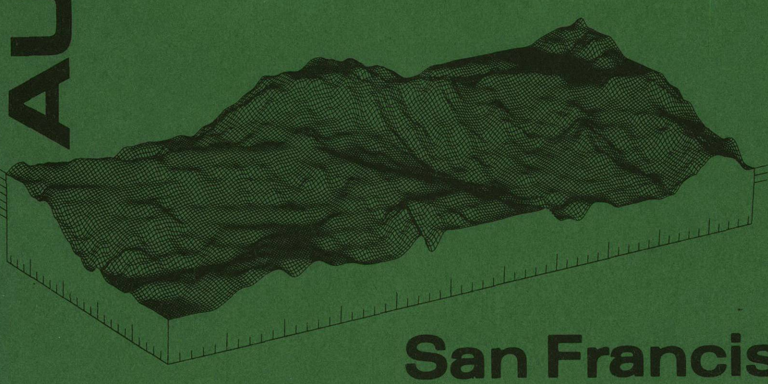
AUTO CARTO III

JANUARY -- 1978

International Symposium on Computer-Assisted Cartography



San Francisco

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AUTO-CARTO III

This third conference on automation in cartography was sponsored by the American Congress on Surveying and Mapping in cooperation with the U.S. Geological Survey. It was also conducted with the full cooperation of the American Society of Photogrammetry.

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Final editing and assembly was done by Wilbur Greenup. His tireless efforts are greatly appreciated.

I would also once more like to offer my special thanks to the entire Committee for their splendid work.

James E. Chamberlain

James E. Chamberlain
Chairman

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AUTO-CARTO III

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OPENING REMARKS

MR. JAMES E. CHAMBERLAIN, CONFERENCE CHAIRMAN: Good morning, ladies and gentlemen. We are pleased and happy to see so many people for the opening sessions of AUTO CARTO III, the Third International Symposium on Computer-Assisted Cartography. The two previous meetings were held on the East Coast, and were sponsored by the Cartography Division of the American Congress on Surveying and Mapping. That proved to be highly successful, and we have been very encouraged with the response that we have received thus far to the West Coast version of AUTO CARTO III. We are happy to report that the meeting looks to be a complete success. Our registration is higher than we had anticipated, and the exhibits have proved to be the best we have ever had, and we are very encouraged by all this. I would like to say at this time that this meeting is a success because of the hard work of a good many people that a lot of you here probably may not even see during the meeting, but they have been involved for a year in the preparation and organization of this meeting, and I think they have done an outstanding job. If I went through the list to name these people and give them their due recognition it would consume too much time. But they have worked long and hard, and they are dedicated to the complete success of the meeting and to making your stay with us here an enjoyable one.

I would like to introduce these people at the head table now and ask them to say a few words of welcome, beginning with Mr. Jon Leverenz, who is the President-Elect of the American Congress on Surveying and Mapping. Jon is very active in the automated cartography program here, and has been for years. He is associated with Rand McNally in Chicago. It is a real pleasure, Jon, to have you with us. Would you like to say a few words for ACSM this morning?

MR. JON M. LEVERENZ: Thank you, Jim. On behalf of the American Congress on Surveying and Mapping I would like to extend a hearty welcome to each one of you today for what I would hope would be a very lively and thought-provoking week. A number of years ago--I will make these remarks short, but I think there are some good things to be said about this conference--a number of years ago it seemed that the time had come for a conference that would focus on automated cartography. The American Congress on Surveying and Mapping, the Cartography Division of that group, planned and organized, with the USGS, AUTO CARTO I; and I think many of you were here at that time. Following on its heels was AUTO CARTO II. Now we have come to AUTO CARTO III. Having attended each one of these, I think I have always gone away rather inspired by the information that I have gained and by the way in which the AUTO CARTO Conferences have been handled. I think the fact that there has been this continuity and this need shown and this tremendous turnout in each one of these is because, first of all, I think the papers -- and I have attended all of the AUTO CARTO Conferences -- the papers and panels were good. The format for the delivery of the papers and for the interchange of ideas from the audience to the panel members was good. That format worked.

The third thing, as I recall, I think there was always a lot of uninhibited questioning from the audience. In fact, it became very thought provoking, and it was very interesting. The fourth thing I think is obvious from the many people that I keep seeing showing up here is that the people that attended, both the speakers and the people listening and interacting in the audience, went away from the Conference obviously with new knowledge and a good update on their AUTO CARTO III knowledge. I think and I hope because of this continuity and this organization we see developing here that this week will be no different than AUTO CARTO II and I. We will all, I think, go away with an increased knowledge of the AUTO CARTO field. So, again, I want to extend on behalf of ACSM a very hearty welcome to everyone, and I hope you will have a good and lively week. Thank you. (Applause.)

MR. CHAMBERLAIN: Thank you, Jon. I would like to acknowledge now also that although this is a meeting of the American Congress on Surveying and Mapping and the US Geological Survey -- It is a co-sponsored meeting -- it would not have been a success I am sure without the complete cooperation of the American Society of Photogrammetry. They have been a big help to us in every way, in organizing and conducting this meeting. It is a pleasure now to introduce to you the current President of the American Society of Photogrammetry, Dr. Vern Cartwright. Vern?

DR. VERN W. CARTWRIGHT: Thank you, Jim. On behalf of the American Society of Photogrammetry, I wish to welcome you all to San Francisco. How many are from outside San Francisco? That is pretty good. Last year this was going to be a great desert if we did not get any rain this year. So, please, when you go out in the streets, smile at the San Franciscans and say, "You've got beautiful weather here." (Laughter.) But we love it this way. You know, we have a change in the weather; we also have a change in technology. In the next decade there will be more changes in photogrammetry and surveying, I predict, than there will be in our lifetime. This is brought about by, in the photogrammetric field, by interactive graphics. We have new tools. Whether you call it data banks, computer cartography, data management systems, data systems -- anything you want to call it -- it is still a matter of semantics, and it is still making maps.

Sometimes you tie demographic data to a geographic basis, which in a way gets outside of map making. In map making you have, for instance, a photogrammetric base, you might have a land survey base, and then you add the different data levels of information. You can add thousands of data levels of information. You can sit down with a little computer, and out pops the information on just the data levels you want to the scale. It is tremendous technology. Within surveying, things are going to be changing in what I would say a drastic manner. I predicted, along with Charles Andrea, that it is going to revolutionize surveying within the next decade. This is all going to be brought about by the NAVSTAR geographic positioning satellite. There will be 24 of these satellites. There are about three up there now. But in 1984 there will be 24 of them up there at 20,185 kilometers. What these satellites will do, they will give us the X, Y and Z positioning to within inches. So, what will be the survey of the future? Will he carry a little black box around, put it out, push a button and get the X-Y position, feed the data mag tape information from that into a computer, have all the controls laid out? The technology is really here.

I can envision in the police department, for instance -- we came up with a system using digital data banks to show the traffic people the conditions that may exist. Say, for instance, there was an accident at Mason and Eddy. Up pops a map on the screen, say on your CRT. With this Telstar information satellite, you will have the police cars, all of the emergency vehicles on this digital map placed in their geographic positions. As they move you can see it, you can see the equipment. This would apply as well to fighting fires and disasters. So, in my opinion and in the opinion of many, this black box revolution is going to start taking place in 1984 when the NAVSTAR positioning satellite is going to revolutionize a lot of our areas. We have a change and challenge in our technology, and I am glad you are all here. We are going to see state-of-the-art conditions. Thank you very much. (Applause.)

MR. CHAMBERLAIN: Thank you, Vern. Before introducing the next speaker here, I would like to take a minute to recognize Dean Edson, who is on my immediate left. Dean is our Program Chairman and Chairman of AUTO CARTO I. He has been involved in digital cartography for a good many years. Dean has worked tirelessly to ensure the success of this meeting. So you will be seeing a lot more of Dean throughout the week. But since he is not speaking to you right away this morning, I just wanted to acknowledge that and give him publicly my wholehearted thanks. Thank you, Dean.

Now, I would like to introduce the current Chairman of the Cartography Division of the American Congress on Surveying and Mapping, and the one who is principally responsible for getting this meeting under way. It was just a little over a year ago that Dean and I met with Dr. Morrison here in San Francisco, and the seed was planted for this particular meeting. I am not sure when Dean and I agreed to organize this meeting when we really realized that all this was involved. It has been a long year of hard work, but we really have enjoyed it. I am sure -- and I cannot speak for Dean, but I have learned an awful lot about the field of automated cartography in just organizing and associating with so many of these very fine people.

Dr. Morrison, the current Chairman of the Cartography Division of the American Congress on Surveying and Mapping. Joel?

DR. JOEL MORRISON: After that introduction, I feel that I should limit my remarks to thanking the organizing committee, because they did most of the work--all of the work, let us put it that way.

On behalf of the Cartography Division of the American Congress on Surveying and Mapping, I would like to welcome you to this, our third in a continuing series of international symposia on computer-assisted cartography. It was in December of 1974, a little over three years ago, that the American Congress on Surveying and Mapping, together with the United States Geological Survey, initiated this series of symposia at the U.S. Geological Survey National Center in Reston, Virginia. In spite of our current preference for the term "computer-assisted cartography," the nickname, "AUTO-CARTO" series quickly took hold.

People have eagerly awaited each successive symposium. The first symposium highlighted the technical progress in computer-assisted cartography, with general attention being paid to what could be done and what was possible. Following that successful symposium, the United States Census Bureau teamed with the American Congress on Surveying and Mapping, and staged AUTO-CARTO II, again at the United States Geological Survey National Center in Reston. AUTO-CARTO II highlighted graphic design and the map reader's reaction to the computer production of maps. We all remember the huge success of the AUTO-CARTO II symposium. Most of us have been repeatedly asked when and where AUTO-CARTO III would take place. Fortunately again, the United States Geological Survey agreed to co-sponsor with the American Congress on Surveying and Mapping this third symposia, and the site was selected in San Francisco.

The theme of this symposium could not be more apropos to my way of thinking: Let's put computer-assisted cartography to work. The "gee whiz" days of computer-assisted cartography are in the past. A few years ago one could reasonably expect major developments to take place in rather rapid succession. Today, the routine aspects of computer-assisted cartography are evident, and will remain so. Implementation problems and data management problems are not insignificant. Economic considerations for small users are extremely important.

Computer-assisted cartography is an established fact of life for most of us today. It probably is true that many of us still tend to think initially in terms of manual cartographic production, and we still seek the map as output. But with each succeeding year we feel more comfortable with the transitions in our thought processes to computer-assisted terms. It is not unlike the coming conversion to the metric system where the thermostat set at 20 degrees means comfort, where the home is seven kilometers from the office, or where 15 milliliters replaces one tablespoon.

For the cartographer, the conventional map produced with computer assistance can be hard copy output. A computerized relief model can be called a DTM, or a photohead can replace a scriber. Transitions are usually difficult, and they take time. The move from manual cartography to computer-assisted cartography is proving to be unusually difficult because of the rapid speed of the transition, the introduction of jargon, and because of the almost complete change in technology utilized by computer-assisted production. We are not through this transition yet. That is why the theme of AUTO-CARTO III is so poignant to us today. We know we can produce maps with computer assistance that not only meet established standards of accuracy and visual effectiveness, but also that are economically viable. Our job today is to translate what can be done technologically and economically into common practice. Computer assisted cartography must become synonymous with the mainstream of cartography so that the adjective "computer-assisted" can be dropped. This is not an easy task, and it is not necessarily as fun or as exciting as it once was.

I hope that each of you during this coming week, in addition to gaining information on recent developments pointing in future directions, gains a greater sense of feeling "at ease" with computer-assisted cartography. You must question the discussants. We need honest appraisals of what does not work as well as the glowing reports of what does work. We need to know the inefficiencies and bugs of a system as well as its efficiencies and selling points. We need to be precise in our terminology and not create needless jargon. These things, I believe, will help to maximize the success of this conference, and it depends to a large extent on each of you in your willingness to ask questions that you have had in the back of your mind, or your willingness to admit shortcomings of your experiences with computer-assisted cartography.

Finally, I must acknowledge the interest expressed by the American Society of Photogrammetry. Increasingly, a welcome commonality of interest among photogrammetrists, people interested in remote sensing, and cartographers is in evidence. This symposium welcomes the addition of the cooperation of the American Society of Photogrammetry in seeking to satisfy this interest.

I bid you all welcome to AUTO-CARTO III. Have an enlightening and enjoyable week. Thank you. (Applause.)

REVIEW OF TECHNOLOGY INTRODUCED AND DISCUSSED AT AUTO CARTO I AND II

MR. DEAN EDSON: The object of AUTO CARTO III, as has been the case in AUTO CARTO I and II, is transfer of knowledge. Certainly one of the fitting ways to start a meeting like this is to review the essence of much of the discussion, much of the technology that was introduced and discussed at previous meetings. I think that we need this refreshing look backwards in order to better appreciate and understand what we are going to be exposed to the remainder of the meeting this week.

To do this I have selected a person who simply excels in qualifications regarding this review of technology, and that is Dr. Bob Aangeenbrug. Dr. Aangeenbrug is presently a geographer at the University of Kansas, and is a super member of ACSM. I say that because he has been extremely active. Dr. Aangeenbrug received his doctorate in cartography from the University of Wisconsin in 1965, and is a Ford Fellow in urban studies and is a past president of Urban and Regional Information Systems Assoication. He was also the chairman of AUTO CARTO II, held two or three years ago in Reston, Virginia, co-sponored by the Census Bureau. Bob, I think with that we will hear from you, and hopefully be super smart and be able to pick up from where we left off a couple years ago and forge on. Bob? (Applause.)

AUTOMATION AND CARTOGRAPHY: A PROGRESS REPORT 1974-1977

DR. ROBERT AANGEENBRUG: Thank you, Dean. It has been a couple of years since the last AUTO-CARTO conference, and some of us are still slightly exhausted from the experiences. There is little question about the importance of these kinds of experiences. Something rather caught my attention as I listened to Joel Morrison. He said that the time perhaps is past for what we may call the cult of "what was invented here works better than that invented any other place, and we can transfer our achievements to every other place". Objectivity is a difficult thing. One of the things I liked about AUTO-CARTO I, and one of the things that convinced me to consider holding another of these conferences, was the kind of atmosphere of give and take and the seriousness of our purpose.

I came back to Washington in the early 1970's out of an atmosphere of revolution that was foisted on us at the University of Kansas in the late 1960's and early 1970's. I was not particularly impressed with the establishment, but I was taught a very quick lesson at AUTO-CARTO I about the massive accomplishments in the federal sector. Literally (quite honestly) for three or four years I pretended that these were not really of any consequence, and, moreover, these feds--particularly the military types--were wasting the taxpayer's money. That was not at all the case. It was a rather humbling experience in part taught to me by the likes of Edson and Schmidt, who involved me in the first AUTO-CARTO conference. An interesting thing in reading over the proceedings was that the reasons why we held AUTO-CARTO I and II, to a considerable extent, were the same. Both Radlinsky and Overstreet stated that essentially we were here to learn about the experience of, say, a large agency's point of view.

First of all, the production demands in cartography require automation. Second, there is a desire for currency, and it is an extremely important one. If we do not do it, I can assure you the television people will take over cartography, if they have not already. At least that was my interpretation. And, by George, if you look at the Sears-Roebuck ad which shows a wall full of little snap-in cassettes for hundreds of computer games--there is a large maket and the retail industry is telling me that they can sell computer graphics and cartography, without substantial input from cartographers. Another thing is, at AUTO-CARTO I I was reminded of the fact that I am not really a cartographer. I was trained at Wisconsin in geography, although I did have some cartographic training, that, according to Robinson, may or may not have sunk in--(laughter). And it did not really matter to me because, for instance, like my colleague, Duane Marble, I was not really interested in cartography. It was a technique that you needed if you studied certain kinds of spatial allocation and/or urban information systems problems. Some of us got involved in automation because the cartographers did not want to get involved. I think that is still occurring. I like the interdisciplinary nature as well as the open-endedness of the mix of designers, academic, and "real" users.

Currency is still a problem for us. We will still have people flashing around new hardware and software which they are either selling us or giving away, while claiming they have the ultimate systems which will solve all your problems with no transferability problems. Currency is important in the public sector, there is no question about that. Instant weather mapping will probably be demanded by the public before long. We now actually find among some of our students in the introductory geography courses an understanding of what a cold front is and what it looks like from the air. Perhaps in four or five years they will be expecting this stuff and perhaps might even understand some of the mathematical attributes of such surfaces. Maybe you do not believe that, but some of our students seem to be looking at the world differently because of graphic images they have seen on TV. That was not so clear to us in AUTO-CARTO I and II.

Another thing that we did learn and we knew about in the previous conferences were the problems we now face with scarce resources. Such resources are viewed in our domain primarily from the point of view that "this great nation cannot do everything, this great nation can't fight all these wars, invent this, and cure all diseases and solve all of humanity's problems". But even as we have become a more introspective society, we are still facing serious problems. For example, something which occupies a lot of the legislators' time is, how to prevent the medical profession from absorbing the entire GNP. The AMA currently appears more threatening in the eyes of some folks than even some of the military-type spenders in the Pentagon. That is kind of good, and it is kind of interesting. The use of graphics in health problems is something that we must be involved in and we have been remiss. The next AUTO-CARTO conference had better discuss some different scalar operators so we can do the cartography of the inside of a lung. I can hear some of the cartographers saying why they do not want to be interested. But the technology and the solution to the problem can in part be contributed to by the likes of yourselves and we can certainly use the results.

Resources are also scarce because the number of educated human beings in this society is limited. Rostow and others, when they talked about the development strategies of the great countries, primarily in the Western world, more or less came to the conclusion that the ultimate society as they understood it was one that was market-oriented, that the real strength of this country is in its market economy based on a skilled labor force and an educated public. The desperation sensed in Saudi Arabia or in a small underdeveloped country is primarily due to a lack of human resources. We are beginning to equip ourselves with technology. Our tools are not half as important as our knowledge about their proper use and utility within the national societal framework. I hope that the return of mathematics as an accepted attribute of a real college degree will return to our universities. Because if you are going to be involved in automation of cartography any longer and really understand it and really use it, you may have to re-evaluate your capacity to use the technology. This may mean you may have to go back to school. Because of this scarcity problem in our society and in others, more of us may actually have to be employed longer and know more in order to assist our own society with its complex problems.

We have developed a need, I suppose, for high-speed and direct dissemination of maps. This was pointed out in both AUTO-CARTO I and II. We are creating something that has been called at various times the virtual map--that is, the map that exists primarily in machine storage and is rarely used as paper copy. No one is going to worry about shrinkage of paper or heat, etc. I think I had several lectures on that, including examples and fieldwork. That may be irrelevant for virtual maps. Of course we are now going to have some new problems. Can you store something electronically and really understand the difficulties you have when you conflate that map with its previous states? A number of other types of difficult problems are going to raise their heads. The virtual map is not going to be a solution to all problems, but it is likely to determine to a great extent how we will be seeing the world. I do not think we will have the end of paper maps, but they are certainly not going to represent the majority of maps or pictures that may be in existence a few years hence.

I was quite impressed in both previous conferences, and I am sure I will be here, with the extensive long-range planning that took place, particularly in several of the larger federal agencies--DMA, USGS, NOAA, Bureau of the Census, CIA, and what-have-you. Obviously some bureaucrats took some risks, spent some money, and did some pretty substantive work in trying to anticipate the need for essentially automated mapping on a continuing basis. I am not really sure whether we can meet those needs. Maybe in the 1980's. I do not think we are ready yet to have machine-readable topographic mapping delivered to every civic agency in every county of the United States and have anyone actually use it. We are still at the stage that these experimental maps are still carried around, in a manner of speaking, in the same flashy way we carried the printout under our arms in the early days of computing, for instance. We are beginning also to address the extended product notion to the variable needs for maps. We are talking about, say, a map that can be rescaled. Its contents can be screened, re-evaluated, added to and deleted from. In a manner of speaking, we are going to demand and develop some massive kinds of overlay systems. This has been anticipated in the previous two conferences, and we hope to find out what progress is being made.

Part of this demand is tied to the need for the facilitation of revision From my perspective at AUTO-CARTO II, I learned of the experiences of the urban mapping folks who had had the benefit or the plague, depending on the point of view, of having to live with the GBF/DIME files or the super geographic base files somebody else gave them. The utility of these files was very marginal because the maps could not be revised very easily. Although intellectually and in terms of some specific experiences they were and could be useful, often they were quickly put on a shelf. That reminds me of the planning reports produced for urban agencies between the 1950's and 1970's, which were made from essentially the same format; you change a few numbers and names, and practically the same comprehensive plan for 1975, 1980, and 1985 is produced by XX and Associates for any city.

I think we are now beginning to re-think what kind of maps we will make available, for example, to urban users. I am not really sure what we are going to do about having to develop, or even think of, engineering accuracy types of maps that the urban folks that are thinking about for cadastral mapping may want. Certainly it is not the kind of stuff I am going to be able to do on my little old "xyz" mini computer. It simply will not do it. In fact, even some of my students are getting bored with the interactive graphics we are doing in our small minis. The demand has changed for more complex mapping systems even in the classroom. This was pointed out, at least in part, at the previous conferences.

Reduction of errors is, of course, something that really concerns us.

Something I learned when I worked at the Bureau of Census and dealt with the urban environment is that the thing most politicians ask first when they get a map or a booklet with numbers about their city is: "Is the thing accurate in terms of my interests or will it emabrrass me or make my city look bad?" They will look at a specific item on that urban map or on the statistical table. The obsession of the public with apparent or real errors, or accuracy, is going to increase as these kinds of products enter public domain in larger numbers. Their expectations are going to be that your maps are, in fact, accurate. This problem of reduction of errors was in part addressed by some of the papers on statistical mapping held in the last conference, and I think we will probably have to re-address ourselves to these. Another reason for holding these conferences is to examine some of the lessons we learned about basic map design. The designer must be in charge, Robinson argued, and the bad map is not primarily the result of the technician's error. One thing I want to point out: no cartographer, pseudocartographer, or geographer can get away with blaming the software, the hardware, or even good old Ray Boyle. If you do not do your homework and do not understand the basic mathematics and the technical aspect of a computer mapping and cannot get someone who can translate for you, please do not put the blame on the technician. As the designer you are responsible in every sense of the word. I was a little frightened by both Robinson and Jenks, as I sometimes am--not for long, as you can be assured. But they kept assuring me and the audience that the cartographer has to be in charge of the map message. Now, we do not know a heck of a lot about learning models. One of the things that rather humbled me was to listen to some of these speakers at the previous two conferences telling us that they do not really know how the human mind operates, or let alone how you would make a mathematical model out of it. Part of these digital maps and part of the design problems we face really have to do with our understanding or our ability to preduct the perceptual consequences of the image we are processing or representing? The answer is, "We don't really know very much." The standard cartographic texts are useful, but they can hardly be used by themselves to address that question.

Obviously, the designer has not really crept into cartography quite as far as he or she should have. Simplicity is a recommendation. And, in fact, the thing the American cartographer is always telling you is that "it's got to be simple". It does have to be simple, especially in the thematic maps. I come from an environment where you put everything on the map, sometimes including stuff you wish was not there. But, nonetheless, I am not ready to really buy the presumption that cartographers, for that matter artists or propagandists in central government, are always able to tell you what to think, or let alone, <u>how</u> to think. That was kind of an unresolved controversy left over from AUTO-CARTO II, and probably a good one to have. Obviously, the cartographers have a great deal of design wisdom. But unless they design maps that are useful for urban analysts or the medical profession or somebody else, others will make their own. After all, Howard Fischer wasn't a cartographer but he got something started. In other words, we may continue to see an increasing number of maps produced by non-cartographers.

Speed of production is, of course, going to cause a real problem for us. It is usually our first concern and, as Dean Edson pointed out in the last conference, it is one of the reasons why USGS is seriously thinking and perhaps has already completed a system of digital cartographic data bases to replace the manually developed series. Speed of consumption will then be our next problem. Are you really ready to produce these many maps? Do you think the public will like what they see? I suppose it is an old rehash of "garbage in-garbage out". But, nonetheless, one of the things that led to AUTO-CARTO II was partially Vince Barabba's concern for the feedback he got when he gave his flashy presentations. He came back home wondering why the reaction of the public was not entirely favorable. They did not like some of the maps. They were expensive, and they sold many copies. But many cartographers and many urban analysts did not understand what they meant. The rate of comsumption is going to increase whether we are involved or not. Somebody will produce some kind of virtual image, and at an increasing rate. Their utility will not be decided primarily by the inhabitants of this room. Hopefully, we will be contributing.

The statistical utility of these maps is something we need to further examine. Kruskal was not really too impressed with the research that has been carried on within the cartographic profession. In the proceedings he indicated that the real basic research in how we measure statistical properties of maps is really fairly marginal. Not enough research has been done. I would like to remind you that basic research is still very, very crucial. Show me a federal agency or university that is not doing basic research in cartography prior to starting new applications work, and I think they will be headed for problems. What encouraged me is that in AUTO-CARTO I and II there were reports on a lot of basic research. My advice to you is, listen to the folks involved in it. Do not be too "quick-results" oriented. We have to learn more about the basic structures, including that of statistical utility.

Let me shift for a minute, though, to one of the things that came out of AUTO-CARTO I and was not stressed as much in AUTO-CARTO II, and that was the emergence of large cartographic systems. They were still developmental in those days. And until I am conviced otherwise, they probably still are. They are expensive and they are impressive; they cost millions of dollars and employ a lot of people. But they are not as yet in the public domain. At the University of Kansas we cannot really use a lot of this technology, but until that moment comes we will not be satisfied. There is some progress on the horizon that I want to talk about.

The USGS is now releasing some products that come essentially from large systems at the, I believe, 1 : 125,000 scale. This is something we all need to take a look at. I hope to hear this time that World Data Bank II is effectively in the public domain. The large systems are not yet delivering to us users what we like to hear or, for that matter, what we can use. But then we will always be disappointed-- we always want more. Nevertheless, the first payoffs for automation and mapping in the public sector, I think, probably are going to depend more on large systems work than they are on small systems work. We do not really understand massive amounts of information and massive data structures. We need to know about them. Indeed, I think this conference is in part possible because of the many men and women with vision that convince large agencies, including DMAC, EPL, CIA, USGS, NOAA, Bureau of the Census, and several large agencies in Canada, to go ahead and build these large systems. The problem of the utility of these to others still remains. The payoff is generally internal; transferability has yet to be accomplished on a large scale. The ultimate payoff, though, is cartographic wisdom; I think that is a worthy goal.

Some remarkable advances have been made in terms of line following, for instance, raster and cathode ray types of interactive systems, in part were made possible because of the investment made by the large system folks. The products are in part here: The DMAC has computer-generated topo maps. CIA has World Data Bank I still in use, and it is a useful teaching and training tool. Hopefully, the second edition will be in the public domain. NOAA is actively engaged. The Department of Energy, Mining, and Resources in Canada is similarly producing goods. We need to know what other progress has been made.

The most dramatic changes took place probably because the small systems were responsible for the transfer of computer mapping to the public domain and within the academic ranks. The small systems brought, say, operational systems within the universities and, in many cases, in small local and state government. That, I think, was of profound importance. That, in turn, may result in state government and universities investing in larger systems. The birth and development and adoption of the mini-based interactive system was accomplished from about 1970 to 1975. This is indeed a remarkable rate of technology transfer. But manual editing is still nearby. I do not think Ray Boyle is yet satisfied that there is a public utility around where a local government can get digitizing and some basic geo-processing done, so that one does not have to depend on a large interactive system and a manual back-up.

Data storage and transmission is still a problem in small systems.

Map files of medium complexity cannot really be processed. All my students want is a map of 105 counties--after all, it is the number of counties in Kansas--and some data and the lines and the roads and a few other things in order to study a real problem. Well, we can hardly get it through out "x-x-x" mini-system at the band rate to the x-y-z hardware that we have on the main frame. This problem has to be resolved, and I hope that it will be.

Another problem is the absence of standards. We do not really have any standards for how one digitizes a line, not that I know of any-way, and none that I can provide for my students. Oh, I can get 19 pieces of advice, including two or three gurus who emerge to tell me they have the only way to do it. Good. If it is documented, I will more than likely listen to you. But that is something we will need we do not really have, although I believe it is emerging, by that I mean very good standards for feature generalization. We do not have very good standards for editing maps. Oh, we have some, but they are still kind of on the horizon.

Classification is another problem. Although, historically, cartog-raphers have done more work with it, it is primarily work on thematic classifications. Cartographers haven't a clue what to do with all that linear spaghetti. That is the kind of classification I am talking about. It does not have to matter who is going to do it, but that is going to have to be sorted out.

At AUTO-CARTO I and II we did have some papers and some discussion about the topologic data structure. As far as I am concerned, that is perhaps one of the most important areas of research. We do not really have very good answers. And although the various speakers were convincing in their wisdom and the need for topology, with which I agree, we need to know even more and we need to have more basic research done. In addition, we really do not know very much about, say, data structure's simpler problem, say, the theory of the line. Peucker was willing to address this and did an excellent job in AUTO-CARTO II. But I am not really sure, and I would like to hear, whether he is satisfied yet. It is difficult, you see, for an urban geographer to teach computer mapping with the off-the-shelf wisdom. That, I hope, will come out of this conference or perhaps some other one.

What are the implications of all this? I think Joel Morrison put his finger on one important point. We are beginning to get the decay of the not-invented-here syndrome. I really like that. Part of the comments made by our keynote speaker in the previous meeting pointed out that the federal agencies are beginning to be forced together for one reason or another, and are beginning to think of not repeating somebody else's work again. In part, the pioneering efforts of some of the international agencies--UNESCO, IGU, and others-- have been of great assistance. Some insightful folks have begun this very difficult and academically not very rewarding process of getting folks together. I think you ought to commend these people for doing that. It is very important that we minimize the duplication. Users must be persistent, though. I would like to see fewer dilettantes. I would like to see people commit, say, ten years or so to pursuing computer mapping. Now, that may be hard and there may not always be a payoff for that, but we will still need it. We will need to support some devoted academes or bureaucrats who do nothing but topologic or line research, color mapping, or something else. We need to demand that they be supported. Because we really do not know a lot of things about automation and cartography.

The federal emphasis, of course, is going to continue in large system work. I would urge you during AUTO-CARTO III to examine the larger scale systems, and to discuss the third dimension. We are currently exploring fish-net type interactive cartographic representations of medical potential service needs for the State of Kansas.

Are we really ready to bring automation to cadastral or utility mapping? Are we ready to map the space outside of the earth? It is becoming a resource, you know, not only of the spirit but also for real. We need to define the purposes of our maps, particularly these virtual or fugitive maps. As was pointed out at the previous conferences, these maps will only exist for a little while. It is kind of marvelous about them; perhaps your mistakes will be short-lived. That is the problem with paper maps, you know. (Laughter). But, on the other hand, automation is also going to allow us to bring folks into the design process who will bring new ideas to it, the ideas of artists and others. In order to take advantage of these ideas we really need to know more about cartographic data structure.

One of the things that AUTO-CARTO I and II tried to accomplish was to get discussion of cartographic data structure started. Although we congratulated ourselves endlessly on how much fun we had and how many good presentations we heard, it is an unfinished task, and probably should be. The cartographer, as a scientist is, of course, somewhat ill-equipped for this task. In fact, much of the contributions to automation in cartography has been made by people like electrical engineers, physicists, and English and Philosophy majors who became programmers. Their contributions will extend the dimensions of the map and the image. Perception and cognition, though, are still going to be problems. We need to think of the creation of mathematical models for what we see, how we see, and how we present it. As Al Ward pointed out, we still need to think on how to express a design through automation. I do not think we are quite ready for that yet, although some of our smaller interactive systems are allowing us to think we are doing it. But I do not think we are quite there yet. But, hopefully, we will hear a report on how far we have gotten.

Another concern we will need to address even in computer graphics, is confidentiality. In the city of Lawrence and in the city of Wichita Falls, where I have some experience, the cable TV systems are technically designed to be two-way communication devices. That is, you could, with some electronic attachment, actually manipulate informatio back to City Hall or some central station. With the addition of mobil communication, sooner or later we will know exactly where you are. I think the public may begin to challenge this kind of worrisome problem I do not want anybody to know where I am in my car. Of course, I am a man of excellent moral principle. That is not really the reason why I just do not want anybody to know. And I think the public is going to examine that question. But then it is not all that profoundly important.

Another issue is a political one, that what we are doing is sometimes so magic that the public, including City Commissioners or directors of X, Y, or Z divisions may say to us, "We love your research and we would like to give you more money, but there are other priorities". Sometimes your dazzling graphics are going to have to be a blend of practical results.

I hope perhaps we can convince some of these agencies that have done so, to begin laying out the specifications for maybe something like the SPSS or BMD package for computer graphics for both large and small systems. I think its time has come. Now we have many people here--Wittick, Marble, Tomlinson, and others--who have really been pioneerin in software exchange and documentation. But we need to pin them down and ourselves, and provide support to see that this ultimately gets established, mainly because duplication of software is getting frightfully expensive.

Well, I always have a tendency to go on and on if I let myself. But I really think this conference is going to be one of interchange. Five minutes more of my time remains. Use them for meditation or discussion. Thank you very much. (Applause).

MR. [illegible]: It is always exciting and interesting to realize that, as Dr. Aangeenbrug pointed out, we have experienced two meetings that could be characterized as associated with anticipation. Indeed, we are looking forward to the emergence of reality in this conference and from here on. In order to better focus on that reality, I will turn the meeting over to Jim Chamberlain to introduce our next speaker.

MR. CHAMBERLAIN: It is a real pleasure for me to introduce to you our keynote speaker for this meeting, Mr. Rupert B. Southard, better known as Rupe to all of us here. Rupe is a close personal friend, and it is a real pleasure for me to do this. He is a real friend also of all of us in the surveying and mapping profession. He has supported this meeting from the very outset, and is responsible for the Geological Survey being the co-sponsor of this meeting. There are a number of other things that I could say about Rupe that are not listed in the biographical sketch that is published. I do not know whether he would want me to say all this, but he is a singer of note, a piano player, an actor, and has a wonderful family. I know that it has been a real effort for him to be here with us at this meeting. He has come at considerable sacrifice to himself and his family, and we are deeply in his debt.

Rupe received his degree in Civil Engineering from Syracuse University, where he majored in photogrammetry. During World War II he served with the Marine Corps as an artillery officer, and in his second tour of duty in 1950 through 1952 he was a Survey Officer for the 10th Marines. Rupe began his Geological Survey career in topographic field surveys with our Atlantic Region in Arlington, Virginia. He transferred to our Washington staff in 1955, where he has progressed to positions of ever increasing responsibility. He was involved with the development of the orthophotoscope, which has contributed much to the revolution that is in progress now in our mapping operations, and the early applications of orthophotography. Following this, he directed the Topographic Division's international activities. In 1965 he became the Assistant Chief Topographic Engineer for Plans and Program Development. He has represented the Topographic Division at many international symposiums and meetings, and has authored numerous professional articles on a wide variety of subjects. He has received a number of awards, including the Department of the Interior Distinguished Service Award. He has been active in professional organizations, and in 1963 was Director of the National meeting in Washington, D.C. of the American Society of Photogrammetry and the American Congress on Surveying and Mapping.

In 1972 and 1973 Mr. Southard participated in the Office of Management and Budget Federal Mapping Task Force. He was the Department of the Interior representative. This task force did an intensive study of all the mapping operations in the Federal government. In 1970, Rupe was named as our Associate Chief Topographic Engineer, and presently he is our Acting Chief of the Topographic Division of the Geological Survey. Rupe, it is a real pleasure to have you here with us, and we are anxious to hear what you have to say.

MR. RUPERT B. SOUTHARD: Thank you. Jim, just a couple of comments about your introduction. You say I am a great friend of all of you in the surveying and mapping community. There are a couple of exceptions. (Laughter.) I notice they are not here today, though. Jim said I supported this meeting from its very inception. Actually, Dean Edson called me after having talked with Joel Morrison, and said that there is a strong request being made for GS to co-sponsor AUTO CARTO III. My recollection is that all I said was "Yes, go ahead." And that is the last time I had any connection with it until this moment.

It is a pleasure for me to be here to give the second keynote address. (Laughter.) I didn't understand a thing Dr. Aangeenbrug said, but I fully believe it -- (Laughter.) -- but I fully believe it, and I agree with all of it -- (Laughter.) -- and I am going to take advantage of some of the things he said to simplify my talk. It has been a very busy weekend for me. Over the weekend I was down at Fresno attending the convention on surveying and photogrammetry at California State there. I was so busy that I lost 50 pounds. That is, with the help of United Airlines. (Laughter.) They misplaced my suitcase, and rather grudgingly returned it to me just before I got here. So, I stand before you in this sartorial splendor courtesy of United Airlines and Fresno.

A few historical items of relevance -- at least I think they are relevant. Back in the early 1880's was a day when Nicephore Niepce pointed his camera out an attic window overlooking his sleepy little country estate in Lille, Eastern France. He hardly dreamed at that time that the result, the world's first photograph, would change the course of society. Niepce was a polite, modest man who preferred his country study to the brilliant salons of Paris. He worked with admirable persistence through 20 years of slow and groping progress before the final breakthrough came. In 1813 a craze for lithography swept over France. Nicephore, who could not draw -- he was an early cartographer -- (Laughter.) -- tried to find ways of copying designs on lithographic stones. He spent three years with various cameras of his own design, using stone, glass, metals and paper, from materials which he sensitized with various chemicals. In 1816 came a success of sorts. He produced weak negatives on paper treated with silver chloride.

The next progress came when he managed to reverse the tones and produce a photoengraving of a lithograph of

Pope Pius VII, which was a winner -- (Laughter.) He lent it to an excited cousin. It is not entirely clear to me -- This part was prepared for me -- It is not entirely clear to me what the cousin was excited about. (Laughter.) He showed it to a friend who promptly dropped it and smashed it. Then he wasn't excited any more; he was sore. (Laughter.) Then Niepce tried his first ever photograph of nature by aiming his camera out the attic window. Eight hours later he closed the camera shutter, and the world's first photo had been taken. The long exposure produced at least one strange effect, in that the sun seemed to be shining on both sides of the courtyard. We still get that a lot. (Laughter.) Except now, of course, with advancing technology it doesn't take eight hours; we can do it right on the spot.

But this very important breakthrough was not to earn a franc for Niepce. In 1829, four years before his death -- and he was in a very financially impecunious stage; he was broke, was what he was -- (Laughter.) -- he signed a contract to share his secret with Paris showman Louis Daguerre, who had dabbled in the field of cartography. And he was excited too. Daguerre saw the immense commercial possibilities of the camera, and it was he who adopted Niepce's original invention so that photography became practical as distinct from possible, and made all of this (indicating) possible. Updating further, June of 1874. Quotation from the June issue of Scientific American. "The French papers seriously discussed today transferring the work of the surveyor to the aeronaut. It has been found necessary to revise the real estate maps throughout France, and it is proposed that a balloonist should photograph each tract of land. This may be practical, since balloonists have already taken such photographs. The estimated expense, however, of three and a half million dollars, makes doing the work by surveyor cheaper."

A hundred-year update. In 1970 at the ASP Symposium on Computational Photogrammetry, our own Dean Edson, who is here and is Program Chairman for AUTO CARTO III, gave a paper suggesting that a digital topographic data bank be established with some rare, but forgivable understatement; he concluded that the total file size for the topographic data bank of the United States will be about three times ten to the 13th characters. To collect such a volume of data and store it in useful form, Dean said, a well thought out system must be developed if the topographic data bank is to be any economic and technical success. Except for the numbers, the point is well taken today. I did not invent that wheel. Dean mentioned it.

In August, 1973 at the ICA meeting on automation, a new trend in cartography in Budapest, the opening address was given by a colleague, Dr. Sandor Rado, who was then chairman of the Hungarian National Committee of the ICA. He called attention to the growth in cartography of automation He pointed out that reason for automation in cartographic work -- and the American language is his, not mine -- "has these following manyfold purposes: rationalization of cartographic work; the updating of the map contents; the objectivation of the map compilation; the improvement of map's expressiveness; and the improvement of the labor condition of people doing cartographic work". There was not much mention in Dr. Rado's remarks of the value of the data itself rather than perhaps in map form.

Jim mentioned that I was a member of the Federal Task Force. He just knew I was going to quote something from the Report of the Federal Mapping Task Force -- didn't you? I'll give you a small segment from that report which is on the subject: "Eighteen federal agencies expended 37 and a half million dollars and 2500 man-years on cartography. This effort includes domestic cartographic compilation and map finishing, but not photographic processing. Most of the cartographic work is accomplished inhouse at numerous facilities throughout the country. The complexity of cartographic techniques varies considerably among the agencies. For example, the efforts of GS, NOS, Forest Service, Soil Conservation Service, Census, and TVA, amount to approximately $24 million, and are devoted to products distributed widely for multipurpose uses, whereas the remaining civilian agencies usually compile products for internal use, which in most cases have less demanding requirements for content and accuracy, and, as a matter of fact, accessibility. Generally, conventional manual methods of compilations and map finishing prevailed through the community." We also found that major agencies with cartographic capability are in the process of developing and implementing computer-assisted automated systems, although no complete system has emerged So far there has been no concerted effort to make these separately developed systems compatible with each other. Complicating the situation are fast-growing requirements to understand the proper relationships of points and areas to social, ecological and economic phenomena in any combination, and to present them in digital or hard copy form as required. The overall national effort to collect and store interrelated spatial data, therefore, can be facilitated by implementing standard automated procedures based on knowledge and principles inherent in the cartographic process.

"We concluded that in aggressive implementation of computer-assisted techniques for digitizing and displaying spatial data the following advantages will accrue: Formation of a sufficiently large base to support fast growing requirements. Greater flexibility to manipulate and portray massive amounts of time-sensitive data through integrating incomplete existing systems; production of digitized information as well as standard hard copy products during one operation; reduced manpower per unit of output; and shortened map and chart production cycle." Remember, this was only about four years ago.

At AUTO CARTO I, when Bill Radlinski gave the keynote address, he called attention to three things. He wrung his hands about the extreme length of time it took to produce a standard topographic map, and quoted some figures which you may remember as taking a project-oriented map, that is, first to last map in a project, of 59 months. And he allowed that was pretty much too long, and that with advancing technology one of the things that must be accompliched is to reduce the time in which we can get that cartographic data into the hands of the user. Regarding cost effectiveness, he pointed out that not very many years ago people presented papers on the subject of automation, they pretty much avoided the cost effectiveness factor like the plague. I think they pretty much still do, but this is my keynote speech, and I am now talking about his. Today it is a different scene, he said. Equipment effectiveness is rising with ever increasing speed to the point where in spite of inflated hardware and software costs, new techniques can truly be competitive. Then he concludes that by continuing to use the new technology aggressively we can at least hold the line on costs, if not indeed reduce them somewhat. Considering the directives of cartographic data, digital cartographic data, Radlinski estimated that the average U.S. topo quad contains many million separate bits of information. That means more than the average map reader could absorb in a year's time, and the topographic sheets of many other countries, as Dr. Aangeenbrug pointed out, contain even more data.

While maps were extremely efficient devices for storing data, even more information together with positional coordinates can be stored in computers. A major advantage (this is an important point, and it is very true and will continue to be true, and needs emphasizing) 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. At AUTO CARTO II, Bill Overstreet pointed out many of the same things, that it is a good thing we are about to investigate, and we needed to be on with it.

A recent article that I will call to your attention in the ACSM Bulletin for November of 1977 is by Bill Riordan, who is Deputy Director for Program, Production and Operations at the Defense Mapping Agency in Washington. Here are a few comments excerpted from that. "Over the past few years a basically manual graphic operation has been rapidly evolving into a mechanized digitized process. What is more, the combination of accelerating technology and aggressive government agency competition for limited resources is driving the community toward a full range of digitally-oriented production equipment. An outstanding example of this is the relatively new LANDSAT technology. LANDSAT-C, soon to be launched, will expand present digital collection capability and produce a lot of data.

"Doppler, along with its logical replacement, the Global Positioning System, will locate positions on the earth within inches -- and many other systems which could be named will lean ever more heavily on digital technology in the future.

"At the beginning of a vigorous and growing program, the Defense Mapping Agency (DMA) has now digitized elevation data over almost seven million square nautical miles of the earth's surface. At the same time, DMA has digitally encoded two and a half million square nautical miles of the earth's surface as far as cultural details such as roads, cities, waterways and so forth. Judging from today's requirements alone, terrain digitization and cultural digitization each will cover ultimately 18 million square nautical miles. A recent internal DMA study was made to forecast the size of the digital data base necessary to meet the needs of weapon systems of the future. It showed a potential requirement for a base composed of ten to the fifteen bits of information. To face these challenges we require more than equipment. We need imagination, we need concepts, and we need organization. It is not hard to foresee that the rising wave crest will have an impact on civilian mapping agencies as well in the not too distant future."

Now, these observations are but a few. They clearly mark the inevitable development of computer-assisted cartography and systems related to it. The development is inevitable; successful development is not. Let us take a few examples of what is presently going on. I will talk to you about what is going on at the Geological Survey. There are people here from Geological Survey who will be taking an active part in the workshops and sessions this week who can tell you a great deal more and in greater detail. We recently conducted, with the help of the International
We recently conducted, with the help of the International
Geographical Union, a searching study of spatial data handling techniques in the Geological Survey. I will point out to you later, from another source, something of the major findings of that study, which was highly enlightening and very helpful. Organizations like IGU, and in particular the Commission on geographic Data Sensing and Processing can be of great help for people to understand problems they may not even know they have yet. Dr. Roger Tomlinson, who is here, is connected with that effort. Roger has talked to me for several years, saying, "Rupert, you must exert some leadership in this area. Follow me." (Laughter.)

To some extent we are exerting leadership. In the Topographic Division (USGS) we have formed a Digital Applications Team in the Office of Research and Technical Standards. That office is headed by Roy Mullen, who is here (indicating). The Digital Applications Team is headed by Dr. Robert McEwen, who is also here. The team is set up with five or six people at the moment. The efforts that they are overseeing are connected with monitoring and setting in motion the research and development necessary for us to get into digital applications. It is, of course, important also for us to do some pilot projects in connection with that effort. Some of those pilot projects are being done with other federal agencies so that we will learn together about what is needed, what can practically be delivered, and what the costs, both in time and resources, may be. Elsewhere in the Geological Survey, the IGU found somewhere around 55 data base efforts going on -- not all big ones, some little ones, some rather specific ones. I will point out a few to you. Of course, one that is very close to our own work is the Land Use and Data Analysis project, involving land use mapping and the digitization of land use and land cover data.

Our Geologic Division is heavily involved with the Coal Resource Data Base, which will require considerable support in digital cartographic data, digital terrain data, property ownership or jurisdictional data, as well as transportation and drainage. The Water Resources Division has considerable data bases, primarily point data for well locations as well as digitized boundaries of hydrologic units such as drainage basins. And on and on and on. As I said, 50 to 55. It is quite possible that as we now are more aware of what others are doing in the Geological Survey, that some of those data bases can be organized in a more efficient and effective way. It may also be that some of them would be better left separate.

Other data system activities in the Geological Survey are: Conservation Division is into digital activities in the coal lease reserve. Royalty accounting is being done, digitally. In the Geologic Division they are also doing Oil and Gas field data digitally as well as Earthquake/Strong Motion Studies. In the Topographic Division work is being done on development of a national digital cartographic data base. Topo is doing, in connection with other federal agencies, an Aerial Photography Summary Record system, which shows both where photography is being flown, has been flown and is about to be flown. We are going into digitized geographic name information as well. Those are just a few examples of the kinds of things that are going on. We are going to be a great deal more heavily involved in spatial data activity, not because we know so much about it, but because we need to know much more. And we feel sure that within ten years we will be primarily digital. Our production system, our operation system and the data that we deal with will be primarily digital, we believe. That is not to say that printed maps will be discontinued, because they won't. People will always want them. They freeze data in time, and they will always be a useful record for that time.

But the requirements for data these days, of course, are voluminous. They have tremendous appetites for data. The more you give the more you have to give. I should mention this: Our priorities for the data we are presently considering digitizing are civil boundaries, rectangular survey systems, surface hydrography, terrain surface and transportation. Those are our primary data categories at the present. The secondary ones are geographic names, manmade structures, woodland, orchards and so forth, and non-vegetated features.

Dr. Aangeenbrug did a better job than I believe I was prepared to do to mention some of the problem areas that need to be not just looked at, not just talked about, but addressed. You will be talking about those problem areas this week, but the list that I would have is exactly the same as the list he would have. We have to deal with digitizing problems.

An estimate that was done by the IGU for what it might take the Geological Survey to digitize all these quadrangle maps of the United States, (which will ultimately number 56,000 at the 1:24000 scale) an estimate ranging from 400 million to 500 million dollars' worth of activity. That is a lot of digitizing. Before we produce that much digitizing we need to be sure people want it that way. So we are going a little slow. We have been criticized for going so slow on getting the right kind of an answer to that problem. One can clearly see that the maximum payoff in putting computer-assisted cartography to work will result only from a carefully planned approach to design of a data system to serve both short-term and long-term requirements of an array of users that we may not even know about yet. That array of users will have a further array of both comprehension and sophistication in either the way they could handle data or the way they would be willing to handle data.

A number of relevant remarks on the subject were offered by Dr. Hugh Calkins, who is with the Geography Department at the State University of New York at Buffalo. In a contribution to the Proceedings of the IGU Commission I mentioned earlier, the Commission on Geographical Data Sensing and Processing in Moscow two years ago, in a paper titled "Information Systems Developed in North America," Hugh cited five important lessons to be learned from the North American experience. I think these apply just about everywhere. "Almost all of North American geographic systems (Hugh said) have been developed in response to specific problems or needs. Consequently, there is no, or little, compatability between systems. Each project is started and proceeded independently, and it is almost impossible to move a system to a new location and use it in solving different problems. Five specific points are discussed below as critical to the future of geographic information system development. There is no clear concept of what constitutes a full geographic information system. The term is used to cover activities such as the Canada geographic information system at one extreme, to simple plotting programs or subroutines at the other. Some standardized concepts of geographic information systems are obviously needed. Two: The format of data before encoding is significant. Well prepared graphic documents, maps, can in fact mean the difference between success and failure. Digitizing is currently the most difficult task to complete. Three: The volume of spatial data is also very significant. This has often been underestimated, and has led to excessive costs or outright failure. Four: The resulting utility of geographic information systems has frequently been reduced by decisions made when the data are encoded. Substantial loss of information such as systems based on a large grid cell cannot be tolerated by all users. Five: The non-technical problems, essentially the management of the system, are equal to or greater than the technical problems.

Sooner than we think, sooner than we guess, virtually all spatial data will be computerized. In most cases the data will be collected and accessed in response to the immediate needs of the primary user. Great care must therefore be taken that secondary and tertiary requirements be considered to the maximum extent possible for effective multiple use of the data. Growth must be planned, not allowed to happen accidentally. Agencies handling large amounts of data must increasingly make known what that data is and how it can be gotten and used. Education of all, but most particularly managers, is a crying need." In that connection, the work that I have mentioned of the IGU Commission on Geographic Data Sensing and Processing can be very helpful. There is excellent work going on at a number of universities, including Kansas and Harvard, the State University of New York at Buffalo, the University of California at Santa Barbara, Wisconsin, and many others. We must take advantage of that work that is going on, and we must talk to each other about what we have learned.

I think symposia like this one are extremely useful in that educational process. The education will need to continue because the rate of change in that technology is at a breakneck pace already, so you cannot turn your head for even a moment. An important point from my own personal observation: Professional societies like ACSM, ASP, IGU, ICA, ISP, and FIG, and others, will need to begin working together for examination of problem areas, as the input of many disciplines will be required for most effective solutions. The whole payoff for this is much too important to let it fall apart over turf battles.

The government agencies, federal agencies, must continue to take an active role rather largely because of the extreme cost of some R & D efforts. If R & D is to be done, it has to be paid for, and the government agencies can make that contribution. While they are making that contribution their work should not be kept secret. It would be much more to the point to sing it from the house tops, even if the research has failed. Sometimes that is more useful than reporting successes, and there is a lot more of it. (Laughter.)

The challenge is an exciting one. Not for a long, long time and maybe never again will cartographers, geographers, surveyors, photogrammetrists, mathematicians, computer scientists, have a rich and rare opportunity like this one to make a real contribution to mankind's wise progress. I would like to give my congratulations to the organizers of this symposium for holding this symposium in sun-drenched California. (Laughter.) The program looks like a very good one. The people that are on the program as speakers and moderators are the best or among the best in the business. I wish you luck. Thank you. (Applause.)

ECONOMIC REQUIREMENTS

MR. DEAN EDSON: The first afternoon session of AUTO CARTO III is now convened, and the first panel session of this afternoon will be on the Economic Requirements. This is an important aspect that we felt should be covered and should be addressed honestly and openly. I think we have a panel that will give us some real insight as to the problems associated with justifying a lot of the things that we are either doing or thinking about doing. To head up this very important panel we have Jon Leverenz, who is currently the General Manager of Cartographic Creative of Rand McNally, Chicago, and, being in the private sector, is very concerned about the economic impact of the kinds of things that are being implemented because, obviously, a commercial firm has to make a profit, and unless you can get hardware and software systems working for you in a profitable way it does not make any real sense. It is certainly a pleasure to again introduce Mr. Leverenz, who, I will remind you, is the President-Elect of ACSM, and will introduce the subject and his panel. Jon?

MR. JON M. LEVERENZ: Good afternoon and greetings again. Thanks a lot, Dean. The Economic Requirements Panel was assembled, and the personnel were chosen to bring us information on the economics of computer-assisted cartography from a number of varied segments of the mapping community. Roy Mullen is from a federal civil agency, United States Geological Survey, and he will talk on economics of digital mapping from the United States Geological Survey's perspective. Dr. Joel Morrison, from the academic community, University of Wisconsin, will talk on a university's special automated cartography requirements and economic considerations. Fred Hufnagel, from a federal military agency, DMAAC, will discuss DMAAC's advanced cartographic system.

As Dean said, I am from a part, only a part of the private industry segment in cartography. I will start talking about the economic requirements by discussing the considerations, some of the considerations of a commercial map firm on the threshold of automation. In talking about a commercial firm on the threshold of automation, my thoughts are going to center basically around the more important considerations that a mapping firm would have to make. Possibly, the title "brink" of automation, rather than "threshold" may be more appropriate, because it connotes a greater risk, and that is usually how the financial management of a firm usually thinks of automation, as quite a risk. But I did settle on "threshold," thinking that it was the doorway to something new, or hoping that it will be the doorway to something new.

The cartography firm of which I speak is concerned with the preparation of maps that are based upon a variety of information obtained from diverse sources, such as existing maps, census data and other statistical data that is being mapped. The operations run the gamut of cartographic operations such as the gathering, interpreting and selecting of data, the geographic research and editing, the compilation of the manuscript map, and the final construction of the various kinds of art work needed to produce multiple copies of the maps.

I will briefly run through these slides to attempt to illustrate some of the operations and some of the materials that are used in map making. (Slide 1) This is the gathering of information and the original manual compilation of the material, the type of detail that is found in such an operation for a land use map at a very small scale. (Slide 2&3) This is the scribe line work, showing the detail again, and a peel coat, which gives you an idea of the intricacy of the open windows to produce a published map of this sort. (Slide 4) The relief and type -- the type is sparse, but this is the relief rendering, giving you an idea of some of the techniques that are needed and must be considered in making a map. (Slide 5) These are the final positives that are used to make the plates which are then used to print the multiple copies. (Slide 6) This is the finished map that is usually produced by one of these firms.

I want to focus the examination even more and make sure that we all understand the type of commercial enterprise that I am talking about. It is really a segment of the community which encompasses those companies that manufacture cartographic products, the sales of which yield a sufficient monetary return on their total investment to enable them to stay in business and to continue to re-invest in product development and production facilities. This cartographic firm is, therefore, quite distinct from non-profit institutional cartography, government cartography, as well as those surveying firms or other industrial and commercial companies where the mapping activities produce products for internal use only or for a few specific technical users.

The basic difference really in all of these is in the profit motive and in the mass market, which, in the long run, determines what will be produced. For if the market accepts the product and buys it, this will enable the return to create that product, will enable a return to cover other expenses as well as the cost of capital investment for that product. The converse is true: If they do not buy it, the profit is not made and it cannot be reinvested, and therefore, eventually the company will not find itself in business. I emphasize market and profit, even though they appear to be rather elementary, because they are the most fundamental considerations when a firm is on the threshold of automation or when it is on the threshold for any investment, for that matter. These commercial firms of which I speak, by and large will produce travel aids such as road maps and street maps. This is just the type of map that I am sure you are most familiar with. (Slide 7) Other examples are globes, and general reference maps for atlases of the world. (Slide 8) These are usually the products that the firms I am talking about produce.

Now, aside from these complexly produced esthetic products, the general market has really rarely shown a great need for the rather unesthetic computer-drawn maps showing specialized distributions. What small market there is for such automated products has usually been satisfied by certain companies' internal map production operation or by an academic or a government source.

Another aspect of the commercial map makers' considerations is that generally its products have the following range and scales. A.) The first scale range is 1:30,000 to 1:50,000 for street maps. B.) The second scale range is 1:300,000 to 1:2,000,000 scale for individual state road maps and atlasas. C.) The third category is the 1:1,000,000 scale to 1:10,000,000 scale for world general reference maps and atlases. Those particular scales and sizes are partly dictated by the size of the printing and manufacturing equipment that can effectively and efficiently produce multiple copies of maps. The mass market also influences the scale for it will spend money for only a limited number of maps and/or a limited size of atlas. So, those two things very much help to determine the map scale and the size of any particular product.

What these two aspects mean to a firm is that when it considers automation, it must consider the type and amount of information it needs in relation to the purpose of the map, which is partly dictated by the market and the detail of information in relation to the scale of the map, which is partly dictated by the manufacturing equipment. These are very important considerations.

Although data banks produced by some government agencies are available to the commercial firm, they usually are too detailed, containing much non-essential information, and they are not structured to the commercial needs. I think this is understandable, but what it does mean is that the firm must consider the fact that it must totally underwrite the cost of developing a file structure and a data base suited to its own needs, both in structure, information, detail and the efficiency of the retrievability of data. The firm is not going to get a tremendous amount of help from the government agencies.
Another characteristic of the commercial firm that must be considered when contemplating automation is its map-film library. The size of the map-film library varies, but it generally contains 25-50 pieces of film elements for each map produced. The elements carry the

scribed lines (see Slide 2), the area open windows which are utilized to print the area tints (Slide 3), and the type and the final plate making positives (Slides 4 and 5). These elements and positives are for a rather complex map, but serves to show the amount of information embodied in a map-film library and indicates the large investment in film.

The number of map elements (sheets of film) also serve as a graphic data base. It would seem that with such a source of separated and classed data that it would be a logical decision to utilize it as a source for digitization. But, on the contrary, these elements are in such condition that they may be updated and redesigned by manual methods, and reasonable size changes may be photomechanically produced at low cost. Actually, the availability of such a map film library raises this question: Is it necessary to invest -- and this is to the people making decisions as to where to invest corporation money -- is it necessary to invest dollars in computer equipment and programs to convert the graphic data base now in element form to digital form only so that it may be plotted in its original graphic form or similar to its original graphic form? This is a basic question. The map film library, therefore, and its value, makes it less likely that the firm will invest in the automated cartography field.

You will recall that the mass market we are serving does not call for great numbers of new maps. I want to emphasize that. Therefore, the commercial firm's work consists of about 20 percent new map work a year and about 80 percent revision of existing map elements. For instance, in the last 30 years in the United States, there have only been about six major completely new commercial world reference map series produced in the United States, only about five series of new state road maps, and only about four new road atlas map series. These are the large series of maps that appeal to the general market that I am talking about which this commercial segment must service.

There have been hundreds of street map titles that have been produced, but once they are produced, the elements are relatively easily updated by manual methods.

So, given these considerations and these factors: 1.) a mass market that supports relatively few well defined map products and does not support frequent new map programs; 2.) an industry with considerable investment in relatively easily revised map elements; 3.) an automated technology and data that has been developed by government agencies and that has had little direct application to commercial needs, and 4.) an ever-changing technology where the emphasis has been upon large expenditures of funds on experimentation with methodology rather than on refining economically sound production facilities; I believe one can understand the firm's less than enthusiastic endorsement of automation.

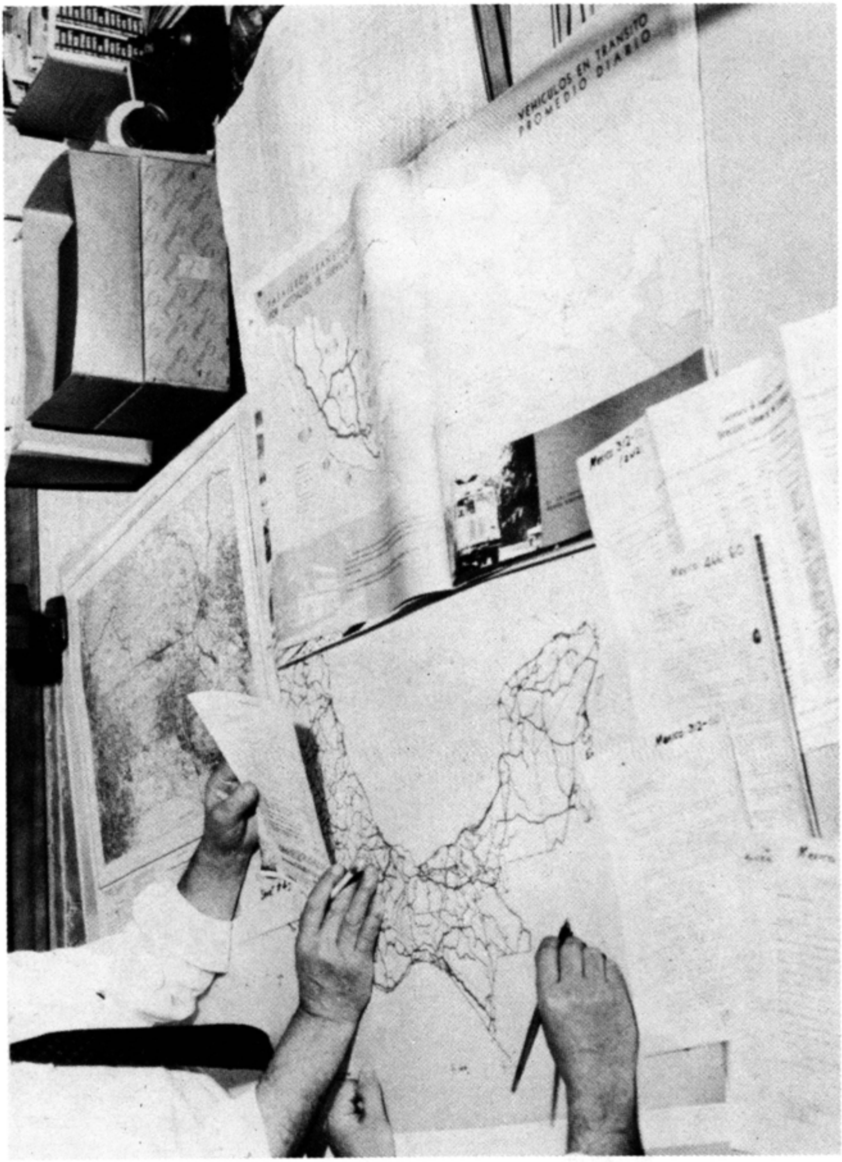
I have presented the foregoing just to establish a basic understanding of the commercial motive, its market environment, and its complex map making system, and how these factors help shape its general attitude toward automation.

In the following few slides, I have set up a model used to compare the manual map-making operation to the automated assist operation in order to arrive at the cost benefit and the economic justification of an automated assistance system. This model may be used by the firm once it overcomes the preliminaries and recognizes some of the automation may be a potential investment. For these slides, unit values and percentages have been used to show the relationship between the automated assist and manual method of map making. This comparison that I am going to make assumes both manual and the automated assist starting from scratch to build a map series. It does not consider, unfortunately, the amount of time and money to develop preliminary data file structures and so on. Slide 9 shows the map making operations and the percent of time in each operation necessary to produce a large scale map of a state. Only the operations that have been proven to work in an automated production situation are considered for this model.

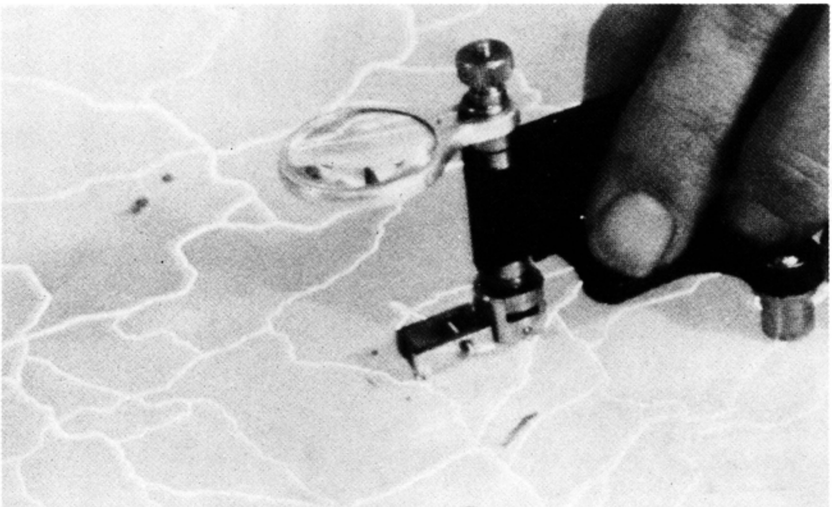
On review, over a long period of time, I feel that efforts in automation have produced operational production systems which have made the automated scribing of lines, the flashing of symbols, and some dye-strip, the blockout work commercially feasible. I feel that efforts in the automation of the stickup of names have not been successful, and, as far as I can see, no operational production system exists that is commercially feasible. Another area that automation has aided has been in reducing the amount of checking necessary by making the checks more efficient and thorough than the manual operation. If you look at Slide 9 you will see that the automatable operations amount to about 30 percent of the time of the total task.

Another fact that we can derive from this chart is that the automated operation decreased the work load in the production area of map making, and less so in the compilation area. Because the production is a lower rate operation, the cost benefits are not as great as 30 percent displacement in time might indicate, because it displaces it into a higher wage-rate area.

Slide 10 shows the manual compared to the automated assist method if we assume that there would be two plots from one set of input information. Based upon a review of our particular manpower at Rand

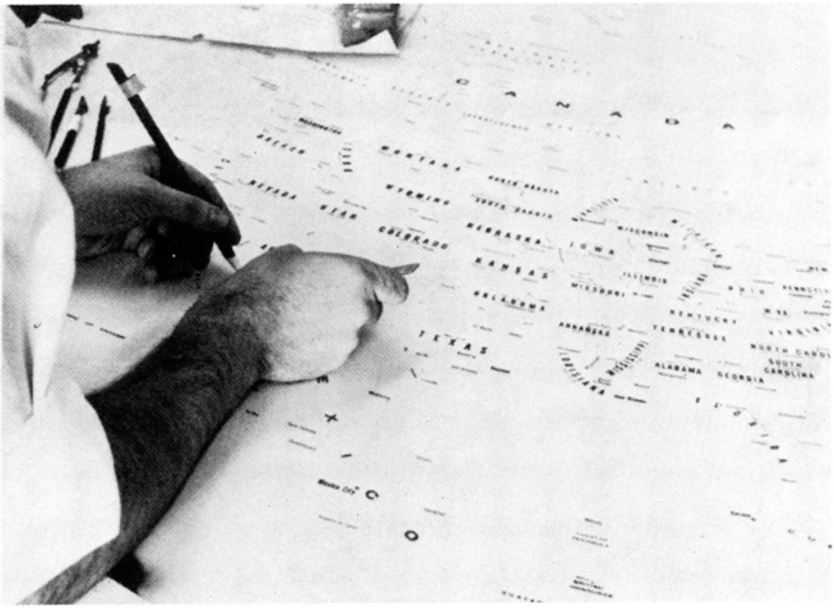


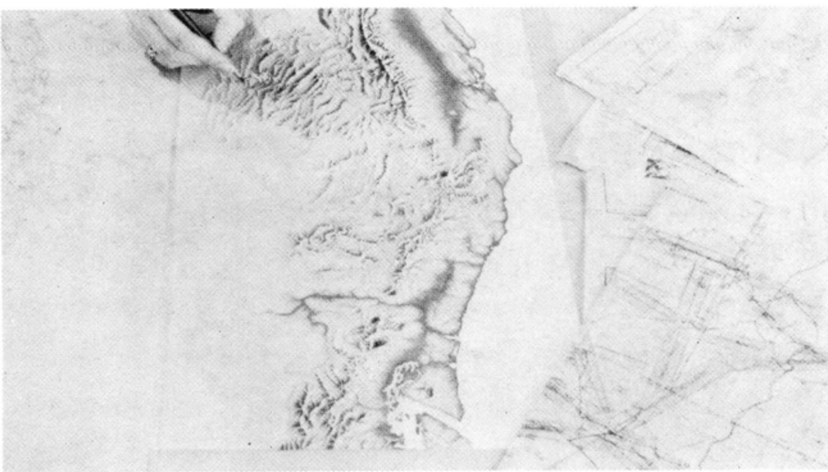
Slide 1



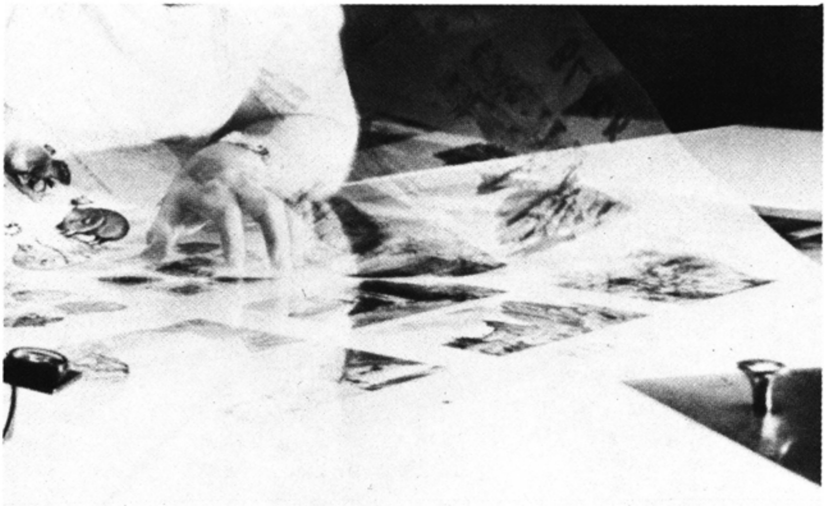
Slide 2

Slide 3

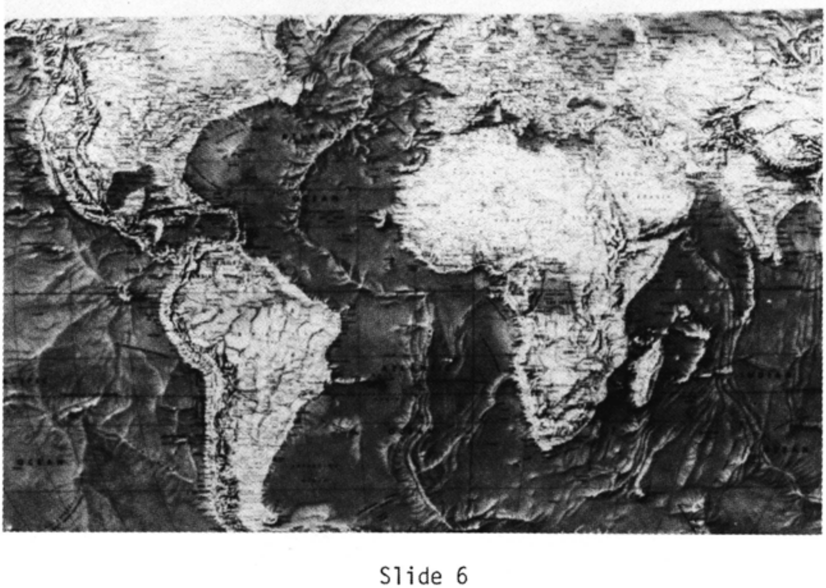

MONTANA
WYOMING
UTAH
COLORADO
NEBRASKA
KANSAS
IOWA
OKLAHOMA
TEXAS
KENTUCKY
TENNESSEE
ALABAMA
GEORGIA
SOUTH CAROLINA



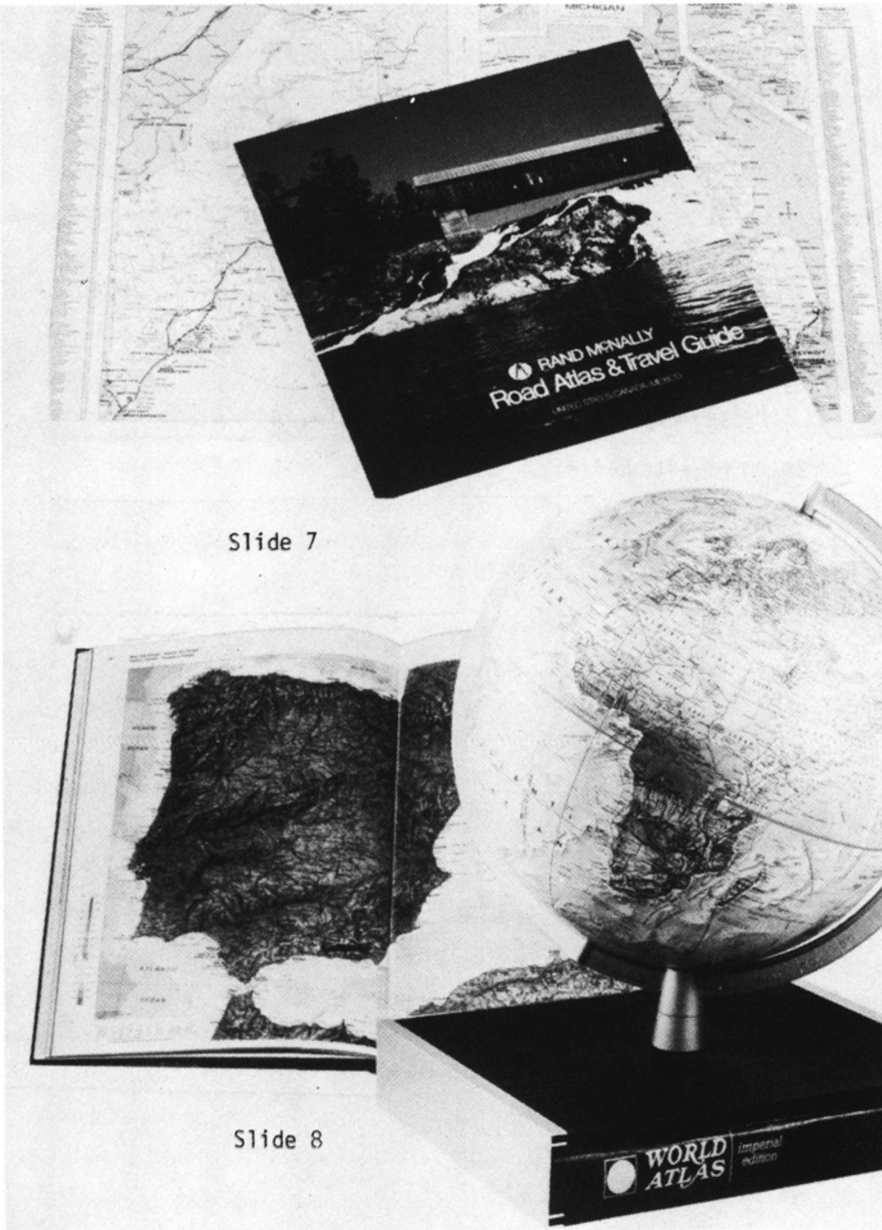
Slide 4



Slide 5



Slide 6



Slide 7

Slide 8

MANUAL MAP-MAKING OPERATIONS (Slide 9)

COMPILATION & RESEARCH	PERCENT OF LABOR	PERCENT OF COSTS
Planning; research; linework, area place, type compilation; and editing	33%	40%
PRODUCTION (FINAL DRAFTING)		
Scribing; stickup of type; area tints; contact and checking.	67%	60%

Proven automatable operations of line-plotting and symbol flashing eliminates:

1. Some preliminary contacting =	4%	
2. Scribing of linework =	20%	
3. Point stick-up =	6%	
TOTAL POTENTIAL TIME SAVINGS WITH AUTO ASSIST =	30%	

RATIO OF AUTO-ASSIST TO MANUAL
ASSUMING TWO PLOTS FROM STORED INFORMATION*
(Slide 10)

	MANUAL	AUTO-ASSIST (1st Plot)	AUTO-ASSIST (2nd Plot)
COMPILATION & RESEARCH			
Planning to Editorial	.39	.35	.06
PRODUCTION & CONTACT			
Organization to final positives	.77	.44	.44
DIGITIZATION & PLOTTING			
Manual digitizing	---	.05	---
Point coding	---	.02	.02
Line coding	---	.10	.02
Editing	---	.02	.02
Plotting	---	.02	.02
TOTALS	1.16	1.00	.58

*The unit value is assigned to the total of the automated assist. All other values relate to it.

McNally, and physical plant, and because 30 percent automation had to be integrated with the total map making effort, it was determined that we could support three manual digitizing stations, two shifts on 240-day year to turn out roughly 25 maps per year all the way from compilation to digitization to plotting and production.

Slide 11 shows the arithmetic to arrive at the cost benefit of automation on a per map basis for one plot. This compares the cash flow between the manual and the automated assist operation, as I said. The operations and the percentages indicated in the charts that I just showed were used along with approximate wage rates and approximate equipment costs.

If we take a five-year amortization of the equipment costs we can arrive at an equipment cost per year.

Slide 10 shows the arithmetic. As I say, we are using 25 maps a year as a yearly output, as I mentioned, and we arrive at 5% less out-of-pocket wage, material and equipment cost per map for the automated assist

Because these figures are actually expense items in determining the corporate income taxes, as many of you may know, they may be deducted from the amount of income the corporation makes and thus reduce the taxable income and the outflow of cash. Because the tax rate is about 50 percent, it means that, in effect, only one-half of this expense is actually deducted, which allows a new savings of only 3% for automation over the manual method. At this particular stage in the cash flow, the savings because of automation is really slight. However, the effect of purchasing equipment is where the large savings of cash is found.

The depreciation of equipment is also an expense item, as you know, and it becomes a credit item, and in effect allows less cash to leave the corporation. So, therefore, the net result is an out of pocket cash flow of 23% less for the automated assist method.

Naturally, the digitizing process and the computer storage would be structured so that it would build a data bank from which maps of varying scales, sizes, and coverage could be recalled and plotted, as I mentioned. It is here, of course, that the real benefit accrues to automation, but, of course, only if the market, as I mentioned, indicates that there is a need for another series of maps. Now, on this particular model I have assumed the ratios on Slide 10 for a second plot, and the savings is 38% more per map for automated over manual. It should be interjected here that no leasing arrangement would enable a sufficient savings for the automated assist method, mainly because leased equipment really cannot be depreciated by the firm and therefore no cash savings can be derived.

CASH FLOW COMPARISON BETWEEN
MANUAL AND AUTOMATED ASSIST ON
A PER-MAP BASIS (Slide 11)

MANUAL		AUTOMATED ASSIST	
Cost/map		Cost/year	Cost/map
1.00 =	Total wage & materials/map		.67
	Total automated equipment cost: 25.71 5 years =	5.14	
	Total maintenance, rent, power, tax, etc.	1.89	
	Total/year equipment, maintenance cost	7.03	
	Approximately 25 maps/year: 7.03 25 =		.28
1.00	Total expense/map		.95
.50	Corporate Income Tax (50%)		.47
.50	Out of Pocket Expense w/o depreciation		.47
---	Depreciation of Equipment/map 5.1 25 maps)		.20
.50	Total out of pocket expense/map		.27

Approximate Net Savings/Map = .23

Slide 12 is the final slide. It shows that with a total equipment investment of a unit value 1.00, and a savings per map that I just determined, and assuming that the market will demand two 50-map series in a four-year period, a four-year payback results which, according to many firms, is a reasonable payback period. So, you are paying back your equipment costs essentially in 3.3 to 4 years. It would appear, therefore, that the cost benefit model indicates the investment to be sensible if the assumptions about the market are true. I do want you to recall that this example did not discuss the money necessary to set up a file system and a structure for the data bank, and that would be one of the final considerations and probably a large number of dollars. It would appear that with the facts that are accumulating concerning cartographic automation, the value of the data bank itself will be positive and will probably exceed the value of the investment to develop the initial file structure and the first series of maps. It is also evident that once the initial series has been produced, there would be a savings in revision, especially at the compilation and research stage. For instance, one entry in the data bank would enable revision, at the appropriate time, of all the map series.

More consistency and accuracy is another positive advantage of an automated plot. These, however, are what I call intangibles, and become tangible only after the data bank has been developed. There are other final considerations before a decision can be made such as, how fast will the equipment become obsolete? Will the positive tangibles of re-use offset the fact that a large deal of money must be expended to deliver and develop a file structure? Then, finally, can the company get a safer and/or larger return on its investment in some other venture? This is always the trade-off.

To summarize and conclude. 1.) The general market requires or demands a relatively few types of maps in large enough quantities to make automation economically feasible to be used in their production. 2.) The cartographic industry that I speak about has a large investment in a film library capable of easily updating to satisfy almost all of the general market needs. 3.) Relatively few operations of the map making process have been really proven to be automatable on a production line basis, approximately 30 percent of the total time. 4.) Relatively little technology is directly transferable from government to industry at this time. 5.) Once the market indicates a great enough need for a new map series, the equipment investment and depreciation makes it a viable investment or so it would appear from the model we had here. (But there still are the unanswered questions of development costs of a file structure and data retrieval systems, and how that will affect the economic decision to automate.) and 6.) How can one really get a measurement on the intangibles of new markets for map products, and re-use of data base material? How can we get a better idea of the economics of this so that we can plug them into the model and get the effects they will have on the investment payback model? Thank you.

Slide 12

TOTAL EQUIPMENT INVESTMENT		1.00

PAYBACK

1. Varies: but assume minimum return is 30% pre-tax return per annum on investment. Therefore, payback should be about 3.5 years

2. Assume two 50 map series over four years.

23% out-of-pocket savings per map on first series of 50 maps	=	.44
38% out-of-pocket savings per map on first series of 50 maps	=	.74
TOTAL PAYBACK IN ABOUT FOUR YEARS	=	1.18

The second person to speak is Roy Mullen. I think many of you know him. He has had 25 years of experience with the United States Geological Survey, and at the present time he is the Chief of the Office of Research and Technical Standards at the United States Geological Survey in Washington, in the Topo Division. He is going to talk about the economics of digitizing from the USGS perspective.

MR. ROY MULLEN: Thank you, Jon. Good afternoon. If Rupe Southard is here I want to say just one thing about that introduction. After the one he got this morning I want to point out that the importance of the job is not directly in proportion to the length of the introduction that you received. I want Rupe to be sure to understand that. (Laughter.) I would also like to say one other thing about that short introduction. I liked it, but I would like to add one thing: There was another highlight in my career, and I do not say that just because I am back here in San Francisco. From 1972 to 1976 I had the opportunity to head the West Coast operation of the Geological Survey's Topographic Division, and I still consider that to be a highlight in my career. There is one other thing I would like to say--If Vern Cartwright is present, and if Vern Cartwright is not present he should have been observant enough this morning to have noticed when he asked how many people were from out of town--I could have told him who all the Californians were, because they all had mildewed shoes. (Laughter.)

I would like to say something about the economic requirements for digitizing in the Geological Survey. I could have, in trying to find a title for the speech, or presentation--it is not a speech; Jon very carefully informed us that we all had 12 minutes. I do not know exactly what that meant after I heard his presentation. (Laughter.) But I would like to say that I want you to listen very carefully, because the amount of money that the Geological Survey--and I should refine that--the Topographic Division of Geological Survey, which are the programs I am going to be speaking about, for the amount of money we spent on digital activities and plan to spend in this fiscal year, you are hearing, in 12 minutes, about $333,333 worth of information per minute. So don't turn your head and don't blink your eyes or anything else, because you will miss about a third of a million dollars' worth. The question arises, can you afford to digitize? There are two paradoxial questions: Can you afford to digitize? And the answer is probably no. The reverse of that is, can you afford not to digitize? And, unfortunately, the answer to that is also no. So that is the kind of position you are in. We do not think we can afford not to digitize map information. We are also, of course, in a position, and I think that position has been stated, and Jon referred to it himself: We do not have the philosophy to digitize to produce another graphic. We do not believe that that is a cost effective way to go. We firmly believe that the collection of the digital data and the management uses of that information after it has been collected are far more important than going through the process of producing digital information so that we can produce some more graphic map products.

The size of the task facing the Topographic Division of the Geological Survey was referred to somewhat by Rupe Southard this morning.

We have about 55,000 plus 1:24,000-scale maps, and I might say that we have adopted the 1:24,000-scale map series as the largest scale map that we should begin collecting digital data for. It also has about the amount of resolution that we think the mapping community, the users of this information, need at the present time. This presents us with a couple of problems. Fifty-five thousand plus 7 1/2-minutes quadrangles; about 40,000 of those are already in existence as graphic products. So how do you go about the process of digitizing those some 40,000 maps that already exist? We are already in the process of producing those other 15 to 17,000 maps. The question arises: Should we begin collecting digital information now at the map compilation stage to produce those maps? The jury is still out on that question. We do not have the answer to that question yet. But I will say this, that we are not doing very much of that kind of thing--that is, digitizing straight from the stereo model.

We have concluded several things about digitizing. As I say, can we afford not to? We have concluded that enough demand exists now for digitizing cartographic information, and are thus devising what we are calling a multipurpose cartographic data base.

We feel it is our responsibility under the National Mapping Program to be the base data collection agency for the federal government. We also feel that producing graphics, cartographic map products like we do in the Geological Survey, to turn over to another federal agency like the Forest Service, who is interested in terrain information, the Bureau of Land Management, who is interested in the land net on the maps, the Water Resources Division, who is interested in the hydrologic units and the hydrology on the maps--we feel that producing those graphics to turn over to them to digitize is not the proper way to go either. Consequently, we are looking at addressing the digitizing problem from those objectives. Our objective is to devise, design, and implement within the federal government the multipurpose digital cartographic data base. How easy that is to say and how difficult that is to do. Because I know there are many of you in the audience who have had some experiences in trying to do these things, and you know how difficult it is.

I might also say that we are taking an approach which somewhat parallels the suggestion made this morning by the good doctor from Kansas who suggested that research not stop. We are doing research at the same time we are doing production work, and we intend to keep it that way and probably not only intend but will have to keep it that way for probably the next several years.

The enormity of the collection task, plus the cost of the task, is staggering. The cost of the task for digitizing the 1:24,000-scale cartographic data base for the United States was estimated by the people who produced the IGU study; it being on the low side from about 60 cents per line inch to $4 per line inch. If we take those figures and apply them to the numbers of inches of line information on the maps, the figures do become staggering--for contours alone, from $141 million to $938 million. The study does point out that these figures are not accurate, that they do not have sufficient data to support those numbers. After reading the report and trying to come up with some numbers from that, extrapolating numbers from that, I assumed, okay, we will average the low to the high, but the number still comes out to be somewhere in the neighborhood of about $500 million. At the risk of giving away company secrets, that is more than we have spent in producing the entire topographic map series for the Geological Survey for the past 25 years.

Also another factor that might be of interest is the fact that while those figures, as I say, did not have any data to support them, we do have some recent figures on a recent digitizing contract that we let. We are doing some digitizing outside the Geological Survey as well as inside, and some interesting numbers come from that. One of the proposers said they could do the work for about 20 cents per inch, which is one-third of the cost used in the IGU report. The highest proposer on that particular request for proposal was $2.20 per inch, more than ten times as much. But some other interesting figures come back in there. The coding, for instance; the proposer who could do the linear digitizing for 20 cents an inch also required 75 cents an inch to code that data. When you consider those two figures together: comparing a company who proposed to produce digital line information at about $1.20 an inch and code it for 15 cents an inch and the company that was going to produce it for 20 cents an inch and code it for 75 cents an inch, it would cost almost $6,000 less to pay $1.20 an inch than it does to pay 20 cents an inch, so that is kind of an interesting little sidelight there.

FROM THE FLOOR: You said $2.20 earlier. MR. MULLEN: What I said was the highest proposer was $2.20. It was not the highest proposer who came in with the lowest bid. One dollar 20 cents an inch is from the proposer who happened to come in with the lowest bid but had a very high cost per inch but a low cost to code that data per inch.

We suggest in the Geological Survey that there are many, many problem areas, and there need to be some important decisions made as soon as possible on the data base design, on developing a true multipurpose data base, on hardware to support such a selection task, and on the software programs in support of the collection, storage, and then support in the dissemination of the volumes of cartographic data that will be developed in this country in the next few decades.

Now what must be done, or should I say, what must we do? And that is not a self-serving statement. We, the people in this room, who are here obviously because we are interested in the development of digital data bases, we think that before any economies can be truly realized, we think that there are these three areas--and there are many others--but these three areas where we need to do some further work. We, the Geological Survey, are involved. I know that the DMA is involved, and I know others are involved also. One, we must truly solve the raster to vector conversion problem. Two, we must be able to tag and code data without requiring labor intensive interactive intervention. We must, say, get after the industry to develop mass storage devices. Another area which I mentioned, the on-line versus the automatic scanning, comes into consideration when we are talking about the development of digital cartographic data bases. There is another factor that we could perhaps consider, and that is the fact that if we have truly automatic digitizing systems, we would not necessarily have to develop that total national cartographic data base at the present time, but do what I would call on-demand digitizing; when someone asks for a certain graphic to be digitized, be able to produce that digital information in a very short period of time. We think that is an area that needs some development work, and I think it is an area where perhaps a philosophy ought to be developed as to how we approach digitizing from that aspect.

I have not addressed the economics of manual or free cursor digitizing versus automatic scanning of line data. The procedures followed to produce the cartographic information are labor intensive, but in spite of that we believe there are certain cartographic information data which may almost always best be digitized manually, not necessarily total automation of the entire process. We are going at developing digitizing capability in that way also. One best guess is that a four- to five-year time span lies ahead before we realize any economies or many economies in the digitizing process. We do not, if you will permit a pun, we do not believe that we can wait to buy in that far down the digital stream. Thank you for listening. (Applause.)

MR. LEVERENZ: Thank you, Roy.

The next speaker is Dr. Joel Morrison, who is the Chairman of the Department of Geography at the University of Wisconsin. Joel is going to speak today on a university's special automated cartography requirements and economic considerations.

DR. JOEL MORRISON: This will be quite a change of pace, I think, from the two speakers we have just heard. There are special economic considerations which a computer-assisted cartography instructional program faces in a university setting. In order to talk to you about these, I would first like to describe the basic characteristics and constraints that mold any computer-assisted cartography instructional program within a university setting. I will then describe three possible stages of capabilities that a university cartographic program could aspire to, and, finally, I will detail our experience at the University of Wisconsin, Madison, in developing our computer-assisted cartography program.

An initial word about economics is in order. As everyone is aware, there is a tremendous cost squeeze in most universities today. I will cite what I believe to be two principal contributory factors: First, a university is heavily invested in human resources, not material or machine resources, and as we all know, the cost of labor has risen drastically recently. Secondly, bureaucratic paper shuffling is consuming an inordinate amount of these university human resources.

Other industries may not be as heavily invested in personnel relative to materials and machines as is a university. And although the cost of human resources in a university has not risen as rapidly as the cost of human resources in the federal government in the past five years, the rise in cost has still been drastic. The second reason is the tremendous waste of the university's human resources that is being forced upon it under the guise of "accountability." These rules are especially prevalent in public universities such as my own, which must answer to both the federal and a state government. A lion's share of the blame, though, must be placed with the federal government. A sizable bureauracy is now a necessity at each institution to merely answer the numerous federally required reports. Much of this is to demonstrate that the university is not discriminating against people on the basis of sex, race or creed, while another large chunk of the reporting concerns the economics of the use of the monies within the institution. These two areas of report answering alone probably ensure that we at the university do discriminate against both instruction and research, the two items that should be our primary aims at the university. However, I will leave my pet peeves for a moment. In summary, let me say that a university does not have a lot of unencumbered money lying around, and I want you to keep that fact in mind as I continue.

It is simply out of the question within the university's budget with which I am familiar to purchase at one time all of the capital equipment necessary for a complete computer-assisted cartographic system. And I am talking about a really small system at this point. Setting up a computer-assisted cartographic facility at a university must be done under constraints in addition to the economic one, and within the following setting.

First, by 1978, it is a pretty safe assumption that any university has a rather large-capacity computer facility. In most cases, this facility has been in existence for some years, and has existed to serve a whole spectrum of disciplines ranging from the university business office to the departments of engineering, physics, art, and so forth. This facility will, in all probability, have the standard statistical and mathematical routines that a cartographer will need in order to classify map data. However, few will have strictly cartographic routines. This is what Bob Aangeenbrug talked to us this morning about; we do need the equivalent of a BMD or an SPSS or something like that in cartography. Most facilities may have some graphic output device and a modicum of graphic software to draw graphs, curves, et cetera. However, few will be able to draw finished copy for map products. Furthermore, interdisciplinary professional jealousies do exist. Assume this scenario, and consider the economic fact of university life described above; then let us view the cartographic discipline in this setting.

