructed maps were then shown to another group of 70 students who looked at each of the reconstructions paired with the original map body and evaluated the similarity of the two. They were asked to score each pair between 1, meaning very different, and 7, meaning very similar. Figure 7 shows the original map body on the right and a reconstruction on the left. The average similarity score for the lefthand map was 3.51. Scores ranged from 2.01 to 3.95.

The information contained in the original pattern of circles shown on the righthand side of Figure 7 was considered the primary message the map author was trying to communicate with this map and thus the degree to which a subject replicated this pattern of circles was the degree to which it was assumed he understood the map message. It was also assumed that those subjects who did the best job of reconstructing this map body did so because they used the most efficient map reading process. An optimal map reading procedure therefore, could be defined in terms of the map reading procedures used by the subjects whose map reconstructions were most similar to the original map body.

THE MAP READING PROCEDURE

Where did subjects look on the map? Figure 8 shows where all 20 subjects looked on the map. Three, not very obvious, clusterings of fixations exist -- one on the title, one on that part of the body where largest circles are located, and one on the legend. Only two large areas were totally ignored -- one to the left and the other to the right of the title where no information was present.

Considerable variation between subjects was found in the number of fixations that occurred on each of the map elements. This paper considers the differences in

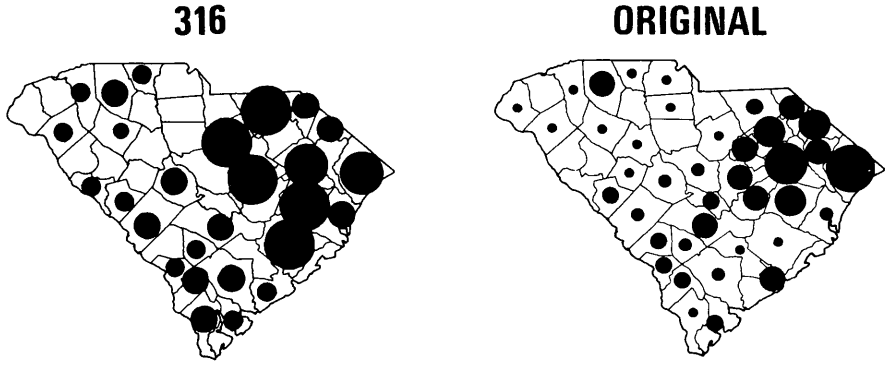


Figure 7. On the right is the original map viewed by all 20 subjects in this experiment. On the left is a sample map reconstruction. In order to evaluate how good this reconstruction was the above pair of maps was shown to 70 other people who were asked to rate the similarity of the two maps from 1 (very different) to 7 (very similar). The average score for the map on the left was 3.51.

number of fixations that occurred on the map body because attention to that part of the map seems most closely related to the reconstruction task. Figure 9 shows the variation between subject in the number of fixations that occurred on the body -- 10 on #306 and 84 on #305. One might expect that a larger number of fixations would allow for more complete visual coverage of the entire body and might , therefore , correlate strongly with reconstruction scores. This is not confirmed by the results of the study. While the reconstruction score for #306 was the poorest, that for #305 was only 10th best out of the group of 20. In fact when the numbers of fixations on the body were correlated with reconstruction scores for the whole group, the correlation coefficient was only .19. Evidently these subjects' understanding of the map message had little to do with the number of times they fixated on the map body. However, when the fixations

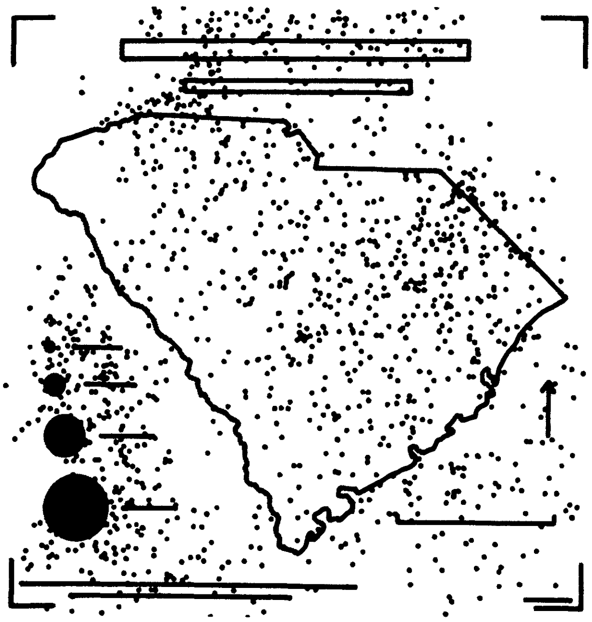


Figure 8. All of the fixations for the 20 subjects are shown above. Note the clusterings of fixations on the title, legend, and that part of the map body containing the largest circles.

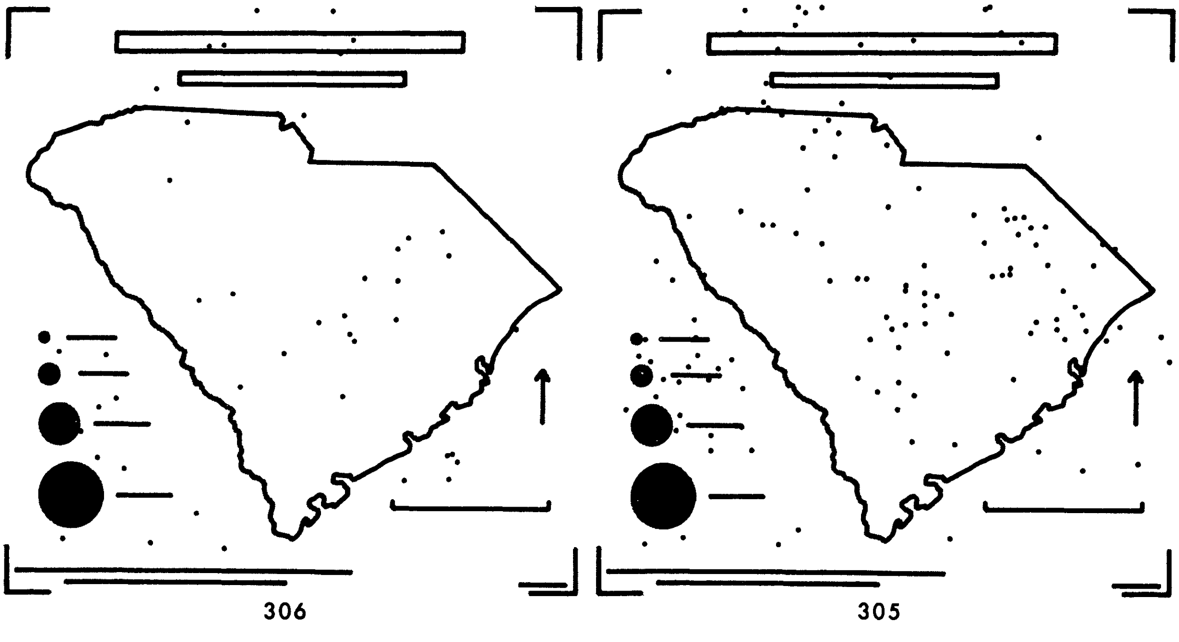
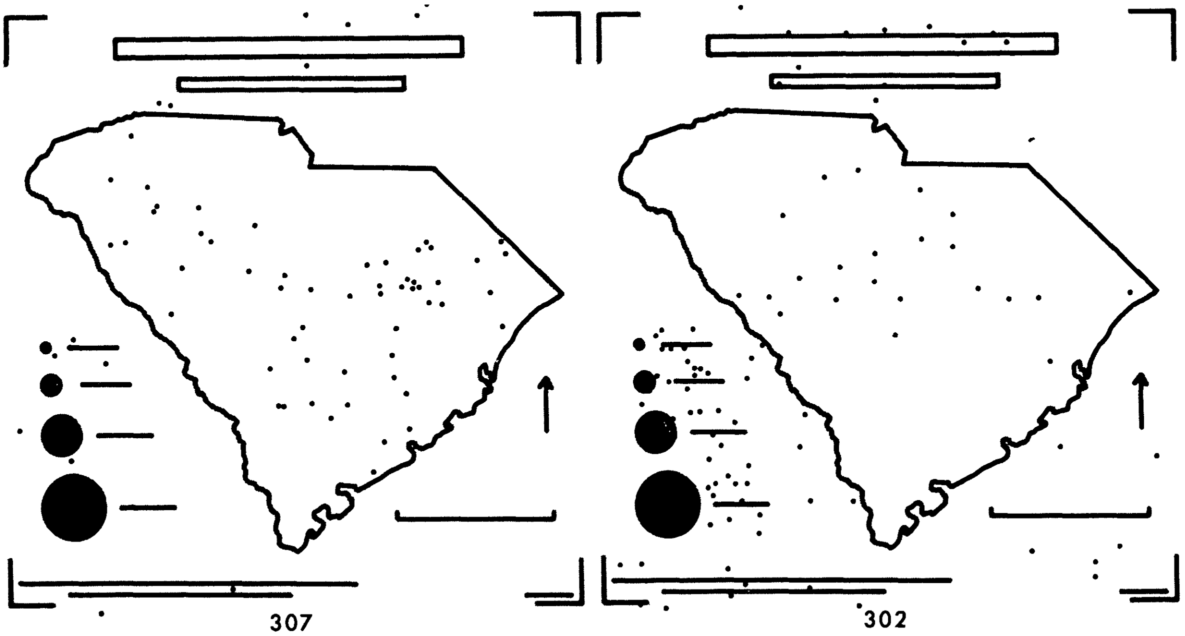


Figure 9. Considerable variation can be seen between these two subjects in the number of times they fixated on the map body. Subject #306 had only 10 body fixations while subject #305 had 84.



307 302

Figure 10. These two records show the variation in the percentage of fixations which occurred on the body. Seventy-five percent of the fixations of subject #307 fell on the body while only 28 percent of those of subject #302 fell in the same area. The subjects that had a higher percentage of their fixations on the map body generally did a better job of reproducing the map from memory.

305 308

Figure 11. Subject #305 looked at the map longest (40.3 seconds) but did a relatively poor job of reproducing the map while subject #308 looked at the map for the shortest time (12.6 seconds) but did a good job of reconstructing the map from memory. It seems there is little relationship between how much time a person looks at a map and his ability to reproduce it.

on the body were calculated as a percentage of total fixations, the results were different. Figure 10 shows the fixations of two subjects. Subject #307 had 75% of his fixations on the body and the 10th best reconstruction while subject #302 had 28% of his fixations on the body and a reconstruction score that ranked 17th. The correlation coefficient between percent of fixations on the body and reconstruction scores for the whole group was .46.

How much time did the subjects spend looking at the map. The total amount of time spent looking at the map by the 20 subjects was 449 seconds or an average of 22.4 seconds per subject. Time spent looking at the map ranged from 12.6 seconds to 40.3 seconds. One might also think that the longer a person looks at the map the better he would understand the map message. The two maps in Figure 11 indicate that this was not necessarily true. Subject #305 looked at the map longest but his reconstruction ranked 13 out of 20 while Subject #308 looked at the map for the shortest time but had the second best reconstruction. The correlation between total time looking at the map and the reconstruction scores was a poor -.17.

Total time looking at the body also does not do an adequate job of explaining a person's understanding of the map message. When time looking at the body was correlated with reconstruction scores, the correlation coefficient was only .11. But when the time looking at the body was taken as a percentage of the total time looking at the map, it appeared to be more important. This correlated with map reconstruction scores at .43.

In what sequence were the map elements looked at by the subjects? When subjects first looked at the map their attention was directed to the central and upper part of the map body as well as to the title as seen in Figure 12 where the first three fixations of every subject are plotted. From this point on, however, the scan paths become more and more individualized. A plot of the last three fixations of all subjects indicates this diversity (Figure 13), and demonstrates that while most subjects began their look at the map in a restricted area they went their separate ways shortly and concluded their scores in many different places. Despite several different approaches to the problem of analyzing map reading sequence, it has not yet been possible to systematically classify the reading patterns of subjects to see if a correlation exists between reading sequence and reader understanding of the map message. Two things have hindered this effort. First, the highly variable length of time spent looking at the map by the subjects creates problems

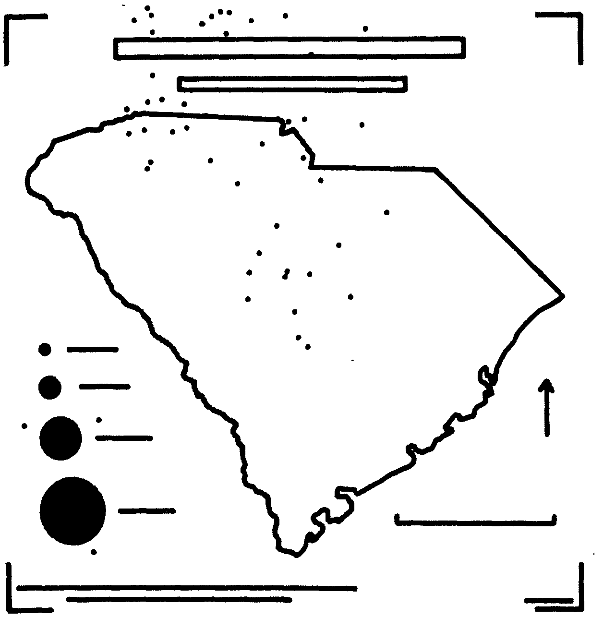


Figure 12. These dots show the location of the first three fixations of all 20 test subjects. Note the concentration of fixations at the beginning of the map scan on the upper part of the map body and on the title.

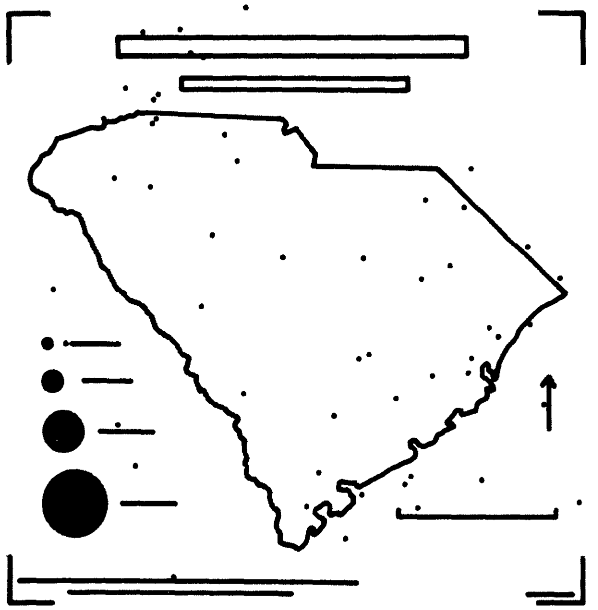


Figure 13. These dots show the location of the last three fixations of all 20 test subjects. Note the dispersion of these fixations indicating that people do not terminate their scans of the map in the same general location.

of compatibility of records, and second, the large percentage of time spent looking at one map element -- the body -- means that there was a significant repetitive factor to take into consideration. Hopefully some technique will be worked out in the future to successfully analyze map reading sequences.

CONCLUSION

In conclusion I would like to restate my original question: Is there an optimal map reading procedure and, if so, what is it? The answer to this is "yes" but it has not been as clearly defined by this study as was originally intended, partly because of the great complexity of the process. There are several aspects of the map reading process that seem to contribute to a better understanding of the map message. A large proportion of both the total number of fixations and the total map reading time devoted to the map body seems to result in better understanding. Apparently this concentration on the body helps to crystalize the map image in the subject's mind. Absolute time, or number of fixations on the body, is not a good indicator because large amounts of time or a large number of fixations may also be devoted to other less informative map elements. The subjects who spent a shorter time looking at the whole map were found to have done a better job of reproducing the map body but it is not clear whether this was due to the fact that a longer look may have clouded their memory of the map or to the existence of some inherent ability of those readers that allows them to process the map information more rapidly. Another finding of this study supports this latter possibility. When a correlation was run between the average duration of both the fixations over the whole map as well as just the fixations on the body and the reconstruction scores, the correlation coefficients were -.53 and -.41 respectively. In other words the best reconstructions were produced by people who had short fixations. It is possible that this relationship may be similar to the inverse relationship existing between fixation duration during reading and reading comprehension, which is in part thought to be a function of reader intelligence. Since nothing is known about the intelligence of the map readers in this experiment, it cannot be determined if there is a cause-effect relationship between fixation duration and reconstruction scores.

This study has determined that the optimal map reading procedure involves a relatively short look at the map, a high percentage of fixations and time concentrated on the map body, and shorter than average fixations. Certainly this study has not provided a definitive description of the optimal map reading procedure but it is the author's hope that it has at least provided the first step in that direction. Cartographers must know more about the map reading process in order to design maps which communicate better. When map design proceeds according to a set of well-tested principles rather than dogmatic conventions, we will all be more confident of our ability to communicate with maps.

THE MAP -- IN THE MIND'S EYE

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INTRODUCTION

The thematic map seems to be a whole that is more important than the sum of its parts. The major body of research that has been conducted over the past half century, however, has dealt with variables related to a map's elements rather than to the information-carrying capacity of the cartographic device. Quite obviously the study of maps is the study of complexes, structures, interactions, and grammars and the most interesting, and at the same time the most neglected, problem is that of map induction particularly hypothesis formation, learning, and concept attainment on the part of the map reader. Although many cartographic studies have been aimed in the direction of these factors they have usually stopped short of the central point which is that perception basically turns raw and unstructured sensed data into coherent wholes.

We may regard perception as a total process that starts with the sensory input of stimuli by the receptors and continues to some high level cortical cognitive transformation. As it stands today the cartographer's knowledge of map perception (as previously defined) is incomplete and we may positively state that the cartographer is obligated to research this topic in order to develop a viable and accurate basis for understanding the map information-transmission process.

The discussion that follows is drawn from research that I have conducted over the past five years on the application of eye movement recording techniques to cartographic research. Due to limitations of time I will not direct myself to explanations of recording techniques to definition of specific terms.* Rather I would like to spend these few moments discussing the interaction between the map and the map reader as manifested by input-output coordination during visual search.

PERCEPTUAL GENERALIZATION

If we assume that we have a map (M) and a person visually examining that display, then we would like to define viewing or the transfer of information as a mapping (F) of the set M to a set I (being the receptors in the viewers eye) in which the following conditions hold:

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* The reader is directed to A.L. Yarbus (Eye Movements and Vision, Plenum Press, New York, 1967, 222p) for a comprehensive discussion of eye movement research.

a) For every element Y in I there is an element X in M such that F(X) = Y

b) If X and X' are two different elements of M then F(X) ≠ F(X').

These two conditions assert that for each element of I there is at least one element of M which is received, and also that different elements of M are not received by the same element of I (See Figure 1.)

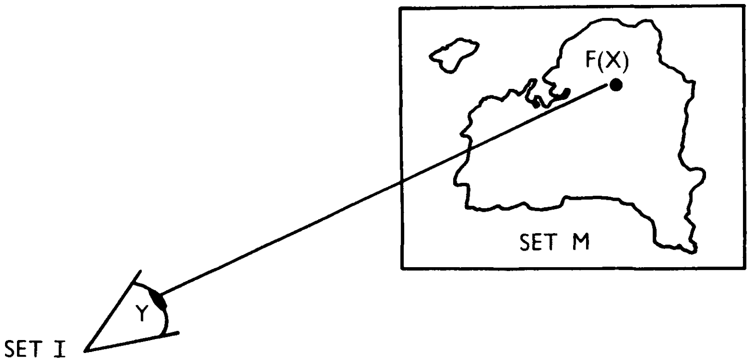


Figure 1. Visual Mapping

Quite obviously this would produce a one-to-one mapping of the visual display and it would be satisfying to know that all of the mapped information was observed by the reader. The human organism, however, operates in such a way as to automatically reduce the information content that it receives. Although it is theoretically possible for the eye to sense up to six million bits of information (a function of the number of visual receptors) the absolute amount of information reaching the brain is reduced because the number of neurons in the visual pathway is significantly smaller than the number of retinal impulses.

This inelegant example is, of course, spurious for several other reasons. First due to spatial variations in the density of the retinal receptor the eye registers only a portion of a scene clearly while the remainder of the display is viewed extrafoveally. As a consequence the reader must foveally attend to specific sections of a display to mentally reconstruct specific aspects of the percept that he is viewing. Acuity, however, is not a steady state as the ability to discriminate objects is some function of the complexity of the display. Although the field of clearest vision can be no broader than physiological limits it apparently does contract under certain circumstances. In any event this feature also necessitates that the reader examine segments of the display in order to perceive the elements of the whole.

The map reader, however, is not a raster scanner or matrix encoder. Rather he attends to selected display items in some sequence. Examine the following illustrations (See Figures 2, 3, and 4.) These are graphic representations of scanpaths for three subjects who viewed the same map. The arrowheads indicate locations at which the subjects fixated long enough to acquire information (250 milliseconds). The point of the arrow is provided to indicate the direction of the scan.

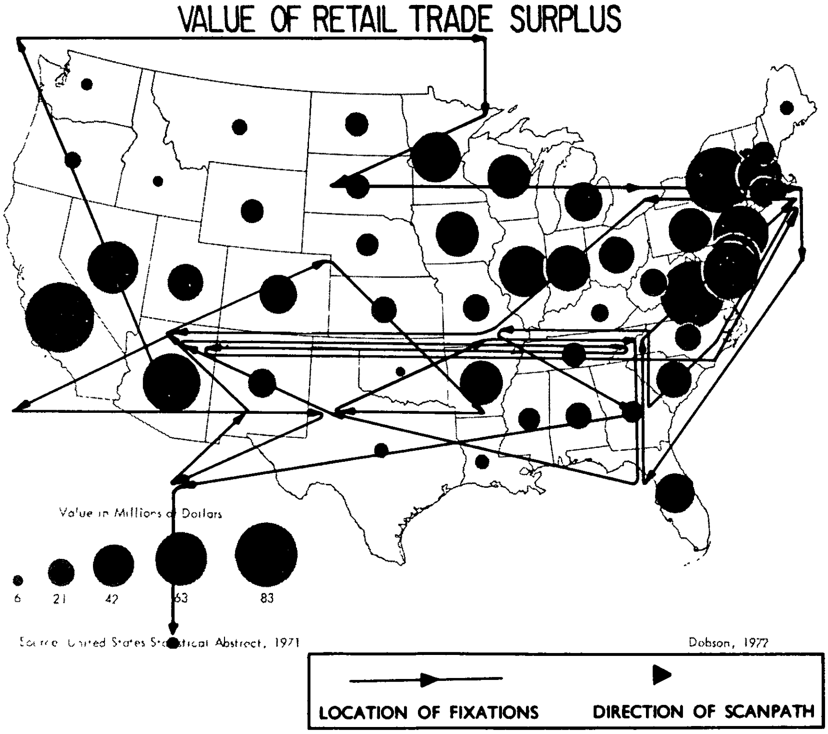


Figure 2. Map Reading: The Sequence of Fixations.
This display illustrates the sequence of fixations that one subject used to scan the display. The following two illustrations show scans for two other subjects.

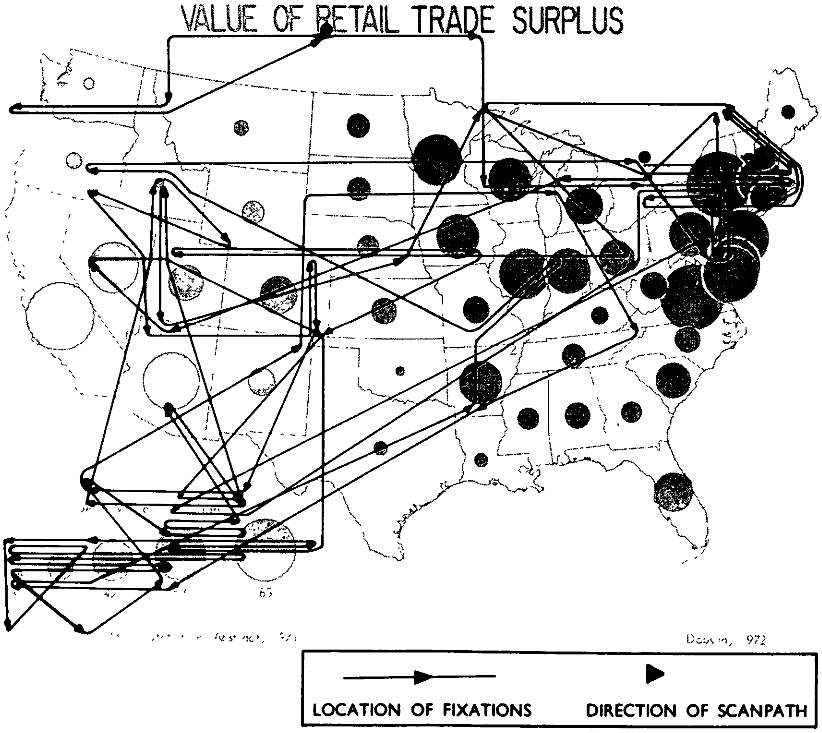
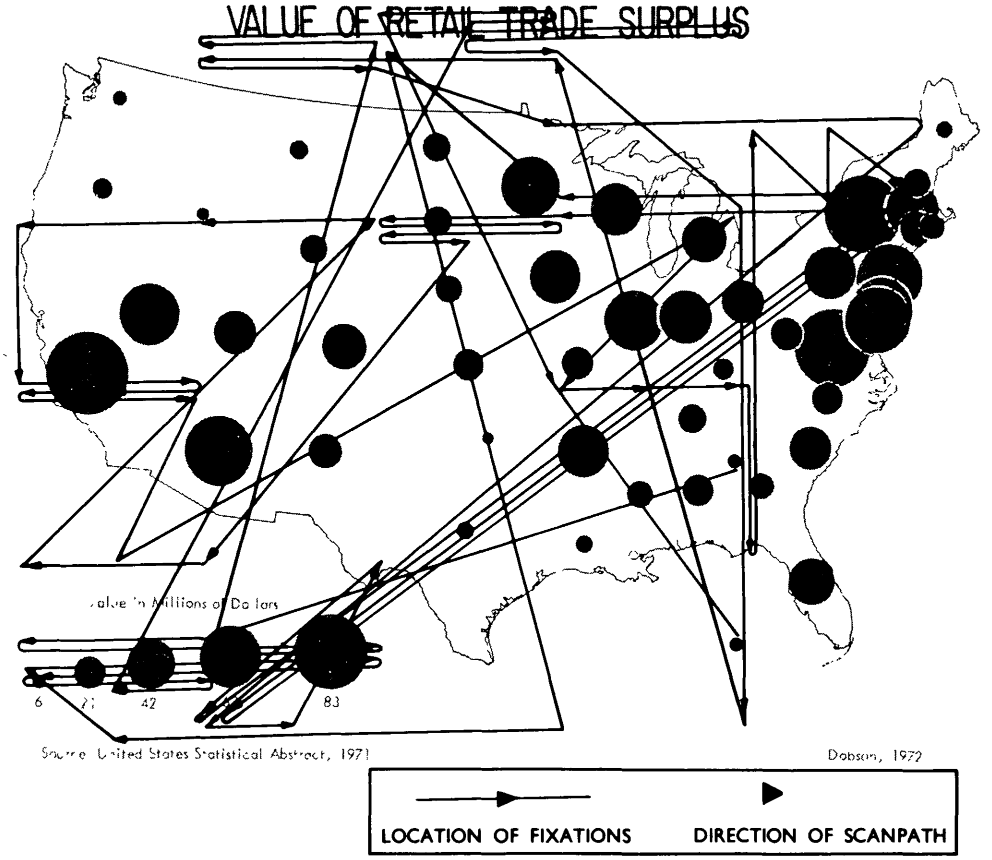


Figure 3



Source United States Statistical Abstract, 1971

Dobson, 1972

Figure 4

The initial phase of map reading consisted of a brief analysis of the look of the map. Attention was paid to the title, legend, and the data symbolized in the map body. Fundamentally, the initial scans were of a reconnaissance nature. After this exploratory behavior the readers settled down to a more comprehensive investigation of the variations in symbology. The major portions of the search time were spent in the more complex areas of the display. Specifically, those locations where symbol size and spacing were most variable were fixated most often with the eye movement patterns evidencing a strategy of sampling only particular locations on the map information matrix. It is quite obvious from an analysis of these scanpaths that these map readers were not processing the graphic image in the same sequence and also not always processing the same information.

GOAL SPECIFICATION

It is in this sense that we must realize that maps as systems are slaves. That is, they depend on outside sources for goal specification. The cartographer has a prominent role in goal specification yet we must additionally consider the map reader as a meta-organizer, that is, he determines and orders the priorities or the goals to be perceived. Typically perceptual tasks are those of discrimination, classification, and matching and we must assume that the viewer examines a map in one or all of these contexts. This in turn suggests that map reading is a decision making process during which the reader assigns some internal meaning to the perceptual experience. For instance if an experienced and a naive map reader were examining the exact same location on a display the pattern falling onto their retinal-neural systems is coded into a set of features that are not influenced by memory or any type of prior experience with the display. Thus both the naive and experienced readers have a retinal map of the same features. Once these bits of information are transduced and placed in storage, continued acquisition of pattern which we can call visual search, varies due to cognitive and experiential differences between subjects.

As cartographers we are, to some extent, unaware of the expertise or map reading ability that our prospective audience possesses. We would like to think that we know our audience and have a conceptual grasp of their abilities. Obviously we must accept that whatever population we address the aforementioned cognitive and experiential differences between map readers will stimulate different patterns of visual search. Nevertheless, as cartographers we would hope that our goal in producing the graphic is conveyed to the reader.

SUBJECT EVOKED VARIABILITY IN VISUAL SEARCH

Although we have postulated that the communication of the map message is hindered as a result of differences in goal specification by the map maker and the map reader it is obvious that the three subjects responded similarly to the displays that they viewed. At the same time there were individually oriented minor deviations in all aspects of visual search that were analyzed. Indeed there appears to be a constancy of performance induced by the "look" of the map and simultaneously a variability in performance evoked by the individual reader. The relationship of these two factors is critical since explanation of this interaction can provide an operational theory that can be used to explain the patterns of visual behavior observed in this example.

We must consider search as a multi-faceted process that is composed of two distinct components -- acquisition and identification. Identification is largely an internal process that relates to categorizing the stimulus. Acquisition however is a measurable process that includes the search for and isolation of the stimulus. Acquisition of an object for investigation can be an extrafoveal or foveal process as the reader may examine an object seen clearly in the foveal field or he may be attracted to a distant (extrafoveal) target. This necessitates that a reader must attend to the direct and clear signals of foveal vision and simultaneously consider the "noisy" transmission resulting from peripheral signal acquisition. In essence a viewer must both focus and disperse his attention during a fixation. This indicates that the momentary attention level for a point in central vision may vary, with an ensuing variation in acuity for that point (Schioldborg, 1971).

If there are numerous objects in the visual field we must consider that the subject is unable to totally isolate a target or his attention during visual fixation. As a result a subject's apperception is dynamic in both spatial and temporal terms. For instance while viewing a target the reader may notice what appears to be an informative object in a peripheral field. In order to overcome the uncertainty about this symbol the subject must foveally examine its location and it is possible that the location may have enough informational inertia to redirect the search procedure of the subject while causing him to devalue or forget his original task. Thus, during the search process goal orientation is a dynamic process. Due to the interactions listed above the sequence of search during map reading cannot be expected to be highly similar. More reasonably, one would expect that the sequence of symbol inspection would be temporally dissonant. Significantly a sequence analysis of twenty subjects' scanpaths provided information leading precisely to this conclusion. Although this line of reasoning may seem unpalatable to the cartographer it does not indicate that the subjects examine different areas of the map, only that there is no common sequence to map reading.

MAP INDUCED CONSTANCY IN VISUAL SEARCH

The information matrix on a graphic display is not, however, examined solely as a function of the attentional properties of the reader. Rather, cartographic and data induced variability such as novelty, complexity, and affective tone combine to provide environmental factors that seduce the uncertainty of the reader and propogate an additional process of attention that can be termed "interest". In this light various portions of the display may attain informativeness as some function of their uniqueness in relationship to adjacent symbolic fields. In a sense, then, we may regard part of the matrix of symbols on the map as informative because they reduce the uncertainty of a specific reader, while we may designate other areas of the display informative to all readers because of characteristics inherent in the symbols themselves (pattern, texture, etc.). Subsequently, the reader interprets the display utilizing a dual search procedure interfacing his goals with those of the cartographer.

We must also consider that a map is a set of meaningfully related stimuli and for any set we can form various meaningful subsets. There appears, however, to be constraints that structure a map reader's patterning attempts. Consequently, the generalization that the reader constructs while examining the map consists of two antagonistic pattern variables -- order and complexity. The map is an entity that has some degree of structure as the result of the orderly relationship of its elements and subelements. These components, however, have multiple relationships with other elements which create a degree of complexity directly related to the order or look of the map. In essence map complexity results from each perceptual unit on the map being a whole with respect to its elements but a part with respect to the display informational environment. As a reader views a map he gradually evolves a pattern representation that has a unified character but at the same time consists of a multiplicity of events.

For the reader the patterns on a map are relatively unstructured or amorphous since the degree of perceptual organization is a function of the variability in context or environment. For instance the displays that were viewed consist of a variety of symbols that can be classified as dominant or recessive display elements. It is obvious that various structural attributes (size, shape, position, chroma, etc.) are so overpowering on a display that there will be dominant elements common to all regional patterning attempts. Due to motivational factors on the part of the subjects some elements are dominant only at individual levels. The eye movement analysis has shown that some of the perceived patterns follow naturally from the structure of the display due to the visual functional dominance of particular elements while other patterns or sub-patterns tend to reflect motivational dominance integrally related to unique subjects. In this context pattern acquisition on maps may be considered as consisting of a number of invariant choices structurally integrated with individually oriented dominant and recessive symbols.

SUMMARY

The interaction of map-induced constancy and subject evoked variability results in different subjects registering highly covaried fixation patterns although the individual map elements are fixated non-harmoniously in terms of sequence. This, of course, raises the interesting problem of viewing context. Display attributes can be rendered sufficiently dominant so that the cartographer can be sure that the reader will examine the element. It has been my experience, however, that no two readers access a display in the same sequence. Can informational equifinality result from non-harmonious acquisition of the same data items? I believe the answer is yes, but discussion of this topic goes far beyond the time we have available today.

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PSYCHOPHYSICAL RESEARCH AND MAP READING ANALYSIS

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In his monograph on "Method-Produced Error in Isarithmic Mapping,"[1] Joel Morrison described four possible sources of error which could seriously interfere with the cartographic communication process. These were: errors in the collection of the data to be mapped, errors produced by the cartographic methods employed, errors in map construction and reproduction, and map reading errors. If we assume that the original data to be mapped is error free, and that no errors are committed in map construction and reproduction, then we are left with "two potentially fertile areas for cartographic research," to quote Professor Morrison: method-produced error and map reading error.

A concern for method-produced error has long been shown by cartographers but has become of critical importance with the advent of computer-assisted cartography. In order to program computers to perform certain cartographic techniques, the techniques must be well defined in mathematical terms. This forces the cartographer to analyze his methods in terms of accuracy, efficiency, and communicative effectiveness.

A knowledge of map reading error is necessary in order to evaluate the communicative effectiveness of a cartographic technique. The study of map reading error should probably be the responsibility of educators, but it has long been neglected by cartographers and educators alike. Thus, we are gathered here for the purpose of discussing map reading error, how to analyze it and how to correct it. For my part, I am here to report on one approach to the problem, a systematic and experimental approach called frame-of-reference psychophysics. This approach is based on a very broad and far-reaching theory of behavior, the theory of adaptation level, developed by the psychologist Harry Helson.[2]

For several years now, cartographers and psychologists have been using various psychophysical methods to determine perceptual errors in reading map symbols. Perhaps the best known methods are those developed by the late S. Smith Stevens and his associates at Harvard University. These are generally called scaling methods because they generate scales in the form of generalized equations from the perceptual responses of individual test subjects. Stevens is best known for his insistence that all perceptual responses should follow a generalized power law expressed by the equation $R= S^n$ or response equals a constant, k, times the stimulus raised to an exponent, n.[3]

The problem with Stevens' view of psychophysics is that it is too rigid, too narrow. Ironically, just as Stevens' view replaced the narrow views of Gustav Fechner and his followers, we must now replace Stevens' view with a broader more systematic approach. Specifically, two arguments may be brought to bear against Stevens. First, the sacred exponent, n, in his power law varies with the conditions of the experiment. Although Stevens accepted this fact, he never offered a sound explanation for it. A second, more powerful argument stems from the fact that the general form of the psychophysical law depends upon the measurement scales employed. As pointed out by the psychologist R. Duncan Luce in 1959,[4] if an ordinal response scale is used with a ratio stimulus scale, then the resulting graph is of the general form of a logarithmic equation. If a ratio response scale is used, as Stevens advocated, then the graph may be in the form of an exponential equation. A more general approach to psychophysics was needed to account for the different exponents in the power law and the differences in psychophysical methodology resulting from the use of different measurement scales.

Before discussing the results of my work with frame-of-reference psychophysics, let me briefly describe the adaptation-level theory. Adaptation-level theory is based on two principles: the bipolarity of responses or judgments, and the pooling of stimuli. Bipolarity means that judgments of any phenomenon are made along a bipolar scale, that is, along two scales which extend in opposite directions, such as hot and cold, bright and dark, or heavy and light. Where each pair of scales meets there is a point or locus of points which is neutral. This neutral reference point is called adaptation level. As distance from adaptation level increases along either of the two scales, the intensity of the sensation increases; so for example, we can go from a purely neutral response to one that is dark, very dark, extremely dark; or in the other direction one that is bright, very bright, extremely bright.

The location of adaptation level, the neutral response, with respect to any given stimulus scale varies from individual to individual, and from one test condition to another. This dynamic aspect of adaptation level is a direct result of the pooling of stimuli. By pooling I mean that adaptation level is the product or pooled effect of all stimulation both past and present. All available stimulation is taken into account before a judgment or response is made. If the condition of the stimulus changes, then the adaptation level will change. Since individuals have been exposed to very different stimuli in the past, their response to a given situation in the present is going to vary with their own level of adaptation.

Certain kinds of visual stimuli may be classified as follows: focal stimuli are those which the individual focuses on; contextual stimuli are those which form a background for the focal stimuli; anchoring stimuli are those which are used as a basis of comparison with other stimuli; and residual stimuli include past stimulation recalled from memory, and any emotional of affective influences which may occur in perception and cognition. In short, the theory postulates that the prevailing adaptation level is the basis for an individual's perceptual judgments and behavior in general.

Adaptation-level theory was first proposed as a possible explanation for map reader response to graduated circles by Kang-tsung Chang in 1969.[5] My first experiment was simply designed to show that the theory of adaptation level could be used to explain the effects of anchoring stimuli on map reading in general. Since Professor Chang had used graduated circles, I chose to test visual map complexity and found results very similar to Chang's.[6] Different anchoring stimuli caused different group responses, and the differences could be explained quantitatively by adaptation-level theory.

Next came a more challenging task, that of reformulating Stevens' power law to include adaptation level as a parameter. Professor Helson had already reformulated Fechner's logarithmic law,[7] but a simple substitution of adaptation level in place of the constant, k, in the power law could not be validated empirically. It was necessary to make another important substitution before the reformulated power law could be empirically equivalent to Stevens' formula. If the stimulus value is redefined in terms of its distance from adaptation level, then this new value, called S_a, may replace the original stimulus value in the power law, and adaptation level may replace k, so we have $R=(AL)S_a^n$ as the formula for the reformulated power law.8/ In essence, we are saying that an individual judges a stimulus in terms of its distance from adaptation level.

To demonstrate this empirically, I went back to our old reliable stand-by, the graduated point symbol, and tested both circles scaled according to apparent value, and squares conventionally scaled.9/ Once again it was shown that anchoring stimuli, in the form of different map legends, caused a shift in the adaptation level of test subjects, and their overestimation and underestimation of the graduated symbols followed the general form of the reformulated power law. One other consequence of this most recent experiment was empirical evidence that the construction of graduated circles according to an apparent value scale, such as devised by James Flannery, does not correct for the underestimation of circle size ratios. It was shown that the assimilation effects of a single anchoring stimulus were the cause of overestimation and underestimation, so that scaling the graduated circles was not as effective in correcting the problem as using several differently sized circles in the map legend.

Many problems have been encountered during the course of my research, and not all of them have been solved. The most persistent problem seems to be in defining adaptation level quantitatively in terms of the different kinds of stimuli that contribute to it. However, this is simply a mathematical problem, an empirical problem that will be worked out in time. With the data we now have from Jon Kimerling's experiments on the equal-value gray scale,10/ I think we can come to grips with the relationship between focal and background stimuli, and their respective contributions to adaptation level.

A second problem area, which I feel is a tremendous area for research, concerns what I call the map gestalt, interpretation of the map as a whole. What psychophysical research has come up with so far is little bits and pieces of a much larger puzzle. Each piece of information gathered in our research has a much larger meaning when placed in the context of the map as a whole. Our experiments have, of necessity, been conducted in isolation; we isolate particular elements of a map for testing, and we discover how the map reader reacts to this particular map element. The map reader's reaction may be different when that element is placed within the context of a very complex map. Map complexity itself requires a gestalt approach because many different factors contribute to both visual and intellectual complexity. I think most cartographers would agree that a multidimensional approach must be taken in this area, but there is probably little agreement beyond that point.

The role of past experience is an especially bothersome problem. How do we measure it, or take it into account? We assume it is responsible for individual variation, but just how does it work? Through education and training we can control to a large extent the experience of map users. This is already an important justification for map reading instruction in the public schools. If we can modify individual adaptation levels to a greater or lesser extent through training, then we ought to be able to get map readers to react similarly to our cartographic products. By similarly I mean each individual should be able to grasp the basic meaning of any given map. That is one purpose of cartographic education. The map reader may interpret the map in many other ways as well, but the basic meaning of the map ought to be conveyed to every individual who picks up the map and reads it.

Finally, one of the most interesting applications of adaptation level may lie in the general problem area of cognitive mapping and spatial behavior. Again if we can modify an individual's adaptation level, then we can probably predict the individual's response to any given situation. The mental conception that an individual has of a place depends on his attitudes, preferences, and experience; in other words, it depends on his level of adaptation to his environment. As his preferences, attitudes, and experience change (as his adaptation level changes), an individual will change his cognitive map. Nowhere is this more evident than in the work of Denis Wood,11/ who travelled through Western Europe with a group of naive young mappers, college-age students. As their knowledge and experience in various European cities grew, their cognitive maps and spatial behavior changed dramatically.

If we assume that an individual's spatial behavior is based on his mental conception of space, then the changing role of adaptation level has obvious consequences. The problem is in determining adaptation level by measuring preferences, attitudes and experience. This is the problem we should be attacking first. If we know an individual's level of adaptation, we can predict his response to any given environment, and we can reconstruct his cognitive map on this basis. The same logic should apply at the group level. The solution is not a simple one by any means, but it is only one other area of research to which the adaptation-level theory may be applied.

With this in mind, we as cartographers should apply the knowledge gained through frame-of-reference psychophysics to our map design. Those of us who are educators should apply this knowledge to our instruction. The widespread applicability of adaptation-level theory and its frame-of-reference methodology offers cartographers the unique opportunity of developing a "New Cartography" based on principles of map perception and cognition, a cartography which is more responsive to map users both in the classroom and in the environment at large.

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IN PURSUIT OF THE MAP USER

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INTRODUCTION

Man's uses of maps are highly varied. Some are simple — a simple locational map for a familiar environment is a good example (it serves superfluously as a navigational device, and might be better assayed as an advertisement). Others are exceedingly complex — examples are numerous, the best probably being reference maps which present masses of data for visual integration and correlation. Some operations and activities depend for their success directly on effective map use; in other situations the role of the map is subtle, but no less critical.

While many maps are created every year, there has been too little evaluation of their use and effectiveness. Further, many maps seem to have been developed without real understanding or concern for the map user. The focus of this paper is on the map user, first, with concern for the man-map behavioral system and, second, with several suggestions about research which might help us understand the map user better. For the cartographer, either as a producer or a researcher, the principal issue is that the map user will be reading the maps which have been prepared for him.

USER, MAP, AND ENVIRONMENT

While there are many things that the cartographer can examine to develop an understanding of the map user and the effect of a particular map, the most critical is behavior — the ways in which the user interacts with the environment (by environment we mean simply the world external to the user). A simple model may be helpful in understanding the relationships among man and his cognitive atlas, his behavior, maps and the environment (Figure 1). The center of concern is man himself, with particular focus on his cognitive atlas. The cognitive atlas is the collection of an individual's cognitive maps, those "images" resident within his memory upon which he relies for guidance in carrying out spatial activities

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(Downs and Stea, 1973). There has been a great deal of work done in cognitive mapping, but there is much more to be learned about the origin, development, and use of these maps, and about their role in spatial behavior. How do the maps in a cognitive atlas guide and encourage patterns of spatial behavior? What effect do these cognitive maps have on the decisions which are made about paths from one place to another, about locations for activities, and so on? What is the role in behavior of maps created for the user by cartographers? How have these cartographic maps shaped the maps in the cognitive atlas, and how are these physical artifacts used directly in environmental interactions? What is the effect of different map designs (different graphic structures and visual hierarchies) on the reading of a map and in the retention of mapped information, on the assimilation of information and its subsequent use?

These questions and others are raised not as separate and individualized problems but rather in the context of a man-map behavioral system. It appears that only by considering map use problems in this context is it possible to arrive at the most reasonable map design solutions (Dornbach, 1967).

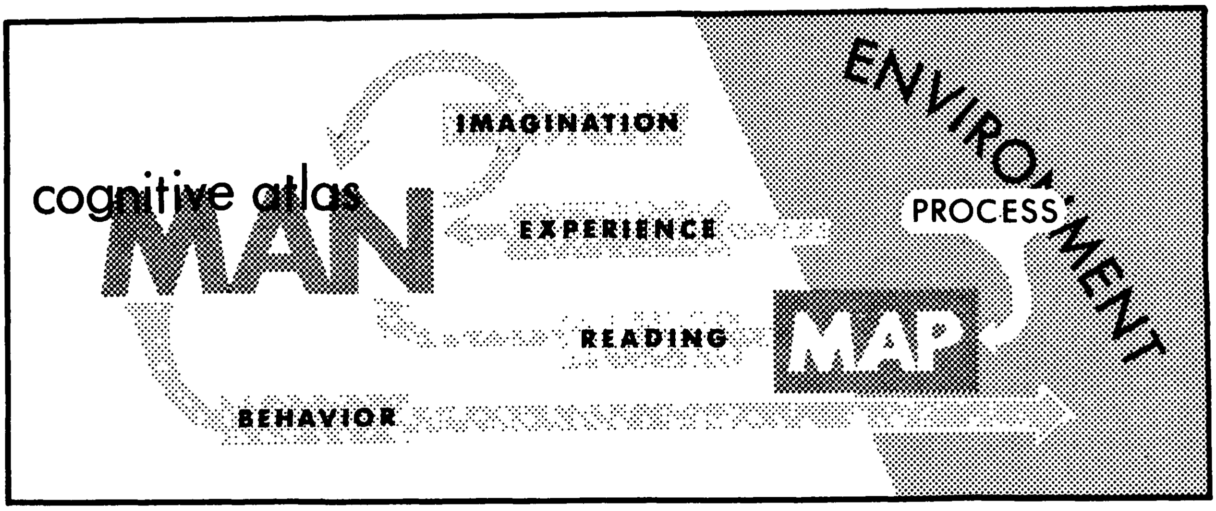


Figure 1. The relationships among man and his cognitive atlas, his behavior, maps and the environment.

IMAGINATION, EXPERIENCE, READING

There are three processes which contribute to the creation of a person's cognitive atlas: imagination, experience, and reading.

By imagination we refer to internal creative activities of the individual. Using the environmental information at his disposal, the map user creates mental images for areas which he has never experienced or "read" about (i.e. has never seen maps of). He takes other maps from his atlas and extrapolates from them, producing a personal image — fictitious to be sure — of areas which he has never seen or heard about. There are an extraordinary number of examples of such creative activity. Post has presented a large number in his ATLAS OF FANTASY (1974). Real world examples are numerous; unexplored areas have served as foci for cartographic expression of imagination — the 1566 map of North America by Zalteri is a good example as are the many cartographic creations representing the "Great American Desert." The role of imagination is an important element in the structure of cognitive maps, from the personal space (home turf) of the child and the economic behavior space of the adult to the cosmographic views of individuals and civilizations.

Experience is the second process by which an individual develops his cognitive atlas. This process has been much discussed and there have been many studies (again, see Downs and Stea, 1973). Experience is the most important process in the creation of cognitive maps of small areas, of the localities where individuals live and work. The process of acquiring information, the development and the continuous modification of the extent, content and structure of an individual's maps of an area is most complex. In order to understand these maps, to determine their characteristics, a variety of different techniques have been used.

Of these techniques the personal sketch map is probably the most important. From Lynch's IMAGE OF THE CITY (1960) to the present time, researchers have been able to learn a great deal about the effect of different spheres of activity and attitudes on individual comprehensions of the environment by having the map user draw a map of an area and its features. Different individuals and groups, or the same individuals and groups at different times, have different cognitive maps. Wood (1973) has shown how cognitive maps develop and evolve in novel environments, while others (including Orleans, in Downs and Stea, 1973) have shown how economic status (and the attendant patterns of mobility), age, and other factors promote differences in cognitive maps and in those aspects of behavior which are highly dependent on use of these maps. Gould, for example, has examined residential preferences, regional images, and environmental ignorance (Gould and White, 1974).

To illustrate the role of experience in map formation, we present two sketch maps of Old Sturbridge Village (an outdoor historical museum in central Massachusetts), drawn by visitors who had been in the village, in the first case, once and, in the second, numerous times (Figure 2). With the maps is a planimetric view of the village, overprinted with a reference grid. This grid has been compiled onto the other two maps to give some indication of how both the extent and the spatial structure of this area have been recalled from the cognitive atlases of these two map users (McCleary and Westbrook, 1974). Note that the sketch maps do not cover the entire area of the village, only those sections of the museum experienced by these visitors. Note further that the space in some areas is much compressed or greatly enlarged relative to the whole.

We can introduce the role of reading by presenting two additional sketch maps of Old Sturbridge Village (Figure 2). These were drawn by two students who had never visited the village but who had studied two different maps of the village as part of a class assignment. With the two sketch maps are small segments of the two maps which they had studied; note that the designs of these maps are markedly different, particularly the graphic hierarchies. The response to the sketch map exercise reflects this difference. The two sketch maps produced were drawn from memory and reflect what these two readers learned from the maps which they studied. It appears that the graphic structures of the maps had a marked effect on the image which the map readers retained. (It is important to note that other students working with the two maps exhibited similar responses and, further, that the two

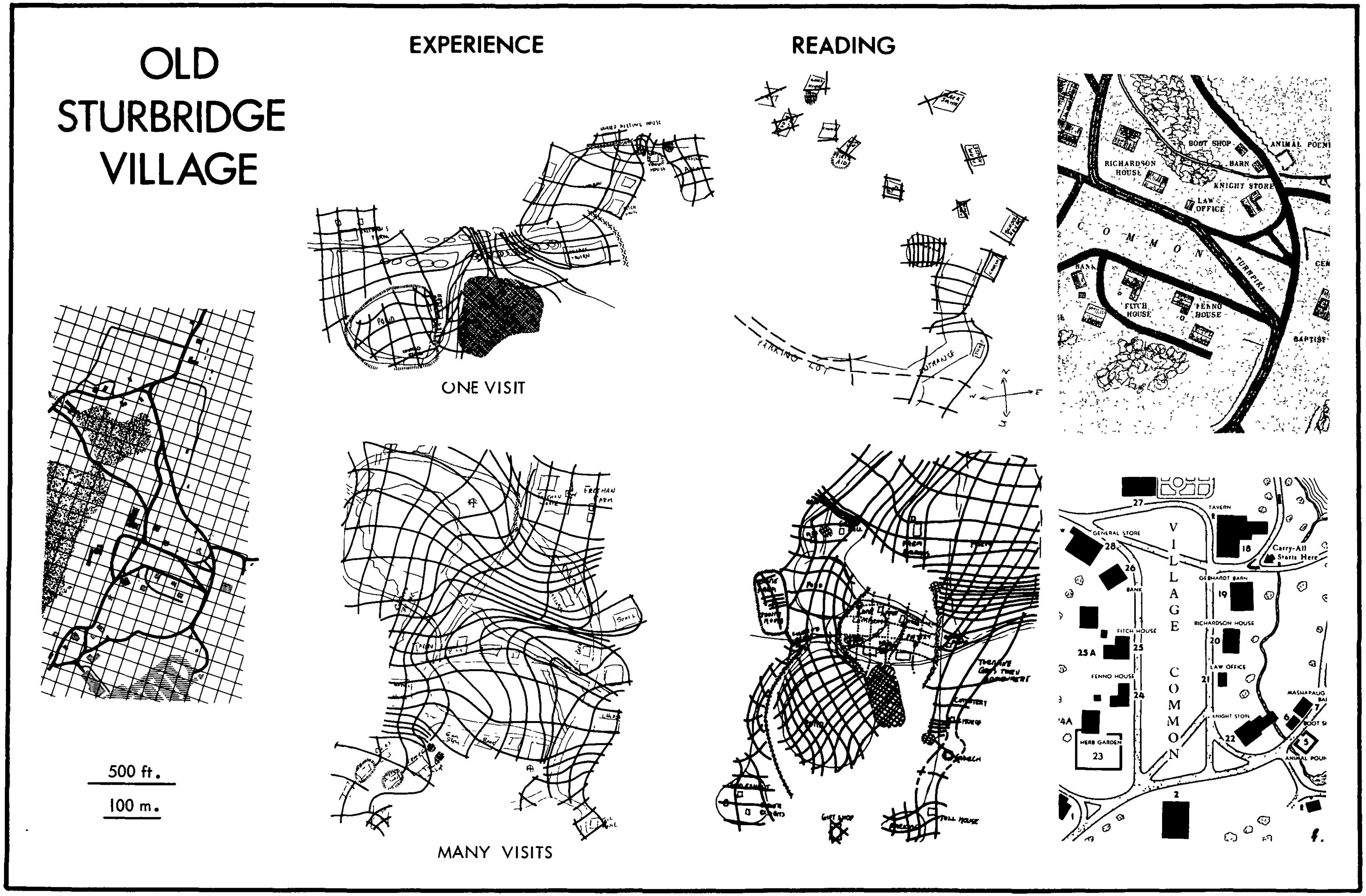


Figure 2. Four sketch maps of Old Sturbridge Village, illustrating the role of experience and reading in the formation of the cognitive map. The grid from the base map (on the left) has been compiled onto the four sketch maps. The two maps at the far right are those studied by the persons who drew the two sketch maps next to them. (See text for additional discussion.)

individuals chosen appear — from the other evidence — to have similar attitudes and "operating styles" in their map-use behavior; thus, the difference in the sketch maps probably reflects principally the characteristics of the maps studied, not the nature of the two users).

There are many questions about map reading and about map readers. There are many studies, covering different elements of the map and different use situations. For this symposium, for most cartographers, the most important research problems probably lie in the map-reading portion of the map learning (or cognitive atlas development) process. It should be recognized, however, that both imagination and experience operate together with reading in the development and evolution of any individual cognitive map. At some scales, for some places, for any of a number of reasons, one of these three may be much more important than the others, but all three will contribute to the formation of a cognitive map.

While imagination and experience could be explored at greater length, in the balance of this paper we shall devote our attention to map reading and to research problems in this area. The concern here is with methodology and particularly with one technique, the psychophysical law and its use.

THE USER AND HIS TASK

Too often, the cartographer approaches the map user and the map reading research problem with his attention focused on the wrong element. As Dornbach (1967) has pointed out, the research process must proceed with the map user and the map use situation continually at the forefront of the cartographer's thinking. While this has been the case in some research studies, in most it has not.

The research done by experimental psychologists working to understand the process of visual perception has served as the example for cartographers who have explored, for example, the functional relationship between the physical size or tone of a symbol and the value associated with the symbol as perceived by the map reader. If such a relationship can be established, then it can be used in the design of maps. While a number of different experimental methods are available, there is the problem that many of them are not adequately understood and some (unfortunately) have been misinterpreted and used inappropriately by cartographers. Altogether too often the cartographer has begun by asking the wrong question.

If, for example, we consider the analytical procedures available for analyzing quantitative map symbols, where the primary concern is to establish a relationship between a set of symbols varied in size and a continuum of quantitative values, then we can look at two different types of procedures.

In the first, the continuum of values or symbols (or a segment of this continuum) is divided into a finite number of categories; in the analytical procedure the map user (operating as a test subject) partitions the continuum into equal intervals (Engen, 1972). In the second class of procedures, the observer makes a direct estimate of a magnitude, either by assigning to each symbol a value, or by establishing ratios among the stimuli in the series (Stevens, 1975). The first type of procedure is generally called "category scaling" (other names used include "equal-interval scaling" and "partitioning"). The second type of procedure has been called "magnitude or ratio scaling." The important consideration to bear in mind here is the task which the observer carries out; in one case the continuum is divided into a group of categories, while in the other values are assigned to the stimuli throughout the continuum. A third class of scaling procedures, poikilitic measures (which includes the just noticeable difference, or JND), is described by Stevens (1975); poikilitic measures are not applicable to the types of problems discussed here.

Engen (1973), Stevens (1975), and many others have discussed the complexities of psychophysics and have described and analyzed the different scaling methods, particularly the differences between category scales and magnitude scales. Comparisons of the results of studies in which both types of scales have been used have led to the conclusion that an observer's categories or equal-appearing intervals generally are *not* equal. They tend to be narrower at the low end of the scale and wider at the high end. Magnitude or (ratio) scales, on the other hand, do not suffer from this problem.

If categories and magnitudes are one important set of oppositions in the phychophysical analysis problem, then the difference between *estimations* and *productions* are a second. By estimations we refer to a task in which the reader assigns a value to a symbol, based upon his perception of the size of the symbol. By productions we suggest a task in which the reader "creates" a symbol to match a value. Important here is a conclusion stated by Stevens (1975,32): "A typical pair of experiments that employed both estimation and production . . . (shows) that magnitude estimation produced a power function with an exponent . . . that falls slightly lower than the slope produced by magnitude production . . . A similar effect occurs in all matching experiments." (The exponent referred to here is "a kind of signature that may differ from one sensory continuum to another," in the equation "$\psi = K\phi^{B}$", where ψ is the sensation magnitude, ϕ the stimulus magnitude and K a constant which depends on the units of measurement (Stevens, 1975, 13).)

The questions which then arise are the following: If a map user, presented with a map, is expected to extract from this map by "reading" values for individual symbols or for groups of symbols relative to one another (e.g. ratios of symbol sizes), then the symbols on the map should be scaled using a functional relationship derived from an experiment set up in that way. Further, since the user's task is to *read* the symbols, estimating values for them, then the symbol scale should be established on the basis of an estimation task, not a production task.

For example, Flannery (1971) developed an algorithm for scaling the size of graduated circles, so that the physical area of the circle and the map reader's perception of it would be consonant with the quantitative values represented. The procedure for scaling the circles was developed based on tests in which map readers were asked to estimate the sizes of circles presented on maps. With the data from these map reading exercises in hand, Flannery set down a procedure to scale circles so that the tendency to underestimate circle size differences would be "corrected." Other experiments have demonstrated the same tendency for circle-size difference underestimation (e.g. Ekman, Lindman and William-Olsson, 1963), while in one study Flannery's algorithm was found to improve the user's reading of this symbol (McCleary, 1963).

In contrast to the studies of the graduated circle, there are a series of studies of the gray scale. Kimerling (1975) (and a number of others before him) has attempted to "determine the functional relationship between the tone of a screen gray area and its perceived value" (119). Recognizing that the method of testing would have an effect on the functional relationship derived, Kimerling developed his scale using the philosophy that "one should choose the testing technique which most nearly parallels the cartographer's method of choosing equal intervals of gray . . . that . . . most closely follows the cartographer's method of gray scale subdivision" (124). The method chosen for his testing was for the subject to produce a gray scale by arranging from a large array of gray patches a series of nine (a category-scaling procedure).

It is interesting to note that many of the gray scales produced show results similar to Kimerling's; indeed, he concludes that his is so similar to that derived by Munsell that the relationship derived in his work "should be abandoned in favor of the well-known Munsell equal value scale" (125). Munsell derived his scale by using a category-scaling procedure, a production task. It appears that only Stevens (1957) and Chang (1969) have derived scales using estimation tasks and their results are different enough from all of the others to raise a number of questions about the readability of many of the gray scales commonly used. Like Flannery, Kimerling sought to develop an algorithm which would aid the cartographer in the preparation of maps; in this case, however, the test results are based on an unrealistic map reader task — we would probably not find the average map user reading the map in the manner Kimerling structured his test.

We have made no effort here to explain the basic aspects of psychophysics or to account for all of the work that has been done; this has been done by a number of authors, particularly Stevens (1975). The intention here is to suggest two things. First, psychophysics is an exceedingly useful methodology for studying many aspects of the map-reading process; Engen points out that "empirically, the power function is probably as well established as is possible for any quantitative relation involving the whole man, and better than any other in psychology" (84). It has proved to be a very versatile methodology and has been applied to many types of data, including attitudes and opinions. Second, it is imperative that cartographers use the methodology correctly and certainly from the proper perspective. We cannot expect effective map use (and behavior) if our symbol scaling (or any other aspect of map design) is based on a relationship derived from a testing program which has asked different or inappropriate questions. The questions which are asked should not parallel the cartographer's method for choosing or producing a symbol, but rather match what the user will do when he confronts the map.

GROUPS AND INDIVIDUALS

Different map users exhibit different "styles" in handling map data. Chang (1969) suggested, from a psychophysical perspective, the possible varieties of individual responses which can occur in the map reading process. For example, while most people will tend to underestimate the physical area of graduated circles, a few will estimate circle sizes correctly or overestimate the quantities represented.

There are many questions concerning individuals. Is everyone alike in their map reading characteristics, or are we all different? Is there one group of people who can be expected to respond with intragroup uniformity, distinctive in their responses from other groups? Most research efforts using the psychophysical law have looked only at groups; results from tests have been aggregated and the average "readability" of different symbols described. From what individual results were these averages derived? How much variability was there? Two experiments suggest directions for further investigation.

A group of 27 college students participated in a magnitude estimation experiment, "reading" the values of 33 graduated circles on six small map-like figures (Figure 3). Group estimates, expressed in terms of the value of the exponent in the psychophysical law, ranged from .68 to .87 for the six different figures; these results are consistent with the findings in other research on graduated circles. Individual exponents (shown in the lower part of Figure 3) ranged from .41 to 1.20. Some individuals proved to be consistent underestimators (the map user who provided the lowest single estimate, .41, had a range of exponents from .41 to .51 and proved to be not only the lowest estimator but also the most "consistent" in the group). Only one reader made estimates which followed closely the group average. There was one consistent "high-estimator," (range, .92 - 1.18) — he was actually reading the circles almost "correctly." Others showed much variability in their exponents on the different figures; two of these are shown in Figure 3.

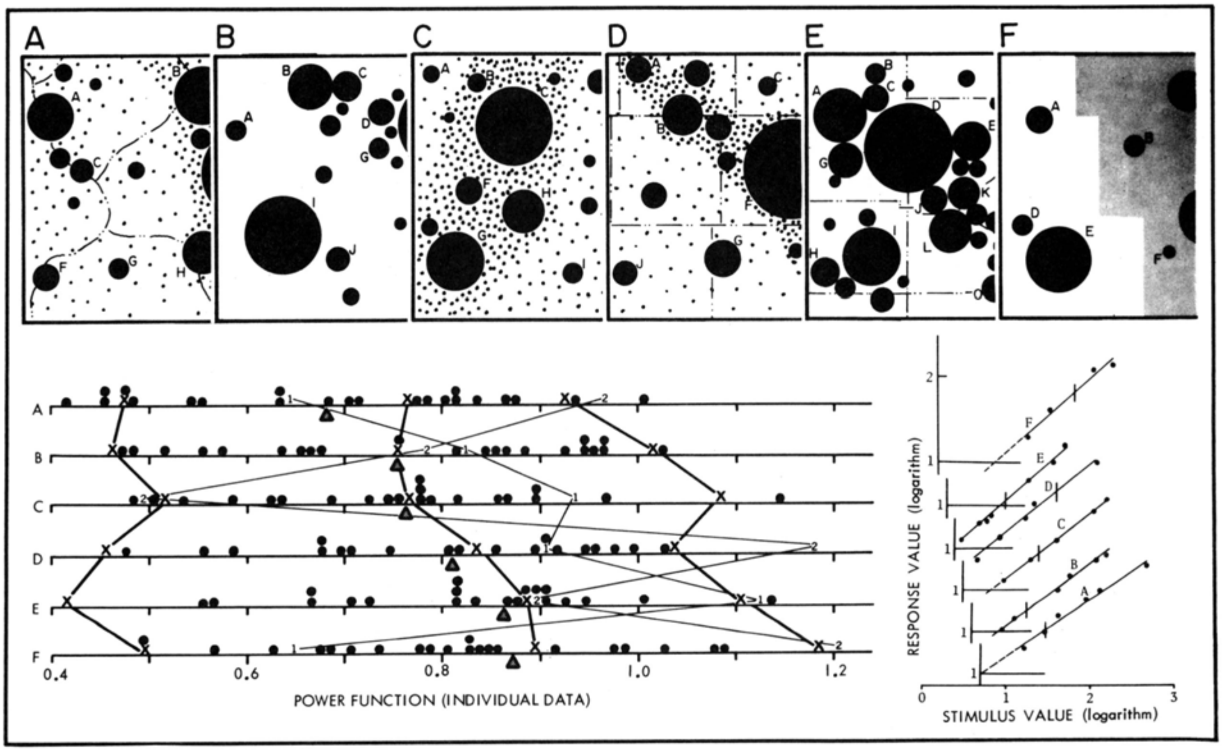


Figure 3. A map symbol experiment. Subjects were asked to estimate the sizes of four to seven circles in the six figures, using one circle in each figure as a standard (e.g. "If circle F represents 30 people, how many people do these circles represent: G, A, I, B, D, and E?"). Left diagram presents power function (psychophysical exponent) for subjects for each figure; the exponents for the lowest (and most consistent) estimator, for the highest estimator, and for the one nearest the group average (this average is indicated by the triangles) are shown, along with the more common (and highly variable) pattern of two other test subjects (see text for additional explanation). Right figure presents average group relationships of the six tests, with individual circles and location of the standard indicated.

There are a number of questions which arise about this test, the test subjects, and the results. While it is not the most advanced research into the problem, it certainly does indicate that there are a number of issues to be investigated, particularly why some readers provide consistent estimates and why others exhibit a great degree of variability. Further, why is it that some readers estimate sizes well above or below both the actual physical size and the average tendency; Cox (1974) provides some ideas, but more remains to be done.

An entirely different map reading task can be used to gain further insight into the characteristics of the individual map reader. Map readers were asked to draw boundaries between dots and groups of dots at positions where they felt the density of dots differed (Jenks, 1973, has reported on similar research). The actual arrangement of dots was random, but there was an overall uniformity of density in different parts of the test figures (Figure 4). Where differences in density were great (twice or more) between the different parts of the figure, boundaries followed a common path. Where the density difference between large regions was slight, and sometimes lost in the "noise" of the randomness of the distribution, the boundary lines were scattered across the surface.

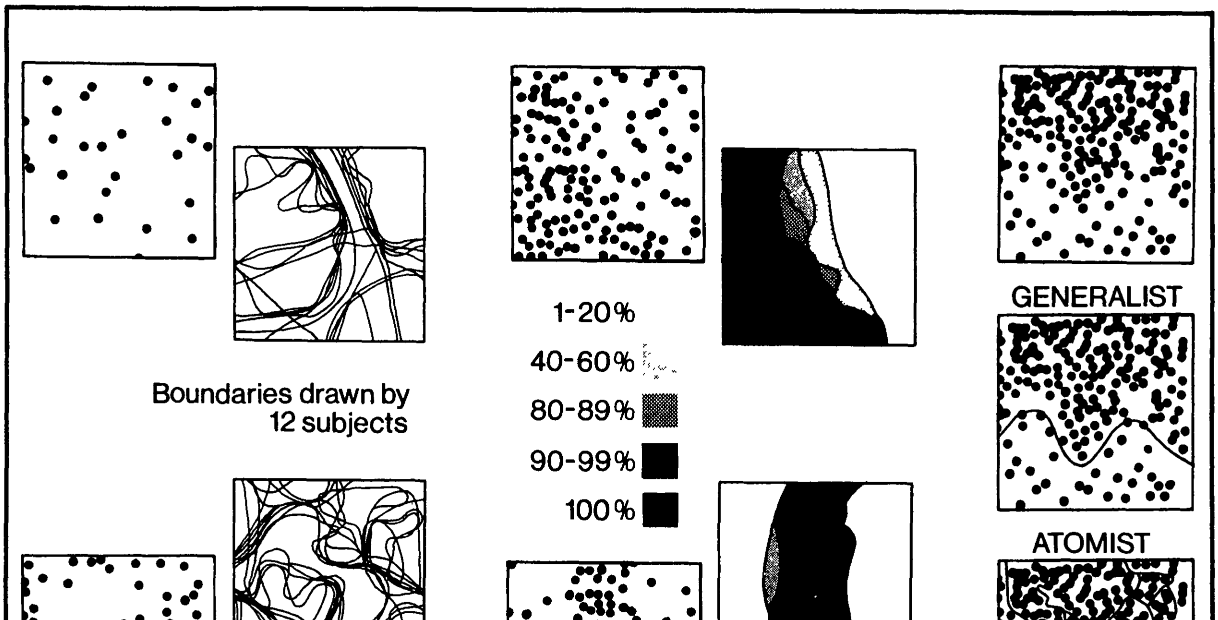


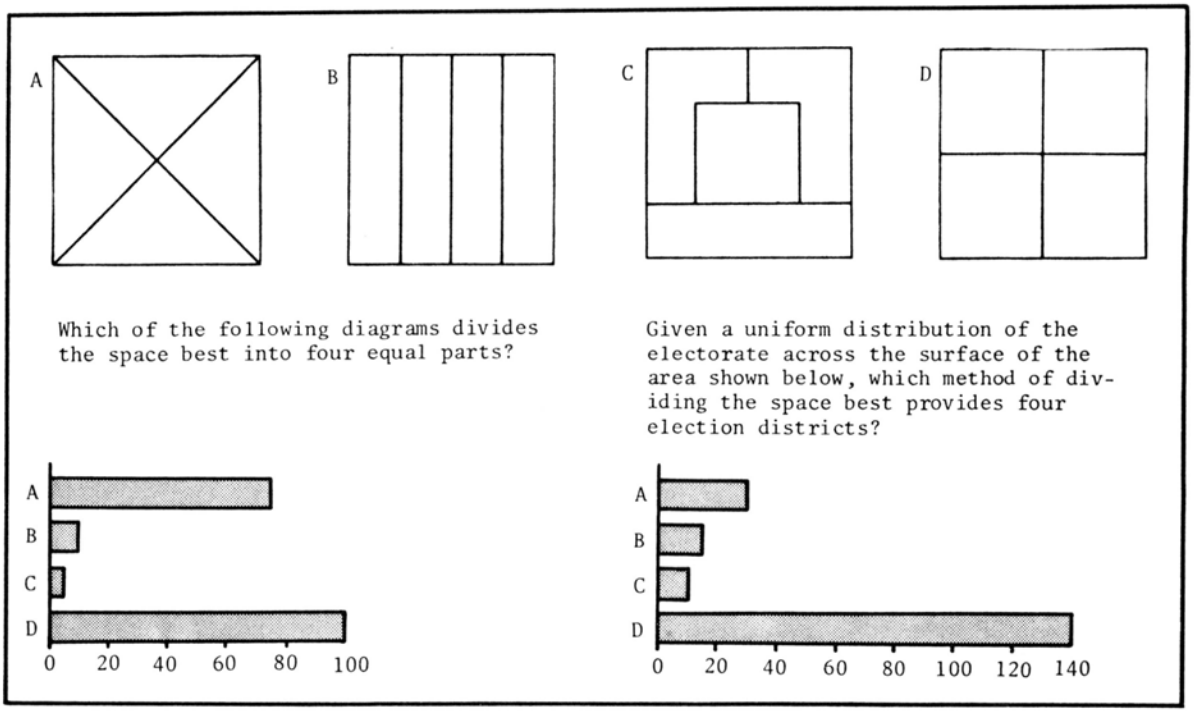
Figure 4. Selected results from a dot-density regionalization experiment. Subjects were asked to "draw boundary lines within each box which will separate dots into zones of different densities." On the left, two boxes and the boundaries drawn by 12 subjects. In the center, the percentages of 41 subjects grouping dots into zones on the left side of the top figure and around the center in the bottom one. On the right, a sample test box, the boundaries drawn by a generalist and an atomist.

With regard to individuals two distinct styles emerged as they carried out the task. These approaches are designated, for lack of a better terminology, the atomist and the generalist. For the generalist the lines are schematic and the "attitude" expressed by the boundary line drawn suggests a reductionist view of the image. The atomist, on the other hand, seems obsessed with detail and may have lost sight of the overall pattern of density. This tendency was exhibited by readers in other map reading tasks, and seems to characterize groups of map readers. No larger program of research has been developed to circumscribe further these two tendencies and define other characteristics of their practicioners.

Further research problems arise from questions which Lewis Rosenthal and I have directed to more than four hundred map users in the last few years. The ultimate aim of our work is to develop a better understanding of the use of maps and the role of maps in forming and reflecting spatial attitudes and behavior.

The two questions which we shall examine here are related to the four diagrams shown in Figure 5. These four diagrams, with their labels, appeared alone on a page with the question. In the experiment, which involved a total of twenty questions, the two questions here were the fourth and the thirteenth in the series.

> "Question 4. Which of the following diagrams divides the space best into four equal parts?"
>
> "Question 13. Given a uniform distribution of the electorate across the surface of the area shown below, which method of dividing the space best provides four election districts?"



Which of the following diagrams divides the space best into four equal parts?

Given a uniform distribution of the electorate across the surface of the area shown below, which method of dividing the space best provides four election districts?

Figure 5. Two questions from an experiment on the use of maps and spatial attitudes. (See text for further explanation.)

Note, first, that the four areas within the four squares are equal in size. Second, in the administration of the test, the order of the four squares was varied so that A did not appear first all the time, and so on. This alteration of order in the presentation of the figures had no effect on the choice in either question. What was different was the choice of the square on the two different questions.

In question 4, half of the map users chose D; most of the others chose A (few chose B or C). In question 13, three-quarters of the users chose D. Of the rest most chose A, with very few selecting B or C. Why? Quite honestly, we do not know. This, and other results from this test, suggests that the same space is different in different contexts. Preliminary sorting, in an attempt to ascertain individual patterns of response (sorting into atomists, generalists, and others) has raised further questions. The whole experiment suggests an extraordinary number of other research questions (among which is whether the order of the two questions has an effect — what if we had switched 4 and 13?).

CONCLUSIONS

This paper is, as a whole and in its separate parts, a suggestion. A model (so general that the term may be misapplied) has been suggested to help in understanding the map user, his cognitive atlas, and — ultimately — his behavior. We have attempted to sort out three activities by which the reader develops his cognitive atlas, looking in depth at the reading process.

We suggest that the cartographer look carefully at the methods of the experimental psychologist and, in particular, at the psychophysical power law. Psychological techniques have been used in a number of studies by cartographers, but in some cases the techniques appear to have been inappropriate or misapplied. The criterion here is the map user — one cannot ignore this most important element in the cartographic process. It is not only important, it is absolutely essential, that systems and standards for map design and symbolization be based on and developed from the perspective of the activities of the user.

Understanding of the user as an individual has been neglected. Perhaps we ask too much when we suggest a program to find out if there are individual differences. We know that such differences exist. We know that there is a great deal of variation in individual responses to similar types of map problems. To develop a reasonable and effective understanding will be time-consuming, frustrating and maybe impossible. It may, in the long run, not even be important.

What will be important about the work is that it should make us more aware — more aware of the user in the broadest possible way — more aware of the map production process and the need to do more than simply put data onto paper.

In an era when more maps than ever before are being produced and used, used to make decisions and direct behavior, used to alter both the physical environment and social and economic systems, it is imperative that we find out more about those who use maps, about those who will "behave" and "decide" using maps, about their abilities and attitudes. Their literacy, is the question. Cartographers need to know what and how well map users read, and then they will be able to write — and educate — accordingly.

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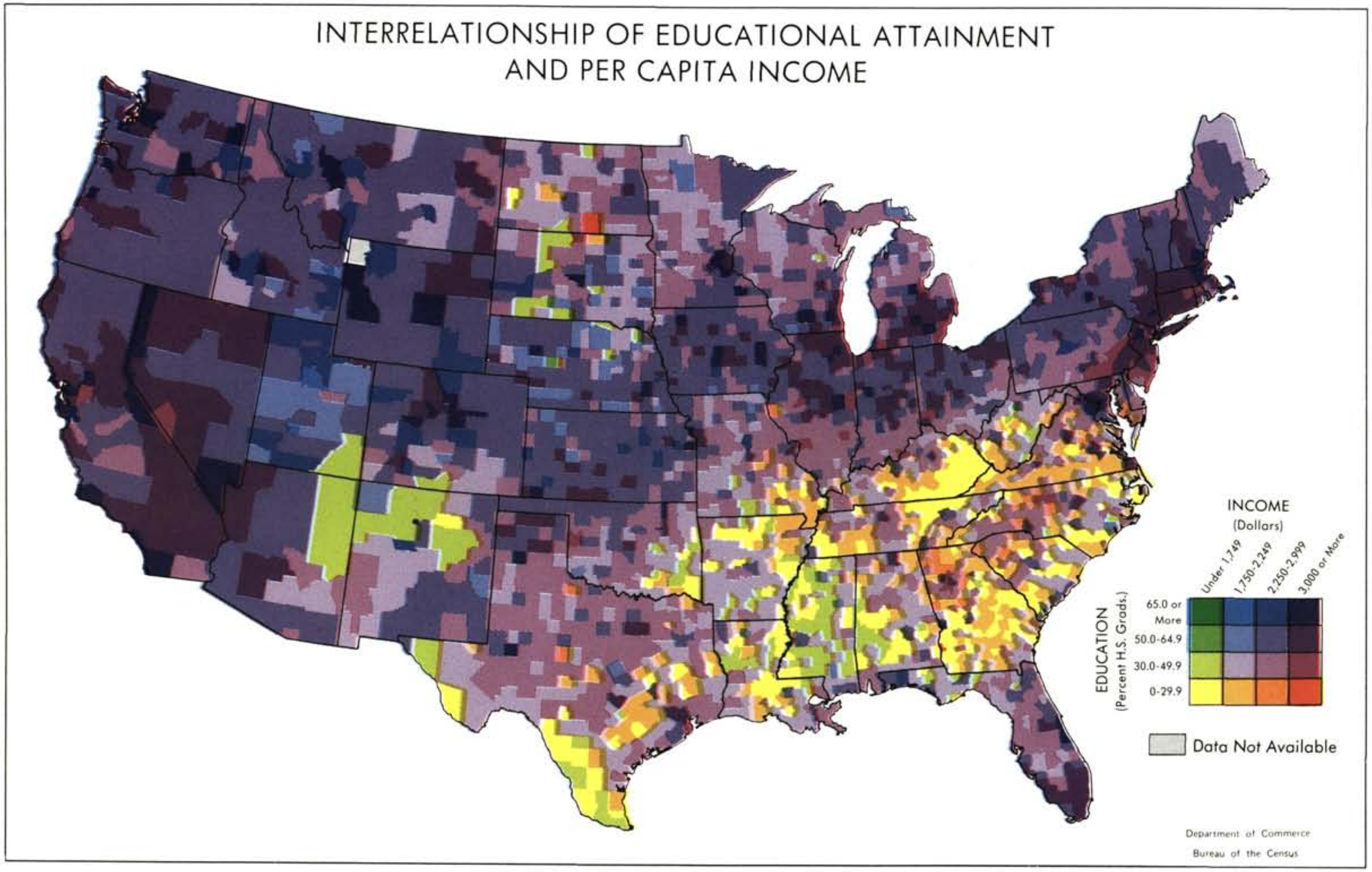
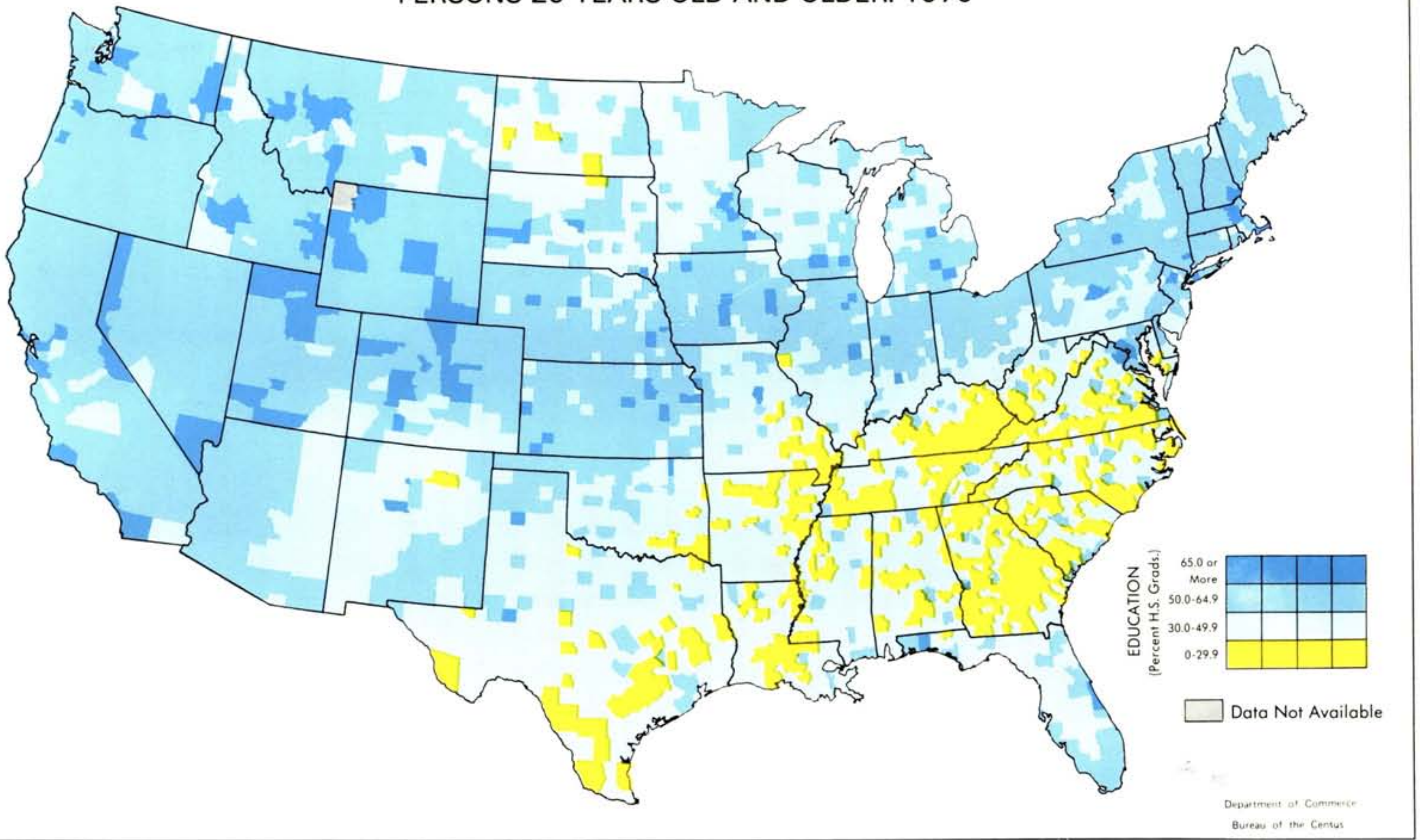


Figure 1. An example of a two-variable cross-map produced by the Bureau of the Census. (See pages 21 and 289.) Figures 2 and 3 on the following pages illustrate the individual maps that were used in preparing the cross-map.



HIGH SCHOOL GRADUATES AS A PERCENT OF PERSONS 25 YEARS OLD AND OLDER: 1970

Figure 2.

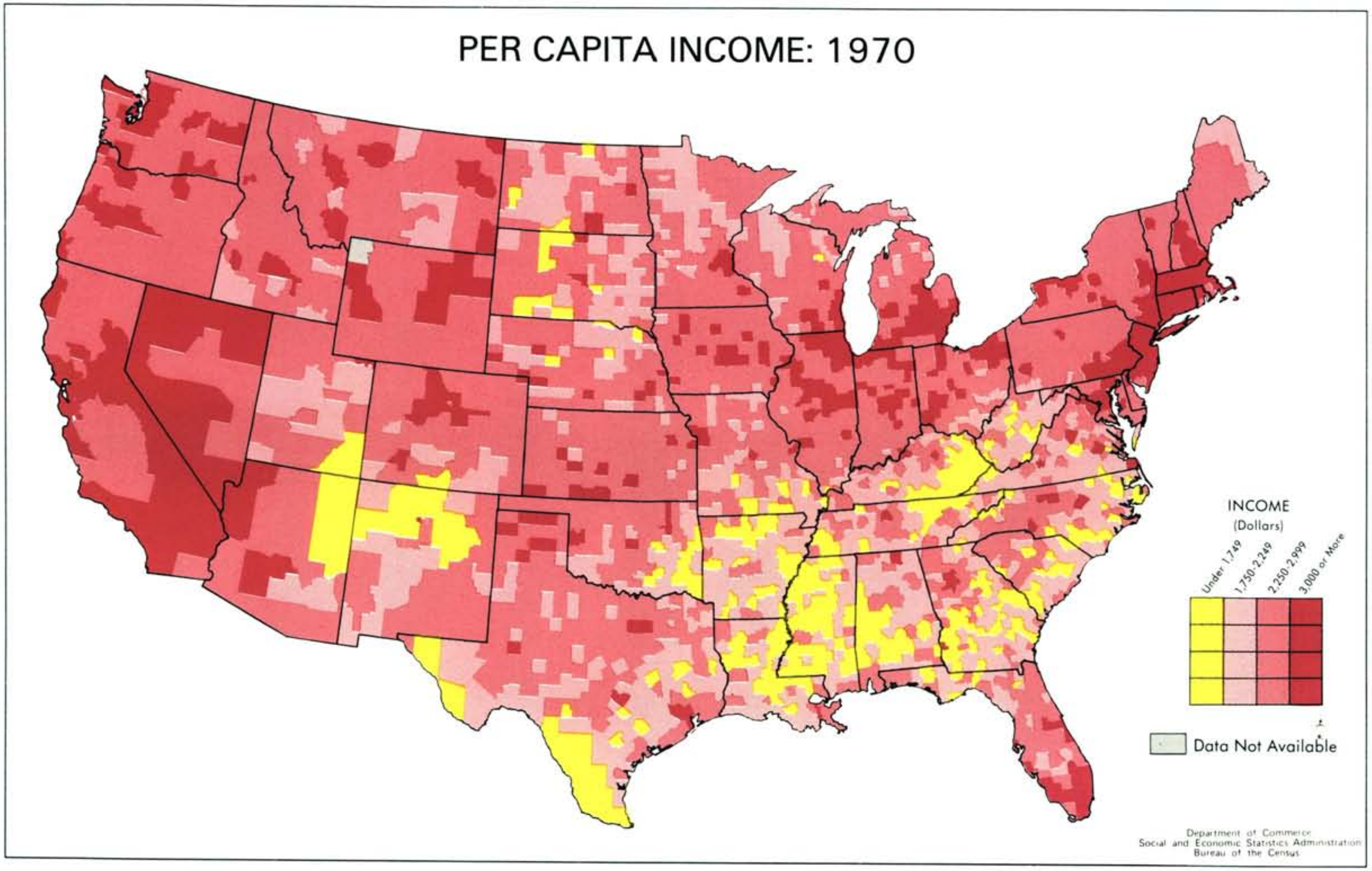
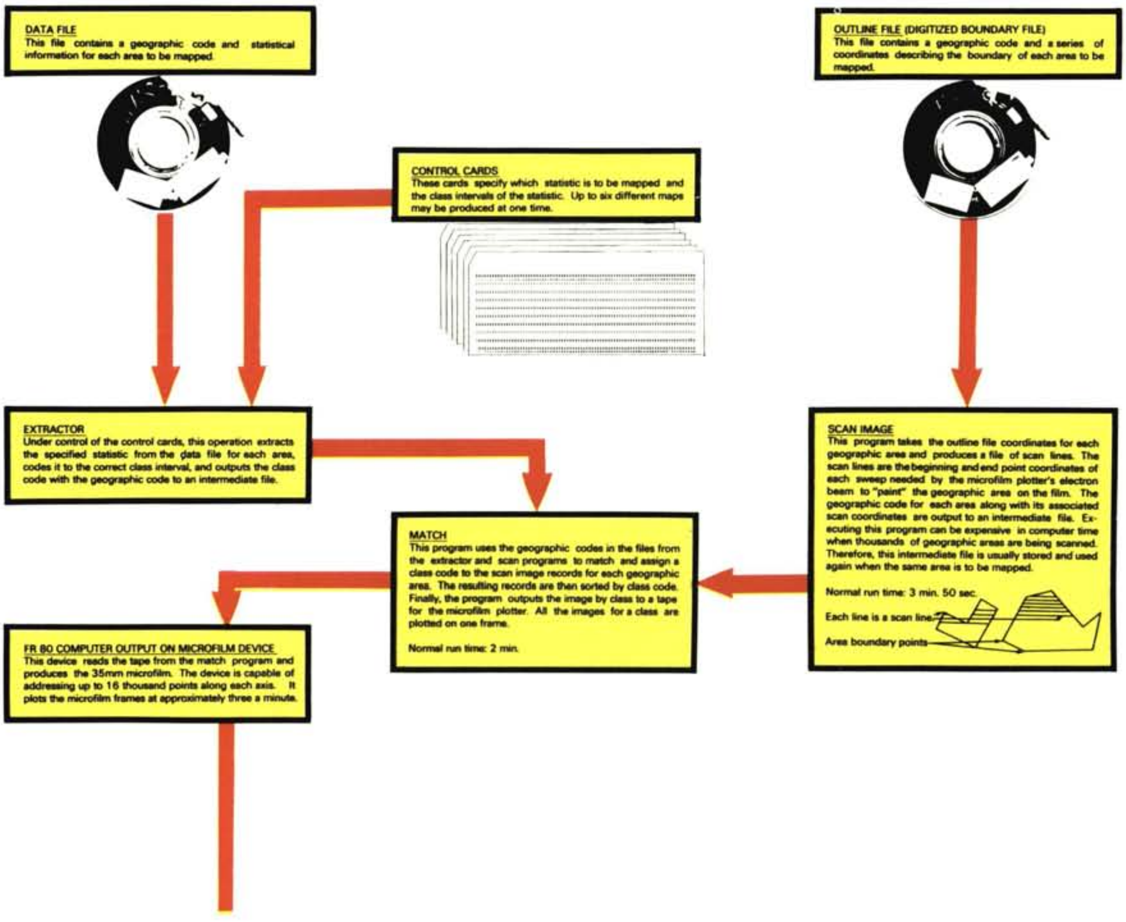

PER CAPITA INCOME: 1970
INCOME
(Dollars)
Under 1,749
1,750-2,249
2,250-2,999
3,000 or More
Data Not Available
Department of Commerce
Social and Economic Statistics Administration
Bureau of the Census

Figure 3.

MICROGRAPHIC MAPPING AT THE CENSUS BUREAU

Translation of Census data files and digitized boundary files to maps via computer output on microfilm.



DATA FILE
This file contains a geographic code and statistical information for each area to be mapped.

CONTROL CARDS
These cards specify which statistic is to be mapped and the class intervals of the statistic. Up to six different maps may be produced at one time.

OUTLINE FILE (DIGITIZED BOUNDARY FILE)
This file contains a geographic code and a series of coordinates describing the boundary of each area to be mapped.

EXTRACTOR
Under control of the control cards, this operation extracts the specified statistic from the data file for each area, codes it to the correct class interval, and outputs the class code with the geographic code to an intermediate file.

SCAN IMAGE
This program takes the outline file coordinates for each geographic area and produces a file of scan lines. The scan lines are the beginning and end point coordinates of each sweep needed by the microfilm plotter's electron beam to "paint" the geographic area on the film. The geographic code for each area along with its associated scan coordinates are output to an intermediate file. Executing this program can be expensive in computer time when thousands of geographic areas are being scanned. Therefore, this intermediate file is usually stored and used again when the same area is to be mapped.

Normal run time: 3 min. 50 sec.

Each line is a scan line.

Area boundary points

MATCH
This program uses the geographic codes in the files from the extractor and scan programs to match and assign a class code to the scan image records for each geographic area. The resulting records are then sorted by class code. Finally, the program outputs the image by class to a tape for the microfilm plotter. All the images for a class are plotted on one frame.

Normal run time: 2 min.

FR 80 COMPUTER OUTPUT ON MICROFILM DEVICE
This device reads the tape from the match program and produces the 35mm microfilm. The device is capable of addressing up to 16 thousand points along each axis. It plots the microfilm frames at approximately three a minute.

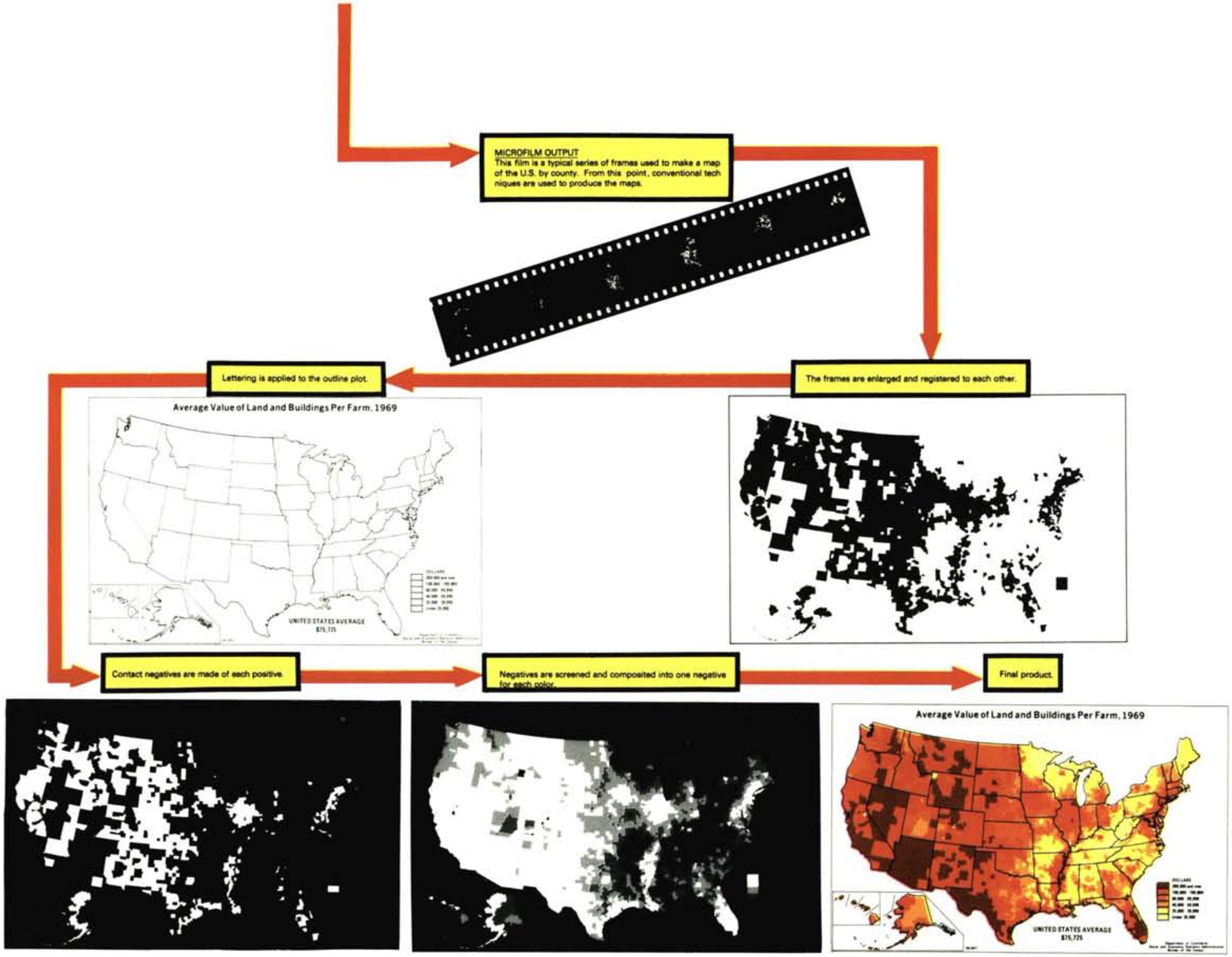
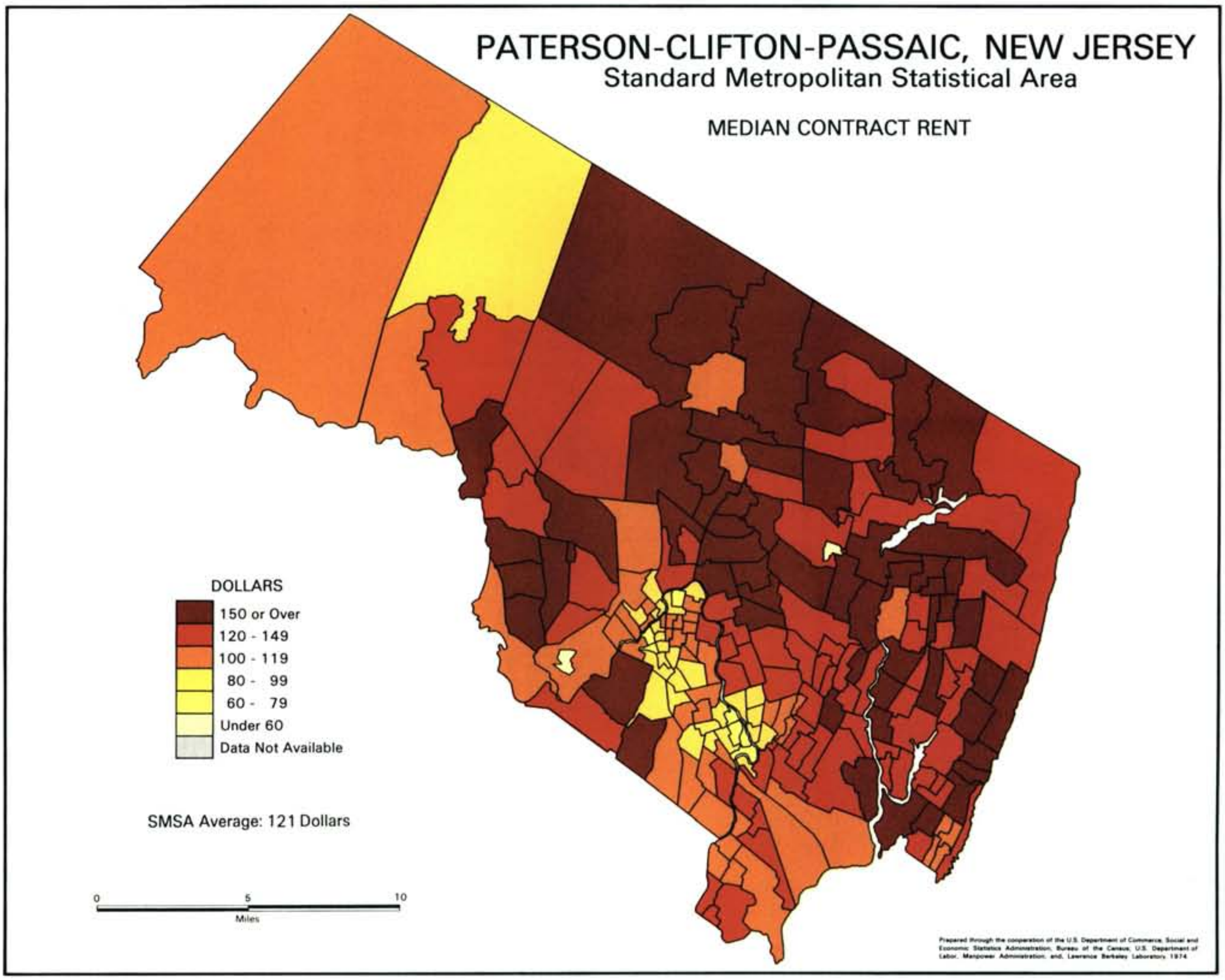
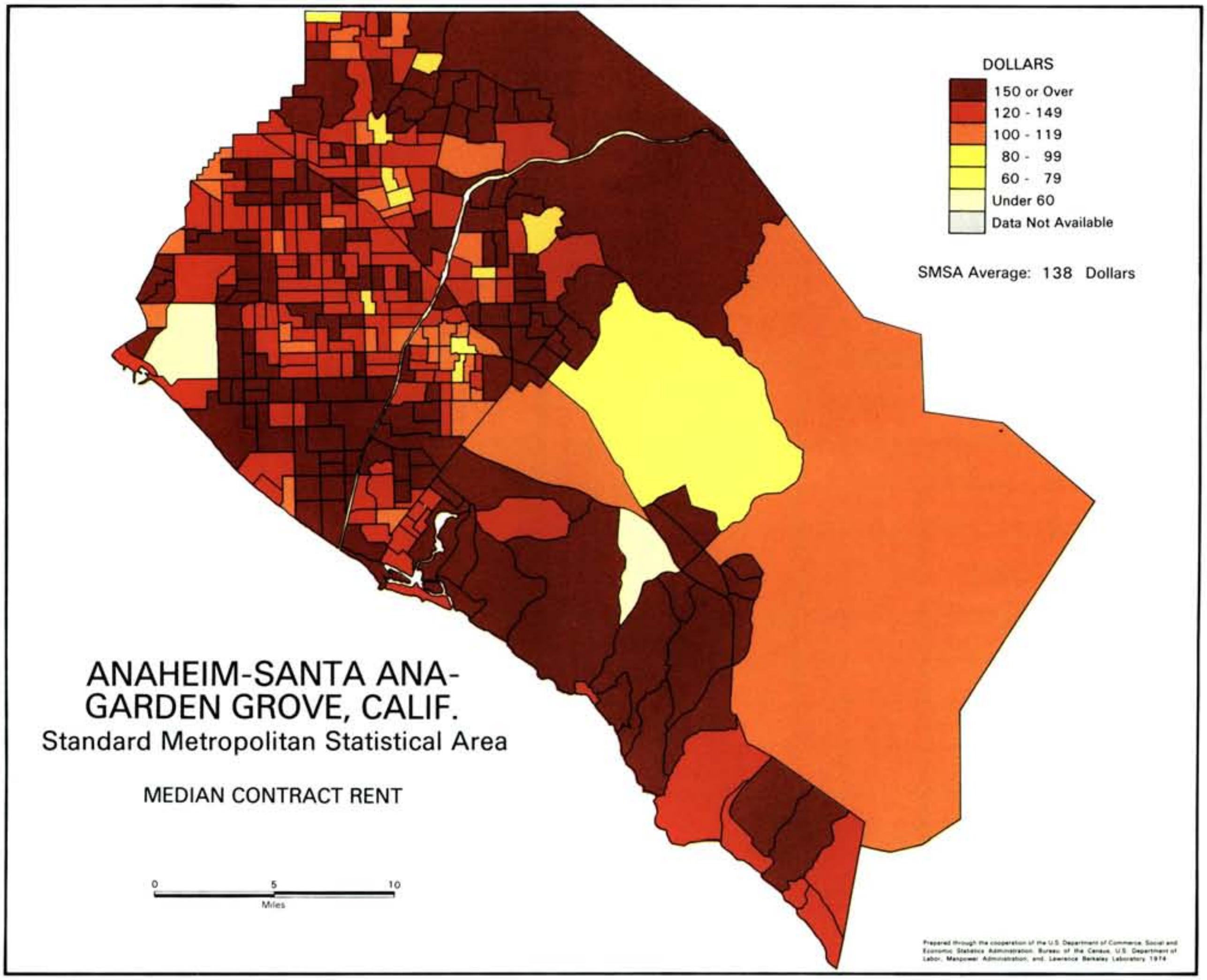


Figure 4. A diagram of the computer mapping system at the Bureau of the Census. (See pages 123-125.)