A university cartographer usually can get his first map drawn with computer assistance by requesting time on the university's existing large CPU and by taking a set of data, processing it, and requesting hard copy output. By analysis, one can characterize then the first two requirements for a computer-assisted university cartography program. These are merely a set of data and the requisite software. This immediately brings to mind an initial stage of development consisting of two priority items for the establishment of a computer-assisted cartographic system at a university. First, a person who can develop or obtain and modify the necessary cartographic software, and second, some equipment that can create or "capture" machine-usable data that can be of use to a cartographer. This represents a basic level capability.

Generally speaking, the cost of processing the data at a university is subsidized, and thus is not of major concern in an academic environment. Likewise, the need for speed is not critical. In instructional use, the need for high resolution is also not critical. The University is not a map production agency, and, therefore, to wait overnight or even over the weekend is not critical. On the other hand, the need for full, complete and easy to understand documentation is critical. The university, when not filling out a required federal form, must impart information to its students. Ease of access, therefore, by many individuals with various levels of training becomes a major requirement. Another major requirement is flexibility of the individual system components.

Truly, one should seek to maximize capability for the minimum cost in a university setting, while utilizing the available human resources to the utmost. This means that it is not necessary to buy a complete working system from one manufacturer at one time, even if that were an economic possibility, but, rather, it is necessary over an extended time period, as money becomes available, to pick and choose individual pieces of equipment, to be able to program the links between these different pieces of equipment, and to select equipment that is, and will likely remain, flexible.

All of this selection of components represents an integral part of a university's education function. Obviously, when one does buy from a number of manufacturers, efficiency is lost in setting up a working system. However, once again, it must be remembered that the university is not a production shop. Therefore, downtime or inconvenience for a few months is not that critical, and often the solution to these problems may turn out to be as instructional as would actual production. Thus, in a university setting, the capacity to create or capture cartographic data and to generate software represents an initial stage in the development of a computer-assisted cartography program. The availability of both machine-readable data and software is increasing each year. Thus, most university cartographic instructional programs should be able to attain a Level I computer-assisted system, provided personnel are present.

A second stage probably consists of gaining in-house remote access to the central university CPU. This, I believe, is the next priority in the game of developing a university computer-assisted system. After the software development and the data creation capabilities have been met, the cartographer, for ease--because we do normally deal with large amounts of data--obtains a remote access terminal to the main CPU for processing purposes. This may be the final stage for some university cartographic programs. It is possible to perform some fairly sophisticated cartographic manipulations with a Level II capability. In fact, some manipulations, because a large CPU is being used, can be more complex than those available in what I will refer to in the Level III system shortly. What a Level II system does not offer is the instructional benefits of in-house, hands-on computer assisted cartography.

A third stage that a computer-assisted cartographic department could follow consists of a major step. This step is not one that all departments should take. This step is to gain a complete in-house capability. In most instances, Level II capabilities are retained as a program moves to a Level III system. The obtaining of an in-house capability is a step of considerable magnitude, and represents a substantial commitment on the part of the university to a cartography program. Accompanying this step are some built-in inefficiencies. Initially, for example, all software must be modified to fit on the smaller capacity CPU that is brought in-house. Considerable redocumentation may also be necessary. Nevertheless, a Level III system coupled with Level II capabilities probably represents the optimal system for educational purposes.

I have outlined three possible stages of levels of development for a university computer-assisted cartographic capability: (1) Software development and data creation capabilities. (2) Remote access to a large CPU. (3) Complete in-house capabilities. Not all departments should strive for Level III development. For those that do, the economics of the university setting will usually dictate, unless some wealthy alumni can be enticed to give the required sum of money, that the third level will be reached with due caution over a number of years. To attain it takes almost continual lobbying for monies from various sources.

I would like to share with you now the information about the system with which I am most familiar, the one we have at Madison. We started in April 1968, by getting a Thompson Division Pencil Follower Digitizer, which was interfaced to a rented IBM 026 Keypunch at a cost of about 18,000 dollars. In September of 1970 we got authorization for a part-time employee to be a software programmer. In March of 1972 we got a magnetic tape recorder interfaced to the Pencil Follower Digitizer at a cost of $8300. In January of 1973 we were authorized a full-time specialist in computer-assisted cartography.

In July of 1974 we purchased a Bendix DATA-GRID digitizing table, with a magnetic tape recorder and keyboard at a cost of a little in excess of $19,000; and in March of 1975, we purchased a Princeton Electronics Products Model 801 graphic terminal at a cost of about $9500. In May of 1976 we purchased the IBM 029 Keypunch interfaced at that time to the Pencil Follower Digitizer for about $2,000, and in February of 1976 we were authorized to purchase a PDP 11/34. The cost was $10,300. We were further authorized to purchase a DIGIDATA 1730, nine-track magnetic tape unit, $6,700, an AED8000 Controller for an 80 megabyte CDC disk drive, $14,900; a DEC writer

LA-36, $1,440, and RT11 operating system and Fortran compiler, an additional 16 K memory for the PDP 11/34 and a disk pack, $3,350. The total cost was in excess of $30,000. Finally, in December of 1976 we were authorized the purchase of a Versatec Model 1200 A electrostatic printer/plotter at a cost of $12,000.

All components are operational by mid 1977. Thus, we can see that essentially we, in Madison, reached a Level I system in September of 1970, a Level II system by March of 1975, and a Level III system was authorized by December 1976. The total expenditure in hardware of the pieces I have mentioned came to slightly in excess of $100,000, not including numerous interfaces, software development to link all of the equipment, and personnel time. This capital equipment cost spread over essentially a ten-year period averages to a little in excess of $10,000 capital dollars per year. Viewed in this light, it is not an especially expensive investment. Granted, the actual investment total committed to the system must be, at a minimum, two and a half times that figure per year when personnel time and material costs are included, still, this translates into only the cost of a full-time senior professor. The hardware costs for the system that we have are finished for the moment, and no additional hardware is contemplated. The benefits from a facility for student training have been considerable, and I think now we are in a position where we can offer in-house full-time hands-on training.

Therefore, for the future the hardware within our instructional program will prove to be cost effective, and one can conclude that the system is a wise investment from an instructional point of view for a university who makes a commitment to go into cartographic education. I thank you. (Applause.)

ADVANCED CARTOGRAPHIC SYSTEM

MR. LEVERENZ: The final presentation is going to be made by Fred Hufnagel. Fred has been an employee at DMAAC since 1948. During this period he has worked on a wide range of cartographic programs there that have led to his responsibilities dealing with advanced automation technology. As I said, Fred is in the Advanced Technology Division of DMAAC, and he serves as a project manager and staff consultant on the development of new techniques and applications dealing with cartographic sources and equipment. The topic of his discussion will be DMAAC's Advanced Cartographic System.

MR. FRED HUFNAGEL: Major advances in computer technology have affected us all, one way or another. In the case of aerospace programs, these advances have had a pronounced impact on aircraft, missile and space navigation systems, as well as aircrew simulators used for training. In turn, these systems are demanding increased numbers of highly sophisticated digital products from our Defense Mapping Agency Aerospace Center, in favor of graphic products. DMAAC recognized this distinct trend in changing user requirements in the mid-1960s. Work was begun, in conjunction with Rome Air Development Center at Rome, New York, and various commercial companies, to acquire and implement a series of automated systems. The new breed of products left no doubt whether to automate. Rather, the question at our Center was what type of systems would best satisfy our production requirements economically and responsively? Today, the developments started in the 1960s are continuing. New capabilities are being integrated into existing processes on an evolutionary basis, as technology progresses. This group of equipments and related software is collectively known as the Advanced Cartographic System, or ACS.

Before describing some of the major ACS components, I want to show a few examples of those programs that are driving our digital data production. First, great emphasis has been placed in recent years on training aircraft crews in digital flight simulators, such as that for F-111A aircraft (Figure 1). Substantial savings will be realized in funds, fuel and aircraft operation and maintenance. Essential to the operation of the simulator is data in digital form that defines the basic characteristics of both relief and planimetric features having radar significance. This data is used in the simulator for computation and real-time display of radar scenes for various sets of aircraft location and range parameters. Derivation of the cartographic input data is performed by the ACS at DMAAC. The right side of the vugraph shows sample portions of the main training area, near Las Vegas, Nevada, that has been analyzed and simulated. The next slide shows, in more detail, how the DMAAC data is produced.

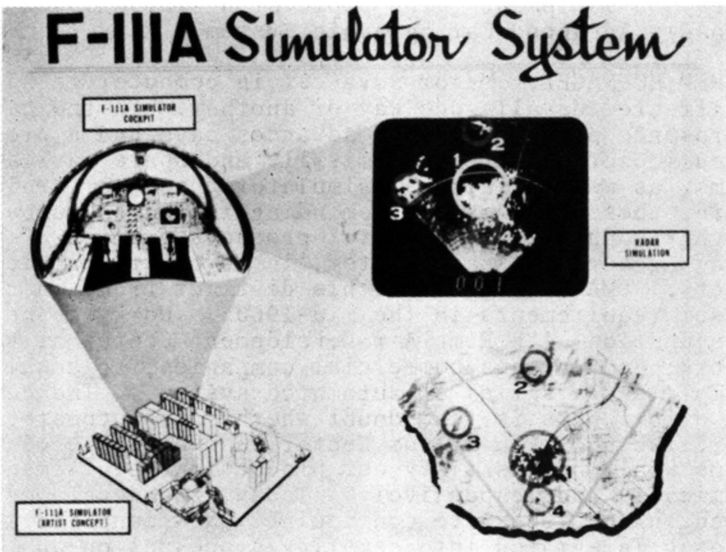


Figure 1

Using a variety of source materials, mostly photography, radar significant features are thoroughly analyzed in terms of size, location, orientation, composition, etc. (Figure 2). Outlines of the features and identifiers are compiled on a manuscript and a related descriptive record--called a Feature Analysis Data Table--also prepared. The manuscript is digitized by the ACS equipments. The descriptive data is also converted to digital form. Both digital records are then merged in our UNIVAC computer system to produce the magnetic tape that is provided the simulator user. The data is used in the simulator computer with a set of transformation software to produce the desired radar scene displays.

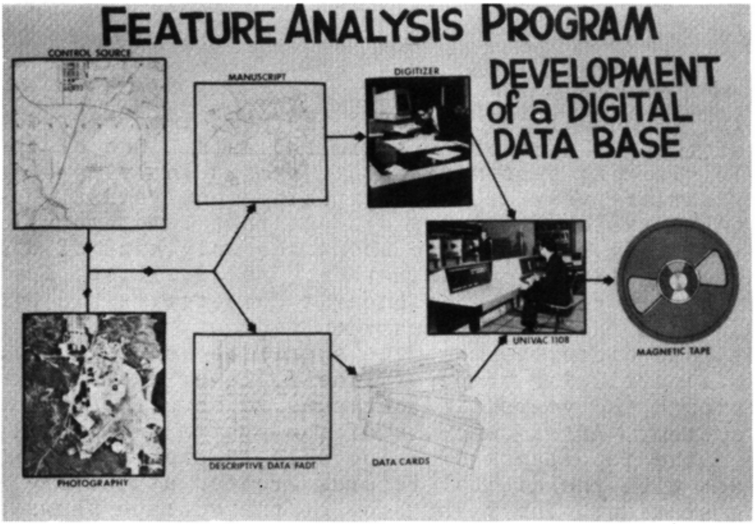
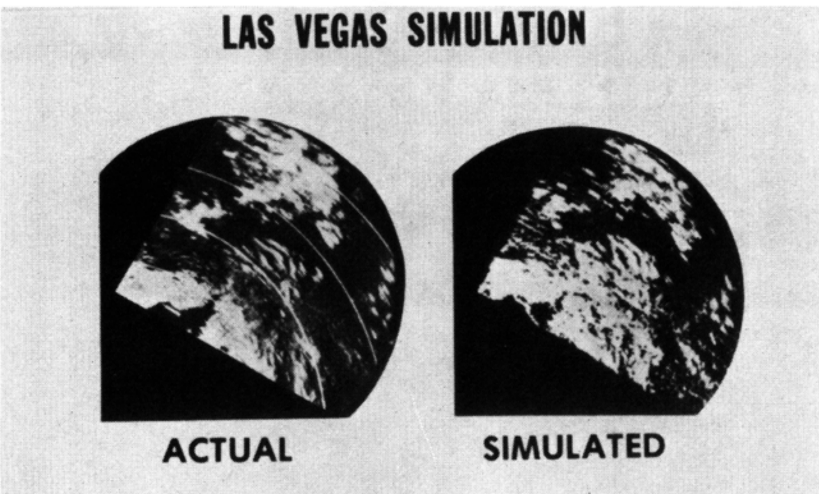


Figure 2



(Figure 3). This slide contrasts an actual radar scene of the Nellis AFB, Nevada, area with a synthetic one in which the radar return from terrain and planimetric features has been simulated.

I'd like to now discuss some of the more important equipment of the ACS that produce digital data. One of the first digitizing systems brought onboard in 1973 to initially satisfy very urgent digitizing requirements was this CALMA system. (Figure 4). At that time, manual line-following systems were about the only kind of digitizing capabilities on the market. We advertised our specification requirements under a competitive bid procurement and the CALMA Company turned out to be the lowest cost bidder to meet the specification. This is how this particular brand of line-follower was acquired and through the years, it continues to be a good production system. After some use of the system, we quickly learned the importance of being able to examine and interact with the ditital records created at the digitizing station. The right side of the vugraph shows a CRT display that we retrofitted to the computer for these purposes.

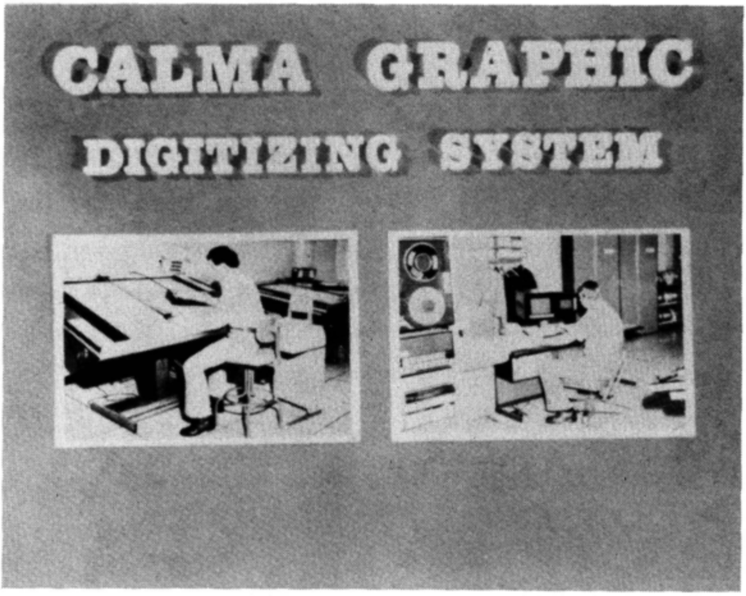


Figure 4

Figure 5 shows the cost figures, in terms of thousands of dollars, for the different CALMA system components.

CALMAGRAPHIC SYSTEM COST ($000)

	PER UNIT	NO. UNITS	TOTAL
○ DIGITIZING TABLES	$ 20	2	$ 40
○ NOVA MINICOMPUTER	12	1	12
DISK UNIT	13	2	26
MAG TAPE UNIT	10	1	10
TELETYPES	1	2	2
READER PUNCH	1	1	1
○ INTERACTIVE EDIT STATION	73	1	73
		TOTAL:	$164

(NOTE/ SOFTWARE DEVELOPED IN-HOUSE)

Figure 5

Figure 6 depicts the next, more elaborate, digitizing system that became operational in 1974. This is our Lineal Input System, or LIS. As you can see, eight work stations are on-line with a DEC PDP-15 computer. A Xynetics proofing plotter and interactive edit station round out the LIS components. Now let's look more closely at one of the digitizing work stations.

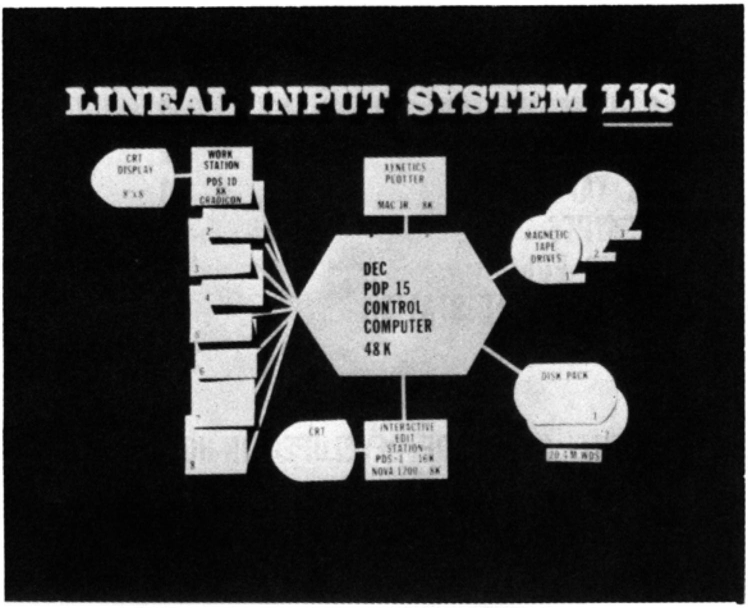


Figure 6

Figure 7 shows the Gradicon table interfaced with an IMLAC PDS 1D minicomputer and CRT display. The CRT not only displays segments of cartographic features for cursory examination and editing, but also menu code listings as shown on the slide. The listings facilitate input of the code identifiers that must accompany the feature data in the digital record.

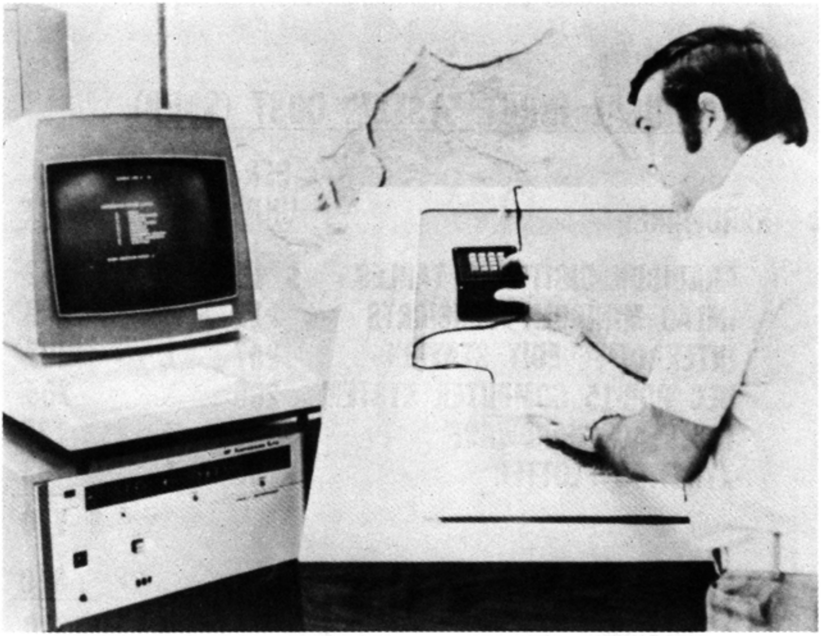


Figure 7

The LIS cost is itemized on Figure 8. As you can see, a large part of the cost was expended on software, both system and application software. In addition to typical functions dealing with feature and feature identifier entry, deletion and related modifications, the software performs a wide variety of other functions such as clipping and joining features, sectioning, table to geographic coordinate transformations, datum shifts, projection transformations, etc.

LINEAL INPUT SYSTEM COST ($000)

	PER UNIT	NO. UNITS	TOTALS
○ HARDWARE:			
GRADICON DIGITIZING TABLES	$ 19	8	$ 152
IMLAC MINICOMPUTERS/CRTS	11	8	88
INTERACTIVE EDIT STATION	207	1	207
DEC PDP-15 COMPUTER SYSTEM	205	1	205
INTERFACE HARDWARE	25	1	25
XYNETICS PLOTTER	93	1	93
			$ 770
○ SOFTWARE:			840
		TOTAL:	$1610

Figure 8

Figure 9 is a picture of our Raster Plotter-Scanner, or RAPS, System that will begin to be operational at our Center later this year. It will be capable of both digitizing single color graphics in a scan mode, as well as plot final negatives, in sizes up to 127cm (50") by 178cm (70"). It will perform either of these functions for a given graphic within 30 minutes, or a fraction of the time and cost now required. While raster systems entail considerably more computer processing, we are taking steps to expand our computer capability for this and other reasons. With the proper balance of computer power, we believe raster technology is the direction to strive for in the future, particularly if one has large volume digitizing and plotting requirements.

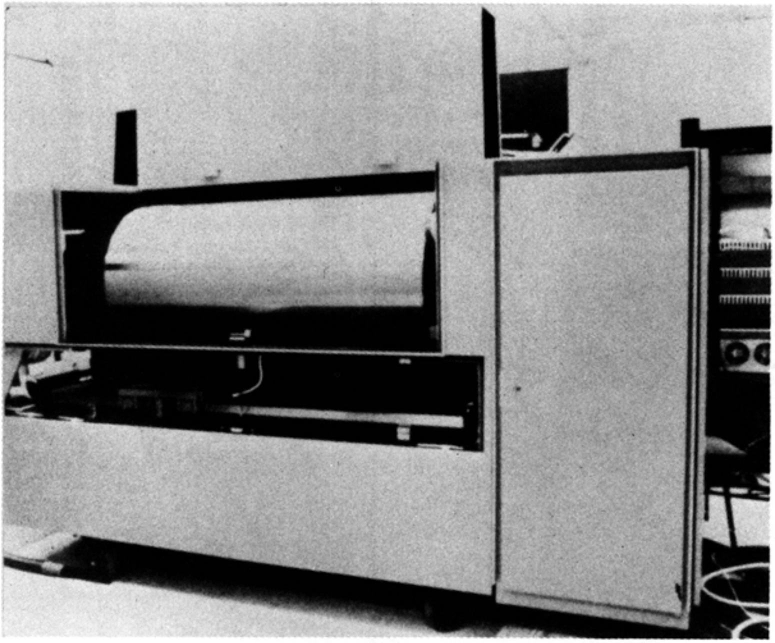


Figure 9

Figure 10 is a picture of the type of color raster scanner system we plan to bring on board in a couple of years. It carries the raster digitizing function one step further by distinguishing between colors, and therefore feature categories, when scanning multi-colored graphics. One application will be to rapidly convert source maps to digital form for more efficient exploitation in the compilation processes.

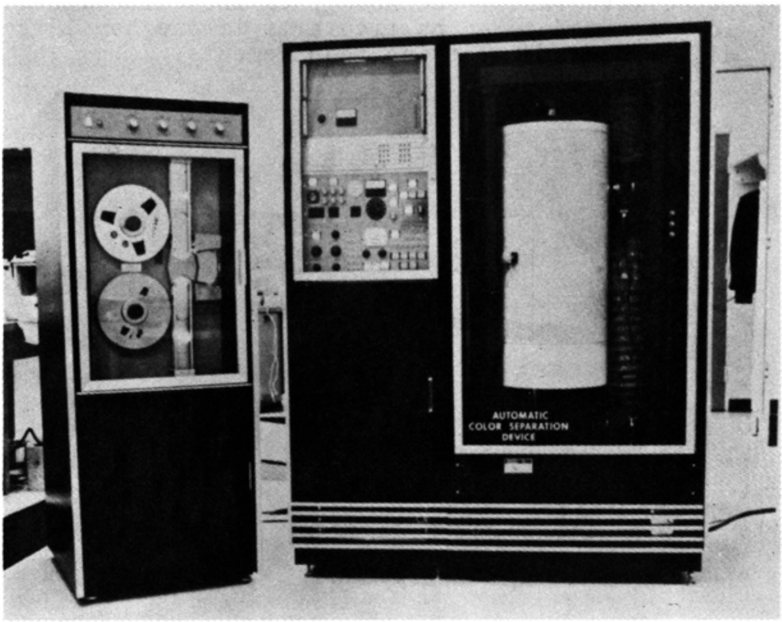


Figure 10

The Aerospace Center has a number of AS-11 stereoplotting systems in operation today. The system shown on Figure 11 is the latest and most sophisticated model of the AS-11 family. The vast majority of these stereoplotter equipments were designed to perform tasks other than digitization of various photographic source materials. However, all of these systems and future acquisitions will be configured to efficiently scan and extract relief data from photo sources, as well as manually collect planimetric features.

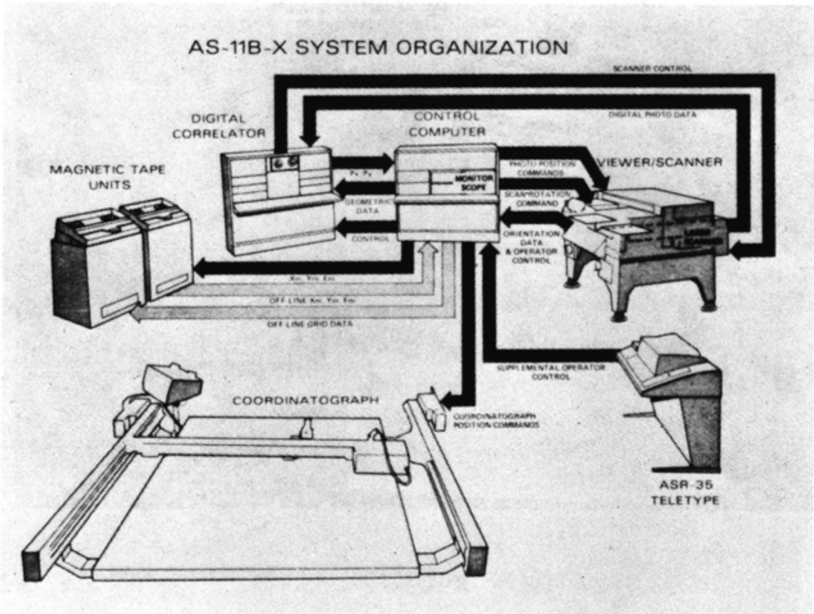


Figure 11

Figure 12 simply shows what the actual components of the AS-11B-X stereoplotter system look like. An effort is underway which is termed Integrated Photogrammetric Instrument Network, or IPIN, System. When fully implemented in about two years, the IPIN will pool all the individual AS-11 stereoplotters together into a single system for increased flexibility and productivity.

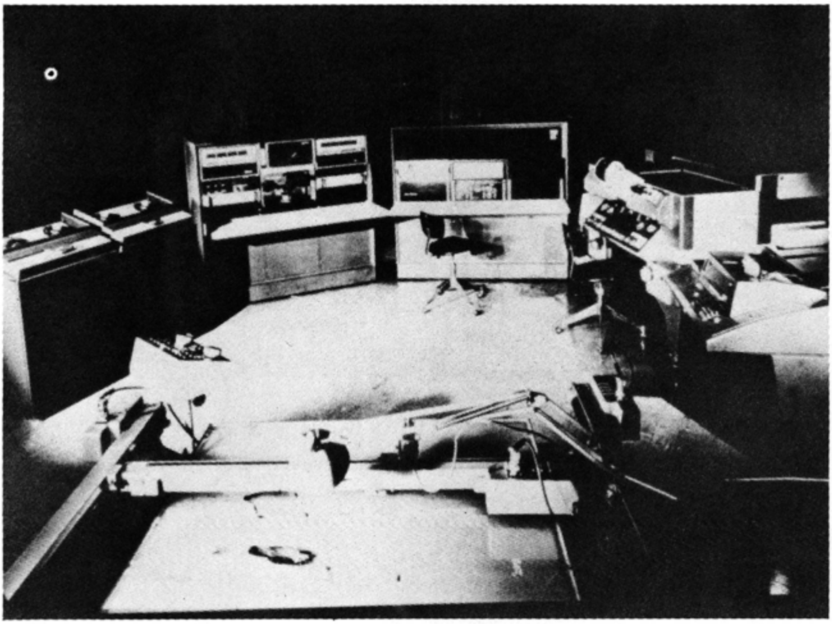


Figure 12

We have several different types of plotting systems and I'm sure most of you are familiar with the type of Gerber plotter shown here on Figure 13. This is our Model 2032 that has been in operation for about five years, and uses a strobe light to plot line work at optional speeds of 75, 150, or 225 inches per minute--depending upon the complexity of the cartographic features.

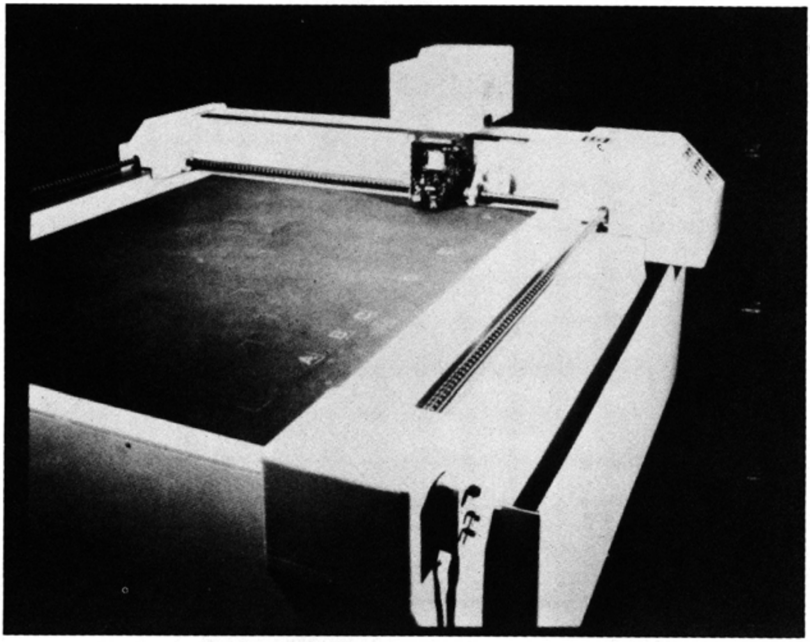


Figure 13

About mid-1978 we will be retrofitting a CRT onto the plot head gantry (Figure 14). The electron beam of the CRT will "write" symbology and alpha-numeric characters onto sensitized film as it sweeps across the CRT face. After all data is plotted for a given CRT location over the film, the process will be repeated for another data set at the next location on the film. The CRT print head is expected to speed up our Gerber plotting by four times.

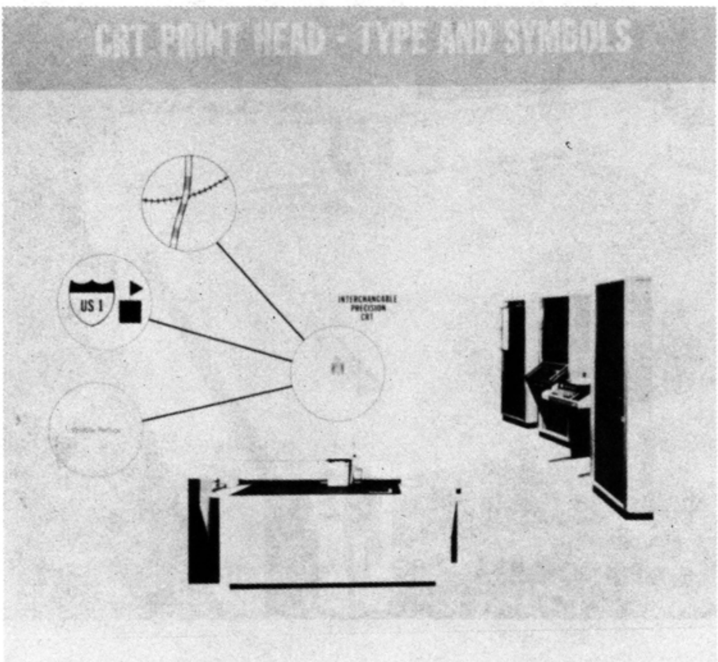


Figure 14

Figure 15 depicts what the CRT head will look like mounted onto the Gerber Plotter. As shown, part of the system is a DEC PDP-11/45 processor system which will manipulate the data and store the digital fonts for the typographical plotting applications.

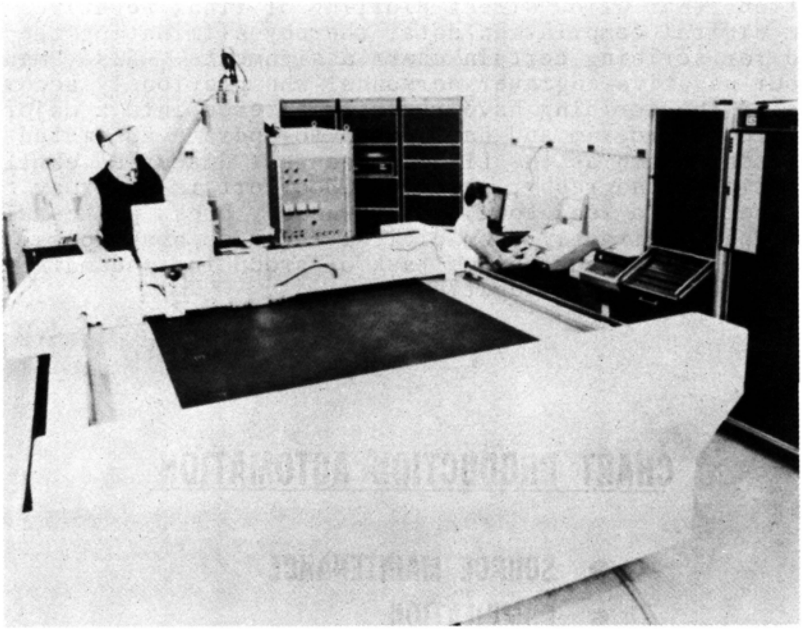


Figure 15

Although the volume of our chart production is diminishing in favor of digital data production, DMAAC expects to continue to support aerospace users with graphic products for a long time to come. As such, we have taken positive actions to automate many of those processes dealing with chart production (Figure 16). In the area of source maintenance, we have reorganized files and established automated management systems to better control the accountability and use of the thousands of map, photo, and textual materials we have on file. As to the fundamental phases of compilation, we are just initiating an R&D effort that will design and implement a system that will mechanize many of the steps comprising these phases and be operated by professional cartographers. At this preliminary stage of development, it is expected that significant use will be made of advanced display devices to take advantage of their ready access and relatively easy interaction with digital data records. With respect to scribing, software programs are already available for one of our major chart series, and others continue to be written, that allow direct plotting of final negatives from digital compilation data, thereby eliminating the need for scribing certain chart assignments. Also, many of our negative engraver personnel who previously accomplished the scribing have recently entered into a major retraining program and have begun to operate automated equipments such as the LIS components I discussed earlier. Regarding lithography, another R&D effort is underway that is expected to lead to a system whereby press plates will be prepared directly from digital records, again possibly eliminating the burdensome task of producing and maintaining large size film negatives.

CHART PRODUCTION AUTOMATION

- SOURCE MAINTENANCE
- COMPILATION
  - SOURCE SELECTION
  - FEATURE SELECTION
  - FEATURE DELINEATION
- SCRIBING
- LITHOGRAPHY

Figure 16

As a final slide, I've attempted to highlight some thoughts on the pros and cons of implementing automated systems on Figure 17. First, as it did at DMAAC, it allows you to produce new types of digital products that previously was not feasible, regardless of how much money or time was available. With more powerful computers being marketed every year, coupled with higher speed digitizing and plotter devices, improvement in production speed and shorter response times are certainly major benefits. Similarly, expanded use of computer processing increases flexibility of operation in terms of the options available for such considerations as workflow, product output, and data exchange. This last consideration is especially important to the Defense Mapping Agency where separate Production Centers are involved. I think there is no question about the ability to raise volume output with automated systems. As to economic savings, each agency's requirements are different and obviously, the cost of any given system has to be weighed against the anticipated savings and analyzed and evaluated on its own merit. By system I mean all three basic components of hardware, software, and people. However, I think generally it can be said that integration of automated systems into manual processes can usually be economically justified where production needs demand high volumes over several years.

Under disadvantages, a heavy outlay of funds is necessary at the start and this, of course, has to be considered as part of the overall economic analysis. Different skills will be required. This necessitates retraining, such as in the case I mentioned earlier at DMAAC involving negative engravers, and sometimes hiring of new personnel. For systems of any size and complexity, facility modification must be recognized and planned for. As an example, it cost 73,000 dollars to prepare the production area for the Lineal Input System I described a few minutes ago.

I hope I have enlightened those who are contemplating the introduction of automation into their cartographic processes. Thank you for your attention.

CARTOGRAPHIC AUTOMATION FACTORS

- ADVANTAGES
  - NEW PRODUCT FORMATS
  - PRODUCTION SPEED IMPROVEMENT
  - INCREASE IN FLEXIBILITY
  - HIGH VOLUME OUTPUT
  - ECONOMIC SAVINGS (HIGH VOLUME--LONG PERIOD)
- DISADVANTAGES
  - LARGE INITIAL COST
  - DIFFERENT SKILLS
  - FACILITY IMPACT

Figure 17

MR. LEVERENZ: Dean has informed me that we are going to have about 15 minutes for questions. All questions should be asked from the floor. I would like you to give your name, and address your questions to a particular person on the panel, please.

MR. TOM WAUGH: My name is Tom Waugh from Edinburgh, Scotland. I would like to go back to Mr. Leverenz's first discussion we had this afternoon. I find it somewhat amazing, somewhat amusing, in fact, in that if you take the kind of figures he quotes and the kind of attitude that he suggests, and divide the figures by a constant factor, I think that talk to a certain extent could have been given by David Bickmore ten years ago. I do not think the difference between automation and manual methods of producing atlas maps is any cheaper now than it was ten years ago. I think what has happened, is that hardware is cheaper, manual costs have gone up, and hardware has gotten better. Therefore there is a slightly increasing gap there between the efficiency of one versus the other. I disagree with quite a few of his assumptions, one being this business of automating a complex manual process. As has been shown time and time again, and I think some of the British Ordinance Surveys in the UK are a graphic example of that, that it is the by-products of automation that will save you the money and the other productions you can produce, not the original thing you actually got in for.

However, it is very interesting that the atlas companies have not really gotten into it, considering it was the atlas company, or Clarendon Press, in this case, that actually started this whole business way back in, what, '63, '62, something of that nature. I think it is surprising that none of them have actually gotten into it. I have a sneaky feeling that when the atlas companies actually take less risk, as they call it, and go into automation, then finally automated cartography has arrived.

MR. LEVERENZ: Thank you for the comments. I think you are right. There were in 1963 or thereabouts, early '60's, there was a tremendous grandiose plan proposed by David Bickmore. However, I think at that time Rand McNally as well as many other commercial firms were looking closely -- and many of the things that David suggested were implemented in various parts of the automated cartographic field. However, still, an automated system, even automating part of a commercial production system such as, as you say, an atlas company, is still not an economically sound investment. That is based upon the fact that the market market does not call for the by-products you talked about. I think that is the one main item. We cannot say, as in many countries, <u>you are</u> going to use this product, and get subsidized by the government, <u>and</u> therefore, produce that product. I tried to make it clear that the market must support the product that is produced. There just are not that many by-products that the market wants right now -- the general market, I speak of. Are there any more questions?

MR. CRAIG SKALET: My name is Craig Skalet with the Geological Survey in Menlo Park. When I was going to school in Wisconsin someone said something to me that has become etched in my mind, and I do not want to name any names, but he was a professor, and his initials are JM. (Laughter.) He said to me that in the future he did not expect automated cartography to be anywhere but in government. The implication being that it was not at that time cost effective for private industry to get involved in it, and he did not see that the future held anything for private industry. I would like someone to comment on whether that has changed, and whether the future holds anything for private industry with respect to automated cartography.

MR. LEVERENZ: I guess I will have to at least make one comment. I think some of the figures that I showed on the slide probably went by rather quickly. Maybe there will be time to talk about them later. But I do think that, yes, in fact I do think that the commercial industry, commercial cartographic industry that I described will be into automation very shortly. I think the cash flow figures shows that there is a lot of potential. Incidentally, this, as the first question intimated, this has changed in the last four years very dramatically to where a four-year payoff is possible, as I indicated. Would there be anybody else who would like to speak to this as far as their idea of the commercial firm and whether they might get into it in some way?

MR. MITCH MODALESKI: My name is Mitch Modaleski. I am with Environmental Systems Research Institute in Redland. Don Cooke helped, I think it was, Pizza Hut locate some 10,000 facilities several years ago using DIME files. That is a commercial application. In fact, I think Don is a millionaire today because of that project. Just the other day, Utah International, situated here in the city, was advertising for a systems programmer type person to do geographic data base development. I do not think there is any question that the commercial sector is already in the business of building geographic data bases or digital cartographic data bases, whatever you want to call them.

MR. JOEL ORR: I am Joel Orr. I am a computer-graphics consultant. I feel obligated to add a few words of motherhood to what Mitch was saying. Maybe mappers just do not realize it, and the map has become an end unto itself, but information is power, and not only for government. Geography happens to be a very convenient way of looking at that information. Whether it is Pizza Hut or the First National Bank who is analyzing good ways to spend their money and probabilities in terms of loaning money and so on, there is a great deal of activity going on in the public sector in this country involving automated cartography as a means to an end, and not as an end in itself. Of course, Rand McNally and people who produce maps in and of themselves, have to look at the potential of automation as far as saving them money and what they do. However, it would probably be wise if these companies -- I am sure Rand McNally has explored this -- would consider the possibility of selling the byproduct, as our friend in Scotland called them earlier, to people who are more interested in the by-products than in what Rand McNally would call the main product.

MR. RAY DILLAHUNTY: My name is Ray Dillahunty, and I am from Geo-science Division of Petty-Ray Geophysical in Houston. When you were talking earlier, you were really referring to what I would consider road maps. Rand McNally, in my opinion, sells more of a public type map than do some companies in the commercial markets that make aerial survey maps, topographic maps, more similar to government type maps. Do you think your figures hold true in that type of application also, or is there a bigger cost advantage or disadvantage in those kinds of applications?

MR. LEVERENZ: I tried to define the fact that there was a different approach for the firm that I was talking about from the firm that is making studies for McDonald's or so on, or for internal use, as I call it, even though, granted, there may be a need for that and a market for it. I cannot really speak for the photogrammetric or the aerial survey type of operation. I am not really that familiar with what market there is, but it would seem the market would be more for a specific product that would be used internally, for oil exploration or something like that, that would be more specialized, as I would call them, computer products. I think the figures that I have for investment and the method of analyzing it is a standard economic method of analyzing a payback. It all depends what figures you plug in there.

MR. PETER WILLERUP: I am Peter Willerup from the Pacific Gas & Electric Company in San Francisco. We are on the verge of entering into the mapping age through the computer. A couple of our sister utilities south of here, in San Diego and Los Angeles, are actually into this computer mapping. I feel sorry that there are none of those representatives sitting up at this panel to discuss that type of computer-assisted or cartographic output that was not only mentioned before that results in maps, that results in information, in management information of such things as utilities, whether they are gas, electric, sewer, water and so on. And I would like to have heard some financial analysis on those types of computer-assisted cartography. Because I think that has been left out completely. You are sitting up there as basically governmental agencies, with one type and a very special type, in Rand McNally, but there is a wide range of uses and management tools, for instances, utilities. But I am sure many other industries would be in the same boat as we are.

MR. LEVERENZ: Thank you. I agree. That was a shortcoming of the panel. Vern?

MR. CARTWRIGHT: Yes. Private industry has come up here. And what they are involved in -- American Society of Photogrammetry, there are about 400 map-making firms in photogrammetry in the United States. A large majority of those have been in digital mapping one way or another for ten years. More and more of them are getting into the interactive graphic system. The thing I would like to ask Roy Mullen, I would like to see if you would share your software with some of us fellows, and also the data you are getting into your data banks. Can we borrow that to make our own maps to the scales we want?

MR. MULLEN: I was prepared, if no one asked any questions -- I had a question to ask myself, and that was: Why didn't somebody say what can you give me tomorrow? That is the good question. Vern, as you know, all of the programs that are developed, software programs to support digital cartography, all of the processes of mapping that the United States Geological Survey develops are all available to the public. They are generally sold for the cost of the reproduction. None of the costs of the gathering that went into that map -- And I would like to comment on that. I wonder how much -- Who was it, Pizza Hut? I wonder how much Pizza Hut would have been willing to pay for the information that they had available from the DIME files to begin with to begin that study of locations? Would they have been willing to pay the access costs for all of that data to make those studies? I think that is the thing. And that is why I feel when I mention our responsibility in the national mapping program is to be the federal collection agency for that data. I will assure you that when that data is collected it is available to anyone and everyone who asks for it and pays for the reproduction cost of it.

Now, what is available? At the risk of delaying and cutting into somebody's coffee time, and everybody that knows me knows that I don't give a damn about your coffee time . . . (Laughter.) . . . there are what we call digital elevation tapes available from the GPM. We have a complete, for those of you who are developing a software system, we have complete 7 1/2 minute quadrangle contour information, totally cleaned data, that is available for any testing or proving of systems that you would like to work with. I would like to be able to say that I knew how much that costs, but I honestly do not. It cannot be very much. It has to be less than $15 or $20 or $30 at the most. All of our information is available and is in the public domain and is requested constantly. We give it out constantly. The DMA tapes, which the Geological Survey has and put into distribution through the NCIC, are an interesting set of data to us, because we continually get requests for information which even DMA agrees was not the cleanest, not the best, but it was the first, and it is available. We have many, many people asking for that information. I have the statistics on it, and it amazes us how many requests, how many repeat requests we have for those tapes from various entities, agencies and commercial people as well. So, people are using that data.

With respect to planimetric information, we are collecting that on a somewhat unorderly fashion -- and I will say "unorderly" from the aspect, as I mentioned, we are going after the development of the digital cartographic data base at the same time we are doing research, and also doing production work. We have a series of pilot projects, those categories that Mr. Southard mentioned this morning: land net, hydrography, transportation net; some of those things are available for some quadrangles. I would hope that someday when the job gets further down the line, somewhere near the percentage of completion of the 24,000 scale quadrangle base of the United States, that we will have most of those data categories all digitized, all ready and available for anyone who asks for them. I might say one other item. Tom Waugh talked about the work done in the British Ordnance Survey, at least partially with respect to the question that Jon addressed with respect to the costs of preparing a map digitally to produce another graphic; I think their estimate, we have found, is pretty good. If you are going to digitize graphic data to produce another or digitize planimetric map data to produce another graphic, it is going to cost you from 15 to 25 percent more to do it that way. The big advantage, as I perhaps only mention slightly, but I will say once again, the big advantage is the thing that Peter Willerup addressed, and that is all of the management uses that that information could be put to if it were available. I think that even if we had the digital cartographic data base, of the one to 24,000 scale maps available, I think you would be glad to get them. But we still have the same problems. Your specific use is going to require larger scale, higher resolution digital data than the one to 24,000 scale base will allow you to use. But, as a planning tool, I think it will still serve the same purposes that the 24,000 graphics do today. It would be the base from which you may further build a digital base for your specific purpose.

We know we are not going to devise the digital cartographic data base that is going to answer every user's needs. We could not afford to wait that long, and we could not afford the cost of developing a cartographic data base that has the answer to every single request that every single user would have, because there are some mighty strange strange requests sometimes for cartographic data. Thank you.

MR. LEVERENZ: I want to personally thank the panel, for the presentations, for their answers to questions, and for the questions from the floor.

CARTOGRAPHIC DISPLAY REQUIREMENTS

MR. DEAN EDSON: The last panel for today concerns the Cartographic Display Requirements. This is intended to be an overview of what people expect of the cartographic community in terms of a more meaningful presentation of information. We have asked Waldo Tobler, currently at the University of California at Santa Barbara, to gather a group together to discuss this very important subject.

Waldo, as I explained, is currently at the University of California at Santa Barbara. He received his Doctorate in Geography from the University of Washington in Seattle in 1961, and has been very active as a U.S. member of the International Geographical Union, the Commission on Geographical Data Sensing and Processing. This has been an extremely meaningful activity, servicing many spatial data activities throughout the world in the last few years. Waldo notes that he is currently teaching analytic cartography, and is also involved in teaching geographic information systems and regional analysis. He reminds me that he used a Benson-lehner plotter in 1957 to draw a U.S. outline map, a long time ago. So, this whole subject does date back. Waldo's hobbies include but are not limited to the invention of map projections, some of which are useful. (Laughter.) I think that is enough for me. If you are ready, I am. Waldo Tobler.

MR. TOBLER: Thank you very much, Dean. What I have tried to do here is get three people with contrasting backgrounds to show you and discuss some technologies. I will introduce them in more detail a little later. But in the order they will give their presentations, Jim Blinn in the middle, is an expert on computer graphics. The reason for asking Jim is to introduce to the cartographic community some of the techniques that they have been developing and which are not sufficiently familiar to cartographers. In the same vein, Harry Andrews is from the Image Processing Institute in Los Angeles, who will do the same thing for image processing techniques. Finally, Carl Youngmann, a cartographer is going to take the perspective of a cartographer on all of this.

Dean Edson mentioned that I had been in computer cartography for 20 years now. My recollection is that the first outline map on the Benson-lehner plotter consisted of 343 points. Since that time there have been much bigger and better data sets prepared. The history of the technology, however, has been that the first attempts were to mimic draftsmen--that is, get the machine to draw a map. We were not too much worried about data structure. I can foresee as an ultimate objective getting the information into the computer and never having to produce the map at all; solving the problems right in the computer. We are a long ways from that objective, if it is really a valid one.

I think my first slide demonstrates, in fact, the importance of graphics. I will show just a few slides, and then we will get right into the substance with the speakers. This diagram is a set of profiles, but they are demographic profiles. On the Z axis is the number of people, and on the X axis--I may have the axes confused here--is the age group. Then, along this way is from 1801 to 1947. I find this is a terrific graphic because you can see the effects in the canyons as they progress. You can see the effects of wars and so on, and it is really a dramatic visual impact. It is quite clear that humans are very good at processing visual information. I do not expect that we will ever not want the computer to do illustrations, and to just solve the geographical problem in the computer. People are very good at solving problems.

The next slide is a map. It is Minard's map, again, very dramatic, of Napoleon's march and return into Russia. You see the broad life line starting with many, many troops, and it gets narrower and narrower as he gets to Moscow, and the black line shows us how he gets back, with hardly anybody left. Again, a very dramatic graphic. I think the point I am trying to make is fairly obvious. Can we go on to the next one? This, to cartographers, will be familiar: ways of showing relief. We have on the left a lady's face with contours and shading, and on the right the Crimean peninsula with relief shading.

The next slide shows this in more practical application. This is a Swiss topographical sheet with shaded relief. I think it is perhaps appropriate--it has been done once already today--but, to remind people in the computer field of the tremendous amount of information on a topographic sheet. It is estimated at about 10^7 on a single sheet. You can calculate very quickly how many sheets it takes to cover the world surface.

The next slide shows a computer shaded relief. This one was done by Mr. Batson, et al., on the image processing facilities that they have in Flagstaff. I show this particularly because the people in computer-graphics have also been doing shading of objects for some years now. The first person in cartography of course was Pinhas Yoeli, who was doing it in 1961 on a line printer. This shows how far the technology has come. I think Jim Blinn will show some things that show how much further one can go with this in computer-graphics.

The next slide shows the kind of illustration you have seen now, quite frequently, probably; it demonstrates the increasing resolution when one changes the spot size. Some of you, I am sure, are familiar with the digital terrain tapes--that is, the sampling using the multiplication with the Dirac brush of the continuous function at fairly coarse intervals. This demonstrates the question of resolution, which I think is going to become more important in cartography, and the next few slides illustrate that.

Some of you may know that in the 1850's geographers were collecting data like the number of whales per five degrees square. If you see the movie, Moby Dick, for example, you will see that in there. Here is the world population by five degrees square, which I assembled. The next slide, please. You will see more of this, I am sure, in the future. Here is the U.S. population. I have now increased the resolution by a factor of 25. U.S. population by one degree squares. Well, quadralateral, technically. The next slide shows the data by county resolution. If you define the resolution of a geographical data set as the number of pieces of data divided into the geographical area involved, to the Kth root of the dimension--in this case, two dimensions, you find that the county resolution is--I have forgotten--3,200 divided into three million, the square root of that. From the sampling theorem we know that you can only see phenomena of a wave length which is twice the sampling interval, if it is not noisy data. So if you want to get real detailed information on the behavior of people, and people have a mean activity locus of about 20 miles a day, that means you need resolution of about a 20th of a county to detect anything interesting about individual behavior. The next slide, please. Also, geographical data are arranged hierarchically. Here we have a typical socioeconomic type of data where we have municipalities, economic areas, provinces, regions, and, finally, the whole country. This happens to be the Netherlands.

One question that I think will be developed further in the future is how you take these very interesting algorithmic manipulations that people do on raster pictures, as I am sure Dr. Andrews will talk about--how do you apply that to polygonal data?

I will introduce Jim Blinn, who is currently at the Jet Propulsion Laboratory, and also at the Computer Science Department at Cal Tech. I first met Jim at the University of Michigan, where he was doing work on a music synthesizer. He was at that time in the computing center. He received both his Master's and Bachelor's degree at the University of Michigan. He was also very influential in developing integrated graphics system, which runs under the Michigan thermal system, essentially a device-independent graphics system, where you sign on on the terminal, and the computer queries your terminal to find out what kind of terminal it is, and then the software appropriately modifies itself so that it will handle output for that terminal, so it does not matter whether you are on a Tectronix or a Hewlett-Packard, or working with a Calcomp or what have you--you use one set of software for all of them. This obviously is the way technology is going to have to go.

He has also worked at the New York Institute of Technology on computer animation, and currently does consultant work for Information International, which does computer animation. Jim left the University of Michigan and went to Utah where, of course, Ivan Southerland and Dr. Evans were working, and got his Ph.D. there in, I guess it is technically, Electrical Engineering. But he is interested in computer representation of three dimensional objects. Jim, do you want to come up here?

(EDIT NOTE: The presentation by Dr. James Blinn has been omitted because his closely-related illustrations were not available for publication. Some other illustrations shown at the meeting were unavailable, or unsuitable for printing, without the need for omission of the speaker's remarks. Dr. Blinn's remarks are omitted, however, following his suggestion, and our concurrence, that they would have little meaning without accompanying illustrations.)

MR. TOBLER: Thank you, Jim. As a cartographer I would have a lot to say about these objects that do not exist, but I will leave that to Carl Youngmann to talk about. Jim has only recently joined JPL. As you probably know, JPL has had a lot of experience with image processing, and I look forward to seeing the two technologies merge.

The next speaker also has a lot of experience in image processing, Dr. Harry Andrews. He worked at Stanford and at Southern Cal. The Image Processing Institute is located there. He has some literature which describes that operation. Harry has published two books on this. I took a course from him one time at Purdue on image processing. He is going to tell us about the work they have been doing there. His own work, I know, has been in image transforms, and I found it very interesting. They are most recently, I think, getting into satellite picture processing, but I will let him tell you about that. Harry?

DR. HARRY ANDREWS: I would just like to say very briefly that, thank you very much, Waldo, for inviting me. I do not know anything about this group. I made the unfortunate mistake of spending two weeks at DMATC, if you know what that means, in Washington, D.C., during the summer. And after that I thought I was an expert. But it is true, I am not. I did leave a little brochure out there in the next room, if you are interested in finding out what we do. Some other material I will leave up here describing the Image Processing Institute, which is an educational facility at USC. Our goal in life is to train image processors. I will leave a lot of this up here. If you are interested, feel free to take some of that material.

I think what I will do today is represent the Department of Defense community. You see, what I do is size up an audience and make sure that nobody in the audience knows anything about what I am talking about, then I represent that other side. Probably you all know about the Department of Defense, but, in any event, we have been funded for -- I guess I should not admit this -- they may want to redirect their funds. We have been funded for a while by an organization known as ARPA. ARPA is a group in the Department of Defense that gathers its funds from the other services before they get their money, so they manage to offend everybody, and then they give it to the university. (Laughter.) We established the Image Processing Institute quite a few years ago, and have been actively involved in trying to manipulate imagery with digital computers for the benefit of mankind. If ARPA is paying for it, it may be to the detriment of the enemy but to the benefit of us.

In any event, what I would like to do today is briefly go through a somewhat historical synopsis fairly rapidly to show you some of the things that have been developed in the past, and to show you some of the direction that we are moving in right at the present. I will go as rapidly as possible, because I would rather entertain questions than entertain you with slides. May we have the first slide. The first slide is where I am from. The next slide is the block diagram which you also saw of our computer facilities. I will not spend much time describing it, simply pointing out that we have a couple of KL-10 computers, which we do our number crunching on interactively, and we pass that data to our exploitation facility station. One of the topics or highlights that I think this conference might be most interested in is in the area of exploitation facilities, the use of high speed digital interactive computers and displays to allow a human to interact with large digital data bases.

Next slide. Before we get into that, I want to show our typical USC girl. Actually, this is an SMPTE slide, but you have probably seen her around. Just to set the tone, let us look at the next slide. She is made up of bits. Those are the four most significant bits of the green component. The next slide shows the four least significant bits of green component.. Essentially what we did was sliced her into 256 levels of brightness for each color, thereby resulting in 24 bits, or eight times three levels of brightness per pixel.

Next slide, please. That is what a digital girl looks like. Now, to just show you some of the things we do interactively on our display devices, we have developed what we call a little menu system, but it is an interactive or visible menu system. If you look very closely you see a little white dot that is approximately adjacent to a box to the right of the imagery. That essentially tells the computer what the operator wants to do next. In this case, the operator simply zooms down onto the airplane, which happens to be an aerial photograph of the Los Angeles Airport. The next slide. That sort of thing can be pursued in greater depth. You can magnify it all sorts of factors; two techniques showing the difference in magnification. All of this is done somewhat instantaneously on less than a 30th of a second type of interaction.

The next slide. Waldo mentioned the concept of image transforms. Really what that means in academia you had to do something mathematical or else you get fired. So what we did is we have tried applying a little mathematics to pictures. It turned out that we kept one step ahead of the reviewers for about three years and managed to publish a paper every time we invented a new transform. Actually, we did't have to invent new transforms; we just looked in some mathematical literature and then published in the engineering literature, and nobody reads both. (Laughter.)

The next slide. Essentially, one way of viewing an image, albeit somewhat artificial, is the fact that an image is nothing more than a matrix in a computer. It could be a very large matrix, maybe 2,000 by 3,000 pixels or picture elements, if you are talking about ERTS type of photography, or LANDSAT. You can break that image up into a sum of other images, as illustrated in the top row, or the bottom row, and you can add them all up and form the original. Now, why might you want to do this? Well, you may want to discover some underlying structure of the image that was not readily evident in the original photograph or original digital version. If you break it up into a set of basis functions known as frequencies, then you end up doing a two dimensional Fourier transform. If you break it up into a set of basis functions known as sequencies, then you are breaking the image up into a set of Walsh transforms.

As I mentioned earlier, we generated as many transforms as we could get away with. Let me show you what just a few of those look like on image. Next slide. Here is our little toy tank broken up into its frequencies. The frequencies are then colored: The low frequency, red; the intermediate, green; the high frequency, blue; and then put back together, so you can get a little feel for what spatial frequencies mean. That is the combination of the individual frequencies. Let us look at the next three slides in succession. There is the low frequency, red. Notice the center of the star, low frequency, and just the circle comes out. The next slide, green, shows the edges of the star, and the number twelve. The spatial frequency of the "12" was an intermediate band of frequencies. The next slide, the blues, show the edge effects and the tank treads.

Next slide. If you are breaking imagery up into square waves rather than sine waves, you could break them up into these functions known as Hadamard or Walsh basis functions. There was a tremendous interest in this sort of decomposition of imagery back when semiconductor technology was running rampant,I guess there still is. The idea here is that switching functions can very easily decompose an image into these sets of functions.

Next slide. There is one transformation that is optimally matched to the image in terms of least squares approximation. That transform comes to us from a technique in numerical analysis known as singular value decomposition. What we will do is we will find the set of basis functions which are best suited for a given image, because that in turn will give us the best means of compressing an image into a few number of coefficients for image compression and transmission over communication channels.

Let us look at the next slide. What I want you to do is tell me in the sequence of slides coming up when you recognize what the image is. This is the sum of the first image and its coefficient.

The next slide is the sum of the first two. The next slide is the sum of the first four. Does anybody wish to hazard a guess?

The next slide is the sum of the first eight. Are there any guesses?

MR.TOBLER: A girl?

DR. ANDREWS: It's a girl? Waldo. Will you be embarrassed. (Laughter.

The next slide, the sum of the first 16. The next slide is the sum of the first 32. The next one, the sum of the first 64. The final one, the sum of the first 128. That is a building, Waldo. And I think we should send you back to the university. (Laughter.) That technique is utilized for image compression. The idea of image compression -- if we may have the next slide -- is to transmit imagery over communication channels with as few bits as possible.

I mentioned earlier the possibility of exploitation facilities where you had digital data bases and wanted to manipulate those data bases. One of the real problems with image exploitation and human interaction with such data bases is keeping the human entertained, or essentially keeping the bandwidth high enough so that the human is not sitting there waiting for an image to be brought up for display purposes. One way of observing this phenomena is simply to admit that we in the industrial, military and civilian complex will never control that industry out there known as television. So rather than trying to get higher resolution displays, why don't we live with the 512 by 512 color real time refresh monitor, and use that as a window to zoom around much, much larger data bases? What we are going to do is a scenario in the next sequence of slides in which we zoom in on this data base, and, if you can imagine, we would be doing this in real time.

Let us go through the sequence. The next slide we zoom down a little lower. The next slide, closer in. The next slide, even closer. The next one -- Does anybody know where this is? Yes, this is Gary, Indiana, one of the garden spots of the nation. (Laughter.) That is not smoke. That is effluent going out into the lake.

Let us go to the next slide and suggest that we may want to even go further than a one-to-one mapping. The previous slide was a mapping. The previous slide was a mapping of one pixel in the original image domain to one pixel on the display. We may want to magnify and artificially introduce data that does not really exist. We might call that interpolation. The mathematicians tell us how to do interpolation under certain mathematical criteria. Here are four or five interpolating functions. The first is called a sample and hold, or a replicator; the second, a bi-linear interpolator; the third a quadratic; and the fourth, a cubic. These all have certain properties in two dimensions. The next slide shows what they look like.

These interpolating functions allow you to have continuity in the zeroth, first, second, third and higher order derivatives at the intersections of the true data points with the interpolated data points. The next slide shows a simple illustration of this where we have taken a 32 by 32 image and interpolated it up to 512 by 512 using the various different techniques. Now, I cannot say or you cannot prove it with this slide, but I am told that certain individuals with trained eyes can actually see the difference in the second derivative of an image and its interpolation function.

Next slide. I would like to now discuss very briefly the idea of spatial warping, the idea of automatically in a computer registering scenes or images from platforms that were never originally intended to be registered. As an illustration, we may consider taking an ERTS photograph or LANDSAT photograph and registering it with a U-2 photograph to see if there have been changes, to see if seasonal effects have been measured, et cetera. What one might consider doing then is taking the first image, number one, and the second image, number two, and finding control points or points of commonality between the two images. This might be done automatically or with the human interacting and then refined automatically, et cetera. Then a two dimensional polynomial might be computed and a "warping" function, as they are referred to, describing the mapping of Image 1 onto Image 2. Naturally, that warping function will not exist in terms of the discreet components or sampling rate of the second image, so we will have to do some interpolation.

When you begin to think a little more about this problem you realize you do not even have to map Image 1 onto Image 2. You could map Image 1 onto Image Imaginary and Image 2 on Image Imaginary, and do all sorts of intermediate types of maps. So let us do that with our favorite building. The next slide will show an original. This is the original building that we will do some mapping with. The next slide is an original. These are the only two originals. Every image hereafter will be phony, phony in the sense that they were generated from those two.

The first sequence will be -- Let us look at the next slide. We will simply map the original, and rather than taking a photograph of the front of the building with the helicopter, we will simply let the computer rotate it. Now you see some difficulties with this process. The fellow who put in the control points forgot a little bit about perspective, and the building gets wider as it goes away from you rather than narrower. So the roof does not look too appropriate. But every pixel in there and every bit of information is in the original.

Next slide. Here we have taken the end view of the original building and simply magnified it by a factor of three and put it in the upper right-hand corner of that imaginary scene. Now, the next slide shows the warping of the front end of the building to exactly register on the end of the building. Now, this is difficult for you to envision without seeing both of them simultaneously, but, take my word for it, if we now take the original end view and this warped front end view and look at the two images through stereo we will see stereo information on the end of the building, because, naturally, you cannot perfectly register two image which were sensed from platforms at different positions. The resulting information, of course, must be stereo if you have done it right.

The next slide shows what happens if you introduce a bit of control point error. You see the curvature that you may not believe in. The next slide shows that on the second sequence.

The following slide is my favorite. This is the one that I always claim is the original, and the first one you saw is the result of undoing the rubber sheet. Imagine what you could do in a court of law with this sort of image process. That is why we keep getting thrown out. (Laughter.)

Next slide. This is a calibration slide. It serves no purpose other than to prove to you that you all have normal vision. You probably see scalloping. By scalloping, I mean you do not see steps of brightness change, you see differentiation or brighter edges at the left than at the right, when in fact with a densitometer or light measuring device there is nothing but a staircase. This is known as Mach banding phenomena, and typically is the beginning of what we call the model of the psychophysics of vision. If indeed you are going to have a computer display imagery at an exploitation station, you might as well realize what your eye is going to do with the image so that you in the computer can precompensate and undo or take advantage of your own visual processes. So this is a technique now being utilized in image compression laboratories to try to get as much information out of the image ahead of the transmitter, knowing that you will never see that information because of your own visual process.

Next slide. This introduces and displays the common spatial frequency response of the eye. You should see, hopefully, a ramp going up and a tapering off of the spatial frequencies over to the right. That is the MTF of your eye. In other words, you cannot see certain spatial frequencies beyond the sampling rate of the retina, and at low frequencies your eye tends to be a differentiator. That is why, in fact, you enjoy crisp images, the edge effects the information content and image enhanced in the high frequencies is very appealing to viewing. Next slide. Using that and some other models of human vision, we put together an image compression system which is compressing imagery in color. The eye has a very, very natural response to color in the following sense: That we do not see sharp edges in chromaticities, we only see sharp edges in brightnesses. You probably have already known that because of your television system in fact takes advantage of that; the NTSC color transmission system does not send high frequency edge information in color; it only sends high frequency brightness information in monochrome. Using this and other models of the human visual process, you will find that we can undo and remove a tremendous amount of information that the sensor gathers, but which you will never see, so we remove it prior to transmission through communication channels. That is what this block diagram is supposed to illustrate.

The next slide shows some intermediate stages. If you could in fact find a volunteer either in this audience or anywhere else who would be willing to let us remove the eyeball and see what an image looks like on the retina after the nonlinear devices, we would expect to see the images on the right. Now, there is no way you can disprove that, right? (Laughter.) Unfortunately, there is no way I can prove it, either. But we think that is what the retina sees after the nonlinear photochemical processes.

Next slide. This shows our original girl in four quadrants, and shows various different color combinations. We have not yet removed the bandwidth. These are 24 bit per pixel images. This is just to prove that we can take the mathematical models we have described, go to the coding domain, and come back. Yet we have not yet compressed. The next slide shows the effect of compression. This is from 24 down to two bits per pixel using what is called a block cosine transform with the various mean square errors there.

The next slide shows the result of a one bit per pixel communication system. Degradation is now starting to be introduced.

Next slide. We have considered developing what we call smart sensors. Actually, we haven't; ARPA has, and therefore we do. ARPA would like to be able to do the following: They would like to be able to put you people all out of business. But, don't worry, don't worry. With us on the project -- (Laughter.) -- you can feel confident.

Essentially, they would like to design what are known as smart sensors. A smart sensor is a device that tries to do things as close to the focal point as is possible, such things as possibly taking advantage of the fact that images are highly non-stationary. By that I mean that the information content, the energy, the edge information, the things we as humans like to see, are very different as you move around the field of view. So we have tried to design a technique that captures automatically this information content and essentially resamples or adaptively scales the imagery such that we can only send over the communication link that which is of most interest to the viewer. So, here we have a little APC, armored personnel carrier. You can see on the right the density of what we call sampling or knots, which is a mathematical term. It explains how you would have to transmit and re-sample the image to get the various parameter reduction ratios you see on the left. The next slide is a down-looking slide of our airport. You can see the system automatically keys on the airplanes and the high edge effect.

The next slide shows the result of an artificial ERTS type of photograph. You can see the airport, et cetera. Next slide. We have done quite a bit of modeling of the process if imaging and what mathematically you might expect an object to suffer when it indeed is imaged onto some sort of film or CCD or other digital sensor.

If we can go through these slides. Typically, today with the technology of discrete sensors, we use a model which is known as a continuous-to-discrete model. We hypothesize that the object we are looking at is continuous, but one that object is in digital form is discrete. Then we ask the question, how can we mathematically manipulate our discrete information to better appropriate the original object, knowing all about the lenses, knowing about the atmosphere, knowing all about the sensor and its nonlinearity, knowing as much as we can about the statistics of the image and of the noise, et cetera. So that is the typical mathematical model that we would play with. Incidentally, if anyone is interested in a lot of the gory details of this and other research, you are certainly welcome to contact me or come up and look at the publications list. We put out a report every six months.

Next slide. Here is a technique developed by the Aerospace Corporation in which we observe a real world imaging system. This slide does not really do it justice. On axis this system is space-variant, but off axis the point spread function is non-symmetric. It really tells us that the image that you would expect to obtain from such a set of optics would have blurs that would vary as you moved around the field of view. The next slide shows what you might do with this sort of information. Here is a simulation in which the imagery is better in focus in the center of the squares and more out of focus at the edges. The question is, what type of mathematical techniques can we utilize to undo this type of blurring distortion? We call this a space-variant distortion because indeed the blur varies as you move around the field of veiw or the space of the image. The three dimensional perspective shows that effect.

Keep in mind the idea of moderate distortion and severe distortion. The next slide will show what we can do to try to undo this type of blur. Now we are talking abour restoration; we are trying to undo the degradations of the previous slide model. Here we have our favorite subject. She is known as Tiffany. Tiffany is available in digital form on magnetic tape, for anybody who might be interested. Up there we see the blurred version of Tiffany with a moderate blur, a blur that was in the middle slide, the previous slide. Here we have an iterative restoration of Tiffany up to about K equals 100; that is our index of information. We call this coarse tuning.

The next slide shows the fine tuning and also illustrates what happens if we try to put too much back into the image that was not allowed to pass through the optical system. The system blows up on us. This is typical of most image restoration processes. They are known as ill-conditioned, a mathematical expression that says "there ain't no free lunch"; you don't get more out than went into this system. So, in fact, we are getting or approximating singularity. You can see in the very last slide a very faint version of Tiffany.

We will look at the next slide, the same simulation with coarse distortion, where she falls apart much earlier at a lower index, K equal to about 58, compared to 100 previously. This was the severe situation. Let us go on. This final sequence is just to illustrate what we are doing with an industrial group that is tied to USC.

A couple of years ago ARPA decided that they wanted to speed up what is known as technology transfer -- that is, getting the ideas out of the universities into the industry without waiting for publication and review cycles, and then somebody in industry picking up the ideas, et cetera, taking two or three more years before they became product lines. So ARPA decided that they would let the tail wag the dog, and they gave the monies to the universities for them to distribute to the industry. You can imagine how far $100,000 goes at a university where graduate students still work dirt cheap, and you can imagine what pain it does when I have to give that same amount of money to the Hughes Aircraft Corporation with an overhead of whatever it is, and they tell me, "Well, that will buy ten minutes of somebody's time." In any event, we twisted and begged and borrowed, and we have teamed up with the Hughes Research Labs to build a smart sensor. This sensor is essentially a CCD device that is designed to fit on the focal plane of an imaging camera that does some non-linear processes known as the Sobel operation; this is an operation that essentially looks for edges, and is very insensitive to noise.

Let me briefly go through these slides, because I really do not know what I am talking about -- You have to be some sort of solid-state physicist to understand. Let us look at the next one. What we want to do is a two dimensional signal processing process in which the charge passes under the various CCD devices that has been sensed with an electronic optical-to-charge transducer. We then take the outputs of these devices, and we want to do a non-linear process. In image processing, non-linear processes are probably the most useful ones. We take the outputs of these four lines, and pass them through an absolute value detector. The unique thing about this smart sensor -- next slide -- is the fact that here is what they call a spill and fill network. In addition to being a solid-state physicist you have to know about plumbing, because they do all sorts of things with charges and wells and liquids which really do not exist.

In any event, this does take the absolute value of the difference of the outputs of the previous pixels, and the output of this then becomes essentially the Sobel operator. The next slide shows essentially the chip that exists. This is a rather large magnification. This device actually is 190 mils by 190 mils, which is very, very tiny.

We are now in the process of building a much smarter device that measures texture off of sensors, and hopefully someday we hope to be able to automatically on-board the platform or the sensor,segment images so we can just transmit segments of interest rather than the entire imagery. Thank you very much. (Applause.)

MR. TOBLER: Thank you very much. I certainly found that very interesting, even if I can't tell a girl from a building in the truncated transform. (Laughter.) Image processing people always pick pictures of interesting things like baboons and girls and buildings.

The next speaker, Carl Youngmann, from the University of Washington, trained in cartography at the University of Kansas. He then went to Columbus, Ohio, and taught cartography there at Ohio State University, did some work with lasers and worked on geographical information systems. At the University of Washington he teaches computer cartography, and has also been involved in what might be called semi-automatic generation of the Coastal Zone Atlas of Washington. Carl?

MR. CARL YOUNGMANN: When Waldo asked me to provide the cartographic perspective on the use of computer graphics, image processing and other advanced technologies, I felt like the housewife or househusband who had won an unlimited shopping trip in a grocery store promotion. I could buy anything I wanted in the technological store, but I didn't know how many guests there would be and whether there would be any vegetarians. To try to sort out what the present menu of technologies can do for us on a practical day-to-day basis, my feeling is that after we have accepted the existence of the things we have talked about and have seen here in the past few minutes, the real problem will be being able to know what we want and how we are going to utilize these devices and processes to represent what we want: What do we require in a computer-generated display? How are we going to utilize image processing systems such as that we have seen? Or a smart sensor? How would we utilize a device such as the one Jim Blinn talked about with which we could create an unnatural world as we would like to see it, and move through it? Where does such a device fit into the day-to-day problems we have to solve as cartographers? We must communicate spatial information to people who are not necessarily going to believe that these things really exist and that the manipulations are, as we have seen them, quite fascinating, but more importantly, reliable.

From the cartographic point-of-view the concerns are many and they are difficult to sort out--indeed, it is hard to get on top of a high enough hill to look over the variety of things we feel are important about cartographic displays. Immediacy of response, accuracy of communication, volume of data to be handled, scope of data to be represented, level of detail, scale, updating and extending images, inversions and analyses that can be made of the information, static-dynamic aspects of information--all seem to be very important. Can we reduce these concerns so that we can at least start to give some structure to the cartographic shopping list?

One thing that we could say first is that accuracy is not really a representation problem. We have been shown that we can take something at one level of accuracy and really give the impression that it is much more accurate than it is, up to a point. Graphic devices are accurate. We will have to accept that.

Secondly, we can assume that the ultimate needs will generate the ultimate response; that technology does provide us the ability as cartographers to do many things--really the capability of doing more things than we actually want to do or need to do at any given point. Basically, we can take the approach that cartography is not wholly, from the computer scientist's point-of-view, an "NP Complete" problem--that is, although there are minor problems that we would say defy computation by sequential digital analysis, cartography is basically a computable problem. It can be addressed by sequential digital processes and probably can be handled in most contexts.

Successful methods, thirdly, are or will be the ones that are low cost, high quality, widely distributed and technologically simple. It is hard to make a technological forecast for 25 years from now. Various advances in solid state physics may end up radically changing the cartographic displays that we have to deal with. We may never ever have a machine such as the one that Harry Andrews works with day to day, but maybe some day we will.

The function of cartographic communications really determines the need for cartographic media. May we have the first Vu-graph (Figure 1), please. To this point, in many cases we have had the tail wagging the dog in that the media available to us many times has determined how we were going to communicate. Perhaps we should now look in the other direction and define what we want to communicate and then select a medium.

Cartographic communication is used in five general functions. Those functions include first what we might call the dispatching function, in which we provide information for decision making in a network--routing of trucks--giving delivery people something on a day-to-day basis so that they can perform their job more efficiently; routing of emergency vehicles; and similar questions of spatial dispatching. The second area is what we might call status reporting, very quickly delivered information about the location and distribution of objects interacting in space. Aircraft control and vessel traffic control systems fit within such a scheme. Item three deals with research, an all-encompassing topic which involves summarizing and analyzing the distribution of geographic phenomena. Such communication is not so much directed to somebody else as it is to oneself, giving oneself the information about the location and distribution of phenomena that are of interest to him or her and being able to change the representation in some way or another so that one might learn something. In that way, researchers come to generalizations, so that they can then proceed to the fourth function: reporting. For reporting, information must be presented in a manner that meets special criteria, like the high quality graphics used for planning documents, census reports, and other similar items. The fifth area is recording, the actual placing of information in a highly retrievable spatial context, useful for reference--surveying data, cadastral information, general purpose atlas information, etc.

These five functions dictate certain kinds of needs. May I have the next Vu-graph (Figure 2), please. I think the graphic environment in which these functions fall really can be boiled down to three major axes. These axes may be independent orthogonal, or they may be interrelated. I show them here as orthogonal. The axes relate the requirements of a cartographic communication function to a display system's capability for immediacy of response, the data capacity, and graphic quality. Each axis is divided into a set of relative classes ordered by increasing capability.

In regard to immediacy of response, we have available cartographic display systems which run from instantaneous response--a second or less, to those systems which provide a timely response--within a few seconds to one minute, and systems that provide what I would call an "assured" response--"If I submit the job, I know I am going to get it back sometime." The second axis, data capacity, starts at the lowest end with one element of information and runs through low data capacity systems--up to say a hundred map elements; then, moderate capacity--a hundred to a thousand elements; next high capacity--a thousand to fifty-thousand elements; and finally, very high capacity systems--over 100,000 individual elements in an image. The third dimension is graphic quality of the final product. This axis extends from extremely crude resolution, the one-tenth by one-sixth of an inch SYMAP style graphic, to what we might call a coarse graphic--the matrix printer, a tenth of an inch by a tenth of an inch output; to moderate graphic quality, on the order of a hundredth of an inch resolution and finally, to fine, high quality graphics of one-five-hundredth of an inch resolution.

The five communication functions are then placed within a framework to show the different levels of graphic quality, immediacy of response, and data capacity required for each.

For dispatching the delivery truck driver can get by with a coarse, SYMAP style output. The output has to be ready once a day when the trucks go out, and the data capacity is of a moderate level. Status reporting has to have a moderate capacity. The information must be clearly presented, although it does not require extremely fine resolution. However, the system must respond almost instantaneously. In research we can deal with coarse quality, but we must have assured response and a high capacity. Reporting and researching require higher quality and higher capacity but only assured response.

Each of us, of course, will see our own specific communication needs in a different light. Indeed, my presentation of the dimensions of our requirements oversimplifies the complexities encountered in matching a graphic medium to a communication function. Furthermore, I have ignored two other significant dimensions: mode of use, which ranges from statis representation to dynamic, interactive graphics and in the extreme to intelligent, reactive representation; and dimensionality--representations of variation in multiple phenomena, multiple spaces, or time.

Now, with this understanding of our requirements we can approach image processing and computer graphics. I think this shows us a place to begin our search. I do not know how interested designers are in creating systems that will match these requirements, but I hope that at least now we have some idea of what kind of dinner we can begin to serve, having won the cartographic grocery shopping contest. Thank you. (Applause.)

MR. TOBLER: Thank you very much, Carl. As an academic, I would have a question for Harry. How do you convince the government to give you money for academic research? Are there any questions?

Thank you all very much, and have a good evening. (Applause.)

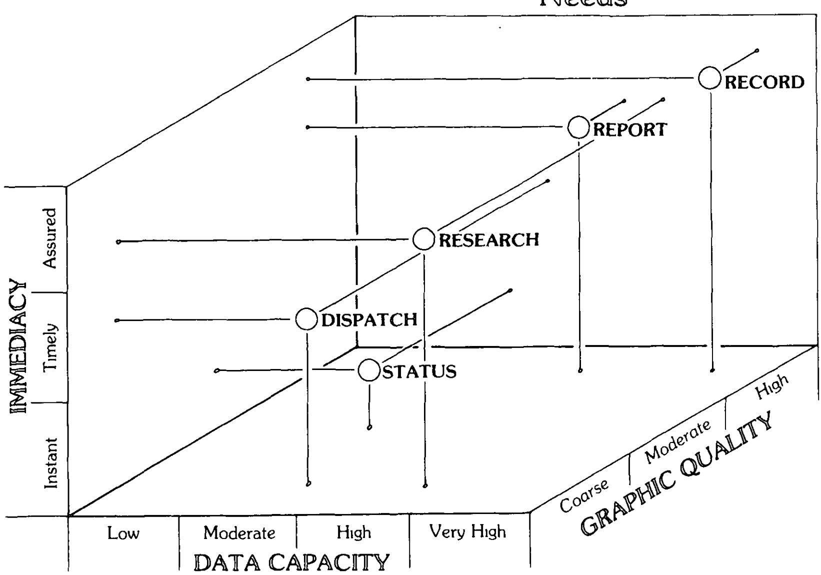
Figure 1

Cartographic Communication Functions

- ☆ DISPATCHING
- ☆ STATUS REPORTING
- ☆ RESEARCH
- ☆ REPORTING
- ☆ RECORDING

Figure 2

Cartographic Communication Needs



DISCOVERING AND EVALUATING SOFTWARE

MR. DEAN EDSON: In order to cover one of the really dynamic dimensions in computer-assisted cartography we have to, of course, address the subject of software. The organizing committee has called upon one of the foremost experts in the field of software to organize and bring to you a look at the present and the future in software. Professor Marble is currently on the faculty at the State University of New York at Buffalo, and has been teaching at various institutions and has had a number of teaching assignments in engineering, business, regional science and geography, and is currently the U.S. member of the IGU Commission on Geographical Data Sensing and Processing. Professor Marble received his Doctorate in Geography from the University of Washington. We are very pleased th have Professor Marble here to help us look at where we are going in the way of software. Professor Marble?

DR. DUANE F. MARBLE: Thank you, Dean. I will say one or two things at the start about the organization of the software sessions today. We are dealing with essentially 90-minute periods. The first hour of each period will be devoted to formal presentations by members of the panel. The last third of the time period will be given over to open discussion. We hope that the members of the audience will join the members of the panel in the discussion. There are several explicit topics set forth. The sesions themselves are ones that I have tried to develop in a focused fashion. They deal, first, with the question of evaluating and developing software in the field of computer cartography and geographic information systems. The two following sessions deal with specific research topics, things that are not yet major and active parts of the field of computer cartography. One of these deals with raster-based approaches to cartographic processing, and the other to problems of management of large volumes of spatial data.

I would like to begin the session on discovering and evaluating software by talking a little bit about the development of geographic software. I have been hooked on computers for a long time, and since it is one of those games people play, to say, "How far back do you go?", I will note that I was once the author of a facetious little pamphlet entitled "How to live with an IBM 604 Calculating Punch," which was a delightful device, and our super-extended installation had, I believe, 34 characters of memory attached to it. We have progressed a great deal since those days. One of the things that we tend to gloss over is how fast we have progressed, particularly in the field of software. This has become evident to us because of an effort that was undertaken about two years ago by the IGU Commission on Geographical Data Sensing and Processing as part of the larger study for the U.S. Geological Survey that Rupe discussed in his keynote address yesterday.

One of the things we did was to prepare a draft inventory of computer software for spatial data handling. This was an attempt to provide fairly comprehensive descriptions of program units, giving enough information so that the reader could find what the unit did and could discover whether it was transferable, or not, in terms of the parameters of his or her own installation. Our effort uncovered about 320 program units. The program unit was a rather loose definition, ranging from things that, on the one hand, looked to be on the order of magnitude of the Canada Geographic Information System, which is a comprehensive system covering all phases of input, storage, manipulation, graphic and other types of output, and constituting something on the order of 120 to 130,000 lines of code, down to specific subroutine modules, many of which were written to assist in cartographic operations. One of the reasons for doing the inventory was to try and find out what was going on, because if we look at the published literature in cartography we find very little dealing with the types of things that we must know in order to progress in software development. Many of the things that we need are relatively unknown. This seems a strange thing to say, but if you cast your mind back on the kinds of things you do when you start to write a program, you will find that there are several critical factors. You need to know something about your data and its data structure. You need to know something about the algorithms; the processes that are used. One of the things that we found in the inventory was an incredibly high level of redundancy in many areas. The simple physical problems of carrying out the inventory were complicated by the fact that we ran out of six letter acronyms for contouring programs. There are more contouring programs and interpolation programs than one would reasonably expect. There is also a great deal of misinformation about how these work.

In many cases there is no information about how they work. Many of the software modules were and still are real black boxes, their operation understood not by the users or the proprietors, but in some cases only by system analysts and programmers who have long since disappeared from the scene. At one time in the course of the draft inventory, we facetiously decided we were going to try and present an award for good documentation. This soon became in my mind an attempt to present an award for the poorest documentation, but we were overwhelmed with candidates, and decided not to present it at all. Most of the systems and program units are very poorly documented. This is one of the factors that has come to light in practically every case that we have looked at. One of the things that contributes to the high level of redundancy is that, when one undertakes software development, one is faced with the problem of how to do it and finds that there is no library of algorithms for spatial data handling that one can turn to.

Suppose you want to find out how to write a contouring program. Where do you go to find out what the prior experience has been, and what is the current state of the art? You will find articles on contouring algorithms scattered here and there in the literature, some in geophysics, some in geology, one by John Davis in the proceedings of AUTO-CARTO II, and others in places that are not normally likely to be found by people interested in cartography.

The common interest in the display and presentation of space and time dependent data covers a variety of disciplines. One of the activities of COGEODATA at the present time is an examination of the methods for handling space and time dependent data in a variety of disciplines such as geography, geology, meteorology, soil science, space science, chemistry, physics, and certain areas of mathematics which are particularly susceptible to graphic display. But the literature in these fields is not really open to people in other fields. If I wanted, for example, to examine the soil science literature to try and find out what they have done on the display of spatial data, I would, quite frankly, not know where to start. One of the things we hope to do in the course of the current inventory operation is to point out where things are happening and to try and identify some of the more interesting existing algorithms.

The draft inventory was completed in March, 1976 and with the sponsorship of the U.S. Geological Survey, the Commission is currently updating and extending the inventory. Outside the door there is a small information sheet which discusses the structure of the previous inventory and the kind of things we are trying to do in the present one.

It is also an invitation to assist us. We need help, because the only way we are going to find the types of information that we require is through individual contact, hopefully with each and every one of you. You are here because you are interested in computer software and interested in spatial data handling. I am sure that in this audience there is probably a volume of software undiscovered, at least as large as that reported in the original inventory. We have been working on the inventory for several months, and have already identified enough new entries to cause us to considerably expand the scope of the final presentation. We had originally thought we would publish a volume, and that now begins to look as if we may have some difficulty in publishing it in three volumes.

Another thing that we are trying to do on this pass through the system is to cover an allied area which is not programs, but rather, cartographic bases in digital form. We received many requests from people interested in cartographic base files, typically something on the order of World Data Bank One. There are a lot of organizations and individuals engaged in producing these files today, and many of them are essentially in the public domain or could be placed there with little effort. But no one really knows where they are or what their characteristics are. So, in addition to the programs, we are going to attempt, at least in passing, to cover those cartographic data bases that have come to our attention.

The inventory results, as I said, will be presented in a series of published volumes which will be available about the end of next year. We are also working with an interagency advisory committee on the operations of the inventory, and after we have completed our initial efforts, there will be a special workshop held in Washington, D.C. for staff people from a number of the federal agencies to examine and discuss our results. I would like to invite your cooperation in this inventory since I think it is an effort that is valuable to all of us. If we can eliminate some of the redundancy and if we can make it easier to find out what others are doing in the area, I think we may begin to progress far more efficiently than we are presently. We have gone through a long, slow period of development. The development path in time follows the typical S-shaped curve, and we have now gone past the bottom inflection point, and we see the field of computer cartography developing rapidly in depth and complexity. Without some central source of information such as the inventory, it is going to be very easy for us to waste significant quantities of resources in the future.

Our panel members today were chosen to talk about some of the problems that people face today in trying to find out about software and how it can be incorporated into a system design. The first speaker is Mr. Carl Reed. Carl is with the Western Governors' Policy Office in Colorado, a 14-state organization which is currently carrying out a system design study for the U.S. Fish and Wildlife Service. Carl will talk to us about some of the experiences they have had in trying to examine existing software and evaluate it in the light of their systems needs. Carl?

EVALUATION AND SELECTION OF EXISTING GIS SOFTWARE FOR THE U.S. FISH AND WILDLIFE GIS

ABSTRACT

The purpose of this paper is to present the results of and lessons learned from the evaluation of geographic computer software as part of the development and implementation of a U.S. Fish and Wildlife Geographic Information System. The main emphasis of the evaluation was on cartographic software, since many of the analysis functions are unique to the U.S. Fish and Wildlife Service. The evaluation was done between March and July 1977. The evaluation criteria were based on a five-month user needs assessment. Originally, 85 systems were discovered. Lack of documentation narrowed this field to 52. Detailed descriptions were prepared for these 52 systems. Each system was then evaluated in terms of 1) operational characteristics, and 2) functional characteristics. This initial evaluation further narrowed the field to 11 complete systems and 14 partial systems. The next phase of the evaluation centered on such things as 1) in-line code, 2) functional characteristics, 3) interface difficulties, and, 4) level of documentation. From this evaluation, we have been able to obtain some of the software (about 30%) required to implement the U.S. Fish and Wildlife Information System, which is now known as MOSS (Map Overlay Statistical System).

1.0 INTRODUCTION

1.1 Goal of Project

This Geographic Information System project is sponsored by the Western Energy and Land Use Team (WELUT) of the U.S. Fish and Wildlife Service (contract #14-16-0008-2155) to promote more effective consideration of the impacts on fish and wildlife resources from land, energy, mineral and water development.

The goal of this two-year project is to develop an operational capability within the U.S. Fish and Wildlife Service (FWS) to accept, store, manipulate and output spatially-related data for use in a variety of FWS programs. This includes not only the data that has been and will continue to be collected by the FWS, but also includes data available in computerized and non-computerized data files of other federal and state natural resource management agencies. This goal is to be achieved by attempting to minimize development of new computer software for the display and analysis of map data. The project started on a prototype basis within selected test applications and will broaden to other applications.

The primary users of this system in its developmental stages are in the Billings Area Office (BAO), WELUT, and the Region Six office. The biologists in these offices are faced with the weekly task of assessing the wildlife resource impacts of various land use changes.

1.2 Description of Major Tasks of the Project

It is helpful to outline the seven major tasks of this project. This report falls within Task II.

Task I Assess the spatial data needs of three groups of users: 1) the Denver Region Six offices of FWS, 2) the Billings Area Office within Region Six, and 3) Special Projects of the Office of Biological Services. Development of a preliminary system design based on these needs.

Task II Survey, assess, and compare existing computer software systems and geographic data bases which are relevant to FWS determined needs. This may include federal, state, and private software and data bases.

Task III Develop an interim software system and test data bases(s) covering the pilot test area(s). (WELUT Montana-Wyoming test area).

Task IV Benchmark-test and evaluate the most promising geographic information system software as determined from Task II.

Task V Integrate and implement the selected software system on a government computer as determined by FWS-WELUT (presently, it is a CDC CYBER 172).

Task VI Test and debug the new FWS-WELUT geographic information system and document it with both users and technical manuals.

Task VII Train FWS personnel in the applications, use and limitations of the system. This task will be on-going throughout the project.

As we shall discuss later, for a number of reasons, Task IV has been dropped.

1.3 Purpose

This report presents the results of the initial evaluation of the "off-the-shelf" computer software for possible inclusion in the U.S. Fish and Wildlife GIS. This evaluation was based on three previous efforts:

1) A five-month User Needs Assessment (Project Report 1.1)
2) A General GIS System Description (Project Report 1.2)
3) A Detailed GIS System Description (Project Report 2.1).

Based on the user needs assessment, the GIS is visualized as containing four major sub-systems. Each sub-system in turn is comprised of other modules (Figure 1). The FWS-GIS must operate under certain operational constraints and must perform certain logical functions. This initial evaluation of existing GIS software was based on 1) operational criteria, such as programming language and documentation, and 2) functional criteria, such as, does the software do polygon intersection. Both operational and functional criteria had to be considered. Suppose a piece of software were not operational on a favored computer, but the function it performs is vital to meet FWS requirements. This software package then received a higher rating.

2.0 THE CRITERIA USED IN EVALUATION

As mentioned above, two sets of criteria were considered. "Operational" criteria refer to the general hardware/software characteristics of a particular program. "Functional" criteria refer to the actual logical function(s) or tasks performed by a piece of software. The initial evaluation and selection process was based primarily on the operational criteria. A second evaluation was based on the functional capability criteria alone. This two-phased selection process was followed to allow the large number of GIS programs to be systematically evaluated.

Table 1 presents the operational criteria for the FWS-GIS. The definition of operational criteria was constrained by the fact that FWS (Region Six) must use either a Data General Eclipse or a CDC CYBER for a mainframe. FORTRAN was selected as the favored language because it is universally applied and generally understood in the GIS user community. The remainder of the operational criteria are based on FWS user specifications, good programming practices, or software transportability considerations. The functional criteria which define required display capabilities of the system are listed in Table 2.

3.0 THE SYSTEMS EVALUATED

Concurrent with the user needs assessment and preliminary system design, documentation was gathered on existing GIS. For the purpose of this project, a system is defined as any piece of GIS software that performs more than one unique GIS function, such as data input, data analysis, and data display. The reason for this division is to separate single-purpose software from multi-purpose GIS software in order to keep the number of systems to be evaluated as small as possible. However, some stand-alone packages were considered for unique capabilities.

Figure 1

PRELIMINARY GEOGRAPHIC INFORMATION SYSTEM DESIGN

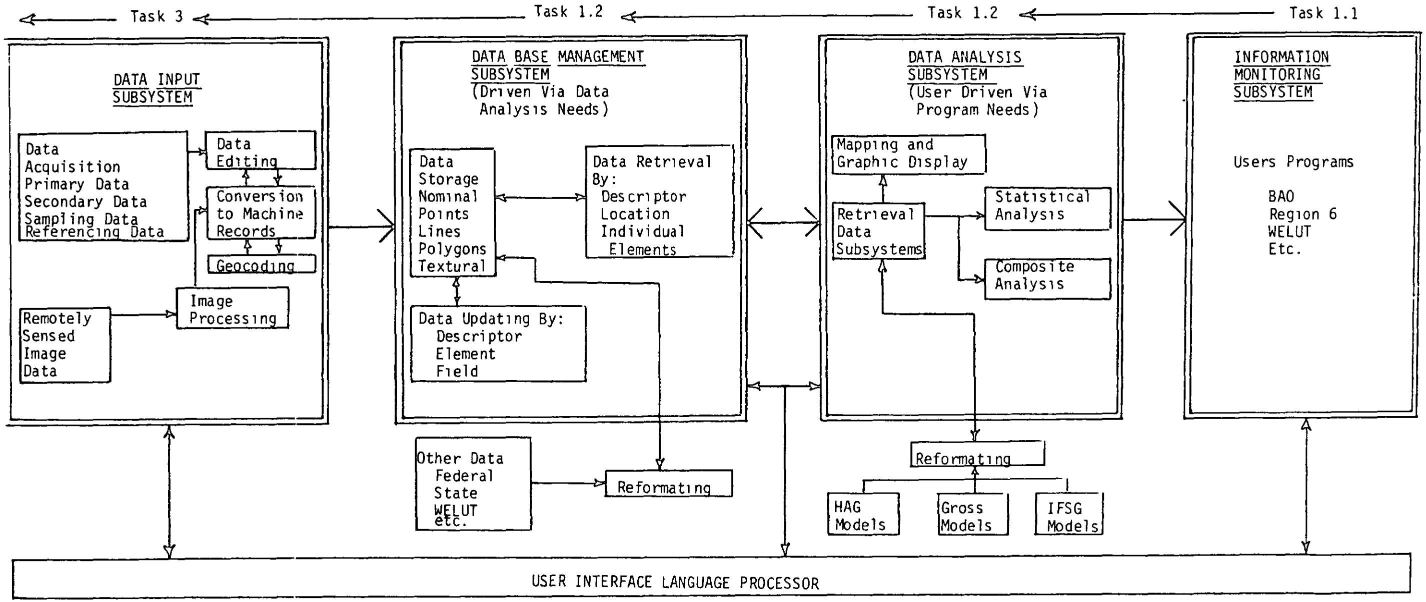


Figure 2 Operational Criteria for Software Evaluation

A. Hardware environment (most to least preferred)

1. Data General/Nova Eclipse
2. CDC
3. UNIVAC
4. IBM
5. Interdata
6. Digital Equipment Corp. PDP II or PDP 10 series

B. Programming Language (most to least preferred)

1. FORTRAN IV
2. FORTRAN V
3. BASIC
4. COBOL
5. PASCAL
6. ALGOL
7. other

C. Available Documentation (most to least preferred)

1. application, user, technical, and implementation instructions
2. application, user, and technical
3. application and user
4. application

D. Modularity of software

yes modular
no non-modular

E. Operation environment (most to least preferred)

1. interactive (end user operated)
2. batch (end user operated)
3. interactive (analyst operated)
4. batch (analyst operated)
5. interactive (programmer operated)
6. batch (programmer operated)

F. Cost of software - Given comparable levels of performance between programs, the least expensive is most preferred.

G. Machine independence - the greater the degree of machine independence of a program, the more it is preferred for further evaluation.

H. Any "off the shelf" program requiring exotic libraries will receive a low priority as to its usefulness to FWS.

I. Whether the software included all necessary modules for a "complete system" input, data base management, spatial analysis, output, and user interface support.

TABLE II

COMMAND	FUNCTION
*ACTIVE	What maps, or parts of maps, are currently active (i.e., can be manipulated and displayed)
DEVICE = LINE PRINTER PRNTR/PLTR PLOTTER SCANNER TAPE DISK	Assign a display file to a peripheral other than a CRT so that alternative hardcopy options are available for map display.
*DISPLAY 1,2,3,...N	Display a set of maps on some output device (see the DEVICE command). These may be either line or cell maps.
*ERASE	Erase the CRT
*BLOWUP	Magnify a portion of the CRT
PROJECTION	Change the map projection
*WINDOW	Manually set a viewing window for display purposes
*RESET	Reset the viewing window to the data base default
*SYMBOL	Generate a symbol map for point data. Somewhere between 20 and 35 symbols are to be available, including the most commonly used cartographic symbols (churches, swamps, and so on).
*LINE	Generate a line map utilizing different map symbologies. These are 18 dash types, railroad tracks, and thickened lines.
*SHADE	Generate a choropleth map (discrete shading) with ability to rotate crosshatch lines and either have the program or the user set the class interval information.
*CONTOUR	Generate a contour map from either point or grid data.

LABEL	Place label information on a displayed map.
LEGEND	Generate a map legend with 1) title, 2) north arrow, 3) scale, legend to label information, 4) different fonts, and 5) either tic marks or a grid overlay. (Note: LABEL and LEGEND will require software generated characters).
THREE-D	Three-dimensional block diagrams
*TESTGRID	Draw a grid overlay on a map of user-specified size.
*GRID	Point-to-grid interpolation

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*Commands with an asterisk are presently operational (8/11/78).

References to different systems came from many sources, including the IGU (1975), McDonald (1975), Power (1975), and from personal experiences of the staff. For each system, documentation on actual system applications, users manuals, and technical manuals were obtained where available. The documentation search ended July 15, 1977. Eighty-five different systems had been defined. Of these 85, we obtained sufficient documentation to write two 5-page standardized descriptions on 52 systems. The standardized descriptions were used as the information base for evaluation.

4.0 EVALUATION PROCEDURE

Only the 52 systems with sufficient documentation were further considered,since undocumented software generally are not portable.

A set of the standardized system descriptions were prepared and distributed to several technical and managerial staff. Each individual was given a week to read and relate each system to first, the operational, and second, the functional criteria. Based on this evaluation each individual decided whether a system should be: 1) considered further for adoption, 2) considered only for functions or algorithms, or 3) dropped from further consideration.

At the end of the week, the group convened to compare the results of individual evaluations. Each system was discussed and voted on. A summary table was prepared of the results and is available in a project report. In some cases, local modifications to the systems will result in characteristics different from those shown in the summary table. The summary should then be viewed as an overview of some of the geographic information systems.

Originally, the evaluation was intended to be purely objective, quantitatively based on the operational criteria. However, in reality, this initial selection process was both an objective and subjective decision process, due to trade-offs in the operational and functional characteristics of each system. A quantitative number could not be derived that would adequately reflect all the components of the evaluation process. Thus, the final decision became one of professional judgement.

5.0 SUMMARY AND FINDINGS OF THE INITIAL EVALUATIONS

Based on the initial evaluation, eleven complete systems and pieces of fourteen systems have been selected for further study. The eleven complete systems are:

COMPIS	-Comarc Corporation
CRIS	-BLM
CMS-II	-Department of Commerce
EPPL 4	-Minnesota Land Management Information System
GIMMS	-University of Edinburgh, Scotland
LUMAD	-USGS Geography Program
ORRMIS	-Oak Ridge National Lab
PLUSX - PLUS2	-University of Western Ontario
WRIS	-U.S. Forest Service
CONGRID	-U.S. Forest Service
MAPDRAW	-Fish and Wildlife Service

The partial systems varied from complete modules to algorithms.

6.0 PHASE II EVALUATION

Both the eleven complete systems and the fourteen "selected functions" were then analyzed in more detail.

Actual systems architecture and program code were studied to determine the transportability, programming techniques, and efficiencies for each system. The pieces of software that rank highest in this evaluation form many of the basic units for the FWS-GIS.

6.1 Phase II Evaluation Procedure

The actual code and additional documentation were obtained for the eleven complete and fourteen partial systems. Two complete systems were immediately dropped at this point. For one, the master backup tape was not readable and for the other, because it was a commercial package (WELUT had made the decision not to purchase commercial software).

The remaining systems were then evaluated on:

1) in-line documentation
2) adherence to ANSI standards
3) user interface procedures
4) options available for a given function
5) did a given function in a given piece of software really do what the Fish and Wildlife Service needed
6) modularity of code
7) did the code look extremely inefficient
8) potential interface problems when integrating into a larger system
9) core required
10) types of data they could handle (point, network, polygon, and/or text)

Each piece of software was evaluated given these criteria. On the basis of this evaluation, it was discovered that no system fulfilled even half of the U.S. Fish and Wildlife requirements. Therefore, every system dropped to partial system status. Of the now 26 partial systems, 12 were dropped due to the lack of proper documentation and a complete disregard of both modern and standard programming conventions. We are now left with 14 partial systems from which to draw software.

7.0 PHASE III EVALUATION

Initially, the chosen systems were to be benchmark-tested. These benchmark tests were to use a standard data set to test the ease of use, efficiencies, and costs of using the different systems. However, for various reasons, the benchmark testing is not being done. These reasons are:

1) insufficient time
2) insufficient manpower
3) the systems are too diverse in their data requirements
4) budget considerations in the project.

The decision not to do the benchmarking is understandable. Given previous attempts by other groups and given the reasons above, results of any benchmark testing would have been either meaningless, disastrous or both. I can only caution others who are considering benchmarking to have the time, money, patience, personnel and endurance required of such an undertaking.

8.0 SUMMARY, LESSONS LEARNED

The major finding of the software evaluation is that no system fulfilled even half of the U.S. Fish and Wildlife requirements for a geographic information system. The second major finding is that only a small percentage of existing GIS and cartographic packages are sufficiently documented to merit the stamp "transportable". The impact on our project is that we have to do much more design and programming than we originally intended.

During the evaluation we learned several things:

1) the evaluations took much longer than expected;
2) no matter how one tries, objective evaluation is not possible;
3) personal bias and ego can almost completely block effective evaluation;
4) what the documentation says and how the system performs may be two different things;
5) much cartographic software coding is "primitive";

6) cartographic and GIS software standards are many years behind MIS and other industry software standards;
7) the political atmosphere of the organization within which one works can effect the evaluation;
8) quite often a piece of software may look very useful, but due to tricky programming, or lack of in-line comments, or lack of subroutine specifications, or machine dependencies, it cannot be used.

Based on these findings, I would like to suggest that when preparing for and doing software evaluations:

1) a detailed list of system requirements be formulated;
2) do not fall for the "my system does everything you need" hard sell;
3) have a committee with people from different cartographic, remote sensing, and GIS backgrounds do the evaluations;
4) know your organization environment;
5) prepare detailed system evaluation criteria (in case your decisions are questioned);
6) consider cost, time of transport and implementation, ease of use, and maintenance;
7) be prepared to take more time than desired;
8) be prepared not to find a complete system that meets your needs.

Lastly, and perhaps most importantly, be ever wary, do not be overly optimistic, and do not let people press you into making a hasty decision.

DR. MARBLE: Thank you Carl. I would like to underline one point that you made in your discussion, and that is the question about the availability of code from commercial sellers of software in this area. We talk to an awful lot of people, many of whom are end users of this type of thing. I will say that one of the things that seems to bother a lot of them is that they do not like buying something that they cannot see. Many people treat their code as proprietary. I think that this in the long run is probably in error, but probably not as much in error as one system salesman who is even treating his system documentation as proprietary, so that if you buy it you cannot even see the documentation

Our next speaker from the panel is Dr. David Cowen. David is with the Geography faculty at the University of South Carolina during the current year he has been on leave and attached to the Division of Research and Statistical Services of the State of South Carolina. He is in the process of initial design of the statewide information system, and an examination of other systems in the southeast. David?

DR. DAVID COWEN: Thank you, Duane. The purpose of this paper is to report on how five states are coping with the promises as well as the frustrations associated with automated methods of cartography and analysis. It will describe existing software activities in the five states. However, it will also attempt to conceptualize the process by which agencies with statewide responsibilities get involved in the business of automated cartography. The paper is based on the results of a survey of resource information systems in the Atlantic Coastal states stretching from Virginia to Florida which was conducted for the environmental affairs section of the Coastal Plains Regional Commission.

The survey, which spanned more than a year, consisted of both a mail-out questionnaire and a series of on-site visitations. My first conslusion is that questions relating to spatial data handling cannot be easily handled on a written questionnaire. Our on-site visitations often revealed things about operations that would not have been possible from the written response; both understatements and exaggerations indicated on the questionnaire became evident during the interview process. Perhaps a major problem could be solved, or at least alleviated, by correctly identifying the appropriate personnel to answer the questionnaire. Responses seemed to vary systematically between administrative, production and systems people.

It should be recognized that state government bureaucratic structures are likely to be more politically entangled than those at either the federal or local levels. In state government redundancy and overlapping responsibilities abound. Based on my experience, this is especially true in the fields dealing with natural resources. Responsibilities are rarely clearly or adequately defined. Agency decisions are based on the growth potential of the agency itself, rather than on demand or efficiency. Concurrent with the goal of self-aggrandizement, is a basic conservative nature of the agencies that mandates for failures to be avoided at all costs. Any discussion of state wide geographical data processes must be constrained by these assumptions.

Applications of automated cartography, in particular, and geographical information systems, in general, in the five Coastal Plains states are limited essentially to six groups of distinct activities. Three of these are located in Florida, with one each in Georgia, South Carolina and North Carolina. Except for a few activities at the highway department and some experiments at VPI, Virginia tends to be sitting back and observing what the other states are doing. This probably is related to Virginia's excellent USGS Cooperative program and the elimination of its Department of State planning. The six ongoing operations can be grouped as follows: two largely in-house developmental efforts at universities: these are at Florida State and my own university, the University of South Carolina. There are two commercially obtained stand alone mini-systems. One is a M & S system at the Florida Highway Department, and the other is a COMARC system at the North Carolina Land Resources Information System. There are also two operations that are closely linked to federally developed data bases and software. One is a USGS LUDA based operation at the Florida Division of State Planning, and the other is the only truly operational LANDSAT data processing center in the region. The latter is supported by the Georgia Department of Natural Resources, and is located at Georgia Tech. I have a few copies of a handout which describes these six operations in terms of concept, hardware, software and future development.

Instead of going through these descriptions, the remainder of the paper will deal with what I believe are some crucial issues in terms of automated cartography and information systems as viewed from the state government perspective.

One overwhelming conclusion derived from our survey is that any involvement of a state government in automated cartography should come only after a set of serious questions have been asked and some serious research to seek answers has been attempted. This has rarely been the case. Before setting a program, a state must ask itself why it wishes to become involved with automated cartography in the first place. Most of the people in this room may view this as a trivial question. After all, "Isn't automation necessary to get the job done better, faster or cheaper?" I suggest that any honest appraisal of the question would raise serious doubts. For all of its glamour, the actual, day to day operation of automated cartography, at the state level, has a pretty miserable track record, and consequently it still must be considered a risky business. Furthermore, institutional considerations represent considerable barriers to the successful implementation of even the best conceived plan. For example, automation is certain to disrupt interagency relationships. It may be viewed as a direct insult to existing manual operations, particularly those in powerful highway departments or geological survey offices. It also requires the sharing of data among rival agencies. There also remain the more obvious and measurable costs in terms of capital and personnel expenditures involved in automating.

It can be argued that, with but few exceptions, states have been badgered into the business of automation as a result of federal initiatives or federal demands. It has been estimated that there are now more than 130 different pieces of federal legislation that demand display and analysis of various land and water related data. When translated to the state level in the Coastal Plains Region, the requirements for the Coastal Zone Management Act, EPA 208 planning, and environmental impact statements have severely stretched the data processing capabilities and the resources of the states. Thus, states often find themselves being unwilling consumers of federally sponsored programs. When existing data, maps and analytical tools are found to be sorely lacking, automation is offered as a flashy means for overcoming deficiencies.

The next topic to be addressed concerns the manner in which a state agency actually gets started in the business of automated cartography. I suggest that there are three alternatives:

1. a push by a university;
2. a push by an ambitious individual within state government who has the proper political connections;
3. an orderly development process whereby statements of objectives and system components are a logical outgrowth of a careful assessment of needs.

The first two approaches prevail by a wide margin over the third. Computer cartography is now a common part of a university curriculum. Universities, especially state supported ones, love nice public service functions with high visibility. Appropriate agency personnel, often ex-students themselves, are easily convinced to channel some money, in the form of grants, to the university coffers. The university can easily conceal the high cost of research and development and usually it can produce some pretty good protoresearch and development costs, little or no opportunity to evaluate your products, no benchmarks, and little technical support.

The second approach to software procurement involves a search in the public domain. Geographical information system software is available from numerous sources such as those listed in the Inven. Although this approach may minimize initial capital expenditures it suffers from lack of support, poor documentation, poor evaluation procedures, high implementation costs, and a lengthy operationalization period.

The third procurement alternative involves sending out an RFP to commercial vendors. This is exactly the approach both the Florida High Department and the North Carolina Land Resources Information System followed when they obtained their M & S and COMARC systems, respectively. In fact, it may be argued that this is the only logical and legal alternative that a state may have. State law often forces agencies to put out RFP's, obtain three responses to a bid, and go through an evaluation process. Unfortunately, the use of commercial software requires considerable faith in the vendor. It also locks one into a particular method of performing functions and may be unable to manage the masses of data that frequently develop over time. Furthermore, many commercial vendors refuse to provide source code that greatly restricts the ability to modify functions or plan for future system designs. Finally, I will leave you with a question, concerning the resolution of the problems provided by the third alternative, that is near and dear to me at this time. Where does one find commercially available software that can be evaluated, installed on an existing main frame, is available in source code and will be supported? I suggest that there are presently very few alternatives on the market.

The six activities in the five states of the Coastal Plains Region are still in their infancy. I believe that they offer an interesting set of diverse case studies which should be observed carefully over the next few years. Hopefully, we will have some more light to shed on these state level perspectives on geographical data handling at AUTO CARTO IV.

THANK YOU.

(APPLAUSE.)

APPENDIX

Recent Geographical Information Systems in the Coastal Plains

1. Florida Department of Administration, Division of State Planning--Information Systems Section.

    a. Concept: The system is the only geographical information system in the region based primarily on the USGS LUDA data base. The Information Systems Section has put together a hybrid set of display and analytical programs. The group is currently producing land use area calculations for each county and developing analysis of land use by soil type for drainage basins.

    b. Hardware: The system runs on the CDC-CYBER 74 Computer at Florida State University. Communication is handled via a Tektronix 4013 graphics tube and two NCR terminals. A UNIVAC printer and Tektronix 4954 digitizer, with a 30" x 40" table complete the in-house system. The system utilizes an 11" Gould 80 dot/inch electrostatic plotter and a 22" Versatec 200 dot/inch electrostatic plotter at FSU.

    c. Software: The base for this system is the automatic polygon building program from the USGS. The program takes LUDA arc segments to construct the necessary polygons. The program has been modified to detect and correct some additional errors. Other programs have been developed to create additional files, perform simple interactive editing functions, merge adjacent sheets and convert to other coordinate systems.

       Some particularly innovative software converts arcs to rasters for area calculations and polygon overlaying. Graphic display, until recently, has been limited to packages such as AUTOPLOT, however, now they have developed their own plotting functions. All programs are in FORTRAN, however, they are not presently well documented.

    d. Future Developments: The group is presently working on the development of a grid cell to polygon conversion program and examining the utility of the Defense Mapping Agency's digital terrain tapes.

2. Florida Bureau of Coastal Zone Planning and the Florida Resources and Environmental Analysis Center (FREAC).

    a. Concept: FREAC, which is part of the Geography Department at FSU, is a software subcontractor to the Bureau of Coastal Zone Planning. Using maps derived from color aerial photography from the Department of Transportation, the group is digitizing bio-physical data for the coastal zone. The purpose of the project is to produce an inventory of land use.

b. Hardware: This system is also connected to the FSU CDC-CYBER 74 computer which is accessed via Tektronix terminals and digitizers at both installations. The Gould and Versatec plotters are the basic display devices.

c. Software: Since the basic function of the system is area calculation the data areas are double digitized. For graphic display they have developed a procedure to "desliver" the overlapping line segments. Programs also exist to convert polygons to grid cells and alter coordinate systems.

d. Future Developments. There is a close working relationship between FREAC and the Department of State Planning Staff. Since programs developed by the two groups exist on the same computer there is easy interchange. Consequently, they often work together in the development of new programs that improve the system capabilities.

3. Florida Department of Transportation, Division of Road Operations-Remote Sensing Section.

a. Concept: This group maintains one of the most fully integrated systems in the Region. They have recently installed a highly sophisticated interactive graphics system. This system is used to supplement a full range of geographically related operations (e.g., stereoplotting, county highway map production, land use and vegetation mapping). The system is considered to be the final stage of a process that begins with aerial photography, and includes photographic processing and photo-grammetric engineering.

b. Hardware: The basic configuration consists of a fully integrated interactive graphics design system which was purchased from M and S Computing, Incorporated. The system is based on a Digital Equipment Corporation (DEC)PDP 11/70 mini-computer. There are two disk packs and a disk data scanner attached to the CPU. Each of the five digitizing stations is basically equipped with two Tektronix graphics terminals and Summagraphics digitizers which have extensive menu capabilities. A large flatbed, Kongsberg drafting table is the main plotting device. The office also possesses a Spatial Data 704 color image processor.

c. Software: The key part of the software is an extensive set of modular programs which are addressable through the keyboard or the menu. The programs have considerable internal documentation and conversational language commands. The key programs for geographical applications consist of: interactive construction of geometric elements, with up to 32 line weights, which can be created by digitizing or by drawing directly on the screen; graphic manipulation; geometric element grouping; selective display modes; geometric measurement, line drawing and symbology; automatic dimensioning; and an elaborate text system, with up to 255 different fonts. (Geographical applications are considered by M and S to be simply a subset of the general graphics problem).

d. Future Developments: The Department plans to add digital linkage of the color image processing system to the M and S network. This will enable them to automatically classify and digitize land cover characteristics from photography. M and S is developing additional geographical software for the Department. The major part of this involves polygon overlaying capabilities.

4. South Carolina Consortium (Coastal Zone Planning Office, Budget and Control Board--Division of Research and Statistical Services, Land Resources Conservation Commission, and USC Computer Services Division).

   a. Concept: Over the past four years the USC Computer Services Division has developed an extensive high quality digitizing, editing and plotting system. This system has primarily been employed to produce updated USGS quad sheets for the Coastal Zone. The sheets were developed from orthophoto quads and new aerial photography. The system now consists of a complex set of display and analytical procedures. By digitizing soil survey sheets, the Land Resources Conservation Commission is utilizing the system to produce composite soil maps at the quad sheet scale.

   b. Hardware: The system runs on the University's IBM 370/168, which is augmented by 7 megabytes of real core and a mass storage unit. There are two Bendix digitizers on-line to the 370. Access and manipulation functions are conducted on Tektronix terminals, Telray CRTs and a Princeton graphics terminal. The graphics hardware consists of a CALCOMP 738 flatbed plotter and a 21" Gould electrostatic plotter that runs on-line through a DATA 100 remote job entry terminal. The graphics hardware consists of a CALCOMP 738 flatbed plotter and a 21" Gould electrostatic plotter that runs on-line through a DATA 100 remote job entry terminal.

c. Software: The programs consist of about eighty modules, written in APL. Permanent data storage is contained in IMS and retrieved through APL. A key feature of this system is the ability to access the functions and edit from remote terminals via telephone. The graphics system was originally designed to digitize and display line segments. Each line was considered to be a boundary between two areas (e.g., low marsh to high marsh). Lines were stored with two labels and could be retrieved as desired to produce a set of overlays or a composite map. Symbolizations and labels were entered through the digitizer. Programs were developed to scale, window, merge, plot various line types, and perform selected editing functions. The system now has evolved into a more extensive information arrangement. At present, polygons can be formed by double digitizing. Other procedures have been developed to form polygons interactively from the existing line segment data base. An extensive set of software packages are also available. These include: SYMAP, CALFORM, SYMVU, AUTOMAP, SURFACE II, STAMPEDE, GRID, GRIDS, and POLYVRT.

d. Future Developments: The S. C. Consortium has a number of procedures in the Developmental stage. These include automatic polygon construction and polygon overlay. They are also involved in several demonstration projects with NASA. Plans are presently underway to install LANDSAT processing software and make it part of the overall system.

5. North Carolina Land Resources Information Service.

a. Concept: The North Carolina Land Resources Information Service evolved as part of the 1974 Land Policy Act. The mission of the Service is to provide the necessary geographical analysis and display capabilities for practically any conceivable application. After developing an extensive request for a proposal, the group surveyed the private market for a total integrated stand-alone system eventually deciding upon COMARC Design Systems. This system has recently been installed and has begun functioning. The service plans to use the system for numerous projects, such as EPA 208. The philosophy of the service, however, is to allow individual agencies to utilize the system themselves for their own specialized requirement. DMA digital terrain tapes have been obtained and a one degree square is being analyzed.

b. Hardware: The system is based on a Data General Eclipse mini-computer with 128 KB core storage and 96 MB disk space. Peripherials include a 9 track tape drive, 300 line/minute printer, a Data General CRT, a Tektronix graphic terminal, a Zeta drum plotter and a Talos digitizing station.

c. Software: The COMARC approach is to provide a full range of data input modes (e.g., polygons, grids, and topography). These data can be stored, manipulated and displayed in a variety of manners. The software consists of two conversational packages. The first, DBI (Data Base Implementation), handles the functions necessary for creating the file. The second, COMPIS (COMARC Planning Information System), handles the analytical and display functions. The software has extensive manipulative and transforming capabilities. Its polygon input format was based on double digitizing, however, the company has developed the ability to read LUDA arc files. The analytical aspects of the software relies on polygon to grid and grid to polygon conversions. The latter procedure being a recent addition to the system. The system also incorporated a polygon overlay system and extensive reporting procedures. Topographical data can be input from grids or directly by digitizing contour lines. Innovative programs convert the contour into grids which can be employed to calculate aspect, slope, drainage, cut and fill and view exposure. The three dimensional perspective plot has an option for overlaying polygons for reference. Polygon plots are typically enhanced manually with the aid of color markers. The company considers their software to comprise an analytical system first, and a cartographic system second. The software is licensed and not distributed in source code.

d. Future Developments: The North Carolina group has requested COMARC to upgrade some of their display programs. They also plan to incorporate LUDA and LANDSAT classified tapes as part of their system. Future plans call for several additional digitizing stations.

6. Georgia Department of Natural Resources--Office of Planning and Research, and Georgia Tech Department of Experimental Engineering.

a. Concept: These groups have established the only truly operational LANDSAT computer tape processing system with the Region, at the state level. They are presently experimenting with the use of LANDSAT as the basis for an integrated system. This system will include a wide variety of other data formats. At present, they are also planning an extensive test of these procedures for one county. The group is involved in producing statewide land cover maps and EPA 208 projects for several regional planning organizations.

b. Hardware: The system is based on a Data General NOVA 2 mini-computer, with 32 KB core storage. There are two disk packs and a dual density tape drive. The system uses a COMTAL color image processor and a Versatec electrostatic plotter. This configuration is one of the least expensive LANDSAT processing systems.

c. Software: The key components of this software relate to LANDSAT data processing. These procedures consist of a hybrid of NASA's classification and geographical referencing programs. The software permits a complete set of interactive analysis of the data on the COMTAL unit. Graphical display programs include IMGRID, from Harvard, and other plotting procedures.

d. Future Developments: The experiments planned by this group should provide excellent information regarding the comparative merits of LANDSAT and LUDA. The intensive experiment within one selected county are designed to obtain detailed cost and manpower requirements.

DR. MARBLE: Thank you, David. That was an illuminating discussion on some of the problems that are faced in a sta getting into this type of activity. One of the things tha both Carl and David have underlined is the difficulty of evaluating existing software. This is something that we originally thought of doing as part of our inventory, and soon stopped for many of the reasons that Carl outlined, because it is very difficult to design any type of a bench-markwhich is usable on more than one or two systems. They have widely varying requirements for data in terms of form quality, data structures, and, in many cases, the producti of the benchmark information for evaluation would be more work than reproducing or rediscovering the software itself The evaluation of software as a computer science topic is a very recent development, and the notion of a software science is a new one. There are techniques being developed, and it is hoped that within the next few years we will be in a better position to design benchmark tests for much of the spatial data-handling software.

The final speaker from the panel is Dr. Kurt Brassel, a colleague of mine from the faculty at Buffalo. Kurt received his training in cartography in Switzerland, and has been particularly interested in the development of algorithms for work in computer cartography. He is also in char of the section of the inventory dealing with computer cartography and computergraphics. Kurt?

FUTURE TASKS IN CARTOGRAPHIC SOFTWARE DEVELOPMENT

DR. KURT BRASSEL, Department of Geography, State University of New York at Buffalo.

The Author has participated in the activities of the IGU Commission on Geographical Data Sensing and Processing to compile an inventory of computer software for geographical data handling; in particular I have been in charge of mapping and display procedures. Based on these experiences, this paper points out some unsolved problems or problems which the author at this time does not know solutions for. I am not a forecaster; I am presenting a very personal view based on my background and my special interests in the field. I am presenting questions rather than giving answers. I would not be surprised that if during this conference someone would tell me, "Well, the future you are talking about is today."

I would like to compare the development of automated mapping with the civilization of a continent and distinguish the following three phases:

DISCOVERY
SETTLEMENT
LAW AND ORDER

Overall, I would assume that computer mapping today is in the settlement phase, and the unofficial theme of this conference: "Let us Computer Cartography Bring to Work" is a good indicator of this. Of course, discovery processes should go on simultaneously. On the other hand, some efforts to set up standards for computer graphics are under way, an indication of first elements to establish a state of law and order.

It is my contention that traditional cartography as an overall discipline has reached a state of 'law and order.' This has caused some problems in the past in that cartographers have not been entirely in charge of developments in automated map production, and non-cartographers have been active in the field. The activities of these cartographically untrained outsiders may be labelled as "map mechanics', and their products were quite often below traditional cartographic standards. But we are now in the phase of settlement, and the need for remarrying map perception and advance map mechanics is generally recognized. Thus, where do we stand today, what is needed, what are the tasks and developments ahead with respect to cartographic computer software? Our future efforts have to be directed toward problems on various levels. The following list summarizes the several points which will be addressed in this brief discussion of future tasks and developments:

- DOCUMENTATION AND COMMUNICATION
- STANDARDS
- IMPROVEMENT OF ALGORITHM EFFICIENCY
- DEVELOPMENT OF ADEQUATE DATA STRUCTURES
- IMITATION OF TRADITIONAL CARTOGRAPHIC PROCESSES
- MODELS BEYOND THE TRADITIONAL MAPPING CONCEPTS

DOCUMENTATION AND COMMUNICATION: The compilation of an inventory of cartographic computer software as mentioned above is a first effort to get an overview of the multitude of programming activities in the field. Experiences with this material show a duplication of efforts (33 choropleth shading programs and 25 contouring programs have been recorded so far) and a general lack of information exchange between the various program authors. A first step to remedy this situation is a more rigorous documentation of program packages and the establishment of channels for systematic mutual communication. This then leads to the establishment of meaningful priorities and avoids wasteful duplication. Other efforts are needed to establish reasonable institutional transfer mechanisms for graphics software: Some institutions and individuals distribute their software free of charge, others take full commercial advantage of their products.

CARTOGRAPHIC SOFTWARE STANDARDS: The special interest groups on computer graphics of the association for computing, SIGGRAPH, is in a process of establishing standards for computer graphics. This brings up the question as to whether similar endeavors should be undertaken with respect to mapping software. Should we define base rules for the definition of map design features in mapping packages and the structuring of command language elements? Is the time ready now, or has computer cartography to settle down further first? An answer to these questions will have to consider such aspects as freedom of the program authors and ease of use of cartographic software by a wide range of users.

IMPROVEMENT OF ALGORITHM EFFICIENCY: A further area to work on is the improvement of algorithm efficiency, i.e. the technical improvement of processes for which algorithms are available at the present time. They include more efficient codification of given algorithms, the development of new and faster algorithms and the design of new strategies to perform a particular cartographic task. To illustrate the last point we use isarithmic shading as an example: If the data base for this task consists of contour records of strings of coordinates without any additional information attached to them, this shading task is rather tedious, if not impossible. If, however, to each contour record some reference pointers to neighbor contours are added, the search for neighboring contours is eliminated. My point here is that for this task it is not necessarily important to develop fast search procedures, but rather, a clever and mutual scheme of algorithms and data structures which will then yield best results. This brings us to the next point of discussion.

DEVELOPMENT OF ADEQUATE DATA STRUCTURES: In the overall automated mapping process, raw data are subject to a data capture process for the creation of machine-readable information in 'input-related' data organizations. Rather than accessing this data by the display routines directly, the spatial information is restructured into a 'goal-related' organization. A display task may become trivial if it can be based on an appropriate data structure. Goal-related data organizations are dependent upon the respective applications; they may range from simple to very complex. Base files to be used for sophisticated cartographic tasks should allow access to the totality of geographical reality. Cartographic base files as virtual maps should facilitate the same mental operations as paper maps or the actual geographical reality. They should be able to provide information about the total neighborhood of a feature if we want to use them for such tasks as generalization or name placement. We may have to go even further by defining neighborhood relations in hierarchical manner, and design data structures which do not only connect map features with adjacent map elements but with significant elements at farther distances as well.

IMITATION OF TRADITIONAL CARTOGRAPHIC PROCESSES: In this phase of settlement, computer cartography has to make efforts to develop procedures for the imitation of traditional map products of sufficient cartographic quality. Being aware of the fact that highest cartographic standards as provided by manual craftsmanship may not be achieved by automated means in all respects the development of more sophisticated models may still provide acceptable map results which are economically feasible. As examples we may mention the imitation of manual hill-shading, map generalization and automatic name placement. In order to approach these problems, we have to go back to the source and find out how traditional cartographers have solved these problems, take their work as standards, and try to find automated solutions.

Other problems relating to higher standards in computer mapping have to do with efforts to improve the map design. Some of these deal with, as it seems, minor details, but they are nevertheless indicative of map quality. Each cartographer is aware of the irregular point symbol densities along boundary lines in vector type shading programs. It is a minor problem, but it needs some attention. Further, the problem of legend design must be taken more seriously by producers of computer maps in order to allow for adequate map communication. Map design adjustments in automated mapping require the computation of non-trivial global map parameters. An example would be the computation of the scaling factor for the unit circle radius in graduated circle mapping which generates an optimum symbol density. A common response would be that this can be done by interactive methods. It is my contention, however, that whenever it is technically possible and economically feasible to fully automate a task, this should be done. Interactive handling of an automatable job is a waste of human and computer resources. Interactive methods have their place where perception and design problems occur. My recipe: Produce by automated means a map which on the average is expected to be the best solution, and then adjust with interactive methods the inadequacies due to individual features on the map.

MODELS BEYOND TRADITIONAL MAPPING CONCEPTS: A further category of future tasks is the development of new cartographic methods which go beyond the imitation of representation by traditional cartography. Recent examples in this group are the design of contiguous and non-contiguous area cartograms by Tobler and Olson, and the use of Chernoff's cartoon faces for multivariate data representation. Among cartographic methods to be developed are displays, which enable the simultaneous representation of two statistical surfaces, and models for dasymetric mapping.

Let me conclude with mentioning a class of envisioned developments which clearly go beyond traditional mapping: Based on recommendations of a group of cartographers, the Defence Advanced Research Projects Agency (ARPA) has put together a catalog of desirable developments in search for maps which allow for improved access to spatial information. We should develop map methods which allow us to feed more information to the brain per time unit. They also desire mapping-by-yourself systems, where the map user can design a map for his needs and according to his map reading capabilities. They further promote real world graphics dynamic displays, which simulate real world experience by 'flying' through geographic base files. Other ideas include maps which match the cognitive abilities of the map reader by replacing the concept of accurate maps by the concept of accurate mental maps, maps which compensate for perceptual distortions. Finally, they offer to rethink the relationship between verbal and visual means to describe space: Are visual maps in all cases the most efficient means to communicate spatial concepts or would verbal description of space in certain instances be advantageous, and how can the various methods be more efficiently combined?

DR. MARBLE: Thank you, Kurt. The presentations that we have had so far have been designed largely to lay a groundwork for discussion. One point I would like to make, particularly about the inventory operations and about some of the things that Kurt has talked about is that the existence of the inventory not only enables us to isolate areas of redundancy, it also enables us to isolate the gaps as well; things that people are not doing. This is very interesting in a research sense.

One general plea about software, particularly in the area of computer cartography: There is a recent book by Nicholas Wirth which is entitled Data Structures Plus Algorithms Equals Programs. It is a good book and I recommend it to your attention. Here we have the converse problem in that we have programs, and from them we must deduce the algorithms and data structures. This is devilishly hard to do. So, one plea I would make to you is that you document your work so that others can benefit not only by your bright ideas, but by your mistakes. In very few of the programs encountered do we see explicit discussion of either data structures or algorithms, and to try to pull them out of existing code is very, very difficult. This is one of the things that we need to do if we are to improve the information transfer in this area.

I would now like to throw the floor open for discussion. You can, as far as I am concerned, make individual points, address questions to members of the panel, or to the panel as a whole. Please, when you speak come to the microphone and identify yourself and your organization.

MR. SID WITTICK: I do not believe that we should forget the benefit of experience that has been brought forth today from the panel members -- these are a set of rules which are going to be useful in our own planning. I think it is perhaps worthwhile to add an encouraging note to some of these comments, and that is that there are some exceptions. At least one system that is attempting to come a ways in this direction. I speak of the GIMS system. There will be a bit of a display outside. I think there are on the order of 20,000 lines of code, including a lot of in-line documentation within those lines. But there are also 10,000 lines of algorithm description that are also associated with that system. It provides an example of a university environment where there has been some continuity, where they have produced a product that is being maintained. It is an example, I think, of a dynamic system that is working towards many of the futuristic things that are being asked for.

DR. MARBLE: Sid, before you go away, let me ask you a question: You have mentioned the documentation that has been developed by you and Tom in Canada. Is it intended to make this widely available? Can people write and get copies?

MR. WITTICK: I remember that you did not get the copy you asked for. (Laughter). We received a request from the director of the program library at the University of Edinburgh, where the program was or is resident, asking whether or not this documentation is available to them. We more or less replied that we would like to make it available to the Program Library Unit so as to make it available to others, but added the catch that they not charge for it.

DR. MARBLE: Do we have other comments or inquiries from audience?

MR. FRED BROOME: Fred Broome, U.S. Bureau of the Census. I would like to ask Mr. Reed or Mr. Cowen if they have found any automated cartographic systems in use in a policy making mode, in a daily activity? If so, would they mention them.

MR. REED: I am aware of one system that is used in a policy mode. The San Jose Police force, about two years ago, got together with IBM to utilize a system called GADS, which is a geographic analysis and display system. The used GADS to work up beat scheduling for the different precincts in the city. I think they are still using it. It is a totally interative system that uses a geographic base file, a street network associated with the police beat, crime and other information, and it uses a refresh CRT. They got all the police officers and the management involved in doing this beat assignment procedure. It is the only one that I am aware of right now.

MR. COWEN: Speaking from strictly the state government level in the five states that we were involved in, I would have to at first glance say, no, I do not see anything that is working on a daily basis in a policy decision role. I think actually some of the work that we have going on in South Carolina comes closest to that in terms of a series of updated maps of seven and a half minute quadrangles and wet lands inventories and land uses that have been developed for the Coastal Zone. Presently those materials are being put into a form where they can be used to make actual decisions about permitting land use activities in the State of South Carolina, in the Coastal Zone.

Part of the evaluation that we are going through right now, to change what essentially was a cartographic system into an information system, is trying to address exactly that need. People are beginning to realize that we are not just interested in pretty maps, we are interested in a lot more than that. We are interested in the area calculations and inventory and overlays and other things that are essential to come to real decisions about things like getting a permit. You have to realize that in most of the states that we are talking about in the Southeast there has traditionally been -- "Well, if you did not tell somebody he could not do something. . ." So now we are faced with the problem if we are going to say, "No, you cannot do that particular development," we need good information to back that up. Otherwise we are going to be in a lot of trouble.

MR. REED: I just thought of two other systems as well. Boulder County in Colorado has the Boulder County mapping project where they digitize a lot of their land use and demographic information and use it to help win arguments in the Common Council to get more bucks. Is Carl Youngmann here? He has been doing some stuff in Washington on the coastal survey and assessment, that is also going to be used, I think, if I remember correctly, in some policy decisions.

MR. AL GORNY: Al Gorny from Central Intelligence. Just a few points. In discussing GADS, which was being used, we had looked at GADS, and GADS was always considered from what we could find to be an R & D effort on the part of IBM and has never been actively marketed or pushed. I agree with the speakers, that it is very difficult to find some of the geographic information systems which are available. As a point, I noticed that Carl had mentioned he had surfaced about 85 originally, and Kurt's Vu-graph mentioned he had found 22. We have also experienced that, when you write away you get back "person not found, system not found, laboratory disappeared," or something like that.

We have also come to the conclusion that it is much easier to evaluate the hardware and the software in the systems of others than it is to define the perfect mix for yourself in a system and to objectively evaluate yourself. In-house development usually requires coordination between various offices within an agency, and sometimes you end up trying to make system analysts or programmers out of geographers and cartographers or vice versa. In many cases current programs or projects may not allow you to get the proper manpower mix or even the manpower at all. You also run into a lack of experienced people within certain agencies in using some systems, and that when system availability, as is in our case, is imperative, that with a mix of hardware and software, it is just much easier to pick up the telephone and make a single call for maintenance versus trying to identify the exact problem yourself and then trying to get the people to come in and agree whose problem it is. Thank you.

DR. MARBLE: Thank you.

MR. AVI DEGANI: My name is Avi Degani, Department of Geography, Tel Aviv University. I was listening with great interest to the three speakers. By listening I could relate much of what was said to my experiences, and I think I would like to share some of this with you. I think that one problem that I have been facing all the time is the increasing recognition that what at one time was a map user has turned out to be a map maker by the aid of computers. I think that we tend to overlook or underestimate the severe problems that arise because of this. What I mean is very simply in the past many people who make use of maps, such as the planners and many other people, used to just refer to existing knowledge in the map making sciences, and prepare just those types of maps that they were asked to prepare and had to use, or else they would go to the map maker and ask him to do one for them.

At present, when so many software packages are available for sale, I think that many people buy the packages and are able to use them as they are, but are not able to understand the algorithms, partially because we do not have the write-ups or the analyses of algorithms, and partially because they are not in the business of doing this, they are just in the business of using maps. There is a great gap developing, and a great many of the maps that are produced today -- and, ironically, by good computers, terrific hardware -- are just very bad maps. I think this trend is increasing and this is very bad.

Another interesting problem which is related somehow is how government at various levels is utilizing the type of thing that we are able to produce in terms of automated cartography. We tend to forget sometimes that a map is only a tool, and cartography is only a technique, and of course, a computer is only a piece of hardware. Because when we go to the government at various levels and we try to promote usage of what we are creating, they most times are unable to define what their problems are. It tends to be a procedure, from my experience, at least, and I think I have heard something of this from Dr. Cowen's remarks and also in Mr. Reed's remarks -- it tends to be a procedure whereby we go to the field, we ask the people what actually do you have to do, what actually are your problems, and they find it very difficult to define.

I have been working for better than a year in Israel on a developmental, what we call "ISRAMAP," which is "Information System for Regional Automated Mapping Analysis and Planning," for the Ministry of Interior. It is supposed to handle regional as well as urban levels building a data bank and so on. We have been spending the better part of the last year going from one mayor to another mayor, from one city official to another city official, and trying to ask them what really are your problems. It turns out that we think we can do more for them than they can appreciate at the moment. I would suggest very seriously that we devote in the next meeting more discussion along this line, because this is quite a gap we have to bridge. Thank you.

DR. MARBLE: Thank you very much. I would like to take an opportunity to underscore your comments. We are somewhat off the question of software per se, but we are getting into the critical area of what constitutes adequate system design. Too often we are concerned mainly with things like software and hardware, and do not pay enough attention to the things that you have mentioned just now and the type of things that Rupe mentioned in his discussion yesterday. In many cases we have found in our examination of systems, not only mapping systems but other types of geographic information systems as well, that the major reasons for failure in the system have not been technical. The hardware has been adequate, the software has been adequate; the system is nearly unused. This is a common scenario, and most frequently it arises out of the fact that system building has been viewed as a technical design problem, and it has been constructed by technicians to do what they think is most useful. It turns out that the system is a perfect tool for answering questions that no one particularly wants to ask. We must be very careful to avoid that. The system design model developed by Hugh Calkins provides a sound basis for this.

One other problem, of course, in the software area is the tendency that if something is there and can be used, then pick it up and use it, whether it is really appropriate or not. We see many cases of that. I think your suggestion about the emphasis in the next AUTO CARTO program was a good one.

MR. TOM WAUGH: I am Tom Waugh, University of Edinburg. I have been a bit distressed by the notes of gloom and despondency that have been passed around this morning. I think I would like to bring a slightly more optimistic or sunny note. I am going to relate it completely to the United Kingdom, and it relates back to Fred Broome's question, which systems are there that are in existence and are being used? And Carl thought one, maybe two, maybe three or something that he knew about. I can give some examples from the United Kingdom where in fact there are systems that are running and have been running, are well documented, the software is available, and are used in a day-to-day production and policy environment. Probably the most obvious is the work of the Ordnance Survey, who produce up to 3,000 maps per year, one to 1250 scale in a production environment by computer methods. They are working on a one to 10,000 scale, the one to 25,000 scale, and they have now started on the one to 50,000 scale. If there were somebody here from the Ordnance Survey I am sure he would say they were all still pilot projects, but I think that they are really being quite serious about it. The Department of the Environment runs a system called LINMAP, which produces fairly crude line printer maps. They produce up to 700 maps a year. It is decreasing at the moment, since the use of the '71 census is dropping. That is used day-to-day in production with fairly well documented software and is used in a policy environment by central government in London.

In my own town, in Edinburgh, the Department of Geography runs a service bureau which services central government agencies in the Scottish area, particularly the Scottish Tourist Board and the Scottish Nature Conservatory, the Scottish Development Department, the Department of Forestry; there are about three or four. They run at least three different sets of software on a day-to-day production environment, two of them being mapping, one coarse mapping, one medium quality and high quality, and they also run SPSS and other facilities. That is day-to-day and is used in a policy environment. These maps and charts and everything are used in committees up the national level. Now, it comes down to whether or not you believe these maps are useful or the tables of statistics or whatever are useful. But I think it should be made quite clear that there is software available which is being used in a production environment, and it is not quite as bad as perhaps has been painted this morning.

MR. REED: I would like to add a little note. I was not trying to be overly gloomy. The reason for that final 30 percent figure was that the U.S. Fish and Wildlife Service does have a fairly unique set of requirements, especially spatial analysis. I should append my little talk by saying that well over half the cartographic requirements are going to be fulfilled by existing software. The most problems we have had are in such things as spatial searches, such as proximity, the kind of thing Wildlife people call interspersion and stuff like that, that just does not exist anywhere in any usable format that we have found. The cartographic software does seem to be in much better shape than that in spatial analysis.

DR. BRASSEL: I would see this problem in a slightly different light. It is not that the products that are produced are not necessarily good for the task which they could be used for, but maybe it is a public relations problem, that government or the agencies are afraid or maybe they are not introduced properly to the new tools. Maybe we should look at that. But a careful introduction and a long process of making these people aware of these tools is probably important.

MR. COWEN: I would like to respond to that also. I have no doubt as to the technological capabilities of a number of systems. Part of my work in terms of giving advice to people, say in South Carolina, has been to look extensively through the inventory to see what is going on. We are well aware that there are a number of places where things are working. The next question, though, is somebody says here is some amount of money, acquire that material and make sure that it works. Now, how can you go to a university setting or even public domain, ask them, "Are you willing to respond to an RFP? Are you willing to do a benchmark test for us? Will you come and install your system and train us in how to use it?" I think there is the big dilemma that one is faced with -- given the constraints in a governmental setting where they think they can go out and buy what they want to off the shelf, they can have somebody install it and give them some training; it does not exist in the field of automated cartography.

MR. TONY VAN CUREN: I am Tony Van Curen from San Bernardino County. We have an application which is one I think is fairly common among government agencies. We are trying to institute a mapping program to handle an enormous data base that was never intended to be mapped. In setting system standards, I would like to emphasize something that I think we are all aware of, and that is, quite often mapping systems are going to have to be integrated into an environment which was not intended for mapping. I hope to see in the future people in computer sciences, people who are more familiar than we geographers, planners and various user groups; put more effort into coming up with means by which we can interface these relatively incompatible data sets. This has been a burning issue with us because we end up having to write a lot of software that we would much rather buy, but we do not have anyone offering it to us.

MR. WITTICK: Just a couple of short comments. With regard to being able to find firms or agencies that would be willing to do all these things in terms of installing and training and so forth; it is a matter of money. If you are willing to pay for it, most places will provide anything, especially in the private domain. We have another system for what I call reference mapping, and there are some people here from private firms, and I am sure they will confirm the fact that if I am willing to pay, they will train me until I am sick of being trained, document till I am sick of documentation.

I have had the good fortune of coming from a conference in Hawaii on management information systems. All the problems we are having here are the same for management information systems as well. We now have the technology and are trying to bridge the gap between the tools and the user. I guess I am going to pose a very simple question: What makes us thing that there are not supposed to be problems? We have tried all the advice being given by various people. We have tried to plan, and people say, "What are you thinking about '86 for? It is only 1977." We tried to get equipment in early so we would have lead time so we can train, and people say, "Well, what are you really going to use the equipment for?" What makes us think that there are not problems? If there were not problems, maybe we would all be out of jobs.

DR. MARBLE: There are certainly problems, Sid. One of the major problems, though, is recognizing what are the problems in the system. As a general comment about attempting to acquire software in this area, one of the things that I would say, based on personal experience and observations, is that it is absolutely disastrous to go into the market with an RFP for a large sum of money. You will get every single commercial firm that has ever done any software for anything coming out and saying, yes, we will do it for you. And I know several systems that have been developed this way at great expense by firms with no knowledge of spatial data handling which at best just "sort of run."

Spatial data is not airline reservations, nor insurance company records, nor bank accounts. We have various special problems with spatial data. These problems are ones that we tend to recognize intuitively because of our work in cartography and allied areas. They are problems that are not generally intuitively obvious to someone from computer science or engineering who suddenly takes up a spatial data handling project. The cases in this area are numerous indeed, as are the horror stories associated with them.

We must remember that in dealing with spatial data we are dealing with something that is quite different from the standard forms of data handling. Sid, and, I think, someone else also mentioned the work in management information systems. There are some commonalities, but there are also some differences. We have to be alert to both the commonalities and the differences. On that point I will close this session.

RASTER-BASED APPROACHES TO MANIPULATION OF CARTOGRAPHIC DATA

DR. MARBLE: The second session today in the software area is one entitled Raster-Based Approaches to Manipulation of Cartographic Data. In the previous session we talked about data structures, and which refers to the way data is logically organized. Typically, in cartographic work we have worked with a relatively simple and traditional set of data structures. The presentations of this panel are designed to introduce us to an alternate approach to cartographic data handling.

The first presentation is by Dr. Donna Peuquet, from the State University of New York at Buffalo. Donna is the technical chief of the SUNYAB Geographic Information Systems Laboratory, and has been conducting NSF sponsored research on interactive editing of raster-mode line data. Donna?

THE NEED FOR RASTER PROCESSING OF CARTOGRAPHIC DATA

Dr. Donna J. Pequet
Geographic Information Systems Laboratory
State University of New York at Buffalo

The Development of Methodological "Traditions" in Automated Cartography:

The earliest computer programs written to manipulate cartographic data most commonly performed repetitive computations which are tedious and prone to human error when performed by hand. These programs represented direct translations of manual techniques for performing these tasks into computer-executable instructions. The data itself were also stored in a format which most faithfully reproduced man's standard analog model of geographic space, i.e., the map. This usually meant that the map was copied, point for point and line for line, into strings of digital coordinates. The necessity of recording these points by hand kept early volumes of digital spatial data very small. With the advent of efficient graphic input and output devices for the computer, an increasing number of operations with an increasing level of sophistication are being performed on larger and larger volumes of cartographic data. These operations, as well as the storage format of the data on which they are performed generally continue to replicate manual methods. This can be attributed to two factors: first, the software was usually written, or at least designed, by individuals trained in traditional (i.e., manual) cartography and not in computer science. Second, the first available devices designed for graphical i/o lent themselves most readily to replication of existing manual methods.

As reliance on the computer for cartographic data processing continued to increase, large collections of data were shared for a variety of uses. Economy of data storage space, efficiency of computer time needed for processing, and the ease and flexibility of using the data became major concerns. A direct result of this was the development of integrated comprehensive software systems to perform all phases of data management as well as a wide variety of descriptive and analytical processes for cartographic data. Thus, it often became necessary, particularly in the case of such a system, to tailor both the software and data storage methods to the characteristics of the computer hardware for the sake of cost-effectiveness. However, in practice this has meant that traditional cartographic techniques were only modified to the extent necessary and not abandoned.

The Representation of Cartographic Data:

Graphic input devices transform area, line and point structures into numeric, computer-readable form by recording spatial coordinates of mapped entities. The basic problem underlying this transformation is that cartographic data are two- or three-dimensional in nature. The coordinates must therefore be structured so as to preserve the two- or three-dimensional relationships, such as "above" or "left of" which are inherent in these data and yet be capable of being recorded in linear or list fashion so that they can be stored in the normally one-dimensional medium of computer memory.

The many formats which have been developed for storing cartographic data in digital form can be classified into two basic types; vector organization, where the basic logical unit corresponds to a line on a map such as a contour line, or raster organization where the basic logical unit of data is a strip or scan line across a data surface with data values recorded along each scan line (cf., fig. 1). The standard television image is the most common example of a raster display. Data organization on the basis of regular or irregular grids can be viewed as a special case of raster organization, since the data can still be referred and processed as rasters. The basic distinction of gridded or cell formats is that the data can be divided just as easily into either vertical or horizontal strips, and the data can be referenced in both the X and Y directions. This contrasts with a raster structure where there is not necessarily a one-to-one correspondence between locations of equal X-values which occur on different rasters (i.e., have different Y-values.)

The most common format used for computer storage and processing of cartographic data has been vector format. If a raster or grid format is used for storage, the data is almost always vectorized before cartographic processing. The reason for this is that vector format is best adapted to retaining the logical map entities familiar to humans. All rivers, roads, areas, and so on are recorded as distinct lines or groups of lines (i.e., vectors). However, it is a very difficult task to retain spatial and topological interrelationships given that all of these vectors must be stored as lists of coordinates. Often, the relationships which are of particular interest have to be explicitly recorded in some way such as separate data items, links or pointers between items. Not only does this inflate the volume of data to be stored and processed, but other relationships not explicitly recorded either have to be calculated using additional computing time, or are forever lost without redigitization.

In contrast to this, individual map features are not retained as discrete entities in raster format. It is therefore extremely difficult, if not impossible, for people to conceptualize cartographic data in terms of arbitrary slices across the data surface. However, this format easily lends itself to representing cartographic, or spatial, data in list form. Individual rasters can simply be listed in sequence. The X - Y locations are also necessarily pre-sorted and location specific within the data list. This means that all spatial and topological relationships are retained as an important part of the data format and do not need to be explicitly recorded.

In addition, individual data items can be accessed directly on the basis of location. Raster formatted cartographic data therefore has neither the time nor space efficiency handicaps that are unavoidable when processing vector data by computer.

Processing of Cartographic Data:

The internal processing of cartographic data is also most commonly performed in terms of vectors. This is again primarily due to the fact that manual cartographic manipulations are predominantly vector-oriented as a result of the relative ease of human conceptualization. This means that vector-oriented techniques or algorithms are the most commonly known and "traditional". In addition, the repertoire of vector algorithms is more developed than raster-oriented algorithms for performing cartographic manipulations. This does not mean that raster-oriented algorithms do not exist to perform all forms of cartographic manipulations. Based upon a preliminary literature and software search, it has been found that at least one raster-oriented technique presently actually does exist to perform each of a wide range of tasks (Pequet,1977a; Pequet, 1977b). However, the majority of these algorithms were developed within other disciplines, most notably image processing (cf., fig. 2).

Even with the existence of these raster techniques, the growing number of installations which utilize data captured in raster format, such as landsat imagery or drum scanner outputs generally have chosen to undergo the time and expense of reformatting these data into vector format for processing. Then, the vectorized data are often converted back to raster format for output.

These raster-to-vector and vector-to-raster conversions represent not only extra processing steps that one may want to avoid simply for general efficiency considerations, but it also turns out that many raster-oriented algorithms are much simpler and thus more efficient than their vector-oriented equivalents. For example, perimeter and area calculation, simple sums and averages and sums of points within areas are reduced to mere counting operations. Calculating the area of a polygon in raster mode requires counting the total number of pixels or their equivalent inside the polygon and then, given the size of each pixel, converting into the desired unit of measurement. Map overlaying consists of performing a logical "and", or summation, of the contents of each of the corresponding pixels or positions of the separate overlays. Windowing and clipping also become simple, again because of the presorted coordinate structure of raster-formatted data. For both tasks, all data before and after the file locations of the desired minimum and maximum spatial locations are simply disregarded. Each location in the file does not have to be tested for being within the desired limits, unlike vector mode clipping and windowing. Many other procedures are just as simple to perform in raster mode since they are non-contextual in nature. In other words, once certain global parameters have veen calculated, determination of the new value for any point is independent of the values for any other point. Rosenfeld calls these parallel procedures (Rosenfeld and Kak, 1976). By his definition, parallel precedures are those which can be performed "in parallel" or simultaneously, on each pixel or raster element. Included here are scale change and projection conversions.

The conclusion drawn from this can only be that machine efficiency, and therefore time and money, are being sacrificed so that computers can imitate traditional paper-and-pen methods.

Present Hardware and Trends for the Future:

As the volumes of automated cartographic data and the sophistication of cartographic systems increase, users are becoming more sophisticated and numerous. Developments in automated cartography have been greatly facilitated by advancements in hardware technology which have increased the speed, capacity and reliability of computers and related hardware.

I/O and data capture devices for spatial data have experienced significant technological advances in the past two decades. Remote sensing devices for spatial data have advanced from aerial photography to complex aircraft and satellite scanners. Satellite imagery, such as that produced by LANDSAT, generates vast amounts of raster-formatted digital data. For example, take the case of a simple orbital satellite with a single scanning system that uses a six bit (64 gray level) code for each pixel. This can scan the entire earth's surface, approximately 5.1 * 10**8 KM**2, say, once every 17 days. With a ground resolution on the close order of 80 meters per pixel, one global data set (17 day's world of data capture time) would require a storage capacity equivalent to 3,060 nine track, 800 BPI, 2400 foot magnetic computer tapes. As the ground resolution increases, the amount of data increases geometrically, as shown in Table 1. Contemplating the amount of computer time needed to process these data further helps in appreciating the magnitude of these data volumes. The processing time shown in Table 1 is based on a nominal 10 milliseconds per pixel of CPU time.

TABLE 1

MAGNITUDE OF SATELLITE IMAGERY DATA

GROUND RESOLUTION	NUMBER OF DATA BITS	TOTAL PROCESSING TIME
100 KM	0.003×10^8	0.5 SECONDS
10 KM	0.306×10^8	51 SECONDS
1 KM	30.6×10^8	1.4 HOURS
100 METERS	$3{,}060 \times 10^8$	142 HOURS
10 METERS	$30{,}600 \times 10^8$	591 DAYS
1 METER	$3{,}060{,}000 \times 10^8$	162 YEARS

A major drawback of most X-Y digitizers is that they require an operator. This limits the speed of recording and introduces human error. With drum and flying-spot scanners, in contrast, the data recording process is automatic once the map is mounted on the device. They can record greater volume of data than manual digitizers and are not as subject to error.

A standard device for graphic output is the digital vector plotter. Since these devices are necessarily mechanical, there has always been a trade-off between speed and accuracy The matrix plotter, however, outputs the image in raster format. This means that the complexity of the map has no effect on the plot time, in direct contrast to a vector plotter where plot time is in proportion to the total line, or vector, length drawn. Matrix plotters use an electrostatic process which is more compatible with solid state technology, thus allowing them to be designed with fewer moving parts and avoiding the trade-off between speed and accuracy while increasing reliability.

Another graphic output device which has come to the foreground in recent years is the cathode ray tube. The refresh CRT allows dynamic and interactive graphics and is useful in the display of space-time dependent data. Raster refresh CRT's are not only tailor-made for the output of raster data, but are also more suitable for drawing complex maps since, similar to the matrix plotter, drawing time is not necessarily adversely affected by drawing complexity although complex maps can cause screen flicker. Of course, performance always deteriorates if vector data are to be displayed because of the then needed scan conversion.

Thus, the devices being developed at present which show the greatest capabilities in terms of reliability, flexibility, and data handling capability operate in raster mode (IGU, 1976a). This is particularly true in the areas of spatial data capture. As a result, there has been and will continue to be a distinct trend toward the use of raster devices for graphical input and output (Teicholz, 1975). There is also an increasing need for efficiency in automated cartography systems due both to the size of the data volumes to be handled and the users' needs for fast and economical response. This means that the space in which the data are stored must be kept as small as possible in order to minimize the amount and consequent cost of the hardware required. Cartographic systems also retrieve and process data efficiently in order to keep response time down to a level which is reasonable to the user.

When technological advances are compared with performance requirements of cartographic systems, a problem becomes evident: cartographic data handling techniques have not kept pace with technological advances in computer related hardware. In many systems, the one installed at the Engineering Topographic Laboratory (ETL) at Ft. Belvoir being a good example, data are entered into the computer in raster format, converted to an internal vector format for storage and processing, and then converted back to raster format for output. These raster-to-vector and vector-to-raster processes are very expensive in terms of computer time (Kothe, 1973). In systems which utilize raster input and/or raster output, a raster-type organization for internal data storage and processing could be used to eliminate these expensive conversions. To decrease the load of vectorization put on their system ETL, a part of the Defense Mapping Agency, has found it necessary to purchase a STARAN associative array processor at a cost of $1.3 million dollars. The irony of this situation is that, while it will do vectorization faster, an associative array processor is specifically designed for matrix and raster oriented operations (Goodyear, 1974).

Conclusions:

Given that the total volume and proportions of cartographic data which are initially captured in raster format instead of vector format will continue to grow at a very rapid rate in the foreseeable future and that the trend of hardware technology toward raster-oriented graphic i/o devices is also a continuing fact-of-life, the inherent inefficiencies of vector format storing and processing cartographic data will soon render this approach economically unviable for a number of production applications. The most direct alternative is for authors and users of cartographic software to make an about-face and start conceptualizing in terms of rasters. Not only may this be beyond the capabilities of the human mind, but traditions do die slowly. Human efficiency is a factor which cannot be disregarded. The ideal solution would be to physically store cartographic data and manipulate it in raster format within the computer, while at the same time allowing the user to think in terms of vectors.

This best-of-both-worlds approach of allowing both the machine and the user to operate internally in terms which each can most efficiently use is not new. This is the basic philosophy behind operating systems, language compilers and database management systems. A substantial amount of literature already exists within the field of computer science on the problems of man-machine interfacing encountered in implementing these types of software.

The fact that almost all current cartographic software utilizes some operating system and higher-level language means that we have already been using this approach, either knowingly or otherwise. The file structure, or format in which data is physically recorded, on a disk, is organized and referenced in terms of sectors, tracks and blocks. This format is logically interpreted by the operating system as another format organized in terms of files and records which are usually ordered differently than their physical location on disk. This format or "schema" is again logically interpreted by a given application program as still another format in which data is organized in terms of map lines or pixels. The final translation is made be the user of the program who usually has yet another logical conceptualization into which he interprets the given data. Map lines may be thought of as topographic contours or census tract outlines. All of these do not require any physical reorganization of the data.

In order to utilize raster techniques in software for cartographic manipulations while allowing the user to conceptualize the data and the processes involved in terms of a vector format, a "front end" needs to be built onto the software which acts as an additional level of buffering between the computer and the user. As with the translation between other schema, no physical shuffling of data is necessarily performed. This does not mean that the user should be fooled into thinking that the computer is manipulating vector-formatted data. It merely offers the user a means of communicating with a raster system via the much more convenient vector-oriented terminology.

We do not have, however, a comprehensive body of knowledge with a complete collection of algorithms and design principles ready to be plugged in. A cartographic software system could be built immediately. However, much basic research on raster algorithm development and the comparative merits of different algorithms to perform equivalent tasks needs to be done. Relative efficiency of various raster and vector algorithms and how each is affected by varying data volumes and combinations of algorithms needs to be rigorously quantified. It therefore needs to be drawn together and interpreted in a cartographic context.

This research is necessary not just for the development of raster-oriented automated cartographic manipulation and production systems, but for the advancement of auto mated cartography in general. Very little basic research has been systematically carried out on development and analysis of either raster or vector algorithms. Only after this has been remedied can we knowledgeably select the best algorithm for any type of automated cartographic application.

DR. MARBLE: Thank you, Donna. The general ground that you laid will now be explored in some depth by discussions of two specific systems, one of which was to be presented by Dr. Nevin Bryant of the Jet Propulsion Laboratory. I was sorry to learn that Nevin has suffered an accident, but the discussion of the IBIS System from the Jet Propulsion Laboratory will be given jointly by David Wherry and Steve Friedman, who have managed to take Nevin's notes and graphics and put together a presentation for us. David, I believe you are going to start.

CARTOGRAPHIC APPLICATIONS OF AN IMAGE BASED INFORMATION SYSTEM

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INTRODUCTION

Machine assisted cartography is often thought of synonymously with vector based computing systems. Recently, raster based processing has established itself as a competing technology in this field. Far beyond its beginnings as an offshoot of unmanned space mission imaging systems, cartographic applications based on raster technology blend the ingredients necessary to obtain rapid, flexible, and accurate processing of highly complex data.

The Image Based Information System (IBIS) is a raster based approach for mainpulating spatial data. Characteristic of IBIS operations are modeling applications integrating a variety of data types, and spatial display methods enabling rapid transformations of data into useful cartographic products. General data management considerations, as well as two IBIS case studies undertaken at the Jet Propulsion Laboratory (JPL) will be presented.

IBIS Data Management Considerations

IBIS is a fully automated raster (image) based information system. The IBIS design is based on a sequence of general purpose programs. The logical grouping of these routines into processing steps enables the handling of very complex problems. Easy operation of the routines by the system user has always been a consideration of the system's designers.

The user of IBIS can integrate raster, tabular, and graphical data types for the analysis of spatial phenomena. Image data sets can be acquired from Landsat imagery or other multispectral scanner sources. Still other image data are encoded or scanned from aerial photographic products. Graphical data, such as maps, are electronically digitized into Cartesian coordinate space and are subsequently transformed into image format. Tabular forms of data are entered into IBIS via a table-structured input. In order to establish a link between these different types of data, an interface between image-based data files and all varieties of graphical and tabular data sets has been provided.

IBIS utilizes digital image processing technology to perform most data base storage, retrieval, and analysis operations. A major advantage of this approach is that the locational aspects of data (x,y reference) are implicitly recognized by position in the raster scan. Representation of data in this manner simplifies the algorithms used in data set editing, the construction of multiple overlays, and the reformatting involved in changes of scale or adaptation of maps drawn in different cartographic projections.

Registering data images and the removal of distortions caused by different map projections are important features of IBIS. These geometric corrections are performed by the implementation of an automated "rubber sheet" alignment procedure. The operation is based on feature location, or some common reference grid such as longitude-latitude.

Special purpose algorithms have been developed for the overlay, aggregation, and cross-tabulation of data from one image with data from other images. The analysis capabilities of the system are extended by the implementation of multi-purpose algorithms designed to perform mathematical and logical operations on these data.

IBIS Case Studies

An examination of two case studies: Illinois coal reserves description, and Orlando, Florida, urban growth mapping, will aid in clarifying the flexibility and desirability of the image processing approach to the manipulation of cartographic data.

The approach selected in these studies employs the Image Based Information System developed at the Image Processing Laboratory of JPL. IBIS was conceptualized and implemented by N. Bryant and A. Zobrist (1977) as an extension of the VICAR image processing system which was originally designed to reconstruct and enhance image data obtained from spacecraft.

ILLINOIS COAL RESERVES DESCRIPTION

Approach

JPL is currently involved in an effort to define and develop advanced systems for mining deep coal seams. In support of this effort, Image Processing Laboratory (IPL) has assisted in developing an image processing scheme to describe regional coal reserves. The Herrin No. 6 coal seam, the most important seam in Illinois in terms of reserves and production, has been selected as the initial target for description and analysis.

Essentially, the image processing scheme utilized for the description of regional coal deposits is quite simple in concept (an overview of the map to image processing steps are provided in Figures 1 and 2). First, the requisite geological information is assembled in the form of maps which are typically isopleth plots of salient geological variables such as surface and seam structure, thickness, local slope, roof quality, etc. Next, the isopleths are transformed into a computer compatible format as strings of x,y coordinates via digitization. After editing and transformation into a special format required for IBIS processing, each isopleth is converted to an image-base. Each image-based map is then assigned gray values to portray a specific data aggregation chosen for analysis. For instance, a seam thickness map might be assigned brightness values to exhibit thickness classes of 0-12, 13-30, 31-48, 49-60, and more than 60 inches. In subsequent analysis steps, the maps are processed to obtain answers to questions or to test hypothesis regarding the Herrin No. 6 coal seam. At the discretion of the analyst, output is produced in the form of maps or tables.

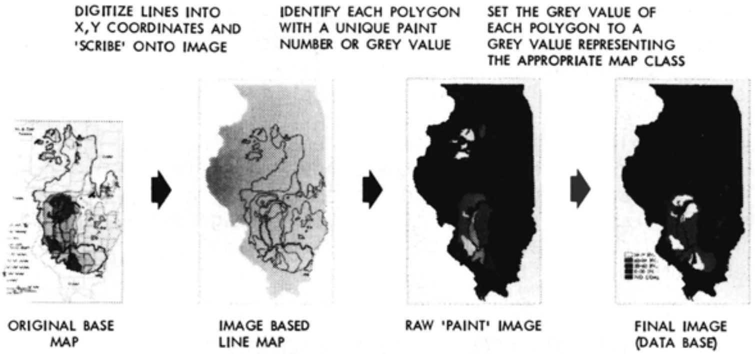

Figure 1. Processing steps in converting an input map to image format. The Herrin No. 6 seam thickness map.

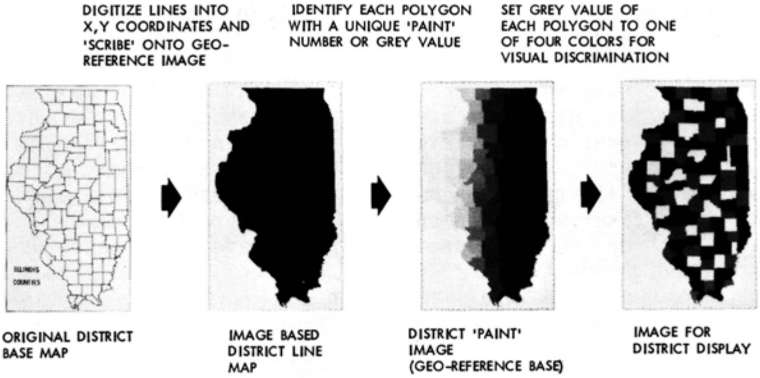

Figure 2. Processing steps in converting an input map to image format. The Illinois county map.

Procedures

Map Digitization and Transformation to Image Format. Four processing steps are required to convert mapped information into IBIS format. First, tiepoints (markers common to all maps) are identified on a selected base map so that each subsequent map can be registered to those exact locations. Second, features of importance such as county boundaries or isopleths are manually digitized on an electronic coordinate digitizer. Third, each digitized map file is converted to image format and simultaneously registered to the base map. Finally, maps are edited to remove any errors introduced during digitization and map to image conversion.

In the Herrin No. 6 study, all image formatted maps are line-representations of geologic variables or political boundaries. These lines which are "scribed" onto an image-base are constructed of linked paths of grid cells (picture elements or "pixels") within a common grid scheme used for all maps. A grid of 1000 x 586 was selected for the Herrin No. 6 application, resulting in an elemental grid cell area of 0.154 square miles.

Editing. Editing procedures are used to correct either the image formatted map (image) or the original file containing the digitized data. Editing is simplified by "painting" regions in the image with unique values (brightness values or shades of gray) and visually inspecting that image for errors.

Painting. For ease in interpretation, painting is also employed to group data into distinct categories, such as zones of equal thickness or elevation. For example, in creating the Herrin No. 6 coal seam thickness image, brightness levels were assigned to equal the upper class limits of any particular thickness map class. In this specific case, every region or polygon representing 30-60 inch thickness on the final seam thickness image (data base) was assigned a brightness value of 60 (see Figure 2). The Illinois county map was painted in a similar manner. However, brightness values were assigned in a manner so that each county is identifiable in extent and location by a unique gray value (see Figure 1).

With one exception, all images were created via a similar processing stream as described above. The Herrin No. 6 map of overburden depth was obtained by differencing images of seam structure and surface relief (Figures 3 and 4).

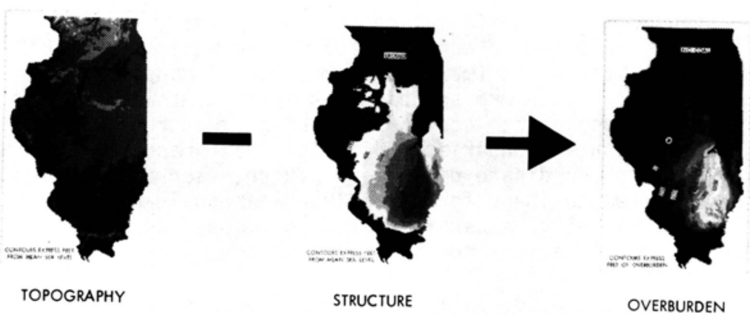

Figure 3. Construction of the overburden map by a process of image subtraction. Data and results for the Herrin No. 6 seam.

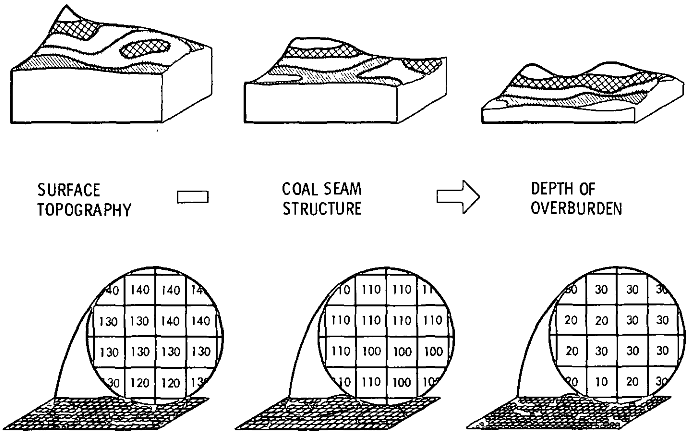

Figure 4. Construction of the depth of overburden map by the process of image subtraction.

Output Format Options. As will become apparent in both case studies, two types of output are available with IBIS -- maps and tables. Tabular output is similar in style and organization to the lists common to many kinds of computer analysis. However, map output is a unique feature of IBIS. Image formatted maps are easily converted into photographic products for display and may be stored on tape or disc as input for future analysis.

Results

Multi-Attribute Analysis. Identification of coal reserves or resources which satisfy a specified list of conditions can be a valuable tool in the evaluation of advanced mining systems. A multi-attribute analysis of maps containing information pertinent to mining systems can produce an inventory of resources containing coal deposits of a specified character. Maps and tables can be output as answers to questions regarding physical, chemical, and locational characteristics of the coal addressed by a new mining technology design. Questions regarding construction access, environmental impact, market transport, and land lease information can also be answered quickly.

A multi-attribute analysis was performed on Herrin No. 6 image maps.

The analysis is focused on identifying the location and tonnage of coal satisfying the following conditions:

Seam thickness of 30 to 60 inches;

Depth or overburden 1000 feet or more; and

Energy content of at least 12,000 Btu/pound[1].

The resource is located by interpreting the above specifications as a logical intersection of the form:

$$(30 \leq t \leq 60) \text{ and } (d \geq 1{,}000) \text{ and } (e \geq 12{,}000);$$

where t represents thickness in inches, d represents depth of overburden in feet, and e represents energy content in BTU/pound. In deriving results, first an attribute window is created for each component in the expression. This is done by masking out areas that do not satisfy the conditions. For instance, coal that does not satisfy the thickness criterion is assigned a value of zero (black) on the final seam thickness image (Figure 5). In like

SEAM THICKNESS MAP

SEAM THICKNESS ATTRIBUTES NOT DESIRED ARE BLOCKED OUT WITH 'BINARY MASK'

IMAGE WITH SEAM THICKNESS ATTRIBUTE WINDOW

Figure 5. Construction of an attribute window by applying a binary mask to the final seam thickness image.

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[1]This list of specifications describes a portion of Illinois coal resources which may be attractive to developers near the end of this century.

manner, masks are applied to the energy content and depth of overburden images to create windows for those attributes. The three attribute windows are logically intersected to form a multi-attribute window (Figure 6). The multi-attribute window is then re-

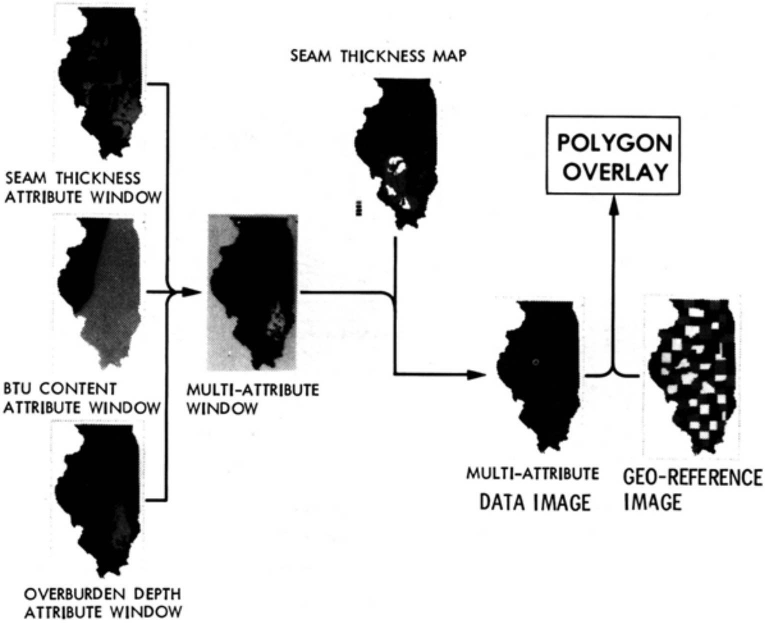

Figure 6. Formation of a multi-attribute window and integration of the Illinois county image (geo-reference base) for IBIS process of polygon overlay.

assigned gray values representing seam thickness which are lost in logical intersection processing. These thickness values are used in subsequent calculations of coal tonnage.

The process of polygon overlay facilitates the aggregation of multi-attribute pixels (image grid cells) per each Illinois county. Subsequent processing transforms these data to an expression of tons of Herrin No. 6 coal satisfying the prescribed conditions in each county (Figure 7). A final output map clearly shows the location of this multi-attribute coal (Figure 8). Associated tonnage calculations are displayed in table form (Table 1)[2]

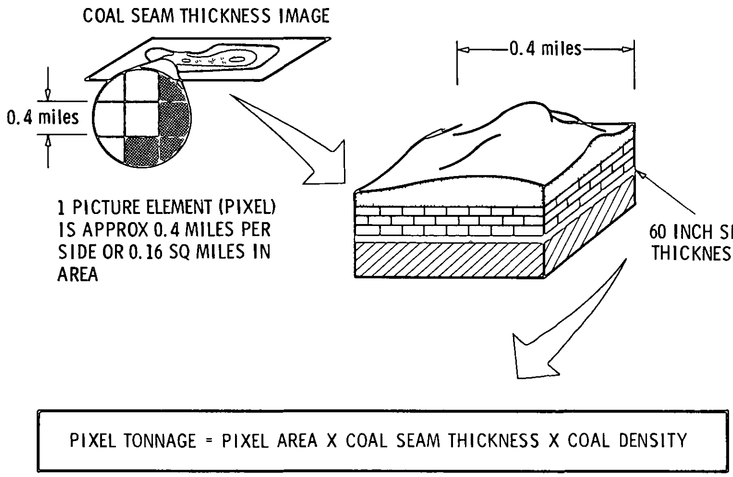

Figure 7. The calculation of Herrin No. 6 coal tonnage.

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[2]Accuracy of the IBIS Herrin No. 6 output tabulations was assessed by Farrell and Wherry (1978). Areal accuracies were observed to be of a high order -- inaccuracies of less than -0.18 percent difference were observed upon comparison to other published materials. Certain tonnage figures produced via IBIS processing exhibited inaccuracies due to differences in coal reserve definitions between agencies supplying input maps to the IBIS process and other verification sources.

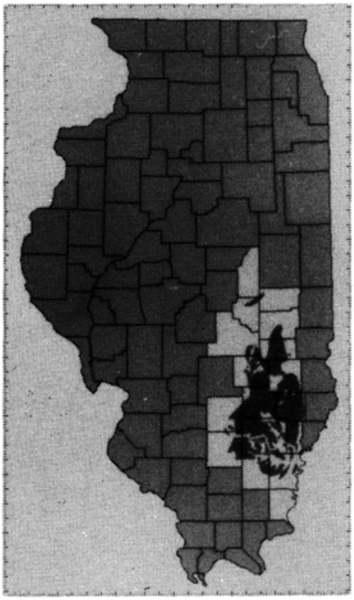

Figure 8. Final Illinois county map displaying the location of Herrin No. 6 multi-attribute coal.

STATE OF ILLINOIS HERRIN NO. 6 COAL BED
COAL RESOURCES BY COUNTY

(TONNAGE EXPRESSED IN THOUSANDS OF TONS)

Table 1. Coal tonnage satisfying restrictions on thickness, Btu content, and overburden depth.

COUNTY	TONNAGE
CLAY	1734339
COLES	283047
CUMBERLAND	783821
DOUGLAS	44226
EDWARDS	621885
EFFINGHAM	1081155
GALLATIN	2041
HAMILTON	410281
JASPER	1204988
JEFFERSON	491929
MARION	467435
MOULTRIE	124513
PIATT	9525
RICHLAND	1469664
SHELBY	217728
WAYNE	2139857
WHITE	558609
	11645043

ORLANDO, FLORIDA, URBAN GROWTH MAPPING

Approach

The Image Processing Laboratory at JPL is developing a data processing package for the Geography Division of the U. S. Bureau of the Census. The package, consisting of IBIS programs and other image processing programs contained in the VICAR system, will be utilized by the Census Bureau to update urbanized area boundary files of the Metropolitan Map Series. It is essential that these maps are kept up-to-date since Federal aid is often appropriated as a function of urban area size. Furthermore, the demarcation of census enumeration districts used in subsequent field applications is partially based on the urbanized area boundary.

Data Processing Requirements. Beginning with the 1980 decennial census, the Census Bureau must provide five year updates of urbanized area boundaries for all Standard Metropolitan Statistical Areas (SMSA) in the United States. Current field based map updating practices cannot be carried into the next decade while still maintaining efficient operating levels. Data must be obtained from new sources, and the time-lag between data collection and map revision must be greatly reduced. Remotely sensed data, such as Landsat imagery, can be processed in a digital image processing system to obtain much of the needed information for map revision. Elapsed time between data collection and map compilation can be greatly reduced with the advanced technology employed.

To complete the map revision process, Landsat data must be integrated with socio-economic data currently available to the Bureau of the Census. Revised maps as well as tabular reports used to summarize urban perimeter changes must be produced. In view of the complex data handling requirements of the task, IBIS has been employed for data management, map revision, and statistical reporting purposes. The Orlando SMSA, located in central Florida, has been selected as the first study area for testing the new package (Figure 9).

Procedures

Since the population of the Orlando SMSA has risen sharply since 1970, it was expected that a significant amount of urban area expansion would be detected. In order to determine if any significant expansion has occurred, three types of data must be integrated: (1) census tract boundary files, (2) census population statistics, and (3) thematic data from Landsat. These data types are integrated through the use of IBIS software.

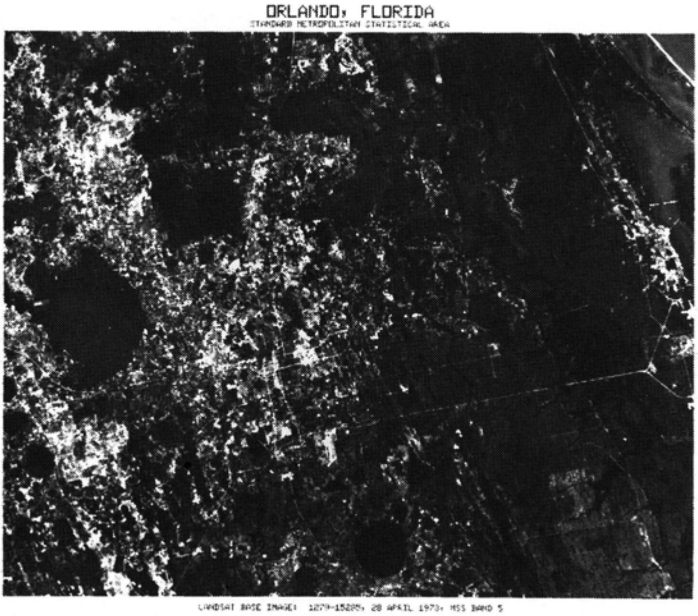

Figure 9. A Landsat image covering the Orlando SMSA.

<u>Forming the Geo-Reference Base</u>. The initial task undertaken is the construction of a geo-reference base consisting of census tract boundary information (Figure 10). The geo-reference base is the primary data plane of the information system. Census tract boundary data, obtained in Cartesian reference form, are transformed into a raster type file to facilitate IBIS processing. Since data will also be obtained from Landsat imagery, the geo-reference base must be in registry with the satellite data. A surface fitting algorithm is utilized to obtain the desired geometric correspondence. The data sets may be superimposed for verification purposes (Figure 11). Once the census tract image has been geometrically corrected, the construction of the geo-reference base is completed by assigning a unique gray value to each region (census tract) within the image (Figure 12).

In order to establish a link between the gray tone representing a specific census tract with the geographical name of that census tract, a special file, termed an interface file, is produced. The interface file can also contain data from other image planes in registry with the geo-reference base, and non-image data as well. Additionally, data within the interface file may be utilized in mathematical functions to derive higher-order information.

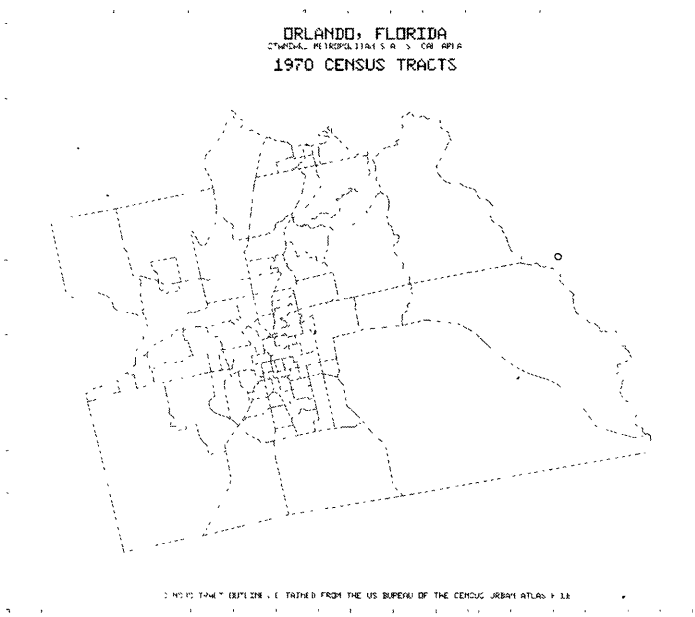

Figure 10. The geo-reference base for Orlando is based on census tract boundaries.

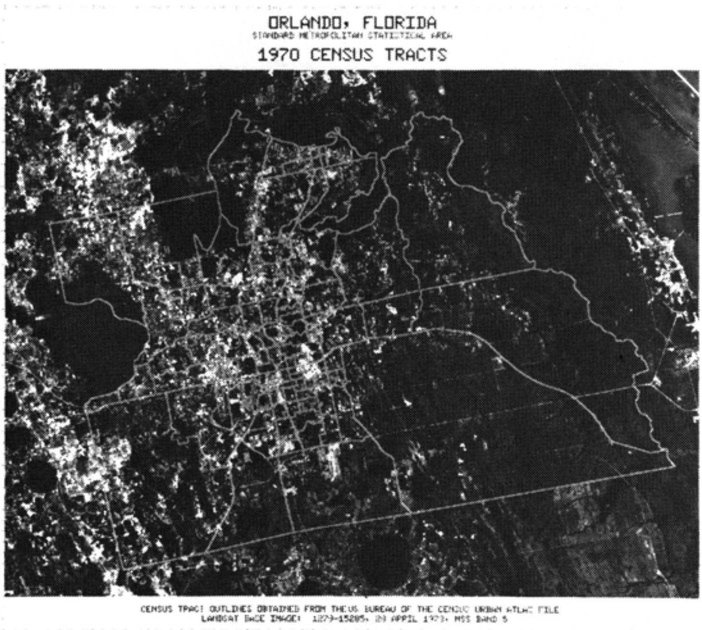

Figure 11. A census tract outline map has been registered to a Landsat image. The two files are merged for visual analysis.

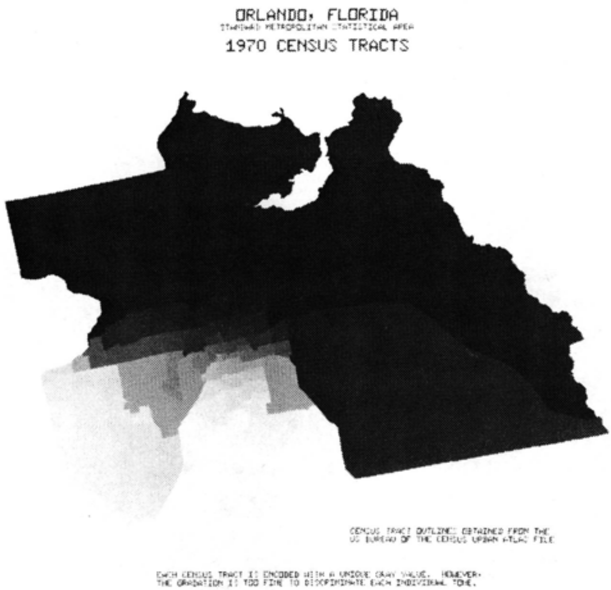

Figure 12. The completed geo-reference base for the Orlando area is composed of several regions, each region having a unique gray tone.

Map Generation. In order to produce a map depicting urban land cover in 1970, areal measurements of each census tract and population statistics by census tract are entered into the interface file. Consequently, population density values can be derived for each census tract. The Census Bureau has determined that a census tract is urban if the population density in 1970 is at least 1,000 people per square mile. This criterion can be used to separate census tracts into two classes, urban and non-urban. A map generating routine may be implemented to obtain an urbanized area map for the Orlando SMSA based on these statistics (Figure 13).

The Bureau of the Census has requested information pertaining to urban expansion since 1970. However, no enumerative data has been gathered since the 1970 census. To obtain an updated map of urban land cover in 1975, a Landsat image has been analyzed. Through the implementation of various digital image processing procedures (Friedman and Angelici, 1978), a map of urban and non-urban land has been produced (Figure 14).

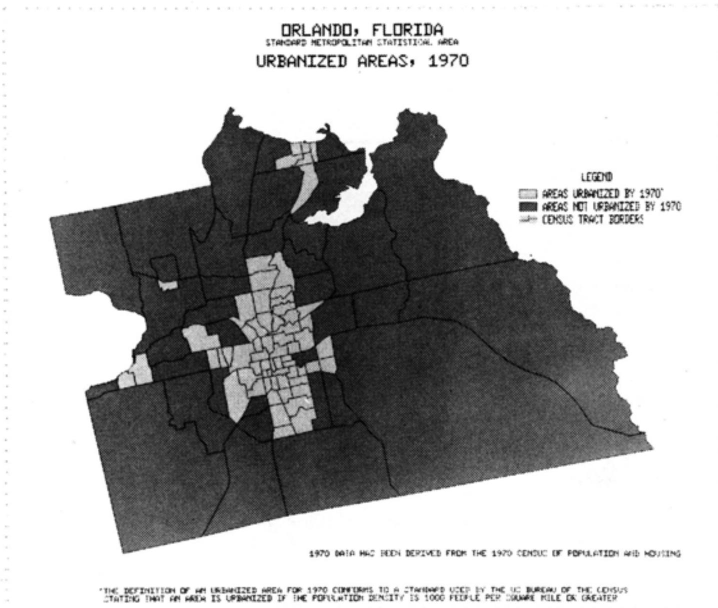

Figure 13. An urban land cover map has been derived from 1970 census statistics.