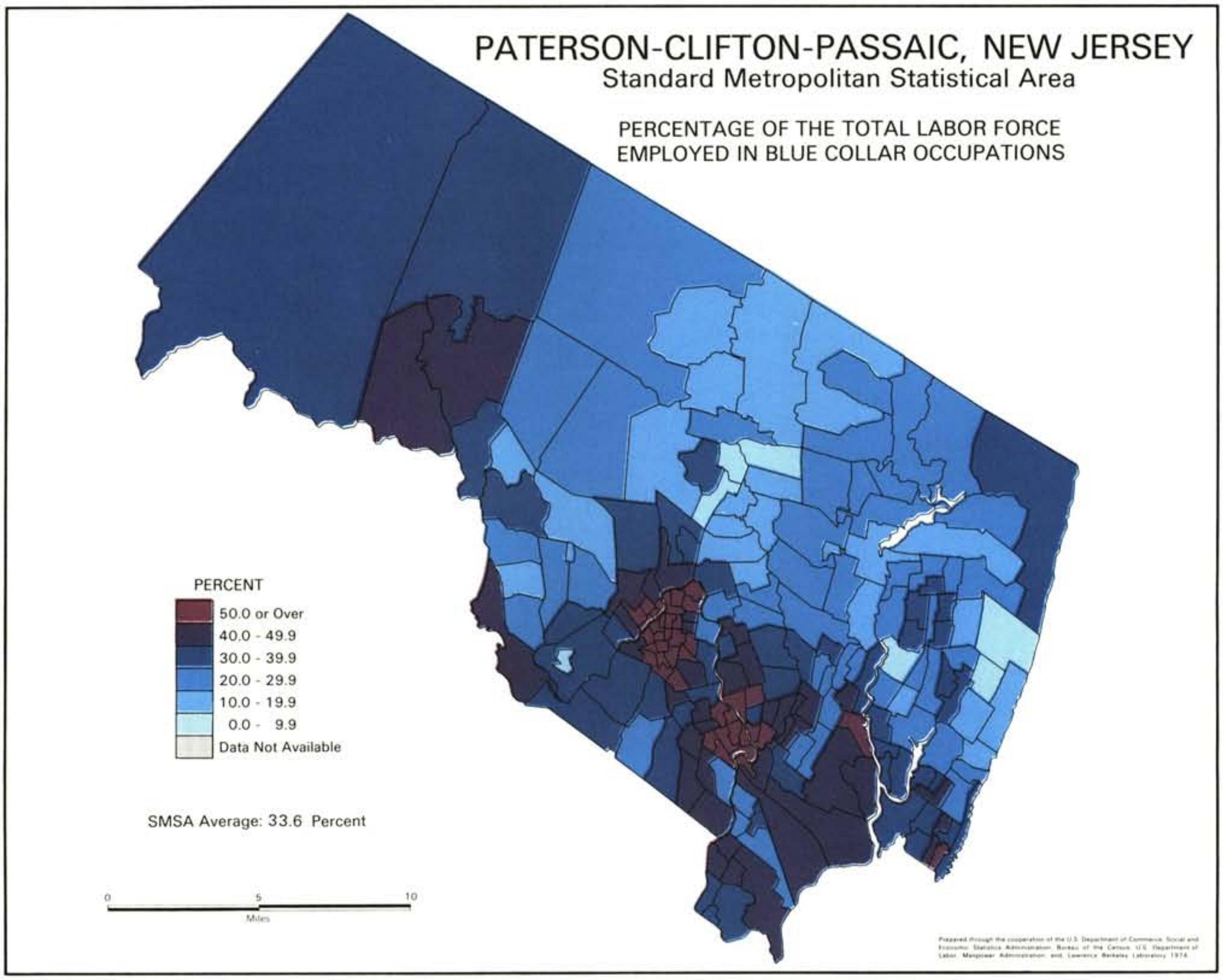
Prepared through the cooperation of the U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census; U.S. Department of Labor, Manpower Administration; and, Lawrence Berkeley Laboratory 1974

Figure 5. This figure, as well as Figures 6, 7 and 8, are reduced examples of the Census Bureau's Urban Atlas Series, described on pages 162-168.



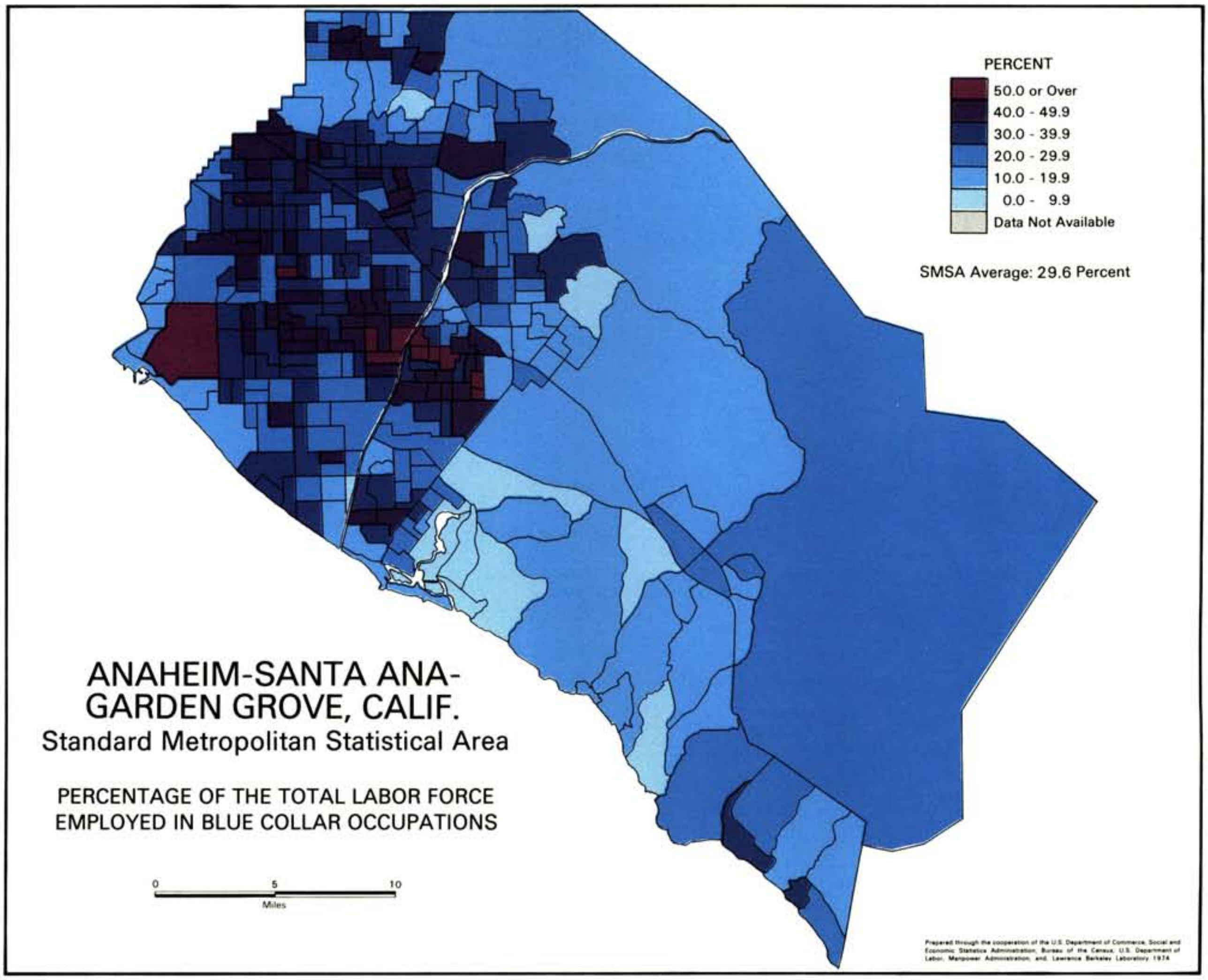
Prepared through the cooperation of the U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census, U.S. Department of Labor, Manpower Administration, and Lawrence Berkeley Laboratory 1974

Figure 6. The Urban Atlas Series was designed to provide a descriptive graphical presentation of basic social indicators from the 1970 census.



Prepared through the cooperation of the U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census; U.S. Department of Labor, Manpower Administration; and Lawrence Berkeley Laboratory 1974

Figure 7. The Urban Atlas Series, of which this map is an example, graphically presents by census tract 12 data items for the 65 largest standard metropolitan statistical areas. Individual census tract outline maps are included with each atlas to assist the user in relating the statistics to local landmarks and specific locations.

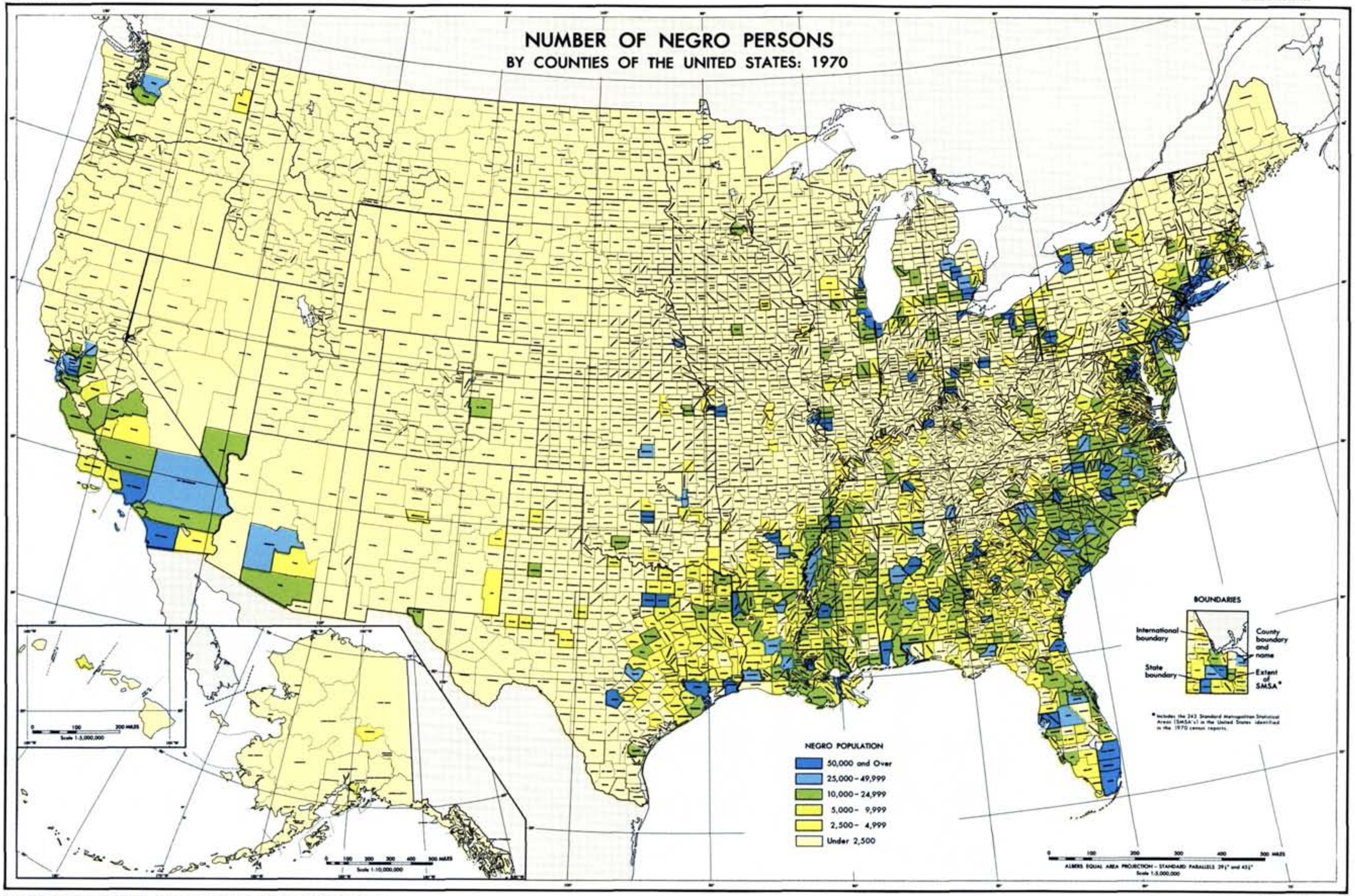


Prepared through the cooperation of the U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census; U.S. Department of Labor, Manpower Administration; and Lawrence Berkeley Laboratory 1974

Figure 8. This example from the Urban Atlas Series was produced by automated cartographic techniques.

UNITED STATES
DEPARTMENT OF COMMERCE

BUREAU OF THE CENSUS



* Includes the 243 Standard Metropolitan Statistical Areas (SMSA's) in the United States identified in the 1970 census reports.

Prepared by Geography Division in cooperation with Population Division, Bureau of the Census, Social and Economic Statistics Administration, U.S. Department of Commerce
Definitions of SMSA's from Office of Management and Budget, Executive Office of the President, February 1971
Population data from the 1970 Census of Population.

NUMBER OF NEGRO PERSONS
BY COUNTIES OF THE UNITED STATES: 1970

UNITED STATES MAPS, GE-50, NO. 47

Figure 9. An example of a choropleth map from the Census Bureau's GE-50 Series. (See p. 179.) A large county like Los Angeles is more prominent than New York City's 5 counties, which are relatively small in area but which have a much larger Black population.

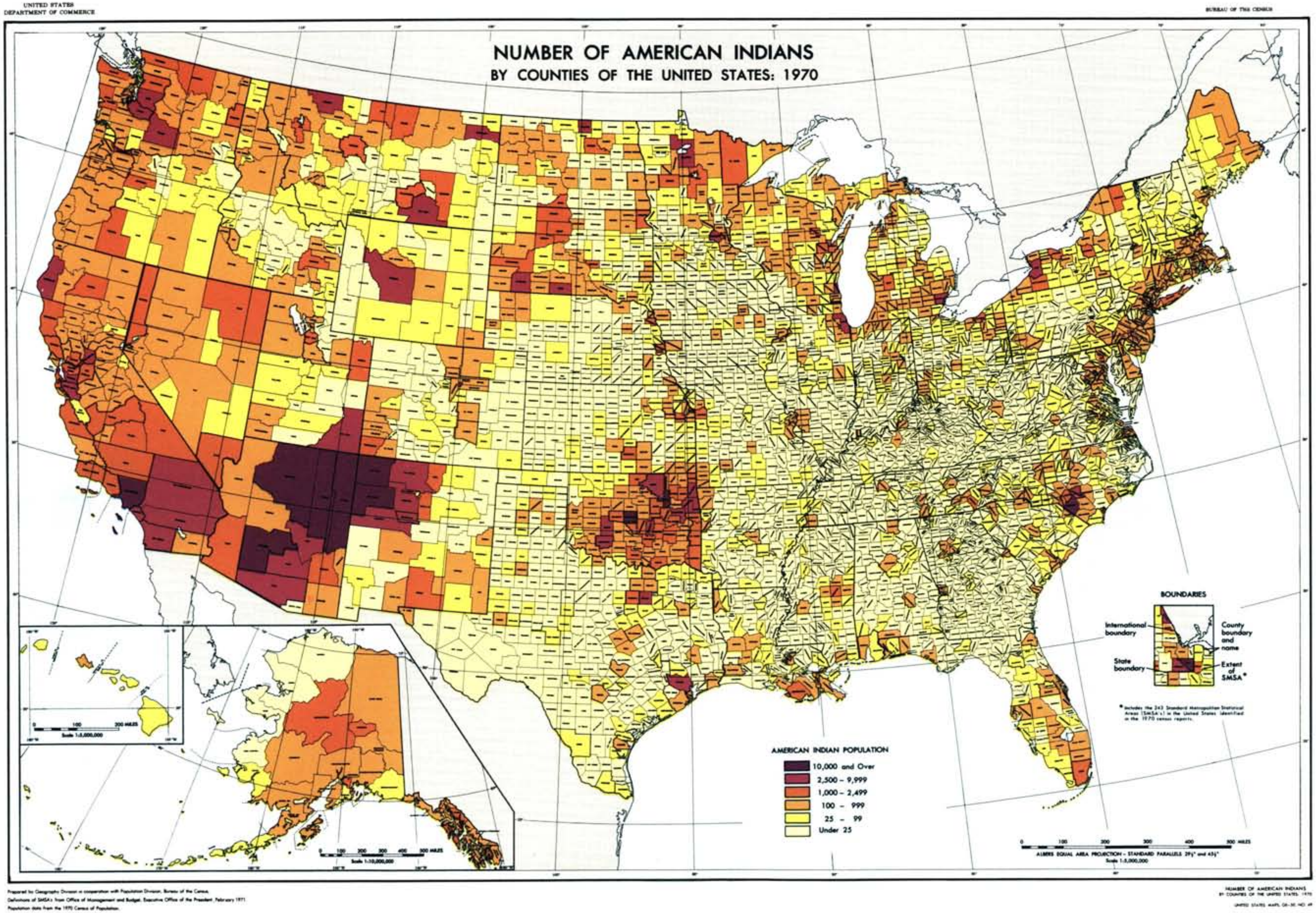


Figure 10. Another example of the GE-50 Series. Compare to Figure 11 on the following page.

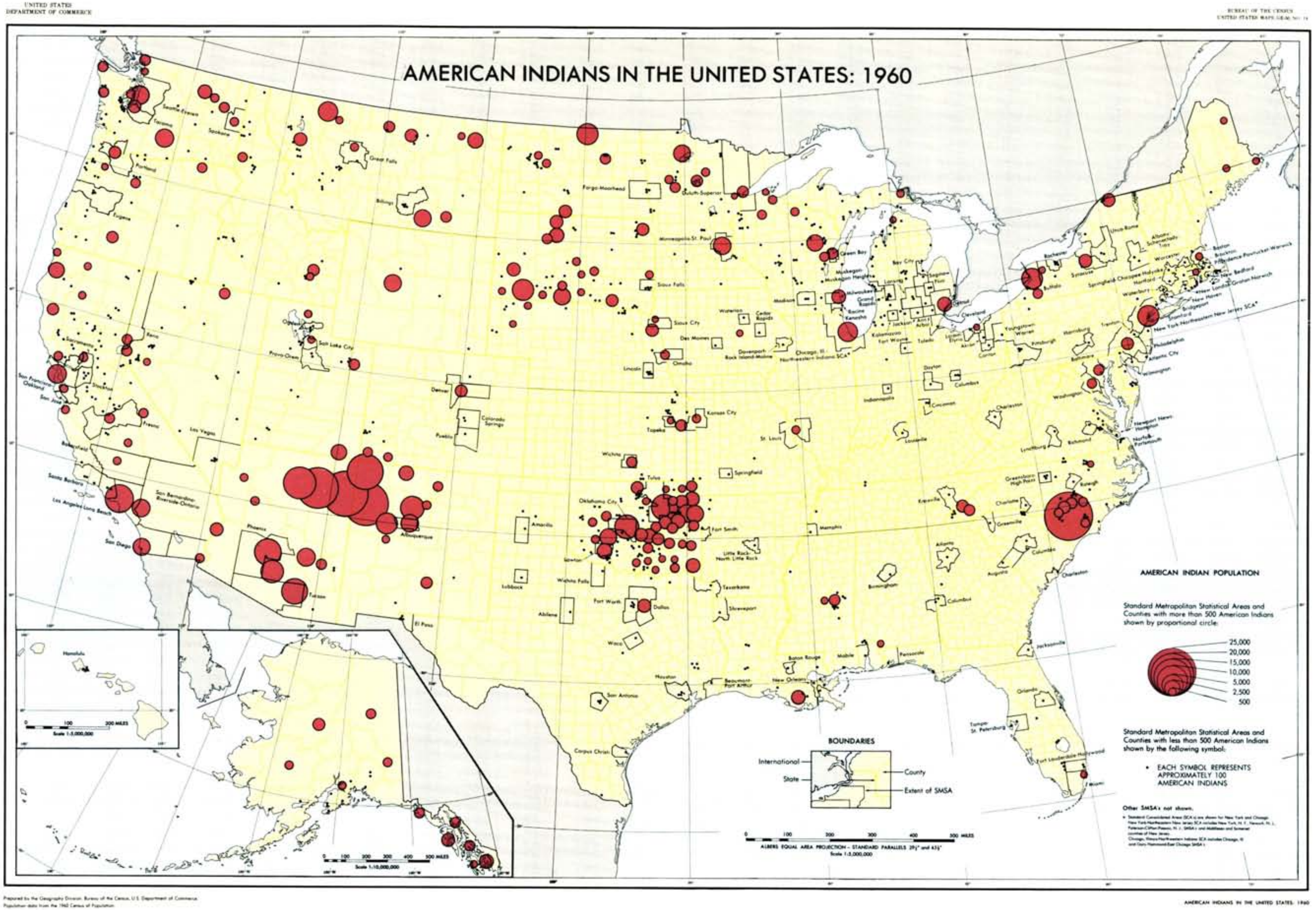


Figure 11. This map illustrating 1960 census data used graduated circles. This method seems to provide a more accurate picture since it does not emphasize those large counties with low population densities such as in Nevada or Oregon.

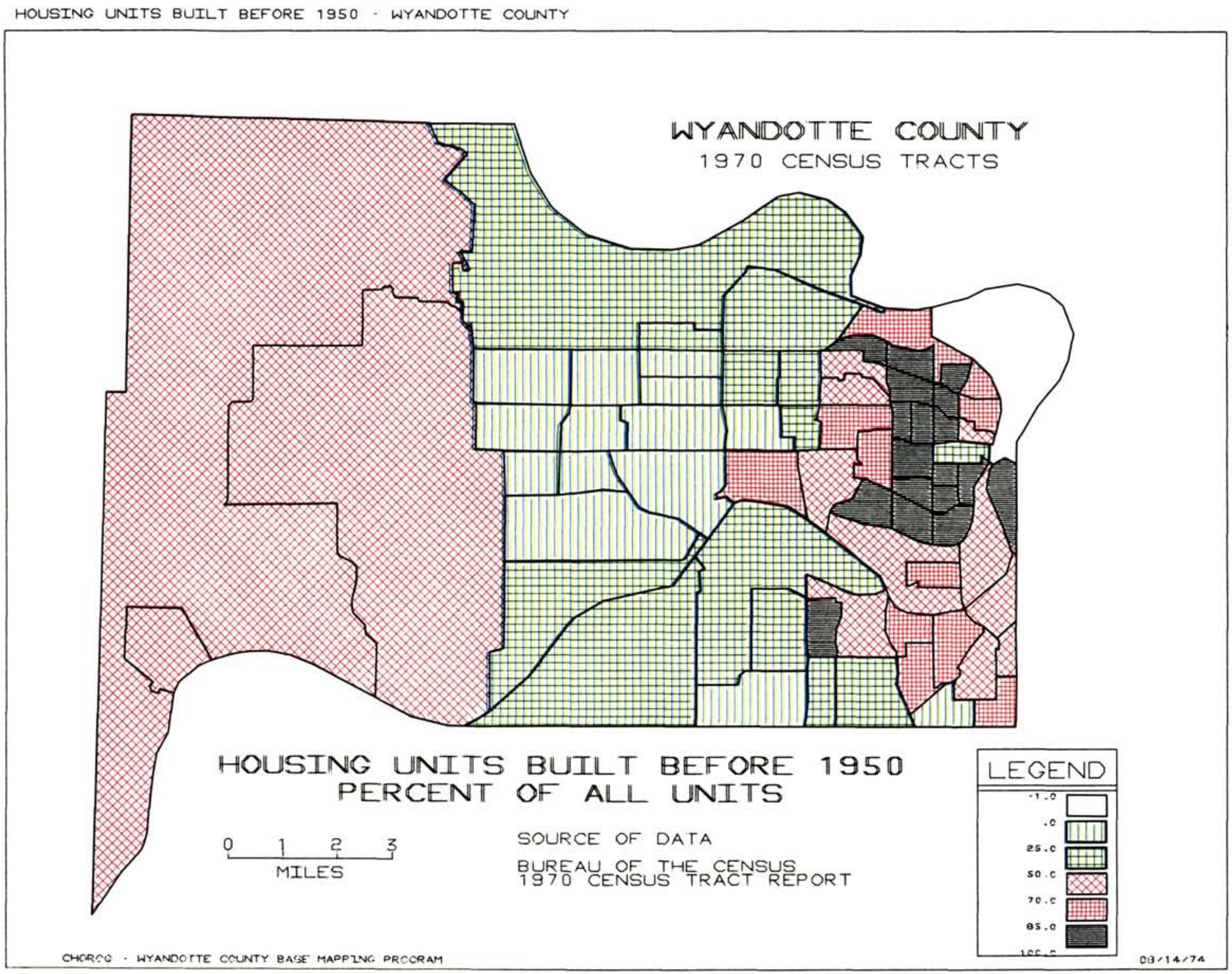


Figure 12. An example of a pen plotter - produced map showing housing units built before 1950 in Wyandotte County, Kansas. (See pp. 469-481)

SMOOTH TRANSITIONS

Not arbitrary arrangement

Nor innapropriate ''blocking''

But smooth and even transition

Figure 13

INDIVIDUAL CATEGORIES AND INDIVIDUAL DISTRIBUTIONS

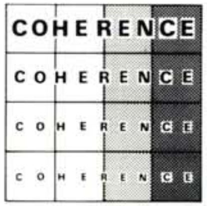


Figure 14

RELATIONSHIP TO SCATTER DIAGRAM

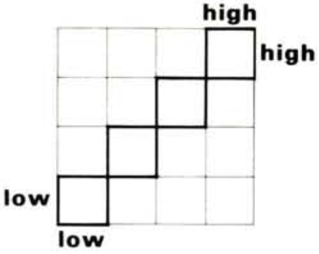
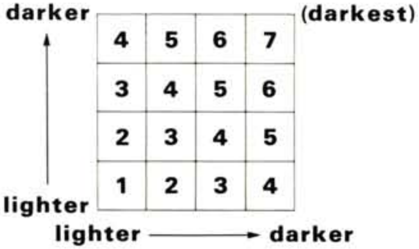


Figure 15

VALUE PROGRESSION



4	5	6	7
3	4	5	6
2	3	4	5
1	2	3	4

Figure 16

Figures 13-16 illustrate the presentation on "The Organization of Color on Two Variable Maps." (See pp. 289-294.)

EMPHASIS ON EXTREMES

(Saturated or dark corner cells)

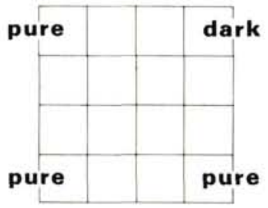


Figure 17

POSITIVE AND NEGATIVE RESIDUALS

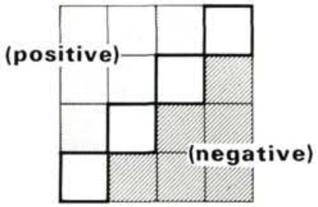


Figure 18

COHERENT DIAGONALS

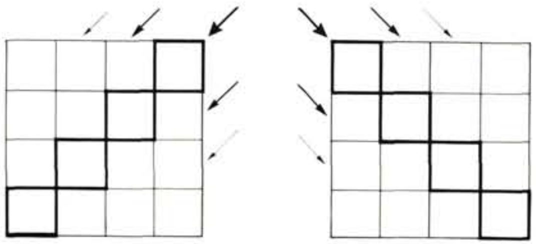


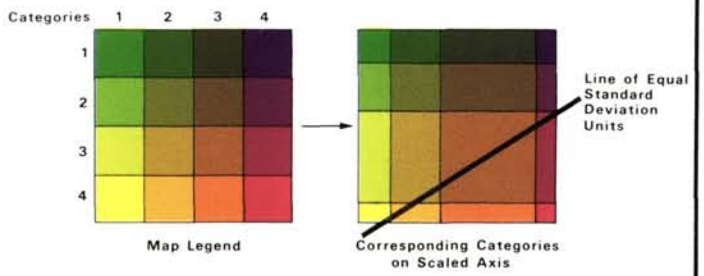
Figure 19

NESTED CATEGORIES

Figure 20

CATEGORIES BASED ON COMPARABLE STANDARD DEVIATION UNITS

Not this



But this

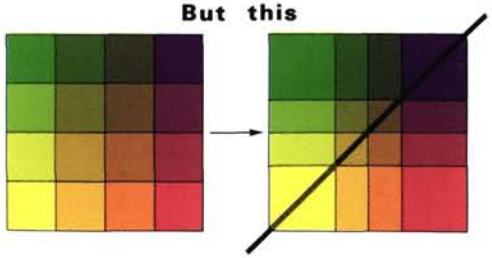


Figure 21

Figures 17-21. See pages 289-294 for the text accompanying these illustrations.

SINGLE COLOR COMBINATIONS FOR EACH CATEGORY

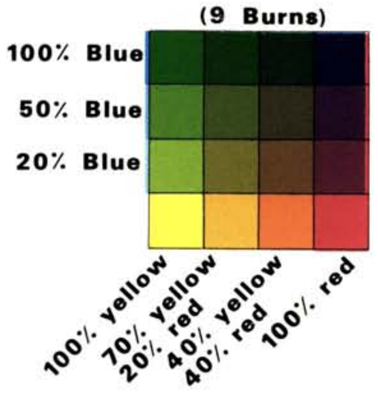


Figure 22A

DEMONSTRATION OF THE METHOD

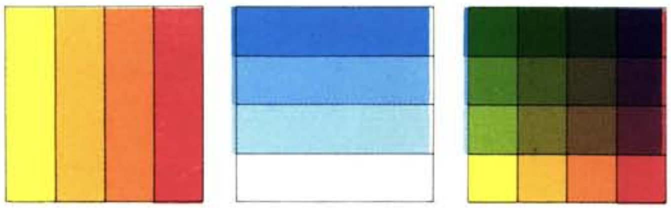


Figure 22B

VISUAL ADJUSTMENTS

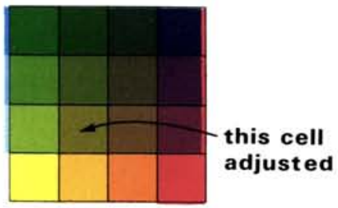


Figure 23

NUMBER OF CATEGORIES

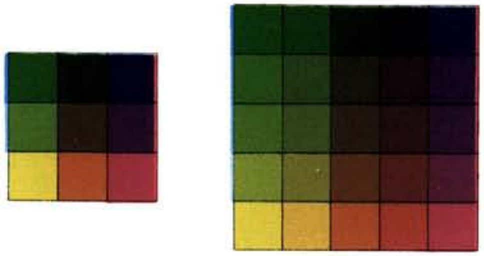


Figure 24

ALTERNATIVE CODING

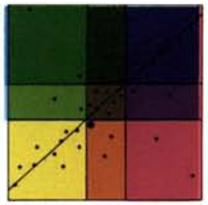


Figure 25A

ALTERNATIVE CODING

Figure 25B

Figures 22-25. See pages 289-294 for the text accompanying these illustrations.

Seminar on Uses of Color

SEMINAR ON THE USES OF COLOR

"The Uses of Color" is not in and of itself a topic in computer-assisted cartography. The computer, however, has facilitated the production of color maps by reducing both the time and the cost involved. It has also facilitated mapping techniques which demand preplanned and complicated symbol systems for which colors, with their multiple visual dimensions, are most useful. The prospect of increased numbers of color maps causes us to look at the processes involved not only in their production but in their design and their capacity to convey information to the map user as well.

This seminar brought together specialists from several disciplines to look at and discuss the ways in which we perceive and use color. Discussion topics ranged from the psychology of color perception to color scaling for the printing process. In the middle of this spectrum of interest is that of the cartographer, who must decide on the colors to be used on maps to promote effective communication of information.

LLOYD KAUFMAN, professor of psychology at New York University, stated that the average quality of maps can be improved if scientific knowledge is brought to bear on the task. He then described some basic concepts involved in the study of color vision, including ways in which we perceive color. Although a great deal is known about the visual system, little is known about the application of these studies to real life situations and more studies are required in this area.

OTTO STOESSEL of the Defense Mapping Agency's Aerospace Center in St. Louis discussed the Department of Defense's activities with the use of colors. His presentation, entitled "Standard Printing Color and Screen Tint Systems for Department of Defense Mapping, Charting and Geodesy," described a color identification system for lithographic printing and a system of dot screens with visual tones of equidistant increments. His 57-page paper of the same title has been printed by the Department of Defense and requests for copies should be sent to Mr. Stoessel, Defense Mapping Agency Aerospace Center, St. Louis Air Force Station, 2nd and Arsenal Streets, St. Louis, Missouri 63118.

In their presentation, "The Selection of Color for the U.S.S.R. Agricultural Atlas," HOLLY BYRNE and RONALD SUMMARS of the Central Intelligence Agency explained the technical and aesthetic solutions to color problems encountered in producing this atlas. For those who may be interested in the specific color combinations chosen, specifications have been included to accompany the text of their paper.

DAVID CUFF of Temple University, Philadelphia, Pennsylvania, discussed "Conflicting Goals in Choosing Colors for Quantitative Maps." Two major and seemingly conflicting goals were identified: first, color should be distinctive or distinguishable, and secondly, color should provide a strong sense of quantity (e.g., more or less). For quantitative purposes the color schemes that seem best are compromises that satisfy both major goals adequately: colors that are distinctive enough one from another, yet seem related and progress logically in darkness and intensity.

JUDY OLSON, associate professor of geography at Boston University, was a former visiting scholar at the Bureau of the Census, conducting research in the field of color perception. Her paper, "The Organization of Colors on Two-Variable Maps," described the structure of the color schemes on two-variable maps such as those produced by the Bureau of the Census using computer-assisted techniques. This type of map is intended to show the interrelationship of the variables while maintaining the identity of each. The color scheme used to encode the distributions provides a case study in the use of color as a cartographic symbol system.

THE USES OF COLOR

Lloyd Kaufman
New York University

One may approach the problem of designing maps from a common sense viewpoint and thereby produce useful and attractive maps. Maps so constructed will vary in usefulness and attractiveness with the experience, intelligence and aesthetic sense of the mapmaker. Although such differences are inevitable when human beings deal with any complicated real-life problem, the average quality of maps may be improved if scientific knowledge is brought to bear on the task. In the present instance a scientific understanding of the nature of the viewers of maps (human beings) can serve to enhance the quality of maps.

Maps, like graphs, printed texts, electronic displays and other communications channels are information transmitting devices. Maps summarize information in a way that is particularly convenient for human users. Thus, a human observer can learn about the distribution of unemployment across the continental United States by merely glancing at a well-constructed map. He could obtain the same information a bit more slowly by looking at a graph and a great deal more slowly by looking at a table of numerical data. The map, by virtue of its pictorial properties, allows the observer to process information in parallel and in rapid sequence and relate it quite directly to meaningful categories of knowledge, e.g., familiar geographical entities. Thus, in some sense a map is a broad bandwidth information transmitting device. However, as in the field of electronic communications, there is little point in transmitting a large amount of information per unit time if the receiver is incapable of handling it. While it may be possible to represent many different dimensions simultaneously in a single map, we can reach a limit beyond which the human mapreader will become confused. Thus, the scientific study of the human as an information processor is quite pertinent to the task of the mapmaker who wants to transmit as much information to the mapreader as can be conveniently handled. To do this he must take into account the amount of time that the reader has available to study the map, the way in which the information is to be represented, e.g., in alpha-numeric form or in terms of coded shapes, the legibility of the elements of the map, the purpose for which the map is intended, and so forth. My main focus in this talk is on color as a means for providing information in maps. Thus, color, as you all know, can be used to replace or supplement alpha-numeric symbols. It is obvious to all of us that such a use of color can have important effects on the rate at which information is communicated to the reader. There must, of course, be a trade-off between the value inhering in the use of color and the economics of color reproduction. I shall not deal here with the latter question but only with the idea that a better understanding of how the human being senses and uses color can enhance the effectiveness of the application of color in mapmaking.

EDITOR'S NOTE: *Graphics accompanying the original presentation are not reproduced here.*

INFORMATION PROCESSING AND RECALL

To see this in perspective let us first briefly review some basic ideas about the psychology of information processing. At one time it was widely believed that the human observer could store only three or four independent items for immediate recall after a brief exposure. Thus, if he were briefly shown a matrix of letters and then asked to recall them, the observer would be likely to report only three or four of the items correctly. However, as Sperling showed, if the observer were instructed to report on the items in only one of the rows of letters in the matrix he had just seen,then he could report on three or four of the items in the matrix. This result established that there is a storage of a great deal of visual information which the observer can scan after the exposure. By the time he reports on a few of the items in this stored image the image will fade, thus accounting for the fact that he seems to remember but three or four items.

Nowadays we believe that information retrieved from the stored visual image is placed in a buffer known as the short term memory. This is where you keep a phone number you had just looked up prior to making the call. As soon as it is dialed the number is quickly forgotten. There is also a long term memory in which rehearsed items are stored. None of what you have stored in long term memory is directly available to your awareness. It must first be called up and placed in the short term storage for you to be aware of it. For example, think of your home phone number. You were not aware of the number until you started to recite it to yourself. The item must be retrieved from long term store before you can use it.

All of these facts and many others were probably reviewed for you in the seminar on Map Reading and Perception. Unfortunately, most of the basic work done in this field of human information processing employed linguistic materials such as letters, numbers and words. In real life we are concerned with things that are less easily segregated into independent items. What are "items" or isolatable features of a woodland scene which is perceived as familiar years after seeing it but once? Also, not enough work has been done on the effects of purely physical attributes of items or stimuli on storage in short term memory. This is the place where the person actually initiates operations on information to solve problems, make interpretations, etc. Surely, some things are more salient and defineable to the perceiver than are others. These most salient things are more likely to be remembered and therefore used in conjunction with other things in interpreting the world. We do not know enough about the factors which affect saliency nor about the ways in which saliency affects information processing. Nevertheless, we do know a great deal about fundamental visual processes which can help us in making judgments as to the discriminability of things from each other. Surely, this discriminability plays a fundamental role in delineating objects and features of an environment for subsequent cognitive processing. Therefore, although we must await further developments in the rapidly growing field of information processing, it is still possible to discuss well known characteristics of the human observer, paying particular attention to his visual system, in order to define his ability to discriminate among things.

PERCEPTION OF COLOR

The biological mechanisms underlying our ability to perceive colors are similar in many respects to the mechanisms associated with the other sensory modalities. The problem for the organism is to transmit information which would permit it to discriminate among thousands of different colors by means of a very limited number of different kinds of receptors in the eye. Thus, any normal human observer can differentiate among thousands of different colors. There may be hundreds of different blues - some more or less greenish and others more or less purplish - and hundreds of different reds - ranging from orange to slightly bluish - and so forth. Each of these colors is qualitatively different from all of the other perceived colors. The eye has a finite number of different kinds of photoreceptor. How does it succeed in preserving information about fine difference in the wavelength of the stimulus despite the fact that there are a small number of photoreceptors? We now believe that the differences among colors are preserved even though there are only three different kinds of cone or color receptor in the eye.

Before discussing the three basic photoreceptors we must consider the color solid. This double pyramid is a summary or model of the various dimensions of color perception. Thus, the rim of the circle contains all of the hues ranging from red through orange and yellow to green and blue and, finally, purple. Purple differs from all the other colors because there is no single wavelength of light which would appear to have a purple color since it can be produced only by a mixture of red and blue lights. The hues on the very rim of the circle are considered to be pure colors -- i.e., fully saturated. If a particular color were impure or relatively desaturated by virtue of being mixed with white light, then it would be placed away from the rim within the color solid. A neutral gray patch is localized right on the central axis of the color sold since it has no hue. It is, as Newton said, the "middling" color of all the colors. Thus, saturation or degree of purity is represented by the distance of a color from the central axis. Shades and tints are located either above or below the color circle. Pink is placed above the circle. A very pale pink is located near the central axis and it fades into white as it approaches the upper vertex. Navy blue, on the other hand, is placed below the circle. This color can fade into black as it approaches the lower vertex. Thus, the color solid is a way in which to represent the dimensions of saturation (purity), hue and relative degree of "whiteness" of perceived hues. In addition to these three dimensions of color, i.e., hue, saturation and shade, we must add the fourth dimension of brilliance. A color of a particular hue and of a particular shade can have the same purity over a wide range of light levels. Turn on six more lamps to view a colored patch on a map and the color may appear to have the same attributes but nevertheless appear to be more brilliant. We shall ignore the fourth dimension of brilliance or brightness in this talk.

PHOTORECEPTORS

This color solid was known to the early workers in the field of vision. Its shape has been altered over time. An alternative model is shown in slide 2. Nevertheless, the basic idea of representing the dimensions of color perception in a single model is the same.

The great 19th century physicist James Clerk Maxwell showed that it is possible to match the appearance of any color by a mixture of no more than three spectral colors. The only constraint on this is that one of the three so-called primary colors could not be duplicated by a mixture of the other two colors. This very fundamental observation led Helmholtz to the conclusion that we do not need a special color receptor in the eye for each perceived hue. Thus, we do not need receptors specially designed for picking up red light, others for green light, still others for blue-green, yellow, orange and violet. We could get along nicely if we have but three kinds of receptors, one primarily sensitive to red light, another kind which responds primarily to green light and, finally, one sensitive to blue light. All of the colors could be represented by the relative amounts of activity in the neurons excited by these three kinds of basic color receptors.

One of the important correlates of color is the wavelength of light. It is well known that light of relatively short wavelength (about 460 nm) appears to be blue, light of 490 nm appears blue-green, of 510 nm green, and yellow at about 575 nm. Light of 600 nm appears orange and longer wavelength light appears red: A change of a few billionths of a meter in the wavelength of electromagnetic energy will cause a considerable shift in the quality of the perceived light.

Except for lasers, which emit nearly monochromatic light, and also light passed through finely tuned interference filters having a bandwidth of about 5 nm, most of the light we see contains a relatively broad band of wavelengths. A surface which appears to be green in color may reflect a continuous spectrum of light to the eye but with a predominant wavelength near 510 nm. All other wavelengths may be present but in different amounts. It is these differences in amount of energy at different wavelengths that determines the color of an isolated surface. I say "isolated" because effects of contrast between a surface and its surroundings can strongly influence the perceived color.

We now know that there are three kinds of photoreceptors similar to those I mentioned previously. One of these receptors will respond maximally to light from the "blue" portion of the spectrum. Thus, if light of 575 nm were to impinge on this receptor the pigment it contains would absorb fewer quanta of that light than it would of light of, say, 450 nm. Thus, blue light would be more likely to cause the "blue" or B photoreceptor to respond than would light of longer wavelength.

The pigment in the B photoreceptor is known as Cyanolable which means that it is the "blue catching" pigment. A second kind of photoreceptor contains a pigment known as Chlorolabe since these G cones contain a green catching pigment. Finally, the normal eye contains cones which respond primarily to red light (the R cones) and these contain a pigment called Erythrolabe. Rushton, who originated the terms cyanolabe, erythrolabe and chlorolabe succeeded in actually measuring the absorption characteristics of two of the pigments in the living human eye.

We have ample direct physiological and psychophysical evidence for the existence of all three photoreceptors.

We even have knowledge of some of the higher-order neural circuitry involved in color vision. Thus, it is known that the outputs of the R and G receptors impinge on common cells which take the difference between the two signals. This difference signal represents the color yellow, thereby confirming an idea proposed about a century ago by Hering.

COLOR MIXING

There are two ways in which to mix colors. In one way we simply add one light to another light by reflecting both colored lights off a screen. This is called additive color mixture. It is possible to take any given color produced by a complex of wavelengths and match it with some mixture of three monochromatic primaries. This mixture of the three monochromatic primaries can now be used interchangeably with the original complex color in other color mixtures even though their wavelength compositions may be entirely different. Such apparently equivalent colors are called matameric matches.

One variant on this method is to print tiny isolated dots of different colors next to each other. Since the eye cannot resolve the separation between the dots their colors are effectively added on the retina - thus producing additive color mixture.

A second kind of color mixture is called subtractive. An example of this is the mixture of blue and yellow paints or pigments to produce a green color. This occurs because the yellow portion of the spectrum of light reflected by the "yellow" pigment is absorbed by the "blue" pigment while the blue portion of the light reflected by the "blue" pigment is absorbed by the "yellow". Light of predominantly green wavelength (although somewhat muddy or desaturated) is left over thereby giving the mixture its green color. Additive mixture of blue and yellow lights, on the other hand, does not yield green. Such a mixture yields a neutral light if the yellow and blue lights are balanced in luminance. When out of balance then the resulting color will be that of the predominant element of the mixture, i.e., either a desaturated blue or a desaturated yellow.

All of these effects of color mixture are completely predictable from known scientific principles. I cannot communicate all of these principles to you in this short talk. However, I refer you to some of the texts cited in the bibliography for full details. The important point to be taken away is that we can specify any color completely. This can be done by determining the mixture of primaries which will yield that particular color. It is not even necessary to conduct empirical studies to discover the mixture of standard primaries which will yield the color. The average or ideal human eye has been studied extensively and tables exist which enable us to go from purely physical measurements of the wavelength composition of any color to the primaries which, when mixed in the proper proportions, will yield that color.

So far I have talked about the appearances of colors when they are viewed as isolated patches. A major effect is also produced by contrast between a patch and its surrounding. Thus, a grey patch seen on a red field will look greenish. In general, there is a tendency for a colored region to cause adjacent neutral regions of the visual field to take on the complementary hue. Some kinds of contrast are to be avoided in printed colors. When truly complementary colors are printed alongside each other a disconcerting effect known as "jitter" may take place, depending upon the wavelength composition of the illuminant and the luminances of the colors. Thus, yellow print on a blue background may appear to move as the eye scans the page.

COLOR FOR INFORMATION TRANSFER

Color is a useful dimension for the portrayal of information. Simple maps which use different levels of luminance to produce several different shades of grey can and have been used to show how some parameter varies with spatial position, e.g., five different shades of grey to represent five different levels of economic activity across some geographical region. Such maps can and have been improved by adding color differences to differences in greyness. In some cases such uses of color are redundant since they merely reflect the same information given by the different shades of grey. However, variations in hue may be superimposed on variations in greyness to convey information about some second independent dimension. We need some experiments to tell us how many different levels can be so represented on a map designed for a given purpose. For example, five different colors and five different shades of grey to reflect five different levels each of two independent parameters may not be useful for a lecturer using a map as a slide in a short talk. However, the same map may be useful to a student who takes time to study it. A dark grey superimposed on a yellow may yield a brownish color which could be hard to distinguish from an orange superimposed on a slightly lighter grey color. It is probably better to use colors which are widely separated on the color circle for such maps. Also, problems may arise if the two parameters are not independent but if they interact, as in the hypothetical example of a map showing unemployment rates together with consumption of certain goods where increases in unemployment may be correlated with decreases in consumption. We may not gain very much in such a case by using two dimensions such as color and shade of grey.

SUMMARY

I cannot do more than hint at the many things we vision scientists may be able to contribute to your endeavors. I would like to close, however, with one word of caution. One male in eight suffers to some degree with some kind of color deficiency. The most common form of color blindness is an inability to distinguish between red and green colors. We have learned a lot about color vision from the study of such deficiencies. For your purposes it would be well to avoid equally bright reds and greens as codes for differentiating places on a map. Blue-yellow deficiencies are much more rare. Such forms of color blindness are attributable to the lack of one of three kinds of cones. There are other kinds of deficiency which are attributable to the fact that one of the pigments of the cone-types may have abnormal spectral absorption properties. A patient study of these problems could allow you to take the more widespread deficiencies into account in designing your maps so that people will be able to read them and make appropriate discriminations despite their deficiencies.

In conclusion, we already know a great deal about the visual system. We know less about how to apply this knowledge to complicated real-life situations. However, it is easy to imagine experimental studies which would allow us to improve the use of the existing basic data.

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THE SELECTION OF COLOR FOR THE U.S.S.R. AGRICULTURE ATLAS*

A Brief Examination of the Use of Process Colors In a Limited Edition Atlas

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Color-coding, that is, the assignment of colors to things represented on a map, is a complex process and a very important ingredient in map design. The success of a map could very well depend on the proper use of color. Using color requires, among other things, a good judgment and a "feel" for color and there are many differences of opinion, even by those with extensive training and experience.

Many questions confront the cartographer when using colors, such as, "Do I use colors just to make the maps more attractive regardless of whether it can be as effective with fewer colors?" The objective of the map should surely have an influence on the answer to whether color should be employed, but the use of process colors, i.e., the use of combinations of only a few basic colors to produce a wide range of tones, will more readily allow one to answer such a question in the affirmative.

Process colors normally used for reproduction consist of transparent inks in magenta, cyan, and yellow. These transparent inks can be used in combination to produce numerous visually-discriminable tones. Artwork is separated into individual overlays for each component tone and three plates are required in the printing process. For map work, we have substituted a transparent red ink for the magenta which allows for the utilization of the conventional red for symbols or line work.

Process colors offer a wide variety of selection from which to choose that is limited only by percentages of the tint screens available. This limitation is minor, however, since utilizing the three primary colors with ten percentage screens including 5%, 10%, 20%, etc. to 90% plus the solid colors and the "zero tones" (absence of each color), it is possible to produce 1,728 physically different tones. Percentages of black mixed with the primary colors will extend the available selection somewhat.

The first phase of a successful process color map is planning. The economy or cost of construction and printing is a major consideration. If it is possible to construct the map with a limited number of colors (less than three primaries, plus black), then this simpler process will reduce the materials and the time needed in both the construction and printing phases. Color association with the

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*<u>U.S.S.R. Agriculture Atlas</u>, *Central Intelligence Agency, U.S. Government Printing Office, Washington, D.C., 1974.*

map subject also plays an important role in planning the color selection. For example, the use of cool and warm colors are associated with temperatures (p. 8 of the atlas), blues with precipitation (p. 12), greens with various types of vegetation, etc.

Color progressions to represent a wide range of numerical values often cause the most difficulty in planning (p. 13 Thunderstorms, p. 55, livestock). Generally it is desireable that each step in the range increase by a visually uniform increment. If the progression moves from one area of the color spectrum to another, the complexity magnifies.

Other aspects of color selection, such as color balance, avoiding color clashes, using more brilliant or stronger colors for small areas, and using softer or pastel colors for larger areas must also be weighed in making a selection. Often single color tones do not blend or work well together. In the color selection of the U.S.S.R. Agriculture Atlas, an effort was made to produce colors with an "earthy" look. For example, the map on thermal resources on p. 8 includes a small amount of red mixed with the blues, green, and yellow, while the yellow, orange, and red have a small percentage of cyan. The darkest blue of the relatively simple three-category precipitation map on p. 12 contains small amounts of both yellow and red. The results are harmonious, "earthy" colors that are neither too contrasting nor garish.

To use process colors, it is necessary to have a controlled color guide from which to select the colors. Although printings may differ even with the same printer, the guide must be the basis for color selection. It is then the printer's responsibility to maintain that control in final reproduction. Inconsistencies by printers sometimes cause cartographers to hedge -- by making selections of greater diversity in order to play safe -- and the results may be less than optimum. Process color chips, which are duplicates of the color guide but are cut into individual pieces, aid in the selection of colors. The chips can be moved and arranged into progressions or can be associated with the other colors used on the map. Hence, a more controlled environment is available for color selection.

Another step in the system employed for the U.S.S.R. Agriculture Atlas was to place the selected color chips on a 3" x 5" card. Each card represented the color scheme for one page of the atlas. As work progressed, quick and easy reference was possible through the use of this color file and the technique was invaluable. As a result of maintaining such a file, we were able to duplicate a color scheme easily when desired for a new page.

The process of selecting color combinations is a difficult one to describe and the evaluation of the results by those who made the selection would probably be biased. For the interested reader, however, we present in the following section the entire set of color specifications used in the U.S.S.R. Agriculture Atlas. It is hoped that this information will prove useful to others groping with the problems, both mechanical and intellectual, of color selection.

COLOR SPECIFICATIONS

The inks used in the atlas are obtained from the Capitol Printing Ink Co., Inc., Washington, D.C. A Capitol Printing Ink (CPI) number is used for ink identification except "off the shelf" Speedlith inks. The yellow, blue, and brown inks are special mixes for CIA with the formulas on file by CPI. The following color inks were used: black (offset dense process black, CPI No. 15418), yellow (process yellow x-1, CPI No. 22813), cyan (process cyan blue x-3, CPI No. 49308), red (speedlith map red x-12, CPI No. --), brown (brown x-9, CPI No. 80257).

	Red	Cyan	Yellow	Other Color
Agriculture's Role in the Economy, p. 4 --				
USSR graph and pie tones	R60			
US pie tones		C70		
Commodity Trade, p. 5 --				
Grain trade				
Net imports	R20	C20	Y100	
Net exports	R20	C50	Y100	
Total Soviet exports and imports	R40	C20	Y100	
Soviet agricultural trade	R80	C20	Y100	
Policy Issues, p. 6 --				
Comparative area				
USSR tone	R40			
Land tone			Y30	
Water tone		C10		
Climatic analogs				Brown half-tone
Environment, p. 7 --				
Thermal Resources, p. 8 --				
Very cold	R10	C70		
Cold	R10	C50		
Moderately cold	R10	C20	Y60	
Moderate	R10	C10	Y60	
Warm	R30	C10	Y60	
Hot	R100	C10	Y60	
Mountain region				Black 30
Moisture Resources, p. 9 --				
Sufficient		C70	Y100	
Inadequate		C30	Y100	
Negligible		C10	Y60	
Mountain region				Black 30
Wintering Conditions, p. 10 --				
Winter grains and perennial grasses				
Excellent	R50	C5	Y30	
Good	R20	C20	Y30	
Satisfactory	R10	C30	Y30	
Less than satisfactory	R10	C50	Y30	
Poor	R10	C70	Y30	
Area of no data				Black 10
Tree crops and berries				
Warm	R10		Y70	
Mild	R10	C20	Y70	
Cold		C30	Y70	
Severe		C50	Y70	
Harsh		C70	Y70	
Winterkill chart	R10	C70	Y30	

	Red	Cyan	Yellow	Other Color
Snow, p. 11 --				
None or very thin	R5	C10	Y20	
Year to year variability	R5	C30	Y20	
Thin to moderate	R5	C50	Y20	
Moderate depth and duration	R10	C60	Y20	
Moderate depth, long lasting	R30	C60	Y20	
Deep, long lasting	R50	C60	Y20	
Mountain region				Black 30
Precipitation, p. 12 --				
Moderate	R10	C60	Y20	
Light		C40		
Scanty		C10		
Weather Hazards, p. 13 --				
Drought				
0 - 5		C40	Y100	
5 - 20	R10	C40	Y60	
20 - 40	R30	C40	Y60	
40 - 60	R50	C10	Y60	
60 and above	R50		Y100	
Sukhovey				
0 - 20	R10	C40	Y100	
20 - 30	R30	C40	Y100	
30 - 50	R50	C40	Y100	
50 - 70	R100	C40	Y100	
70 and above	R100	C10	Y100	
Surrounding tone/mountain region				Black 20
Water tone		C10		
Thunderstorms				
0 - 20	R10	C60	Y20	
20 - 40	R30	C60	Y20	
40 - 60	R50	C60	Y20	
60 - 80	R60	C60	Y20	
80 and above	R100	C100	Y20	
Stormy Weather, pp. 14-15 --				
Soils, p. 16				
Chernozem	R100	C60	Y100	
Chestnut	R100	C40	Y100	
Gray and brown forest	R60	C40	Y100	
Sierozem	R40	C40	Y100	
Alluvial	R20	C40	Y100	
Mountain	R20	C20	Y100	
Podzolic	R20	C20	Y20	
All other				Black 10
Agricultural Land, p. 17 --				
Meadows, pastures, orchards	R40	C5	Y100	
Arable	R5	C60	Y100	
Non-ag tone/land tone	R5	C5	Y20	
Zone of agriculture				Black 5

	Red	Cyan	Yellow	Other Color
Agroclimatic Regions, p. 18 --				
Arctic agriculture/alpine	R20	C40		
Farming for local market	R20	C40	Y60	
General farming			Y60	Black 10
Diversified, commercial		C50	Y60	
Drylands grazing	R20		Y30	
Regional Crop Calendars, p. 19 --				
Crop bar		C70	Y100	
Frost free period		C40	Y100	
Average daily temp. above freezing			Y30	Black 10
Snow		C20		
Technology, p. 20 --				
Fertilizer, p. 21 --				
Mineral and organic fertilizer				
Mineral fertilizer	R100		Y40	
Organic fertilizer	R10		Y40	
Zone of agriculture				Black 5
Organic fertilizer (chart)	R20	C10	Y60	
Mineral fertilizer (chart)				
Delivered/weight/composition	R70			
Planned	R70			Black 20
Irrigation and Drainage, p. 22 --				
Irrigated land use	R40		Y40	
Drained land use			Y40	Black 10
Concentrated irrigation	R100			
Scattered irrigation	R40			
Concentrated drainage				Black 100
Scattered drainage				Black 30
Surrounding tone	R20	C10	Y40	
. . . in Southeast European USSR, p. 23 --				
Share of irrigated land	R50			
Major irrigation system				
Existing	R50			
Planned	R20			
Irrigation map				
Major irrigation area	R40			
Surrounding land tone				Black 5
Water tone		C20		
Terrain				Brown half-tone
. . . in Soviet Central Asia, p. 24 --				
Same as p. 23 except:				
Major irrigation area (inset)	R50			
USSR land tone (inset)				Brown 30
River Reversal, p. 25 --				
Diversion potential of rivers		C30	Y50	Brown 30
Kama-Vychegda-Pechora	R40		Y50	Brown 30

	Red	Cyan	Yellow	Other Color
Ob'-Irtysh-Tobol	R40	C20	Y50	Brown 30
Land tone				Brown 30
Water tone		C20		
Mechanization, p. 26 --				
Mechanization, p. 27 --				
Total production of farm equipment		C40		
Delivery of farm equipment		C70		
Inventory table tone	R10		Y40	
Land Use, p. 28 --				
Fodder		C50	Y100	
Grain crops	R60		Y100	
Industrial crops		C100		
Other	R30		Y100	
Surrounding land tone	R20	C10	Y60	
Water tone		C50		
Zone of agriculture				Black 5
Land Use, p. 29 --				
Wheat	R30		Y100	
Barley	R60		Y100	
Corn		C60	Y100	
Surrounding land tone/Typical system	R10		Y60	
Water tone	R20	C10	Y60	
Zone of agriculture				Black 5
Trends chart tone	R10		Y60	
Erosion Control, p. 30 --				
Area of dust storm/chart tone	R10		Y40	
Surrounding land tone	R20	C10	Y60	
Water tone		C50		
Pest Control, p. 32 --				
Pesticide background tone	R10		Y40	
Pesticide trends totals	R40 (op R10)		Y40	
Pest Control, p. 33 --				
Insects and diseases tone	R10		Y40	
Crop tone	R20	C10	Y60	
Plant and Livestock Breeding, p. 34 --				
Environmental Modification, p. 35 --				
Hail control areas	R70			
Surrounding land tone	R20	C20	Y60	
Water tone		C50		
The System, p. 36 --				
Management, p. 37 --				
The Government		C40		
The Party	R30			

	Red	Cyan	Yellow	Other Color
Rural Population, p. 38 --				
Rural population chart tone	R10		Y40	
Education attainment chart				
Higher education	R100			
Incomplete higher education	R70		Y100	
Specialized secondary education	R70	C20	Y100	
General secondary education	R50	C10	Y100	
Incomplete secondary education	R40	C10	Y100	
Primary education	R20	C10	Y60	
Less than primary education	R10		Y40	
Rural population proportion				
60% or more	R70	C40	Y100	
40-59%	R70	C20	Y100	
0-39%	R50	C10	Y100	
Change in rural population				
Over 15% increase	R70	C40	Y100	
0-15% increase	R70	C20	Y100	
Decrease	R40	C10	Y100	
Rural Settlement, p. 39 --				
Populated places eliminated				
0 - 9	R20	C10	Y100	
10 - 29	R20	C30	Y100	
30 - 49	R20	C50	Y100	
50 or more	R50	C40	Y100	
Population of rural settlements	R100	C40	Y100	
Organizational Forms, p. 40 --				
Proportion of agricultural land				
Zone of agriculture	R20	C10	Y60	
Surrounding tone	R10		Y30	
45 years of socialized agriculture				
Background tone	R10		Y30	
Chart bands tone	R10	C10	Y30	
The Collective Farm, p. 41 --				
Field crop rotation	R30	C10	Y100	
Fodder crop rotation	R10	C10	Y100	
Vineyard	R10	C50	Y100	
Pasture	R10	C30	Y100	
Garden	R10	C30	Y30	
Surrounding land tone	R10	C10	Y30	
Water tone		C30		
Private Holdings, p. 42 --				
Percentage of private livestock	R20	C30	Y100	
The State Farm, p. 43 --				
A sovkhoz in transition				
Arable land	R30	C10	Y100	
Hay	R10	C10	Y100	
Woodland	R10	C50	Y100	
Pasture	R10	C30	Y100	
Garden	R10	C30	Y30	

	Red	Cyan	Yellow	Other Color
Surrounding land tone	R10	C10	Y30	
Water tone		C30		
Number of sovkhozes				
Background tone	R10		Y30	
Chart bands tone	R10	C10	Y30	
Production, p. 44 --				
World Production, p. 45 --				
USSR	R100			
US		C70		
Other tone	R20	C10	Y60	
Wheat. . . Other Crops, pp. 46-53 --				
Crop distribution	R60			
USSR comparison bars	R100			
US comparison bars		C80		
Production, sown area graph tone	R20	C40	Y100	
Production map				
Production proportional circles	R80	C20	Y100	
Zone of agriculture				Black 5
Surrounding land tone	R20	C20	Y100	
Water tone		C50		
Livestock, p. 54 --				
Meat production chart tone	R10		Y40	
USSR comparison bars	R100			
US comparison bars		C80		
Livestock, p. 55 --				
Number of livestock chart tone	R10		Y40	
Cattle, swine, sheep and goats				
0 - 1	R10		Y40	
1 - 10	R20	C10	Y60	
10 - 20	R40	C10	Y100	
20 - 30	R50	C10	Y100	
30 - 40	R70	C20	Y100	
40 and above	R70	C40	Y100	
Marketing and Consumption, p. 56 --				
From source to consumer				
Gosplan	R20	C20	Y50	
Private plot		C20	Y50	
Average diet				
Sugar		C50		
Milk	R80	C50		
Fats and oils	R20	C20	Y100	
Meat and fish	R80	C20	Y100	
Vegetables, fruits and eggs	R20	C50	Y100	
Grains and potatoes	R20		Y100	
Weights and Measures, p. 57 --				
Weight	R30	C30	Y70	
Yield conversions		C30	Y70	

	Red	Cyan	Yellow	Other Color
Administrative Divisions, p. 58 --				
Latvian/Uzbek	R10			
Azerbauan/Kirgiz		C10		
RSFSR			Y30	
Turkmen/Ukrainian		C10	Y30	
Lithuanian/Tadzhik	R10	C10		
Estonia/Moldavian/Armenian	R10	C10	Y30	
Belorussian/Georgian/Kazakh	R10		Y30	
Surrounding tone				Black 5

CONFLICTING GOALS IN CHOOSING COLORS FOR QUANTITATIVE MAPS

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In choosing colors for a map or series of maps it is essential to first identify the purpose of the color scheme, and second to be aware of the three dimensions of color (hue, darkness, and intensity) and how they can be used to accomplish that purpose.

An important distinction to make is between the use of colors for qualitative differences versus using colors to symbolize quantitative differences between map areas. This discussion will focus on colors used for quantitative differentiation — a task in which two separate major goals may be identified and seen to be in conflict. (*Minor goals may be identified tentatively as follows: equal-appearing intervals, hues appropriate to the theme being mapped, and variety in colors from one map to the next.)

1. One major goal is to have distinctive or distinguishable colors for each of the different classes or categories being mapped. Colors should be distinctive enough that a reader can easily identify an area's category by reference to the legend. On isarithmic maps, colors need not be quite so distinctive one from another because the orderly arrangement and labelled isolines make identification easier. On choropleth maps, however, with their complex patterns and changing settings for each color, there is need for more distinctive colors to satisfy this first goal.

2. The second, and conflicting, goal of a color scheme on a quantitative map is to provide a strong and unambiguous sense of quantitative change. The sequence must be a family of colors which appear related, and within which there is obvious progression that gives a reader the impression of — not one kind versus another — but rather of more and less of the same thing, i.e., the impression of changes in quantity only.

In order to satisfy the first goal, what sort of scheme and what color dimensions are useful? To achieve maximum distinguishability, especially with a large number of classes to map, we would select logically a series of colors widely

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* *Editor's Note: The graphics accompanying this presentation are not reproduced here. However, descriptions of the various slides are provided on page 288.*

spaced in hue, such as this sequence which encompasses much of the color circle from red through yellow and green to blue (Slide 1). Such a scheme is not suitable for quantitative maps because the colors are so widely separated in hue they suggest differences in quality, and also because the scheme puts yellow, with its unavoidable lightness, in the middle of the scheme, thereby making a sequence from darker through lighter to darker at the other end — very illogical in the darkness dimension and not conveying well the concept of quantitative differences.

If we were to be equally extreme in satisfying the second goal, i.e., providing a strong sense of quantity change, we would probably choose only one relatively dark ink and apply it at various strengths (Slides 2 and 3). This often is done, it certainly entails a logical progression of darkness and intensity, and it does give map readers the desired quantitative impression. Such schemes though, are limited with regard to the first goal since they allow only a few distinguishable classes.

To be less extreme in bowing toward either goal we might choose a series of colors spanning a part of the color circle; for example, a series through the warm side from red through orange to yellow, or through the cool side from blue through green to yellow (Slides 3 and 4). These are a great improvement, in regard to the second goal, over the red-orange-yellow-green-blue schemes, because there is much greater coherence and sense of relationship in the shorter range of hues: oranges seem intermediate between red and yellow because they are evidently mixtures of the two; and even greens are recognized as mixtures of blue and yellow. More important is the position of yellow in each of these two general schemes. Since it is at the end, there is logical progression of darkness from the inherently dark red hue to inherently light yellow in one case, and from inherently dark blue to yellow in the other case. Such schemes, therefore, make use of the darkness characteristics of the hues they employ.

The locical progression of darkness that depends on the character of hues would prevail even if inks were applied full strength with colors rendered at high intensity. But the logic of darkness change is not always enough to ensure that a scheme gives readers the intended quantitative message. In this case (Slide 5) the intense yellow at the intended low end of the scale is too often interpreted as representing large quantities; so it is necessary to screen the yellows and generally weaken or wash out the colors at the low end of the sequence as in this example (Slide 6) which does convey the impression of quantity changes but with some sacrifice in regard to the first goal. Undoubtedly a weak reddish-yellow like the second lowest in this series lacks a definite hue personality: it cannot readily be called a yellow, or any nameable hue, and that may impede the recognition and identification of map areas assigned that color.

So, the schemes that seem best for quantitative purposes, as seen in this brief exploration, are compromises that satisfy both major goals adequately: their colors are distinctive enough one from another, yet they all seem related and progress locically in darkness and intensity. A number of such schemes can be devised, but not a large number, I think, especially if the single-ink schemes are excluded. Often we may feel the need of a large number of schemes when designing a series of quantitative maps, preferring to use a different scheme for each new theme in the series. If that procedure is followed doggedly, there will likely be some unsuitable schemes, failing with regard to either the first or the second goal.

Another approach to a map series is to find one scheme that is effective and pleasing, and then to stick with it. The approach is used in the 1969 Census of

Agriculture by the U.S. Bureau of the Census, known for its automated production procedures, but at the same time an example of a series using well-chosen inks and screens. The color scheme may satisfy the second goal more completely than the first, i.e., sense of sequence is very strong, but distinguishability at the high end of the scale is rather uncertain — largely because county boundaries have been omitted for a most desireable clean and uncluttered look (Slides 8 and 9). This may be called monotonous by some designers; but I think map readers are likely to enjoy the repetition of color scheme — quickly adjusting to it, and then romping through the series, just absorbing information. If a scheme used in this repetitive way does promote transmission of information, then that is ample justification for its use.

The following slides accompanied "Conflicting Goals in Choosing Colors for Quantitative Maps"

Slide 1 A five-color sequence resembling that on Census Bureau G-50 Series, Map No. 7, with the following inks being applied full strength: red (PMS 184), orange (PMS 151), yellow (PMS 121), green (PMS 353), blue (PMS 312).

Slide 2 and Slide 3 Two single-ink sequences using red (PMS 185) at 100%, 60%, 40%, 20%, and 10%; and blue (cyan) at the same five strengths.

Slide 4 A five-color sequence like that used by the National Atlas of the United States, 1970, page 196, with these specifications.

PMS 185	100%	60%	40%	20%	—
Process Yellow	—	—	60%	60%	100%

Slide 5 A five-color sequence like that used on Census Bureau G-50 Series, Map No. 8, with these specifications.

Cyan	100%	100%	50%	20%	—
Process Yellow	—	30%	100%	100%	100%
Magenta	10%	—	—	—	—

Slide 6 A five-color sequence like that used by Goode's Atlas (14th Ed.) page 26, for Birth Rates, with these specifications.

PMS 179	80%	50%	30%	10%	—
Process Yellow	80%	70%	70%	40%	30%

Slides 7, 8 and 9 Three maps from the atlas, 1969 Census of Agriculture.

THE ORGANIZATION OF COLOR ON TWO-VARIABLE MAPS

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There are many types of maps on which color may serve a useful function. Color may be used to enhance or clarify information, it may be used to increase the visual appeal of a map, and in some cases it may be an indispensable ingredient in the system of encoding complex information. An example of the use of color to encode complex information is its use on two-variable "cross-maps" such as those currently produced by the U.S. Bureau of the Census. (See Figure 1, page 251.) 1/ This technique presents two quantitative variables on the same map, and the symbol system, a fairly complex one when considered in detail, is a set of color combinations. The construction of a color scheme for two-variable maps must be based on several logical considerations, or restraints, such that the scheme forms a coherent system. It is the development of this set of color combinations and its logic relative to the map message that is discussed in this paper. Such a color system represents a specific employment of color and is presented as a sort of "case study."

In attempting to construct an outline of the ideas involved in the color scheme, it is necessary to keep clearly in mind the objective, or the intended message, of the map. It is assumed that a map of this type is multipurpose in its intent in that it should convey information about the relationship between the variables (particularly the strength of relationship and the spatial distribution of the evidence) and at the same time maintain the identity of the two separate variables. We can then list several specific messages that should therefore be obtainable from the map. What such a list of messages demands is a color scheme with a very extensive, built-in figure-ground system such that the reader can think, for example, "category two on X" and see it, "anomolies" and see them, and so on. While it cannot be hoped that everything about the distributions can be clearly encoded, this type of map must at least show a larger number of specific messages than either (a) two separate maps of the distributions or (b) the map of residuals which deals with the relationship but does not keep the two variables differentiated. If the cross-map fails to communicate its multiple messages, there is not much point in using the method, except perhaps for its eye catching novelty value.

Given the general purposes of these maps, then, there is one more assumption on which this paper rests. It is that the color scheme will determine the look of the map rather than vice versa. We might develop the color scheme on the basis of the spatial distribution of category combinations but for mechanical as well as theoretical reasons, the color scheme will be developed more or less independently of the spatial distribution here and it is assumed that the map's spatial message will follow.

The considerations in the development of the scheme, then, include:

(1) All colors must be distinguishable. If they are not, there is no reason to divide the data into so large a number of intervals. The colors must be distinguishable not only in the legend but in the map context as well; they must look different from one another on the map and any patch of color on the map must be matchable with its corresponding box in the legend. The alternative to this constraint is a map whose interpretation is based on quite different concepts of pattern recognition than those of traditional map reading, a subject that deserves attention but is too complex to include here.

(2) At the same time that the boxes must be distinguishable from one another, the transitions of colors should progress smoothly and in a visually coherent way. An arbitrary arrangement of sixteen distinguishable colors would make the map impossible to comprehend, and inappropriate "blocking" of colors, i.e., inappropriately similar groups of neighboring colors, may also be misleading. (See Figure 13, page 264.) Ideally, the set of colors should be such that all neighboring pairs look "equally different" from one another.

(3) The individual categories of each distribution should be visually distinguishable or coherent and the two distributions as a whole should be separable from one another. This implies that there is a coherence along each row and along each column and that rows have some element of unity, columns some different element of unity. (See Figure 14, page 264.)

(4) The arrangement of the colors as presented to the map reader in the legend should probably correspond to the arrangement of a scatterdiagram of the pairs of distributions. (See Figure 15, page 264.) In other words, the color representing low values on both distributions should be in the lower left, the color representing high values on both maps should be in the upper right. Perhaps the cells of the appropriate diagonal (the positive is shown in Figure 15) should be emphasized to aid the reader in recognizing the relationship to a scatterdiagram.

(5) Since readers generally associate darker values of colors with higher numerical values in the distribution, tones should progress from lighter to darker on both variables. The combinations should result in approximately equally-dark values along diagonals, progressing from lightest in the lower left to darkest in the upper right. The numbers in Figure 16 (page 264) represent relative degrees of darkness.

(6) Because two-variable maps are intended to show the relationship between the variables, it is important that the reader be able to detect easily the positive and negative evidence on the map. Since the correspondence of extreme values weighs most heavily on the relationship, the extreme categories (legend corners) should stand out the most. Colors which are either visually saturated (i.e., pure in appearance) or are dark in tone might therefore be used for corner cells while relatively desaturated tones might occupy the center cells. (See Figure 17, page 265.)

(7) To show positive and negative residuals, that is, areas where the values on the second variable are either considerably greater or considerably less than would be expected from the value on the other variable, there should be a coherence in the triangles of cells above and below the main

diagonal. (See Figure 18, page 265.) (Again the figure refers to the case of a positive overall relationship). Residuals are an inherent characteristic of a relationship between variables and the prominence of residuals on the map should reflect the degree of relationship.

(8) Also related to the intention of conveying relationship, positive diagonals (lower left to upper right) and negative diagonals (upper left to lower right) should have visual coherence, particularly the two main, or longest, diagonals but also the secondary ones. (See Figure 19, page 265.) This coherence allows the reader (theoretically, at least) to see strong and weak evidence of a relationship. To alleviate the difficulty of achieving coherence in both the positive and negative diagonals, an alternative is to establish strong coherences for one set of diagonals and then orient the legend according to whether the general relationship is positive or negative. Such an alternative leads to contradictions of several other criteria, however, such as "the darker the more" (See #5).

(9) Because of the difficulty of mentally sorting large numbers of colors in the legend, a legend such as the four-by-four might be visually subdivided into a smaller number of categories, say two-by-two. We might call this a nested categorization. In the example in Figure 20, (page 265) yellow and purple tones would provide evidence of a positive relationship, green and red of a negative relationship, and an equal mixture of all four would indicate no relationship between the two variables. The advantage of this type of four-by-four scheme over a simple two-by-two (yellow, red, purple, green) is that there remains considerable detail about the individual distributions at the same time that the simplicity of a two-by-two scheme is maintained for purposes of depicting the relationship. Whether readers can indeed utilize a matrix large enough to be so nested remains an open question, however.

(10) The color scheme should relate to the data in such a way that the map relationship reflects as closely as possible the statistical relationship between the distributions. To achieve this, it is necessary that units whose values fall close to the line of average relationship on the scatter-diagram also fall in the cells of the main diagonal of the color legend. If we cannot assume that a dominance on the map of the colors in the diagonal indicates a strong relationship, then we must accept these maps as inefficient not only in conveying but even in <u>containing</u> information about the relationship between the variables.

We might be tempted to base the diagonal cells on a regression line, but because there are two regression lines (X on Y and Y on X) and often no reason to choose one of these as opposed to the other, it is necessary to choose some more neutral line of relationship. Equal standard deviation units provide comparability between the values on the two variables and the scatter about the line of equal standard deviations is indeed a function of the closeness of relationship. Hence, the diagonal cells should fall along the line of equal standard deviations and class breaks should be at equivalent standardized values on the two variables. (See Figure 21, page 265.) 2/

(11) To simplify the mechanics of producing the colors, each separate category on each individual distribution should be assigned a specific combination of screens and/or hues. This minimizes the number of printing plate burns (i.e., exposures) to produce the scheme. In the example in Figure 22A category one on the map of the first variable is solid yellow, category two is medium yellow plus a light red, etc., and for the other variable, specific shades of blue (including zero blue) have been assigned. This scheme is similar to the scheme used on the Fort Worth map shown earlier except that on the Fort Worth map yellow was assigned to the category which is blank here. Assuming one color separation sheet for each category on each variable, this scheme (See Figure 22A, page 266) requires three burns onto each of the three color plates -- yellow, red, and blue -- a total of nine. If we choose simply some combination of screen values for each of the sixteen boxes such that as many other principles are observed as possible, we may have as many as 48 burns (3 colors times 16 cells) unless we adopt a different system of color separations than separation by class interval. In addition, we would not be able to demonstrate so easily the basic idea of the two-variable map. With the simpler system, such as the nine-burn or that used in the Fort Worth map, we can demonstrate as follows (Figure 22B): first the map (or legend) of variable one is presented in the red and yellow tones (note the vertical orientation); then the second map (or legend) in tones of blue (note the horizontal orientation). Then the crossed version is presented as a direct combination of the two separate sets of colors, noting that the yellow remains yellow where it does not overlap with other colors, while the yellow plus blue in the upper left results in green, red plus blue in the upper right results in purple, etc.

(12) While the mechanics are certainly of practical importance, the structure of the scheme (i.e., its development as a combination of colors on two individual maps) must also be comprehensible to the map user and the resulting combinations should <u>look</u> like combinations of the specific colors involved. To illustrate, note the cell second from the left and second from the bottom in the final scheme in Figure 22B. While it is indeed a combination of the particular medium yellow and light red of variable one with the light blue of variable two, it <u>looks</u> out of place. [Note: Since problems such as this are highly dependent upon the specific inks and paper used, Figure 22B (page 266) may or may not effectively illustrate the idea.] Either some adjustments must be made in the specific screen value choices for the legends for each of the two individual variables or that specific cell must be adjusted to fit the scheme visually. (See Figure 23, page 266.) Mechanically, it is simpler to adjust the screen choices for the second category of each distribution but there is nothing inherently wrong with adjusting a single cell; the map is, above all, a visual communication device and must be designed as such.

(13) The number of categories to be used should not exceed the number that can be dealt with by the reader nor should it be so few that the map has too little information. The three-by-three matrix is both mechanically and visually more simple than the four-by-four arrangements and may actually convey more to the reader. Five categories, on the other hand, can be smooth and aesthetically appealing but lead to both mechanical problems and severe problems of distinguishability, especially in the map context. (See Figure 24, page 266 .)

(14) Finally, there is the problem of the rectangular nature of the legend cells and the effect on the map message. This results in a two-fold problem, one of which is that the reader expects to see only the side-sharing legend colors next to one another in a map representing a highly-organized spatial arrangement of two variables. Ideally, however, if the two individual distributions are highly related, one should expect the colors of the diagonal to dominate the map and these cells share only a point in the legend rather than a side. This is a rather subtle problem but an important one so far as the reader's ability to grasp the map as a whole is concerned. Secondly, the message of relationship is affected and areas of equal residual value (i.e., of equal distance from the line of equal standard deviations) may not look "equally residual" on the map. For example, a map unit may fall into an off-diagonal cell even though its X and Y values are very close to the line of equal standard deviations as illustrated by the observation indicated with a large dot in Figure 25A (page 266). To alleviate such a problem, perhaps we should consider a color scheme arranged parallel to the line of equal standard deviations while at the same time visually maintaining the categories for the two individual distributions. (Figure 25B, page 266). Such a scheme might include two distinctly different patterns such as stripes and coarse dots to represent the two distributions but for simplicity, in Figure 25B they are simply labelled with appropriate category numbers. A combination of hue and value change indicates closeness to the line of equal standard deviations: yellow indicates very close; light red and light blue, slight negative and positive residuals, respectively; dark red and dark blue, the larger residuals. This represents quite a change in the technique itself and hence, shall be pursued no further here.

CONCLUDING COMMENTS

These numerous considerations do not complete the list of things that should be kept in mind in constructing a color scheme for a two-variable map. They simply illustrate the complexity of the problem. The real test of utility of such maps comes not in simply developing a scheme of colors which theoretically obeys the maximum number of constraints; the development of the color scheme is basically a preliminary step. The real test is whether people can deal with the maps themselves and can accurately extract both spatial and statistical information. No amount of examination of separate components of the color scheme will tell us whether a two-dimensional array of colors can be grasped as a coherent whole to say nothing of whether the structure of that scheme coincides with the structure of information that is intended to be grasped from the map, thus enabling the reader to assimilate its information.

The use of color to encode relatively complex sets of data requires considerable forethought. The list of constraints to be kept in mind is long and some will undoubtedly be sacrificed in final decisions, but while there is little hope of an ideal system, we can at least strive for the best possible.

Two final notes I would like to include are first, that while some schemes are certainly better than others, it takes at least as much effort to consciously develop the "worst" scheme as to develop the "best." That is encouraging; even when our schemes have gross faults, if we have exerted any positive effort at all we find that they do contain a lot of information. Whether our readers can extract that information is yet to be studied. Secondly, these two-variable color-coded maps probably require a reasonable amount of mental effort and perhaps more than other representations of the same information. But the compelling fascination of the coding scheme as well as the initial attraction of attention induced by their colorfulness probably means that we at least have a captivated reader. While our concerns with good mapping should indeed take us beyond such a consideration, the captivated reader is certainly a good start in map communication.

ACKNOWLEDGEMENTS

This paper has resulted from a summer of employment at the U.S. Bureau of the Census. Many of the ideas presented here have developed through discussions with colleagues at the Bureau and in academia; the lack of references reflects only the difficulty of crediting the appropriate persons and not a lack of appreciation on the part of the author.

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Seminar on Automation in Cartography: Small Systems

SEMINAR ON AUTOMATION IN CARTOGRAPHY: SMALL SYSTEMS

This seminar disucssed the design and use of a small system, including its use in thematic mapping. A small cartographic system, as defined by A. R. Boyle, chairman of the seminar, is one which is centered around a minicomputer which allows interactive editing and incorporates the ability to produce many variations of a map in a short time. The small system should cost no more than $100,000.

Speakers represented Canada, Great Britain, the Federal Republic of Germany, and the United States. They discussed the various systems being used or implemented in their respective organizations.

Dr. A. R. BOYLE of the University of Saskatchewan (Canada), as chairman, provided an overview of small systems development in his paper entitled "Small Automated Cartographic Systems." State and local governments, governmental agencies and similar authorities considering converting their cartographic operations from manual to automated procedures must give consideration to the financial commitment required and to the component entities of a cartographic system. He discussed the work of the Graphic Systems Design and Application Group at the University of Saskatchewan, which has been involved in developments in automated cartographic systems utilizing available hardware and software.

The Natural Environment Research Council of Great Britain is involved in a wide range of disciplines in environmental science. SARAH B. M. BELL, representing the Council's Experimental Cartography Unit, described her organization's system and its use as a practical tool in regional problems of the environment. Her paper, written with D. P. BICKMORE, was entitled "Interactive Cartography at the Experimental Cartography Unit."

Dr. J. M. ZARZYCKI, Director of the Topographical Survey, Survey and Mapping Branch, of the Canadian Department of Energy, Mines and Resources, discussed "The Approach to Automated Cartography: Topographic Data Banks in Canada."

The major thrust of the Topographic Survey is towards the completion of 1:50 000 topographic maps of Canada and the revision of existing maps. Digitized terrain information, initially looked upon as a by-product of maps, is now stored in digital data banks which permit simple access, update, and retrieval of information. The terrain information data base and data bank concepts are integral parts of the system. Other features of the system, including hardware, were also discussed.

"Computer-Assisted Thematic Mapping With a Dedicated Minicomputer" was the title of the paper presented by WOLF D. RASE of the German Federal Research Institute for Applied Geography and Planning. This organization is developing a small, user-oriented information system for spatial research and planning on the Federal level. The computer-assisted production of thematic maps is one of the most important functions in this system. The hardware for mapping purposes consists of a digitizer, a flatbed plotter, and an interactive storage display. These graphic devices are controlled by a minicomputer with some peripheral equipment. Three groups of applications, including error-minimizing digitization of points and boundary networks; drafting of thematic maps with different levels of quality up to immediate use for printing; and the interactive design of maps and diagrams, were also discussed.

RICHARD PRYTULA of Canada's Dynamap, Ltd., discussed the considerations that should be taken into account when acquiring an interactive graphics system. He concluded that the system should meet the agency's needs; it should be efficient, flexible and have the full support of the manufacturer.

HOWARD CARR of the U. S. Army Engineer Topographic Laboratories (Fort Belvoir, Virginia) briefly described current hardware developments and associated software at the Army Engineer Topographic Laboratories.

SMALL AUTOMATED CARTOGRAPHIC SYSTEMS

A. R. Boyle
University of Saskatchewan

Small automated cartographic systems have wide applicability for provincial, State, municipal and similar authorities, in application areas such as geology, soil science and forestry and also in individual departments of large mapping agencies. In fact they can be used where there is a need for a medium output of maps which need compilation by experts in a particular area of work. Many such groups have found that they cannot provide the necessary speed of response to demand by purely manual methods, and realize that it is now necessary to enter the digital age of mapping. It is only in this way that variations of map content and modifications can be made, without excessive individual effort each time. Special applications such as land use planning have also created an atmosphere of change.

The preliminary commitment is a serious one requiring a minimum financial outlay of at least $100,000. More importantly the commitment requires an acceptance of new ideas and methods by the present manual cartographers. However, it appears that the time is now ripe for change and manual cartographers realize that their skills are still essential, even if used in a rather different way.

The entities of a cartographic system are made up of digitization, storage, interactive display and edit, and drafting. All these entities require separate data control and are then bound together to form a compatible system. The initial financial commitment may be relieved by using contracted facilities for some of the entities. It is not possible to do this for interactive display and edit as that is the main interface between a digital system and the manual cartographic compiler; it must be in-house. Moreover, it must be one which can operate on data at very high speed, be very flexible and very easy for the cartographer to use. Without this facility the human control of the mapping is absent, or at the very best causes uneconomic production of overlay sheets, which have to be scrapped or manually corrected by pen and ink.

On the other hand, the digitization of maps and aerial photographs can often be subcontracted, and this will be advisable for many small users. It may also be possible to obtain data already digitized from other establishments. The subcontracting facilities are only recently emerging from the development stage, but can be reasonably applied to contouring and culture in photogrammetry and to pure irregular line data, such as for contours and hydrology, on existing map overlays.

The annotation of the lines digitized remains as a major amount of work for the user, but it can generally be most efficiently done in-house on an interactive display and edit facility.

Subcontracted work has until now generally been carried out by manual digitization methods, but the output is then not only expensive but may be unreliable. However, manual digitization will always be very important for point location data, and for updates and corrections too detailed to be done interactively on the display. It is thus recommended that a manual digitizing table should form a part of the interactive display and edit facility. Although the table need not have a very large work area; the integration of digitized data from part maps into a whole, is now a simple software procedure.

Although drafting is the entity in the system with the longest history, nevertheless serious organizational problems arise. Most users converting to digital methods have created a reputation for high quality mapping, and they are not prepared to allow this to suffer because of any advantages of automation. There is no need for quality to suffer, but, while adequate precision drafting systems are certainly available, they are expensive and require special facilities, as they draft with light-heads moving over photographic film. The cost of such a unit may well be two to three times that of the display system mainly because of the precision mechanisms involved.

It should be possible to use contract facilities for drafting, but these do not appear to exist as yet. There is definitely a need for centralization of this type of work as only a large user, or small users working in a group, could warrant the funding and upkeep.

At one time digitizing and drafting tables used specially constructed electronic directors. These have now generally been replaced by simple minicomputers which give greater reliability and flexibility; they are still treated by users as 'black boxes.'

An interactive display and edit facility needs a control very similar to that for a drafting table, but with very much higher operational speed. An operation that may take an hour in digitization or drafting must be completed within seconds, otherwise the cartographer will become irritated and prefer to return to his pen and paper methods. Such a high speed of control with the large amounts of data in cartography requires the employment of software in assembler language. It cannot be obtained by the use of a display terminal on line to a remote computer or by operating a minicomputer system in FORTRAN. Many developers have used FORTRAN because it was easy to write. It produced results adequate for research use, but much too slow for production. Bit-manipulation assembler routines take longer to write, but then control the data with an acceptable speed, so that a complete map may be drawn on the CRT screen, or modified, in seconds. Such systems are now available and can be treated as control 'black boxes' in the same manner as those for the digitizers and drafting tables.

The storage of cartographic data in small establishments is not really a problem and a magnetic tape library is usually adequate. Individual tapes are selected as required for a specific area, and these fitted to the appropriate controllers.

A proper cartographic system design must take care of the interconnection of the separate entities. This not only involves hardware but also software. Generally such software is of a computational character but may also involve programmed manipulation of the data (e.g. sorts and selections). These interconnecting programs may be run on any external computer or, if within the capability, on one of the control minicomputers. It is in such processes that the user may become involved in special program modification or additions to meet his particular needs. In general he will not be concerned with modifying the control programs except for such aspects as the possible addition of specific symbols.

The costs of the minicomputer controllers are so low compared with the peripheral devices and software that it is normal to apply individual controllers to each device and not attempt time-sharing with its attendant software overheads. The separate controllers are usually connected by interprocessor buffers or, if over a longer distance, by magnetic tape transfer. Telephone lines are usually too slow to handle the very large amount of data involved in topographic mapping. The system designer must check that data compatibility is maintained. He may decide to group a number of peripherals onto one controller, or it may be necessary to duplicate or triplicate some entities once the work load has been analyzed. It is not essential that all controllers be of the same type or make. However, if they are, then there are advantages relative to maintenance and to continued operation in the case of the failure of one unit.

It should be stressed that the use of the term 'small' does not in anyway infer a reduction in quality or flexibility of product; those may well be enhanced. It is merely related to a user with relatively small volume of work.

To this stage, only pure cartography, generally of a topographic nature, has been considered. However, there are now many groups involved in thematic mapping. In some of these the precision and detailed mapping requirements may be reduced, but there is often a greater degree of computation required; in some case, in fact, only the largest computers will suffice. In such cases the small cartographic system described here, becomes a highly intelligent terminal making repeated references to the larger computer. In other cases, much of the computation work can be carried out on one or other of the minicomputer controllers as these devices are now becoming powerful in computation and work well in high level languages.

As much work as possible should be carried out in-house. Experience has shown that a program working slowly on an in-house machine is normally cheaper and often preferable from a turn round time to a similar program used on a central computer facility. There are of course limits to these possibilities, but few appear in the cartographic processes.

The Graphic Systems Design and Application Group at the University of Saskatchewan and the writer, have been involved in developments as described here since 1960. The first system, in the United Kingdom, involved specially designed electronic directors for drafting and digitization, as minicomputers were not then available.1/ The second, for the Canadian Hydrographic Services, proceeded on the same lines, but with the much more reliable minicomputers as controllers, other computational programs being run on IBM or CDC machines.2/ Since that time the Group concentrated some three years of effort on interactive display manipulation of cartographic data 3/, and interactive manual digitization.4/ The last two years have been concerned with aspects of control manipulation of attributes of points, routes and areas and this work is still progressing.5/ 6/ An overall review of the present state-of-the-art is given in footnote 7.

Software development before 1970 did not require great speed of operation; reliability was the most important criterion. The work on interactive display and edit of cartographic data, however, soon showed that ease and flexibility of handling cartographic compilation was not enough, but that speed was essential for true interaction. There is a very big difference between an 'interactive' and a 'query and answer' system. Very few new manipulative facilities were actually created after the first year of work; all the subsequent work was concerned with ease of use and speed of operation. This involved the design and often redesign of the data format (it is in fact a multiple format system), the directory system, and the recording of cartographic changes made so that the user had complete control to remake changes, and then even change those again, as often as he needed. A speed of response of two seconds was always the aim and in most cases this was attained, even though such computations as changing projection from longitude-latitude to Mercator might be involved. Some programs were first written in FORTRAN to check out the operation usefulness and then converted to assembler to obtain speed. It was easy to change line descriptors, point labels, positions and shapes, and complex routines were written to give greater and greater simplicity of use in polygon manipulation and line-to-line end and T junctions, for example. For later processes lines might have to be reversed in direction or groups of data selected for particular uses. Some changes were to be relative to the databank, and some to special output for a specific map. It is a fast and powerful control and can operate as a self-standing system connected to any user's own system. The internal control formats are only matters of interest to a specialist in such control programs; the user normally only sees the data in an IBM-or industry-compatible I/O format.

Some of the programs developed by the Graphic Systems Design and Application Group are treated by others as purely computational, e.g. 'scale and rotate' and projection changing. The computational approach on an external computer was used for some years, but it was expensive to run and often created appreciable errors and, moreover, errors which increased as scale increased--a most unfortunate happening. After some time of irritation at these processes, these programs were rewritten to become ones which were called 'incremental mosaicing,' a process very similar to the cartographic manual methods but of much higher resolution. It was found that these programs would run easily in a minicomputer and as a result were low cost. The accuracy stayed constant at all scales without round-off or other errors.

Concepts similar to those used in cartography were then applied to the manipulation of attribute data relative to locations, routes and areas. The display thus became an emryonic Geographic Information System terminal; only those aspects which could be regarded as 'control' have so far been developed by the Group. The aim is to fill a need for the supply of information in a presentation which can easily be assimilated by the planner, who would then use his own mental modelling processes. There has so far been a complete avoidance of any aspects of computer modelling and true, complex, computation. Processes such as statistical manipulation of data and overlaying of polygons are on the dividing line, and can be treated in either way depending on circumstances. In all the control aspects developed, speed of response, flexibility and ease of use have been paramount guidelines. In many cases the system can be self-standing for a normal planner, but whenever referral to a larger computer is required the system can then act as a very intelligent terminal. In all its analyses of attributes, the basic background cartographic display manipulations play a most important part, and full use is made of those facilities.

The latest work of the Group is concerned with increasing the availability of low-cost and easily handled massive storage of data, so that this can become an integral part of the control system. This not only provides a capability for faster access but makes confidentiality control very much easier and more definite--this, of course, is now most important when socio-economic data is being examined.

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INTERACTIVE CARTOGRAPHY AT THE ECU: REGIONAL GEOGRAPHY A LA MODE

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INTRODUCTION

This paper describes the Experimental Cartography Unit's system and its use as a practical tool in regional problems of the environment. It also discusses interactive working and the Unit's development of this technique over the last four years.

BACKGROUND

In 1974 the Natural Environment Research Council (NERC) decided that the Experimental Cartography Unit should formally become one of its component bodies, both in order to provide a "service function" to other institutes within the Council, and in order to continue to develop research within the field of automated cartography -- a process initiated by the Council nearly ten years earlier. It is unnecessary for me to dwell on the helpfulness of becoming formally part of the Research Council, and, in consequence, of being able to plan cartographic aspects of environmental research on a reasonably long term basis with many of our institutes.

Perhaps I should explain that the Natural Environment Research Council (NERC) is concerned in a range of disciplines across the board in environmental science. Besides geology and oceanography, there are experts on geochemistry, geomorphology and geophysics: equally so in hydrology, physical oceanography and marine biology: and, at a time when few disclaim interest in ecology, NERC's Institute of Terrestrial Ecology is acknowledged as one of the world's leading organisations concerned with research in this field. These specialists are, by their nature, continually engaged in "surveying" and in collecting data, often on an extensive spatial basis. Much of their "survey" is different in method to that of the topographical surveyor, and some of it assumes a base map. But the demarkation line between topographical survey and these thematic surveys has much less significance today than it had 10 or 20 years ago. Today there are more demands for geographical information about regions on a quantitative as well as qualitative basis, and for mapped information covering a wide range of coherent topics.

To this need, computer systems can bring a number of important facilities; the most important, perhaps, is the ability to correlate different sets of information about the region from data assembled at different scales and with different reliabilities -- "scale variable cartography." The ability to derive additional information from the facts observed is also important (oil field prospecting from geophysical sampling and from bore holes is an obvious example; slope and aspect derived from contours is another; forcasts based on mathematical modelling is a third). Another facility is that of offering geographical information in a great variety of graphical forms, from the ephemeral to the definitive -- from a quick simple CRT display at a terminal 50 miles away, to complex maps or atlases printed in many colours: (and the difference in cost between these two forms does not necessarily favour traditional methods). These are the kinds of thing that geographical information systems are about; and today they are no longer figments of imagination.

In the NERC case much of the data that we collect is in digital form, or at least comes for mapping in that way -- often as a mass of x/y/z triplets. But this kind of information loses much of its significance unless it is set against a wider topographical context. To understand patterns of global seismology, the eye needs some world base map; to comprehend current movements in the Irish Sea, coastlines and bathymetry are essential. Other kinds of environmental data -- e.g. vegetation mapping -- may be collected on a sampling basis, and topography seems likely to play an important part in establishing sampling frameworks, particularly if the right information is available in digital form before the sampling survey starts. In these kinds of case the Council's main effort and expense is in collecting, analysing and displaying the specialised data; it follows that if the specialised data anyhow requires computer processing, then base map information is also desirable in that form.

At the same time, we are well aware of the difficulties posed by cost factors in developing new work based on computers in this whole field. These difficulties do seem to be particularly great if the automated system is designed to do little more than can be done by manual methods, and is, at the same time, noticeably more expensive. And where the automated system has to be constrained to producing exact copies of "hand-made" maps, experience seems to show that traditional cartography still remains cheaper: at a time of widespread under-employment there is some danger that such a form of automation may seem socially unacceptable. Of course this argument does not, of itself, justify more sophisticated systems, which must depend on a range of input and output requirements that may be quite unusual in cartography, sensu stricto.

ECU PROCESSES

Although this paper is particularly concerned with interactive cartography, it is necessary to say something about the context in which this takes place, and to describe, briefly, the equipment and the processes that precede interactive work.

PRE-INPUT EDITING

We find that at any one moment we may be handling seven or eight different projects for quite separate areas, subjects, scales, etc. In addition, over 90% of the work is for "new" mapping -- as opposed to the translation of existing maps to digitised form. This is a far cry from "factory cartography" and from a steady throughput of greatly similar documents. Before any document is digitised, a careful detailed study is made of the compilation, so that it can be marked up with its appropriate feature codes, and so that the relationships between different areas that can be derived from the data, once it has been digitised, will be available.

Our system assumes that automated cartography must give back more than a line for a line and a point for a point. Complex areal patterns into which the data falls are part of the essentials that the system should be able to provide. The anticipation of these patterns is, like most forms of pattern recognition, very considerably aided by human editing: we do this generally -- but not exclusively -- before digitising.

We have already emphasised that some of our data comes in the form of point information, e.g. values at each of several thousand points, for a dozen or more different mineral elements derived from samples of stream sediment. Although such data comes to us checked and on a reel of tape, there are still editorial problems in anticipating and organising its cartographic relationships with, e.g. the stream pattern, the geology, etc.

DIGITISING

We are still operating on two "high accuracy" D-Mac digitising tables purchased in 1970. However, both of these now output data on-line to a single PDP-11/05 (plus disk) which checks the arrangement and syntax of the data and protests appropriately if it is unhappy. We also continue to use an overlay sheet of coated paper which is scratched by the digitising point to record what has and what has not been digitised. The digitising is generally by stream mode, for no better reason than that experiment with the kind of shapes and scales involved shows that this is often the quicker and better way for us. But the capability of selecting points and splining through them is there, and is used both in digitising and for adding lines in interactive work on the CRT. The output from the digitising process is a Dectape.

FORMATTING

This stage of our operation translates the PDP-11 Dectape from digitising table co-ordinates to those of the map projection required, e.g. British National Grid, and into the format of our two computers -- PDP-15 and PDP-9 (each with 24k of 18 bit words). At the same time separate sheets or parts of sheets are automatically placed in their correct juxtaposition, and their dimensions can be adjusted by bilinear transform is required. At this stage too, unnecessary co-ordinates that have accumulated during digitising are eliminated so as to produce a tape with just sufficient co-ordinates to produce faithful playback at 1:1.

A very important aspect of this processing is that of representing the digitised data on disk in a properly structured form. Each point or segment of line is allotted a unique number or identifier by the system. This can be found by the operator as and when he requires it, either by pointing at any part of a displayed map, or by naming the identifier on his teletype and seeing it displayed. The development of a cartographic data structure (see Appendix A) has been a prime concern of the ECU over the last four years, and we believe it to be basic to the ability to provide rapid retrieval of information from disk; and that, in its turn, is crucial in our interactive graphics. We particularly acknowledge the work done in this field by our colleague Dr. L. W. Thorpe.

Recently we have grouped programs for formatting digitised data on to disk so that they can be operated in batch mode, i.e. unattended overnight. Note also that the programs involved are 'exportable,' and by the end of this year we hope that these processes can also take place on the Univac 1108 system (see below): alternative routes are always desirable.

CHECK OF POSITIONAL ACCURACY

In our system the next stage is to play back the data set as a plot at digitising scale, so that a critical examination can be made solely of positional accuracy. Again, the process of computer playback takes place unattended and overnight -- over the night after the formatting run in a production schedule. Playback is by our AEG Geagraph flat bed plotter and on to film covering the 1.4 x 1.4 metres of the table. Our light spot projector, in this case, is purposely instructed to use line widths thinner than those on the original compilation. The checking stage that follows, since it is concerned only with comparing positional accuracy and presence as between the film positive and the original, can be a rapid one; and the eye and mind of the checker can concentrate on ensuring that all original lines have been reproduced faithfully. Mistakes (which may be due to errors on the part of the operator during digitising, or -- more rarely -- on the part of the equipment) are corrected either by re-digitising (this of course entails reformatting, etc.) or directly through interactive graphics -- a much more rapid process, but a difficult one, e.g. for isolated shapes not intersected and located by other line patterns. A program called OVERLAY, which identifies line intersections, is a help in splicing new work to old with a minimum of redigitising within each line segment.

FEATURE CODING AND AREA CHECKING

After establishing positional accuracy, the editor now needs to ensure that feature codes have been correctly allocated to lines, and hence that the different areal patterns held in the information system are correct; and -- if that is what is wanted also -- to ensure the direct production of masks for a coloured map. Again, there are, by design, a number of methods available within the ECU system for this check.

The quickest way to call up each set of coded areas on the CRT and to see that each is correctly self-contained. But this involves the editor or operator in having access to the CRT, and with non-time-sharing computers (such as the PDP-15 or PDP-11 range) this leads to queuing and its tiresome consequences such as shift work. (The answer is to use a time-sharing computer system, and that is one of our main reasons for linking to a Univac 1108; this point is discussed further in Section 3).

An alternative way is to use our plotter, in its overnight mode, to play back maps of each different type of area. Typically, we may have 50 types of area to a specific data set, and to save time and cost we can combine up to 5 or 6 on to one plot by using different boundary symbols. Furthermore, we can reduce scale so as to get, say, 9 or 12 of these mini-plots on to one night's working on the plotter. (Bear in mind that the positional accuracy of the work should already have been dealt with -- this check is to ensure that all coded areas are complete and "watertight.")

In the past we have found that feature code checking is a meticulous and slow chore that tends to increase exponentially with the complexity of the data set or sets, as when, e.g. topography, soils and administrative boundaries of the same area are overlaid. Any one line segment in the data set can well be the boundary and carry the codes of five different areal patterns to its right and left. To mitigate this, we are now developing an automatic checking program that will work through each feature code, examining the start, end and direction of each line segment. In this way the program will identify any that remain unclosed or odd: from this catalogue of suspects the program will then produce a tape that will display (CRT or overnight plot) a machine-made correction trace; indeed, it seems likely that the system itself can be taught to correct some, at least, of the errors it finds (but informing the editor when it has done so).

It will be obvious that once the system knows how to access the areal patterns in the data base, it can, from this knowledge, address other matters. For example, it may be desirable to omit all areas of less than 1 hectare of a particular feature -- say, woodland -- when playing back a map at a smaller scale, or to omit them when contiguous with some other feature, or when that category of woodland has some associated statistical measurement. The range and variety of possibilities is formidable. And the fact that many map makers or map users have never contemplated that they could manipulate geographical information in this way does not mean that, given the opportunity, they would not find this a powerful additional cartographic tool. This kind of manipulation on large and complex data sets does, however, demand really efficient and powerful computing linked, e.g. to a Codasyl-based data management system; since that inevitably tends to be expensive, and in short supply, it also points the need for efficient computer communication links -- a field of prime interest in modern computing, and one in which the quantities of data necessary for cartography pose special problems.

AMALGAMATION OF DATA

Another facility of the system is that of amalgamating data -- both in terms of topics for the same area and in terms of area by area relationships. The ability to amalgamate -- and to un-amalgamate -- data is frequently a useful short cut for the cartographic editor, e.g. enabling him to isolate one group of features or one section of the map where there are heavy corrections, and then to reassimilate them with the other elements of his map. In another instance, where ecological information about coastlines, rivers, lakes, etc. had been gathered by grid square, it was possible to map it automatically to the actual segment of coastline or river that fell in the appropriate square. The amalgamation programs are also valuable tools in handling edge match discrepancies; a narrow edge strip of the two adjacent sheets can be unamalgamated from the main files and presented on the CRT, so that the edges can be tidied up heuristically in rather the way in which these things are handled manually; most of our edge-match problems seem simply not susceptible to rule of thumb solutions which could be neatly encoded in an ad hoc program.

DIGITAL DATA IMPORTED FROM "OUTSIDE""

If it was only able to handle data that it had digitised itself, the ECU's main objective would be defeated. There are within NERC -- and outside it -- a growing number of data collecting agencies who satisfy three main conditions: (a) concern with an environmental problem that has significant geographical variations; (b) data that is in digital form (usually x/y/z); and (c) a need to see it expressed graphically as well as statistically. In the early stages of data collection most organisations develop their own idiosyncrasies of digital format: quite often these seem to be imposed by the particular equipment available to them. But sooner or later there comes a need to exchange data, and with it the usual teething troubles and frustrations of translation from format to format. NERC is currently developing its data exchange system, which becomes particularly important where there is a range of different equipments and an interest in seeing the effects of processing data with someone else's more elaborate programs and on equipments that may offer more elegant graphics.