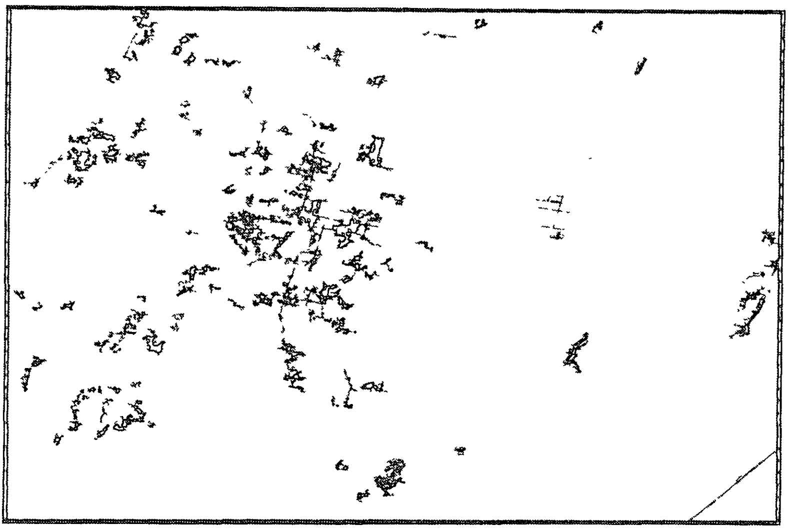

Figure 14. An urban land cover map derived from digital image processing of a Landsat image, 1975.

Map Integration. Before the areas of urban expansion between 1970 and 1975 can be delineated, the two urban area maps must be integrated. The two images are combined in an additive process, reducing the number of data planes to one. A final map product depicting urban land in 1970 and urban expansion between 1970 and 1975 is obtained (Figure 15).

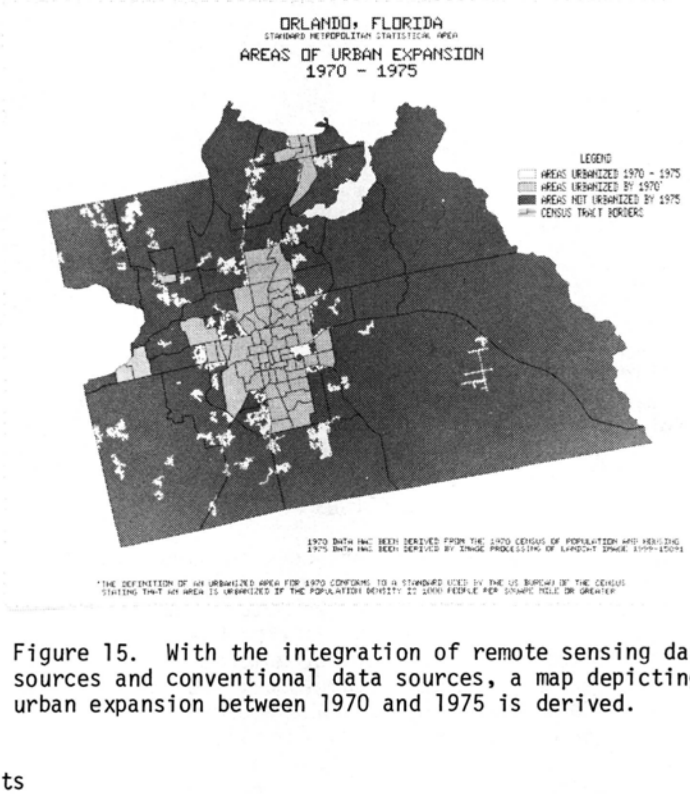

Figure 15. With the integration of remote sensing data sources and conventional data sources, a map depicting urban expansion between 1970 and 1975 is derived.

Results

The Geography Division of the U. S. Bureau of the Census has obtained a depiction of the extent of urbanization within the Orlando SMSA in 1975. Major areas of urban expansion as evident in the final map have indicated where census tract boundaries and enumeration districts may require revision prior to conducting the next census. A tabular report summarizing the land cover changes between 1970 and 1975 has also been generated (Table 2).

PAGE 1.001

URBANIZED LAND COVER STATISTICS FOR THE ORLANDO SMSA
ORLANDO, FLORIDA
1970 AND 1975

1970 STATISTICS BASED ON THE 1970 CENSUS OF POPULATION AND HOUSING
1975 STATISTICS BASED ON URBAN CHANGE DETECTION FROM LANDSAT IMAGERY

			1970 POPULATION STATISTICS		1970 URBANIZED LAND COVER STATISTICS		1975 URBANIZED LAND COVER STATISTICS		URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975		
	CENSUS TRACT NUMBER	TOTAL ACRES PER TRACT	NUMBERS OF PEOPLE	DENSITY PER MILE SQUARED	ACRES	PCT	ACRES	PCT	ACRES	PCT	MAJOR
1	101.00	268	719	1884.4	269	100.0	268	100.0	0	0.0	
2	102.00	451	4370	6207.2	451	100.0	451	100.0	0	0.0	
3	103.00	472	3402	4613.7	472	100.0	472	100.0	0	0.0	
4	104.00	160	3235	13134.0	160	100.0	160	100.0	0	0.0	
5	105.00	194	3983	13125.3	194	100.0	194	100.0	0	0.0	
6	106.00	487	3937	5170.4	487	100.0	487	100.0	0	0.0	
7	107.00	831	2852	2196.0	831	100.0	831	100.0	0	0.0	
8	108.00	934	5494	3756.4	934	100.0	934	100.0	0	0.0	
9	109.00	328	1777	3462.6	328	100.0	328	100.0	0	0.0	
10	110.00	372	3372	5803.4	372	100.0	372	100.0	0	0.0	
11	111.00	434	2800	4129.3	434	100.0	434	100.0	0	0.0	
12	112.00	569	4897	5506.7	569	100.0	569	100.0	0	0.0	
13	113.00	754	5476	4647.4	754	100.0	754	100.0	0	0.0	
14	114.00	490	1257	1642.9	490	100.0	490	100.0	0	0.0	
15	115.00	509	3222	4053.8	509	100.0	509	100.0	0	0.0	
16	116.00	1227	4772	2488.6	1227	100.0	1227	100.0	0	0.0	
17	117.00	1633	11539	4523.1	1633	100.0	1633	100.0	0	0.0	
18	118.00	605	2763	2924.2	605	100.0	605	100.0	0	0.0	
19	119.00	2521	4904	1245.1	2521	100.0	2521	100.0	0	0.0	
20	120.00	765	4857	4064.5	765	100.0	765	100.0	0	0.0	
21	121.00	577	4213	4669.4	577	100.0	577	100.0	0	0.0	
22	122.00	1084	5499	3338.0	1084	100.0	1084	100.0	0	0.0	
23	123.00	3629	5468	1149.5	3629	100.0	3629	100.0	0	0.0	
24	124.00	3575	2610	467.3	0	0.0	1260	35.3	1260	100.0	YES
25	125.00	895	2657	1899.5	895	100.0	895	100.0	0	0.0	
26	126.00	582	3910	4299.3	582	100.0	582	100.0	0	0.0	
27	127.00	874	6119	4480.7	874	100.0	874	100.0	0	0.0	
28	128.00	1066	4327	2597.9	1066	100.0	1066	100.0	0	0.0	
29	129.00	703	3231	2940.9	703	100.0	703	100.0	0	0.0	
30	130.00	1717	7023	2617.9	1717	100.0	1717	100.0	0	0.0	
31	131.00	1503	1259	535.9	0	0.0	1048	69.7	1048	100.0	YES
32	132.00	1539	4820	2004.3	1539	100.0	1539	100.0	0	0.0	
33	133.00	792	5042	4074.0	792	100.0	792	100.0	0	0.0	
34	134.00	1245	6535	3356.2	1246	100.0	1246	100.0	0	0.0	
35	135.00	5125	1717	214.4	0	0.0	442	8.6	442	100.0	
36	136.00	4247	5921	974.1	0	0.0	301	7.1	301	100.0	
37	137.00	817	4826	3780.7	817	100.0	817	100.0	0	0.0	
38	138.00	1176	7344	3996.0	1176	100.0	1176	100.0	0	0.0	
39	139.00	806	2793	2217.0	806	100.0	806	100.0	0	0.0	

Table 2. An excerpt from a statistical report. Urbanized land cover statistics have been derived for 1970 and 1975.

CONCLUSIONS

It is hoped that the two applications covered have facilitated an understanding of the utility of IBIS for cartographic applications. Modeling of data with either of the two data bases described in this paper is not limited to the specific problems addressed. Once an IBIS data base has been constructed, numerous questions may be posed. In the Herrin No. 6 coal seam study, the parameters of depth of overburden, seam thickness, and Btu content, may be modified to derive more extensive information about coal reserves. With the addition of other data planes, questions of a more diverse nature can be answered. Other types of information may be derived from the data base constructed. For Orlando, population density levels may be subdivided into several classes to portray a more complex model of the urban environment (Figure 15).

Several other applications have been implemented with the Image Based Information System. For the Columbia Regional Association of Governments, a pollution potential model was constructed of the Portland, Oregon area (Logan, 1978). A model has been used to predict the potential benefits of a conversion to solar power energy sources for the city of Los Angeles (Angelici, 1978). Other applications requiring an information storage and retrieval system with cartographic display capabilities are coming into view.

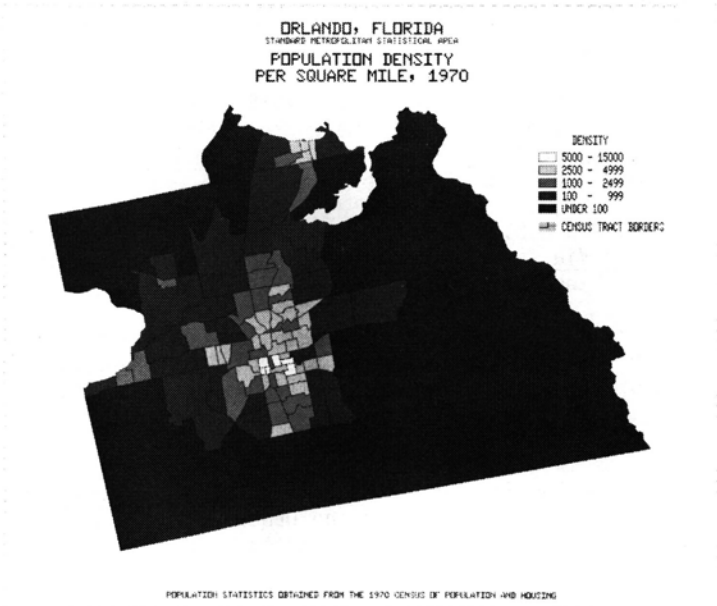

Figure 16. A choroplethic map depicting several levels of population density has been constructed from the Orlando data base.

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Logan, T.L., 1978, "Monitoring Airborne Health Impacts Through Spatial Crosstabulation Techniques: The IBIS Approach," Data Resources and Requirements: Federal and Local Perspectives, Sixteenth Annual Conference of the Urban and Regional Information Systems Association, 1, Washington, D.C., pp. 339-350.

DR. MARBLE: One point that I would like to make which is implicit in the previous presentation which I would like to make explicit, is that all this work was done using raster-based data structures. The same type of work could have been undertaken using vector organization of the data, but, in many cases, some of the operations shown, specifically the polygon overlay operations, would have been considerably more difficult to implement.

The third panel presentation is by Dr. Robert DeZur of ESL, Incorporated. Dr. DeZur received his Ph.D in mathematics, and is currently manager of the analysis group in the Earth Resources Laboratory of ESL. He will talk about the IDIMS system.

DR. ROBERT S. DEZUR: I had no really prepared talk. What I thought I would do is talk about the data flow through our system, and, if we have enough time, I will go through some examples of some of our recent projects. First slide. I should say first of all that our GIS type system is quite a bit like the IBIS system, as the previous speakers have discussed. It consists primarily of three basic modules, a GES or geographical entry system; an IDIMS, or interactive digital image manipulation system; and, an ERIS, or earth resources inventory system. Most of our application projects have to do with resource inventories and are reasonably complex. The reason that we do raster type processing is that the bulk of our data is in that type format.

I am speaking now of an operational and production oriented system as evidenced by the number and sizes of the various projects that we are completing or have completed. For example, we have just completed a timber inventory of Western Washington that consisted of an area of about 20 million acres. We did a water resource study for the State of Idaho of about 18 million acres; a Tansy Ragworth inventory in the State of Oregon, of about 15 million acres; and we have done various demonstration projects varying from three to five million acres. So we are talking about a lot of data going through our systems in a rather short time.

The GES system is set up to digitize polygonal boundaries, control points, flight lines or sample points and the like, and provides the framework for generating the transformations by which to register the map base to LANDSAT imagery or whatever the data base might be. IDIMS itself is a collection of image processing routines that are used in digital data processing. ERIS, the earth resources inventory system, basically provides the framework for handling the tabular data, generating and manipulating such files, and providing for the statistical analysis and regression routines that are used in our various studies.

One word about the tabular data, for example a project for the State of Oregon. In the course of this study we had something like 3,000 sample photo points that were photo-interpreted, where at each point information was provided for about 75 different variables. In addition to this PI data, we had some 300 sample ground plots where 75 to 100 variables were measured or reported on for each of these particular data points. Each time an operation is performed in the ERIS system a file is generated. So there are hundreds and hundreds of files being generated and deleted during the course of an inventory analysis.

May we have the next slide, please. I took this slide from one of Dr. Bryant's papers that he wrote in September of last year in which he compared the IBIS system to the ESL system. One unfortunate thing about this particular slide is that it gives one the idea that we are discussing sequential processing when indeed parallel processing is being carried out. A lot of the tasks noted here are going on simultaneously. The Vu-graph is to be read top to bottom, left to right, and continues across the page that way.

Several of the routines mentioned here have been updated, so it is not entirely correct as presented. But the left-hand column essentially has to do with the image processing phase of our analysis, and handles LANDSAT or digital terrain data, or any type of multispectral data. The middle column has to do with our GES system in which we define the study areas. In our particular GES system we begin by defining a geoblock. May I have the next one, please. So our basic GES structure data base looks something like that. We first of all identify geoblocks on either the map base or on LANDSAT imagery. Then, associated with each geoblock, we have a number of overlays to control the data. So, following down through the chart, for example, Geoblock 2, Overlay 2, we have a number of areas, a number of junction points and a number of line segments. These are reassembled in our system then as shown in the lower right-hand corner. Over on the right-hand column, basically we do our data summaries and enter the tabular data into the ERIS portion of our system and process it to generate either graphic products or a formal written report.

I will go through each portion of the data flow more carefully. Next slide, please. Again, this is an overview of the GES system, taking the map data, generating the strata, utilizing the classified results from LANDSAT processing, and providing strata summaries using the various routines that are available in the IDIMS system, and outputting tabular data to the ERIS system. Next slide. This is going to overflow the board. But starting up in the top center with the design of the geoblock, this generally pictures a flow of the data showing some of the parallel processing going on within our system.

First of all, design or choose geoblocks, digitize administrative strata, flight lines, control points and so forth, coming down the center portion, and then start generating various transformations that are used to register the raster type data with other data types. While this is happening over on the left-hand column, we are beginning the pre-processing of LANDSAT data, if that is our data source, and going through more or less standard routines to turn out a classified image. At the same time control points are being selected from the imagery, generating more transformations and storing all of these so that they are available for the strata summaries that will be utilized by the ERIS subsystem. Going now to the extreme right, we are able in our GES or IDIMS routines to summarize data, taking combinations of up to seven strata overlays. So, thinking of these are seven images, looking at the intersections of the various polygons that result from these, we can summarize our data in this particular manner, feed the results into our ERIS system for use in the statistical analysis portion of an inventory study, if that is what we are doing. Also, we generate graphics files, register and geometrically correct our imagery, so that certain customers can have their pretty pictures, I guess.

Next. This is a slide showing some of the transformations occurring during the GES phase of our processing, showing how we register uncorrected LANDSAT data, change to a 50 meter grid, and generate transformations between the LANDSAT and the ground coordinate system to locate various sampling units and that sort of thing. This is a schematic showing how a very simple stratsum algorithm might work. On the upper left-hand corner we have three strata that have been digitized. I am thinking of these as images now. In the upper right-hand corner we schematically represent these three strata, and just counting across each line we note the number of pixels that occur in that particular line segment, and creating a file for this purpose we record that information. Then we manipulate such files in an appropriate manner.

The ERIS portion of our system, is essentially a collection of software routines, again for data and statistical manipulation. We have the general routines noted -- under file manipulation -- filter, append, merge, sort, and sample pairing. Sample paring is, of course, important, because we usually utilize three kinds of data, and we pair them and analyze the paired data quite frequently. Under arithmetic and statistical routines--sample amalgamation, predict, and minitab. Out minitab statistical routine is a standard version that comes from Penn State University. Next, please. This is a description of the minitab capabilities. I will not go through all of them. One thing I can say about the ERIS portion of the analysis is that it is the most time consuming part of the entire study. Image processing probably occupies about ten percent of an effort. The geographic entry system, digitization and so forth, probably about 20 percent. The remainder is taken up by our ERIS processing--a very large volume of data is being processed through the system.

Next. This is an example of some tabular data collection sheets that photo-interpreters use--these generate a large number of variables for each of the data points in question. Next, Again, just a sample of the kind of information that might be collected by photo-interpreters while interpreting certain kinds of imagery. Next, please. Here are several examples from an ongoing project of the type of data flow through the ERIS system, showing how we use various routines, and the data manipulation capabilities of the system. I will not bother going through all of the general routines or the descriptions. But you can see that it is fairly complicated, and, as I say, it presents a horrendous bookkeeping problem keeping track of all the files, what was done where, which can be deleted, what must be kept for posterity, so to speak, and so forth. Here is another example with large scale photographic data. The next one has to do with low altitude photography.

Next, please. Here is an example of some output products, perhaps in a forest inventory project. As a result of our stratsum runs, we would provide the total number of acres by ownership class (in this particular project), and by forest type. In general, there would be a large set of tables of this sort. Or, something more complicated, as in the next. We perhaps would fill in a table like this for a forest inventory. These are basically for in-place mapping type studies. In general, however, as a result of all the ERIS processing, we generate an estimate of a particular attribute for a forest inventory. For example, it may be basal area or volume by ownership class or perhaps just a confinement to a given area of a particular state. We would give standard error estimates, confidence limits and so forth. The inventories are pre-designed for an allowable error and an acceptable confidence limit for the estimates.

Next. To demonstrate the previous material, I chose an Oregon project, Douglas County, an area of about 3.2 million acres. The project required a timber volume inventory, and an in-place thematic mapping study. Both studies were supported by the multistage sampling technology, and we used supporting photographic data for the raster type LANDSAT data. This shows Douglas County approximately in the center of the screen. We can go through these rather rapidly. Next slide, please. Let me summarize what the project was. We were to estimate the net total volume for

Douglas County and provide an analysis of treatment opportunity groups for managerial decisions.

Next, please. These were some flight lines that were going to be flown to help in the second stage sampling procedure. Next. This slide depicts the fact that we are using a multistage sampling approach, which will use ground data, aircraft data and auxiliary LANDSAT information. Next. Again, just a sample of a flight line being flown with a different type of projection. Next. Some low altitude photography. I think it was at 4,000, or something like that. Next. Just a photo of a ground plot, which turned out usually to be an acre in size. Next. That appears to be backwards, but it is a first step output from our classifier, showing a masked LANDSAT classification of a part of Douglas County.

Next. This is an ownership map of a part of Douglas County. I have forgotten what the colors represent, but there are three ownerships for the acreage represented. Next. We have here the same region, showing eight classes that are color coded forest types. Notice that ownership boundaries and township boundaries are also shown. Next. This is a blown-up version of the prior slide showing 18 treatment opportunity groups along with the digitized township boundaries and the ownership areas. Next. That is a similar subsection. Next. This is a similar area in Douglas County again, showing these opportunity groups. I think that is all. (applause.)

DR. MARBLE: A number of years ago I was on the faculty at a major Midwestern university which had a computerized student record system. This had been developed internally by the university, and after some use they decided to improve it. An outside system analyst was brought in and after several days of looking at the system, he said, "This is absolutely remarkable. It is one of the most beautiful examples I have ever seen and should be documented in the professional literature." We said, "Why is it so remarkable?" He replied, "It is the most beautiful example I have ever seen of the one-to-one implementation of quill pin techniques on an IBM 360."

Yesterday a number of people remarked that we should attempt to automate more conventional cartographic operations I would like to take the liberty of suggesting that perhaps we may not want to do just that. One of the points in the discussion in the panel so far is that there are alternate ways of looking at things. As our tools change, so, in many cases, must the way we look at the world that we deal with. This question of the organization of data, whether it is handled in vector (line format) or in raster format, which is a somewhat more difficult one for us to envision, may prove to be quite important to us. Attempts to follow traditional manual techniques and implement them on the computer, including traditional ways of thinking about cartographic data, may cause us to fall into some very serious inefficiencies. The suggestion being made here is not that raster data structures and raster processing is going to save the world. Rather, it is an alternate way of doing things which in some circumstances may be considerably more efficient than traditional approaches.

We must think about new ways of doing things. Yesterday in Dr. Tobler's panel we were exposed to a number of developments in the display area of image processing. The two example systems that were discussed here both evolved out of LANDSAT processing operations where a tremendous volume of data was originally captured in raster or scanned format. The incorporation of digital line data into these systems in raster form was, of course, more efficient than attempting to convert the large volume of raster data back into line format for vector processing. We have a number of devices, some of which are on display in the exhibit area, which are raster-oriented devices. Last night I saw a very interesting little movie put on by one of the exhibitors about a raster device, a scanner, and a raster color processing system. There are other types of devices that handle data in this fashion, and I think that we are going to be confronted with the capture of more and more data in raster format, and we are either going to have to decide to process in this mode or to start working very intensively on very efficient algorithms for the conversion of raster to vector data.

At this point I would like again to open the meeting to general discussion. I know there are other people that have been working on raster systems and are interested in these things. Perhaps one or more of them might like to make a comment.

MR. JON LEVERENZ: I waited, I think, a long enough time to let the people that had something to say about rasters get up. This does not deal exactly with raster but it appeared to me when I heard the discussion on the Herrin No. 6 coal seam that it seemed to be a rather simple process of putting together the three attributes and narrowing it down to where they all occurred together. It probably is not as simple as it looks, but I wondered what the reason was that we, first of all, or why the State of Illinois -- and I have somewhat of a vested interest there, because I pay taxes -- what reason the State of Illinois had for developing an automated system to do something that it appears could be done manually.

Perhaps I am back a few years, but I would like to know what the advantage is, I would like to have them point it out a little more clearly to me the advantages of the raster scan or computerization of the data and manipulation of it this way rather than just a semiautomated type of thing where the data would be input by manual methods and so on.

DR. MARBLE: I think you actually have two questions there. One is the question of why go to an automated analysis scheme for this type of operation. The second is, why do it using raster-mode processing? Do our panelists from JPL want to comment on that?

MR. DAVID WHERRY: Let me describe the processes which were involved in producing this case study. I was going to include in the talk initially the conceptualization of the project and discuss how it does appear to be an automation of a very old process, basically, of that of looking through a series of overlays to find an area exhibiting several attributes. I believe that what we have done in automating this process, although it has taken a great deal of money and a great deal of time to initially encode the maps into digital form, is to provide more flexibility in data analysis. The power of the system is that once the maps are encoded, one might ask any one of a number of questions about BTU content, seam thickness, etc., for whatever kind of maps were encoded -- distance from railroads, topography, land ownership, whatever, and obtain multiattribute results very quickly. The results that you saw presented of the multiattribute analysis after the maps were encoded were pro duced in about five seconds of computer time. Other questions can be asked after the maps are encoded, one after another, with equally rapid results. That was the theory behind the automation of the system.

Traditionally, I believe, that looking through a series of overlays will get you some results, it will define the window, but then the window has to be perimetered, the window then has to be manually manipulated as far as achieving tonnage or whatever. As far as the raster approach, we only work in rasters, number one. Secondly, to use a vector approach, an approach of, let us say, vertices to describe polygons, to look through a series of overlaying polygons to look at an intersection of data sets, is extremely time consuming and takes a great deal more computer time to operate. Also, the algorithms are far more complicated. In the raster approach it is a trivial matter of merely blocking out those sections of the image which are excluded from the window, one at a time, and what you have left is the multiattribute window. It is just a matter of masking the image. I am not sure if that answers the question. Do you need any more clarification?

DR. MARBLE: One point about manual operations on maps. They have been with us for a long time. One of the things that we have learned about them is that they are very costly. If you have a fairly simple question that is going to be asked once, you can extract the information from the map. If you have a lot of questions that are going to be asked in a variety of different forms, then you very rapidly run into rather substantial costs for handling the operation in manual form. Dr. Roger Tomlinson, the Chairman of the IGU Commission, has developed some useful data on this, and it is amazing to me how early the crossover point is and how the low cost effectiveness of manual versus automated methods.

It it were just the case of the single question presented here as an example of the operation of the system, I suspect that we might well worry about the comparative costs of automated versus manual methods. But, as the panelists pointed out, the ability exists now to answer a large number of questions, and this underlies the development of a number of digital, spatial, natural resource data bases, for example, the one that is being developed by the Geology Division of the U.S. Geological Survey dealing with coal resources, where a number of questions are to be asked about the coal resources of the United States and where not only such things as the coal content and overburden computations are available but many, many other things as well. The operation that was illustrated here, and quite well, was that of polygon overlay. And the polygon overlay operation is one which is difficult and complex to carry out in a vector mode data organization. It is a relatively trivial one in raster format.

MR. DAVE DAY: My name is Dave Day. I am with Canadian National Parks. I am not all familiar with the raster system or raster processing, but while you were giving your demonstration of IBIS and the three case studies, you put on the screen quite a few photographic products with different levels of density for your classifications and so on. Are those necessary for processing, or are they just done for our benefit? Is most of the work internally done, or do you have to actually go through those steps and redigitize as you go along?

MR. FRIEDMAN: In order to distinguish each of the polygons, it is implicit that they have to have a unique gray tone value. We can have up to 32,000 polygons in this way. Since you cannot see the gradations, we have enhanced them using contrast stretching so they are digitally discriminable on the screen. Yes, they do have to have a discreet value.

DR. MARBLE: I think the question was whether the photographic products were necessary in every stage of the process, and the answer is that they are not.

MR. JOHN RIDDLESEE: I have a technical question. My name is John Riddlesee, Petty-Ray Geophysical, Houston, Texas. In terms of the storage of raster data, particularly when it is very voluminous -- I am thinking in terms of a thousand dot-per-inch raster on 40-inch square sheets. Are there any techniques developed that relate to the storage of such data and sparse matrices? In other words, where you have particularly the thematic representations in raster form, are there any techniques where, say, only one percent of the cover or a few percent of the area is actually covered by the information you want, while not having to store the regions with blank information. Is there any sparse matrix type storage for raster data techniques that have been developed? That is for anybody on the panel.

DR. PEUQUET: Yes, there have been quite a few techniques developed to compact raster formated data, just as there have been for vector data. One of the most common ones is run length encoding. You simply record the significant data points and the distance between them, instead of recording all the blank space explicitly.

There has been some mathematical research on sparse matrices that I have read which was put out years ago as IBM technical notes, but they have not been applied until very recently when large memories permitted handling really large matrices. But, yes, there are quite a few things you can do.

DR. MARBLE: I might point out that there is some similarity here between the technique used for data compression in the raster area and the techniques that have been successfully used in developing the large scale mathematical optimization programs using sparse matrix storage techniques. Are there any other questions or comments?

MR. RAY DILLAHUNTY: My name is Ray Dillahunty, and I am with Petty-Ray Geophysical in Houston. I have run across the concept of collection of raster data using stereo digitizers or stereo plotters and the consequential compaction of data using that kind of method. Is there some work being done in this area with the people in the cartography industry, or very much work, should I say?

DR. MARBLE: Could you perhaps clarify what you are talking about. Are you talking about digital terrain models?

MR. DILLAHUNTY: In the past I think most contours have been digitized using stereo photographs in a vector form where you digitize a contour of a hundred foot in a polygon type of thing, closing the entire contour. I have run across a little bit of literature where you set up a rather automatic digitizing concept so that your stereo plotter is going in an "X" direction across the stereo photography, and you are recording only the differences in elevation, and the distance between your digitized points in this manner. If you are digitizing flat surfaces, you greatly reduce the number of XY coordinates that you are using. I think that this is sort of the raster concept that she was addressing in her talk. Is that enough information?

DR. MARBLE: Yes, I think it is clear. A number of the automatic devices for deriving terrain information from stereo photographs do work in that manner. For example, the Gestalt photomapper system that in installed at the Geological Survey. There is a fairly complete discussion of this hardware in a recent issue of Photogrammetric Engineering, which reviews a number of the different systems and talks about this approach to it. I also understand from talking to people in the Topographic Division that the Survey plans on releasing a certain amount of terrain data in this form within the next few months. They will be producing DTM's, using the Gestalt photomapper, and this will be made available through NCIC. I am not sure about the timing of this, but I suspect it will not be very long.

As far as data compression in this format is concerned, I do not know. I am not sure I am too aware of that. Is Bob McEwen or someone else from Topo here that could talk about that? Well, I guess not. You might talk to them directly if you would like a more specific answer to that question.

MR. HARRY HEARD: Harry Heard, Institute for Advanced Computation. I have two cost questions I would like to have the panel address. One is, can they define the cost allocation in terms of the percent of total cost related to data capture. The second is, can you give us some idea relative to raster data systems of the cost on a unit basis to process information -- for example, something like the cents per pixel per attribute?

DR. MARBLE: I would be delighted to have the information myself.

MR. FRIEDMAN: So would I.

MR. WHERRY: I am really not prepared to reply to that. I basically do not know anything about the cost effectiveness of the raster-based image processing, so I think it is going to have to be referred to Dr. Bryant at some future date or perhaps somebody else can address the question.

DR. DEZUR: I can say in our studies on a per acre basis for inventories we are about two to four cents per acre, in that range.

DR. MARBLE: There is a very real difficulty in deriving cost figures on systems of any type. This has been something that the IGU Commission has been very concerned with, and we have been very frustrated over it in the past. Many of these systems are developed in a fashion that sort of parallels the way things used to work when I was dealing with NASA some ten, twelve years ago as an earth resources investigator, we were being asked what was the costs of the system? We said, "Well, what is the cost to put up the satellite?" They kept telling us that that was not important!

You have major uncontrolled cost elements in these systems. In many of the areas we really need much more precise cost information, not just about how many CPU seconds were consumed, we need the actual cost functions for it. Digitizing, both table digitizing and mass digitizing is an area in which this information does not exist today. This is an example; some of the mass digitizers like the drum scanners are raster oriented devices. But we are hard-pressed to produce actual cost figures in this area. Even in cases where we have examined existing systems, where they are running these devices, many governmental agencies and scientific institutions that do this work are not set up within a proper cost accounting framework to produce the information. This information is something else we need very badly in order to make intelligent decisions in this area.

MR. BILL JOHNSON: Bill Johnson, Lawrence Berkeley Laboratory. I would like to address the gentleman from JPL and ask what is the availability of this software involved in IBIS, and, in particular, the software involved in registering polygonal files with your LANDSAT raster data? And under what circumstances was the IBIS system developed?

MR. FRIEDMAN: First of all, IBIS is a subset of VICAR, which is our image processing system. That is currently available via COSMIC, which is a government clearing house for data. IBIS as a subset of VICAR has currently been under development for the last couple of years, and the software has been funded via various NASA grants, therefore, it is also in the public domain and can be made available at cost.

DR. MARBLE: The VICAR system is indeed in the public domain and is available and being used in a number of places. I will note that it is somewhat IBM dependent, which you might read "very" IBM dependent.

DATA BASE MANAGEMENT SYSTEM APPROACHES TO HANDLING CARTOGRAPHIC DATA

DR. MARBLE: Our third session today is organized around the problem involved in storage and management of spatial data. Many cartographic applications have utilized moderately sized to small data files. Very few of them, until relatively recently, have had an opportunity to use large volumes of spatial data. One of the truisms in computer processing of any type of data is that if you have only a small amount of data on hand, it is difficult to produce large increases in efficiency and savings, simply because you are not carrying out very many operations. However, as data volumes increase we find ourselves rapidly confronted with the problem of not being able to afford access to the data. As we look at the development of potentially large digital data bases, we must face the fact that we are going to have to worry and worry hard about managing these in an effective fashion in order to attain economic viability in their use.

One of the techniques that has been adapted for non-spatial data is the notion of the data base management system. This is a very complex software system which essentially stands between the applications user and the physical data itself. It permits the applications programmer to maintain a logical view of the data which may be, and quite often is, greatly different from the actual physical organization of the data in the computer. The important notions here are those of logical and physical independence of the data. However, when dealing with spatial data, particularly that containg large volumes of coordinate information, we have found that we run into some peculiar problems. The speakers today are going to address, first, the conceptual problems involved in handling spatial data, and then discuss a specific example which tries to utilize a data base management system approach to the manipulation of cartographic data.

The first speaker is Dr. Roger Tomlinson. Roger is chairman of the IGU Commission on Geographical Data Sensing and Processing. Roger?

DIFFICULTIES INHERENT IN ORGANIZING EARTH DATA IN A STORAGE FORM SUITABLE FOR QUERY*

DR. R. F. TOMLINSON: The purpose of this paper is to identify some of the methodological problems inherent in organizing a store of earth data in a form suitable for query. Earth data are here defined as those that describe the earth's shell, ocean and atmosphere and they are attached to a specific location; they are usually stored and displayed in the form of maps. Topographic maps, land use maps, soil maps, geological maps, vegetation maps, weather maps, oceanographic charts, population maps, and geophysical maps are well-known examples of stores of such data. To take advantage of the calculative capacity of existing computers to analyze these data, increasing amounts of them are being converted to digital form. Furthermore, instruments that gather earth data, such as sensors mounted on satellites, automatic gauges in streams, sounding devices on ships, and ground topographic surveying instruments, are now providing their data directly in digital form. The volume of earth data in digital form is thus growing rapidly. However, because of the discipline imposed by use of current computers, many of the relationships between data elements hitherto visually derived from maps must be more explicitly specified if the digital data are to be organized effectively for query. This raises some questions about the nature of such spatial data and spatial relationships that have not been widely discussed or resolved within the discipline of geography, or in other disciplines. These questions are outlined below, and some initial steps to resolve the problems are proposed.

A map can be thought of as a structured file in which entities, conditions and events in space are recorded. For maps of earth data the structure presupposes some conceptual model of the space occupied by the globe, suitable units for its measurement, an adequate transformation from the curved surface of the earth to

* This paper is the outcome of discussions in the past year between Stephen Gale, Michael Goodchild, Ken Hare, David Hays, Fred Lochovsky, Duane Marble, Dick Phillips, Azriel Rosenfeld, Mike Shamos, Dennis Tsichritzis and Roger Tomlinson, held under the auspices of the International Geographical Union Commission on Geographical Data Sensing and Processing.

the plane surface of the map, and the use of graphic conventions for representation of real world entities. The appropriateness and validity of current cartographic practice are not called into question in this discussion. Extremely large volumes of useful information can be, and are, stored on conventional maps. In general, the locational values of the contents of the map rely on establishing a series of identifiable points on the ground by multiple measurements between them, and between the points and extraterrestial bodies. The established points are "filed" on the maps according to their measured relative positions. Elements of thematic data are then located by observing or measuring their relationships with easily identifiable features already stored in the file, and they are recorded by inserting them in the appropriate place in the file, that is, by plotting the observations on a map.

The spatial relationships between entities,[1] relationships such as contiguity, adjacency, nearness, connectivity, above, below, between, and inside are occasionally explicitly defined by conjoint symbols (villages connected by roads, stations marked on railway lines) or by written values (distances between points). However, more frequently they are implicit in the file structure and must be determined by visual estimation or measurement and calculation.

When information is extracted from a map, it typically includes a mixture of the values of entities and the relationships between entities, appropriate to the question being asked. The utility of a map as a source of information is good at first consideration, in that the storage medium is also the display medium. When the data of concern are explicitly recorded on the map, retrieval is swift. Similarly, brief and simple estimations or a few straightforward measurements seem to yield a reasonable return for effort. However, when information extraction requires many measurements or calculations to determine relationships implicit in the file structure of a map, the task rapidly becomes tedious and error-prone. Although map sheets can be a compact and symbolic form of data storage, the number of sheets required to contain even a small amount of the spatial data already gathered from a particular area of the earth may be large. The time and effort of information retrieval increase in proportion to the volume of graphic data to be handled. In fact, increasing the data

1. Conditions and events are subsumed.

volume rapidly limits the type of retrieval operations that are economical, to the point where it can be extremely time-consuming, laborious, and costly to extract even the data actually written on one or more maps. In short, the limitations of human retrieval capabilities place a severe constraint on the utility[1] of maps as sources of large volumes of spatial data.

The continually improving storage and calculative capabilities of computers have been seen as a way to overcome the limitations of human efforts in retrieving and handling mapped data. Numerous systems for the storage and handling of map data in digital form have, in fact, been developed since the early 1960s. The use of computers requires that the data be in machine-readable form. At present, in 1978, the process of conversion from map (graphic) form to digital form, usually referred to as "digitizing," is still technically cumbersome and demands effort and expense. More significantly, the volume of digital data required to reproduce adequately the information content of a conventional map is substantial, perhaps rather more so than anyone had realized. One example can be drawn from the Land Use Mapping and Data Project in the U.S.A. The entire project involved 359 map sheets at a scale of 1:250,000. This relatively small number of maps is estimated to have more than 1.5 million inches of line data which will be digitally described by approximately 68 million x,y coordinate pairs. Topographic maps, as a category, appear to have somewhat larger amounts of information per square inch. A preliminary estimate of 235 million line inches of contour data alone has been made for the sheets available in the 7.5-minute, 1:24,000 U.S. Topographic Series. At a resolution of 12 points per inch, the contour data would require a digital record of 2.8×10^9 x,y coordinate pairs. At 175 points per inch, they would require 4.1×10^{10} coordinate pairs. Decisions have not been made on whether to digitize contours as lines, and on the resolution with which such lines should be recorded, but these figures clearly indicate that data volumes are so large that they must have a significant impact on design specifications for stores

1. The "utility" of a source of information for decision making purposes is dependent on 1) the relevance of the information to the decision, and 2) the ease with which pertinent information can be sensibly extracted from the store of data. Human retrieval capabilities affect the latter aspect of utility.

of digital spatial data. One logical way of handling the problem of data volume is perhaps to reduce the amount of information demanded for activities that use digital spatial data, to a volume more directly related to their needs. There is, however, a long and valuable tradition of accuracy in cartographic displays that will not be overturned overnight, and present practice is to attempt to portray the information as accurately as possible within the limitations of the instruments used.

As increasing numbers of maps are digitized and as data gathering institutions, particularly those concerned with environmental earth data, develop and implement techniques that generate data directly in digital form, some of their stores of data become very large. The U.S. Geological Survey, for example, has over 50 systems handling a wide variety of earth data in digital form. The aggregate volume of such data already in machine-readable form in 1977 is approximately 500,000 million bits.[1] Conservative estimates indicate that this will grow by more than 250%, to 1.7 million million bits, by 1981. Other institutions have similar objectives and expected growth patterns. It can be assumed that computers will become better and cheaper, and that the developing processes of institutional management will tend to match data production to handling capability, or more particularly to computing capacity. There is, however, cost associated with the use of computers, and the volume of data to be processed has a marked impact on that cost. We are rapidly passing the point where it can be assumed that "the computer will handle it," and we should ask ourselves how large volumes of spatial data can be organized efficiently.

Large volumes of data are not new in the world of computer science. Certainly, on a commercial basis, data base management systems have been developed that permit efficient handling of very large data bases for specific requirements of retrieval and manipulation. The principle of any current data base management system is to organize the data in such a way that paths are established to retrieve the entities required for specific enquiries, and at the same time to specify adequately the relationships between the entities that are pertinent to frequent enquiries.

1. A bit is the smallest unit of normal machine-readable information. One regular reel of magnetic tape can hold up to 300 million bits and one regular disk pack can hold up to 800 million bits.

To achieve this, the entities of concern, the relationships of concern, and the operations to be performed on the data must be unequivocally specified before the required data base can be generated for the data base management system. Defining spatial entities of the kind usually found on maps presents no major methodological problem. An adequate schema based on the representation of entities as either points, lines, or areas (with areas being a peculiar kind of line), can be devised. The entities have a variety of spatial or aspatial attributes attached to them. The spatial attributes, the coordinate or locational information attached to the entity, define the selected information content of the graphic image of the entity and its spatial position. The aspatial data record the desired information content of the value or values of the entity. Point entities are usually adequately spatially defined by a coordinate pair. Line entities, however, are typically characterized by a great deal of locational information. This difference in the volume and nature of spatial identifiers is what has made some types of earth data relatively easy to handle (those adequately represented by points), whereas others impose a substantial burden of data processing.

It is in defining the spatial relationships of concern and the suite of operations to be performed on the data that methodological problems arise. The notion of relationships in two or more dimensions has had some discussion within the field of geography, and in other fields, but we still do not have too clear an idea of what we mean by "relationships between entities." It is not certain at the moment that we could adequately define a comprehensive, internally consistent set of relationships that would allow us to devise a logical storage schema for a general-purpose store of earth data. Nor is it clear how the relationships might best be stated. The relative utility of languages of dimensionality has not been widely examined.

The spatial relationships that need to be defined within a data base, the most suitable language or languages for defining such relationships, and the selection of the suite of operations to be performed on the data must be determined in the context of the purpose of the data base. Perhaps the concept of a general-purpose store of earth data is not a useful (or desirable) objective, and earth data should possibly be assembled in a wide variety of logical schemas, each related to a certain category of questions. The problem still remains of defining the purposes of concern, identifying the methodology, and establishing the patterns of inquiry associated with each purpose.

Because earth data are usually gathered by some institution and are arranged and stored for the perceived constituency of that institution (or parts of that institution), there is a commonly expressed feeling that pragmatic choices of data organization have already been made in the light of user needs, and that despite a possible risk of institutional bias in the provision of data, no serious problems exist. That view is being called into question, frequently by those most closely involved with digital data handling in the traditional data gathering institutions themselves. There are several reasons for this. Many of the systems for handling spatial data developed to date have fallen into disuse because they served no users adequately or economically, or served only a very limited range of users. Many data sets are multipurpose in nature (topographic maps, for example) and can reasonably be included in many logical schemas for different systems of inquiry. The resolution of complex questions concerning the environment and social interaction with physical resources will require data from various sources to be used in concert and in a way that will allow the relationships between disparate entities to be adequately determined. In fact, little work has been done on the nature of the questions that we ask of spatial data, and we do not adequately understand the relationships between the logical schema of a data set and the types of questions that can be answered from it.

A map produced and used by a human is, in a very real sense, a data base management system. The graphic product represents the organization of the data in a logical schema, and displays the data so that a human can determine the nature of the entities and the relationships of interest. Some of the drawbacks of this process, which were mentioned at the beginning of this paper, seem to be repeated in existing digital data base management systems. The following brief comparison of the human and computer-assisted approaches is instructive, as it focuses attention on the underlying nature of the problems.

1) In both human and computer-assisted approaches, if the required information is to be easily found in the file and extracted from it, the entities and relationships concerned must be explicitly defined (written) in that file. The greater the volume of data to

be handled, the more this holds true, and, by definition, the digital data base management systems are designed to handle large volumes of data.

2) If in either approach the relationships between entities are not explicitly defined but are implicit in the file structure and have to be derived by measurement and calculation, then retrieval of required information is laborious. It can be argued that computers have a vastly greater capacity for explicit measurement and calculation than humans have, and that therefore they are useful for such spatial data handling. However, the fundamental purpose of digital data base management systems and, presumably, the gains in retrieval efficiency inherent in them are based on the premise that they provide paths that allow explicit determination of the required entities and their relationships. It seems to be defeating that purpose (and hence the current utility of data base management systems) to rely heavily on computer capability to calculate relationships within a data base management system. Obviously there must be a trade-off between explicit definition of spatial relationships and the calculative capacities of computers. This trade-off is not fully understood and probably depends on how computers compute as much as how fast they compute. It also depends on the capabilities of a particular data base management system and how frequently a particular relationship is queried. This will be explored further below.

3) Computer data bases as well as maps can be displayed in graphic form. Modern interactive display devices also allow the human to manipulate, to some extent, the contents of computer storage so displayed. It can be argued that this capability makes it unnecessary to define all spatial relationships explicitly in the digital file; when they are needed they can be observed. Undoubtedly a human has an excellent mental facility for pattern matching and pattern recognition, and can use this capability to advantage on a small amount of displayed material, for recognizing both the nature of entities and the spatial relationships between them. Given simple images and straightforward tasks, such as allocating a contained centroid to a polygon, this approach can be very efficient. The weak link in the process is the sensory channel capacity[1] of the human, which limits the volume of graphic

1. Human "channel capacity" is the maximum rate at which bits of information can be transmitted to the brain through all human sensory channels.

information that can be made available to the human mind. This limitation thus constrains the mind's effectiveness in scanning large amounts of data, such as many maps sheets, or examining complex features, to determine the shortest path through a very intricate network, for example. Again, there must be a trade-off between the explicit definition of spatial relationships in digital spatial data management systems, and the use of display to permit human observation and interaction. This trade-off is not now understood clearly. Similarly, there must be advantages to be gained from increasing the pattern recognition capability of computers, perhaps through the use of array processing machines. These ideas will be explored further below.

It was suggested above that current digital data base systems might allow spatial relationships to be implicit in their data base structure and even, at some cost, subsequently calculated. The question arises as to whether the underlying structure of the existing commercially offered systems seriously inhibits or prohibits the implicit or even explicit definition of spatial relationships.

Most of the well-developed commercial data base management systems currently available assume that the relationships between entities can be described in structures based on network models, founded in graph theory, or on hierarchical models, which are a special case of a network model. Systems that utilize relational data structures based on the mathematical theory of relations are now being developed, but there are only a few reported instances to date of any such commercial systems being used to handle spatial data. From the limited evidence available, some comments can be made about the hierarchical structure. A data base management system employing hierarchical data structures was adopted for some of their files by the U. S. National Water Data Storage and Retrieval System.[1] The Groundwater Site Inventory File in that system currently contains inventory data describing the location, geohydrologic characteristics, construction and

1. Water Resources Division, U. S. Geological Survey. 1975. "WATSTORE - The U. S. Geological Survey's National Water Data Storage and Retrieval System" and "The National Water Data Storage and Retrieval System of the U. S. Geological Survey Users Guide" U. S. Geological Survey, Reston, Va.

production histories, and field measurements for approximately 250,000 groundwater sites. A total of 370 million bits of data are stored. The entities are points with related aspatial attributes. The locational information is minimal, consisting only of coordinates for the point locations of the grounswater sites. The locational data are essentially treated as aspatial values amenable to plotting, contouring, and straightforward forms of statistical analysis. The data are indeed spatial, but little is actually demanded in terms of spatial query. The file is, however, an example of a large volume of point data being handled by an institution with the aid of a data base management system, in a manner that fills the immediate needs of the institution.

In contrast, an attempt was recently made to use the same approach of hierarchical structure to handle data that described the boundaries and attributes of oil leases off the coasts of Mexico and California.[1] It was found that the hierarchical concept does not allow the definition of graphic entities other than points (and presumably dendritic patterns). Links in the hierarchical model are implicit; they do not have to be labeled, but between any two record types there can be at most one link. This can, to some extent, be overcome by using two or more hierarchies in concert, but only at the cost of data duplication. The hierarchical structure prohibits the asking of questions that involve items from disjoint records. This implies that definition of spatial relationships within a hierarchical structure is cumbersome in many cases and impossible in others, and calculation of spatial relationships inherent in the data is severely inhibited.

Data structures based on the network model arrange data in one or more interconnected graphs. Record types are used to represent the entities, and the "links" are used to specify the relationships between sets of entities. The network at once offers more flexibility than the hierarchical approach, but it imposes the burden of specifying every "link." Phillips[1] moved to a network structure for the representation of the oil lease boundaries mentioned above, but found that the data volume incurred by specifying the linkages between every node used to define the graphic polygon boundaries was prohibitive. An alternative schema was

1. Phillips, R. 1977. "A Query Language for a Network Data Base with Graphic Entities" University of Michigan, Ann Arbor, Mich.

devised based on a simplified block structure of the oil lease boundaries. This allowed a limited set of queries to be developed and the system was improved. The lesson that seems to come out of this experience is that present data base management systems employing a network approach are useful for small, simple sets of spatial data but are cumbersome for the storage and query of most of the data types common to topographic maps, for example.

Relational data management systems are a more recent development. They allow the results of formal relations theory to be applied to problem solution, but as yet none are known to have been applied to the task of handling spatial data.

The three approaches have been compared[1] in general terms, but not in terms of their capability to handle spatial data. There appear to be problems inherent in adapting some of the existing data base management systems to handle large volumes of spatial data. There is no clear understanding of the relative applicability of the various types of data structure inherent in existing data base management systems to the problem of specifying spatial relationships. Also, as mentioned earlier, there are substantial methodological deficiencies in defining spatial relationships themselves.

Many of the questions raised so far could be regarded merely as interesting areas for academic study, except that answers to them are needed before any sensible plans can be laid for making large volumes of digital spatial data economically amenable to query. In the interim, such volumes of digital spatial data are accumulating in numerous agencies.

There is a tendency to use the data base management systems that have already been acquired and supported by an agency, simply because they exist. Similarly, data tend to be stored in archival formats, which are related more closely to the method of producing the data than of using them, because it is assumed that the user can perform the necessary reorganization of such "pure" data. There is an appealing logic in this approach. The user of

1. Date, C. J. 1975. "Relational Data Base Systems: A Tutorial" Proceedings, 4th International Symposium on Computers and Information Science. Plenum Publishing Corporation. pp. 37-54.

the data can presumably specify the types of query more clearly than can the data gathering organization. If the user reorganizes the data, he clearly has an interest in organizing them efficiently. The fallacy in the approach is that for many types of multi-purpose data, for example, the LANDSAT digital imagery, there are many more users than there are patterns of enquiry, and each user is faced with the task of reorganizing archival data. Repeated efforts, for example, must have been expended by innumerable users in many research centers to re-orient the LANDSAT data spatially and stretch them numerically to overlay a standard topographic map. This surely has placed a substantial burden on the use of the data and is typical of the multiplication of overhead costs that occurs when data are provided to many users in forms that are not amenable to query. Clearly a trade-off is possible between a distributed responsibility for data organization and the centralized provision of data organized for efficient query. That trade-off, however, can occur only when the agencies concerned have a much better understanding of the relationships between data structure and query. Unfortunately, the volume of data that exists is already large and there is a commitment to further growth. When large commitments of funds and staff have been made in building a specific data organization, it is difficult to reverse the process. There will be a natural tendency to try to work with the data bases that have already been created, rather than to reorganize them. This will limit the number of queries that can be economically answered from the data, and therein lies the constraint that poor data structures place on future investigation.

In summary, the underlying methodological problems and difficulties of using modern methods for handling spatial data are as follows:

1) There is no widely accepted and clearly defined set of spatial relationships between entities.

2) There are no clearly identified categories of spatial query which can be specified in terms of the operations that they require to be performed on spatial data.

3) It is not clear whether the use of modern data base management systems is inhibited because of the present imprecisions outlined in 1) and 2) above, or whether the relationships and

queries are adequately defined from a user's standpoint and it is the technology of data base management systems that is inadequate.

4) There is no clear understanding of the relative applicability of the various data structures inherent in existing data base management systems to the task of recording spatial relationships.

5) There is little understanding of the relationship between the need for explicit definition of spatial relationships in digital data base management systems, and the use of display to permit human observation and recognition of relationships.

6) There is little understanding of the relationship between the need to specify spatial relationships explicitly for data base management systems and the calculative capacities of present and future computers.

7) There appears to be no competent source of advice within the profession of geography or elsewhere which can provide answers to these questions at this time.

The remainder of this paper will suggest several initial steps that can be taken to address these problems, that in turn may lead to lines of investigation with potential for their solution.

Proposed initial investigations

The following approaches are mentioned sequentially, but they must be regarded as interrelated and interdependent topics. They may draw on activities previously considered in one or more disciplines, which, because they were not considered in context with problems of more general concern, were perhaps thought to be esoteric within the host discipline and thus attracted less attention than they deserved. It is important to recognize the relationships between the various aspects of the work and bring them together.

1) A clearer definition of spatial relationships can be drawn from work already accomplished in the field of picture processing and

pattern recognition. Schwebel and McCormick,[1] as part of work on scene analysis, provided a focal point for developing a taxonomy of spatial relationships. They examined one axiomatic characterization of such relations, namely, how stable are they under various mathematical operations on the related entities. If one wishes to structure a data base to handle different types of spatial relations, perhaps the most crucial aspect is the ability to handle mathematically different types of relations and it may not be necessary to worry about every possible semantic interpretation of what the relation represents physically, as long as the syntactic properties can be captured.

Very useful contributions to the semantic problems inherent in defining spatial relationships have been made in recent years in the fields of linguistics and cognitive psychology. Clark, Carpenter and Just,[2] and Clark and Chase,[3] among others, have examined the semantics of reasoning and the process of comparing sentences with pictures. Workers in the fields of architecture and structural engineering, notably Winston[4] in the MIT project MAC, have made a systematic attempt to define spatial relations as expressed in words defining scene descriptions. Workers in picture processing, in particular Freeman[5] and Haar,[6] under the guidance of Azriel Rosenfeld at the University of Maryland, have described mathematical and computational expressions which can be used to embody the semantic content of these terms. They have also experimented with constructing maps from relational scene descriptions so encoded.

1. Schwebel, J.C. and McCormick, B.H. 1970. "Consistent Properties of Composite Formation under a Binary Relation" Information Sciences, 2, 179-209. 2. Clark, H.H., Carpenter, P.A. and Just, M.A. "Semantics and Perception" in Visual Information Processing, W.G. Chase, Ed., Ch. 7, 311-381. 3. Clark, H.H. and Chase, W.G. 1972. "On the Process of Comparing Sentences Against Pictures" Cognitive Psychology, 3, 472-517. 4. Winston, P. 1970. "Learning Structural Descriptions from Examples" MIT Project MAC, TR-76. 5. Freeman, J. 1973. "The Modelling of Spatial Relations" Report TR-281, GJ-32258X, Computer Science Center, University of Maryland, College Park. 6. Haar, R. 1976. "Computational Models of Spatial Relations" Report TR-478 and 1977. "Generating Spatial Layouts from Distance and Bearing Information" Report TR-528, MCS-76-23763, Computer Science Center, University of Maryland, College Park.

The extension of this line of investigation could lead to an internally consistent classification of types of spatial relationship, expressed in mathematical terms, which in turn could lead to a more precise definition of specific spatial relations between entities. The relationships between data base structures and types of spatial relationships could then be more clearly examined.

2) When one approaches the task of defining categories of spatial query, one finds that the epistemological foundation in geography is less than firm. Gale[1] takes the view that although questions themselves may be taken simply as the primary realizations of an inquiring mind, needing no further justification, what does require definition is a) the language chosen for description and inference, b) the specific axioms or assumptions, and c) the method of judging whether the elements of a theory satisfy the specific inquiry. These, in turn, are not completely free choices; they are functions of the subject of the question, the kind of theory under consideration, and operational concerns (for example, information processing). The types of questions, the overall pattern of enquiry, are to a considerable extent dependent on the criteria that the investigator sets up to determine whether the answers are reasonable and satisfying. The characteristics of query are thus directly related to our experience or perception of the world in which we live and, using Lowenthal's[2] phrase, to the "geographical imagination" in providing concepts and principles upon which to build a common geographical epistemology. In any thorough examination of the nature of geographical questions, it is hard to avoid some discussion of these issues, yet this interface between methodology and philosophy is difficult to write about without either a careful exploration of the meaning of experience itself or the making of substantial presuppositions. I suspect that the same may be true in other natural and social sciences.

It is possible that the next increment of progress toward the definition of types of spatial question, and the types of operations on spatial data, may be made initially through empirical investigation.

1. Gale, S. 1975. "Simplicity, Again, Isn't That Simple" Geographical Analysis, VII, 4, 451-457. 2. Lowenthal, D. 1961. "Geography, Experience and Imagination: Towards a Geographical Epistemology" Annals of the Association of American Geographers, 51, 241-260.

One can approach the task by working either from operations to classes of query, or from classes of query to operations. A useful step would be a thorough examination of a series of existing systems of spatial data handling, to identify clearly and in detail the types of query that have been recognized to be needed, the types of operations that have been used in responding to these queries, and the types of data structure already found useful. The work could proceed from recent descriptions of several geographic information systems undertaken by the IGU Commission on Geographical Data Sensing and Processing.[1] However, it would require a considerably deeper examination of the systems than has been undertaken thus far.

As a parallel step, it would be useful to bring together some of the lists of operations that have been developed by various workers. Tomlinson[2] differentiates between logical operations and physical (computer) operations and between logical operations and "data manipulations." A logical operation is described as a change in data value, a comparison, or a movement of a data element. A change in data value, for example, can be accomplished by any of the physical operations of addition, subtraction, multiplication, or division, either singly or in sequence (multiplication and division are in themselves a sequence of the physical operations of addition or negative addition). The result of the sequence of physical operations, however, is a logical operation, the change in data value. The ranking of data manipulations is based on the increasing number of logical operations they contain. The simplest capability is basic data retrieval, a single logical "Move" operation. The second level is the result of two logical operations, and includes data manipulations such as summary, elimination of linear distortion, classification change, selective search, scale change, projection change, or measurement of straight-line distances between points. Data summary, for example, is achieved by the combination of the logical operations "Move" (to acquire data), and "Change in Data Value." Five other higher levels are recognized, each containing manipulations that require increasing numbers of

1. "Computer Software for Spatial Data Handling," "Computer Handling of Geographical Data," and "Second Interim Report on Digital Spatial Data Handling in the U. S. Geological Survey"
2. Tomlinson, R. F., ed. "Environment Information Systems", Proc. Unesco/IGU First Symposium on Geographical Information Systems, Ottawa, 1970.

logical operations. Existing geographic information systems and the types of query that they can handle are classified with respect to the rank of the manipulative capability, volume of data, and type of location identifier employed. Recent work by Peuquet[1] has established a list of operations (data manipulations) involved in handling spatial data in raster structures. Goodchild[2] has briefly listed operations (data manipulations) relating to the types of spatial entity (points, lines, areas) being handled. It would be interesting to see how the nature of the operations (data manipulations) varies with the type of logical schema being addressed and with the type of entity being handled. It would also be valuable to see if there is any correlation between levels of operations (data manipulations) and types of query.

Little work has been done on defining the categories of question inherent in any specific pattern of enquiry addressing earth data. In simplistic terms, there are two types of query. The first is satisfied by a descriptive answer to the questions asking what, where, and when (past or present). The second is satisfied by an explanatory answer to the questions how and why (past or present) and, by extension, what, where, and when in the future. The second is central to scientific inquiry and subsumes the first. It is possible that most stores of data are structured to service only the first type of query. Gale[3] has suggested a four-part partition of kinds of enquiry which may form the basis for identifying the categories of query that can be handled by existing data banks. He recognizes a) descriptive, b) normative, c) strategic, and d) evaluative types of query. Descriptive questions are essentially the first type of query described above. Normative questions are concerned with what ought to be. They contain assumptions about goals, which in turn influence how goals should be measured and the structure and content of data banks needed to facilitate such measurement. Strategic questions are somewhat different. They concern the organization of rules that govern the behavior of the entities, the way in which the data may be used. They require that

1. Peuquet, D. 1977."Raster Data Handling in Geographic Information Systems" Harvard University Symposium on Topological Data Structures for Geographic Information Systems, Oct.
2. Goodchild, M. J. 1977. "Geographical Data Elements" Mimeo.
3. Gale, S. 1977. Personal Communication.

data be organized in a manner that reflects the constitution or framework of the institution (discipline), so that answers can be derived that are acceptable in terms of the role of the institution (discipline) and that can be translated into practice. Evaluative questions concern the measurement of relative performance, the monitoring of activities, and the learning based on that experience. It would be interesting to determine whether the queries asked of existing data banks can be seen to fall into these categories, and whether these categories of query demand mutually exclusive logical schemas of data. Similarly, it would be interesting to find out whether the categories of query each employ essentially the same suite of operations for data manipulation, or whether there are any significant subsets of operations related to different categories of query.

3) The applicability of the data models in existing data base management systems to the problems of handling spatial data was called into question earlier in this paper. They obviously cannot be used for all kinds of spatial data, but that does not mean that they are not appropriate for particular environments. Drawing a line between realistic possibilities and wild expectations is very important at this stage of their development. If an application can be handled by an existing data base management system, it is very costly and unwise to "re-invent the wheel" in a specialized spatial data system. On the other hand, the introduction of a particular data base management system without proper analysis can increase the cost of data manipulations and hamper future applications.

Given a clearer understanding of spatial relationships and types of query from the previous lines of investigation, it may be possible to start to identify logical schemas that can usefully be employed to organize spatial data for various types of query. The ease or difficulty of fitting such logical schemas to the hierarchical, network, and relational approaches of existing data base management systems might then be assessed. The resulting effect on accuracy and geographic resolution could be evaluated with respect to the consistency that should be true for the data. Data language sketches of each type of operation (data manipulation) could be generated and the ease or difficulty of relational operations performed on the data within each approach could be assessed.

This line of investigation can be extended to an evaluation of specific existing commercial data base management systems. For each system to be assessed, a data definition language program could be written for each logical schema. A data manipulation language program could similarly be written for the suite of operations (data manipulations) associated with each logical schema. On the basis of these programs, the existing systems could be compared with respect to their facility for handling each logical schema and type of operation. As a first step, the evaluation could be based on the ease of programming, from which can be extrapolated comparative costs and performance. Subsequent evaluation could be based on benchmark tests. The primary objective of this line of investigation is to establish which applications can be handled well by existing systems. However, where substantial problems are observed in fitting certain logical schemas and types of operations to the existing approaches, recommendations for new data models and data languages could be made in a more specific way. Criteria for establishing a new type of data base management system might be one outcome of this line of investigation.

4) There remains the uncertainty of whether our present difficulties arise not so much from our current ability to define the characteristics of spatial relationships and types of query as from an inadequate level of development of data base management systems. It is reasonable to ask whether there are lines of investigation that would provide data base management systems with more flexibility, perhaps with the ability to handle fuzzy definitions, and perhaps with the capacity to reorganize their own data structures in response to frequently used types of query.

One line of investigation can perhaps proceed from work on cognitive structures being undertaken in the fields of linguistics,[1] cognitive psychology,[2] and artificial intelligence.[3] Hays[1] suggests that human information structures can be viewed as a series of layered networks (systems) where a construction in one becomes an elementary unit in the processes of the next. In this way a human can proceed from the sensory monitoring system to abstract ideas through a series of networks, each actually describing the

1. Hays, D. "Cognitive Structures" Unpublished mimeo. 2. See for example Olrich Neisser, "Cognitive Psychology." 3. See for example Stewart Dreyfus, "Artifical Intelligence."

next at a different level of resolution, abstraction, type of thought, and degree of belief. Fuzzy concepts are handled at different levels from those of ordinary concepts. As pattern matching is implicit between networks, an inferential capability is provided. The human intellectual process can thus be thought of as regulated iteration between the networks, and creative thought results from the association of concepts in different networks. This type of structure may be useful for the design of data organizations to allow answers to the questions of how and why. It is probably already possible to model digital simulations of the networks, but the relationships between those networks may contain such complex computations that a much more powerful computer architecture than that currently available would be needed to simulate them elegantly.

In existing data base management systems, any substantial change in the logical schema requires a total rebuilding of the system. As there is a direct relationship between the design of the logical schema and the type of questions asked, a major change in the nature of questions implies substantial redesign. However, work is being performed by Merton and Fry at the Data Translation Project at the University of Michigan on the dynamic restructuring of data bases. Techniques now exist that allow a system to recognize the nature of frequently made queries and automatically to establish related files that contain the data for adequate responses. It would be interesting to determine whether these techniques could be incorporated in a data base management system either to reduce the necessity of defining all types of queries at the outset of schema design or to improve access to data thereafter. Recent developments in the Data Translation Project also include the concept of an "aggregate schema." This is not the same as a CODASYL subschema capability, but actually allows separate schemas to be merged so that the user can retrieve according to the combination of two or more individual schemas or views of the data. This resembles Hays' view of human coordination of concepts from separate networks and may represent the next step in improvement of the design of data structures.

5) The path tracing concept, inherent in all existing data base management systems, is designed to maximize the efficient use of existing computers, which are sequential processing machines. This concept may indeed be a fundamental limitation of current

technology. An important line of investigation must be the effect of replacing path tracing with pattern analysis, and sequential processes with array processes, both as separate steps and in combination.

One of the few areas where the human mind is demonstrably more efficient than existing computers is in pattern recognition and picture processing. It is not known whether the human subsequently processes such data on a raster basis, but at least the visual sensory input originates as a raster of excited retinal cells from which measurements and comparisons are made. Peuquet[1] has asserted that raster processing of spatial data has substantial benefits over sequential processing, and she has closely examined a suite of raster-based operations and the algorithms associated with them. In Hays' concept of human data structures, the networks are effectively low-order patterns and the relationships between them are pattern-matching operations.

Undoubtedly the area of pattern analysis is the one in which the human is effective, provided that the patterns are behaviorally established in the mind and the pattern can be mentally accommodated.

The limitations of human channel capacity and experience possibly constrain the degree to which pattern analysis can be used as a surrogate for explicit definition of spatial relationships in a digital data base management system. The outcome of that inquiry will probably depend on the availability of array processing computers and the replacement of human pattern analysis with machine pattern analysis.

Array processing computers are already in existence. The Goodyear STARAN machine and the CDC STAR machine are string processors which act as array processors. Complete array processors are under development in the United Kingdom and in North America. Their capabilities have only minimally been applied to the problems addressed in this paper. but the possibilities are substantial. One of the reasons why better data organization is

1. Peuquet, D. 1977. "Raster Data Handling in Geographic Information Systems" Harvard University Symposium on Topological Data Structures for Geographic Information Systems, Oct.

required is that large data volumes are expensive to handle on existing computers. There is every reason to suggest that those at the forefront of computer architecture design have the opportunity to examine thoroughly the current difficulties in organizing spatial data for economical query and to contribute to the answers.

The use of array processors with substantially improved memory capacity and improved ability to move data between memory and processing capacity may lead, with other lines of investigation, to the design of new data base management systems for spatial data. These, in turn, may prescribe new languages of dimensionality for the adequate description of spatial phenomena.

Certainly there is a pressing need for the current difficulties to be resolved by concerted research effort in several fields if there is to be any sensible planning of ways by which large volumes of earth data can be made economically amenable to query.

DR. MARBLE: Thank you, Roger.

Our next presentation is by Dr. Richard Phillips, of the University of Michigan, and Dr. John Sibert, from the Los Alamos Scientific Laboratory, who are going to discuss a cartographic query system for management of off-shore oil leases, in which they try to implement some of the ideas that Roger has talked about. The paper will be presented essentially in two parts, and both authors will speak.

A CARTOGRAPHIC QUERY SYSTEM FOR MANAGEMENT OF OFF-SHORE OIL LEASES

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DR. MARBLE: Thank you, Roger. Our next presentation is by Dr. Richard Phillips of the University of Michigan, and Dr. John Sibert, from the Los Alamos Scientific Laboratory, who are going to discuss a cartographic query system for management of off-shore oil leases, in which they try to implement some of the ideas that Roger has talked about. The paper will be presented essentially in two parts, and both authors will speak.

DR. RICHARD PHILLIPS: Could I begin with the first slide, please, which is the title of the paper that Duane Marble just quoted to you. I want to use that as a lead-in to my remarks, because it is an unfortunate choice of title. It unfortunately connotes a specialization of application which is really not present in the system we are going to describe. There are two terms in the title I do not like. "Query system" has an implication of a fairly static repository of data, about which the user can only ask a series of structured questions; that is not the case. Also, the fact that I have put in the specific application, that is, off-shore oil leases, leaves the mistaken impression that we have tailor-made the system to handle only that type of data base; it is quite general. Dr. Tomlinson talked about so many geographic information systems that have died for lack of use--probably in many cases because they have been developed for a specific application or have been doomed to failure for a variety of other reasons. In fact, the system that we are going to describe is indeed a generalized data base management system, just of the type that Roger was talking about.

If I could just perhaps recount a couple of the things that he has said, and just remind you what the term "generalized data base management system" has come to mean today. First of all, we are talking about a very large collection of data. Now, large can take on a great many meanings, but we are talking about such a large collection of data that we cannot build a single specialized way of handling that data and expect it to work on any data selection. It also implies that we are never going to have a main memory-resident data set. We are going to have to develop techniques we can use to efficiently extract data from relatively slow secondary storage devices. Also there has to be a rich query language. The user should be able to form a variety of fairly sophisticated criteria for extracting data from the data base, but, more than that, a generalized data base management system must allow the user the capability of modification; he should be able to delete items that are in the data base, add new items, alter the items that are presently there--all contingent upon some security overseer who is deciding who can do which of those particular operations. Then, in addition, we usually think of a reporting capability being present in any generalized data base management system. This can be a tabular report or, as we will see, we can consider the system we are going to talk about today as having a graphical reporting capability. Dr. Sibert will tell you in a moment that the final product of this generalized system in many cases is a thematic map which summarized the queries that the user has asked of the system. Could I have the next slide which summarizes a couple of points about data base management systems. A data base management system is, after all, a collection of entities--and I will try to stay away from the data base jargon. I do not want to bore you with that. But we generally talk about a collection of entities, and these could be employees in an employee data base, they could be cities in a population data base--anything that we can consider as being important in the collection of data with which we are working. The attributes that are associated with these entities are usually scalar attributes--and here I simply mean a single value associated with perhaps a city and its population or a city and its name.

What is important in this system that we are discussing today is what I call graphical attributes. This term connotes both geometry and topology. Graphical attributes are important in the system that we are describing today because I need to have the capability of not only asking for a query based upon the scalar attributes, but I want to issue queries based upon adjacency; for example, show me two geometric entities or cartographic entities that adjoin one another, or give me the results of a query that is based upon a neighborhood or a vicinity consideration. And therefore I need to have these graphical attributes associated with this data base management system as well. Computer graphics plays a very important role in this system we are describing. It is by no means an afterthought. It does not take a back seat to traditional querying and produce after-the-fact graphical results as a postprocessing step. It plays a vital role in the system in several ways. First of all, and probably most obvious, computer graphics gives us this important window into a complex data set that allows the user to not only print a series of numbers that result from a complicated query, but also to take a cross section, a cut through the data base, and show a two-dimensional profile of the data base. In addition to the obvious display of data that is there, we also talk about the use of computer graphics for input operations. I have already given an idea of that in that we want to be able to use graphical attributes like adjacency and nearness. We want to be able to use those kinds of concepts as part of an input query, so graphics plays an important role in the input to this data base in forming queries. One of the most important uses of computer graphics will be discussed by Dr. Sibert, and that is thematic map production.

Roger talked about data models and the familiar terms hierarchical, network, and relational. When we set out to build this data base management system, we tried to re-invent as few wheels as possible. In so doing, we tried to use the machinery that data base people had developed over the years, to make use of the tremendous amount of money and effort and research that has been expended in data base management systems. We searched for the most obvious data models that would suit our needs. Roger mentioned hierarchical, the tree type of approach. A natural application of that would be in describing an employee data base in a company or in describing the structure of an airplane--a fuselage with wings connected to it, and a tail connected to the fuselage, and so on. The generality that one can achieve with a hierarchic or tree structured data base is certainly not enough for the type of data base management system that we sought to develop, primarily because it does not provide the capability of expressing these topological relationships that we want to use both in querying and in display of the information.

A network system on the other hand does permit these relationships. If you are familiar with graph theory you will think of a network model of a data base as simply the entities, these generalized quantities that I have talked about earlier, all connected by arbitrary paths. The paths imply relationships among the data entities. Each of the entities then has its attributes. If we can construct an arbitrarily complex relationship among all of the entities, we should be able to achieve the generality we are looking for. In fact, we did decide to use a network approach. Roger mentioned the relational system where one does not impose any structure on the data; the developer of the data base does not even think of relationships among data. In fact, he allows the user to simply express all of the queries in terms of set operations, where he forms unions and intersections of sets of entities which have certain things in common. The network system proved to be the most flexible for our application. Then we started to look at the commercially available systems. Roger already mentioned some of the shortcomings of commercial systems.

Generally, a data base management system consists of three major software modules. There will be the data description module, where the developer of the data base can, with a fairly simple language, express the relationships among all of the entities that are going to be in the data base. Then there is the data manipulation language which, once the data base is built, is used to do the actual extraction of information from the data base, to do the modifications that the user subsequently requests. How does the user do that? Well, the third major software component is a query language module, and this is where the user can fit together the criteria that he wants to use to extract information, to make modifications, and to generate reports. The system that was used is called ADBMS, by the way. It was developed at The University of Michigan and is an acronym for A Data Base Management System. It has the attribute of being written entirely in FORTRAN. The standard network model, which was proposed by the Committee on Data Systems Languages, which has come to be known as the Data Base Task Group, developed a COBOL interface. Anyone who has ever tried to do any programming in COBOL, which is other than business-oriented, knows the difficulties in trying to do things like draw a square, for example, or express any other sorts of geometric relations.

ADBMS does have the advantage that it has a FORTRAN interface, but it does not have a query language associated with it. The rest of my remarks will deal with the major work that we did on this project, and that is developing the query language module which could use the data manipulation language and the data definition language which is inherent in ADBMS.

Figure 1 shows what is called a data base schema. I again will refrain from dwelling on the specific application that was the impetus for the development of this system, but I just wanted to show you a graphical representation of a schema. This is what this particular data base looks like to the developer of the data base. Each of the rectangles represents one of the entities that can be in the data base. We have color coded these just to distinguish the graphical entities, which are in green, from the ones that have only scalar attributes. This is an oil lease data base. If anyone is interested, we can talk about the details later. But the lines joining each of the rectangles represent the network configuration, the implied relationship that exists between each of these entities in the data base.

The important thing that had to be done in developing the specific system that we are describing today is to develop a query language that would totally shield the user from this structure; he should not have to know anything about the implied relationship among each of these entities. He should only know that all of these entities are present for him to interrogate, and he should be able to form a query which involves any of these entities and any of the attributes of these entities without regard for how tortous the path may be to get from one of the entities to the other. He should be able to blithely say, "find," and state his query, and have the system do all the work for him. And that is really what

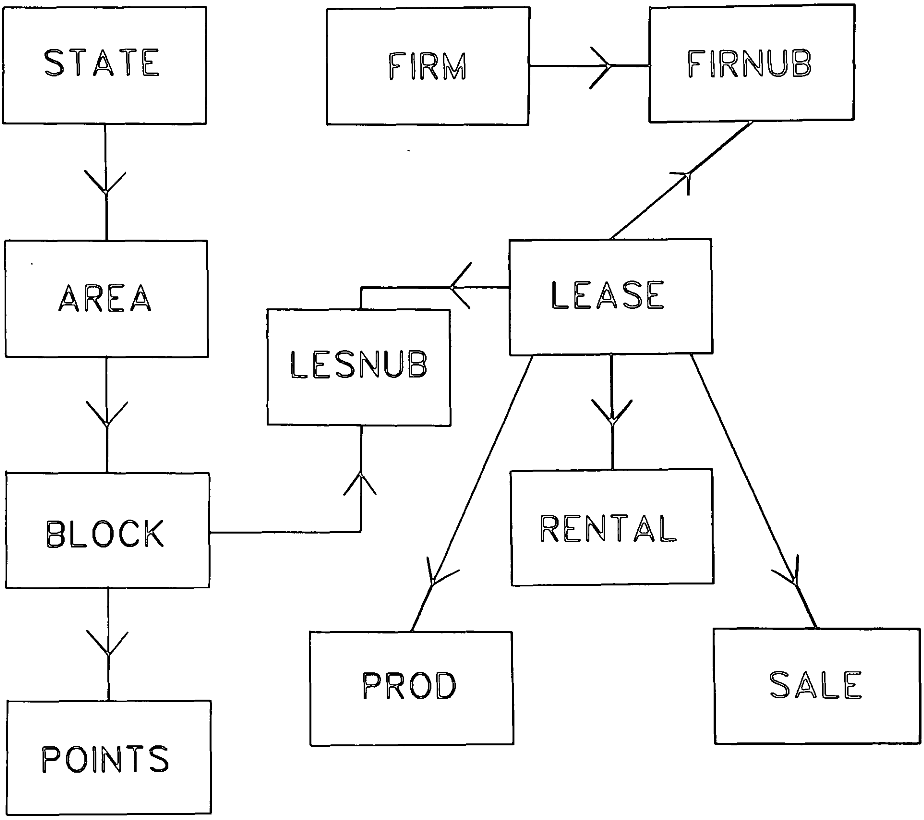

Figure 1. Data Base Schema

we set out to do and I think we have accomplished. In describing the query language, I will just briefly make a couple of points. The idea, as it always is, is to make it English-like so that it is easy for an untrained user to learn the language. More than that, it should be easy for someone who knows it well to abbreviate it. All of these attributes have been built in.

Path finding is the operation I just described of actually being able to find the way around the schema based upon the query that is specified by the user. Generalized accessing simply means the system had to be able to, without regard for how many attributes each of these entities had, find all of the occurrences of them that were implied by the user's query. As a query example, a user might say FIND LEASE WITH SUM (OILP) > SUM (GASP). In place of the word "lease" you can simply substitute any of the other entities found in the schema in Figure 1.

SUM happens to be a function that operates on one of the attributes, oil production, for one of the entities. You can replace SUM with any other function that seems reasonable to you--square root, average, or whatever. We are saying find all the leases in this system with the sum of the oil production greater than the sum of the gas production. Once that is done, we would like to graph the results. Just to show you what the graphical output would look like, consider the next slide. The user will eventually have the capability of completely defining the graph background in order to produce, if he wishes, report-quality output. He will be able to represent the data on the graph with histograms, bar graphs, regressions, or whatever he wishes. This slide is an example of a graph that has been produced by this system as it stands today. It shows the oil production, for a particular lease that had previously been selected, as a function of year of production. I want now to turn this over to Dr. Sibert who will talk about one of the most important aspects of this system, that which allows us to produce thematic maps.

DR. JOHN L. SIBERT: Thank you Dick. I am going to have to be a little bit more specific about our system because the maps do not make too much sense otherwise. They are specific to our data base application. I would like to begin with a little background about the geographic definition of the outer continental shelf leasing survey. This is similar to the public land survey, with which most of you, I am sure, are familiar. In fact, in most cases the public land survey has been extended into the water to include the outer continental shelf area. It is organized in several levels of agglomeration. The largest level is called an area. It is analogous to a country in size. The basic unit of the survey is called a block, and is approximately equal to a quarter township in the standard public land survey. In addition, for each block in all of the areas--currently we have Louisiana and Texas offshore areas--we have stored the latitude and longitude of the block's corners. In most cases that is four corners. Some of the blocks are irregular in shape and have more than four. Here is a sort of pseudomap portraying one of these areas (slide not available). You will note that one of the squares or blocks is shaded in red, so this is the approximate size relationship between the block and an area. The coordinates we have, again, represent the corners of all of the blocks.

When we wish to produce a map we assume that we have already retrieved a set of leases according to the sort of criteria Dr. Phillips was talking about. Normally, for this particular application, what we want to map are the leases since we are interested in managing the off-shore leases. Obviously, the system is much more general than that. The first step then is to link from these leases to the blocks in the survey which contain the leases, and then linking from each block to the coordinates so we have a complete definition of the blocks. Finally, we must decode the legal description, because when tracts are leased originally they are defined by a legal description, and, in many cases, the description is straightforward because it is simply block number N, area number M.

What I just described is illustrated in Figure 1. After finding the lease record, you will notice that there is a link through a thing called lesnub to the block record. The nubs are artificial records which allow us to do many-to-many linkages. So there is a link from the lease, to the lesnub, to the block, and we can link backwards up from block all the way to state and downward from block to points. We need the lesnub because some leases are a little bit more complicated in their legal description and, in fact, consist of more than one block or parts of more than one block or more than one part of one block. The description is given in simple English in a manner that is probably familiar to most of you; for example, the southeast quarter of the northwest quarter of block number N.

In order to protray the leases accurately, we must be able to store that legal description in the data base, link it to the appropriate lease, and then decode the description so that we can draw only the part of the block that actually is included in the lease. As an illustration, in order to decode the above description we first bisect the north and west sides of the block. It is easy to compute, and gives us the northwest quarter. We repeat the operation for the southeast quarter of the northwest quarter. Having done that for all of the leases we are interested in mapping, we are then ready to portray them. We have several different mechanisms for doing this. Before I describe them in more detail I thought I would mention the hardware we use.

The data base management system is currently resident on a CDC 6600, and (for anybody who is interested in that kind of detail) occupies approximately 140 K octal words of core storage. The data base itself resides on a disk. We are currently involved in building a new version of the data base with data for '75 and '76. The version we have now only has data through '74. We expect that quite soon the size of the data base itself will surpass a megaword. The output devices we use are: 1. For immediate display, a Tektronix 4000 series cathode ray storage tube display. I imagine you are all familiar with them. There are quite a few over in the vendors' area. This allows us to protray a map or a graph immediately on the screen during the retrieval process so we can look at it, get a good idea of what we have. We can also modify the display by adding additional information. 2. We have as part of our task the production of relatively high quality color output. For this we need a somewhat different hardware device, the I.I.I. FR-80 with 35-mm color camera. This device is basically a PDP-15 minicomputer which drives a high-resolution, fast-phosphor CRT. A 35-mm camera with program controlled filters is mounted over the CRT. By changing filters on the camera, redrawing the map or other graphic on the CRT screen, and multiple exposing the film, it is possible to produce a variety of colors on the output.

We allow several mapping options, the most popular are called new, old, lease, and area. New erases the screen or advances the film before the map is drawn, so it is pretty obvious what it does. Old adds additional material to the map that has already been drawn. The lease type map portrays only the leases themselves, while the area type map draws in the survey lines as a sort of background grid system. I have several examples of these maps. The first is a lease type map. You can see across the top of the picture the coastline of Texas, then Louisiana. The leases are portrayed as little red filled-in squares. These happen to be all the leases that had produced anything before 1975 in that area. As you can see, it would be very difficult from this type of map to identify a specific lease.

Figure 2 is an area type map which while retrieving the blocks also retrieves the areas which contain them, and portrays all of them as background. This is a much more useful form because now we can, particularly when we make a hard copy and look at it a little more carefully, identify specific leases and determine their location. However, if you want to portray more information about the scalar attributes of the data it becomes necessary to view a smaller area at a larger scale.

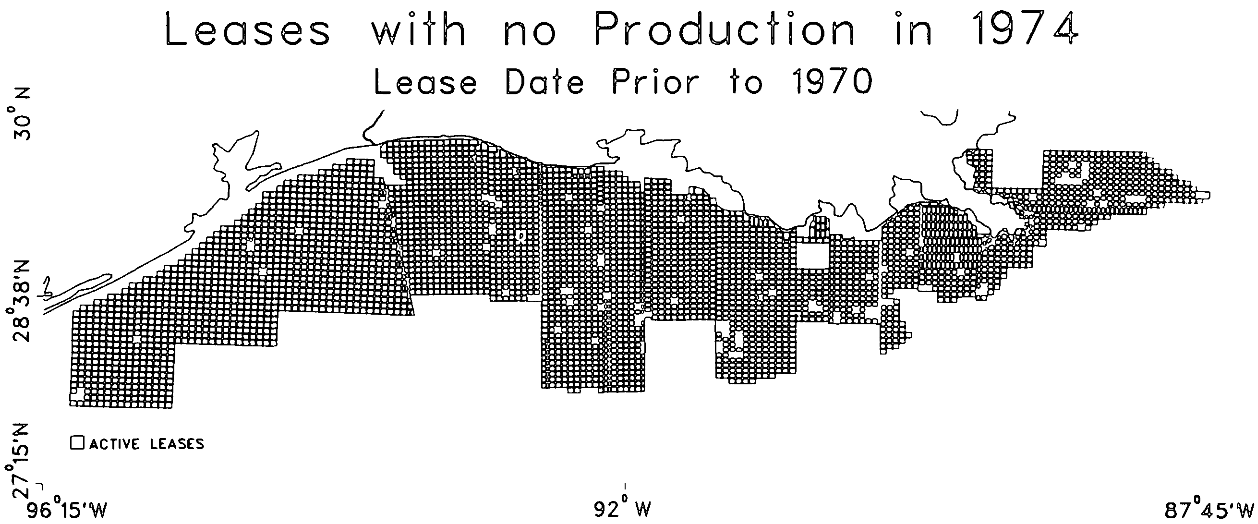

Figure 2. Area Map

DR. MARBLE: Thank you. We have a third member of our panel who is not going to make a formal presentation, but who is going to comment in part on the presentation of the other speakers in the light of his own experience, and this is Mr. Robin Fegeas of the Geography Program at the U.S. Geological Survey. Robin has been heavily associated with the development of the computerized land use mapping system, and we will have some comments from him. Robin?

MR. ROBIN FEGEAS: You must forgive me if my remarks do not seem well prepared. I discovered just about ten minutes before the session what my role was going to be. But, sitting here I had a few questions which have been bothering me for some time since we are just beginning to get into thinking about managing a large data base, a land use data base, for the entire country.

Just to go down some of these questions. The first: At what level of development are data base management systems? Are they adequate? Can we make good decisions right now? We have been told the hierarchical model cannot hold the relationships we need. The relational model is still very theoretical; no good examples have been yet brought into the market operationally. The network model, which Dick Phillips and John just discussed, seems promising, as their presentation showed, but it still puts a burden, namely in having to specify your relationships ahead of time, well-defined, and any relationships you might want to impose later on creates large overhead in update. Basically, the data base has to be restructured completely.

The second question I had was just how much of an overhead are we going to pay for using data base management systems? The objective, that of data independence, is a very admirable one, one which should allow us to use our data for many more purposes than if data independence did not exist. But, still, we have to pay a price in efficiency and, perhaps, in computer storage. I have been told at our computer center in Reston, Virginia, we just had installed a commercial data base management system, System 2000--which the Water Resources Division will be using. The computer center people are complaining that just this one application of a data base management system will drain the resources of the hardware and software there so that it will preclude other users.

Of course, this brings in another question: What role do minicomputers play in this data base management scheme? More and more, minicomputers are being used and will be used, and I think this is the wave of the future. So, where do they come? It appears the systems as they are thought of today to use a lot of resources which are not available on even large minis.

Another question I have is one of management. The use of a data base management system requires a new position, a new expertise, namely that of a data base administrator, one who can oversee all the requirements of the different people who will be using the data base, and then structure that data base accordingly so that all users can use it. At the Geological Survey we just were presented with this problem, and a position description has just gone out. We are going to get a data base administrator, perhaps. It is unclear as to what his powers will be, but all in the field or most in the field now agree that this position should be a very powerful one. In the present bureaucratic structure when you introduce a new powerful position, it is difficult. That consideration will have to be made. That concludes my questions.

DR. MARBLE: Your raised a number of interesting questions, Robin, which do need to be addressed. The particularly interesting one, this question of the organizational changes that come about when you start talking about the management of large quantities of data. It represents a change in view on the part of the organization. Many organizations, governmental and private, have used and accumulated large stores of data, most of which has been oriented toward individual users. I have my data, you have your data. Occasionally you may want to borrow mine and use it, and that is all right, and I will tell you about it, perhaps. But when you start recognizing that data within an organization--and I use the Geological Survey as an example, since it is a data-oriented organization--constitutes just as much of a resource to the organization as an individual company's buildings and trucks and aircraft, then you have to start worrying about how this utility is to be managed for the best good of the organization. It becomes necessary to institute an administrative structure. This notion of a data base administrator who has certain powers over the data, does not own the data any more than the bank manager owns your money, but he does have certain powers to regulate the way in which it is used. This is largely to prevent people from falling over themselves, and one side inadvertently changing portions of the data base while another side is trying to use it, of insisting on consistent definitions of data elements, things of this sort.

Robin mentioned the potential problem of resource use with a data base management system. I do not think that we should sit down and say that the data base management system is utilizing such a large volume of computer resources; the problem is that we have a lot of data. A case in point, the use of System 2000 by the Water Resources Division; there are very large data volumes involved and a large number of users, many of whom wish to access the information in an interactive fashion. This places a load on any computer facility that has to be dealt with in one fashion or another. If the facility is operating at or near capacity, even small additions in demand can, of course, have great impacts. How about questions or queries from the audience?

MR. MITCH MODELESKI: Mitch Modelski from ESRI. Roger, I do know of one experiment where a relational data base management system was applied to geographic data, and that is geoquell. Are you familiar with this? Geoquell is a front end to GIRAS, which is a relational data base management system currently operational at Berkeley on a DEC 11/70, running under UNEX. This data base management system is written in C, a language developed at Bell Labs. I would like to contrast this particular experiment with another program with which I am familiar to demonstrate just a couple of examples. GIRAS was asked to draw 90 simple polygons once, and it took about five minutes to do so with a Tektronix scope. Many of the people that ran that experinent felt that it was a failure.

I would like to contrast this particular experiment with ARITHMACON, a program that Marv White is currently developing for the Census Bureau. Many people will say that the comparison is unfair because ARITHMACON is running on a PDP10 under Macro-11 Assembler, and an 11/70 can't hold a stick to that particular machine. However, I think the important difference lies in the way the data was modeled. When I examined the data structure of geoquell, it turned out that they were storing nickel records, namely, from coorinates to coordinates and right polygons, but no left polygons. ARITHMACON explicitly stores not only the from and to, left and right, but orders these with a set of relations that involve boundary and co-boundary across all possible combinations -- say, the boundary of a line, the boundary of an area, co-boundary of a point, the co-boundary of a line, and so forth. The type of queries that can be processed with ARITHMACON far exceed the types of queries that can be processed by the generalized data base management system whose geographic front end was simply developed after the fact to demonstrate that the marginal cost of an application would be lower, given a generalized data base management system. But the particular data model that was used in GIRAS was not appropriate to geographic data where the graph, to me, is the ultimate thing we have to be careful about. So, in closing, I guess I might just comment and say that we might be able to store all the relations for some of the data, and some of the relations for all of the data, but not all of the relations for all of the data. (Laughter.)

DR. MARBLE: Thank you, Mitch. (Applause) One of the people involved in the study group that Roger mentioned was a computer scientist specializing in data base management systems, Dennis Tsichritzis of the University of Toronto. About a year and a half ago Dennis, Donna Pequet and I were talking about these systems. There was no real question in our minds that if we were going to handle really large cartographic data bases they were going to have to have to be handled in an efficient manner, and the data base management system approach is the way this is done in most areas. After some discussion, Dennis made a remark that I think is still quite pertinent. He said that in dealing with spatial data one of two things must be the case. Either you people (geographers and cartographers) really do not know what you are talking about, that your statements about spatial relationships and the things you are trying to do with all these points and lines and areas are poorly put together, and that if you sit down and try and think about it properly, you will be able to place the things you are doing within the context of existing data base management systems and they will work for you. Or, on the other hand, you may actually have something new, which from the standpoint of people working in computer science and data base management systems would be most exciting because, he said, we are getting awfully tired of yet another airline reservation system. (Laughter.)

Part of the work of the IGU study group has been to try and develop some insights into this area. I think that one conclusion that has come out of the work is that it is probably the latter case rather than the former, and that there are indeed some unique characteristics of spatial data. For example, within the concept of a data base management system it is the entities that are considered to have attributes and not the relationships, whereas in spatial data we frequently have attributes attached to the relationships themselves, such as distance. So we may very well be working in an area which is going to provide a great deal of interesting development for people in computer science as well as cartography, geography, and other areas in the earth sciences. Are there any other comments?

DR. AANGEENBRUG: I want to pursue this comment of yours about data management from a policy point of veiw. I would say, to venture a guess, that if you got a powerful data base manager in USGS somewhere, that unless there were complete cooperation from the top down in defining that job, and that job was made as unpowerful as possible, it would not work. Data is not owned by a single person in a single agency. If you create somebody that has too much power -- and I am standing here having been such a person in the university, controlling the entire budget with a small computer, so to speak. It was the wrong kind of thing to do for a university, and if the system didn't crash, the power position did.

It seems to me that the function of a data base manager could be that of, say, a catalog librarian rather than someone who you have to get past. Because in many of the large agencies -- I will not name some that I used to work at -- it is rather difficult if the computer division controls the operational aspects of the division. After all, that is not why it exists. It is a facilitative thing. So I would suggest perhaps not at this conference but another, maybe in public administration, if you pursue this question, do not create a very powerful data base manager, would be my advice. A very capable technical one, yes. They should not have a very high rating, because primarily what you are dealing with is a conceptual model. The decision to standardize every chunk of information within the vast divisions of, say, USGS as a management-administrative decision must be made by the policy makers first. Otherwise it won't work. They will not let it.

DR. MARBLE: The concept of the data base administrator is one which is somewhat strange to many people. I will not try and elaborate on it here. There is an excellent book dealing with notions of data base administration as well as a very good shorter discussion in James Martin's book on Principles of Data Base Management. It is a position which is strangely structured administratively since the person is not just a librarian. The post combines the duties of a librarian, a technical standards committee, and a number of other things as well. Sid?

MR. SID WITTICK: Before I make a comment, I would like to ask Dick whether my impressions are accurate, that the application that you just described is operational and has indeed been successful on existing data sets.

DR. PHILLIPS: Oh, yes, it is operational. There are some planned enhancements to it, but it has been operational for six, eight months.

MR. WITTICK: That was my impression. I think it makes the point very, very well, that there are areas where we have been very successful, and it is usually when we try to take on a reasonable size task, a reasonable size volume of data in a temporal framework. I think we are guilty as a set of professionals in some instances of trying to operate at too large a scale. I think even in terms of very large problems posed by the USGS's and the Census's of the world, I wonder if in their manual systems, and, indeed, these are systems as well as any others, we can demand the same standards that we are demanding of the computer systems we are trying to create? For example, I wonder whether all the maps that exist within these mapping agencies currently are all consistent and uniform and standard in terms of their ability to be manipulated? They evolve through time, and I think we should start trying to design systems that we know are going to have to be replaced, data structures we know are going to be replaced, but such that we can save money while we try to do it.

DR. MARBLE: Sid, three large, burly representatives of the Topographic Division will be waiting for you near the exhibit area. (Laughter.)

MR. BOB RANDELL: I am Bob Randell from the University of Saskatchewan, but do not expect me to be as erudite as Dr. Boyle. I am just a biologist, but I am very much reminded of a situation that exists in one of Lewis Carroll's works where a country prepares a map which is a one-to-one representation, and then makes it illegal to unfold the map because it cuts out the sun. Now, how big does a data base get before it gets bigger than the original? (Laughter.) (Applause.) To what extent can you, especially now we have space platforms -- how much data do you need to store that you cannot obtain, say, at the next ERTS path, especially when a lot of these data are now available locally if you have just a small radio station? I know radio amateurs who can process ERTS signals.

DR. MARBLE: That is an interesting question. It was posed, I think, for the first time in print about 13 or 14 years ago in a joint paper presented to the American Institute of Astronautics by William L. Garrison, and it contains an illustration showing a rough globe of the earth entitled "World's Largest Data Bank." This is indeed a question one has to really address: "How much data does one want to retain? What are the necessary things to retain? What is the balance between current operational needs and long-term archival structures? We could very easily end up drowning in data, particularly as the direct digital data capture techniques increase in efficiency and the volumes generated from them escallate. Are we going to keep everything forever? That is a policy decision, and one that tends to fall under the area of data base administration within an organization. There are a lot of questions in this area that are at the present time relatively unanswerable. But we are going to have to find operational answers to them within the next few years or find ourselves neck deep in difficulties.

MR. KEN PYLE: I am Ken Pyle, and I am from San Diego County. I would like to address the problem of a one-to-one relationship. Because if you look at what a county does in the way of mapping, with records kept currently in a totally disjointed, uncomprehensible and very often conflicting style, then I think you begin to realize that it is desirable to establish a base which does in fact represent a one-to-one relationship with the ground. If you are familiar with mapping at the city and county level throughout the country, I think you recognize that most mapping occurs in this disjointed fashion. There are little groups of drafting technicians squirreled away here and there and everywhere competing against one another in many cases, surely contributing to job security, but nevertheless representing a tremendous duplication and loss of the tax dollar. Now, we can very well go on and create automated systems in the very same fashion -- particularly with minicomputers coming through so quickly. But, what we will have again is a series of automated programs for each specific or specialized use within the city and county, none of which are compatible with one another, and all of which represent a tremendous waste of the tax dollar. Now, if we are going to actually resolve this problem and create a system that will be a cost-effective use of the tax dollar, then we better get everything together, put it on a one-to-one basis so it represents the real world, not a map world, and make sure that it can be used by all the necessary users.

From a manual standpoint you know this is almost possible today. We could create a series of large-scale maps with multiple overlays. In fact, in San Diego County we have an intermediate scale, a regional scale in which we have done that. We have 180, 200 overlays to a base map which you can put together any way you want. We have 50 people in my section doing mapping. We do not do any maps for ourselves. We do them for others. What we have to look at is the fact that, first of all, we need that one-to-one relationship because of the administrative work that we have to do on a daily basis that engenders the information in maps, and, number two, which is heartening to me because I see the trend happening here, that we have to recognize that maps are merely a graphic display of the data that we wish to show, that we wish to use. We do not make maps for the purpose ofmaking maps. We make maps to show information. Consequently, we are talking really about data base management with the capability of a graphic display that comes out in the form of maps as well as others. From our standpoint we are working on the basis of one-to-one relationship. We are building our data base based on ground calculations, engineering calculations being direct input into the system. I think if we do not work that way, all we are going to do is build our own specialized little system that will serve my department's purposes, but certainly none of the other 50 departments in our county, because they will all be getting their own. So I am in favor of a one-to-one relationship.

DR. MARBLE: I think you are using the term one-to-one relationship in a non-standard and confusing sense. In a cartographic operation we tend to interpret the form of Lewis Carroll's map as one-to-one. Mr. Carroll mentions another map, in The Hunting of the Snark, which references yet another solution to our data problem. I believe it was the Bellman's map which unrolled contained absolutely nothing. Somewhere between these two extremes we must reach a balance. We have come to the end of our scheduled time. Thank you.

DATA GENERALIZATION AND ATTRIBUTE CODE SCHEMES

DR. MARBLE: The two topics that we are about to take up cover data generalization and attribute code schemes. Our first speaker is from the Federal Republic of Germany, Dr. Hans-Jorg Gottschalk. He comes to us with a background in geodesy and surveying. He is associated with the International Cartographic Association, and will talk to us on data generalization. Thank you.

DR. HANS-JÖRG GOTTSCHALK: Thank you, Dr.Marble. It was about three years ago when I was here on AUTO CARTO I, and I was able to present a cartographic system which was prepared by the German Council of Research for mere research purposes. Now I am able to show you some of the work which has been done with this system. This is mainly work on generalization. Cartographic generalization is one of the most complex problems in cartography, and to find a model for cartographic generalization means to find a mathematical formula describing this very complex procedure in cartography. You could compare this to finding some kind of a cartographic world formula. There are approaches for the solution of this problem. Those of you who were in Moscow in 1976 might have read a paper given by Vasmut 1976, who tried to find a formula describing all the procedures being carried out in producing topographic maps. But nobody knows whether this formula works or not. There is no experience with this, and I think there is no experience especially in practice. Thus, the only way to solve the problem of generalization is to cut it down into pieces being so small that they can be handled.
Generalization procedures are simplified, and the interdependencies are reduced to what is possible. The simplified procedures are mathematically formulated and computerized. This is the way computer assisted generalization has been done until now. The partial solutions and their results will be presented in this presentation. The general idea is that it is not possible to define a computer program being able to do all generalization work. It is understood that the program does the routine work of the cartographer, whereas the cartographer corrects the results of the work of the program by means of interactive editing facilities. Let me show you a slide. This is the type of data to be digitized, and this is the type of map we were able to derive from the digitized data shown before. This map has been produced by simple operations, and you will notice that, for example, there is no displacement in this type of map. You see the symbolizations are very simple. It has been adapted to what is possible in automated cartography, and also the hill shading has been done automatically, Gottschalk 1974. Now, the definition of generalization programs starts from what kind of features have to be generalized. The cartographic elements may be points and lines. Lines may be curved lines or polygons. The lines may form network structures as nodes

and edges. In topographical maps, lines may represent surfaces or surround areas, like vegetation areas. Accumulation of points may form areas. The most common operations carried out in generalization is to smooth lines, to select lines and other cartographic elements, and to displace them after smoothing if their distance gets too narrow. There are many smoothing techniques -- for example, filtering by means of arithmetic means, splines, or dropping points of polygons (Jancaitis 1973). Smoothing can be applied to surfaces. There is an example made by Waldo Tobler in 1966, and others.
The degree of smoothing is defined by the scale to what the map is to be generalized. Although there are statistical laws giving the necessary loss of information by generalization, the last decision whether a line is properly smoothed or not is made by the cartographer. The parameters of the program are changed as long as the solution is accepted by him. This means an interactive working. If we deal with curved lines, they may be contours, roads, or lines surrounding vegetation areas. They can be smoothed, for example, by means of a gliding arithmetic mean where you use a special weight function; the degree of smoothing is due to this weight function. There have been a lot of publications about this, so I need not repeat. To smooth polygons may be a little more difficult. Usually polygons will form political borders and things like that, and political borders will coincide, for example, with other topographic items like rivers or so. And if you treat them independently you will have discrepancies in the result. So, polygons are a little bit difficult to handle. There are several methods to do this. Just drop some points out, let us say, every fourth or fifth point, or considering the length of edges between two nodes or the distance of a point from the connection between its two neighbors. If the distance is below a certain limit, the point is dropped from the polygon.
These cartographic line elements usually form network structures, which are generalized by dropping the less significant nodes of the structure. If you regard surfaces represented by contour lines, you can look at each contour line and regard it apart. You can simplify contours by smoothing, for example, each contour separately or by smoothing the surface represented by the contour lines. I will show you an example. Have a look at these contour lines. They have been derived from calculating a function using these points being marked

there, and then systematically you can leave out the points due to the form or the shape of the contour lines, and you see the result when you successfully drop points from the surface. The first one contained about 83 points. These are the 53 points. These are 43 points, 33 points, and 13 points. You see that the main characteristics of the shape of the contour lines are kept in shape in the performance of this kind of generalization (Gottschalk 1973).

The next procedure that has to be performed is to select lines for the generalized map. You see here the drainage of a map digitized. The next slide shows the drainage transformed for the scale of one to 50,000, whereas the generalized lines were generalized for the scale of one to 200,000. You see the operation of smoothing has been carried out, and the operation of selection has been carried out. You can either do this interactively or you can just drop out lines which are shorter than a certain limit, say, two centimeters or so. So, every line which is shorter than two centimeters does not appear in a generalized map. Of course, this is a very simple model.

Next. If you come to network structures you must apply another method. The method of dropping lines shorter than a certain limit from the structure they are forming does already mean a selection. The criterion of the length, however, is not sufficient. It is possible to form a matrix of all the nodes of the structure containing the connections from one node to all the other nodes of the map. So the nodes connected, say, the intersections connected with many other intersections are more important than those being connected to only a few points of the map. The connections can be weighted according to the importance of the line -- that is say, if there is an important road intersecting with a less important road, the weight of the point is different from this. The result of all these considerations is a cardinality-matrix, the eigen values of which were already mentioned this morning, which are used for the decision whether a node of the structure is removed from the structure or not in the generalized map (Franke 1973). If you should show the next map. What you saw before was the digitizing of the scale one to 10,000. Here you see the generalized map generalized to this system that I have declared before. You see for the scale one to 25,000, one to 50,000, one to 100,000, one to 200,000, and you see that the main structure is kept whereas the less important roads or intersections

between lines are dropped from the picture.
Let me show you the next slide, please. On this picture you see the main procedure which has to be applied to displacement. Applying all the procedures I have mentioned means treating a problem sequentially which is not a sequential one. As a result of these manipulations there will be intersections of lines which should not intersect, or lines will be so close together that the minimal dimensions for distances of two separate objects in a map remain below the threshold necessary for the scale of the map. At these parts of the map, the results of these simplification operations, as I have described before, have to be corrected by displacement performed either by interactive operations or by batch processing. What is to be done by displacement can be seen from this slide. You see above, the road and houses or street and houses. In changing the scale from, say, one to 25,000 to one to 50,000, you have to widen up the road. You must find an algorithm for this. One solution for this is a topological algorithm which regards this drawing as if it is on a cloth of rubber, and then you make some calculations in order to widen up the road and let the houses be apart from what they were before. You can solve this problem either by interactive solutions or by batch processing. I will show you some samples for interactive solutions. See, here some subjects which are smoothed and simplified, and you see that the houses are lying within a road. They have to be moved out so that they lie on the side of the road. This shows the display and shows the principle of the operation. You have a joystick or something like that, and by marking these two points there, you give the direction where the house has to be displaced. The result after giving a certain command is this one, so that the houses have been removed and the road is free of them (Christ 1976). Here is the problem where a creek or stream intersects with the road. The principle applied in generalization is that, generally, the creeks are kept in their situation and any other object is shifted. Here you see the operation on display, and here is the result, that has come out after this interactive operation on the display.
It turned out while performing interactive solutions that the interactive solution takes more time than we had thought before. This made it necessary to find some other solution. There is another disadvantage. If two cartographers do the displacement work at the same object at the same time or if one cartographer does the

same work twice, the result will not be identical. This made it seem useful to reduce the interactive solutions in favor of batch solutions, letting a program make the decisions, and process the whole map automatically, the result being at least uniform, is not better than the interactive solution. There are two ways for the solution of the displacement problem in batch programs. They depend on the shape of the data, either raster data or lineal data. Here you see some samples of displacement problems. You see on the left-hand side the digitized features, and on the right-hand side you see the same object after the displacement procedure, which is done completely by batch program.

The next one, please. Here you see another example. You see the road, which is on the left side, which has been digitized, and then it has been widened and the houses have been shifted. Of course, the contour lines, too, have been shifted downward (Lichtner 1977). There are some otherprograms which work in a similar way, but the most difficult problem is to find out the part where displacement is needed. Here, the solution is comparatively simple if the data are given in raster form. Distances of lines can be detected by means of the distance transform and other known raster operations (Weber 1977). I will show you the result. The next slide, please. Here you see a problem of displacement. You see on the left-hand side a road and a creek, and the dark object has to be moved or the road has to be moved to the left side, and the circle, the object shaped like a circle on the upper part of the picture, will have to be removed for the room is needed by the road. In order to give you an impression or how it works, you see in the middle of this slide a raster which consists of vectors which are showing the amount of displacement which has to be done in each of these points. All of the features are transformed to a raster, each of the raster points containing a vector, showing whether the two objects are too narrow, too close together or not. Where it is very black there you see that the bigger part of displacement is needed. Then you shift the whole thing according to what is necessary. The result is on the right-hand side. Here you see it once more, an enlargement. Black means that the displacement has to take place. If the vectors are smaller you see that there is no displacement necessary (Christ 1978).

Next slide, please. You see another problem which deals with generalizing, here of houses in the scale of one to 5,000 to the scale of one to 25,000. You see that

the houses have to be simplified in the way shown by the next slide. You see the main operations that have to be done, which are marked by the red line. You must omit some parts of it, you must enlarge some, you must drop some edges and so on. The result of this operation is that, for example, houses, the areas of which are too small, are put together and others are dropped from the picture and so on. In order to perform this kind of generalization the houses are digitized. All these operations are performed in the blocks which consist of houses surrounded by the streets(Hoffmeister 1978).
I come to the end now. You see here there are digitized houses in the scale of one to 50,000, and they have to be generalized to the scale of one to 200,000, where the single house representation has to be transformed to an area representation. You see, these are the digitized houses, and these are the areas which are calculated from the digitized houses. To come to a conclusion: During the performance of this generalization work it turned out that the interactive part of the computer-assisted generalization needs far more time than has been thought of before. The results of the known experiments on computer-assisted generalization show that more work has to be done on programs solving more problems than they do now and that interactive working should be reduced as much as possible.
Thank you.
(Applause).
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DIGITAL CARTOGRAPHY AND ATTRIBUTE CODES

DR. MARBLE: A small change in our program. Our speaker on attribute code schemes should have been Roy Mullen from the Geological Survey. Instead, Dr. Robert McEwen is going to talk to us on this topic. Bob is supervisory research cartographer with the Topographic Division USGS, and is currently leader of the Division's Digital Applications Team.

DR. ROBERT McEWEN: I appreciate the very short and to-the-point introduction. As has been noted, I am not Roy Mullen. However, he is sitting in the second row and if there are any difficult questions asked of me at the end of this presentation, I will be glad to refer them to Roy. I am with the Topographic Division and the Digital Applications Team (DAT) and would like to speak about some of the things we are doing and how that relates to data you may acquire from the USGS National Mapping Program. Most of our data distribution will be through the National Cartographic Information Center (NCIC). I do not know whether they have any digital related information in their workshop here but during the next year or so they will be incorporating digital data in their information.

I would also like to say a word about previews of coming attractions. Not to distract from this meeting where we have the privilege of speaking informally, but both Roy and myself have prepared papers for the ASP-ACSM meeting in Washington at the end of next month. There is also a digital terrain model symposium in May in St. Louis and Dr. Elassal of the DAT is presenting a paper on data management. Another paper will be presented by Brunson and Olson on digital terrain model accuracy and the equipment used by the Topographic Division to gather data.

We are organizing our data in two distinct types of files. As you might expect, being in the cartographic surveying profession, we are organizing horizontally and vertically. We have files that we call DEM's, digital elevation models, and we also have files which we call DLG, digital line graph, for the horizontal information. We are gathering this information with a number of pieces of equipment. There is not enough time here, nor is it perhaps appropriate, to go into a great deal of detail. But presently a lot of the horizontal information is being gathered with manual digitizers. The vertical data that is going into the DEM files is being primarily gathered with Gestalt Photomappers (GPM-2); we also have some other orthophoto instruments digitized. The GPM-2, in the process of making an orthophoto, creates digital elevation data on tape. We also have two M&S editing systems, Gerber and Calcomp plotters, and we are in the process of installing additional digital plotters at this time.

Back on the DLG and DEM files. We have categorized those in three levels. The first level is basically unedited data -- I will not say "raw" data because sometimes we have taken the raw data and done a little bit of clean up to get it organized. But basically, Level I is the data as it has been gathered. The Level II data represents an editing function performed on the Level I data. Blunders, such as lines that do not quite intersect and lines that cross where they should not, have been edited to make a clean file. The third level of data represents, in the DEM case, elevation data that has been tied to planimetry -- in other words, the elevations have been tied to planimetric features such as roads, streams and so on, so that you have a consistent set of data. It is a normal function when you are making a map to make the contours cross the streams at the appropriate places and so on. It is the same conceptual idea in the Level III for the DEM.

In the DLG case, Level III represents a topological editing of the data, so that we have a perfectly consistent graphic that is topologically edited. In other words, as you walk around all of the nodes, you will have a consistent set of areas that you cross and come back to the same area. If you follow around polygons you will always have the same polygon on your left, and you will come back to the starting point. We think this is important, and it represents a commitment of the Topographic Division to service geographic information systems which, we believe, require topologically edited data.

For purely graphic purposes, many of the Level II types of data would be appropriate. I think it has been said before, that we are not convinced we want to digitize graphics just to make additional graphics. It may turn out as time goes on, that we will get a feedback from the digital files to speed up, modernize, and increase efficiency in our map-making operations. At the present time this may not be completely cost effective, but we believe there is a commitment to gather data that can be used for geographic information systems. And we believe that to do this we need DLG-3 data.

We have a set of computer programs that have been developed for processing planimetric data. The data gathering procedures and the processing result in the final output of an organized and formatted DLG-3 file. The programs are called the Unified Cartographic Line Graph Encoding System (UCLGES). (Nobody could pronounce that, but the closest we could come was "Uglies"). It is presently operational on our IBM 370/155 and we made a conscious decision that we would only have that program in one place so that we could maintain it.

Documentation and information about the program has been written, and there is no reason why that cannot be shared with the community, although I do not know that it has been published in any form. The program requires the operator on the digitizing table to encode the nodes, and then encode lines and then encode the areas, for a planimetric graphic. We work one category of data at a time. The program goes through and performs various topological edits, throws out data that is not correct, produces a proof plot, and then the operator goes back and adds and deletes until he gets a final graphic that represents the map that he is digitizing. Finally, an output file is created, and it would be this file which would be available through NCIC. A file is organized into lists of nodes, lines and areas. Each of these can have attribute codes connected with them, which I will describe in a moment.

We are presently gathering data for a limited number of pilot projects and are proceeding very deliberately to test our own capability to gather data and also to test the cartographic community to see if it can really make use of the data that we gather. We are digitizing basically from 7 1/2-minute maps. One project, recently completed in the State of Idaho, involved some 212 quadrangles in which we digitized political boundaries, the public land net, and some forest boundaries. The purpose of the project is rather interesting, because it relates to a forest inventory in which the idea was to classify Landsat pixels multispectrally and then automatically drop those pixels into the right county or the right public land section or the right forest ownership, and to do this all in a computer without ever having to overlay a graphic.

Another project is being conducted with the Bureau of Land Management, the U.S. Forest Service, and the Bureau of Fish and Wildlife. It is in southeast Oregon and includes 38 quadrangles. We are digitizing boundaries, transportation, hydrography and some cultural features. We have another project with our Geologic Division within the USGS which relates to coal resources. We have digitized DLG data for the public land net and political boundaries, and have also gathered DEM data. We have several other pilot projects that are either just getting started or being considered. As those materialize we will gradually make that information available. I will not promise that all of this pilot project data will be distributed. There is always the chance that some of it will be erroneous or for one reason or another is not complete.

Now, I should say a word about the National Mapping Program and the base categories of data that we have jurisdiction over and to which we are primarily paying attention. If you look at a 7 1/2-minute map you will see the base categories. They are very obvious, but you ought to stop and think about them for a moment. What is on a 7 1/2-minute map? There are the contours, some boundary information, hydrography, and transportation features such as railroads, roads and trails. You will see some information about surface cover, such as orchards and vineyards as well as the woodland tint. You will see hydrography both as streams and water bodies and wetlands. There is other information such as names and also information about the coordinate system - the state plane coordinate systems, the UTM, and the geodetic coordinates.

These are all proper ingredients for a 7 1/2-minute map and constitute the base categories of information we are responsible for in the National Mapping Program. It is to these that we will primarily pay attention in our digitizing. We are basically a cartographic data gathering, maintenance, management and distribution organization. We intend to carry through and follow these types of functions when we move into the digital domain.

Attribute codes have not been discussed too much here but we have given them quite a bit of thought, and have prepared a document that describes some of our codes. A small part of that will be in the paper that I am giving at the ASP-ACSM meeting. It is perhaps that third level that was described earlier in the day when civilization settles down to law and order and locks everything into some defined numbers.

We have code numbers that are basically seven digits, separated into a three-digit major code, a period, and a four-digit minor code. The major code, the first three digits, refers to the base categories of information that I previously mentioned -- the categories of the National Mapping Program. For instance, there is a code for transportation, a code for hydography, and so on. The minor code, four digits to the right of the decimal point, has unique numbers to describe node information, line information, and area information. It is rather interesting to consider what you want to encode as a line and what sort of a number should you give to it. Let me give you a few examples.

On our maps we show divided interstate highways. There is a definite symbol for highways that have a median of a certain width. It is perfectly appropriate not to digitize both of those roads, but simply digitize down the middle of the median strip, and assign a code, "divided highway." You also run into a different consideration when the road divides and each lane goes its own separate direction. You now have to digitize each direction of traffic, and you have to label it an interstate highway with restricted access and one-way traffic. Then a problem came up: can we possibly convey in numerical attribute coding the direction of the traffic? Is there a number that says I am traveling this way or that way along the line? We decided in that particular instance there was probably no way; somebody is simply going to have to look at the graphic to find out which way the traffic goes. All we have said in the numbers is that it is restricted to one-way traffic.

There are many other cases of this. In the hydrography area we started to consider the questions that would be asked in the computer about hydrography, and we realized in the water resources area that there are many routing types of questions. Since we are digitizing streams in one file and the water bodies in another file, you can come to a situation along a stream where you do not know where to go to connect with the next stream that flows out of the water body. So we are forced to put in an artificial line across the water body which maintains connectiveness between the in-flow and the out-flow of a water body. We also realized that we have to digitize the banks of streams as well as the center lines where we have double-line streams. We also have situations where we have to digitize on either side of islands, because there are alternate routings in getting down the stream. We have done a fair amount of thinking about this, and I am not going to go on any further in this particular meeting, but I would call your attention to the document that we have prepared, and we would welcome your comments and criticism and suggestions as to how this data can be made most useful to people who have applications for it. Obviously one function of an attribute code is to search on it so you can pull certain information from the digital files.

Moving on for just a moment to the digital elevation models, which I indicated were being gathered primarily with the GPM-2. We have over a thousand of these quadrangles digitized. The GPM-2 generates more data than we feel is necessary to put into the files. We are presently going through a data thinning, organizing and filing procedure and establishing a management system so the data can be distributed. We are starting to do this with some of our backlog and I anticipate either late this spring or early summer that some of these files will be available through NCIC. The files are generally regular arrays but there is a provision in the file structure for irregular arrays of digital elevation models. So, we have accommodated both types.

In closing, I would mention two other items; NCIC distributes the DMA digital terrain tapes from the 1:250,000-scale maps, and we also have contours for the Jewel Ridge, Virginia quadrangle digitized as an experimental data set. Thank you. (Applause.)

DR. MARBLE: Thank you, Bob. That was an interesting discussion, and I think enlightening to all of us in terms of its promise for the future. Are there any questions for these speakers?

MR. EDSON: I would like to add a footnote for the record. I would like to recognize a couple of gentlemen attending AUTO CARTO III who have been involved in much of the work Dr. Gottschalk described. These two gentlemen are from the Institute for Applied Geodesy in Frankfurt, Theodor Johannsen and Fred Christ. Would you stand up, please? You may want to contact these two gentlemen in the event also that you have questions later on. Thank you.

MR. LEN JARVIS: I am with B. C. Hydro Power Authority. I would just like to hand Dr. Gottschalk this little sketch. It sort of illustrates the problem which I am proposing. The sketch illustrates a fairly typical utility mapping problem where you are digitizing a facility's map which shows, let us say, gas mains and electric underground in the same road allowance, in the same street at a digitization scale of, say, one inch equals 100 feet. The actual separation between a line representing the gas main and the line representing the electric underground is really quite small. These two facilities may be in real terms only a foot apart. Now, the difficulty is that if it has been digitized at that large scale, and then the wish is to display the information on a smaller scale, let us say, one inch equals 200 feet, then on a conventional CRT, you run into the problem of lines actually merging, the distinction between them being lost. Now, if I have understood Dr. Gottschalk's generalization discussion properly in terms of the data shifting, he is able to put attributes to the information such that when the road allowance will be re-scaled from one inch in 100 feet to one inch in 200 feet, he can in fact maintain the same visual separation between the tightly spaced gas main and electric underground cable so that the separation will still show properly at the smaller scale. I hope Dr. Gottschalk understands the inquiry, and maybe he can comment.

DR. GOTTSCHALK: Yes, I think I understand it. The problem is to which of these two lines you want to keep in place.

MR. JARVIS: I showed a solid and a dotted line. Let us say for the sake of argument that the solid line should always show to scale at the correct offset from the road allowance, and, therefore, the dotted line should always be, say, at a fixed display scale from the solid one.

DR. GOTTSCHALK: It depends on what we call the minimal dimensions, the minimum graphic dimensions which bring the two lines apart. If you refer to graphical minimal dimensions, you must draw the two lines 0.3 millimeters apart. What you must do before is decide which of the two lines you will keep in its place and which of them will have to be displaced.

MR. JARVIS: So, you are saying that given I make the choice initially, then I can in fact solve that problem.

DR. GOTTSCHALK: Actually, we did not think about this problem as far as some kind of cadastral work, I think, less than topographical mapping.

MR. JARVIS: Yes, it is definitely not a topographic problem.

DR. GOTTSCHALK: It is up to your definition of how to do it. I suppose that you can use this type of operation for this.

MR. JARVIS: That is very interesting. I won't take any more time here, then, but I should for my own edification follow that up with you at some time. Thank you very much.

DR. GOTTSCHALK: Perhaps you might want to discuss that with Dr. Johannsen and Christ.

DR, MARBLE: Do we have other questions?

DR. KURT BRASSEL: Kurt Brassel, SUNY, at Buffalo. I have a question for Dr. Gottschalk. You have shown a topographic map, a generalized topographic map, which includes several map elements. How did you correlate the various generalizations of the various map elements? Do

I understand right that this may have been done by a raster structure?

DR. GOTTSCHALK: My idea concerning the first map was, if there are objects being correlated in the digitized map, and if you process them with the same operation -- let us just say if you take a gliding arithmetic mean with the same parameters to all of the features, you can easily calculate it mathematically. If there was a correlation before, there must be a correlation after this application of the gliding arithmetic mean. It is just transformed. But there is still a correlation. This is proved when we, for example, smoothed the contour lines and the drainage using the same parameters in this gliding arithmetic mean formula. It proved that the drainage was still running in the valleys. Perhaps when you have been in Frankfort you have seen this large map there, and you could see that they really remain inside, the range that was expected.

DR. MARBLE: We are finished for the day. Thank you.

DIGITAL HARDWARE: MASS DIGITIZATION

MR. DEAN EDSON: Hardware. This is where the action is. I am really looking forward to the next six sessions. Because of the immense amount of progress being made in the area of hardware development it was necessary to devote a major share of the program in AUTO CARTO III to the subject of hardware.

Ray Boyle from the University of Saskatchewan has come to moderate this very important panel, and to my knowledge there is no one who has a better grasp of the total hardware picture than Ray. In the way of formal introduction, Ray is a native of England, and has been in some form of automated cartography since 1960. When you consider that this is 1978, that is a fair time to be involved in a relatively new field. He is currently teaching electrical engineering at the University of Saskatchewan. Ray received his advanced degree, Doctorate in Chemistry, from the University of Birmingham in England, and has been in Canada 13 years. That really accounts for a marvelous disposition. Canada is a great place to live, and if you do not believe it, just ask Ray sometime. At any rate, it is a pleasure for me to have Ray here to have him take charge of this very important part of the program. So, without any further ado we will turn the program over to Ray and launch into our Hardware.

DR. RAY BOYLE: Thank you, Dean. It is, as usual, an honor to be here at these AUTO CARTO meetings, and I am very impressed with the very large number of people coming to this one, showing the enormous interest in this field at this time. Over the period of time that I have been involved with automated cartography, we have been hitting our heads against brick walls; nobody wanted to listen, nobody was a believer, but things have now broken through on many fronts -- the psychological front and very much in the last few years on the hardware front. I will talk more about that later. Dean described me as a moderator; one of the reasons he asked me to come along is that if it is necessary I am also an inciter, so do not expect me necessarily to damp anything down. The only thing I damp down is people who talk for too long in too long-winded a way; I am quite strict about this. The signal that I will give if in my opinion you are speaking for too long is a digital one (indicating).

The things that we have to talk about have been selected by me as the most important ones. If you do not like these areas and you think there should be others, then only blame me. I am an individual, so I have no department that you can blame and no government organization.

In the next hour and a half, or little longer, we are going to try and cover a six-month university course. It is a teaching, an edcational operation. The people on this panel are not here as representatives of their organization or of their company. They are here as representatives of a methodology. I have asked them to be completely fair in their descriptions of things that are wrong, as well as things that are good. We do not only want descriptions of things that work; we also want to know the things that are available or are being used at this time but which have serious problems. There are many of these and in fact, I think that there are probably a larger number of things that do not work than do work.

The panel members will each have about five to ten minutes as an introduction to say why they are on the panel and what is their area of expertise. I have tried to be representative in my selection of people. You will notice that this is quite a large panel; there are others that I would like to have had on this panel, and I hope they will speak from the audience.

As far as the organization of time is concerned, it is not a proper division to have one and a half hours for digitization and then three hours for mass storage. They are about equal in problem and in advancement at this time.

Do not forget that this is your meeting. It is you who have to keep the discussions going, you who have the questions to ask. I hope the people on this panel will be the resource people, the inciters to your questions. And I will generally try to keep the ball rolling; if everything else fails, Efraim Arazi, on my left here, can always tell one of his wonderful stories.

I think that for the first time in my life I wrote a pre-paper for this session indicating what we would not be talking about; I think that that is a unique departure. I hope you will find it useful. It was to give you the general background of the things that we have discussed in earlier AUTO CARTO meetings. In these AUTO CARTO meetings we are always trying to give you the next stage of advancement. You have the exhibitors to give you the present state of advancement. So, if they should feel left out and ask why things are not being covered, then that is the reason. We are talking about the next stage on this panel; the exhibitors are there to show you the present stage.

Company names will be mentioned. We are not trying to avoid this. They are of great assistance in our work. Without them we would not be in business in automated cartography. No one should hesitate about using a company name. If I hear one person using it more than five times I will suspect he is a salesman, but --

(Laughter). Your work here today, the sort of questions you ask, the sort of responses we give, will advance or retard new developments appreciably. However, I believe that nothing will stop them; these developments are bound to happen and the die is cast. Nevertheless, if you can gain the necessary background, if you can pass this onto your administrators, if you can appreciate the good from the bad and make your proper decisions, you will advance the state of the art very considerably from this meeting. The high number of participants makes me think that we will be getting good results.

During my present sabbatical year I have been visiting many different countries, and examining their assessments of their future requirements in automated cartography. Some of these have been by internal committees and others by external consultants. A few of these are good. In general -- and I am going to be quite honest about this -- I have never seen such a pile of garbage in my life. You must be very careful about such "assessments." Maybe we have to have assessments of assessments, and even assessments of assessments of assessments. I do not know how we deal with this, but it is clear you cannot avoid -- and I am presuming you are all here as cartographers or pseudocartographers -- doing your own thinking, your own cartographic thinking. Other people can help you in other areas, but cartographic thinking you have to do yourselves. You cannot farm that out to somebody and pay him to think for you.

The first discussion area -- digitization -- is one that has been a bottleneck for a considerable number of years. I have been personally involved over the last few months, particularly as I had the opportunity of working at the U.S. Geological Survey.

I am an electrical engineer; I like designing systems that have real applications. I also like trying to design for five years hence.

I really believe that the things that are being developed now, will meet your needs almost entirely in automated cartography. Over the next five years your tools will have become all that you need as we presently see automated cartography. Let me avoid saying anything about geographic information systems; that is slightly different. That is my opinion; you will be able to form your own opinion from our discussions. It even makes me wonder whether I should not get out of this business of automated cartography entirely and look for other challenging problem areas. Perhaps this is the last and most exciting hardware meeting we will have in the AUTO CARTO series. From now on it may be straightforward engineering. There will be problems; there will be troubles, there will be minor variations, but to me, it looks as if breakthroughs have occurred on every front.

DIGITIZATION. We have limited ourselves in the next discussion to scanning digitizing. We are not going to avoid talking a little about manual digitizing; we are not going to avoid talking a little about automatic line following. However, these are not the subject matters of this panel. We are talking about large throughput digitizing. At one time it was called mass automatic digitization, but we did not like the acronym, so we changed it to mass digitization.

The discussion is covering scan-to-line or scan-to-vector conversion software as well. Perhaps this is an infringement on the software panel, but it is an integral part of the hardware. We heard yesterday about the possibilities of working entirely in raster format, but I think that at present most people want the vector format for their data. So we will regard this as a necessary adjunct to the actual scanning operation.

The panel is representative of the general state of the art. We have generalists who have seen, by putting out contracts, what is happening in many areas. We have Joe Palermo and John Baumann, from RADC. One will talk more about hardware and the other will talk more about software. I have also asked Joe Palermo to give you a general introduction to the subject. Some of you will not know the problems of automatic scanning so, before we get into too much detail, we must have some background. Richard Clark from ETL will tell us about some of their problems and what they have been doing on scanning. Bill Switzer is from the Canada Geographic Information System. He has been doing digitization, scanning digitization for a very long time from about 1966; in fact, probably the longest period of time as far as production operations are concerned anywhere. In the experimental runs I have been doing this year, he has been most helpful and has proved to me that the costs of automatic digitization are very economic indeed. I am very grateful to him for the work he has done. Tom Kreifelts from Germany has been doing experimental work over there. He is basically a mathematician and has been working on the scan-to-line conversion. Efrain Arazi on my left will be talking about the hardware. One of the reasons he is here is to make it clear to you that such units for digitization are available "off the shelf."

Most of these people will be talking about drum scan digitizing, but we also have asked Leonard Laub from Xerox (who is really mainly concerned with the mass storage panel) because he knows the work that is being done with the laser scanning flatbed operations; these may well overtake the drum method, as they should be cheaper and faster. We are talking about complete sheets scanned in a few minutes, however much data there is. We are talking about costs of one hundred dollars per mapsheet when we say "good economics." I am now going to hand the microphone over to Joe and ask him to introduce the subject of mass digitization by scanning.

MR. JOE PALERMO: Basically what we are talking about, when we talk about raster scanning, is the need for high speed digitization of large volumes of data. We have already seen, there are a number of different ways of doing this. There are flatbed scanning systems. Some of them employ self-scan solid state arrays, and these go up to a thousand elements. You can adjust these to be anywhere from a thousandths of an inch up to four or five thousandths of an inch in resolution, and you would make a pass over the sheet by moving the head. You also have rotating mirror laser scanners. In this you would typically get to the order of about 500 lines per inch or about two thousandths of an inch, and you would move the scan head. The drum scanners are basically what we have now. We have a number of different types. We have the reflective black and white scanner, and this is typified by a raster plotter scanner, technology resides at companies like Image Graphics Inc. (IGI). This is on the order of, approximately, 26 minutes for a full format scan, which is 122 centimeters by 175 at .025 millimeter resolution. We also have the reflective color scanner. That technology base resides in a number of different companies, one being SCI-TEX. We have some work being done by IBM and some work being done by Hamilton Standard. In these areas we are basically mentioning scanners that go up to 12 or so colors, on the order of 12 to 16 colors, and approximately a thousand lines per inch. We look at the scanners, and we have some general attributes. For economic reasons in generating the scanners, whether it be flatbed or the drum types, about the highest resolution you will normally find is a thousand lines per inch. They have some other ones, you can vary most of them from approximately 250 lines per inch, or four thousandths of an inch spot size, up to a thousand lines per inch.

There is a wide range of these products that you can buy off the shelf or one of a kind. Resolution alone does not really buy you very much. We have to be able to repeat what we scan, and repeatability on these instruments is normally on the order of plus or minus one least count. If we are talking about a thousand lines per inch device, you are normally talking about a one mil repeatability. Accuracy is distinct from repeatability and is the ability to locate in absolute manner any point on the surface of the chart, and typically, these, in an absolute fashion, are on the order of plus or minus two or so counts. So we would be talking about plus or minus two mils for the finer scanning systems. Some of the scanned results will be talked about and ways to handle them. If we are now looking at a large format chart, let us say 40 by 60 inches, we are taling on the order of about two and a half billion pixels in that chart. This is a very large amount of data. Most of the people today run-length code their data. We are not talking about photoimagery where each pixel is distinct, we are talking about charts, and we can run-length code to reduce data volume. It still ends up with a very large amount of data which has to be put somewhere -- on disk, on tape, and stored.

We are taling about a discreet system that would operate in approximately a one mil viewing plane, and it does not do many things that the human eye does. The human eye will look at something like a brown contour running over a green background area, and will see the same brown contour overprinted on a white area. The actual color scanning system, when it sees those, will be looking spectrally at the colors and will see, in many cases, varying colors. It is a difficult task to separate those and recognize brown under a number of varying different background conditions. Also, since we have a discreet system, we are going to have to quantize the output data, usually at the finest one mil steps. When we are viewing this type of data, you encounter problems of, say, an aperture half filled and half not filled, whether it be a black and white scanner or a color scanner. What does the scanner actually see? If we are looking at a four mil line, would our output be on the order of two, or so, mils, or would it be on the order of five mils? When you go to use this later on it is important, for the quality of the output product, that these types of scanning problems be taken care of by the system, either on the scanner or by some backup system. We also have a number of other situations which are encountered which have to be handled, and they are not basically yet being handled, I think, by most of the hardware you will hear about. That is processes like screened data. It is, basically using 120 line screen, the color scanner, using a one mil aperture, is going to see areas of color and areas of background, or white, or whatever happens to be screened on. This is going to greater generate a deal of data. Ways have to be arrived at to be able to detect these screens and outline these screens, because the massive amounts of data you get from picking up the individual dots basically burdens the system, and it would take a lot more time to process than you would actually like to use. Also, there is an increasing use of process color, which is a very difficult situation to handle. The one mil scanning aperture is going to see individual process color dots and will not tell you what the apparent color is. You have to take a macro view of that, and that, either, takes some sophisticated optical system, or it is going to take a large scale processing system to be able to get a macro view of colors.

Basically we are all scanning data for a purpose. Some of us would like to be able to manipulate data in a totally raster form. You heard something about that yesterday. The SCI-TEX system does that, it will work with that. We are also talking about, in many cases, if we want to actually change the data -- if we want to scan it, if we want to change scales, we are going to have to start generalizing data, things like this. You will hear about this. We may have to convert from raster like line to vector formats and things like that, you are also going to hear about that. Scanners alone will not solve your problem. We have to have systems which back them up. One scanning system which I was going to mention is the raster plotter scanner. I have two slides. This is a view of the drum subsystem of the raster plotter scanner. The black and white scanner is capable of 16 shades of gray. Resolution is 400 lines per centimeter over the drum. Spot size is .025 millimeters. Repeatability is plus or minus that element. The absolute accuracy over the system is plus or minus .05 millimeters. This is arrived at by having temperature control within the cabinet for the drum and the bearings, things of this nature. The lead screws tolerances are plus or minus one degree Fahrenheit to arrive at that mechanical accuracy. Also we have a substrate thickness compensation. We are looking at things which have to be in the system. If we are scanning for a four mil black and white film or a seven mil black and white film, the actual dimensions or the length dimensions you will get around the drum will vary or change by approximately 20 thousandths of an inch. This has to be compensated for somewhere. We have chosen to do it on the hardware on the fly. The format, as I say, is 122 centimeters by 175. At .025 millimeters we can scan that format in 26 mintues. We are going to end up generating about two and a half billion pixels, if you had a binary format, in about 26 minutes. Next slide, please. The associated processing system of this scanner consists of a PDP 11/40. It operates under CAPS -11. We decided on that system because we really did not need more than that. It has approximately 32K of core, 16 bit words. It outputs to two nine-track 1600 BPI, 125 inch per second mag tape units.

Now, these mag tape units, in order to handle that volume of data, even in run-length coded format, have to operate simultaneously. What is actually done is that the output from the system is, the even scan lines like two, four and six, and the odd ones, one, three, five and seven, are put on alternate tape units, so anybody who wants to decode this data would have to have this same type of setup. 125 IPS is necessary to keep up with the output data rate. The copy, it can scan now, is black and white, positive or negative. It can scan transparencies, translucent or opaque, black on white or white on black. This is simply handled by a flip of the switch. These systems are being used. They have been put in, on an initial basis, at the Defense Mapping Agency Aerospace Center and the Topo Center down in Washington. They are initially starting to use our backup by software, and they should be going into a production mode in the relatively near future. Thank you. (Applause.)

DR. BOYLE: I will have to ask Efraim to come to the microphone next. We are going essentially along the order of the table. I would like to stress the fact that there is a difference between people who want to digitize the separations of which there are a very, very large number; these are the straight separations which make up, say, for example, 1:24,000 areas, or to take a color printed map and scan it. These are very different jobs, and I would like to stress that difference when you are doing your thinking.

MR. EFRAIM ARAZI: My talk will be divided also into two panels, today and tomorrow, because the system I am familiar with, the Sci-Tex RESPONSE Design System, comprises a color separation or black and white scanner, a graphic interactive station with soft display, which is an inseparable part of the scanner, -- as you will see in a minute -- and also a laser plotter; a high precision laser hard copy plotter which outputs the 40 by 72 inch format separations which are generated in the system.

Our background, very briefly; Sci-Tex is an industrial company which has developed with its own funds for the graphic arts industry and for the textile industry which I will describe in a little while as a fairly high performance scanning and editing system for color work. We have installed to date 76 of these systems around the world. They are installed in the United States, all over Europe and in the Far East. The equipment used, the RESPONSE 200, includes the scanner which I will be describing this morning as well as the color television interactive display and the laser plotter.

This is our first visit, our first call on the cartographic community. We found to our great delight and surprise that our equipment -- which has been, by the way, already deployed in some industrial and some Government organizations for over three years -- is apparently capable of handling some of the finest cartographic products that are around. Let me start with one of the more difficult experiments in scanning, that of scanning a printed map. I will ask my associate to show progressive combinations, but first put all the layers together. This is a corner of a standard USGS 1:24,000 scale topographic map that was scanned on our scanner. I will explain in a few minutes how this scanner operates. As the sample is lifted layer by layer, let me say that in one pass the scanner separated the eight colors that were in use in this particular map. Ilan, you can flip through the separations now. These are by now perfectly clean separations. They are clean not because the scanner is perfect. I will be the first one to admit that while scanning color reflectance copy, there are some problems that have to do with either creased papers or with inks printing on top of other inks.
You will probably remember that cartographers do not pay great attention to brown lines printing over green areas and other such over prints. Let me ask Ilan to show us the original output -- take the brown color, the blue color, any one of them. If you look carefully, you will see under the word "Hyco River" a shadow of a line, a very thin line, which is really a line in another color. This particular sheet is the black printer. These are picked up by the scanner, except they are cleaned up later by the combination of the software that exists in the equipment. The equipment has software that will identify, locate by its continuity, by its location or proximity, all sorts of errors that were picked up.

Let's go back to the original drawing. Now, Ilan, if you can show us the other contour map that we obtained by scanning a black and white transparency. This is displayed with absolutely no retouching, no manual intervention, no editing whatsoever. This is typical of the quality that can be obtained. Now, let us turn off the projector, and I will very briefly describe the attributes of the scanner.

As I mentioned before, this scanner is part of a problem-solving computer system which is deployed all over the world. The scanner we now have accepts opaque or transparent material in sizes up to 36 by 36 inches, in up to 12 colors. The scanner operates at 200 scanning lines per minute at a resolution of about 1000 lines per inch. It recognises the color on the fly at the rate of about 250,000 picture elements per second, and codes them in run-length coding, and sends them to the disc memory. We use disc storage as an intermediate storage. The systems can be made available with 20 megabyte or a 300 megabyte disc store. The 300 megabyte disc store has so far taken care of any and all cartographic products we have run through at the sizes specified, although these may include up to 1.6 billion picture elements. Apparently the coding efficiency is such that we had no trouble with overflow.

The equipment is self-teaching in color recognition. Basically, if the system operator places, say, a printed map or a transparency on the drum of the scanner, all he has to do is aim the scanning head onto the colors in use, and to press a button indicating "this is color no. 1, this is color no. 8, etc." The computer system recognises the particular reflectance characteristics of each color. Once the scanning is initiated, it recognizes and stores every picture element labelled with the particular code, also keeping an eye on the colors surrounding it, and sending a file of run-length encoded data, to the disc. So, this is a very brief explanation of the operation of the scanner. I will be very happy to go into greater detail on its attributes in response to questions which may come later. Tomorrow we will also discuss the interactive editing station which is used to clean up all the data and all the errors that creep into the scanning process.

Thank you (Applause).

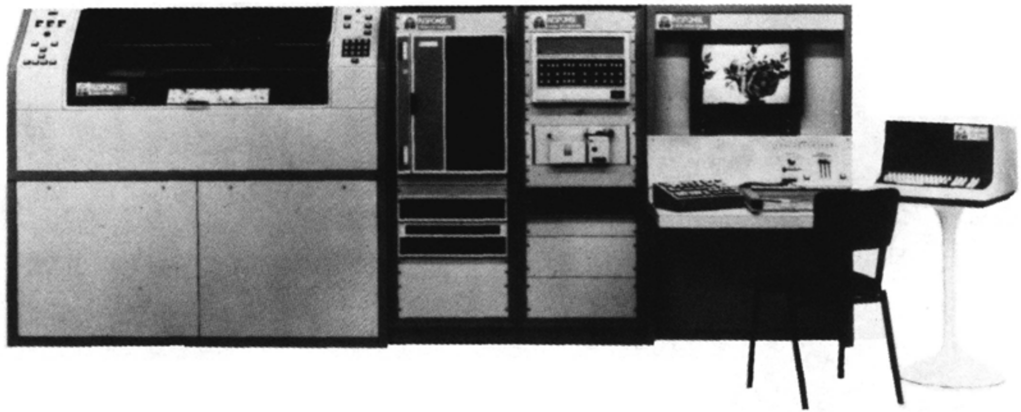


Fig. 1 The SCI-TEX RESPONSE - 200 Raster Design System.

DR. BOYLE: I think that adds an exciting new dimension. I mentioned that this scan editing will be added into the part that is called "small operational systems" tomorrow where Christian Hoinkes will be taling more about the vector. But I am getting Efrain Arrazi to talk in sort of a complement to this about the raster editing. So, for those of you interested in raster editing, I think that should be a good discussion tomorrow. The next one along the line is John Baumann.

MR. JOHN BAUMANN: I will try to keep my remarks fairly short here so we don't get the digital gong from Dr. Boyle. (Laughter.) In 1969 RADC exhibited a color raster scanner at the annual ASP-ACSM meeting in Washington. At that time that scanner generated quite a bit of interest. There were always a large number of people around the booth. We were hoarse at the end of the week. There was one question which came up very often, however, and that was, "How are you doing at scanning litho sheets?" Our answer to that at that time was, "Well, we really haven't done too much of that yet." What would be the possible application of it in the future? We saw it as a scanner for scanning hand-drafted manuscripts and for scanning black and white separation negatives.

Since that time there have been a number of experiments with scanning lithographic sheets. We can see that there are a large number of problems to be overcome in that area. We have been developing software mainly with the intent, again of scanning black and white color separation negatives or hand-drafted manuscripts while continuing to investigate the problems of litho scanning. As Dr. Boyle said previously, mass digitization, in this case raster scanning as we were mainly talking about this morning, means not just raster scanning and creating a tape in raster which would then be used by somebody, but also to process the data to put it into a lineal or a vector form which is more easily acceptable to the user.

Most users do not have either the hardware or the software processing capability at this time to handle raster data as raster data. It takes getting this raster data into a vector format so that the user can access the data, perform symbolization of the data, and other manipulations such as scaling.

There are a number of alternatives to raster scanning, as Dr. Boyle mentioned, and we do not want to dwell on them here. One is automatic line following. Semi-automatic line following is also being investigated. There has been a large investment in hardware in the government and also a large investment in software in the government. For private people to be using raster scanners which are inherently expensive, becomes a very difficult and never ending task to show that the raster scanning can be cost effective. There are some companies, however, some of them represented in the exibit area, who can take raster scan data and actually provide services for a particular user to raster scan the data and convert the data to a vector format.

Getting back to the lithographic scanning or actually scanning of color separation negatives and the problems involved, I see that probably one of the main problems now is the conversion of symbolized data and data which has broken lines in it which occurs by color crossing into the vector format. Over a number of years, and, as a matter of fact in 1969, the ability to convert from raster to lineal was really in its infancy. Most of the people who were doing that work were experiencing great difficulty either in processing time involved to do that conversion or in creating a large number of errors in the conversion. That was not acceptable, because that is the main reason for going to raster scanning, you can scan the data, pick up the information very cleanly and with very little degradation from the original. Since that time, a number of people have gone with a skeletonization type algorithm which thins down the raster data to a single element, and then the single elements can be strung together into a lineal format.

But the problem exists again, and I think this is the main point I want to get to, is that if we are going to scan lithocharts or color separation negatives with its symbolization such as railroad tracks with its tics, intermittent drains, and if you look at any map or chart of this area, almost every drain on there is an intermittent drain, that would at this time entail manual digitizing. So those problems I think still have to be attacked in the future in order for mass digitization to become a useful tool to most everyone.

Thank you. (Applause.)

DR. BOYLE: Thank you very much. I think Richard Clark is the next one down the line. Richard is from the Engineering Topographic Laboratory at Fort Belvoir.

MR. RICHARD CLARK: I am not sure whether I was selected as a representative of methodology that did not work or methodology that did work, since we have some of each. We at ETL became interested in raster processing along about 1967. About that era, XY digitizers were coming out, and everybody was trying them out and finding out that they did work but they were rather slow; a rather slow means of getting high density data into digital form. We thought there must be a faster way. We knew of some of the Canadian work through IBM with drum scanners, some work that I believe Bill Switzer is connected with. We awarded a contract to IBM to look into a drum scanner plotter for us. The plotter was tossed in because of commonality of hardware.

Our needs, as we saw them at the time, were more for digitizing planimetric type information than contour information, as we felt that the contouring problem was being taken care of more by other automatic means like the UNIMACE and automatic contouring programs. If I could have Vu-Graph No. 1. In 1972 IBM delivered a laboratory model scanner plotter which we used as a test bed to determine what would work, what wouldn't work, what we could do with raster data, and things of that nature. This device had a 24 by 30 inch format, and scanned in one mil, two mil, or four mil spot sizes. We determined later that four mil was a bit crude, but would pick up a goodly portion of the coarse line work, or I should say the low density line work. Two mils would pick up nearly everything. When you got into doing some actual contour scanning where the contours were very close to coalescing or where there was any other high density information, one mil spot size was necessary. Scan times typically were around 20 minutes for the four mil spot size, and double that, 40 minutes for the two mil, and 80 minutes for the one mil, which we considered was a fairly realistic time for getting that volume of information in.

Format-wise, we had two formats to select. One was a run-length coded format, which put out four data bytes per transition. The other was a pure binary form, which simply flooded data out, as you will see in Vu-Graph No. 2. The 19 by 22 inch format, which was typically our image area, and for a 250 spot per inch, which is the four mil resolution, you can see there are 26 million bits of information coming out. On the right are the number of reels of magnetic tape at 1600 BPI, with no compression--that is, one bit of information per bit on the tape. We have two-tenths of a reel of tape in this case. Further on down we hit the thousand lines or spots per inch; you can see we are starting to build up data in a hurry--418 million bits of information--and we are up to 1.6 reels of tape. Remember, this is 1600 BPI. If you jump to the bottom and look at a 50 by 70 inch format, which is the image size of the new DMA scanner, you can see the tremendous volume of information that is coming off that scanner. We reach over ten reels of tape if we have no compression. Well, of course, we will be using compression; run-length code will be employed since ten reels of tape becomes rather prohibitive to be carting around and storing.

The IBM scanner, just in passing, had several modes on it. As I said, it was also a plotter and plotted at the same resolutions, one mil, two mil and four mil. But, in addition, it had color scanning and gray shade capability. The color scanning capability used a two-path system, with a dichroic mirror to split the path essentially into the red and blue elements, and was found to be relatively unsatisfactory for discriminating colors. We also found that on the input end it was a bit difficult to actually encode in color. Here we are talking about inputs manuscripts that have hand-drawn center line information, with no symbolized information. It is one thing to do this with pen and ink, and it is another thing to do it with colors. We found it was a bit difficult to color encode, and especially to do it with colors that could be picked up reliably by the scanner. So, our use of the device has been almost exclusively for strictly black and white scanning.

I might point out that there is no magic cure-all in software that is going to make up for sloppy draftsmanship on the input document. If your hand happens to shake when you are drawing a road or stream or whatever, that is pretty much what is going to come out the other end, unless you have an editing device to go in and actually do some straightening at that point or putting in the proper curvature. If I could have Vu-Graph 3. This is just a quick overview of the process we are talking about. The raster scanner is on the left. Regardless of the computer doing the software work for you, most of the raster processing operations involve a thinning operation, (also called skeletonizing or cloud elimination), and, some kind of automatic editing to pick up line breaks, perhaps, and typically a vectorizing process. As Jay pointed out, it is not absolutely necessary to vectorize your data. You can go through the whole system and stay strictly in raster. It is quite fast to do it that way. But most users either for editing purposes or data base type work, want to have some form of vector output in there.

Could I have Vu-Graph 4 now. This represents data that was already scanned. You can see the staircase effect in some of the lines. This would be a proofing output. May I have the next Vu-Graph. This simply shows what the lines look like after the thinning process was accomplished by the software. We are down to one spot wide, whatever that spot happens to be. Next slide, please. Typically you run into places, such as the junction of this stream network, where there is a break in the data. Automatic editing can take care of small breaks like that. Next one, please. It has increased the information by one spot and caused continuity through that junction. Next slide. The vectorizing process, which is also called raster-to-vector conversion or linealization, creates some type of vector format from this data.

We are on the output end of things now, consisting of somewhere in the neighborhood of six or seven classes of data. Each one of these classes would have been a separate overlay or a separate data sheet going into the scanner, as it only handles one class of data at a time.

Next slide. We also have areas, in addition to straight line networks such as roads and streams. Now, areas, are very nicely handled in raster format. All you need to go in with is the outline of the area. It can be a relatively coarse scan such a four mil in this case. The draftsmanship of the lines does not have to be as critical as with roads and streams. The area is filled on an output process with whatever class or whatever symbol it is that you want. In this case I believe we have the orchard symbol in there. It does not really matter what the symbol is, it will fill these areas, and then, if desired, will suppress the border around the data.

May I have the next one. One passing comment on the raster output end. I will not dwell on that because another panel will be covering output, but with raster data you can also do some other tricks such as merging and suppressing of data. As I indicated, you can suppress the line, and you can merge all of your classes of data to make up one sheet, such as shown on one of the earlier Vu-Graphs with the various roads and railroads and so on. It is a very simple operation in raster to do that. If you want to suppress one class of data in favor of another, that is also very easily accomplished in raster. Software-wise, I will give you a quick sketch of the process we went through. We started out with some programs that ran on an IBM 1130, and we marked our progress into days of computing time per overlay. We came up the scale with some 360 programs, and we got our time down into hours of overlay. Later, very similar programs were run on the CDC 6400, and the time per overlay was down into minutes.

The handwriting on the wall all of the time seems to be that if you could afford a drum scanner, the big problem was what were you going to do with all that volume of data? We did not feel that sequential processors were going to cut the mustard, so to speak.

In 1974 we started some work through Goodyear with their associated array processor called the STARAN, as shown on this Vu-Graph. The STARAN works with 256 bit by 256 bit arrays. Because of its array architecture, the STARAN is ideally suited to raster processing. This was why we looked into processing on the STARAN. The STARAN has access to all data on a content addressable basis rather than strictly on a coordinate addressable basis, as you have with your sequential processors. You have operations going on in parallel, whether it be arithmetic or search or logical operations. This means you can acquire any data from memory in a single memory step without knowing its location. We processed quite a bit of data through the STARAN, enough to come up with some representative times and we also produced an output map called Lake Istokpoga. If I could have the next Vu-Graph. I show this because it represents the different classes of data that were processed. We started with 11 overlays, all of them hand drawn. As you will see, it is relatively sparse data. We processed the whole thing with four mil technology--four mil spot size, and four mil output spot size. The total STARAN time to process all of this information was 39 minutes. Of that, three and a half minutes was actual STARAN time. The rest was devoted to tape I.O. time, which, to me, was the first glimmer of light that raster processing really could be cost effective. We have another program that is being installed at ETL currently which will do essentially the same thing except it now works with two mil and one mil technology, which means now we can get into the finer data and can get rid of some of our coarse line work where the staircase effect from the raster processing shows up.

We have also found out some other interesting applications of the STARAN for processing raster data. One of them is line separation by line width. Here we are getting into a form of deciphering or decoding of symbolized data, where we have selected line work that was specifically drawn at a controlled line width. This shows the line drawing that we scanned in. This is one of the line weights--I have forgotten which one it is, I think perhaps the seven mil line--that was separated out from the rest of the data. Here the secret is to start with controlled line widths, not just plain hand drawn lines. I might mention here also that line width processing time is a function of the width of the line; since you are doing line thinning it will cost you so much for each iteration on the line thinning before you get down to unity width. So it behooves one to not have too coarse a line to thin. We can see various applications for this line width detection, because you can now go in and code various classes of data by line width. You can have perhaps, as they have here, road classes. Or, you could have three or four classes of contour lines which could be decoded in the software simply by the line width. We hope to be pursuing this further.

Even though we started out excluding contours from the raster process, we soon found out there was a good application--in fact, I think perhaps one of the biggest applications of raster processing--for digitizing some of these massive amounts of already existing contour plates that the various services and other organizations have. We are in the process of starting a contract with the STARAN people to write a program we are going to be calling Contragrid. This will essentially replace the operation going on at the DMA Topographic Center now, where they manually digitize contour sheets on a floating arm graphic recorder. Of course, you recognize that can be a massive number of lineal inches of data on a contour sheet. If I could have the last Vu-Graph. This would be a typical contour sheet that somebody has to sit down, (I believe shackled to the equipment), and manually digitize. We think this is a prime application for raster processing. We know that the data can be scanned in. You may have to use one mil spot size to pick up all of the fine line work or, more particularly, line spacing. We know that the numbers that appear in there can be recognized and then be deleted out.

The hard part with all of this is how do you associate the elevations? Because it is just a series of lines to the software until you put an elevation tag on it. The STARAN software will be doing a sizable amount of automatic elevation detection. Part of it will be done by going in with a list of the index contours at the borderlines. A good portion of the automatic processing can be done just based on that information. We are certainly going to need some interactive capability in there to pick up the elevations that cannot be done automatically. We may be able to use the actual numbers and do character recognition (some of that work was done earlier by IBM) to further augment the recognition process. The rest of the contouring program will be simply to break up this information into a uniform grid of elevations and store this for data base work.

I hear Ray's magic hook over here, so I will sum this up quickly. Feature tagging is another area that we want to get into, and this will be, as I see it now, predominantly based on the line width detection. One other area of a slightly different type scanning that we are getting into is with a laser plate maker. We have a contract with EOCOM Corporation to make a laser plate maker for the DMA Hydrographic Center. It will use a laser to scan along a curved platen. We have talked about flatbed digitizers, and we have talked about rotating drum digitizers. This application uses a stationary curved platen-type dgitizer.

The world around us is now becoming increasingly involved with raster processes of one kind or another. I still see the software as being the weak part of the link, but I think we are close to solving that part of it. As Professor Marble said yesterday, there are applications for raster and there are applications for XY digitizing, and it behooves one to pick the right one or else the operation may not be very cost effective. Thank you.

Dr. Boyle: Thank you very much. The next one is Bill Switzer.

Mr. WILLIAM SWITZER: Thank you, Ray. Good morning, ladies and gentlemen. First, let me thank you for the opportunity to come and talk to you about the application of an operational geographic information system. I would like you to note the name. It is a geographic information system. It is not a system for automated cartography. There has been some confusion in the last little while as to the name of the system as a result of a name change in our organization. It is the Canada Geographic Information System, and the name of the organization is the Canada Land Data Systems Division.

I am going to talk to you about an operational information system that is a solution, not necessarily the solution, to the problem of raster to vector or line segment data. This system makes use of an optical drum scanner developed by IBM, and delivered to us sometime in late 1967. The software has been fully operational since the beginning of the '70's. Currently we use two methods to get data into our data base. We make use of the drum scanner, about which I am going to talk further and blind hand digitizing a technique with which everyone is familiar.

As an aside, and partially in response to problems raised by an earlier speaker, I will briefly describe our recent acquisition of an interactive editing system from a commercial software house. The system is called AUTOMAP; we do have the source code. It is written in Fortran 5 and comes with a pre-processor to convert it to Fortran 4. It is written in a structured programming fashion and consequently it is very modular. The company that provided the package will train us to our heart's content and will support it, provided we have the dollars. But, it would have been naive of me to assume that they would let me see the software before I put my name on the dotted line.

We intend to use AUTOMAP's interactive editing capabilities to take data directly from the drum scanner have it edited by our technicians, and pass it on to the rest of the system.

AUTOMAP also provides intelligent digitizing, however, at this time we do not plan to use AUTOMAP in that fashion.

Currently we specially prepare our documents for scanning. We scribe them, not because of scanner requirements, but, because our software algorithms that analyze the raster data require a controlled line width. We hope to rewrite those algorithms in the near future so that we will be able to take data that has been prepared in the field, scan it, and using the AUTOMAP software, have our draftsmen edit the data. But these are future developments.

Today, we start with thematic data, maps of both the spaghetti and the classification or descriptive information, as our source document. The classification or descriptive data is converted to digitial format in a conventional way using key to cassette devices. The spaghetti or line information is scribed. The scribing tool produces a controlled line width. That document is put on the drum scanner, the output is on a nine-track magnetic tape. The scanner is run off-line, and the output goes to our CGIS software. Currently we generate not only our own data base, the image and descriptive data sets but in addition we can produce data in AUTOMAP format or in the INTERMAP format. INTERMAP, as some of you may know, is an interactive editing and digitizing system developed by Ray Boyle.

The drum scanner is several years old. It has a fixed hardware resolution of short one millimeter. The scanning time for a typical size document is about 15 minutes; the maximum scan size, 122 by 118 centimeters , black and white. The output is, off-line to a nine-track, 800 BPI, unlabeled magnetic tape. The volume of data for a typical size document is in excess of 40 million data points. Of course the problem is how to get rid of the excess data, at a reasonable cost and in a reasonable time frame. Averaged over 667 executions, the program that does the basic processing from raster to initial line segments costs slightly in excess of $20, and takes slightly less than 30 seconds of CPU time on a 370-168. I do not think that this is an excessive cost nor an excessive amount of time.

Since this is a mass digitization panel, the last foil will describe a project that we completed this summer on behalf of another federal government agency, Statistics Canada. We were asked to produce a data base for a significant area of Canada, approximately two and a half million square miles. We started with map sheets of varying scales. The system is capable of taking map sheets at various scales and processing them into a single coherent data base. But, for time and cost considerations we compiled the maps into slightly in excess of map sheets at the 1:250,000 and 1:500,000 scale.

The project took about six elapsed months and about 30 man months of effort. The costs were in the order of 60 to 70 cents per line inch. These cost figures are per true linear inch and are based on a sample of 12 maps from the 300. It is difficult to say if the sheets were typical . I believe the costs to be high

ie. the sample maps were typical. The average density of the 12 sheets was 841 inches.

That gives you a very, very brief introduction to a system or a solution to a problem. I will be pleased to answer any questions you may have on the project. Thank you.

DR. BOYLE: Thank you very much, Bill. He was also running the experimental work for my tests which I was doing with an experimental run on digitizing the 1:24,000 series for the Geological Survey, taking the separations which we pre-prepared by some of the photo mechanical work. Quite a bit of this was done at Menlo Park. Dick Zorker here was one of the people who was doing this work for me. We found that by doing a very small amount of image preparation we were able to make the whole process of digitizing and the conversion afterwards very much more efficient. Dean Edson has all the reports on this, and if anybody wants to follow up on that sort of experimental stage, no doubt they can. I was most impressed for my own purposes in the results that I did get.

If I could have Leonard Laub. His name is on the second one, for mass storage, but Xerox has also done quite a bit of work with the digitizing systems, so I have asked him to spend some time on this.

DR. LEONARD LAUB: Xerox, of course, is not immediately and visibly in the cartographic business, but Xerox clearly is in the business of handling documents or objects containing text, line drawings, graphs, the sorts of things which are used in business establishments and offices. That has proven to be motivation for an area of technology which seems to be quite germane to the immediate concerns, in that it is gradually being understood that however many trees you might want to plant, and however renewable a resource paper may be, even if you think you can get all the paper you might want -- storing it is another issue, getting to it is another issue, sending it from place to place is yet another issue -- so it is gradually becoming clear to Xerox and other companies in the document and business systems areas that some sort of electronic manipulation of the documents which are handled in business is appropriate. By manipulation I really mean everything that has to do with the document; its creation, whether it is typewritten text, line drawings, or even continuous tone images, half tones or colors. After the creation of the image you may want to store it locally; you may want to modify it; if it is words, you may want to do some word processing, for instance, reduce the average number of syllables in the words so it is more comprehensible to whomever, to your high executives.

After you have done all that you want to do locally with the document you may want to send it someplace else. In fact, you may want to send it many places simultaneously. You would like to have the people to whom you are sending it be able to access it today, tomorrow, next week, be able to get it either by its direct name or by some generic code, get it as part of a group. In other words, you want to be able to search over some data base using various types of keys in order to extract whatever document is of interest. Of course, in the midst of all of this you want to move vast quantities of stuff and you do not want to lose anything, nor to ignore the fact that people are very used to the good aspects of paper -- namely, that you can hold it and look at it and caress it, and also that it is capable of carrying rather a lot of visual information, at least of a subjective nature. It looks nice, typically. Good clean printing or nice reproduction of a drawing certainly looks pleasing, and the objective information may not be all that conveys the impression of value that a piece of paper has to its user. If it doesn't also look nice, if it is not crisp and sparkling looking, it may not please its user even though it conveys the same objective intent. Very few of us are totally objective. You will notice my ears are not pointed; I am not objective either. I have a great subjectivity, and I would hate to give up nice clean serif or sans-serif type faces for ASCII five-by-seven dot codes in reproduced text.

Now, this is not clearly agreed upon in the industry, to the extent that there is an industry of people doing electronic manipulation of documents, and, indeed, a lot of electronic document sending is now being done with a matrix type of printing. At Xerox the decision has been made for a variety of reasons that this is not good enough. Thus, when we consider scanners of the sort which you might want to take a document, the original, say, and send it into a system, or the scanners which you might use to take electronically transmitted or stored or retrieved or created document and get it out of the system onto paper in some hard or soft copy form -- soft copy being what you get when you just want to see, for editing or quick look purposes what is in that mass storage system and pull it up on a CRT -- in all cases we have taken our aesthetic inclination quite far. All of our scanners, hard and soft work at quite high resolution so that we can indeed reproduce all sorts of type faces. Suddenly all kinds of people in Xerox know what is Times Roman, what is Helvetica. They even know what a serif is. It is, of course, a good test to see whether the display is working well enough.

I come to you today not so much to give an advertisement for Xerox in the cartographic community, because this liaison is just really beginning, and we would like to improve it because we have the capability of responding to specific and non-corporate needs, as to tell you some of what we know about scanning of paper objects and transparencies. It so happens, for instance, that the need is incumbent upon us, if we want to reproduce various type faces of various sizes and do so almost as well as does good lithography, to scan with a spot no bigger than about two mils (about 50 micron). This, of course, is well understood by the people who make drum scanners for typographical purposes, the K. & S. Paul and Hell scanners and, of course, all the more recent ones. But it is also incumbent in the business world not to make users wait minutes and minutes. It is all very well to say that we prefer to have cleanly reproduced type faces, but it will not help us very much if it takes, say, 20 minutes to get a sheet of paper through. That is just not fair. It won't work. You can say it may take 20 minutes to find a piece of paper in the file cabinet, and it may sometimes take forever because you took it out last week and you did not put it back in or you put it in the wrong place and you'll never find it again. That is another problem.

It is much nicer if we can say that the new technology, which, of course, costs money, and, also of course, changes operating methods and requires acclimatization, at least in its performance aspects outdoes all the old technology. So, a very important aspect of work at Xerox on scanning has been speed combined with high·resolution. Our aim has been to produce scanners which can, for instance, move legal size documents covered with typescript logos, etc., resolved to two mils or better over their entire area, at a rate of two per second, into and out of a system. Now, we have to bear in mind that seconds and minutes are different things. The rates at which we scan, making scans of five or ten or fifteen thousand resolved spots across a page rapidly enough to scan that whole page in one half second, lead to data rates of several tens of megabits per second. Given the capability of digitizing at such rates, jobs which presently involve much tedium can be performed very quickly. From the base case of 500 milliseconds for an 8.5" x 11" page, time for scanning larger pages scales with area, leading to scan times of seconds for any likely cartographic sheet size. This is to be compared to the many minutes required by a typical drum scanner for digitization of standard size sheets, and shows about two orders of magnitude improvement in the rate at which images can be introduced to a computer system. The use of automatic sheet feeders permits this improvement to be practically realized when dealing with large numbers of images. Without such feeders, time consumed by manual insertion and removal of sheets can greatly exceed scan time.

So, speed that high may be more than many people need. Someone will ask about the enormous data rate; I will say two things with respect to that. One of them is that obviously we have to deal with it at Xerox. Our concerns have been met in part by dealing with a lot of special compression algorithms. Run-length encoding was a good point of departure, but we have gone past that into some more specialized, and, of course, some more proprietary techniques. Typically, with text or line drawings, we can compress somewhere between ten and twenty to one. The other aspect is that we felt forced, even with all the compression that we might be able to do, to investigate mass storage so as to accommodate the gigantic volumes of data that result when you start taking tens or hundreds of thousands of documents and storing them up. But mass storage is another issue, and I personally will be back to talk to you later in the morning about that. Right now I would like to describe some hardware, give you an idea how all this "gee whiz" stuff is built and a little bit of an idea of the practical or production environment in which it lives.

One device is intended to produce a repetative line scan with a red beam from a helium-neon laser. In order to deflect the beam we have to blow it up to a larger diameter and then bounce it against, as Ray Boyle pointed out that I should call it, a "multifaceted rotating mirror". We typically call this a polygon, but in this audience I know I'd better not. (Laughter). That scanning beam is then sent either against a sheet of paper or, if the device is an output scanner, against the xerographic belt or drum, the selenium photoreceptor, which is used to pick up images. That drum is then given its electrostatic treatment, covered with toner and the toner is transferred to plain paper. So, this sort of device is used as a printer. In fact, this type of device is very similar to the heart of the new Xerox 9700 printer which does indeed output legal size pages of two mil resolution, two per second.

It is appropriate to mention the modular characteristics of construction that we exploit in order to make these devices. Typically we accept the fact that our business machines are complex and that, no matter how well we might train the service personnel, we would rather that they did not have to come out too frequently and that, when they did, their jobs could be condensed. So, the difficult parts of the equipment are typically built into modules, and they are intended to be interchangeable with one another. The laser and beam shaping optics reside on a plate which can be removed from the main chassis and replaced in the field if necessary. In all these scanners, the main optical system produces a high-speed scan. The scanned line is being traversed every two or three ten-thousandths of a second. Then, a cross scanner is used to move that line across the page. So, at the rates of which I have been talking, the rates at which these machines typically work, that cross scan will take about half a second to cover a normal page. In this prototypical form, there is no document feed. In the more elaborate devices which are already coming into production, we have exploited our expertise in rapid paper motion. The basic scanner is thus built into a bigger machine which will feed paper quite rapidly and automatically.

These are samples of laser scanners, both for input and for output, which are beginning to become products not for cartography, but they are beginning to become products nonetheless. I guess the most directly useful thing I can say here is that the corporate development program, the usual multi-million dollar multi-hundred man year sort of thing which is aimed at satisfying what is perceived as a large scale corporate need, just because it happens to be very similar to the uses you have here may be indeed very beneficial to you. Further questions are, of course, welcome. Thank you. (Applause.)

DR.BOYLE: We are going to continue our panel discussion on mass digitizing. I am going to ask Dr. Kreifelts to give us a few minutes talk on their experiences in Germany on this matter.

DR. KREIFELTS: For the last three years we have run an experiment in Germany (ARLIP project at GMD) concerning automatic digitizing with raster scanners. I will give you a brief summary of the procedure we applied and some of the results. The starting point is a black and white map which is scanned on a large format drum scanner. We use an Optronics drum scanner which can take documents up to the size of 50 by 52 centimeters. Let me stress two points. One has already been mentioned this morning. The document has to be of good quality and high contrast, because what is lost during the scanning process is later on missing in the line file. With a low quality original one has to spend more time in manual error correction than one would otherwise have to do. The second point is that with our procedure, all lines on the map are treated alike, regardless of thickness and significance.

The result of the scanning is a binary image of the map, the 1-pixels representing line work and the 0-pixels, background. This binary image is then transformed by the

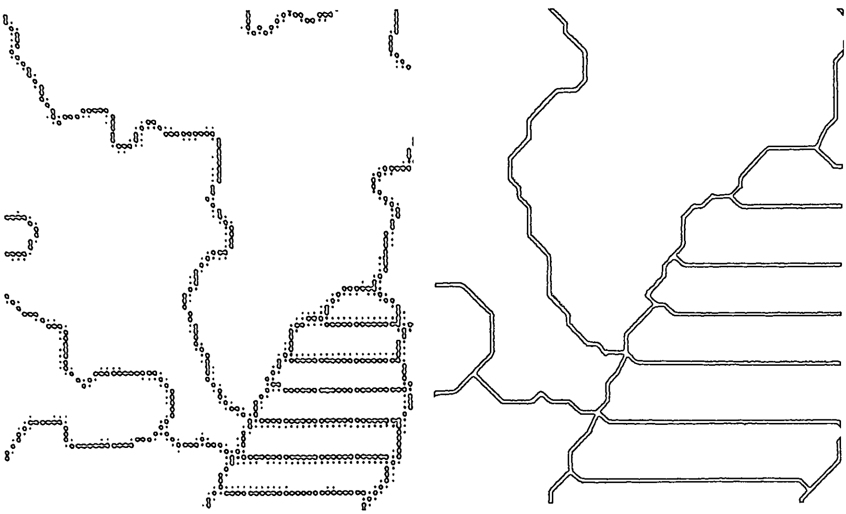


Fig.1 - Binary image, skeleton, and extracted lines.

raster-to-vector-conversion program to a line file consisting of strings of coordinates and a node file consisting of the coordinates of the nodes and references to the lines which meet in the respective nodes. This node file is very useful for constructing a polygon file from the line and node files, which is used in connection with, for instance, land use maps. The node file is also useful for detecting errors when digitizing contour maps. The technique we applied in the raster-to-vector-conversion program is the line thinning technique, which has also been mentioned this morning.

May I have the first Vu-Graph, please (fig.1). This shows the binary image of a map, in this case the municipality boundaries of Bavaria. The fat dots represent the skeleton. The skeletonization is the first step of the raster-to-vector-conversion. Hereafter the nodes are extracted, and then the lines are followed. May I have the next Vu-Graph (fig.1). This gives an impression of what the lines look like without any data compression.

I come now to the results. May I have the next slide, please (fig.2). This shows on which types of maps we have tried this program out, the size of the documents, the scanner step size, which is usually four mils, but occasionally can be two mils or one mil, the overall line length, which varies between 13 and 65 meters, and the number of lines and nodes encountered in the various maps, which is between roughly 1,000 and 16,000 lines.

May I have the next one (fig.3). This gives you some information about the program performance. It shows how much CPU time and how much core storage is used, and what the computer cost is for each linealization job. The test were run on a Siemens 4004/151 computer, which if compared to an IBM/360-50, has roughly twice the speed and the same instruction set. The core storage used is well below 100 kilobyte, and we think we can push it further down, below 64 kilobyte. We will try to implement the algorithm on our PDP 11/70. If you divide the dollars by the meters it boils down to between four and six cents per inch of digitized line. Of course this is only the running cost for the raster-to-vector-conversion. Thank you.

type of map	size [cm]	scanner step size [μ]	overall line length [m]	lines (nodes)
contour	28x48	50	62.60	5096
county boundary	40x43	100	13.00	984 (169)
community boundary	50x50	100	65.20	16414 (10500)
land use	50x46	100	28.60	1930 (1225)

Fig. 2 - Results of raster-to-vector-conversion.

type of map	overall line length [m]	CPU time [sec]	core storage [kbyte]	computer costs [US $]
contour	62.60	1017	93	110.20
county boundary	13.00	275	56	29.80
community boundary	65.20	1115	67	120.80
land use	28.60	393	59	42.60

Fig. 3 - Performance of raster-to-vector-conversion program.

DISCUSSION

DIGITAL HARDWARE, MASS DIGITIZATION

DR. BOYLE: Thank you very much. That is the end of our panel. I wish to mention the people that I would like to hear from in the audience. I would particularly mention Eocom. They are laser scanning and reproducing digital data directly onto printing plates. If anyone is here I would be pleased to hear a few words from them.

I would also ask if there is anyone from DEST. Unfortunately on this panel we have not had a representative of a different method of scanning using a "brush," "comb" or "broom" method.

Broomall is an example of one of the only groups of people doing service digitization by scanning. I think they should be commended for this; there is a great shortage of this in North America and I think there is a great need. I think that maybe some government departments are to blame for the fact that they keep this work much too closely to their chests and want it all in-house instead of setting up outside facilities which people at universities and others can use. I would like to see a much greater growth of these service bureau type of operations for scan digitizing and also for precision drafting, another area where there is great shortage and I feel a great need in this country.

The floor is now open to questions.

MR. MITCH MODELESKI: Mitch Modeleski, ESRI. Ray, this is directed to you. Do you know any operations that have used rasterization to produce a clean DIME file.

DR. BOYLE: Use raster data to produce a clean . . ?

MR. MODELESKI: DIME file.

DR. BOYLE: DIME file. No, I am sorry, I do not. If Duane Marble is here he might be able to tell you, or if a representative of his group is here they could answer that. I am sorry, I cannot.

MR. TOM WAUGH: Tom Waugh, University of Edinburgh. I believe it was Tom Peucker at AUTO CARTO I, when faced with presentations like this, said, "Well, we're not really talking about hardware, we're talking about big ware." (Laughter).

That prompted a university colleague near me, when he saw the ETL description, to say, "If you gave one percent of that to the universities," I should imagine it gave Jon Leverenz a corporate heart attack to look at some of those costs. Two of the speakers actually gave costs, but it seems to me that those costs in fact were running costs. They were not set up costs of buying the equipment, setting up the software. When one looks at the ETL setup, the STARAN and all the rest of it, one wonders how many maps would have to be generated to cover that initial cost. Could someone from ETL or any of the other speakers respond to that question?

MR. CLARK: That is a very good question. I do not have the figures at my disposal on how many maps it takes to amortize the costs of all the equipment we are talking about. We are in research and development -- not using that as an excuse, but in research and development we are more interested in developing the methodology and then determining whether it is cost effective enough to go on into production or semi-production mode. But there is certainly a sizable outlay of cash involved in any computer system. The STARAN computer system probably, a million and a half dollars is a conservative figure for the cost of that. It is not being used strictly for automated cartography but also on other projects, and that is an important difference in the STARAN over some of your other sequential processors where you suddenly find yourself totally dedicated to processing just raster data because of the time involved. The software projects are developmental. The costs vary all over the place. The drum scanners; the cost of developing a drum scanner I do not think is too important right now.

We had about half a million dollars into the IBM drum scanner, but the cost to duplicate that certainly is much lower. I have not had any recent estimates, but at one time after the development contract, about $150,000 was a going figure to reproduce the piece of equipment we had.

MR. ARAZI: I want to drive a very strong point home. As system engineers with experience in graphics, the SCI-TEX Corporation regards the cartography problem to be just one more graphic problem, to the extent you are dealing only with graphic features of those maps. If your purpose in life is to take a collection of all separations or producibles that you have, put them into digital data bank in order to update them in the future or to go from one scale to another or to start meshing together LANDSAT imagery with topographic imagery, for those kinds of work, those are mostly graphic enterprises. I am not talking about rectifying pictures or photogrammetry or all those other activities. To the extent that you want to stay in the graphic realm, we happen to have already installed, as I told you, '76 equipment that have a fixed firm price and do a very simple act: They will scan a piece of opaque or transparent imagery which can be a colored thing such as a printed map, or it will take less effort if it is a separated sheet, permit you to view it and edit it and correct and manipulate it on an interactive display, which is a color television type display, later output it into a 72 by 40 inch film, all for a fixed price of $400,000. Then you have to pay $28,000 a year for maintenance and software support. Those are very firm prices all over the world. So this gives you a number on how much it costs to have a digital in and out system for handling cartography.

DR. BOYLE: I think I could add to that, that if you are only interested in digitizing units, then about half of that.

MR. ARAZI: Yes. If you do not need our laser plotter, if you do not need the output device, and you just have need for the digital data, the scanner alone is in the $200,000 bracket. The scanner with the editing station and with all the computers that go with it is $325,000.

DR. BOYLE: That figure was given, and also the figure of the run costs, say, on a 360 and 370 computer. These costs were given in the talks. I think they are fairly realistic. They proved out to me this summer, anyway. Does anyone else wish to comment?

MR. DICK STOVER: Dick Stover with Broomall Industries. I would like to say a word about our system, which has been developed by private industry. It involves about eight years of development. Our approach has been to work with existing interactive systems, since there has been quite a growth of those. To add to a system of this type is about a $200,000 cost for our kind of system. Now, we do raster scanning, software, vectorization, and we then interactively edit the data. The cost of three to four hundred thousand will cover an entire system with all capabilities. As I say, $200,000 would be a system to add to an interactive graphic system. Now, we are doing scanning with a paint brush arrangement such as was mentioned here earlier, and we will have a presentation in the workshop across the way at 11:30 and one again at 4:00, which includes some work on an interactive tube with this kind of system. Thank you.

DR. BOYLE: Thank you. I think to go back to Tom Waugh's question. When people ask me about this I never recommend that they should buy these systems themselves unless they can keep them in very full operation. This is why I want to see a growth of service bureaus.

MR. KEN SMITH: Ken Smith, Bell Northern Research, Ottawa, Canada.

I have two questions I will pose to anyone on the panel. The first question is: Has anyone done much work on the automatic recognition of characters on the items that they are scanning? The other question is: What percentage of the time does the cleanup and the editing phase of the work have to the scanning process.

MR. CLARK: I can address the first part. We had some work done by IBM about six or seven years ago on character recognition. The work there indicated that the potential for doing character recognition, and here we were shooting for strictly hand drawn characters, looking for, first of all, the recognition rates on totally unconstrained handwriting, and then adding constraints until we got the recognition rate up to some reasonable level. Constraints in this case were simply to box the character in as far as the total height and the width, and then starting special features on the character such as slashing an "0," a serif on a "7," that type of thing. We reached recognition rates with about three sample sets, somewhere in the neighborhood of 92 to 96 percent recognition.

The biggest problem here was in getting the draftsmen to be consistent in the data set. As long as the same draftsman was drawing the characters on the same day, why, you could get fairly high recognition rates. But to do it over a long-term basis, the recognition would drop. We have not pursued that any further, except that some of that work is being utilized in our Goodyear program on the STARAN. We perhaps will be using those techniques in the Contragrid program that I referred to in picking off the numbers that exist on contour sheets where that should be a much easier problem, since most of them were very highly constrained characters when they were drawn.

DR. BOYLE: Is there anyone else on the second question?

MR. PALERMO: The second question about the amount of editing that has to be done. I think it was pointed out by a couple of people that the amount of editing that you have to do is directly dependent on the quality that goes into your system. If you have a high quality black and white positive and you just want an image of your data, then the amount of editing is very little. If you have a multicolored graphic and you have to deal with things such as mixing of colors, and/or color shading, then you have to start doing a great deal more editing. The old adage "garbage in, garbage out" is going to happen everywhere if you have a very poor manuscript. Any editing that would basically have to be done would have to be for a special case, your case, and what type of graphic you are doing and what input system you have. As a general question, I do not think we can really answer that, because we do not know. Depending on what inputs you have and what type of editing you are doing -- the amount of editing would have to be looked at from that point of view.

MR. BAUMANN: To go one step further there. The amount of editing which is required on some of the newer methods of linealization -- namely, those such as Broomall is doing, and the skeletonization routines being performed at other places in industry or in government, produce very good outputs which require very little editing. Again, as Joe mentioned, though, that input is very critical.

MR. ARAZI: From our recent experiments, if you start with a manuscript of good quality and you want it digitized -- say, for example, a topographic map, and topographic maps are, as far as we are concerned, the most difficult maps to handle, if you work with manuscripts you only have to spend about an hour per sheet scanning and verifying it and filing it. An hour per color sheet.

If you work with printed maps, if you work with a map that somebody brought you from Japan, a topographic map, and you would like to digitize it, and you do not have the reproducibles, the scanning is again about an hour, but then you have to spend anywhere from five minutes to one hour per square inch fixing it up, correcting it. It is a learning curve process. It has to do with what they call process color printing or multicolor tint printing and how many colors are in use.

The map that we projected in the early part of my presentation took in the vicinity of half an hour per square inch the first time around for an operator, someone who never dealt with cartography before. This can be further reduced.

MR. CLARK: One more point, Ken. If you drop me a line at ETL I would be glad to send you a report on that character recognition study.

DR. BOYLE: I would like to make a point about editing. One of the reasons I so like automatic scan digitizing is that I have very, very little correction to do. The data is almost perfect and anything that is not perfect could generally be dealt with entirely automatically. However, you have, of course, pure "spaghetti" coming from your device and you have to do labelling. This is sometimes called "editing" but is different. We are now looking at methods of reducing the amount of this labelling work appreciably -- for example, on the contours, only interactively label the index contours and then automatically label the intermediates. On the estimates I was doing on the standard one to

24,000 topographic sheets this summer, it looked as if we had about two hours of interactive labelling to do for all separations for one map.

MR. SMITH: I am interested in capturing not so much topographical maps as large scale urban maps with utility information, and I am looking towards being able to produce a complete data base from which I can do networking concepts. As I see the automatic scanning so far, we have a long way to go yet before you can tell me the size of pipe and what fits together and characteristics of wire and what-not.

MR. BRUCE OPITZ: I am from the Hydrographic Center of the Defense Mapping Agency. We will be getting a scanner that RADC is developing, the color scanner. To our best estimate, total editing time including editing that is not involved in scanner problems but which is involved in changes we have to make to the product for a final output, totally in raster is about five to one, five hours of edit time to each hour of scanning is about our best estimate, five to six to one. I have a question involved in one of the costs I heard. It was from the Canadian experiment where it was 60 cents per lineal inch. Is that what I understood for center line digital data?

MR. SWITZER: For what?

MR. OPITZ: For center line digital data. That seems to me from my experience to be kind of a high cost. I envisaged that the cost would be quite a bit less than that. That is on the order of what we are achieving with our manual lineal systems.

MR. SWITZER: That is the total cost of taking the data from its map format into its digital data base -- total cost, not just the cost for resolving the raster to scan. That includes a 25 percent overhead to cover managerial costs that are not directly recorded.

The data that I have indicates that the cost for the 12 maps that I picked out at random is 55.46 cents per inch. Again, I added a factor to that to cover the additional overhead.

FROM THE FLOOR: Yes. As I say, that seems to be on the order of what the lineal digitizing is currently costing, manual total cost, about that much per inch.

DR. BOYLE: I find it difficult to understand this high figure. It is entirely different from the cost of the work you did for me. We are talking about a hundred to one difference.

MR. SWITZER: If you take the numbers I gave you and you multiply them by the number of lineal inches I think there are in the total maps processed, then the cost for the entire project works out to be about three times the figure I have in front of me, so I suspect that the 12 maps chosen were not necessarily representative of the total, but it does at least give a feel for what the costs per inch are.

DR. BOYLE: I just do not understand it. I agree with Bruce Opitz, and I do not understand that figure.

MR. SWITZER: As I say, the costs come from our internal accounting system that records the computer costs and the manpower effort that goes into it.

DR. BOYLE: Are there any other questions?

MR. MIKE GREEN: Mike Green, University of Wisconsin. It is my impression from the talks that I have heard today that mostly what you are talking about is an efficient means of digitizing line drawing type of things. I wonder what equipment the panel is familiar with with digitizing formats that have gray tones associated with them, like, for instance, aerial photographs.

DR. BOYLE: This is really not part of the discussion of this meeting, but perhaps somebody would like to answer that.

MR. PALERMO: There are some raster systems that are around basically made for imagery. One that comes to mind immediately is known as the laser image processing system. That was produced by CBS Labs before they sold out. That system is basically capable of imagery, digitization in 256 levels of gray and down to on the order of two or so micrometer spots. There is also a transmissive system which works with a laser, single channel, and transmits through the imagery to acquire the total gray shade range of the imagery. With reflective systems you have the problem of going through the emulsion twice and basically doubling the density level. So you are limited on most of those systems to densities that are on the order of one. Transmissive systems are working on scanning up to two and better. That is the only real system that I have seen that has been in the field for a long time that will output a digital tape in 256 shades of gray from an image.

MR. GREEN: Could I ask the gentleman from Xerox if they have done any work along these lines?

DR. LAUB: Thank you for prompting me. I was about to tell you anyway. (Laughter). The output process that Xerox likes to use is Xerography, and that is not a very linear process, so output of continuous tone images almost has to be half tones. Based on that we have to have very, very good schemas, even somewhat better than the ones we have been talking about so that we can make proper variation in size of half tone dots from a screen that might be as fine as 250 per inch. We are doing that sort of thing. We are also scanning in half tone documents and are scanning in true continuous tone devices and electronically generating half tone dots for the output. So all of this is part of the work. This includes color work. Branching off from the color work there has been some multispectral scanning. Actually, it is sort of active scanning which is directed out into the world, and has even been employed in Southeast Asian countries. So, yes, such work is going on. It is also being done at Kodak, and I suspect elsewhere.

MR. JON LEVERENZ: Someone mentioned four to six cents per lineal inch. What does that refer to? Define one, please.

DR. KREIFELTS: That is the computer cost for the raster to vector conversion. You put the scanner tape in and get a disk file out with the lines, and the cost of the job comes to about four to six cents per inch line work.

MR. LEVERENZ: Mr. Switzer, you said 60 to 70. How does this four to six --

MR. SWITZER: The 60 to 70 is the total cost. It is not just the raster to vector --

MR. LEVERENZ: Yes. But how does the four to six cents compare with the --

MR. SWITZER: Costs are very, very difficult to pin down as well. In our case we buy time from a commercial service bureau. So we pay the commercial service rates. If we had in-house systems conceivably the costs that I quoted would be lower, possibly they would be higher as well. So that has an influence on it. I cannot tell you, as I do not have the figures in front of me, as to the actual cost per lineal inch from the raster to the vector. All I can give you is the average cost of running a particular program that does that over the past three or four months.

DR. BOYLE: I think that the 50 to 60 includes Bill Switzer's salary -- (Laughter).

MR. HARRISON: My name is Harrison, Australian Army Survey. I would like to ask Dr. Laub if he could indicate whether he is working in the analog or digital domain, and if he is working in the analog domain, what he sees as the real problems in converting that to digital format.