One of the main demands by all environmental scientists is to have their data sets "contoured"; and there abound a multiplicity of programs, each liable to produce significantly different results (although in fact rarely compared). In 1974 the ECU acquired for NERC use the large American program SACM (Surface Approximation and Contour Mapping) from ACI of Houston, and this is now mounted on both an IBM 370/195 and the NERC Univac 1108. This is not the place to discuss automatic contouring programs, none of which is perfect (broadly speaking, the smaller, the worse). They produce different results from hand contouring, both in terms of factual consistency and of graphic cosmetics; with data sets of thousands or tens of thousands of points they score heavily. Like most contouring programs, SACM first derives a grid of values from the data; contouring or the drawing of cross-sections or perspectives, etc. is handled as a second and subsequent stage, and its output is a tape which can be played back on whatever graphics device is convenient -- e.g. a Calcomp drum plotter. We are able, for example, to arrange for SACM tapes to be imported to the ECU, where they can be plotted direct by our flat bed machine, where that is required; alternatively, they can be introduced into our system, structured on disk and edited interactively in relation to other data, e.g. topography, already there.

As we develop the potential of our 9600 baud link line to the Univac 50 miles away, so we expect to see more and more interactions of this kind - and, hopefully, to the point at which it is of no concern to the user which machine is doing what. There are, for example, groups of problems in Engineering Geology that demand just this kind of conversation between an expert geologist and data deriving from relief, land use, drift geology and bore holes. Another field in which this kind of graphical interaction seems to be required emerges from the building of mathematical models of environmental processes. This work has of course the added complication that it may introduce a dimension of dynamics into the cartographic display; we clearly have a lot to learn about how we can best read dynamic maps, let alone how we can interact with them; the computer-generated film can have a useful expository element about it, but as a research tool it has severe shortcomings.

The assumption that contouring is the only valid method of displaying a mass of observations at points that are spatially distributed seems to come all too naturally to those unfamiliar with alternative cartographic forms. But there are cases where it is important to show a number of separate surfaces simultaneously, or to display by symbols the exact quantities as observed at points and to let these speak for themselves. The principal problem of using quantified point symbols arises in areas of congestion where they tend to overlap and obscure each other. (The solution of moving the symbol away from its true location so as to be legible cannot but distort the pattern, and hence seems questionable; equally unsatisfactory is to use larger and larger scales to give more room for a particular style of symbol.) Our rather unoriginal solution is to use wind-rose type symbols where the vector indicates the quality measured and the line length of the arms shows the quantity. This has been extensively adopted in geochemical mapping, where it is, as ever, important to see through the specialised information to the topography, etc. below. In this case we import tapes (in an agreed exchange format) and display them on CRT so as to determine optimal scaling for the symbol arms, or carry out any other editing required before final plotting of positives.

CARTOGRAPHIC "FINISHING"

Given a clean data set, it is gratifying how rapidly finished reproduction material emerges in all its crisp elegance; cleaning the data is still a long slog, so it is just as well that there are some rewards. The quality of work from automatic plotting machines does seem as high as anything produced by hand; but despite this, very little attempt has been made to explore new graphic possibilities in cartography, and only too often these expensive and elegant machines seem forced to mimic manual specifications laid down fifty years ago.

Apart from drawing attention to this unhealthy symptom from which we all seem to suffer, we mention here two aspects of cartographic finishing that we have found important in ECU practice. (I do not propose to discuss the particular refinements of plotting tables, light spot projectors, or even laser beams, which are adequately dealt with in manufacturers' literature.)

First, it seems noteworthy that high resolution graphics can sometimes contribute to derived geographical information more cheaply and rapidly than by computational means. For example, one particular conservation need was to identify land in the Shetland Islands that lay more than a quarter of a mile from roads. The road network was plotted using a thick symbol whose width represented half a mile at a selected scale. The resulting black "bands" were then masked by the coast and water to produce the areal pattern required. The same technique has also been applied to deriving slope from digitised contours. While these methods lack the finesse and flexibility of a computational approach, they can provide extra routes to a particular solutions.

Secondly, is the ability, which we now have, to organise a tableful of plots for unattended overnight operations; automation is intended to be automatic. This procedure depends on an accurate sectionalising of the large area of our plotting table so that different maps (or the different colour/tone components of a single map) can be assigned to different areas of the table by giving appropriate offsets to different sets of corner points. The master program that controls the process is mounted on one of the Dectapes on our PDP-9, and details of the offsets required, plus the symbols and pecking patterns for the lines and points for each separate plot are punched up on paper tape ad hoc. The program calls up its map data from magnetic tape which has come -- on the completion of editing -- from the disk. The output -- waiting on the table in the morning -- is a film positive, ready for developing, preparation of peel coats (whose peeling is vastly simplified by the omission of any lines that do not form the boundaries of particular colour masks), tint laying, plastic colour proofing and, finally, lithographic machining -- assuming, of course, a traditional cartographic end product whose multiplication is, of itself, a not uncostly business.

INTERACTIVE GRAPHICS IN THE ECU

This section of the paper describes in some detail the development of the ECU's approach in this interactive field. It will be evident that one use of interactive graphics in cartography is as a means of rapid -- and hopefully economic -- correction of errors introduced in collecting or in processing data; another use is in making modifications necessary for smaller scale playback, for new maps, and the like. These uses of interactive graphics assume that the cartographic end product is a printed map. Another use for interactive graphics is comparable with the work of computer aided designers and it assumes that the ephemeral map as displayed and interrogated on a CRT will itself become an end product. In our own immediate experimental work over the last four years we have concentrated on the former, and we believe that this experience leads in to other uses. As time sharing systems become more general, as interactive display terminals become cheaper and more widespread, so interactive cartography does seem certain to become a practical and useful supplement to the printed map.

PRIMITIVE STAGES OF INTERACTIVE GRAPHICS

It is sometimes assumed that interaction demands very expensive equipment -- large fast disks and refresh displays. This is not the case. Of course there are disadvantages to implementing interaction cheaply and simply; many of these became evident in the first interactive system in the ECU. This was working as a part of our automated process in early 1971.

The map data was, in those days, held on magnetic tape, with a summary of each line and point in a core table. A cheap storage display (c. 2000 Tektronix 611) was used to display the map -- to see that all was well. On a storage display the picture is plotted once and remains visible for up to an hour. A cheap joystick (500), that was merely an 18 position switch, was used to provide interaction. The joystick directed a "refresh" cursor about the display screen, using the 611's small refresh point plotting ability. Our computers were a PDP-9 and a PDP-15, each (then) with only 16k of core (neither with time sharing, of course). With this system it was possible to "window" into any desired part of the map, magnifying it on the screen. The operator could indicate any line or point and delete it or change its significance by altering the feature code. If he required a hard copy he could take a polaroid photograph of what was on the screen. The disadvantages of such a tape-based system could be summarised as follows:

> It is not very interactive. Specifically, it takes a long time to read the data from tape for plotting.
>
> In addition, the whole data set must be read. It is not easy to skip or search for parts of it.
>
> Lines cannot be read backwards, as is necessary when joining two lines together.
>
> No data can be inserted into the middle of the data set.
>
> The display screen is not large enough to display a whole map in legible detail, nor accurate enough to be used for checking absolute positions of data (though relative positions are displayed).
>
> In more general terms, it is wasteful to have a dedicated computer for on-line work of this kind, since valuable computer time is wasted while the operator deliberates. On the other hand, effective time sharing demands a major computer.

INTERACTIVE CARTOGRAPHY IN OPERATION AT THE ECU NOW

The main differences between the humble beginnings of interaction and the current ECU system are in speed and the number of types of interaction that can be performed. In consequence, the ways in which the system is used are also changing. The operators still use the system extensively for error correction, but now it is becoming fast and powerful enough to be used by editors for "post-input" design of new maps, if necessary in an interrogatory mode with the specialists who collected the original data in attendance.

The vast increase in speed (about tenfold) and in the number of different interactions is possible through a major change in the way the map data is held. Now it is on disk backing store (10 million word disk pack) in the form of a direct access file structure called "Mark I". This structure allows the operator direct access to any line or point on the map (assuming that its identifier is known). Thus he can read only a required type of feature, or combination of features, or, as before, the whole data set. The structure is briefly described in Appendix A; and each interactive graphic function in the system is discussed in Appendix B.

The main facilities included in the interactive graphics package, in conjunction with data organised by the Mark I data-structure, are shown in Figure 1. In general these facilities can be used either by typing in co-ordinates or identifiers at the keyboard, or -- more usually -- by indicating points and lines on the displayed map on the screen using the joystick.

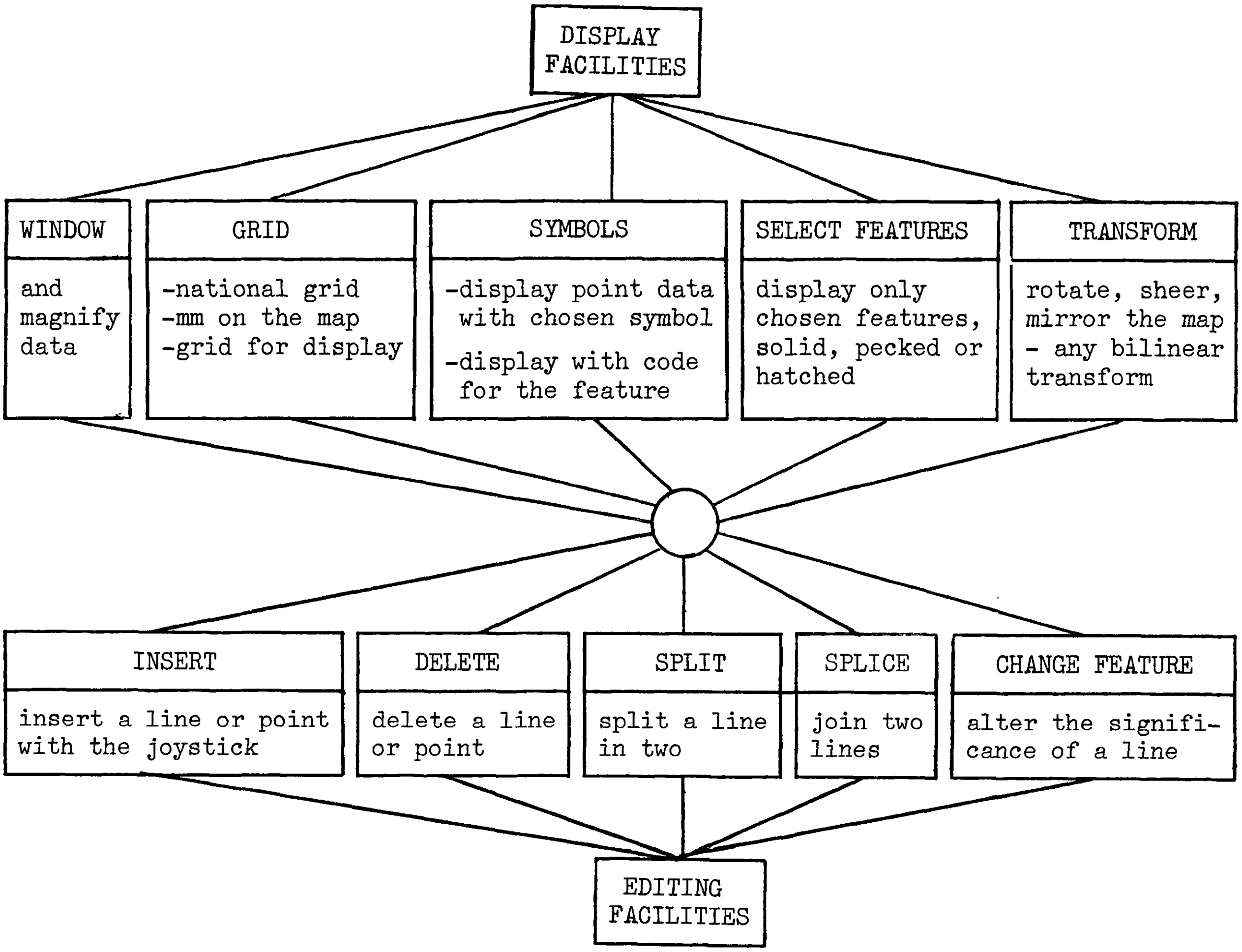


Figure 1

INTERACTIVE GRAPHICS FACILITIES

How far does this present system based on our Mark I structure overcome the disadvantages of our original system with its reliance on magnetic tap backing store?

> It is more interactive. Because of the Mark I structure it is possible to access only the relevant parts of the data from disk as and when required. So there are more ways of solving correction problems and each operation is completed much faster. (Observe, however, that another speed limit has now been reached, for the data can now be read from disk rather more quickly than it can be plotted on a storage display.)
>
> Lines can be read backwards, as well as forwards, enabling them to be joined.
>
> New data (e.g. corrections) can be inserted anywhere in the data set.
>
> The hardware (storage tube) is still relatively cheap and simple.

CURRENT ECU DEVELOPMENTS IN INTERACTIVE CARTOGRAPHY

In spite of these improvements, two significant disadvantages remain. The first, and operationally the most serious, is that the system still is not a time sharing one. The very fact that the interactive process is a faster and more practicable cartographic tool now serves to attract more work to it; this tends to lengthen the queue of frustrated people waiting to use it. The second disadvantage lies in the fact that the storage displays are small and have low resolution; hence they require more "blow ups" of complex areas, more separate checking stages, etc., while providing a relatively "unmap-like" display. Current work is concerned to meet these two main problems and some closely related issues.

TIME SHARING

We have placed great faith in the sophisticated potential of Univac 1108 that has recently been acquired by NERC especially in the matter of time sharing and of data management. A link to that machine -- 50 miles away -- by a 9600 baud private telephone line, plus a PDP-11/05 communication concentrator will, we believe, enable us to use this "remote" equipment from within the ECU as though it was our own. (At the time of writing we already have three teletype terminals linked simultaneously and successfully in to the system.) However, if we are to increase the number of graphics terminals in the ECU from which map editing can take place, the display hardware needs to remain as cheap as possible. With this in mind, we are developing our graphics software so that it can be used on similar storage tube displays (Tektronix 4010) to those we have been using over the last four years -- including the ability to use the available refresh capability in these displays to point at or enhance details or the stored picture.

UNIVAC SOFTWARE

Our graphics terminals plus our communication link should now serve as periscopes into the data on the Univac. They should also enable us to transmit data in both directions, to use our own software on the Univac, to use existing Univac software (e.g. statistical packages) to process our data, and to revamp many of our existing programs for more efficient operation in the much greater freedom of a large computing system. We look for benefits, in particular, in the use of Univac's

Data Management System 1100 (now usable by us in Fortran).

LARGE HIGH RESOLUTION DISPLAY

We are currently commissioning the new HRD 1 plotter produced by Laser-Scan Ltd. of Cambridge. This is only the fourth of these equipments to be manufactured, and the first to be used in predominantly cartographic mode. This display (which draws particular lines and symbols and does not operate on a purely scanning basis) will be driven by our PDP-15. We anticipate that it will draw at about the same speed as the storage tube, but over an area of roughly 100 x 70 cms., as opposed to 20 x 15 cms. We shall be using its refresh capability to rather the same effect for interrogation as on the storage tubes. Furthermore, the display itself will be "accurate" and without the pin-cushion distortions of the (very much cheaper) storage displays. Its higher resolution should also enable it to display lettering elegantly and rapidly, and enable us to annotate maps. And since the ECU data structure enables us to generate and store records of areas, we anticipate that Laser-Scan will give us the ability to shade in colour patterns direct for use as reproduction material, though whether this will be economical is another matter. In the first instance we expect to use Laser-Scan primarily as an interactive editing display, with the assumption that the final data will be plotted as now -- unattended overnight. However, hard copy of any display can be provided in microfiche form; eventually we hope also to develop a "long light lever" from the Laser-Scan that will provide cartographic quality film positives at scale.

While Laser-Scan has all the appearance of being a valuable cartographic tool, the hard fact remains that it costs about 20 times more than a storage tube -- and we shall have only one. Our operational plan, therefore, is to carry out as much routine editing as we can on the small storage tube terminals and use Laser-Scan for complex areas or for problems demanding the accurate display of large maps which seem likely to result from the increasing geographical extent of the data bases we are able to hold on the Univac.

CONCLUSIONS

OTHER TYPES OF DISPLAY

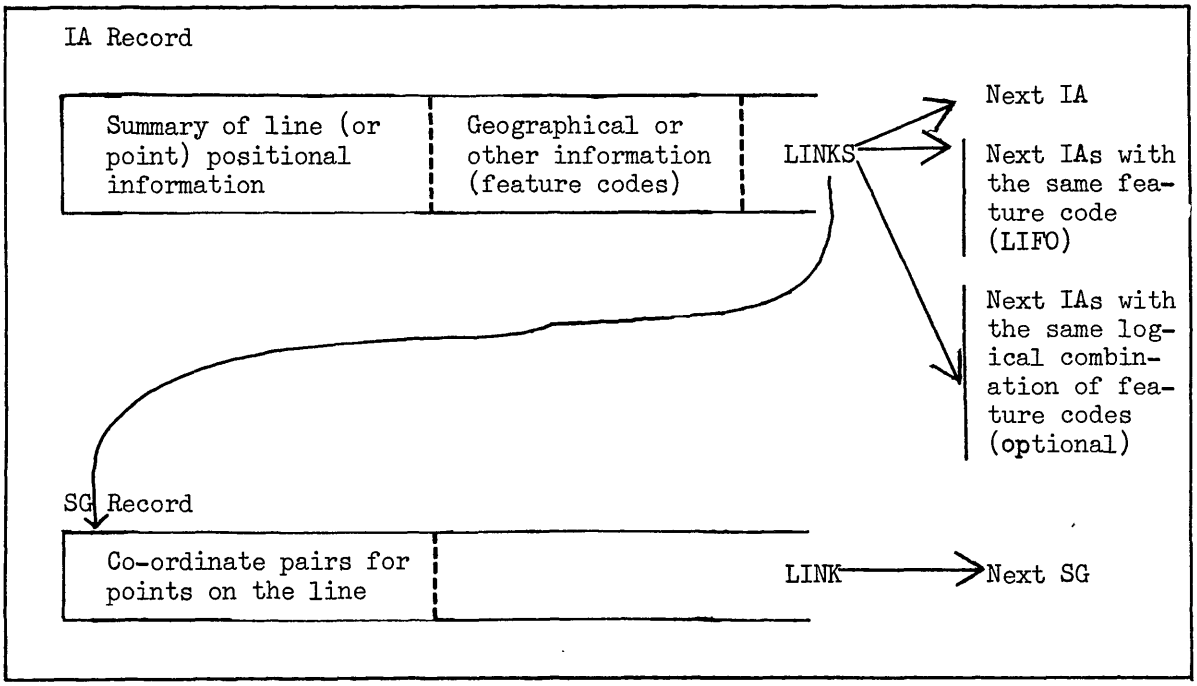
In discussing the route which we are taking so far as interactive cartography is concerned, it is worth noting the speed with which technology is still advancing in this field. One alternative to our storage tubes-plus-Laser-Scan configuration would be the use of display that plots entirely in refresh mode, and does so at least ten times more rapidly than on a storage display or a Laser-Scan. In these devices each vector must be replotted about every thirtieth of a second to remain visible, and consequently a buffer or satellite computer is required to hold the current picture for refreshing or for interaction (usually via a light pen). However, these refresh displays (which are of great value in many computer-aided design applications) do not have screens much larger than those of storage displays; they also tend to cost about as much as Laser-Scan (i.e. 20 times more than a storage tube). For the future, too, there is the likelihood of colour displays and a whole rather dazzling range of television-type possibilities, with greater or less possibilities of interaction, and at costs which may eventually become "economic."

Developing countries, faced with real problems of health and hunger, may well feel that the money and effort spent on trying to set up geographical information systems could be more practically employed. Some may be concerned about loss of jobs; some about lost craftsmanship; others have argued that the working cartographer yearns for new gadgets and the technical challenge of automation is a socially valuable end in itself. Many more will be worried about making large capital investment at a time of such singular technological change. But, surely, these problems are characteristic of any renaissance, and cartography today is certainly in a state of flux.

This, we conclude, is a proper setting for an "experimental cartography" which should play its part in examining new means of understanding the environmental patterns and processes on which we all depend.

APPENDIX A: THE MARK I DATA STRUCTURE

Each sinuous line or individual point in the data is represented as an entity in the data-structure. A point has a single 'IA' (image attribute) record. A line also has one IA record or descriptor, plus one 'SG' (segment graticule) record containing all the internal points for the line in order of digitising. Each IA can be accessed directly by its identifier. IAs can also be read sequentially; either all of them, all with the same feature, or all with the same logical combination of feature codes. SGs can be read sequentially, or a single SG can be accessed from the corresponding IA.



APPENDIX B: A BRIEF DISCUSSION OF HOW EACH INTERACTIVE GRAPHICS FUNCTION IS CURRENTLY IMPLEMENTED

JOYSTICK TO DATA STRUCTURE: BRIDGING SOFTWARE

The joystick cursor is displayed by the same software device handler (for the Tektronix 611) as displays other refresh markers and stored lines and points. When the operator indicates a direction of N, NE, E, SE, SW or NW with the joystick, the software updates the position of the cursor by the minimum amount in the direction indicated. After a timed wait, which may be 'long' or 'short,' depending upon the value of 'Z-button' that the operator can depress on the joystick, the joystick direction is sampled again and the cursor position updated in the appropriate direction. The current cursor position on the screen is returned at the end of the sequence, signalled by the operator depressing the 'Z button' in neutral. The screen co-ordinates of the cursor are transformed according to the current window and other transform, if any, on the displayed map. The transformed co-ordinates are matched to the start and end points of lines, or single points, held in the IA records. Only the IA records of the feature(s) last plotted are accessed or read. The search is conducted first within a tolerance, and second, if that is unsuccessful, for the nearest start or end of line or single point. The operator is informed which entity has been chosen with refresh markers, and can choose to continue the search for other entities in the vicinity without moving the cursor, if he wishes, although in general this is not necessary.

WINDOWING, MAGNIFYING AND SCISSORING

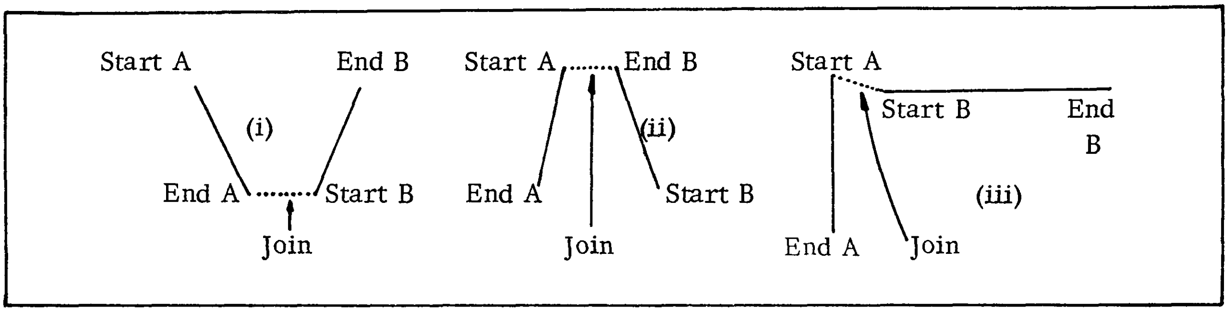
The desired window may be specified either by indicating the centre on the current plot with the joystick and the magnification with a function button, or by typing the map co-ordinates of its origin and its magnification at the keyboard. Only two to a positive integer power or one is allowed. This means that the multiplication of co-ordinates from the data can be accomplished in assembler, by simple shifts, if desired, to increase speed for computers with no floating point processor. Determining which sinuous lines of the data lie within, or partly within, the current window is performed by using two algorithms. Firstly, the maximum and mimimum points reached by every line are held in the IA record. If a conceptual rectangle round these does not overlap the window, then no part of the line can, and the SG record containing the co-ordinate pairs is never accessed. If there is overlap, each vector in the line is tested by a software implementation of Ian Sutherland's clipper divider algorithm, and that part, if any, that lies within the window is plotted.

SPLINING IN LINE INSERTION

The operator can insert a line by specifying the start point with the joystick cursor, any number desired of internal points, and the end point. The graphics package will join the points given either by straight lines or by a smooth curve. For the latter cubic splines are used, calculated by a modification of Maconologue's algorithm.

JOINING TWO LINES

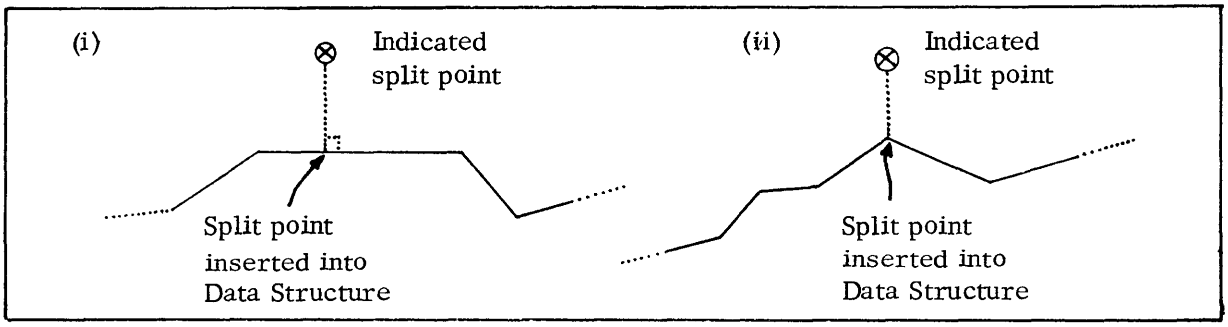
The operator indicates which two lines he wishes to join either with the joystick cursor or by typing in the two identifiers. The program calculates which of the three possible ways of joining the start and end points of the two lines produces the shortest joining line, deletes the two original lines, and adds to the data structure a new line consisting of both originals plus a straight join.



In case (iii) it is necessary to read either A or B backwards and reverse the original order of the co-ordinate pairs on storing.

SPLITTING A LINE

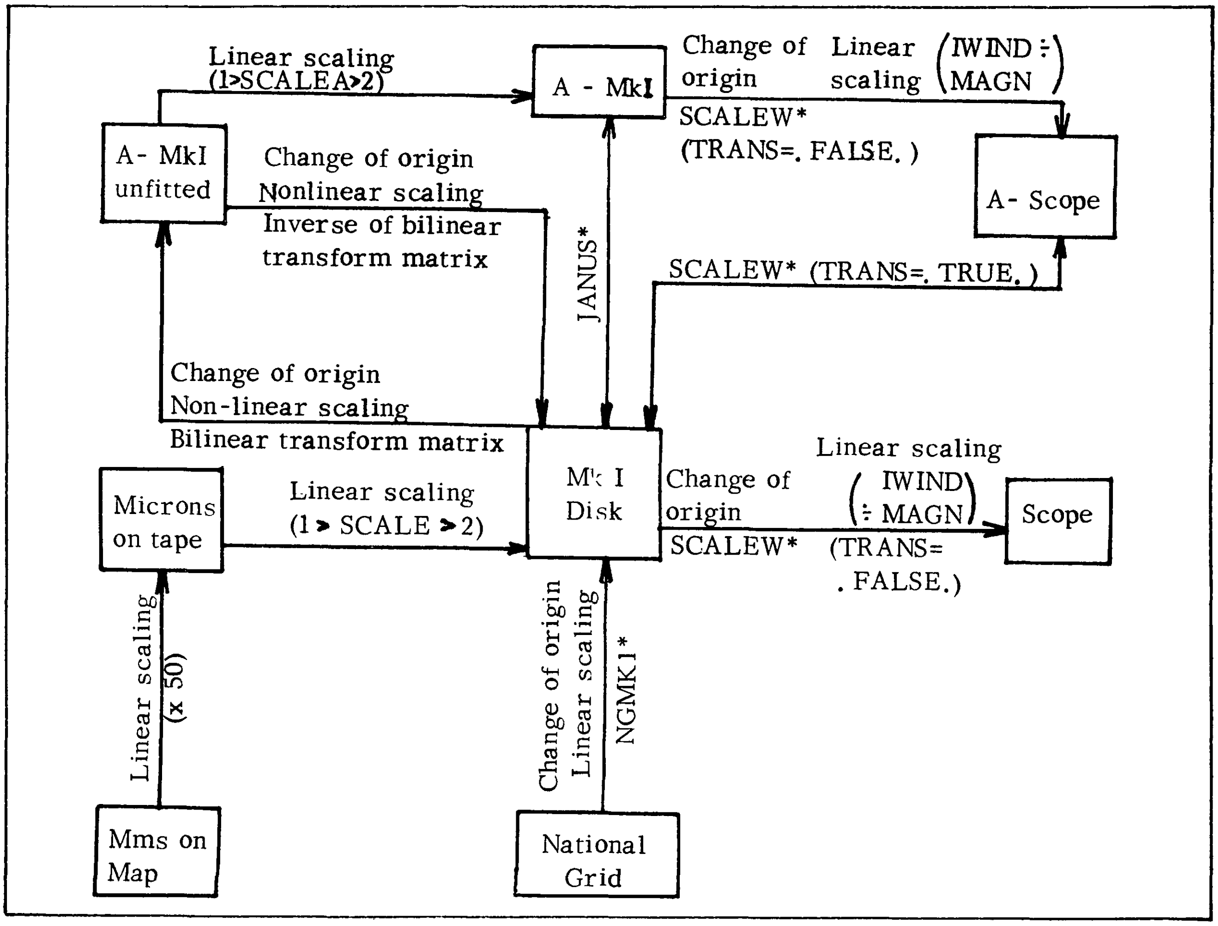
The operator indicates the point at which he wishes to split, using the joystick cursor. The program will split the line either at the base of a perpendicular thrown from the indicated split point on to the line (i), or, if no such perpendicular exists, at an existing internal point on the line (ii), always providing that the distance from the indicated split point to the calculated split point is a minimum for the line.



Each straight vector comprising the line is considered in turn. Two algorithms based on spike removal and line tolerancing reject the calculation of a perpendicular base if the indicated split point is too far from the current vector. The calculation for the perpendicular involves floating-point processing and is thus lengthy. For a small percentage of the vectors a perpendicular is calculated. Either the base or an existing internal line point is fed to a fast algorithm for finding the nearest of a series of points to a given point. (This is also used in the bridging software, B.1). The original line is deleted and two new lines inserted into the data structure.

CO-ORDINATE SYSTEMS AND TRANSFORMS

The systems and the routines used to move between them are indicated below.



If a generalised transform is desired, the operator types in four new 'corner points' for the transformed map, and a three by three matrix, and its inverse, is set up to produce the required transform.

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THE APPROACH TO AUTOMATED CARTOGRAPHY: TOPOGRAPHIC DATA BANKS IN CANADA

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The planning, management and control of man's exploits on the earth require accurate and up-to-date terrain information. Traditionally, terrain information has been provided in the form of a wide range of maps and charts, which are mainly derived from or are overlaid upon a topographic map, or a skeleton of it, to depict an almost infinite variety of themes.

With the advent of computer technology, and the recent advances in computer graphics, the concept of collecting and communicating terrain information has changed. The increasing power of the computers, accompanied by a general decrease in their cost, is making a positive impact on the terrain information managers, commonly known as map makers and cartographers. It is now possible for civilian organizations, operating within a modest budget, to produce digital terrain data and to store these data in digital data banks, which permit simple access, update and retrieval of information. The method of portraying terrain information in the form of a topographic map will stay with us for a long time although the format and the graphics will in the future vary considerably from the traditional cartographic nomenclature.

These developments, in addition to the offer of better drafting accuracy, and flexibility in the choice of the type of output, led to the decision to develop the Canadian Automated Cartographic data system. In order to understand the approach taken by the Surveys and Mapping Branch to data banks and automation in cartography, one must realize that the major thrust of the Topographical Survey is directed towards the completion of 1:50,000 topographic maps of Canada and the revision of existing maps. To date approximately one half of the total of 13,150 sheets at 1:50,000 scale has been compiled. The task of completing the remaining ± 6,600 sheets and of keeping up-to-date the increasing number of map sheets is large by any standard.

New mapping is more directly related to specific development projects such as pipelines, roads, transmission lines, etc., and consequently requires a rapid response, and offers the depiction of specialized information.

The digitized terrain data were initially looked upon as a by-product of the map. However, within the present concept of terrain information being stored in digital form, as the basic source for all sorts of graphical and numerical presentation, the digitized data are of prime importance. This digital terrain information is stored in digital data banks, which permit simple access, update and retrieval of information. The concept of a digital data base provides a more flexible data storage for the user.

A digital data bank comprises collections of data stored in files; in such a way they can be accessed and retrieved in an orderly manner. Just as books might be withdrawn from or replaced in a library by using the catalogue shelf number and book number, so can an item or file be accessed or retrieved in a digital data bank.

A digital data base, on the other hand, is not restricted to only elementary operations on files and on sequential data in files arranged in a specified order. The data themselves become the primitive elements. They are stored as entities without reference of any application and without any need for the user to know their physical location in storage, either as a file or as an item in a file. By means of appropriate software the data base system accesses the data and brings them into association to fulfill the user's requirement or to provide the answer to the user query. The operation is similar to putting a question to a researcher in a library. The researcher would access the data in the books and bring them together for study to enable the question to be answered.

At the present time, the file system structure of the automatic cartography system is capable of supporting an extensive data bank facility. The data organization has been chosen for further evolution to a full data base system; developments are now underway for the subsequent use of a data base in conjunction with certain thematic application areas.

The cartographic feature was the fundamental element in the cartographic digital data file in the system, when first produced. Around this feature was formed the basic record, which consisted of the cartographic feature code, the qualifier code, and the coordinates defining and locating the feature.

The subsequent level of production software provides more comprehensive services and scope for greater modeling of the data. The first system led to a glut of cartographic feature codes. The next level permits a generalization of the code structure so that variations or divisions within a cartographic type or class of feature are described as attributes.

The association between features is encoded so that it can be used in processing when required. (See Figure 1). For example, the embankment of a railroad would be stored in terms of the coordinate definition of the railroad. Thus, there is not redundant data definition and the association can be used in the preparation of the map graphic, especially where conflicts are likely to occur between map features.

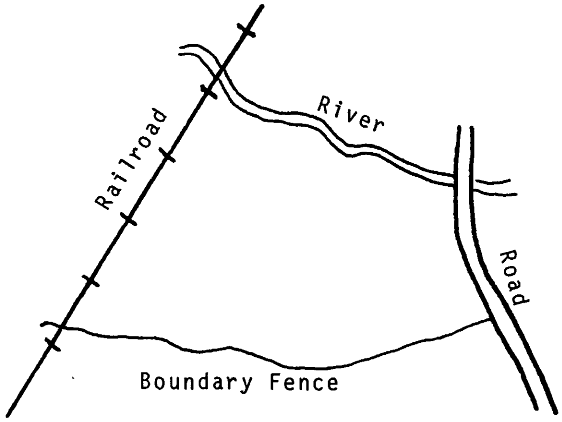

Figure 1

The present system is shown diagramatically in Figure 2. The system is designed to be expanded if need be, to handle up to 60 digitizers and 6 automatic drafting machines in the map production area. The system has a "distributed" structure and can support, in addition to the map production equipment mentioned above, many mini-computer based sub-systems, each of which may be physically remote from, but on-line to, the central site, as in the case of the sub-system of the Geological Survey of Canada. Each sub-system can typically contain one automatic drafting machine, six digitizers and seven terminals. The links between the sub-systems and the central facility are digital data communication links. Further, for data query operation, the system is capable of accepting a large number of enquiry terminals.

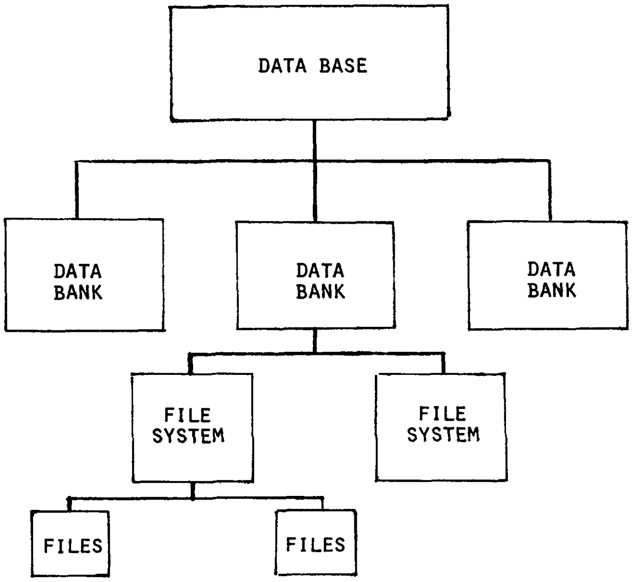

Figure 2. Organization of Data for a Data Base

The drafting machine draws the graphic from a computer controlled cartographic digital data file. The feature to be drafted can be automatically selected as can the symbolization, the scale, the projection etc. Moreover, since the 1:50,000 map acts as the foundation for many thematic maps, the extension of the system is evolving as a general purpose cartographic facility. Thus, the version of the software now being completed accommodates the needs of other areas, e.g., those of the Geological Survey maps.

The input to the present auto-carto system for the production of the National Topographic Series maps is provided by digitizing existing scribed map sheets or edited map manuscripts, compiled by photogrammetric methods. Since approximately one half of the 1:50,000 NTS sheets still remain to be compiled and some of the existing sheets in the populated areas must be recompiled during the revision process as they do not meet the accuracy standards, we have embarked on a development program of a system which would permit to input into data base of the terrain information digitized directly on the photogrammetric plotting instruments. This approach has two basic advantages:

- It eliminates the necessity of digitization of compilation graphics.
- Utilization of the stereo model for the production of x, y, z coordinates directly from the stereoplotter offers a higher resolution than the compilation graphics.

The second advantage is particularly important when the ultimate objective is to create a terrain information data base and data bank.

The major research and development effort of the Topographical Survey is directed towards devising such a system and evaluating it from the point of view of the overall economy and operational performance.

Other developments include the progressive introduction of improved peripheral hardware which the modularity of the system design allows -- say, the introduction of laser digitizers and laser drafting machines, and the continuing development of application software to satisfy the requirement of each application area and discipline connected to the system, both on-line and off-line. Here a distinction is made between the "system" software and the "application" software. In the work of the Surveys and Mapping Branch, the system software would include such matters as the extraction of data on grid sheet lines from data organized on graticule sheet lines, and the drafting of graphic primitive elements. The application software would be concerned with the assembly of the primitive drafting elements to form symbols or with the creation of symbols in some other manner for topographical maps, aeronautical charts and atlases.

An automated cartography system directed exclusively to the task of replacing human draftsman limits its cost effectiveness. By introducing the terrain information data base and data bank concepts into the system and utilizing these data to provide a variety of specialized information to a multitude of users, the full power of the automated cartography system is realized, thereby, greatly improving its cost effectiveness and economical working.

When embarking on the road of automated cartography one must realize that the computer alone will not solve all the problems. One must let the computer do what it can do best and leave to the human those functions which he can best perform. An interaction between the computer and the human will most likely provide satisfactory and economical solution.

One must also guard against the temptation of creating something new just for the sake of employing new technology and also against employing new technology to copy the manual methods slavishly.

Our objective is to devise a flexible terrain information system which will meet the needs and requirements of the present and of the future.

COMPUTER-ASSISTED THEMATIC MAPPING
WITH A DEDICATED MINICOMPUTER SYSTEM

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Landeskunde und Raumordnung

INTRODUCTION

The Bundesforschungsanstalt fur Landeskunde und Raumordnung (Federal Research Institute for Applied Geography and Planning) is concerned with spatial research and analysis on the Federal level in Germany. One of the major tasks is the development and maintenance of a spatially oriented information system for data acquisition, analysis and presentation in written, tabular and graphic form. Thematic maps are the best tool to visualize spatial distributions because they combine analytic, synthetic and documentary functions. To take full advantage of fast data retrieval and analysis capabilities, design and drafting of thematic maps have to be integrated into the system.

Several constraints are imposed on the development of the information system in general and the computer-assisted map production specifically:

- Limited resources, mostly in respect to qualified personnel. Due to old-fashioned budget regulations it is easier to get a million marks to buy hardware than fifty thousand to pay a programmer. Other regulations set salary limits at a level not acceptable to qualified EDP personnel.
- Results have to be provided as quickly as possible. The bottlenecks in the well-established cartographic production process at the BfLR have to be circumvented as quickly as possible by computer methods without making obsolete too much existing machinery for reproduction and printing.
- Political pressure to cooperate with other government or government-funded agencies. As everyone in the field knows, cooperation does not save time and money in all cases.

HARDWARE

Data storage, retrieval, analysis and related functions require a medium to large scale data processing system with sufficient primary and secondary memory space and computing power. Such "number crunchers" are available everywhere; their use is common practice as is the use of data management and analysis software.

The production of maps, however, requires special machinery not available at the average computer center -- graphic input: digitizer; high precision output: flatbed plotter; fast output and interaction: graphic CRT display.

The most economical solution to control these devices is a dedicated minicomputer with the necessary peripherals. The configuration, illustrated in Figure 1, consists of:

- DEC PDP-11 minicomputer
  - moving head disk drives (2)
  - fixed head disk drive
  - IBM compatible tape drive
  - dual DECtape drive
  - card reader
  - line printer
  - paper tape reader/punch
  - terminals
- Tektronix 4002A storage display terminal with joystick
- Calcomp 738 flatbed plotter with tape unit and offline-online switch
- d-mac pencil follower (CAMAC-Interface) (Figure 1)

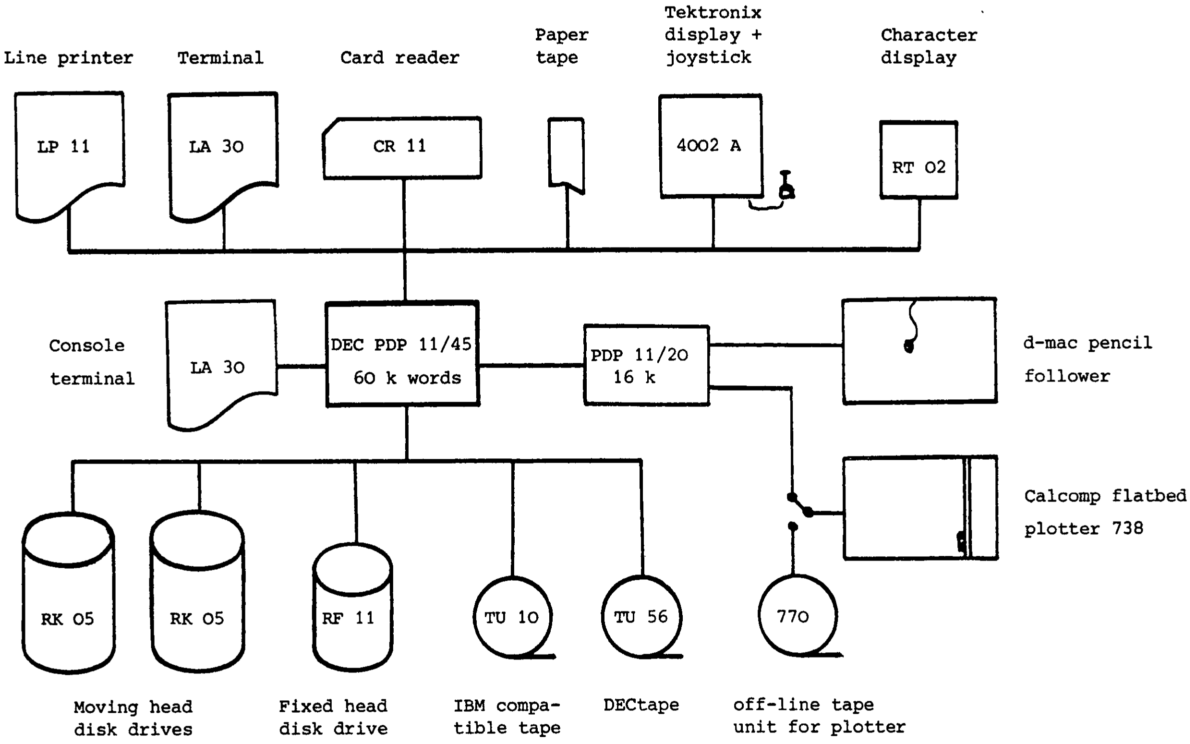

Figure 1. Hardware configuration at the Bundesforschungsanstalt für Landeskunde und Raumordnung

The selection of the devices may not look optimal to everyone. Besides the fact that the system was ordered four years ago, criteria other than technical specifications played an important role, e.g., proven reliability, maintenance service, and availability of basic, functional application software. For example, we decided not to buy a more advanced digitizer because we were not able to get maintenance service for it. Of course we have learned a few things in the meantime. 1/

To improve performance a PDP-11 model 45 with hardware floating point replaced the original 20 a year ago. At the moment we are switching over to a system which allows multi-programming and simultaneous operation of a digitizer and plotter under control of the 20 processor.

APPLICATIONS

Programming efforts have been concentrated on three groups of applications (in order of priority): 1) error-minimizing acquisition of geometric data base, especially boundary networks; 2) medium to high quality production of statistical maps for immediate use in the reproduction and printing process; 3) interactive design of statistical maps, interactive spatial analysis.

The logical sequence would be to develop the design system first and then to produce high quality output. The need for a fast solution to our production problems, however, required us to delay the interactive system. It is undoubtedly easier and faster to write a few plot programs than an interactive display system. That bought us some time for the design and development of the interactive system.

Besides the basic device-dependent software, all programming is done in FORTRAN. Again that might not look like the optimal solution, but we have found that FORTRAN makes a lot of things easier, especially the integration of existing software or the transition to a more advanced operating system.

ACQUISITION OF GEOMETRIC DATA BASE

The base data for thematic mapping can be classified into the usual three-level hierarchy of geometrical coding:

- Point: Reference point or point representation of a reference area
- Line: Flow lines, like streets, energy or communication flows
- Network: Area-oriented: boundaries; Edge-oriented: traffic network

The transformation of points and lines from base maps into computer-readable format imposes no serious problems. The necessary accuracy is moderate. In most cases the base maps are already generalized and curved lines are composed of a small number of straight lines. Orthogonal coordinates are the appropriate encoding and storage mode.

Things become more complicated with the digitization of networks, in our case, boundary networks. To avoid the shortcomings of simple coding schemes, like the representation of an area by a closed polygon, we use a data organization resembling what is known on this side of the Atlantic as "World Data Bank Format."

A reference area is defined by a list of numbers. These numbers represent "segments" or "arcs" whose coordinates are stored in a second table or file. The sign of the segment number indicates the direction in which the coordinates are stored in respect to the reference area. 2/

With conventional off-line digitization the sources of error are numerous: manual enumeration of segments, table construction, arc end point coincidence and so on. The elimination of errors from the graphic file is a tedious and costly business. Thus we designed and implemented an interactive digitization program to monitor the acquisition process, to check constantly for error conditions, and to correct errors if possible or at least give warning messages to the operator if a nonrecoverable error occurs. 3/

A small 32-character display, indicator lamps, acoustical alarms and an array of 16 special function buttons, besides the normal keyboard input, facilitate the dialogue between operator and system. The Tektronix display is used to get graphic replay of the digitized coordinates. At the moment we are testing a computer-controlled cassette recorder to assist the character display function; the operator should be able to keep his eye on the map instead of reading the display.

The computer-assisted digitization process has many advantages in comparison to off-line procedures. Nevertheless, we are not completely happy because it still requires a human operator (two are better). At the moment we are looking into the possibilities of fully automatic acquisition of boundary networks. As far as I can see, there are no conceptual but rather a few technical problems to solve.

We have also developed some additional programs for aggregation of the basic network to arbitrary regional divisions, transformation into other representations -- e.g. closed polygons or optical centers, and area, segment and coordinate reduction and generalization.

PRODUCTION OF STATISTICAL MAPS

The need for immediate relief from labor-intensive steps in the map production process, the existing machinery for reproduction and printing, and the limitations in respect to qualified EDP personnel led to some kind of incremental approach to automated cartography. As I mentioned already we decided not to wait for an interactive design system but to provide solutions for our production problems as quickly as possible. These solutions might be preliminary and will become obsolete sometime, but they are working.

Figures 2 and 3 are examples of the preliminary solutions. Manual grouping of data, area shading and coloring are time-consuming and prone to errors, as is the size calculation of proportional symbols and the elimination of hidden lines and areas. Now these steps are done by program which results in considerable savings in labor cost and time. Alternative designs of the same map, e.g. with different class intervals or shading, can be done without additional costs except for computer time. 4/

If a design has been accepted as final draft, the outlines of the areas are scribed on a plotter, separated by colors. The scribed outlines are copied on standard peel foil and peeled by hand. This procedure is still too time-consuming.

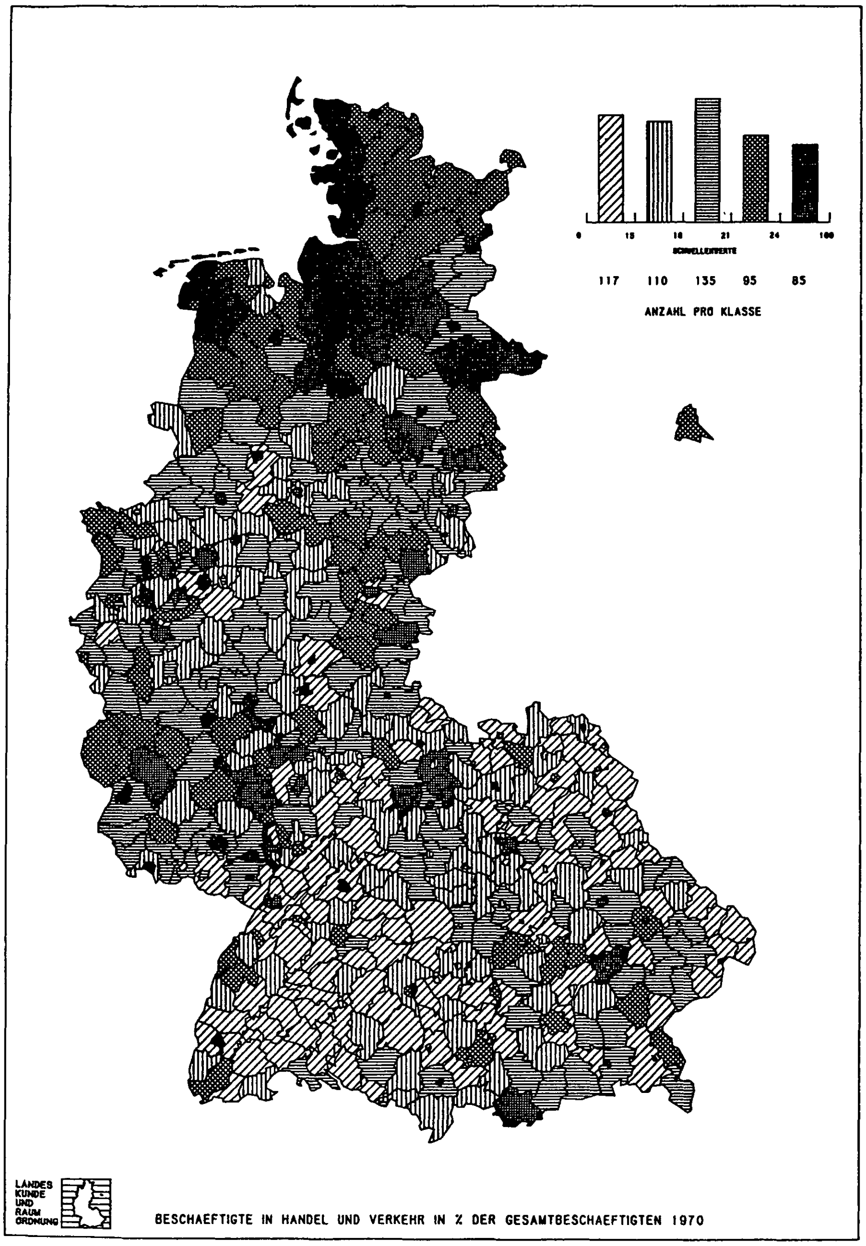

Figure 2. Choropleth map. 542 Counties, Federal Republic of Germany

For less high quality we plan to eliminate full color printing and to use scribed area shading to avoid manual work.

Of course we also use other representation techniques like contour lines, profiles, perspective drawings, etc., which are used at many places around the world.

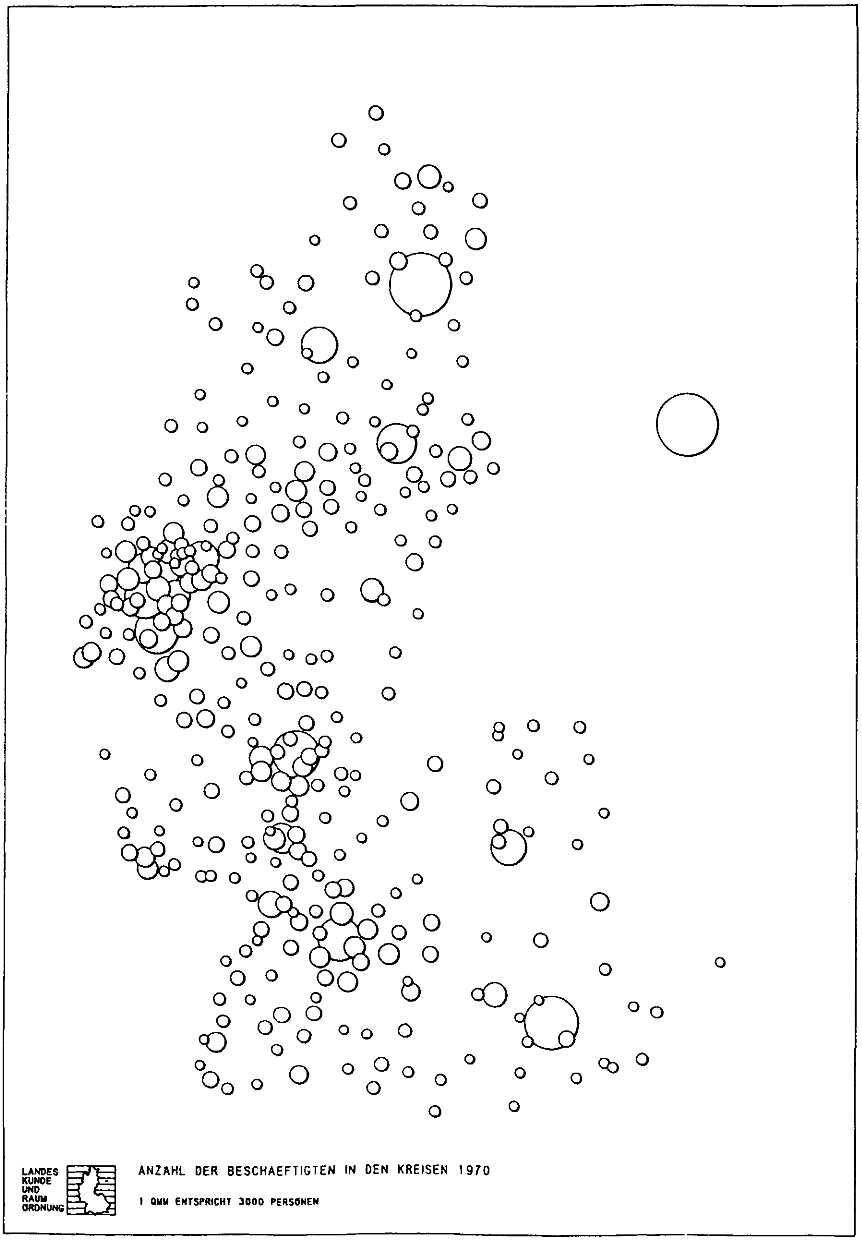

Figure 3. Proportional symbols. Hidden lines removed by program.

INTERACTIVE MAP DESIGN

To find the best alternative for a specific map, the current trial and error approach is cumbersome and time-consuming because mechanical plotters are very slow devices. If computer assistance is to be extended to more complex steps like placing of legends, diagrams, and lettering on the map sheets or minimizing overlapping areas by moving proportional symbols, the use of CRT displays and interactive graphic manipulation becomes inevitable.

Our system, called CAMS for Computer Augmented Mapping System, is built around the Tektronix storage display terminal under control of TCS (terminal control system by Tektronix, a set of FORTRAN subroutines exercising basic display and interaction functions). I do not intend to go into CAMS in detail. A short description of the capabilities and the design philosophy should be sufficient in this context.

With the help of CAMS the user, namely the cartographer or the researcher, should be able to do the following design steps interactively:

- Define and read in a specific geometric base file
- Select, if necessary, a subset from the GBF
- Define and read in a file with statistical figures for the areal units
- Do arithmetic transformations, e.g. calculations of percent values, combined with logical decisions on the statistical figures
- Group the data into classes; find the optimum by changing the thresholds or an optimizing algorithm
- Choose the appropriate mapping technique and the transformation parameters, e.g. area shading, size of proportional symbols, etc.
- Place the legends and statistical diagrams on the map
- Place textual information in different size, font and type on the map
- Make hard copy on the plotter
- Store the map in a library
- Retrieve a stored map
- Manipulate a retrieved map, e.g. change the place and orientation of proportional symbols, text and diagrams
- Print out lists of original and transformed data, directories, etc. and provide other aids

The system is designed to give as much help to the user as possible. Besides typing in the keywords and parameters the user can pick the command words from a menu by positioning the crosshair. The parameters are defaulted; one of the next steps will be the implementation of predefined procedures: frequently used command sequences stored in a file and called by a simple name. 5/

The bottleneck in the system is the display unit; the lack of selective erasure forces a complete replay if only one vector is changed. The display speed is relatively slow; one vector interpolation takes 2.5 msecs. One of the possible solutions would be to use two displays -- one for the menu, one for graphics; or one storage tube for overview, and a refresh display for menus and manipulations.

One of the most important facts in designing and implementing CAMS was the experience that an interactive system is a quantum jump compared with batch programs. It is certainly not sufficient to add dialogue to existent cartographic programs. To ensure both fast access and user friendliness, much attention has to be paid to an appropriate data and file organization, which again requires a lot of programming effort.

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Seminar on Automation in Cartography: Software

SEMINAR ON AUTOMATION IN CARTOGRAPHY: SOFTWARE

This seminar focused on the software which supports cartographic and related activities. It dealt with the dissemination and use of the software, as well as technical problems, and the cost and utility of specific geographic applications. The first session, held Monday afternoon, was chaired by MICHAEL MCCULLAGH of the University of Nottingham (United Kingdom). The second session was held on Tuesday afternoon and chaired by JOHN DAVIS of the Kansas Geological Survey.

LARRY W. CARBAUGH represented the Bureau of the Census' Data User Services Division and spoke on the Bureau's data files for computerized cartography. Since 1970 the Bureau of the Census has developed and made available for purchase a variety of computer products including computer programs, geographic coordinate files and data summaries for geographic areas, designed for use in automated cartography. The dissemination of these products has, however, obligated the Bureau to provide some measure of support either in terms of software consultation or the distribution of correction and update material. This fact, combined with the differences in computer hardware and the increase in the number of data files, has added to the complexity of the dissemination problem.

GEOFFREY DUTTON reviewed the "Software of the Harvard Lab for Computer Graphics and Spatial Analysis." For the past ten years the Laboratory has been involved in the design, development and dissemination of software for use in automated cartography. Programs which it distributes include GRID, CALFORM and POLYVRT. Programs currently under development include INPOM, ASPEX, CELLMAP, PRISMAP and GEOGRAF. The paper reviewed the current software development activities of the Laboratory and its attitude towards the design and dissemination of software for use in automated cartography.

Representing the Kansas Geological Survey, ROBERT J. SAMPSON discussed "The SURFACE II Graphics System," which is designed to manipulate single valued surfaces. It is both a research tool and a production device. Examples of both applications were presented.

ROBERT MERCREADY of George Washington University and the Department of Defense discussed the "Software of a Department of Defense Fully Integrated Computer Mapping System." This computer mapping system was developed by Harvard University's Lab for Computer Graphics and Spatial Analysis, and was designed primarily for non-computer personnel. It combines into a single package four independent computer mapping programs: SYMAP, GRID, CALFORM and SYMVU; a statistical program, SPSS; and a world-wide geographic base file derived from World Data Bank I. It has been applied successfully to high priority Department of Defense projects, and its success clearly underscores the value of computer graphic manipulation and presentation of complex, interrelated variables.

"Neighborhood Computations for Large Sets of Data Points" is the title of a paper by KURT BRASSEL of the Department of Geography, State University of New York at Buffalo. In it he explained an algorithm for the generation of a geographic base file for information pertinent to point locations (data points). Given the locations of the data points, the algorithm generates area delineations which are based on a Thiessen polygon approach. The Thiessen polygons are then used to build up a data structure describing the neighborhood relationships of the set of data points. In this algorithm the Thiessen neighbors are searched for among points in a certain neighborhood of the centroid only. This search, therefore, is essentially local and allows for efficient processing of large sets of data points.

NICHOLAS CHRISMAN, in the second presentation of the Harvard Laboratory for Computer Graphics and Spatial Analysis, described the GEOGRAF program, scheduled for release in 1977. He stated that the attitude towards space inherent in an automated system should be a more fundamental consideration than technical constraints. A topological approach to spatial representation offers a more complete and sensitive tool than that available through grid systems. Two main weaknesses of the existing topological systems must be overcome to fulfill the potentialities: 1) An automated system to combine two networks into a single intersection network must be designed to compete in cost with the simplicity of grid overlay; and 2) a means of storage must be designed which can respond easily to the varied requirements of cartography and spatial analysis. The GEOGRAF project at the Laboratory for Computer Graphics is an attempt to provide a solution to these problems. This paper reviewed the design decisions and presented a tentative schedule for certain targets.

KRISTER SELANDER of the Nordic Institute for Studies in Urban and Regional Planning discussed some developments in computer graphics for urban and regional planning in Sweden. His paper is reproduced in the section entitled "Seminar on Automation in Cartography: International Developments" on pp. 542-549.

ARTHUR NOMA of the Defense Mapping Agency's Topographic Center presented an overview of that agency's integrated semiautomated cartographic system for producing topographic maps.

Computer programs for drawing isoline or contour maps from scattered data points can be categorized into three general groups: triangulation procedures, global fit procedures, and local fit methods. Computer algorithms for contouring spatial data differ in subtle ways that affect the appearance of the maps which they produce. If a contouring system is very flexible, many errors may be avoided by selecting the best combination of parameters and methods for a particular map and a specific objective. This requires, however, an evaluation of the performance of different mapping techniques under different conditions. JOHN C. DAVIS of the Kansas Geological Survey presented the results of an empirical analysis of contour maps of a subsurface horizon as an example of such a comparison.

One of the conclusions reached at the seminar was that there is a need for a standardization of programs developed as software packages. Moreover, decisions need to be made regarding the best approach to the dissemination of software, to standards of documentation and to the amount of handware needed.

DATA FILES FOR COMPUTERIZED CARTOGRAPHY FROM THE U.S. CENSUS BUREAU

Larry W. Carbaugh
U.S. Bureau of the Census

As a result of the 1970 census, the Bureau of the Census has developed and released hundreds of machine-readable data files describing the characteristics of the population of the United States. In addition, other machine-readable files have been developed which describe the location and extents of the areas from which these statistics were gathered. The release of such files provides researchers with the means of analyzing the characteristics of the populations and the spatial relationships of these characteristics through the use of the computer. The purpose of this paper is to outline the contents of these files, highlight some computer display programs developed by the Bureau, and to provide some comments on the distribution and support problems associated with release of machine-readable data.

DATA FILES

Because of the cost and volume of data, the Bureau of the Census cannot publish all the data summaries that it tabulates, nor can it provide data for all the areas recognized in a census. However, by producing the summaries on computer tape, the Bureau can release large amounts of data for many geographic areas.

In general, the files that are available from the Census Bureau contain data summarized by geographic area. Data are provided for the political subdivisions of the United States such as States, counties, minor civil divisions, and places, as well as for other areas such as blocks, census tracts and census enumeration districts. The data presented include characteristics of the population of each area such as age, sex, race, family income, educational attainment, employment status, occupation, and industry. Also included are data on the housing stock such as vacancy status, tenure, plumbing facilities, rent and value. A complete description of the items contained on the data files is presented in the 1970 Census User's Guide Parts I and II, which is available from the Bureau of the Census for $5.25.

POINT OR AREA DESCRIPTION FILES

In addition to the computer tapes containing data, the Bureau maintains tapes of geographic reference files. These files contain identifiers such as latitude and longitude coordinates which locate the centers or the boundaries of the areas presented on the data files mentioned above. They include:

U.S. Centers of Population - a one-tape file containing the latitude-longitude coordinates for the 1970 census population centers of counties in the U. S.

Master Enumeration District List (MEDList) - contains latitude-longitude coordinates for each enumeration district (ED) identified in the 1970 census. Each ED record also contains codes for all higher level areas. Nine reels of tape.

DIMECO - contains latitude-longitude coordinates describing the boundaries of all counties in the United States. One reel of tape.

GBF/DIME - a "computerized map" for the urbanized portion of 200 metropolitan areas, containing latitude-longitude and state plane coordinates for the intersections of all map features (i.e., streets, railroads, streams, etc.). Codes identifying census tracts and blocks are contained on these files.

SMSA census tract boundaries - files containing latitude-longitude coordinates describing the boundaries of census tracts in all standard metropolitan statistical areas recognized in the 1970 census.

COMPUTER PROGRAMS

In an effort to extend the usefulness of these census files, the Bureau has also developed several computer programs to display geographically identified data. They include a printer-oriented computer mapping system, GRIDS, and a line printer-oriented program, CENPLOT. In addition, the Census Bureau has initiated a clearinghouse for information on computer tapes designed to process 1970 census products such as the geographic reference files. Further information about this clearinghouse activity can be obtained from the Data User Services Division, Bureau of the Census, Washington, D.C. 20233.

OBTAINING THE DATA FILES

In general, the computer files mentioned above are available at a standard cost of $80 per tape reel. Technical documentation is included with each purchase of a file, but it can also be purchased separately for $3 per file. Additional information on the tape files available from the Census Bureau can be obtained from: Chief, Customer Services Branch, Data User Services Division, Bureau of the Census, Washington, D.C. 20233.

DISTRIBUTION OF COMPUTERIZED DATA AND SOFTWARE

Before I close, I would like to comment on the development of computerized data files and programs and some of the problems associated with their distribution. While the development of machine-readable data and computer programs has increased the capability of researchers to analyze the complexity of today's world, the release of such data files carries with it an obligation to provide some form of assistance to users of the files. This obligation includes the development of adequate documentation, notification of errors or updates, and, in the case of programs, some installation consultation. This obligation is further complicated by the wide variety of computing equipment now available. Therefore, unless this obligation is carefully considered beforehand, and adequate staff and proper materials are prepared, users of such data files will become extremely frustrated and the usefulness of the data will be diminished.

NEIGHBORHOOD COMPUTATIONS FOR LARGE SETS OF DATA POINTS

Kurt Brassel
State University of New York at Buffalo

INTRODUCTION

The growing use of cartographic data banks for mapping calls for an efficient and flexible organization of geographic base files. Traditionally, spatial data are stored by overlaying a grid on the area of interest and recording the properties of the grid cells. In another approach the coordinate values describing the perimeter of an area unit are used for location identification.

Recently Peuker and Chrisman have reported on projects ('Geographic Data Structures' and 'Geograf') that utilize more advanced storage techniques (Peuker and Chrisman, 1975). Peuker stresses the need to assign a list of neighbors to each spatial entity. In such a system data on a statistical unit would include, for example, not only a description of the polygon outline, the center identifiers, and information on the characteristics of the unit, but also a list of identifiers corresponding to the areas contiguous to it. Neighborhood relationships can also be established for point-based data sets by assigning to each data point labels that identify its neighbors. This neighborhood relationship can be illustrated by a triangulation pattern in which each data point is connected with its neighbors by a line. Since there are various ways to define data points as being neighbors of a point A, the selection of neighbors is an ambiguous process. Among various triangulation approaches Delaunay triangles can be used to determine the neighborhood of a data point (Boots, 1974).

Another way of defining a neighbor-based data structure for a set of data points is to attribute an 'area of influence' to each data point and thus to create a set of polygons describing the 'pattern of influence' of the set of data points. Such a pattern can be created by drawing perpendicular bisectors between neighboring data points

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Editor's Note: The author has expressed his gratitude to Professor T. K. Peucker who provided funds from his research grant to make this project possible; thanks are also due for his suggestions leading to this algorithm, and general advice. The project has been subsidized by funds of the Swiss National Foundation (Schweizerischer Nationalfonds), the Office of Naval Research, and the Laboratory for Computer Graphics and Spatial Analysis, Harvard University.

The author has also expressed his thanks to R. Fowler, Simon Fraser University, for his testing and revision of the computer program to this algorithm.

as seen in Figure 1. The resulting polygons are called Thiessen polygons. The major problem in generating Thiessen polygons, however, is to specify the Thiessen neighbors, i.e., the data points whose Thiessen polygons are contiguous to the Thiessen polygon of the point in question. Once these neighbors are found, they can be used to generate a triangulation pattern. By definition Delaunay triangles correspond to the connection of Thiessen neighbors. The Thiessen approach, therefore, can be used to generate both types of base files: to store triangulation as well as space allocation models.

Various authors have discussed the generation of Thiessen polygons (Thiessen 1917, Whitney 1929, Keeney 1971), and recently Rhynsburger (1973) has published a method for analytic delineation of Thiessen polygons. Searching for the Thiessen polygon about a data point A, he constructs perpendicular bisectors to all other points of the data set and extracts the innermost polygon formed by these lines about the center. This innermost polygon he calls the 'interior envelope' (Rhynsburger 1973, p. 137). Since this process of generating interior envelopes is repeated N times (where N = number of points in the data set), about N*N*6 perpendicular bisectors are to be generated, which is inefficient for large sets of data points. The basic source of this inefficiency is that Rhynsburger uses a global method to solve a local problem. In order to define the polygon outline of one data point, his algorithm consults the whole population of points, rather than only points in the neighborhood. The problem, of course, is that the neighbors are not known at the beginning of the procedure.

The present paper describes another approach to generating Thiessen polygons which uses local processes and thus is suitable for processing large sets of data points.

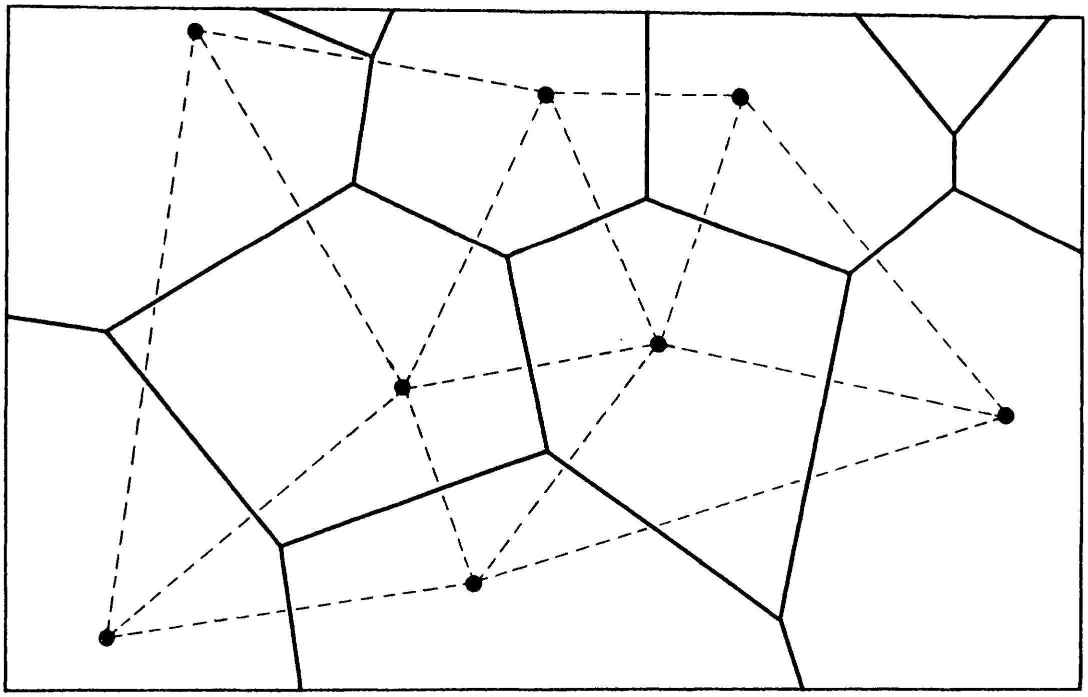


Figure 1. Sample of a Thiessen polygon structure showing the data points, Thiessen polygons (solid lines), and Delaunay triangles (dashed lines).

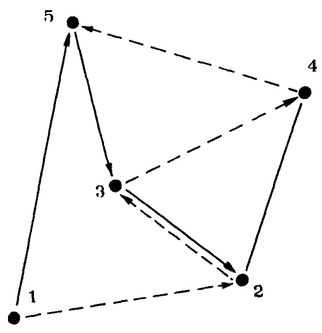
BASIC CONCEPT OF THE PRESENT ALGORITHM

In this discussion a centroid is considered equivalent to a data point. A polygon edge is defined as the locus of all points equidistant from two centroids and not closer to any other point in the data set. Locations equidistant to three centroids (and not closer to any other centroid) are called vertices. Pairs of polygons with a common edge are called neighbors (Thiessen neighbors), and pairs of polygons with a single vertex in common are called half-neighbors. The terms "neighbor" and "half-neighbor" are pertinent to both polygons and data points.

Given a set of data points in the plane, the first step sorts these points in both x- and y- directions, and assigns to each point the following pointers:

-XUP pointer, points to the next centroid in positive x-direction
-XDN pointer, points to the next centroid in negative x-direction
-YUP pointer, points to the next centroid in positive y-direction
-YDN pointer, points to the next centroid in negative y-direction

The XUP and YUP pointers are visualized as arrows in Figure 2.



Point identifier	Coordinates x	Coordinates y	Pointers: Positive x direction XUP	Negative x direction XDN	Positive y direction YUP	Negative y direction YDN
1	1.0	1.0	5	-	2	-
2	11.0	2.5	4	3	3	1
3	5.5	6.5	2	5	4	2
4	13.5	10.5	-	2	5	3
5	3.5	13.5	3	1	-	4

Figure 2. Pointer structure used for the computation of Thiessen polygons.

The basic strategy used for the computation of Thiessen polygons is to first find edges, vertices, and neighbors of a first point A (compare Figure 3). Assuming that a first true neighbor X of A is known, we are searching for the next true neighbor of A in clockwise direction and find centroid B and a vertex V_1. This clockwise search is repeated until the originally known point X is found as the next true neighbor in clockwise direction ($X \rightarrow B \rightarrow C \rightarrow D \rightarrow Y \rightarrow X$). At this time the entire polygon about A is known, and the search is continued by finding the polygon about a centroid contiguous to point A, e.g. point B. Already known neighborhood relationships ('B is neighbor of A') and known vertices and edges, however, are not computed again, but reused in this step. The search continues by completing all polygons contiguous to A, and then all polygons contiguous to the polygon about B are computed, etc. Starting at data point A, the search is spreading radially, and it is completed as soon as the farthest polygon is processed.

Given this strategy, the following problems remain to be solved:

1. To develop a procedure which finds the next true neighbor (B) in clockwise direction of an already known true neighbor

(X). Implicitly this problem is identical to finding a vertex V delimiting the perpendicular bisector between A and X.

2. To find a first neighbor X of an area A.

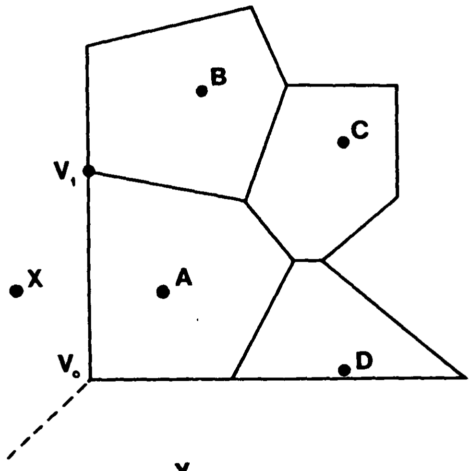


Figure 3

THE SEARCH FOR A THIESSEN NEIGHBOR

The search for the next true neighbor of A in a clockwise direction from B is performed essentially in three steps:

- find a possible neighbor
- find a highly probable neighbor
- find the next true neighbor and the respective vertex.

The first two steps are illustrated by Figure 4 below. Assuming that A is the centroid of interest and point B is known to be a neighbor of A, then we assume the next neighbor (clockwise) will be within the sector defined by the lines x_B, ab, and y_A. We are therefore searching for a highly probable neighbor C' within this sector. This is done by starting at the known points A and B and examining the data points in the sequence of either of the four pointer structures XUP, YUP, XDN, or YDN. Starting at point B we proceed along the XUP (positive

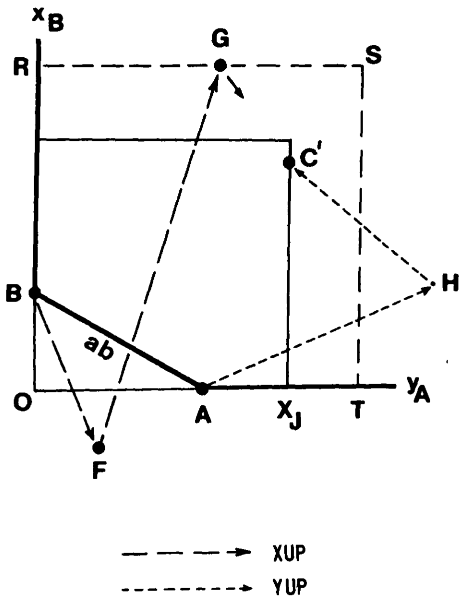


Figure 4. Search for a highly probable neighbor. Point A is the centroid of interest, B is already known as being a neighbor of A. The highly probable next neighbor C' is found by alternately following the pointer sequences in positive x-direction (XUP) and positive y-direction (YUP), and picking points in an 'innermost' truncated square. Depending on the relative position of points A and B the search may be performed in another quandrant and with other pointer sequences from among XUP, XND, YUP, and YDN.

X direction) sequence until we find a point within the quadrant (B→F→G). Point G is a possible neighbor and, in connection with points A, B, and G, implicitly defines a truncated square (ABRSTA) which is used for the search for a highly probable neighbor. Starting from point A and proceeding along the YUP pointer sequence (positive y-direction), a point C' is found within the said truncated square. C' defines a still smaller truncated square, and the search for a point within this new truncated square is continued along the XUP sequence (starting from point G). Switching between these two pointer sequences, the search is repeated until no further point is found in the innermost square. The point creating that square (C') is then called a highly probable neighbor.

In most case the highly probable neighbor C' is the next true neighbor (Figure 5). Even though point C' defines a smaller square with respect to A and B, point C

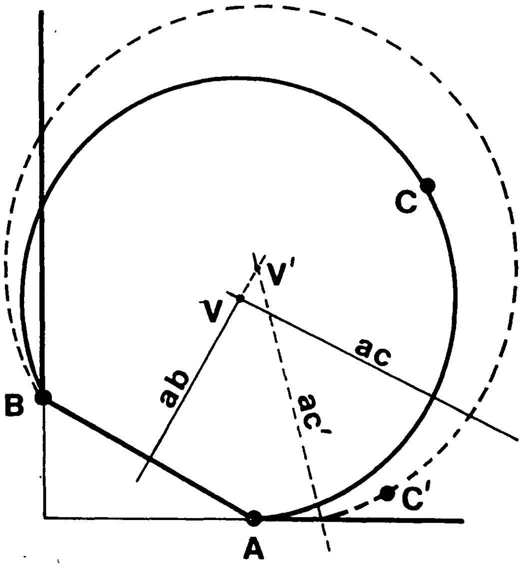


Figure 5. Search for a true next neighbor (circle test). Given a highly probable neighbor C' with respect to points A and B, a vertex V' (circumcenter of the triangle ABC') and a circle is defined. If there is no other data point within this circle, then C' is a true next neighbor, otherwise such a data point (C) is the new highly probable neighbor, and the circle test is repeated.

is the next true neighbor in clockwise direction. V' is the polygon vertex as defined by points A, B, and C', and V is defined by A, B, and point C. By definition V' cannot be a Thiessen polygon vertex because a point C is closer to V' than the three equidistant points A, B, and C'.

To replace the highly probable neighbor C' by the true next neighbor C, the circle through points A, B, and C' (centered in V') is drawn and a search for centroids within that circle is performed. In this search -- which we call the 'circle test' -- the discussed pointer structure is used in a similar fashion as before. If a point is found within the circle, a new (smaller) circle is constructed and the circle test is repeated. Point C is a true next neighbor if there is no centroid within the circle about A, B, and C.

If point B lies in another quadrant with respect to point A, the search is conducted in an appropriate sector using an appropriate pair of pointer sequences (XUP/YDN, XDN/YDN or XDN/YUP).

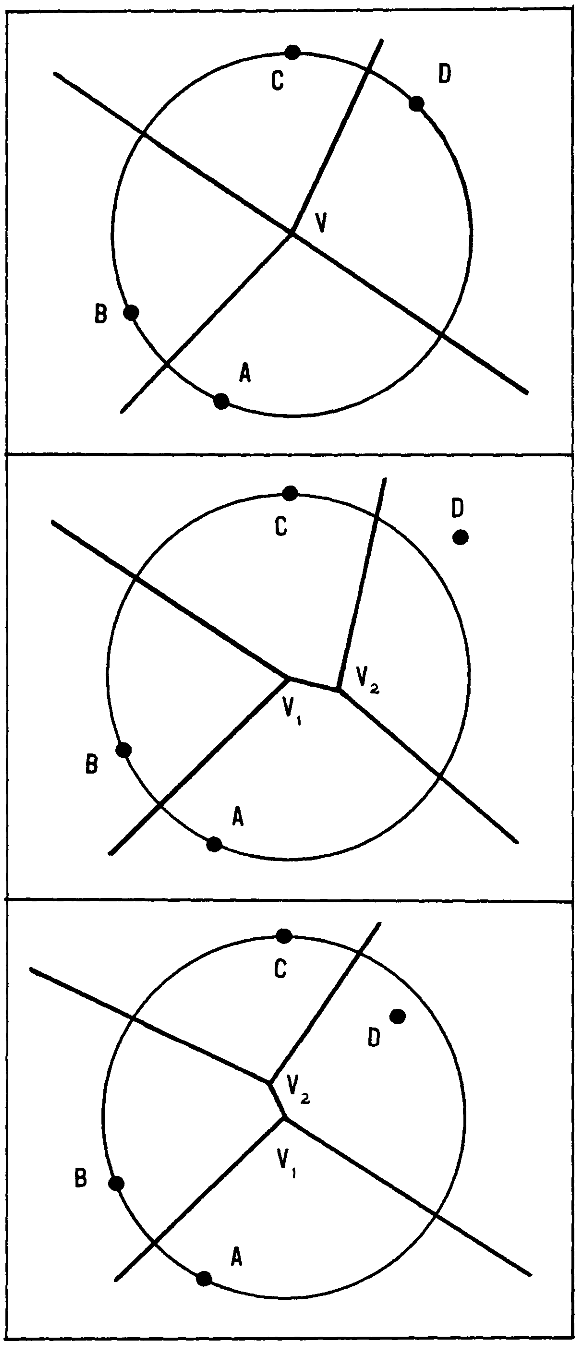


Figure 6. Four data points located on the same circle about the circumcenter V are pairwise halfneighbors (a). By shifting one data point (D) by an infinite small distance the halfneighbor relationships are eliminated (b,c).

If a point D (Figure 6) is located on the outline of the circle as defined by A, B, and C (and assuming that no point is within the circle), then the polygons about A, B, C, and D have one point in common, and two of these centroids are pairwise half-neighbors each. In this situation the new point D is shifted by a very small amount so that it lies either within or outside the circle (Figure 6, b, and c).

So far we have assumed that we can find at least one data point in a search sector as shown in Figure 4. A further assumption was that at least one neighborhood relationship is known as we start our procedure.

The basis of these two assumptions is demonstrated by the procedure discussed in the next section.

BORDER PROBLEMS AND INITIALIZATION

With respect to Thiessen polygon generation, a set of data points in the plane can be divided into two subsets: one type of data points generates closed polygons (Polygons 4-9 and 12 in Figure 7), the other subset generates open polygons (1-3, 10, 11, 13-15). For all points generating open polygons there will be at least one sector as defined in Figure 4 in which no next neighbor will be found. In order to allow the search procedure as outlined in the previous paragraph to be used for both cases, the following solution has been found:

- The set of N Thiessen polygons is assumed to be bounded by a rectangular border line (parallel to the rectangular coordinate system used). The four border lines can be arbitrarily defined.
- Four dummy data points are added to the data set, one across each border line.

The rectangular border line and the location of the four dummy points are illustrated in Figure 8. Assuming that the polygon about point A is searched for, the four dummy points are situated across each four border lines such that the line connecting point A with any dummy point is perpendicular to the respective border, and divided in half by it. In other words, if point A originally generates an open polygon, at least one of the four dummy points will be found as a true next neighbor, and the perpendicular bisector between point A and this dummy point represents exactly the predefined border outline.

After the polygon about A has been computed, the dummy points have to be shifted to a position across the newly processed centroid B. This implies a change of both the coordinate values of the dummy points and their location in the pointer structure. If a delimitation of the set other than by a rectangle is desired, then the arbitrary borders have to be positioned an adequate distance from the data points and the polygon structure has to be clipped in a subsequent step (Figure 7).

This concept of using a predefined border and dummy points allows for initializing the search procedure as well. A corner of the bounding rectangle by definition is an element of the centroid closest to it. Assuming that A in Figure 3 is closest to the corner point V_0, then V_0 is a Thiessen vertex generated by A and its two dummy points X and Y. X then can be used to find the true next neighbor in clockwise direction (B).

CONCLUSION

This paper has presented an algorithm for finding Thiessen polygons and Thiessen neighbors for a set of N data points. Given four border lines delimiting the set of data points, the process picks out the data point closest to the lower lefthand corner, finds its neighbors and computes its Thiessen polygon. This is done point by point in clockwise order. The search for one neighbor point includes a step to find a highly probable neighbor within a predefined sector and, as another step, the 'circle test', which finds the true next neighbor. In both these steps only data points in the neighborhood of the data point in question are consulted. For this search four additional dummy data points are added to the data set. These points are located in a way that open polygons are delimited by border lines as defined above. Once the polygon closest to the lower lefthand corner is generated, the polygon contiguous to it is processed. Ideally the processing spreads radially and is completed as the polygon farthest to the lower lefthand corner is determined. Since this algorithm finds Thiessen neighbors and polygons in a local process, it can be applied for large sets of data points.

A PL/1 program of this algorithm is being developed, and a first test run for 300 data points has resulted in an execution time of about 10 seconds on an IBM 370/165 (Figure 9). This program is presently being further tested and revised by R. Fowler, Simon Fraser University.

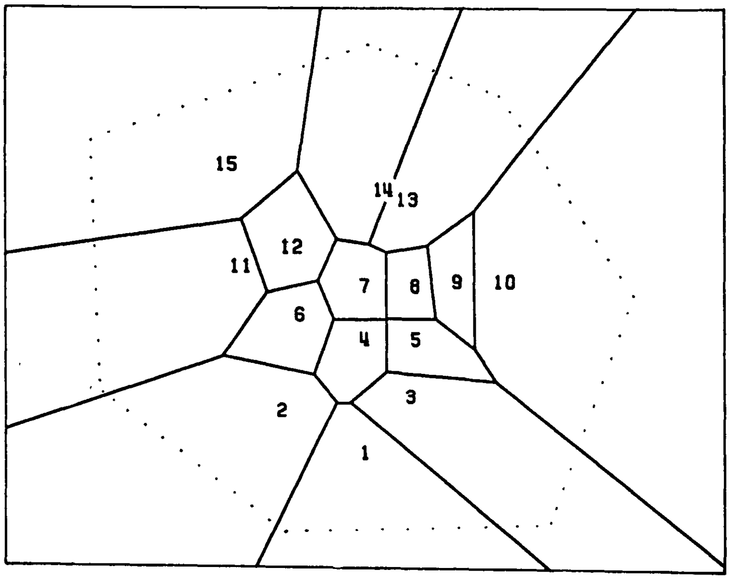


Figure 7. Closed and open Thiessen polygons. The possibility of polygon clipping is indicated by a dotted outline.

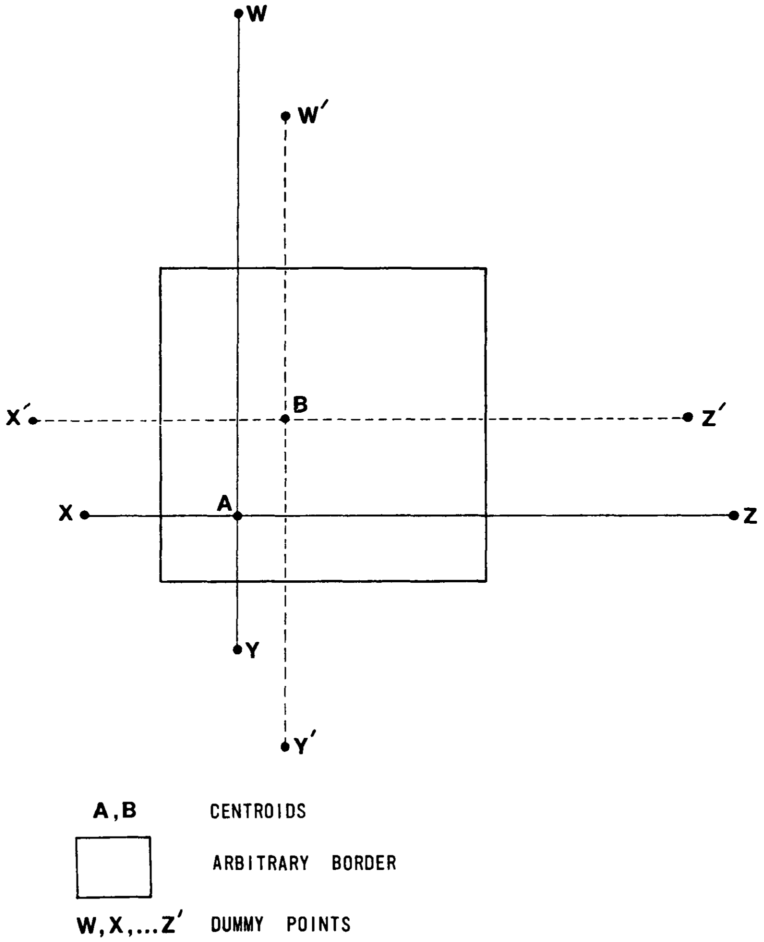


Figure 8

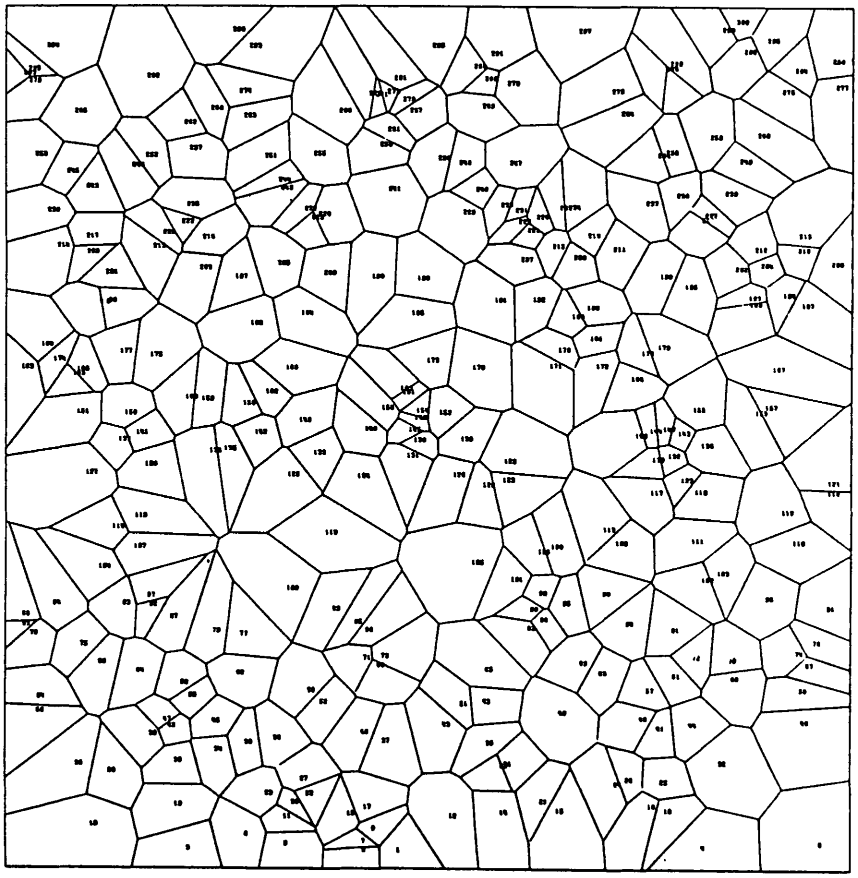


Figure 9. Sample plot of Thiessen polygons (300 randomly generated data points).

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TOPOLOGICAL INFORMATION SYSTEMS FOR GEOGRAPHIC REPRESENTATION

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INTRODUCTION

The development of geographic information processing has occurred at such an explosive rate that we risk losing sight of our basic mission to understand spatial distributions and processes. Decisions originally made by adopting specific tactics in the organization of information now threaten to split our efforts into widely divergent streams. On one hand, grid systems may originally stem from programming expediency, but they are now reinforced by a supporting technology of satellites, raster scanners and special purpose computers.

The alternative to grid processing has also developed, but in radically different directions. Originally characterized as polygon or line and vertex systems, the new development has created a family of geographic information systems based on topology. The division between these two approaches transcends the technical arguments of efficiency and practicality. For, each approach imposes different attitudes with regard to the nature of space.

I cannot pretend to present both sides of a balanced debate between grid and topologic philosophies. Grid systems have many successful and perceptive proponents, plus large public financing for their hardware requirements. I wish to concentrate here entirely on the topological approach, presenting first the underlying ideas and an evaluation of the main weaknesses of existing attempts to implement them. Second, I will review the organizing principles and present status of the GEOGRAF project now under way at the Laboratory for Computer Graphics and Spatial Analysis.

I believe that topological systems will offer more effective geographic representation than that available through the grid approach. But I also hope that the gulf between the two philosophies does not become so wide that dialogue becomes impossible between their supporters. The final product of spatial analysis should take precedence over the transitory exigencies of data processing.

ASSUMPTIONS OF THE TOPOLOGICAL APPROACH

The first task of any project should be to define the eventual goals of inquiry. Developing a system to represent geographic entities requires the acceptance of some assumptions about the nature of space. Unless these assumptions are clearly stated, there will be a gap between expected and actual capabilities. Many systems fail not because they operate incorrectly, but because they do not provide as complete a spatial tool as required.

ENTITIES, CLASSES AND ATTRIBUTES

Dealing with space at the human level of experience, we are always dealing with aggregation and generalization. For different purposes we identify objects at different scales. A metropolitan area is a useful unit for analysis at the national scale. Each community must be distinguished inside the metropolis as analysis becomes finer. Eventually individual blocks or land parcels become the important spatial unit. The unifying factor in the progression parcel-community-metropolis is that some spatial aggregation is appropriate at any given scale. While the spatial unit has internal structure, our level of analysis allows it to be considered indivisible and relatively homogeneous in its attributes.

Thus for a given purpose, we naturally tend to distinguish a given set of discrete geographic entities. The criteria used to determine these entities usually form generic classes based upon specific attributes. For instance, the land use class consists of industrial, residential, agricultural, and other zones. By implication these uses are mutually exclusive, and so is their geographic expression. Similarly, linear objects such as roads can form a class which has network structure. In either case, the class is a set of geographic entities derived from a common set of attributes, thus sharing spatial character and structure.

Every entity has internal consistency at a particular level of analysis, and shares properties with similar, disjoint entities. But the entity need not have a specific size, shape, or orientation. It need not and should not be broken down to fit smaller cells, nor should it become mixed with others if it crosses some arbitrary gridding. The integrity of each geographic entity should be preserved.

NEIGHBORHOOD RELATIONSHIPS

Because they are located in a particular manner on the surface of the earth, all geographic entities are related to one another. The relative location of entities, in fact, describes the armature for spatial interaction and the overall structure of a class. Within the class of countries of the world, the contiguity, for example, of France and Germany is a significant fact. Within the class of land use, the proximity of residences to pollution generating facilities is similarly critical. Analysis of geographical information must take into account the basic connectedness and interdependence of all geographic entities. If an artificial unit such as a grid is used, the relationships are not those of the underlying geographic entities.

TOPOLOGY

A simple, concise means to maintain the integrity of entities, and to represent neighborhood relationships exists in the flexible science of topology and its dealings with the manipulation of networks. In our linguistic description of places we find the essential units of topological representation. In the case of France, we recognize that it is an area bounded by a set of frontiers with other countries and with the oceans. These frontiers are another sort of entity, dependent on the countries for definition, but serving a linear, not an areal function. The French-German frontier cuts across the Lorraine plateau, then follows the Rhine, terminating at Basel. This terminal point is also the terminal point of other frontiers. The relationships of areas, lines, and points in this example could be formalized by using a topological structure of polygons (cycles), boundaries (edges), and nodes.

Topological notation emphasizes the generic structure of geographic entities by stripping down to essentials. When dealing with complex problems where classes of zones overlap, the topological principles force us to recognize that only one network, the combined intersection set need be defined.

EXISTING SYSTEMS

The growing family of topological systems attests to the relevance of these concepts in a broad range of fields. Unquestionably, the original impetus can be found in the rapid creation of the DIME files for the 1970 Census. (Maxfield and Cooke, 1967). These concepts have been refined in the POLYVRT (Laboratory for Computer Graphics, 1974) and BZIS systems (Blumberg, 1974) among others. Also, the NRIS and LUDA systems demonstrate a parallel development without direct links to DIME.

Reviews of development and comparisons of relative efficiency of some of these systems have appeared and do not require repetition (Chrisman, 1974; Peucker and Chrisman, 1975). I wish instead to focus on the future of topological systems by describing first their main weaknesses and finally some attempts to solve them.

WEAKNESSES

Although topology offers a natural and effective means to formalize geographic information, there are a number of important needs that are poorly served at present. In general the weaknesses are not conceptual, they represent gaps between theory and reality to be filled by programming effort.

LEAST COMMON GEOGRAPHIC UNIT

The most important difficulty involves what has been called the "polygon overlay" problem. Most of the development of topological systems has centered on city street networks and administrative zones. In these applications the nature of the network frequently can be known from the start. The city block is a very reasonable choice of indivisible unit for the DIME files. A topological structure can be based entirely on hierarchical groupings of this unit with very little distortion. However, topological systems must seek applications with substantially different ground rules. In environmental situations, particularly, there is no unit which can be identified from the start as the common denominator. Attempts to do so are doomed to answer only limited questions (viz. James River Project).

Typically environmental data is composed of a series of classes of polygons which must be intersected and stored in an integrated system. To perform this task without recourse to the simplicity of a uniform grid is a great challenge, although the conceptual process is understandable. Taken together all the polygonal classes form a single network of zones which are the intersection set of all the classes. These zones may not bear direct relationship to any single class, so they need a new name: Least Common Geographic Units (LCGU's). Before the topological systems can claim generality of application, a procedure to effectively create the network of LCGU's from a complex set of polygonal and linear classes must be built. I do not think the existing, rather tradeworn answers to polygon intersection are capable of processing complex networks at a reasonable cost. The computational complexity must be lowered, and also the ability to recognize equivalent but slightly differently coded features must be enhanced.

DIRECTORIES

The second main weakness in existing approaches concerns the relative importance of information and methods to manipulate it. Too much emphasis is now put on data banks, and too little on software to use them. The relationship should be symbiotic; new software should allow refinement of information structure. At present, the DIME file is the main product of the DIME development. Beyond the maintenance modules and the address-matching capabilities, very little DIME software exists. I believe this lack is caused by the rigid external structure of the DIME file which seriously inhibits the design of an efficient internal data structure. There is only one type of record, the two point segment, in the DIME file. There are no directories that allow other information to be easily extracted. The topological relationships between geographic entities should not be merely theoretically possible, but also practically available. For instance, to use the DIME file to extract the outline of a zone, one should have an easier way than duplicating all records, sorting the whole file, and then linking segments. While the present DIME system allows for concise, compact external storage, there should also be a concern for internal processing requirements. It seems a waste to recreate directories from scratch for each program run.

GEOGRAF

Fulfilling the potential of the topological concepts is a challenge that has already attracted a number of researchers. Because most of the other projects are incomplete, the focus of this paper is the GEOGRAF project at the Laboratory for Computer Graphics. I will summarize the basic principles which underlie GEOGRAF and describe some of our early decisions in the system design. The audacity of our undertakings prompted a colleague to call the project MEGALOMANE I. But, in spite of high goals, I believe the project is reasonable and its goal attainable.

COMPLETE TOPOLOGY

The initial assumption behind GEOGRAF is an unqualified acceptance of topological analysis applied to geographic representation. Each class of geographic entities is taken to be a network of a known basic structure. A complex system of many classes is reduced to a single underlying intersection network. This lowest level has the structure of polygon, chain, and node developed for POLYVRT. The external data structure for POLYVRT which uses a multi-segment chain as the basic unit will provide the startling point. Above the lowest level, each entity is described in terms of components at the lowest level. A GEOGRAF representation should be a faithful translation of all spatial relationships into the data base.

STORE DIRECTORIES

Not only will all relationships be entered, they will be readily accessible through a software-generated internal data structure. Tables recording the chains incident at a node, the chains around a polygon, the lower level chains forming upper level boundaries, and more will all be constructed once and stored in the basic GEOGRAF data structure. The ease of access to this information should promote generality of application, flexibility of use, and efficiency of operation. The basic file structure required to operate these directories should be working by January 1976.

NEW PROCEDURES

In particular, many operations which now place large demands on computer resources can be restructured because of easy access to full topological information. If GEOGRAF is to work, the first priority must be the ability to combine diverse networks into the structure of LCGU's. In a previous paper (Chrisman, 1974) I have presented a method which, given access to full topological information on two networks, performs the work of intersection. The method presented operates at or near a linear order of complexity, because there is no need to compare every entity with every entity if the network connectivity is used. This procedure will require considerable experimentation, but the prototype should be working by October 1976.

A GEOGRAPHIC OPERATING SYSTEM

The mechanical programming problems of building a large and complete software system are monumental. The design of software for this project has been made subservient to a very demanding list of criteria. GEOGRAF should address the broadest range of applications and should be applicable to very large data files. The package should be built to foster transfer of geographic data and software without imposing arbitrary standards.

To implement these requirements GEOGRAF is being developed in a subset of FORTRAN amenable to transfer to all large and medium scale computer systems. Also the more restricted memory sizes of mini-computers have not been ruled out. In order to accomodate almost unlimited numbers of geographic entities and to operate with reasonable efficiency, a virtual memory system will allow constant interaction between software and storage. The resulting GEOGRAF package will consist of a set of subroutines that provide a basic geographic operating system. Requests will be made in a natural geographic manner without concern for the precise method of storage, internal or external. We plan to develop a number of complete programs using this environment, but the operating system should be useful for other projects. While such a system may expand indefinitely, the target for first release is in 1977.

SUMMARY

By offering a complete topological data management system in a flexible computer environment, new avenues for spatial analysis can be opened. The connected structure of geographical entities should foster the development of analytical procedures sensitive to spatial interdependence, rather than statistical independence. Spatial data collected for mapping can provide the base for more rigorous spatial understanding. GEOGRAF and similar systems should significantly enhance the ability to manipulate urban and environmental information.

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CONTOURING ALGORITHMS

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INTRODUCTION

Computer algorithms for contouring spatial data differ in subtle ways that affect the appearance of maps which they produce. Most operate by estimating the value of the surface at a regular gridwork of points across the map area. Contour lines are then drawn through this grid by mathematical interpolation.

The grid intersections are calculated by some form of weighted average of nearby data points. "Nearby" points are selected according to different search constraints. In some algorithms, surface dips are projected from the control points to the grid nodes being estimated. The effectiveness of different combinations of weighting function, search patterns, and projection techniques varies with complexity of the surface being mapped and the amount of control; some widely used programs may produce maps which are seriously misleading. Despite claims to the contrary, it is impossible at the present time to cite a single contouring method which is superior under all conditions.

If a contouring system is very flexible, many errors may be avoided by selecting the best combination of parameters and methods for a particular map and specific objective. This requires, however, an evaluation of the performance of different mapping techniques under different conditions. Results of an empirical analysis of contour maps of a subsurface horizon are presented as an example of such a comparison.

CONTOURING ALGORITHMS

Computer programs for drawing isoline or contour maps from scattered data points can be categorized into three general groups. These three basic approaches are embellished almost endlessly, however, making direct comparisons between different programs difficult. Comparative studies are important because conflicting claims have been made about the relative merits of the various alternatives as incorporated in commercial software packages. Few user groups have the financial or technological resources to develop their own computer contouring programs; most much purchase one of the packages marketed by hardware suppliers or vendors of proprietary software. This paper presents empirical comparisons of performance between some of the more common features incorporated in the most widely used class of contouring algorithms. These comparisons were made using SURFACE II, a general-purpose contouring package written by R. J. Sampson (1975 a & b) for the Kansas Geological Survey. The program is highly modular, and the various components can be combined to emulate most commercial contouring procedures.

The most obvious computer contouring approach is incorporated in various triangulation procedures, which simulate the process of manual contouring. Lines are projected from each data point to the nearest three points, dividing the map area into triangles. The points where contour lines cross the triangles are established by linear interpolation down the sides of the triangles. The final step is to connect points of intersection that have equal value to form contours. Essentially this process represents the surface as a "geodesic dome" composed of flat triangular plates (IBM, 1965).

Modifications include fitting curved rather than flat plates to the triangular areas, subdividing the basic triangles into finer subtriangles of similar form, and restricting the manner in which control points are connected so the resulting triangles are as nearly equilateral as possible.

The principal advantages of this procedure are the directness of the methodology and the fact that all control points must lie on the contoured surface. The principal drawbacks are the non-uniqueness of the triangular mesh, which can result in different patterns of contour lines for the same data, and the extreme slowness of the procedure as compared to gridding routines.

An alternative methodology includes the global fit procedures, in which a complex mathematical function of the geographic coordinates is fitted to the control point values. Polynomial trend surfaces and double Fourier surfaces are examples. Basically, global fit methods are an extension of statistical regression procedures into two-dimensional space. The equation which represents the surface is usually calculated so the sum of the squared deviations of the surface from the control point values is a minimum. Trend surface procedures are widely discussed in the geologic literature; a general treatment is included in Davis (1973). Modifications include two-stage procedures for fitting small "trend surfaces" to local areas of residuals from the global trend surface (McIntyre, and others, 1968).

The advantage of global fitting as a contouring procedure is its extreme computational speed. Its disadvantage is that it provides a very poor map of the data, as it is impossible to represent the detail in most mapped variables with any single, tractable equation.

Local Fit methods estimate values at the nodes of a regular grid across the map from a weighted average of the control points nearest each grid node. Contours are laced through the grid work by linear interpolation between the nodes to find the points of intersection of the contour levels with the grid lines. Points of common elevation are then connected to form the contour lines.

Estimating the regular grid of values is called "gridding" and consists of two steps. First, the nearest neighbors must be found. The simplest procedure is to take the n nearest points to the grid node being estimated. With certain distribution of control points, this may result in unconstrained estimates of the surface, if all the nearest points lie on one side of the node to be estimated. Constraints may be introduced to insure some equitable radial distribution of the nearest neighbors used. These include a quadrant search, where n points must be found in each of four quadrants around the estimated points, and the octant search which carries the concept of radial constraint one step further (Walters, 1969; Batcha and Reese, 1964).

The second step is the estimation of grid values from control points that have been located in the first step. The estimates may simply be weighted averages, where the control points are weighted by a function of their distance D from the grid node. The most commonly used functions decline with distance at least as rapidly as $1/D^2$ and some decline as rapidly as $1/D^6$ (J.A.B. Palmer, 1973, personal communication).

A more elaborate procedure which is widely used in commercial contouring software divides the estimating process into two phases. During the first phase, the dip of the surface at each control point is found by fitting a weighted least-squared plane to the surrounding control points. In the second phase, these dips are projected from the control points that surround a grid node to that location. An estimate of the surface at the node is then made as a weighted average of these projections (Osborn, 1967; Jones, 1971).

Most commercial contouring programs are combinations of different weighting functions, search procedures, and a great variety of other modifications on a local fit procedure. The superiority of specific combinations is loudly proclaimed by their proponents, but the relative merits of the more elaborate procedures are questionable. It should be noted that, in addition to drawing isoline maps, commercial contouring packages usually have the ability to construct block diagrams, isopach maps, and maps of other transforms of the surface. Although these embellishments may greatly add to the cost of a particular package, and may be very important in their own right, they do not affect the relative performance of the contouring procedure.

The primary advantages of the local fit method derive from the intermediate gridding step; this allows storage of the mathematical representation of the surface as an array in the computer. Storage is minimized and the process of drawing contour lines is speeded. Two or more variables can be compared (by isopaching or other methods) even if they are measured at different locations, because the grids, rather than the control points, are compared. However, the gridding step also is the cause of most of the drawbacks of the local fit method, especially the distressing tendency for contour lines to sometimes pass on the wrong side of control points in areas of low dip, or when excessive smoothing of contour lines is performed (Walden, 1972).

An empirical analysis was performed to evaluate the differences between some of the more widely used variants of the local fit procedure. A geologic subsurface structure map was constructed in an area of moderate to dense well control. The test data set includes all wells drilled to the top of the Pennsylvanian Lansing-Kansas City Group in Graham County, Kansas, to the end of 1974. This includes approximately 3,000 wells in an area 30 x 30 miles square. Surface values are in feet above sea level, so statistics of errors are also given in feet. The fidelity of the computer-drawn map to the original control points was found by back-calculating to each well location from surrounding grid nodes. The root mean squared (RMS) error of these differences is a measure of the scatter in values of the contoured surface around the true surface. A large RMS value indicates the procedure is ineffective, or inaccurate at the data points. The skewness of these differences is a measure of bias, or tendency for the surface representation to consistently fall above or below the correct values.

Figure 1 is a plot of RMS error and skewness of control-point errors for maps constructed by an algorithm which used various numbers of nearest neighbors, selected without constraints on the search pattern. Grid nodes were estimated by averaging the control points found, after weighting by a function which declines at the rate of $1/D^4$. Both RMS error and skewness increase as the number of nearest neighbors increases. Other plots for weighted projection methods and octant or quadrant search patterns are essentially identical to this illustration.

The influence of different weighting functions on control-point error is shown in Figure 2. Errors were found by back-calculating from a surface created using eight nearest neighbors, no search constraint, and no projection of dips. A function which is heavily influenced by nearby control points creates a surface representation which has the smallest RMS error and skewness. In contrast, a surface created using a slowly declining weighting function is smoothly undulating and has many of the averaging properties of a global fit surface. Search constraints and projection of dips do not significantly alter the degree to which the map representation honors the original control points.

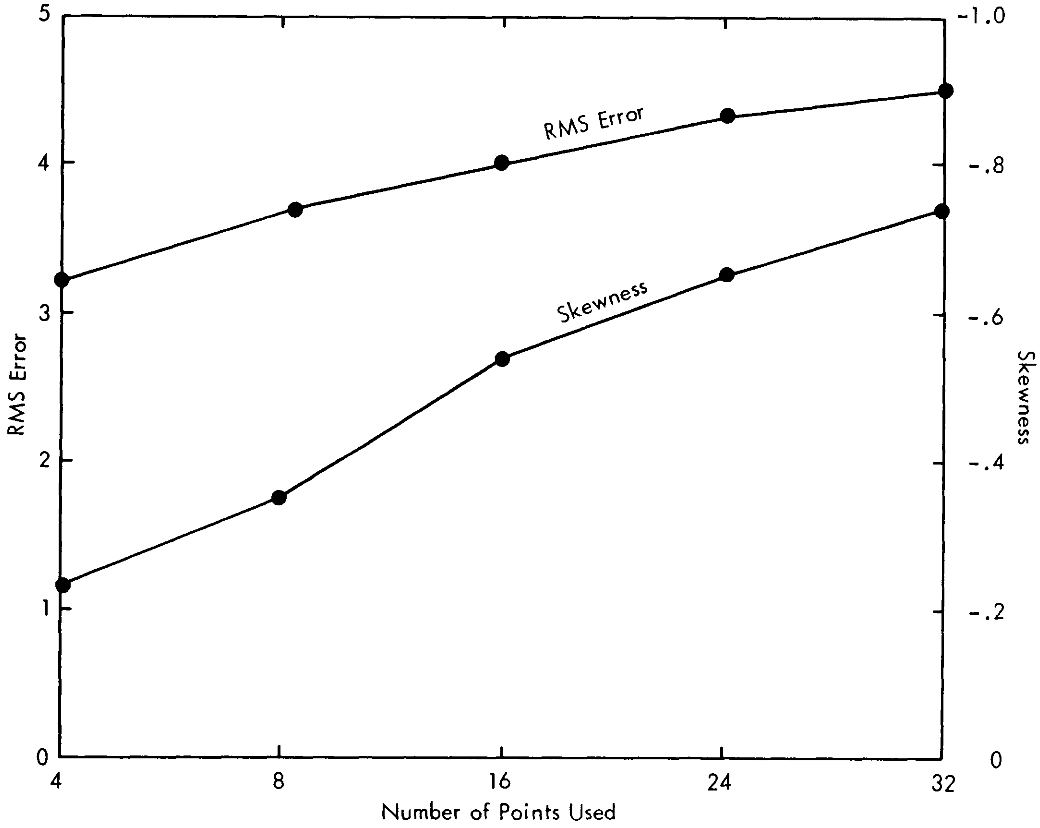

Figure 1: Error at control points for nearest neighbor searches without projection of dips at control points. RMS error is given in feet.

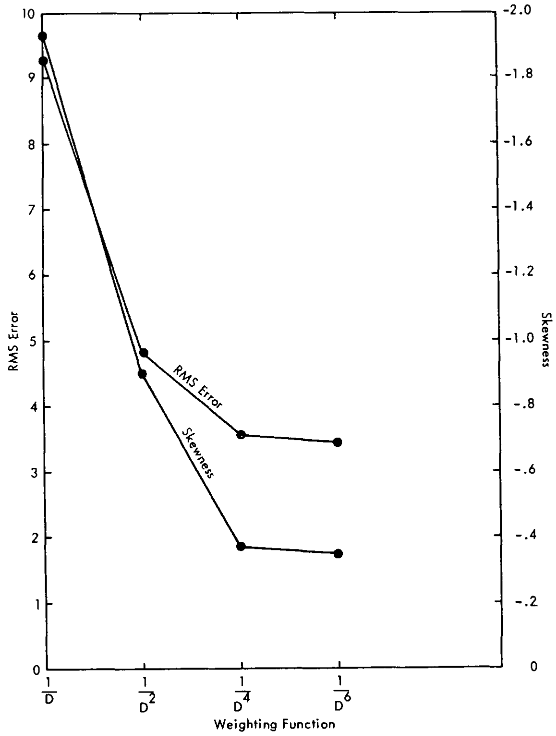

Figure 2· Errors at control points for nearest neighbor searches using eight points, without projection of surface dips at the control points, for different weighting functions. RMS error is given in feet.

The primary objective in many contour mapping exercises is, however, not to represent the available data as accurately as possible, but to estimate with minimum error values of the surface at locations where no control is available. In petroleum exploration, for example, structural contour maps are used to predict the locations of potential targets such as closed positive structures or anticlines prior to drilling. The ability of various algorithms to produce accurate estimates at locations where no control exists was checked by an empirical test using the same set of subsurface data. The well data were first divided into two subsets, one containing approximately 700 wells drilled prior to 1952, the other containing about 2,700 wells drilled after that year. The set of early wells was used to generate structural contour maps which were checked by comparison with the structural elevations at the "blind," post-1952 locations.

Figure 3 summarizes the estimation errors made by various combinations of search patterns and numbers of control points used in the estimation process. The algorithm weights control points according to a function which drops off at the rate of approximately $1/D^4$, with or without dip projection. Bias is expressed by the mean error, which is a measure of the average tendency for the algorithm to underestimate or overestimate. RMS error is a measure of the inefficiency of the estimating procedure.

Ideally, a contouring algorithm should have both a low bias (i.e., it should be accurate) and a low RMS error (i.e., it should be precise). There is little difference in precision between the various combinations considered, but there are large differences in the amount of bias. Methods using large numbers of nearest neighbors have less bias, because the estimate has the character of a statistical average and the law of large numbers is operating. Use of dip projections significantly increases the bias, especially in areas where

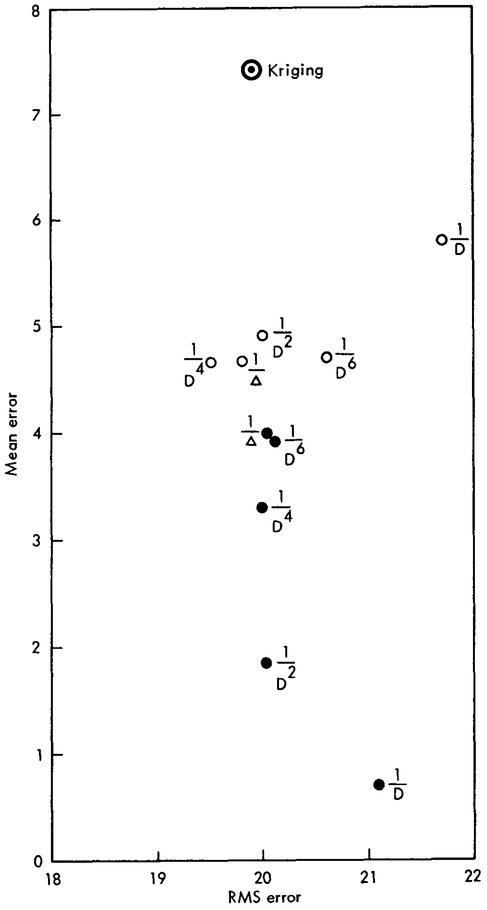

Figure 3: Errors at estimated points for different search patterns and numbers of points used in the gridding algorithm. Estimations are calculated as standardized averages of control points weighted inversely to the square of distance. Squares represent nearest neighbor search, circles are quadrant search, and triangles are octant search patterns. Solid symbols are methods without projection, open symbols are methods with projection of dips.

control density is low and local gradients may be high.

An example of the effect of different weighting functions on estimation error is shown in Figure 4 for an algorithm which uses an octant search constraint. Weighting functions which drop off slowly have the lowest bias but the highest RMS error. Again, this is because they are assuming the characteristics of a global averaging process. Relationships in this plot are typical of those for other combinations of search constraint and number of control points used, although the scales may be shifted somewhat.

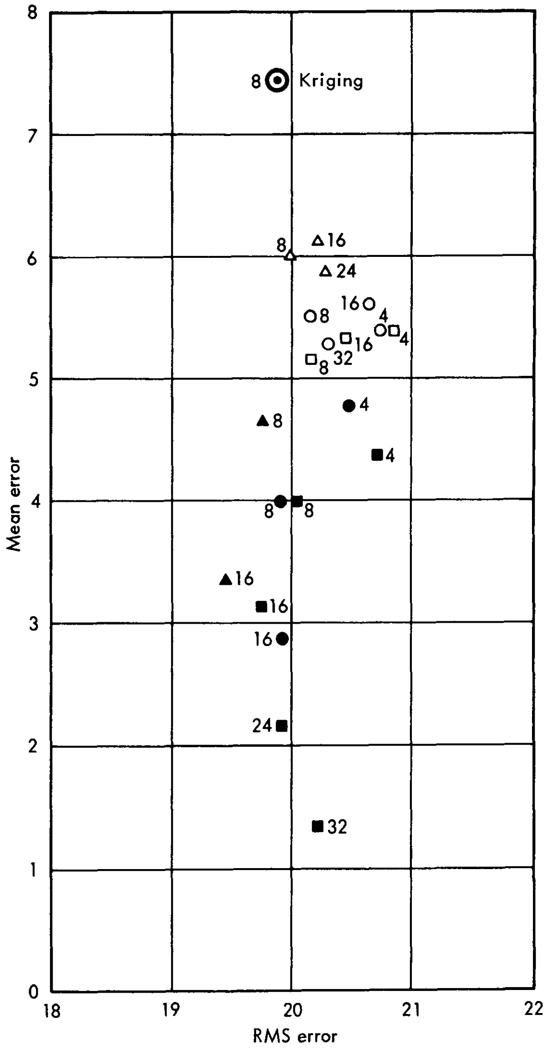

Figure 4: Errors at estimated points for different weighting functions, using an octant search with two points per octant. 1/Δ represents standardized inverse distance-squared weighting. Solid symbols are for procedures without projection of surface dips, open symbols are with projection.

The distressing (although not surprising) conclusion from this empirical study is that the different objectives of the contouring procedures considered are not mutually obtainable. An algorithm which faithfully honors the original control points should utilize a weighting function which drops off extremely rapidly with distance, and which uses only a few nearest neighbors. However, such an algorithm will produce poor predictions or estimates at locations where no control is available. The best estimating procedure might be one that used 16 or 24 control points in each calculation of a grid node, and which weighted distant points relatively heavily. This, of course, would provide a poor reproduction of the original control points.

Since it apparently is not possible to specify a combination of features that will lead to a map that is "best" in both a representational and predictive sense, the selection of features should be based on the specific purpose for which an individual map is made. This requires a contouring package which contains a variety of alternative procedures under the control of the user. There is, in addition, a third selection criterion, based on a practical constraint: Figure 5 shows increases in computation times related to the number of nearest neighbors used by the algorithm. For routine or production contour mapping, the cost criterion may be equally as important as fidelity or predictive ability.

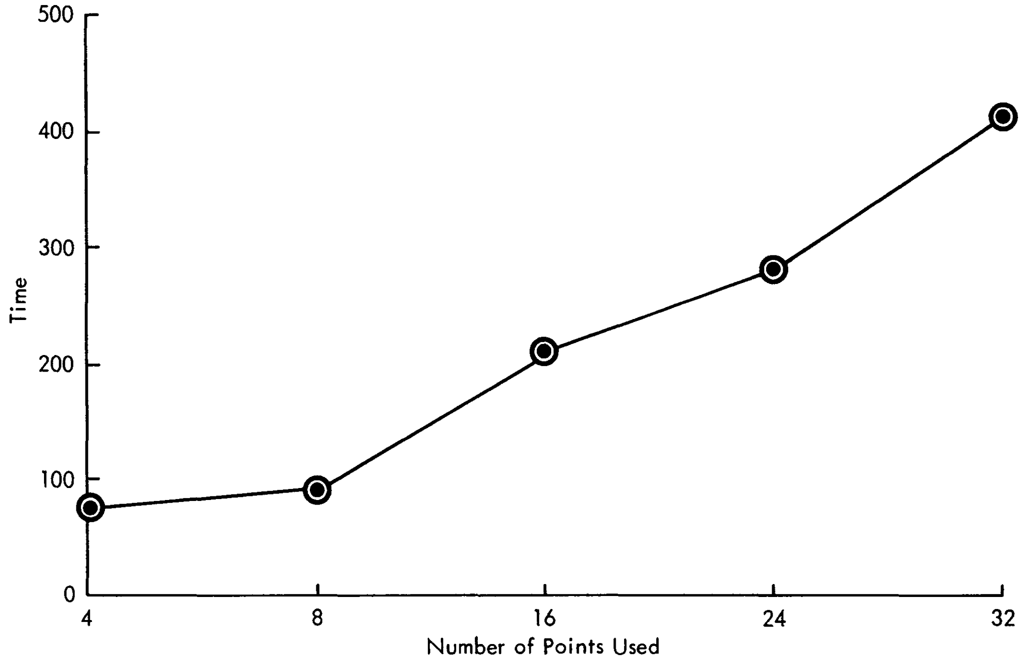

Figure 5: Run times for gridding phase of SURFACE II, in hundredths of seconds of Honeywell 635 CPU time, for nearest neighbor searches without projection of dips at control points. Dip projection increases run times by a constant factor of (no. data points)/(no. data points + no. grid nodes).

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Seminar on Land Use Mapping

LAND USE MAPPING

The seminar on Land Use Mapping was held in two sessions. Chairman for the Monday afternoon session was JAMES R. WRAY, while the Wednesday session was chaired by OLAF KAYS. Both are with the U.S. Geological Survey's Land Information and Analysis Office.

At the Monday session, participants heard presentations describing the U.S. Geological Survey's land use mapping program -- its approach and products, its geo-information system (including automated cartography output), and parallel research in remote sensing technology, with its prospects for automated input of spatial data as well as automated thematic output. Abstracts of the three presentations appear in this section. Presentations at the Wednesday session were made on various aspects of land use mapping, including the employment of remote sensing, local assessors' maps, and land use data systems.

JAMES R. ANDERSON discussed "The USGS Program For National Land Use Mapping and Analysis," which provides systematic and comprehensive collection and analysis of land use and land cover data on a nationwide basis. Begun in 1975, initial coverage of the United States is planned for completion by 1980. Individual land use/land cover maps and their associated data will be released as they become available following compilation. The presentation described the classification system, land use mapping source materials, standard map products for nationwide coverage, demonstration map products for selected areas, and the geo-information system, with sample computer graphics and statistical products. User assistance and cooperative projects were described, along with supporting analytical studies and continuing research in the state of the art.

"Automated Cartographic Inputs and Outputs for National Land Use Mapping and Analysis" is the title of the paper by WILLIAM B. MITCHELL, who described a geographic information system that relates the land use data generated by the U.S. Geological Survey's land use mapping program to data from other sources. The system can provide data in graphical and/or statistical forms for a wide range of user applications. The presentation described the underlying methodology, input data sets, sample outputs generated by automated cartography, development of software, availability of data in computer format, development and availability of software, and the prospects for application. The rising expectations for applications and/or requirements of regional, State, and local users of geographic information systems were weighed in relation to possible geographic information system designs. Experiences, opportunities, and problems in related operations and research at the U.S. Geological Survey were discussed.

Parallel thrusts supportive of the U.S. Geological Survey's nationwide land use mapping program are the analysis of land use data and the continuing research in inventory technology and its transfer. One component of this research is comparative land cover analysis and change detection using remote sensors aboard aircraft and satellites. JAMES R. WRAY, chairman of the first session, discussed "Automated Interpretation and Analysis of LANDSAT Digital Data for Land Cover Inventory and Change Detection." He stated that the LANDSAT multitemporal and multispectral data in computer compatible form make satellite observation a promising element in an evolving operational system for land cover inventory and change detection. LANDSAT's modest resolution poses opportunities, as well as limits, and helps us to anticipate what higher resolution would require of future information handling facilities. Even now its digital format is not only an aid to land cover classification but also to area measurement, statistical analysis, and automatic preparation of thematic maps. Its multitemporal coverage also allows us to consider seasonal aspects of land cover as well as more lasting changes.

The presentation illustrated the versatility and limitations of land cover classification from multispectral scanners aboard satellite platforms. It showed sample products, integration into a geo-information system, some prospective uses and users, and encouraged a continued research and development. One proposal to those interested in automated thematic cartography -- such as the detection of land cover change -- is that such information does not always have to be in map form. The predictability of the stable satellite platform and our ability to determine the location of data points may serve as a map substitute for some requirements for geographic information. This may not only hasten the availability of land cover information for making land resource management decisions, but also may hasten the automated preparation and reproduction of any thematic maps derived from spatial data in cellular mode.

ELLIOT AMIDON, of the Pacific Southwest Forest and Range Experiment Station of the Forest Service, U.S. Department of Agriculture, discussed the Wildland Resource Information System (WRIS), a computerized system for storing and manipulating data about land areas. It can edit, retrieve, update, overlay, plot, calculate, and store spatial data. WRIS digitizes land units -- termed polygons -- in each layer of mapped information by a scanning method. The U.S. Forest Service's California Region is using multistage sampling and WRIS to acquire forestry inventory data. Maps produced by WRIS for each of five national forests have three layers of data. Some 300 to 500 maps are processed in a year by a three person staff using a high-speed batch computer terminal. The paper was entitled "Land Unit Mapping with the Wildland Resource Information System."

D. R. FRASER TAYLOR, professor of geography at Carleton University, (Ottawa, Canada) examined the current role of "The Land Use Map in British Local Planning." He argued that currently the role of the map is a minimal one and discussed several reasons for this. He examined the issues involved in incorporating the map in the emerging geographic information systems being developed by local authorities in Britain. He further argued that while the potential of the digital map is great, there are substantial difficulties involved in realizing this potential.

JOHN BEHRENS of the Bureau of the Census' Governments Division looked at maps from the viewpoint of a user of such maps. In his paper, "Tax Maps and Their Land Use Implications," he described the essential and optimal features on cadastral maps used by assessors for tax purposes. In the United States, assessors' records collectively represent the most complete inventory of land parcels, even though sometimes limited to the taxable. Because they are basic and complete, they lend themselves to integration with a comprehensive land data system sensitive to the needs of officials other than assessors, and to the needs of the general public.

"Multi-Dimensional Maps Through Digital Image Processing" was the title of the paper by R. M. BATSON of the U. S. Geological Survey's Geological Division in Flagstaff, Arizona.

Image processing techniques originally developed for exploring the planets can be applied to any data set in which "brightness" values can be arranged in a television-like raster of rows and columns. Data sets may consist of actual television pictures like those taken by LANDSAT, matrices of terrain elevation, or parameters of land use, or a variety of geological and geophysical information. Color compositing, introduction of stereoscopic parallax, and "relief" shading can be used to show each data set in a distinctive way within a single composite map image.

OLAF KAYS of the U.S. Geological Survey's Resource and Land Investigation (RALI) Program, served as chairman of the second session and in his paper described a cooperative user survey to identify and close the gap between State planning data use and Federal data map products. Planners were asked to evaluate comprehensive atlases, orthophotos, and maps showing distributions. Based upon the response, it was determined that further communication between the two groups was needed. The RALI Program will institute a series of Federal/State workshops to further investigate the issues identified by the users. The paper was entitled "Evaluation of Natural Resource Data Products by State Data Users."

JOHN M. MORGAN and DONALD OUTEN of the Maryland Department of State Planning described "The Maryland Automated Geographic Information (MAGI) System," a grid-based, computer-assisted system for the storage, retrieval, manipulation, and display of geographic data. The MAGI System was implemented for the Maryland Department of State Planning by the Environmental Systems Research Institute to assist in the preparation of a generalized State land use plan. The following methods associated with the implementation of the MAGI System were discussed: the collection and digital encoding of selected geographic (physical and cultural) data, and the design and development of geographic data handling programs and procedures. Current applications and limitations of the MAGI System were also discussed.

GEORGE HALASI-KUN of Columbia University (New York) prepared a supplemental paper on the New Jersey Land Oriented Water Resources Data System (LORDS). He described the conditions of the State from the viewpoint of interdisciplinary data gathering concentrated in water interaction on the natural environment. The system not only combines general information on water resources and climatic conditions, but also includes demographic, geologic, land use and sanitation data, together with reference listings, map descriptions and lists of State-owned lands and historical sites. A detailed description of a ninety square kilometer area was given from the data bank and included maps and descriptive materials. The advantages and disadvantages of storing data by computer, microfilm, and MTST (magnetic tape/selectric typewriter) were also discussed.

LAND UNIT MAPPING WITH THE
WILDLAND RESOURCE INFORMATION SYSTEM

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INTRODUCTION

A wildland manager, like his urban counterpart, must combine land, labor, and capital to produce socially desirable goods and services. In forest administration, land is a particularly vital factor in resource planning. That wildland managers must keep track of their land is indisputable. The only question is: To what degree should they do so?

My particular concern is forest inventory in general, with emphasis on National Forest timber lands. What species of timber are there and how fast do they grow? Answers to these and other questions are of major economic importance. National Forests have a timber cutting goal or allowable cut which directly affects employment and income in rural communities. The level of the cut is largely based on analysis of inventory data.

Inventory data should be provided with a precision appropriate to the resource values at stake. Historically, information needed for extensive forestry was met by ocular estimates. In the last few decades, numerous sampling designs have been developed to improve these estimates. Initially the statistical designs were simple, but implementation required extensive field work and manual data collection. The dramatic decline in computation costs experienced in that last 15 years has radically changed inventory design. Expensive sample-plot work is minimized by using complex statistical designs made practical by computer technology.

The U.S. Forest Service's Wildland Resource Information System (WRIS) continues the trend of substituting computer-oriented inventory system designs for manual data collection in the forest (Russell and others 1975a). WRIS was developed at the Pacific Southwest Forest and Range Experiment Station. It can compile and display geographically distributed resource information. It provides location data affecting management decisions. Although initially developed for timber inventory specialists, it has general resource application. Its key element is the polygon of known area and classification. Collectively these land units form a map. Computer programs provide the means to edit, process, store, retrieve, update, and display land units.

WRIS has been used to compile geographic information for the Stanislaus and Eldorado National Forests in California, and data from three other National Forests are now being processed. In every case two main phases must be completed. In phase one, opportunities for silvicultural treatment are mapped. Normally three map overlaps or layers for the same area are required. In phase two, the classes defined and identified in the first phase are sampled. Forest inventory data customarily collected include timber volume, growth, and structure measurements. Together these two phases provide the quantitative timber information essential to the computation of the National Forest's allowable cut.

THE SPATIAL DATA BASE

A National Forest timber inventory begins with aerial photography. Both the photographs and the maps compiled from them are at several scales. The resource photography is interpreted according to regional standards, and the delineations are rectified onto planimetric maps. The map format may be systematic like the familiar U.S. Geological Survey 7-1/2-minute quadrangle. But foresters are also accustomed to the General Land Survey township which can be highly irregular. A standardized format aids our method of map digitizing but is not essential.

The land units, or polygons, exhaust the mapped area. All polygons, including any blank or null area, are identified. Every polygon has a unique numerical identity in addition to its classification or descriptive label. Our data processing method imposes two requirements on polygon boundaries. Boundary lines must be wide and dense enough to be detected by an optical scanner. Lines must join other lines including the map border. In practice, this means that polygons cannot occur within one another, such as an island in a lake. Additional lines are drawn to join the island to the shore, and the polygons created are assigned labels.

Map layers or overlays are filled with polygons having mutually exclusive labels. In our inventory work in California, we have found three layers adequate. One map shows delineated silvicultural conditions or opportunities termed treatment classes. Another map contains naturally or administratively determined conditions termed management components. The components are actually constraints that limit the number of treatment alternatives. The third layer shows political and administrative boundaries.

WRIS programs enable the land manager to retrieve and display overlaid map information for any combination of maps as well as to tabulate acreages. This capability allows the manager to evaluate the interactions between biological conditions shown on the treatment class map and the edaphic, geologic topographic, aesthetic, and other constraints embedded in the other two maps. Then the manager can determine realistic management opportunities tied to specific land areas. After land treatments are performed, any changes reflected on maps can be inserted into WRIS without resorting to a new mapping project.

SILVICULTURAL TREATMENTS

Silvicultural treatment classes serve dual purposes. First, their names reflect biological conditions within the land unit that has a potential for treatment. Second, the treatment classes function as volume strata for sampling. The map scale is 4 inches per mile (1:15,840).

Treatment classes mainly describe wild stands which will be converted into managed even-aged stands over many decades. The hundreds of categories occurring on the maps are maintained for display, but aggregated for statistical sampling. The six broad categories are:

- Highly decadent, overmature stands.
- Poorly stocked stands of all classes.
- Mature stands.
- Two storied stands having a mature or overmature overstory and a younger understory.
- Young sawtimber stand.
- Pole and sapling stands.

MANAGEMENT COMPONENTS

Management components reflect natural or administrative factors affecting timber management alternatives on a given National Forest area. Boundary placement depends strongly on the classifier's personal knowledge because many key variables are not mapped, such as "tractor loggable," "cable loggable," and "landscape sensitive." Clearly a practical knowledge of logging engineering is required to delineate these categories. Categories vary slightly between forests, but seldom exceed 20. Since the number of components is less than the number of polygons on the silvicultural treatment maps, scale can be reduced to 2 inches per mile (1:31,680) and computation cost reduced moderately.

ADMINISTRATIVE BOUNDARIES

Only National Forest, ranger district, and county boundaries are delineated. It would be expensive to digitize each township separately because each has only a few lines. Instead a map at the scale of 1/2 inch per mile is drawn with all administrative boundaries on one sheet. This procedure helps achieve a substantial saving in processing expense.

LAND UNIT SAMPLING

A multistage sampling design is particularly applicable for inventorying insects, range vegetation, and trees (Hazard and Stewart 1974). In two-stage sampling, samples are drawn from the primary sampling units. In an early application of multistage sampling, the four stages were Apollo 9 satellite photographs, aerial photography at representative fractions of 1:12,000 and 1:2,000, and ground plots. Only 10 field plots were needed to estimate the gross cubic feet of timber on 6 million acres in Louisiana, Mississippi, and Arkansas with a sampling error of 13% (Langley 1969).

The multistage sampling scheme used for two California National Forests starts with conventional aerial photography rather than satellite imagery. It is designed to minimize the cost of field work while providing a timber volume estimate with a 10% standard error. The design takes advantage of increasingly precise volume estimates at each stage.

Sampling begins with delineation of treatment-class strata on aerial photographs. Intermediate stages are successively larger-scale photographs, with successively decreasing ground areas. The last stage consists of ground plots. Volume estimates at each stage are used to draw a sample at the next lower stage with probability proportional to estimated volume. Calculations follow the reverse path. Ground sampling estimates are expanded according to the probabilities previously estimated for each higher stage until volume for the entire forest is estimated. This method yields unbiased estimates with the sampling error determined by the precision of the predictions at each stage.

Multistage sampling is an efficient design, but has the disadvantage of being operationally complex. A major difficulty is the need to measure elevations accurately at low flying heights over mountainous terrain in order to calculate photo scales. By products of space development, such as laser altimeters, and on-board computers, will solve the elevation data problem. These tools and multispectral cameras favor the application of a multistage sampling design.

FACTORS AFFECTING SYSTEM DESIGN

MAPPING SYSTEM TECHNOLOGY

The past decade has seen a three-stage transition in methods from completely manual map data collection to hand-guided machine operation to automatic scanning. In keeping with the technology of the times, the first data-collection format was an arbitrary grid (Amidon 1964). With the grid cell approach, setup cost is negligible, but the direct cost of handcoding is high. Cell contents are described by a variety of codes, such as shades of grey caused by overprinting as in the SYMAP system (Harvard University 1973). More detail is available with codes of two characters per cell, yielding 2,304 to 4,096 distinct possibilities with a 48- to 64- character print chain (Amidon 1966). Fixed grid systems remain because the ubiquitous line printer is an inexpensive graphic output device. A recent urban system development called GRIDS can process massive amounts of census data (U.S. Bureau of the Census 1972).

Several systems are expressly designed for natural resource management applications. Enough cost and productivity data are available to judge each system as an investment alternative (Amidon 1974). Systems with hand-operated digitizing methods fall in the moderate initial investment cost category, or the range of $15,000 to $30,000. An example is the Map/Model system of the University of Oregon, used for regional as well as forest problems (Arms 1970). Another example is NRIS, or Natural Resource Information System, developed for the U.S. Department of Interior. It uses a manual digitizer with a plotter attached for on-line editing (Raytheon Co., Autometric Operations 1973). WRIS is at the low end of the high initial cost category with $65,000 investment enough for an automatic scanner and a manual digitizer. Really large investments generally are associated with military or space agencies. One experimental scanning system both digitizes and plots on film. Only the film is kept for long-term storage (Diello 1970). In a large investment class by itself is CGIS, or the Canadian Geographic Information System. A drum scanner was built solely to digitize full-sized, scribed map sheets for an expected input of 20,000 especially prepared maps. Forestry information is just one of many layers of data. Agricultural spatial information and socio-economic file data comprise the bulk of the data (Tomlinson 1967).

SOURCE MAP CHARACTERISTICS

WRIS has broad capabilities for handling land unit data. Although the system was designed to meet the needs of timber management planning, it is unaware whether polygon labels represent timber, range, or even urban data. Control over map production was a distinct advantage because timber type maps could be compiled so as to facilitate subsequent processing. We know from past experience that the maps would normally contain irregular lines and less than 500 polygons, and that the smallest land unit would be 5 acres. Such characteristics assume importance when data storage strategies are being considered, if it is known that 10,000 polygons can occur in just the timber type layer on one forest. Data-compression algorithms which exploit the occurrence of straight lines are of little value to us. Usually only administrative boundaries are straight and comprise only a small part of the total boundary data stored. Knowledge of the approximate number of polygons expected to occur affects trade offs between line and label storage in the computer memory. The expectation that land units should exceed 5 acres is of value to search and error-detection programs because smaller areas can trigger an inspection.

Land unit labels--polygon attributes--are simple for management component and administrative maps. Forest-type symbols on silvicultural treatment maps are complex for two reasons. First, some symbols do not exist in the computer's character set and the equivalent must be established. Second, the sequence and position (numerator/denominator) of the map symbol is an implicit code. Symbol transcription rules must be defined and memorized by label encoders. Every polygon label by X, Y location is keypunched and examined by editing programs. Out of thousands of possibilities, about 1200 different forest type labels of 36 characters or less are found in a forest type map. Essentially, the original map detail is preserved on magnetic tape for flexibility. The individual land units can be aggregated into any sampling strata required for a given statistical design.

COMPUTATIONAL FACTORS

The generally decentralized nature of the Forest Service's organization favors direct computer communication from regional headquarters to the individual National Forest. Map and associated resource file data are initially compiled and stored in the forest supervisor's office. And most of the questions for the information system originate there also. With continued progress in miniaturization, computer mapping may one day be feasible at the forest level.

At present WRIS is operational at the regional level with high-speed access to a medium-sized computer in batch mode. Three people process 300 to 500 maps a year at a regional office. Centralized processing has several advantages. Although the computer is a shared, general-purpose device, the peripheral equipment is not. Digital plotters have numerous alternative uses, but scanning microdensitometers are mainly used for scanning aerial photographs and maps. One scanner can serve the entire U.S. Forest Service's California Region.

THE IMAGE DIGITIZING SYSTEM

Nearly all computer mapping systems rely on manual methods to digitize land units directly from a map. The intent is to avoid either copying the original map or preparing a source map especially for digitizing. An important exception is the Canadian Geographic Information System. Full-sized scribed map sheets are rotated on a drum, where a stationary sensor detects densities or "grey" levels. But the hardware, which costs several hundred thousand dollars, has no alternative use. WRIS requires a reduced map image in order to use commercially available, multipurpose scanning digitizers. Most maps are not copies but drawn for scanning as well as general field use.

BASIC CAPABILITIES

WRIS is an operational production tool for storing the boundaries and calculating the acreages of all mapped polygons for a National Forest. At least three people are required for continual processing, one of whom can perform system maintenance. Proliferation of options is avoided since the system already exceeds 20,000 FORTRAN statements. Even the hand digitizing alternative is considered a mixed blessing. It does enable simple maps to be processed at less cost than scanning, but at the price of more maintenance. Since WRIS is designed for production the following list of capabilities may seem austere:

1) Maps are prepared for input to the system. Aside from a few basic drawing rules, the maps can be any format or scale that can be photographically reduced. We have had maps 3 feet by 5 feet reduced eleven times commercially onto a 4- by 6-inch "105" high-constrast copy negative.

2) The arbitrary coordinates established at scanning time can be transformed into general coordinates. The options are geographic (latitude/longitude), State Plane (Lambert Conformal), Transverse Mercator and Universal Transverse Mercator.

3) Map editing is performed by using local coordinates identified as rows and columns on line printer output. Most errors are detected by programs which selectively display just enough graphic data to correct the problem.

4) Software was developed in standard FORTRAN compiled by UNIVAC's EXEC 2 executive system.* Current implementation is by the EXEC 8 version for two remote UNIVAC 1108's, one 30 and the other 1,200 miles away. A senior programmer should be available to install the system and provide some assembly language programs for efficiency. Documentation in the form of printed material and program comment cards is available.

MAP DATA PREPARATION

The rules for map preparation are simple. Strict adherence to the rules is, however, extremely important. Processing cost depends on map quality because editing is the major expense.

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*Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

Polygon boundaries to be digitized by scanner are drawn in ink on stable plastic. All lines join others including the map border. Polygons cannot overlap one another, and the entire mapped area is labelled; empty polygons are not allowed. All non-boundary information, such as labels and coordinates, are written with a non-photo blue pencil.

Selection of the appropriate line width will depend on each user's circumstance. Optical scanners, particularly high-speed models, offer a limited number of apertures and spacings. To compensate, map reduction can be varied to accommodate the available scanner settings. Alternatively, for a fixed reduction, line width can be varied. Instructions for achieving an optimum balance between aperture and spacing alternatives are available in a user's guide (Russell and others 1975b). For our largest maps, 2 feet on a side, and a negative reduced tenfold (10X), we normally scan a thousand lines and readings (rows and columns). More intricate maps can be resolved by taking more density readings but this increases computer processing cost.

MANIPULATIVE OPERATIONS

Once the polygon data are correct a few manipulations are performed. Multistage timber volume inventory requires map "windowing". A rectangle subset of the timber type layer is randomly selected. Within the frame acreages are calculated automatically. A display accompanies photographs to the field for ground plot delineation.

Forestwide acreages are also accumulated by using logical operations. For each township the forest type layer is overlaid on the management component map. The intermediate, output map consists of polygons formed by the intersections of polygons in the two input maps. The polygon labels on the output tape are a composite of the input labels. The output tape becomes input for overlaying the third layer, administrative boundaries. Conceptually this pairwise process can continue indefinitely. In practice the output polygons fragment with each successive layer. Since polygons of insignificant size are automatically assigned a null label, output becomes less useable with successive layers. System computational restrictions usually take hold before the proportion of "slivers" can become excessive. Two limitations inhibit fragmentation. First, the polygon count for the two input files and the output file cannot exceed 2,000. Second, a pair of polygons cannot cross each other more than 800 times. As a general rule, to stay within these constraints the number of polygons in each input file should not exceed 500.

Composite maps can be plotted, but normally just an acreage table is needed. The simplest form is a list of every polygon with its area and perimeter. In the next level of aggregation, every polygon is assigned to a class. The acreages in an overlay are shown by categories in a two-way table. Finally, acreages can be accumulated over any group of townships by merely arranging the township-acreage decks in the desired sequence.

SUPPORT PROGRAMS

Digital map data are written on magnetic tape, staged to Fastrand drums for processing, and written onto tape again for permanent storage. The tape usually includes a file, or collection of records, for each township layer. Backup tapes contain duplicate files for each of the 200 to 300 maps per forest. A forest's timber type file may have as many as 1,000 distinct labels.

As the regional data base grows, support programs assume greater importance. Computer programs provide the basic functions of file searching, packing, and copying. Other routines give map data summaries in varying degrees of detail and facilitate sorting, checking, adding or deleting labels. Detecting incorrect labels requires maintenance of a master label file. This drum file is a list of all permissible labels on a forest for each type of map. The number of labels depends mainly on the complexity of the forest type layer, but fluctuates between 1,000 and 2,000 labels per forest.

Maps are drawn automatically by a digital plotter. We rely mainly on the Calcomp 1136 incremental drum 3-color plotter, but have an EAI 430 flatbed plotter in reserve. A very complex Calcomp plot requires 45 minutes of work. One color is used to plot control points, x and y scales in map coordinates, a title, and polygon boundaries. A constrasting color is used for polygon labels to make visual editing easier. The few plot options are available for resolving the occasional, highly complex map editing problem. A plot can be a variable rectangular frame, and the scale within it varied by supplying a blow-up factor. Polygons can be identified by label or automatically assigned a sequence number. Since printout is less expensive for editing, almost all maps are plotted only in final form.

COST

In 1973, the direct cost to process a typical township (36 square miles) was about $200. Now that five National Forests in California are in process, the work flow is well established and editing methods have improved. Current cost for a highly complex, million-point scan is $170. Because less than a fourth of the cost is for labor, system expense is closely tied to the general cost of computing. The assumption that equipment can be rented is well justified, except possibly for the input scanner. The number of maps to be digitized will determine whether an investment of at least $40,000 in a scanning microdensitometer can be amortized.

RESEARCH AND DEVELOPMENT

The stimulus for additional development now comes more from operational problems externally generated than from internal innovations. A key problem is tape reading or writing, particularly on peripheral digitizers and plotters but also at the computer center. Careful maintenance helps minimize the error rate, but cannot eliminate the problem. We plan to store our processed data in demountable disk packs instead of on tape. This change will nearly solve the reliability problem for the permanent data base, but not for the peripheral devices.

Another problem over which we have more control but still cannot eliminate is map defects. Although it is well known that input quality is of paramount importance, ink problems persist -- particularly in line width and density. One solution is a change from ink to scribing, but the additional cost of map drawing may exceed the present loss caused by editing. Despite quality control problems with ink, tracing followed by scanning is less expensive than manual digitizing of the original copy, except on simple maps.

The bottleneck in a system will vary with the level of output. Our PDS 1010 scanning microdensitometer is accurate but slow -- 10 hours are required for a typical million-point scan. Its replacement is expected to accomplish this task in less than 10 minutes. This speed will permit repeated scans to find the best "slice" separating lines from background. The final selection can be made by a built-in minicomputer, resulting in savings in both computer time and manual-editing labor.

To date, we have relied on printout and occasional line plots for editing map data. A paper-saving alternative is the cathode ray tube (CRT). Of the many types, the storage-tube type of CRT appears most economical because it needs refreshing only at hourly intervals by a computer. Resolution is adequate for forest maps, and editing with a light pen should be quite rapid. The CRT editing approach has been used on a production basis for automated hydrographic charting (Graphic System Design and Applications Group 1972).

FUTURE PLANS

SPATIAL ANALYSIS

Until now the production orientation of WRIS has prevented the inclusion of capabilities that would provide new spatial information. Current measurement and analysis techniques simply consist of area calculations and map overlays. These dominant functions are expected to be enhanced by adding manipulative techniques ranging from simple tabulations to complex spatial analyses. For example, the occurrence of points in polygons has sampling applications. Calculations of distances between nodes in a network is basic information for a transportation analysis.

Logical operations, such as overlaying maps or sieving data, can be extended. Currently data for each township or quadrangle is processed independently of data for its neighbor. Overlaying and sieving operations across map borders is a logical next step.

The ability of a system to generate certain artifical shapes has found urban application (Tomlinson 1972). Bands or corridors at varying distances from roads aid logging and forest transportation analyses. Similarly, one can generate a circle about a point, such as a pulp mill site, and calculate the timberland area within it. Ground sampling within the circle will estimate the volume of wood in the "timbershed."

More advanced techniques of spatial analysis are seldom operational--presumably because of high computation cost. An exception is terrain data analysis in which elevations are used to compute slopes, aspects, and visibility between points (Sharpnack and Akin 1969), (Amidon and Elsner 1968), (Travis, Elsner, Iverson and Johnson 1975).

MINIATURIZATION

WRIS is characterized by bulky source maps, intermediate printouts, and final plots. The original map and a few copies for field annotation must be full-sized. All subsequent products are subject to miniaturization. Paper printout from the editing process may be eliminated by a CRT. Usually one final plot per map is enough. Map, table, and text copying for distribution accounts for nearly all the material subject to reduction.

Storage and handling cost of materials for distribution can be greatly minimized by microforms. Different forms include roll microfilm and microfiche (National Microfilm Assoc. 1973). Each form has a range of reductions. The most widely used are 20:1 (20X), 24X, 42X, and 48X. The best reduction factor for our needs is 24X and 48X, and microfiche appears to be the most desirable form.

Source maps or plots on plastic or paper will be photographically reduced. Text and tables can also be handled the same way, or the material written directly on film under computer control. This process, whereby paper is eliminated, is called computer-output-microfilm or COM (National Microfilm Assoc. 1974). Polygon acreages and administrative summaries will be reduced 24X or 48X onto 4- by 6-inch COM microfiche for distribution. Although the forms are generally regarded as office material, portable viewers are available for field use.

MAINTENANCE

Software is currently maintained for National Forest use on UNIVAC 1100 series computers. Conversion to the IBM 360 computer system is being carried out because it is widely available.

Two of our National Forest data bases need updating already. Currently our updating process is based on replacing information on a township basis. We can update by using logical operations and the usual editing techniques. But just replacing an entire map sheet is simpler.

More National Forests are communicating with central computers over data terminals. Acquisition of large, reliable data bases will soon lead to requests for interactive, conversational connections between the field and the regional data bank. The centralized batch-processing mode of data reduction will remain unaffected. The processed data will be deposited in a storage and retrieval system for access by all National Forests and maintained indefinitely.

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THE LAND USE MAP IN BRITISH LOCAL PLANNING

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The purpose of this paper is to present, in the brief span of time available to me, some thoughts on the role of the land use map in British local planning. The topic is a large one and I am unable to present all of the arguments and ideas so I shall concentrate on what I feel are some salient points. Cartographers, especially those in the field of computer assisted cartography, tend to be optimistic and many of them come close to resembling automated versions of the cartographic Billy Grahams mentioned by Professor Robinson this morning. The result often is a difficulty in clearly distinguishing *potential* from reality and to be constantly arguing on the basis of what *ought* to be rather than what *can* be in the light of existing circumstances. Julius Nyerere of Tanzania once said, "While others try to reach the moon we try to reach the villages" and I would suggest that there are analogies to this viewpoint in the field of cartography and that our optimism for the potential of our new mapping processes and techniques be tempered by a degree of *pragmatic realism*.

I am in the midst of a research project funded by the Department of the Environment in Britain. The Department of the Environment asked the Experimental Cartography Unit, now a research arm of the Natural Environment Research Council, to examine the current role of land use mapping in local planning in Britain with a view to determining if the automation of map production would lead to an improvement. I was asked, as an outsider, presumably not belonging to either the central government or local government, to be senior researcher in the project. The first stage of the project was a survey of 15 selected local authorities in Britain and this was completed over the course of the summer. Consequently the data which I am using as a basis for this paper are very recent indeed.

The main thrust of the arguments I am going to make today is that in the real world of local planning in Britain the land use map, despite our feelings as cartographers, is currently felt to be of very limited use. The reasons for this are:

- Land use maps are historical documents which are constantly outdated by changing situations.
- The amount of analysis possible from such maps is limited. The data on them are not quantifiable, at a time when planning is increasingly interested in quantities and statistical information.
- Maps of this type are expensive to prepare and reproduce.
- Such maps lack scale flexibility, and there are both problems and costs involved in setting a synoptic picture from the multiple large-scale sheets required to cover a county or district.
- The costs of a full scale base survey of land use are high.

The conceptual base and methods of map production will have to change. The map must become part of the overall management of information relating to land and, whether this information is managed by computer or by manual means, it is clear that the map is only peripheral at present. Like many cartographers, I see the advent of the digital map as giving us the potential technical tool to revolutionize land use mapping but, rather than concentrate on extolling the potential advantages that computer-aided cartography can bring like so many other speakers have done, I want to concentrate on some of the problems which must be overcome before that potential can be realized. My examples will be drawn from British local planning. I cannot cover all areas of concern but it is obvious that the problems fall into two main areas:

- The organizational and administrative, and
- The technical

Before proceeding further I think a little background information and definitions are in order. First, what is meant by local planning? British planning has always had a strong "control" element with effective control residing largely at the local level. Local government has recently been reorganized in a major way with structural changes coming into effect in England and Wales in 1974 and in Scotland in 1975. The main result of these changes has been the reduction in the number of authorities and a reducing of many boundaries. There has also been a change in the responsibilities of authorities. The situation in very simplistic terms is that there are a number of counties with a statutory responsibility for what are known as structure plans, and a number of districts within each county which have a statutory responsibility for local plans. I am using the term local planning to refer to both counties and districts. The district responsibilities are seen as the detailed application of broader planning strategies determined by the county councils. Consequently, the county structure plan would set the conceptual planning framework in which each district would implement district, topic or area plans. Planning permission involves consultation between county and district and although it is relatively easy to determine which topics are clearly county matters, such as highways, and which topics are clearly district matters, such as planning permission for household alterations, there is a large "grey" area where the responsibilities are much harder to define.

From the outset, and perhaps not surprisingly, the definition of land use and hence land use maps posed problems. Section 22(i) of the Town and County Planning Act suggests that the "control" definition would be largely related to, "...the carrying out of building, engineering, mining or other operations in, on, over or under land, or the making of any material change in the use of any buildings or other land." Thus "operations" or "uses of land" are stressed. (Here it is worth noting that local authorities have only very limited control over agricultural land. Planning permission is required only for farm houses not other buildings or uses.) It became obvious from the outset of our survey, however, that concentration on the control function alone would miss important issues relating to land use and land use mapping. The concept of physical planning to which the control type definition applies was seen by the local authorities only as part of the planning process, a means to an end rather than an end in itself. The process of land use "control" and land use "planning" was often seen as an inseparable part of a corporate planning process. A clear indication of this was given from the way several local authorities collected and stored information relating to land. Information both on the uses and the activities relating to an individual property were being recorded. Land use is therefore defined, or rather defined itself, both in terms of activities on the land and of the operational use of that land.

Earlier I suggested that if the map is to be useful then it must become part of the overall management of information relating to land and identified two broad problem areas to be overcome before this can be achieved, i.e., first in the organizational and administrative field and secondly, in the technical field.

Here I should like to re-emphasize a basic point which has been made many times before: information management cannot be separated from the overall management process. Consequently if the map is to become part of this process then both the technical problems and the conceptual and administrative problems will have to be overcome. If cartographers are to be user oriented then it is simply not good enough to concentrate only on technical and conceptual problems and to suggest as some do that we should limit our activities to that area only. In the field of land use mapping, if we use the analogy of the car designer that Arther Robinson brought up this morning, then perhaps our starting point should be the management system, the problems it faces, the resources it has and how the map can fit. From this a variety of possible technical solutions will emerge. We have enough examples of mapping systems being designed whose aggrieved originators claim are not welcomed or fully utilized by the user. The only person to blame for this is the designer. Cartographers tend to assume that the value of the map is so obvious that everyone within the local authority structures both realizes and accepts this. Our survey has revealed that for Britain this is simply not so. The level of "graphic awareness" varied enormously from authority to authority but, although there were bright spots, the level of awareness of the value of maps was low. There is clearly a need for more cartographic education and proselytizing.

It is perhaps ironic that it is the computer and statistically critical planners who will be the most difficult to convince. In none of the large computer-based information systems being built by local authorities in Britain has the map been integrated to any extent. Computer-aided cartography cannot be considered separately from the overall management of data by computer; the map should be seen as an integral part of the data system, not simply as an afterthought added on for cosmetic purposes, as tends to be the case at present. Those who have had so much difficulty themselves in having computer-based information systems accepted will in turn have to be convinced of the value of integrating the map into their systems. This is but one small part of the wider problem revealed in the presentations and discussions this morning between Robinson, Bachi, Jenks and Tobler, and the unanswered questions which remain.

In Britain, the first step in land use map design is an examination of the planning aims of the authorities concerned, the physical and human resources available to them, and the way in which information relating to land is managed. One might argue is this the cartographer's responsibility? Surely we should be given defined needs as perceived by the user and simply provide the technical expertise to meet these needs? My point is that if the cartographer does not start with the organizational and administrative milieux in which his product is to be used he may end up providing a virtually useless product. It is no use designing a beautiful and highly efficient Cadillac if all your users want is a 150 cc. Honda!

As time is short, very briefly more of the technical problems that arise are:

- Data collection and update
- Point, area and line segment systems
- Scale of unit -- where is the scale
- Etc.

TAX MAPS AND THEIR LAND USE IMPLICATIONS

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THE NATURE OF PROPERTY TAXATION

There remain almost 66,000 primarily local units of government in the United States which have the power to levy property taxes. They do so to such an extent that the yield from such taxes almost reached $51 billion for the 12 months ending with March of 1975, 1/ well past the $50 billion annual level for the first time. Most of the total consists of local taxes, still dominated by levies on property, primarily realty. In calendar 1974 property taxes accounted for 82.8 percent of total tax revenue of $58 billion 2/ collected by local governments. This is slightly lower than the corresponding proportion of 86 percent represented by $33 billion in local property taxes five years earlier, but in absolute terms the trend is still definitely upward.

What people pay as property taxes results from applying a tax rate, or combination of rates, to assessed values. Arriving at such values is the climactic third element in the public function known as assessing. The two rather crucial preliminary tasks are discovery and listing of the taxable property. In some countries the national government does the job as part of administering a net wealth tax. In the United States, assessors are still primarily local officials, though in recent years the States of Maryland and Montana have joined Hawaii in making the assessing function a State responsibility.

At any level, assessors are basically appraisers, their assignment being to estimate a value for each taxable property in the jurisdiction concerned as of a specified date, at the "highest and best use" of the property. "Highest and best use" is generally deemed the one most congenial to the site and thus likely to yield the optimum net return, actual or imputed, to the property owner. It is often the same as "zoned use" or "actual use" but need be neither. 3/

Assessing is considered done well if the values resulting from it are uniform, at the level prescribed in governing constitutional provisions and statutes. In one-third of the 50 States that prescribed level is "market value," or something with the same meaning. In the other States legal provisions specify one or more levels or relationships to market value for all or specified types of property. Though attained more frequently than in the past, the legal standards remain important goals in several places. The study of sales prices and assessed values for the 1972 Census of Governments produced, for single-family houses, median area assessment-sales price ratios more than 25 percent below the legal standard in 27 out of 37

Editor's Note: The views expressed are those of the author and do not necessarily represent those of the Bureau of the Census.

States. 4/ Uniformity evident at the de facto assessment levels actually existing is reflected in a median area coefficient of dispersion of 20.2 percent, for 1971. This means that any given assessed value in the county or other jurisdiction involved can be as much as 20 percent higher or lower than what the median relationship between assessed values and sales prices would indicate.

TAX MAPS AS PART OF THE ASSESSMENT PROCESS

Obviously an assessor is necessarily continuously interested in the parcels of realty situated within the jurisdiction -- where they are located, how they are used, how much they are worth, and what changes occur in any of such respects. As a natural consequence assessors as a group possess the most complete inventory of land parcels available in the United States. Taken together, and with due allowance for the many variations comprising so decentralized a whole, the entire assemblage of tax maps, parcel identification systems, and property information records in the care of assessors can be looked upon as America's locally autonomous fiscal cadastre, encompassing something more than 83 million taxable and 2 million exempt parcels. Tax maps (also called "assessment maps") and an associated parcel identification system are fundamental essentials conditioning assessment effectiveness. In many areas they have also become important reference elements in improvements achieved for other governmental functions such as deed or title registration, land use planning, zoning, and the siting of public facilities. Even property not taxed is affected, not only because assessors must gauge its influence, if any, on the taxable component, but also because exemption and tax immunity can be transitory, beginning or terminating in response to a change in ownership or use.

In the contemporary setting of public sensitivity to property taxation, influenced by an impatient technology and by disputes about its burdens and beneficiaries, tax maps are receiving comprehensive attention. New York State embarked on a program four years ago to promote standarization among tax maps existing in its local assessing jurisdictions, as part of a computer-assisted reassessment effort. In June of this year the Massachusetts Department of Corporations and Taxation recommended, to local boards of assessors in that State, certain guidelines for tax mapping. At the same time the assessment standards committee of the International Association of Assessing Officers is circulating among the IAAO membership a draft of recommended standards for maps to be used by assessors.

NATURE OF TAX MAPS

Because their basic purpose is to make possible the discovery, listing and valuation of taxable realty, tax maps necessarily show boundary lines, dimensions, and a unique identifier for each parcel. In its draft, the IAAO committee suggests that the basic record is a "map drawn to scale and delineated for lot lines or property lines, or both, with dimensions or areas, and identifying numbers, letters, or names for all delineated lots or parcels." Going further by way of a description from the California State Board of Equalization, the committee refers to the basic map as a "graphic description or picture of land. It shows the relative size and position of the land with respect to other properties, to roads, highways, and to major topographic features." 5/

The maps are actually parts of an identification system, interrelated via parcel identification so that those using it can find any given property and trace its history through any succession of changes in ownership and use.

As the Massachusetts guidelines make evident, modern day systems often include basic aerial photography and its associated photo indexes, ground control standards base manuscript maps, the tax maps themselves with associated planimetric and topographic maps, and also an index card file or similar component providing cross-referenced ownership information and parcel identification numbers.

Map sheet sizes and map scales are uniform within individual States. In Massachusetts the recommended sheet size is 24 inches by 36 inches. New York State uses sheets meansuring 30 inches by 42 inches. Maps scales are commonly set with regard to the density of settlement. In rural areas, for example, the scale may be one inch to 400 feet, or one inch to 200 feet. Semi-rural areas would have a scale of one inch to 100 feet, while in heavily populated places the scale would become one inch to 50 feet.

The maps naturally show the rights-of-way of roads and streets, highways, railroads, power and transmission lines. Also plotted are water and sewer easements, streams, lakes, and even ditches. Townships, range, and government lot numbers are also shown for areas included in the government survey.

USES OF TAX MAPS

As their nature implies, tax maps constitute the initial resource available to the assessor for accomplishing the discovery function. Unless all parcels in the jurisdiction are represented on the maps, there can be no assurance that all taxable realty will in fact be assessed and taxed.

Using the maps to discover property naturally leads to their use in valuation activity. The assessor's basic estimate of value, for any given property, is always in relation to estimates of value for all others. This is the essence of uniformity, a fundamental goal of assessing. Tax maps, together with associated records in the system, provide the means for an overall view of a block or neighborhood or entire city, and thus contribute to uniformity among resulting assessed values.

Because values are constantly subject to change, however, in response to or in spite of a change in ownership, or a change in the physical characteristics of the parcel, or a change in external circumstances affecting the parcel, tax maps are also subject to change and must reflect those which have mapping consequence. The assessor necessarily uses tax maps to keep abreast of change, hence maintaining them is essential to their usefulness.

The major uses mentioned above have given rise to a consensus among assessors to keep tax maps as simple as possible, restricting their data coverage largely to physical aspects cited. Many assessors, for example, omit house numbers, assessed values, and names of owners from tax maps, including such data on associated maps or records in the information system.

The same is true for land use information. The assessor is always aware of zoned, actual, and highest and best use of parcels, because the assessor necessarily considers such information in arriving at value. The linkage between tax maps and land use occurs via parcel identification, and the associated records in the system.

LAND USE IMPLICATIONS

Because tax maps are basic and complete, they lend themselves to integration with a comprehensive land data system sensitive to the needs of officials other than the assessors, and to needs of the general public. In some cities and counties today, planning and other officials already make effective use of tax maps or associated records in accomplishing specific objectives.

An added stimulus to all this, of course, is computer technology. Assessors in many places long ago mechanized assessment roll preparation, and at least 50 of their number have begun computer-assisted valuation for residential properties, via multiple regression analysis. Computerized mapping is being similarly explored, and in some instances, adapted to use. One example is Forsyth County, North Carolina, where it is hoped that a fully integrated land records information system will begin serving the public by April 1976. Mr. Cam Easton, the Tax Administrator, and Ms. Eunice Ayers, Register of Deeds, have cooperated from the outset on a system that will provide instant access to data in the assessor's and recorder's offices, the planning and zoning department, the building inspectors office, and other local departments. Census data, down to census tract coverage, can also be used with the system.

The assessor, of course, is most conscious of immediate responsibilities involved in the assessing function, just as other officials are of their own priority tasks. As land data systems become multi-purpose, therefore, in keeping with optimum use, the need for coordination, at all stages, can be expected to become more important.

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MULTI-DIMENSIONAL MAPS THROUGH DIGITAL IMAGE PROCESSING

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The synoptic, multispectral view of the Earth provided by LANDSAT images has proved extremely useful to geologists studying regional trends for small-scale geologic mapping. These digital images lend themselves to a wide variety of computer manipulation to improve their interpretability.

Application of digital image processing to geologic investigation requires a different approach than its application to most land-use problems. The distribution of geologic formations, rock and soil types, and surface structures is so complex that pattern recognition and automatic mapping routines rarely produce output useful to a geologist (Soderblom, 1975). The philosophical approach to these problems is therefore one of presenting the "cleanest" image possible to a human image interpreter, and displaying the largest amount of data possible in such a way that they can be visually discriminated in a single-image, multi-dimensional map.

The use of color in the presentation of multispectral data is a common way to increase the information content in an image. In a LANDSAT image different bands of the visible and infrared spectrum are routinely composited as color images. However, any set of data in which points are defined by their magnitude and coordinate positions can be treated as an image. The data set need not have been an image initially. Multiple data sets with overlapping coordinate positions but with magnitude variations between sets can be treated as multispectral images. Correlations between data sets can then be evaluated on the basis of color variations. For example, a wide variety of data was taken from Lunar orbit by remote sensing techniques during the Apollo program. These data are arranged in terms of latitude, longitude, and intensity and can therefore be placed in an image array, with intermediate positions filled by interpolation if necessary. Such parameters as gravitational variation, magnetic field intensity variation, and surface brightness in some given wavelength of visible light can therefore be presented as a single color image with each parameter considered to be a different spectral band of the image. Complex correlation patterns become readily visible by their color in such a presentation.

Some data, traditionally presented as contour maps, can be clarified by presenting them as images. For example, digital terrain data sets like those prepared by the Defense Mapping Agency consist of rows and columns of terrain elevations of 63-metre intervals. They can be displayed as images by computing the reflected brightness of each slope segment using an idealized illumination model (Batson, Edwards, and Eliason, 1975a). The image thus formed is a synthetic image of a three-dimensional model. Synthetic stereoscopic pairs can be generated by introducing parallax into such an image by displacing a picture element as a function of its value. The obvious application of this technique is in the shaded relief image discussed above. When an image with introduced parallax is viewed with an image without parallax a strong stereoscopic illusion is produced. When merged with a

LANDSAT image, a stereoscopic pair can be made that greatly enhances the interpretability of the scene (Batson, Edwards, and Eliason, 1975b). Although digital terrain data are the most obvious data type to which the relief and stereoscopic techniques can be applied any data that can be contoured can be presented, and commonly clarified, by this kind of presentation.

The digital processing algorithms used for this work are designed to operate very rapidly on small computer systems such as the DEC PDP 11/45. The time required to make a shaded relief image of a data set consisting of 1400 lines by 1800 samples (2.5×10^6 values) is about 30 minutes on such a machine. It commonly is economically feasible, therefore, to make a composite map displaying five parameters or dimensions (three in color, one in shaded relief, and one stereoscopically) through image processing methods.

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LAND ORIENTED WATER RESOURCES DATA SYSTEM IN NEW JERSEY

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INTRODUCTION

In choosing New Jersey for developing an environmentally oriented data bank system and for evaluating extreme surface flows in smaller areas, there were several considerations. It was felt that efficient environmental resources planning needs interdisciplinary data gathering concentrated in water interaction on the natural environment. To succeed in developing a model for a land-oriented water resources data bank, a region with a variety such as New Jersey seemed to be appropriate.

New Jersey is a State of contrasts in many respects. Not only is it one of the most densely populated regions of the world (400 persons per km^2 with an area of 20,295 km^2), sandwiched between two overpopulated metropolitan areas (New York City and Philadelphia), but 45% of its territory is still forest. The highly urbanized area has only two cities with a population over 100,000 inhabitants and accounts for 19% of the land. Some 27% of the region is agricultural with one of the highest per hectare dollar value for crops produced in the U.S. The transportation network, both highway and railroad, has the greatest traffic density in America. The chemical industry of New Jersey is one of the most developed in the U.S., however, its largest industry is still recreation related to the Atlantic Coast bathing beaches. The mineral industry, especially in dollar value of minerals produced per km^2 is within the top 16% of the U.S. Artificial and natural lakes, including swamps, occupy 9% of its surface and the territory of the State is bordered by fresh or salt water except in the north.1/

Geologically, 60% of the region is underlain by cretaceous or later sediments, which are primarily unconsolidated sands and gravels, including the area of the famous Pine Barrens Natural Park. Twenty percent of the State, the most densely populated part (over 10,000 persons per km^2) consists of triassic shale and sandstone with basalt flows or diabase intrusions. The remaining 20% of the region is underlain by precambrian crystallines and early or middle paleozoic limestones and shales.

Editor's Note: In this paper the author updates his article, "Water Resources Data Bank in New Jersey and Computations of Extreme Flows" which appeared in G. C. Vansteenkiste, Modeling and Simulation of Water Resources Systems, North Holland Publishing Company, 1975.

The climate of the area is moderate with an average rainfall of 1200 mm/year. Periodically, severe droughts occur such as in the years 1961-1966 with an average rainfall of 800 mm/year. The extreme point rainfall intensity for 24 hours reaches 250 mm value in many parts of the State with a 2-5 years frequency. The northern half is characteristic for moderately high mountains (up to 600 m). On the other hand, the southern half is flat with less than 70 m above sea level. The whole area can be characterized as one of smaller rivers with a watershed less than 250 km^2 (except Delaware, Passaic and Raritan Rivers) and with many natural and artificial lakes. The evapo-transpiration and interception average 450-55- mm from the annual precipitation. The ground water availability indicator has a value from 0 to 450 mm yearly, depending on the permeability and storage capacity of the geological formations in accordance with the yearly precipitation.2/

Finally, the last but never the least reason in selecting the area for developing the data bank was the fine cooperation of the N.J. Bureau of Geology and Topography with the Columbia University Seminars on Water Resources by making available over 90,000 well records and other valuable land use, demographic, geologic and surface-flow data, and by materially supporting the whole project. Furthermore, the N.J. Department of Community Affairs helped to develop the program as it will be described in "The Technique of the Data Bank."

BASIC PHILOSOPHY IN DATA COLLECTING

Environmental data collecting reflects the interaction of water on the natural environment. The inventory of natural resources is gathered from the viewpoint of their utilization by man. Since water and its quantity and quality are of utmost importance to life, the data bank is water resources oriented. It should give basic information about water quantity and quality in connection with surface streams including extreme values and ground water storage capacity based on permeability of the geologic subsurface. A climatic description of the area as primary source for water is also needed. Inasmuch as land use development is the source of demand for water, both for consumption and for treatment, it is necessary to identify current water distribution, sewage systems, treatment and polluting activities (point and area pollution). As additional information, an inventory of other natural resources -- including geologic survey, land use, geographic description, together with areas utilized for transportation, historic sites and public spaces -- is essential.

Man being in the center of any evaluation of the environment, updated demographic data are also an important part of the data bank. Demographic information, based on the latest census, gives area density, concentration of the population within each community, and each community boundary.

Finally, data collecting and its importance is governed not only by demographic and water resources information, but also by real estate values in land use. Taxation is an excellent indicator for defining the grade of importance of the area in question. Therefore, data from tax maps and locally maintained information, after being evaluated and computerized, should also be incorporated as part of the data bank.3/ Tax considerations lead to the conclusion that the smallest land use unit for the data bank may cover 3 hectares in settled areas and 12 hectares outside the community. Later, it was decided that 4 hectares (10 acres) should be the smallest cell of information, using 1:63 360 scale basic topographic maps for graphical consideration.

The itemized information of the data bank may be stored by computer, by MTST (magnetic tape/selectric typewriter), or by whichever method best fits the character of the gathered data. The advantages and disadvantages in the case of the New Jersey data bank will be discussed later.

AVAILABLE WATER AND EXTREME SURFACE FLOW VALUES

The most important part of an environmentally oriented data bank is the water resources inventory and the computation of the available water with its average and extreme values, including the ground water capacity of the area.

The various sophisticated methods such as those of unit hydrographs, flood frequency, log Pearson Type III curves, etc., give excellent values for larger areas. It is generally accepted that the available data can be interpreted with a workable accuracy only for a time no longer than twice that of the period of observation. This means that for computation of 100 year extreme flow it is necessary to have at least 50 year observations, which may be available for larger rivers in many regions but almost non-existent for smaller streams. The need for data on peak and lowest flow occurs at random and in emergency conditions; therefore, there are no collected data nor is there time to collect data for longer periods.4/ Since these methods are based on probability, the curves at their lowest and peak value are less reliable. Extending the curves and forecast extreme values for periods twice as long as the observation can give already a ±20-30% error. Further extension of any forecast makes the computations highly unreliable as estimates in regional planning. On the other hand, regardless of the size of the watershed, these methods give excellent average flow values for streams for which there is a shorter observation period or no data, but where conditions are similar to those of known and recorded watersheds. Analogous difficulties can occur with surface flow formulas using too many parameters. In general, they are based on probability computations and so the errors and deviations accumulate.

Despite these shortcomings, it can be efficiently evaluated and utilized with the help of local geologic survey and meteorologic conditions data, establishing correlation and similarities between permeability of the geologic subsurface and extreme values of the meteorologic records on one side, and the extreme flows from smaller watersheds with an area of less than 250 km^2 on the other side. For watersheds over 250 km^2 in area, the geologic and meteorologic conditions have less effect on extreme flows except in regions, such as certain areas of Australia, Midwestern United States, Soviet Union, etc., where greater uniformity of these factors prevail.

The approach in New Jersey utilized over 90,000 well records and 101 selected stream gaging station statistics gathered in the period 1945-1974 for the wells and 1882-1974 for the streams. Furthermore, historical flood data and point rainfall intensity observations for the period 1825-1882 were also taken into consideration.

The developed formula of peak runoff has the following pattern:[6]

$$Q = (P_1 . P_2).(i_1 . i_2).A^{-e}.(C_v . C_e)$$

where

Q = peak runoff in $m^3/sec. km^2$
C = coefficient which varies from 0.5 to 147 according to geologic and climatologic conditions (coefficients for vegetative cover and concentration of the watershed not included)
A = area of watershed in km^2
C = configuration of terrain (geographic region and slope characteristic): 0.32 for plains up to 0.5 for Alpine type mountains
P_1 = permeability factor of the soil and of the geologic subsurface with a value from 1.0 to 18.5
P_2 = urbanization factor, from 1.0 to 14.0, in accordance with the impervious land use and permeability of the geologic subsurface
i_1 = 24 hrs. point rainfall intensity, from 0.5 to 2.0 (0.5 for 35 mm/day; 1.0 for 125 mm/day; 2.0 for 250 mm/day)
i_2 = storm characteristics, from 1.0 to 4.1 (depending on the size and pattern of the extreme storms and on the wind velocity)
C_v = coefficient of vegetative cover, from 0.95 to 1.05 (from 40% to 70% watershed area covered by forest)
C_c = concentration coefficient, from 0.90 to 1.05 (0.90 for elongated shape or at least 1.5; 0.95 for horseshoe-shaped and 1.05 for fan-shaped watersheds)

For lowest runoff (50 years?) a similar formula based on the 1961-1966 drought in New Jersey was developed as follows:

$$Q = C.A^{-e}$$

where

Q = lowest runoff (50 years?) value in $1/sec. km^2$
C = coefficient depending on the geological subsurface from 0 to 5.75
e = 0.065 [7]

The validity of this approach was confirmed by observation for watersheds up to 100 km^2 in area. If the catch basins have an area of over 100 km^2, this computation method is not recommended because of a complexity of factors influencing the lowest flow.[8]

Based on the above principles, the surface runoff extreme values were computed and the results, organized by hydrogeologic regions, were put in the data bank with a value of an area of one square mile. As a by-product of this method, the ground water capacity of the various hydrogeologic areas was also established.

TECHNIQUE OF THE DATA BANK

Based on the outlined principles, the Bureau of the Statewide Planning of the N.J. Department of Community Affairs, and the Bureau of Geology and Topography of the N.J. Department of Environmental Protection, with the help of the Columbia University Seminars on Pollution and Water Resources, developed a data bank system in two general parts; data were recorded from many sources and files.

The information system was originally conceived for the purpose of developing a system capable of continuous revision which would permit the quick assembly of data relative to land use planning. With the cooperation and assistance of the Department of Community Affairs and the Bureau of Geology and Topography, there has been developed a system of land use, regional, geologic, geographic, and environmental maps and fact sheets covering the entire State of New Jersey. The aspects of the system consist of four group items:

The first part:

- Computerized land use data based on real estate values (because of insufficient funds not yet available)

The second part:
(in operation)

- Atlas Sheet Descriptions - Bulletin #74, Geologic and Geographic Factors and References - N.J. Information System
- Block Descriptions - An MTST (magnetic tape/selectric typewriter) printout of 16 environmental factors specifically identified with the above maps
- Block Maps - A series of maps covering about 88 km^2 (34 square miles) each or 6' latitude and longitude based on the rectangular coordinates in use by many agencies for filing purposes since 1890
- Geodetic monuments, aerial photo coverage, map collection since 1855, and publications of the Bureau of Geology and Topography

Real estate values, detailed land use and similar data are assembled from tax maps and from information maintained locally or by the appropriate County Board of Taxation assisted by the Bureau of Local Property Tax, Department of Treasury. This information is computerized by the Bureau of Statewide Planning, Department of Community Affairs, which uses the State Plane Coordinate System for the location of the centroid of properties. The Plane Coordinate System is a legally accepted system for designating property corners with $\underline{x}$ and $\underline{y}$ values in feet. The origin is a point ESE of Cape May at 74° 40 min. West Longitude and 38° 50 min. North Latitude with $\underline{x}$ = 1 000 000 and $\underline{y}$ = 0.

This coordinate system is shown on the Federal USGS 7.5 min., Quadrangle Maps. Origin was selected for easy handling and to always have positive values.

The part of the system covering physical parameters of the environment such as geology, topography, drainage basins, water and other resources, together with the specific types of land use such as historic sites or sanitary landfills, is based on the long standing Rectangular Coordinate System. The (17) State Atlas Sheets are the base for the system with the map number being the first two digits of a seven-digit number. There is a uniform rectangular grid for each Atlas Sheet consisting of (25) blocks, most of which are 6 min. of latitude by 6 min. of longitude. Each full block (designated by the third and fourth digits) covers an area of approximately 88.0 km^2 (34 square miles) and only 228 maps, based on the block, are required to cover the entire State. Each block is divided into (9) rectangles of 2 min. of latitude and longitude (the fifth digit) which can then be again divided in a similar manner into (9) squares (6th digit); and finally into (9) units each of which is 30 acres or 0.12 km^2 (7th digit).

A computer program successfully developed which will permit the regional data of the Rectangular Coordinate System to be further subdivided, by using additional digits, into a unit of approximately 0.013 km^2 (3.3 acres), or by further subdivision to 0.0014 km^2 (0.36 acres). The Department of Community Affairs found it most convenient when using tax data to determine the $\underline{x}$ and $\underline{y}$ coordinates of the centroid of the tax units for use in a computer program. Conversion from $\underline{x}$ and $\underline{y}$ coordinates to the appropriate block number under the Rectangular Coordinate System, or vice versa, is easily done on the computer. Thus the two systems of data presentation are compatible.

Furthermore, there have been prepared from the tax data base so-called "Quickmaps" of land use with a 7-acre unit. This is the smallest area that can be shown with a distinct symbol under the present program developed for Passaic Township, which covers 32.4 km^2 (12.5 sq. mi.) and has some 6,000 tax parcels. Identification of locations using the Plane Coordinate System is, of course, easy because it is a Cartesian Coordinate System referenced on the USGS Maps of New Jersey. The development of larger grids is easily accomplished.

The Rectangular Coordinate System, used for the State Atlas Sheets, is confusing at first but, as indicated above, can be used to locate a specific area by extending the normal 7-digit reference number to the 8th and 9th digits. For the purpose of the data bank, however, only 4 digits are required to produce maps covering the 88 km^2 (34 square mile) area of the block. To assist in converting to other coordinate systems, each block map has the latitude and longitude and the $\underline{x}$ and $\underline{y}$ coordinates given for the lower left-hand corner of the block. Since the New Jersey State Atlas Sheets are based on a scale of 1 mile to the inch (1:63360), a mechanic's rule can be used to measure distances in feet to within about 61 m (200 feet) of the actual location on the ground.

The data bank, based on the State Atlas Sheets, has developed into four parts:

- General information about the Atlas Sheet area given as a descriptive tabulation with a uniform format (printed in book form) containing such information as extreme surface flow, ground water capacity and recommended lot size for domestic well and septic tank, etc.

- Block descriptive material including some of the specific items from the Atlas Sheet summary, but giving data which apply specifically to the 88 km^2 (34 square mile) area of the block (stored on tape, each block individually)
- Block maps (the series, which is to be expanded to between ten and twenty multi-parameter maps as data becomes available, consists of six maps: population, water supply, sewage and sanitary landfills, drainage basins, land use, and geology with well records -- on microfilm)
- Geodetic monuments' description, aerial photo coverage 1:24 000 from 1961 and 1972, together with map collections covering the entire State from 1855 to 1975 (in easily reproducible form on polyester film, photo, overlay map or map form)

The system is supplemented by base maps and Atlas Sheet overlays. It is possible to revise or enlarge the amount of material provided for the Atlas Sheet or blocks by transferring the existing tape information and the additions or corrections to a new tape. Map changes for each block can readily be accomplished by changing the microfilm in the appropriate Atlas Sheet microfilm jacket. Given the 4-digit reference of the system, maps and descriptions can normally be recovered within minutes.

There were many changes as the work progressed from the initial concept. The general information about the Atlas Sheets was originally planned for issuance through the MTST (magnetic tape/selectric typewriter) as needed. The information contained on these Atlas Sheet descriptive summaries has proved to be of such general interest that it is now proposed to print a source book of environmental parameters which will include the Atlas Sheet descriptions for all 17 sheets with key maps to show counties and municipalities described within the Atlas and the block references needed for more detailed information.

There was much discussion as to whether the block maps should show only a single environmental factor. Experimentation suggests that it would be desirable to go ahead with the four basic maps with multiple parameters on some and complete the coverage in these four areas for the entire State before going on to other equally desirable block maps.

The population map at present shows not only the municipal boundaries, the average population density for the municipality, and the percentage of the municipality in the block being considered, but also shows the main highways and urbanized areas where the population density is over 1,000 inhabitants per square mile (or 2.59 km^2).

The water supply map shows service areas for water by company with the political boundaries of the municipalities. Also indicated are the major water supply lines and surface water intake points. Because of clutter on this map, the major water wells have been placed on the geologic map.

Sewage maps indicate the public and semi-public sewage systems and sanitary landfills and show the areas served by each sewage company, their main trunk lines, sewage treatment plants including capacity, and used or abandoned sanitary landfill areas.

The drainage basin maps show the actual streams as shown on the Atlas Sheets or the so-called County Stream Maps. The drainage divides, as shown on the Drainage Basin Map of New Jersey overlay, are also indicated. Flood-plain delineation, stream flow information, points of diversion, and points of potential pollution may be indicated on these maps in the future.

Land use maps are based on 1972 aerial photo (1:24 000) and 1973 EROS Image Space Photos (altitude 250 miles) evaluation, and their classification complies with USGS Circular 671 (1972): B. Anderson, "A Land Use Classification System for Use with Remote-Sensor Data" and with USGS Land Use Data Analysis (LUDA).

The geologic map has been assembled from the most recent data and may, from time to time, be modified to give additional information. The characteristic industrial public supply and other wells from 90,000 well records assembled in 1945-1973, are shown; from these logs geologic cross-sections may be constructed.

The State Archaeological Society is ready for the preparation of maps showing archaeological and historical sites, including for the former, sites which have not yet been published. A method of flagging the block map, so that such an unpublished archaeological site will not be endangered by construction, has been developed. It may be that this map will include other items connected with the general interest in our heritage and history.

A transportation routes block map has been investigated and samples prepared. Other areas would include public utilities, airport locations, and Federal, State, county and municipally owned lands for recreation or other purposes. A map series prepared for any particular activity will require only 228 block maps. Where there is only a limited number of blocks needed to show sites for a particular activity, reference to the appropriate special block maps could be included within the Atlas Sheet descriptive material or prepared as a special listing.

It is believed that the work completed so far indicates that the data bank is compatible with other land use or water resources data systems, makes the maximum use of available files in various State agencies, is flexible enough to permit retrieval from many different points of view, and is capable of quick and easy expansion whenever the need arises. The material prepared for the data bank is a necessary first step for any computer program which may be developed for this type of information especially when it includes a larger than 20,000 sq. mi. (or 50,000 km^2) area. Similar considerations must be given in case that a wealth of point-type information is available.

DESCRIPTION OF THE LAND ORIENTED RESOURCES DATA SYSTEM IN NEW JERSEY (LOIS-LAND ORIENTED INFORMATION SYSTEM AND LORD-LAND ORIENTED REFERENCE DATA)

The material presented here is mainly part of the Water Resources and Land Oriented Information System which is based on the New Jersey Bureau of Geology and Topography Topographic Atlas Sheet Rectangular Coordinated System. A diagram showing the use of the system is included. The maps and narrative data are filed by the Atlas Sheet and block number, or the first four digits of the Rectangular Coordinate (the first two steps in the diagram). The total area of an Atlas Sheet is about 800 square miles (2,072 km^2); of the reference block about 34 square miles (88 km^2); of a unit (7th digit designation) about 1/4 x 3/16 of a mile or about 30 acres (0.12 km^2). Each full block covers six minutes of latitude and longitude as compares to the 7.5 minute USGS Topographic Quadrangle Map. For convenience, the two minute wide strip, the right edge of each Atlas Sheet (05, 15, etc.), is included with the blocks immediately to the left (04, 14, etc.).

As of September 1975 there are six available maps for blocks of sheets 21 through 37 microfilm printouts.

The six maps provided are Geology, Drainage, Water Supply, Sewage and Sanitary Landfills, Land Use and Population. On the Geologic Map the location of major industrial water wells is indicated. On the lower right of the Drainage Maps you will find the name of the 7.5 minute USGS Quadrangle Map or maps which cover the area of the block. The Water Supply Map shows municipal boundaries for orientation, the service area for water supply, water intakes, major water distribution mains, reservoirs. The Sewage and Sanitary Landfill Map indicates the sewage service areas, sewage treatment plants, main trunk lines and sanitary landfills. The Land Use Map gives classifications for various land uses. The Population Map shows the average population density of the municipality and the percent of the municipality shown within the block with urbanized areas (1,000 inhabitants per square mile) and main highways.

Narrative data on the MTST printouts are provided: a) for items which pertain to or explain conditions within the entire Atlas Sheet, and b) information about items which are found on a particular rectangular coordinate block.

A legend sheet indicating the symbols and significance of terms used on the six maps is available. For the Geologic Map, depending on the complexity of the geology of the area, there are one or two pages of legend explaining the geologic symbols and rock formation designation letters.

A complete sample of the data bank pertaining to Phillipsburg Town (block #24-21) is provided below. The following pages show examples of the six maps, as well as a map of atlas sheets of New Jersey, a diagram showing the use of the rectangular coordinate system, and community boundries of Atlas Sheet #24.

BLOCK #24-21

A. Bloomsbury, Easton

B. Delaware River-Lopatcong Creek, Musconetcong, Pohatcong

C. 1. Phillipsburg - Non-recording temperature and precipitation gauges

2.

Map No.	Location	Period of Record
153	Delaware River at Easton, Pa.	1967-
155	Lopatcong Creek at Lower Harmony	7/9/45
156	Lopatcong Creek near Stewartsville	7/9/45
157	Merrill Brook at Ingersoll-Rand Dam, Phillipsburg	7/9/45

BLOCK #24-21 (continued)

3.	153	Delaware River at Easton, Pa.	1947-1951,1957-1960, 1963-1964, 1967-
	346	Delaware River, Phillipsburg-Easton Bridge (free bridge)	1965-
	351	Lopatcong Creek at Phillipsburg (Alt. 22 Bridge)	1964-

Water Quality Standards: (explained in Atlas Sheet description) FW2

D. Kittatinny Limestone (θok), Jacksonburg Limestone-"Cement Rock" member (Ojr), Epler Formation (Oe), Rickenback Limestone (Or), Allentown Formation (θa), Leithsville Formation (θl)

E. 1. Physiographic Province: Appalachian Valley and Ridge
Subdivision: Kittatinny Valley
Major Topographic Features: Kittatinny Valley
Elevations (ft. above sea level): ridges 400, valleys 150
Relief (ft.): 250

Physiographic Province: New England (Reading Prong)
Subdivision: N.J. Highlands
Major Topographic Features: Scotts Mountain, Pohatcong Valley
Elevations (ft. above sea level): ridges 1100, valleys 150
Relief (ft.): 950

2. a. Normal Year: 47"
Dry Year: 35"
Wet Year: 61"

b. January: 30° F
July: 74° F

c. 226 days. Last killing frost: 4/25; first killing frost: 10/15

3. Not available as of 12/74.

F. State, County Owned Land and Major Semi-public Areas
Div. of Parks and Forestry - Delaware River Recreation and Access Areas
Lopatcong Water Company - Private Watershed
Peoples Water Company - Private Watershed

G. Water Well Records

Location	Owner	Year Drilled	Screen Setting or Depth of Casing	Total Depth	g/m Yield	Formation
24-21-172	Peoples Water Company	1966	23	65	3,000	Qed
24-21-172	"	1967	58	82	3,500	"
24-21-172	"	1967	46	66	3,000	"
24-21-173	Steckle Concrete Company	1967	128	188	75	"

. . . .

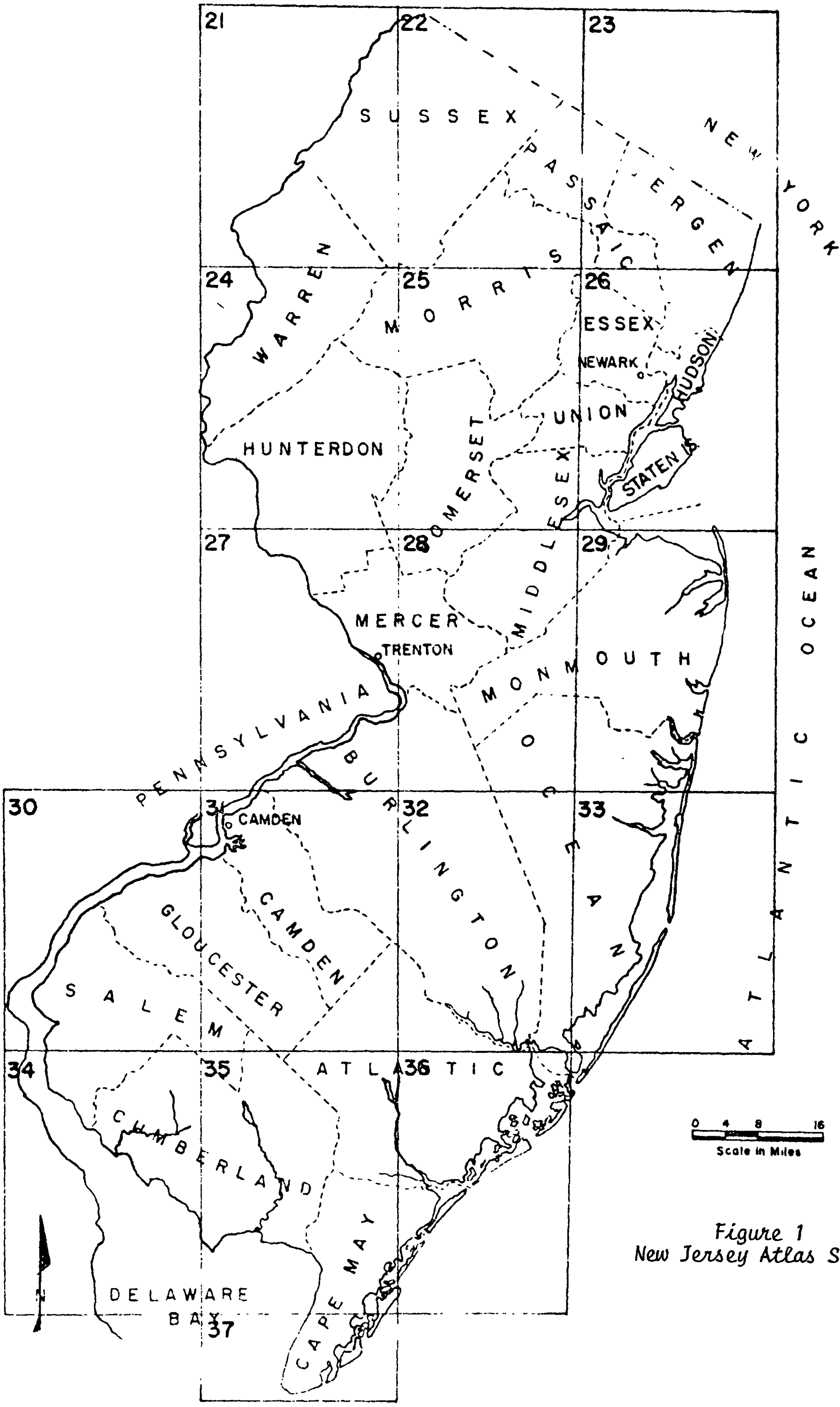


Figure 1
New Jersey Atlas Sheets

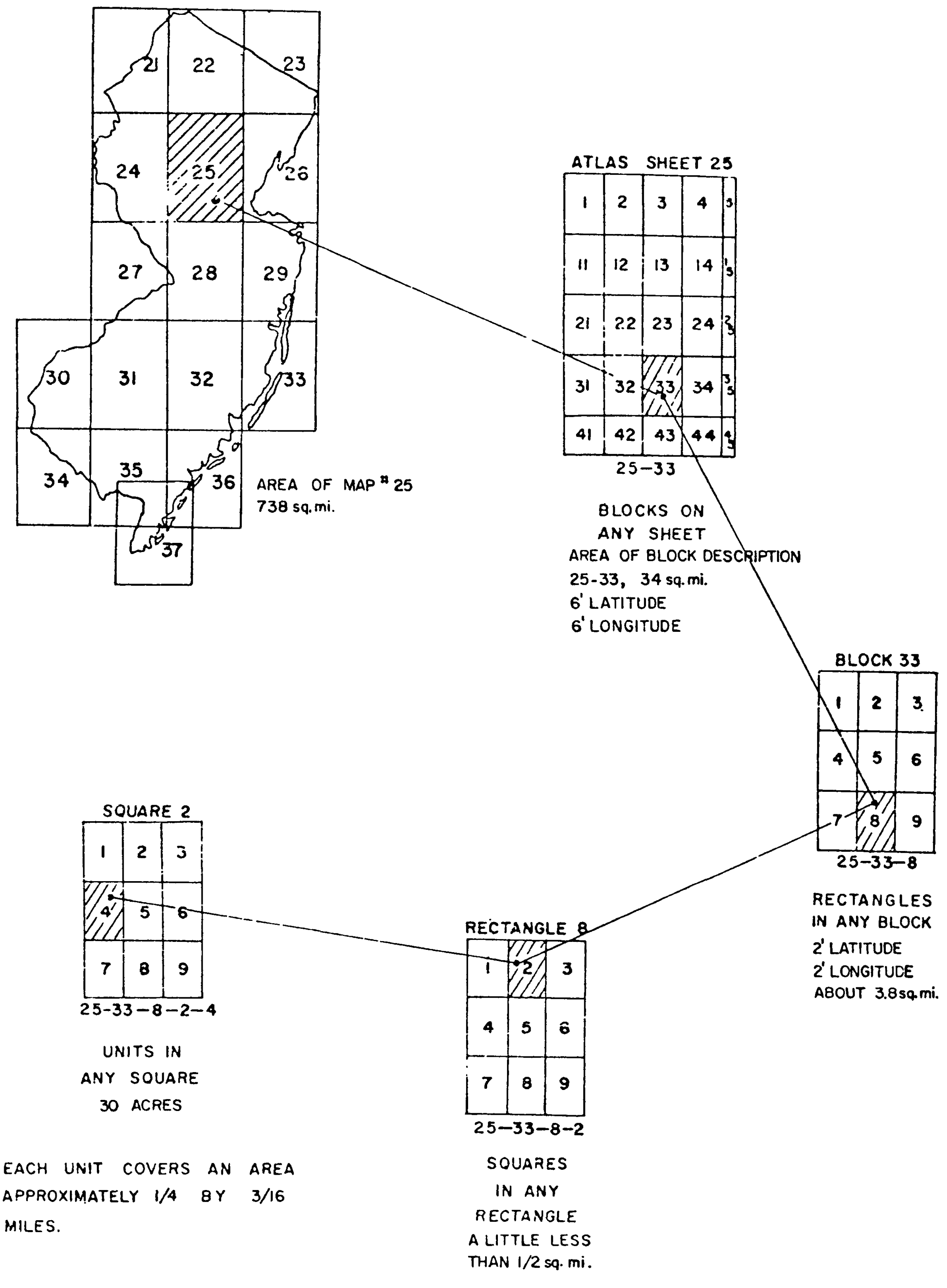


Figure 2. Diagram showing use of New Jersey rectangular coordinate system. To locate a facility at 25-33-8-2-4

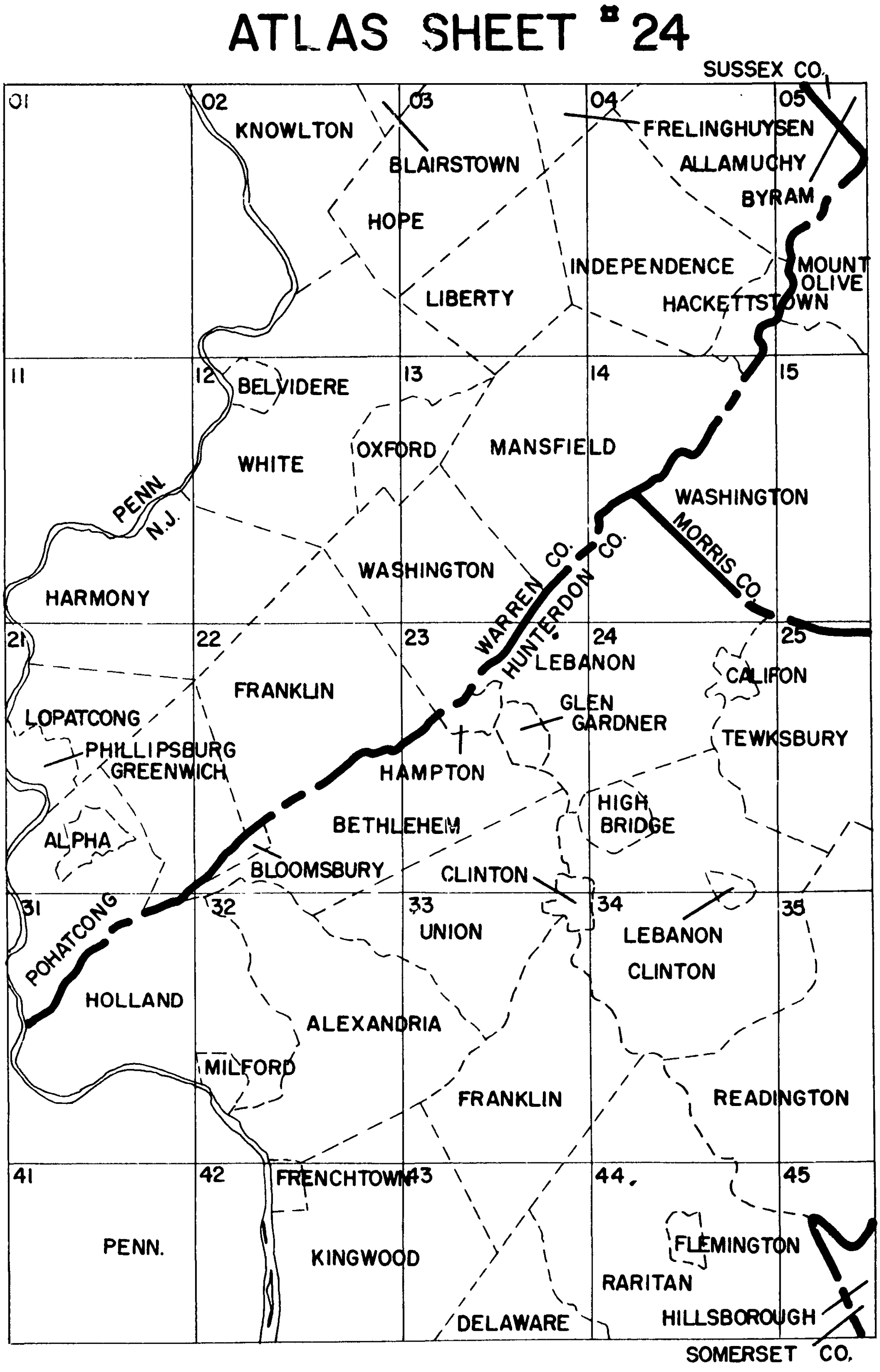
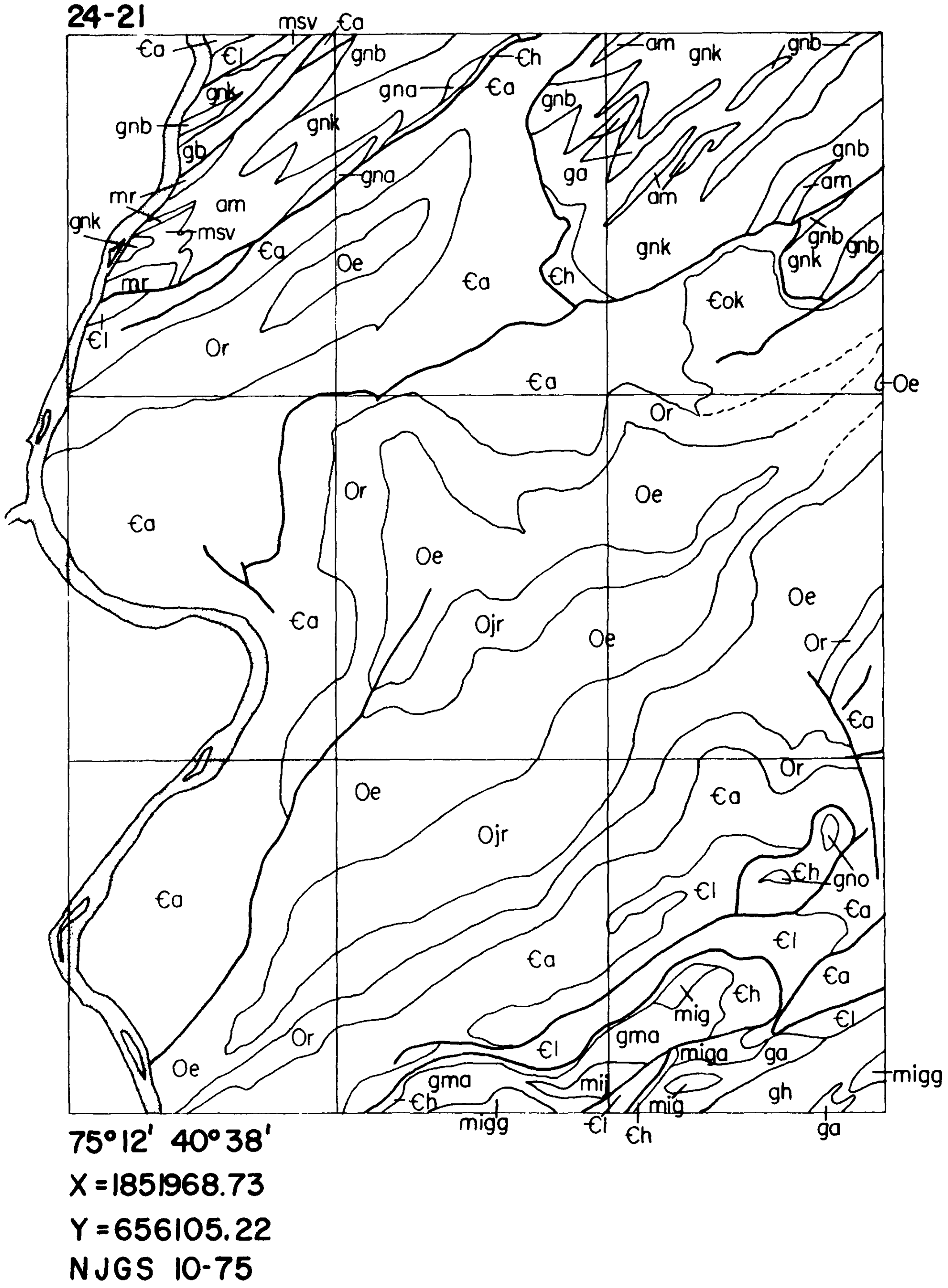


Figure 3. Community boundaries of Atlas sheet #24

Figure 4
Geological Map



EDITOR'S NOTE: Due to space restrictions, a listing of map legends has not been included.