DR. LAUB: Luckily I can avoid the second question, because the answer to the first is that we are in the digital domain. Later on in the mass storage session I am going to be talking about some analog storage which winds up looking quasi-digital -- that is certainly analog-made-discrete. The half tones I was just mentioning in reference to another question are also analog-made-discrete. But we have decided as a corporate direction to do everything digitally. This lets us format any type of scan together with any type of computer data combined with voice, combined with telemetry, combined with God knows what, and also, to permit expedient access to it, search over it, whatever you might like. We have accepted the ideas that computers will be managing all of these data bases and transactions, so everything will be digital. (Amen).

MR. ARAZI: I think a remark well worth noting is that every color magazine you look at, every commercial catalog you look at, about 40 percent of the color photographs that are reproduced in processed colors are these days being separated by digital scanners. There are in the United States some 600 or 800 color separation scanners made by three or four companies which have the data converted into digital form for a variety of internal purposes, and are reproducing extremely high quality graphics in processed color. So, the digits are clicking along. They may not go in and out in the computers -- the data may be kept internally. But the business of taking pictorial data of the highest quality, digitizing it, and outputting it again in a color separated form is here, is now. Those people are working sometimes at 5,000 lines per inch scanning, and scanning color transparencies with any density range which is obtained by photographers. So, this state of the art has been around for six, seven years now.

DR. BOYLE: Are there any other questions?

DR. ROBERT AANGEENBRUG: I am a little bit concerned about your figure of five hours editing per one hour, say, acquisition. Did I hear that correctly, that there is a great deal of editing time or whatever you call it "annotation," I suppose, Ray . . .

DR. BOYLE: That is the same figure that I said. I said two hours when the digitizing time is about 20 minutes.

DR. AANGEENBRUG: I wonder if some of the panelists could comment on what quality personnel or what kind of training or what kind of preparation could go on, say, either in your institution or in ours to providing you with employees that would know how to do this facet. Because you alluded to the learning curve in terms of edit process. What kind of skills are you looking for? It is fairly significant to us in higher education.

MR. ARAZI: As far as our SCI-TEX experience, most of the people that are employed in operating our graphic design systems are not people with higher education. It is basically a technician job. If their editing has to make up for faults in the incoming document -- I will take the extreme case: You are requested to scan a printed map. Your problem in life is to find faults in the graphics which emanate from overprinting of colors or from an array of facts that have to do with screening in the original, and to prepare the data, to go through the data to straighten it up prior to digitizing and/or conversion to vector, it is not a job for an academically trained personnel, it is a job for the graphic technician. The same kind of people who are doing scribing, and it is actually a more interesting occupation for the very same kind of people.

If the job is to label, to identify features, that is more of a cartographic job, and that is more in the two hours per scan type category. But it is a straight cartographic job except that we give them a very, very fast graphic unit. You have your 12 layers together on a color television screen. If you annotate on one layer, you immediately update on all the other layers. You have some ground survey data that you want to update, you want to change the nomenclature on something, you can do it on all layers together. So, basically, you have a very high power pantograph with a color television screen display, and you do your usual cartographic work. But, here again, you know the kind of person that does that.

MR. SWITZER: Maybe I can comment on the one example that I used for volume processing. Looking at the information I have in front of me, it says that what we term manual error correction, which is the correction of the cartographic data, if I can call it that, just correction of the spaghetti where we join lines together, et cetera, took approximately one half hour of five and a half hours manual effort. So that the average effort was five and a half hours for each of the maps, and approximately one half hour of it was devoted to MEC. Now, in addition, of course, there is some other editing in the sense of capturing the classification data, so there is some editing that goes on at that stage, but this suggests it is considerably less than 50 percent.

DR. BOYLE: Are there any other questions? We will now close down this panel with very great thanks to the members of this panel, and we will start on the mass storage panel, if they will come to the rostrum, please. (Applause).

DIGITAL HARDWARE: MASS STORAGE

DR. BOYLE: I think that we are now ready to start on the other most exciting area that goes with mass digitizing. As you saw from some of the figures of the amount of magnetic tape necessary to store a map, you realize that you have to get into other means of storage. I am not a great believer in high density tapes for the future, but one of the great breakthroughs that has occurred, and I do say occurred, on an experimental and a very advanced experimental stage, is the method of drawing dots by laser beams onto disks from which you can then extract the data and use it in the ordinary way. The density of packing that you can have will no doubt come out in the discussions. If it needs any prodding I will drop in a few figures myself. We should have had John Davis from the National Security Agency, but maybe he has been tied down somewhere and muzzled, so we do not have him today. He was to have been the introducer. He has very wide knowledge of the work that different people are doing, and I am sorry he is not here. Maybe he will turn up this afternoon, in which case he will have the opportunity to speak.

I am going to ask Mr. Jamberdino from Rome Air Development Center, who has a fairly general knowledge of the different people again in the area, to speak a little longer than the others and speak first to give you more of the general background of this type of storage.

To me, it looks as if it is a vital necessity for cartography; it is a very good thing that it came along. In cartography we are riding on the backs of people who have developed these things for other aspects, partly for home video television work, partly for people like Xerox who want to store their data in digital form. These things have not been primarily developed for cartography. I think that we have to realize that in many of these very expensive developments, cartography just does not have the funds. We are very lucky that these developments have occurred. What we want to do is learn from them now, learn the capabilities, learn how we can use them, what are the difficulties, how we can interface to the sort of thing we want, how we can perhaps twist their arms a little to change the design to be a little more suitable for our applications. So, Mr. Jamberdino, would you now come up, please, and introduce this work.

HIGH DENSITY RECORDING FOR MASS STORAGE

MR. A . JAMBERDINO: Dr. Boyle, thank you for that introduction. As you have just mentioned this is the first time that I have heard that I was to present an overview of MASS STORAGE TECHNOLOGY DEVELOPMENTS, so if I stumble a little there will be two reasons for it. First of all, I'll be recovering from the shock; secondly I may seem to dwell an inordinate amount of time on this subject because last night I called my wife and she said we are going to get another 12 to 18 inches of snow today. Topped with the three feet of snow that is already on the ground right now, I feel pretty happy to be here. So, if I linger awhile, I'm sure you will know the reason why.

To begin with, Dr. Boyle, I would like to congratulate you on assembling such a distinguished collection of speakers. I am sure that with the people represented here, the audience will receive a complete, comprehensive update on where todays technology is for Mass Storage. So rather than pre-empt their presentations, I will concentrate on our (RADC's) involvement in the mass storage data handling business.

At Rome Air Development Center, we are somewhat proud of the fact that we have what we call a full spectrum laboratory. Under this charter we exploit technology developments from initial concepts, through exploratory development, advanced development, engineering development, and even to a pre-production type of a model. With that, we have access to all technology bases -- at least we feel we do -- with all the technology bases pertaining to a particular subject. Therefore the numbers you see on my viewgraphs will reflect our interests in not only today's problems but those we postulate as future requirements. So when I start talking about one gigabit recorders, it obviously does not reflect todays commercial data handling needs but what we in the Military feel are going to be the data rates of the future.

In addressing the problems of super wide band recording technologies we were forced to address meaningful record times and therefore extremely high packing densities. By addressing these extremes, I believe that we have generated some alternative approaches that will be applicable to your particular needs, that is the mass storage needs unique to the catographic community.

May I have the first Viewgraph please. (Fig 1) We sort of walked into the mass digitization or mass storage arena through the backdoor. The scenario represented here typifies a classic C^3 (Command, Control, Communications) operational situation, where information is transmitted either by land lines, airborne, or satellite sensors

C^3 TACTICAL EXPLOITATION

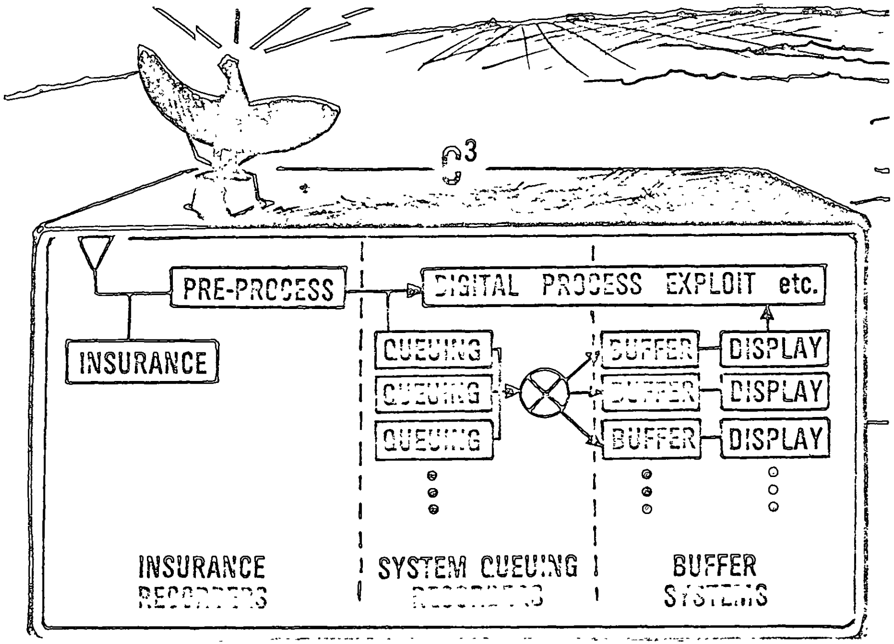


FIG 1

to a central exploitation facility. The information there will be collated, analyzed and assembled into a single product for the Tactical Commander. Our mission then is to provide the necessary technology base to accommodate the data handling or data management tools to accomplish this horrendous task. To accomplish this task we at RADC have generated three basic system configurations. The terminologies used are our own and do not necessarily reflect the Air Force's nomenclature. Consider first what we call the insurance recorder; that is a device where, all of the information that is transmitted has to be recorded or somehow stored in the event, and, hopefully this will not occur, that the system, the major exploitation system, becomes inoperative. And, as we know in computer technology today, that certainly doesn't happen. In the event it does occur however, we had to consider the necessary technology to provide an insurance recorder or insurance devices. In doing so, with the crazy numbers, I mentioned -- multi-megabits per second, gigabits per second, etc., data rates coupled with a scenerio of a 24-hour workday, where information is being transmitted in either a continuous mode or at discrete intervals at very high data rates, totally different approaches to conventional data storage had to be addressed. Typical daily volumes of 10^{12} bits demanded alternative recording technologies namely the holographic recording approach, and the high density magnetic recording devices that I will discuss later.

The next class of devices we call the "queuing" devices. Here the purpose of this device is to get the appropriate amount of information to the appropriate analyst, to the appropriate display system or what have you, so he can do the exploitation that is necessary for a finalized product. To accommodate this scenario we at RADC generated technology investigations into basically emulating the IBM computer transport. Typically, investigations towards start-stop times on the order of milliseconds, shuttling speeds on the order of a thousand of inches per second, on 2 inch instrumentation recorders, and duty cycles commensurate with 24-hour workdays, so as to allow a computer programmer the environment he is used to when handling a volume of data at this magnitude were initiated. The emphasis here then is to provide the data handling tools necessary to accommodate a number of analysts, or photo interpreters in a timely manner. The requirement here calls for medium access times (seconds), instant replay, and the capacity to accommodate very large volumes of data. Again, I will defer our solutions to this problem to later.

Finally, the third category of development, we have named the "Buffer Device". For lack of a better term the "Frame Buffer". In this scenerio consider a frame of say the "LANDSAT" sensor. Each frame contains 10^9 - 10^{10} bits. A PI must interrogate each frame, isolate the area of interest, perform any editing, if required, then produce the processed output for further exploitation. This then calls for a much faster access, primarily on-line type of access with the flexibility of access to any data bit in milliseconds, and ideally on an erasable, reusable medium. Here we are addressing the alternatives of laser and electron beam disks. Both offer the data rate and volumes that we have postulated.

Next Viewgraph please. (Fig 2) That sort of sets the stage on the crazy numbers that I have postulated earlier. This viewgraph summarizes the various approaches that we have exploited. I would like to direct your attention to the last column of this viewgraph. Here I have tabulated on the top line what is available today in the state of the art. The bottom line depicts future predictions for that technology. To relate these numbers to what I think you are more familiar with, take, for example, the chart that Dick Clark mentioned this morning where he needs eight to ten IBM compatible 1600 bits per inch tapes to accommodate, say, one chart, or one map. The technologies represented here can accommodate on the order of 3700 maps or charts on just one single roll of tape, film or disk.

As you go down the column in the magnetic longitudinal technology, we have just delivered a 270 megabit per second recorder, which relates to a packing density yielding 2×10^{11} total bits of storage on one reel of tape. With this development we also had to address bit error rates. For the kind of readout fidelity required, error correction and detection schemes were exploited, and typical error rates of 1×10^{-6} were achieved. This machine however, is consistently achieving a BER in excess of 1×10^{-7}, and depending on the sophistication of the error correction scheme 1×10^{10} BER is achievable. Going down the chart, magnetic rotary technology has successfully demonstrated storage capacities on one roll of 3×10^{11}, and BER's of 1×10^{-6}, on similar 14-inch diameter, two-inch wide tape.

Going further down to the disk technologies, both electron beam and laser beam disk approaches are being exploited. I won't dwell on these capabilities because I'm sure that both Dr Laub and Mr Zernike will explain them in more detail. Typical storage capabilities of 5×10^{10} and 10^{11} bits have been predicted with single channel rates approaching 300 megabits per second. Again, the people on the panel, I am sure will be more specific and give more detail. Finally still another approach we are pursuing for gigabit type applications is the holographic recording approach on moving film. Here again, using this as a potential storage device, we postulate these kinds of numbers: 10^{11} - 10^{12} bits total stor-

SUMMARY OF POTENTIAL CAPABILITIES

	BANDWIDTH INPUT/OUTPUT	PACKING DENSITY BITS/CM^2	TOTAL BIT CAPACITY
MAGNETIC LONGITUDINAL	270 MBPS 600 MBPS	1.4×10^8 4.3×10^8	2×10^{11} 7×10^{11}
MAGNETIC ROTARY	20 MBPS 60 MBPS	6.4×10^6 6.4×10^6	1.2×10^{11} 9.5×10^{11}
DISK (ELECTRON BEAM)	- 200 MBPS	- 1.3×10^7	- 1×10^{10} Per Disk
Disk (LASER)	- 200 MBPS	- 6.8×10^7	- 5×10^{10}
LASER HOLOGRAPHIC	900 MBPS 3 GBPS	1.5×10^6 3.0×10^6	1.9×10^{10} 1.8×10^{12}

FIG 2

age on a 14 inch reel. We have also demonstrated a consistent 1×10^{-6} - 1×10^{-8} bit error rates using this approach. In terms of ranking the magnetic longitudinal and rotary head are available now; electron beam and laser disk, and laser holographic approaches are in the experimental model stages of development. We are sponsoring these technologies and all have potential of meeting tomorrows data handling needs.

Let us go on to the next Viewgraph. (Fig 3) These are photographs of the equipments that I have discussed. The center photograph as I mentioned before we have just delivered, the 270 MBPS longitudinal recorder is currently operational and we are accommodating 2×10^{11} bits storage capacity per reel with a bit error rate of 1×10^{-7}.

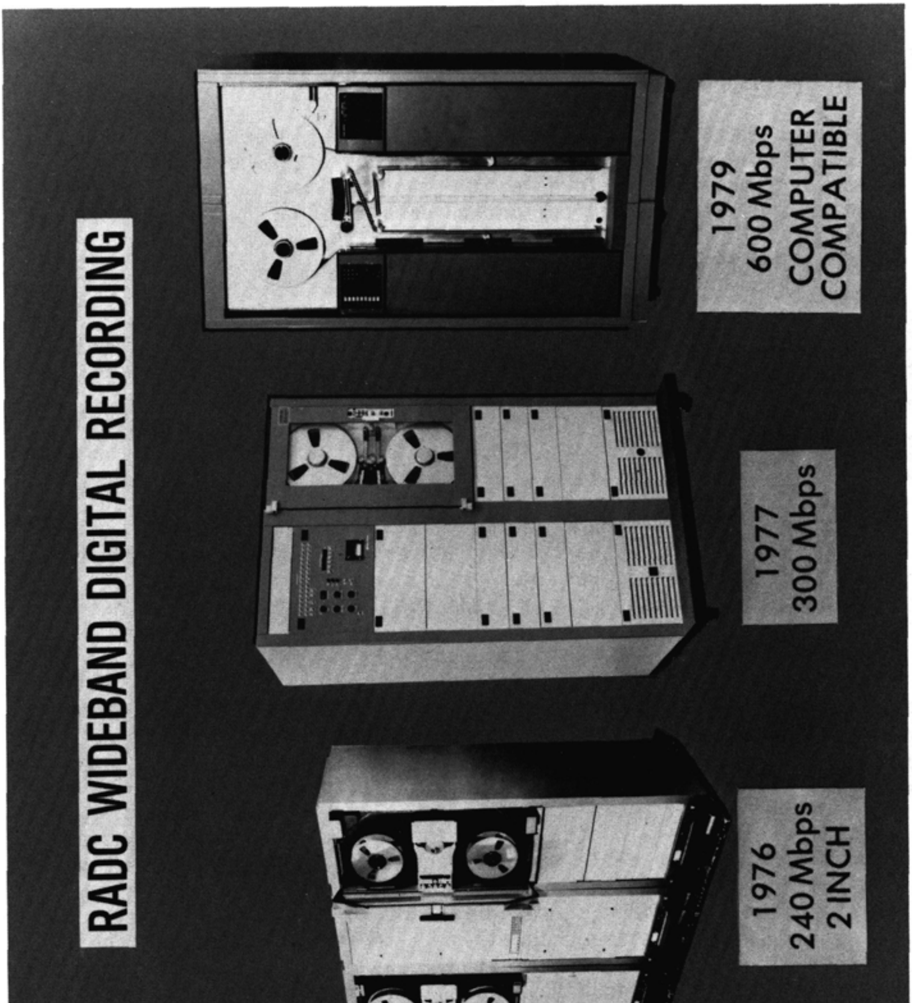
Again, the data rate represented here does not apply to today's commercial rates but if one thinks for a minute the time it would take to present say the "LANDSAT" image to a PI - 10^9 bits would require approximately 17 minutes at todays computer I/O rates. I believe that data transfer rate then will become a very important parameter in the very near future.

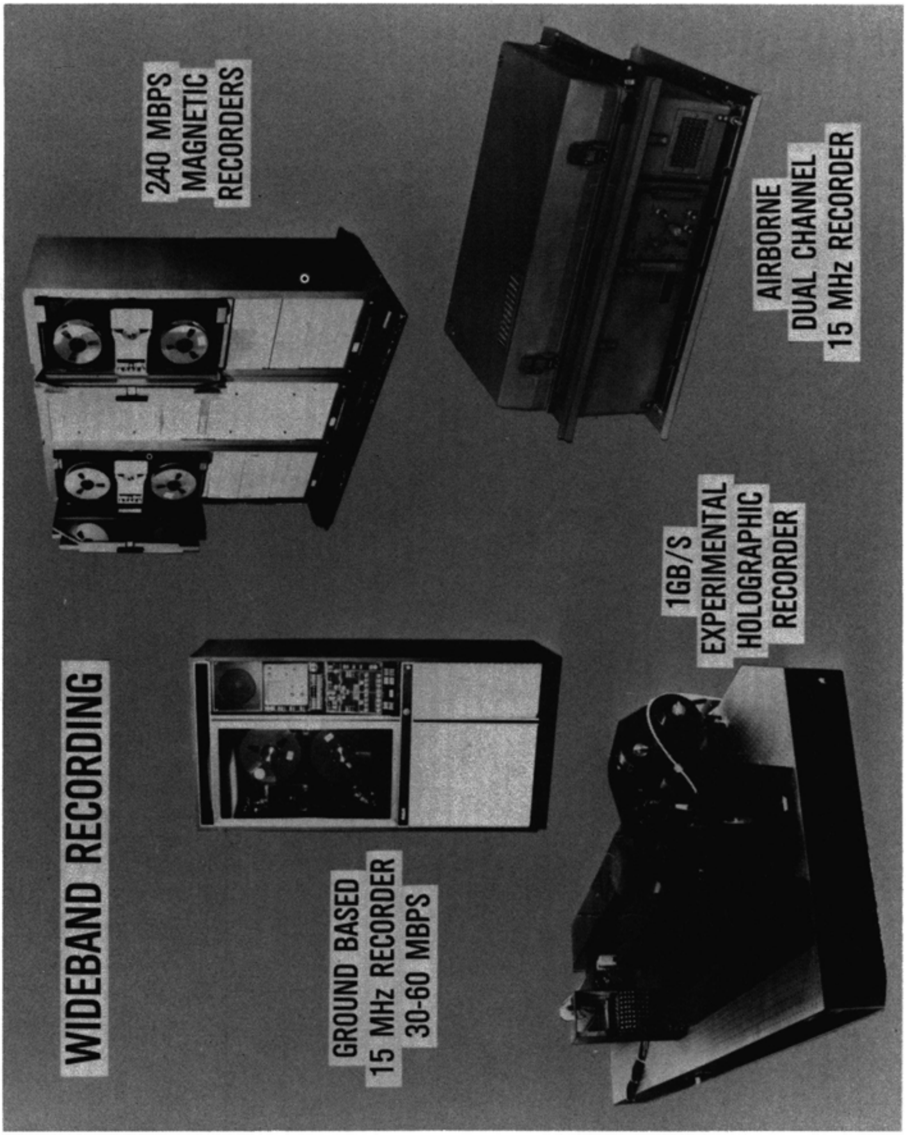
Figure 4 (upper left). This a is a picture of the rotary head device we developed. Here again, this approach has been exploited in the early '70's. Today we are achieving something like 30 and 60 megabit data rates, but, more important, the packing density is equivalent to, and slightly exceeds the longitudinal approachs.

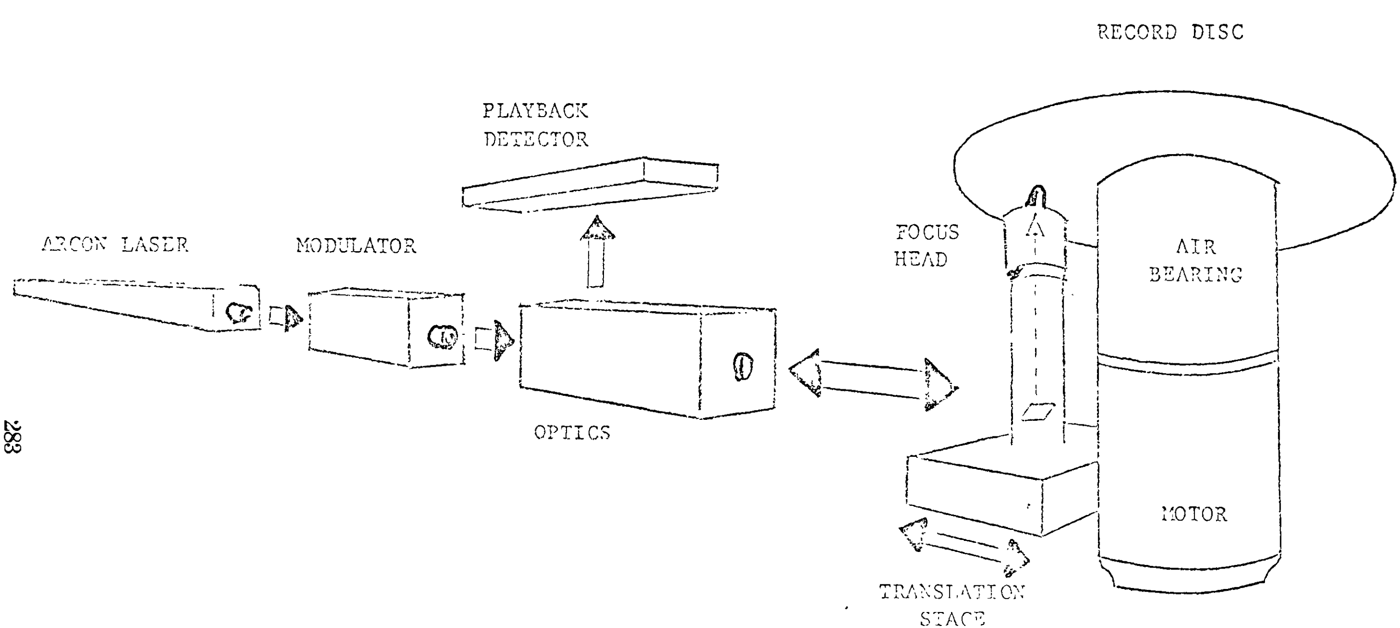
Figure 4 (lower left). This is a photograph of the holographic recorder currently under development. We are using high resolution silver halide as the recording material (35MM and 70MM). We have demonstrated input output rates in excess of 700 megabits per second and bit error rates of 1×10^{-6} and 1×10^{-8}. Total capacities for this device are 10^{11} - 10^{12} bits on a 14 inch reel.

Figure 5. This is a photograph of the RADC developed HRMR, Human Readable Machine Readable mass storage device. We are presently evaluating its ultimate capability. Here we have a flexibility of recording on microfiche, three different formats. One format contains 3×10^7 bits storage on a single three by five microfiche. Another alternative would be textual data in terms of pages of written texts, and then finally a third, graphic data, all three computer generated. The total storage capacity on this device right now is about 10^{11} bits, and access time, I think, is on the order of 15 seconds.

Next Viewgraph. (Fig 6) This is an artists conception of an optical video disk. Again, the panel members will go into much more


RADC WIDEBAND DIGITAL RECORDING
1976
240 Mbps
2 INCH
1977
300 Mbps
1979
600 Mbps
COMPUTER
COMPATIBLE


WIDEBAND RECORDING
GROUND BASED
15 MHz RECORDER
30-60 MBPS
240 MBPS
MAGNETIC
RECORDERS
1GB/S
EXPERIMENTAL
HOLOGRAPHIC
RECORDER
AIRBORNE
DUAL CHANNEL
15 MHz RECORDER



OPTICAL VIDEO DISC RECORDER

FIG 6

detail, so I will just brush over it lightly. We have become very excited about the potential that this device offers. As you will see this approach offers the potential of 10^{10} - 10^{11} bits of storage on a 1/4" x 12" disk, access times of milliseconds and cost predictions of $10 per disk. Literally a computer programmer's dream. Again, I won't dwell on this subject but as you can see the disk resembles a home phonograph record.

When considering an electron beam disk approach data rates, spot sizes and access times are similar to those of the laser disk approach. We are addressing a disk format on silicon dioxide target, and we are looking at the following characteristics. 100-400 MBPS, 10^{11} bits storage, 50 msec access times. You should be aware that when using an electron beam approach, all components would have to be bottled into a vacuum type environment.

Now let me try to summarize what I have just said. In our opinion, high density recording technology offers a cost effective solution to the mass data storage problem. Several approaches are available: magnetic (longitudinal and rotary head); electron beam (silver halide and S_iO_2), laser beam conventional and holographic (silver halide and thermoplastic). Each technique has its advantages and its shortcomings. Magnetic recording technology is rapidly approaching its packing density limitation and has very questionable archival characteristics. It is however, reusable and is the most utilized, understood and versatile approach available today. Electron beam technology offers orders of magnitude improvements in packing density as well as bandwidth, plus the advantages of reusability (S_iO_2) and archivability (silver halide). It is, however, component size limited and requires a vacuum environment. Laser beam technology, in both conventional and holographic formats offers orders of magnitude in storage benefits and is archival in nature, however, it requires post-processing support. The fundamental technology having been developed, it now becomes a matter of time and dollars to continue the engineering development to fulfill specific requirements.

Thank you, Dr Boyle.

DR. BOYLE: We will probably ask you to come back. We now have about 25 minutes, and I am going to ask a pair of manufacturers now to speak, but try not to duplicate things. They are working in unison on this, Leonard Laub from Xerox and Frits Zernike from Philips, will be talking to you about the techniques of producing these discs and the type of hardware operations. First of all, Leonard Laub will tell you the first part of the story, and then Frits will tell you the second part. Would you like to start off?

DR. LEONARD LAUB: Here again, as with scanning, the use of disc storage for data is a piggyback phenomenon. This is perhaps an even more elaborate one than the business of scanning, because the origins of this technology in its present form do not even start with a company like Xerox, which has fairly clean and objective needs for data storage and can quantify them in terms that amount to stacks of paper and number of dollars saved. They go back to the much more subjective and, at least in some people's thoughts, larger type of market having to do with home entertainment. I used to work with Zenith Radio Corporation, and, of course, Frits works for part of the great Philips organization. Those two companies as well as several others around the world had decided that it would be a good idea to provide people with players for television records, something very much analogous to a phonograph. You put in a record, push a button and the recorded program becomes visible on your television set. You hook it up to the antenna terminals, the nice idea being in the United States that this would be something new to sell for the manufacturers such as Zenith who had already put a color television set in every conceivable home.

In Europe the justification was a little bit different, in that the government-operated broadcasting is typically so "good for you" and so restricted in its accessibility that people do not get as much television as presumably they want. Video players would enable them to buy their television programming to see when they want, even programs which are not "good for you". These are all possible market-building aspects and may someday be explored. I regret to say that at the moment, even though the technology of the home video disc player is very well in hand in a number of companies, up to the point of nice product engineering, the market perception on the part of the manufacturers is a little bit hazy. They are not even sure whether, even at the impressively low manufacturing cost numbers they can achieve, this will be something that the world really wants. So, as a really low cost consumer device the home video disc player may be a bit in coming. However, parts of the technology which went into the home video player are forthcoming. They are forthcoming either as specialized types of video player or, in the context of today's concerns, data players and, finally, data recorder-player devices. I would like to introduce to you some of the origins of this to give you a feel for what it is that is common, and then we can get to the more specific aspects of what is happening, and Frits will tell you about the more recent work.

What I am going to describe to you is a hopeful glimpse of the future. Here is a view of what could be a typical scene in a school, and, if you change the roles of the people somewhat, a typical scene in a home sometime in the not too distant future: A young lady is being instructed by a combination of live instructor, and material, curriculum, guidance, testing or other material which is on a video disc. The video disc rereads its material through a television set to which it is connected.

Now, this typed player, known generically as an institutional player, has the property that it can be operated just as a program source, which means that you can put in a disc, push a button and sit back for the next half-hour while the program unreels, but is also capable of being controlled entirely by a computer, either a micro-processor or, by tie-line, some gigantic computer. In that role it can serve as a local mass storage device, local resource or library for an educational operation which is controlled by the computer, an interactive education approach in which students are shown material and then are tested, and on the basis of the testing and on questions that the students may ask. The computer decides where to go next on the disc. Instead of going to the very next section which is, say, English II, it will instead go to the remedial section on how to spell a word or what are these funny squiggles called letters, whatever type of remediation is called for. Or, if no remediation is called for and the second section is not needed because the student already knows it, the computer will zip over to the third section. This exploits the idea of random access on the disc and is, of course, one of the properties that everyone who uses disc-type storage likes. Now, here is a disc: This particular example is probably the simplest sort of optical disk. It is a sheet of vinyl plastic about six mils or 150 microns thick which has been embossed with a pattern of circular tracks. That whole pattern is pressed on to the disc, not in a line-at-a-time or spot-at-a-time fashion, but simultaneously over the whole area by shoving that piece of plastic into a steam-heated press and letting it sit there for about 15 seconds.

Now, that is a very rapid type of information transfer, when you consider that the disc contains a half-hour of TV program. In more objective terms, assuming that the content of the TV program can be described in objective terms, this is a transfer rate of something on the order of 10^9 to 10^{10} bits per second. It takes 15 seconds to duplicate this whole thing. I might point out that this ultra-simple flexible transparent disc costs only about a quarter to make. Even the much more elaborate types of discs which protect the data much better and work in more sophisticated players, some of which Frits Zernike will mention, are still likely not to cost their manufacturer more than a dollar in volumes of maybe a few thousand. Now, this is just as true whether what is recorded on these discs is picture or data. Now, what do we mean recording? What is actually on the disc. The disc contains, in the video case, a spiral track. The spiral track is probed by a light spot which comes in from a microscope objective suspended over the disc, and then typically the disc spins and moves back and forth under the objective, or the objective moves back and forth over the disc.

That radial motion provides, if you wish it, a rapid access. On the disc, there is a time scale that goes round in a circle, so that the supposed one dimension of time is actually made to cover a two-dimensional area. And, as is the case with all other discs, radial motion enables you to get coarse time positioning, while the tangential motion obtained just by waiting for the disc to come around gives you fine time positioning. So, if you do not want to start at the beginning, if you want to get right to, say, one specific frame of video, or, if this is data, one bit of data, you do not have to, say, unreel a thousand feet of tape to get to it, you just go to the right radial location on the disc and wait some milliseconds for the right azimuthal location on the disc to come around. This is the sort of thing which comes out of the video disc when you send its signal into the right sort of decoder, and that into a TV set. But there are no little pictures on the video disc; all there is is an array of little marks. The tracks that I was mentioning contain marks which are about six-tenths of a micron across, and about one or 1.2 micron from one to the next.

At this, they are not as densely packed as they might be. In fact, this video disc technology is based on an arbitrary attempt to place a half-hour of video onto a disk; the density potential of this type of storage is much higher.

Now, where is the video? For one thing, there is no area marked out -- I am talking about tracks. In fact, one turn of the spiral, one rotation of the disc is what encodes one frame of video. Remember that a television image is actually made up of a bunch of scan lines. Anybody with access to a television set -- and that is a fairly large sample of the population -- can see these scan lines anytime he likes. The TV process works by taking a two-dimensional image and scanning it and making a one-dimensional signal out of it So, in the case of the video disc, that one-dimensional signal is encoded along a track. The method of encoding is something similar to what is used in video tape. It is a frequency modulation type of encoding in which no attempt is made to preserve the gray scale by levels, by depths of recording. Instead, what you are doing is making a mark and then making a space and then another mark. The duration of this mark and the duration of this space both contain information.

I want to trot out a pet peeve of mine, and that is the jumbling of the words "digital" and "binary". Here is a wonderful example of a system which is binary: Either you are in a mark or you are not in a mark, two states in terms of depth of depression or of presence or absence of mark. But the duration of this mark is continuously variable. An analog signal in this case is being recorded; it has no discrete levels. Mark boundaries are not located only at fixed clock positions. In the case of video recording the differences are subtle. But, let me assure you, each of these marks is of a different length, and the center-to-center distance from mark to mark is also different from one to the next. This is a binary system, it is not digital. However, it is quite possible to make the marks unitary, to make each mark like the next. That leads to a very conservative form of data recording, conservative in the sense that each of these well-defined marks has the job of carrying only one bit. But, it so happens that you can make about 10^{11} marks on the surface of one disc of about 30 or 35 centimeters diameter, about 12 to 14 inches. That means that even if you use this very conservative type of data recording scheme you can pack about 10^{11} bits on a disc. One you have done it, either by some master recording or by some local recording -- these techniques I will mention later, and Frits will have much more to say -- you can then replicate it.

The economic basis of these video discs for home presentation is the idea that once you have made a recording on the surface, that you can copy it with surface-pressing methods, such as embossing molding or casting, similar to the method of production of phonograph records. That is why the cost of replication is so low, and that is why it is so fast to replicate: it is because you are copying a surface all at once. It is different, for instance, from copying a film or a tape, in which you must run through the entire length of the film or tape each time you want to make a copy.

Once you have the surface with the marks on it, in order to get the information out, the principle that is employed is to make, let us call it here, an "optical stylus", a small spot of light. "Small" depends on who is doing it and for what purpose, but typically the diameter of the spot of light in the plane where it is well focused will be somewhere between three-quarters of a micron and one-quarter of a micron, quite a compact spot. Because of the nice property of photons that you can put a lot of them in a place (This is different, by the way, from electrons; just a practical point, that you can concentrate light almost arbitrarily, whereas there are strict limits to the concentration of an electron beam), you can put a lot of pep into this small spot. Reading is not a particularly hard job; even a fairly faint light, such as a one or two milliwatt laser, suffices to make a bright enough spot to read the signal. In recording, depending on the materials and rates, lasers of five or ten or twenty milliwatts frequently are sufficient to enable you to make an "optical stylus" capable of making readable marks at a rate of five or ten million per second. But, at any rate, we are using light spots as though they were styli.

Now, this gives rise immediately to several nice things. One of them is that the only thing which is touching the information-bearing surface is a spot of light. When we are reading, all we have to do is make sure that we do not turn up the reading laser so high as to start melting or otherwise deforming the surface. All of these thermal effects have a very well-defined threshold. Staying below it means that you can read the same area again and again and again and nothing restrictive happens. The information is quite unaffected by reading. The other is that there is no problem in filling in most of the volume between the lens and the information-bearing surface with some transparent but solid stuff, such as a plastic or glass cover which can be as much as a millimeter thick. What this means is that the surface actually exposed to the world -- to the fingerprints, the dust, whatever -- is way, way out of focus relative to the surface on which the information is being recorded. If you use, say, a millimeter thick cover, the cross-section of the light at the entrance surface is a couple of millimeters across. That means that, except for really big globs of dirt, the light beam doing the reading does not know there is dirt or even fine scratches on that external surface. The information is thus quite nicely protected; you can now seal this inside layer away from atmospheric pollution and other nasty things. So, those are some of the nice things about using light.

Now, in order to get the densities that are called for, in order, for instance, to put tracks one micron or one and a half microns apart, it is not necessary to build a super-precise machine. I have, and many other people have gone through the exercise of buying the air bearings, the granite tables and the various other devices which are necessary to make a rotating spindle which wobbles by less than one micron -- it is a very hard job. It is the kind of thing that gives a good old-time engineer a lot of pleasure. I am not old enough to be old-time and am not an engineer, but rather a physicist. I have, however, learned from some very potent engineers that a practical technique which does a better job than even the most solid and most expensive type of stable table is to take any old spindle, maybe a $40 synchronous motor with Class 3 ball bearings that wobbles a great deal, and chase after the wobbling that spindle introduces by use of servos. Now, place a disc on this spindle. Every time it goes around, it has probably moved in and out, in the case of video discs, probably 100 or 150 microns, which is 100 or 150 times the track-to-track spacing. It is doing this perhaps thirty times each second.

Luckily, another thing we can do with light is to steer it. In the optical system is a mirror against which the light beam bounces. This mirror is tipped according to a servo loop which decides whether the spot has gone off to one side or the other of the track. The result is that even though the disc is moving like so, with the servo loop closed, the spot stays in the track -- not off as is shown here -- and moves exactly the same way the disc does. So, we make up for the imprecision of the machine with a servo loop. We take a wobble that is 100 times or maybe even 300 or 500 times greater than our tolerance and crunch it back to essentially nothing. The same thing has to be done out of that plane, in that the discs are typically very wavy, in the sense that the plane which is to be read, whether it is on the surface or buried inside the disk structure, does not stand still vertically to the half micron or so precision that is called for by the depth of focus of this tiny spot; it moves up and down tens or even sometimes hundreds of microns.

So, we put the lens in a voice-coil type device, have it dance up and down, again in response to a servo loop, and voilà, we have what looks like an extremely precise machine, even though it is cheap and simple and light and not really very precise at all. We do this by having recorded the disc in such a way that is has guidance information on it in the form of the tracks. Once those tracks are there, it is possible for the servo loops to acquire them, chase after them, and track them very, very nicely, no matter how rapidly the disc moves around.

Now, I have been discussing the case of light going through a transparent disk. It is equally possible, and many people find it advantageous, to have the light bounce off a disk whose information-bearing surface is reflective. One process that is used in the Philips consumer video disk is to make the disk itself a rather thick transparent object, say, one or 1.1 millimeter thick, of something like acrylic plastic, have the little marks made on the far side, cover those marks with metal and then smear a little lacquer or other goo over the back so that fingers and other scratching instruments coming in from the back cannot do any damage. Handling of the disc only makes scratches on a surface which is, again, out of focus compared to the reading layer. So, this type of disc actually produces a very pretty picture even when badly handled. I personally have made some grievous thumbprints, fingerprints, even noseprints, on discs skidded them across the floor, and so forth, and they look quite nasty afterwards, but the reproduced picture looks excellent. You can do everything short of bending the disks in half or really deeply scoring them with, say, a screwdriver, and the picture is substantially unaffected. Now, in error rate terms, this means that the raw error rate of the disks is typically better than 10^{-4}, and if care is taken it can be as good as 10^{-6}. That error rate is stable despite storage and despite usage. This is a very important matter, because all the clever error correction codes in the world may not help you if storage or usage degrades the information over a period of time.

In the consumer type of video disc, the marks are depressions, pressed into the surface in the active molding, casting or embossing process. The point here is that it is easy to make mass produced discs if they are copied by a surface replication method. Optically, these little depressions act like dark areas, and a complete optical equivalent to them is openings in a continuous metal film; I think Frits will have something to say about that. The point here is that while a lot of people, particularly the people in this room, are interested in central maintenance of some sort of archives and widespread low-cost distribution of it, and so would want to use this sort of video player technology with a mass replication just as it is, a lot of other people, and certainly Xerox is among those, want to do local recording of information with the same speed and flexibility as the playing is done. For those people, instead of surface relief, instead of dimples or bumps, it seems a better idea to make marks in the form of, say, openings in a metal film or some other thing which you can produce directly with a focused laser spot.

Now, typically, in the laboratory production of master disks for video recording, rather bulky and heavy duty equipment is used, with the idea that here, cost is no object; you do not have to perform marvels of engineering, you just build a solid machine and do the job. So this machine has a lens in a rather beefy type of focus servo -- that lens is looking down on this metalized surface -- and as the disk spins the surface is being marked very precisely by a focused beam of light which comes down through the lens and is turned on and off by a light modulator, a shutter of sorts. That is what produces the marks. The disk spins continuously but the light beam is not always on, so you get sort of a Morse code pattern on the surface of the disc. This type of recorder is the one which is used to make, as I say, master records for mass replication. But, a lot of laboratories, so many -- well, not all will stand up and be named -- but many laboratories are working on technology of using the servos in the player, using the idea that the player is a good device for following a pre-established track with a light spot and keeping it in focus, keeping on that track, and turning the players into recorders, retaining the small package. A typical machine may be about a half meter across, about 18 inches or so, and about six inches high. A disc cartridge about 13 inches wide goes in through this slot. This is an example of a machine which is essentially equally happy being a recorder or a player. The only substantial difference is that in its recording mode it has a more powerful laser and light modulator inside, compared to the player, which uses a continous beam of rather low power.

Players of this type now exist. Thompson-CSF, for instance, will be selling machines of this sort during the early part of '78, and within a month or so some people in the U. S. will be lucky enough to take delivery of one of these. I may even take delivery of one of them if I can persuade some people in New York. As video players they will be quite useful. But machines of not significantly greater size than this will become available as recorders, recorders which offer high data rate, into the tens of megabits per second, high storage density and rapid random access (tens of milliseconds or, at worst, hundreds of milliseconds access, as people now get with magnetic discs, and, of course, for the same reasons.) So this is likely to be more than just an archiving device, more than just a giant bucket or bathtub into which to throw your gigabits and terabits and whatever -- there are some new prefixes and I have not gotten them all straight for 10^{18} and whatever. Some people, I hear, want 10^{21} bits; that is a DMA-bit. (Laughter.) However many you have, it is not going necessarily to be true that you put them all in a format which is dense and cheap, but which is awkward. That may very well be appropriate for some main archive, but I think you will find more and more that there will be the type of flexibility now associated with the 10^7, 10^8, 10^9 bit level -- it is going to be associated instead with the 10^{11}, 10^{12} and maybe even to the 10^{13} and 10^{14} bit level, the sort of flexibility associated with cartridge discs which are loaded by unskilled operators, queried or written by computer and accessed very, very quickly.

The concept of packaging the disc is one which is under active exploration. Various people have various needs for protection. In the Thomson player it has begun to be approached on the basis, not of making the disc itself intrinsically rugged, but of putting it in a cartridge. I just want to show you some detail of that. The package that goes in the slot in the other machine has a tray which contains the thin flexible disc previously described. That tray locks into a box, into a sleeve, as Thomson call it. You then shove the whole works into the player. The player retains the drawer, grabs the disc, lifts it up and spins it for playing purposes. When it is done, it drops the disc back into the drawer, and then you take the sleeve and shove it back into the player; the whole locked package comes out, and so human hands never touch the disk. This is the loading and unloading sequence. This type of packaging is, of course, only one of many that have been thought of. You might say in general this area of exploitation is just beginning to be well defined. It is with the aid of some people from, for instance, RADC who are in touch with specific needs that questions of how much protection and how expensive a package are finally being addressed in some rational way.

I hope that I have been able to give you some feeling for the potential of this technology in image and data storage and retrieval; it is definitely forthcoming. Thank you. (Applause).

Dr. RAY BOYLE: Frits Zernike from Philips will be continuing on the second part of the description of hardware, another hardware manufacturer, continuing from where Leonard Laub discussed his part this morning. They have gotten together, so there hopefully is no overlap. I have great pleasure in asking Frits to come on and continue what I felt was a very interesting description of the work by Leonard Laub this morning.

MR. FRITS ZERNIKE: Thank you. We heard a lot now about analog disks. I would like to talk a little bit more about the kind of thing that I am involved in, which is strictly digital disks, and digital very much in the way in which Len Laub this morning said he would not like to consider digital disks: we have either a hole or not a hole, and every hole we have is a bit. I will go into that a little more in detail, because it is not quite that simple, a little later. But, basically, it is a hole or not a hole. The difference between our system and what I would like to call the consumer video disk system, is that in the video disk you can spend a great deal of money making a master-making machine and a process which can make thousands and millions of disks, which you can then buy for a few dollars. Of course, if you buy it for a few dollars that means that somebody makes it for a quarter. But you can do that because you spend a lot of time making the master. We are looking at a rather different application, which is the application in which you make only one recording of your data, so you have a completely different kind of machine that you have to do that with.

Let us look at those differences just a little bit. In analog TV; as I said, you spend a great deal of money on the master-making machine. The master-making machine then makes the record very much in the same way as a phonograph record is made, it is essentially an embossing method. But the more basic difference is that you are not really all that concerned with the number of errors in your disk, because the TV system always has a number of so-called flywheel circuits. If you look at, for example, the way you people see me standing here, obviously if there were a red dot behind me all of a sudden on this wall or a blue dot on this red wall, you would know that that blue dot should not be there, so you can do a certain amount of error correction, so to say, in the machine itself. When you do digital data recording you do not want to do that, because usually the redundancy of the data has already been eliminated, and you want every bit that you can get.

Now, the machine that we are working on, and Len Laub was working on a similar thing, and there are more people doing it, is what we like to call a DRAW machine, a direct read after write machine. That means that we have a machine on which we record -- we do not have to develop-- we record and we can read that recording immediately after. When I say immediately after, I really mean we read it a few microseconds after we have written it. What we can do is this; we can record a string of data, we can store that string of data in a buffer. We can read it back out again as soon as we have recorded it. If it is not right, we say, well, let us record it once again. The only penalty that we pay for that is that we cannot use the full raw data capacity of the disk. So, in order not to have to rewrite too very, very often, we also have a certain amount of error coding in our system. What we have done at this moment, and it is still very much an experimental type of thing, is we have decided that we have an error correction system, which can correct three errors, but we have decided that as soon as we see more than two errors on our read-back system, we say this is no good, let us write it once again. With the data we have now it looks like we would pay for that in an overhead of maybe 80 percent. In other words, we have to have 1.8 times as much raw data capacity as the actual data capacity which you as the user would see.

What we basically do to do this recording is very simple. As we call it, we burn holes in a thin metal layer, which is on top of either a plastic or glass disk, or actually I should say it is on the bottom of it because, as Len pointed out this morning, we read it through the plastic or through the glass; again so that any kind of handling that you do will not show up. You can indeed put a big thumbprint on the glass and you will never see that in the data. That also means that we can make what we call an air sandwich. We put two of these disks back to back and seal them, so the actual information is completely sealed. We can seal it in a clean room, and when it gets to you it is still clean because it is sealed. The question that many people ask me is: yes, but you burn the metal out of the hole, and doesn't that metal splatter all over the place? Well, that is not what happens. What really does happen? I have an inkling, but I am not about to tell you, because I am not that sure of it, and nobody else knows what is going on yet. But it is not really splattering the metal out. Something else is happening, and there is basically no material being evaporated from the layer. So that is a problem we do not have.

Let me tell you some of the advantages and maybe disadvantages of this system. As I said already, one of these advantages is the DRAW capability, which gives us a possibility of correcting the errors as they happen, so to say. Another advantage which we think is definitely there, but we do not know yet because we have not been in the business that long, is that we think that the thing is archival. Basically, if you compare a magnetic tape, which could lose its direction of magnetization-and does, to a hole in a metal sheet, then I think you will all agree with me that that hole in the metal sheet is more durable than the magnetic disk. But whether it is really archival for seven or ten years, well, maybe in seven or ten years I will be able to tell you that, because that is really what it does take, when you come right down to it. There is another advantage which some people may call a disadvantage, and that is that the material is not erasable. Once you burnt that hole, that hole is there. Now, to some people that is a disadvantage. To other people this is an advantage. Think, for example, what would happen if a big company were to present its books to the IRS written in pencil. It would never go. I think in recent history we have a couple of examples of erasability which we would just as soon not have had. Another thing that we think is maybe an advantage, but I can well understand that maybe to this audience it would be a disadvantage, is that we make only one at a time. We make one record because, basically, the people who are making that record want only that one. They want to have it as an archival record of their computer program or all their company records or whatever it is; they do not want any more than one. They do not want to pay for it, either. Our machine as it stands now can indeed only make one. But, as Dr. Boyle said this morning, depending on -- I am also here, of course, somewhat doing a little bit of market research -- if there are a lot people who say, "Gee, we would really like to have a machine that could make a hundred or a thousand," which, mind you in the thinking of the video disk people, is still a very small number, there is basically no reason why one couldn't develop a machine that could make a hundred or a thousand disks rather cheaply.

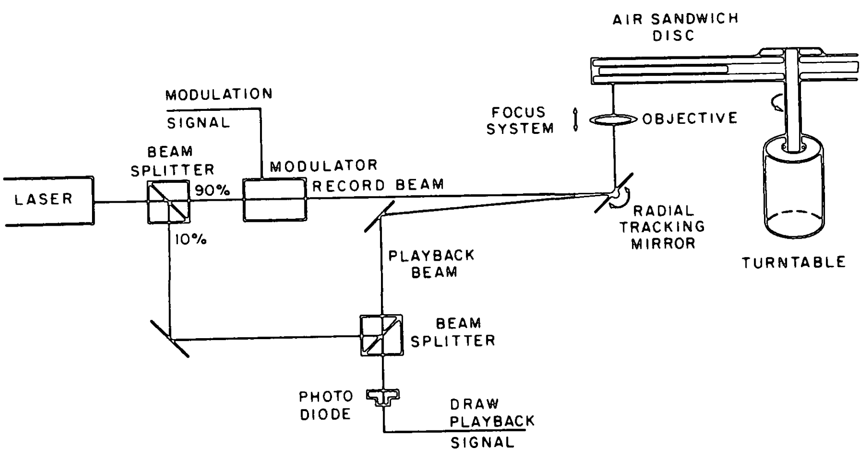


Fig. 1

Let me just show two pictures. Figure 1 is basically a schematic diagram of a machine which we now have a few of. As you can see, there is a turntable and an air sandwich disk. You can see there actually two disks with appropriate spacers in between. Actually, the space here is shown much larger than it is in reality. It is only about a hundred microns in reality. The objective comes up from the bottom. That just happens to be better from a practical point of view. Here again is the radial tracking mirror that Len talked about this morning. Actually, what we have found is that in our recording machines we would just as soon not have this mirror; we would just as soon go with an air bearing turntable. Air bearings turn out to be not all that expensive, so you can make a very good solid machine.

The particular machine that we are talking about uses a helium neon laser. We split off part of the beam here and put it back in at a small angle. That beam, this lower beam, is our read beam which, when it comes to the disk, is just a few hundred microns behind the writing beam, and reads the signal that we have just written. You can see the other beam, the more powerful beam here, has a modulator in it, a modulator which just essentially turns the beam on or off, and that burns the holes in the disk, which make the pit. Now, when you say you burn holes, most people sort of think of holes the size of a small drill. Of course that is not the case. The holes that we are talking about are on the order of a micron or less than a micron in size. On the particular machine we are now working on, and have been using for quite some time, we have been a little lazy; we get on the order 1.5×10^{10} bits per 30 centimeter diameter disk. We could get more if we wanted to, but we wanted to start with this. The holes that we have or actually the bit density that we have is about 30 million per square centimeter, or 200 million per square inch. That is because we still have a fairly large track pitch of two microns, and holes of about a micron.

What does a disk like that look like? Well, the only other slide I would like to show you is Figure 2. Here you can see a very much experimental machine. This is the second model that we built. As you can see, the disk has pretty colors on it, which come from the fact that every one of these tracks that you see here have about 500 lines per millimeter, which in spectroscopic technique is known as a diffraction grating, which breaks up the white light into its colors. Of course, we made this picture for the annual report for North American Philips, so we said let's put some light behind it and get all the pretty colors. This particular machine as you can see is very much experimental. It is all set up on an air bearing sled.

Fig. 2

The motor has an air bearing in it so that this spindle actually turns very smoothly, and without wobble, because even though you have two micron track spacing, you want to keep that very much the same, to within about .1 microns so that you do not get cross-talk between the different tracks, and we are able to do that.

This particular machine works with blue light from an Argon laser. An Argon laser gives you lots of power. This way we do not have to worry about all our optics getting anti-reflection coated, and what have you. We can make changes very quickly and so on. We have, indeed, other machines that look much better than this one, but I do not have that pretty a picture of them. They work with a helium neon laser. I should perhaps also say that at this point we are routinely recording at a rate of about two megabits per second. And, as I have already mentioned, we get one and a half times ten to the ten, or one and a half or two times ten to the ten raw number of bits on the disk. The only other thing I mentioned already that I really should say, as I said in the beginning, that we burn one bit per hole. That is not really quite true, because our holes do not all have the same lengths. We use the so-called Miller code, which is also used in lots of communications and in magnetic data. So what we have really is three kinds of bits. One is one unit length long. One is one and a half units long. One is two units long. Basically, we are already edging into the kind of thing that Len Laub talked about this morning.

If you think of what one could possibly do in the future, by putting in more than one bit per hole, one could certainly go a lot further. I think that numbers such as 10" bits per disk for a 30-minute disk are certainly not out of the question. But I would rather leave you with the numbers that we do now at this moment have, because, as I say, even that is in the developmental stage. So, if you say, "When can we have this?" Even that will be a few years from now. So I would rather stick to those numbers rather then, "What might we do developmentally in a year or two years from now?" Thank you very much. (Applause.)

DR. BOYLE: Thank you very much. Maybe there is a question -- And I am asking this on behalf of the audience, which I think would come up: If you are going to copy a disk, what are the sort of costs of copying a disk to re-write it -- in other words -- in the system you are talking about. Is it somewhere between ten and a hundred dollars to do it that way? I am not talking now about pressing.

MR. ZERNIKE: If you talk about taking the record and just re-recording it, it would basically, on the records that we have at the rate that I am talking about which is four revolutions per second, 240 per minute, it takes you about four hours to fill up a record. So, all you have to do is have a player and another recorder, and you could re-record that one record as many times as you want. So, basically, it would be the cost of the man who was sitting there doing it, who could just put the record on and walk away. The machine does it itself. And the cost of the record. What does a record cost? When I got into this business years ago I was once told by my then-boss, "Don't ever name a price, because if you do you'll be held to it later." So I would rather not. But it certainly is not or would not be in the hundred-dollar variety. It would be much cheaper than that. I think in the kind of thing we are look ing at it is very much the case that we are looking for a very cheap record. We would rather make the recorder a little bit more expensive and keep the record cheap. Because a lot of the customers that we have talked to now want this type of machine for an enormous amount of data recording. If you talk to the satellite people and you hear the number of data they get, it's no wonder the weather reports are so bad, because they don't know what to do with it.

DR. BOYLE: The other thing that occurred to me is the aspect of the archival characteristics. People get worried that, oh, we can't possibly edit it, we are stuck with the data that's on there.

This is not, of course, true, because you only have to run a magnetic disk in parallel with your optical disk on your computer, and you can put your updates onto magnetic, and periodically make a new optical disk.

MR. ZERNIKE: Yes, you could do that. Again, it depends on what the customer wants. We see this disk very much as what computer people call tertiary storage, the type of thing where you have done all your editing, you really do not ever want to re-write that. You record it once, and that is what you want to keep. If you are interested in erasability, then we can think of a jury-rig of how to do it. We can always leave a certain amount of space on the disk. I did not go into this, but the way we record the disk now is that we sector it, and at the end of each sector we leave a certain amount of open space in which we can write, "Disregard this sector because it was all wrong". Those are the ones where we find more than one error and we re-write that again. So, if we have a good sector that we later on want to re-write, we could do what is called posting. You could go back and say, "Don't take this one, but go and look on Sector No. So-and-So for what we wrote there later". Personally, I do not like that idea. I feel very strongly that if people want erasable material, let them go to magnetic disks or magnetic tapes. This is more the thing you want for final archival material.

DR. BOYLE: In cartography, however final your data --

MR. ZERNIKE: Sure.

DR. BOYLE: Revision of maps is one of the most important things and a continuing thing, and this is how it could be used.

MR. ZERNIKE: I agree. I agree.

DR. BOYLE: I think it would be updated or disregarded and a new section put on your magnetic tape.

MR. ZERNIKE: You would read out the main part of the data from the optical disk and then make your corrections.

DR. BOYLE: Yes. That is straightforward. The other question that I had asked, which I was hoping perhaps you would say a little bit more about, but you could later, is that some people seem a little worried how they would connect one of these disks to a computer, how they could convert these holes into meaningful data. To me, as an engineer and knowing teletype units and so on, there does not seem to be any problem in this. But I just wondered if it is a straightforward, simple interface?

MR. ZERNIKE: Yes, it is that. We have heard that question enough so that we are at the moment working at interfacing one of our machines to a PDP 11, mainly because we see that interested people come in and say, "Can you really do it?" We would like to be able to say, "Yes, here it is. We have done it." But basically it is the same kind of interfacing that you have to do with any peripheral.

DR. BOYLE: Good. Thank you very much indeed. I think now we might go on to Dr. Zech, if he would come on and tell us about the work at Harris Electronic Systems Division (Melbourne, Florida).

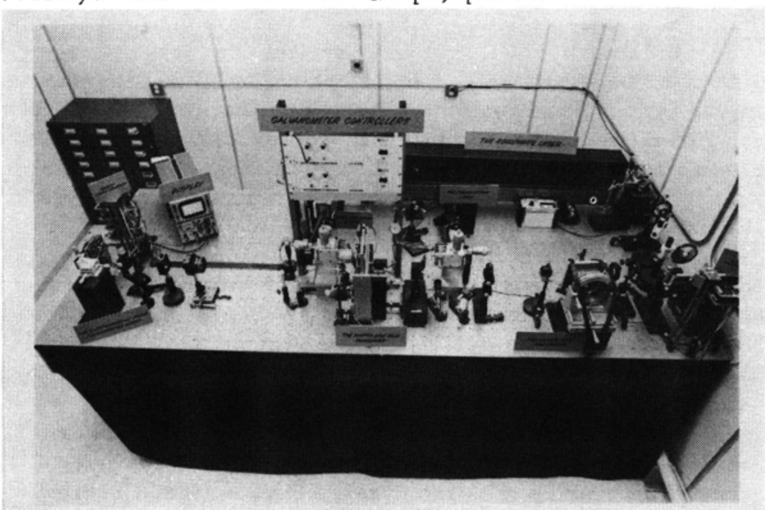
DR. R. G. ZECH: Thank you, Ray. I guess I have a number of confessions to make. First of all, I am a pseudocartographer (in that I know enough to be conversant about the subject but not enough to be helpful) and I am also a holographer. Does anyone remember what holography is all about? (The potential it once appeared to have for high-density data storage?) Does anyone care? (Laughter)

Actually, Al Jamberdino of Rome Air Development Center mentioned in his presentation several holographic systems which Harris is developing for Mr. Jamberdino's organization. The first is the holographic Human-read Machine-read (HRMR) System which, as Al pointed out, is a microfiche mass memory system. It is based on something called "synthetic" or computer-generated holography (actually, a sophisticated form of multi-level laser recording that produces a 68-bit micro-hologram). Data is stored archivally at a density of 1.25×10^6 bits/sq. in., and recorded and read out at 0.5×10^6 bits/sec. Al also mentioned the holographic wideband recorder/reproducer system, which is capable of recording and reproducing data at very high rates. We have achieved at this date recording and reproduction rates of 750×10^6 bits/sec. I might also add that the storage density of the data is approximately 10×10^6 bits/sq. in. Those of you familiar with magnetic technology, either video or instrumentation recorders, know that this is five to ten times better storage density and three to ten times better rates than those achieved with state-of-the-art magnetic technology. Although I did not come to talk about those two systems, they do illustrate that holography is still around. I also have a certain amount of pride in them, since I have been associated with them for going on seven years now.

What I really came to talk about was something that we call the DIGIMEM (now MASTAR - Mass Archival Storage and Retrieval) System. It is a direct digital laser recording (non-holographic) system. It is the basis for an archival mass storage and retrieval system we are developing for NASA. The purpose of this system is to archivally store LANDSAT and other types of remote sensing data. We are not in any way associated with "Video Disk," although what has been said earlier about this technology provides a very relevant background to what I am now going to talk about. Let me just give you some numbers for your consideration, because this particular system, although not a "cartographic" storage system, certainly is a remote sensing system in that what we intend to store archivally is raw LANDSAT data. Now, "raw" begs a definition here because I am not sure yet what it may mean. It may mean as the data comes off the line -- that is, as it is telemetered down to the earth. It may be after the data is processed. A multispectral scanning scene produced by LANDSAT A and B has the digital data equivalent of 2.4×10^8 bits for every scene. As I understand it, after radiometric and geometric corrections are made, its data content increases to about 5.1×10^8 bits per scene. That is a considerable amount of data when you reflect upon it. At any rate, what exactly are we doing for NASA? We are going to build for them a 10^{15}-bit archival optical mass storage system. The plan is to have it operational sometime in late 1984.

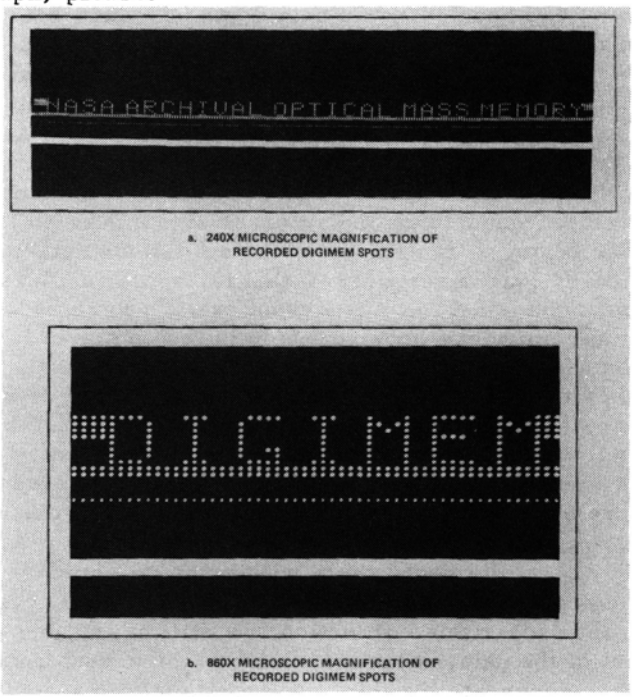
As I pointed out, the DIGIMEM System is indeed based upon laser recording, but unlike the type of laser recording (video disk) we have talked about earlier today, in which data is serially recorded, we record using a multiplicity of parallel channels. On our experimental breadboard we use eight channels, plus several channels for synchronization and other overhead purposes. The recording format is something I call a "squisk". The term squisk means a "square disk". We like many features of a disk, yet the fact of the matter is that we must handle (transport and store) the data records, and we would like to be able to handle them without human intervention. For that purpose we have designed and are building rotatable carousels (to provide rapid random access) in which to store the squisk data records. Now, these data records will not be as big as a video disk. They will be, let us say, about half the size (6 to 8 inches diameter). We plan to store about 5×10^9 bits per data record, which will correspond to approximately ten LANDSAT multispectral scanning scenes -- in fact, we will make it exactly ten, plus overhead data. The record and readout rates have not been established, but I think we are projecting something in the range of 20 to 100×10^6 bits/sec. We are talking about bit error rates on the order of 10^{-9} (corrected), or less. A baseline plan is to have 1×10^{14} bits on-line and 9×10^{14} bits off-line. There is no reason why all 10^{15} bits could not be on-line. The data record (squisk) access time -- and the assumption made here is that we will have multiple readers -- will be about ten seconds worst case for any of the unit records. The file access time -- that is, the amount of time it will take to go from a given LANDSAT scene to any other LANDSAT scene on the same data record -- should be no more than some small fraction of a second, say, one tenth of a second. Finally, we are developing the DIGIMEM system to have two attributes which we think are quite logical at this point. It will have the capability of writing in both machine-readable and human-readable formats. I will show some examples of that a little later. In addition, the DIGIMEM data records will be replicatable in a straightforward and inexpensive way, and this in part explains the reason why we are using smaller data records. It will probably also explain the reason why the spot sizes (information packing densities) that I am going to talk about are not as small as those being talked about by Fritz Zernike and Leonard Laub.

Let us go from the abstract to something a little more concrete. Would you show the first Vu-Graph, please.



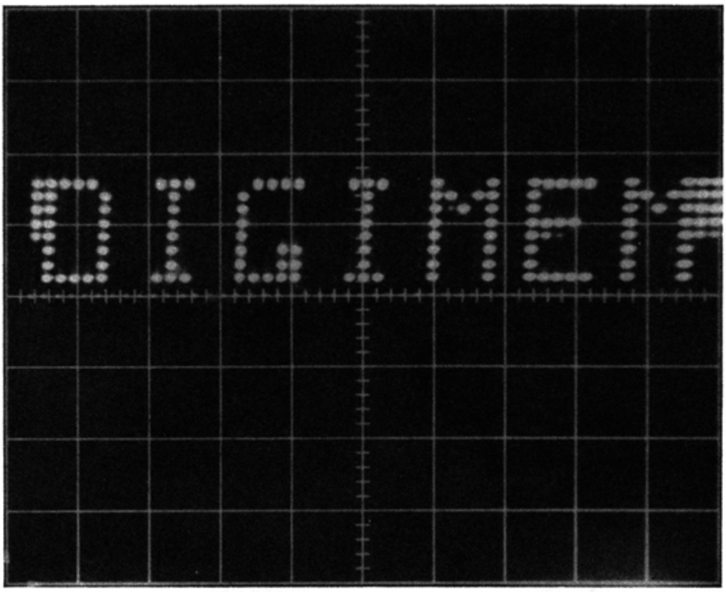
VuG. 1-Feasibility breadboard Model of a Laser Optical Recorder

This is our breadboard DIGIMEM system. It appears somewhat complicated. I suppose it would not do you any justice for me to go through and explain everything that is in the system. I will, however, point out the major components. We use a helium neon laser, and, again, as Fritz said, because we are lazy we use a very large helium-neon laser, a Spectraphysics Model 125, which gives us probably 10 times more power than we need. We have an acousto-optical linear modulator array which serves as an input device (changes electrical signals into optical signals). This is the device located here. We have 32 channels available, although at this time we use only 8 of the channels for data, as will be clear when I show you a format example. We use several other channels for other purposes. The actual recording takes place here in a rotating, flexible film transport, an extremely simple device. And we do, indeed, use an air bearing platen. The air bearing has been shown to hold depth of focus -- that is, the planarity of the recording film in the region where it is being exposed, to $\pm$ 2 μm. Further downstream in the system is something we consider relatively unique, the agile photodetector array. We call it an "electronically agile" photodetector array. An agile, or adaptive, array is required because no matter how well the servo system works -- which in this breadboard is composed of scan-descan galvonometers and an error signal derived from a separate laser beam, a tracking band and split diode detector -- we are still only "coarse servoing"-- that is, some residual positional error remains. In the present case, we are recording on a rectangular piece of film with a hole in the center of it that is mounted on a rotating spindle -- we found it didn't really matter whether the piece of film was square, circular, or rectangular -- any shape seems to work pretty well provided the air bearing is well designed and the spindle hole is centered. For recording, we put the film in, we record on it, and then we take it out. We are using a photographic emulsion at this time. We process the film, and then put it back in the system for readout. No matter how carefully done, there will be misalignment (decentering) on the order of several mils. The galvo system corrects for this, but even after this correction, we still have some slop in the readout of the data, measured to be on the order of several microns. To compensate for this, we oversample in space -- that is, if we are reading out eight data bits, we use 32 photodetectors, four detectors for each data bit, so that we can have uncorrected random spatial displacements up to $\pm$ 1 bit and still detect the data correctly. We are also oversampling in time, a form of peak detection. I should point out that this system concept, despite the complexity conveyed by the Vu-Graph, is quite simple. We also found it to be remarkably reliable. On one occasion we selected at random a data record, put it in the reader, and allowed the system to operate unattended, with no special environmental requirements, for 72 hours. It was reading data as well after this period of time as it had been when we initially began reading data out. But, more interestingly, we found that no special requirements are required for reliable system operation. We do not use a clean room environment. We used a commercial photographic film, Eastman Kodak Type SO-173, as it comes from the box. And despite the lack of obvious precautions, the system works remarkably well. Next Vu-Graph, please.



VuG. 2-Examples of Digital Data Recorded with the DIGIMEM Breadboard that is Simultaneously Machine Readable and Human Readable

In this Vu-Graph I am showing you an example of the types of spots we record. This gives you an idea of the human-read capability of the system. Now, as it turns out, this same human-read data is also machine readable. That is, the same characterters are read (decoded) by our electronics, and can then be manipulated electronically or displayed on a CRT screen. The very high magnification photomicrograph shows all the details that I think are necessary to understand the concepts. We record in a byte-oriented format -- where by "byte" I mean eight bits at a time. I should stress here that in everything we do, we try to be compatible with existing hardware. The bit sequence at the beginning of the letter "D" are signature bits. They are used for countdown -- they tell the electronics when to read user data. The two bits on the bottom of each column of spots are called data location bits. They help the electronically agile array work by providing a basis for peak detection. The single bit in between is for synchronization. Finally, at the top of this photograph, the wide band is the coarse servo correction track. Next Vu-Graph, please.



VuG. 3-Electronic Readout of Optically Recorded Digital Data That is Also Human Readable

This is a picture taken from the face of a CRT, which is Z-modulated using the same human readable data that was shown in the previous Vu-Graph. I might point out that the spots forming the alpha-numerics are approximately 2μm in diameter. They are on 3.5μm centers. There was no special reason to choose these values. We were able to record 1μm spots on 2μm centers if we chose, but this was simply an easier way to do it. The information packing density is about 5×10^7 bits/sq. in. The user record/readout rates at this time are 1×10^6 bits/sec. Next Vu-Graph, please.

MASTAR
PLAN AND GOALS

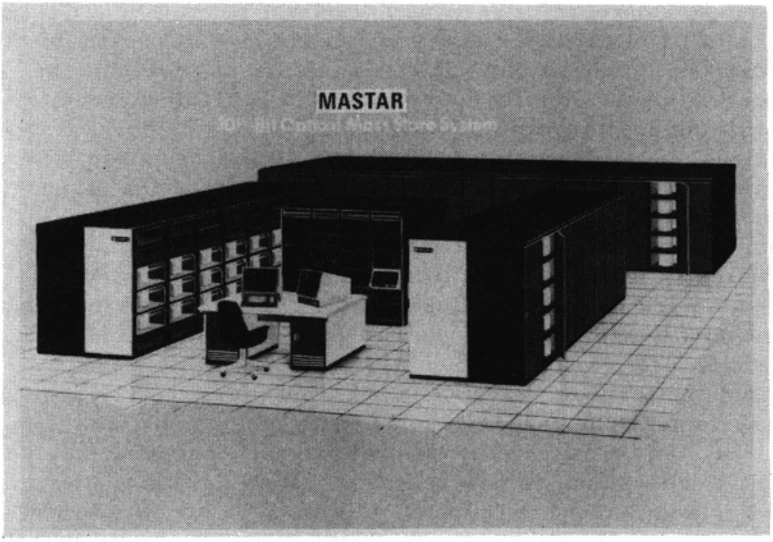
SYSTEM PARAMETER	o PAST BREADBOARD (1976-1977)	o PRESENT ADVANCED BREADBOARD (1978-1980)	o FUTURE ENGINEERING MODEL (1982)	o FUTURE OPERATIONAL SYSTEM (1984)
STORAGE FORMAT	FLOPPY DISC*	FLOPPY DISC*	FICHE*	FICHE*
PACKING DENSITY (Mb/IN ^{2})	50	100	100	250
RECORD/READ RATES (Mb/s)	1	10	50	100
UNIT RECORD CAPACITY (BITS)	10^6	10^8	5×10^8	8×10^9
UNIT RECORD ACCESS TIME (SEC)	–	–	10	1
DATA FILE ACCESS TIME (SEC)	–	–	1	0 1
TOTAL MEMORY STORAGE (BITS)	–	–	10^{13}	10^{15}
RECORDING MEDIUM	AgX FILM	AgX FILM	AgX FILM?	EP OR METALLIC THIN-FILM?

*NOW 4" X 5" SHEET FILM – 9" AND 12" DISCS ARE COMMERCIALLY AVAILABLE, AND MAY BE SELECTED FOR FUTURE SYSTEMS, THESE FORMATS AND "SQUISK" CONCEPT ARE CLOSELY RELATED

DATA ARE PRELIMINARY, ACTUAL SPECIFICATIONS TO BE DETERMINED BY ONE OR MORE END-USERS

VuG. 4-Plan and Goals for the Hardware Evolution of a 10^{15}-Bit Archival Optical Mass Storage System

In this Vu-Graph I have summarized what we have done, what we plan to do during the next year (1978), and then what we plan to do in the future (1979-1984). As you can see, at present the performance of our feasibility breadboard is relatively modest by comparison with video disks. This year (1978) we shall become considerably more sophisticated, and by 1982 we will be delivering somewhere -- perhaps to Goddard Space Flight Center, perhaps to Dr. Heards's institution, the NASA Ames Institute for Advanced Computation -- this is unsettled at present -- an engineering prototype fully operational at a 10^{13}-bit storage level. If everything goes according to schedule, we will be delivering an operational 10^{15}-bit system sometime in 1984. I suppose the parameters that are of greatest interest would be those in the last column relative to 1984. "Fiche" is more or less a misnomer. I really did not know what to call it at this time. I do not believe it will be in the end a film of the type we are using now. I think a squisk is probably closer to the type of format that we will eventually use. But, as you can see, the information packing density of 2.5×10^8 bits/sq. in. will be several orders of magnitude better than what can be achieved with present day magnetic systems. The record/readout rates of 100×10^6 bits/sec., of course, can be matched by several magnetic systems. Bell & Howell, I understand, is now selling a system that is capable of recording and readout at 160×10^6 bits/sec. on 42 tracks with 33,000 bpi track density (1.2×10^6 bits/sq. in.) -- a very impressive magnetic system. You might note that sometime over the next five we will go through a transition in which we will elect to use instead of silver film either a thin metallic film type material, such as that mentioned by Fritz Zernike, or an electrophotographic film. There are several of the latter available today that are most attractive, in particular the CdS EP film being developed and now produced by Coulter Systems Corporation, which is an inorganic electrophotographic material with a speed measured in microjoules per square centimeter and resolving power measured at 1,000 cycles/millimeter. Next Vu-Graph, please.



VuG. 5-Artist's Concept of 10^{15}-Bit Archival Optical Mass Storage System in which 1×10^{14} bits are On-line and 9×10^{14} bits are Off-line

Finally, this is an artist's conception of what the 10^{15}-bit mass storage system may look like. I feel that a little artistic license was used there. I suspect the volume (size) of the actual system may be larger than is shown here for a number of practical reasons. Although, quite honestly, in principle it is possible to store 10^{15} bits in the conceptual system that we show here. The on-line data will be in the front two rows of cabinets, while the off-line storage will be in the rest of these cabinets.

I think I will end my presentation here. In summary -- optical mass storage systems with very high capacities and on-line rapid access are feasible, are being developed, and will be available for cartographic applications in late 1980's. Thank you very much. (Applause.)

WIDEBAND OPTICAL STORAGE

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ABSTRACT

This paper has five purposes. First, to focus upon the key relationships that bound the technology choices for large, archival, digital storage devices; second, to identify the motivations for selecting the optical technology for a petabit-exabit level storage system (10^{15}-10^{18} bits); third, to present a generic example and a specific implementation of a terabit-level optical storage device; fourth, to characterize the global design space constraints that will allow one to build a technology-limited optical store; and fifth, to sketch the outline of the BYTERON concept, a wideband 10^{16}-10^{17} bit optical store concept and contrast its performance to that of an optical store that is in operation today.

INTRODUCTION

The first purpose of this paper is to provide a perspective for assessing a given technology's value to the computational community. It is asserted that four key relationships establish the worth of a mass storage device: 1) technology maturity, 2) hardware costs versus access time to a substantial quantity of data, say a megabyte, 3) the relationship between storage capacity and access time and 4) the memory bandwidth-storage cost product. In the paragraphs that follow it will be seen that optical storage provides a technology that becomes increasingly attractive as a wideband archival store in the petabit-exabit storage volume range.

Technology maturity is most simplistically represented by the relationship between unit cost of storage (cents/bit) and time. Figure 1 illustrates this relationship for the current storage technologies. First, note that the dependent variable, hardware cost, ranges from 10^3 to 10^{-7} cents/bit over a 20-year time span. The rate of decrease of hardware cost with time is smaller for the maturing technologies; e.g., core and magnetic disks. In contrast there is rapid cost progress in the newly exploited technologies, particularly in semiconductor devices wherein gate density per chip is rapidly approaching 10^6. It is significant that, when introduced in the late 1960's, optical storage, as represented by the UNICON, was already orders of magnitude lower in cost than other wideband technologies. Even then this storage technology competed with punched cards and

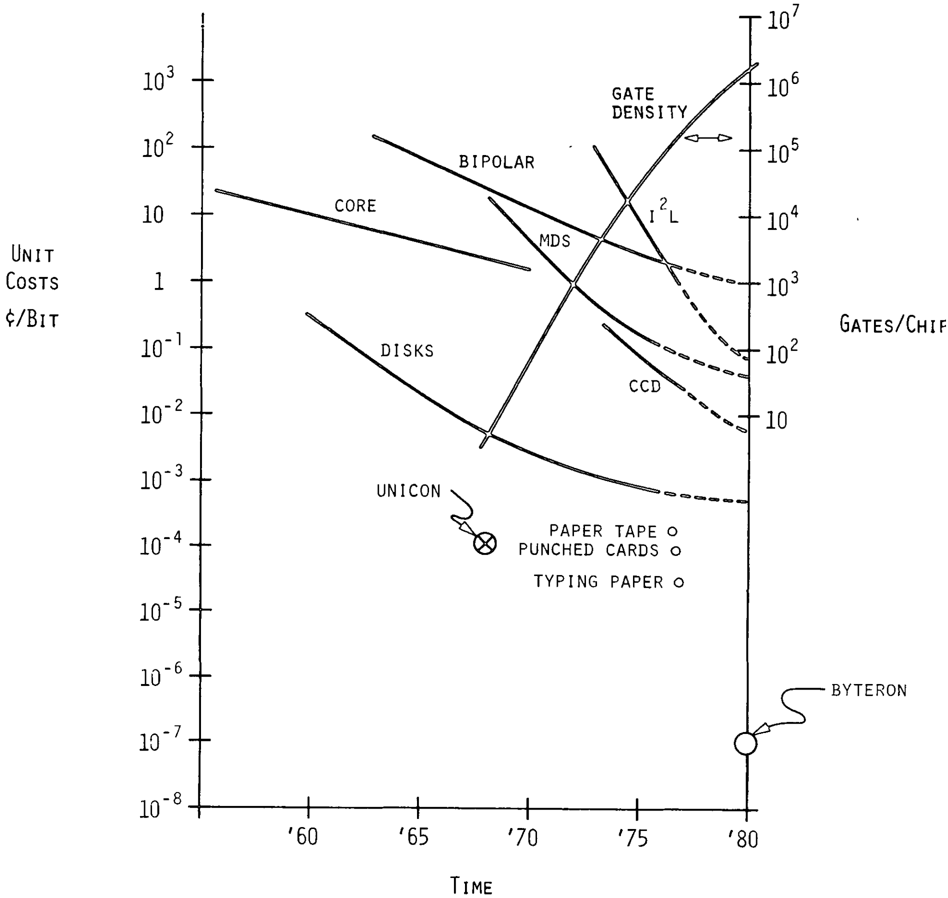

Figure 1. Read/Write Storage Cost and Complexity Versus Time

paper tape. Economies of scale are expected to enable optical storage to become even more competitive in the near future. It is projected that hardware costs for a BYTERON scale optical store, that could be available in the 1980's, will be of the order of 10^{-7} cents/bit over a 20-year time span. It is reasonable to conclude that neither semiconductor devices nor magnetic storage technologies will ever compute in the petabit-exabit storage range where optical devices are economic.

The ready availability of large scale storage, with large memory bandwidth, may be expected to have a significant impact upon the architecture of future computation systems. A cornerstone of the new design philosophy will be that wideband archival storage will be essentially free.

Figure 2 illustrates a second key relationship for storage technologies. Note that the access-time dimension of Figure 2 may be subdivided into two regions. Below approximately 10^{-3} seconds, data access is performed electrically. Storage volumes are constrained by costs to on-line capacities of the order of megabytes (8 bits/byte). Unless very significant, and as yet unknown electrical storage methods are developed in the future, charge-coupled devices and magnetic bubble shift-register-type memories not withstanding, inevitable cost constraints will continue to force mass storage to the mechanical access domain, where large scale data availability, even with wideband channels, will be in the 10^{-3} to 10^{3} seconds time range. Thus, on-line library-scale storage ($>10^{12}$ bits) will continue to be dominated by mechanical-access devices.

The on-line capacity variable in Figure 2 may be subdivided into three domains. On-line storage below 10^{8} bits is generally available from a single aggregate of hardware. A few assemblies support the transition gap range, where one or a few devices with removable media, typically including tapes and disk packs, provide economic cost and performance. Magnetic-device technologies, which represent over 30 years of continuing development, currently dominate the high-storage capacity. Large magnetic tape libraries, typically containing in excess of 100,000 tapes, are found in the long-access-time multiple-device domain. Over a hundred of these libraries are now automated.

Optical storage, which very early demonstrated fast access methods and higher storage densities, has been slow to develop. A key feature of optical storage is its capability to exploit economies of scale. The total on-line storage for optical devices may grow into the 10^{14}-10^{18} bit range, without sacrificing either memory bandwidth or

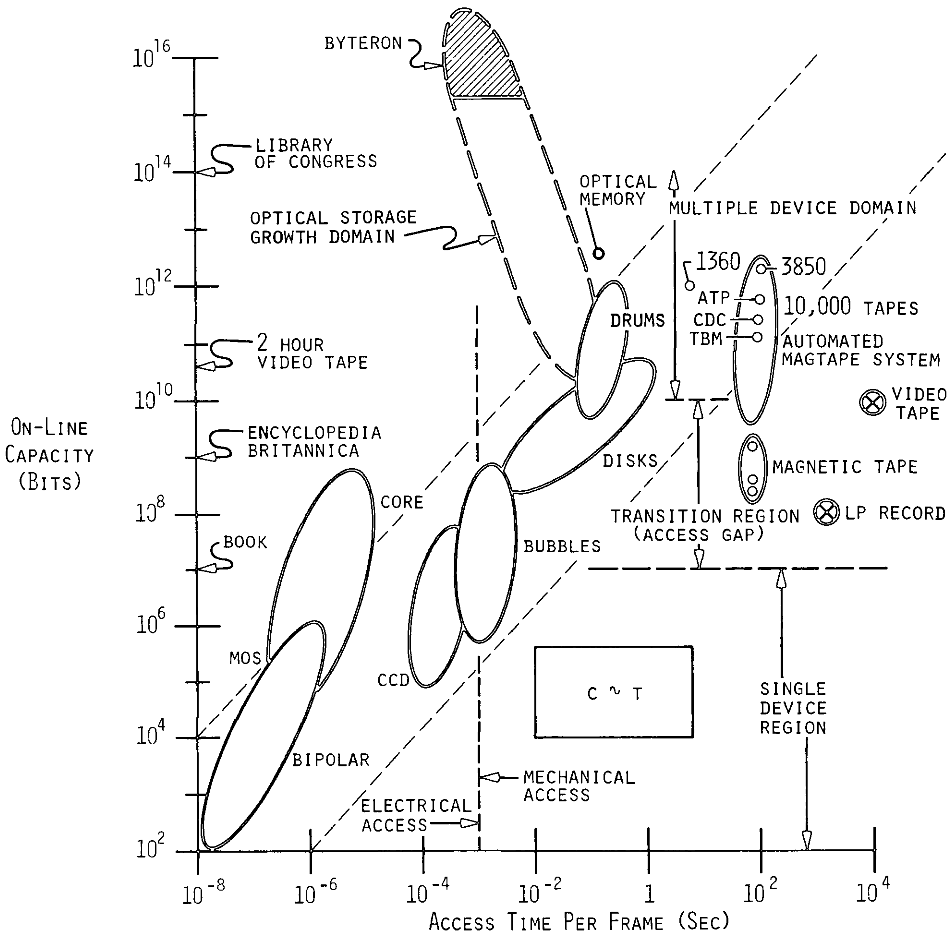

Figure 2. System Capacity Versus Access Time Write/Read Storage

access time. For example, storage strategies and hardware technologies embodied in the BYTERON concept, are projected to enable millisecond access to multiple volumes of data with gigabit/second read bandwidths.

A third key storage technology overview relationship is illustrated in Figure 3, which relates unit hardware costs (cents/bit) to the access time to one megabyte of data. Semiconductor devices, which primarily provide fast access to data, dominate the high cost area. Mass storage devices, which focus upon economic storage, are far less responsive. In a large-scale sense, the hardware cost per bit tend to vary inversely with the square root of the access time to a large block of data. Devices on the left half of Figure 3 generally tend to be more complex; devices on the right tend to be mechanical. The laser (optical) storage technology is seen to depart markedly from the general trend. Because it incorporates a relatively few complex devices and may easily exploit high storage density, a single optical mass storage system may perform the same storage functions as the 30 tape drives in an automated tape library. System reliability should accordingly be greater.

An important fourth key relationship needed for evaluation storage systems is a measure of storage quality. Strehlow[1] proposed that the product of device cost and memory bandwidth be used. He suggested that the product of an economic figure of merit (bits/cent) and a technical figure of merit (bits/second), be used to rate all storage devices. Figure 4, which plots this storage Figure of Merit 'Q' ($bits^2$/cent second) versus on-line capacity (bits), compares the major memory technologies in this dimensionality. In this representation the electronically-agile memories dominate the high-cost low-storage volume domain. To increase the storage Figure of Merit for a given on-line capacity, it is essential that very significant improvements be achieved in both device hardware cost-performance and bandwidth. It will be seen that order of magnitude improvements in both cost and throughput are essential to improve a given technology's storage Figure of Merit.

The intermediate storage range in Figure 4 is dominated by disk technology with the (optical) video disk, assuming it can be marketed economically, yielding the highest figure of merit (in the 10^{10} range). The terabit storage range is populated by automated magnetic tape libraries and two types of optical storage devices: 1) the silver-halide IBM 1360 PHOTOSTORE, and 2) the metal-film storage media devices -- the UNICON 690 and 190. The domain of the ultraviolet laser

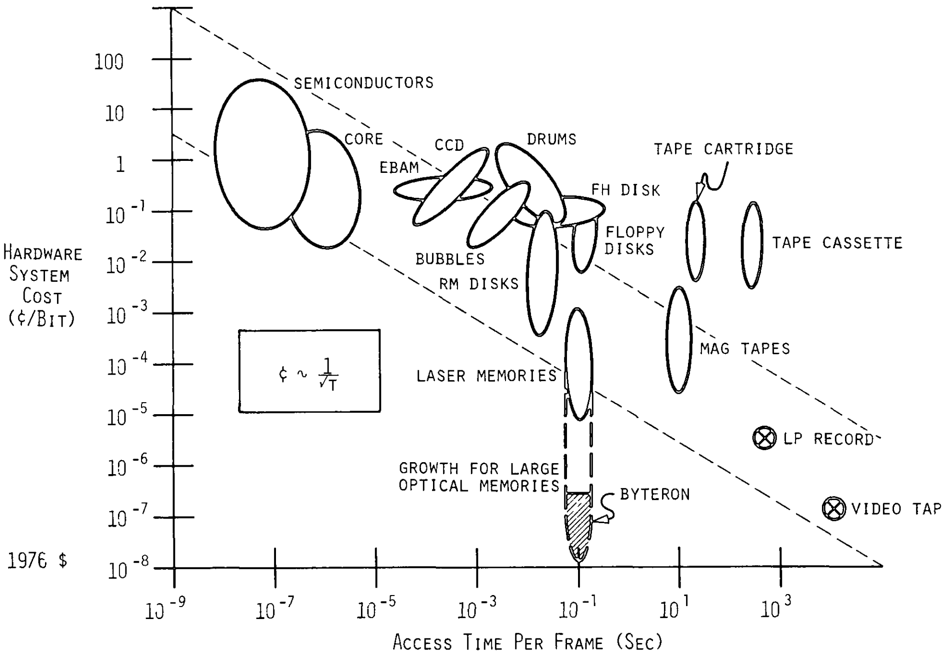

Figure 3. Cost Versus Block Access Time Write/Read Stores

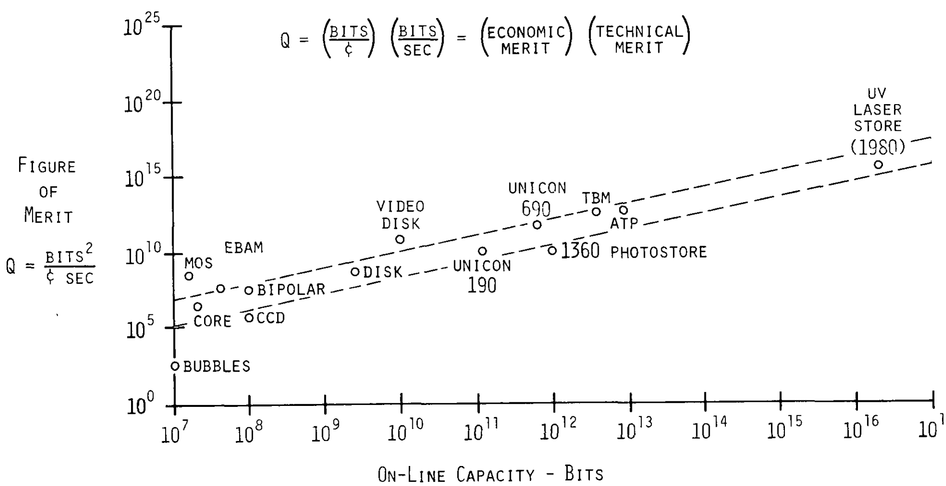

Figure 4. Limiting Figures of Merit of Advanced Mass Storage Hardware Systems

store (BYTERON) is 10 petabits and beyond. The projected figure of merit of this device, 10^{16}-10^{18}, stems from its greater inherent bandwidth, higher available storage density and overall device simplicity.

MOTIVATIONS FOR INTEREST IN METAL-FILM PETABIT-EXABIT OPTICAL STORAGE TECHNOLOGY

Since the early 50's, large-system users have witnessed a widening gap between needed and available storage hardware for responsive, direct access, archival-quality tertiary memory. By 1974, some commercial and government organizations already had tape libraries containing in excess of 200,000 reels of magnetic tape.[2] System requirements analyses continue to predict yearly file growth rates of fifteen to twenty percent, with on-line 1980 data base sizes in the 10^{12}-10^{15} size range. Studies by the U. S. National Archives indicate, for example, that U. S. government organizations yearly produce 9,000,000 reels of magnetic tape data.[3] Permanent (multi-century) storage for approximately two percent, or 200,000 reels per year, of this data is needed now. Furthermore, as industry and government sources continue to convert to digital control and computer automation, to maintain competitive cost postures, the magnitude as well as the rate of file size growth will continue for the indefinite future.

Unitl recently, the firmly entrenched magnetic-storage technology provided sufficient growth in storage density and cost progress to discourage new technology growth and retain market dominance. There are unequivocal indications, however, that growing requirements for lower storage costs, increased storage density and archival-quality storage, cannot be met by continuing advances in magnetic tape technology.[3]

During the last decade, magnetic technology has been exploited to produce most of today's mass memory systems. Current magnetic-tape mass memory systems are little more than automated tape files that are cost-justified on the basis of temporarily reduced need for expensive disk storage, reduced labor costs, and increased performance derived from the now-displaced manual tape files. The cost benefits, however transient, are real and elicit user satisfaction from improved tape system reliability and reduced reruns.

Video-tape systems have been implemented by IBM, CDC, and Ampex, using either reel or cartridge magnetic tapes, to produce competitive, virtual-disk storage systems. Scores of Calcomp automated CCT libraries also number among the over fifty automated-tape storage systems that are either operational or planned to go on-stream within this year.[4]

Only two of the many optical storage technologies, that have been investigated within the last decade, have demonstrated sufficient merit, at the 10^{12} bit storage level, to challenge the well-established magnetic technology. The IBM 1360 PHOTOSTORE, which was the first introduced, implements electron-beam exposure of wet-processed silver-halid film. The 1360 ultimately evolved as a slow, low bandwidth, but capacious store.[5] The only other practical optical storage technology to appear uses a laser to write directly upon a metal-clad polyester film A system based upon this technology has recently been developed by the Institute for Advanced Computation. The original UNICON 690 read/writ unit, after extensive modification, was configured as a complete syste including all the software for Call-By-Name file access management, fo use as a terabit archival store.