Figure 5
Drainage Basin Map

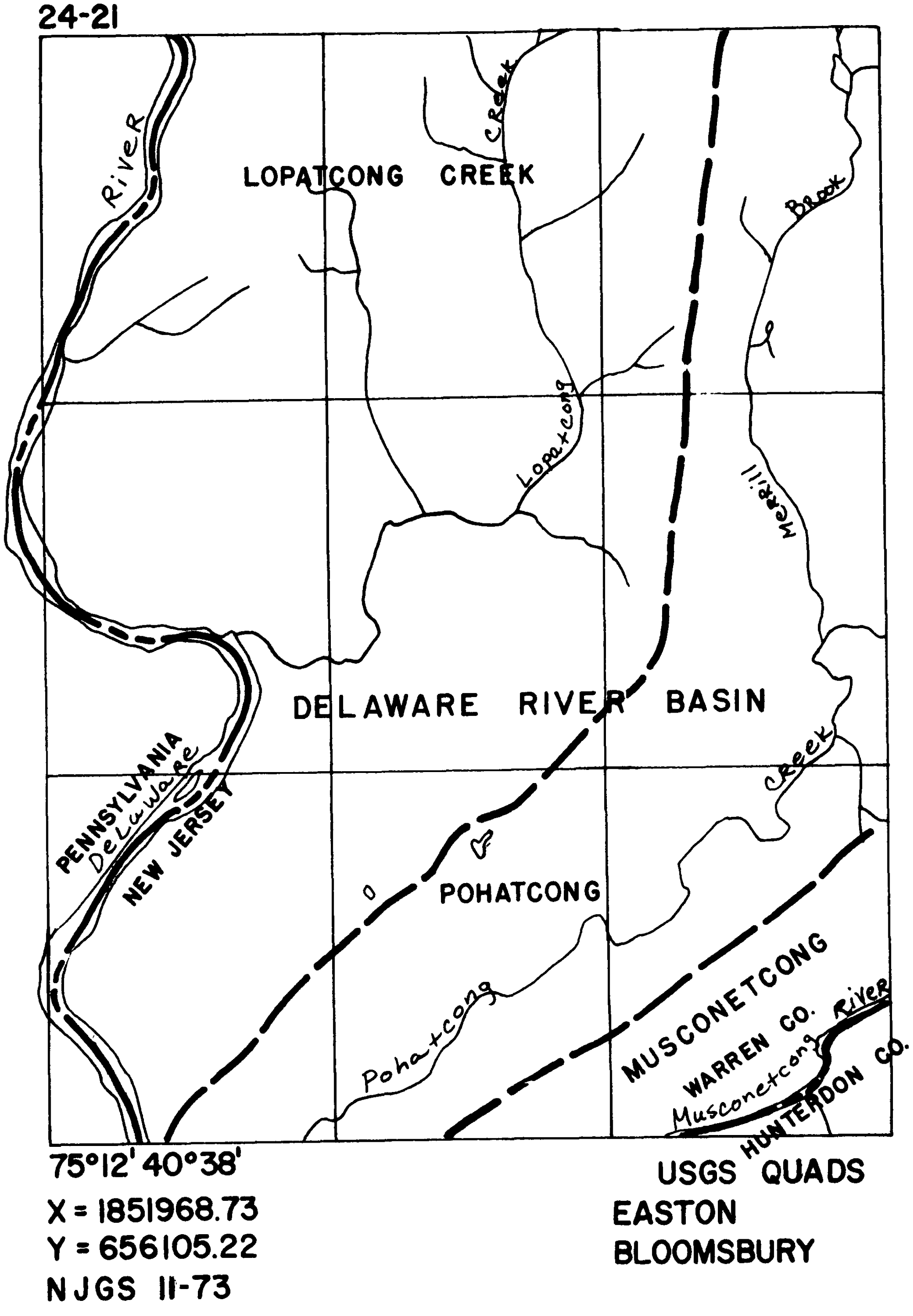


Figure 6
Water Supply Map

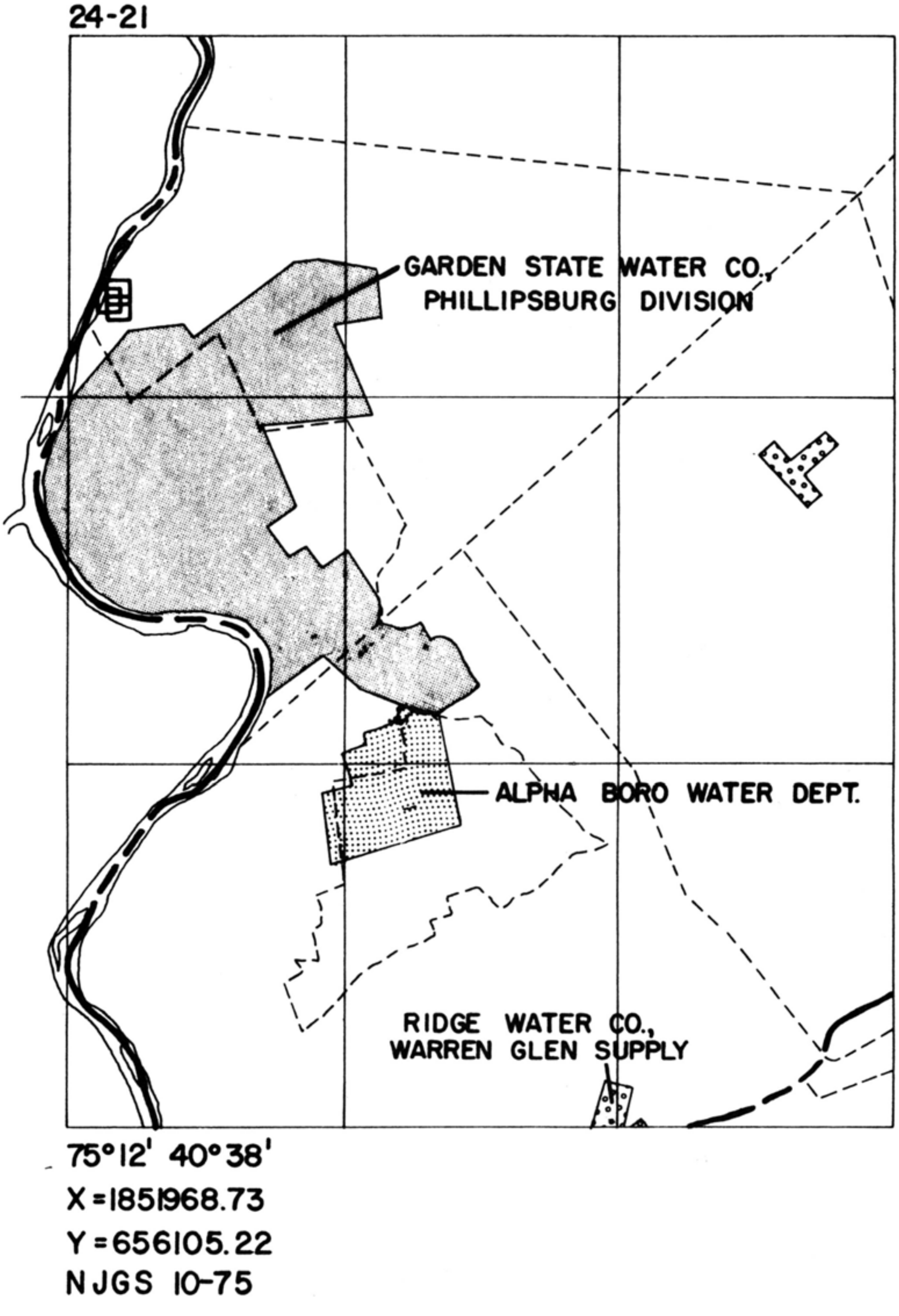


Figure 7
Sewage, Landfill Map

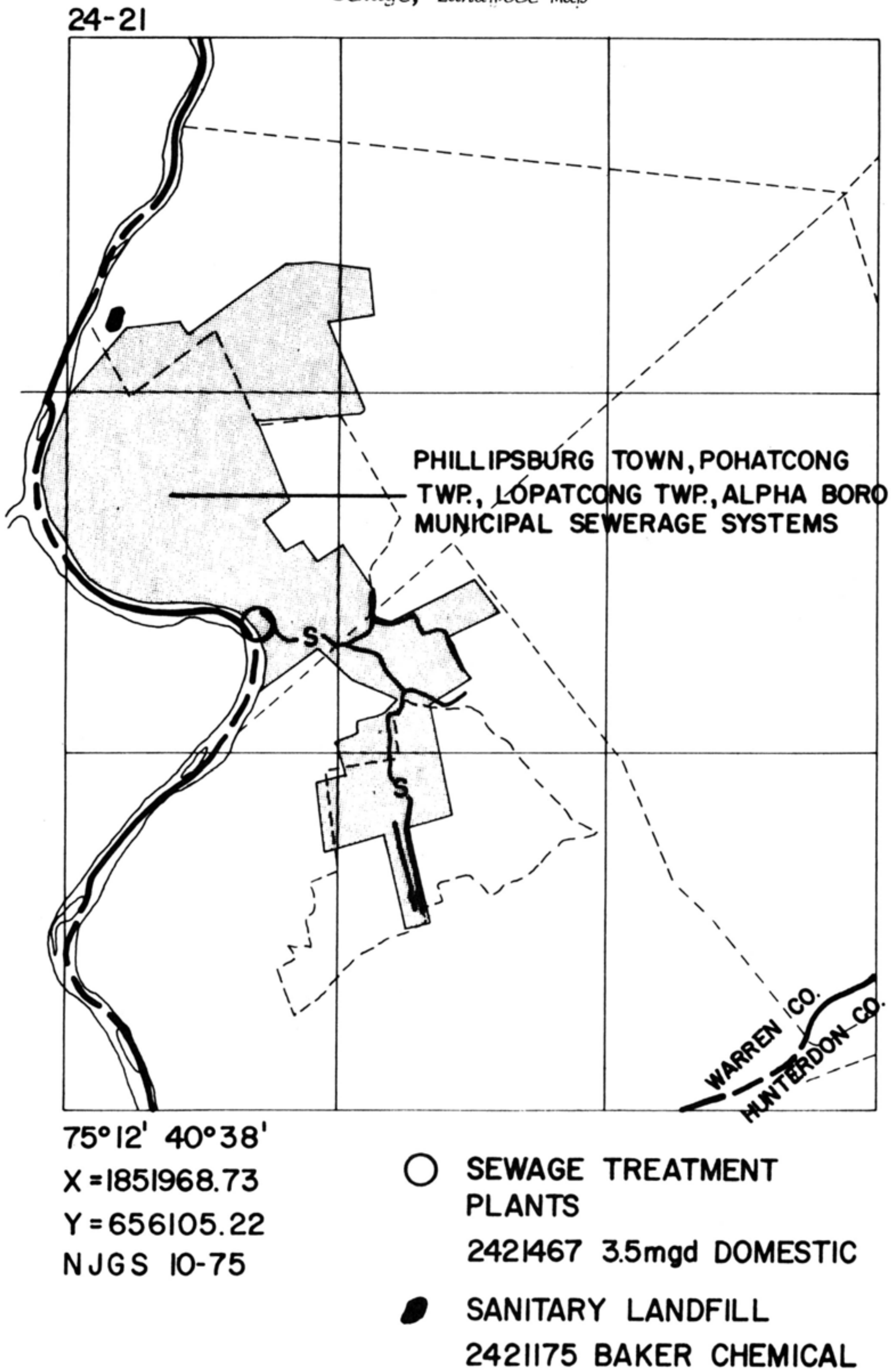


Figure 8
Land Use Map

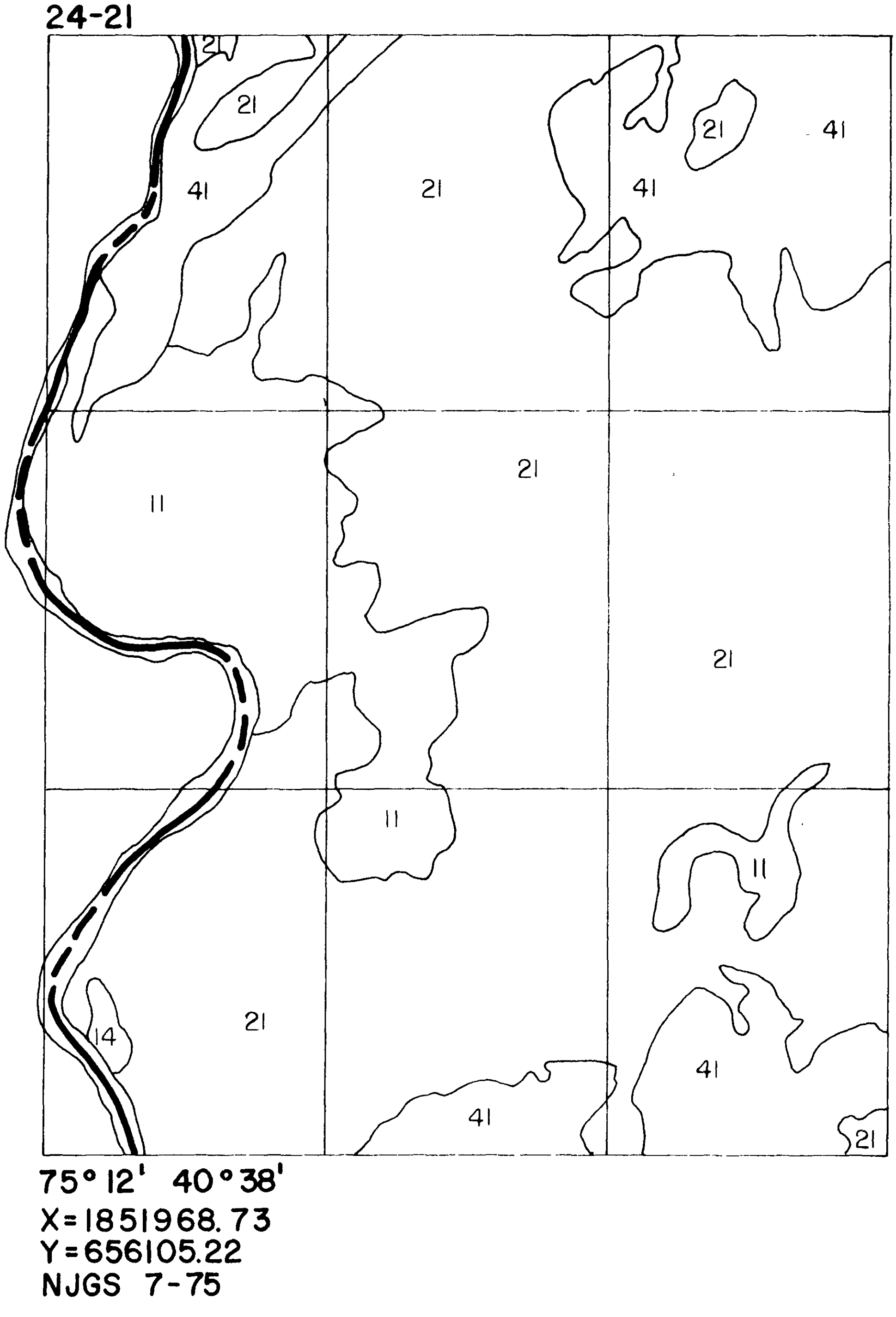
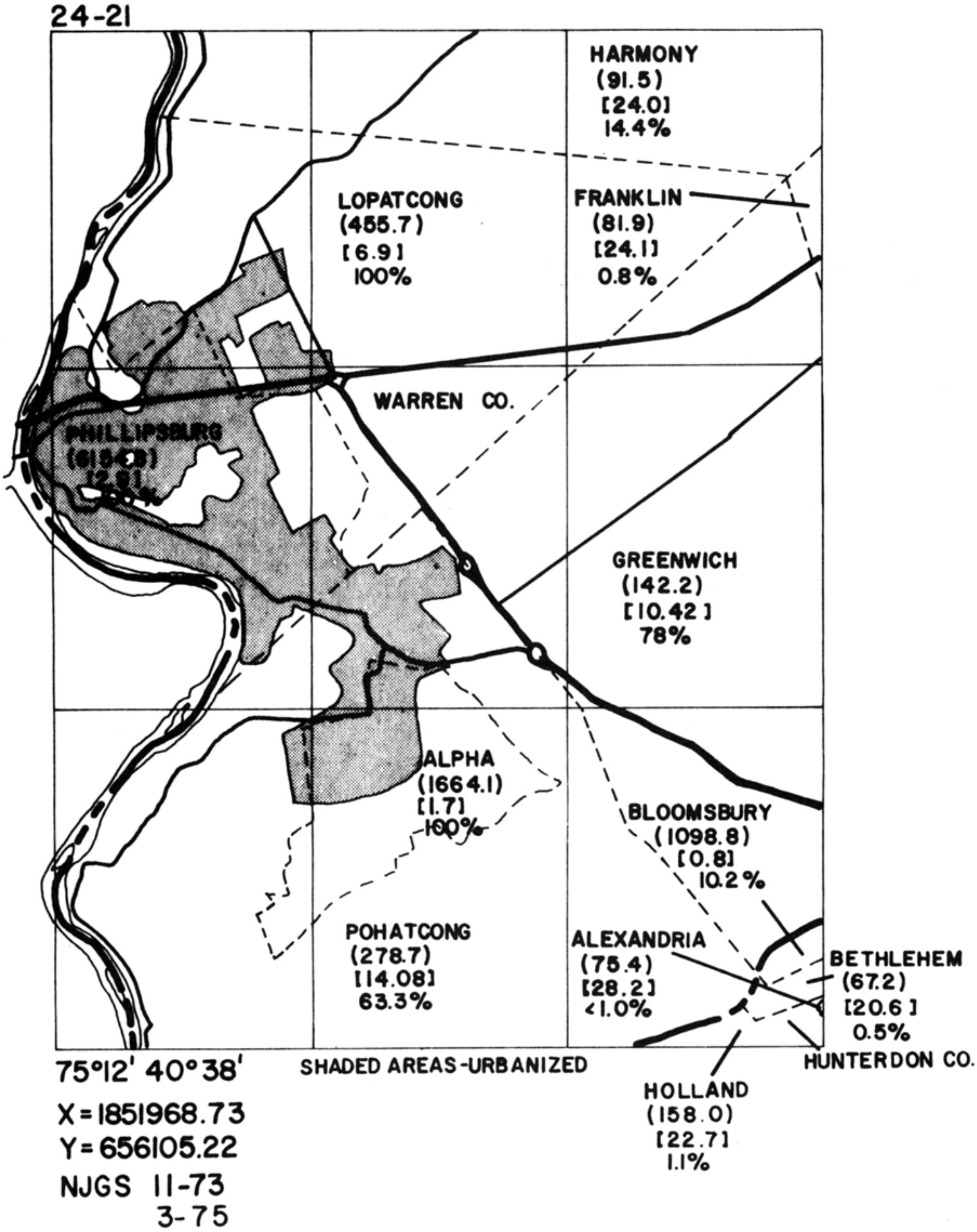


Figure 9
Population Map



BRIEF ANALYSIS OF THE USERS

The request profiles of the users of the data bank are expected to result from user query categories as follows:

- Point information: information sought by a citizen or corporation such as prospective owner or builder who is interested in a point or limited area, where he needs all information which can influence his future construction or planned use of his property
- Area information: information sought by a planner from the local, county, State or Federal level who needs all information which can affect the planning decisions
- Vertical, group information: specified governmental or research agencies or corporations interested in special group information only, such as Bureau of Water Pollution Control
- Horizontal, point or areal information, prevent or avoid: looking for information concerning a point or an area, possibly only of a certain type, due to some legal or financial problem

Any one of these user categories may involve request matching or cross-correlation of information.

STORING DATA BY TAPE, FILM AND COMPUTER, INCLUDING ITS EVALUATION

Studies were conducted as to methods of storage and retrieval at lowest cost and highest efficiency. The gathered data were classified as follows:

- Areal or map type information
- Descriptive type data including references
- Point type information or data pertaining to smaller standard size area, especially in land use, streamflow records, water quality gaging stations, etc.

The available methods could be summarized into:

- Computerized data systems
- Map type information service based on maps and microfilms
- Descriptive MTST methods

It was determined that all or most of the information in the program would have been compiled in a descriptive or map-type form before the data could be put into a computer program. In seeking information on the data required and method of storage and recovery, discussions were held with experts in computer science dealing with various computer programs including data bank. 9/ As a result of these discussions and from preliminary estimates of what would be required for New Jersey, it was found that once maps were prepared for use with a microfiche reader/printer, recovery would be quicker (about 30 seconds) than by using computer plotting devices. Furthermore, the survey revealed that regions of less than 50,000 km^2 in size could not use efficiently a computerized system unless they are part of and tied into a larger system. On the other hand, any other method such as microfilms, tape recording, etc. cannot compete with a computerized one if they embrace larger areas or have a wealth of itemized point type information.

Therefore, it was decided to have a data bank with a combined method using:

- Microfiche films and printer/reader for map-type information
- Magnetic tape/selectric typewriter's tapes for general descriptive and reference material and
- Computerized system (Fortran or similar) for land use, stream-flow record, water quality control, etc.

This combined method has the advantage of considerably cutting the cost by 94% in establishing the data bank (from an estimated $1,000,000 in 1972 to a real $60,000 in 1973/74) and the efficiency of information service for such size of area as New Jersey is better than any other non-combined system including the computerized one since it needs the least time for recovery. The disadvantage of the method is its apparent complexity. But, even with such diversity in training the necessary personnel and in purchasing the needed equipment, there could be no comparison in price including budget for continuous service and maintenance of equipment because of the still high cost of the computer at present. A further disadvantage of the combined system is a capacity limitation. Therefore, the whole data bank must be prepared in such a form that it can be converted easily into a fully computerized system. The itemized information should fit without any difficulties for computer feeding, storage and recovery in the future.

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NOTES

1/See also Kemble Widmer, The Geology and Geography of New Jersey, Princeton: Van Nostrand, 1964.

2/George J. Halasi-Kun, "Aspects Hydrologiques de la pollution et des ressources en eau, dans les domaines urbains et industriels," Actes du Congres: Sciences et Techniques An 2000. Paris: SCEF, 1971.

3/For better orientation and recording, information about the geodetic survey network monuments was added (13,600 monuments).

4/George J. Halasi-Kun, "Data Collecting on Water Resources and Computations of Maximum Flood for Smaller Watershed," International Symposium on Water Resources Planning, Vol. I, Mexico, 1972.

5/George J. Halasi-Kun, "Improvement of Runoff Records in Smaller Watersheds Based on Permeability of the Geological Subsurface," Symposium on the Design of Water Resources Projects with Inadequate Data, Vol. I, Madrid: UNESCO-WMO-IAHS, 1973.

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7/George J. Halasi-Kun, "Ground Water Capacity and Extreme Surface Flow Values of Smaller Watersheds," Proceedings of Columbia University Seminars on Pollution and Water Resources, Vol. V, 1974 (in print).

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9/See also: Enviro Control, Inc., The Development of a Procedure for Acquiring and Disseminating Information on Water Use, Vol. I-II, Washington, D.C., 1972.

Seminar on Interactive Map Editing

SEMINAR ON INTERACTIVE MAP EDITING

Current methods of interactive map editing were discussed at this seminar, which was chaired by CARL YOUNGMAN of the University of Washington. Since maps are public graphics they are subject to public scrutiny and must be accurate. A basic consideration is that absolute accuracy entails infinite cost. Interactive graphics on the other hand allows more complete editing at a reasonable cost.

HAROLD MOELLERING of Ohio State University made a distinction between real and virtual maps in his presentation, "Interactive Cartography." Real maps represent tangible reality subject to verification by direct observation. A sheet map is an example of a real map. Virtual maps on the other hand exist in abstract form as, for example, the image which appears on the face of a cathode ray tube (CRT) screen. Virtual maps are easily edited or manipulated. Current trends in computer-assisted cartography are exploring conversion methods between real and virtual maps. Batch processes in automatic cartography will give way to interactive graphical techniques because of the advantages of person-computer interaction. A review of the literature reveals that interactive techniques are most advanced in automatic sheet map production and that rapid progress is being made in the geographic information systems (GIS) field. Further research is needed regarding cartographic symbol displays and human factors in interaction.

R. DENIS WHITE gave an informal presentation about current work on "Control Languages for Interactive Mapping" at the Harvard Laboratory for Computer Graphics and Spatial Analysis. Numerous mapping programs have been developed in the last ten years and various types of control languages have been used. Some of the desirable properties of interactive mapping languages have been included in these programs. The characteristics of mapping system languages in contemporary research extend from earlier work and embrace 1) dictionary features to allow the mapper to redefine or symbolize map entities; 2) a natural language syntax; and 3) statements for controlling important cartographic processes.

In his slide presentation on "Interactive Mapping with Interactive Raster Graphics, MICHAEL FISHER discussed the interactive graphics system at the University of Kansas. Entitled "MAPS", the system is able to show time-sequential data, and three-dimensional graphs; it is able to edit/alter map features with little delay and to access individual points.

MARVIN WHITE of the Bureau of the Census discussed ARITHMICON, a program under development by the Bureau of the Census to correct bad coordinates of the GBF/DIME-Files. He described the advantages of supporting a map file edit operation with an access system based on the topological principles of cartography set forth by Corbett. Topics for further research were also suggested.

STEPHEN W. KINZY of the Omaha City Planning Department described ODIS, an On-Line DIME Implementation System for updating and correcting the GBF/DIME-File. Since 1973 the Omaha/Council Bluffs Metropolitan Area Planning Agency and the City of Omaha have been involved in the development of on-line DIME capabilities. The author looked at specific problems involved in the development of the system and the overall potential of teleprocessing for GBF/DIME-File maintenance. ODIS was compared to the Census Bureau's CUE (Correction, Update and Extension) program and differences and similarities were evaluated. Finally, a few remarks were made regarding national GBF/DIME policy and management as viewed from the local level. His paper was entitled "ODIS vs. CUE: A Look at DIME File Maintenance."

LAWRENCE SNIDERMAN of Michigan State University presented a paper entitled "An Interactive GBF Creation and Computer Mapping System." Many persons with varying capabilities and divergent purposes use computer mapping. A major problem results from delays in creating and processing GBF's suitable for thematic mapping. An interactive systems for the creation of GBF's and computer maps has been designed in an effort to expedite the process considerably. The system, an integrated set of FORTRAN programs, is designed for general use in an on-line interactive mode. The role of this system in a daily work schedule has been to decrease the turnaround time of both GBF creation and computer-mapping as well as allowing easy access for general users needing mapped information in a relatively short period of time.

WES SHEPHERD of the U.S. Army Engineer Topographics Laboratories, Fort Belvoir, Virginia, described current hardware and associated software used by the Topographics Laboratory. This slide presentation focused on systems configurations and how they are used.

One conclusion that arose from the seminar, according to chairman, CARL YOUNGMAN, was that no one has yet developed a theory as to how interactive map editing should be accomplished. What is needed is a set of principles similar to those used in cartography.

INTERACTIVE CARTOGRAPHY

Harold Moellering
Ohio State University

INTRODUCTION

In the last two decades great strides have been made in the application of machinery, especially computing machinery, to assist with cartographic tasks. The large bulk of this past work has been carried out with batch-oriented cartographic systems. A good review of the state of the art is presented by Peucker (1972a, 1972b), and Taylor (1972). Although batch production techniques still receive the bulk of the attention in computer-assisted cartography as evidenced by Gutsell (1973), Csati (1974) and the British Cartographic Society (1974) and probably will remain so for the final production of sheet maps, one can detect active recognition that in many ways interactive techniques can enhance many of the tasks in a computer-assisted cartographic system. These trends have been reviewed from differing points of view by Edson (1974), Boyle (1975), and Moellering (1975). These developments are also having an effect on the philosophy of thematic cartography as discussed by Morrison (1974). One would expect that such an impact will be even more keenly felt as time progresses.

CURRENT DEVELOPMENTS

To date the application of interactive techniques to cartography is still in its initial phases; however the fundamental feasibility of the approach has been proven at the laboratory stage. The fundamental advantage of interactive techniques is that one can establish man-machine communication, where there are tasks that one performs much better than the other. Machines are far better and faster at numerical data handling tasks and computation than a person; on the other hand, a person can rather easily perform certain kinds of logical operations that can be very difficult to replicate with computer algorithms. Hence, man-machine interaction allows the combining of the advantages of the person and the machine into a capability which is far more powerful than either approach alone.

Although the application of interactive techniques to cartographic problems is still in its early stages of development, a number of already existing uses can be distinguished. Of immediate interest to large governmental mapping agencies is sheet map production. Perhaps the most productive area to date has been in the use of interactive techniques for map digitizing and editing. One of the leading workers in this area is Boyle (1973, 1974a) who has produced an efficient interactive digitizing system which has effective editing capabilities, while Rhind (1974) details work proceeding at the Experimental Cartography Unit in London. Interactive thematic cartographic systems have also been developed, examples of which have been produced by

Youngmann (1972), Peucker (1973), and Hessdorfer (1975). In both cases the systems relate to "macro area" systems displaying large areas.

In contrast to the above examples, where the map or map display is the final output product, one can examine the status of several geographic information systems, experimental or prototype in which the emphasis is on solving specific problems in addition to producing a cartographic output. Examples which may be cited are by Phillips and Geister (1973) who developed a water quality display and analysis system for the U.S. Environmental Protection Agency, Christiani (1973) who has developed an interesting urban information system, and Schneider (1974) who reviews developments in transit route planning.

REAL AND VIRTUAL MAPS

If one is to analyze and discuss these developments in an orderly fashion, it is useful to distinguish between two possible types of cartographic products generated by these systems; real and virtual maps. A real map is one which has a tangible reality about itself and can be recognized as a map by direct observation. Perhaps the clearest and certainly the most widely used example is that of the ordinary sheet map. There are also several other kinds of real maps, produced by a wide variety of plotting devices on paper or film sheets, both general and thematic, which look very much like conventional sheet maps. There are however, several additional types of cartographic products which are fairly different from conventional cartographic products, the microfilm plot from a Computer Output Microfilm device as discussed by Broome (1974), as well as the Computer Animated Film (Tobler, 1970), (Moellering,1973), which can be viewed directly from the film.

In contrast, the virtual map is one which when displayed to the viewer looks like a real map, but has no physical reality in the form seen by the viewer. Perhaps the clearest example and certainly the most widely used kind of virtual map is the one which appears on the face of a CRT screen. The image qua image does not have a physical reality of its own, but may exist in some other nonimaging numerical or information state in some type of electro-mechanical storage device, computer or otherwise. The particular advantage here is that the image is of a transient nature and generally fairly easy to alter or edit as is necessary. It is also possible to store a virtual image in analog form on video tape. When viewing the spatio-temporal dynamics of a Computer Animated Film, the image is of a virtual type which simulates motion or change. The animation is not in the film itself, but an illusion of animation is created by the sequential display of the films. Although an individual frame may be considered a real map, the animated sequence is of a virtual nature. It is also possible to store virtual maps in an optical format. For example, it is possible to store Fourier transforms of maps (Wingert, 1973) or holograms of cartographic images as described by Youngmann (1974), either of which are not directly viewable, but can only be seen when converted into the proper display format for viewing.

It is interesting to note that it is possible to view current trends in computer-assisted cartography as exploring conversion methods between real and virtual maps. Current work in digitizing reflects efforts in efficiently converting a real map into a form which can be displayed as a virtual map, which then can be more easily manipulated in this form, and finally used to produce a real map product. Researchers have also come to realize that virtual maps are more easily edited and updated, especially in view of recent developments in computer technology. It is clear on a conceptual level that interactive techniques provide an efficient means for manipulating virtual maps. (Consider the problems of batch digitizing before interactive digitizing was developed.) Upon completion of manipulating the virtual map, it is a relatively straightforward step to produce a real map for the user.

It can be said that interactive computer techniques are still under active development. The body of literature pertaining to interactive computer techniques had been scattered widely, but a recent book by Newman and Sproul (1973), annual meetings on computer graphics and interactive techniques (Lucido, 1975) and a journal named Computers and Graphics, (Schiffman, 1975) have all helped to put communication and exchanges of ideas in this area on a more systematic basis. Further proposed developments for interactive cartographic systems have been voiced by McLelland and Moritz (1974), Edson (1974), and by Hoinkes (1974). These three papers represent proposed developments for large governmental agencies interested in proven technology before being willing to invest the millions of dollars into production systems for sheet maps. At the research level in cartography and computer graphics, it is clear that the pace of new developments will continue. It is reasonable to presume that these large governmental agencies will proceed with experimental and prototype systems in order to be able to test current techniques and also adapt the newest techniques before committing to production cartographic systems.

IMPACT ON GEOGRAPHICAL INFORMATION SYSTEMS

If one is to discuss the application of interactive techniques in cartography one must also include in the discussion a consideration of Geographic Information Systems (GIS) which in many cases produce a cartographic output. Initially, perhaps it would be helpful to define two basic orientations of a GIS, the first being an institutional system and the second being a research oriented system. An institutional GIS is one which is usually managed by a governmental agency and generally contains a reasonably large data base. In many cases the purpose of the system is seen as providing data to other agencies in that governmental unit such that these offices can intelligently solve their analytical problems. Some individuals even regard a GIS as a data utility. Because of their size such systems are usually batch oriented. Examples of such a system are Minnesota Land Management Information System, Natural Resources Information System, and Canadian Geographical Information System, (Tomlinson, 1972). A research-oriented GIS is much more specific in terms of the problems to be analyzed and hopefully solved. Phillips (1973), Peuker (1973), Boyle (1974), and Osleeb, Moellering and Cromley (1975) are examples. In most cases such research-oriented systems are interactive. It is also common for such systems to incorporate a substantial amount of display of virtual maps with CRT devices. Many have the capacity to produce real maps as well.

Although almost every GIS has the ability to do some geographical data handling, only a limited number have the ability to perform more extensive types of analytical operations. It is contended here that the usefulness of such research-oriented systems can be considerably enhanced by adding more analytical power to them.

Figure I shows two distinct components of such a system. The first is a cartographic display capability, essential to an interactive GIS. These techniques are fairly well developed as shown by Boyle and Peucker. The second facet of the system is that of spatial analysis. This implies the application of analytical techniques developed principally in geography, but also including analytical techniques developed in other areas, to the solving of specific problems which the system has been designed to examine. In some circles this capability has been called formal modeling, but the scope of this type of analytical approach is really much broader. As an example, many of the kinds of analytical techniques of concern here were discussed at a NATO Advanced Study Institute held at Nottingham in 1973 (Davis and McCullagh, 1975). It is interesting to note that there is at least one example in geography where an analytically oriented GIS has been designed and built with a very extensive analytical capability, but lacks an interactive capability. The system is named NØRMAP and has been developed by Nordbeck and Rystedt (1973). It is clear that NØRMAP would be much more convenient to the user if it were to incorporate an interactive cartographic display capability.

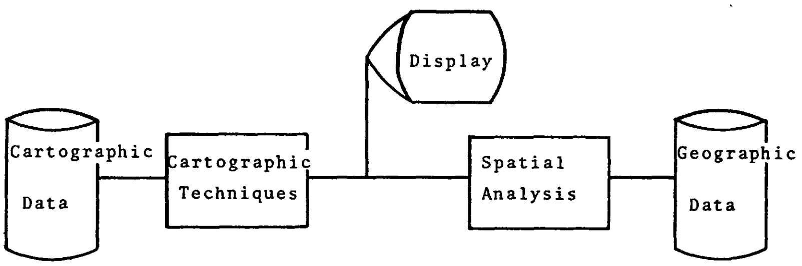

Figure 1. Schematic Layout of Analytical Geographic Information System

An alternative way to view the situation is shown in Figure 2. Here there are three fields represented, cartography, geography, and computer graphics. Although research is active in each of these fields individually, it is not uncommon to have a research task incorporate two of the three fields. For example, in intersection A the traditional approach in geographical analysis is to apply modeling and/or analytical techniques to geographical data, using cartographic techniques to produce intermediate working maps and also produce a final map of the results of the analysis. The bond between geography and cartography has always been very close. Many batch-oriented GIS fall into this intersection. Intersection B, incorporating techniques of cartography and computer graphics, especially interactive techniques, has resulted in systems which generate cartographic output and have no analytical power per se, although they may have some data handling capability. It is possible that such a system should be considered as belonging to a separate class of Cartographic Information System (CIS) rather than some subset of a GIS. Intersection C, which includes geographic techniques and computer graphics, has been little used because invariably the geographic output at some time is cartographic. In passing one could note that some computer graphic people have fallen into the trap of examining geographic problems while ignoring cartographic concepts; this has inevitably led to trouble. Finally, intersection D is where the real power of such an analytical system really lies. Here one finds systems which incorporate a cartographic display, computer graphic techniques and geographical analysis usually with virtual maps. These systems are a combination of analysis and display integrated with man-machine interaction. The amalgamation of all these approaches will result

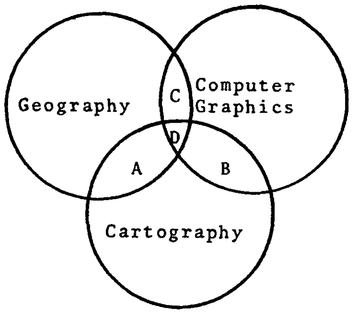

Figure 2. The relationship between Cartography, Geography and Computer Graphics

in very powerful systems indeed. For the immediate future it is suspected that this sort of system design will be primarily relegated to research-oriented systems focused on specific problems or on a small class of problems.

NEED FOR FURTHER WORK

It is clear that work to investigate the full integration of these techniques as envisioned in intersection D of Figure 2 is still very much in progress. One can envision many more systems of this kind being designed and built before standardized approaches are clearly defined.

However there are several tasks which require more research in order to accomplish the above goal. The first of these is to conduct more research in cartography on symbol displays for virtual maps along the lines of Wong and Yacoumelos (1973). The large bulk of research along these lines to data has been conducted in the examination of static symbols for real maps. Although some of these notions can be transferred to virtual maps, more explicit research in cartographic symbol perception should be carried out relative to virtual maps, particularly dynamic symbol displays. Noncartographic works like Huggins and Entwisle (1974) are helpful, but more explicit cartographic examinations are necessary.

A second area of research work requiring fuller definition in the cartographic domain is that of ergonomics, human factors, relating to interactive aspects of the types of displays mentioned above. This entire set of notions has hardly been touched as it relates to cartography. Again, one can utilize suggestions from research carried out in other fields as by Foley and Wallace (1974). However these concepts should be examined in an explicit cartographic setting.

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MAP EDITING USING A TOPOLOGICAL ACCESS SYSTEM

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NEIGHBORHOODS

A file structure and access system in which the boundary and coboundary operators E^i_j, described by Corbett in "Topological Principals in Cartography," are implemented affords the user excellent editing capabilities. With these operators, one may construct the fundamental neighborhoods of any point, line segment, or area. These neighborhoods are the smallest definable areas, in terms of the topology, completely surrounding the object under study. Some neighborhoods and their computations are shown in Figures 1, 2, and 3.

Every record in a geographic file which refers to a particular object, e.g., a line segment, falls within the fundamental closed neighborhood of that object. Thus, analysis of errors and the effects of changes are limited to that neighborhood. This is a great advantage, particularly for interactive editing, since the editor need only examine the few records in the neighborhood of the object under study. For line segments this is generally fewer than a dozen records. Furthermore, the editor may be able to restrict his attention to even fewer records due to graph theoretical constraints discussed below.

GRAPHS AND THE KIRCHOFF ANALYSIS

Every set of segments, e.g., the neighborhoods illustrated above, generates two graphs corresponding to the two ordered pairs described by Corbett. The 0-cells (points) and their ordered incidence relations give the primal graph while the 2-cells (areas) and their ordered incidence relations (adjacency relations) give the dual graph. These two graphs are duals because they are embedded in an orientable two-dimensional manifold. This powerful constraint provides the basis for several consistency edits. The usual DIME block and node bounding edits verify the consistency of representation of the dual graphs. These tests determine only whether there is a loop in the primal graph of a block or in the dual graph of a vertex.

There is available a more general and informative analysis based on a theorem by Kirchoff.1/ This analysis yields three numbers for each component of the graph: the number of chains between essential points; the number of cycles; and the number of acyclic chains. This analysis characterized the homeomorphically irreducible graph, i.e., the simplest topologically equivalent graph, to the given graph.2/ Figure 4 shows such an analysis.

Only certain codes are possible for particular features. The dual of the coboundary of a vertex must be a single component and a set of loops, i.e., there must be zero acyclic chains. Figure 5 shows the dual graph around vertex 45. If there were an error in encoding, the chain would be open or have a tail. If vertex 45 were replicated elsewhere on the map, there would be more than one component. Figures 6 and 7 show such cases. This test will reveal all topological inconsistencies an coding, except replicated block numbers, if applied to every node.

To detect replicated block numbers we examine the graph code for the boundary of the fundamental neighborhood of the point. That boundary must be a set of loops, usually only one, otherwise there is an error. More than one loop may occur if there are lakes inside the boundary. A replicated block appears as an additional component. We can also test for consistency of the coordinates assigned to vertices using the boundary of the neighborhood. The test is whether the point falls within its neighborhood. If not, there is an error in the coordinates of the central point or some boundary point. Figures 8 and 9 show the series of edits for point 226, whose coordinates are erroneous.

Errors that result in acyclic chains, e.g., missing segments, are always in the coboundary of the endpoints of the acyclic chain. The error detected in Figure 10, an open chain ending at vertices 1004 and 1003, would also be uncovered in the coboundary edit around each of those vertices. The editor may now restrict his attention to only these two points, which are automatically annotated.

ORIENTATION AND RETRIEVAL

In the Arithmicon system, 1-cells (segments) are specified by a pair of ordered pairs: (A,B), (C,D). The interpretation of that pair of pairs is A = from vertex, B = to vertex, C = left block and D = right block, so that an observer standing on A -- the from vertex, facing B -- the to vertex, would find C -- the left block, on his left and D -- the right block, on his right. This representation, which includes orientation, i.e., distinquishable left and right, is possible because the graphs mentioned earlier are embedded in an orientable two-dimensional manifold.

There are two possible orientations of a single 1-cell: (A,B), (C,D) and (B,A), (D,C). The second orientation places the observer at B facing A with D on the left and C on the right. Both orientations refer to the same 1-cell. To provide a unique representation of a 1-cell, (A,B), (C,D), the following convention is observed in Arithmicon: Choose the orientation in which $A < B$ unless $A = B$, then choose the orientation in which $C < D$. If both $A = B$ and $C = D$, the 1-cell is not orientable and already has a unique representation.3/

Oriented retrieval is accomplished in Arithmicon by assigning a + 1 coefficient to the retrieval pointer for conventional orientation and - 1 coefficient for the opposite orientation. Coefficients for successive retrievals are added. This provides a convenient indicator, even before the actual retrieval, of which 1-cells are interior to the requested region and which are not. Interior segments will have coefficient zero, since they will be retrieved twice -- once with a + 1 coefficient and once with a - 1 coefficient. Boundary segments will have a + 1 or a - 1 coefficient since the retrieved region will be on the left side or right side of the boundary segment, but not on both sides.

FUTURE RESEARCH

Every field in a DIME file generates a graph and that graph may be analyzed using the Kirchoff algorithim. Street names, which we are now implementing on Arithmicon, may be examined at the end points of components for misspellings. ZIP codes and address ranges present more difficult editing problems, since they are not as constrained as street names, but with the Kirchoff analysis, we will be able to limit the search for possible errors to likely candidates.

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3. A non-orientable 1-cell, (A,A); (C,C), would be a loop from a back to a interior to C.

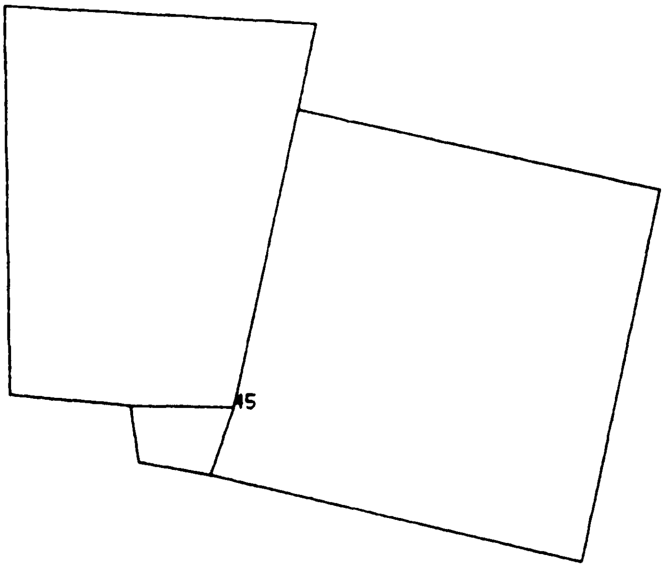

Figure 1. The closed neighborhood of vertex 45.

$$E_1^2 E_2^1 E_1^0 (45)$$

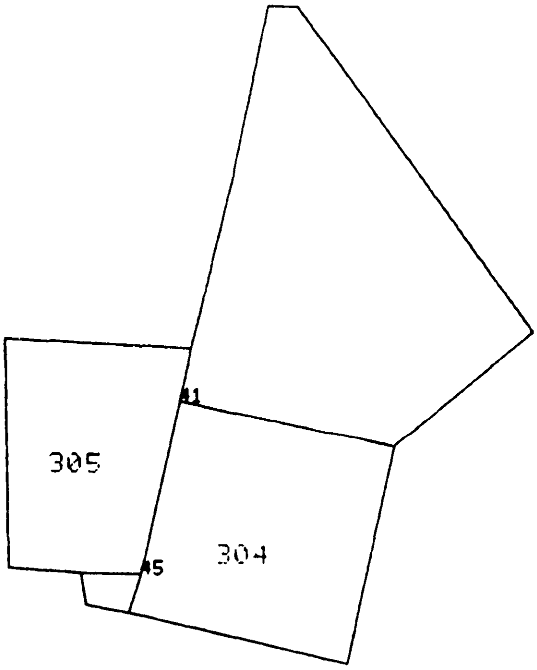

Figure 2. The closed neighborhood of segment

$$(41,45);(304,305) = E_1^2 E_2^1 E_1^0 E_0^1 (41,45);(304,305)$$

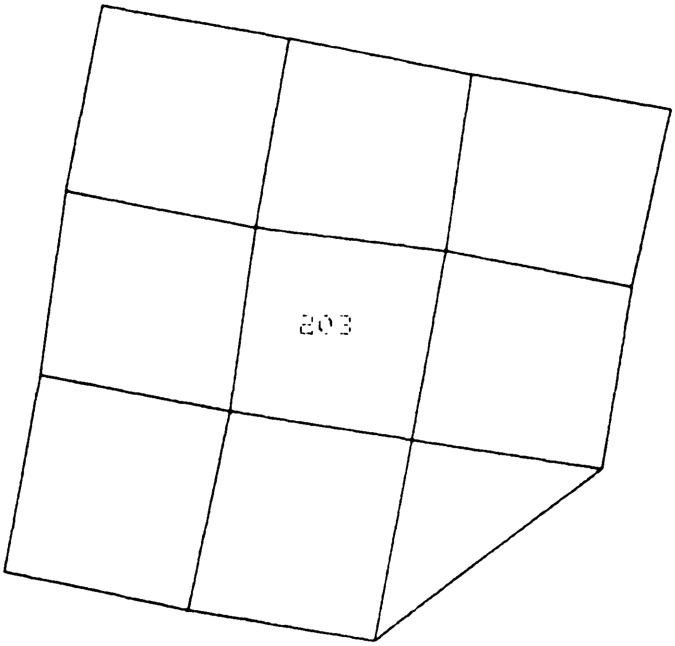

Figure 3. The fundamental neighborhood of block 203.

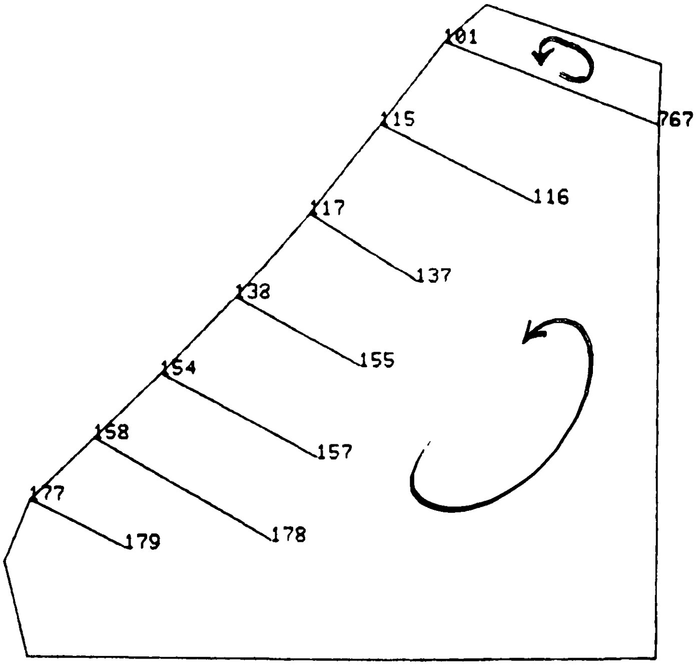

Figure 4. Kirchoff analysis of block 107: 1 component, 15 essential arcs, 2 cycles, 6 acyclic arcs and 14 essential points. Essential points are labelled. Cycles are indicated by arrows.

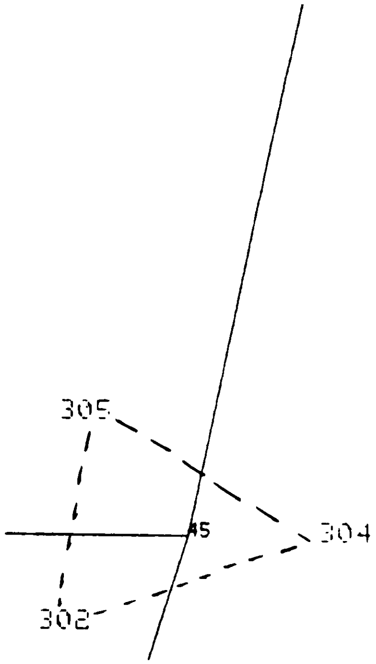

Figure 5. The dual graph around vertex 45 is a single cycle with one arbitrary essential point.

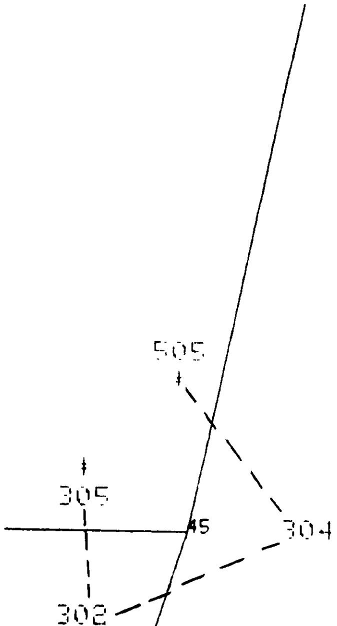

Figure 6. The dual graph around vertex 45 is a single acyclic arc with 2 essential points, which are labelled with asterisks (*).

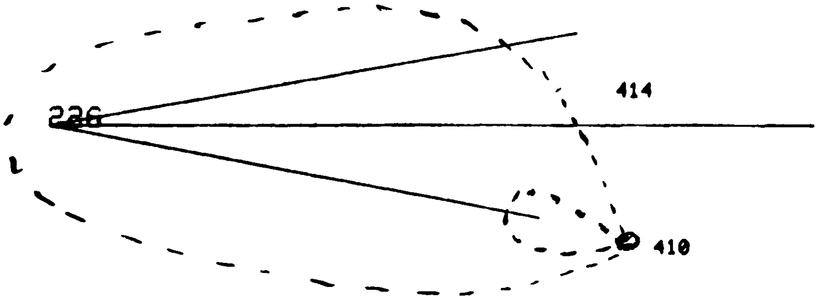

Figure 7. The dual graph around vertex 226: 2 cycles, 0 acyclic arcs, 1 essential point (410). This graph is permissible.

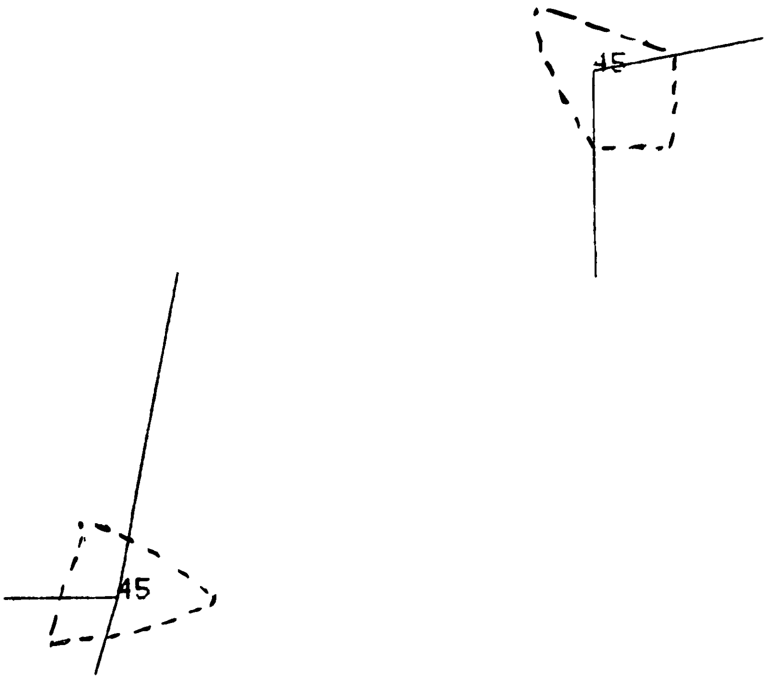

Figure 8. The dual graph around vertex 45 consists of 2 components, due to replication of vertex number 45.

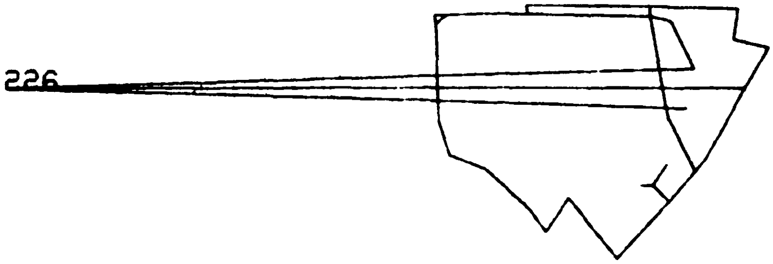

Figure 9. Vertex 226 lies outside its fundamental neighborhood.

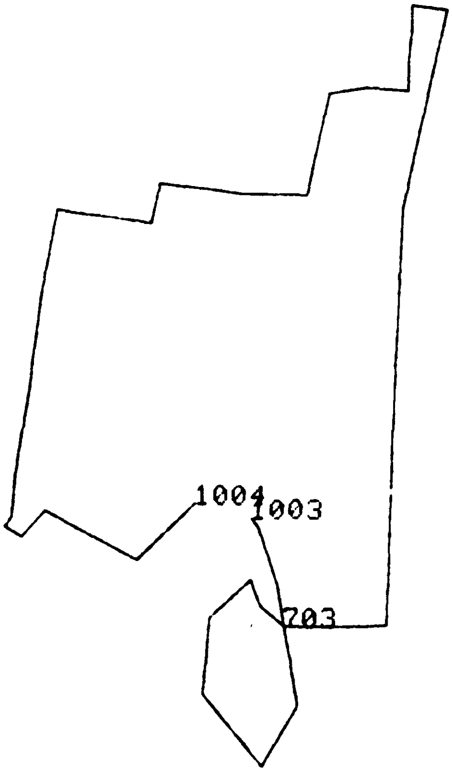

Figure 10. The boundary of the neighborhood of a vertex has acyclic arcs. The essential points are labelled.

ODIS VS. CUE:
A LOOK AT DIME FILE MAINTENANCE

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INTRODUCTION

On behalf of the City of Omaha, I would like to thank both the American Congress on Surveying and Mapping and the Census Bureau for inviting us to participate in this symposium. I especially would like to thank the Census Bureau for their courage and foresightedness in creating the DIME Geographic Base File System which has provided cities, such as Omaha, with a much needed geographic tool by which new data processing technology can be locally applied to solve urban problems. DIME, without question, has become an important breakthrough in the development of local geographic information systems throughout the United States.

Although the development of DIME and its associated technology is a good beginning, it can and must be continually refined with additional sophistication being built into the system. This will enable it to become "institutionalized" as one of the primary tools that planners, researchers, and decision makers can rely upon to provide the right answers to the many questions and problems that face American cities. Toward this end, DIME must be implemented as an ongoing program within every SMSA in the United States. For this to become a reality, the principle problem with DIME, that of maintenance, must be resolved. In Omaha, we have locally designed and initiated an on-line DIME implementation system named ODIS (On-line DIME Implementation System) as a partial solution to the problem of DIME file maintenance. ODIS has allowed DIME maintenance to become a very simple and efficient operation and has helped refine DIME technology into a more usable product for local government.

In Omaha, as early as 1968, we recognized the potential of DIME technology and thus began our involvement with the Address Coding Guide Program, which eventually evolved into the DIME System. Between 1968 and late 1974, the DIME Program in the Omaha area had been beset by many problems and delays which more than once had almost terminated the program. But in 1974, a number of critical decisions were made which led to the creation of ODIS. This afternoon, in describing ODIS, I would like to first discuss the system's evolution; secondly, analyze the mechanics of the ODIS Program in comparison to it companion batch system CUE; and finally conclude with a few observations about national DIME file policy as viewed from local government.

THE EVOLUTION OF ODIS

To understand the operation of ODIS, an explanation of both Omaha's data processing environment and the development of the ACG-DIME System is required, because ODIS is a by-product of a highly successful data processing system from local government and the frustrations of local agencies to implement the DIME system in Omaha between 1968 and 1974.

Omaha is the central city of the Omaha-Council Bluffs SMSA containing over 65% of the SMSA's one-half million population. The SMSA is made up of three counties in two states, Douglas and Sarpy Counties in Nebraska and Pottawattamie County in Iowa. The data processing structure for local government within the SMSA is fairly simple. Douglas County is the only county within the SMSA with its own computer installation, and the City of Omaha is the only city within the SMSA that now participates with Douglas County in the use of that facility.

DOUGLAS COUNTY SYSTEMS AND DATA PROCESSING CENTER[1]

The Douglas County Systems and Data Processing Center (DCSDP) is a cooperative city-county venture serving the needs of both jurisdictions (the City of Omaha and Douglas County). The center was first established in 1967 for the purposes of:

1. Developing a computer center offering the latest technology to departments in batch and teleprocessing modes;
2. Organizing a professional staff offering systems and programming capabilities to maximize computer usage;
3. Encouraging the concept of sharing common data bases with each county and city department, adding to and retrieving from data based at the computer center.

DCSDP is an IBM shop containing two computers: an IBM System 370, Model 155 with 2,000K available memory, and an IBM System 360, Model 40 with 256K available memory. The shop also contains 12 tape drives and a disk storage system consisting of 24 IBM 2314 disk spindles and 10 IBM 3330 disk spindles. The center operates under OS/MFT. DCSDP has a fulltime staff of over 80 and operates 24 hours a day, 365 days a year. Financing of the data processing system has been accomplished through approximately 95% local county, or city funding. The annual budget of the center is $1,800,000 and is paid for by 40 governmental departments and user agencies within Douglas County.

One of the major functions of the center has been teleprocessing inquiry begun in 1969. Today the teleprocessing network of DCSDP consists of over 125 remote CRT and typewriter terminals, answering between 20,000 and 25,000 daily user inquiries. The principle teleprocessing applications maintained by the center include:

1. Douglas County Real Property System, (Ownership, assessment, tax and permit information are available by owner's name, legal description, property address and account number.)
2. Criminal Justice System, (Municipal, District Courts, and Police records are available by name, ticket and warrant number, address, driver's license and record bureau number.)

3. Douglas County Auto Title/Registration/Tax File System, (Automobile records are available by owner, license, title and registration number.)
4. Douglas County Governmental Accounting System, (Inventory and purchase orders are available.)
5. Douglas County Hospital System, (Admissions, laboratory, and accounting records are available.)
6. Omaha Street Inventory System, (Street characteristics/conditions, traffic accidents and volumes are available.)
7. Omaha Sanitation Inventory System, (Sewer location, type, condition, and sewer plant maintenance data are available.)
8. Industrial Wastewater Sampling System, (Industrial water quality condition data are available.)
9. Public Works Cost Accounting System, (Manpower and machinery accounting are available.)
10. Structural Condition and Content System, (A classification system of commercial and industrial buildings maintained by the Omaha Fire Division.)

In addition to the above teleprocessing systems, DCSDP maintains a large number of data files and software for city-county departments and agencies. The center is a recognized census summary tape shop, and maintains a majority of the 1970 census summary tapes for the SMSA. DCSDP also maintains a library of statistical/engineering programs, computer mapping packages (SYMAP, SYMVU, SAMPS, GRIDS, and C-MAP are among the mapping programs available. The center also operates a 30-inch Calcomp drum plotter.), and two powerful software systems; IBM's Information Management System (IMS) and Informatics Mark IV File Management Systems, in addition to the traditional data processing languages (COBOL, ASSEMBLER, BAL, FORTRAN). This user oriented software has provided important tools for data management for city-county government.

The Douglas County Systems and Data Processing Center has been described in some detail because it is one of the major reasons why it was possible to develop ODIS in Omaha, for without the necessary data processing technology available at DCSDP, the system could not have been created. The data processing environment in Omaha is fortunate to consist of only one computer installation for local government because this has allowed us to avoid the problems of competing computer centers with diverse hardware and software configurations. Additionally, the center has allowed governmental users to maximize the effectiveness of their data processing budgets through the consolidation of systems development and data requests. In recognition of the quality and efficiency of the Douglas County Systems and Data Processing Center, the National Association of Counties distinguished the center in 1973 with a County Achievement Award.

THE OMAHA ACG-DIME PROGRAM, 1968 to 1974

In 1967, the Metropolitan Area Planning Agency (MAPA) was established as the SMSA's regional planning agency. One of the first projects undertaken by the agency (under a HUD 701 Planning Grant), was the creation of the Address Coding Guide (ACG), for the urbanized portion of the Omaha-Council Bluffs SMSA in preparation for the mail-out/mail-back 1970 census. The ACG was created in the four months between

May and August, 1968. The work was conducted by three clerks using commercial directories of the metropolitan area as basic sources. The project required a total time of 1.37 man years to complete and expended over $7,000.00. Although the completed ACG reflected the accuracy or error inherent in the commercial directories and the subsequent coding, it nonetheless provided a 1967 address file for the urban SMSA. Upon completion of the ACG, the program was terminated and the clerical staff reassigned.

In 1970 (under another HUD 701 Planning Grant), MAPA participated in the Address Coding Guide Improvement Program. As part of this program, the Metropolitan Map Series (MMS) map sheets for the Omaha SMSA were corrected and updated to 1970, and DIME features added to the MMS and ACG. The Metropolitan map sheets for the Omaha area were created from the 1967 U.S. Geological Survey Quadrangle Maps and had never been adequately checked for accuracy. During the ACG Improvement Program, numerous conflicts with the local maps became apparent. Many of these conflicts were resolved and corrected in a large part by extensive field work, although many errors still remain that could not be corrected due to the project's time limitations. The map problems encountered during this program and more recently have demonstrated the absolute necessity for up-to-date local maps and aerial photos as a source for both address coding and MMS revision.

The addition of DIME features to the ACG created its own set of problems. Due to the time frame in which this work was to be accomplished (4 months), the ACG was assumed to be entirely correct, thus prior editing was not done and a determination of the accuracy of the 1967 ACG was not made. Additionally, it was found that close supervision of the coding staff was required, thus cutting down on the efficiency of the program. In spite of these problems and others the project was completed and the materials returned to the Census Bureau on August 3, 1970. The ACG Improvement Program involved a staff of six working for a total time of 1.46 man years (coding) and expended almost $17,000.00. The result of the program was a 1970 set of Metropolitan Maps with DIME features added and a DIME file which included the 1967 Address Coding Guide with the 1970 DIME features. With the completion of the ACG Improvement Program in 1970, as with the creation of the ACG in 1968, the program was terminated and the staff either laid off or assigned to other activities.

On July 10, 1972, almost two years after the completion of the ACG Improvement Program, MAPA received the digitized version of the ACG/DIME file. Shortly thereafter, a limited number of ADMATCH runs were made against the file from local data with fairly good results (we had an 84% match rate against the 1970 Douglas County Auto Registration File and an 86% match rate against the 1970 Housing File created by MAPA for the SMSA). As a result of this an other work with the file in 1972 and 1973, the file was estimated to have no more than 10% residual error in both the address and topological data; however, the coordinate information on the file was in considerably worse condition with approximately 25% of the coordinates in need of redigitizing.

Between the time DIME had been received in Omaha and late 1974, the program was nearly terminated for four basic reasons:

1. The unavailability of funding for DIME through Federal grant programs. HUD, who had previously funded the preceding two programs, suddenly refused to fund the DIME Program as part of MAPA's 701 Planning Grant.
2. The inability of MAPA to retain the technical staff assigned to the program, largely because of discontinuous funding and administrative problems.

3. The lack of broad based local governmental support for the program due to unfamiliarity with the technology and local applications, and the lack of confidence in the accuracy of the file.
4. The lack of an established maintenance program at the Federal level to correct and update the file (CUE was not implemented on a national level until 1973).

By the end of 1974, MAPA had expended well over $35,000.00 on the development of DIME from the initial creation of the ACG in 1968 and had a file that was in fair condition for 1970 analysis, but was badly in need of correction and update. At this point, the prospects for implementing DIME were very pessimistic. One of the only reasons the DIME program was kept alive in Omaha during this period was due to the loyalty and dedication to the program of a very small group of technical people who remained convinced if its overwhelming potential. This enthusiasm was helped in no small part by the Center for Census Use Studies' DIME Workshop Program.

As a result of this technical group's persistence, a number of critical decisions were made by local administrators in 1974 to locally create and fund a DIME Implementation Program.

The two most important decisions made during 1974 were in regard to:

1. The DIME maintenance methodology to be utilized in Omaha, and
2. Financing and staffing the DIME Maintenance Program.

The first decision made was to develop our own maintenance program locally. This decision came after an extensive review of the Census Bureau's Correction, Update and Extension (CUE) Program, implemented on a national level during 1973. We looked at the CUE Program in detail for its application to both Omaha's DIME file and data processing environment. As the result of this review, two major problems became apparent. First was the problem of the program's funding and administration. Based upon our previous experiences with DIME, it became obvious that a continuous level of funding was required for the CUE Program, both to employ an independent DIME staff and to pay for local data processing to keep continuity in the program. In 1974, direct funding for the CUE Program in Omaha, either locally or from the Federal Government, was impossible.

The second major problem with CUE was in regard to its batch-based correction and update system. In Omaha since 1969, we had been using on-line correction and update systems with very good results. They had proved to be far superior to batch systems for files requiring continuous maintenance such as DIME. By 1974, a high level of sophistication had been achieved in the development of teleprocessing systems by the Douglas County Systems Data Processing Center. Thus, it appeared obvious that the answer to DIME maintenance in Omaha was to utilize the teleprocessing system. This decision led to the creation and development of ODIS.

In 1974, a second decision was reached in regard to financing and staffing the DIME Maintenance Program. Once we had determined to develop our own maintenance program locally, we also had to finance and staff the program. Unlike the problem with CUE funding, which required money for both personnel and data processing, ODIS only required data processing funds to begin the program (ODIS was estimated to cost approximately $17,000 for the system's work and programming required to place DIME on-line). By broadening the base of the DIME Program to include the City of Omaha directly as well as MAPA, it was found that the necessary data processing funds were available on a 50% split. We discovered that it was much easier to obtain data processing funds rather than staff funds from Federal or local programs. By shifting

MAPA's funding approach for DIME from HUD funding to DOT Transportation Planning funds for data processing, MAPA was able to finance 50% of the system, the other 50% came from local funds earmarked for data processing from the Omaha Public Works Department. By August, 1974, MAPA and the City of Omaha had signed an agreement to create ODIS, and a staff (the ODIS Technical Committee) was also made available on a part-time basis from both organizations to begin the program.

ODIS developed in Omaha because of the availability of a sophisticated data processing environment and as the result of years of frustration in implementing the DIME Program. In Omaha, we became convinced that the only way a DIME maintenance system would be built, considering past experiences and local resources, would be if DIME was to become "institutionalized" as a basic reference tool for geographically based data required by local government. In order for this to be accomplished, DIME maintenance had to become inexpensive, fast and efficient. Additionally, all DIME maintenance would have to be handled locally with existing personnel. With the creation and development of ODIS, those goals have been accomplished.

ODIS - ON-LINE DIME IMPLEMENTATION SYSTEM

ODIS integrates the three DIME implementation procedures of correction, update, and extension into a unified program. In addition, ODIS allows for daily maintenance of DIME for update and error correction. ODIS does not totally abandon the Census Bureau's guidelines and procedures; on the contrary, we have been extremely careful to utilize Census Bureau standards and most of the technical procedures covering MMS revisions, interim block renumbering, node numbering, addressing, etc. The Census Bureau has done an excellent job in documenting these standards and procedures as part of the CUE Program. The only area involving basic disagreement between ODIS and CUE is that of the CUE edit and batch environment approach to DIME maintenance. Instead of using computer edits to first correct DIME for 1970 and then update it in a batch environment, we have integrated correction and update into one simple manual procedure, with the results transacted to the DIME file via our on-line system.

In explaining the mechanics of ODIS, three individual elements of the program shall be discussed:

1. ODIS Technical Committee
2. ODIS Geocoding
3. ODIS Teleprocessing

ODIS TECHNICAL COMMITTEE

When ODIS was created in 1974 and the involvement of local government expanded to include the City of Omaha, a technical committee was established between the participating organizations to serve as a management mechanism for the program. The purpose of the committee was to initially provide the specifications for the on-line computer system. Today, the committee's role has been expanded to include decisions on technical matters regarding both the CUE and ODIS Programs as they relate to the Omaha DIME file, and to coordinate local usage of the file. The Committee also supervises the manual geocoding work involved in correcting and updating the file to 1975. This committee's structure has worked extremely well and is excellent proof that intergovernmental cooperation can solve DIME problems. The committee's structure has been predicated on the need for DIME as a local tool and the inability of any one agency within the Omaha area to adequately upgrade and maintain DIME because of financial, staff, and data requirements. The ODIS Technical Committee now consists of five permanent member organizations, each with a specific responsibility:

1. Metropolitan Area Planning Agency (MAPA) - serves as the policy organization for DIME because of Census Bureau requirements. MAPA represents and is responsible for the ODIS Program in rural Douglas, Sarpy, and Pattawattamie Counties, as these areas are not now directly involved involved in the program. MAPA has also supplied 50% of the data processing funds.
2. Omaha City Planning Department - serves as the City of Omaha's coordinating organization and is responsible for the ODIS Program in urban Douglas County (the City of Omaha). City Planning is also providing a computer terminal for ODIS and the source materials for Omaha.
3. Omaha Public Works Department - is providing DIME geocoding staff and has supplied 50% of the data processing funds.
4. Omaha Police Division - provides the technical day-to-day supervision over the geocoding work. (The coding supervisor for the ACG Improvement Program in 1970 is now working for the Omaha Police Division and has fortunately been allowed to participate as the clerical supervisor for ODIS.)
5. Douglas County Systems and Data Processing Center - is providing the technical systems analysis, programming, and data processing services.

ODIS GEOCODING

The ODIS Program consists of two basic phases, one for development of the system (correction, update, and extension operations required to bring DIME to current (1975) status) and one for maintenance of the system (continuing updates and correction of DIME beyond current (1975) status). When the program was initially created in 1974, a geocoding staff could not be funded, so it was hoped that the ODIS Technical Committee could, on a part-time basis (as we all had other duties) do the manual goecoding work required, but in January, 1975, the Omaha Public Works Department was able to hire three staff members (two of whom had worked on the original ACG Improvement Program in 1970) with Federal unemployment funds (under the PWSE Program); thus we have been able to proceed at a much more rapid rate than originally anticipated. The ODIS geocoding staff is working toward the completion of the ODIS development phase (within the Omaha area). Upon completion of that program, the Omaha City Planning Department will assume the ODIS maintenance phase as part of our routine subdivision regulations, annexation and addressing duties, thus "institutionalizing" the program as part of our normal governmental procedures.

ODIS geocoding consists of three activities:

1. Metropolitan Map Series (MMS) revisions.
2. DIME record review.
3. On-line transaction of the revisions.

The MMS correction and update activities under the development phase is designed to revise the MMS to 1975 from local source materials (aerial photos (1 inch equals 200 feet), plat maps (1 inch equals 200 feet)). For this part of the program, we are strictly following the CUE procedures for the MMS revisions, although we have gone a step further and are maintaining the original MMS scribecoats and overlays in Omaha. The result of this first activity is to correct and update the MMS map sheets for use as the primary source documents for DIME record review.

The second ODIS geocoding work activity consists of a review of DIME records by census tract against the revised MMS map sheets and address maps. For this portion of the program, we have selected only primary DIME segment and topological features from the file for review. From this abridged version of the DIME file, DCSDP has prepared separate census tract computer listing which list all street and non-street features within the tract by record identification number. This listing is then reviewed against the corrected and updated MMS for DIME record correction and update. The result is a listing that reflects changes and deletions to the records within the census tract. We also have an ODIS create form for those records that must be created. Thus, when a census tract is reviewed, the DIME records within the census tract should not only be correct but also up-to-date.

The final and simplest ODIS geocoding activity is the on-line transaction of the revisions made as part of the previous record review. The ODIS Teleprocessing System consists of eight DIME record display formats, on-line to a CRT terminal with one add-update display format for on-line transactions (see request and response #1, on page 442). The add-update display is the most complete, with all primary segment, topological, coordinate, and local code information available from it. The add-update display for this geocoding activity is accessed by record identification number. The system's update capabilities allow for changes to be made in any record on the file by simply entering the proper action code (C for change, D for delete, and A for Add) and then entering the revised information in the proper field. The computer then performs logical edits on the revised information to verify the proper entry of valid information. If the edits locate any errors within the revised information, the display indicates the error for correction. When the display is correct, the new record revised the master DIME file and acknowledges the successful transaction. Additionally, the ODIS update capabilities allow for either deletion or creation of records. The ability to create new records will allow us to continuously extend DIME beyond existing DIME file boundaries.

With the completion of the above ODIS geocoding activities, we have not only been able to correct the residual errors within the 1967 Address Coding Guide and the 1970 DIME features, but we have also updated DIME to the present time. The system works with the census tract as the basic correction unit. Thus, once the tract is revised, it is available for local use. Although the ODIS Program does correct DIME to a high level of accuracy, we still intend to run the revised DIME file against the Census Bureau's CUE edits as a final logical check of the file.

ODIS TELEPROCESSING

ODIS has been created as the teleprocessing system under IBM's IMS (Information Management System) Program, on an IBM system 370 Model 155 computer. As explained previously, the heart of the teleprocessing system is the add-update display format and its associated edits. In addition to the add-update feature of ODIS, a data retrieval system has been created with eight specific DIME information displays. The displays are available from a "request menu" which indicates both the fields necessary for a response and the special function key required for the display. This system also allows for any record identification number appearing on a response screen to be activated to return to the add-update display format for that record. A description of the eight displays follows (see "request menu" and "request/response" numbers 2-9, pp. 145-149).

2. Inquiry by address - The fields necessary for a response are address, street, and area code, if different from Omaha; the response is the add-update screen with the requested record. (Inquiry by address allows us to have limited ADMATCH ability on line. As one application of this ADMATCH on line, the Omaha Police Division plans to utilize this capability to determine whether or not a call for police service is within the City limits of Omaha and thus within their jurisdiction or outside Omaha's City limits and in the jurisdiction of the Douglas County Sheriff.)
3. Boundary Nodes within a Map - The field necessary for response is map number; the response is a series of display screens with a list of all census tract boundary nodes within a map and the associated map-set-mile coordinates for the nodes.
4. Internal Nodes within a Tract - The field necessary for a response is census tract number; the response is a series of display screens with a list of all internal nodes within a tract and the associated map-set-mile coordinates for the nodes.
5. Blocks within a Tract - The field necessary for a response is tract number; the response is a series of display screens with a list of all census blocks within a tract and the associated place and MCD code, additional room is available for transportation zone and police cruiser district.
6. Block Face Chaining - The fields necessary for response are tract number and block number; the response is a display screen showing all records and associated information with the block number requested. (This display and the following two displays allows us to easily check the topological structure of any block within the file.)
7. Internal Node Chaining - The fields necessary for a response are map number, tract number and node number; the response is a display screen showing all records and associated information with a node number requested.
8. Boundary Node Chaining - Same as internal node chaining, but for census tract boundary nodes.
9. Street Name Chaining - The field necessary for a response are street and area code; the response is a series of display screens with a list of all records and associated information for the street requested. The request has the flexibility of selecting all records within the file with different area codes (as shown in Appendix 1-6) or with the same area code.

The advantages of an on-line system vs. the batch environment approach, to DIME are impressive. The most obvious advantages being the efficiency and speed of teleprocessing for file management. Additionally, it has been well established that systems having a large number of manual operations such as CUE are more inclined to have larger error rates than systems requiring few manual operations. By utilizing an on-line system, the number of manual operations has been reduced, thus making the system not only more efficient but less prone to error. Also, on-line systems such as ODIS can be built with various safeguards so as to minimize whatever errors do occur. Finally, teleprocessing systems make it possible for DIME to become as dynamic as the urban environment it portrays. The interactive nature of teleprocessing allows DIME to be as current as the corrections and updates available to it, whereas within a batch system corrections and updates are allowed to accumulate before processing. Thus, where a batch system will probably be maintained on a monthly basis if not longer, an on-line system can be maintained daily.

In summarizing the differences between ODIS and CUE, we will look at the basic system design of both systems.

CUE - CUE first corrects the 1970 DIME file utilizing the Census Bureau's computer edits, then updates DIME as a separate program. Finally the DIME file boundaries are extended under yet another program. In correcting the 1970 DIME file, CUE makes the assumption that the 1970 MMS maps and ACG are correct and then utilizes logical edits to to check the file. The edit list produced by this procedure must then be reviewed and each potential error solved. The results are then coded onto coding forms, keypunched and then run against DIME with the revisions edited prior to changing the master file. If no errors are made in coding and keypunching, the file is then hopefully, logically corrected.

ODIS - ODIS combines the three maintenance activities (correction, update and extension) into one program. Additionally, ODIS does not make the assumption of the basic accuracy of the 1970 MMS, or the 1967 ACG, because of prior experience with the maps and addresses. The first part of ODIS is to correct and update the MMS as our primary source for DIME record review. This is done on a census tract by census tract basis. Upon the completion of the MMS revision, we then review census tract printouts of DIME records with the revised MMS maps and current address maps. Once completed, we have identified all errors and updates that must be made to the DIME records within the tract with a final product being a printout containing: 1) all old DIME records, 2) all revisions, and 3) coding sheets (ODIS create form) with any additions. These revised printouts are taken directly to the terminal where the changes, deletions, or additions are made to the census tract. As part of this process, the revisions are edited for accuracy and if any problem arises, the operator is immediately notified and the problem is solved. ODIS eliminates the need of problem solving for "potential" errors that would have to be solved under the CUE Program. Also, the immediate edit response of the on-line system allows us to correct any input errors automatically while the data is still fresh in the mind of the operator. DIME extension (or the addition of new DIME records) under ODIS is completed in the same manner as normal DIME records added to the system. Once the tract records have been added, the new information is immediately available for any further revisions.

CONCLUSION

In conclusion, I would like to make a few observations about national DIME policy as viewed from local government. In Omaha, as in many small and medium size cities throughout the United States, we tend to be isolated from many of the new innovations and technology developed at the Federal level. In many ways this is not a negative situation because it allows us to receive this newly created, untested technology and refine it through local application. In the planning profession we call this approach, eclectric planning, the method of utilizing the experience and example of others, modifying and refining that example to our own requirements, and then applying the results to our own specific situation. ODIS is a perfect example of this method. ODIS utilizes the DIME technology developed by the Census Bureau during the late 1960's and early 1970's, but has refined it in terms of a maintenance program to more adequately meet our own local needs. Additionally, ODIS is not an original creation but rather an idea we brought back from the Atlanta DIME Workshop in 1972, after viewing the instructional system TIDE[2] (Terminal Interactive DIME Environment). The reason I mention this is to illustrate what I think is the proper and necessary role of the federal government and its administrative branches such as the Census Bureau and their response to the technology needs of local government. The federal government should provide three basic things:

1. A source of new innovative technology.
2. The necessary transfer mechanism between this technology and local government.
3. Continuing financial support of local government in applying this technology to meet both local and federal needs.

In response to this first item, the Census Bureau in the mid to late 1960's began a very vigorous research development program through the Census Use Study to develop innovative technology for the 1970 census. As a result of that program, DIME and much of the associated technology were created. The Bureau had most certainly taken a step in the right direction. Unfortunately, the research and technology begun so well under this program has seemed to come to an end. The failure of the Bureau in contunuing their vigorous pursuit of this new technology with an open mind to new approaches, will, I am certain, have far reaching implications.

As a data user in local government who relies very heavily upon the technology developed by the Census Bureau, I would very seriously recommend that the Census Bureau resurrect this very important program. Additionally, the role of the Census Use Study should be expanded to include not only research into DIME maintenance and applications and other geographic base file approaches, but also the creation of a Federal Resource Center for DIME and other geographic base file technology. There is a very real need for the creation of a central source for GBF related documents and software developed at all levels of government throughout the United States. Thousands of dollars are spent annually by local government in the development of duplicative geographic base file technology. This money could potentially be saved by the creation of such a resource center.

Secondly, the Bureau also began through the Census Use Study another excellent program designed to transfer the technology developed as part of the DIME system to State and local government. The DIME Workshop Program begun in 1972 has yielded spectacular results on the local level as the consequence of workshop graduates applying their training in their local communities. Without questions, this program has been one of the Bureau's most successful and should most certainly be continued. In Omaha, the DIME Program would not have continued after 1972 had it not been for the DIME Workshop Program and the local graduates of the program. That program had been so successful that we recently conducted our own DIME/ODIS Workshop in Omaha, utilizing many of the materials of the Census Use Study's original DIME Workshop Program.

Thirdly, and probably most importantly from the local view is the question of financial aid to local government in assisting the development and maintenance of local technology. Probably the most basic problem that local government has had in developing DIME systems nationally has been the lack of continuous Federal support for the program (the on-again off-again approach most certainly does not work). Additionally, there has most certainly not been a unified Federal approach to funding DIME programs. Since the Census Bureau has not until recently directly funded DIME on the local level, they should have at least made sure that other Federal agencies would approach DIME funding in a unified manner. In Omaha, HUD has consistently refused to fund DIME since 1972, although Lincoln, Nebraska, less than 60 miles away, has received substantial HUD support for DIME and related activities. I am afraid this is not an uncommon occurrence nationally. If DIME is to be utilized as part of the 1980 census within the U.S., the situation must radically change. Additionally, if DIME funds are to be made available, who should they be made available to? The regional agencies, as have been the tradition in the past, or to local government. One of the basic problems over the past few years has been the inability of regional agencies to maintain DIME programs that are vitally dependent upon local government for source materials and data processing. I would recommend that maybe a funding split between local and regional agencies for specific DIME maintenance products would be a much more efficient and effective mechanism for DIME development and technology transfer.

In Omaha, the creation of ODIS has definitely not been an overnight development, but rather, has been the evolution of the hard work of many people and organizations. The system is proof that intergovernmental cooperation can and does work effectively to get things done. ODIS or CUE in the final analysis are not the only or maybe the best systems for DIME maintenance, but they are two distinctively different systems, both of which should have potential application in many SMSA's throughout the United States. It is critically important that the technology that has produced DIME, CUE and ODIS, be allowed to continue for the end result, I am certain, will positively effect the quality of local and federal decision making and hopefully provide the needed solutions to urban problems.

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REQUEST 1

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                   D I M E   F I L E   R E C O R D   U P D A T E
RECORD NUMBER 021315                                       ACTION CODE
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- - - - - - - - - - - - -   F R O M     N O D E   - - - - - - - - - - - - - -
           NODE         MAP                     STATE PLANE CODE
            MAP SET MILES         STATE PLANE           LAT  / LONG
          X-COORD  Y-COORD      X-COORD  Y-COORD      X-COORD  Y-COORD

- - - - - - - - - - - - - - - T O     N O D E - - - - - - - - - - - - - - - -
           NODE         MAP                     STATE PLANE CODE
            MAP SET MILES         STATE PLANE           LAT  / LONG.
          X-COORD  Y-COORD      X-COORD  Y-COORD      X-COORD  Y-COORD

- - - - - - - - - - -   L E F T   B L O C K   F A C E   - - - - - - - - - - -
  ADDRESS             TRACT   AREA   STR         PLACE   ZIP    TRANS   CRUZ
LOW    HIGH   BLOCK BASIC SUF CODE   JUR   MCD   CODE    CODE   ZONE    DIST

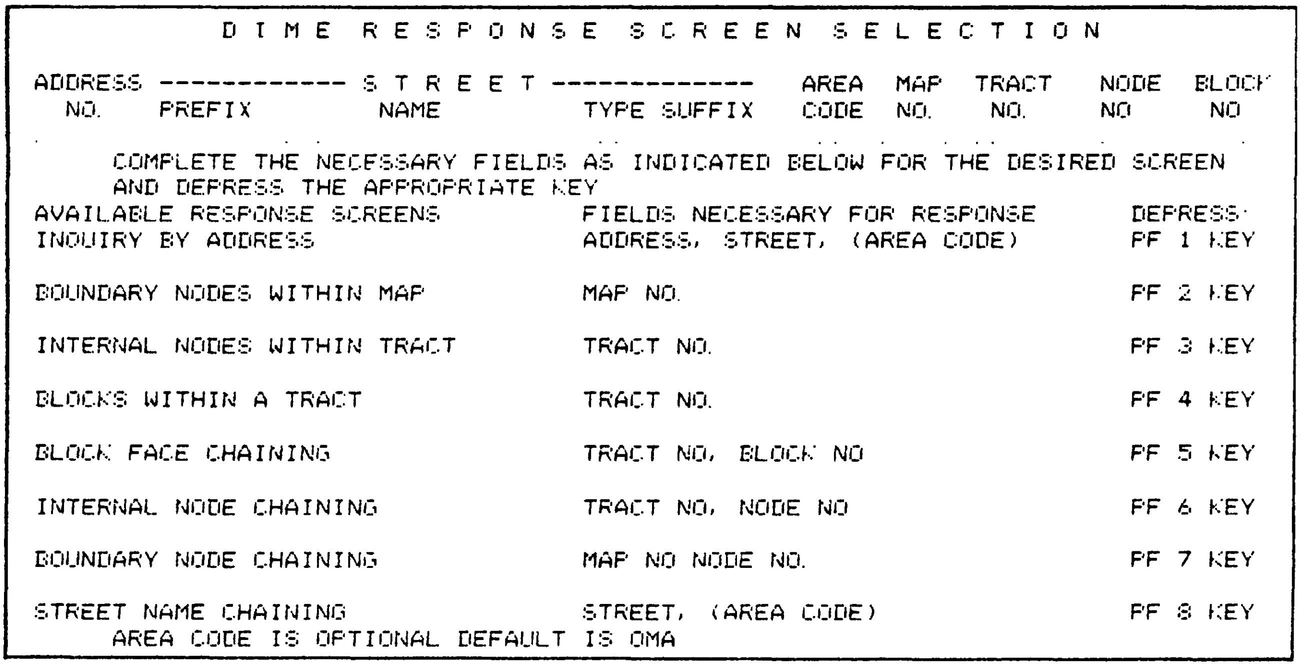

- - - - - - - - - - -   R I G H T   B L O C K   F A C E   - - - - - - - - - -
  ADDRESS             TRACT   AREA   STR         PLACE   ZIP    TRANS   CRUZ
LOW    HIGH   BLOCK BASIC SUF CODE   JUR   MCD   CODE    CODE   ZONE    DIST
```

RESPONSE 1

```
                   D I M E   F I L E   R E C O R D   U P D A T E
RECORD NUMBER 021315                                       ACTION CODE
        PRFX       STREET NAME        TYPE   SUF   NON-ST    COD LIM
               MADISON                ST
- - - - - - - - - - - - -   F R O M     N O D E   - - - - - - - - - - - - - -
           NODE   73    MAP  7                  STATE PLANE CODE 55
            MAP SET MILES         STATE PLANE           LAT. / LONG.
          X-COORD  Y-COORD      X-COORD  Y-COORD      X-COORD  Y-COORD
          015523   007337       2980677  0576650      0959357  411947
- - - - - - - - - - - - - - - T O     N O D E - - - - - - - - - - - - - - - -
           NODE   72    MAP  7                  STATE PLANE CODE 55
            MAP SET MILES         STATE PLANE           LAT  / LONG.
          X-COORD  Y-COORD      X-COORD  Y-COORD      X-COORD  Y-COORD
          015395   007332       2980000  0576595      0959381  411946
- - - - - - - - - - -   L E F T   B L O C K   F A C E   - - - - - - - - - - -
  ADDRESS             TRACT   AREA   STR         PLACE   ZIP    TRANS   CRUZ
LOW    HIGH   BLOCK BASIC SUF CODE   JUR   MCD   CODE    CODE   ZONE    DIST.
 1501   1699  403     28      OMA    OMA   075   1825    68107

- - - - - - - - - - -   R I G H T   B L O C K   F A C E   - - - - - - - - - -
  ADDRESS             TRACT   AREA   STR         PLACE   ZIP    TRANS   CRUZ
LOW    HIGH   BLOCK BASIC SUF CODE   JUR   MCD   CODE    CODE   ZONE    DIST.
 1500   1698  315     28      OMA    OMA   075   1825    68107
```

REQUEST MENU



```
              D I M E   R E S P O N S E   S C R E E N   S E L E C T I O N

ADDRESS ------------ S T R E E T -------------   AREA   MAP   TRACT    NODE   BLOCK
  NO.    PREFIX        NAME         TYPE SUFFIX   CODE   NO.    NO.     NO      NO

     COMPLETE THE NECESSARY FIELDS AS INDICATED BELOW FOR THE DESIRED SCREEN
     AND DEPRESS THE APPROPRIATE KEY
AVAILABLE RESPONSE SCREENS          FIELDS NECESSARY FOR RESPONSE       DEPRESS
INQUIRY BY ADDRESS                  ADDRESS, STREET, (AREA CODE)        PF 1 KEY

BOUNDARY NODES WITHIN MAP           MAP NO.                             PF 2 KEY

INTERNAL NODES WITHIN TRACT         TRACT NO.                           PF 3 KEY

BLOCKS WITHIN A TRACT               TRACT NO.                           PF 4 KEY

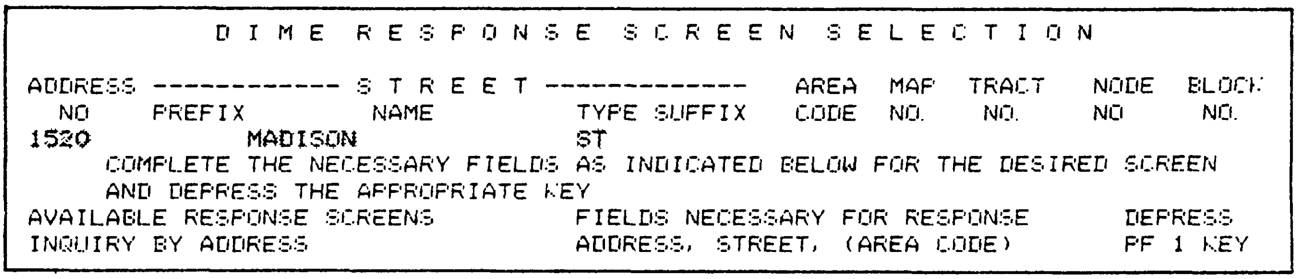
BLOCK FACE CHAINING                 TRACT NO, BLOCK NO                  PF 5 KEY

INTERNAL NODE CHAINING              TRACT NO, NODE NO                   PF 6 KEY

BOUNDARY NODE CHAINING              MAP NO NODE NO.                     PF 7 KEY

STREET NAME CHAINING                STREET, (AREA CODE)                 PF 8 KEY
     AREA CODE IS OPTIONAL DEFAULT IS OMA
```

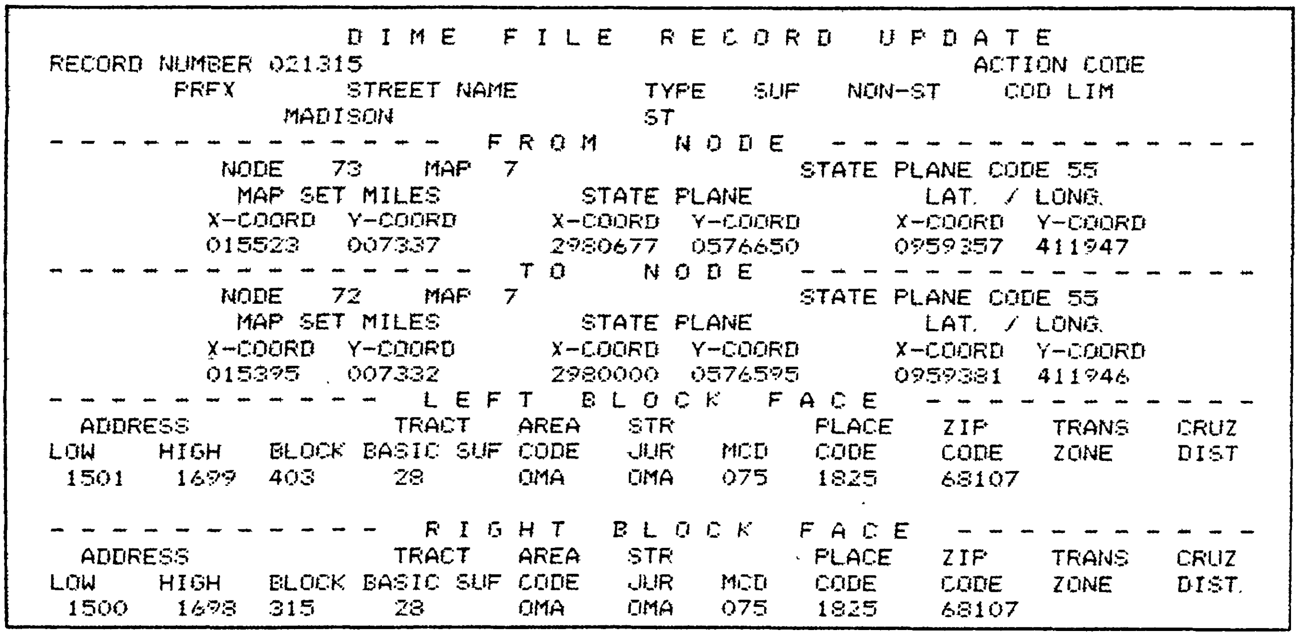
REQUEST 2



```
              D I M E   R E S P O N S E   S C R E E N   S E L E C T I O N

ADDRESS ------------ S T R E E T -------------   AREA   MAP   TRACT    NODE   BLOCK
  NO     PREFIX        NAME         TYPE SUFFIX   CODE   NO.    NO.     NO      NO.
1520            MADISON             ST
     COMPLETE THE NECESSARY FIELDS AS INDICATED BELOW FOR THE DESIRED SCREEN
     AND DEPRESS THE APPROPRIATE KEY
AVAILABLE RESPONSE SCREENS          FIELDS NECESSARY FOR RESPONSE       DEPRESS
INQUIRY BY ADDRESS                  ADDRESS, STREET, (AREA CODE)        PF 1 KEY
```

RESPONSE 2



```
                     D I M E   F I L E   R E C O R D   U P D A T E
RECORD NUMBER 021315                                          ACTION CODE
      PRFX        STREET NAME       TYPE   SUF   NON-ST      COD LIM
           MADISON                  ST
- - - - - - - - - - - - - -   F R O M    N O D E   - - - - - - - - - - - - - -
              NODE   73    MAP  7                 STATE PLANE CODE 55
               MAP SET MILES           STATE PLANE             LAT. / LONG.
              X-COORD  Y-COORD       X-COORD  Y-COORD        X-COORD  Y-COORD
              015523   007337        2980677  0576650        0959357  411947
- - - - - - - - - - - - - - -   T O     N O D E   - - - - - - - - - - - - - - -
              NODE   72    MAP  7                 STATE PLANE CODE 55
               MAP SET MILES           STATE PLANE             LAT. / LONG.
              X-COORD  Y-COORD       X-COORD  Y-COORD        X-COORD  Y-COORD
              015395   007332        2980000  0576595        0959381  411946
- - - - - - - - - - - -   L E F T   B L O C K   F A C E   - - - - - - - - - -
   ADDRESS                 TRACT   AREA   STR           PLACE    ZIP    TRANS   CRUZ
 LOW     HIGH   BLOCK  BASIC SUF   CODE   JUR     MCD   CODE     CODE   ZONE    DIST
  1501    1699   403       28      OMA    OMA     075   1825     68107

- - - - - - - - - - - -   R I G H T   B L O C K   F A C E   - - - - - - - - - -
   ADDRESS                 TRACT   AREA   STR           PLACE    ZIP    TRANS   CRUZ
 LOW     HIGH   BLOCK  BASIC SUF   CODE   JUR     MCD   CODE     CODE   ZONE    DIST.
  1500    1698   315       28      OMA    OMA     075   1825     68107
```

REQUEST 3

```
                D I M E   R E S P O N S E   S C R E E N   S E L E C T I O N

ADDRESS ------------ S T R E E T -------------  AREA  MAP   TRACT   NODE  BLOCK
  NO.    PREFIX         NAME        TYPE SUFFIX  CODE  NO.    NO.     NO.    NO.
                                                        7
    COMPLETE THE NECESSARY FIELDS AS INDICATED BELOW FOR THE DESIRED SCREEN
    AND DEPRESS THE APPROPRIATE KEY.
AVAILABLE RESPONSE SCREENS          FIELDS NECESSARY FOR RESPONSE       DEPRESS

BOUNDARY NODES WITHIN MAP           MAP NO.                             PF 2 KEY
```

RESPONSE 3

```
NODE   MAP  X-COORD  Y-COORD   NODE   MAP  X-COORD  Y-COORD   NODE   MAP  X-COORD  Y-COORD
 701    7   015153   010725     702    7   015196   010780     703    7   015217   010808
 704    7   015455   010834     705    7   015453   010729     706    7   015449   010649
 707    7   015450   010548     708    7   015447   010415     709    7   015453   010330
 710    7   015451   010250     711    7   015452   010075     712    7   015385   010040
 713    7   015333   010013     714    7   015303   009997     715    7   015287   009976
 716    7   015272   009976     717    7   015201   009971     718    7   015093   009975
 719    7   015021   009977     720    7   015523   010248     721    7   015594   010246
 722    7   015662   010246     723    7   015734   010246     724    7   015799   010245
 725    7   015802   010330     726    7   015804   010416     727    7   015803   010549
 728    7   015800   010651     729    7   015802   010834     730    7   015804   010909
 731    7   015870   010649     732    7   016004   010649     733    7   016072   010648
 734    7   016141   010646     735    7   016202   010648     736    7   016203   010671
 737    7   016302   010669     738    7   016347   010673     739    7   016397   010671
 740    7   016414   010671     741    7   019227   009977     742    7   016414   010618
 743    7   016474   010621     744    7   016574   010626     745    7   016689   010621
 746    7   015869   010245     747    7   015935   010243     748    7   015934   010185
 749    7   015932   010057     750    7   015992   010055     751    7   016052   010054
```

REQUEST 4

```
                D I M E   R E S P O N S E   S C R E E N   S E L E C T I O N

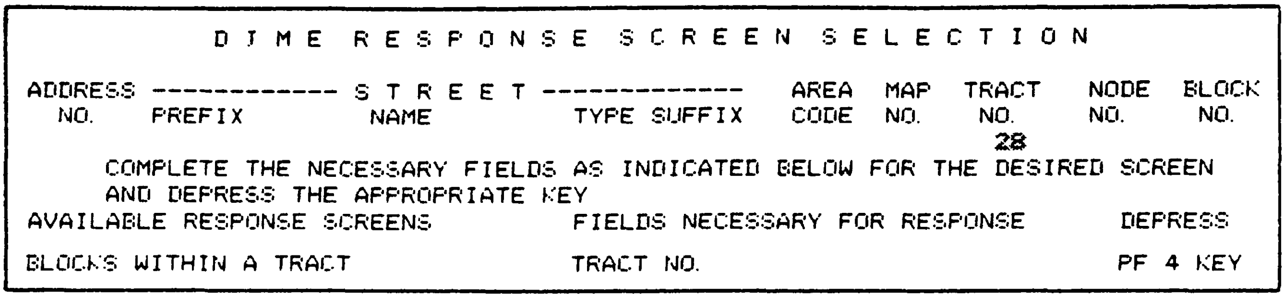
ADDRESS ------------ S T R E E T -------------  AREA  MAP   TRACT   NODE  BLOCK
  NO.    PREFIX         NAME        TYPE SUFFIX  CODE  NO.    NO      NO     NO.
                                                               28
    COMPLETE THE NECESSARY FIELDS AS INDICATED BELOW FOR THE DESIRED SCREEN
    AND DEPRESS THE APPROPRIATE KEY
AVAILABLE RESPONSE SCREENS          FIELDS NECESSARY FOR RESPONSE       DEPRESS

INTERNAL NODES WITHIN TRACT         TRACT NO.                           PF 3 KEY
```

RESPONSE 4

```
NODE   MAP  X-COORD  Y-COORD   NODE   MAP  X-COORD  Y-COORD   NODE   MAP  X-COORD  Y-COORD
   1    7   015009   007961       2    7   015076   007959       3    7   015015   007839
   4    7   015078   007844       5    7   015149   007843       6    7   015216   007841
   7    7   015279   007846       8    7   015342   007845       9    7   015406   007868
  10    7   015420   007824      11    7   015466   007887      13    7   015008   007716
  14    7   015076   007714      15    7   015153   007719      16    7   015218   007718
  17    7   015289   007716      18    7   015344   007715      19    7   015407   007720
  20    7   015512   007717      21    7   015589   007724      22    7   015637   007723
  23    7   015776   007694      24    7   015858   007729      25    7   015080   007583
  26    7   015150   007581      27    7   015188   007587      28    7   015213   007586
  29    7   015283   007591      30    7   015346   007590      31    7   015388   007589
  32    7   015411   007588      33    7   015413   007653      34    7   015458   007594
  35    7   015512   007656      36    7   015511   007591      37    7   015594   007595
  38    7   015642   007596      39    7   015145   007525      40    7   015193   007523
  41    7   015240   007524      42    7   015285   007530      43    7   015343   007525
  44    7   015391   007524      45    7   015460   007527      46    7   015518   007531
  47    7   015643   007534      48    7   015197   007468      49    7   015240   007466
  50    7   015283   007465      51    7   015347   007463      52    7   015390   007462
```

REQUEST 5

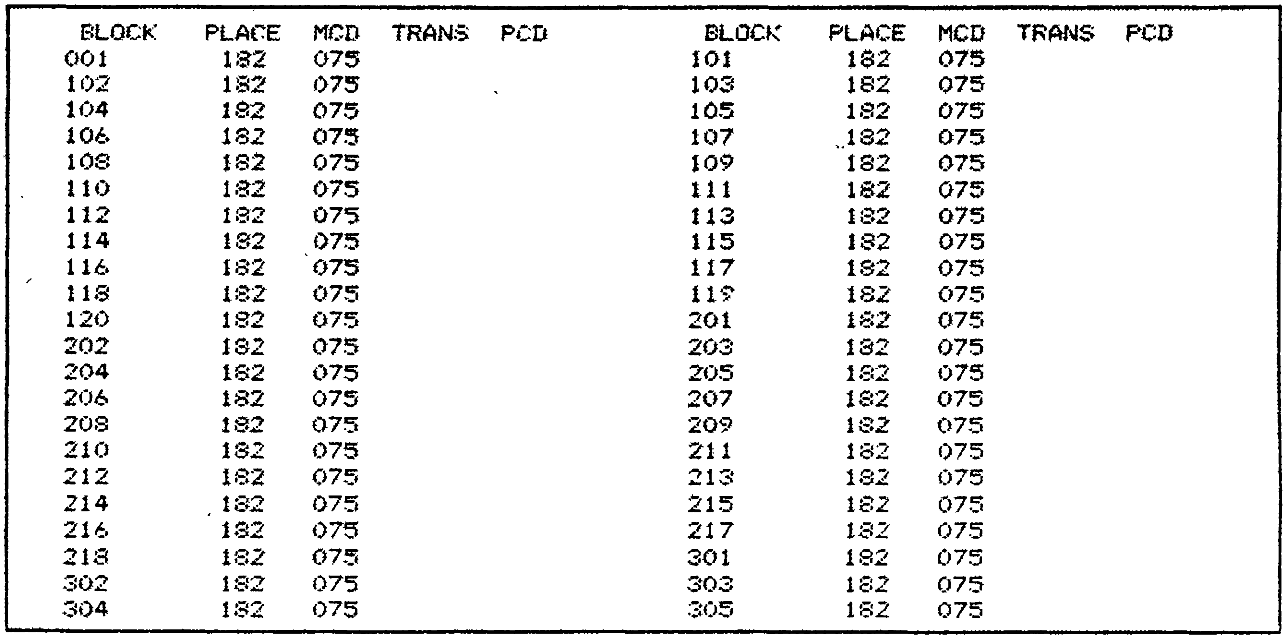


```
                D I M E   R E S P O N S E   S C R E E N   S E L E C T I O N

ADDRESS ------------ S T R E E T -------------   AREA  MAP   TRACT    NODE  BLOCK
  NO.    PREFIX         NAME          TYPE SUFFIX   CODE  NO.    NO.     NO.    NO.
                                                                 28
     COMPLETE THE NECESSARY FIELDS AS INDICATED BELOW FOR THE DESIRED SCREEN
     AND DEPRESS THE APPROPRIATE KEY
AVAILABLE RESPONSE SCREENS            FIELDS NECESSARY FOR RESPONSE       DEPRESS

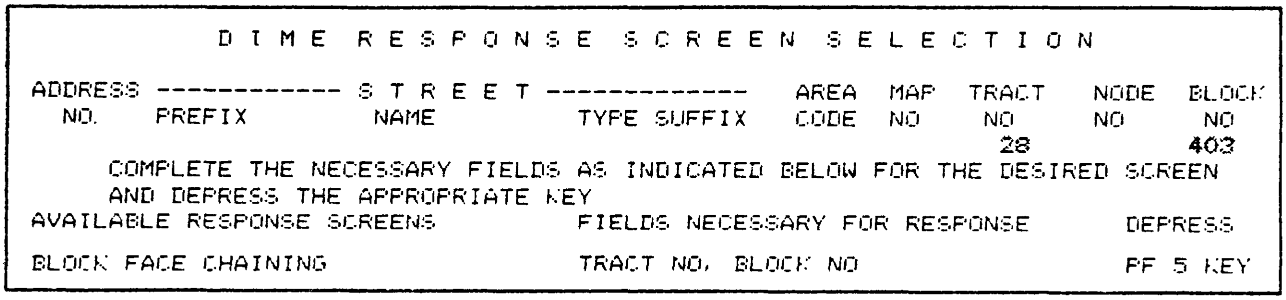
BLOCKS WITHIN A TRACT                 TRACT NO.                           PF 4 KEY
```

RESPONSE 5



```
   BLOCK    PLACE   MCD   TRANS   PCD              BLOCK    PLACE   MCD   TRANS   PCD
    001      182    075                             101      182    075
    102      182    075                             103      182    075
    104      182    075                             105      182    075
    106      182    075                             107      182    075
    108      182    075                             109      182    075
    110      182    075                             111      182    075
    112      182    075                             113      182    075
    114      182    075                             115      182    075
    116      182    075                             117      182    075
    118      182    075                             119      182    075
    120      182    075                             201      182    075
    202      182    075                             203      182    075
    204      182    075                             205      182    075
    206      182    075                             207      182    075
    208      182    075                             209      182    075
    210      182    075                             211      182    075
    212      182    075                             213      182    075
    214      182    075                             215      182    075
    216      182    075                             217      182    075
    218      182    075                             301      182    075
    302      182    075                             303      182    075
    304      182    075                             305      182    075
```

REQUEST 6

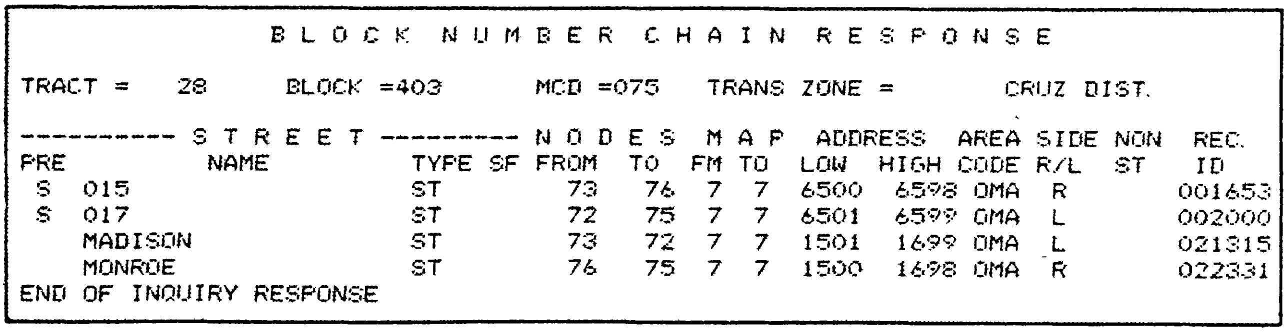


```
                D I M E   R E S P O N S E   S C R E E N   S E L E C T I O N

ADDRESS ------------ S T R E E T -------------   AREA  MAP   TRACT    NODE  BLOCK
  NO.    PREFIX         NAME          TYPE SUFFIX   CODE  NO     NO      NO     NO
                                                                 28             403
     COMPLETE THE NECESSARY FIELDS AS INDICATED BELOW FOR THE DESIRED SCREEN
     AND DEPRESS THE APPROPRIATE KEY
AVAILABLE RESPONSE SCREENS            FIELDS NECESSARY FOR RESPONSE       DEPRESS

BLOCK FACE CHAINING                   TRACT NO, BLOCK NO                  PF 5 KEY
```

RESPONSE 6

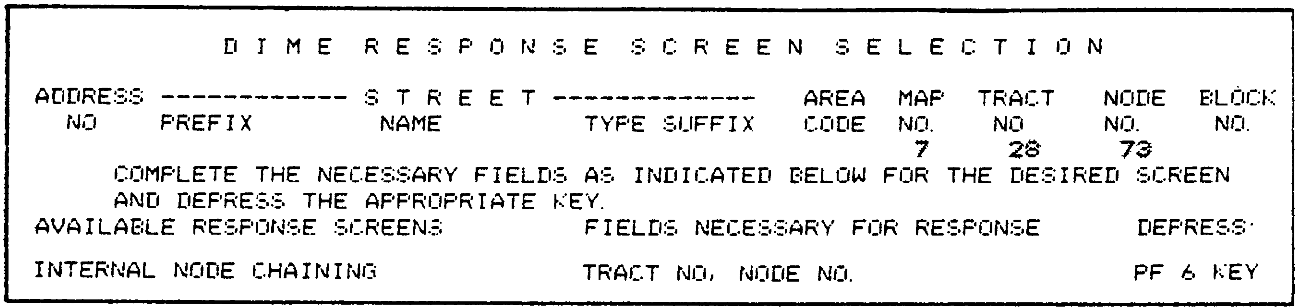


```
                  B L O C K   N U M B E R   C H A I N   R E S P O N S E

TRACT =    28     BLOCK =403       MCD =075    TRANS ZONE =        CRUZ DIST.

---------- S T R E E T --------- N O D E S  M A P  ADDRESS   AREA SIDE NON   REC.
PRE           NAME           TYPE SF FROM   TO  FM TO  LOW   HIGH CODE R/L  ST    ID
 S  015                       ST        73   76   7  7  6500   6598 OMA  R        001653
 S  017                       ST        72   75   7  7  6501   6599 OMA  L        002000
    MADISON                   ST        73   72   7  7  1501   1699 OMA  L        021315
    MONROE                    ST        76   75   7  7  1500   1698 OMA  R        022331
END OF INQUIRY RESPONSE
```

REQUEST 7

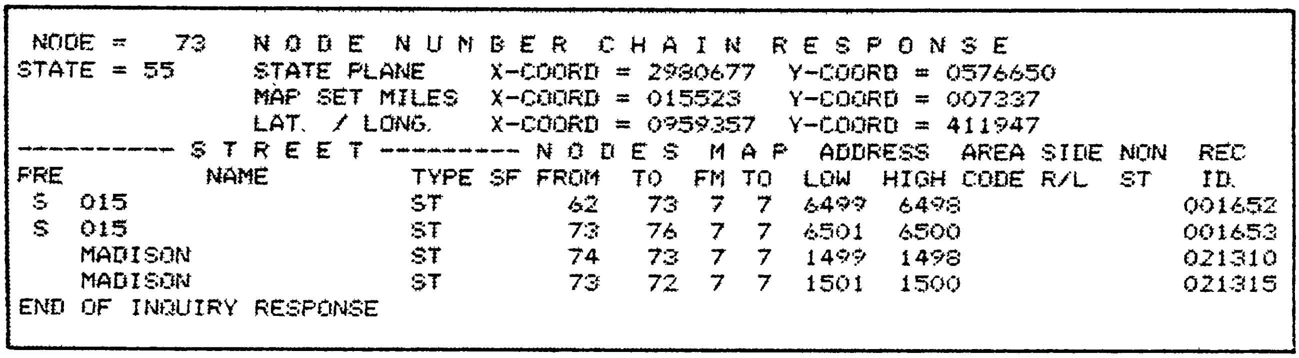


```
                D I M E   R E S P O N S E   S C R E E N   S E L E C T I O N

 ADDRESS ------------ S T R E E T -------------   AREA  MAP   TRACT   NODE  BLOCK
   NO    PREFIX         NAME           TYPE SUFFIX   CODE  NO.    NO      NO.    NO.
                                                         7     28      73
       COMPLETE THE NECESSARY FIELDS AS INDICATED BELOW FOR THE DESIRED SCREEN
       AND DEPRESS THE APPROPRIATE KEY.
 AVAILABLE RESPONSE SCREENS             FIELDS NECESSARY FOR RESPONSE        DEPRESS

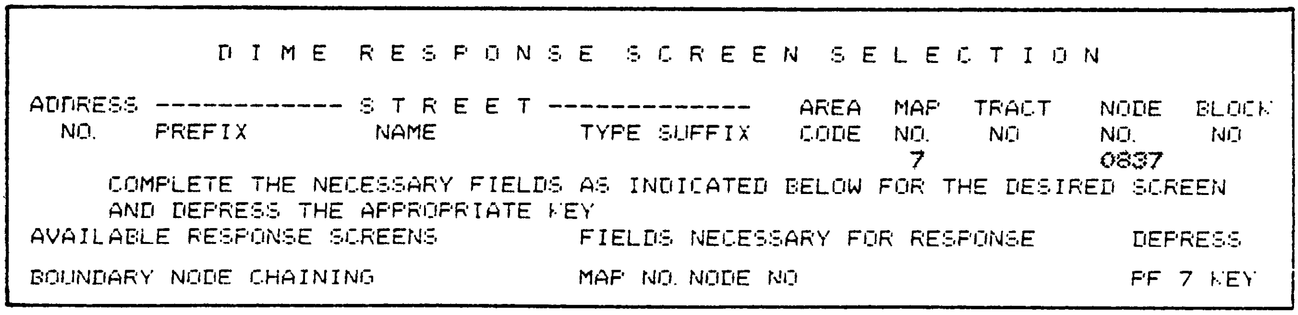
 INTERNAL NODE CHAINING                 TRACT NO, NODE NO.                   PF 6 KEY
```

RESPONSE 7



```
 NODE =    73   N O D E  N U M B E R  C H A I N  R E S P O N S E
STATE = 55      STATE PLANE    X-COORD = 2980677  Y-COORD = 0576650
                MAP SET MILES  X-COORD = 015523   Y-COORD = 007337
                LAT. / LONG.   X-COORD = 0959357  Y-COORD = 411947
---------- S T R E E T --------- N O D E S  M A P  ADDRESS  AREA SIDE NON  REC
PRE          NAME          TYPE SF FROM  TO  FM TO  LOW  HIGH CODE R/L  ST   ID.
 S  015                    ST        62  73  7  7  6499  6498                001652
 S  015                    ST        73  76  7  7  6501  6500                001653
    MADISON                ST        74  73  7  7  1499  1498                021310
    MADISON                ST        73  72  7  7  1501  1500                021315
END OF INQUIRY RESPONSE
```

REQUEST 8

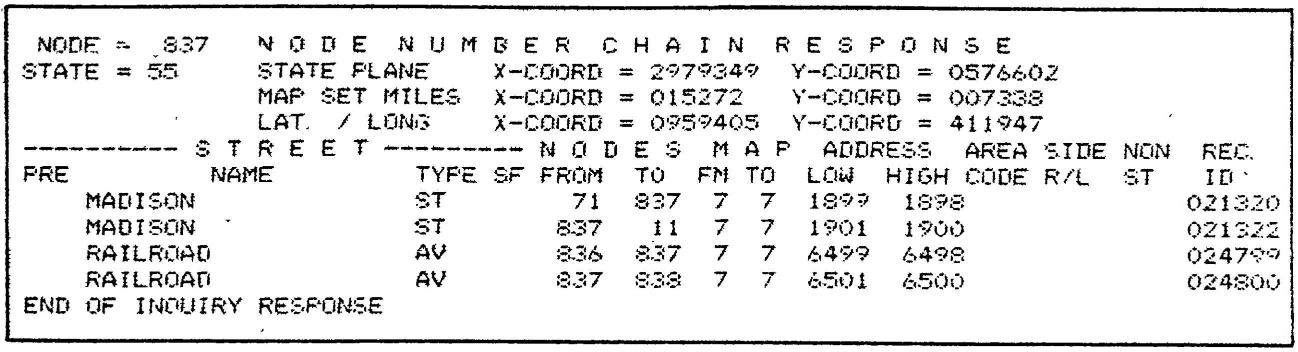


```
                D I M E   R E S P O N S E   S C R E E N   S E L E C T I O N

 ADDRESS ------------ S T R E E T -------------   AREA  MAP   TRACT   NODE  BLOCK
   NO.   PREFIX         NAME           TYPE SUFFIX   CODE  NO.    NO      NO.    NO
                                                         7            0837
       COMPLETE THE NECESSARY FIELDS AS INDICATED BELOW FOR THE DESIRED SCREEN
       AND DEPRESS THE APPROPRIATE KEY
 AVAILABLE RESPONSE SCREENS             FIELDS NECESSARY FOR RESPONSE        DEPRESS

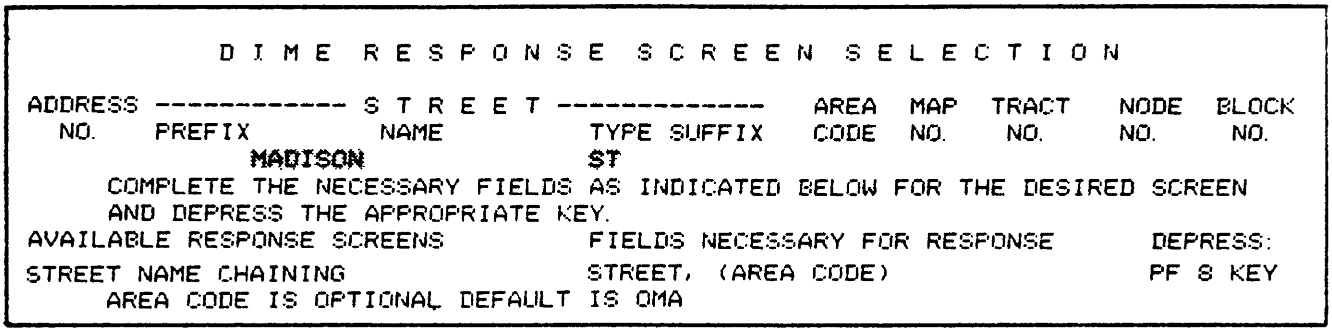
 BOUNDARY NODE CHAINING                 MAP NO. NODE NO                      PF 7 KEY
```

RESPONSE 8



```
 NODE =   837   N O D E  N U M B E R  C H A I N  R E S P O N S E
STATE = 55      STATE PLANE    X-COORD = 2979349  Y-COORD = 0576602
                MAP SET MILES  X-COORD = 015272   Y-COORD = 007338
                LAT. / LONG    X-COORD = 0959405  Y-COORD = 411947
---------- S T R E E T --------- N O D E S  M A P  ADDRESS  AREA SIDE NON  REC.
PRE          NAME          TYPE SF FROM  TO  FM TO  LOW  HIGH CODE R/L  ST   ID
    MADISON                ST        71 837  7  7  1899  1898                021320
    MADISON                ST       837  11  7  7  1901  1900                021322
    RAILROAD               AV       836 837  7  7  6499  6498                024799
    RAILROAD               AV       837 838  7  7  6501  6500                024800
END OF INQUIRY RESPONSE
```

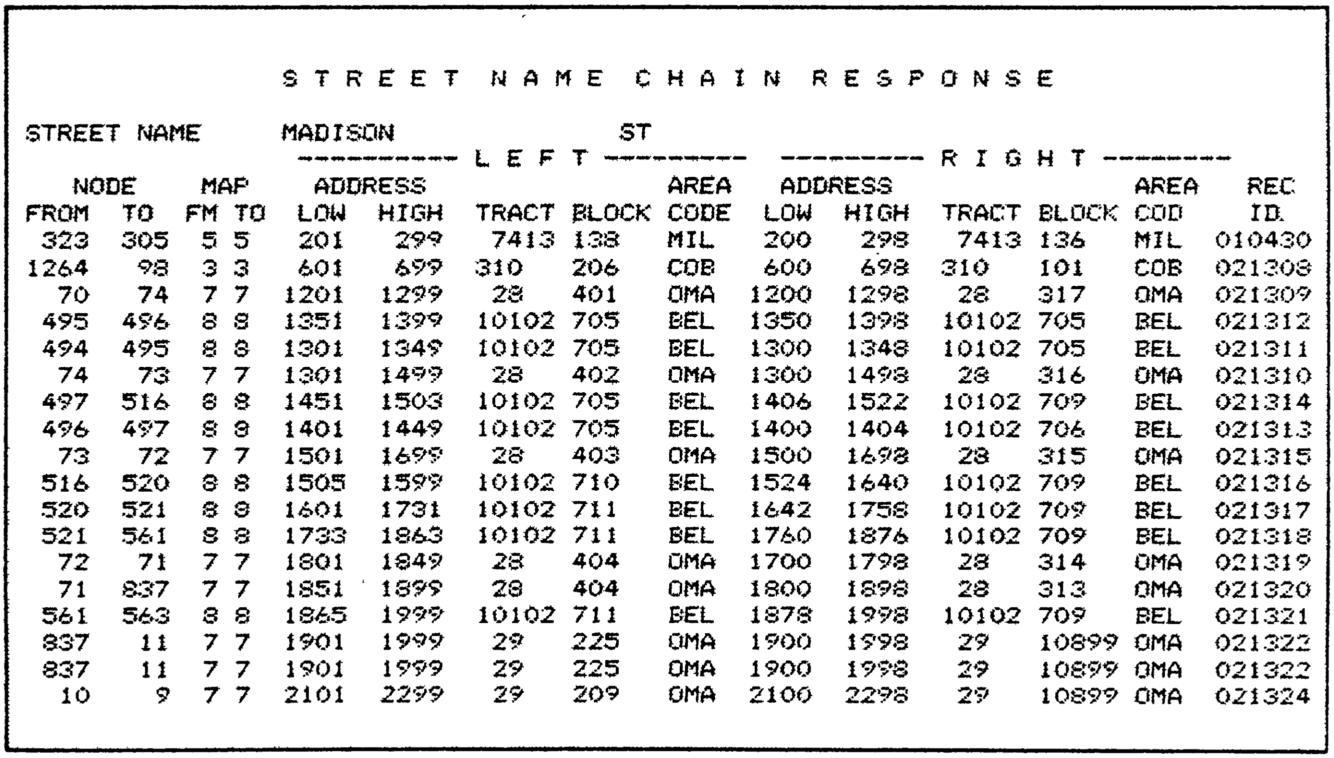
REQUEST 9



```
                D I M E   R E S P O N S E   S C R E E N   S E L E C T I O N

ADDRESS ------------ S T R E E T -------------   AREA  MAP   TRACT   NODE  BLOCK
  NO.   PREFIX         NAME         TYPE SUFFIX   CODE  NO.    NO.     NO.    NO.
             MADISON                ST
     COMPLETE THE NECESSARY FIELDS AS INDICATED BELOW FOR THE DESIRED SCREEN
     AND DEPRESS THE APPROPRIATE KEY.
AVAILABLE RESPONSE SCREENS          FIELDS NECESSARY FOR RESPONSE       DEPRESS:
STREET NAME CHAINING                STREET, (AREA CODE)                 PF 8 KEY
     AREA CODE IS OPTIONAL DEFAULT IS OMA
```

RESPONSE 9



```
                  S T R E E T   N A M E   C H A I N   R E S P O N S E

STREET NAME      MADISON              ST
                 ----------- L E F T ---------  --------- R I G H T --------
  NODE     MAP    ADDRESS                      AREA    ADDRESS                    AREA    REC
FROM   TO  FM TO  LOW   HIGH   TRACT BLOCK CODE   LOW   HIGH   TRACT BLOCK COD     ID.
 323  305  5 5   201    299    7413 138   MIL    200    298    7413 136   MIL  010430
1264   98  3 3   601    699   310   206   COB    600    698   310   101   COB  021308
  70   74  7 7  1201   1299    28   401   OMA   1200   1298    28   317   OMA  021309
 495  496  8 8  1351   1399   10102 705   BEL   1350   1398   10102 705   BEL  021312
 494  495  8 8  1301   1349   10102 705   BEL   1300   1348   10102 705   BEL  021311
  74   73  7 7  1301   1499    28   402   OMA   1300   1498    28   316   OMA  021310
 497  516  8 8  1451   1503   10102 705   BEL   1406   1522   10102 709   BEL  021314
 496  497  8 8  1401   1449   10102 705   BEL   1400   1404   10102 706   BEL  021313
  73   72  7 7  1501   1699    28   403   OMA   1500   1698    28   315   OMA  021315
 516  520  8 8  1505   1599   10102 710   BEL   1524   1640   10102 709   BEL  021316
 520  521  8 8  1601   1731   10102 711   BEL   1642   1758   10102 709   BEL  021317
 521  561  8 8  1733   1863   10102 711   BEL   1760   1876   10102 709   BEL  021318
  72   71  7 7  1801   1849    28   404   OMA   1700   1798    28   314   OMA  021319
  71  837  7 7  1851   1899    28   404   OMA   1800   1898    28   313   OMA  021320
 561  563  8 8  1865   1999   10102 711   BEL   1878   1998   10102 709   BEL  021321
 837   11  7 7  1901   1999    29   225   OMA   1900   1998    29   10899 OMA  021322
 837   11  7 7  1901   1999    29   225   OMA   1900   1998    29   10899 OMA  021322
  10    9  7 7  2101   2299    29   209   OMA   2100   2298    29   10899 OMA  021324
```

AN INTERACTIVE GBF CREATION AND COMPUTER MAPPING SYSTEM

Lawrence Hugg
Lawrence Sniderman
Michigan State University

INTRODUCTION

The Office of Health Services Education and Research (OHSER), of the College of Human Medicine at Michigan State University, has been producing computer generated thematic maps since 1968. We have been utilizing them in conjunction with efforts to create continuously monitored profiles of the health status of various urban communities in the State of Michigan. In this endeavor, OHSER has served as a consultant to help local governmental agencies initiate and maintain various computer assisted statistical and cartographic systems for the processing and display of geographic information. For the most part, these services have included questionnaire development, coding and editing procedures, statistical analysis, GBF creation, and computer mapping.

Since many people with varying capabilities and divergent purposes use our facilities for computer mapping, several concerns have emerged. One of the concerns results from possible delays in creating and processing Geographic Base Files (GBF) suitable for thematic mapping. While computer maps are quick and efficient to use in the long run, their implementation may be a long and arduous process. A second problem encountered concerns a method by which users can produce computer maps. This method would have to be versatile, easily understood, have user feedback and relatively quick turnaround.

An interactive system for the creation of GBFs and computer maps has been designed in an effort to expedite both processes. The system, an integrated set of FORTRAN programs, is designed for general use in an on-line interactive mode. The first part of the system, the GBF creation process, takes a set of digitized coordinated nodes and combines it with a defined set of outline strings to produce master GBFs. Other routines are used to create GBFs in a suitable form for thematic mapping with the SYMAP,[1] CASP,[2] and CALFORM[3] computer mapping programs. The second part of the system, the interactive computer mapping preprocessor, enables users to produce computer maps from various on-line GBF files using their own data and selected parameters. The user has a choice of different sizes, class intervals, and selected legend information for each particular map. Output, in the case of SYMAP, is either sent directly to the user's terminal or routed to a line printer. CASP and CALFORM maps are sent directly to an off-line plotter. With this system, the user can make line printer maps for immediate use as "scratch" maps and plotter maps for more finished production work.

EDITOR'S NOTE: Support for this project contributed in part by funds from ECHO PROGRAM, Genesee County Health Department.

GBF CREATION PROCESS

The creation of a GBF is essential for computer mapping in that it defines the individual zones that are assigned statistical values for choropleth mapping or identified the points used to interpolate statistical surfaces for isopleth mapping. In our work, we have found that choropleth mapping has much utility for both the analysis and presentation of geographic information. Therefore, all of our GBF creation efforts have been pointed towards compiling GBFs solely for choropleth mapping.

The GBF creation process is a relatively easy to follow procedure integrating a set of digitized nodes with a set of defined node strings combined in correct order to achieve a GBF suitable for computer mapping. Other elements in the process include debugging, adjusting, and conversion techniques.

To begin the process, a suitable base map showing the configuration of the various areas is needed. Nodes, which are points on the map where lines intersect, change direction, or terminate, are marked and assigned a unique number. The base map is then put onto a digitizing table where the cartesian coordinates of each node, along with its unique node number, is recorded in sequence.

Having defined all the necessary nodes, the next step is to ascertain the node strings which define the outline of each individual area or zone. The zone node string definitions are a set of instructions expressed in tabular form, that specify, in clockwise order, every node in each zone within the GBF.

The cartesian coordinates of each node and the zone node string definitions are stored on-line in the computer and are combined through a program called MAKEMAP to produce a GBF in our central format. The central format contains a set of records for each zone in the GBF. Each record contains information for each node that is used to define a particular zone. Each record includes the X,Y coordinates of the node, the node number, and the zone number that is being defined.

At this stage error checking and debugging are carried out with the help of several pen plotter routines. There are two types of errors possible in any GBF created by the present process. The X,Y coordinates may be located inaccurately or improperly referenced. The zone node string definitions may be incorrect or incomplete. The program PLTDIG plots all of the zones of the FBF in the scale that it was originally digitized. PTPLOT plots the node number for each node of the FBF at the X,Y location of that node. By overlaying the plot from PLTDIG on the base map and referencing the plot made by PTPLOT, one can determine if the node X,Y coordinates are inaccurate or if the zone node string was incorrectly defined. Once an error has been found, it can be corrected by going back to either the zone node string definition file or the digitized X,Y coordinate node file to make necessary changes. At this point, the original GBF is then debugged or a new GBF can be constructed.

After all errors are found in the GBF and it has been verified, it needs to be adjusted to a standardized form matching the other GBFs in our library. A routine that rotates the entire GBF to prescribed angle, adjusts all node X,Y coordinates to a 0,0 origin, and scales the GBF to a standard format is utilized to make these changes. Simple line plots are used to verify these changes after they have been made.

We use three different mapping programs; SYMAP, CASP, and CALFORM, each requiring a GBF in a slightly different format. The central format GBF needs to be converted to a format suitable for use in these three computer mapping programs. The GBF is converted into each of the other formats and entered into the MAPSET interactive computer mapping system.

It should be noted that we also have routines that convert any of the three mapping programs GBFs back to the central format. Thus if we receive a GBF from an outside source in either SYMAP, CASP or CALFORM formats, we can convert it to our central format and adjust it for entry into the system.

One aspect of our method of creating GBFs that adds to its flexibility is the ability to produce several different GBFs from a single set of digitized nodes. By defining all the nodes needed, different zone node string definitions can be used to create several GBFs. This can be useful when more than one GBF is needed for a particular place. For example, GBFs of census tracts, police precincts and school attendance areas can be constructed from one set of digitized nodes and the properly enumerated zone node string definitions.

INTERACTIVE COMPUTER MAPPING SYSTEM

As our library of GBFs grew and demands for computer generated maps increased, we found it difficult to remember what GBF corresponded with what data set and which parameters were used in each appropriate situation. Further, much of our time was taken up in just producing maps which did not allow us adequate time to study in-depth the data being mapped. Turnaround time was also very slow since we were operating in a batch mode. What we needed was in integrated system that would combine the previously created GBFs with data under the constraints of certain needed parameters to produce computer maps interactively and so simply that any user with a minimal amount of training could produce his own maps. This system would prove expecially useful in our workings with users in local community governmental offices in their needs for the cartographic display of information.

MAPSET is such a preprocessor system for making computer maps. MAPSET acts as an interface between the interactive user and the batch oriented computer mapping programs. It allows anyone with a minimum of computer mapping knowledge or knowledge about computers to make a computer generated map. One can enter data and save it as a permanent file, or use data already on a permanent file, specify several different cartographic parameters, and obtain a SYMAP, CASP, or CALFORM computer choropleth map for any GBF in the MAPSET system library, all interactively by using a computer initiated question-answer routine.

A computer initiated question-answer routine was developed in an attempt to lead users through the process of creating a computer map. The user is prompted through "menu selection" for the information needed to bring together a GBF, data, and several cartographic specifications. Receiving responses from the user, the system checks for valid replies, takes appropriate action, and prompts for a new response. The entire process terminates when the user has finished producing one or more computer maps.

Our maps are produced for two main purposes: for use in publication and for immediate study of geographic data. We included SYMAP in the MAPSET system to allow the user to produce low quality line printer maps at a computer terminal in about ten minutes. The SYMAP maps are used as "scratch" maps for the immediate interpretation and analysis of geographic information and for making decisions about the choice of appropriate cartographic parameters (shadings, class intervals, etc.) for more finished work. These are quick to produce but too low quality for publication. For publication purposes, we found that CASP and CALFORM maps were of a high enough quality for reproduction and printing. However, they have to be disposed to a pen plotter extending turnaround time to about one day.

CONCLUSIONS

The interactive GBF creation and computer mapping system has been utilized in health planning and urban policy in a variety of situations. The bulk of our work has been in published reports of various urban communities on such topics as social indicator mapping, environmental deficiency reporting, and health and medical care status. Individual researchers have used the system for their own varied research directions in analyzing geographic data. Instructors at the College of Human Medicine have used maps produced by the system for their teaching needs. The simplicity, flexibility, and rapidity of the system has enabled many individuals to use computer maps, opening up this form of graphic presentation to a wider audience. The overall role of the interactive GBF creation and computer mapping system in a daily work schedule has been to decrease the turnaround time of both GBF creation and computer mapping as well as allowing easy access for general users needing mapped information in a relatively short period of time.

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Harvard University

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Seminar on Urban Information Systems

SEMINAR ON URBAN INFORMATION SYSTEMS

This seminar was held in two parts. The first session, held Tuesday afternoon, was chaired by DUANE MARBLE of the State University of New York at Buffalo. The second session was held on Wednesday and was chaired by BARRY WELLAR of the Ministry of State for Urban Affairs, Ottawa, Canada. At the first session representatives of State and local governments discussed local mapping efforts based on local information systems. The second session focused on current research and experience in the field of urban information systems.

DELMAR ANDERSON of the Central Intelligence Agency described the use of analytical maps for showing the results of a model for school locational planning in Topeka, Kansas. Urban information systems can provide valuable inputs to the decision-making process. Toward this end a model, based on linear programming techniques, for the locational planning of schools was presented. The major problems addressed were residential area growth, fulfillment of desegregation requirements, and school attendance boundaries. A favorable response from school officials resulted from the analysis and interpretation of maps produced from the findings of this model.

RONALD DOMSCH and KENNETH MAI are with the planning departments of Wyandotte County and Kansas City, Kansas, respectively. Their presentation, "Computer Mapping and Its Impact on Kansas City, Kansas, and Wyandotte County," focused on various forms (choropleth, dot and street) of mapping in Kansas City through use of the GBF/DIME-File. Rather than suggesting the use of a massive, all-purpose program, emphasis was directed on small modular programs linked with different operational files. Some of the uses of urban mapping included a street sign inventory for highway safety, various population distributions, and street maps for repair bids.

DUANE MARBLE, session chairman, addressed the keynote problem of exchange in his paper entitled, "Technology Transfer and Urban Information Systems: Some Common Problems." The author stressed the high occurence of redundency in computerized efforts, especially in the field of computer graphics and mapping. As a partial solution to this dilemma, it was suggested that greater use be made of the Geography Program Exchange, the Continuing Software Inventory, and Case Studies of Geographic Information Systems.

VICTOR DAVIS of the City of Atlanta described the "Georgia Computer Mapping Program," a joint effort of four governmental agencies and three private utilities. The presentation was introduced by a short film depicting the dangers in a lack of knowledge and a lack of common efforts for computer mapping, particularly in the context of public utilities. A plea was made for accuracy, cooperation and uniformity in urban mapping. The mapping advantages possible from an address-coded file keyed to building centroids were stressed.

At the second session, chairman BARRY WELLAR commented on the roles of computer-assisted information systems and computer-assisted cartography in the field of urban governance. His paper was titled "Computer-Assisted Information Systems and Computer-Assisted Cartography: Tools or Tinker Toys of Urban Governance?." He examined this relationship in terms of the purposes, ways, and extent of use. Of particular importance was the matter of how the technologies have evolved vis-a-vis changes over time on the part of persons and activities associated with urban governance.

NICHOLAS VAN DRIEL of the U.S. Geological Survey described a new method by which USGS is able to communicate geologic information to planners for land use planning. Composite factor mapping is featured and is useful for identifying various land use areas. The cost of such a method is minimal and the system easy to operate. The computer mapping system used cell-formulated storage, analysis and output to combine geologic, hydrologic and other physical information for environmental analyses in Montgomery County, Maryland. The paper is entitled "Geologic Information in a Computer Mapping System for Land Use Planning."

GEORGE FARNSWORTH of the University of Southern California discussed the ZIPSTAN Standardization System, a computer methodology for standardizing street addresses to facilitate retrieval of geographic coordinates from geographic base files for mapping purposes. One reason computer-assisted cartography is not extensively employed in urban information systems is the problem of data preparation. One approach to the problem is the ZIPSTAN program which converts many variations in street addresses to a standard format. The system is available from the Bureau of the Census at a nominal cost.

CHARLES E. BARB, JR. of the University of Oklahoma described principal concepts and determinants in the evolution of DIME technology and compared current technology with observed interests and needs of municipal operating agencies. This technology, as originally developed by the Census Bureau, is of marginal quality and much time, effort and expense is necessary to operationalize the GBF/DIME-Files for particular needs. He concluded that there is only limited congruence between DIME technology and local agency interests and needs.

ANALYTICAL MAPS FOR SCHOOL LOCATIONAL PLANNING

D. E. Anderson
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INTRODUCTION

School locational planning, expressed perhaps in more contemporary terms, is viewed as the planning activity that attempts to answer such questions as:

- Where to locate individual school attendance zone boundaries?
- How should students be allocated to schools to satisfy desegregation requirements?
- Which schools should be closed when schools are underutilized?
- How should the city grow relative to existing school facilities?
- Where should additional classrooms (protables, in particular) be built?
- Where should new schools be built?
- How many buses are needed and how should they be routed?

These questions consume much time and are seldom done with the most efficient tools available. This paper illustrates how maps of linear programming solutions, which are referred to as analytical maps, can aid in providing meaningful and expedient answers to many of the questions posed above.1/ Examples of such maps are presented here based upon data collected in 1972 for a case study of Topeka, Kansas, a city with a population of about 150,000. The emphasis of the paper is on the presentation of the results of a linear programming application for school locational planning through the use of maps rather than on the formulation of models.

THE MODELS

Two student-allocation models based on linear programming were used in the Topeka case study. These two models minimize total student travel distance to schools. One model satisfies this objective when students are allocated to neighborhood schools; the other is a model for desegregation. That is, constraining equations restrict student assignments to schools by race. Both models state that all students

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EDITOR'S NOTE: The research on which this paper is based was conducted by the author in conjunction with fulfilling the requirements for the Ph.D. in the Department of Geography and Meteorology at the University of Kansas, Lawrence, Kansas. The views expressed are those of the author and in no way represent those of the Central Intelligence Agency.

must be assigned to schools while school seating capacity cannot be exceeded in the process. A summary of the model objectives and the restrictions on the objective functions is provided in the table below.

Two Types of Student-Allocation Models

	NEIGHBORHOOD	DESEGREGATION
OBJECTIVE:	Minimize Total Student Travel to Schools	Minimize Total Student Travel to Schools
WHEN:	All Students Must Be Assigned	All Students Must Be Assigned
	School Seating Capacity Cannot Be Exceeded	School Seating Capacity Cannot Be Exceeded
		Student Assignments By Race Cannot Exceed Some Fraction of School Seating Capacity
		Student Assignments By Race Must Satisfy Some Minimum Fraction of School Seating Capacity

DATA REQUIREMENTS

The models specify three principal data requirements:

- Collection of data that permits mapping the spatial distribution of student residence by grade level.
- Acquisition of data that characterizes the inconvenience of travel between student residence and schools, such as travel distance, vehicle operating costs, or travel time.
- Acquisition of information that defines the effective seating capacities of schools.

In the case of the desegration type student-allocation model, the seating capacities of schools and the spatial distribution of student residence have to be known by race as well as by grade level.

School administrations typically record the location of student homes by street address. Because of this, a capability for matching students to a given geographical location must be obtained in order to use the student-allocation models. Where the U.S. Bureau of the Census DIME files have been created, a basic mapping tool is available from which student address matching can proceed for determining the exact number of students by grade level living on a given block.2/ In the case of Topeka, address matching is accomplished manually. This manual operation in 1972 involved aggregating the exact number of students by grade level for some 24,000 students into blocks which were subsequently coded for computer retrieval.

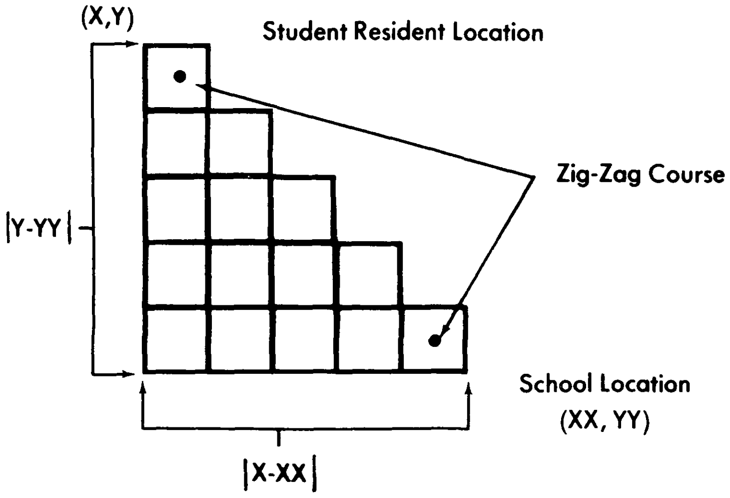
The distance students walk to schools, as approximated by the computer calculation of the horizontal plus vertical differences between two sets of x,y coordinates (referred to as rectilinear distance in (Figure 1), was used rather than vehicle operating cost or travel time as the measure of student travel to schools.

The use of the other two measures (vehicle operating costs and travel time) did not seem particularly appropriate at the time of the study since Topeka was then transporting only some 200 to 300 special education students of the 24,000 or so students enrolled in the school district.

Information defining the effective school capacities was also obtained from the school administration. The map of Figure 2 shows the approximate size and date of construction for the twelve junior high schools that were in use in 1972 and upon which the case study focused.

Figure 1

RECTILINEAR DISTANCE



Formula for Calculating Rectilinear Distance (D):

$D = |x-xx| + |y-yy|$,

Where

(x,y) is the centroid location of the student resident location

(xx,yy) is the centroid location of the school site.

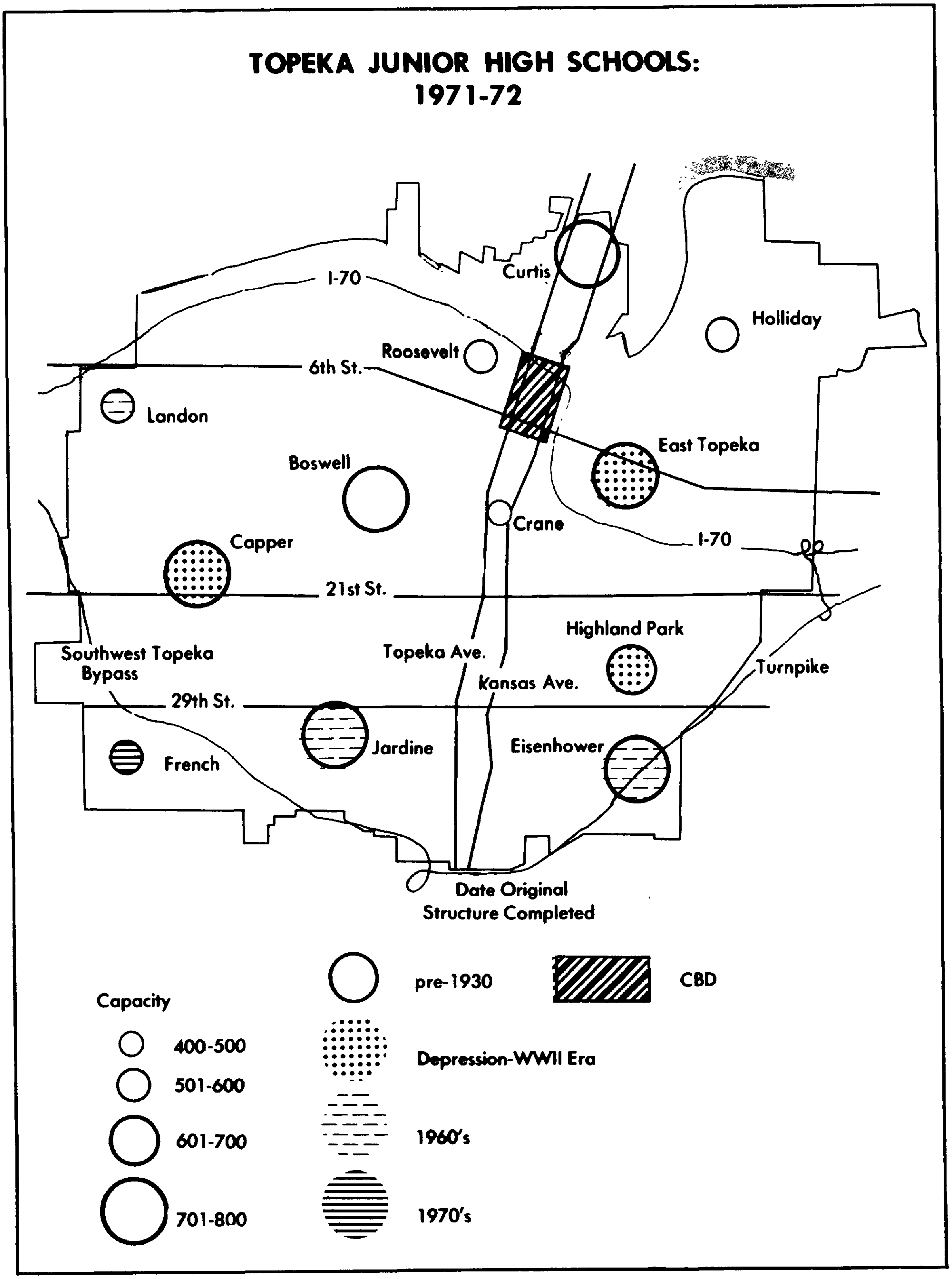
RESULTS

A few of the results based on the Topeka case study are now presented using analytical maps to address the questions: Where to locate individual school attendance zone boundaries? How should students be allocated to schools to satisfy desegregation requirements? Which schools should be closed? and How should the city grow relative to existing school facilities?

DRAWING NEIGHBORHOOD SCHOOL ATTENDANCE ZONE BOUNDARIES

In those school districts where students are assigned to their neighborhood schools, school attendance zone boundaries must be drawn come the start of each school year. One of the principal concerns of the school planner is drawing the boundaries such that the distance children live from school is not so far as to be an unreasonable distance to travel each day. Ideally, student travel should be minimized.

Figure 2


TOPEKA JUNIOR HIGH SCHOOLS:
1971-72
Curtis
I-70
Holliday
Roosevelt
6th St.
Landon
East Topeka
Boswell
Crane
I-70
Capper
21st St.
Highland Park
Southwest Topeka Bypass
Topeka Ave.
Turnpike
Kansas Ave.
29th St.
Jardine
Eisenhower
French
Date Original Structure Completed
pre-1930
CBD
Capacity
400-500
501-600
Depression-WWII Era
601-700
1960's
701-800
1970's

The map of Figure 3 shows the boundaries of neighborhood school zones based on minimizing student travel distance as compared to the boundaries drawn by the school administration for the 12 Topeka junior high schools. The shaded area reflects graphically the differences between the optimal and the actual attendance zones or the cost of deviating from an optimal pattern. In particular, these disparities in attendance zone assignments reflect a basis toward assigning students to the newer schools rather than to the closest schools. French and Landon are the two newest junior high schools in Topeka (refer to Figure 2) and neither is centrally located relative to the geographical distribution of students. This is supported by the fact that the model only assigned students to these schools in the amounts of 48.4 and 32.1 per cent of their capacities, respectively. School officials might rightfully argue that these newer schools would be operating at unrealistically low capacities if the model results were implemented. If such were the case, an additional constraint could be added to the model to assure that a minimum, acceptable number of students were assigned.

DESEGREGATING SCHOOLS

Court ordered school desegregation is a perplexing problem for any school administration. One of their principal concerns is limiting the travel between where students live and their assigned schools while still satisfying Department of Health, Education and Welfare requirements. The map of Figure 4 shows an example of a graphical output from a desegregation-type student-allocation model. It is thought that such a map could aid school officials when attempting to develop a school desegregation plan.

In this particular case, the map depicts Black student assignments to each junior high school when the enrollment in each school must be at least 6.5% Black. This percentage is one-half of the overall proportion of Black student enrollments in Topeka junior highs; their proportion of total enrollment is 13 percent. A similar kind of map could be constructed based on the model results for White students.

CLOSING SCHOOLS DUE TO DECLINING ENROLLMENTS

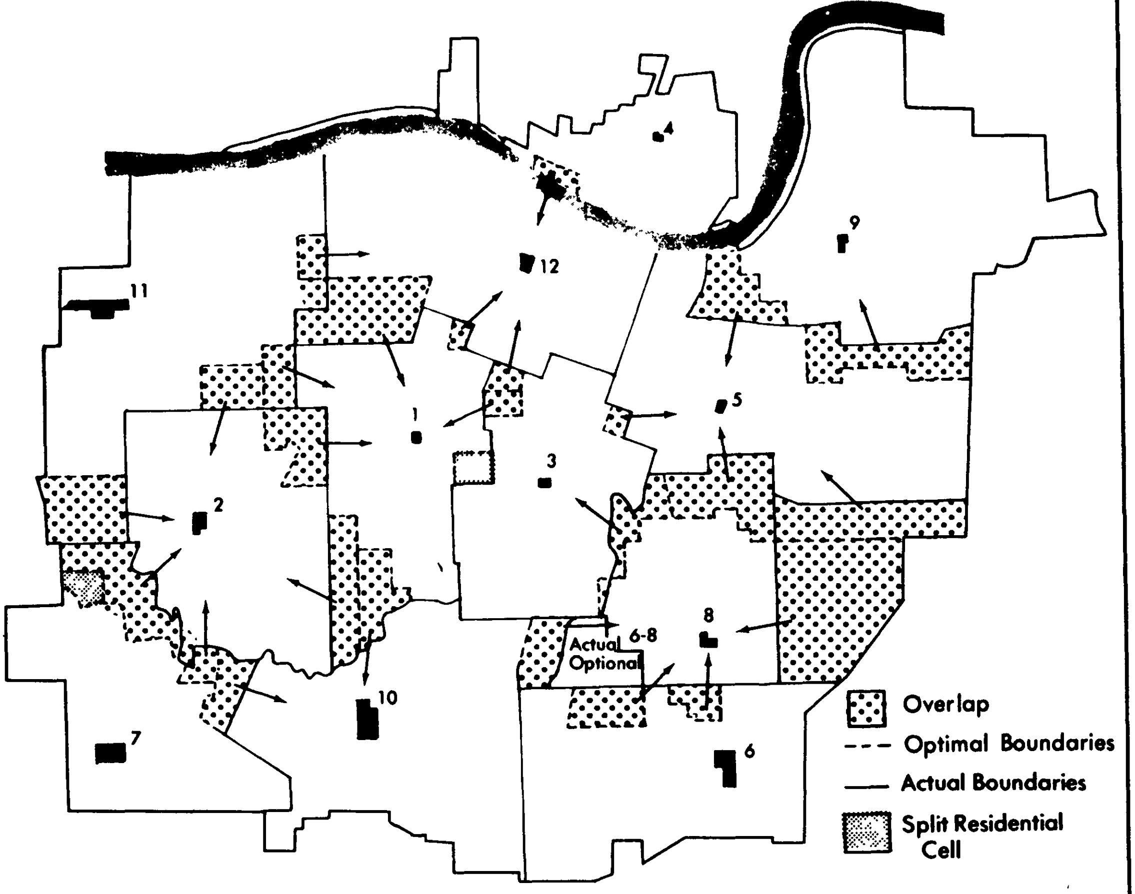
A pervasive problem throughout much of urban America today is that of having to close school facilities due to declining school enrollments. Even some relatively modern schools that were built just after World War II, particularly in the new suburbs of that time, are now being closed. Ironically, these same schools ten to twenty years ago were full, and in many instances, were overflowing just as shcools in new suburbs are today. Also, and as a consequence, smaller and older schools built 35 to 40 years ago are being closed so that their students can be transferred to these more modern schools that are now underutilized. Such is the case today in Topeka.

The Crane and Curtis junior high schools (refer to Figure 2), which were built in the 1920's have been closed and their students have as a result been transferred to nearby schools -- those with relatively modern facilities and declining enrollments in their immediate attendance areas. This was accomplished not without resistance from parents living in the immediate vicinity of the schools closed. A quotation provided by a Topeka citizen is pertinent:

> I'm looking very hard from a property owner's standpoint as well as a parent's standpoint. If you tear out all my schools, it's going to drop my property values. I moved into this area because of the schools. 3/

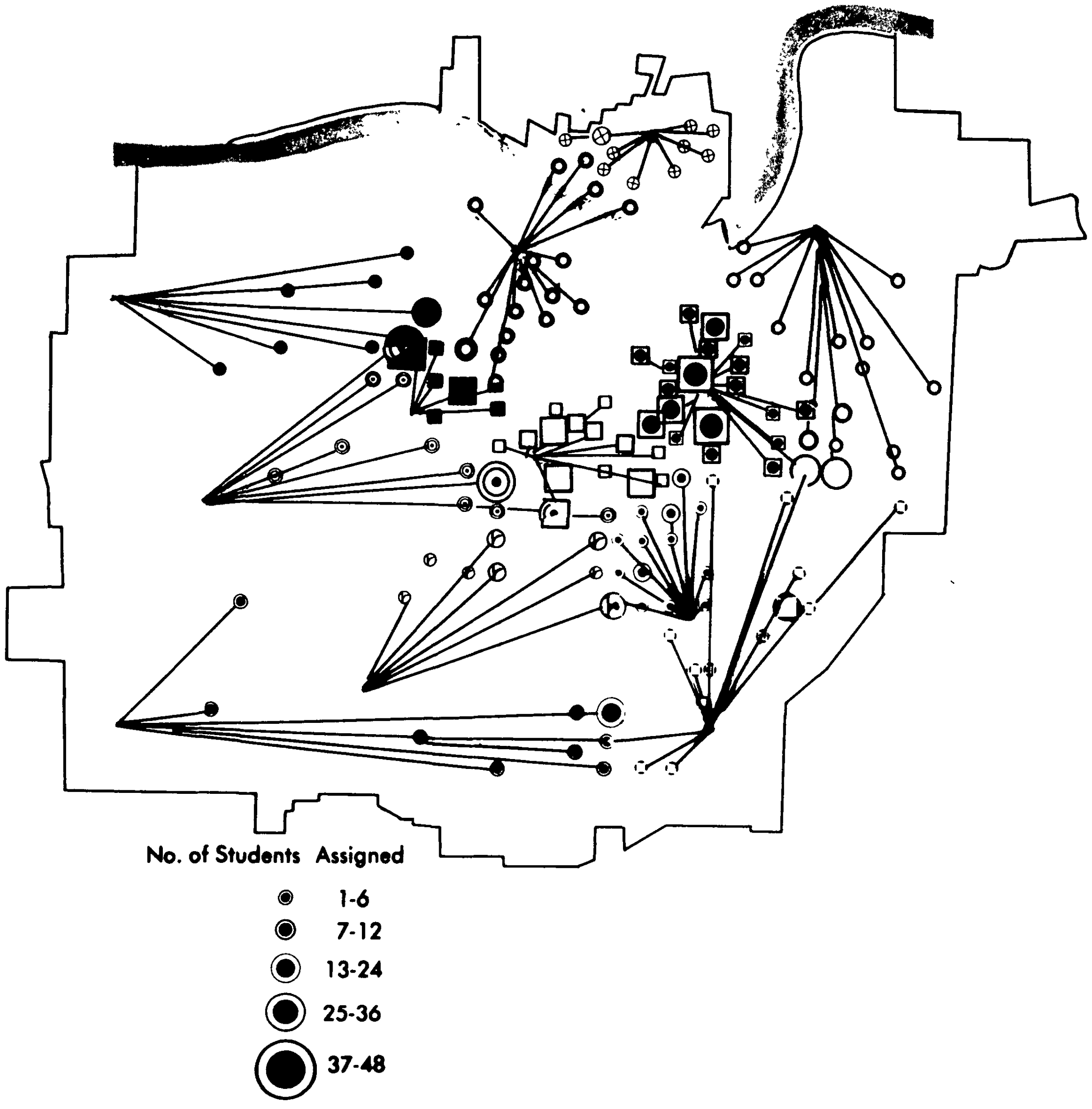
Figure 3

OPTIMAL VS. ACTUAL JUNIOR HIGH SCHOOL ATTENDANCE ZONES



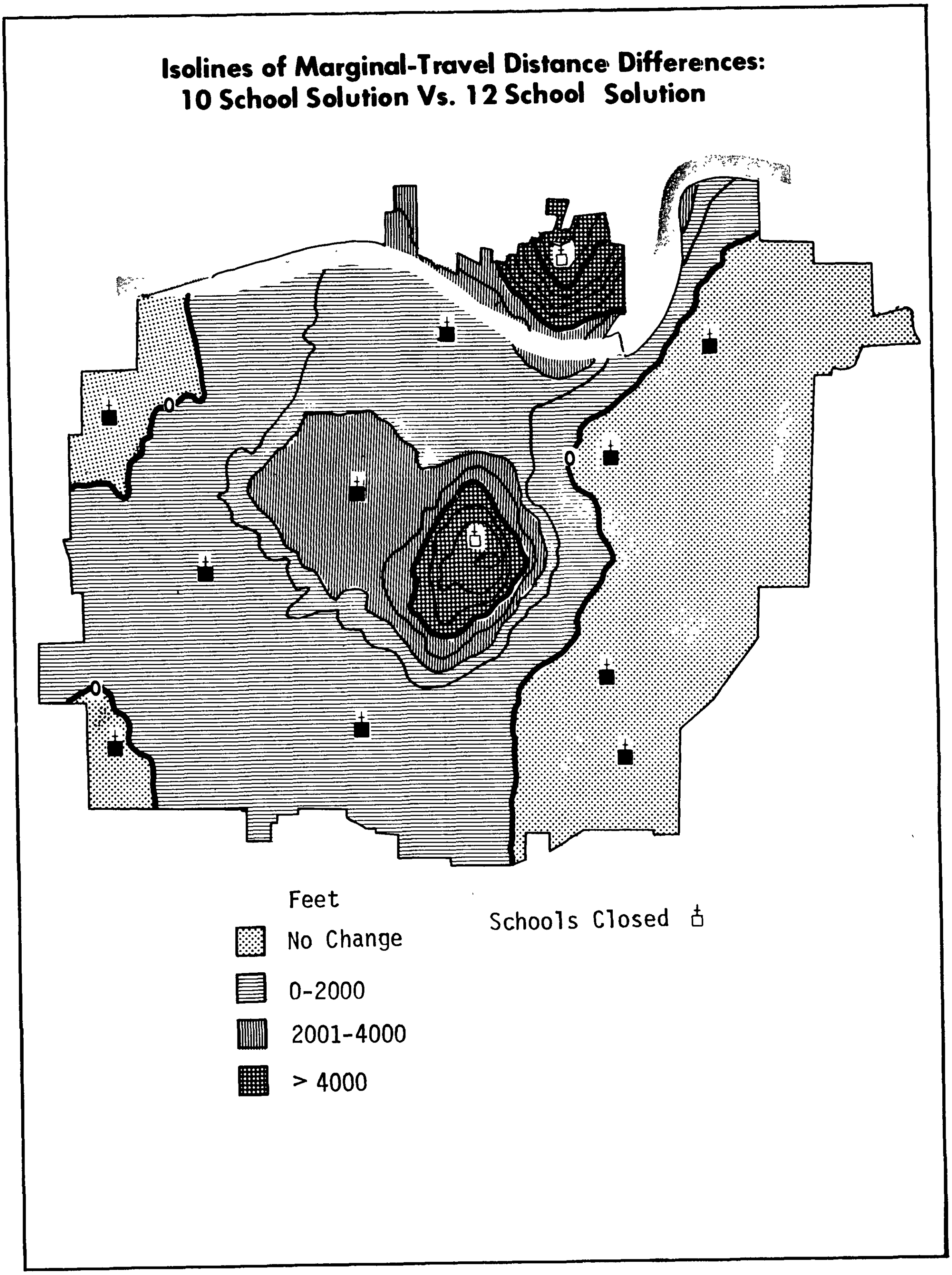
Sch ID	Sch Name	Cap	No. of Students Assigned	% of Sch Cap
1	Boswell	736	736	100.0
2	Capper	732	732	100.0
3	Crane	456	421	92.3
4	Curtis	346	228	57.6
5	East Topeka	800	567	70.9
6	Eisenhower	750	507	67.6
7	French	570	276	48.4
8	Highland Park	612	492	80.4
9	Holliday	524	407	76.2
10	Jardine	750	711	94.8
11	Landon	533	218	37.1
12	Roosevelt	570	425	74.6

Figure 4



BLACK STUDENT ASSIGNMENTS: A TWO-RACE STUDENT-ALLOCATION MODEL OUTPUT

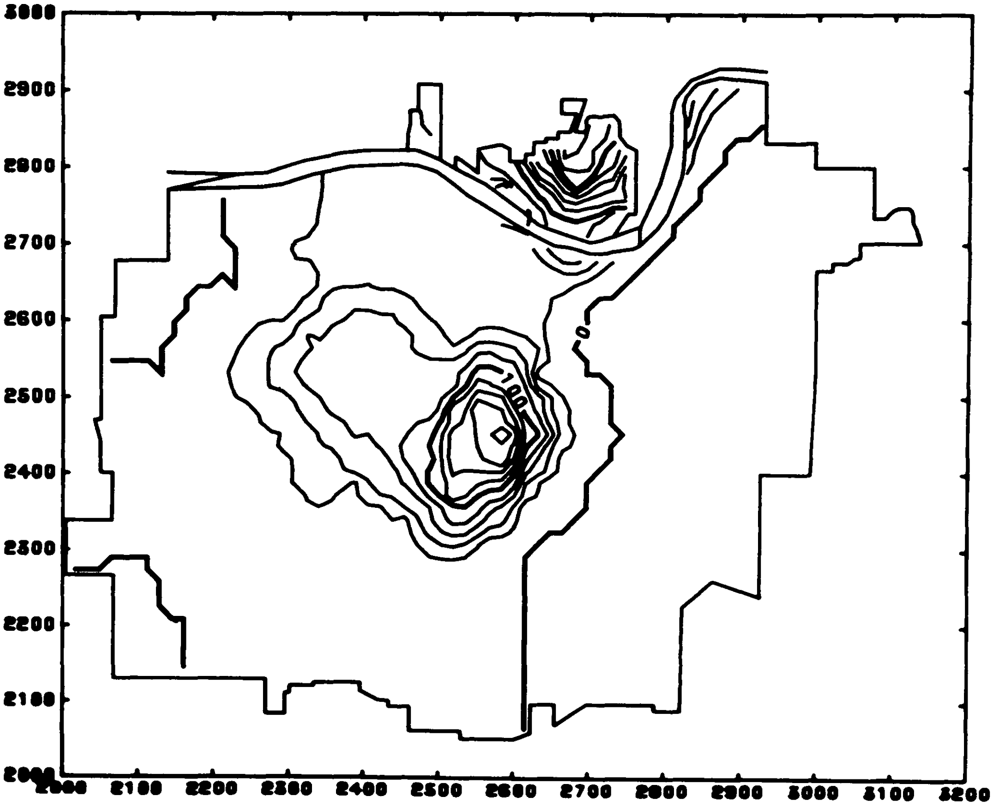
Figure 5


Isolines of Marginal-Travel Distance Differences:
10 School Solution Vs. 12 School Solution
Feet
▒ No Change
▤ 0-2000
▥ 2001-4000
▦ > 4000
Schools Closed ♁
0
0
0
0

Maps based on student-allocation model results can show the impact of closing schools on student travel; and, subsequently, provide a measure of school closure impact on residential property value. The isopleth map of Figure 5, for instance, shows the areas most affected when Crane and Curtis junior highs are closed. This map was constructed from the computer-produced isoline map 4/ of Figure 6. Note that a much larger area throughout West Topeka is "devalued" in relation to junior high school locations than in East Topeka as a result of the school closures. In a similar way, the spatial impact of closing other schools could be analyzed or an evaluation could be made to determine which school closure -- Curtis or Crane -- had the least spatial impact.

Figure 6

SURFACE II ISOLINE MAP



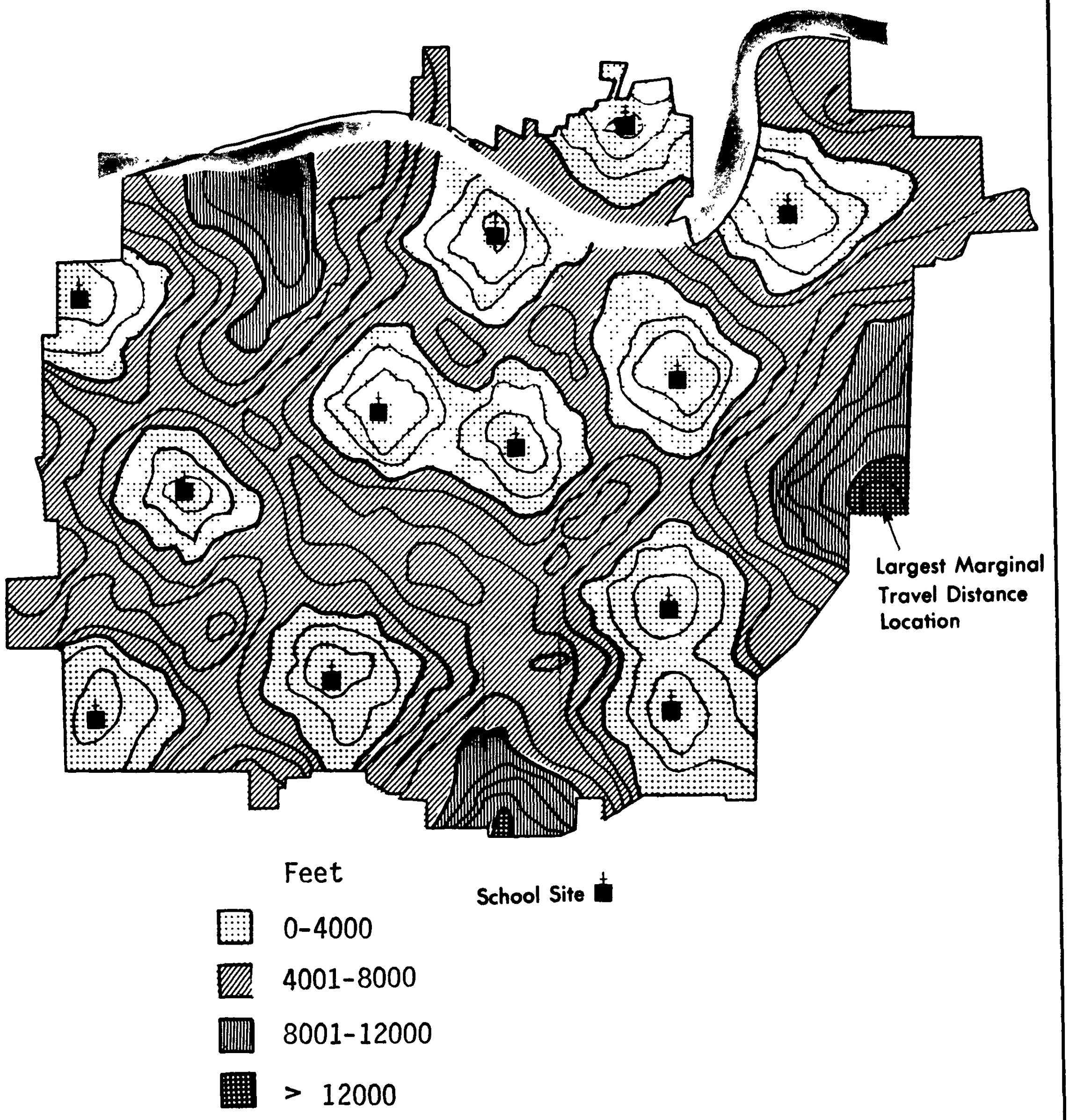
DETERMINING WHERE TO ZONE RESIDENTIAL DEVELOPMENT RELATIVE TO SCHOOL FACILITIES

The concern expressed in the quotation by the citizen of Topeka toward closing schools should make the point that schools have an important bearing on where people decide to live. It, therefore, is only logical that city planners should seriously consider the importance of school locations in their residential zoning plans. When doing so it is thought that maps based on student-allocation model results should be of some help to the city planner.

The isopleth map of Figure 7, for instance, shows the best and worst locations for residential development relative to school locations. In the worst situation,

Figure 7

Isolines of Marginal Travel Distance to Neighborhood Junior High Schools



housing development per every student added to the school district would result in adding 8,000 feet or more student travel for the school system as a whole. Residential development in the best locations would result, on the other hand, in increasing total student travel from zero to 4,000 feet per student increase due to building more homes. Zero travel in effect would result when homes are built immediately adjacent to school sites.

SUMMARY AND CONCLUSIONS

The emphasis in this paper has been on the use of analytical maps for school location planning. In particular, the paper has illustrated how maps based on linear programming solutions for minimizing student travel to schools can be used to help resolve such issues as closing schools, desegregating schools, and determining the location of neighborhood school zone boundaries. In some instances, it has been shown how these types of maps might be useful to city planners as aids for zoning residential developments.

In concluding, two lessons have been learned in the process of producing the analytical maps exhibited here.

First, efficient, expedient mapping techniques, that only automation in cartography can provide, must be employed for determining where students live relative to school locations. That is, without such a mapping capability, the analytical process or application of a mathematical or statistical model cannot be effective, especially, if one is concerned about saving money and time in the process of producing maps. This is particularly true if the application is going to be made in a very large city, one much larger than Topeka, Kansas. I was fortunate in my Topeka study in that the school district had already performed a basic mapping task for me: matching student addresses in order to determine the exact number of students by grade level living on any given block. As noted earlier, the school administration is conducting this work manually. But, this is unusual and they deserve much credit since they became concerned about their data base for mapping applications sometime before the DIME innovation. What is particularly lacking in their operation now is further application of automation in cartography. The software and hardware for producing plots of where students live by grade level is one automatic mapping application that would serve them particularly well. It is unfortunate that this additional extension to their capability has not been made, especially, given the effort they have gone to in developing their data base.

Secondly, I would like to emphasize that the maps exhibited in this paper took time to construct. The most time-consuming chore involved coding and key punching the output or results provided by linear programming. A simple routine is needed in the software that will output the results onto tape or cards in a form compatible with a mapping system. My point is that expedient ways of getting the model results onto maps must also be given a great deal of consideration before applying such an analytical tool as linear programming. Most library programs for statistics and math do not provide options for outputting the results to a plot tape or cards which then can be used as input to mapping software. In most instances now, one merely obtains from the computer reams upon reams of line-printer output, containing the results you want, but results that are meaningless until displayed on a map.

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COMPUTER MAPPING AND ITS IMPACT ON KANSAS CITY, KANSAS AND WYANDOTTE COUNTY

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This paper is divided into two logical sections. The first section will deal with the base maps and tools available to local users and the software developed to utilize them. The second section will outline some of the applications of these items and the local impact of the applications as a whole.

MAPS, TOOLS, AND SOFTWARE

The developmental work in computer-aided cartography locally is focused around two separate but related geographic base files. The first is a GBF/DIME-File on which work began in February, 1972. The second is a parcel file 1/ which was initiated in August, 1973. No applications of the parcel file have been made to date inasmuch as research and development of the file itself is not quite complete. However, most of the mapping related software developed for the DIME file is applicable at the parcel level.

Both the parcel file and the DIME file are based on a single base map used by most governmental entities within the city and the county. This base map consists of a series of maps each covering a quarter-section of land at a scale of 1:1 200. The maps were produced by sterophotogrammetric methods. 2/ The maps depict all planimetric features, are contoured at two-foot intervals, are gridded with the Kansas Plane Coordinate System, and contain other cosmetic and notational features. We feel that the success of our base mapping programs to a great extent is based on these highly accurate base maps.

The DIME file was developed from the original file created for the Kansas City Metropolitan Area by the Bureau of the Census and is maintained using Bureau of the Census standards although in a slightly different format. Several additional fields are also present. One new concept implemented here in conjunction with our DIME file is what we have termed the Contour Node File. For each non-linear DIME segment this file contains a list of additional coordinates more extensively describing the feature. These points as well as the original DIME nodes were digitized from the base maps mentioned earlier.

Editor's Note: Examples of the maps discussed, the GRAFPAC subroutines, and selected software for shading polygons are provided on pp. 475-481. An example of a pen plotter-produced choropleth map can be found on p. 263.

With these products and tools as a dependable base, a number of computer cartographical programs were developed for informational display purposes within the city and the county. These are choropleth mapping, dot mapping, and street network mapping all with a pen plotter. Additional mapping programs utilized but not developed locally include CHORO, 3/ GRIDS, 4/ and SURFACE. 5/ The graphics software developed locally is all written using a graphic output system called GRAFPAC II.

GRAFPAC II consists of about forty FORTRAN subroutines designed to communicate graphic output information from a compiler-level language to a graphic output device. The system has been implemented on IBM, Honeywell, and CDC computers and a number of different plotters including Calcomp, Benson/Lehner, and UCC. Although thorough documentation is not known to exist, the basic documentation of the subroutines as implemented in Kansas City has been completed.

GRAFPAC II has its origins in a set of specifications proposed by the SHARE Standard Graphic Output Language Committee entitled GRAFPAC, Specifications for Standard Graphic Output Subroutines. 6/ GRAFPAC software was originally written at the University of Kansas by Dr. F. James Rohlf and others. A major rewrite of the early software by Carl Youngmann and Stephen Hollis at the Institute for Social and Environmental Studies resulted in GRAFPAC II. We are utilizing a slightly modified version with several local additions.

CHOROG is a FORTRAN mainline with subroutines designed to produce choropleth maps on a pen plotter. The input consists of SYMAP-type outlines of each area, data values for each area, legend information, and a set of parameter cards establishing various map characteristics, data classes, and shading patterns. A typical map of Wyandotte County produced on a layout of typewriter page size requires about five minutes time on an IBM 370/145 under DOS/VS and about ten minutes plotter time on a Calcomp 905/936 system. Of technical interest in CHOROG is the method used to shade polygons and to describe the shading. In order to clarify following terminology, each polygon is to be shaded with a particular "pattern" of lines where each "pattern" consists of one or more "shades." Each "shade" is a set of evenly spaced parallel lines. The description of the pattern for a particular data class consists of one or more five digit codes each of which describes a shade. The five digit code has the following interpretation:

Digit 1 - the pen or "color" number for this set of parallel lines (zero implies that the shade is blank and no lines are drawn).

Digit 2 - the coded angle (counter-clockwise from the positive X-axis) of the lines.

Digit 3 and 4 - the spacing in hundredths of inches between successive lines (zero is interpreted to mean one inch).

Digit 5 - the coded fractional offset from normal at which to begin drawing the evenly spaced lines.

The explanation of digit 5 is obscure at the very best, and can best be explained by its usage. In order to improve the appearance of an output map it is desirable to have adjacent polygons with identical patterns have their shade lines merge at the boundaries rather than miss by a random distance. To allow for this cosmetic refinement in the output all shade lines begin at an appropriate integer multiple of their spacing parameter (digits 3 and 4) from the origin of the coordinate system used to define the map. This alone, however, will not accomodate a pattern consisting of two shades which are co-parallel and which require alternating lines to be of different pen widths or colors. One of those sets of parallel lines must begin at the integral multiple of the spacing plus one-half of the spacing. Patterns with three sets of co-parallel shades require additional offsets of one-third and two-thirds for two of the shades. Digit 5 is a coded number which allows the offset spacing required for this type of shading.

DOTMAP is a FORTRAN mainline with subroutines designed to produce dot maps on a pen plotter. DOTMAP does not produce maps from point data which would then be clustered into "dots" as one might suspect. Rather, it provides another means of displaying data aggregated by area. For each polygon in the map a number of dots is calculated from the input data value for the polygon. This number of dots is randomly distributed and mapped in the polygon. The input is identical to input for CHOROG with two exceptions. The definition of class levels and their corresponding patterns are replaced with the number of "things" to be represented by a single dot. The other exception involves a modification which has been implemented but is not thoroughly tested at this time. It concerns the input of "exclusion polygons." The input of one or more exclusion polygons defines areas on the map in which no dots are to be placed. This modification is being made at the behest of users who did not appreciate dot maps displaying people living in the middle of the county lake or with residential housing units in the airport runways.

MAPDIME is a loose-knit collection of FORTRAN mainline programs with subroutines which map sections of the DIME file and optionally label streets with their name or other information, optionally draw node numbers at nodes, and optionally draw characteristically distinguished network lines with different colors or pen widths. Input to the programs consists of a DIME file and a total of two parameter cards. Additional input locally consists of our contour node file mentioned earlier. Parameters governing the placement of street names on network segments are embodied in the software but could easily be input. The parameters will not be explained in detail inasmuch as they are actually an implementation of a set of rules constructed to locate street names in an acceptable manner on an output map. These rules apply to an ordered set of segments which are linked end to end and which all have the same name. The software provides each such "chain" of segments (complete with name and coordinates) to the subroutines which label the segments. Multiple consecutive blanks are compressed within the name. The standard character size and the minimum character size are established at input. The rules of name placement follow.

1. Each segment with a length greater than a parameter-specified distance will have the name plotted on it.

2. The accumulated length of a series of segments on which no name is plotted cannot exceed a parameter-specified distance.

3. Each series of connected segments must have a name plotted on at least one segment unless the longest segment in the series is less than a parameter-specified distance.

4. Names are plotted on single segments and do not pass over endpoints unless the length of the name exceeds the length of the segment on which it must be plotted.

5. An attempt is made to plot all names on segments which will hold the name without reducing character size. In the event this is not possible, the character size and the spacing between characters is reduced within limits to make the name fit.

Node numbers are plotted at nodes in such a fashion as to not overlap segments or possible street names, although overlap does sometimes occur. Such mapping has not been attempted at map scales smaller than one inch to five hundred feet since the characters become too difficult to read. Output devices with better resolutions should be able to produce maps at slightly smaller scales than this. A great deal of reduction will not be possible without more complex software due to the average length of DIME file segments and the size of readable characters.

In addition to the programs discussed, a number of cartographical programs are used which do not produce maps. Rather, they use the DIME file linked with operational files such as the street inventory file as an internal map to perform functions which would otherwise be performed on maps. Examples of such uses will be discussed in the second portion of this paper which deals with the usage and the impact of the computer cartographical software used by Kansas City, Kansas and Wyandotte County.

USAGE AND IMPACT OF COMPUTERIZED MAPPING

The impact of computerized data processing and mapping has been felt in many applications in Kansas City, Kansas. Most of these applications have been developed in the last two years by the staffs of the Department of Planning and Development and the Wyandotte County Base Mapping Program. The GBF/DIME-File has been the base on which most of the graphics capabilities developed to date stand on.

Extensive corrections and revisions have been made to the DIME file originally released by the Bureau of the Census. The 1"=100' topographic base maps previously mentioned have made possible a high degree of accuracy in the Wyandotte County DIME file. Of particular importance to our computer graphics applications is the fact that all nodes in the DIME file have been digitized from the quarter-section maps instead of the Census Bureau's Metropolitan Map Series (MMS) maps. It is estimated that the nodes are digitized to an accuracy of ±3-5 feet of their true location.

Auxiliary data files have been developed and keyed for use with the DIME file. The contour node file, containing about twice as many nodes as the DIME file, has been mentioned earlier in the paper. An address file containing a record for each address along a DIME file segment has been in existence for about three years. On its completion, the parcel file, also mentioned previously, will replace the address file.

During the summer of 1974 an existing file containing physical characteristics of the streets was keyed to the DIME file through a manual coding effort. The street width, curb width and height, type of surface material, base material, and last date resurfaced. This file has been especially useful to the Street Department.

A Highway Safety Act grant has been received from the Kansas State Highway Commission to cover half of the costs in developing a street sign inventory for Kansas City, Kansas. The data will be collected in the spring and summer of 1976 by taking films of all the streets (photologging) and extracting the data from those films. Information collected will include color, shape, size, and condition of the sign, the sign legend, distance from the street, height off the ground, and an x-y coordinate location. The street sign inventory file will also be keyed to the DIME file.

The most frequent use of computer mapping in Kansas City, Kansas has been the production of choropleth, or shaded-area, maps of both locally collected data and data from more common sources such as the 1970 Census of Population and Housing. These choropleth maps are most often plotted on the Base Mapping Program's Calcomp 905/936 plotter, but some are also done on the computer line printer. Most of the locally collected data begins as address-coded individual records. It is then matched to tract and block or other geographic areas using the GBF/DIME-File and the Census Bureau ADMATCH program. The data is then aggregated by geographic area and mapped.

Data aggregated to geographic areas is also sometimes mapped by using a random dot within polygon mapping program. This mapping technique gives the visual density effect of a dot map while protecting the privacy of the data by not mapping the exact location. Choropleth maps and dot maps have been produced from data from the local County Assessor's annual census, the Comprehensive Employment and Training Act (CETA) client monitoring system developed in Kansas City, Kansas, a local study of the developmentally disabled, housing code violations, and several maps have been made from Juvenile Court data.

A variety of applications has been developed that uses the DIME file directly for mapping. The basic map is a street map showing streets (and non-street segments, if desired) and has the street names plotted on the map. This mapping program will make the map at any desired scale. The only problems develop when the map is too small to show the street names. Small maps can be plotted without street names. For purposes of working with the DIME file, node numbers can also be plotted on the map.

As a front-end for the DIME file mapping routine, a DIME-in-polygon program has been developed. Given any arbitrary polygon it will extract all parts of the DIME file within that polygon. Any segments that cross the boundary of the polygon one or more times will be broken so that all parts of the segment within the polygon are retained. The DIME file produced by this program can then be mapped by the DIME file mapping routine. This process has been useful for making maps of the DIME file in sections. The accuracy of the digitizing can be checked by overlaying these plots on other base maps. Maps of the DIME file have also proven to be the best maps of the city available. In the last year the Street Department requested a set of DIME file maps to be used in street cleaning. The plots were made at 1"=500' and then cut into street cleaning areas. After being laminated in mylar the plots are a durable and useful map for the men cleaning the streets.

A related type of map was made for the Street Commissioner by plotting a map of the city at 1"=500'. Street names were plotted on the map and the color used to plot the street segment indicated the surface material of the street. This map was used to determine where the concrete and asphalt streets were located so that plans could be made for patching. At the same time that the map was made, the length of concrete and asphalt streets was computed to be used as part of the information in requesting bids for street repair.

A similar map was also plotted showing which streets had curbs on one, both, or neither side. This map was useful in setting up street cleaning areas because it is necessary to have curbs for the street cleaning machine to pick up dirt and sand.

Another useful application has been developed that does not produce maps as a final product. This program reads in a set of polygons and then processes the DIME file computing the length of the street segments in each area. The boundaries of the Street Department districts have been altered, based on data from this program, to make the areas more equal in size.

Plans are being made for many more mapping applications. For the parcel file, maps will be generated to edit the digitizing of parcel outlines and the entry of parcel data and to display parcel related data. Similar types of graphics will be developed during the Street Sign Inventory project. It is important to note that in developing the graphics software no attempt has been made to build a grandiose all-purpose system. Rather, small modules with single specific functions have been written. These modules can easily be combined in a variety of applications. By developing these applications in a modular fashion and basing them on the DIME file, it is possible to combine several different options on a map. Thus, a basic street map can be made, then street names can be added, node numbers can be added, and non-street features can be added. In the future it will also be possible to add street sign locations and parcel boundaries. It is this modular approach that has made computerized mapping flexible and useful to Kansas City, Kansas.

The past and proposed work in Kansas City, Kansas and Wyandotte County has demonstrated that an accurate DIME file can form a solid foundation sufficient to support a wide variety of mapping applications. It has demonstrated that this modular approach makes the application of computer mapping techniques very flexible in supporting many users. It has also shown that computer cartography is a very useful tool in bringing about increased awareness of the spatial nature of urban phenomena, both for decision-makers and technicians alike.

We believe that Kansas City, Kansas does not present a unique situation. The basic tools and techniques can be applied in any city. Using a solid foundation and modular approach, it should be possible to build up the necessary support and resources required to develop a strong and flexible computer mapping capability.

REFERENCES

1. See Thomas M. Palmerlee and Ronald E. Domsch, "A Parcel Identification and Data System: A Case Study in Implementing Information Systems," Papers from: the Eleventh Annual Conference of the Urban and Regional Information Systems Association, (Atlantic City, 1973), pp. 393-407.

2. The maps were produced by M. J. Harden Associates using precision aerial photography from a Zeiss RMK-15/23 camera with a six inch focal length lens. Wild B-8 and Kelsh stereoplotters were used for plotting. The ground control was of second order accuracy utilizing EDM equipment and one-second theodolites.

3. CHORO - Institute for Social and Environmental Studies, University of Kansas, Lawrence, Kansas.

4. GRIDS - Southern California Regional Information System.

5. SURFACE - Kansas Geological Survey, Lawrence, Kansas.

6. The draft of the GRAFPAC specifications was prepared in August of 1966 by P. Pickman of Bell Telephone Laboratories, Incorporated, Whippany, New Jersey. SHARE is the Society for Helping Avoid Redundant Efforts.

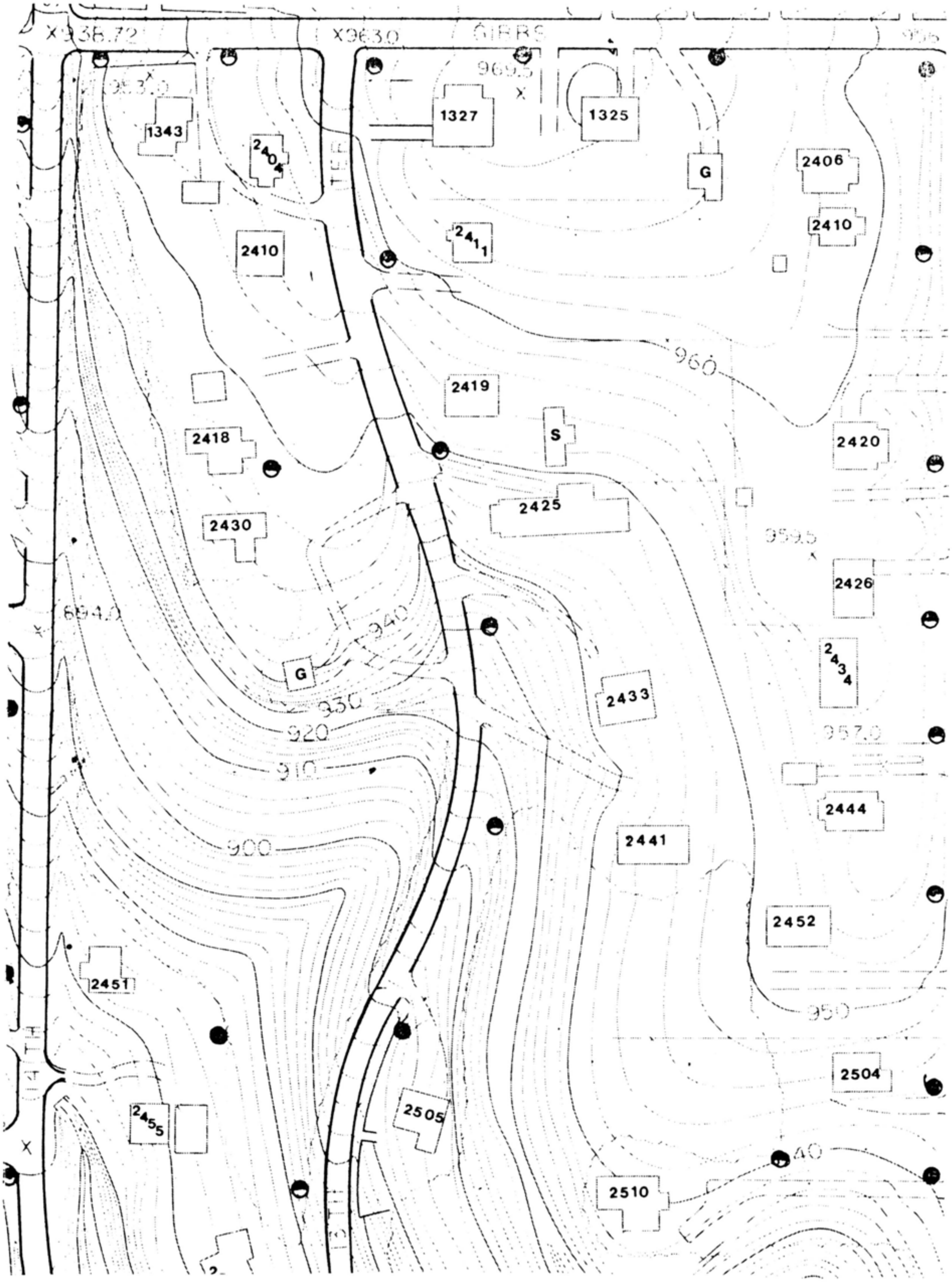

Figure 1. Topographic Base Map

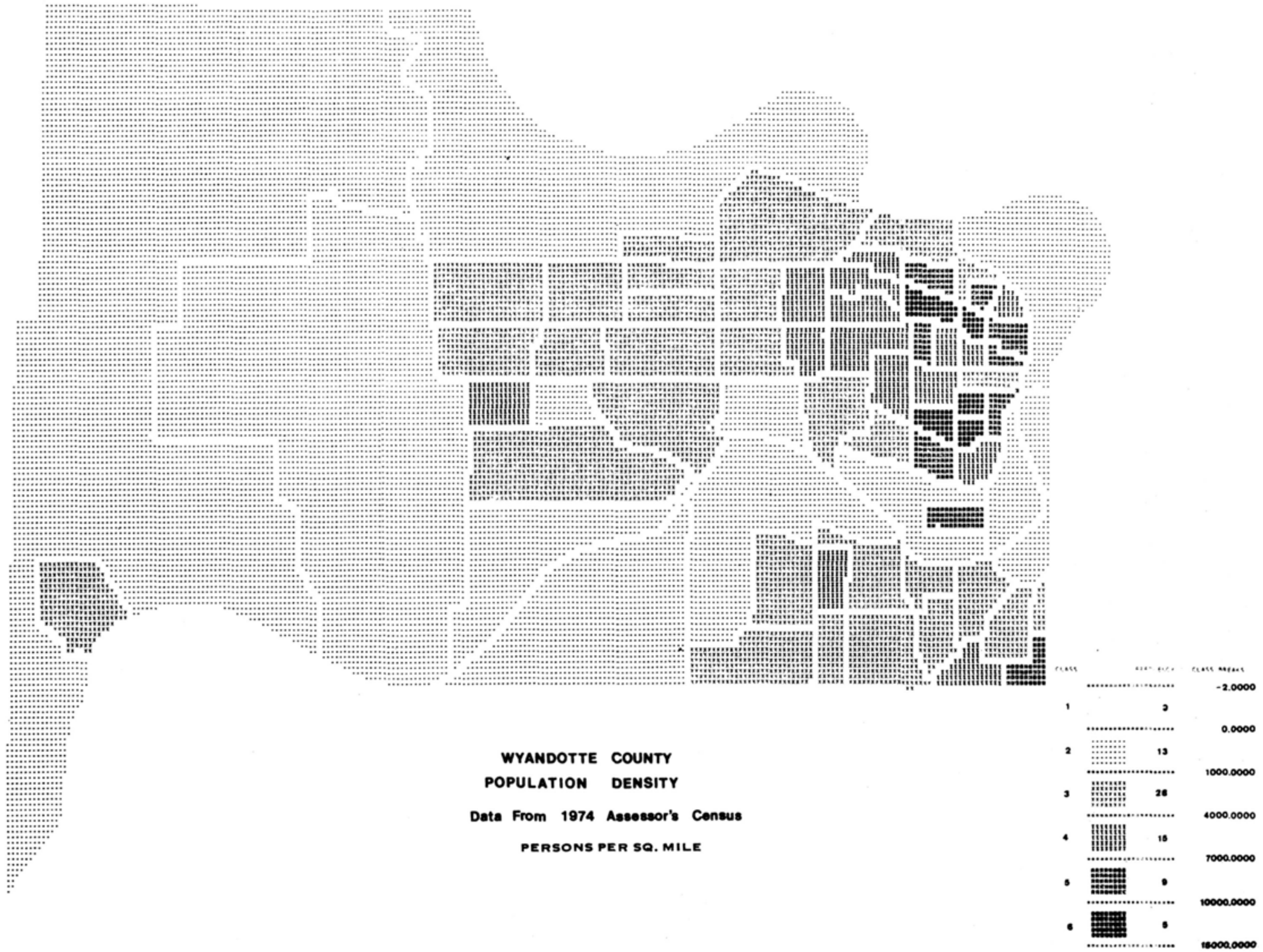

Figure 2. Line-Printer-Produced Choropleth Map

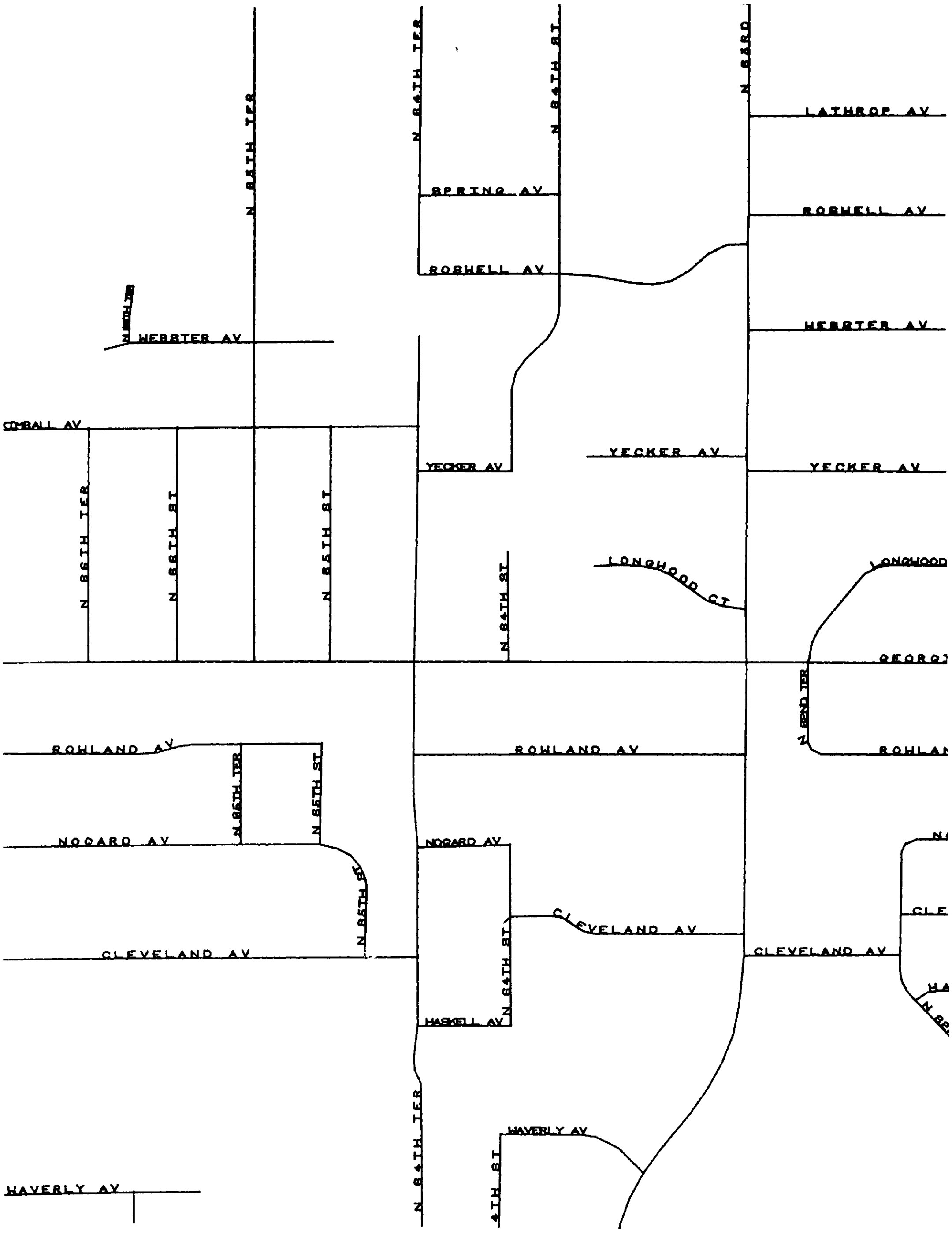

Figure 3. Street Map Generated from the DIME File

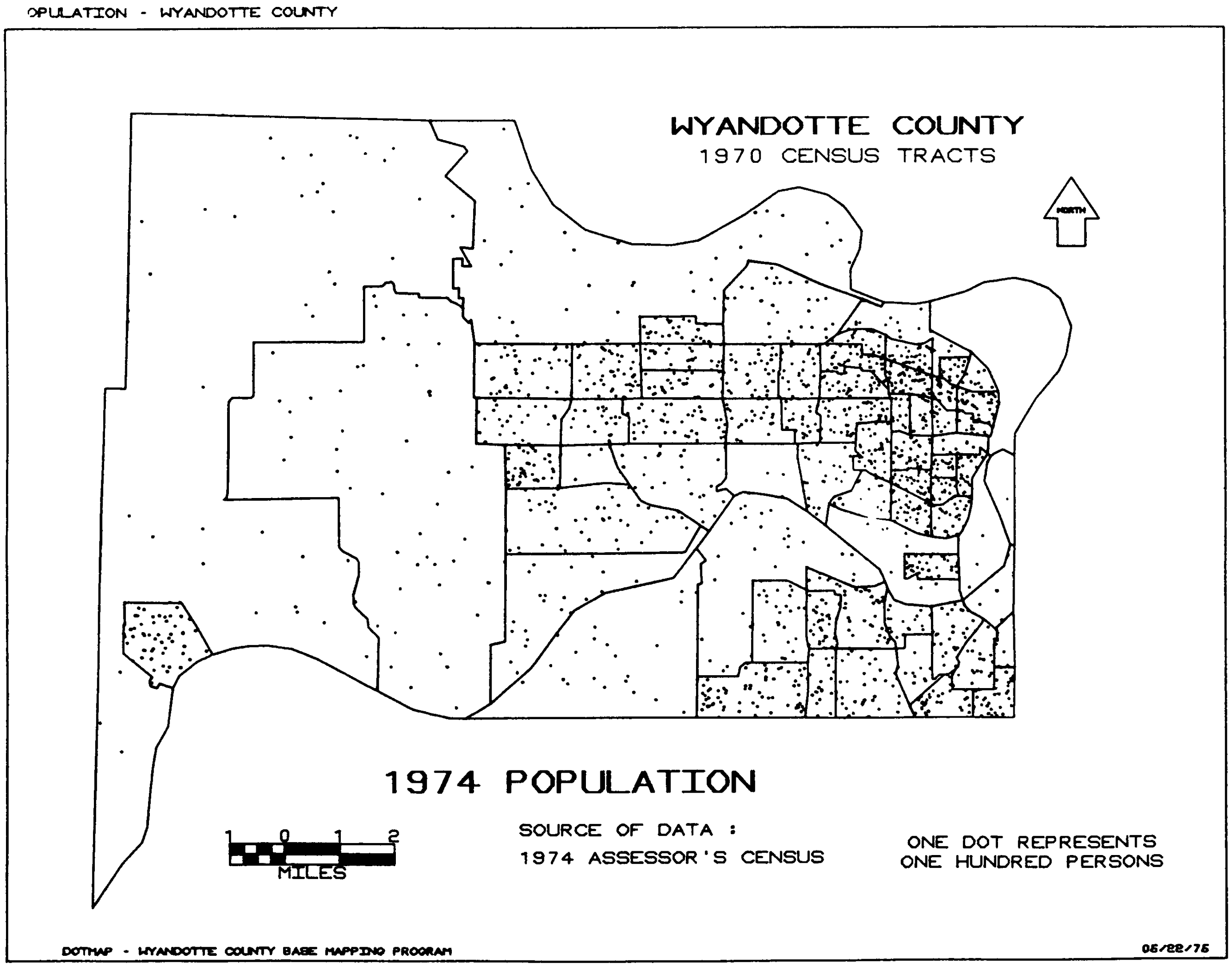

Figure 4. Example of dot map showing 1974 population of Wyandotte County

GRAFPAC Subroutines

ADVANG - ADVANG completes plotting on the current drawing and positions the paper (or film) for the next plot. The plotter will then be set to prepare another plot the same size as the one just completed. (If another plot of a different size is to be made, OBJCG should be called).

ANGLEG - FORTRAN function to compute the angular direction of the vector formed by two ordered points.

BLIO - This subroutine is written in GMAP (the assembly language for the Honeywell-635). It performs the machine-level I/O for writing the plot instruction tape for the Benson/Lehner Draftomatic plotter.

BLPLTG - This subroutine sets up the actual plotter instructions for the Benson/Lehner Draftomatic Incremental, Off-Line, Rotary Drum plotter.

BOX - The routine computes the coordinates of the four corners of a rectangle.

CCINST, INSTCC - This is a GMAP (Honeywell-635 assembly language) subroutine which manipulates the bit configuration and stores instruction bytes used with the CalComp Remote Plotter/Controller Model 210.

CC210G - This routine creates and writes the plot instructions for the CalComp Model 210 Remote plotter.

CC763G, PLOT - This subroutine provides the interface between subroutine PLTITG and the CalComp PLOT subroutine for the various CalComp plotters.

CIRARG - This subroutine will plot a circular arc which is an exact curve within the physical limits of the plotting device. This is presently implemented so that the maximum distance between the true arc and the secant lines does not exceed .01 inches. (Although greater resolution could be achieved with most devices, the difference would be hardly noticable).

CIRTRG - This routine determines the (X,Y) coordinates of the end points of a line segment connecting the edges of two circles.

COMNDG - COMNDG reads a designated file containing "commands" for GRAFPAC. A limited set of frequently used functions is available.

CSIZEG - CSIZEG either sets the character size to the standard for the named device or sets the character sizes given by the user. Presently 0.16 inch is the standard size for all devices. The character size actually refers to the height and width of an envelope into which the character can be imagined to fit. The envelope includes clearance for both horizontal and vertical spacing.

CTABLG - CTABLG draws a legend table for the routine CHOROG or any other routine requiring a legend of shades.

DEVOFG - This routine ends the current plot and "turns off" the currently open device.

DEVONG - This routine sets parameters in the AMODES array which cause the specified device to be turned on.

DIVDG - DIVDG is called by LEGNDG to decode the internal codes used by GRAFPAC to define how to draw each of the symbols.

ERRORG - This routine writes out the error message, obtains a trace of subroutine calls in reverse order, closes all files, dumps the AMODES array, and aborts the job.

FPTBCD - This routine converts a floating point number (FORTRAN REAL) to BCD using a Fw.d format so that the number can be plotted using routine LEGNDG.

HAXESG, VAXESG - HAXESG and VAXESG are described together due to their relationship. They are called, generally as a pair, to draw horizontal and vertical axes of graphs.

FINISG - A call to this subroutine signifies the end of all plotting for the currently open device and output file. It is a signal to GRAFPAC II to perform the required action to wrap up the plotting output (turn off the device, rewind the plotting tape, etc.).

ICHARG - This subroutine obtains a specified "character" from a "word" and returns it in a new word left-justified with trailing blanks (FORTRAN format A1).

IDENTG - This routine labels a plot for identification and optionally creates a new plot number so the plotting device may be stopped for manual operation.

INCRPG - This routine is an internal routine used by GRAFPAC as an interface for plotting routines for devices for which the incremental pen movements must be supplied.

INTBCD - INTBCD converts an integer number to BCD (using an Iw FORTRAN format) so that the number can be plotted using the routine LEGNDG.

LEGNDG - This routine will plot a string composed of characters, numbers, and special symbols at a specified location.

LINESG - LINESG will move the pen to a specified point (with the pen up or down) or connect a series of points (pen down).

LNINRP - LNINRP determines that portion of a line which is interior to a rectangle.

MINMAX - MINIMAX determines the minimum and maximum values of the elements of an array.

NEWPNG - NEWPNG switches the designated plotting pen to the pen specified.

MODESG - MODESG initializes the parameters in the AMODES labeled common area.

OBJECG - OBJECG establishes the actual physical size of the object space and makes appropriate entries in the AMODES array.

ORIENG - ORIENG sets the orientation for plotted symbols to a specified value.

PATRNG - PATRNG calls SHADEG to shade a polygon with a series of shades to produce a pattern.

PCHARG - PCHARG "packs" a character into a designated position in a word.

PLTITG - PLTITG serves as the interface between all higher level GRAFPAC routines and the device - dependent routines.

POINTG - POINTG plots centered symbols at a series of specified points.

ROTAXG - ROTAXG rotates a series of points about a specified point by a specified number of degrees.

SEGMTG - SEGMTG plots a series of line segments defined by their end points.

SHADEG - SHADEG shades a polygon with a series of parallel lines at a given angle and spacing.

SMODEG - SMODEG initializes certain parameters in the AMODES array which are actually plot characteristics.

SUBOBG - SUBOBG calculates the subject to object space transformation values.

SUBJEG - SUBJEG establishes the limits of the subject space for the next plot.

SYMPTG - SYMPTG will plot a symbol defined by a relative coordinate system at the specified point.

TABDVG - TABDVG initializes that part of AMODES array which is unique to the particular device requested.

XINCHG, YINCHG - To convert an X or Y coordinate from an object space coordinate to subject space coordinate.

XUNITG, YUNITG - To convert an X or Y coordinate from a subject space coordinate to an object space coordinate.

Selected Software for Shading Polygons