The technology base, evolved during the successful development of this laser storage unit, has been used to investigate the viability of future, low-cost, on-line archival storage systems with capacities far greater than may be obtained by magnetic storage methods.

There are many compelling reasons for interest in very large scale laser archival storage technology. The most important technical reaso are the following:

1) The technology is simple and may well be the only one economically viable at storage levels of 10^{16} to 10^{18} bits.

2) Data are permanently recorded. No energy is required to hold information indefinitely.

3) Read-while-write capability enables on-line error detection and correction so that error-free data is recorded.

4) Mechanical contact with the record medium is eliminated and head crashes cannot occur.

5) Data densities in the 10^{10} bits/square inch are potentially available and a 10^{16} bit storage system may occupy 1,000 cubic feet or less.

6) Mechanical tolerances are tractable.

7) Data records may be read an indefinite number of times since read operations are nondestructive. Recorded data may be stored indefinitely.

8) All of the data tracks within the field of view of an objective may potentially be read simultaneously at gigabit per track memory bandwidths. Multiple read heads may be used to provide bandwidths that are limited only by electronics.

9) The inertialess optical beam may be scanned at gigabit rates to yield nanosecond access times to random data fields.

The initial capital investment needed to build a 10-petabit system is not small. Furthermore, considering the extremely limited market, the high risk, and the low potential return on investment, there is currently little business incentive to attract the risk capital needed to bring the technology to fruition. Nevertheless, the potential hardware and storage costs savings at the bit level are still very interesting. The potential media cost for a 10^{16}-10^{18} bit store are so low (of the order of 10^{-10} cents/bit), that archival storage would be essentially free. Hardware costs, however, may run as high as 10^{-7} cents/bit. Sponsorship by an agency of the government will doubtless provide the incentive for bringing the optical technology to the forefront for large-scale archival storage.

THE IAC ARCHIVAL LASER STORAGE SYSTEM

The decision tree of Figure 5 gives a quick overview of the design base for an operating optical storage system, the IAC UNICON 690.

Melted metal-film optical memories are functionally similar in performance to fusible-link read-only memories; data bits, once written, may not be altered. A 500 milliwatt 514.5 nanometer wavelength argon-ion optical laser source is used to melt the metal film to post a pattern of bits on a metal-coated flexible plastic strip. The same laser is used to record and read information stored on each of the 450 on-line strips. When a strip is mounted and vacuum-retained, on either of two redundant 10-inch diameter drums, individual parallel data tracks may be recorded or read by the servo-controlled, mirror-directed laser beam.

After a strip is formatted (initialized), data are directly recorded wherever the high-intensity laser beam is focussed. A logical "1" is recorded by melting the 12.5 nanometer thick noble-metal-coated film that was previously vacuum evaporated on the upper surface of the 7-mil thick polyester strip. Once melted, the metal residue forms an annulus, the lowest potential energy form for a ruptured molten film. The exposed base film provides a 4 percent surface reflectance that yields a logical "0". The unmelted rhodium film has a 62 percent reflectance that provides a logical "1". Because of the impervious nature of the melted noble metal and the chemically inert characteristics of the heavy plastic strip, neither strip wear nor chemical oxidation are projected to impact the permanently recorded data integrity for several tens of years. These characteristics are responsible for the superior archival quality of an optical-memory data store.

Efficient discrimination between a logical "1" and "0" is provided by the large change in record surface reflectance that occurs within a

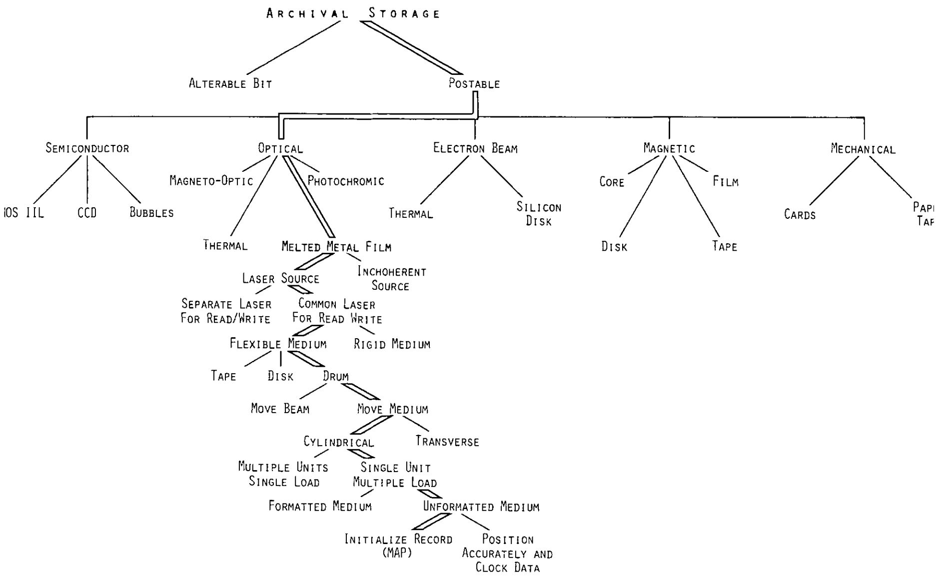

Figure 5. Optical Permanent Storage Decision Tree

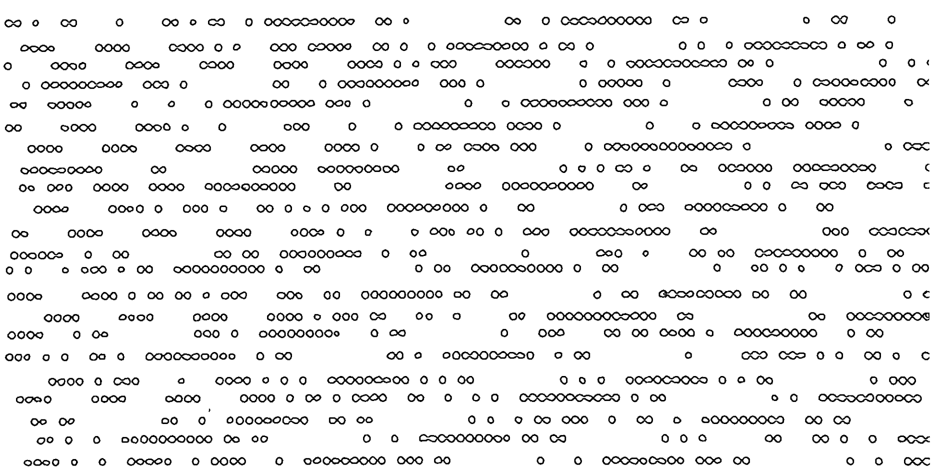

Figure 6. Electron Micrograph Replica of a Typical Data Record

few nanoseconds after writing begins. The read-while-write direct-recording characteristics of the metal-film recording medium are exploited by system analog electronics, to ensure that error-free data are always recorded. Unless the surface reflectance is reduced below a well-established reference level during recording, a finite state machine (FSM) logic encodes a write error and automatically initiates rewrite of the FSM information. After several unsuccessful retrials, the FSM aborts the write process, selects a new area of the record medium on which to write, and reports the performance to the supervisory system.

Figure 6 illustrates a negative copy of an electron micrograph replica of typical data patterns produced on the plastic strip. The annular nature of the "1" bits is not revealed in this photograph. However, several important features of the data record may be observed in this figure when the average spot size of 3.5 microns is known: 1) the bit spacing is equal to the bit diameter, 2) the average track spacing is 7.5 microns, 3) there is a statistical fluctuation in recorded spot size, 4) the track spacing varies, 5) the recorded information is highly directional, and, 6) the data density could be at least doubled if the adjacent track spacing were reduced. As currently implemented, the bit cell is 3.5 x 7.5 microns; the data density is approximately 2.5×10^7 bits/square inch.

Four levels of error correction are currently included in lowering the raw bit error rate from 10^{-4} to 10^{-10}. During write operations, read-while-write electronics insure that error-free data are recorded, and that an on-strip record is retained containing the detailed information about each track. On-line validation of previously-written words is also encoded by a unique, highly redundant error pattern. To force independence of error statistics, all records are also redundantly written on a spatially separated area on the strip. Each record is written with its check sum for single-bit error detection. Polynomial error correction is also provided by an (80, 64) Fire Code, implemented in the hardware for on-line multiple-bit burst error correction.

While the 10^{-10} error rate of recently recorded data is marginally acceptable, dust build-up may occur over a long period of time and cause the error rate to deteriorate. Three approaches are planned to further reduce the error rate and extend the archival quality of the data: 1) add an additional on-line hardware implemented error correction code to bring the bit error rate to 10^{-13}, 2) blow a jet of dry nitrogen on the record surface when an error is detected, and, 3) under software control, completely regenerate the record from the redundant file copy whenever an uncorrected error is detected on either copy of the data. These methods are projected to give an archival error rate at the system level on the order of 10^{-12}.

SYSTEM ARCHITECTURE

The system architecture of the IAC direct access layer storage system is illustrated in Figure 7. A Digital Equipment Corporation (DEC) KI-10 (36-bit) processor and the central memory comprise the bus-orgar zed host machine. A group of three DEC PDP-11 (16-bit) processors communicate through specially-designed high-speed data channels and memory-mapping interfaces to provide five data and control functions: 1) memory management, 2) access control, 3) master-file directory access and security, 4) data structure manipulation, and, 5) laser subsystem control. The three processors effectively interface at the central memory bus level to minimize demands upon the host and retain the needed subsystem autonomy. The laser subsystem processor (controller) manages the 18 strip-storage containers, the two read/write drums, the on-line accessed memory strips, the tracking system, the continuous bit-stream pattern recognition system (that enables use of an unformatted data medium), and all of the data verification and erro correction logic necessary to achieve an acceptable system-level error rate.

The PDP-10 host processor operates under a version of Bolt Beranek and Newman (BBN) TENEX, release 133 monitor. A TENEX process, UFS, manage the laser memory file system and provides a very friendly user interface. Functioning as a high-latency ($\sim$ 10 second), high-bandwidth (5 megabaud) virtual disk, the system responds as a Call-by-Name File to enable system access to any of the 450 on-line memory strips. Currently supporting up to 512 simultaneous user directories, with 8,192 files per directory, the laser memory provides user-accessed permanent storage of up to 8 TENEX pages (512 x 32-bit) on the 11,606 tracks recorded on each plastic strip. Because the UFS software provides a highly-impenetrable isolation between users, files may be, and are, efficiently recorded sequentially. File access to a track of pages mimics a disk seek at the system level.

Separate system-support software controls the management processor. Briefly stated, a myraid of laser-system hardware, management, and con trol functions are handled by assembly-language-level software, that intricately interlocks the mechanical and electronic components of the system and provides a high degree of user data protection. An ultra-conservative hardware and software design policy was implemented in th system design and development as the loss of one fully recorded strip of data could represent the storage equivalent of 5 to 10 rolls of magnetic tape.

SYSTEM PERFORMANCE

The laser storage system was originally designed to provide tertiary storage to support the ILLIAC IV array processor. User data files wer to be transmitted over the ARPANET for storage and staging. ILLIAC IV

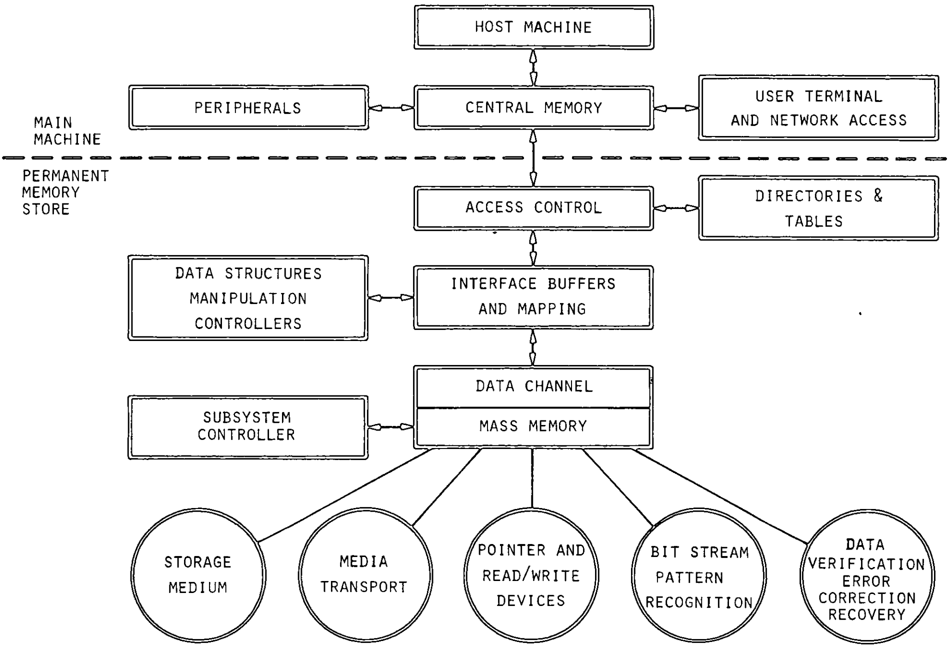

Figure 7. General Configuration of a Permanent Store

results files were to be stored on the laser memory for subsequent use perusal using TENEX processes. This heritage resulted in a TENEX-oriented record structure with up to 8 records per data track. Data words of 64-bit length are derived from ILLIAC IV requirements. One ILLIAC IV page (1024 64-bit words) is recorded as 4 records on a track.

The PDP-11 controller software restructures its 16K data access from central memory as 16,784 bit pages. System software enables the laser store to handle either 32- or 36-bit words from central memory. When 36-bit words are recognized, they are handled redundantly as both left and right justified 32-bit words; 36-bit words reduce the record efficiency by a factor of 2. Reconstruction of the original word is handled, during read, by effectively or-ing the redundant middle 28 bits. Storage of 36-bit files on laser memory is only half as efficient as 32- or 64-bit files. Each record consists of a 256-bit quadredundantly recorded header, 16K bits of data, 260 bits of error-correction code, and 128 checksum bits. Each of up to 8 fixed-format records of 20,928 bits on the 11,606 data tracks, is transmitted at a peak data rate of 5 megahertz. The average data rate, when all of the record keeping and redundant operations are accounted for, is approximately 3 megahertz.

GLOBAL DESIGN CONSTRAINTS ON PETABIT-EXABIT LASER ARCHIVAL STORE

There are seven major global design limits that establish bounds on the volume of design space within which all metal-film stores may exist: 1) recorded spot size, 2) data cell size, 3) write bandwidth, 4) read bandwidth, 5) media surface speed, 6) record width, and, 7) record environment. These variables unite to form an equation of state and define a design volume, a subspace of which permits a practicable optical store to be designed.

Record spot size is limited by spherical aberration and diffraction to approximately a wavelength. Spots of the order of a wavelength have been recorded with a 514.5nm laser. It is projected that a lower limit for the spot size of 0.3 microns may be achieved with a near-ultraviolet laser.

Cell size on the UNICON 690 is limited by the tracking system. Each track is resolved by a line-following, sample-data servo system that places data in the space between clock bits previously recorded on the record surface during initialization. An integrating track system, that follows a reference established by a laser interferometer, should permit bits to be recorded in every bit cell. Accordingly, a 0.3 x 0.3 micrometer cell size represents an upper storage limit of nearly 10^{10} bits/square inch.

Write bandwidth is limited by the physical mechanisms of laser-induced material damage. Tests indicate that laser-induced damage may be produced reliably with picosecond length pulses. A mode-lock gas laser, operating at 87 megabits/second, or a quadrupled, mode-locked, solid-state laser, operating at 1000 megabits/second, may thus establish a reasonable upper limit to the write bandwidth.

A unique characteristic of optical stores enables multiple-track reading. To the extent that the tracks may be resolved, focussed upon a detector array, and electronically deskewed, all of the tracks within the field of view of an objective lens may be read simultaneously. Since over a thousand adjacent tracks may be easily resolved, 128 bytes of data may be read simultaneously; each of the 1,024 tracks may be simultaneously read serially at detector-response limited speeds. As solid-state detectors are available with nanosecond response times, a read bandwidth upper limit is probably 1024K megabits/second, per read head. Multiple read heads may be used, of course, to produce read bandwidth that is practically unlimited.

Media speeds must remain significantly below the velocity of sound if vacuum loading is to be used to retain traction between the storage medium and the record drum. A reasonable upper limit for linear speed is approximately 500 feet/second. Higher surface speeds could be attained in a vacuum with the forfeit of single media replacement.

Recording media width is limited by economic producibility and accurate mensuration. Since a laser interferometer may reliably measure distances up to 50 feet, record width becomes constrained by more pragmatic considerations. The length of a data sheet is governed by the mounting mechanism. Single sheets of 8-10 foot length could readily be handled.

The most serious limitation to storing information at submicron levels is dust. Methods have been developed to sandwich the record material. Data may be recorded and read within the focal depth of an appropriately designed optical system. Thus dust will no longer limit storage lifetime.

The preliminary design parameters for the BYTERON, a 10^{16}-bit laser archival store, have been selected as a subspace within the above constraints. Assuming a 0.3 micron spot, a 0.3 x 0.3 micron storage cell size, and a 90 percent storage efficiency, 1.74×10^6 square inches of record area will be required. If the largest conveniently manufactured record width is set at 48 inches, 36,328 lineal inches of record space will be required. A little over 350 data sheets of 96-inch nominal length will more than suffice for storage. A mechanical storage mechanism, that will provide on-line indexed access to individual data strips, could be conservatively constructed within 1,000 cubic feet if the film were loaded on a 3-foot diameter drum.

(Film sheets and drums of this size are currently used in laser recorders in map making.)

It is of value to consider briefly some of the comparative storage parameters for the BYTERON and UNICON 690. A convenient medium for comparison is the set of fully recorded 1600 BPI CCT data tapes; some relative parameters are listed below:

TABLE 1: STORAGE COMPARISON

PARAMETER	UNICON 690	BYTERON
Tapes/Strip	5	30,000
Tapes/Pack	125	750,000
Tapes/System	2,250	$> 10^7$

SUMMARY AND CONCLUSIONS

This paper addressed a substantial conceptual advance in laser archiva storage technology. A device, called the BYTERON, focusses an ultraviolet laser beam upon a recording medium to create a permanent data record. The new technology represented by this recording methodology leads to attractive storage densities, per-bit hardware costs, multirack read bandwidths and on-line storage capacities in the petabit-exabit range (10^{15}-10^{18} bits). Because each data record is permanent, truly archival storage ($\sim$ 25 years) may be obtained at data densities that are beyond the range of magnetic storage technology. Direct access may be provided, to the storage equivalent of over 30,000 1600 BPI magnetic tapes, in less than a quarter of a second. A remote user may select a file from the storage equivalent of tens of millions of magnetic tapes in seconds.

Optical storage technology, when extended to the petabit-exabit storag range, offers an exciting opportunity to obtain a truly archival storage at per-bit hardware and medium costs that are lower than that of any other known media. Inherently a simple device, an optical storage system may be constructed in a small volume because storage densities of the order of 10^{10} bits/square inch are potentially attainable. Read and record bandwidths in the gigahertz range are projected and limited only by electronic device technology.

ACKNOWLEDGMENT

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DR. BOYLE: Thank you very much. We are getting bigger and bigger systems, you see, in our discussions. I am now expecting Bill, warning him that he must have 10^{20} bits when he starts his talk. (Laughter.) I would just like to mention that on some calculations I did this summer, it looks as if we could put one topographic quad sheet, if we compacted it in a clever way, into 10^7 bits. That means, just to give you some of the parameters, on a 10^{10} bit optical disk we could get a thousand topographic quads, just to give you some idea of the calculations, the way they work out. The last one we were talking about was, of course, very, very much larger than that. Remember, every time the digit goes up in the power, you are ten times. Bruce

Mr. BRUCE OPITZ: I am from the Defense Mapping Agency, Hydrographic Center. My role, in the Advanced Technology Division, is more as a potential user of some of these devices that you have heard about here today than a developer. You heard during the keynote speech that DMA is looking at a future data base requirement in the mid to late '80's of 10^{15} to 10^{16} bits. To give you a feel for the problem that we are all facing, certainly DMA is facing, 10^{15} bits is the equivalent to a minimum of one million conventional magnetic tapes. That is a true minimum. That is not allowing the industry standard of 20 percent of a magnetic tape being used, and that is not allowing any backup. So, when you are talking about 10^{15} , or 10^{16} , we have tremendous problems unless some of these devices we've heard about today become a reality.

Currently there are some systems available which are billed as mass storage systems -- Calcomp, Precision Instruments, IBM, CDC, and Ampex. These systems are typified by a medium amount of storage, 10^{11}, 10^{12}, or in that range, on-line. The key to those systems is that they offer on-line storage to a large computer center; they use conventional methodology, not the kind of optical techniques that we were talking about today; and that they are typified by horrible mechanical devices; most of them look like a Rube Goldberg device.

What we are looking for is something closer to a video disk or perhaps Digimem system for high density storage. One of the things that we as users must start to do, and I think this has been indicated by some of the comments, especially from North American Philips, is to start giving some feel of just what our requirements are. DMA is currently involved in looking at the configurations that will be required in the late '80's time frame. Some of the questions that we have to ask ourselves and provide answers to the developers of these hardware devices is, do we really need on-line access? Or is an off-line access, similar to the way we operate our tape libraries today, is that sufficient? Is our prime inter-largely archival? I think I should define archival as being slowly changing. And I think most cartographic data is slowly changing in terms of every six months or much less than that -- not that you are going to record a file and keep it there forever. But you are going to record a file and slowly change it so you can afford to look at it as an off-line archival medium. If we are going archival, are we going to have one copy of these devices or two copies hooked into our major computer center? Or are we going to look at this as an off-line device, still using some conventional medium like mag tape or magnetic disk, in an on-line mode, copying from the mass storage, perhaps optical storage, to the magnetic disk, and using that as the transfer medium to our computing system?

Another question and one that has been brought up is that is there a requirement for duplicating the file in the form that it is being stored, or will duplication continue to be on the basis of sending out mag tape? Is the user community at large going to require these massive amounts of data, or are they only going to be held in a few major repositories like NOAA, GS, DMA -- and are they the only people who are going to require the mass storage? I just want all the users here and potential users to start thinking about these questions now, not tomorrow, and to start a dialog with the hardware developers so that we can make sure that the right technology for our purposes will be pursued. This technology is off in the '85, '90 time frame, I feel, at the very least. What we have right now is, at very best, some devices which are maybe a half step beyond being laboratory curiosities. We are a long way from a true integrated system for practical use. Thank you. (Applause).

DISCUSSION

DIGITAL HARDWARE, MASS STORAGE

DR. BOYLE: Thank you very much. I think we have now completed our panel presentations. The floor is yours.

MR. BILL ROSEMAN: Bill Roseman, Iometrics Corporation. I would like to point out for those of you attending this conference that there is a small company in this area down in Santa Clara that does have a video disk, prototype; it is up and working. I am sure that if any of you get down in that area that they would be more than willing to show you the disk in operation so you can actually see what this mystifying video disk actually looks like in operation. Thank you.

DR. BOYLE: Can you give the name of the company?

MR. ROSEMAN: The company is Videonics of Hawaii, Inc., and they are located in Santa Clara at 3022 Scott Boulevard.

DR. BOYLE: I am also sorry that Leonard Laub had to go, but he would also be very pleased, I am certain, to see any of you down in Los Angeles at Xerox. There are some very interesting things to be seen.

MR. ZERNIKE: The comment I would like to make is that maybe Leonard Laub would like to have all of you come down to Los Angeles. Please do. I definitely would not like to see all of you come to Biercliff because we do want to get this thing developed at some point in time. (Laughter).

MR. ZERNIKE: All I can say in answer to the comment from the company in Santa Clara: We do have video disks, and we can show them. We make them every day. I can tell you that as far as analog video disk is concerned, some of you may remember the end of the movie "The Sting." I can tell you that Robert Redford does an absolutely perfect job of falling down, because I have seen him fall down and come back up thousands of times now by showing the video disks to interested customers. I would rather not do it another thousand times, thank you.

DR. ZECH: I would just like to extend an invitation to all of you who might want to come to Melbourne, Florida, particularly at this time of year -- I assure you, the weather is beautiful. We would be happy to not only show you some disks, but we will show you an HRMR system, a wide band recorder-reproducer system, an acoustic traveling wave system, and some of the other wonderful mysterious things that are going on in electroptics. I think the point I am trying to make is that it is not that I am sure Fritz Zernike at Philips does not know how to make disks, it is not that Harris Electro-Optics could not come out with some sort of product. What we are trying to do is, first of all, find out what the problem is. Once we have established what the problem is, to try and find a systems oriented solution to it. Although I did not mention it, over the last year or so, part of my relationship with NASA has been to slowly accumulate information about real needs. NASA is a very big organization. As I am sure it should be clear now, Dr. Heard is pursuing a somewhat different approach than what I am suggesting for yet a different part of NASA. Thank you.

MR. JAMBERDINO: As long as everybody is inviting everybody, I would invite anyone, if you have the guts, to come to Rome, New York. (Laughter). There is about four and a half feet of snow, and I am running out of a time and place to put the snow. I would like to make some comments, however. The point was well made that one should define your requirements. We have heard inputs here from 10^{12}, 10^{13}, and 10^{16} kind of memories. You people are unique in that you have these kinds of requirements. I also mentioned the fact before that it took 30 years and three billion dollars to bring the magnetic technology to where it is today. I do not assume that it is going to take that much, but unless you people give us the requirements that you need and back it up with money, we will stay here and tell you all the beautiful things that can be done in the future. There is a very big problem in terms of defining your needs and backing them up with money. That is all I have to say.

DR. BOYLE: Yes. It needs cartographic thinking. I myself like the idea for automated cartography, I am not talking about LANDSAT imagery -- only chunks of 10^{10} bits. Could I quickly ask Harry Heard if we will be seeing anything of this down at the NASA Center when we go on Friday?

DR. HEARD: Yes. We will open the Unicon and let people actually look at the various parts of it so they get a feel for the technology.

DR. BOYLE: Thank you.

MR. HAL MOELLERING: Hal Moellering, Ohio State University. I have a general question which I would like to address to the members of the panel. There was a recent issue, special issue of the Institute of British Geographers. I think it was Volume II, No. 1, new series. It was devoted specifically to cartography. The lead article in that volume was by Robinson, Morrison, and Merky. The title of the article was "Cartography, 1950 to 2000." They were reviewing the developments in cartography, some of the innovative developments and techniques in terms of computers and so on. They were making some suggestions and predictions about some of the products of the future. One thing they mentioned which I have not really heard here, and that is the type of product called the orthophoto map. Now, one of the problems that has been discussed here is the cost of digitizing. In orthophoto maps, you are essentially processing the information optically all the way through. Now, it is true, if you are going to produce orthophoto maps, at some point you are going to have to put annotation on the map -- names, things like that -- which cannot be gotten, say, with their photos. So, there is some digital information processing going on. However, if you do produce things like orthophoto maps, it seems that then you are essentially finessing, or perhaps might be able to finesse, a large part of the digitizing process, whereby you are taking the information you are gathering at some point, air photos or other sources; you are digitizing into the numerical domain, then processing it into the numerical domain, and then re-transforming it back into the graphic domain, and then produce the map. Is it not possible, say, using something like orthophotos to maintain your information in a two-dimensional optical state instead of some kind of linear numerical state, and thereby -- perhaps we shall say "finesse" a good part of this problem of digitizing or scanning, however you like to call it?

DR. BOYLE: Would anybody like to respond to that? I think you have beaten them.

MR. JAMBERDINO: I think we need the definition of orthophoto.

MR. MOELLERING: An orthophoto map, an orthophoto is essentially a type of air photograph which has been rectified optically to look as if it is orthogonally viewed from all points in the image. That image then could be printed on a map, and you could add other information like important highways or, say, political boundaries, names, things like that which would not appear in a photograph. But what you have done, you have gathered this information with an optical system, you have kept it in that domain. You are obviating a lot of the problems that you might get from making these transformations. And, digitizing is essentially a transformation from some kind of graphic domain into a numeric domain.

MR. PALERMO: Not addressing the problem of actually going to an orthophoto type of a storage or medium, the problem basically driving DMA today, and therefore driving governmental labs like RADC and ETL, is not the production of graphics. They have had digital systems in-house for a number of years, and in some cases, like Hydro Center just produced their first digital production graphic. It is the call for other digital cartographic products which are necessary for the systems being used within DOD, and DMA is one of those agencies that has to produce this data. It is not a question of whether we can get around it with some other product. That question has already gone by. Most of DMA's problems now in the production of these products is how do we most economically produce digital data? It is not a question of whether we are or whether we are going to get around producing digital data. It is, we are doing it, we have to do it. What is the best way of getting it? The data has to be stored. What is the type of system for the future that is going to have to store these amounts of data? The thing that industry and the commercial field has to answer above and beyond that is, is it necessary for them to go to a digital data? The DMA has been tasked that they will, and they are. That is the basic difference driving all of these systems, many of the government DOD labs and the other areas.

MR. OPITZ: I would like to make a comment on that, too. The Hydrographic Center, in addition to supporting the fleet, also has a charter to support the Merchant Marine. And we sell our products, which are currently hard copy products, to the Merchant Marine, and the digital products are mostly going to support advanced weapon systems. But I think it is a big mistake for us to look and think that we are going to get away with producing only hard copy products in the future. There are more and more signs of the user, of the civilian user requiring a digital product. In the hydrographic area there are coming along both collision avoidance systems and navigation systems which are going to require digital charts. There have been experiments, some systems have been sold, where data was supplied by the vendor. The Navy has been looking at collision avoidance systems using digital charts. More and more, at least in the hydrographic area, the digital product is going to become a requirement. I think that maybe all the mapping agencies are going to have to look at the point where the digital product is going to become more popular and more demanded than the hard copy product.

DR. BOYLE: This means that both your ends will be digital: Your collection of data and your output will be digital.

MR. MONTERO: I would like to pose not a question, but a thought. And that is, with the capability of extremely fast mass digitization as we heard this morning, and the capability of virtually immediate processing of those data, is not perhaps it more worthwhile to consider re-scaling original source material and storing that rather than spending enormous sums of money for mass storage devices? Any comments?

DR. BOYLE: Would anybody like to comment on that?

MR. OPITZ: I think a lot of the same comments apply.

MR. ZERNIKE: The comment I would like to make, as I said before, I do not want to quote prices, but certainly the kind of mass storage that we are now talking about to customers in other fields will not go past -- and I think I am being quite generous -- will not go past a hundred thousand dollars for the recorder and $50,000 for the player. As a matter of fact, I think they will be quite a lot cheaper than that. That includes the interface but does not include the computer, quite obviously. Again, if you compare that to what Dr. Heard was talking about, that would not be mass storage. It would be small storage.

DR. BOYLE: I think we have to look at the job we are trying to do. You must do your cartographic thinking. We are talking here about things that are possible to do at this time.

MR. GENE SLOTTOW: Gene Slottow, University of Illinois. I just wondered, in considering these various memories, you might remark on how you compare the electron beam memories, which I think did not get too much discussion this afternoon, along with these other mass memories.

MR. JAMBERDINO: There are a very few electron beam capabilities in the industry now. We have tweaked several. You know the work GE is doing on Beemos, I think Datamation is another company; CBS is no longer in the business. It went from CBS to EPSKO to CARSON-ALEXIO, and we lost the people that did it. Image Graphics is doing some work in this general area. I think the fact that it has to be enclosed in a vacuum type of a system creates a difficulty, and how many bits can you really store and how many tubes, if you will, are going to be required. This is still a question. I think we are still in the exploratory domain at this point in time.

DR. BOYLE: Gene, I wonder if you could just comment on this work at the University of Illinois where you have been doing some experimental work -- on the use of optical disks in teaching systems. I was very intrigued by the comment I had from there, that one of the important things was to speed up the access to less than a hundredth of a second, because students just could not stand to wait for a tenth of a second for their answers.

MR. SLOTTOW: I do not think that last one is quite right. When you get to a tenth of a second as far as a student is concerned, it is instanteous. If you wait a few tenths of a second, then that becomes noticeable. Most of the design in the Plato system, for example, at the University is essentially built around the idea of a one-tenth of a second response time. There is not much work, I think, in the use of disks so far in educational systems. The disks are primarily used for just archival storage and for lesson materials. For a person working on-line, he is really interacting with the computer with a very, very fast transfer memory, and working at something like a hundred million to six-hundred million bits per second transfer rate between the main memory and the storage memory, the time sharing memory. That is one of the reasons why you can support 500 to 1,000 people with that kind of response time.

There is some work going on in video disk investigation, more or less along the lines of the discussion this morning and early this afternoon, in which holes are basically produced in metal film. This will provide a rapid access support memory to some kind of future terminal.

DR. BOYLE: Thank you. Waldo?

DR. WALDO TOBLER: At ten meter resolution, and depending a little on how you quantize it, ten to the 13 is roughly adequate to have the whole topography of the earth stored. In the United States there are approximately 35 to 40,000 topographic maps now in existence, and I do not know the comparable number for the whole world; and, of course, there is the bathymetry and so on. Could you make an estimate how long it would take to get that information into one of these mass storages? Because, as you recall, Shimmof said that at current 6,250 bits per inch tape drives, it would take 30 years, 24 hours a day, to fill up one of these memories. Is this a reasonable problem? Is this a problem?

DR. BOYLE: All these things are problems, yes. (Laughter). I did some estimates on the 1:24,000 series, the topographic quad series for the states, and it looks as if a good operational period of time for digitization was five years. This was with acceptable cost and high data quality. I think to answer that "off the cuff" would be asking for trouble. Was there another comment?

MR. TOWNS: My name is Towns from Graphics Technology in Rockville, Maryland. We all know the RS-232 interface that is used in machines talking to each other in a standard, ASCII formats, and so forth. Is any sort of planning or thinking going on along this line to try to standardize the methods by which such obviously highly technical interfacing is going to have to be done for these new machines? Any planning being done for the future so that, if we do have a very fast recording holographic system, we can standardize for those of us who have to make and store data?

DR. BOYLE: The interface will have to be directly into the storage system. I do not think you could use one of the slower standard interfaces for this. It will be special for a particular minicomputer. I see a mini-computer being directly attached by its own interface, and then that mini-computer will talk to something else by one of the standard interfaces.

SOFT COPY DISPLAY

DR. BOYLE: Ladies and gentlemen, we are now going to talk about the soft copy displays needed in cartography, looking at it from the hardware side. We had a preliminary preview of this in the Monday discussion with Waldo Tobler's group. We think we have to define this more closely in engineering terms in order to find out our needs. This is very much a matter of making certain suggestions to you to get your reactions -- what do you want in cartography?

Mr. Pucilowski from the U.S. Electronics Command will unfortunately not be able to come. CDC was also not able to come. I do not know whether Pucilowski could not come because he did not like the spelling of Ft. Monmouth, which came out in the program as Ft. Mammouth -- (Laughter) -- but, at any rate, we have two very expert people here. We have Gene Slottow, who is certainly one of the fathers of plasma displays; and Bob Durbeck from IBM, at San Jose, who has also done some very exciting work in new types of displays.

Before they start I will give some of my thoughts on this matter.

The workhorse of most cartographic interactive display operations at the moment is the Tektronix series, particularly the 4014 display. Very good quality displays, but they do have limitations in their ability for cartography. We have to use the lights dimmed in the room; they are not quite large enough; we cannot overlay an optical image -- that is, an existing map separation and a digital one, because the linearity of the cathode ray tube is not exact enought to enable this to be done. This is one of the reasons that I have felt that the plasma display, where we have a whole array of mechanically fixed pixel points, enabling non-linearities to be programmed out, has considerable advantages for the future of the map community. We can have large size, even full map dimensions. Another advantage of the plasma display, is the fact that it is erasable point by point, just the same as it is writable point by point. It is a storage device, and you can enter information in vector form and then scan it to output in raster television form.

There are many interesting and useful side issues relative to the different displays which I hope will come up and I hope we can develop in our discussion. Ideas of requirements are certainly much more vague in this than in the digitizing and storage areas. We need your help, we want your comments to start to move. There are many possibilities, but the needs are not quite clear.

There is another area of displays which I do not think either of the gentlemen here will be talking about, but has recently been coming to the fore. Many people are now using map information in geographic information systems and have said to me, "I have to put on a show of my thematic maps, and I need one of those big Sony or Advent projection displays." I say, "Well, you know, it is not very good resolution" -- "That doesn't matter. We'll take the lower resolution, but we know that this method goes over well with a crowd of people who just want to see general imagery on a geographic information display basis."

I do think there is now a requirement coming up for these relatively low cost television projection display units tied into a mass memory. It has to have its own refresh memory, of course, to make it equivalent to the storage display, when tied onto a computer. I have not actually seen one myself. There are many such as the Ramtek display, which uses an ordinary colour television monitor. Presumably, these can be attached to a projection unit.

Maybe Dick Clark could say a little more about the unit they have at the Experimental Topographic Laboratory, where they have one of these Advent displays. They are using only two colors of the three color projection tube, the green and the red. They feed these from the computer and if you sit in the audience wearing red and green glasses, you see three-dimensional images generated by the computer on the screen. We are not quite certain where the use would be, but it is delightful to watch, and, again, maybe the method for geographic information systems and thematic maps which have to talk to politicians and the general public.

I have learned in my travels that much depends upon the presentation of data to the uninformed user if geographic information systems are going to go. They do not really like these small displays that have to be examined closely. They want to stand back and look at it on a wall; they do not mind if it is not quite such a good image.

I am now going to ask Bob Durbeck to start. He is from IBM in San Jose. He is going to open the discussion and tell you about some of the work they have been doing. I think he is also going to ask you questions. He is going to give you ideas and say, "What do you think? What would you like to do in these areas?"

DR. ROBERT C. DURBECK: Thank you very much. First I would like to say that it is a pleasure for me to be here today. I also want to make it clear that I am very new as far as cartography goes. My only direct association to this field prior to your conference here starting Monday is that I worked as a surveyor for part of one summer. To calibrate you on my background and interests, I am manager of the Exploratory Technology Department in San Jose Research at IBM. We have been involved in such things as display systems (which I will be talking about today) in magnetic recording, and in beam-addressable recording (similar to some of the work and projects you heard about earlier today). We have also been involved in printing, image processing, and even some semiconductor work. I hope to share with you some of my overviews on displays, which may be conditioned a bit by my involvement in all these different technologies and efforts.

As I said before, Monday was really my first introduction to the problems and issues you face with automated cartography. I find some of the decision-making processes (such as whether you automate or how you would go about it, what equipment you would select and so forth) are very similar to some of the decisions we go through in many technical areas. In preparation for this panel discussion, I listened very closely to the earlier panel discussion on Monday on display requirements for cartography. I must admit, at the end of that discussion, although I felt I had learned quite a bit about some exciting work at JPL and the University of Southern California, I really did not learn too much about what your display hardware requirements really are. For example, Carl Youngmann was sufficiently vague in his presentation that I find myself in a very unique "carte blanche" situation where I can guess what you really want. I will be talking more about that later.

Following our panel presentation here, I hope we can open this session up into a dialogue of what you think you would like for large-scale, high-resolution color displays, and what possibly could happen in technology in the next decade. I will allude to some things that may be appearing on the scene. I would also like to share some of my initial guesses of what you could use for displays fruitfully with you, but I will spend most of my time discussing a group of display technologies which I think have the potential of being useful to you. Let us assume that you build up your display data bases and that you have all of this information in your data files. Let us also assume that you wish to temporarily exhibit a map format with overlays and so forth before you commit this to hard copy--perhaps you never want a hard copy, thus, the term used earlier, "soft copy." I am presuming (and guessing) that it would be very valuable for you to have a very high resolution display, with many millions of picture elements (which I will shorten and call PELS), with several colors as a minimum, with gray scale, and with overlay capability (either slides or other types of overlay). My basic premise is that a group of technologies that could basically offer this capability are those involving light valves. I believe that they offer a very promising scenario for future high resolution, high picture content, displays.

What do I mean by a light valve? The foils the projectionist is using here are static light valves. The slides used in the Kodak carrousel back there are light valves. The type of light valve I am talking about, though, is a dynamic one. It can be changed rapidly. You can write on it, erase it, and put new images on it. You can project it, either onto a screen this large, for example, if you so desire on a front projection screen, or you can back project it on to a smaller screen for direct viewing. You all have seen numerous examples of the latter; some slide projectors come equipped with a back projection screen.

Maybe now we can have the first foil (foil No. 1). I will start with foils and will be moving to slides and back to foils, so hopefully it will not be too confusing. This first foil is meant to show the questions I had (and have) concerning what type of displays are really needed for cartography. I am not now considering the type of displays that are used for interactive design. What I am talking about here are displays where you will want to display a large map or large parts of a map.

Questions. What type of speed do you need? How many picture elements or PELS do you need per second? What is minimally acceptable, what is the desired speed? How many colors and hues and gray scale levels do you really need? What size of display do you want? How about the total number of picture elements? Are a million satisfactory? Probably not. Are ten million? Perhaps you need 50 million. These are the types of questions I would like to get back to after we have had our formal presentations here--in terms of a question and answer period with the audience.

Could I have the next foil (foil No. 2), please. Let me just say that you are not alone, as they say in the science fiction world. There are a lot of other potential users of displays who have the same type of questions and probably have the same type of generic, high picture content, display needs that you do.

Let's look at the area of computer-aided design, for example, for engineering drawings, for laying out semiconductor chips where they need very high resolution (where we are talking about tens of thousands of circuits on a chip), at computer simulation, special document distribution, and computer-aided instruction. We saw a slide presented earlier that typified the latter type of application. For electronic mail, where you may have a letter transmitted--not physically--but electronically, you may not really want a hard copy. You may want to only view it on the display screen. And it may contain NCI--"non-coded information," may contain a picture, or may have a signature. The total picture element content needed to display NCI is quite high.

Let's consider business displays and conference room type applications (just like you are looking at right now). You may want a similar display in a conference room where you can dynamically change the image. The next level above this is to go into teleconferencing, where you can have groups of people talking to one another across the country, for example, and where you can each be looking at the same display and be updating it in real time. Other potential applications include, of course, military war room--even newspaper composition, where newspaper editors would like to see what the page of the newspaper looks like before they go to press; you can project up an image of the page for editing. Light valve projection technologies are capable of doing these types of applications.

In the field of scientific data presentation, one of the key possible applications there is in seismic data for oil drilling and, of course, there are many others.

So, you are not alone. The encouraging word here is that I think over the next decade there will be technologies that will deliver high resolution color displays, not only for cartography but for all these other applications. The total aggregate of applications will mean it will be economically feasible for these types of displays to appear at a reasonable cost. May I have the next foil (foil No. 3), please....just a little bit of background about the range of displays that are potentially possible. I have taken my own classification here, starting on the left (in foil No. 3) from the low end displays (down to one or two line type prompting displays) all the way up over here to the right where you have very high performance, high quality systems that require very new display technologies. In between we have the bulk of the modern display applications today: highly interactive graphic systems (using light pens), Tektronix type storage tube, and many of the commercial alphanumeric type CRT displays.

Now, what technologies span these ranges of applications? Could I have the overlay on that foil now, please. This combined foil (included in foil No. 3) is a little busy, but hopefully it will be readable. Let's talk about the very low end displays for just a moment (and then I am going to drop that particular area and not talk about it for the rest of the day). Typically here one thinks of light emitting diodes, electrochromic displays, liquid crystal displays, and some mechanical type displays. Here we are talking about a few dozen or at most a couple hundred characters. As you get into the low end graphics and interactive systems, you find that the CRT, our good old enclosed glass tube, is the predominant technology there. Also, a relatively new technology that I think Gene Slottow will be talking about a lot more in the next talk is the gas panel technology shown there. That technology is growing, and is the flat panel display for certain application area. In the region where we get into highly interactive graphic systems and medium quality non-coded information, the CRT is still king. It represents at least 90 percent or maybe 95 percent of the total. For comparison sake I have shown TV quality with the arrow.

Now the gas panel, obviously, can be and has been extended up to much higher PEL content and greater utilization than shown in the foil, but it faces severe competition with the CRT. The CRT can be extended somewhat, and one of the types of extension is the Tektronix storage tube, which provides good resolution capability, and is becoming extensively used.

But the generic technology class which looks like it could expand out further, out into the greater demand and needs for higher and higher quality, more function, color, gray scale, so forth, seems to be high resolution light valves. I will be talking about these light valves for the remainder of my presentation. It is my opinion that these light valve technologies will be the area to really look for in the future for the types of displays that I think you will want in cartography.

Could I have the next foil (foil No. 4), please. Let me go over just a few of the advantages of projected light valves in general, and then I will get into some specific technologies within the light valves category that have been developed over a number of years, and then I will lead up to something new that looks quite interesting today. Basically, when you have a light valve, the same single technology and hardware can be used to make a variety of display sizes. You can have anywhere from a ten inch by ten inch to a wall size display--same basic technology, depending on just how you design your optical projection system. You can have either wall or back projected displays. If the light valve resolution is high, you are almost unlimited as to the number of picture elements that you can have. I will put some numbers on that a little later. It is quite high compared with what we are used to today. If you project, you obviously can always have image overlays. You can have slides as overlays. You can have previously written images that have been developed used as overlays. You can have color by co-projection. It is also possible to implement a moving cursor with a joy stick.

If you have non-structured light valves (and I will get into what I mean by that--but just remember "non-structured," means no structure in the light valve) then the number of PELS is really only limited by the addressability of the projected light valve. In other words, the technique with which you write on the valve and the acceptable size and cost of the projection optics may be more limiting. The light valve itself, as will be shown, is basically not the limiting factor.

May we have the next foil (foil No. 5), please. Let me just take you through a few of the typical erasable light valve technologies that have been developed over the last half decade. I do not pretend that this list is exhaustive. For example, I will not talk about the GE projection system, and I will not mention the Sandia work on ferroelectrics. But let me start first with the Deformographic system that has been developed at IBM, and that some other people have worked on, too. The FAA has purchased a few of these systems developed by IBM, and have used them in an experimental mode for air traffic control. Essentially, the technology uses an E beam, like in a CRT, which writes on a dielectric elastomer package, and the resulting charge deforms the elastomer. Then by reflecting light off the elastomer through a Schlieren optical system an image is created on the screen. I will say more about that later.

There has been work done by Westinghouse on large arrays of micromechanical deflectors. Again an E beam is used to develop a charge on the little deflectors. When you shine a collimated beam of light on those deflectors that have been deflected due to the charge, you direct light onto the screen. Thus you can write an image in that way. Xerox has worked for many years on the Ruticon system, which is another variant. They optically image a CRT, or a TV type system, onto a photoconductor coupled with an elastomer. Then the phenomena is very similar to the Deformographic system, just a different way of introducing deflections into the elastomer. There also has been work done, most notably by Hughes (but also by Xerox), on an optically addressed liquid crystal light valve, and Hughes has a commercial product out today based on this technology. Basically they image a CRT, like a TV image, via fiberoptic face plate, onto a photoconductor which acts as a voltage divider to selectively switch the liquid crystal. It is not quite the same technology as used in the liquid crystal watch, but it is similar in concept, and I will mention more about that later.

More recent work has been on laser-addressing liquid crystal cells, where you thermally write spots on the liquid crystal using the power of the laser. IBM has been working on this approach, some of this work is in my area. Western Electric has also followed up on some of the earlier work in this field at Bell Telephone Laboratory. It turns out you can use either semiconductor lasers (little gallium arsenide lasers which are about the size of a grain of salt) or you can use fairly large gas lasers to address these liquid crystals. You thermally write with the laser on the liquid crystal cell. You can erase images very rapidly with an electric field. I will be saying more about this technology later.

May I have the next foil (foil No. 6), please. This is a pictorial of the Deformographic system, the first one that was mentioned on the last foil. Here you address the backside of a dielectric disk--I believe they actually use mica. You deposit a charge with a deflected CRT beam. This charge then creates minute little deformations on the elastomer on the other side. If you image with a light source as shown, and have a Schlieren optical projection system, then these minute deformations on the elastomer show up as black on the screen. That is the way that technology works. The FAA has used several of these systems.

Let me say that this system is very good in a vector mode. You can get tens of thousands of vectors up on the screen. It is not quite as good in a raster mode because of the adjacency effects of the minute deformations; they tend to write one another out. But in a vector mode you get a very large number of vectors.

May I have the next foil (foil No. 7), please. The next system I will discuss is the Westinghouse mirror matrix display. What they have is a large array of very small deflectable flaps. These are 50 micron in size or 2 mils, if you feel more comfortable with English units. Essentially what they developed was a technique based on semiconductor processing technology to etch out these tiny little flaps. They are like tiny little toadstools, only they have cuts in them, if you look at them from on top. An E beam then addresses these flaps and deposits a positive charge (because of secondary emission it actually becomes a positive charge rather than negative). When you develop this charge these little flaps deflect because of the capacitive effect.

Could I have the next foil (foil No. 8), please. When these flaps deflect, they redirect the projection light such that it reaches the screen whereas it normally doesn't. Let me show you the optical system (foil No. 8). Here you have the light source. Here also is that array of mirror matrix targets I was just referring to. If we take an undeflected little valve or flap, the projected light is reflected back and it hits the stop. It hits the mirror and gets deflected out, so that the light never reaches the screen. Now we look at a target element that is deflected; the light is deflected around this light stop and gets to the screen. Thus, the image of the flaps that are deflected appears on the screen. Westinghouse worked hard developing this, and came to a fairly fruitful conclusion: It is a viable technology. The difficulties come about when you start to require up near a million PELS or higher. The yield on making every one of those little flaps work gets to be a problem, and also the contrast ratio for adequate light levels on the screen becomes a problem. But, no doubt about it, the technology provides a fairly high overall resolution system.

May I have the next foil (foil No. 9), please. This is the Ruticon system of Xerox. Essentially, shown here is the projection light source, and the CRT which is imaged onto a combined photoconductor-elastomer system. Everything else is very similar to the other projection systems. Where the light source rays are undeflected (where there is no modulation or no deformation in the elastomer) no light gets to the screen. Where deformed, light will get past the stop and be imaged onto the screen. I have seen some very good images based on this technology.

May I have the next foil (foil No. 10), please. The Hughes system is a little more sophisticated in terms of modern thin film techniques in the sense that it requires a many-layered photoactivated liquid crystal cell. Essentially what they have developed is a dielectric mirror. That is, a mirror that is non-conducting. They project an image onto the photoconductor. Where the light impinges, the resistivity of the photoconductor is reduced, and this creates a charge pattern on one side of the dielectric mirror. This charge pattern then appears across the liquid crystal, locally changes the birefringence of the liquid crystal, and the charge pattern appears as a projected image. The cell has no storage, however, so that you have to have the subject image on at all times when you want to view it in projection.

What is the advantage of doing this? Well, you can project the image from a small CRT, say, a one- or two-inch CRT, with which you can get high resolution and many spots very economically. You also do not have the problems of linearity and so forth you do with high divergent CRT tubes, and the result is you can project a small image up much larger. Thus, it is a way of converting a CRT into a large projection screen display fairly economically.

Hughes has a unique way also of introducing color directly into this technology, but I will not get into that today.

May I have the next foil (foil No. 11), please. Now, how do you in general introduce colors from light valve displays? Well, you do it by super-position of images. The schematic on this foil is that of the Hughes approach, but it is a fairly well known technique. If you have a white light source you can have three targets with green filters, red filters, for example, and blue filters--three primary colors--and produce many colored images, depending upon what you are writing on each of the three channels (which could be considered the light valves in this case). If you had a two-color system, for example, with just two filters, you can produce either of the two primary colors on the secondary color, or black on the secondary, or black on either of the two primary colors. Thus, you have those options even with just two channels or light valves. If you go to three light valves, your color combination possibilities go up substantially.

May I have the next foil (foil No. 12), please. The technology I want to spend a little more time on now is one we are presently working on as a research project. Essentially what we do is use a laser to thermally write on a liquid crystal cell. Here on the left side of the foil is the laser beam. Here in the center is a liquid crystal cell, where the liquid crystal material is sandwiched between glass plates and two conductive coatings; one is transparent for projection. When you align the liquid crystal by an electric field, all the molecules are lined up in the same direction and the liquid crystal looks clear, like water. When you thermally address the cell with the laser, you locally heat it and it then rapidly cools and provides scattering in the given area (focal-conic structures). Where these molecules are completely disoriented, they scatter light very well at angles of up 20 to 30 degrees, typically, so that when you project the cell onto a screen, those spots appear black. You can erase the cell by just applying an AC field across it for 10 to 20 milliseconds.

Could I have the next foil (foil No. 13), please. I am going to, in a few moments, show you a slide of some light valves fabricated based on this technology, plus some slides of images that have been projected from these light valves. But first I want to cover what one can do with this technology, where we are today and how far we feel we can extend it. To begin with, you can write these microimages with spots as small as 6 microns, although we typically work with 12 micron spots. You can project this image very large, of course. You also can have the overlays that we talked about before. The fact that you have an unstructured target means that the number of PELS is not limited by ultra high linearity requirements on the addressing beam. If instead you have individual deflectable tiny elements or flaps that you address with a beam; you have to make sure you hit those flaps consistently on center or you introduce Moiré patterns. Here, with a non-structured light valve, you do not have that problem.

We are aiming this technology to provide at least a million picture elements or above. One million is the lower end. To date, we have demonstrated up to three million picture elements. We see no reason why it is not possible to achieve at least 16 million PELS. If you exclude any of the potentially unseen problems of addressing the liquid crystal cell, we feel that technology should be capable of supporting up to 50-60 million PELS. We have demonstrated 36,000 characters. That is about the number of characters on a newspaper page. The technology will do limited gray scale and limited color. Right now we have a three-color system plus black. There is inherent storage in the display element. The display image will remain as long as you want, but can be erased rapidly. It does not require an expensive refresh buffer like a CRT. You really only have to have enough buffer to cover the next line or two, so there is great economic savings there.

I would like to switch now to some slides which show what one is able to do with this type of technology. These images are representative of light valves in general, but these happen to be done with the laser liquid crystal technology. First slide (slide No. 1). This is one of our people in the laboratory, Anthony Dewey by name, with our first display demonstration. In the slide you can see one of our early images. In the pair of tweezers that you can just see, he is holding a gallium arsenide laser that writes this entire display. A very tiny thing. The package that goes around it is the size of your fist, but the galium arsenide laser is very tiny.

Could I have the next slide (slide No. 2), please. This slide shows you an example of one of our light valves. Included is a quarter for size reference. There are almost 20,000 characters written on this cell, 16 pages of about 1200 characters each. The PELS written look milky here. When we project them they look very black and dense on the screen. In fact, depending upon the optical projection system, we have shown contrast ratios up to as high as 40 to 1. However, practical engineering trade-offs indicate you would probably be operating at more like 15 to 1. These are reflective cells. We write on one side of the cell, project off the other. We also did some work on transmissive cells. This type is also shown on the slide. It is a completely different technology but gives basically the same results.

For those of you who have any background in liquid crystals, we are using the class of smectic liquid crystals. I won't say any more about that, except that when the liquid crystal molecules are uniformly lying in one direction, they are very transparent. When we put them in the scattering mode, via the thermal writing process, they form a focal-conic texture.

Could I have the next slide (slide No. 3), please. This slide shows the quality of characters obtained with the first display demonstration unit. May we have the next slide (slide No. 4), please. This is the first of several illustrations of some of our early work. I am sure you recognize this gentleman. This slide gives you an idea of the contrast we can get from this display. This was done with a million PELS display, a thousand by a thousand PELS. May I have the next slide (slide No. 5). This is a type of resolution chart. This was scanned data. We scanned it much in the same way you people do with photographs in cartography. We scanned it, digitized it, stored it on a disk file and wrote it directly out onto the liquid crystal cell. Again, from this slide you get an idea of the attainable resolution and of the contrast ratio from this image.

Next slide (slide No. 6), please. As shown on this slide, we can introduce color. I mentioned before that this was done with two liquid crystals. You can also do it on the same liquid crystal with two separate images and protection systems. This shows that what you can do by having only two primary colors, in this case green and red. You also have the secondary color as background and you can have black in addition to all of this. As shown, it is possible to get nice, crisp colors out of this technology. If you don't like that particular color combination--may I have the next slide (slide No. 7)--we can write one in another color. You can change colors rather rapidly just by changing the color filters, and we can do that with a turret arrangement. May I have the next slide (slide No. 8), please. This gives you an example of many characters on the display, and shown here is only 14,000 characters. This is, again, a million PEL display. These pictures were taken about two months ago. Within the last month we have upgraded this system to 2.36 million PELS, and have displayed 32,000 characters.

May I have the next slide (slide No. 9), please. This shows our second demonstration unit along with the liquid crystal cell used. Next slide (slide No. 10), please. Here again is how we created the colors I showed on the earlier slides. It is a subtractive color system so that if you write an image on the green light valve, and if you write a second image on the red one, and you put them together, what do you see? Well, these characters appear red, these characters appear green, and when both images are co-written, they appear black.

Next slide (slide No. 11), please. This again was a scanned image. There is no gray scale here. It is done strictly by pseudo half tone, by dot clustering. We artificially create a larger dot by using many smaller dots to simulate the technique used by newspapers and magazines. May we have the next slide (slide No. 12). That happens to be the building I work in, and it gives you an idea of another type of display we can project. That finishes the slides. Could I have the last foil (foil No. 14), please. Let me just say to those of you who might be interested in some of this work, there are several reports available already on this technology. The two that are out thus far include one in the SID proceedings of last year, and there is also an updated report in the proceedings of the Society of Photoptical Instrumentation Engineers. In the next SID proceedings there will be two papers related to this technology.

Thank you.

DR: BOYLE: Thank you very much. That was most interesting. (Applause.)

Let us have Gene Slottow have his talk now, and then we will go to questions after that. I am certain there will be quite a number of questions about this first talk as well. Gene?

Some Key Questions

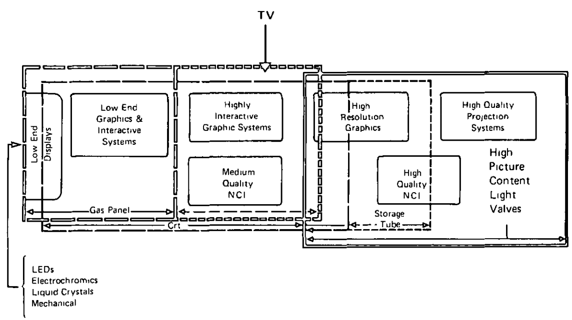
- SPEED (pels per second) – ?
  - minimum acceptable speed
  - desirable speed
- COLORS AND HUES – ?
  - minimum number acceptable
  - desired number
- SIZE OF DISPLAY – ?
- NUMBER OF PICTURE ELEMENTS (pel) – ?
  - minimum number acceptable
  - desired number
- $ – ?

Foil No. 1

Other Potential Users of High Resolution, Color Displays

- Computer Aided Design
  - engineering drawings
  - semiconductor chip layout
- Computer Simulation
- Special document distribution
- Computer-aided instruction
- Electronic Mail
- Business Data Display
  - conference room
  - board room
- Scientific Data Presentation
  - seismic data
  - medical teleconsultation
- Teleconferencing
- Military war room
- Newspaper composition

Foil No. 2



Foil No. 3

Advantages of Projected Light Valves for Large, High Resolution Displays

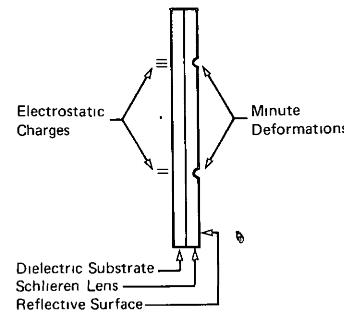
- Single technology and basic hardware can be used for a variety of screen sizes and shapes
- Wall or back projection
- Very high number of picture elements (pels) possible if light valve resolution is high
- Overlays, color by co-projection, and cursors easily implemented
- With "non-structured" light valves, number of pels essentially limited by addressability of projected light valve and acceptable size of projection optics.

Foil No. 4

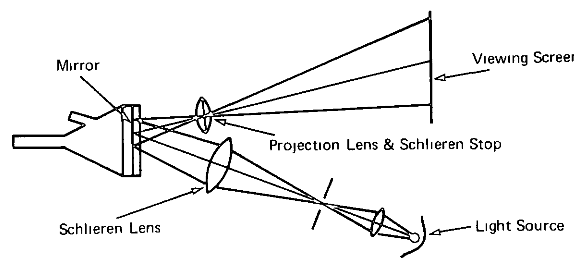
Light Valve Technologies

- o Deformographic
  - – IBM
  - – E-Beam/Elastomer
  - – Better for vector mode than raster
- o Micro Mechanical Deflectors
  - – Westinghouse
  - – E-Beam/Light Valve Matrix
- o Ruticon
  - – Xerox
  - – CRT/Photoconductor/Elastometer
- o Liquid Crystal Light Valve
  - – Hughes, Commercial Product
  - – CRT/Fiberoptic Face Plate
  - – Photoconductor/Liquid Crystal
- o Laser Liquid Crystal
  - – IBM and Western Electric
  - – Ar or GaAs Laser/Liquid Crystal
  - – Thermal Write Process, Field Erase

Foil No. 5



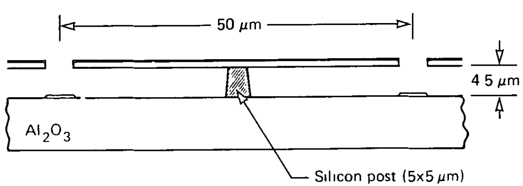
a) Deformographic Mirror Structure



b) Schlieren Optics

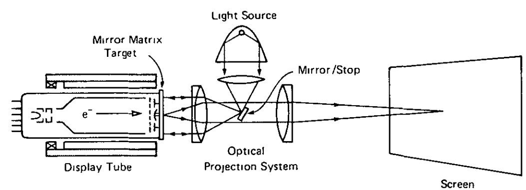
Foil No. 6

Westinghouse Mirror Matrix Display



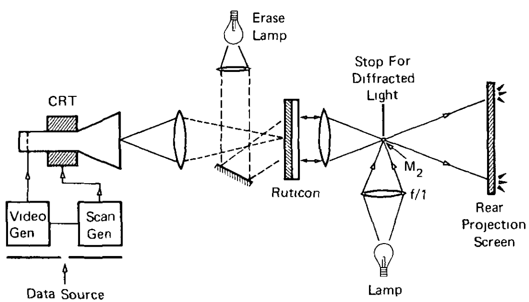
Foil No. 7

Westinghouse Mirror Matrix Display



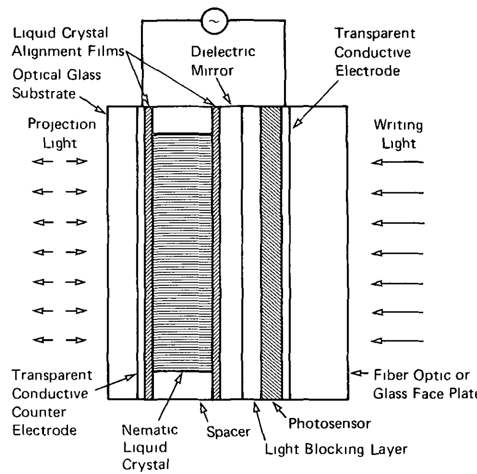
Foil No. 8

Ruticon Display System



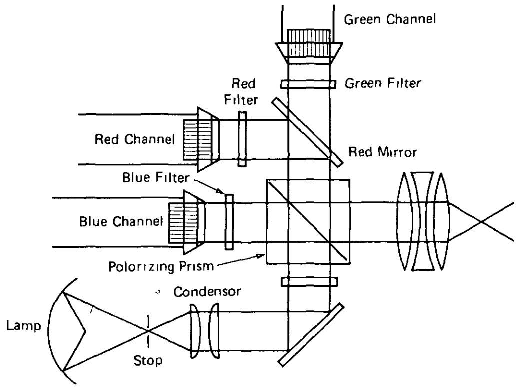
Foil No. 9

Hughes AC Photoactivated Liquid Crystal Light Valve



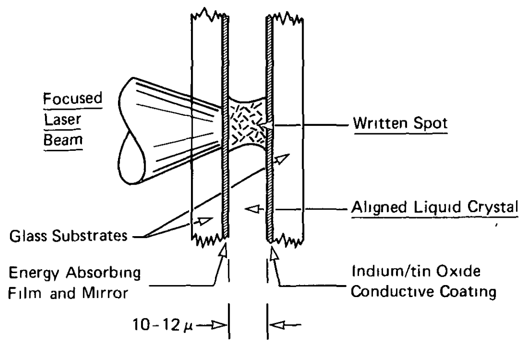
Foil No. 10

Schematic of Liquid Crystal Light Valve Color TV Projector



Foil No. 11

- Approach is to thermally "write" on the liquid crystal Rapid cooling of the material after heating leaves liquid crystal in a disordered state. (storage)
- The disordered state scatters light
- Electrically erasable



Foil No. 12

Laser Liquid Crystal Display

Characteristics of Technology

- Microimages written on liquid crystal cell with laser
- Projection display (wall or back projection screen)
- Graphic or pictorial overlays
- Unstructured display element allows very large number of pels without ultra high linear performance demands
- Aimed at high end; $\geqslant 10^6$ pels
  - up to $\sim 16 \times 10^6$ pels with single gas laser
  - projection optics and L C. cell will support up to $\sim 6 \times 10^7$ pels
- Up to 36,000 characters demonstrated
- Grayscale and limited color (three colors plus black)
- Inherent storage in display element, no refresh needed
- Selective erase – easily implemented

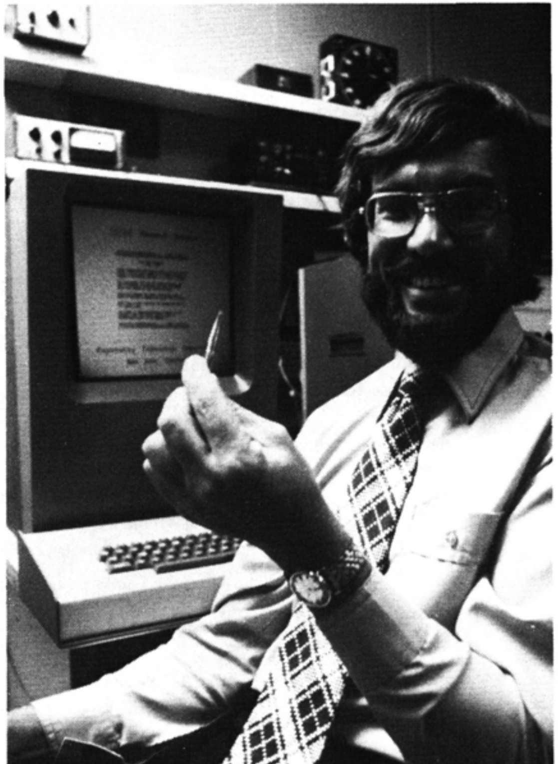
Foil No. 13

References:

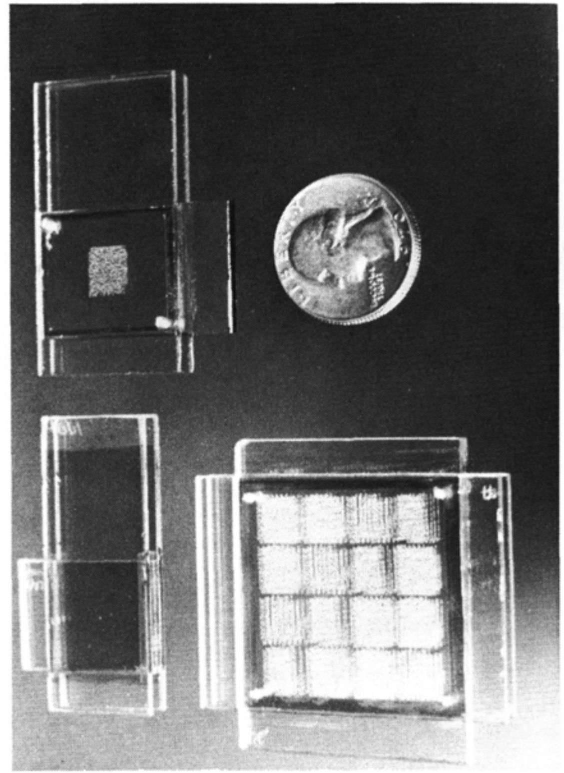
Dewey, A.G., et al , "A 2000-Character Thermally-Addressed Liquid Crystal Projection Display", SID Proceedings, May 1977.

Dewey, A G , et al., "A Laser Addressed Liquid Crystal Projection Display", Proceedings of Society of Photo-Optical Storage Materials and Methods, San Diego, August 25-26, 1977

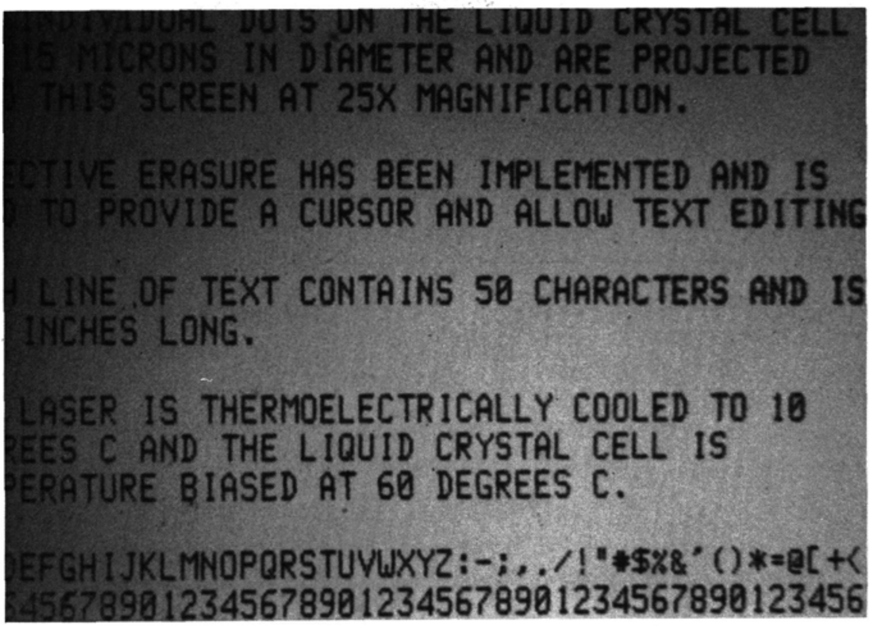
Foil No. 14



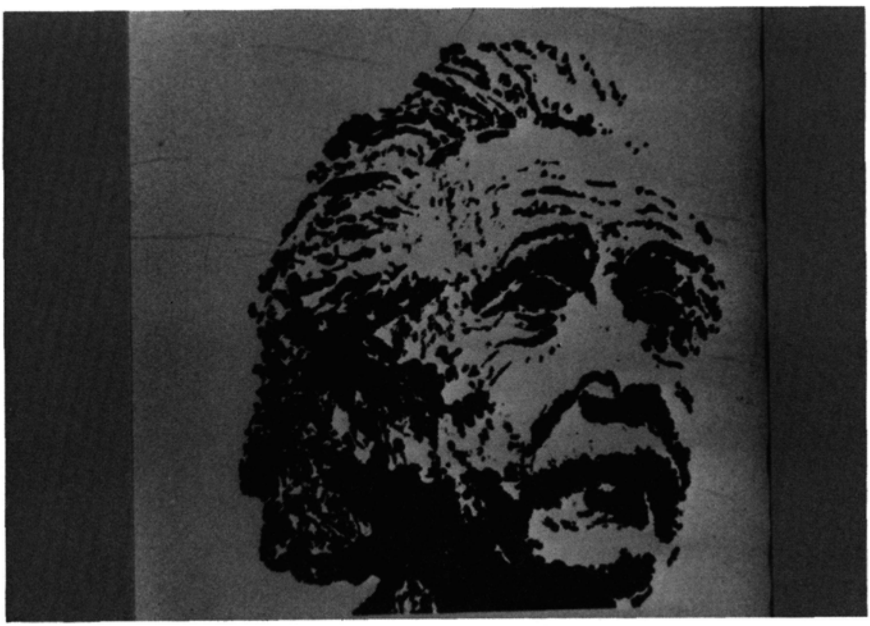
SLIDE NO. 1
FIRST DISPLAY DEMONSTRATION UNIT



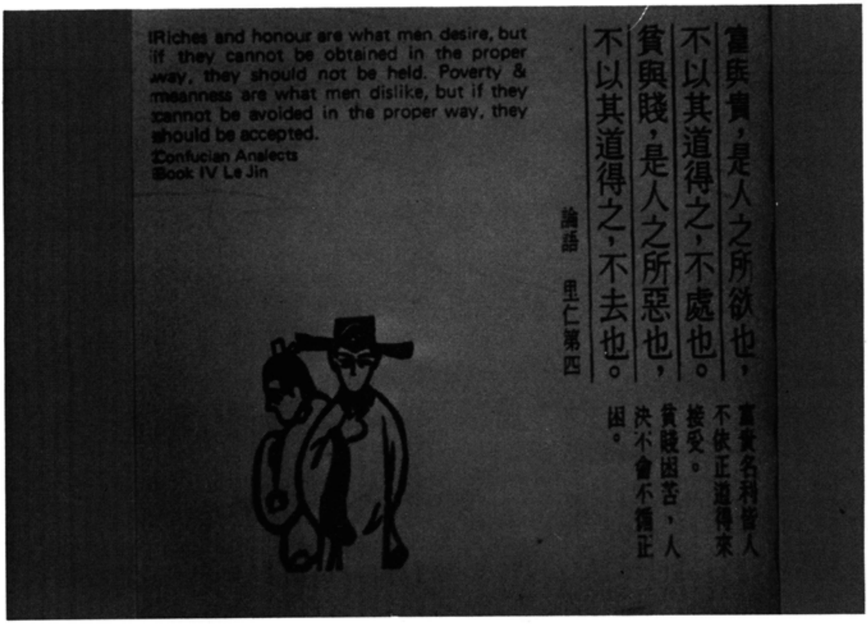
SLIDE NO. 2
LIQUID CRYSTAL CELLS



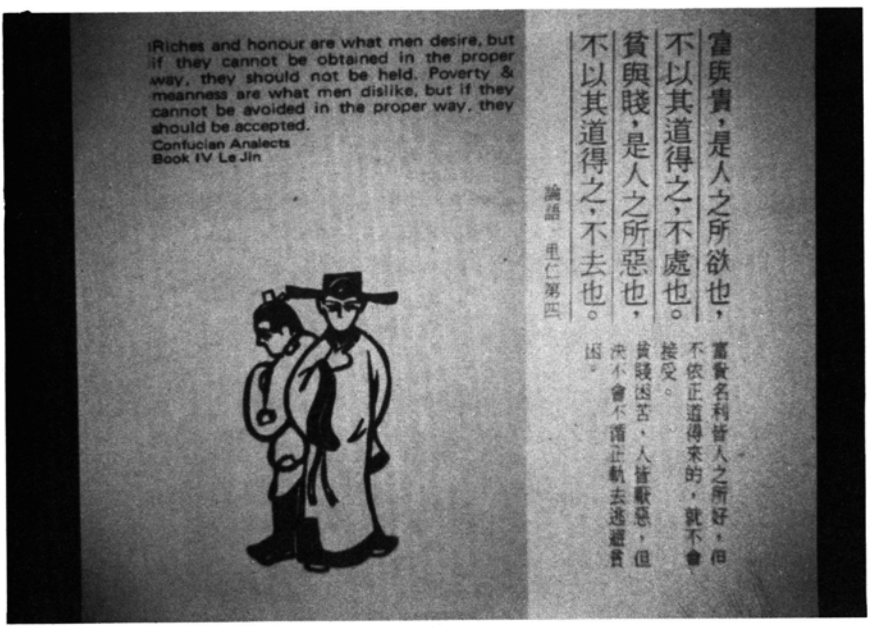
SLIDE NO. 3 - CHARACTERS ON FIRST DISPLAY UNIT



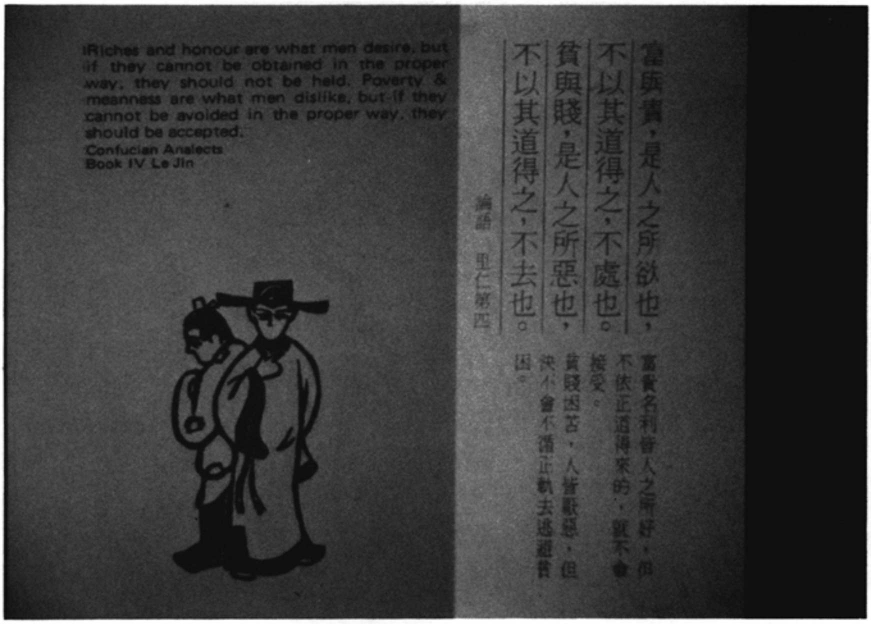
SLIDE NO. 4 - 10^6 PEL, B & W DISPLAY



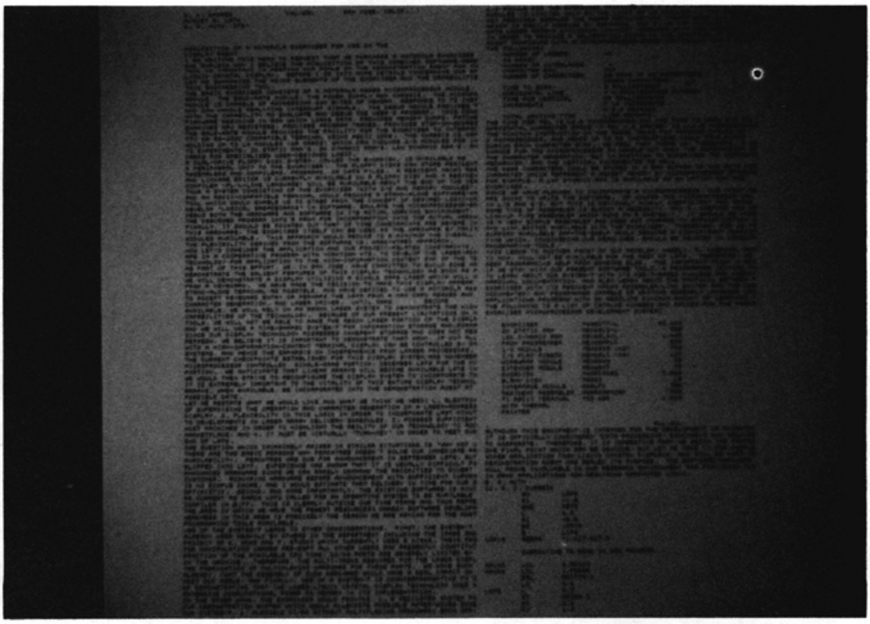
SLIDE NO. 5 - 10^6 PEL B & W DISPLAY



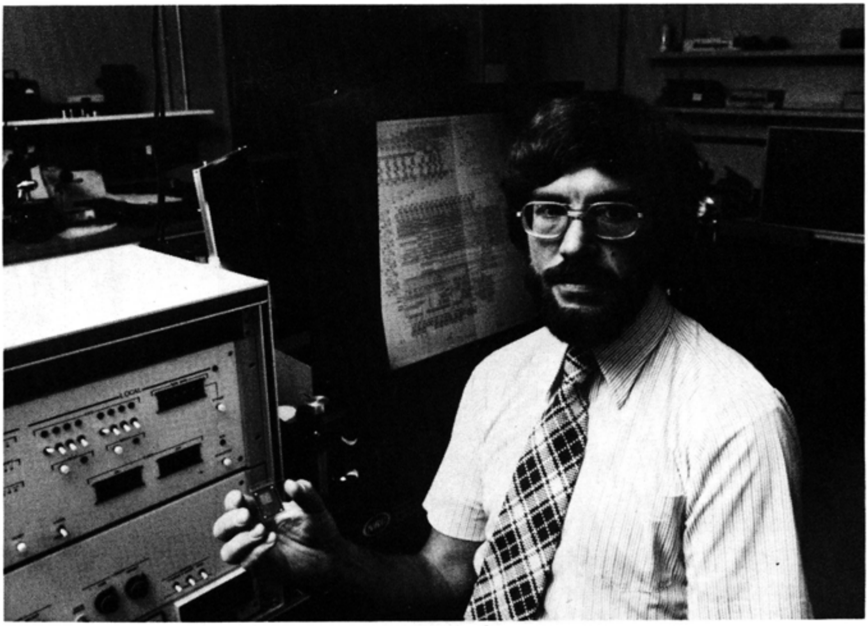
SLIDE NO. 6 - 10^6 PEL THREE-COLOR PLUS BLACK DISPLAY
PRIMARY COLORS - RED & GREEN



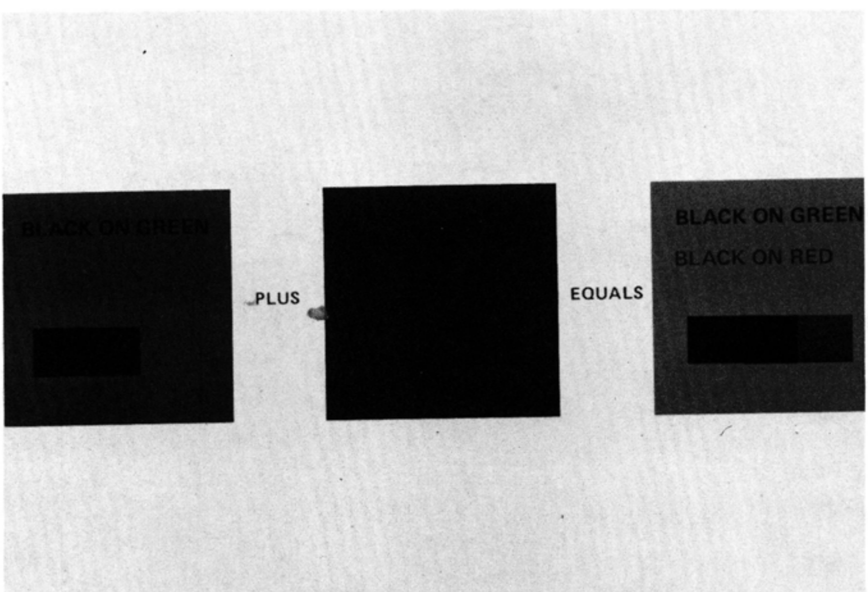
SLIDE NO. 7 - 10^6 PEL COLOR DISPLAY - PRIMARY COLORS: BLUE & GREEN



SLIDE NO. 8 - 10^6 PEL DISPLAY, 14,000 EQUIVALENT CHARACTERS

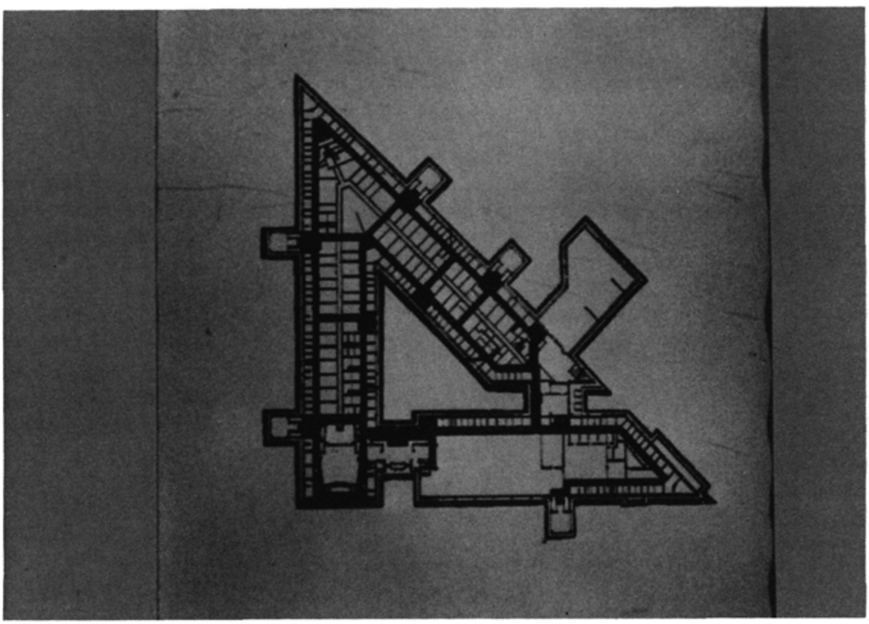


SLIDE NO. 9 - SECOND DISPLAY DEMONSTRATION UNIT



SLIDE NO. 10 - COLOR COMBINATIONS WITH TWO PRIMARY COLORS

SLIDE NO. 11 - 2.36×10^6 PEL, TWO COLOR DISPLAY (SIMULATED HALF-TONE BY DOT CLUSTERING)



SLIDE NO. 12 - 10^6 PEL, B & W IMAGE

PLASMA DISPLAYS

DR. GENE SLOTTOW: Gas discharge displays in the form of the A.C. plasma display panel are commercially available today with over 250,000 light emitting elements. Furthermore experimental panels have been fabricated with over one million light emitting elements. This capability for storing and displaying large amounts of information suggest that these displays may find applications in cartography. In this talk I hope to provide a brief introduction to the A.C. plasma display, to convey some feeling for the appearance of images on the display and to indicate some trends in development.

Gas discharge devices can present information in a variety of ways. In the Nixie[R] numeric indicator, for example, an appropriate voltage impressed across a selected shaped cathode produces a visible glow in the shape of the desired numeral. In more recent numeric indicators appropriate combinations of segment discharges form the numerals. More attractive and more complex characters are formed by dot discharges selected from an array of discharge sites. Only this last approach has value for the high information displays useful in cartography.

When the number of dots in a display is as high as one hundred thousand, this device can provide attractive and useful displays for both alphanumerics and graphics. Such a large number of discharge sites can only be managed when the access electrodes are shared by many sites. The concept is illustrated in Figure 1 which represents an early plasma display panel. On the outer side of the front dielectric sheet is a group of horizontal electrodes. Each electrode is associated with a row of electrical discharge sites. On the outer side of the back dielectric sheet is a similar group of vertical electrodes. Each electrode is associated with a column of discharge sites. Each discharge site is then associated uniquely with the electrodes that intersect at that site. The aperture plate between the dielectric sheets provides strength for the entire structure, and also confines the discharges. In later versions of the plasma display panel the aperture plate is eliminated, the pressure and the electric field being adaquate to confine the discharges.

Figure 2 shows a section view of the device. The upper electrode in the plane of the page is othogonal to the lower electrodes coming out of the page. At a single site the circuit is equivalent to three capacators in series as shown in the lower part of the figure. When a sufficiently high voltage is impressed across the electrode, the voltage across the center capacator exceeds the threshhold for electrical discharge. When the discharge takes place, however, it will extinguish itself because the electrons moving to the upper surface and the ions moving to the lower surface reduce the voltage below the level needed to maintain a discharge. The pulsed discharge and the associated pulsed light by themselves do not provide a very adequate display. but the accumulation of the charges on the surface which reduce the voltage across the device will actually enhance it if we reverse the polarity of the voltage applied across the entire device. The conditions are thus established for another discharge which, in turn, prepares for a third discharge. An alternating voltage applied across the electrodes produces a sequence of discharges. In appropriate gases there is a range of voltage which will sustain a discharge sequence but, by itself, will not produce any discharges at all. The plasma display in this mode is bistable.

Turning a cell "on" is equivalent to producing a starting discharge by placing an apropriate voltage across the elctrodes which intersect at that site. This establishes the surface charge needed to start the sequence. To turn a cell "off" a controlled discharge is established which removes enough of the surface charge to terminate the sequence. After this, although an alternating voltage is present across the electrode at that site, no discharges are produced and no light is emitted. In the "on" state light is emitted once every half cycle. Figure 3 shows an early plasma display panel, vintage 1966, which looks like an 8x8, but was only connected to a 4x4 driver.

Figure 4 shows the structure of the Owens Illinois Digivue[R] panel which does not contain an aperture plate. Glass base plates provide strength for the entire panel. Electrodes are deposited directly on these base plates and are covered by dielectric films. The electrodes are not transparent but they are only about three thousandths of an inch wide and the light that conveys the information actually comes from around the electrodes.

One way to visualize the plasma display structure is to think of a thermopane window. On the inside surface of one of the two panes a set of horizontal electrodes is imbedded. Similarly on the inside surface of the second pane a set of vertical electrodes is imedded. The intersections of these electrodes defines the discharge sites which can emit light.

Figure 5 shows a commercial plasma display panel fabricated about 1968. This panel contained 128 electrodes on each surface. This picture also shows the flat plasma panel being used as an optical projection screen. This arrangement allows the superposition of digitally generated information on the optically generated image.

In a possible application current information could be superimposed on an optically projected map.

Figure 6 also illustrates the superposition of images, this time on a 512x512 Digivue panel fabricated about 1970. We begin to see now what these devices look like, and from that perhaps we can estimate how useful they might be in cartographic applications.

Figure 7 shows the use of a 512x512 display to graphically illustrate the structure of the panel itself. The drawing, of course,is not to scale. The dielectric films are about one thousandth of an inch thick, while the gap is about five thousandths of a inch.

Figure 8 shows a standard set of characters on a 512 512 panel. Most of the upper case letters are formed from dots of a 7x9 matrix while the lower case letters use smaller numbers of dots. More precisely, each character is built on an 8x16 matrix which includes both the space between lines and the space between characters in the same line. This is a standard character set in the PLATO cmputer based education system at the University of Illinois, and is stored in read only memory at each teminal.

It is easy to prepare alternate character sets which are transmitted to the terminal where they are stored in random access memory. Figure 9 shows an experimental character set which was designed to resemble the widely used characters found in much printed material. Most of the characters are formed on the 8 16 matrix, but the upper case M and W required a 12x16 matrix. Figure 10 shows the appearance of gothic script on a 512x512 panel. Figure 11 shows the appearance on the 512x512 panel of a mathematical graph, in this case the sum of two sine waves close together in frequency.

Finally, Figure 12 shows a map of the United States on the 512x512 panel. Also shown are the locations of the more than 1000 terminals in the University of Illinois PLATO computer based education system.

Most of the images I have shown so far contain characters or line drawings that do not require gray scale. The one exception is the section view of the panel in which there is some shading. More complex images with limited gray scale can be shown by the use of ordered dither, a procedure much discussed and investigated recently at the Bell Telephone Laboratories. In this technique, which is related to half tone photographic processes, the luminance is sampled at positions on an image which correspond to the picture elements on a plasma display. If the sampled luminance exceeds a threshhold value the corresponding element in the plasma display is turned "on." If below threshhold it will be turned "off." Within a submatrix chosed by the user the threshhold is different for each picture element. With this technique the full resolution of the plasma display is retained in the halftone process, and the contouring effects so often seen in digitized images do not appear. Figure 13 shows an example of an ordered dither image on a 502x512 plasma display.

There is another approach to limited gray scale in which a discharge site can exhibit several "on" states with different intensities. While the basic ideas have been confirmed experimentally, it has not yet been possible to implement the procedure on large panels.

How about color in plasma display panels? Although to my knowledge there are no commercially available devices, good color has been obtained from phosphors that are deposited within the panel, and are excited by radiation from the gas discharge. With a gas that emits little visible radiation, visible light comes almost entirely from the phosphor. With neon the resulting color is a mixture of the neon orange and the phosphor color. Work has been done on both single color and on multiple color displays.

For cartographic applications it would be desirable to have displays larger than 512x512. Again, nothing is commercialy available, but a few 1024x1024 panels were fabricated by Owens Illinois for the U.S. Air Force When these panels were made in 1973 they were tested by addressing 16x16 sections. It was not until 1975 that Roger Johnson at Science Application Associates connected them to electronics that could address and sustain the entire panel. Figure 14 shows four 512x512 images displayed smultaneously on the 1024x1024 panel. Although the panel has some broken lines, the photograph conveys some of the visual effect o the million bit plasma display.

The interest in large panels has stimulated the development of structures that depart considerably from the basic "thermopane" structure but which still retain the essential relations among exciting electrodes, dielectric, and gas, Figure 15 shows a plasma display developed by Control Data Corporation for use with army maps. The map is supported flush against the back of the panel and is viewed by an observer through the transparent panel.The observer also sees the computer generated information superimposed on the map.

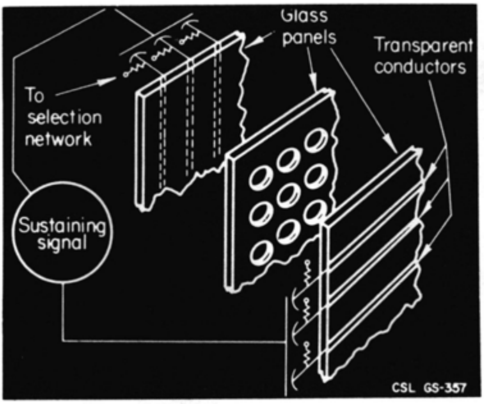
The gas in this device is confined to the interiors of narrow capillary tubes made of glass. The exciting electrodes run along the capillaries on one side of the panel, and across the capillaries on the other side. Pulsed discharge sequences are sustained at the selected intersections. It is expected that 1024x1024 panels at 30 lines per inch can be made in this way, and that by using a modular approach, any desired size can be reached by adding modules.