```
DOS FORTRAN IV 360N-FO-479 3-8          PATRNG            DATE   11/09/74      TIME     14.39.01

0001                SUBROUTINE PATRNG(X,Y,N,IPAT,M)                                      PATRN 01
          CPATRNG       *** GRAFPAC CHORO *** - SHADE A POLYGON WITH A PATTERN           PATRN 02
          C                                                                              PATRN 03
          C             RON DOMSCH / JUNE 1974                                           PATRN 04
          C             WYANDOTTE COUNTY PLANNING BOARD                                  PATRN 05
          C                                                                              PATRN 06
          C         X,Y   - ARRAYS OF COORDINATES OF POLYGON PERIPHERY POINTS            PATRN 07
          C         N     - LENGTH OF X AND Y ARRAYS                                     PATRN 08
          C         IPAT  - INTEGER ARRAY OF SHADE CODES USED TO MAKE THE PATTERNS       PATRN 09
          C         M     - LENGTH OF IPAT ARRAY                                         PATRN 10
          C                                                                              PATRN 11
          C         THE CODES IN 'IPAT' ARE 5 DIGIT CODES AS FOLLOWS - DIGITS 12345      PATRN 12
          C                                                                              PATRN 13
          C         -----------------------------------------------------------          PATRN 14
          C         | DIGIT 1       | DIGIT 2     | DIGITS 3&4        | DIGIT 5       |   PATRN 15
          C         | (COLOR CODE)| (ANGLE)     |'SPACE' IN INCHES| (OFFSET)      |    PATRN 16
          C         |----------------------------------------------------------|     PATRN 17
          C         | 0: NO LINES | 0:   0 DEG. | 01: .01 INCHES   | 0: 0  *SPACE |    PATRN 18
          C         | 1: P1=C1    | 1: 30 DEG.  | 02: .02 INCHES   | 1: 1/2    "  |    PATRN 19
          C         | 2: P2=C2    | 2: 45 DEG.  | 03: .03 INCHES   | 2: 1/3    "  |    PATRN 20
          C         | 3: P3=C3    | 3: 60 DEG.  |                  | 3: 2/3    "  |    PATRN 21
          C         | 4: P1=C4    | 4: 90 DEG.  |        .         | 4: 1/4    "  |    PATRN 22
          C         | 5: P2=C5    | 5:120 DEG.  |     ETC.         | 5: 3/4    "  |    PATRN 23
          C         | 6: P3=C6    | 6:135 DEG.  |                  | 6: 1/5    "  |    PATRN 24
          C         | 7: P1=C7    | 7:150 DEG.  |                  | 7: 2/5    "  |    PATRN 25
          C         | 8: P2=C8    | 8: INVALID  | 99: .99 INCHES   | 8: 3/5    "  |    PATRN 26
          C         | 9: P3=C9    | 9: INVALID  | 00: 1.0 INCH     | 9: 4/5    "  |    PATRN 27
          C         -----------------------------------------------------------          PATRN 28
          C                                                                              PATRN 29
0002                COMMON /SHADE/ IPEN,THETA,SPACE,OFFSET                               PATRN 30
0003                DIMENSION X(N),Y(N),IPAT(M)                                          PATRN 31
0004                DIMENSION DEGREE(8),FRACTN(10)                                       PATRN 32
0005                DATA DEGREE/0.,30.,45.,60.,90.,120.,135.,159./                       PATRN 33
0006                DATA FRACTN/0.,.5,.3333333,.6666667,.25,.75,.2,.4,.6,.8/             PATRN 34
          C                                                                              PATRN 35
          C         DECODE THE 'M' SHADE CODES IN IPAT                                   PATRN 36
          C                                                                              PATRN 37
0007                NN=N                                                                 PATRN 38
0008                DO 100 I=1,M                                                         PATRN 39
0009                I1=MOD(IPAT(I),10)                                                   PATRN 40
0010                I2=MOD(IPAT(I),1000)/10                                              PATRN 41
0011                I3=MOD(IPAT(I),10000)/1000                                           PATRN 42
0012                I3=MOD(I3,3)                                                         PATRN 43
0013                I4=IPAT(I)/10000                                                     PATRN 44
0014                I4=MOD(I4,10)                                                        PATRN 45
0015                IF(I4.EQ.0) GO TO 110                                                PATRN 46
0016                IF(I2.EQ.0) I2=100                                                   PATRN 47
          C                                                                              PATRN 48
          C         SET THE VALUES IN THE COMMON BLOCK SHADE FOR ROUTINE SHADEG          PATRN 49
          C                                                                              PATRN 50
0017                IPEN=I4                                                              PATRN 51
0018                THETA=DEGREE(I3+1)                                                   PATRN 52
0019                SPACE=FLOAT(I2)*.01                                                  PATRN 53
0020                OFFSET=FRACTN(I1+1)                                                  PATRN 54
```

COMPUTER-ASSISTED INFORMATION SYSTEMS AND COMPUTER-ASSISTED CARTOGRAPHY: TOOLS OR TINKER TOYS OF URBAN GOVERNANCE

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INTRODUCTION

The Urban and Regional Information Systems Association (URISA) based its 1974 Conference on the themes of Resources and Results. Examination of Conference Proceedings 1/ makes it apparent that managers and operators, professionals and laypersons, and users and suppliers have only begun to deliberate the extent to which computer-assisted information systems are tools or tinker toys in the processes of urban governance. The activities of the Panel on Information Technology and Urban Management of the Organization for Economic Cooperation and Development (OECD) 2/ will most likely go a long way towards generating much needed facts, and insightful interpretations in this regard. Further, a ministry-sponsored symposium 3/ will further explore this topic. However, it does remain that the universe of interested parties (for example, elected officials, government personnel, the public) is by no means convinced that computer-assisted information systems (C-AIS) can be assigned, by selected criteria, to the appropriate tool or tinker toy bin of urban governance capabilities. 4/

As far as computer-assisted cartography (C-AC) is concerned, the overall assessment must be somewhat the same. 5/ We are all aware, as with computer-assisted information systems, that some aspects of the capability or configuration are being utilized (as tools), and some parts/activities represent the tinkering phase or stage. What is of primary consequence in a discussion of computer-assisted cartography as a tool or tinker toy in urban governance is, of course, the purposes, ways and extent of the roles. That is, the amount of tooling or tinkering must be examined in the context of ends to which C-AC is put.

CONTEXT FOR ASSESSING C-AIS AND C-AC UTILITY IN URBAN GOVERANCE

The ends to which computer-based information systems and computer-assisted cartography are put is the focal talking point of this statement. During the past

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EDITORS NOTE: The views expressed are those of the author, and do not necessarily represent those of the Ministry of State for Urban Affairs.

several decades increasing amounts have been expended on computer-driven means of specifying, acquiring, processing, disseminating, displaying and applying urban data. 6/ Hence, the topic warrants serious debate.

There are a number of criteria (data or transactions volume, cost per unit of activity, cost of physical space and amenities for accommodating 200 or 2,000 clerks versus one computer and peripherals, etc.) associated with the desire to shift from manual to computer-assisted information systems. However, personal communications and experiences, as well as the extant literature, indicate that the ranking criteion may very well be that of time. Concern about the time factor has involved, in the main, attempts to ensure the timeliness of data and transactions, and to bring them on line with user needs (human or otherwise) in decreasing time spans. Bearing these criteria in mind, and particularly that of time, let us look to the urban agent or activity served by computer-assisted information systems and computer-assisted cartography.

RELATING TECHNOLOGIES AND THEIR USERS AND USES

If we look upon urban government change agents in human terms, then we are speaking about managers, operators, planners, researchers, administrators, etc. Translated into functions, they are management, operations, planning, research, administration, etc. The fundamental point of concern, when relating C-AC and C-AIS to these persons and functions, is to determine the why and how which underlie the ways and extent that both the technologies and the agents and functions have shifted on their respective manual-to-automated spectra.

The distinction being made between people (agents) and functions (what people do) is by no means new, but it is very important in the context of this paper. That is, both the agents and/or the functions can legitimately be considered in manual-cum-automated terms when examined from the standpoints of what is done (product orientation) and how things are done (process orientation). 7/

Due to the significance attached to this point, a brief elaboration is offered. A function or application may readily lend itself to an algorithmic expression. As a result it can be automated, leading to real time or near real time outputs or determinations. That is not to say that the human agent relates to the function or application in the same fashion. The human agent may perceive the function via a mental process which defies algorithmic representation. Further, it may simply be beyond mental human capacity to handle the function or application (e.g., traffic control) in the way that a computer-assisted or computer-driven capability could.

With regard to the human agents of urban governance (and I do not apologize for the apparent triteness of the statement), the job does not necessarily define the person. This means that we must bear in mind, then, the ways and extents, and reasons behind them, that people have changed in terms of self-perception or perceptions about computers, as a consequence of the evolution of this technology. To repeat, and emphasize the point, it is necessary to appreciate two kinds of ends to be served -- people and functions -- when considering C-AIS and C-AC as tools, tinker toys, or some combination thereof as they relate to the products and processes of urban governance.

INVENTORY AND ASSESSMENT OF C-AIS AND C-AC TECHNOLOGIES IN URBAN GOVERNANCE

The contents of this section are based on a discussion of Figure 1, "Relationships Between Urban Users and Usage of Computer-Assisted Information Systems and Computer-Assisted Cartography." A cursory look at Figure 1 reveals immediately a high degree of aggregation. First, there is no distinction made between levels of government (Federal, provincial or State, county, regional, municipal) which play a role in affairs urban. Second, there is no elaboration with regard to either agents or functions of urban governance.

These jurisdictional and functional distinctions were developed in detail in earlier papers, 8/ and are not central to the general arguments of this report. Rather, they are important in the development of supporting statements for the series of "impressions" advanced, and summarized in Figure 1. The work "impressions" is chosen advisedly, it is noted, as the observations set forth are not based on a statistically valid empirical study. Instead, they represent findings based on experience with and reading about C-AIS and C-AC developments, users, and usages in both Canada and the United States, and in Europe to a lesser extent.

By way of explanation of what is depicted in Figure 1, consider the entries manager-management, and researcher-research. In my view, most urban managers have a relationship with the technologies that is becoming mentally comfortable. I do not propose that managers as a whole have an electronic symbiosis with the technologies, but only that over the years an attitude of "live and let live" has developed. Further, the managers' mental sets of "acceptables" have reached the point where the technologies are regarded as something more than mere tinker toys.

As far as urban management functions are concerned, however, relationships with the technologies have not undergone a similar progression. In my view, the management function still uses and regards the technologies as tinker toys, and has not yet rendered itself (or been rendered by exogenous forces) as a series of activities which extend much beyond a kind of lock-step body of events that do not lend themselves to an automated mode of replication and decision-taking.

With regard to researchers, I perceive there to be a relatively different state of affairs in place. Researchers, and particularly those who have engaged in modeling activities, or have been trained in the use of quantitative techniques and dynamic systems, relate very well to the technologies in mental or orientation terms, and perceive the technologies to be tools of their trade.

Insofar as technology usage in the research function is concerned, it is well up the manual-automated ladder, but has advanced somewhat less quickly along the Tinker Toy-Tool axis. My explanation of this is that while researchers have an affinity for time compression in carrying out tasks (e.g., large-scale simulation exercises), desire to use the technologies is not sufficient to readily make them serve those ends. That is, it is one thing to conceptualize and design an application on paper or in principle, and often something else to make the technology serve that end, in practice.

As a final remark in this section, a two-fold reminder is offered. This is, we must look to the purposes, ways, and extent of C-AIS and C-AC roles in urban governance, and we must bear in mind changes occurring in both the fields of technology (C-AIS and C-AC) and of urban governance (people and functions and activities). To ignore these difficult to handle but fundamental points is to opt for tinker toy evaluation by default.

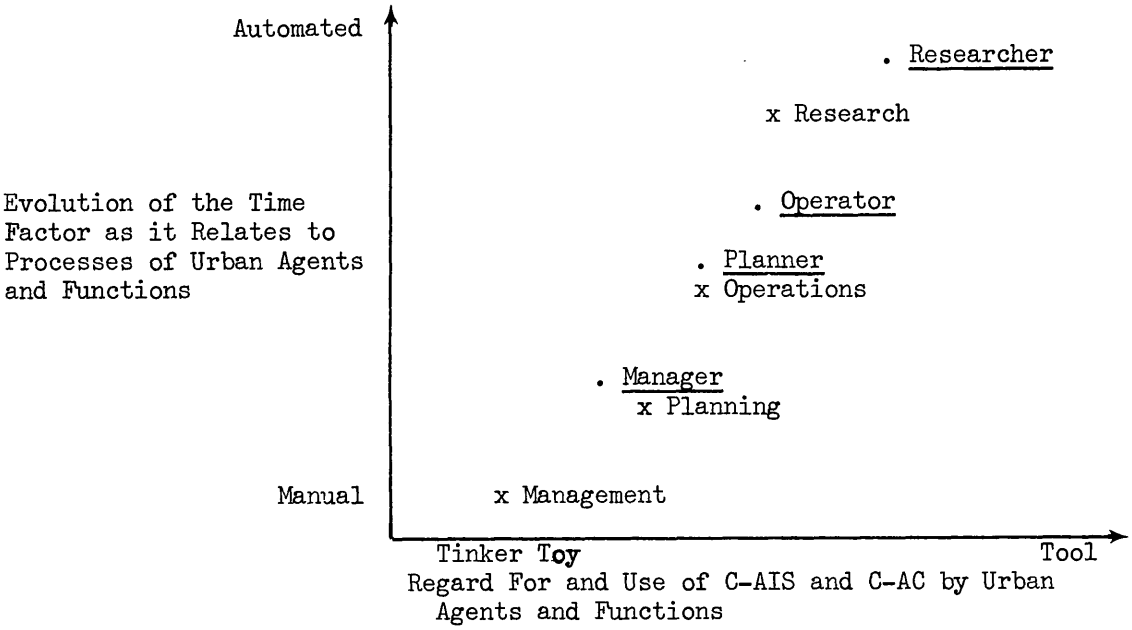

Figure 1. Relationships Between Urban Users and Usages of Computer-Assisted Information Systems and Computer-Assisted Cartography

Purpose of C-AIS and C-AC Use / Activity[2]	Legislation	Policies	Programs		Projects	
	Introduce	Introduce	Introduce	Manage & Administer	Introduce	Execute
Transportation		L	L	M	M	H
Engineering				M	M	H
Environmental Control			L	L	L	L
Building Inspection				M	L	M
Land Records		L	M	M	M	H
Public Utilities			L	M	L	M
Finance		L	M	H	M	H
Assessing		L	L	H		M
Revenue Collection			L	H	M	H
Welfare			M	H	L	H
Library				M	L	M
Voter Registration				M		M
Police			M	H	H	H
Fire		M	M	H	M	M
Code Enforcement						L

Notes: 1/ L=Low, M=Medium, H=High. An empty cell conveys the impression of either trace or nil C-AIS or C-AC use for the activity.
2/ The list of activities is illustrative rather than exhaustive.

Figure 2. Purpose and Extent of Use of C-AIS and C-AC for Selected Activities of the Urban Operations Function 1/

C-AIS & C-AC VIS-A-VIS URBAN OPERATORS AND OPERATIONS

The earlier acknowledgement about risks in inferring what people are, based on an analysis of what they do, points up a problem inherent in this type of "impressions" paper. That is, while one can go to the literature to find out what is being done by someone or by an agency, that is very far removed from learning anything about that entity. Unfortunately, symposium objectives as well as time and space constraints are such that a detailed examination of pertinent materials, or on-site visits to installations to discourse with people are neither warranted nor feasible. Hence, the reader must be content with an unbalanced treatment of operators and operations in the context of C-AIS and C-AC usage.

For reasons of complexity, both analytical and cartographic, Figure 1 is not used as the model for further diagrams in the paper. Instead, for example, operations are considered in terms of 1) what they are (types of functions), 2) the status of C-AIS and C-AC usage by function (high, medium, low), and 3) the use made of C-AIS and C-AC during the course of the operations process. To further reduce the magnitude of this task, without loss of generality, discussion is limited to four outputs: legislation, policies, programmes, and projects. Again, since this topic has been addressed in an earlier paper, 9/ the various aspects of product evolution (recommend, introduce, manage and administer, and execute) are not elaborated upon here. The final qualifier is that inputs from operations to the management, planning and research functions are precluded due to space constraints. (It is strongly recommended, however, that any follow-ups to this paper investigate 1) the connections between combinations of process functions and the output of products, and 2) changes in the process functions themselves as a result of C-AIS and C-AC outputs linking the functions. Discussions with a variety of officials point this up as a crucial urban policy research activity area).

The functions shown in Figure 2 are representative of those carried out by municipal, Provincial State, and Federal governments. Those functions, as well as a number of others, represent the channels by which governments deliver goods and services to the public. Insofar as operations are concerned, the contents of Figures 1 and 2 are reasonably consistent. That is, C-AIS and C-AC are regarded as contributing more to projects than to programmes than to policies than to legislation, with the full range of high (H), medium (M), and low (L) being associated with the status of C-AIS and C-AC usage in the operations function.

The location of operations on the Tinker Toy-Tool axis is explained by the majority of H's and M's registered in the Execute Projects column of Figure 2. With regard to the Manual-Automated axis, it is my impression that much remains to be done before time savings or benefits are part and parcel of C-AIS or C-AC/operations-based activities. Clearly, the policy activity and several others are exceptions to this impression, but as a rule time savings or time compression remain more as potential than actual accomplishment.

With regard to persons in operations, that is, operators, they were touched upon in an earlier section. Figure 2 suggests that they are now using C-AIS and C-AC to introduce projects and programmes for a variety of functions, and for a very limited number of policy-related activities. Evidence contrary to my impressions is solicited, particularly since we are dealing with the catalysts (people) who will play a major role in the evolution of C-AIS and C-AC in the operations component of urban governance. In sum, operators use C-AIS and C-AC in carrying out existing responsibilities (probably set in place during the days of manual methods), and in initiating new endeavours, and hence their placement away from the origin of Figure 1.

It merits noting that operators and operations are shown in Figure 2 to be very consistent with what they should be doing. That is, the matrix is skewed heavily in the direction of projects, which is most appropriate given the nuts-and-bolts responsibilities of this component of urban governance. If the distribution were not of that general order, then there would be great and justified cause for worry about the performance of the agents and activities comprising this function.

C-AIS AND C-AC VIS-A-VIS URBAN MANAGERS AND MANAGEMENT, PLANNERS AND PLANNING, AND RESEARCHERS AND RESEARCH

Each of the agents and functions of this section are intimately related to operators and operations, given that the latter constitute the basic agents and apparatus of urban governance. By way of explanation, management depends upon the operations function for the delivery of goods and services to the citizenry. On the other hand, operations is directed by management as to nature, timing, distribution, etc. of goods and services. Planning, among its other tasks, is involved in relating different operations functions (e.g., transportation, public works, and assessment) in an overall plan for the community. Conversely, operations activities as a rule are bound or constrained by the larger goals and objectives of the planning function. Similarly, the ultimate urban governance constituent for research outputs is the operations function. Operations, in turn, translates research outputs into goods and services to be delivered to the citizenry. Finally, operations specifies the nature of its problems to research, and thereby directs at least some aspects of the research function.

For those reasons, as well as space limitations, the three components are grouped in this part of the paper. It is necessary, as a result, to change slightly the format between Figures 2 and 3. Hopefully this will not reduce either the validity or utility of impressions which follow.

As an introduction to Figure 3, let us consider several questions in the context of suggested cell entries. Reading from the row (function, activity) and column (type of use) headings, illustrative questions would be as follows: 1) "To what extent does the Management Function employ C-AIS or C-AC to Analyse Data so that it may Introduce Policies?"; 2) "To what extent does the Planning Function use C-AIS or C-AC to Evaluate Operations so that it may Introduce Projects?"; and 3) "To what extent does the Research Function use C-AIS or C-AC to Analyse Trends so that it may Introduce Programmes?". As shown in Table 3, my impressions lead me to suggest that representative assessments are low, medium, and high, respectively.

Before proceeding with an analysis of Figure 3, it is important to stress that the entries do not, by any means, imply that there is a "rightness" to what the functions are doing in terms of the type or extent of C-AIS or C-AC usage. Further, they should not be construed as suggesting that a "high" recorded for planning is more consequential than a "low" for management for a common activity and type of usage. They are, rather, impressions of the degree to which the technologies are employed by the functions as they carry out their activities in the various domains, and nothing more.

In this regard, and to ensure that the distinction being made is related to the earlier reference about algorithmic expression (p. 483), and the lock-step characterization of the management function (p. 484), a statement by Drucker merits repeating. That is, "The basic decisions of government - the substance of politics -

cannot be made subject to automatic rules, there would be no decision left." 10/ If one substitutes "management" for "government" with respect to "basic decisions," (a substitution which I would not readily propose for either "planning" or "research"), then the point is surely made even more apparent. Namely, one may equate management, planning, and research function activities, or regard them as synonymous, but in doing so one incurs the risk of comparing dissimilar entities. No such action is taken, nor can be logically inferred from the paper.

In looking at Figure 3 from an overall point of view, the entries fall in line in a general sense with the contents of Figure 1. Management, which as a rule has a legislation and policy focus, has not advanced much beyond the project and programme components in terms of using the technologies. Planning, on the other hand, has attained solid footing in the project and programme components, and is beginning to make modest inroads in the policy and legislative domains. As for the research function, it is perceived as having reached the state where C-AIS and C-AC are integral to virtually all aspects of activity associated with the research-sponsored legislation, policies, programmes, and projects.

Purpose of C-AIS and C-AC Use 1/	Legislation	Policies	Programmes		Projects	
Function Activity 2/	Introduce	Introduce	Introduce	Manage & Administer	Introduce	Execute
Management						
Interpret Constituents' Preferences and Needs					L	
Analyse Data	L	L	L	M	L	
Evaluate Recommendations	L	L	L		L	
Allocate Resources			L		L	
Evaluate Operations			L	L	L	
Planning						
Collect Data	L	M	L		M	M
Analyse Data	L	M	M		H	H
Evaluate Operations			L	M	M	
Prepare Plans	L	M	L		L	
Prepare Forecasts		M	M		M	
Research						
Collect Data	M	H	H		H	H
Test Hypotheses					H	H
Develop Theories	M	H			H	H
Develop and Calibrate Models		H			H	H
Analyse Trends	H	H	H		H	H
Prepare Forecasts	M	H			H	

Notes: 1/ L = Low, M = Medium, H = High. An empty cell conveys the impression of either trace or nil C-AIS or C-AC use for the activity.
2/ The list of activities is illustrative rather than exhaustive.

Figure 3. Purpose and Extent of Use of C-AIS and C-AC for Selected Activities of the Urban Management, Planning, and Research Functions

So as to be consistent with the previous section, it is not appropriate to refer specifically to the axes of Figure 1. If the foci of management are the legislation and policy domains, then Figure 3 substantiates the placement of that function along the Tinker Toy axis. That is, management is using the technologies for purposes not in its prime purview, i.e., it is clearly in the tinker toy stage. With regard to the Manual-Automated axis, it is my impression that management is not using the technologies to perform activities which are consequential and heavy consumers of management time.

With regard to the research function, I perceive it to have fully incorporated C-AIS and C-AC in its primary domain, projects (in the sense of research projects). Further, it has reached the stage where the technologies are becoming an increasingly integral part of the ways and means for advancing thrusts in the legislation, policy, and even programme spheres. In addition, the research function uses the technologies for activities which lend themselves exceedingly well to time compression for the full range of purposes.

Planning, our third function, is placed between the management and research functions. This is perceived to be the case for reasons which are situated between those set out in the two preceding paragraphs. That is, planning uses the technologies in modest degree to carry out tasks which are amenable to time compression, and has gone beyond its conventional domains (projects and programmes) to make inroads in the legislation and policy spheres via C-AIS and C-AC.

CONCLUSION

The objective of this paper was to set forth a series of impressions on the purposes, ways, and extent whereby the management, planning, operations, and research functions of urban governance employ computer-assisted information systems and computer-assisted cartography in the performance of their associated activities. As noted at the outset, there is little if any solid, comparative documentation on this topic. In fact, we are only beginning to appreciate how enamoured we have been of the usage of the technologies in urban governance, to the virtual exclusion of hard looks at the ways and consequence of these usages. Hence, while cost-benefit, cost-effectiveness, etc. analyses are terms of long standing, we are just beginning to seriously consider how we might go about making broad scope determinations in these regards.

During the course of the paper the functions have been related to each other via a set of ends for activities -- legislation, policies, programmes, and projects. In that framework some impressions were advanced. The next step is to examine the framework and adopt it or modify it, with the understanding that we are long overdue to come forward with ways and means for rigorously examining the consequences of C-AIS and C-AC usages by purpose, ways, and extent. It seems eminently reasonable to suggest that the "counterfoil research" proposition of Illich may very well be the overriding principle that should direct our efforts towards that end. 11/

As for the impressions advanced, I look forward to hearing or reading other perceptions or facts of where we are at, as information exchange is one of the keys to the rational and sensitive evolution of this field.

REFERENCES

1. Urban and Regional Information Systems: Resources and Results, Volumes I and II. Papers from the Twelfth Annual Conference of the Urban and Regional Information Systems Association (Pomona, N.J.: Management Sciences, Stockton State College); 1975.

2. For further information contact Directorate for Science, Technology and Industry, OECD, Paris, France.

3. A symposium entitled Information Technology and Urban Governance is scheduled for the Conference Centre, Ottawa, in February of 1976. One of its objectives is to "Ascertain and subject to critical debate philosophies and methodologies underlying the evolution of information technology as a component of urban governance."

4. For an insightful and provocative discourse on this and related technological concerns, see Ivan Illich, Tools for Conviviality (New York: Harper and Row, 1973).

5. Under most institution-based circumstances, computer-assisted cartography would not be treated as something distinct from computer-assisted information systems, but would be considered instead as part of that generic field. They are treated as distinct entities here so as to be in concert with Symposium organizers who had automated cartography as their focus, and who sought relationships between auto-carto and urban information systems, uses of color, map reading, land use mapping, etc.

6. Details on this topic are provided by the International City Managers Association (ICMA), the International Union of Local Authorities (IULA), journals such as Public Administration Review, Proceedings of the Urban and Regional Information Systems Association, and, of course, governments at the Municipal, Provincial/State, and Federal levels.

7. For further discussion along these lines see B. Wellar and L. Lavallee, "A Methodology for Selecting R & D Studies in a Policy Oriented Organization," Computers, Local Government and Productivity. (Forthcoming) Papers of the Thirteenth Annual Conference of the Urban and Regional Information Systems Association, Seattle, Washington, 1975. (Pomona, N.J.: Management Sciences, Stockton State College).

8. See, for example, Wellar and Lavallee, op. cit., and A. Saumier and B. Wellar, "Results," Urban and Regional Information Systems: Resources and Results, Volume I Papers from the Twelfth Annual Conference of the Urban and Regional Information Systems Association (C. Davis, J. Rickert, V. Di Matteo, eds.). (Pomona, N. J.: Management Sciences, Stockton State College, 1975) pp. 7-22. Also published as "Results Accruing from Information Systems in Urban and Regional Governments: Contexts, Identification and Measurement, Appreciation." Discussion Paper B74.27. (Ottawa, Canada: Ministry of State for Urban Affairs, 1974).

9. Wellar and Lavallee, op. cit.

10. Peter F. Drucker, The Future of Industrial Man (New York: New American Library, 1970) p. 125.

11. Illich, op. cit., pp. 84-90.

GEOLOGICAL INFORMATION IN A COMPUTER MAPPING SYSTEM FOR LAND USE PLANNING

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INTRODUCTION

The U.S. Geological Survey (U.S.G.S.) is investigating methods for communicating relevant geologic information to land-use planners and decision makers. If geologic information is to be used effectively in the planning process, it must be understood by planners so that it can be combined with other planning factors. Several special mapping projects of the U.S.G.S. have been successful in transmitting technical planning related geologic information to nongeologists. This paper describes a geographic information system which permits a planner to combine different types of mapped information.

SYSTEM DESIGN

In order to be of maximum use in a planning office, a geographic information system should combine map overlay capability, scale flexibility, speed, and ease of operation. The traditional method of hand-drawn transparent overlays is easy to use, but is costly and time consuming, and limits the number of maps that can be practically combined. The computer-aided system which was chosen to satisfy the requirements for this pilot study uses cell format, line printer maps, and manual digitizing. The Multi-Scale Data Analysis and Mapping Program (MSDAMP) was developed at the Land Use Analysis Laboratory of Iowa State University. The cell format was selected for input, storage, and output, because it provided the most understandable and inexpensive way to overlay, or composite maps with the computer. Output maps are produced on a line printer because it is the most universally available output device and is consistent with the cell format. Manual digitizing has a high degree of accuracy, can be done in the planning office by clerks, and does not require any equipment acquisition.

DIGITIZING

The process of converting to machine readable form is called digitizing. For this information system the digitizing is usually done by a team of two people, one reading the map and the other one recording. A regular sampling grid with a dot at the center of each cell is superimposed on the source map to be digitized, and the latitude-longitude address and map unit code for the mapped unit are recorded for each cell. To speed up the process, only the first cell of a repeating unit (scanning from left to right) must be recorded, and the rest are accounted for by recording the number of repeat cells. Digitizing speeds range from 300 to 1,500 cells per hour, depending on cell size and map complexity.

COMPUTER COMPOSITE MAPPING

Once the factor maps are digitized, information from the different maps can be composited by the computer on a cell-by-cell basis. Figure 1 illustrates how three factors can be composited. In this example a planner wants to locate a development so that it avoids shallow bedrock, trees, and surface water. The top row depicts the source map divided into cells and the second row shows diagrammatically how the digitized maps look to the computer. In the next step, the planner assigns numbers

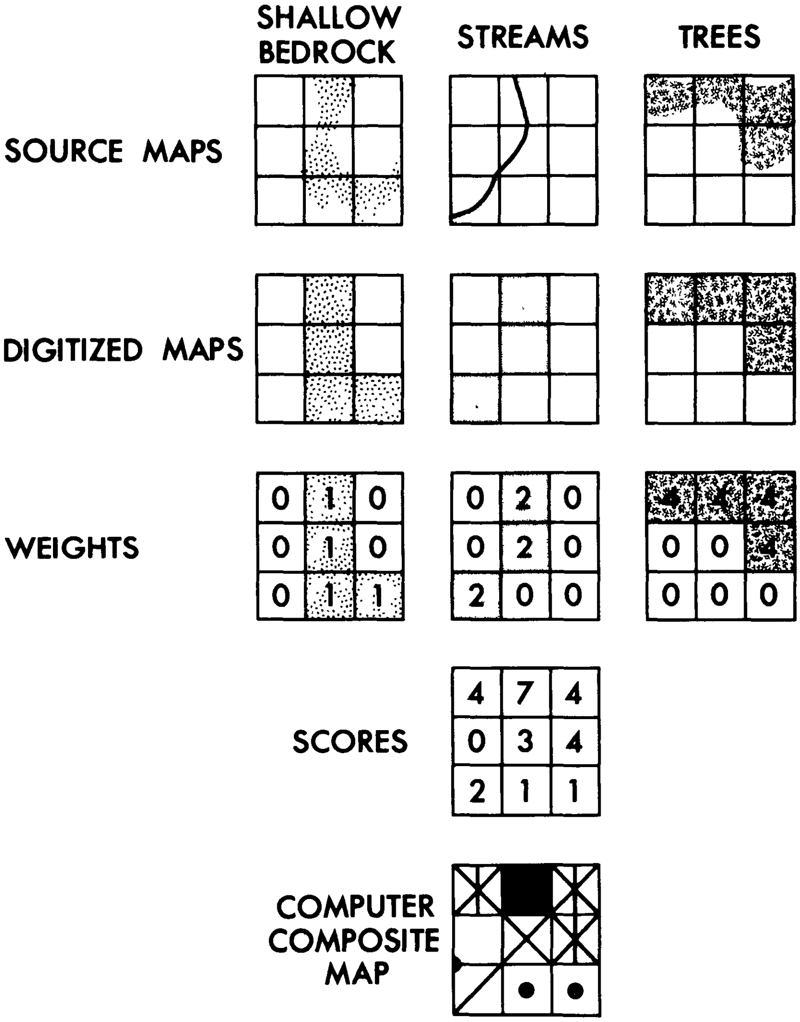


Figure 1: Example of compositing

or values (weights) to the presence or absence of the factors. The computer takes the numbers recorded for each cell and adds them to produce a score. Finally the composite map is produced on a line printer with the symbol the user has assigned to each score level. In this example, light cells indicate more desirable areas for development and dark cells are less desirable.

The computer program permits the use of any integer numbers for factor values so that each combination of the factors can have a unique score. In this example using values 1, 2, and 4 produces scores from 0 through 7, and each score represents a particular combination of factors. This capability to separate the factors on a composite map can also be used to assign different weights to the factors. For this analysis the planner has judged that the presence of trees is 4 times as important as the presence of shallow bedrock and twice as important as the presence of surface water. Another planner might weight these factors differently and derive a substantially different composit map. This weighting capability is a useful feature in a decision-making process because it provides a means of visually displaying different opinions and permits more logical discussion of opposing viewpoints.

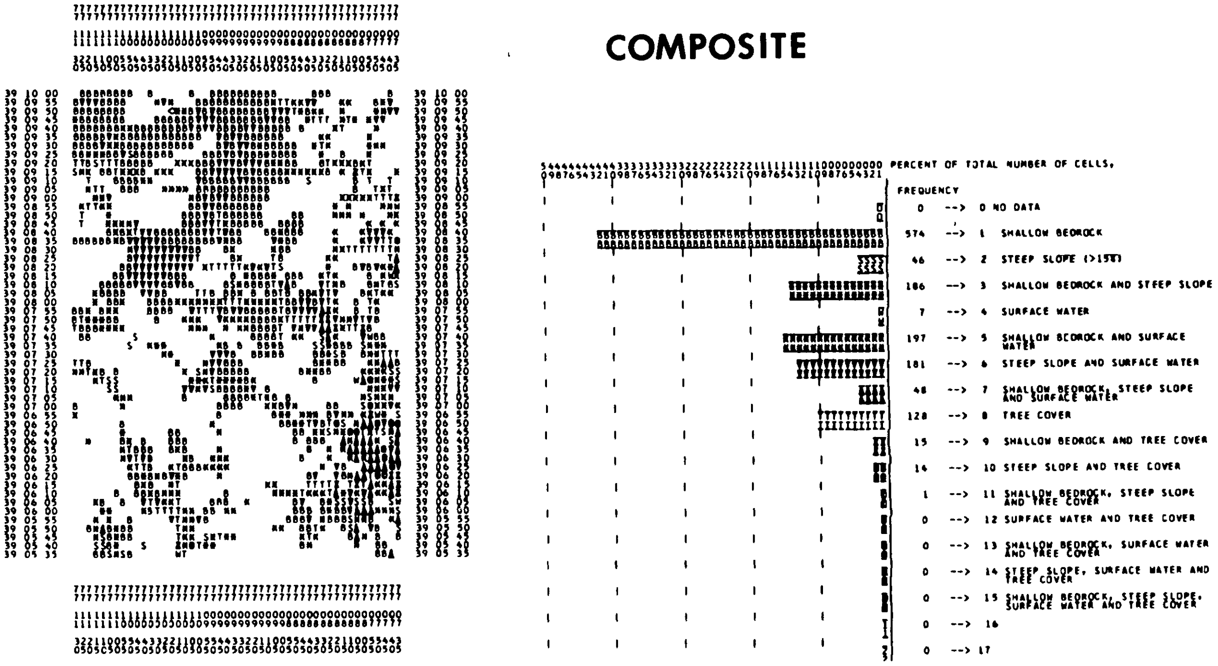
APPLICATION OF THE SYSTEM

Montgomery County, Maryland, located just north of Washington, D.C., was selected as a test site for the information system because of the interest expressed by environmental planners in the county and because of the availability of recently published, planning-oriented geologic information.

The Montgomery County Folio, published at 1:62,500 scale, includes topography, surface water, bedrock, surface materials, bedrock contour, and overburden thickness. All of these maps, except overburden thickness, have been digitized. Additional factors, including vegetation, slope, and land use, have been digitized for a small portion of the county.

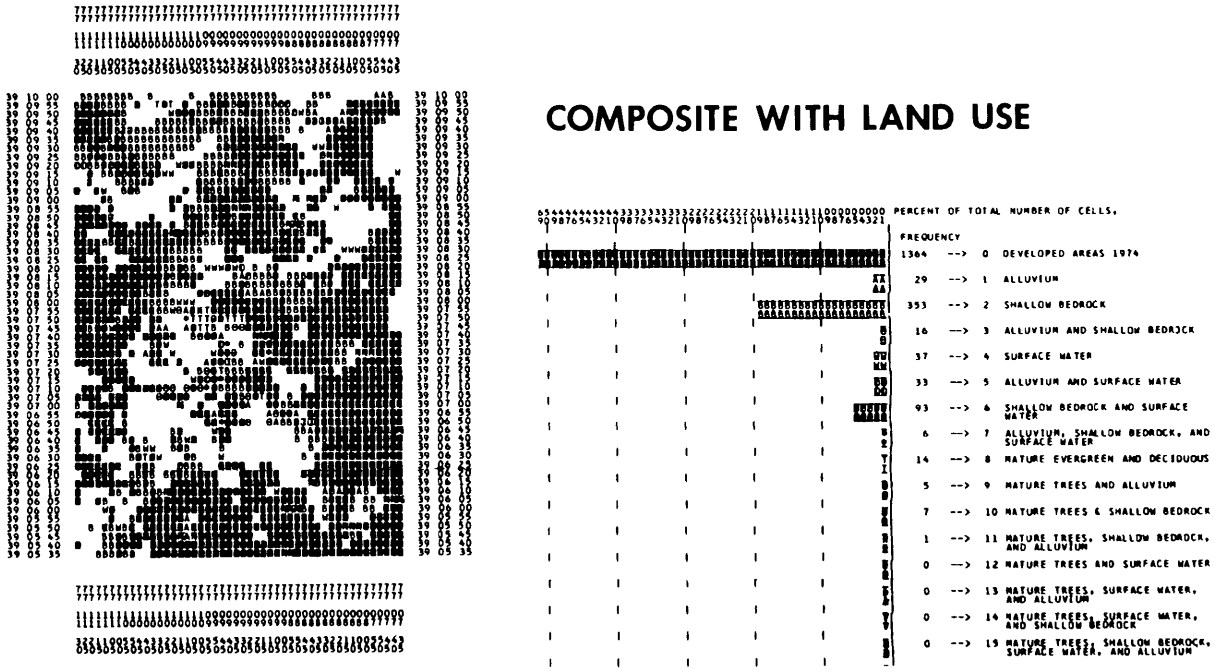
Planners in the Environmental Planning Division of the Maryland-National Capital Parks and Planning Commission (MNCPPC) have used the information system to examine an area in which urban growth will be stimulated by new and improved transportation facilities. The Shady Grove Planning Sector is an area of about 20 square miles (52 km^2) which will be affected by the construction of a terminal station for the Washington Rapid Transit system (METRO) within the next five years. Natural conditions which would affect future urban development were analyzed with a view toward directing this growth to minimize damage to the environment and avoiding unnecessary construction problems.

The factors chosen were: presence of steep slopes (15%), shallow bedrock, alluvium, surface water, and mature trees. Presence of the first three factors on a site would increase construction costs. Mature trees and surface water are resources the people of the county wish to preserve. These five factors were composited by the computer to produce a map showing natural conditions affecting urbanization (Figure 2). The blank areas on this map are those in which none of the five factors occurs, and darker shades of gray indicate various combinations of two, three, four, or five of the factors. In order to remove areas already developed, all the various types of land use were collectively called developed and committed land, and combined with the natural factors to produce the final composite (Figure 3). The darkest symbol on this map indicates presently developed land not warranting further environmental consideration; undeveloped areas with no natural limitations are shown in white, and undeveloped areas with various combinations of natural



```
FREQUENCY
   0  -->  0 NO DATA
 574  -->  1  SHALLOW BEDROCK
  46  -->  2  STEEP SLOPE (>15%)
 186  -->  3  SHALLOW BEDROCK AND STEEP SLOPE
   7  -->  4  SURFACE WATER
 197  -->  5  SHALLOW BEDROCK AND SURFACE
              WATER
 181  -->  6  STEEP SLOPE AND SURFACE WATER
  48  -->  7  SHALLOW BEDROCK, STEEP SLOPE
              AND SURFACE WATER
 128  -->  8  TREE COVER
  15  -->  9  SHALLOW BEDROCK AND TREE COVER
  14  --> 10 STEEP SLOPE AND TREE COVER
   1  --> 11 SHALLOW BEDROCK, STEEP SLOPE
             AND TREE COVER
   0  --> 12 SURFACE WATER AND TREE COVER
   0  --> 13 SHALLOW BEDROCK, SURFACE WATER
             AND TREE COVER
   0  --> 14 STEEP SLOPE, SURFACE WATER AND
             TREE COVER
   0  --> 15 SHALLOW BEDROCK, STEEP SLOPE,
             SURFACE WATER AND TREE COVER
   0  --> 16
   0  --> 17
```

Figure 2: Composite computer map of Shady Grove area, Montgomery County, Maryland



```
FREQUENCY
1364  -->  0  DEVELOPED AREAS 1974
  29  -->  1  ALLUVIUM
 353  -->  2  SHALLOW BEDROCK
  16  -->  3  ALLUVIUM AND SHALLOW BEDROCK
  37  -->  4  SURFACE WATER
  33  -->  5  ALLUVIUM AND SURFACE WATER
  93  -->  6  SHALLOW BEDROCK AND SURFACE
              WATER
   6  -->  7  ALLUVIUM, SHALLOW BEDROCK, AND
              SURFACE WATER
  14  -->  8  MATURE EVERGREEN AND DECIDUOUS
   5  -->  9  MATURE TREES AND ALLUVIUM
   7  --> 10 MATURE TREES & SHALLOW BEDROCK
   1  --> 11 MATURE TREES, SHALLOW BEDROCK,
             AND ALLUVIUM
   0  --> 12 MATURE TREES AND SURFACE WATER
   0  --> 13 MATURE TREES, SURFACE WATER,
             AND ALLUVIUM
   0  --> 14 MATURE TREES, SURFACE WATER,
             AND SHALLOW BEDROCK
   0  --> 15 MATURE TREES, SHALLOW BEDROCK,
             SURFACE WATER, AND ALLUVIUM
```

Figure 3: Composite computer map of Shady Grove sector, Montgomery County, Maryland

factors are depicted in shades of gray. A transparent overlay showing the current master development plan for this area was superimposed on the computer composite map and several areas of conflict were apparent. These conflicts, where environmental damage would result from the proposed development, were resolved by using the computer composite map to revise the master plan for the Shady Grove sector.

The environmental planners in Montgomery County have used the computer information system to locate a sanitary landfill. This type of site selection is a process of elimination of undesirable areas on a reconnaissance level, followed by detailed investigation of favorable sites. For initial reconnaissance, the undesirable characteristics composited were the presence of surface water, shallow bedrock, and poorly or excessively drained surface materials. The composite map (Figure 4) shows in dark symbols combinations of one, two, or three of the undesirable features. The white areas on the map have 20 feet or more of well drained surface material with no surface water present. These favorable areas were further screened with factors such as land ownership, population density, and transportation routes.

In summary, the application of this geographic information system in the Maryland-National Capital Parks and Planning Commission's Environmental Planning Division has provided the planners with a readily accessible source of objective, planning-related, earth science facts, and an inexpensive, rapid and flexible tool for combining these facts with various biases to produce decision alternatives.

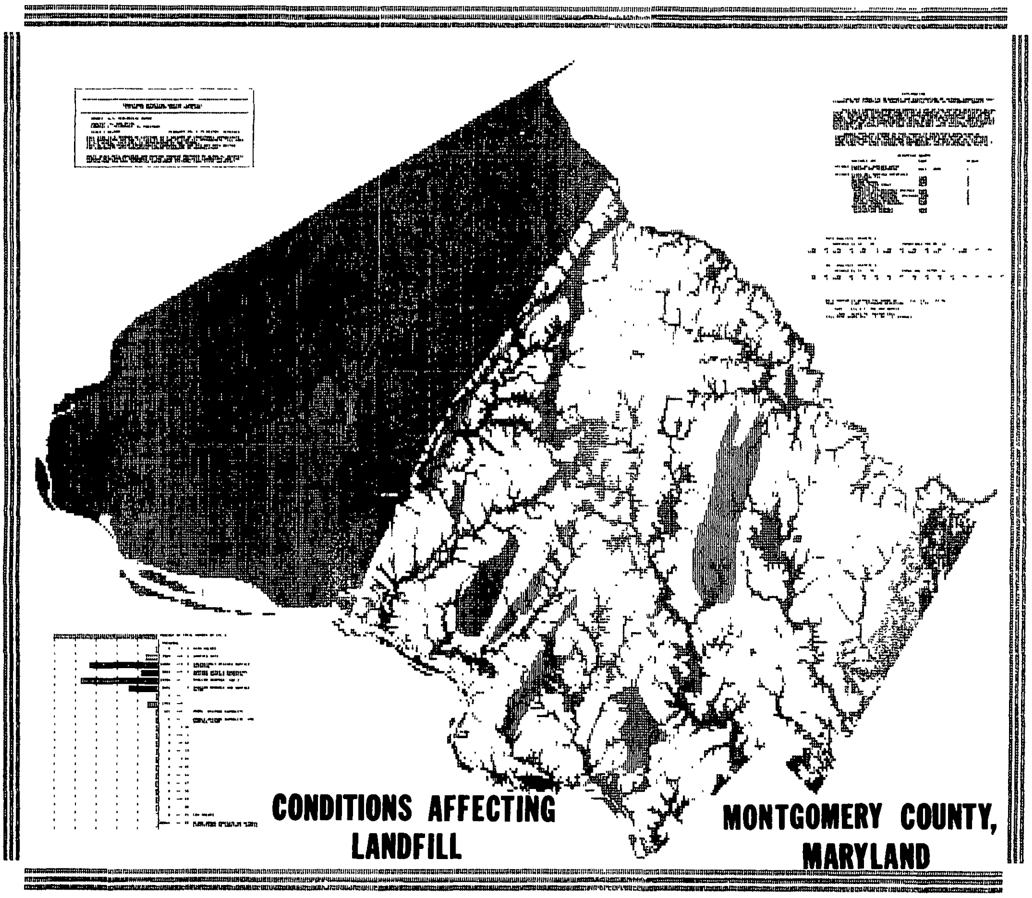


Figure 4: Composite computer map of Montgomery County, Maryland showing conditions affecting landfill

THE ZIPSTAN STANDARDIZATION SYSTEM

George L. Farnsworth
University of Southern California

It is curious that computer-assisted cartography is not more widely used in the urban setting, considering its quite long history and highly developed technical state. Conventional statistical techniques as represented by such computer packages as SPSS and BIOMED* are far more widely used in urban applications than equivalent statistical mapping systems. Indeed, while it would be very difficult today to find an urban statistician willing to calculate regression statistics on an old Frieden calculator, many cities still have draftsmen generating statistical maps with the techniques of twenty years ago. One result of this situation is that statistical analysis has found rapidly increasing applications but at the same time geographic analysis has remained relatively static.

It is my feeling that a major cause of this phenomenon is that preparation of a given data file for non-spatial statistical analysis is substantially easier than preparation of the same data file for computer cartography. We encounter numerous examples of police departments, welfare agencies and others who seem willing to convert their records to machine-readable form for analysis but who omit the street address or any but the simplest geographic identifiers (ZIP code, precinct, etc.) from the conversion or analysis. The U. S. Manpower Administration, for example, sponsors a system called ESARS (Employment Security Automated Reporting System) used by almost all states for statistical analysis of characteristics of the unemployed but which does not contain the applicant's address or any geographic level below county.

By now it should be well known that in urban areas, street addresses are convertible into geographic coordinates or other kinds of location codes (census tract, block) since such methodology at least in rudimentary form, has a long history. The truth is, however, that until recently actually performing the conversion from street addresses to other location codes was quite troublesome and involved substantial manual work. Since the early 1970's the Census Bureau's GBF/DIME System has provided a machine-readable index to the conversion and the ADMATCH system a software product to assist in making the conversions.

The ADMATCH system itself was an advance over some earlier techniques used at Census and elsewhere but is finally being replaced by the UNIMATCH system for actually comparing addresses to the DIME records. Without going into detail about UNIMATCH, which has already been widely described, it is enough to say that it is a very fast and flexible system for implementing various matching rules to achieve very accurate and complete address conversion.

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* SPSS(Statistical Program for the Social Sciences) and BIOMED (Biomedical Statistical Program) are two sets of computer programs which produce various types of statistical analyses.

Proper use of UNIMATCH, however, frequently requires some prior processing of the records to ensure that the house number, street name and other address components are in known positions and formats. The ZIPSTAN system is designed to automate this process, known as "standardization." Operating under a user command language, the system parses and performs syntax analysis of the input addresses to recognize, isolate and standardize the various address components. Thus a typical address such as "918 N. Washington St." might use any one of several variants for words as "north," "Washington," "street" and might also contain apartment indicators, and various punctuation symbols.

The following forms would all be standardized to the identical output address as shown:

918 N Washington St.   Los Angeles CA 90065
918 North Washington St.   LA Calif 90065
918-B No. Washington Str.   L. A. Cal. 90065
918½ N. Washington St.   Los Angeles 90065 CA
00918 N. Washington St.   LA CA 90065
918-920 No. Wash. Strt.   Los Angeles, California 90065
918 NORTH WASHINGTON STREET   LOS ANGELES, CA90065
918 N. WASH. ST. APT 17   L.A. 65 Calif. 90065

Standard output address would be generated in fields as shown:

FIELD	LENGTH	CONTENT
House No.	7	918
Prefix	2	N
Street	25	WASHINGTON
Suffix	2	ST
City	20	LOS ANGELES
State	2	CA
ZIP	5	90065

Not shown are fields for additional prefix and suffix abbreviations, apartment numbers, house number suffixes and status codes.

Provision is easily made for translating to or from street names, variants or street codes and city or town codes. The ZIP code alone may even be used to generate a city name and state.

In standardizing the Census GBF/DIME-Files for coding addresses, it is possible to skip records for non-street features, convert city codes to names and drop selected fields not needed, all in one pass of the input file.

The ideas behind ZIPSTAN are not particularly new or unusual but the implementation is successful in providing an easy system to use and one which is flexible enough to handle a wide variety of situations. The "standardized" address picked out by ZIPSTAN can be as short as 5 digits (when only ZIP code is to be used) or as long as 100 characters when a full address including house and apartment numbers, street name, city, state and ZIP are all to be included. Components can be in fixed or variable positions within the input records and as much or as little data may be picked out of the input records and added to the standardized address for output.

In addition to its use for standardizing addresses, ZIPSTAN may be used to convert other fields, select or reject certain records, perform various selective file copy and editing functions and print portions of the input file.

The system, like UNIMATCH, is written in IBM Assembly Language for the 360/370 series of machines. A complete User's Manual is in final preparation and the combination ZIPSTAN/UNIMATCH system is available from the Center for Census Use Studies at the U. S. Bureau of the Census. Along with UNIMATCH the system has been widely used around the U. S. and in France (with some modification).

Although I myself am no longer at the Census Bureau, I am continuing development of ZIPSTAN and UNIMATCH at the University of Southern California where we are in the process of joining with several users in Europe to produce a new integrated system in COBOL. I invite comments from users of ZIPSTAN and similar systems which could be incorporated in any new versions.

THE CONGRUENCE BETWEEN U.S. CENSUS DIME TECHNOLOGY AND OBSERVED LOCAL OPERATING AGENCY GEOGRAPHIC INTERESTS AND NEEDS

Charles E. Barb, Jr.
University of Oklahoma

INTRODUCTION

The purpose of this paper is to briefly review the basis of U.S. Census DIME technology and to compare its applicability to geographic information system needs of local public agencies. The paper is drafted in semi-technical terms that should be understood by geographers and cartographers without extensive background in DIME technology.

EVOLUTION OF DIME TECHNOLOGY

The current basis of DIME technology is best understood in a historic context and through comparison with the earlier SACS system. Both DIME and SACS are based upon automated geographic reference directories, or "geographic base files," at the street segment scale of detail. Figure 1 summarizes the record content of the two files. From a functional perspective, both types of segment records include an address element and a geocode element. The process of street address geocoding involves searching the address element of the records in a file to find the segment along which the address falls, and extracting selected geocodes from the segment record found. This search-extraction process is computer-resident.

SACS

SACS stands for Street Address Conversion System, which originated at the University of Washington about 1963. 1/ The system was developed in recognition of a need to computer geocode street addresses, particularly the large number of addresses being collected in regional transportation origin-destination surveys.

SACS was based upon a file of street segments which were described by segment end "node" coordinates. (The file of street segments was limited to those along which street addresses would logically occur.) The focus of SACS was to translate street addresses to point coordinates which would then enable point plotting and,

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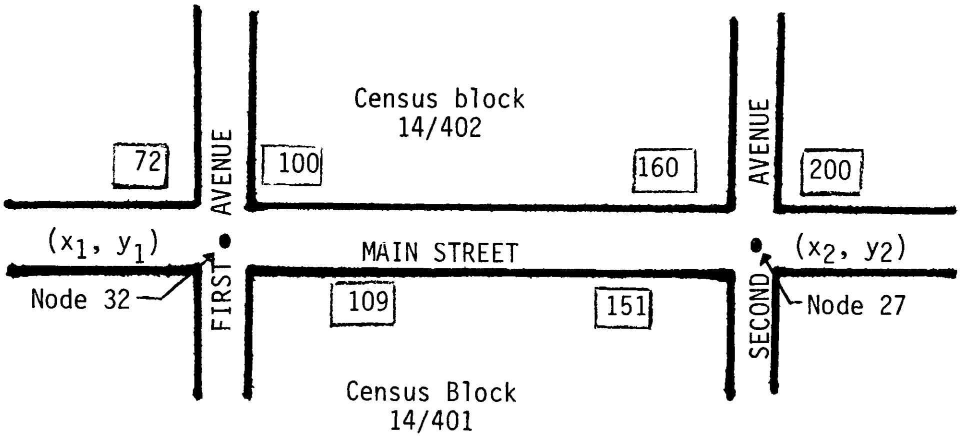
Editor's Note: Dr. Barb's background in the technology was derived through eight years of systems and applications research at the Urban Data Center, University of Washington.



SACS Street Segment Record	Illustration Content	DIME Segment Record
Address element		
Street name	MAIN	Segment name
Street type	STREET	Segment type
Low left address	100	Low left address
High left address	198	High left address
Low right address	101	Low right address
High right address	199	High right address
Geocode element		
- (not included) -	14/402	Left census tract/block
- (not included) -	14/401	Right census tract/block
Low node number	32	Low node number
High node number	27	High node number
Low node x,y	x_1, y_1	Low node x,y
High node x,y	x_2, y_2	High node x,y

Figure 1. Conceptual Content of SACS and DIME record.

through point-in-polygon processing, 2/ subsequent translation to area codes. The elegance of the system lay in its efficient segment file structure, the interpolation of coordinates for individual addresses from the segment record, 3/ and the emphasis upon coordinate rather than area code manipulation of data. At the time the system also maximized the potential of limited computer power available.

Subsequent University of Washington research in street segment file construction methods 4/ emphasized cartographic accuracy both in the selection of underlying system map resources and in policy governing the abstracting of street networks to line segments. The coordinate precision sought for the system was ± 10 feet which matched the accuracy of commonly available municipal map resources of the era and which also allowed for a unique coordinate to be interpolated for individual addresses.

By 1968 SACS had been conceptually promoted with the Dominion Bureau of Statistics and National Capitol Commission in Canada; Portland, Oregon and the U.S. Bureau of the Census. In that year a prototype city-wide Seattle system became operational and was broadly advertised for local use. Significantly, public agency response was negligable which was a first indication that there was a problem with broad local adaptation of the technology.

It is also useful to parenthetically note that not until 1969 was network minimum path application of the SACS street segment file recognized.5/ This application necessitated an additional set of criteria for street segment record definition and directory completeness, one of several redefinitions of the file's purpose and content.

U.S. Census Activities

The principal geographic problem recognized in the 1960 decennial census was the lack of a comprehensive and uniform metropolitan map base with which to conduct the field enumeration and later to geographically describe small area statistics.6/ The solution to the Bureau's map problem was the Metropolitan Map Series. While derived from a U.S. Geological Survey map base, the Metropolitan Maps were only coarsely drawn to meet the Bureau's limited representational purposes defined at that time. The Bureau's program in automated, segment-scale geocoding evolved later.

Early Bureau experimentation in automated geocoding, at the census tract-scale, occurred during the 1963 Economic Census.7/ The experiment employed a street side approach which represented a direct computer translation of the manual census tract street index. In 1965 the Bureau embarked upon the Address Coding Guide (ACG) program which employed the same segment-side approach but at the individual street segment level.8/ The limited focus of the ACG was to translate street addresses to nominal census tract and block area codes. Point coordinate geocoding and street network applications were not part of the ACG concept.

In 1966 the New Haven (Connecticut) Census Use Study was initiated, in part, to explore the potential of computer mapping local data geocoded through an ACG. As a result of this research the street segment-based DIME file was proposed as an alternative to the ACG.9/ The DIME approach had two advantages: (1) it eliminated the redundancy of the ACG (DIME essentially merged the two segment-side records into one segment record), and (2) it enabled, through graph editing, a method of examining the completeness and coding accuracy of a file.10/ This latter attribute was particularly important to the Bureau because it was becoming apparent that local efforts at coding ACG's were turning out badly. The DIME approach was accepted in 1968 and at the same time the Metropolitan Map Series was designated as the map base for the files. Local agency coding of the DIME files occurred in 1969 and 1970 and, again, due to inadequate funding and supervision, a poor quality job was done.

It is significant to note that the DIME file, within the Bureau's frame of interest, constitutes a census area boundary segment file rather than a street segment file. This difference becomes significant in street network-related minimum path applications. (The extraction of a usable network file from a Census DIME file is not a trivial undertaking.) It is also important to understand that the basic DIME file -- without node coordinates -- fulfills the Bureau's basic need for file editing and interest in translating street address to nominal census area codes. The Bureau subsequently inserted node coordinates into their DIME files as a low priority project by digitizing nodes on Metropolitan Maps. The Bureau's interest in the coordinate precision of a DIME file remains limited to coarse representational purposes.

In summary, SACS was conceived to translate street addresses to point coordinates to enable point mapping and, through point-in-polygon processing, area coding. The system was initially conceived as a tool for micro urban socio-economic analysis of street address-identified data resources. DIME technology, also segment-based but representing a description of census area boundaries, was developed by the Census Bureau to support internal needs and also to facilitate small area chorologic analysis. Coordinate precision and network application of DIME files is secondary. Minimal Federal funding and project supervision of DIME file coding by local agencies has resulted in a marginal file which requires considerable additional local investment before it can be used. The Bureau's current thrust is to clean up the files for application in the 1980 decennial census.

OBSERVED LOCAL AGENCY INTERESTS AND NEEDS

Experience in Seattle mentioned above, and research into long-term geocoding system developments elsewhere, 11/ suggests local adaptation of DIME-type technology is proceeding slowly. A significant question is -- why? It is proposed that, in part, the reason is that we have been distracted with the notion that DIME technology is the "answer," and the Federal Government has been preoccupied with selling a packaged system for self-serving reasons. This course has been taken in place of analyzing existing and evolving local agency interests and needs in geographic description and analysis, and developing necessary technology to meet them.

Local agency operational interests and needs and their congruence with DIME technology is suggested by a brief examination of a few familiar municipal functions. Time and space limit discussion to merely a suggestion of the type of examination that should be undertaken.

ASSESSMENT

The assessment function involves land and its development. The unit of interest is a legally and precisely defined land parcel. Of course in many cases a parcel does not have an assigned address and in most cases today is geographically referenced in legal rather than street address terms. Obviously inherent to the interests and needs of this function is a parcel data bank including extensive attribute descriptors of property and particularly its legally described location and extent.

BUILDING INSPECTION

The building inspection function involves structures under development and, possibly, ongoing monitoring of their condition and use. The unit of interest is the structure and sometimes dwelling and commercial units within a structure. The inherent interest and need of this function is a mixed structure/unit data bank also including extensive attribute descriptors.

TRAFFIC ENGINEERING

The traffic engineering function includes street and "street furniture" inventory and maintenance. Street furniture broadly includes on-street parking spaces and meters, traffic signs, and traffic channelization. These are generally described in an engineering precision. Inherent to the interests and needs of this function is a mixed resource data bank including engineering quality geographic descriptors.

DISTRIBUTION UTILITIES

Distribution utilities include telephone and electrical and gas power utilities. The utility function requires description of distribution networks which are frequently not congruent with streets and census statistical area boundaries. For sub-surface networks in particular, in-place facilities must be described with engineering precision. 12/ Inherent to the interests and needs of this function is a network-based, engineering-quality facility data bank including extensive attribute descriptors and probably including customer information.

In summary, local operating agencies have concern and responsibility for a range of geographically located land and facilities which they need to have described to various degrees of geographic precision. In most cases their needs for geographic precision are far greater than the ± 40 foot accuracy claimed for the Metropolitan Map Series or obtainable from a DIME file. Local agencies are also operationally and administratively concerned with a broad range of attributes of the land and facilities beyond their geographic location. These interests and needs are more closely met by special purpose, facility-oriented data banks than geocoding systems conceived principally for socio-economic analysis.

CONCLUSION

The brief description of the origin of census DIME technology reveals that it is a tool for relatively coarse, urban-scale socio-economic analysis, particularly as related to the decennial census. A brief analysis of local agency functions suggests that local agency operational and administrative interests and needs are more geographically precise than census DIME files can support and more substantively based than geographic location. Two principal conclusions are drawn from the discussion.

First, given the current basis of U.S. Census DIME technology, local public agencies should not look to it to meet their broad and complex operational geographic coding and cartographic interests and needs, directly.

Secondly, to meet local agency needs and interests in most cases, a relatively broad local technology infrastructure will have to be developed. The Census Bureau's DIME system will probably be recognized as a small element in this infrastructure. At this time of initial infrastructural development, greater emphasis should be placed upon the transfer of concepts such as DIME graph-theoretic coding rather than the transfer of packaged but often inapplicable systems.

REFERENCES

1. SACS research was initiated and directed by Dr. Edgar M. Harwood, Professor of Civil Engineering and Urban Planning. See: Robert B. Dial, Street Address Conversion Systems, Urban Data Center Research Report No. 1 (Seattle: University of Washington, 1964). The University of Washington's decade-long research program in automated geocoding technology has been principally funded by the National Science Foundation.

2. By point-in-polygon analysis is meant a computer-resident process of determining in which polygon, described in terms of perimeter vertex coordinates, a point geocode falls. The approach enables flexible tabulation of data by statistical area. See: Helaman R.P. Ferguson, *Point-in Polygon Algorithms*, Urban Data Center Research Report No. 7 (Seattle: University of Washington, 1971).

3. Point geocodes obtained from SACS commonly included "block face" coordinates representing the midpoint between segment-end node points and including on appropriate setback distances from the segment, and "unique address" coordinates which represent a proportional interval along (but set back from) the segment based upon the house number. Block face coordinates, being assigned consistently to all addresses falling along a segment side, represent a sub-block aggregating key.

4. Hugh W. Calkins, *Operations Manual for Street Address Conversion System*, Urban Data Center Research Report No. 2 (Seattle: University of Washington, 1975); and Richard Arthur O'Neal, "The Geographic Base File: Its Specification and Development," an unpublished master of urban planning thesis, Department of Urban Planning, University of Washington.

5. Matthias H. Rapp, *The Minimum Path Assisgment System and Its Application to the 1969 Seattle Shelter Allocation Project*, Urban Data Center Research Report No. 4 (Seattle: University of Washington, 1969).

6. William T. Fay and Robert L. Hagen, "Computer Based Geographic Coding for the 1970 Census," a paper presented at the American Institute of Planners Conference, Portland, Oregon, August 14, 1966.

7. Herman H. Fasteau and George Minton, *Automated Geographic Coding System*, 1963 Economic Censuses: Research Report No. 1 (Washington, D.C.: U.S. Bureau of the Census, 1965).

8. Fay and Hagen, *op*. *cit*.

9. Donald F. Cooke and William H. Maxfield, "The Development of a Geographic Base File and Its Uses for Mapping," *Urban and Regional Information Systems for Social Programs*, Papers from the Fifth Annual (1967)Conference of the Urban and Regional Information Systems Association, ed. by John E. Rickert (Kent State University, 1969).

10. The acronym DIME stands for Dual Independent Map Encoding which underscores the concept of dual or redundant coding of census area boundaries as a graph. Each segment is encoded as a link in a network and again as an edge between adjacent census areas. This coding enables the editing of a Dime file for closure around a census area or around a network intersection.

11. Charles E. Barb, Jr., *Automated Street Address Geocoding Systems: Their Local Adaptation and Institutionalization*, Urban Data Center Research Report No. 9 (Seattle: University of Washington, 1974).

12. Interestingly, some information system designers are turning to describing subsurface distribution networks in textual rather than cartographic form due to the limitations of recording information on and extracting information from maps.

Seminar on Data Structures

SEMINAR ON DATA STRUCTURES

This seminar was chaired by DAVID RHIND of the University of Nottingham (United Kingdom) and dealt with theoretical data structures supporting geographic and cartographic systems.

THOMAS PEUCKER of Simon Fraser University (Burnaby, British Columbia, Canada) presented "A Theory of the Cartographic Line." The line, composed of n segments, is partitioned into subsets until each subset has a band with a width less than a predetermined threshold. At each step the partitioning process is performed by selecting as starts and ends of the subsets those points which touch the sides of the bands. Applications of the theory are useful for locating line intersections, line matching (determining if two lines are actually the independently encoded representation of one line), and point-in-polygon search.

JAMES CORBETT, who delivered a plenary paper on "Topological Principles in Cartography," commented on the use of file data structures which describe the neighborhood of a point or a segment. Historically, the basis for such file structures is embedded in our legal system, a system which uses descriptions of visible objects and landmarks and distance measurements originating from these visible points.

LAWRENCE H. COX of the Census Bureau's Statistical Research Division discussed "Applications of Lattice Theory to Automated Coding and Decoding." The collection and dissemination of data from a set (e.g., a geographic region) may be viewed as the result of aggregation and analysis on a subset basis. These subsets define a partition of the original set and are generally encoded in a manner consistent with the partial ordering induced by set inclusion. It is not uncommon for this partition to be the intersection of several independent partitions, each representing a meaningful scheme of disaggregation of the data (e.g., the division of the United States into States and counties and into standard metropolitan statistical areas for the publication of economic statistics). Given the atomic sets in the induced partition and their associated codes, the lattice representation of the set-theoretic hierarchy generated by these subsets is constructed. This facilitates the comparison of the various schemes of aggregation present and the computation of best possible upper and lower bounds for sets not directly constructable from this hierarchy. List processing techniques which reflect the setwise partial ordering are employed, resulting in a data structure well-suited to set-theoretic computations which is designed to tabulate and analyze data coded to the hierarchy. These structures are of particular value in the identification and protection of statistical data of a sensitive or confidential nature.

DEAN EDSON is with the U.S. Geological Survey's Topographic Division in Menlo Park, California. This division is in the process of examining and redefining the mapping program for which the organization is responsible in order to better serve the country's needs for basic cartographic data. It is anticipated that in addition to the need for a family of general-purpose maps, which USGS will continue to produce, there will be a growing requirement that such material be presented in digital form. It is intended that the National Mapping Program will provide cartographic information in graphic and digital form to the extent needed. His paper dealt with a cartographic data base which is specifically structured for this purpose.

A THEORY OF THE CARTOGRAPHIC LINE

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Simon Fraser University

INTRODUCTION

The basic difference between the approach taken in this paper and those in other studies of the line is that it is postulated that a line has always a certain thickness.

The concept of a line having an areal extent is not too obvious to the mathematician who usually thinks of the line as a locus with zero width. The cartographer can, however, feel comfortable with it; in fact, the basis of many manual line generalizations is the idea of widening the line with decreasing scale. Since the curvature of a line has to be larger than the width of its generalized equivalent in order that it does not disappear within the black area of the line, with decreasing scale, a line a) occupies a larger area, b) the curvature of the line decreases and c) it can be defined by less points. The reduction of points for the definition of the line can also be called an increase of abstraction in the definition of the line.

The presented theory can be associated with an alternative explanation. A line is a combination of a number of frequencies, each of which can be represented by certain band-widths. The break-up of a line into series of bands, therefore, could be equated with the stepwise removal of the high frequencies from the line.

Before going on, however, a few terms should be explained in detail. A line is here defined as a sequence of connected points. A connection between two points in a sequence of points is called a segment. The extent of a line is its number of segments. We thus exclude from this discussion those lines which are defined by one or several mathematical functions since their characteristics and problems are quite different from the discretely identified lines.

To the cartographer, the use of the term "line" for what we intend to discuss might be quite obvious. However, other terms such as chain (Chrisman, 1974), chord (O'Callaghan, 1975), segment, arbitrary line (H. Freeman, 1975), random line, snake

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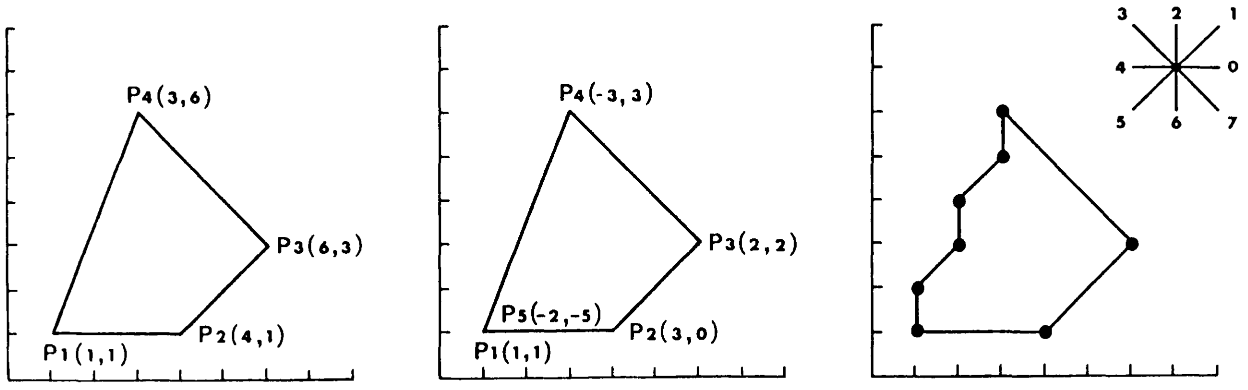
(Clement, 1974), etc., have all been used. Most of them, however, can lead to misunderstanding if transferred to another discipline. Chain is also used for a type of line encoding (Freeman, 1961); chord is a straight line in photogrammetry, as is segment in several disciplines. The term "arbitrary line" could be misleading in cartography since a cartographic line is never arbitrary, with at most arbitrary deviations from a straight or smoothly curved line, etc. Furthermore, some of the definitions like chain (Chrisman, 1974), and snake (Clement, 1974), imply additional topological information. Therefore, it might be safer to use the general term "line."

In computer graphics, the number of line segments per line is usually relatively small, it is, however, frequently very large in cartography. Lines with more than 1,000 points are not rare in some storage systems (Schmidt, 1969). It is therefore logical that the interest to develop better algorithms for line manipulation is very great in cartography. This paper is a contribution to these efforts through an attempt to formalize some characteristics of lines, after a short discussion of the most frequent encoding systems.

The most straight-forward form of discrete encoding of lines is by the absolute coordinates (Figure 1a) of the points along the line. The order of the point in the array of coordinates gives the sequence of points. If the lines are discontinuous, their connectedness can be given by a continuancy label (the structure of many plotting commands) or a dummy point which indicates the end of one line and the start of the next.

For the incremental mode, an absolute start is given for every line, but the subsequent points are encoded in terms of their distance to the previous points (Figure 1b). This approach sometimes reduces storage requirements since the increments can be given by shorter storage units (e.g., 16 bits); some computations can be faster, like the computation of the length of a line -- but for most line manipulations the absolute coordinates of the points have to be computed.

The third very common encoding mode is called "chain encoding" (Freeman, 1961, Freeman and Shapiro, 1975). A line is broken into straight portions of equal change in the x- and y- direction. This results in eight unique step directions which can be encoded in three bits (Figure 1c). Therefore, a byte of six bits can contain two steps. For bytes of eight bits, the first bit can be a continuation code and the other three are either step-indicators or continuation counters (Tomlinson, 1974).



Absolute Incremental Chain

Figure 1

There are other encoding systems (see for example, Pfaltz and Rosenfeld, 1967, for skeleton encoding), but they usually have to be converted into absolute coordinates for most computations.

Although the presented theory is implemented on the basis of the absolute coordinate scheme, it is unimportant which coordinate scheme the reader is used to. Indeed, certain computations are more efficient in some of the other schemes.

THE CONCEPT

A line of any extent can be defined by

1) A general direction and a band with
2) A width, and
3) Its length

Different ways of computing the general direction will be discussed later. At this time it can be said that the general direction of a line can be any direction; the reduction of a problem to a solution is however faster the closer the general direction approaches the direction of the minimum bounding rectangle.

The band is the bounding rectangle, given a certain general direction (Figure 2). In other words, the sides and ends of the band are parallel, and perpendicular, respectively, to the general direction, totally enclosing it. In set-theoretic notation this can be stated as follows:

$$L^1 \subset B^1,\ L^1 = P_1, P_2, \ldots.\ P_i, \ldots.\ P_n \qquad (1)$$

Where L^1 represents the total extent of the line, and B^1 the band of the total line and P_1 to P_n all the points of the line.

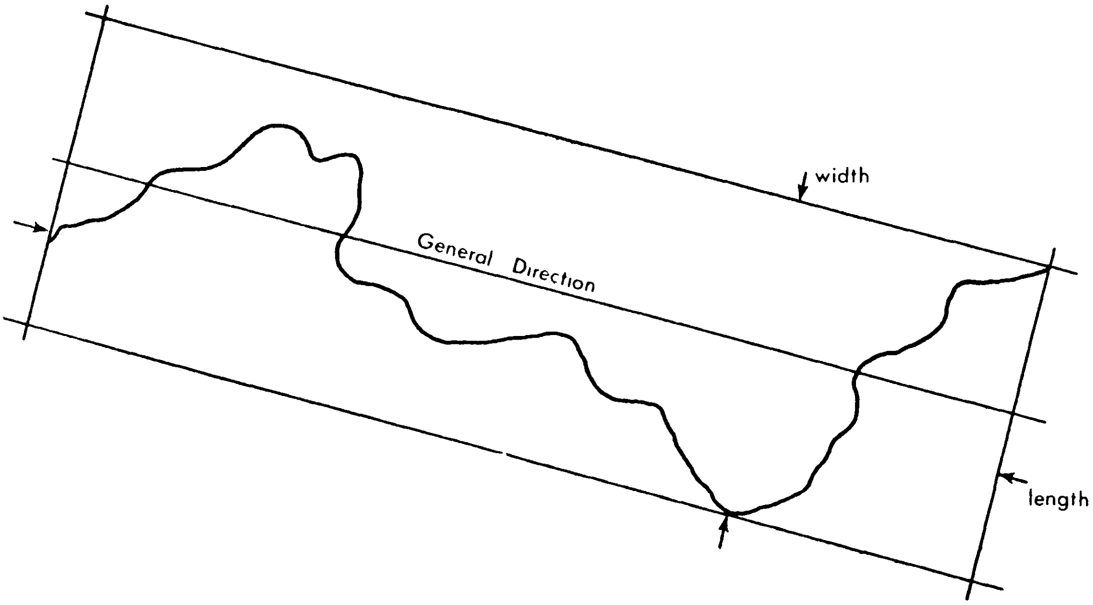


Figure 2

A line of n points can be subdivided into up to n-1 sublines, each with its own characteristic band. At the highest degree of abstraction it is represented by only one band, at the lowest degree it is represented by n bands. At the highest degree of abstraction the band is generally the widest, at the lowest, the bands have a zero width. In other words, with decreasing degrees of abstraction, the area covered by the band decreases (Figure 3) although it can remain the same from one step to the next in exceptional cases.

$$B^1 \geq B^2_1 \cup B^2_2 \geq \dots \bigcup_{i=1}^{k} B^k_i \geq \dots \bigcup_{i=1}^{n} B^n_i \qquad (2)$$

Here, the upper subscript indicates the order of abstraction and, implicitly, the number of sub-bands.

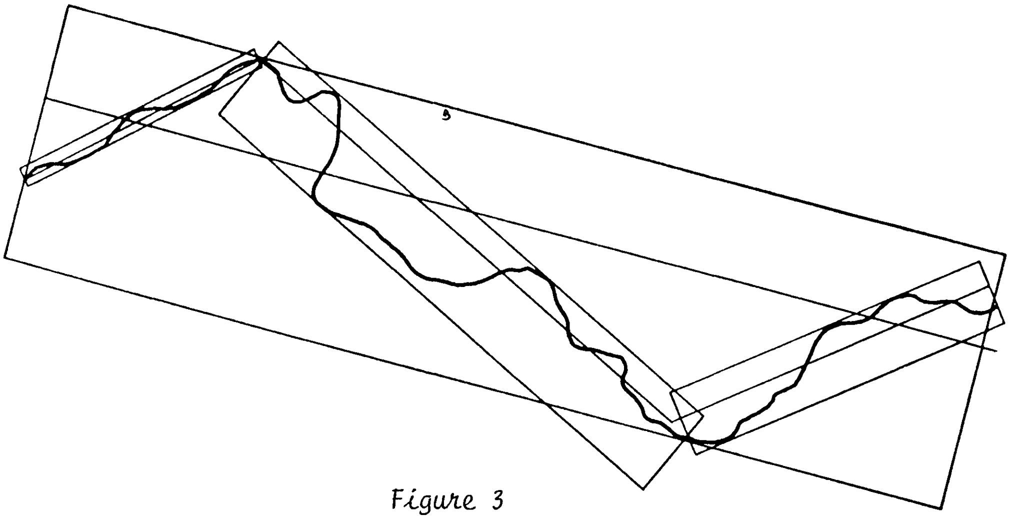


Figure 3

(2) can be proven with one reservation. If one breaks up a subline at step i into two sublines at step i+1, the limiting case is that the two resulting bands have the same width and direction as the previous band in which case the combination of the two bands is identical to the original band. In all other cases the bands have to have a different direction and therefore leave some portion of the original band unoccupied. Although the new bands can have portions outside the original band, these portions are insignificant since they do not contain any sections of the line. The width of a band can actually get larger from one level to the next. These degenerate cases can be easily detected and circumvented in the implementation of the theory by breaking the line up into sections if the width of the band is larger than a given portion of the length.

According to (2) a line with n points has n levels of abstraction with a total of $\frac{(n-1).n}{2}$ bands. It is the objective of the theory to keep the computation at any time on the highest level of abstraction that the particular problem allows. The critical issue of the theory is to find the highest level in any different type of problem. Some applications of this approach will be shown after a discussion of different types of bands.

THE TYPES OF BANDS

A multitude of bands can be constructed from a line. The right type depends upon the frequency at which the characteristics of the band must be computed (the higher the frequency the faster the computation has to be), the particular speed of convergence (the slower the problem converges the smaller the band has to be), and on the special characteristics of some encoding systems.

The band which can be computed most quickly is the bounding rectangle which is orthogonal to the coordinate system. One axis of the coordinate system is the direction of the band and the extreme points in the direction of the other axis mark the width of the band. This method has been used for a long time to test situations like the potential intersection of two segments. The major advantage of this type of band is its computational speed. Since all four sides have to be computed every time, however, it is not always the fastest, because with other types one often has to compute only two sides.

For chain encoding (Freeman, 1961) and skeleton encoding (Pfaltz and Rosenfeld, 1967), a band at an angle of 45 or 135 degrees can be of advantage. The eight steps of the chain encoding can be converted into steps to the left or right of the 45 degree and the 135 degree directions with four counters keeping track of the maxima and minima. The wider margin will then give the length of the band and the smaller one its width. Similarly for skeleton encoding half the block-distance of a rhombus gives its extension in the four 45 degree directions.

An easy compromise which the author has adopted for most of the implementations of the theory is to link the start and the end of the line and take that as its general direction. The advantage of this approach is again speed. Its disadvantage is that the band can become relatively large in cases where the line is closed or nearly closed.

A more involved approach which should bring better results is to find the principle axis of the point set. This method should produce a band which is fairly close to the minimum band.

Freeman and Shapiro (1975) have shown that this minimum band can be produced via the bounding convex polygon. The minimum band and the bounding convex polygon have at least one side in common. The minimum band can therefore be constructed by computing the convex polygon and then testing for each side whether the resulting band is smallest.

LINE GENERALIZATION

The theory of the cartographic line has initially been conceived as an afterthought to the development of a algorithm for line generalization (Douglas and Peucker, 1973). This algorithm was developed at about the same time in at least two other papers (Ramer, 1972; Duda & Hart, 1973). Therefore, the execution of the idea has to be explained only as far as it relates to the theory (Figure 4).

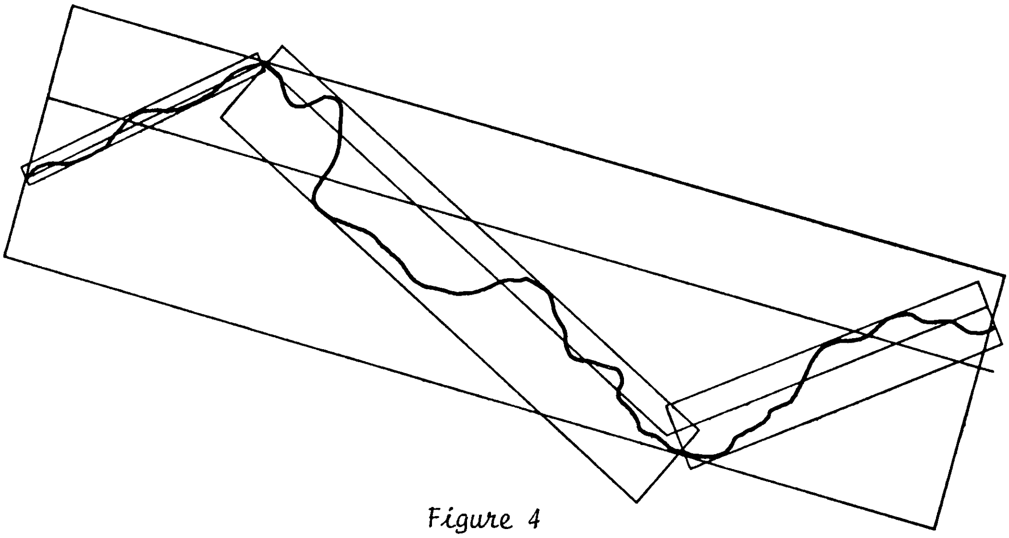


Figure 4

The line is partitioned into subsets until each subset has a band with a width less than a predetermined threshold. At each step, the partitioning process is performed by selecting those points which touch the sides of the bands as starts and ends of the subsets.

The actual implementation of the concept is somewhat different (Douglas and Peucker, 1973). The general direction of the line is given by the link between its start and its end. For every point, the vertical distance from the link is computed and the point with the maximum absolute value is retained as the new point which divides the line in two portions which are subsequently treated independently the same way (Figure 5).

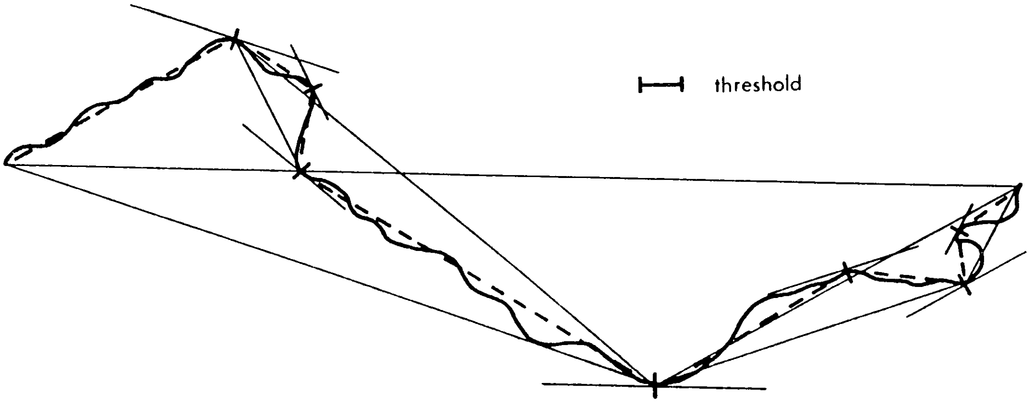


Figure 5

LINE INTERSECTION

In cartography, lines can be very extended, i.e., contain many segments. When the computations involve two or more lines, the speed of traditional algorithms usually develops in proportion to the product of the extents of the two lines. The intersection of two lines is a good example. The traditional approach tests every segment of one line against every segment of the other line. There is usually a pretest involved which checks whether the bounding orthogonal rectangles of the two segments overlap and return with a "false" signal if they do not. But even this pretest can be rather time consuming if it has to be performed at a frequency of the product of the number of segments of the two lines.

The concept of the band of a line can be of substantial help. It is quite obvious and easy to prove that the intersection(s) of two lines have to be located within the parallelogram which is built by the intersection of the two bands (Figure 6). Since for the second step only the portions of the lines within the parallelogram are used, the second pair of bands tend to be much smaller. Therefore, the problem tends to converge to the pair of minimum bands (two single segments) very quickly.

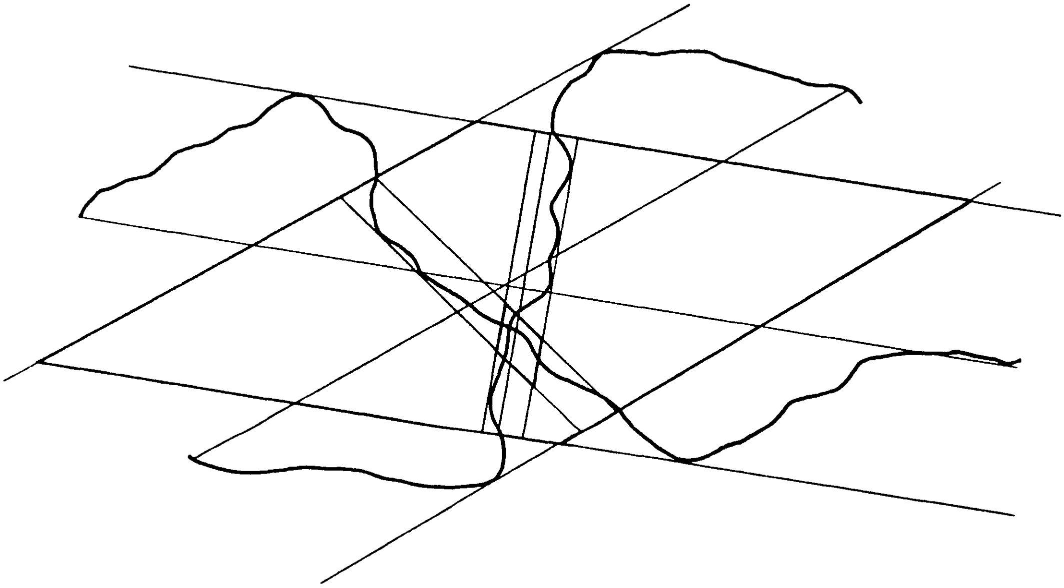


Figure 6

The practical implementation of the approach takes advantage of several simplifications characteristic of the problem. For one, only the width of the band has to be determined. Furthermore, the parallelogram is not derived but the process is shortened to close to half by constructing the band of one line and then immediately finding the portion of the other line within the first band, etc. (Figure 7). Also the process is stopped when the remaining lines consist of a total of six or less segments because the conversion process with less segments can run into complications.

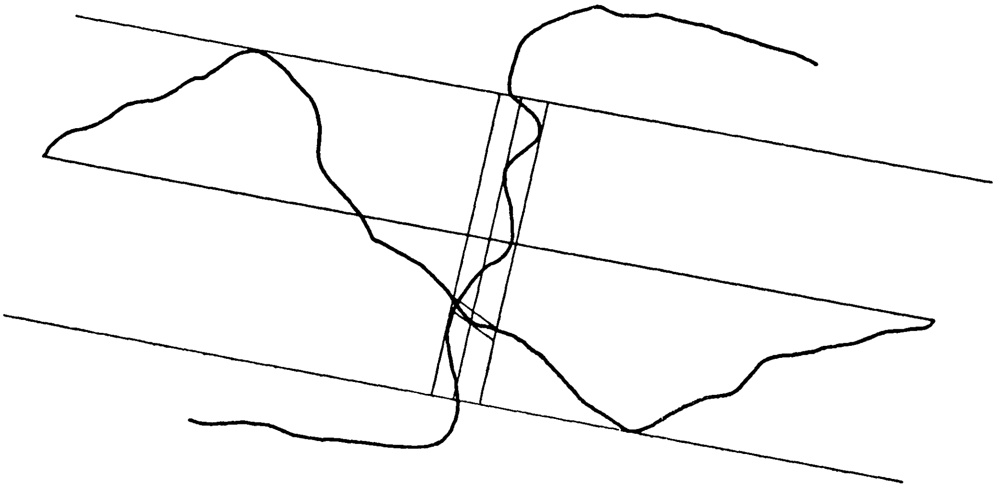


Figure 7

There are other precautions which take action if the procedure is in danger of converging slowly or has reached a dead end loop. If the "raw length" of the line (the distance between start and end of the line) is less than three times its width, the line is partitioned into three portions which are processed one after the other.

The savings in computer time over the traditional method are impressive. For example, in the implemented algorithm, the multiple intersection of two lines with 120 points each was achieved in 1/23 of the time of the traditional method. This would mean a ratio of less than 1/200 with 1,000 points per line.

LINE MATCHING

Another problem which can be solved very elegantly by the band approach, but can be a tedious problem without it, is the test whether or not two lines can be considered to be the independently coded representations of one line. Encoding usually produces two types of factors which will cause two digital representations of a line to differ:

- Encoding noise or digitizing errors
- Differences in the choice of the sampling points

A method which measures the degree of agreement of the two representations is therefore desirable.

This can be done by the requirement that the bands of the two lines overlap at a certain percentage. If, therefore, the error variance of the digitizing is known, one can construct the bands with a width of twice that variance and then test whether or not the bands of one line overlap with the bands of the other at more than a given percentage.

POINT SORT AND POINT-IN-POLYGON SEARCH

The point-in-polygon problem has been attacked many times but to the author's knowledge, only three so far have developed algorithms which employ less than all the segments of the polygon for the test whether a point is inside or outside a polygon (Pfaltz and Rosenfeld, 1967; Loomis, 1968; James, et al., 1973).

The concept of the band can also be used for this purpose if the procedure has to be performed several times for one polygon, or if several points have to be sorted into a number of polygons.

If the data structure is based on "chains" (i.e., portions of lines with topological indicators, see Chrisman and Little, 1974), the chains can be used for the first case (one polygon -- several points). Otherwise, any procedure can be used which partitions the polygon boundary into three or more portions. In the second case (several polygons -- several points), a chain structure has to be produced if it is not available.

The basic idea of the sorting procedure is that the problem space can be divided into three parts -- the area left of a band, the area right of it and the band itself. If one or more points fall into the band, the level of abstraction has to be lowered and bands of several subsections employed. The level is lowered until there are no points left within the bands.

It is quite clear how this approach can be used for the case of one polygon. First, the boundary is broken down into three or more portions. The bands of these portions are constructed and the first point tested. If any of the bands have to be split, every new band is stored with its direction and dimensions (a tree structure would serve the purpose best), to be used for later tests. Of course, this approach is economically feasible only if the number of points to be tested is relatively large.

In the case of several polygons and several points, the method can already be feasible with relatively few points because it avoids a loop in which a point has to be tested through all polygons. For this problem, the chains have to be grouped to lines which divide the problem space in a successive order. The first divide the total area, the next two the two areas left and right of the first, etc. When all chains have been used, all points are sorted in. In other words, the method uses a chain only once, no matter how many points are involved.

DOUBLE LINE AND OTHER LINE SYMBOLS

It is hoped that the theory of the cartographic line will be useful to problems yet to be discovered. It should also serve as a guideline for the solution of problems which seem to be less connected with the theory. As an example, the construction of the double line and other line symbols will be discussed.

Several algorithms are known which construct double lines around a given line or one new line at a given distance from an input line. The procedures usually simply reconstruct every point at the given vertical distance to one or both sides of the line. As Figure 8 shows, the procedure can get totally confused when very small zig zag lines occur.

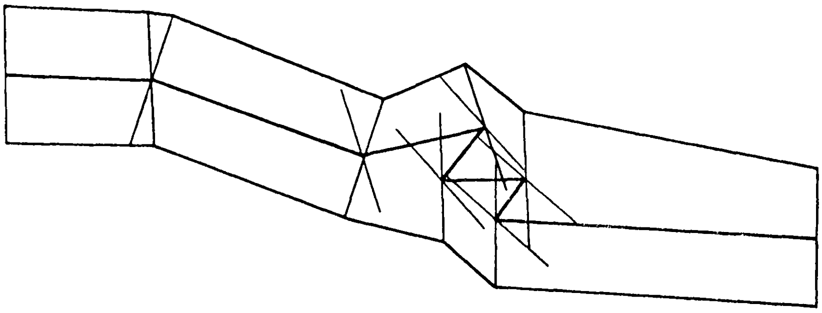


Figure 8

For a solution within the framework of the above concept one has to realize that these zig zag lines would disappear if the double line were filled black. It is therefore advisable to generalize the line with an offset of half the width of the double line before producing the double line. If the resulting corners are undesirable, additional points can be inserted between the points by a smoothing routine.

Dashed lines pose similar problems. If the distance between two starts of dashes is called the unit distance, any segment shorter than that unit will cause problems for this type of line drawing. The line should therefore also be generalized before the construction of the line symbol.

CONCLUSION

This paper presents a theory of the cartographic line which has already resulted in some algorithmic manipulations of lines and promises to serve for more applications. The theory, however, is also helpful for the understanding of the cartographic line itself. Only a slim attempt has been made to exploit this aspect of the theory. It is hoped that others will pick up the idea and expand it as part of a growing body of cartographic theory.

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APPLICATIONS OF LATTICE THEORY TO AUTOMATED CODING AND DECODING

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INTRODUCTION

The potential of a data base lies beyond its being a repository of coded facts or observations. The data items give form and structure to the information content of the data base, which includes the totality of all facts and conclusions derivable from the interrelationships between data items relative to the data base as a whole. In many applications, this information can be meaningfully interpreted in terms of the set-theoretic hierarchy generated by the data set. In these cases, mechanisms to construct and analyze this hierarchy are necessary to the efficient manipulation and utilization of the data. This paper describes techniques and a computer system for examining the hierarchical relationships which exist between component subsets of the data set and for organizing, managing and accessing the data base in a manner consistent with this hierarchy. The system employs the advantages of a random-access computing environment.

The impetus for the research and the initial application of the resulting computer system is in the area of geocoding and statistics dissemination. A geographic region, such as the United States, has been partitioned in several ways along different lines: geographic (states, counties), economic (standard metropolitan statistical areas, major retail centers), political (congressional districts) and demographic (urbanized and rural areas, census tracts). Each basic region (set) in these partitions is assigned a unique code. Data keyed to these geocodes and perhaps to other (subject matter) codes are collected and statistics are tabulated and published on the basis of the coding hierarchy thus formed. The problem which then arises is that of identifying all statistical inferences derivable from these publications, thereby capturing a major portion of the total information content of the data base. This amounts to constructing the lattice representation of the Boolean algebra generated by the codes. This lattice is of particular importance in editing the tabulations to improve the quality and statistical confidentiality of the final publications.

THE DATA STRUCTURE

$\underline{X}$ denotes a finite set and $X(i) = \left\{X(i,j) : \bigcup_j X(i,j) = X,\ X(i,j) \cap X(i,l) = \emptyset \text{ for } j \neq l\right\}$ partitions of $\underline{X}$, $i = 1,\ldots, m$. Each $x \in X$ is assigned a unique code $(j(1),\ldots,j(m))$, indicating that $x \in X(i,j(i))$ for $i = 1,\ldots,m$. Henceforth, $\underline{x}$ will be synonymous with its corresponding code. We identify all containment and equality relationships $X(i,j) \subseteq X(k,l)$, $X(i,j)=X(k,l)$, and, more generally, those partitions $X(i)$ which are refinements of other partitions $X(k)$. The goal is a data structure and retrieval system which reflects the characteristics and set-wise interrelations of the data items and allows for efficient manipulation and management of the data base.

The input file consists of data records, each keyed to a unique $x \in X$. A file image of the reference set $\underline{X}$ is created, each record of which has the form $(i(1),....,i(m),N)$, where $(i(1),....,i(m))$ is the code corresponding to $\underline{x}$ and $\underline{N}$ is the unique record number identifier of the record $\underline{x}$, determined by a fixed enumeration of the elements of $\underline{X}$.

To each basic set $X(i,j)$ are associated $\underline{m}$ lists $L(i,j;s)$. $L(i,j;i)$ is an ordered sequence of record numbers of records corresponding to elements $x \in X(i,j)$. For $s \neq i$, $L(i,j;s)$ is an ordered list of all $X(s,l)$ for which $X(i,j) \cap X(s,l) \neq \emptyset$. These lists are formed by sorting the file $\underline{X}$ $\underline{m}$ times, once on each field/record number. Subsequent to the first sort, the final record numbers $\underline{N}$ are assigned. These lists, as modified and manipulated by the system described below, are sufficient to perform all set-wise analyses. No further sorting of the file is necessary to query or update the data base.

Containment and equality between basic sets in different partitions are easily identified: $X(i,j) \subseteq X(k,l)$ if, and only if, the only entry in $L(i,j;k)$ is $X(k,l)$. Pairs of opposite inclusions are equivalent to equality.

Unions and intersections are easily computed via list merging and matching techniques. As the lists are increasing sequences of integers, these operations are quickly and efficiently performed in a minimum of core. To intersect the sets $X(i,j)$ and $X(k,l)$, the list $L(i,j;k)$ is referenced to determine whether the intersection is void or not. If not, two elements from $L(i,j;i)$ and one element from $L(k,l;k)$ are consecutively flashed into core. If the element from the second list equals either of the elements from the first list, this element is removed from both lists and is added to the intersection list and the next element from both lists are brought into core. If the element from the second list is less than the larger element from the first list and unequal to the smaller, it is discarded and the next element from the second list is brought into core. If the element from the second list is larger than the larger element from the first list, the smaller element from the first list is discarded and the next element from the first list is brought into core. This process is repeated until the larger element from the first list is greater than or equal to the element from the second list. The comparisons above are then made and the procedure proceeds recursively until either list is exhausted. Set-wise unions may be computed in an analogous manner.

All sets constructible from the basic sets are expressible as disjoint unions of the sets $Y(v) = \bigcap_{i=1}^{m} X(i,j(i))$, $v = (j(1)),....,j(m))$. The sets $Y(v)$ are the atomic elements in the lattice generated by the partial ordering induced by the codes. The $Y(v)$ are computed and to each is associated an increasing sequence of the record numbers of the records $x \in Y(v)$. The lists $L(i,j;i)$ are then replaced by ordered lists of those $\underline{v}$ for which $Y(v) \subseteq X(i,j)$ (i.e. $Y(v) \cap X(i,j) \neq \emptyset$). The resulting data structure is sufficient to perform all set-theoretic constructions and comparisons relative to this hierarchy in a quick and computationally efficient manner.

The computation of intersections is performed as described above, the only difference being that the lists being merged are ordered lists of subsets rather than elements. This consolidation improves the speed and minimizes the storage requirements of the intersection process. Similarly, set-wise unions are computable in relatively few operations and the problem of alternative descriptions is rendered tractable. More precisely, let $U = \bigcup_{i \in I, j \in J} X(i,j)$ denote a union of basic partition sets over index sets I and J (e.g., a union of certain counties and places within a State). It is meaningful and frequently necessary to determine whether U is expressible in a different (perhaps more succinct) manner (e.g., as a standard metropolitan statistical area). Working only with element by element descriptions of the sets X(i,j), the lists L(i,j;s) for $s \neq i$, and the remaining sets in the universe, this problem can be solved only through an exhaustive sequence of list comparisons. The redefined L(i,j;i) greatly improve this situation and facilitate the computation. For each $p \notin I$, a list G(p) of those q appearing in field p of any L(i,j;i), $i \in I$, is formed. This amounts to grouping for each $p \in I$ those sets X(p,q) which intersect U. The sets $U(p) = \bigcup_{z \in G(p)} z$ are all upper bounds of U, each along a particular component direction in the hierarchy. The U(p) are of interest in and of themselves from a statistics dissemination standpoint. Moreover, any alternative description of U must be expressible in terms of the U(p). In particular, a "more succinct description" of U could generally be defined as U(p) for which U = U(p) and U(p) = X(p,q). These are easily identified.

This data structure can be maintained and updated routinely. The addition or deletion of records from the reference set X will alter the definition of the Y(v), but as all sets X(i,j) containing a given Y(v) are characterized by the condition v(i) = j, all necessary edits and alterations to the data structure may be identified and effected in a straightforward manner.

INITIAL IMPLEMENTATION AND APPLICATIONS

The reference set X is a universe of some 9,200 basic records which comprise the geographic reference file employed by the U.S. Bureau of the Census in tabulating statistics for the 1972 Census of Manufactures. This set represents a geocoding of the United States into 50 States and approximately 3,100 counties, 5,900 places and 264 standard metropolitan statistical areas. The programs are written in Fortran IV and the system will soon be run for testing in an interactive environment on a PDP-10 computer. The system will subsequently be implemented on a Univac 1110.

One of the responsibilities of a statistics gathering and disseminating body such as the U.S. Bureau of the Census is maintaining statistical confidentiality in protecting the identities and responses of individual respondents. If a candidate cell for publication is deemed a disclosure and is to be suppressed from publication, the remaining cells in the publication tables must be examined to determine to what extent they can be employed to compute estimates of the suppressed cell. If the finest such estimate computable is also deemed a breach of statistical confidentiality, additional cells must be suppressed until an acceptable equivocation of the value of this statistic is reached. These additional suppressed cells must then be protected in like fashion. The result is an extremely complex logical and computational problem fueled by the cascading effect of suppressions and estimates proliferating through the publication hierarchy. The only way to effectively manage and control this process and strike an acceptable balance between the conflicting goals of maintaining statistical confidentiality and maximizing the quantity and quality of the published information is through the construction and analysis of the set-theoretic lattice generated by the publication hierarchy. The lattice provides a natural mechanism for defining the order of processing and for driving the tabulation programs, while computing best estimates of suppressed cells to assure that confidentiality is maintained. This is an intended purpose of the system described in this article. Its other major function is as a standing geographic reference file, with obvious extensions and applications to any logical hierarchy generated by a set of codes.

ACKNOWLEDGEMENTS

Throughout the course of this research, the author has collaborated on a continuing basis with Patricia Griffin and Marvin White of the U.S. Bureau of the Census. Mrs. Griffin is responsible for programming the system, Mr. White provided expertise in the area of data processing in a random-access environment, and both individuals have made valuable contributions to the conceptual and computing aspects of the problem. The author acknowledges their contributions with gratitude.

DIGITAL CARTOGRAPHIC DATA BASE
PRELIMINARY DESCRIPTION

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U.S. Geological Survey

CARTOGRAPHIC DATA BASE DESCRIPTION

The expanded scope of the National Mapping Program includes the establishment of Cartographic Data Bases which reside in the public domain and are available for retrieval and reproduction on demand. These data bases fall into two general media categories: graphic and digital. The types of data involved are those generally included in the U.S. Geological Survey topographic maps and are referred to in the National Mapping Program as base category data.

The National Topographic Program will be modified, extended and renamed to serve better the basic cartographic data needs of the country. The new National Mapping Program (NMP) will continue to provide a family of general purpose maps of greater scope than heretofore. In addition it will provide basic map data in a variety of forms useful to the division, other agencies, and the public both for preparation of other maps at various scales and for numerical and statistical analysis of map data. These data forms will include, but not be limited to, color separates, feature separates, or digital data (based on geometric distribution of digitized information).

Base map data categories are:

1. Reference systems: geographic and other coordinate systems except the public land survey network.
2. Hypsography: contours, slopes, and elevations.
3. Hydrography: streams and rivers, lakes and ponds, wetlands, reservoirs, and shorelines.
4. Surface cover: woodland, orchards, vineyards, etc. (general categories only).
5. Non-vegetative features: lava rock, playas, sand dunes, slide rock, barren waste areas.
6. Boundaries: portrayal of political jurisdictions, national parks and forests, military reservations, etc. This category does not fully set forth land ownership or land use.
7. Transportation systems: roads, railroads, trails, canals, pipelines, transmission lines, bridges, tunnels, etc.
8. Other significant manmade structures such as buildings, airports, and dams.

9. Identification and portrayal of geodetic control, survey monuments, other survey markers, and landmark structures and objects.

10. Geographic names.

11. Orthophotographic imagery.

It may be noted that this list does not include photography other than that implied in producing the data categories. However, aerial photographic coverage, without being converted to orthophotos or other base map categories, will be a significant component of the NMP.

The Digital Cartographic Data Base (DCDB) to be developed and maintained by the U.S. Geological Survey (USGS) will be a standardized source for base categories of digital cartographic data principally for the United States. Its implementation will apply the techniques of generalized data base management to produce an integrated approach to the storage, retrieval, and maintenance of digital cartographic data. Data for the DCDB will initially be drawn from existing qualifying sources such as the several series of current USGS topographic maps. When complete, the DCDB, along with the current graphic data base (maps), will be an additional medium for USGS distribution of cartographic data to the community of cartographic data users through the National Cartographic Information Center.

Figure 1 illustrates the DCDB concept, its software interfaces, and its relationships to users of digital cartographic data.

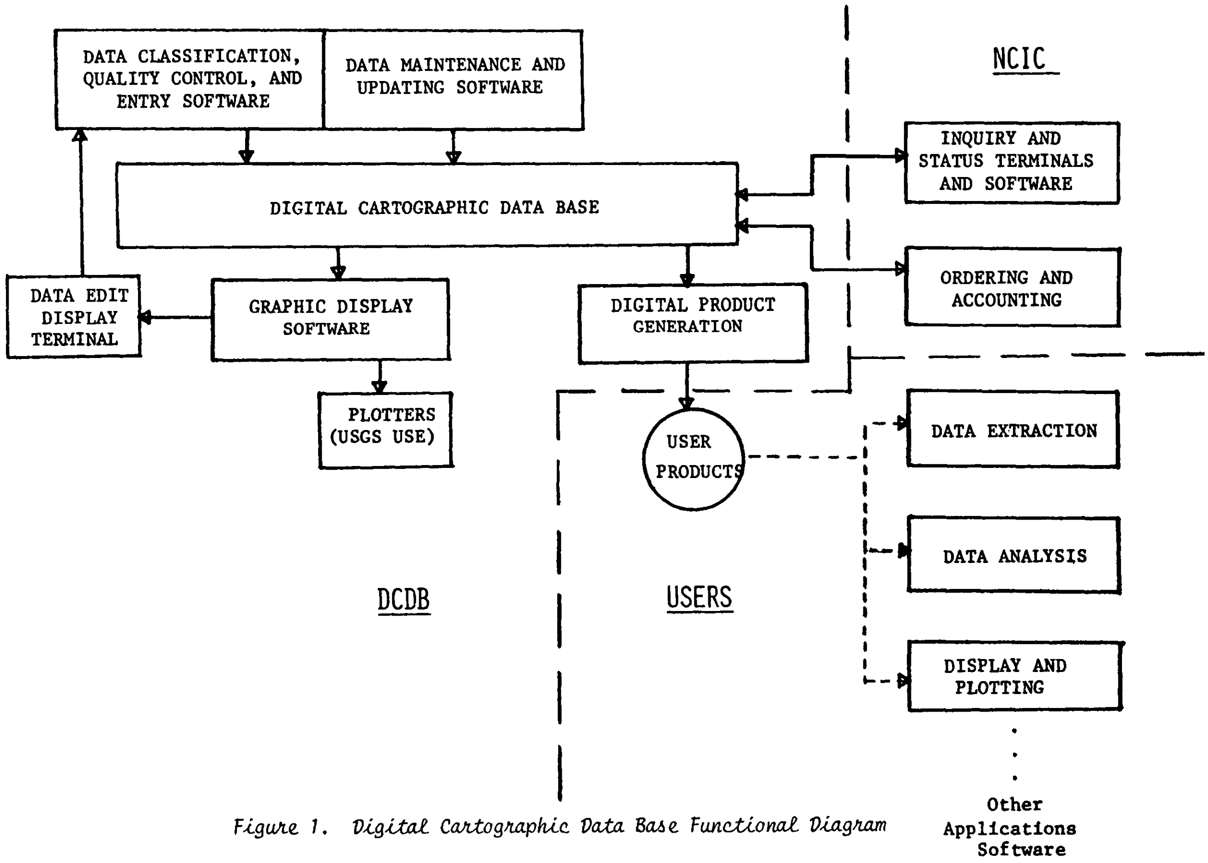


Figure 1. Digital Cartographic Data Base Functional Diagram

Cartographic data for the United States are currently being made available by the USGS in several series of topographic maps at standard scales combining data of many base categories. These data normally comply with National Map Accuracy Standards and are presented in a standard map projection with standardized symbology. Most of these data are also available, on special order, as color-separation film reproductions. Color separates contain the data that would be placed on the map by a single printing plate using a single color, and when available, are in the same scales, projections, and standards as the published maps. These color separates, which constitute the graphic data base, form the major input basis for the definition of data to be included in the DCDB. Five base categories of data have been selected for inclusion in the Digital Cartographic Data Base pilot project: County and State Boundaries, Rectangular Survey System (section corners, etc.), Surface Hydrography, Terrain Surface Elevation, and Transportation. These categories have been selected based on availability of data and initial indications of need expressed by potential users of the DCDB.

DCDB OBJECTIVES

The DCDB will provide selected cartographic data in digital format responsive to current known requirements and structured to expand and evolve as the user community gains experience with digital data and refines its requirements.

By providing management to the DCDB, USGS will establish standard data formats and software interfaces throughout the community of digital cartographic data users, which should help to coordinate orderly development of digital cartographic analysis technology and reduce separate developments of equivalent applications in different formats by different users. USGS will also have the background responsibility to serve as a clearinghouse for applications software developed in forms compatible with the established formats, and for inter-user status communications, with the DCDB as the common reference point, to provide answers to such questions as, "Is what I intend to do with this data already done ...? -- by who, when, etc.?"

Through use of the DCDB and automatic plotting equipment, USGS and DCDB users may acquire the capability to produce certain graphic products not now available. These products would include maps to non-standard scales and projections, combined maps from different base categories, non-standard symbols, colors, etc., and other products that users might identify.

Digital and graphic data taken from the DCDB will be made available to users through the National Cartographic Information Center (NCIC). Although the details of the inquiry and order handling processes have not been resolved, it is known that requests will be handled by a combination of index graphics, which will contain approximate assessments of the data coverage over geographic cells, as well as by detailed computer data base search and retrieval routines. The codes used for the storage and retrieval of cartographic data will be consistent with those used in NCIC's Indexing and Referencing System. In this way DCDB data will be treated as subsets of the total cartographic data set available through NCIC.

In addition to the new products available to users, the DCDB will enable USGS to provide more effective service to users of current standard products through improved operations internal to USGS. These improvements will result from a more rapid update cycle for the materials used to produce topographic maps, improved availability of status information on map revisions and other projects in progress, and possible release of new data in dynamic digital files in less time than required to produce finished maps.

SCOPE OF PROJECT

The development now being planned will be a pilot project to define, design, implement, demonstrate, and evaluate the DCDB. The procurement will include definition and implementation of a data base structure, installation on a USGS-designated computer, and demonstration of data entry, data access, retrieval, and graphic display, data maintenance, and status summary software. Data standards will be developed along with the ability to grade data according to accuracy, reliability, and standard classifications within base categories. Table 1 describes a tentative two-digit spatial accuracy code for the DCDB. A primary objective of the DCDB will be standardization of feature categories (such as kind of highway, etc.) and data reliability codes.

A set of sample data complying with the specified standards will be included in the pilot DCDB for demonstration and evaluation. The pilot project will demonstrate and evaluate all primary data base program modules.

BASE CATEGORY I - COUNTY AND STATE BOUNDARIES

This data category will be designed to include the boundary lines of the 50 States and the county boundaries within each State. State and counties will be described as areas enclosed by boundary lines and the boundary lines will be defined as to type (State, county) and feature identification where the line corresponds to a physical feature such as a river or highway. The exact format of the data storage will be determined as part of the DCDB pilot project definition and methods such as points connected by line segments, polynomial fits to points line segments defined by end points, etc., will be evaluated for storage efficiency and ease of entry and retrieval. The areas will be described by FIPS Codes and access to the data will be through the FIPS Codes or through geographic coordinates. A typical access request by geographic coordinates would specify all boundaries of a given type enclosed within a polygon defined by corner coordinates. The data would be returned in spherical coordinates -- geocentric latitude and longitude -- in radians.

Potential growth to Base Category I Data might include civil townships, towns, cities, State and national recreation and preserve lands. The common attributes of these data are that they are manmade political data, and are most frequently not apparent from physical features or aerial photography.

BASE CATEGORY II - RECTANGULAR SURVEY SYSTEM

This data category is somewhat similar to Base Category I in that it contains the areas and boundary lines defined by the rectangular survey system administered by the U.S. Bureau of Land Management. It therefore includes corner and closing point data and monument data in addition to boundary lines and enclosed areas. Certain land grant areas -- French in Louisiana and Spanish in California -- will also be included where required.

Figure 2

Proposed Accuracy Codes

Positioning Accuracy Code	Scale Equivalent	Positioning Method	Expected 90% Tolerance	Decimal Storage	D M S Output
9	1:2,400 and larger	Precise geodetic position	NTE 1 metres	+31.7051875 +111.6070167	31° 42' 18.675" 111° 36' 25.260"
8	1:2,400 to 1:6,000	3rd-4th Order Geodetic	NTE 5 metres	+31.705188 +111.607017	31° 42' 18.68" 111° 36' 25.26"
7	1:6,000 to 1:14,000				
6	1:14,000 to 1:20,000				
5	1:20,000 to 1:35,000	24,000 map scaling	NTE 13 metres	+31.70519 +111.60702	31° 42' 18.7" 111° 36' 25.3"
4	1:35,000 to 1:70,000				
3	1:70,000 to 1:130,000	Intermediate-map scaling and protracted plate	NTE 30 metres	+31.7052 +111.6070	31° 42' 19" 111° 36' 25"
2	1:130,000 to 1:300,000				
1	1:300,000 to 1:1,000,000				
0	1:1,000,000 and smaller				

The suggested identifier codes for rectangular surveys are given below.

Marker Code		Marker Type Code
Marker Code (Map)	Type of Mark Code	Symbolization (Plotter Output) Code
9	Brass cap monument	00
8	Other found corner	01
7	Accepted	02
6	Plotted	03
5	Witness corner	04
4	Reference monument	05
3	Location monument	06
2		07
1		08
0		09
		10
		11
		12

The spatial accuracy and data origin codes of Table 1 will also apply to this data category and access eill be through the same parameters as Base Category I.

This category will have the potential to expand to include new survey data.

BASE CATEGORY III - SURFACE HYDROGRAPHY

Surface hydrography data will include all perennial drains, intermittent drains greater in length than 600 metres, and perennial open water where the smallest dimension is 15 metres. Drains will be defined as line segments and nodes, described by type, implied flow direction by ascending node numbers, and text. Open water will be defined as areas described by boundary lines consisting of the land/water interface and text. Both types of hydrography features will contain horizontal data only and be accessible through the text names or geographic area methods.

The Water Resources Division of the U.S. Geological Survey maintains an extensive data base of surface hydrography data. A logical extension to the DCDB would be the cross-referencing to these data. In addition, the DCDB has the potential to include hydrology features such as marshes, flats, dry lakes, intermittent open water -- controlled or uncontrolled, rapids, falls, aqueducts, wells, springs, glaciers, etc., in addition to the base data described above. Selected expansion to include these data types will be determined by the needs of DCDB users.

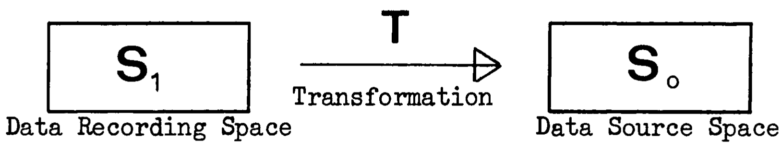
BASE CATEGORY IV - TERRAIN SURFACE ELEVATION

This category will contain all basic elevation data for the DCDB. These data represent the third dimension of the real world and are graphically presented as contour intervals and spot elevations on topographic maps.

In the digital domain, three-dimensional data are as easy to represent as two-dimensional data, and ideally it would be desirable to implement an elevation function above a horizontal grid. This function could be described as points defining segments of planes, fitted analytical coefficients, or other forms, and would directly provide the data most commonly required for digital applications. In practice, an enormous volume of data has been collected; these data are represented as contour lines on a flat surface, and this form of elevation data presentation is widely used and will continue to be demanded by users. General purpose transformation software between contour intervals and three-dimensional grid formats for terrain elevation data will, therefore, be appropriate as part of the DCDB applications software if grid format data are widely utilized. However, the costs of converting existing data would be high, and no clear mandate currently exists which makes conversion necessary. It is, therefore, proposed that the DCDB provide for entry, storage, maintenance, display and retrieval of terrain elevation data in three forms, and for data to be entered in whichever form they are available for given areas.

The three different ways for documenting hypsography of an area are: elevations at regular intervals along terrain profiles, planimetric traces of contour lines, and elevations at planimetric points of critical elevation or slope change. In every case, a terrain point is spatially defined by its coordinate components with respect to some three-dimensional space S. It is essential that the space S be itself a Euclidean space or can be transformed to one, in order for the terrain data to be susceptible to geometrical manipulation. The space S may or may not be Earth related. However, the usefulness of terrain surface data in a data base setting will almost always require a space S which is Earth related.

For any set of terrain surface data, two coordinate spaces are assumed to exist: Data Source Space S_0, and Data Recording Space S_1. The Data Source Space S_0 is the coordinate space in which source material for terrain surface data are documented. It is usually a non-Euclidean space with planimetry represented on some map projection and elevations reckoned from some reference surface. The space S_0 could be also a three-dimensional Euclidean space; such as geocentric, local secant, etc. In every case, spatial coordinates of points in space S_0 are usually transformed during the digitization process to some arbitrary coordinate space which we will refer to as the Data Recording Space S_1. Efficiency of storage, digitizing equipment, and terrain data source material are factors which affect the choice of this transformation T. It is essential that the terrain surface data file contain a definition of the transformation T and its parameters. The relationship between the coordinate space S_0, space S_1, and transformation T are schematically represented by the following figure:



The logical organization of terrain surface data files will be presented in terms of two data records: header record and terrain surface record. A typical file will contain one header record and many terrain surface records. In terms of storage space, requirements for terrain surface records are by far the most imposing, and optimization efforts in their structuring are most rewarding.

This category of data will be limited to terrain elevation data.

BASE CATEGORY V - TRANSPORTATION

Base Category V will contain primary elements of the U.S. transportation network including roads, railroads, and power and pipelines. Roads will be categorized by type such as limited access, heavy duty, medium duty, light duty and unimproved. Several classifications exist for roads and it will be a goal of the DCDB to identify, standardize, and integrate these systems. The pilot project DCDB will include single and multiple track standard gage railroads and selected (trunk) pipelines and powerlines. Transportation features will be defined as lines with nodes, and the lines will be associated with feature classification. The format of their description will be determined in the definition of the DCDB and result from trade-offs considering accuracy, storage required, and ease of entry, maintenance, display and retrieval. The data will be horizontal only, with elevation available from Base Category IV. Data origin, accuracy, and reliability codes will be described by codes similar to those defined in Table 1.

Roads under construction and proposed roads constitute important data to planners and are a potential area of Base Category V expansion. In addition, other transportation features such as non-standard gage railroads and carlines, canals, inland shipping routes, interstate route overhead clearances, and communications links could be later included as need indicates.

DATA STRUCTURE REQUIREMENTS

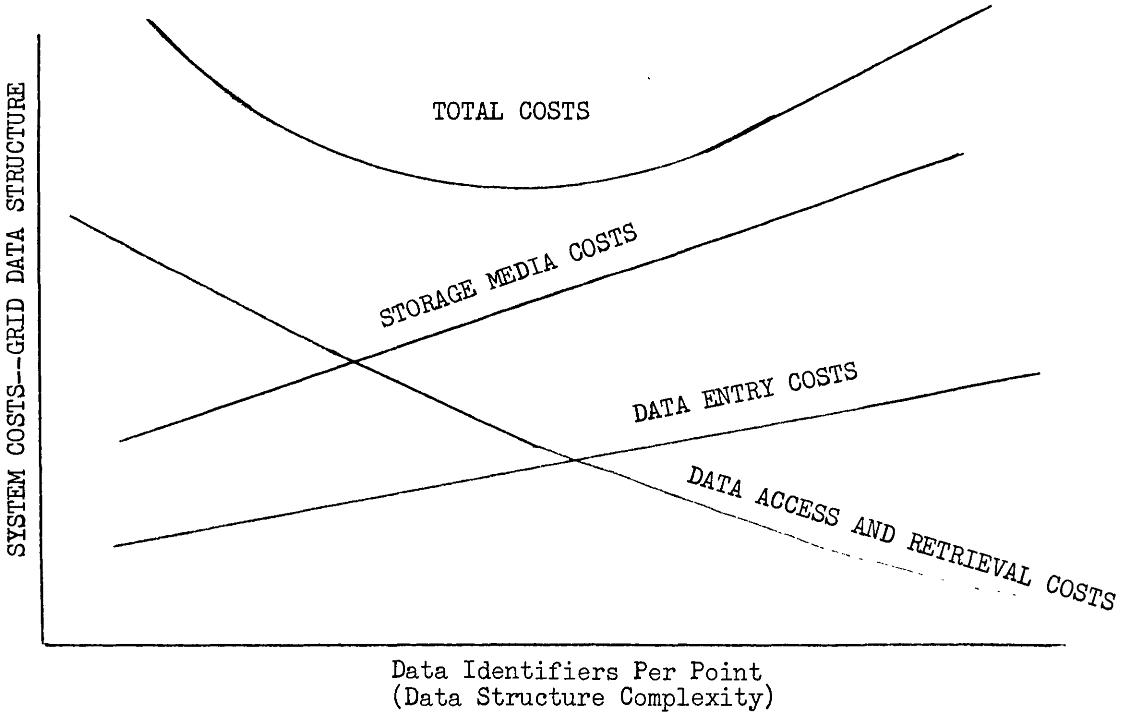
The potential benefits of an integrated Digital Cartographic Data Base are only realizable if the data are structured (organized) in a way that meets the system objectives. A considerable technology has evolved concerning the management of large computerized data bases, and this technology focuses on the data themselves as the end product to be created, maintained and distributed to users. This development is in contrast to earlier views of digital data processing which focused attention on the processing programs and data were simply "input" and "output." The emerging Data Base Management (DBM) technology has resulted in several DBM languages of which one system (System 2000 developed by MRI Systems Corporation) has been procured by the USGS for application in our Water Resources Division. Computer main-frame manufacturers are now generally offering their own DBM systems also. These systems are in general targeted at commercial applications such as personnel systems, sales, and inventory control, etc., and may be applicable to the DCDB. Special emphasis will be directed at evaluation of these available systems in the DCDB pilot project definition to determine their application potential to the DCDB. Good data base design requires trade-off of conflicting requirements to achieve optimum response to the objectives of a specific data base. Requirements definition and trade-offs will be a significant task in the DCDB development.

Figure 3 illustrates a typical trade-off the DCDB optimization must consider. This figure shows that, for a typical Base Category of data and a typical data structure, how minimizing storage media cost conflicts with minimizing data entry, access, and retrieval costs. Optimum resolution of this conflict requires evaluation of the combined effect on total system cost. Figure 3 illustrates summary data. Data entry costs, for example, would be supported by frequency of data entry and unit entry processing cost, data entry software development cost, etc. Although the numerical values attached to the curves shown in Figure 3 are not often well known, the trends are usually well understood and good system design requires early evaluation of these factors for a particular system.

Since the DCDB will be an active, working data base, it is necessary to organize the data in such a way as to minimize massive searches for data access, updating, and retrieval.

Data entry, updating, access, and retrieval software will itself be a significant development item if an existing DBM language is not selected, as will maintenance of this software. The DCDB structure should minimize the complexity required of this software. In addition, users of digital DCDB projects will be acquiring and developing applications software to accomplish their analyses of the data. It is necessary to avoid placing a requirement for a high degree of software sophistication on the data users because of the direct relation to their costs for applications software development.

Figure 3. Illustrative CDB Trade-Off



As one views the spectrum of user requirements for cartographic data in digital form, it becomes immediately apparent that the initial DCDB will not satisfy everyone. However, there are some concepts related to structuring data which will enhance the usefulness and flexibility of the data base at a reasonable dollar investment in terms of structure design, file building and storage. The most fundamental of these concepts deals with the total relationship of all features identified in the DCDB. This relatedness concept is best described as the topology of a region.

In considering a topological structuring approach, we find that the relatedness of features can be expressed in two-dimensional space by the intersections or junctions of like or unlike features. In the context of Base Category features, if each of these intersections or junctions, which are referred to as nodel points or nodes, is assigned some sort of identification and has a spatial reference such as a latitude or longitude or map projection coordinates, this group of points represent a topological framework to which other data can be related. When the topological framework is filled in with Base Category feature data and plotted, a base map is formed.

Some specific examples of nodes are given in Figure 5. Within this illustration we find the following:

Road intersections	nodes A, C, E
Road ends (terminations)	nodes G,
Road and drain intersection	node B
Section line and drain intersection	node K
County boundary and road intersection	node D
Drain and open-water intersection	nodes H, J

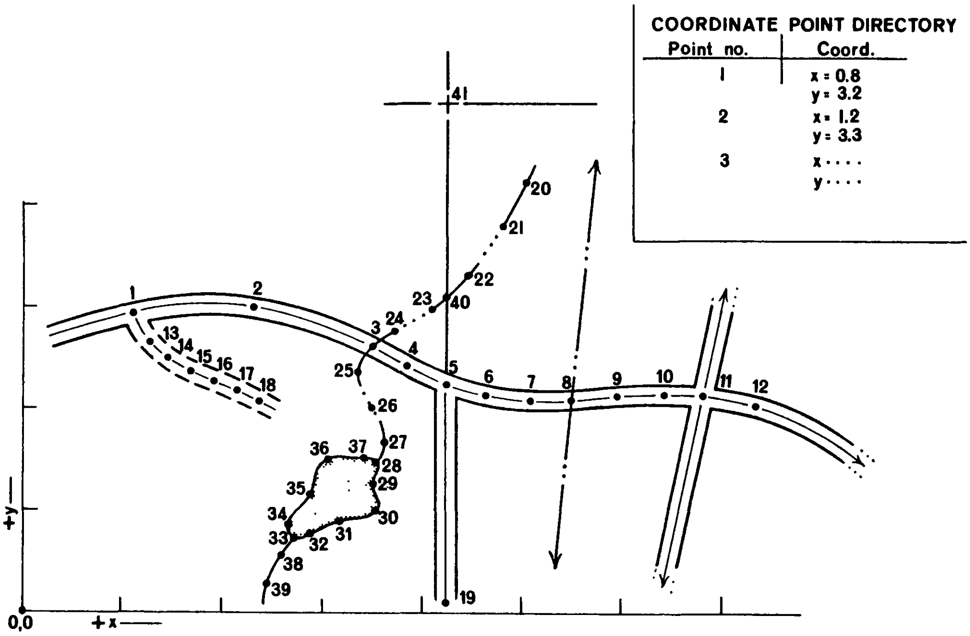
The formation of the features which connect the nodes is of three types:

1. Straight lines which need only end points to be defined;
2. Simple curved lines which require either end points and a radius or three points; and
3. Random-shaped lines which require a string of closely spaced points to approximate the line location. Such lines may represent centerline location, boundary location or physical interface such as shorelines.

In any case, the actual location of features is spatially definable as coordinate points. Figure 4 illustrates the use of coordinate points to define some typical features. Note the numbering is random.

These coordinate points constitute the root level of data, so this is where the data base structure begins. In order to store and retrieve the coordinate (root) level of data, a point directory is assembled. As illustrated in Figure 4, each set of point coordinates is stored with a corresponding point number.

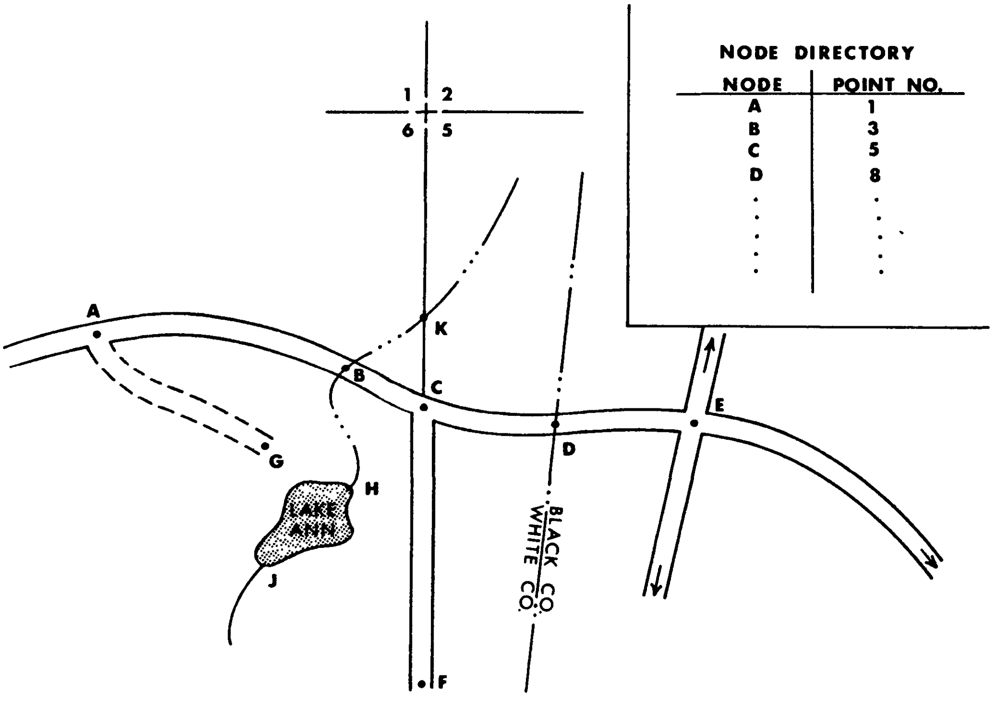
The second data structure level to be established is accomplished by setting up a directory of nodes based on corresponding points. Since we store point coordinates only once and at the root level, a node framework could be plotted by noting point numbers in the node directory, retrieving the corresponding points and plotting each as a separate coordinate point. Figure 5 indicates this relationship and notes the start of the topological data structure levels.



COORDINATE POINT DIRECTORY

Point no.	Coord.
1	x = 0.8 y = 3.2
2	x = 1.2 y = 3.3
3	x . . . . y . . . .

Figure 4. Points - The minimum number of spatial coordinates needed to define the centerline of linear features, the center of point features, and the edge of area features.



NODE DIRECTORY

NODE	POINT NO.
A	1
B	3
C	5
D	8
.	.
.	.
.	.
.	.

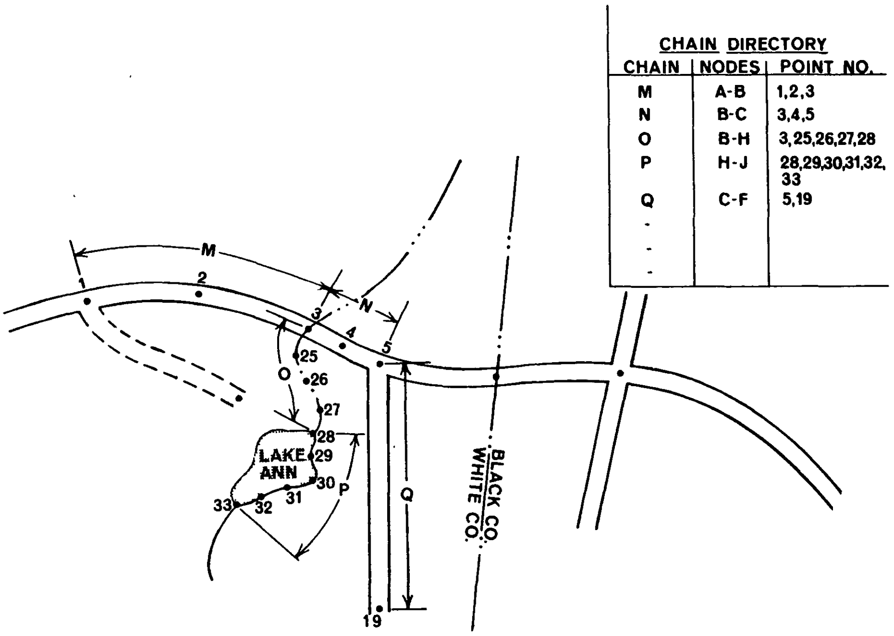
Figure 5. Nodes - Those points which represent the intersection of two or more like or unlike features or the point which represents the end of a linear feature.

The next data structure level involves identifying the string of related points which define a feature from node to node. These are called chains. Figure 6 illustrates the chain identifier for strings of points between nodes. A chain therefore represents a line segment between two nodes.

A feature such as a road, a drain, a lake, or a boundary is usually made up of several line segments or chains, so it is important to establish the third data structure level called chain groups. As an example of chain groups, let's consider a road several miles long. This road would be identified as a series of chains and would be assigned a single chain group number. In order to plot the road, the chain group directory is consulted to find the proper chains, then the node directory is consulted to find the proper coordinate points from which the road is plotted.

Networks of roads and drains, which can be identified as networks, will appear in a network directory under two specific types -- branch network for hydrology and block networks for transportation. This directory permits important name identifiers such as drainage basins and major river networks to become data retrieval descriptors. The network directories constitute the fourth level of data structure. These relationships are illustrated in Figure 7.

The user query level utilizes geographic names and feature codes for basic data retrieval. Data generally will be organized into logical area modules such as 1:100 000-scale quadrangle which represents 30 minutes of latitude by 60 minutes of longitude. Each module would be referenced by 32 sub-modules which would be called a data reference page. These 32 pages correspond to the 7½-minute quads in each module.

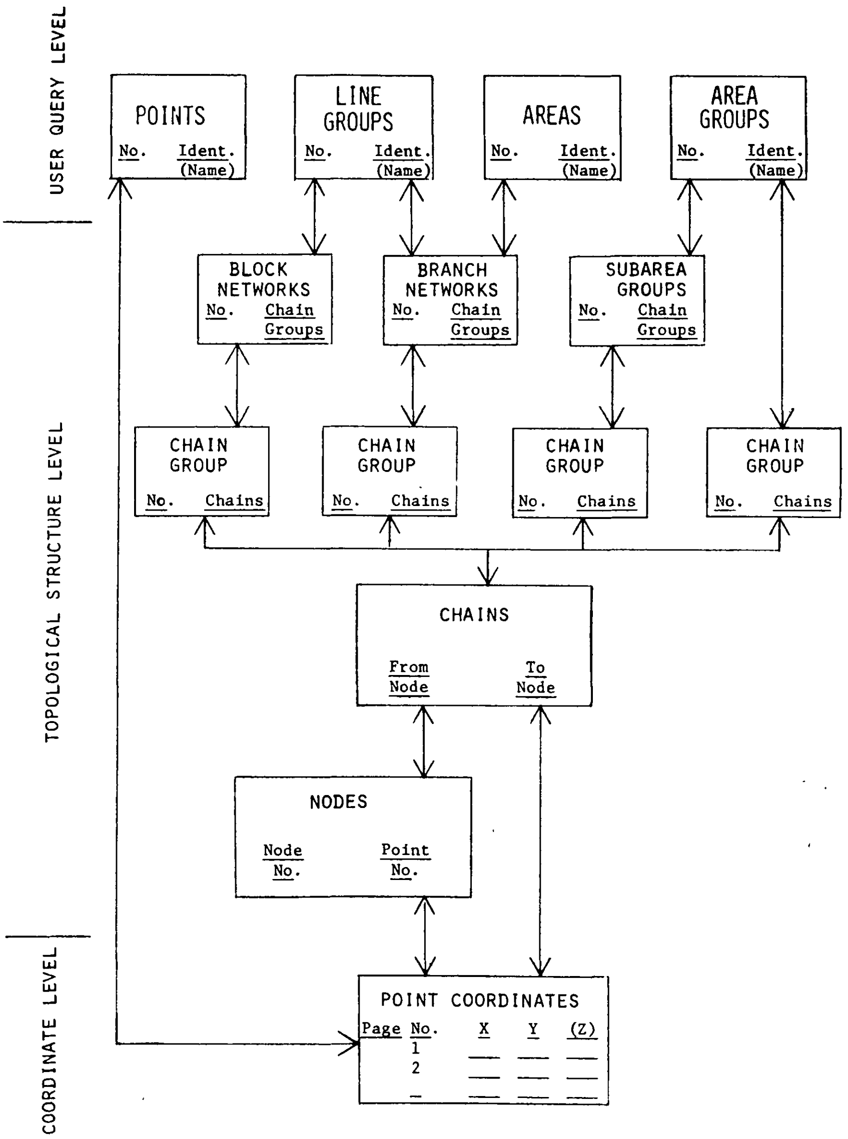


CHAIN DIRECTORY

CHAIN	NODES	POINT NO.
M	A-B	1,2,3
N	B-C	3,4,5
O	B-H	3,25,26,27,28
P	H-J	28,29,30,31,32,33
Q	C-F	5,19
.		
.		
.		

Figure 6. Chains - The series of coordinate points needed to define a linear feature between two nodes. When the linear feature is straight, only the end points (nodes) will appear in the Directory (see example Q).

Figure 7. Data Base Structure Concept

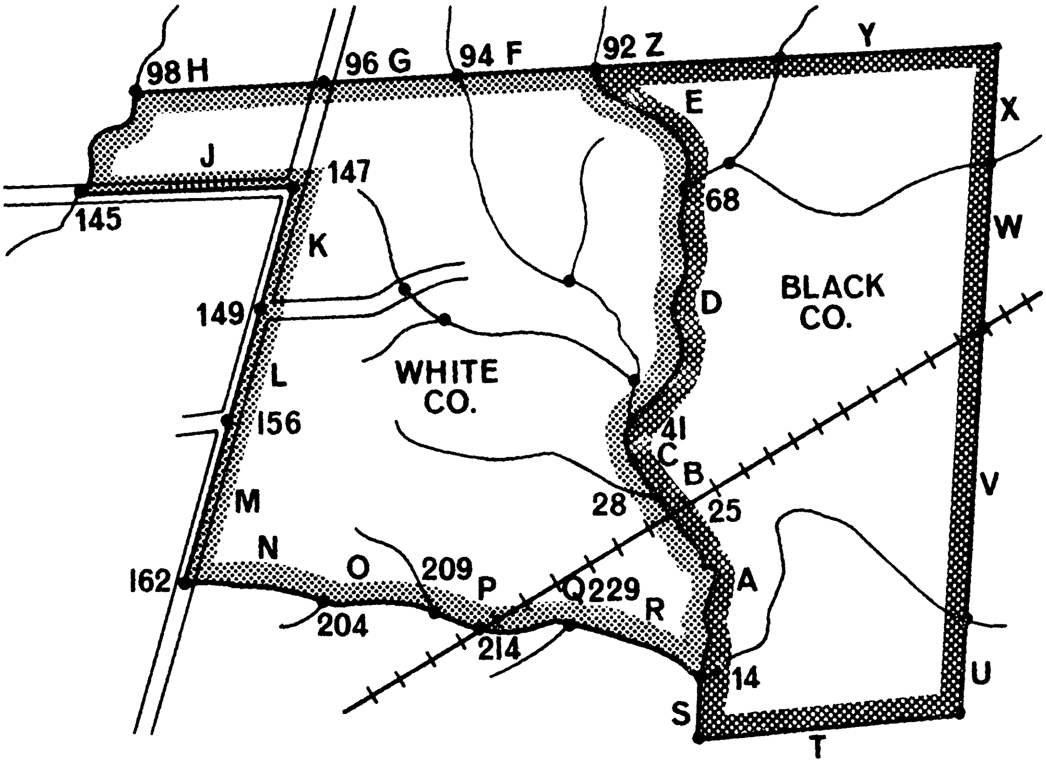


It is important to recognize that points, chains, and chain groups can be shared by almost any number of features. This structuring technique provides a basis for potential users to obtain copies of the point, chain and node data and establish their own higher order directories for specialized use without having to redigitize the root data.

The structuring of area groups such as counties, States, sections, etc., is established in a manner similar to networks. Using this approach, a complete closed area is identified at the chain group level such as sections, counties, land grants. These small area units are aggregated upward to become regions, States, national park management areas, etc.

One of the important aspects of this structure concept is the use of geographic names at both the highest topological structure level and the user level. Figure 8 illustrates how a name is used as a retrieval descriptor for an area such as a county.

Figure 8. Chain Group for White County



CHAIN GROUP NO.	CHAINS
1	A through R
2	A through E S through Z

AREA GROUPS

CHAIN GROUP	NAME
1 =	WHITE CO.
2 =	BLACK CO.
1+2 =	WET BOTTOM WATER DIST.

Some of the attributes of a topological data base structure can be identified at the outset as follows:

1. We estimate that the amount of data residing in the DCDB will reach or exceed 2×10^{10} points. This is based on 50,000, 7.5-minute quads as the primary data source, each containing an estimated 400,000 points. In terms of reels of magnetic tape, if standard 2,400-foot reels are used as a recording medium and the recording density is 1,600 bits per inch and it takes an average of 20 digits to define a point, then it would require 11,000 reels of tape to record just the point coordinate data. Obviously searching a file this size is not a minor consideration and with the proposed data structure which includes appropriate pointers and identifiers retrieval time can be minimized.

2. The topological structure provides a point framework upon which the data file can be easily updated just as junction points on a map are now used as a basis for revision. This is probably the most significant attribute from a data management standpoint.

3. Retrieval of specific data for a given area will be a high demand retrieval mode. This structure permits logical and direct retrieval as opposed to a spiraling type search.

We envision a system of software modules organized as follows:

Creation Modules: This set of modules is responsible for capturing raw data and extracting from it the information required by the data structure to process the data to meet users' requirements.

- Data Capture: Converting data from graphic (e.g., mylar separations) form to digital form.
- Data Formatting: Converting the digital data created in the previous step to a form which includes all necessary identifiers and topological relations implicit in each data set.
- Data Structuring: Entry of data into the archive, using the internal data structure that will be used for all subsequent references to the data.

Maintenance Modules: This set of modules will permit verification by staff members of the correctness of items in the DCDB, and editing of them where necessary. The data structure can be expanded through these modules to enable possible new categories of retrieval, and tests performed to insure that performance standards continue to be met.

- Updating: File maintenance, primarily by interactive graphic inspection, to allow manual insertion, replacement and deletion of data items.
- Data Structure Enhancement: Defining new entities within the data structure (based on information already in the system), thus expanding the categories of data available for retrieval. This does not mean altering the data structure, necessarily; rather, the data structure should be inherently capable of extending itself.

- o Testing: Routines will be involved, routinely and as required, to examine the performance of the data base in crucial tests.

Retrieval Modules: This is the user interface and includes preprocessing of the DCDB to extract user-requested information, followed by output of data from the system in proper format.

- o Preprocessing: A user may request intricate subsets of information from the DCDB. This may involve, for example, assembling a number of quad sheets together, changing scale and/or projection, requesting certain features that are spatially coincident or arbitrarily close together, or multiple overlays with certain features selected out. Such tasks are inherently within the power of the data structure, but would not normally take place in the absence of a user request.
- o Graphic Output: Interactive display and plotted output must be available, the sophistication of which is essentially limited by the graphic output hardware.
- o Digital Output: Machine-readable files can also be output, mainly on magnetic tape. A variety of formats should be possible without special intervention. DIME files or World Data Bank format files, for instance, ought to be among the standard output options, as well as matrix conversion for certain types of data (especially terrain).
- o Software Dissemination: Users should be able to acquire software for using data from the DCDB.

The DCDB will include status and summary record data such as entry/update date, source, accuracy and reliability, and data access history with applications data. This will enable users to determine if the analysis they intend to perform on the data has already been accomplished or if applications software is already developed.

The DCDB must ultimately include interactive graphics for data editing, file building, update and retrieval. The requirements to provide for this capability will be evaluated during the design phase of DCDB development.

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Seminar on Automation in Cartography: International Developments

SEMINAR ON AUTOMATION IN CARTOGRAPHY: INTERNATIONAL DEVELOPMENTS

In this session representatives of several nations reported on developments and experiences in automated cartography in their respective countries. The session was chaired by ROGER TOMLINSON, representing the International Geographical Union (IGU).

In his introductory remarks ROGER TOMLINSON discussed current developments in several countries. Britain, which had an early start in the field, has since progressed rather slowly. France has basically adopted and modified the U.S. GBF/DIME System. Sweden, on the other hand, has been an independent innovator and is perhaps in the forefront of automated cartography. Little computer development has taken place in the Soviet Union, although there is a substantial need for that country to develop information systems. The Third World has yet to develop substantial automated cartographic capabilities. As yet there are no formal journals that really reflect the concern of cartographers in this field. The International Geographical Union (IGU) is compiling an inventory of computer software. This report should be available in early 1976. A software exchange program is also sponsored by the IGU. In cooperation with the United Nations, the IGU is creating teams of experts to help with the establishment of automated cartography in the developing world.

KRISTER SELANDER, of the Nordic Institute for Studies in Urban and Regional Planning - NORDPLAN, discussed recent developments in Sweden with regard to the use of computer graphics in urban and regional planning. The first part of the paper described a simple system for graphical presentation based on a Calcomp plotter and developed within an inter-Scandanavian research project. The objective of this project is the development of a prototype urban information system. Experiences and applications of the system in a pilot study were presented. The function of the Swedish color plotter (Ink Jet Plotter) was described and compared with an incremental plotter. The last part of the paper considered the problem of creating a graphical display system with a minimum of handware dependence.

ROBERTO TORFER MARTELL represented the Mexican Studies Commission for the National Territory. This agency is a branch of the Ministry of the Presidency and is in charge of the natural infrastructure and human resources inventory which are presented in cartographic form and made available to both the private and public sectors. The author described general developments and plans in two areas: 1) activities in the field of photogrammetry, photointerpretation, and geodesy; and 2) the development of a geographic data base and software capacity. His paper is entitled "Automation and Cartography at the Mexican Studies Commission for the National Territory."

MANUEL REJON NUNEZ, representing the Geographical and Statistical Society of Mexico, discussed the cartographic activities of that organization. He described an historical atlas of Mexico City which will be published shortly. The atlas will analyze the four epochs of growth of Mexico City from 1300 to the present and will include maps of the Aztec Empire, maps of the Spanish Conquest, maps of the Revolution, and maps of the present day.

JOSE KLEBER FIALHO of the Brazilian Institute of Geography and Statistics (IBGE) submitted a paper entitled "Results of the Application of Computerized Cartography in Brazil." His paper explained the components of the Brazilian cartographic system, its activities and products, and described the software developed to support automated cartography in that country.

COMPUTER GRAPHICS IN URBAN AND REGIONAL PLANNING: SOME DEVELOPMENT PROJECTS IN SCANDANAVIA

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INTRODUCTION

The aim of the Inter-Scandanavian project, NIMS, is the development of a prototype for a computerized geographical information system for municipal planning purposes.

From the very beginning of the project a great deal of the efforts has been devoted to the development of systems for graphical display. A graphical display system adapted to Calcomp-compatible hardware equipment is now in operation. The experiences gained by using this system in practical planning applications have, however, initiated further development of a more general and flexible system for graphical presentation; this system is called GRIMAS (Graphical Information Management System). This paper will present the motives for the development of GRIMAS and to some extent describe the characteristics and technical features of the system.

To start with, however, I will describe a special device for plotting, the so-called color jet plotter, developed at Lund Institute of Technology in Sweden. This plotter, which can directly produce hard copy color pictures, is frequently being used for planning-oriented graphical presentation.

The access to the color jet plotter has been an important reason for the development of GRIMAS. Practical experiences have pointed out a need for a general graphical display system which would allow the use of several types of existing plotters and which is at the same time easily adaptable to future equipment.

THE COLOR JET PLOTTER

A unique feature of the color jet plotter is that it makes use of three fine ink jets in the colors red, yellow and blue; these jets act as the recording styli. They can be electrically controlled at frequencies as high as 100,000 dots per second by a new process developed at the Department of Electrical Measurements at the Lund Institute of Technology. Jets are created when small drops of ink pass under high pressure through three nozzles. Such a jet will draw a line when it hits the paper on a rotating cylinder. Between the nozzle and the paper the jet passes an electrical circuit, which can be on or off. When the circuit is on, the drops become negative and repel each other. This changes the jet to a spray and the "line drawing" is interrupted. To prevent the spray from painting the paper, the drops are absorbed by a positive electrode. Figures 1 and 2 explain the principle.

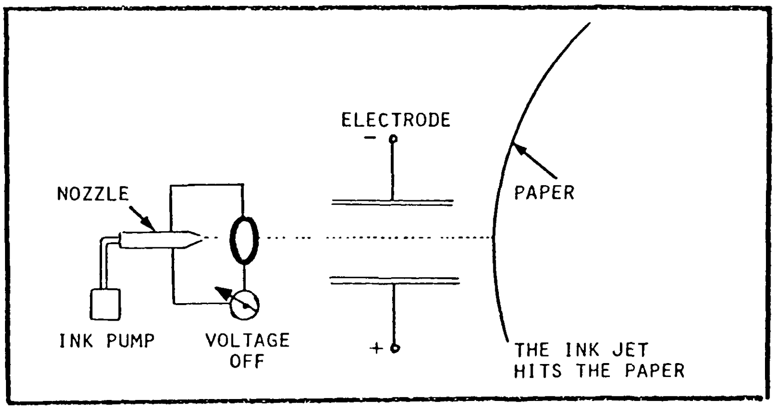


Figure 1

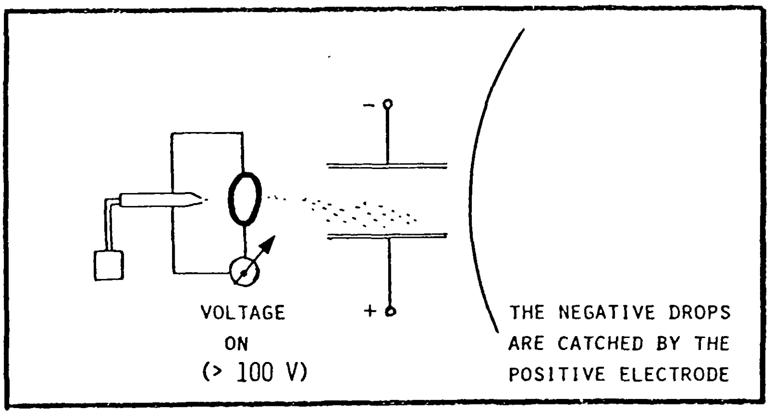


Figure 2

The color jet plotter consists of four parts: drawing unit, tape unit, buffer storage and control unit. The drawing unit consists of a drum which holds the recording paper and which is rotated at high speed by a motor (1,000 rpms). A screw drive moves the recording head carrying the three ink jet systems along the surface of the drum. Each jet draws five lines per mm and for the largest plotter (map size = 65 cm x 60 cm) 3,500 lines are drawn for the total map. The plotting time is about 9 minutes for this map size, independent of the complexity of the picture.

Since ink jets are used in the plotter, no special demands are made on the record receiving surface. Thus, nearly all kinds of plain paper can be used and even films for overhead projectors can be prepared.

An overall view of the plotter is given in Figure 3.

The user of the color jet plotter controls the plotting by creating a magnetic tape containing only binary zeros and ones. The plotter will interpret a zero as "voltage off" and a one as "voltage on." This means that a color picture is represented by three binary matrixes on a magnetic tape.

One difference between an incremental plotter and the color jet plotter is that the total picture in the form of three matrixes must be accessible to the computer at every moment during the creation process. Due to the size of the matrixes, these have to be stored on an external storage, which causes time consuming shuffling between core and external memory of matrix parts during the plotting process. The software developed for the color jet plotter uses a paging technique to minimize these shuffling times.

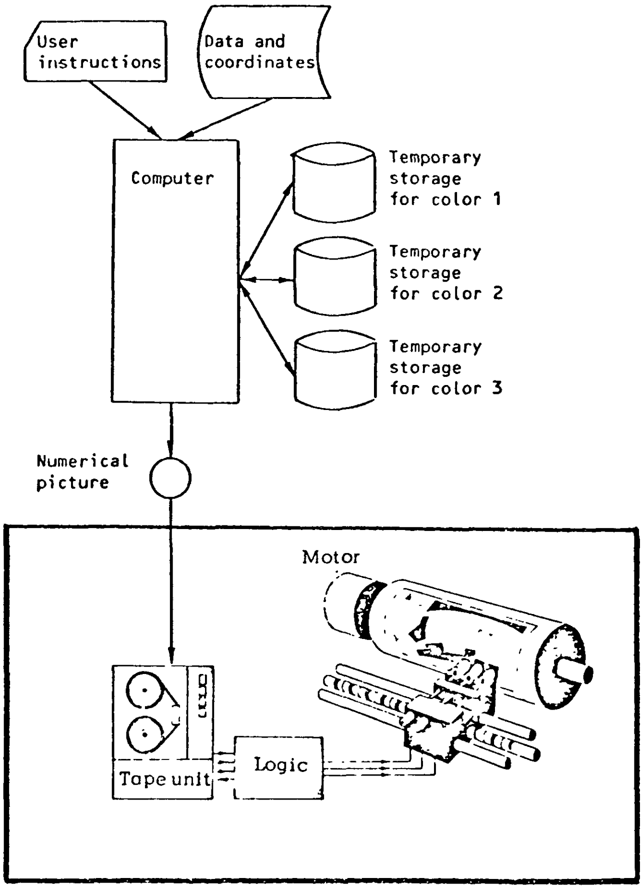


Figure 3

By using the color jet plotter the problem of hidden lines and surfaces in three-dimensional plotting is solved automatically. With access to the total picture at every moment, it is very easy for the user to erase parts of the picture where plotting already has been performed.

In order to generate a color picture with the color jet plotter, a rather complex software is needed. Therefore, a comprehensive program system, COLOR, has been developed. The system is coded in ANSI Fortran and can be implemented on many different computer systems with only minor changes. It is presently running on UNIVAC, IBM and ICL computers.

COLOR provides the following three general classifications of plotting software:

1. BASIC software consists of routines for plotting a line between two points in arbitrary color and width, a shaded surface in arbitrary color and shading pattern (there exist 15,625 different color/shading combinations), and plotting a text in arbitrary color and size.

2. FUNCTIONAL software consists of several routines for plotting figures and for special areas of application. For example, routines are included for plotting rectangles, circles, and previously prepared "background pictures" as well as scaling routines for handling coordinates in different scales. This part also includes a comprehensive graph and histogram system which can handle scaling and axis manipulation automatically.

3. APPLICATION software is the highest level of COLOR. It contains application routines which enable even users with little programming experience to plot complicated pictures. For example, routines are included for handling 3D information needed for grid maps, contour maps, perspectives, and 3D bar diagrams.

THE GRIMAS SYSTEM

As pointed out above, the main reason for the development of the GRIMAS system has been the need for a general and flexible graphical display system as independent as possible of the graphical equipment itself.

The system is an integrated part of a computerized information system for municipal planning. So far its main task has been to serve as a basis for further research in this field.

SOME DEFINITIONS

In order to facilitate the following discussion, it will be necessary to define some of the terminology which will be used.

OBJECTS are the smallest basic elements in the information system to which data are collected and assigned. The objects are divided into OBJECT CLASSES, i.e., individual streets, census tracts. For each object a unique IDENTITY is required.

In order to describe the characteristics of an object, DATA are collected. In a geographical information system the LOCATION of an object will often be recorded, either directly by the use of coordinates, or by relating the object to another already located immobile object, usually referred to as a SPATIAL REFERENCE OBJECT.

For the information system of which GRIMAS is a part, it is assumed that the location coordinates for an object form any of the geometrical configurations of a point, a segment or a polygon.

DATA BASE STRUCTURE AND DATA MANAGEMENT SYSTEM

GRIMAS requires a data base structure where data for object characteristics and coordinates are stored in separate files according to Figure 4.

As stated above, GRIMAS is part of an integrated geographical information system. The system components are shown in Figure 5.

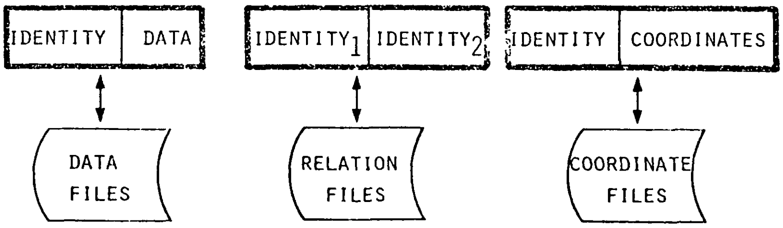


Figure 4

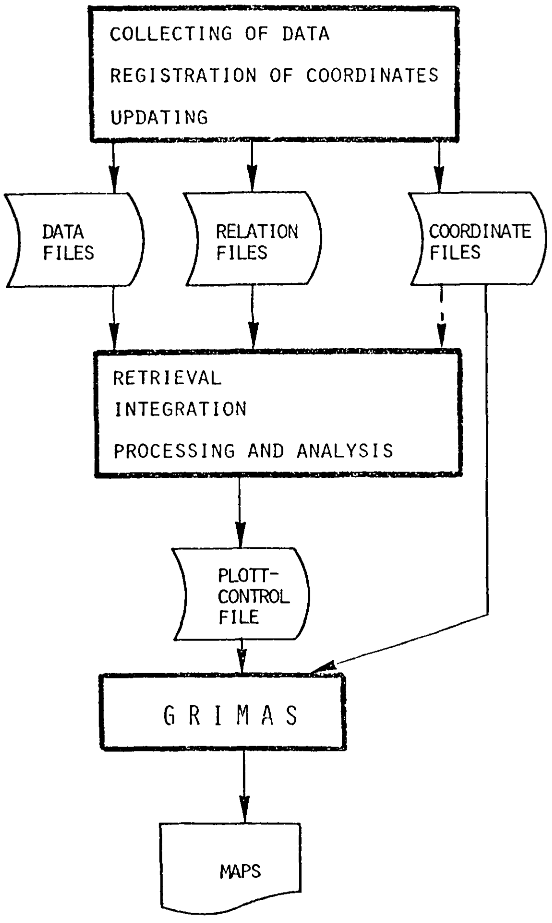


Figure 5

The following main requirements have been considered in the design phase of GRIMAS:

1. It should be possible to display graphically in one run of the system one or several optional regions selected from the total area included in the information system.
2. It should be possible to display simultaneously in optional and variable scales maps for various regions.
3. The system should be as simple as possible to adapt to different kinds of graphical hardware equipment.
4. It should be possible to display at the same map or on separate maps any combination of coordinate referenced object classes.
5. It should be possible to add in a simple way new plot-plotting functions to the system. Such programming should be independent of the hardware equipment.
6. The display should be specified by a simple parameter language.

GRIMAS SYSTEM FLOW:

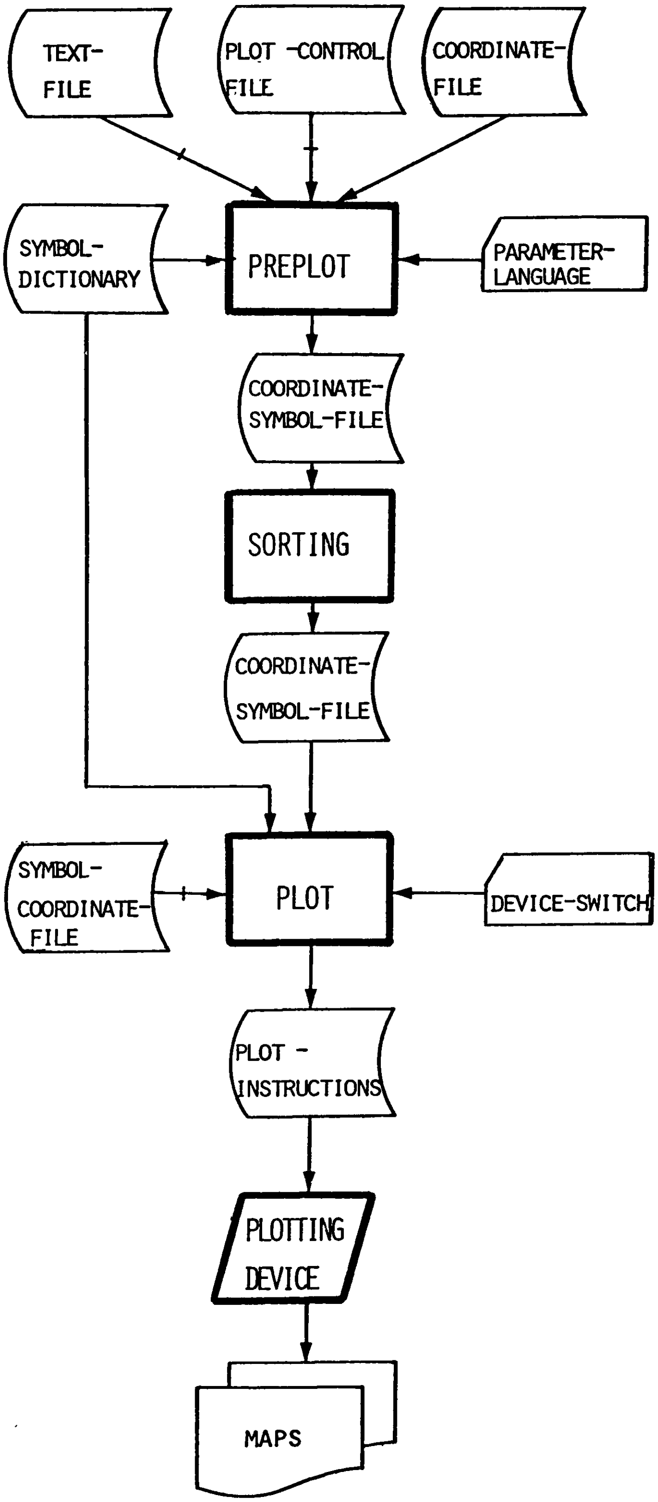


Figure 6.

THE TECHNICAL SYSTEM DESIGN

To fulfill the demand for hardware independence only very basic procedures for the actual display functions are used. These are:

- draw a point
- draw a line
- shade an area
- write a text string

It is assumed that all more or less complicated plotting symbols can be combined from the components above. This implies that the only requirement for using certain equipment for plotting a symbol is the existence of software for the basic plotting procedures of which the symbol is combined.

The process for map production with the GRIMAS system can be divided in three phases. These are shown in Figure 6 .

In the first phase each coordinate is labelled with a physical map-sheet identity. The number of sheets depends on the scale of the map and the size of the sheets. The coordinates are then transformed to a coordinate system corresponding to the size of the sheets. The information from the plot-control file (if existent) is transferred together with the sheet numbers and the transformed coordinates to an output file.

The second phase is the sorting of the coordinates in order to bring coordinates belonging to the same sheet together.

In the last phase the sheets are sequentially produced. As can be seen from Figure 7 below, input consists of a coordinate file, an optional plot-control file and a text file. The first two files have standardized record formats.

THE COORDINATE FILE:

OBJECT-CLASS	OBJECT-IDENTITY	GEOMETRIC FORM	POINT NUMBER	X-COORDINATE	Y-COORDINATE

THE PLOT -CONTROL FILE:

OBJECT-CLASS	OBJECT-IDENTITY	SYMBOL CODE	PAR 1	PAR 2	PAR N

Figure 7

The plot-control file has the following functions: The shape of an object graphically displayed is determined by symbol numbers and parameters in the plot-control file. The location of the display is determined by the coordinates in the coordinate file. Each symbol number refers to a specific sequence of instructions in the plotting module of the system. Such a sequence is mapping a set of coordinates (representing a point, a segment or a polygon) into one or several new sets of coordinates corresponding to the symbol to be plotted. The new set of coordinates thus in fact constitutes the plotting symbol by using components of points, segments and polygons. The reproduction procedure contains no actual plotting instructions. The programming of each symbol is entirely independent of the plotting equipment.

The actual plotting will then take place in a subsequent program step common to all previously programmed plotting symbols. The four basic hardware-dependent plotting procedures mentioned above will now be used to plot points, lines areas and text strings. It should be pointed out that this part of the plotting program is entirely independent of the program sequences performing the mathematical plotting of the symbols.

This will allow new drawing symbols to be easily included in the system by adding a new sequence of program instructions with no influence on the previous programming.

Furthermore, the already existing plotting symbols can be used when new symbols are designed. This will simplify the programming of new symbols.

AN EXAMPLE

The following example has been developed to clarify the design of the parameter language and is illustrated below.

A municipality has data for the following object classes: individuals (1), street segments (5), parks (6), railway lines (9), parking lots (10) and census tracts (15).

All object classes have locational references by coordinates stored in a common coordinate file. Processing and analysis have been performed and have resulted in a plot-control file for the object classes: street segments (5), parking lots (10) and census tracts (15).

1: PLOT THE OBJECT CLASSES 5,10 AND 15 ON ONE MAP IN
THE SCALE 1:20000 FOR THE SUBREGION DEFINED BY
X-MIN = 62000, Y-MIN = 2000, X-MAX = 72000, Y-MAX = 9000.
THE PLOTTING SHALL BE CONTROLLED BY THE PLOT-CONTROL FILE.

2: IN THE SAME RUN
PLOT THE OBJECT CLASSES 1,5,6,9 and 10 IN
THE SCALE 1:5000 FOR THE SUBREGION DEFINED BY
X-MIN = 63000, Y-MIN = 2100, X-MAX = 70000, Y-MAX = 8000.
THE OBJECT CLASSES 1 AND 6 SHALL BE PLOTTED ON THE SAME
MAP WHILE THE OBJECT CLASSES 5,9 AND 10 SHALL BE PLOTTED
ON SEPARATE MAPS. THE IDENTITIES FOR 10 SHALL BE PLOTTED.
NO PLOT-CONTROL FILE SHALL BE USED.

IN BOTH CASES THE COLOR JET PLOTTER SHOULD BE USED.

To specify the stated mapping problem to the GRIMAS system we have to write the following parameters:

```
*STD 4,,7,19,21
*REG 62000,2000,72000,9000
*SCL 1:20000
*SIZ 190x250 MM +
*TXT 'PARKING'
*COM 5,SYMB,NOTXT; 10,SYMBONLY,NOTXT;15,SYMB(7),NOTXT
*STD ,,,17
*REG 63000,2100,70000,8000
*SCL 1:5000
*TXT ACCESS TO PARKS'
*COM 1,STAND,NOTXT; 6,STAND(2),NOTXT
*TXT
*NEW 5,STAND,NOTXT; 9,STAND(15),NOTXT; 10,STAND,STAND;
*END
```

AUTOMATION OF CARTOGRAPHY AT THE MEXICAN STUDIES COMMISSION FOR THE NATIONAL TERRITORY

Alberto Torfer Martell
Comision de Estudios del Territorio Nacional

INTRODUCTION

The purpose of this paper is to present the work done in the Studies Commission of the National Territory regarding the implementation of a geographical data base and the automation of cartography. To understand how useful both developments can be to our organization, the scope of our work should be kept in mind.

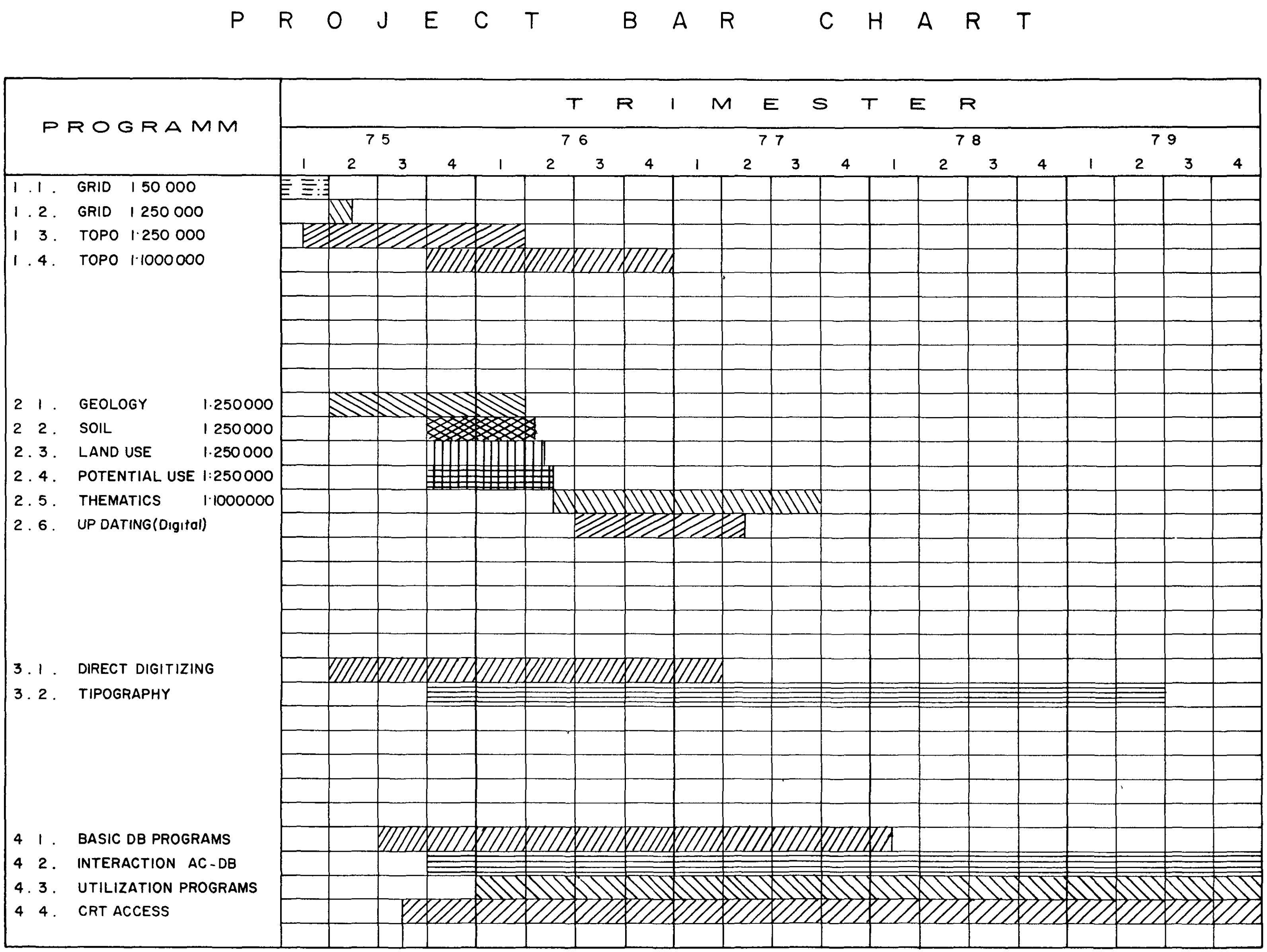
The Commission is in charge of the production of the topographical, geological, land use, soils and potential use maps for the whole Mexican Republic. This work is being done at 1:50 000 scale and to get full coverage we will need 2,354 maps for each series. The work is being done completely at our unit, using the techniques of photogrammetry, photointerpretation and geodesy. Right now, we have printed over 576 topographical maps and over 1,071 thematic maps (See Figure 1).

The topographical map has all the information regarding orography, hydrography, and human works. The geological map has information about rocks, soils, mines and exploration sites. The land use maps show the activity to which the land is being dedicated, along with the classification of types of cultivation, the technology used in development of land, the classification of vegetation, and a very important aspect -- the distribution of population.

The soils maps give information on the physical, chemical, and biological characteristics of soils. The potential use maps show the best way to use the land, what it needs to prevent erosion, what infra-structure should be built to develop the region faster and more fully. It can be stated that the information produced by CETENAL (acronym of Comision de Estudios del Territorio Nacional) represents about 80% of the information needed to make a good decision in planning the development of a nonurban region.

In the few years of the existence of CETENAL, the usefulness of the information produced has been amply demonstrated. What we are trying now is to help users even more by providing alternate ways of presenting information. We estimate that this will be one of the best ways to justify the investment made in the elaboration of our base maps.

Figure 1


P R O J E C T B A R C H A R T
PROGRAMM
T R I M E S T E R
75
76
77
78
79
1
2
3
4
1.1. GRID 1 50 000
1.2. GRID 1 250 000
1 3. TOPO 1:250 000
1.4. TOPO 1:1000 000
2 1. GEOLOGY 1:250000
2 2. SOIL 1 250000
2.3. LAND USE 1:250 000
2.4. POTENTIAL USE 1:250000
2.5. THEMATICS 1:1000000
2.6. UP DATING (Digital)
3.1. DIRECT DIGITIZING
3.2. TIPOGRAPHY
4 1. BASIC DB PROGRAMS
4 2. INTERACTION AC-DB
4.3. UTILIZATION PROGRAMS
4 4. CRT ACCESS

OBJECTIVE OF THE AUTOMATION OF CARTOGRAPHY

To have a broader view of the problems of a region, you have to generalize the information you are presenting, simplifying by selection, modifying or eliminating the features shown on a base map.

Cartographers do this when they develop a derived map by extraction and generalization of the information presented in a base map. At the same time a change of scale may be used. This process can be computer-assisted by adding digitizing, computer processing and plotting activities.

However, the implementation of these last steps is quite expensive. So, to really absorb the cost there must be enough production once the production line has been established; a significant production time decrease is also needed. Otherwise automation will not be significant or useful. Unfortunately this cannot be accomplished by a simple system, especially with the topographic map.

The digitizing process is a time-consuming and laborious operation in which the best equipment is needed. One should be able to digitize at the same time the photogrammetric compilation is being done to avoid as much as possible the need to retrace any feature. Some steps of the production of the base map itself would also be automated. The use of scanners or line followers may be an alternate way to fulfill the need to speed up the digitization process. This applies mainly to the topographic map. With the resources maps the situation is not so critical because the number of lines separating the different properties is much less than the number of lines for a topo-map.

The cost of the digitization can also be spread among other products. We are trying to make at least two different derivative maps -- at 1:250 000 and 1:1 000 000 scales -- and we are using the information in digital form to build the geographical data base.

Right now, the programs that handle the information of level curves and of hydrography have been finished, as well as the programs to handle the polygons of the resources maps.

Our equipment is an H. Dell Foster RSS 400 II Graphic Quantizer and a H. Dell Foster RSS 700 Plotter. We use a general purpose IBM 370-135 computer for our calculations.

The interrelationship between automatic cartography and the geographical data base will be done by means of several programs. One transforms the polygon data base built at the processing stage for the 1:250 000 scale map to the cell data unit used in our data base. This may be the only sensible way of constructing it, since the manual coding of all the information is quite time-consuming. Another program will form from the digitized contours a more or less crude digital terrain model included in the geographical data base.

OBJECTIVES OF THE DATA BASE

The purpose of the data base can be stated quite easily: To put into computer-compatible form, all the information produced by CENTENAL in order to be able to ask any type of question by selecting, comparing, or merging the information.

To get a flexible system it was decided that the query language should be flexible and it should allow for easily growing types of questions. So, it was decided that the questions should be built with logical operands like 'and', 'or', 'not' and their combinations.

This more or less automatically shifted the decision to a cell system; the Mexican Republic was divided according to the sizes of our maps. That is, a cell of the 1:50 000 map equal to the size of the whole 1:10 000 map, the cell for the 1:250 000 scale is equal to the whole 1:50 000 scale map. To code the properties we have for each cell a basic header that tells us how many superficial properties are coded and the address of all of them and how many lineal properties and the addresses of the lineal property descriptors. The point properties are treated as a special case of the lineal property; all properties are identified by a code.

Also several special functions have been programmed which form the basic building blocks for the questions. These functions are of two types: relational and logical.

The relational functions are:

MAYORQ - Greater than
MENORQ - Less than
ENTRE - Between A1 and A2
DIFERE - Different from
IGUALA - The same as

The logical functions are interrelated by the logical operands and, or, not (or their combination) and use the relational functions as arguments. They are:

PRO (A1, A2, A3) Property, the arguments are:

A1. - Which should be the code number of the property evaluated
A2. - Is a relational function
A3. - Is the value against which we are comparing

UNADE (A1, A2, A3, A4) - one of A1 and A2 -- are code numbers of properties; between them the system will compare, as marked by the A3 argument, which is a relational function, against the value given in A4.

PROP (A1, Entre, A3, A4) This function serves to find when the property coded in A1 is between the values given in A3 and A4.

EVALUA - Evaluates the properties of a place.

VALOR - Prints the properties of a cell.

CERCA - Orders the system to work also with the neighbors of a cell.

IBUSCA - Used with CERCA to find a property.

With the point and lineal descriptors there is also a special set of functions. They are:

PUEBLO (A1) Find Towns and the related information by coding the number of the town.

HAYVIA (A1, A2) Find the communications linking a town. The type of communication is given in number A1; in A2, the number of the town is coded.

SERPOB (number a, b, c, d, e, f, g) Gives the information of the services already given to a town.

SERPO (A1, A2) Gives the list of proposed services for a town.

These functions are not all the ones that can be programmed. Indeed every question could be stored in a library and could be used in future references. An example of a question is given in Figure 2.

Figure 2

```
                    LECHE                    CATE # 76042
      LOGICAL FUNCTICN LECHE%NE
      LOGICAL PRC,UNADE,MAYCRG,MENCRG,IGUALQ
      EXTERNAL MAYORG,MENORG,IGUALG
C              PRCGRAMA PARA CETERMINAR LAS SIGUIENTES CCNCICIONES PARA
C              LA CELIMITACICN CE UNA CUENCA LECHERA.
C              1.- PENDIENTES MENCRES DEL 8/1CO.
C              2.- TERRENCS NC SALITRCSCS.
C              3.- TERRENCS NO RESEALCSCS.
C              4.- TERRENGS SIN USC FCRESTAL.
C              5.- TERRENOS SITUACCS A MENOS DE 2200 METRCS CE ALTITUD.
C              6.- TERRENCS CCN SUELC FIRME%SIN PANTANOSE.
C              7.- TERRENCS CCN SUELCS PERMEABLES QUE NC SEAN ROCCSOS.
C                QUE NO PRESENTEN GLEYSCL,VERTISOL, SCLCNETZ,
C                PLANOSOL,LUVISCL,PODZOLUVISOL,ACRISCL,NITOSOL,
C                HISTOSOL C LITCSCI NI COMC SUELO PRECCMINANTE,
C                NI COMO SECUNCARIC. TAMPOCO DEBEN TENER RCCAS IGNEAS.
C              8.- TERRENOS EN LCS CUALES CUALQUIERA DE ENTRE PRESA,
C                BCRDO, CEPCSITC DE AGUA, LAGUNA,LAGO, MAR
C                O TERRENC LACUSTRE, NC OCUPEN MAS C53 VO100
C                DE LA SUPERFICIE, AL NIVEL QUE SE ESTE BUSCANDO.
      M#90
      N#1CO-M
      LECHE#PRO%58C4,MAYORG,8CE
     X    .AND..NCT.UNADE%56C2,56C4,MAYCRG,ME
     X    .AND.PRC%57C2,MAYCRG,ME
     X    .AND..NCT.UNADE%63C1,64C6,MAYCRQ,ME
     X    .AND..NCT.PRC%105,MAYCRG,22COE
     X    .AND..NCT.PRO%603,MAYCRG,CE
     X    .AND..NCT.PRC%52C5,MAYCRG,ME
     X    .AND..NCT.UNADE%39C2,3924,MAYCRQ,ME
     X    .AND..NCT.UNADE%51C3,5113,MAYCRQ,ME
     X    .AND..NCT.UNADE%44C2,4414,MAYCRQ,ME
     X    .AND..NCT.UNADE%42C2,422C,MAYCRG,ME
     X    .AND..NCT.UNADE%46C2,461C,MAYCRQ,ME
     X    .AND..NCT.UNADE%3CC2,3C14,MAYCRQ,ME
     X    .AND..NCT.UNADE%4CC1,4CC6,MAYCRQ,ME
     X    .AND..NCT.UNADE%41C1,41C2,MAYCRQ,ME
     X    .AND..NCT.UNADE%42C2,422C,MAYCRG,ME
     X    .AND.UNADE%23C1,23C2,MAYCRG,NE
     X    .AND..NCT.PRO%2303,MAYCRG,50E
     X    .AND..NCT.UNADE%4C1,413,MAYCRG,5CE
      RETURN
      END
```

The time required for the manual coding of the information is as follows:

A.	- Land use	114 Man-Hours
B.	- Potential use	64 Man-Hours
C.	- Geology	64 Man-Hours
D.	- Soils	80 Man-Hours

E. -	Topography	80 Man-Hours
F. -	General information for the sheet	96 Man-Hours

Although there are not enough statistics, it has been estimated that the total man-hours required, when the process has been semiautomated by the use of the digital information from automated cartography will be 10% of the time shown before.

CONCLUSION

The work done so far has convinced us that the use of digital equipment for automated cartography is feasible from a technical point of view. From an economical point of view the feasibility depends in great measure upon ourselves, the users. At CETENAL we are trying hard to integrate a system that will allow us to gain significant economies in the use of digital equipment.

We have by no means all our short term plans in a completely satisfactory way. We have made mistakes in the conception of several programs and are also far from having a modular system. However, with the experience we have to date, we are sure to improve our work.

The complete use of our data base may still be years in the future, since for a data base to be useful it must have complete information.

We are processing the information by state but foresee that development will take us at least six years.

Nevertheless, we are encouraged by the versatility the query language has shown and regard it as a very useful tool for planning and development.

BRAZILIAN CARTOGRAPHY

Jose Kleber Fialho
Brazilian Institute of Geography and Statistics

THE BRAZILIAN CARTOGRAPHIC SYSTEM

Owing to continental dimensions of the country, about 8,511,965 sq km, and due to the fact that its territorial expansion and regional development have evolved somewhat unevenly, Brazil has considered it essential to conduct meticulous surveys which, when translated into charts and maps, depict not only the physical aspects of its territory but also the geographical occurrence of its natural resources.

To harmonize the growing demand for charts and maps and other cartographic documents with available resources, the government was led to combine these activities and to create one sole cartographic system, encompassing all governmental and private entities, in order to ensure the proper conditions of efficiency and rationality.

Cartographic activities thus constitute a huge undertaking which demands the use of specialized personnel and equipment. The proper planning and implementation of these activities requires not only the consolidation of efforts and funds of all our domestic cartographic organizations, but also their centralization and coordination.

The cartographic activities of the Brazilian Institute of Geography and Statistics ("Instituto Brasileiro de Geografia e Estatistica," or IBGE) are regulated by Law 5878 of 11th May 1973.

This law establishes the fundamental activities of IBGE which are contained in Article 2, which translates as follows:

> Article 2 -- It is a basic goal of IBGE to provide necessary information and studies of a statistical, geographic, cartographic and demographic character for the knowledge of the physical, economic and social conditions of the country, its particular purpose being the establishment of economic and social plans and the benefit of national security.

Editor's Note: This paper is based on information supplied by the Superintendency of Cartography and elaborated by the Department of Cartography.

The goal described above is further embodied in the article immediately following which reads:

> Article 3 -- For the fulfillment of the basic goal prescribed in Article 2, IBGE will act chiefly in the following areas...
>
> III - surveys, analyses and studies in the fields of statistics, demography, geodetics and cartography;
>
> IV - geodetic and topographic surveys, mapping and other cartographic activities.

Within these guidelines, IBGE participates in the national effort covering research and cartographic production which, according to the established laws, follows a course of natural development.

THE NATIONAL CARTOGRAPHIC SYSTEM

Cartographic activities in Brazil are consistent with one single system -- the National Cartographic System -- which unites all public and private entities whose purpose is the execution of cartographic works or other similar activities which are necessary for the socioeconomic development of the country and the national security.

Mapping in its various forms is processed through the leading cartographic organs of the national system.

a) National Cartographic Organizations:

IBGE - Instituto Brasileiro de Geografia e Estatistica (Brazilian Institute of Geography and Statistics of the Planning Office of the Presidencia)

DSG - Directoria do Servico Geografico (The Geographic Service Administration of the Ministry of the Army)

DHN - Directoria de Hidrografia e Navegacao (Hydrographic and Navigation Administration of the Naval Ministry)

DEPV - Directoria de Eletronica e Protecao ao Voo (Electronics and Flight Protection Administration of the Air Force Ministry)

DNER - Departamento Nacional de Estradas de Rodagem (National Highways Department of the Transportation Ministry)

DNPM - Departamento Nacional de Producao Mineral (National Department of Mineral Production of the Ministry of Mines and Energy)

b) Regional Cartographic Organizations:

SUDENE - Superintendencia do Desenvolvimento do Nordeste (Superintendency for the Development of the Northeast)

SUVALE - Superintendencia de Desenvolvimento do Vale do Sao Francisco (Superintendency for the Development of the Sao Francisco Valley)

SUDAM - Superintendencia de Desenvolvimento da Amazonia (Superintendency for the Development of Amazonia)

SUDECO - Superintendencia de Desenvolvimento do Centro-Oeste (Superintendency for the Development of the Center-West)

SUDESUL - Superintendencia de Desenvolvimento da Regiao Sul (Superintendency for the Development of the South)

These latter organizations participate on a contractual basis in mapping work in accordance with their regional interests.

c) State organizations which take care of the major cartographic necessities within each State.

d) Private Organizations: Enterprises engaged in cartographic projects and similar activities make up the Associacao Nacional de Empresas de Aerofotogrametria - ANEA (National Association of Enterprises engaged in Aerophotogrammetry).

THE CARTOGRAPHIC COMMISSION

Mapping in Brazil is subject to a policy of development, to a basic plan and to permanent coordination.

With this purpose in mind, Decree-Law no. 243 of 28th February 1967 created the Comissao de Cartografia - COCAR (Cartographic Commission) for the purpose of providing this coordination.

COCAR is composed of representatives of official and private organizations. Its function is the coordinated implementation of the plans and projects of the Brazilian Cartographic System. It is accountable to the entities that comprise the National Cartographic System.

THE REPRESENTATION OF THE BRAZILIAN TERRITORIAL SPACE

Brazil uses the following classifications for the plane, graphical and conventional representation of its territory:

1. With respect to the dimensional representation:
   a) planimetics
   b) plane-altimetics
2. With respect to the informative character:
   a) general, when they provide regular information
   b) special, when they record information that is particularly aimed at a single class of users
   c) thematic, when they present one or more specific phenomena; the dimensional representation serves then to situate the theme

Besides these, other cartographic documents such as photo-mosaics, photomaps and orthophotomaps may be presented in conventional form, pictorial map or shaded relief.

Regarding the essentially dynamic aspect of planning and, in order to accompany the technological evolution of cartography, technical norms are developed by the respective official agencies which aim to attain the best standards of precision in the corresponding field of application.

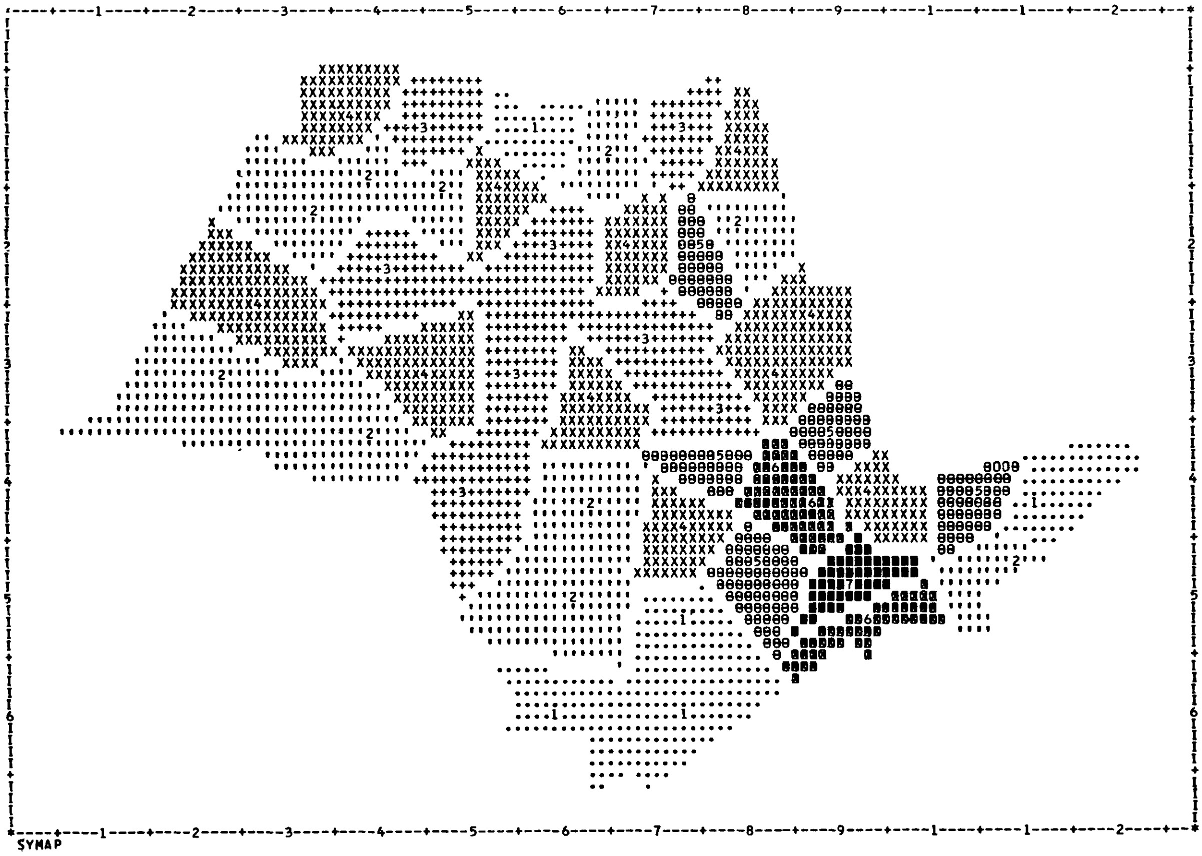
In this respect IBGE establishes the norms pertaining to the Fundamental Geodetic Network, upon which all the cartographic activities of the country are based, as well as those norms which pertain to general maps of scales under 1: 250 000; the Geographic Service Administration, an agency of the Ministry of the Army, is responsible for the norms which regulate the production of the General Maps series, with 1: 250 000 to 1: 25 000 scales; the Hydrographic and Navigation Administration, an agency of the Naval Ministry, is in charge of all nautical charts regardless of scale; and it is the duty of the Electronics and Flight Protection Administration of the Air Force Ministry to establish norms for aeronautical charts.

Such norms were elaborated in accordance with international agreements and conventions ratified by the Brazilian Government.

THE PRESENT SITUATION OF BRAZILIAN CARTOGRAPHY

The cartographic infrastructure of Brazil is a concern of both official and private enterprises; it is the responsibility of IBGE, through the Superintendency of Cartography, in its turn responsible for the Geodetic Plane-Altimetric System of Basic Support.

Our country has a vast geodetic network which covers a considerable area of its territory, extending to the Brazilian frontiers with Uruguay, Argentina, Paraguay, Bolivia, Venezuela, the Guyanas and Surinam where it is connected with the Inter-American Geodetic Network.



```
 SYMAP
TIME =    0.0


FUNDACÃO I.B.G.E. - SUPED - DEGEO - SERVICO DE ATLAS
ESTADO DE SAO PAULO - DENSIDADE DE POPULACAO
PROXIMAL MAP



DATA VALUE EXTREMES ARE          7.56      1023.44



ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
       ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

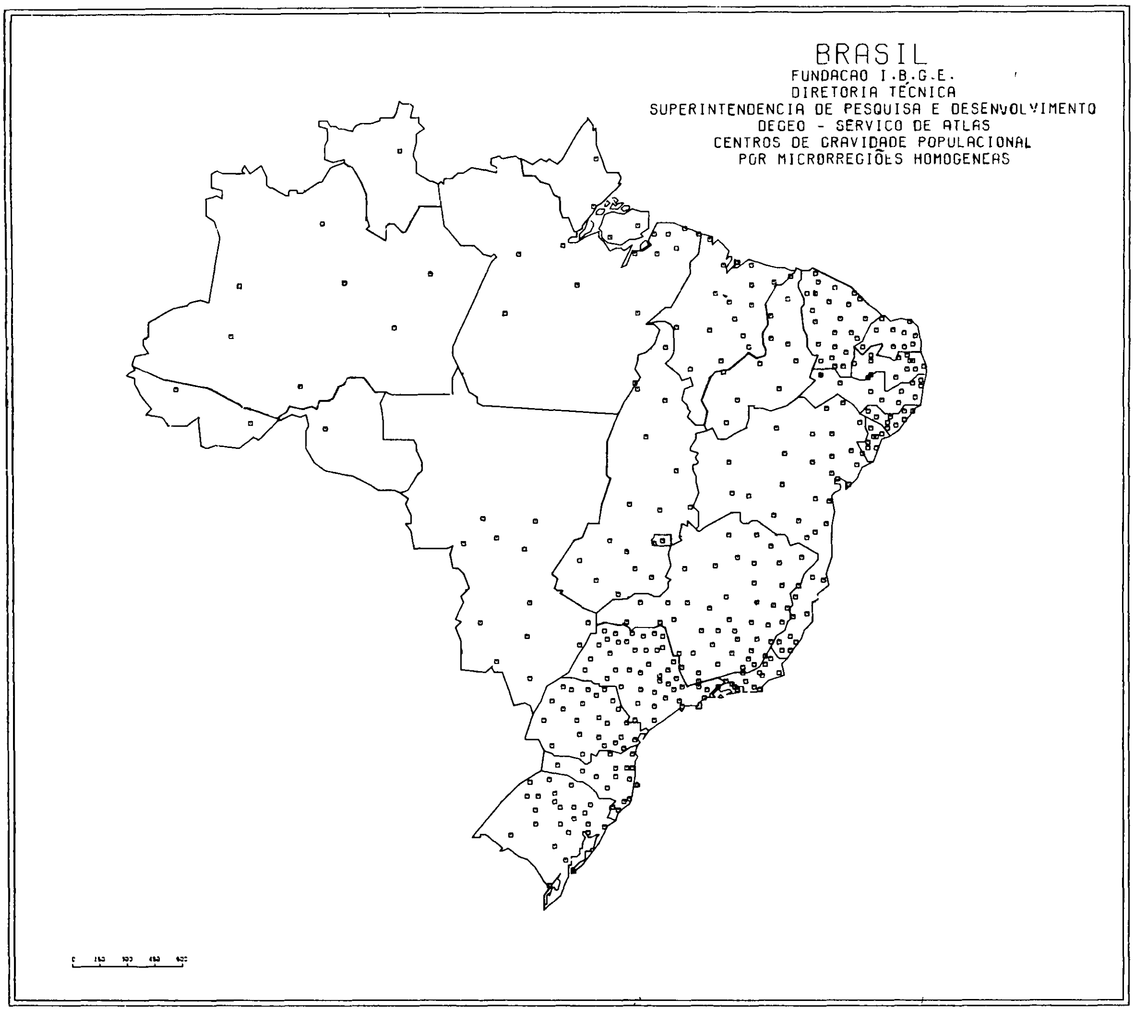
   MINIMUM      7.56      19.64     28.94     38.23     56.82     94.00    279.89
   MAXIMUM     19.64      28.94     38.23     56.82     94.00    279.89   1023.44

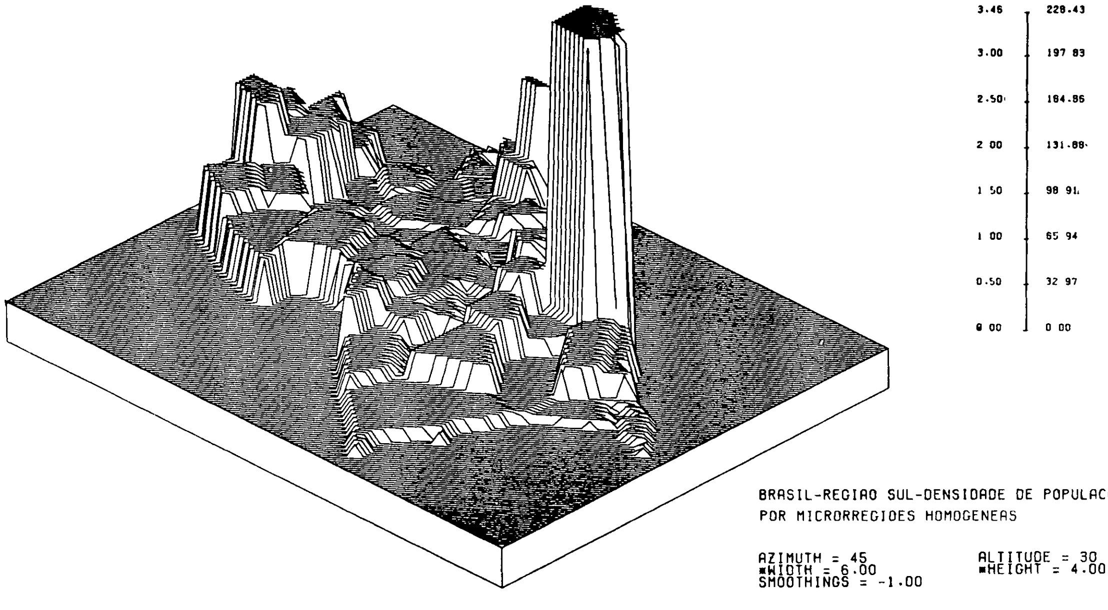
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

               1.19       0.91      0.91      1.83      3.66     18.30     73.19

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL          1         2         3         4         5         6         7
          ======================================================================
           ......... ''''''''' +++++++++ XXXXXXXXX 000000000 ▓▓▓▓▓▓▓▓▓ █████████
           ......... ''''''''' +++++++++ XXXXXXXXX 000000000 ▓▓▓▓▓▓▓▓▓ █████████
  SYMBOLS  ....1.... ''''2'''' ++++3++++ XXXX4XXXX 000050000 ▓▓▓▓6▓▓▓▓ ████7████
           ......... ''''''''' +++++++++ XXXXXXXXX 000000000 ▓▓▓▓▓▓▓▓▓ █████████
           ......... ''''''''' +++++++++ XXXXXXXXX 000000000 ▓▓▓▓▓▓▓▓▓ █████████
          ======================================================================
  FREQ.          5        10         8        11         5         3         1
       1   I..1..I   I''2''I   I++3++I   IXX4XXI   I00500I   I▓▓6▓▓I   I██7██I
       2   I..1..I   I''2''I   I++3++I   IXX4XXI   I00500I   I▓▓6▓▓I
       3   I..1..I   I''2''I   I++3++I   IXX4XXI   I00500I   I▓▓6▓▓I
       4   I..1..I   I''2''I   I++3++I   IXX4XXI   I00500I
       5   I..1..I   I''2''I   I++3++I   IXX4XXI   I00500I
       6             I''2''I   I++3++I   IXX4XXI
       7             I''2''I   I++3++I   IXX4XXI
       8             I''2''I   I++3++I   IXX4XXI
       9             I''2''I             IXX4XXI
      10             I''2''I             IXX4XXI
      11                                 IXX4XXI

TIME =    0.0
```





BRASIL-REGIAO SUL-DENSIDADE DE POPULACAO
POR MICRORREGIOES HOMOGENEAS

AZIMUTH = 45
*WIDTH = 6.00
SMOOTHINGS = -1.00
ALTITUDE = 30
*HEIGHT = 4.00

As to these geodetic plane-altimetric first order surveys, up to December 1974 the total extension of the triangulation network amounted to 28,780 kilometers with 2,952 established vertices; the polygonals comprised 4,379 kilometers with 183 stations and the trilateral, 26 HIRAN and 31 SHIRAN stations, besides the setting up of 31 satellite geodetic stations.

MAPPING

Until a few years ago, Brazil had urgent need of cartographic documentation.

With the growth of a national interest in providing elements that enable planning in the various sectors, and thanks to the evolution of operational techniques, the capability of producing charts and maps has developed considerably in the country. Present map availability is as follows.

MAP SERIES 1: 1 000 000

This series aims to provide a cartographic basis for geographical studies, for economic planning and for the transportation routes in general. It is a document of general use that gives an overall view of considerable areas of our territory. It constitutes, furthermore, a fundamental element for proper execution of studies and analyses and the background for the preparation of various special thematic maps. Another very important application of the series is its use in the development of the Aeronautical Chart of Brazil.

The development of International Maps of the World at 1: 1 000 000, meets standards and agrees with the international conventions established by the United Nations Conference that took place in Bonn.

All mapping up to now has been done at this scale. The series is composed of 46 sheets which were published in 1971/1972 - 2nd edition. Some of them have already been republished, after due updating by means of ERTS and RADAR pictures or by topographic mapping of demographic information, the highway and railway systems, places worthy of records, and man-made works that have been constructed.

GENERAL MAP SERIES

Government and public interests in general have brought about a demand for maps of the various States of Brazil.

In drawing up these maps, norms and specifications are applied in accordance with the interests and the aspects that have to be emphasized, also the scale and the projection are maintained, consistent with the cartographic representation of the area.

According to the particular necessities of each of the 21 States and 4 territories, various scales have been used.

SPECIAL AND THEMATIC MAP SERIES

The Brazilian Government is committed to the task of providing the necessary means for setting up a process of spatial organization of its territory, in order that conditions may exist for its rational occupancy.

Special attention is therefore given to technical and scientific research which supports these specific studies.

The Brazilian Cartographic System cooperates by supplying the bases for the thematic studies utilizing multi-spectral ERTS and RADAR pictures for research work on oceanography, hydrology, geology, soils, etc.

MAP SERIES OF BRAZIL

This item refers to the issue of a series of maps of Brazil composed of: Brazil and its schools, of purely didactical character; Brazil -- physical and political, at 1: 5 000 000 scale; and political maps with basic colors at 1: 2 500 000 scale -- providing an overview of specific aspects of each cartographic element, featuring hydrographic basins, relief units and the artificial works at their updated stage, as well as functional urban regions.

VARIOUS MAP SERIES

Many entities also publish maps for tourism and atlases of many kinds such as general, regional or of a specific State, etc.

The range of cartographic documents described above fulfills the assistance requirements for general needs and for specific planning in the various sectors.

TOPOGRAPHIC MAPPING

The extent of mapped areas in Brazil at 1: 50 000 and 1: 100 000 scales grew to approximately 2,916,750 sq km in December 1974, corresponding to 34.03 percent to its territory. Currently work is being done on about 2,205,000 sq km, 25.7 percent of our territory.

These data are indeed remarkable if the large expanse of territory is taken into consideration.

1. Map Series at 1: 250 000 Scale
   Due to occupancy characteristics and development in the Amazon area, mapping at 1: 250 000 is being considered, however, there are no plans for larger scale mapping in the near future.

2. Map Series at 1: 100 000 Scale
   The goal of this series is to reach areas of average population size where natural resources may need research and exploration. Execution is based on aerophotogrammetric surveys with plane-altimetric terrestrial control, permitting complementary geological studies, land use, etc.

3. Map Series at 1: 50 000 Scale
   This series shows densely populated areas, with a high level of socio-economic development. Its development is based on the same methods used for the 1: 100 000 scale maps.

DATA PROCESSING IN BRAZILIAN CARTOGRAPHY

The considerable progress made in the field of electronic data processing has enabled public and private corporations to participate in this technical-scientific field and introduce the use of computers in their organizations.

This use is not restricted only to the establishment of new equipment but, as a matter of fact, it implies the rationalization of methods and processes put into practice and, thus, the introduction of mechanization or automation must be preceded by feasibility studies that define the targets to be reached and enable the degree of economy attained by its use to be verified.

Brazil, as well as the entities that compose the National Cartographic System, have been making continuous progress in data processing.

In the field of cartography, Brazil has been developing and implementing software projects dealing with aerotriangulation adjustment; it has been processing data obtained in the field for automatic correction and weighting and producing information with far greater speed and accuracy.

The electronic data processing done in cartographic work and in similar activities is utilized by the principal official agencies, such as IBGE, the Geographic Service Administration of the Army, the Electronics and Flight Protection Administration of the Air Force, and private enterprises affiliated with the National Association of Enterprises and engaged in aerophotogrammetry.

We shall focus below on the principal projects, uses and versions developed in the field of Brazilian cartography.

THE PLANNING OFFICE OF THE PRESIDENCY - IBGE

With due consideration given to the functions of the IBGE -- which operates in the fields of geodetics and topography, cartography and geography -- data processing is being put into practice at the level of field and office operations not only for general cartography, but also for thematic purposes.

As to geodetics and topography, the programs are carried out so as to provide Brazil with fundamental geodetic support, especially where priority plans have been established.

THE SPATIAL GEODETIC PROJECT

The spatial geodetic project makes use of four programs: one deals with estimates used in tracking satellites; the other three deal with the reduction of data collection at the stations by the geoceiver, which supplies the values of λ and H of these stations.

1. Estimates are provided through the calculation of the time of passage (hours and minutes) of the satellite, its angles of elevation, propagation and delay of the transmissions, etc. These data are calculated for each satellite in a single operation. This program allows the calculation of 90 day estimates for six stations and up to nine satellites.

2. The Program for Reduction of Doppler Data (consisting of three programs).

   a) The first has as its end reformulating the precise ephemerides received at the NWL, in such a manner that they are compatible with the Solution Program (see below).

   b) The second is for the purpose of converting the collected data in separate blocks per passage (orbit) to be used as input in the Solution Program.

   c) The third is the Solution Program which is designed to execute the mathematic processing necessary to calculate the coordinates of the stations in order to transform them into the reference system for our use. These programs were supplied by the U.S. Defense Mapping Agency Topographic Center (DMATC), having been converted from the UNIVAC 1108 system to our IBM/370 system by technicians of both DMATC and IBGE.

3. The program of Geometric Geodetics performs the planimetric adjustment of first order triangulation nets and polygonal geodetic lines. It is the outcome of the original HAVOC program, converted into the IBM/370 system. This program performs, by means of coordinates, block adjustment of the hook-up and triangulation net, as well as of the polygonal lines, in separate jobs.

In the area of geography, the programs have been developed along lines that help forming a data deck by means of processing of statistical, geographic and cartographic data; the aim is to use this data deck for the preparation of digitized cartographic bases for the Nation, for micro and macro regions, States and provinces in spatial programs of thematic geographic cartography.

Another objective is the utilization of the transformation of geographic coordinates into systems of appropriate projections, contour points, cities, geographic centers, centers of gravitation of the population of the above mentioned territorial units and, furthermore, the amplification of automated cartographic equipment, for digitization of geocartographic data and the execution of plotter outputs, directly for reproduction, by the system of separation of colors, recording in scribecoats and peal coats.

PROJECTS OF THEMATIC AND STATISTICAL MAPS, CARTOGRAMS AND GRAPHICS

Four programs are utilized.

1. SYMAP version 5 (Laboratory for Computer Graphics and Spatial Analysis, Harvard University) for studies and analyses of spatial facts and phenomena and related qualitative and quantitative data.
2. SYMVU version 1 (from the same source) for the production of tridimensional plots for studies of geography and the computation of quantitative facts based on statistical data.
3. BASIC SOFTWARE (from California Computer) utilized for subroutines of control of the Calcomp Graphic System.
4. FUNCTIONAL SOFTWARE (from the same company) for the making of graphs, cartograms and all types of unidimensional plots.

A Calcomp Plotter is used for automated cartography with a 7,000 system. Cartographic programs are being developed in aerotriangulation adjustment; the following have already been installed:

1. The transformation of coordinates and inverse - DECART (Jozias Ribamar) which enables geographic or planorectangle networks to be calculated at the desired scale.
2. Timebelt Change - DECART (Jozias Ribamar) permits the noting of sheets with meridians of distinct origin and in opposite directions.
3. Convergence Calculation - DECART (Jozias Ribamar) is used in subsidiary calculations intended for the elaboration of topographic sheets.
4. Condensation and confirmation of models - DECART (Jozias Ribamar) used to check instrumental and calculated coordinates in photogrammetric models.
5. Band adjustment (Coast and Geodetic Surveys, Schut, Ackerman) allows the calculation of aerotriangulation by polynomial, iterative methods, etc., without conditioning the number of bands of models or the quantity and the positioning of points of support.
6. Definition of the perspective centers (Inter American Geodetic Survey, Santoro, McKenzie, Ackerman) using methods of intersection, direct measuring of photogrammetric models for the determination of the perspective centers.
7. Semi-analytic triangulation (McKenzie, Ackerman) a process on a fixed basis, either variable or an oscillating perspective center.
8. Block adjustment (Inter American Geodetic Survey, Schut, McKenzie, Ackerman) with versions that permit the adjustment of large blocks of aerotriangulation with even over 1,500 models.
9. Analytic aerotriangulation (Coast and Geodetic Survey, Schut, McKenzie) for the orientation, formation and the calculation and the connecting of photogrammetric models.
10. Calculation of Projections - DECART (Jozias Ribamar) for generating network of UTM, LAMBERT, Polyconic and Geocentric coordinates.

THE AIR FORCE MINISTRY: ELECTRONICS AND FLIGHT PROTECTION ADMINISTRATION

This agency concentrates on the installation and development of programs that furnish precise and trustworthy data of great importance for aeronautical charts such as: radio-navigation charts; maps of the terminal area; charts for instrument landing approach, landing charts; traffic charts; charts for radar landing approach; climb charts; obstacles charts, and aeronautical charts at 1: 1 000 000 scale.

Secondly, this agency serves the Brazilian cartographic community in such areas as aeronautical information as well as general cartographic information.

The projects already set up and in process of development comprise:

The Cartographic Cadaster - TRC-03 for the purpose of giving access, in simple and practical form, to pertinent information, available not only for airfields and radio-aids, but also any geographic and geodetic cartographic points which may interest flight protection.

1. Transformation of the TM (UTM, LTM, GAUSS - TARDI, GAUSS - KRUEGER) coordinates into geographic-TR-01.
2. The generation of TM coordinate tables in any subsystem (UTM, LTM, etc.) serving for the supply of coordinates for the corners of the TRC-02 map sheets.
3. Systematic articulation of the map sheets beginning at the "millionth" (1: 1 000 000) and going to the "half-millionth" (1: 500 000) in multiple divisions of 9 inches (sheet 1: 500) -- subroutine AIDT.
4. The generation of tables of plane coordinates for plotting the projection coordinatography following Lambert, with two standard-parallels at any scale and magnitude - TRC-04.
5. Computation of airways, terminal areas, coordinates of position controls and flight procedure, following normal geodetic behavior (great circle sailing) MAP.
6. Distribution of issues of all publications with computerized addressing, AIS.
7. Polygonal calculation in geodetic long lines, in accordance with the Sodano and Rainsford formulas - TOP.
8. Doppler positioning calculation by means of instruments such as: MARCONI and MAGNAVOX 702 - HP - DOPSAT.
9. Calculation of Datum Shifts parameters.
10. Aerotriangulation with independent models - Schut OSU - McKenzie and Ackerman adapted to the /360-40.

Currently under development are the following:

1. The Cadaster of Computerized Airfields.
2. The generating of punched tape for the printing of publications by photocomposer.

3. The edition of the booklet "MANAE" -- (Manual of Assistance to Aerial Navigation - ENROUTE), elements provided by the Cadaster of Airfields through punched tape for printing in photocomposer.
4. Multipurpose technical integrated Cadaster of airfields and vicinities.
5. Aerosurvey Data Deck comprising: the Cadaster of Airfields and the Cadaster of Aerophotography.

THE NATIONAL ASSOCIATION OF ENTERPRISES ENGAGED IN AEROPHOTOGRAMMETRY (ANEA)

Our purpose here is to describe the principal applications of the electronic data processing now in current use among the enterprises affiliated to the ANEA and applied to cartographic works and similar activities.

Considering the large number of enterprises and the diversity of projects currently being undertaken, the subjects will be discussed in general.

BAND AND BLOCK AEROTRIANGULATION

Programs installed in data processing centers which serve the enterprises:

1. Determination of perspective centers (McKenzie).
2. Band and block adjustment (McKenzie).
3. Band formation with independent models (Schut).
4. Band formation with independent photos (Schut).
5. Band and block adjustment, with analogically, semi-analytically and analytically formed bands (Schut).
6. Block formation and adjustment with independent models (Ackerman).

HIGHWAY PROJECTS

Programs installed in data processing companies or in engineering consultant firms:

1. Directrix calculation, plane and profile.
2. Transverse section calculation, digitized in restituting apparatus.
3. Volume calculation of excavated cuts and fill-ups.
4. Land distribution calculation by the Broockner method.
5. Projected highway costs calculation.
6. Offsets calculation covering also other elements for highway locating.

URBAN AND RURAL, TECHNICAL AND FISCAL CADASTER

Programs installed in data processing firms:

1. The calculation of thoroughfare sections facing buildings and real properties, starting with the digitization of stereoscopic models of existing maps or of orthophotomaps.
2. Automatic plotting of property boundaries and any other visible element which can be identified in the stereoscopic models.
3. Field complementary data collecting directly in the form of punched cards for use by automatic plotters.
4. Calculation of the sale value of properties and the cost of public utilities for establishing rate and tax values.

HORIZONTAL AND VERTICAL, GEODETIC AND TOPOGRAPHIC NETWORKS

Programs set up in firms engaged in data processing or in table computers which belong to the aerophotogrammatic and topographic firms themselves.

1. Compensation calculation of trilateral, polygonal and triangulation networks.
2. Rear and forward intersections calculation, as well as of excentric sightings in order to determine the supplementary points of support.
3. Compensation calculation of the geometric leveling networks.
4. Trigonometric levelings calculation.
5. Barometric levelings calculation.
6. Ellipsoidal coordinates calculation, of the tracking satellite stations by geodetic receivers exploring the Doppler effect.

Appendixes

APPENDIX I
AUTO-CARTO II STAFF AND COMMITTEES

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Special Thanks to IBM Corporation, Saxon Business Machines and Trans World Airlines.

APPENDIX II

INTERNATIONAL SYMPOSIUM
ON
COMPUTER-ASSISTED CARTOGRAPHY

(Sept. 21-25, 1975)

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