In conclusion I would like say something about status and trends for plasma displays. These devices, in both A.C. and D.C. forms are widely used for small numeric indicators and for alphanumeric displays of several hundred characters. For several thousand characters and for graphics, only the A.C. device is sufficiently well developed. Here the cathode ray tube provides formidable competition. The plasma display, however, has its advantages. It is rugged physically, it requires little volume, and the quality of its images is very high. The high image quality is particularly important when a user works close to his terminal for extended periods of time. At present the cathode ray tube display is less expensive than the plasma display, but with the economies of volume production, and particularly with the current development of integrated circuits for plasma displays this cost difference should disappear.

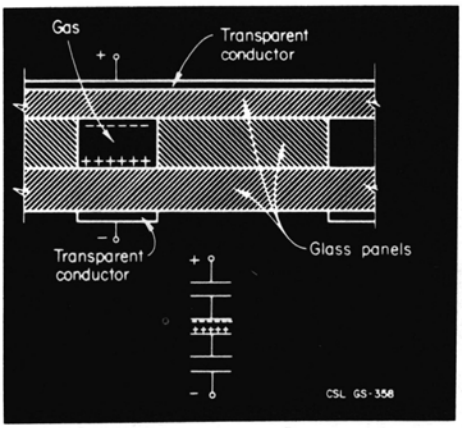
If you would like to learn more about plasma displays, there is a large and growing literature that is readily available. The following two references have extensive bibliographys and will provide a useful guide to this literature.

(1) R.N. Jackson and K.E. Johnson,"Gas discharge displays: a critical review," in Advances in Electronics and Electron Physics,vol. 35, New York and London: Academic Press,1974
(2) H.G. Slottow, "Plasma Displays," IEEE Transactions Electron Devices, vol. ED-23, pp. 760-772,July,1976

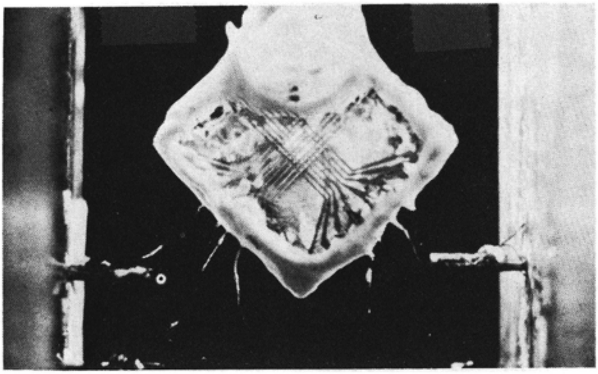
Thank you very much for your attention.



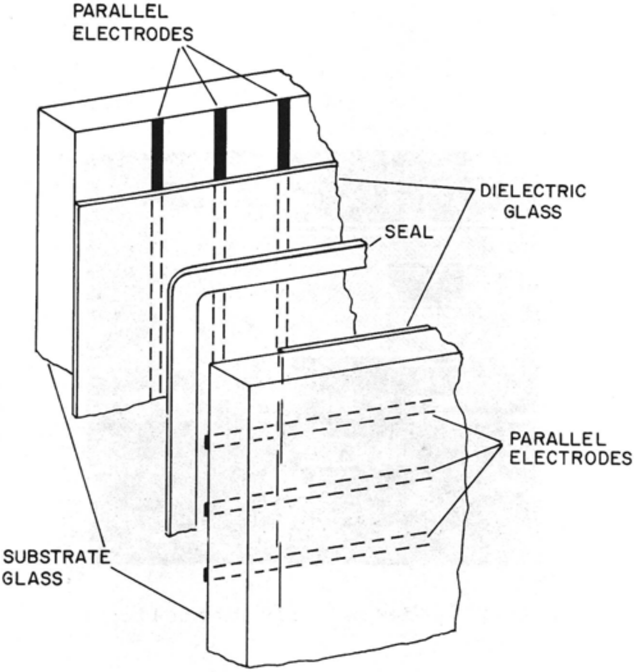
1 Early Plasma Display Structure



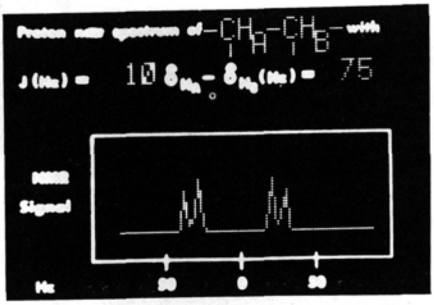
2 Section View of Early Plasma Display



3 Photograph of Early Plasma Display (1966)

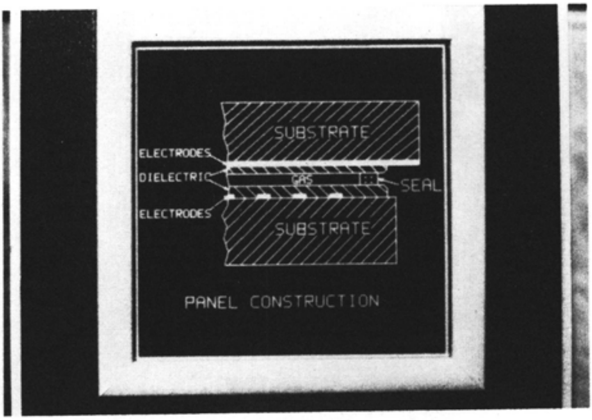


4 Owens Illinois Digivue^{R} Plasma Display Structure

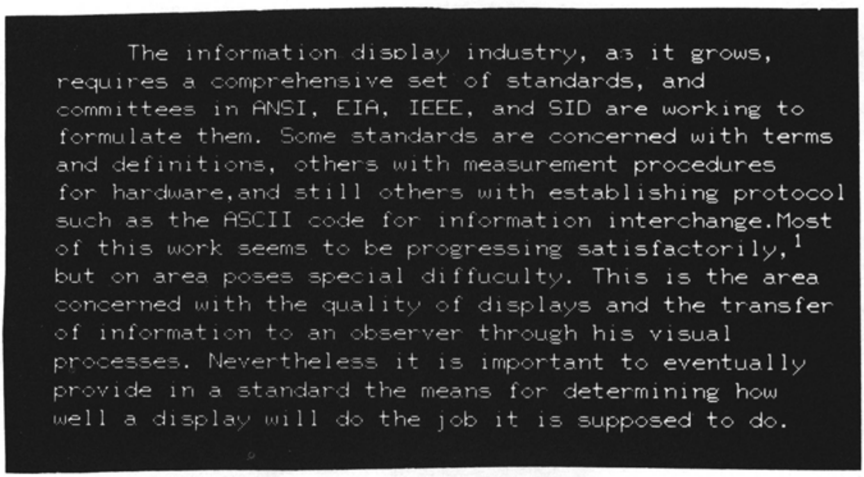


5 Superposition of Computer Generated and Optically Generated Images on 128x128 Digivue[R] Plasma Display 33 Electrodes per Inch

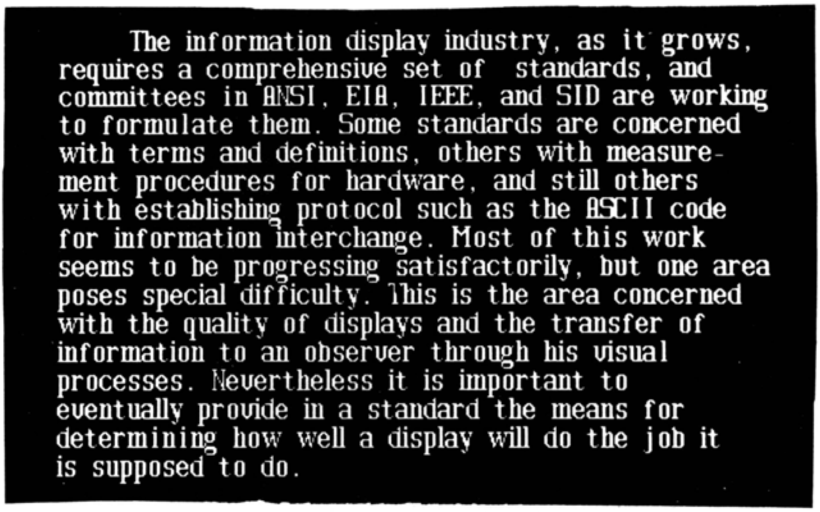
6 Superposition of Computer Generated and Optically Generated Images on 512x512 Digivue[R] Plasma Display 60 Elctrodes per Inch



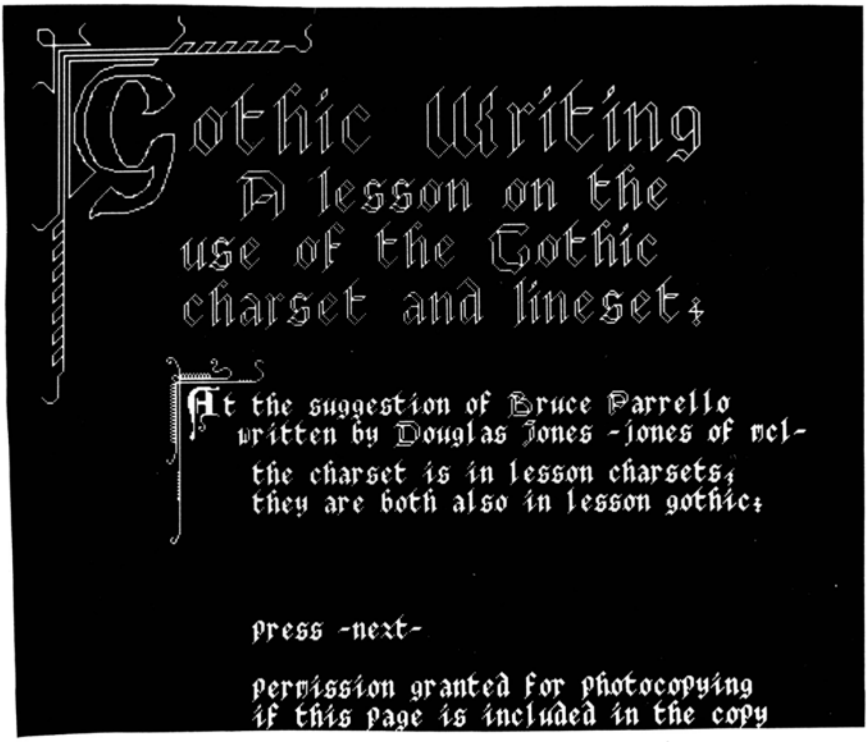
7 Image of Panel Structure on 512x512 Panel



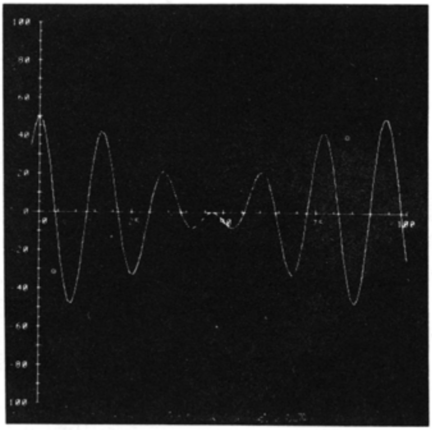
8 Standard Character Set in Plato



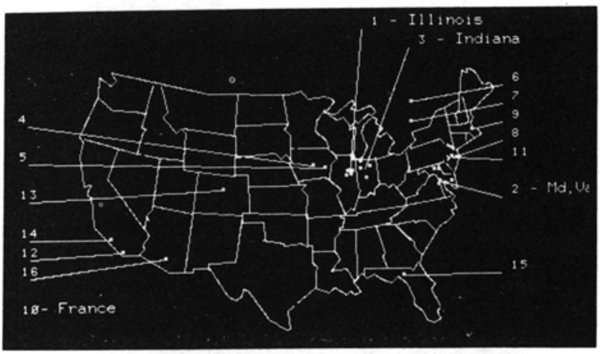
9 Experimental Character Set in Plato



10 Gothic Script in Plato

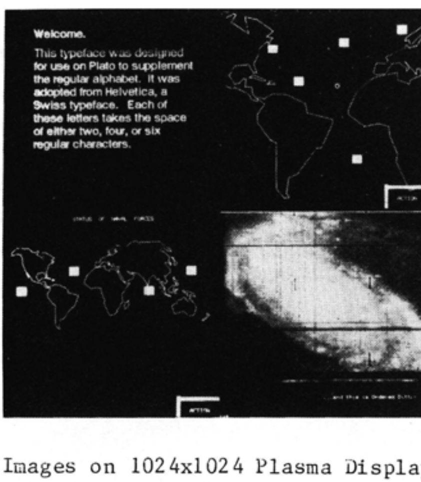


11 Two sine Functions close together in Frequencey
512x512 Panel

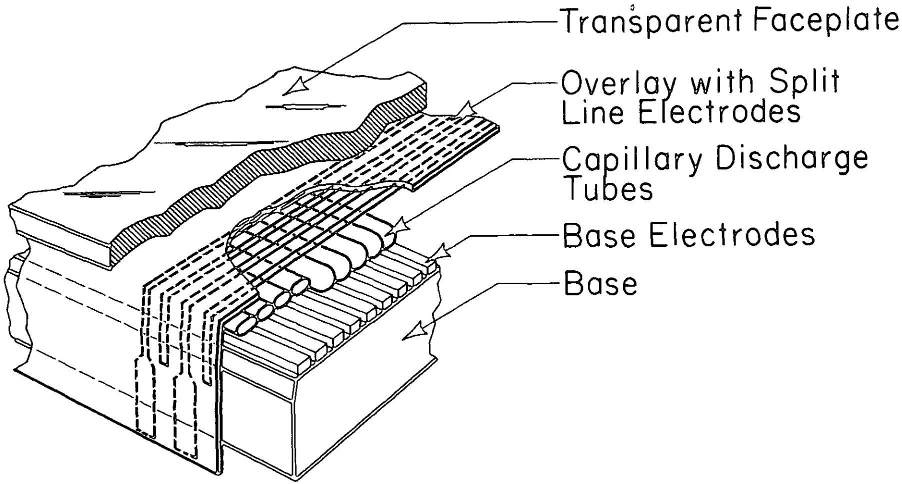


12 U.S. Map showing Plato Sites 512x512 Panel

13 Ordered Dither Image on 512x512 Panel



14 Four Images on 1024x1024 Plasma Display Panel
83 Electrodes per Inch



15 Structure of Control Data Capillary Plasma Display Panel

DISCUSSION

SOFT COPY DISPLAY

DR. BOYLE: Thank you very much indeed. For the last few minutes the floor is open for any questions that you might have on these technologies.

MR. TOM WAUGH: Tom Waugh, University of Edinburgh. I was a bit disappointed in some respects in the discussion on soft display, because the kind of time scales we are talking about, the kind of resolutions we are talking about by 1982 for some of these things seems a bit disturbing, when in fact there are some very big high cost displays around already. The laser scanner, RD-1, for example, made by Laser Scan in Cambridge, England, has a 4,200 million picture element, resolution of 70,000 lines at a screen a meter wide, variable intensities and so on and so forth. There is also a very good passive plotter as well. There are, indeed, many of those devices already around. It also has the advantage that it has cartographic editing software, which they will sell you for a mere $10,000.

However, one of the things I would like to ask or suggest in this discussion is whether or not we actually do want very large accurate displays? I have a feeling that most editing or for most cartographic tasks the size of, say, for example, the Techtronix 4014, about two feet on a side, is probably large enough for an operator to handle. What is more useful is the kind of thing demonstrated in that Hewlett-Packard, which has a very fast zoom-in zoom-out capability, so one can go in and take a look at a bigger picture than the display actually shows, very fast. But not many displays actually have that capability and at a reasonable price. I think the pressure to get very large high quality displays might be misplaced to a certain extent in the cartographic field. What we should be aiming at is displays of about two feet on a side with fairly good resolution but with backup support which allows zooming in and out of larger virtual pictures.

DR. BOYLE: Thank you, Tom. I do not think I will ask the producers of the technology to answer that, but somebody in the audience may like to comment. I think we are in doubt as to whether we want these large displays. Some people say they must have them, some people say they are not necessary. I am very interested in other people commenting on that for the future.

MR. DURBECK: I could answer the first part of that question on laser scan. Actually, that is a large scale display technology, but it writes very, very slowly, and is not reversible. I believe they use a strip of media, and they have to re-write the image, and it does not fall on the normal classification displays. Also, it is very expensive. It is probably in the quarter million dollar cost range, so it is not the normal display tool that one normally talks about.

MR. JIM WHEELER: Jim Wheeler, M. B. Associates. Some years ago I was involved in quite a number of different elements in the display game for aeronautical work, and since then I have done some work with simulators, and have had a bit of experience with the cartographic game. One of the three things that are important in displays generally, and they are not necessarily completely addressed here, I think, to satisfy my own interest, and that is accuracy, resolution and light intensity. For example, cathode ray tubes in past years I found difficult to get better than about a tenth of a degree of angular accuracy out of them, for example, when used in heads-up displays in aircraft. I see nothing to increase that accuracy very much. So, if you really want precise cartographic information rather than relative, you have to do a bit of work to get the accuracy.

It is also quite a push to get enough light intensity for normal sunlight viewing. In the gas tube displays I did a little work which ended up in the gas tube display operation which Beckman is now operating. I think one of the things that Dr. Slottow has not indicated, and perhaps he would comment on this, is what is the resolution, number of elements per inch or per millimeter that is now obtainable. And the other advantage it seems to me of the gas tube display, or the LED display, is that when you build the unit, you can build in the accuracy and it stays there. You do not have non-linearities in curvature. In the liquid crystal operation, which the gentleman from IBM discussed, we had no indication of the intensity nor of the problems of getting the accuracy that might be necessary for very precise cartographic work. The other question which Dr. Boyle, or someone else in the audience might answer, and that is, the questioner before me asked about whether a zoom task with a blowup of a local section is what you really need for cartography, or whether you need the large scale display. If you have a large scale display and adequate optics, of course, you can image this and produce a whole map at one time, and that might have an advantage over the zoom process, or it might not. But if someone could comment on this I would appreciate it.

DR. SLOTTOW: Let me begin. The question was about the light output, the intensity, essentially -- luminance, really, and the irregularity of the plasma display panel. These electrodes are put down by photolithographic process. This gentleman is correct in saying one of the advantages of this kind of display is that you have very, very accurate placement of the discharges which occur at the intersection, and they do not change because it is just a matter of the lithographic process used in the first place. The density of lines is 50 per inch. So that means you have 3600 elements, picture elements, per square inch. This is on a 512 by 512 array. That is over 260,000 elements. Now, a number of smaller ones have been made. A number of displays of this type that you find in IBM products are 50 lines per inch, and somewhat smaller number of elements. But, there the amount of information that is desired to be displayed is, of course, less. The best that has been done, to my knowledge, so far is 1024 by 1024 elements at a density of 83 lines per inch. I showed some pictures from the face of that tube. Brightnesses or luminances are typically in the order of 40-, 50-foot lamberts.

As far as one comment, too, about the zooming. Of course, with this technology you can do the same kind of zooming that you see out there in the Tektronix because that is really a matter of the software system.

MR. DURBECK: Regarding the same issues with the laser liquid crystal. What we are able to do is about an accuracy of about one-quarter spot diameter today, so that means in our present 1500 by 1500, we are getting an accuracy of about one part in 60,000. I think we could do better if we really tried. We demonstrate that every day, every time we go back and erase the single dot. If we missed it, we would not erase it or we would re-write a wrong one. We have not had any trouble that way. As far as intensity, this depends upon the light source that you put into it. I can give you a couple of different examples. If you take a simple hundred watt tungsten halogen bulb impinging on a 15 by 15 inch screen -- this is typically what we do in the lab, you have an output of around -- it is about the same number that Gene mentioned -- it is around 60-foot lamberts, which is very bright, actually. You will find that even with the room lights completely on, you tend to turn the bulb down a little bit. Around 40 to 50 is more comfortable. But that could be increased by just increasing the bulb. If you want to go to full wall size display, you would have to go an arc lamp, and there you are almost unlimited. But, obviously, on a wall screen projection you cannot have much in the way of room lights. But in a back projected, even up to several feet by several feet, you can get quite high relative contrast, certainly well in excess of ten to one, even with full room lighting. By the way, several of these robots are available for viewing, and if some of you feel inclined you can come down and see some of these.

DR. BOYLE: Could I just add to this question on zooming? One of the important things, of course, is the speed of addressing the points. Are these two methods as fast as the ordinary CRT, or do we have a time difference when you are re-addressing?

DR. SLOTTOW: Let me give you some numbers on that. The frequency of the sustained voltage that maintains the image is typically 50,000 Hertz. There are several different modes of addressing. One is to address a single point at a time. If you address a single point at a time, either writing or erasing, you will then change 50,000 points per second. But, actually, any type of matrix display you can do better than that because you can address more than one dot at one time. The one thing that you cannot do with any kind of a matrix display where you have some kind of a coincident selection system, is that you cannot take a square and then write, let us say, three different dots at the corners but not write the fourth one. Because if you, for example, pick the top two, you selected two vertical lines, if you take two on the side, you have selected two horizontal lines, then you have automatically selected that fourth corner. Of course, what you do, you just write the top two and then one of the bottom ones. You can in fact write up to a line at a time if the circuitry that you put into the system will allow it. So, on a 512 by 512 system, that would allow you to write or erase at a rate of 25 million bits per second, which you normally would not do. In the circuitry that has been provided in the more recent devices, you can write up to eight or sixteen dots at a time, and that is a limitation only on the circuitry, not in the panel itself. This corresponds to about 800,000 bits per second.

I should point out a very important fact, and that is that as these new technologies develop, there are always problems with them. One of the problems -- at least an apparent problem -- with the plasma display was that it was not compatible or presumably not compatible with microelectronics. So you had to sort of work out the schemes that got you around that problem in the beginning. Since then, though, the interest and the demand for this technology has gone up to the point where specially designed circuits from, say, Texas Instruments, are now available. The microelectronics for this technology is available or is becoming available. I think there are several different models of circuitry out in the TI catalogs. I think if we would ask what is the most important thing that has happened in the last couple of years to plasma display technology, I would not say somebody has shown color, or somebody has shown gray scale; I would say it is the microelectronics, the logical integration that has become available for the plasma display technology, so you can now take the next steps in your stride.

DR. BOYLE: Do you want to make a comment?

MR. DURBECK: Yes. As far as the update time, it depends upon where you are. If you are working on the upper end of the stream, you want to update suddenly something in the lower end, it could take as long as about 200, 250 milliseconds. If you are updating the same region you are working, it could be as low as 35, 40 milliseconds. It is in that time range.

DR. BOYLE: I wonder, if to answer the last part of the question, I can ask if you have given any thought as to whether we do want large screen displays in cartography. I would be very interested to hear your comments on this.

MR. EDSON: I guess my answer to that is somewhat philosophical. I think that one of the problems we face in developing automated systems is credibility.

I can visualize the city councils -- and this is fairly typical -- where a great number of variables are pulled together and displayed as some graphic, showing the dire consequences of this or that happening or not happening, and at the end of this no one really believing that this analysis has any real meaning or credibility, whereas the use of a large display as this analysis is actually generated with a group like that, is going to permit a group of decision makers to actually perform the basis of the analysis as it goes along, step by step, display each of these and the result of various subcomponents of this analysis, and finally coming to a conclusion that everyone does in fact believe, and on which they will base a sensible decision. I think I can see it used for that sort of thing, where we need to work together, groups of decision makers working together on a large display. I really think it is in the future.

DR. BOYLE: Thank you. One last question.

MR. JIM STEWARD: I am Jim Steward, AMOCO Production Company. I really did not come to ask any questions as much as to comment on what Tom said. It has almost been answered by the speaker ahead of me.

In the oil business we have the cartography problem that you talk about in terms of geography, but we also have the problem of decision making. And that problem is a very severe one to us, because we are constantly asking or trying to interpret subsurface things like geology and geophysics and all the combinations thereof. It becomes a group decision. So it is necessary to have multiple people working on display. This, despite all these zooming techniques, throws out the small screen very quickly. Now, granted, you could put ten people in a room and give them each a Tektronix and have these Tektronix operating in parallel and make it possible for anyone to alter and to be seen back and forth between each other. But I do not think this will work any more cheaply or probably even as well as one large display. We have been looking at this problem for quite some time, looking for a large display, and then talked with the gentlemen on your panel. But I think that Tom -- I wanted to chastise him, really -- I think he is like a lot of people who can see in his own situation that, yes, the human being does not need to look at a 40 inch by 40 inch map which is the standard in the oil industry, but they are so used to looking at it that you are going to have to go through a process at least of building these big display devices and maybe backing down ten years from now. But I do not think you are ever going to satisfy them without doing it first.

I have a favorite story I would like to tell to show you the kind of thing you can get into if you are not careful and if you do not think about the user. About 15 years ago I can remember when we had our first program that we had borrowed from somebody that we had finally adapted to our system to give a nice three-dimensional look on the face of a CRT, at that time a 40/02A of a subsurface geology picture. We were so proud of it, and we showed it. Among the people we showed it to early in the game was one of the senior vice-presidents of the company. I never got quite as big a chewing out in my whole career as I got from that gentleman, because he told me, "You're wasting your time, you're wasting the company money. If I have a geologist on my staff who can't see three dimensions on an ordinary contour map, I don't want him working for me." So, we had to continue that work for at least six or seven years on the q.t. We never really told him we were continuing to upgrade and work on this. We did it for the simple reason that I think all the rest of you -- particularly the younger people -- try and find a geologist coming out of college now from the good schools who is not working with a computer, who is not using three-dimensional display pictures, and it is a tough problem to find someone like that. We are ready for those people now. You are going to go through this. Tom's idea that, "Do you really need it?" I think you could probably do a lot of psychological work to prove you did not need it. But if you are going to be successful you must remember that the user is still king, and the user wants it in the board room. He wants a display, he wants to work as a group. These big systems are necessary. I think you will find that you are not going to sell as many of these units as we sell the little CRT's to put on everybody's desk. But there is a market here, and I think the people should use it.

DR. BOYLE: I think that is a good point on which to end. I would like to thank our team members of the panel who have worked so hard. Thank you.

HARD COPY DISPLAY

DR. A. RAYMOND BOYLE: This morning we are going to talk about hard copy output. This is, I think, an interesting phase. Of all of the areas of automated cartography, hard copy output has for a number of years been the most professionally operated part on a production basis. We have been using Gerber 32 plotters with light heads, Kongsberg plotters, et cetera, giving very, very high quality outputs, but very, very slow. That is the main thing. They are expensive but slow. We have had to look at other methods of getting hard copy out. And, of course, getting a scanning output is one of the important processes in this. We have a number of people on the panel this morning with the expertise in this area. I do not think it is at a final stage as far as cartography is concerned, but it is getting to a very advanced state.

I am very anxious to learn more on this subject from the people here this morning. We are going to start off by asking Norman Smith to come to the panel. Norman Smith is from the National Ocean Survey. As far as I know, he is the only person in a production operation of maps or charts, in his case, using a scanning process. It is the MBA information systems scanner. I have seen it in operation. He will tell you about his expertise and experience in this area, the good and bad things that he has encountered. So, Norman, if you would take over the microphone, please.

MR. NORMAN SMITH: Good morning. Thank you very much, Dr. Boyle, for the observation that we are operational with our system. We at the National Ocean Survey sometimes call our approach to the automated cartography problem the "crowbar" approach in that we have a reasonably small budget, and we have to make everything that we do purchase, work and produce an output product to satisfy a production need. This approach also trains our manual cartographers and other people in the system to the fact that they need to contribute heavily to the development of these systems. A little background. The National Ocean Survey produces nautical charts for the boating public, for commercial shipping, and also for other Government agencies. We have on issue some 1,000 nautical charts. Our problem is a limited budget to produce the color separation overlays for these charts on a timely basis. I think that the subject was referred to earlier in the discussions as the impetus behind the conversion to automated cartography.

I would like to say a couple of words about the overall automated cartography system at the National Ocean Survey. Back in the early and mid-sixties, the field acquisition systems were automated on our fleet of ships to provide digital data for hydrographic surveys. In the late sixties we purchased conventional vector flatbed plotters and started building an overall programming system to output a chart image, including symbology and line work, and resolve all the other problems involved. In the early seventies we purchased a five-table digitizing system to convert to digital form the data that were coming in in graphic form from other Government agencies. Our data come from many different sources other than our own field acquisition systems. There is a contract under way at the present time to build a digital data base for all of our published graphic data.

So, you can see that we have a total system--from data acquisition to the final product. Of course, what I am going to talk about right now is the output device, the raster plotter. As Dr. Boyle said, we went out for a raster plotter because of the inherent speeds achievable by this technology. Using a conventional flatbed plotter system to produce color overlays for some 1,000 charts per year, which is one of the goals of the agency, and to re-publish those charts on an average 1-year basis, which is quite a bit more often than they are being published at the present time, it turned out to be uneconomical to do that task with conventional flatbed plotters because of the extreme times involved per plot. So we issued an RFP for an output device. MB Associates, Information Systems Division, here in the Bay Area, came in with a proposal to design and construct a high-speed raster plotter system, which we designated the Nautical Charting Automated Plotter (NCAP). The fundamental requirements for the system were that it was to operate as an off-line stand-alone system, much like the conventional flatbed plotters, and would use our existing computer facilities for software development and support. The production requirements dictated that we needed a maximum 1-hour plotting time for a color overlay, regardless of the complexity of the overlay. And, of course, retaining high resolution and high accuracy, better than that of the flatbed plotters, so that we could get good registration between color separation overlays and be consistent with our National Ocean Survey charting standards. We wanted to have the recording on a commercially available stable base material. By that I mean, we did not want to get into special order films or anything of this sort. We are plotting on a commercially available Kodak Estar base reproduction film which our standard manual reproduction system is using for publication negatives.

As delivered, the system has lived up to those requirements. The contract called for the raster plotter hardware; a software package consisting of user routines to perform linear, cubic, and circular interpolations of data points; symbolization; interior fill of irregular areas; and two special purpose programs--one to build the symbol table, and one to convert our standard flatbed plotter tapes to raster format. And, in addition to that, two raster processing routines to do the lineal to raster conversion. Could I have the first slide, please (Figure 1). This is a picture of the system at the factory. It does not look like that in our establishment. On the right-hand side you can see the control computer that drives the system. It is a NOVA 820 computer system with disk storage and magnetic tape input for the drive tape. In the second bay over is the drive unit for the Spectra-Physics laser, which is the light source in the plotter. At the far left is the plotter cabinet with the doors open, showing access for mounting film to the drum. The computer system operates under a disk operating system (RDOS) which allows us to update programs and drive the system. The input tape, as discussed earlier, is in run length encoding for data compaction. Run length encoding specifies total consecutive on or off raster elements for a specific raster line (2 on, 100 off, 5 on, etc.).

The basic specifications of the plotter are accuracy of plus or minus 0.001 inch; a raster count of 800 lines to the inch in both the X and Y dimension; and a full plot size of 42 inches by 60 inches, which corresponds to our lithographic plate size for printing nautical charts. As stated earlier, we are plotting on 0.007-inch thick or 0.004-inch thick Kodak Estar base reproduction film. We have a circumferential correction for the thickness of the film, as someone mentioned earlier. There is some 0.014-inch error involved there if you do not correct for the thickness difference of films. Could I have the next slide, please (Figure 2). This is not as pretty a slide, but without the cabinet on the unit. The laser is located horizontally underneath the table. The beam travels toward you on the left-hand side and then travels through a series of two electro-optic modulators (EOM) which perform the shuttering of the beam, if you will. Then it is directed up through the table by turning mirrors, down parallel to the drum axis, and then to the beam forming optics, which are on the left-hand side up there. The drum rotates at 600 rpm, and the plot is completed by plotting a raster line around the circumference of the drum, one rotation at a time. The carriage carrying the spot-forming optics is impulsed during a dead part of the drum, and the next line is plotted in that fashion. A full plot takes about 1 hour.

You see a lead screw arrangement for the optical spot-forming optics, but the position is actually optically encoded to a photo etched linear scale. As the drum rotates, the pulses to plot on the film are clocked out by a precise optical rotary encoder mounted to the drum axis. Next slide, please (Figure 3). This is just a test plot that we put out. I would like to display a couple of these just to show you what kind of quality the system yields. This is just an array of vectors to observe the behavior of the software at all different orientations. Next slide (Figure 4).

This is a blowup of actually two sections of that preceding slide. You can see the break in the middle of the slide. On the right-hand side, looks like about the fourth line in from the center, is the straight line in the direction of rotation of the drum, which, as you can image, would be a very straight line. You see the stepping effect of the raster. I think you have seen this on some earlier slides and in some of the other discussions. Each of those steps, again, is one eight - hundredth of an inch, or one and a quarter mils (0.00125 inch). On the left-hand side is the same thing, 90 degrees away, such that the straight line in this case is plotted one dot per revolution. So you can see the repeatability of the system.

Next slide, please (Figure 5). I would like to get into a few of the products that we are plotting on an operational basis. This is what we call a channel tabulation, which informs the mariner of the controlling depths for an entrance channel to a port or other area. We had been plotting these for a number of years on conventional Calcomp flatbed plotters using a scribing tool. We have converted these over to the raster plotter for a couple of reasons. The image is much better than the scribed image and requires much less manual editing when the plot is completed. Also, this gives us a good opportunity to wring out the raster software and operate the plotter in a production mode with all the pressures of production schedules and users that may not understand the complexity of what we are doing.

I will mention some computer times, which, again, have been referred to as "not cheap." We are running our software on a 360/195 at the NOAA installation in Suitland, Maryland. An image like this is using about 1 to 2 minutes of CPU time on that system. It includes about 150 to 200 linear inches of line in an image like this. We are at the present time running about 40 of these per month on a production basis. We have been running since April of 1976.

Next slide, please (Figure 6). This again is another product that we are running operationally. This is a facility tabulation, a listing of facilities available at marinas that is printed on the cover of our small-craft charts. Something like this typically takes 3 to 4 minutes of CPU time to run, and contains 4 to 5 linear inches of line work. We are running on the order of 5 to 10 of these a month on a production basis. A negative image is plotted by a simple change of film. We are not doing anything in the software to convert from a positive to a negative image.

Next slide, please (Figure 7). There were some comments earlier about nomenclature, or labeling, on the charts. This is a test we are running as to acceptability of lettering from the automated system.

Again, referring to another comment, I appreciate fancy lettering and serifs and all that kind of thing as much as anyone, but it does complicate the process of going to an automated type system. I do not know how many fonts of lettering we have had on our charts in the past, but we are now trying to reduce it to four basic styles. This is a Newton medium font (Figure 7), or very close to it. We are trying to reduce our type fonts to a Newton type letter, which is a single-stroked letter that does not contain any of the fancy serifs or embellishments. What we are doing here in this test is trying to see how far we can go--I do not know how well you can see it on these large letters--they are rounded on the ends, and there is some point at which that is going to be unacceptable. But if we can produce letters in this way, we do have the programming and the experience right now to digitize our labeling as it exists on color separation negatives, enter it into our digital data base, and plot it back out on the raster plotter. We have the program to position the letters and to compose the names. Now we are looking at just what kind of letter we can output that will be acceptable.

Next slide, please (Figure 8). I thought I should at least throw in a little bit of propaganda for the agency. This is really a test of the interior fill software. Because we do not have anything akin to area fill on a flatbed plotter, we are not actually doing anything on a production basis with this, but this is an example of where we took a NOAA seal like you would paste on your window in your car, and digitized it on our digitizing system, and then converted it to plot data for the raster plotter. The top part is a test of that area fill algorithm. Next slide, please (Figure 9). I do not know how well this shows up, but this is to give you an idea of the type of data that we are talking about. This is a little different from the contour data and line data that have been discussed largely up to this point. What we are talking about is largely symbolized data represented by soundings, dotted lines for indeterminate shoreline, and other types of symbolization. There is another kind of interesting aside to this. I cannot see it too well from this angle, but you will notice some kind of irregular lines along the shoreline. This is somewhat of a change from the classical way of showing these data. This represents a ledge area, which in the past has had a very fancy, very nice looking symbol. But this is an attempt to stylize it in a different way, which is much more easily handled by our cartographic programs. In this case we have had that accepted by our management. Although on this particular chart, the negatives were not produced on the raster plotter, we did scribe these on a flatbed plotter, and the chart has been published in this form. So, that is another dimension to this automated cartography thing; there needs to be some change in the basic specifications for a chart. We are doing it on a case-by-case basis. But I would agree with the gentleman yesterday from one of the oil companies who made the point that we do have to produce a graphic that the user is used to seeing to develop our credibility before we can move on to totally different products. I would say that probably in a few years this whole subject of hard copy display could well be something entirely different.

I would just like to present, again, a few computer figures. We have a production chart that we are working on at the present time, which, as is always the case, computer turnaround being what it is, was not completed in time for me to bring an example with me. But I do have a few figures to give you an idea of processing times and sizes. The chart that I am talking about is a full-size National Ocean Survey nautical chart. The final product contains about 14,000 linear inches of line. It is fairly typical. This is a chart that contains a little more detail in terms of depth contours and a little more detail in terms of topographic contours than many charts, but is pretty typical. Included in this are 17 million raster points. We are storing the raster points in four bytes, so that is 68 million bytes of information that we have to process in the computer system to produce the image. Time-wise, on a 360/195, I estimate that we will expend about 90 minutes of CPU time to produce this image. That is quite expensive, but when you figure the manual time involved to produce the same image, the cost is really, even at this stage of the software development, cost effective. I think the advances in array processors which we are actively looking into right now--the Goodyear processor and also the ILLIAC system that I think the tour will go to--will bring software costs down considerably in the next few years and make this a very viable way to produce graphics. I would like to make one other point. The things that we are running operationally at the present time are not necessarily suited that well to a large bed raster plotter. But, again, they do provide us a very useful test-bed in a production environment to wring out the software and also to educate the present system with getting used to working with that type of product.

Thank you very much.

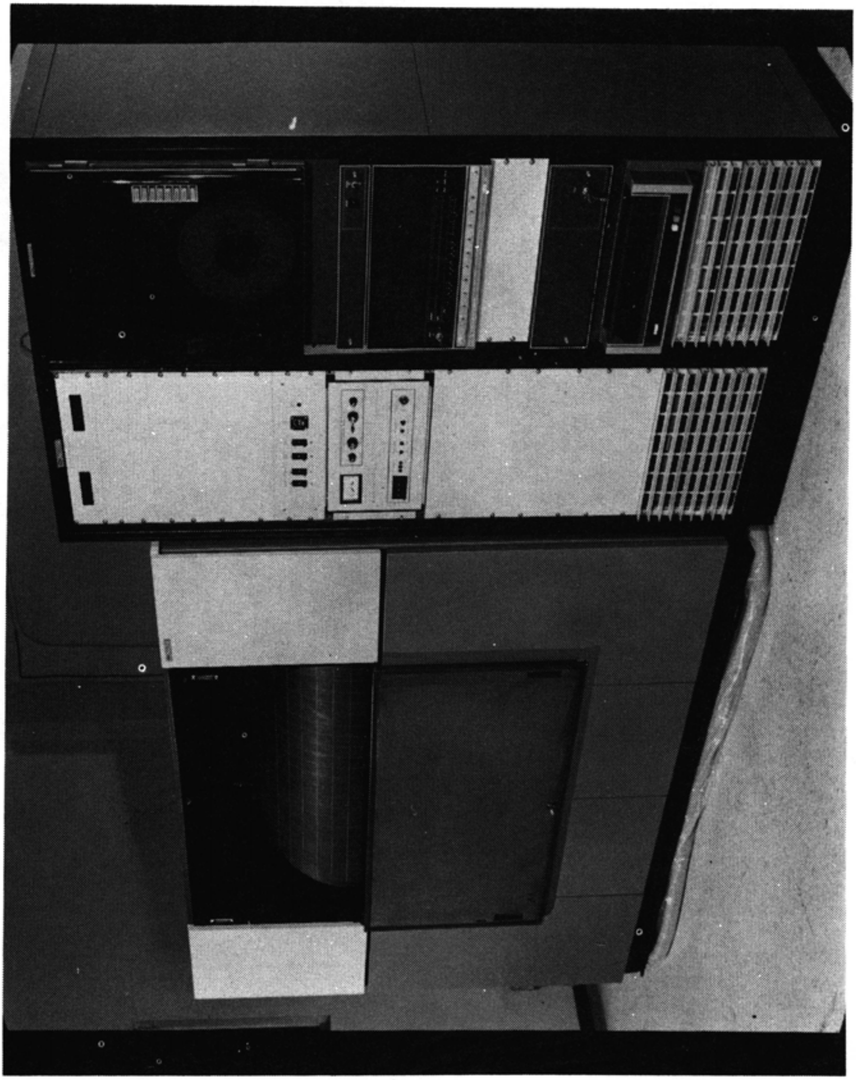


Figure 1

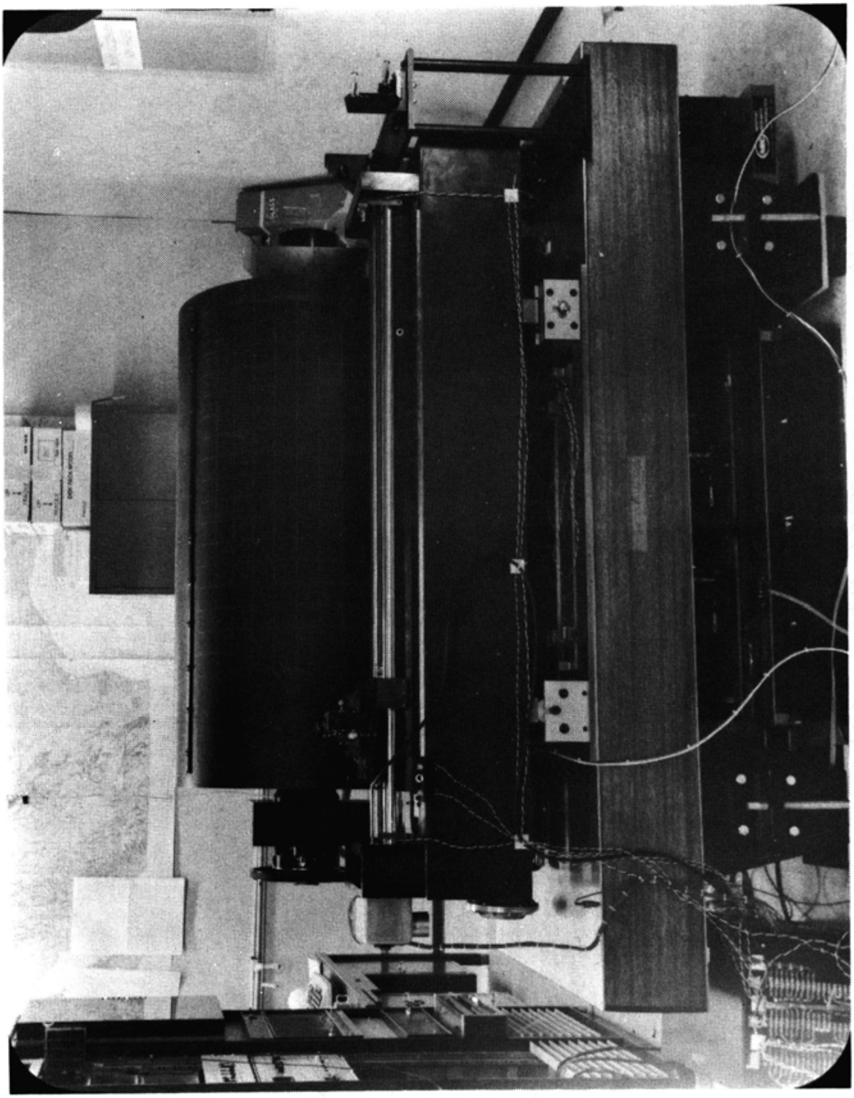


Figure 2

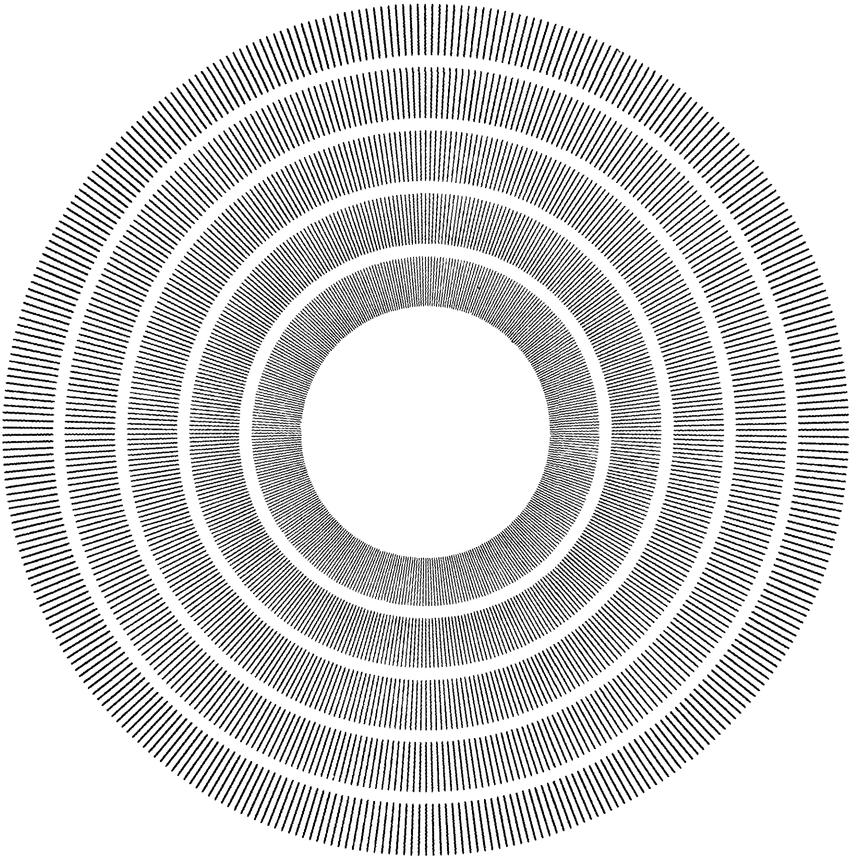


Figure 3

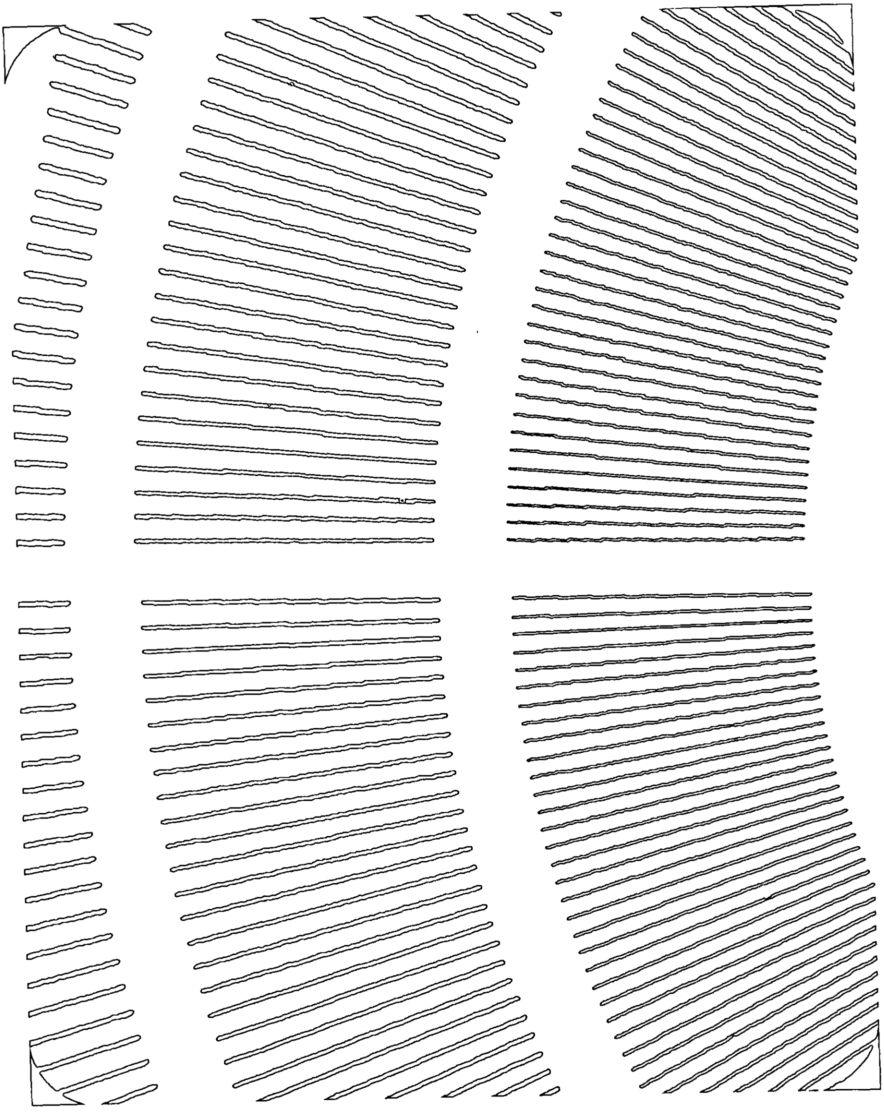


Figure 4

CHART 18447 (C&GS 690 SC)

LAKE WASHINGTON SHIP CANAL TABULATED FROM SURVEYS BY THE CORPS OF ENGINNEERS-SURVEYS TO JULY 1975								
* SEE FOOTNOTE					PROJECT DIMENSIONS			
NAME OF CHANNEL	LEFT OUTSIDE QUARTER	MIDDLE HALF OF CHANNEL	RIGHT OUTSIDE QUARTER	DATE OF SURVEY	WIDTH (FEET)	LENGTH * MILES)	DEPTH * (FEET)
SHILSHOLE BAY ENTRANCE RANGE	16 8	31 9	A 7.0	7-75	300-100	1 0	34
LARGE LOCK TO LAKE UNION	25.5	27.5	21.3	7-75	100-300	2.2	30
PORTAGE BAY REACH	24.1	26.8	24.8	7-75	350-200	0 8	30
PORTAGE CUT	27.6	30 1	23.8	7-75	100	0.4	30
UNION BAY REACH	27.0	28.0	19 2	7-75	100-200	0.9	30

A. THE CHANNEL HAS SHOALED ALONG THE EDGE· A DEPTH OF 23 8 FEET WAS AVAILABLE IN THE INSIDE HALF OF THE QUARTER.

* CONTROLLING DEPTHS IN CHANNELS ENTERING FROM SEAWARD IN FEET AT MEAN LOWER LOW WATER BELOW THE LOCKS AND AT LOW REGULATED LAKE LEVEL ABOVE THE LOCKS PROJECT LENGTHS ARE IN NAUTICAL MILES

NOTE-CONSULT THE CORPS OF ENGINEERS FOR CHANGES SUBSEQUENT TO THE ABOVE INFORMATION

PRODUCED BY COMPUTER ASSISTED METHODS

Figure 5

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA

U S DEPARTMENT OF COMMERCE

Figure 8

NO	LOCATION	TIDES: MEAN RANGE-FT	TIDES: DIFF (HRS) SAN FRANCISCO	DEPTH: APPROACH-FEET(REPORTED)	DEPTH: ALONGSIDE-FEET(REPORTED)	SERVICES: BERTHS-ELECTRICITY	SERVICES: RAMP-SURFACED-NATURAL	SERVICES: REPAIRS HULL-ELECTRONIC-MOTOR	SERVICES: MARINE RAILWAY-FEET	SERVICES: LIFT-FIXED-PORTABLE-TONS	SERVICES: BOAT RENTAL ROW-MOTOR-CHARTER	SERVICES: BOAT RENTAL HOUSE-SAIL	SERVICES: MEALS-LODGING	SERVICES: TOILETS-SHOWERS / PUMPING STATION	SUPPLIES: WINTER STORAGE-WET-DRY	SUPPLIES: CHART SALES	SUPPLIES: WATER-ICE-BOTTLED GAS	SUPPLIES: GROCERIES-HARDWARE	SUPPLIES: BAIT-TACKLE	SUPPLIES: DIESEL OIL-PUMP-TRUCK	SUPPLIES: GASOLINE-PUMP-CAN
1	NEW HOPE LANDING	3 0	+7¼	15	10	BE	S				RM		ML	TSP	W		WIB	GH			P
2	DEAD HORSE ISLAND	2 7	+7¼	8	8	BE		HEM	70	F75	RMC		M	TS	W	C	WI	GH	BT		P
3	SNODGRASS SLOUGH	2 7	+7¼	10	5	BE						H								P	
4	ANDRUS ISLAND	4 0	+6¼	20	4								M	T			WI				P
5	SACREMENTO RIVER	2 3	+6¼	20	20			H M		F2				T	D		W				P
6	STEAMBOAT SLOUGH	2 3	+6½	10	12	E							M	T	W		WI	G	BT		P
7	STEAMBOAT SLOUGH	2 3	+6½	10	8	BE							M	TS	W		WI				P
8	MINER SLOUGH	2 3	+6½	8	5	BE	N						M	TS	W	C	WI		BT	P	P
10	COURTLAND	2 3	+6¾			B							M	T			WI	G	B		P
11	COURTLAND	2 3	+6¾	12	10	B			16	F1	RM		M	T			WI		BT		
14	CLARKSBURG	2 3	+7¼	12	12	B			20	F2											C
15	FREEPORT	2 3	+7½	20	15	BE		M	17		RM			T	W	C	WI	H	BT		P
16	FREEPORT	2 3	+7½	12	12	BE					RM		M	T			WI	GH	BT	P	P
17	SACRAMENTO	2 3	+7½	16	8												I		BT		
18	SACRAMENTO RIVER	2 3	+7½	18	15	B								T			WI		BT		
20	SACRAMENTO RIVER	2 3	+7¾	12	9	BE							M	T P			W		T		C
22	OAK HALL BEND	2 3	+8	20	20	BE							M	T	W		WIB	H	BT	P	P
23	RIVERSIDE	2 3	+8	8	20	BE	S				RM		M	T	W		WI		BT		P
24	CHICORY BEND	2 3	+8¼	10	10	BE	N							T					BT		P
26	SACRAMENTO	2 3	+8½	6	6	BE	S										WI				P
27	BRODERICK	2 3	+8½	13	5			H M	36					T	D						
27A	BRODERICK	2 3	+8½	8	8	BE							M	T			WI		T		P
27B	BRODERICK	2 3	+8½			BE		H M							WD		W				
29	SACRAMENTO RIVER	2 3	+8½	12	12	E		H M					M	T	WD	C	WI	H			
30	SACRAMENTO RIVER	2 3	+8½	18	8	BE							M	T			WI		BT		
31	SACRAMENTO RIVER	2 3	+8½	18	18	BE							M	T			WI				P

(+)DENOTES HOURS LATER (-)DENOTES HOURS EARLIER
THE LOCATIONS OF THE ABOVE PUBLIC MARINE FACILITIES ARE SHOWN ON THE CHART BY LARGE PURPLE NUMBERS
THE TABULATED 'APPROACH-FEET(REPORTED)' IS THE DEPTH AVAILABLE FROM THE NEAREST NATURAL OR DREDGED CHANNEL TO THE FACILITY
THE TABULATED 'PUMPING STATION' IS DEFINED AS FACILITIES AVAILABLE FOR PUMPING OUT BOAT HOLDING TANKS

THIS TABULATION WAS PRODUCED USING COMPUTER ASSISTED METHODS.

Figure 6

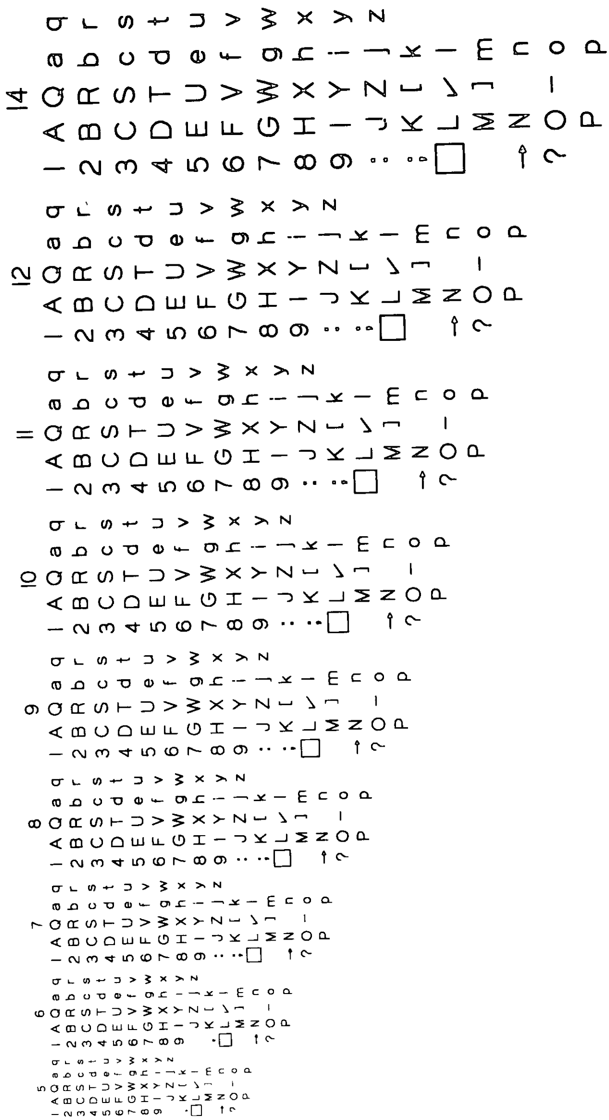


Figure 7

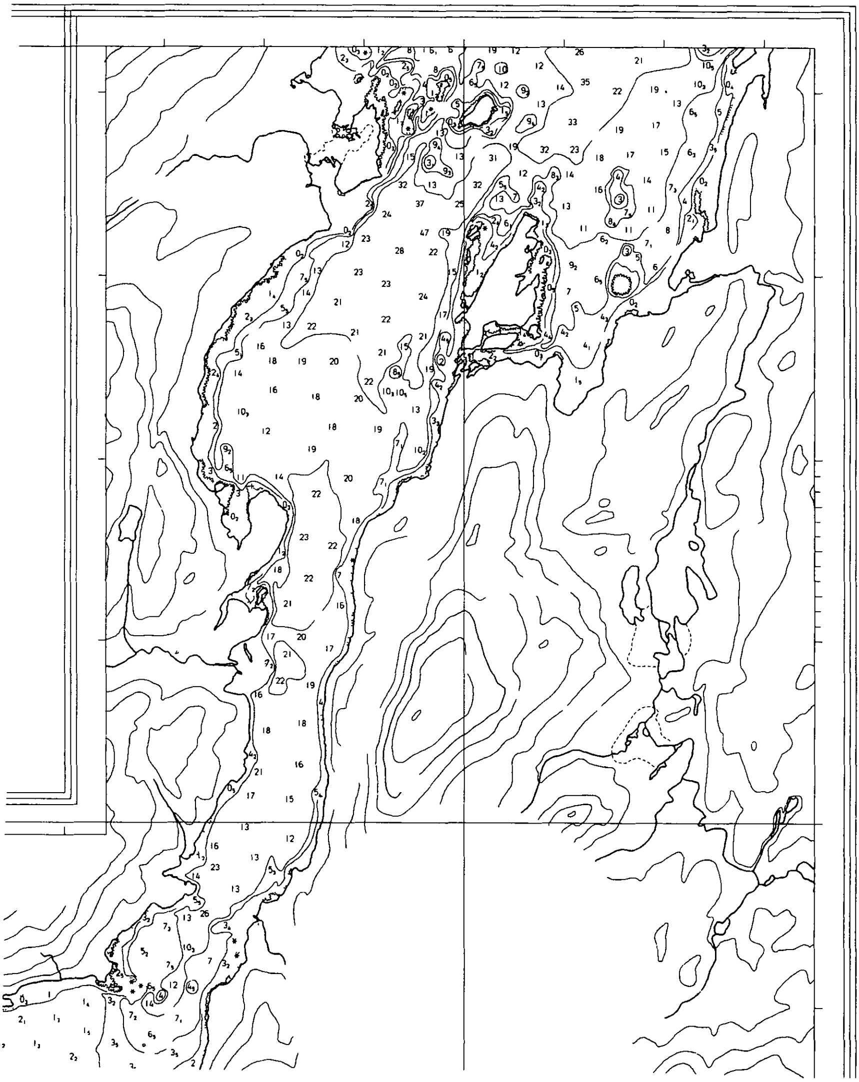


Figure 9

DR. BOYLE: We are going to ask Bob McGrath to come up. Bob McGrath is from DMA Hydrographic Center, and has had considerable experience with the different types of systems being developed.

MR. ROBERT MCGRATH: Thank you, Ray. Good morning. I think we should get into a little bit of background as to what the Hydrographic Center does. Mr. Bruce Optiz alluded to it briefly yesterday. We produced two types of products. One is digital products; typical uses would be radar simulators and collision avoidance systems. The second type of product is hard copy charts. These are navigational charts to support the fleet and worldwide maritime trade. These hard products are, as I said, the meat of our effort. We have been, for a period of time, using computer-assisted cartographic procedure. We have not gotten into raster technology yet, but we do have basic systems, the LIS in particular, where we capture data in digital form, classify the data -- that is, define whether it is a road, shoreline, coastline, or whatever -- create a data base and format charts for navigation and a number of other uses. I would like to address the use of the hard copy plotters in the production environment. I am not going to talk about the coming laser technology or the scanner operations that will improve production. But I will discuss some of the problems that were encountered in using the flatbed plotters. There are two plotters in use, the Xynetics and the Gerber.

The Xynetics is used primarily as a proofing plotter to check the accuracy of the information captured on the Lineal Input System. One of the problems is the ability to check the positioning accuracy of our data but not the classification accuracy. The Xynetics is not capable of generating line weight symbolization and charts produced full point and line symbolization is required. Therefore, it would be possible to have a city boundary in a correct position but classified incorrectly through an operator error when the data was captured, it would appear on the chart with incorrect symbolization (incorrect line weight.) An oil pipeline has a special symbolization that is used when display on a chart. It appears as a dashed line with a dot on the end of each dash. If it were incorrectly classified it might appear as a solid line in the proof plot. These are the things..........

These are the errors that could not be check on the Xynetics plotter. The Xynetics plotter is a good device for a quick positional check on the accuracy of the data, but it does not present a detailed enough picture to the operator. He cannot verify sufficient feature classification accuracy.

The effect is the operator would complete collecting the information he required and prepare for a color separation computer run on the Gerber. Color separation operations can require two or three hours to complete for one chart. On the Xynetics the same proof plot take ten or fifteen minutes. If the data is incorrectly classified, the Gerber run is wasted, and must be repeated. Our solution to the problem is to add a classifications information symbolization to the Xynetics plot program. One point that is worthwhile making here: When plotting a point feature on the Xynetics a (+) tick mark is used, just a tick mark to indicate that there is something there. No symbolization for a buoy or sounding. You would not get the depth. Incorrect feature classification would go undetected. Again, the solution is to add a more detailed symbolization package to be operated on the Xynetics.

Once the data collection is completed and the operator is satisfied, the data will be processed to achieve color separation and the specific formating required for the chart itself, generating four separate color plates for reproduction. The Gerber is the primary device now in use. It operates in three modes and is being expand to include a fourth. The three modes are: running with an ink pen, (seldom used), running with a scribe (also infrequently used), and the use of the photo head. The use of the photo head has several problems involved with it. The aperture wheel employed by the Gerber has only 24 apertures. This presents a rather limited symbolization capability if you have a wide range of symbolization to be presented. Since you are working with light sensitive film, the room where the film is being shot is in subdued lighting. It is inconvenient and difficult for the operator to change the aperture wheel and extend the range of his symbols. That is a problem. It is a limiting factor. It also increases the production costs as you go through your daily operation. When tracing a line on the Gerber, it is necessary to slow down physical movement of the aperture selecting to obtain the desired line weight. With each movement from the beginning of one line segment to the end of another the Gerber physically stop and mechanically snap the shutter even though there may be a continuation of the line. The problem, again, is time. You are slowing down for the mechanical operation of the aperture. It may not sound like much, but if you are dealing with highly convoluted lines that have many thousands of short segments, this increases the run time considerably. The problem here again is time, operator time, hardware time and production time.

The fourth method that I alluded to is expansion of the Gerber with a CRT print head. We have high hopes for the CRT print head. We have not taken it in our shop yet, but we do expect to have it very shortly. The CRT print head is a device that will mount on top of the Gerber in place of the photo head right on the current gantry, so there is a minimum of change to the equipment itself. The CRT print head also has a separate PDP 11/45 used to drive the print head. There are no photo apertures, as the name implies. The procedure is to sweep an electronic beam on the CRT, and it in turn imprints on the film. The advantage here is that associated with the 11/45 there is a large disk area where all symbols will be available at any one time. When a character is to be flashed, the machine will read the character code, go out to disk, read in the symbol and sweep the feature, the character or the symbol. Another and crucial point here that is going to save even more time: The CRT print head has an area of approximately three inches square that is a usable surface. The plan obviously is to sort all of the data that will appear on the chart in production, reduce the data up into a series of "pages" approximately three inches square, and move the CRT print head from page to page, sweeping all of the information in that three-inch square at one point in time, doing it at the speed of a CRT capability.

With the other system, the photo head, if you wanted to flash a sounding of 29 fathoms, the print head would move to the position of the first digit, the two, select the aperture, take time for it to spin around, flash the two, move to the position for the second digit, the nine, select the aperture, spin again, and then flash. All very time consuming problems. The gantry does not move that fast, either. It moves rather slowly. Again, all these things add up to limited production and increases in cost. The advantage of the CRT print head is realized when we reduce the data to be plotted into a series of "pages" and read the data back a page at a time; process each page, read each of the symbols, whether they are a buoy symbol or a sounding or a segment of a line -- the gerber will print all the information from one position for each page. There is no continuous back and forth motion of the gantry for individual symbols across the film itself.

We estimate that we will be able to process a chart that is 40 by 60 inches in approximately 15 minutes. That is a marked improvement. That is a savings of hours over what it is required right now. There is another advantage that has not been mentioned. If your font library resides on disk, you have a much greater repertoire of characters and fonts that can be reference at any period of time. Even though you are limited by disk storage, there is the capability to store a series of fonts libraries off-line on tape and read in the font library you are specifically interested in when required. It appears to HC that the CRT print head will, in today's non-raster type environment greatly increase our production capacity. I hope I have pointed out some problems that you are either getting into or are working with already and will be able to commiserate with and say, "Yes, I had that problem, too."

Thank you.

(Applause.)

DR. BOYLE: Thank you very much, Bob. I think that the CRT head has considerable application, particularly for upgrading the work of those who have large slow flatbed plotters which are very good for symbology and for names. I am not quite so convinced for linear work whether this paging process works, having lived through the abortive attempts by the USGS in the late 1960's--some of you might remember the very small error that can occur because the non-linerity in the CRT pages is immediately obvious from across the room. Pages have to be very, very precise indeed and I am not certain that this can be maintained using a CRT print head. Certainly, for a quick look, but for final precise drafting, I want it to be proved to me yet that it is good.

Now I am going to ask Richard Kidwell to come to the stand. Richard Kidwell is a user. He is in the Publications Division, Office of Research and Technical Coordination, at U.S. Geological Survey in Reston, Va. We have had several good discussions, and he has given me very large amounts of things to think about on the use of the scan plotting to handle a large amount of symbology, the areas of symbology, and so on, used particularly in the geological maps. I was very impressed with his thinking on this, and I asked him to come along to be representative of a user having a need of this sort of thing. So, Richard, if you would take the stand, please.

MR. RICHARD KIDWELL: Good Morning. Computer-assisted hardware copy display devices currently being evaluated in the Office of R&TC are the cathode ray tube plotter, the rotating mirror laser beam plotter, and raster drum plotters. The applications that we have are for film separations for LANDSAT data derivative maps, printed lithographic map sheets, geophysical maps, area fill for thematic maps, and automating the map lettering and symbol placement.

The principle hardware used for these applications has been Optronic's scanner/plotter. This device has an 8-by 10-inch drum. Routinely, it can scan or plot an image on a sheet of film in about 5 minutes at two-thousandths of an inch raster. An interesting application is a vegetation map for Nigeria, which is seeking a site for a new capital. Each of the separations for this vegetation map was plotted out as an open window from LANDSAT tapes by Pat Chavez at the USGS Flagstaff Office. There are six classifications. We had six plots of this sort (figure 1), all at the 8- by 10-inch size. To complete the plotting, band 7, which is in the near-infrared spectrum showing continuous-tone imagery of the ground, was produced with a minimum density of 0.40 and maximum density of 1.40 (figure 2). Band 7 image was enlarged 10 times and halftone screened for printing in each of the six land classifications areas. The open-window separations, also enlarged 10 times, served as masks for the band 7 LANDSAT imagery. In the final printing, each of the six classified areas was printed in individual ink colors with the band 7 imagery printing in each of these areas. Thus, you have a different type of map than normally presented, where the classified areas are printed as color tints over an image base. In this application, the image base itself printed in each of the classified areas, giving more detail in this 40- by 60-inch map at a scale of 1:100,000.

The next example is a map of the greater Washington, D.C., area with separations produced on a Mead Technology Laboratories rotating mirror laser plotter. The dots are generated as a fixed two-thousandths spot. The raster spacing on centers is one and three-quarter thousandths, which results in overlaping dots in a matrix to produce each pixel in the proper gray value (figure 3).

This is a view of the device itself, the rotating mirror is at the lower left corner. The copy that is to be scanned or printed is in the trough with copy size limited at this time to 14- by 24-inches. It takes about 2 1/2 minutes to print a separation. The map published for these separations is 24 inches square; so two sets of scans were made and joined photographically for the final printing. There was quite a bit of mosaiking to put the final copy in perfect register owing to computer processing of the LANDSAT data and the base-map linework. The device itself appears to have worked well. Separations were produced for the black, cyan, yellow, and magenta printers. The tints for each of these processed colors were derived from the pixel dots in the matrix. In the case of the Washington Urban Area map, Mead used an 8- by 10-inch matrix. This is one of the actual separations (figure 4). There are three separations sandwiched together on this slide. The cyan and magenta, and the black. You can get an idea of how they go together. Each one of these would be produced one at a time on the plotting device. The small circles that you see drawn around some of these pixels were used to register the copy perfectly. As I mentioned, there had to be some mosaiking to make a perfect fit. There were no register marks generated in the production of these separations, which is another item that I think is important to have. Register marks should be electronically generated with the copy. A pin-register system on these devices would be an additional improvement in the assembly of the separations.

This is a view of the Information International CRT device used at the Bureau of Census. The images are generated on the cathode-ray tube and photographed by camera within the device on 35-millimeter film. The problem that we have had with this type of device is that the gray values are not too well controlled, there is some loss in definition, and a registration problem exists. Here is a 22-times enlargement of the separations to publication size. The data, which are the black masses you see on the copy, have rounded edges but would normally be rectangular shaped (figure 5). Some of the areas were so small that we could not screen them with a conventional halftone screen so we used a random dot screen, which looks like so many worms, that captured most of the fine detail. The separations couldn't be registered perfectly; so the process has not been used in production. One thing that we are doing, though, as a result of this evaluation, is to have designed a very fine random-dot screen to use on LANDSAT data, where the imagery is very small and you do want to capture data now lost with conventional halftone-dot screening. We expect delivery of this new screen later this year.

In the reprinting of maps from lithographic edition prints, we are currently using a graphic-arts HCM color scanner in our USGS Branch of Printing. Size limitations are 19- by 23-inches. It produces one separation at a time in about 30 minutes at two-thousands of an inch raster. This slide shows the quality of a contour separation made from a lithographic sheet that has no green woodland overprint (figure 6). When we use a green overprint, the contours essentially cannot be separated as they do not reproduce well. So it has a limited use in topographic map feature separations; however, adequate process-color separations can be made for reprinting. On the other hand, for reprinting geologic maps, we make yellow, cyan, and magenta process-color separations and reproduce these quite faithfully. However, when we have to scan the map in two or more parts, which is reasonably frequent because of our large map sheets, the result is marginally acceptable. The device is a continuous-tone imaging scanner that produces halftone screen copy by exposing through a screen in contact with the film. There is difficulty in making each of the separations a perfect match along the join edges from both equipment and film processing limitations. The continuous-tone generation devices have this limitation in contrast to hard-dot generating device of the laser type.

For geologic-map area-fill separations, Al Williamson, of the Corps of Engineers in Vicksburg, Mississippi, made a set of separations at two-thousandths raster for us on an Optronic's scanner. The line copy was scribed at roughly 25- by 30-inch size. It was reduced in size to 5 by 6 inches, and area fills were produced for each one of the mapped units. These separations were then enlarged five times for publication. In the enlargement to five times, we had ten-thousandths-inch pixels and occasionally double-size pixels to twenty-thousandths line width, whereas the original copy was scribed at five-thousandths (figure 7). However, by overlaying the scribe copy, and screening each of the open windows with a 120-line screen, it smoothed out the ten-thousandths pixel steps so that you really don't notice the stepping too much along the perimeter of the area fill. We plan to go into production with one or more of these jobs with areafill separations made by Corps of Engineers and line separations by USGS. The cost is approximately $1,500 for a set of 18 separations on 30- by 40-inch film, which is comparable to or a little less expensive than what it would cost us to produce the separations by the conventional peel-coat method.

Area measuremnt is also available by scanning and impractical to obtain by manual methods.

A SCI-TEX North Amercian Corporation System evaluation on reproducing feature separations from a topographic lithographic sheet with green woodland was sucessful. The SCI-TEX system includes a 36-inch-square scanning drum, color video terminal, and a 42- by 75-inch laser drum plotter. I believe this will be discussed later by the SCI-TEX people; so I will skip over this example. The demonstration on this equipment indicates that our maps can be processed on this equipment because of its color CRT terminal, large size, and laser-dot capability.

An experimental geophysical map was produced by Richard Godson, USGS Denver Office. The geophysical data are initially collected from aerial sensors in digital form. Film separations were made on an Optronic's drum plotter by dividing the digital data into 17 groups for gray level plots using the equipment's 0 to 255 gray-level steps. The yellow ranged from no yellow at 0 to solid yellow at the mid-point or 128th step and back down to no yellow at step 255. The cyan separation ranged from solid color at 0 to no color at the mid-point or 128th step. This technique places solid cyan at the low sensor intensity and yellow at the middle of the intensity range while at the quarter point an equal amount of yellow and cyan mix to make green. At the high end of the gray scale, magenta ranged from none at 128th step to a solid at 255th step. This permitted magenta to print at the high end of the scale and a equal amount of yellow and magenta to mix at the three-quarter point for orange (figure 8). These separations were enlarged to publications scale and halftone screened but not printed as that was not part of this test. A proposed West Virginia State map is planned with a modification of this procedure. The principal thing learned from this test was that the continuous-tone separations must b prepared to accommodate the lithographic printing density range of 1.0 for the film separations if lithographic printing is planned. The low density point should be 0.40 and the high density 1.40 for predicatabl color-printing results.

The most recent letter and symbol-placement application involves Optronic's 17- by 22-inch Pagitron raster drum scanner/plotter. The estimate is about 10 hours of equipment time to handle 600 symbol and text placements on a 30- by 40-inch geologic test map process in four parts 17- by 22-inches each. Rotation of symbols and lettering is a software problem that must be resolved for success.

In conclusion, hardware devices and software exist now to produce cartographic separations for multicolor map publications. Open window for fill areas, production of separations from printed lithographic maps for republishing and LANDSAT derivative map applications for complex maps are cost effective, if properly selected. Geophysical maps and symbol placement are likely effective applications. Linework and lettering applications need more study. Continuous-tone film separations should have a density range of 1.0, from a low of 0.40 to a high of 1.40, to fit the lithographic-printing limitations. Plotting at two-thousandths of an inch appears adequate for linework while open windows may be plotted or camera enlarged to ten-thousandths of a inch pixel size provided the window areas will print with screen tints to smooth the pixel steps along the color boundary and thereby improve the register appearance. A pin-register system is needed on the devic to assist in the assembly of the separations for final printing. Thank you for your attention.

ILLUSTRATIONS

Figure 1.--LANDSAT open window negative.

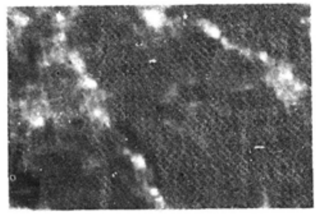


Figure 2.--Halftone image band 7.

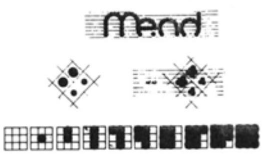


Figure 3.--Mead's gray value matrix.

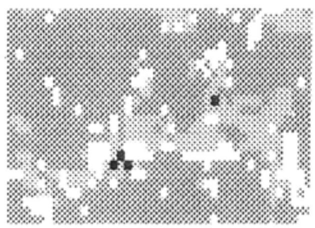


Figure 4.--Mead's color separation.

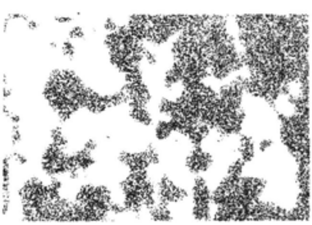


Figure 5.--LANDSAT CRT separation random dot screened.

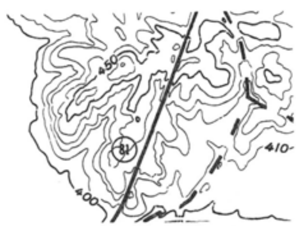


Figure 6.--Contour separation from color lithographed edition. Red roads would not separate from brown.

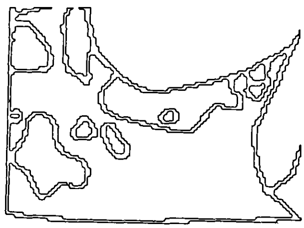


Figure 7.--Stepping of pixels in plotting of scanned line work.

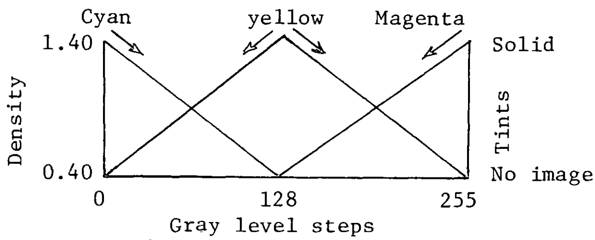


Figure 8.--Color separation schema for geophysic test map.

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Information International, Culver City, California

Mead Technology Laboratories, Dayton, Ohio

Optronics International, Inc., Chelmsford, Massachusetts

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Persons

Chavez, Pat, Jr., Computer Center Division, U.S. Geological Survey, Flagstaff, Arizona

Godson, Richard, Geologist, U.S. Geological Survey, Denver, Colorado

Williamson, Albert N., research physicist, U.S. Army Engineer Waterway Experiment Station, Vicksburg, Mississippi

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Overstreet, William C. and others, U.S. Geological Survey, "Provisional Map Showing Land Use Based on Interpretations of Vegetation Federal Capital Territory, Republic of Nigeria", 1977.

DR. BOYLE: Thank you very much. (Applause). We are now going to ask Mr. Gray to come to the microphone, from the DMA Hydrographic Center. He is going to talk about going directly to the printing plate. It is necessary for us to go to, as you have seen in almost all of these discussions so far, to make the photosensitive sheets and then go to a plate for printing -- cannot we directly make the photoprinting plate? He is, I think, mainly going to concentrate on that aspect of the work. So, I will introduce Mr. Gray of DMAHC.

MR. CHARLES R. GRAY: Thank you, Ray. The emphasis until now has been on the automation of the cartographic procedures that apply to a particular product. I want to discuss the graphic arts procedures that are going to be the tail end of the cartographic procedures and how they get from procedures to the hard copy chart or map, which is the Defense Mapping Agency's primary product. The paper chart and map is here today and is going to be here for many years to come. We do not look for its immediate demise with all these digits and widgets floating around. We are just going to change the procedures as to how we get to this final product called paper. This is a sample of a product that the Defense Mapping Agency Hydro Center puts out, not too dissimilar from either of our two sister centers, Topographic or Aerospace Center. Just the data on it is different. It is still paper. We have to get to the press plate. We have to print this product.

In 1972, when the Defense Mapping Agency was formed, an active R&D program was established to develop an automated means of producing maps and charts and all of their related products. As a result of this R&D program and later programs designed to achieve automation, a subtask was established to develop a digital to press plate capability. In 1975, the laser plate maker evolved from this subtask. Just last year, in September of 1977, a developmental contract was let by the Engineering Topographic Labs -- Fort Belvoir -- to the EOCOM Corporation in Irvine, California, to develop this equipment to meet chart specifications submitted by the Defense Mapping Agency Hydrographic Center. This equipment is scheduled for delivery in December of this year. It will provide the Defense Mapping Agency a read/write scanning capability. It will provide the capability to use existing chart and map files, of which all three centers, including the new Hydro-Topo Center, have an immense storage file of reproduction negatives and positives, which are currently their primary source for producing their products. We do expect to use these for many years. We do not expect to see them hauled away in the trash truck just because magnetic tapes are here. Tapes have not proven totally reliable yet.

At a later time, digital equipment will utilize the raster data which is in final edit format, and will command the Platemaker to expose a film for storage and proofing and a diazo plate to be used on the large format, 43 by 60 inch, three color offset presses that we use at the Hydro Center. This capability will support the Foreign Chart Program or the Foreign Chart Subsystem.

The Foreign Chart Subsystem will provide the Defense Mapping Agency, Hydrographic Center, with the capability to fully utilize all the chart material received in its treaty agreements with foreign countries for the interchange of information. The Foreign Chart Subsystem's three components -- the color raster scanner, which is currently being built by Hamilton Standards, a raster editing device, a raster finishing plotter, and/or the laser plate maker -- will increase production and allow the Defense Mapping Agency to meet its future requirements without any additional manpower costs. More and more real time commitments and requests are coming in to DMA for its products, and it just stands to reason that it is easier to manipulate data in digital format on a time basis than it is in analog format. It presently takes about three months or longer to cycle a chart through the Hydrographic Center from the time that the request comes in until the time the paper product goes out the front door. Time is manpower and manpower is expensive -- so comes the digital domain.

What prompted the digital plate maker? For about four years a number of commercial companies have been involved in the development of this technology, primarily around the newspaper and printing publications requirements, 18 by 24 inch format. This would do for our publications, but that is all. We in the Defense Mapping Agency use plates as large as 47 and a quarter by 60 inches. We require high resolution, just a little bit better than you read in the newspaper by scanning with a 25 micron spot size. We need multi-burn plate composition capability, and we want to merge digital and graphic data using automated and conventional methods to expose our diazo plates. As I said before, we have a very large chart/map file of information that we do not plan to dispose of, so we do want to have both capabilities, the digital and conventional technology-both-to make plates for the time being.

The future products that we at DMA will print with automation should not require any increase in manpower. We propose in the facsimile mode to use the chart original. This is made from the hand assembled manuscript compiled in the carto area, and then go directly to a press plate and a new negative. The laser plate maker is not going to just make plates. It is also going to produce a film negative simultaneously. We expect to be more flexible in the handling of different types of graphic input than we are at the present time. Everything now is manpower intensive, and we expect to reduce a good portion of this. We will store data in lineal format, and convert to raster for scanning on the plate maker and film plotter.

We expect to realize pre-press savings, in manpower costs, and some material costs, mostly in the stripping, and negative engraving areas. We expect to supply our users, the Naval and Maritime Fleet with a quicker turnaround time as their needs are identified for the DMAHC Charts. The laser plate maker will have new demands placed on it in the future. As new and better lasers become available, we will be looking at these. Lower powered lasers, visible lasers, to expose new plate emulsions in the visible range. This is the electrostatic, electrophotographic materials that are emerging. I have actively been going around the country in the last twelve months taking a look to see what is out there. There are new materials available and they will be available in the future in the sizes we at DMA need. Right now, again, they are geared toward the newspaper and publishing industry. We need two and a half times that area from 18 by 24 to 47 by 60 inches.

We expect to use low power helium neon or YAG lasers rather than the big, high power argon lasers used in this device when the spectral output and the photosensitivity of the new plates match up. We expect to use these electrostatic plates which will provide higher resolutions and speed on the press rather than the current plates that we use, which are brush grained aluminum diazo plates, if they are cost effective. In the future the DMA can expect to have master and slave units for transmission of graphics between centers or to meet other field requirements. This potential does exist, and in real time as is demonstrated by some newspapers. We do expect electronic screen generation as a future requirement in the development of the laser plate maker. The Defense Mapping Agency currently uses 120 line standard screens. We will be looking at the capability to generate this type of screen electronically as the plate is being recorded rather than manually the way we do it now.

The future may hold direct to press plate color separation. We do not have a large interest in this, since our product does not involve the type of color separation that probably most of you are familiar with. But we want to monitor this development. Some of these technologies are here today, and as they are refined or developed, the Defense Mapping Agency will monitor them closely for potential use, providing they prove cost effective over the current state of the art. These developments must prove to be economically realistic.

In our discussions with personnel from EOCOM Corporation, the technical people propose the three module construction which can operate in a same location or in a different location tied together by coaxial cable. As you look at the LPM, the first unit on the left is the read unit. This is the one that will accept the original or the paste-up and read it, using a four milliwatt helium neon laser. The one in the middle, or the one on the end, depending upon which way it is configured, will be the film writer. This will use a ten milliwatt air-cooled argon laser, and it will expose conventional ortho and reproduction type materials up to 60-inch format at four, seven and ten mil thicknesses. Let us say the one on the far end, then, will be the one that does the job. This is a two and a half watt argon laser, and is the plate exposing laser. It is a water cooled laser, and it will be a closed loop type of water cooling so we don't waste all the water that flows down the Potomac.

The plates that DMA will use are the plates we currently have on hand right now. This is the RPB type plate, 47 and a quarter by 60 inch, which is a brush grained plate, diazo roll-on emulsion. The Topographic Center, where we anticipate moving within the next five or six months, uses a Western Litho negative plate. That plate also is a candidate for this laser, and it does fall within the spectral range of the laser. The peak spectral range of these plates is 372 nanometers. The spectral range of the exposing laser is 363.8 nanometers. So, most of the energy and efficiency will be in the right range. The configuration is an internal drum scanner. It is three units, as you can see up here. It will accept negatives or positives as input. It will output a film or a plate or film and a plate. You can control either/or; you do not always have to generate a film. However, in the case of the DMA chart/map product, the film is the data base, it goes into file at the present time for storage. As we update our product, we store the newest version of that update. That is why we must still have the film. So, until such time as the DMA digital data is totally reliable, and this is coming, we still must rely on our film base technology to back up our products.

There are no particular special humidity or temperate conditions for this laser plate maker, other than just a clean operating area. We expect to put it in a room, in the plate maker area, near the press room. The temperate range it will operate effectively in is 60 to 80 degrees, relative humidity from 20 to 80 percent. The only additional feature that has to be established in the complex where this is going to be is a little darkroom where the film exposing module will be put, along with its own dedicated processor for the repro material.

From a graphic arts standpoint, these are the requirements or specifications that were established by the Hydrographic Center for this unit to meet. It must accept a 49 by 62 inch paste-up, or "flat" for scanning. It must accept a 47 and a quarter by 60 inch grained aluminum plate, and on this the maximum image size, can be up to 41 by 59 inches. It must record a 120 line screen, 4 percent to 91 percent tint, 5 to 95 percent half-tone. Provide a plus or minus two mil line weight or image resolution compared to specifications now available on standard charts and maps. Accept positive or negative copy. Provide registration of color separated images to plus or minus two mils. Provide even density across the plate, whether it is a solid, line or half tone. We do not feel that we have to sacrifice any image quality whatsoever just because we are going to automation. We have a good product now, we want to keep it that way or improve it. It must produce a press-ready single-plate exposure every 15 minutes or less at maximum image size, 41 by 59 inches, two or more exposures per plate. It must provide multiple exposure capability to plate for single color image composition. It must provide negative for proof or storage capability. It must provide a clean plate non-image area, dirt-, scratch-, and/or scum-free. It must operate in a white light environment. Laser plates supplied or recommended must operate using standard and/or alcohol dampening systems. It shall except an in-house pin registration system.

Now, these specs are just a little bit more than the newspapers require more along the line of commercial printing, and this is why I say, we are not going to back off on any image quality just because we are going automation. Thank you. (Applause.)

DISCUSSION

HARD COPY DISPLAY

DR. BOYLE: Thank you very much. The floor is yours for questions for the next 15 minutes. We have overrun our time a little, but I think they have been very interesting presentations, and you now know the people you can approach when you have to make some of your own decisions.

MR. RAY DILLAHUNTY: Ray Dillahunty. I am with Geoscience, Houston, Texas. I was just curious as to what the resolution is for the CRT head for the flatbed plotter you were using or intend using. I did not hear any comments as to resolution.

MR. McGRATH: The resolution is supposed to be plus or minus one mil. One thing I did not mention about the CRT print head: The characters are going to be presented in a raster form. The significance of this is that when you rotate a character, you rotate the entire raster. With the old techniques, when you rotated the character the character would tend to separate a little bit. By presenting the thing in a raster form it preserves its contour and the relative positioning of all the points. You get a better picture with the individual character.

DR. BOYLE: If there are no more questions, SCI-TEX offered to run their film. They have a rather attractive film of some of their manipulations. Thank you.

GENERAL TECHNOLOGY - AUDIO INPUT/OUTPUT

DR. BOYLE: Ladies and gentlemen, we will get cracking on the last session of the hardware panels. We are going to be talking about a very interesting aspect of small systems. This first part is particularly concerned with audio input, and, as a corollary to this, audio output.

We have many times regretted the number of errors we get from keying in information. There seems to be a considerable loss of information between our thinking and our fingers, unless we are very experienced typists, and most of us doing editing or digitizing work are not in this category. We do, however, have a very good communication link between our thinking and our speaking. Most of the speech input units that have been developed are only good at working on single words, but have quite a good vocabulary, and can, in fact, have multiple vocabularies. So you can have one vocabulary for one type of data and a vocabulary for another. It is quite another aspect if you want them to understand complete sentences the syntax of sentences and so forth.

The audio output side, which will be discussed by a small company from Palo Alto, Telesensory, is also very effective as a feedback. In other words, if you are digitizing the numbers on a hydrographic chart, and say "393," the unit immediately answers back after the analysis, and in its own voice, "393." Without conscious thinking an automatic loop is formed in your mind. If it misrecognizes your words because you were out drinking too much beer the night before and it comes back as "494," you say, "No, 393." It if keeps answering back "494," well, either you go and have a drink of water, or you retrain the program, because your voice has changed over the period. I find it is very important to have audio feedback whenever I have audio input.

I have always used speech input -- as a single word input with a vocabulary of about 50 words -- as one of the exercises I give to fourth year electrical engineering students at the university. We give them a microphone, a bunch of transistors, a mini-computer, and say, "Go to it." They have about 20 hours altogether to do this work. Some of them only get about 50 percent recognition, but others obtain 95 percent readability from the results. It is not a terribly difficult thing to do if you keep it simple, and, particularly, if you ask them to only do the digits and maybe you say, "Well, don't call it five, call it fifer," so that it is distinguished from "four" quite clearly. It is a very good exercise for students. I should think we have done this project about 25 times at our university with different students. All have made it work.

Against the idea of expensive military systems, you might be interested to know there is a small company in this area -- actually, it is in Los Altos on San Antonio Road, called Heuristics -- making one of these units for the computer hobby market. It is supposed to be on the market, in fact, this month. I saw it about six months ago in their shops; it works extremely effectively, costing about a thousand dollars. It has a good vocabulary and full learning routines. It is done on micro processors with the program in Basic. It is a delightful little unit.

I also visited another small company, Telesensory, and we have Mr. Walko on this panel. Unfortunately, Mr. Obester was called away to Washington and Mr. Walko, at the last minute, has offered to tell you a few of the things that are going on in audio output.

I was very impressed with their pocket calculator for the blind, which has audio output. It had a switch on the side and you can change it from English to German and to Arabic. Guess why it's in Arabic? I took a recording of this; I do not know how it is going to come out over the microphones and the loud speakers, but I will later play a second or two for you.

I am then going to ask Major Broglie from Rome Air Development Center, who has been involved in the audio input side and knows what different people are doing. There are many different systems. I know that the USGS at Reston are experimenting for geographic name input. Other people are using them for audio input of hydrographic soundings.

This is a small panel, but I think we will be able to cover most of the areas and enable you to ask questions. I feel audio is a very simple, powerful addition to both digitizing and interactive editing. Now the recording. (Whereupon, a tape recording was played by Dr. Boyle). That is audio output from a micro processor. They are just bits stuck together to make them sound as if they are words. All right, Major Broglie.

MAJOR JAMES BROGLIE: Thank you, Dr. Boyle. I would like to present, from the RADC point of view, what has gotten us into the area of voice input for cartographic applications. Rome Air Development Center, as has been mentioned by Mr. Jamberdino earlier, is a full spectrum laboratory dealing with basic research through experimental development, advanced development, and, finally, engineering development. I would like to present this paper in four parts, starting with the history of automatic speech processing, which led us to the application of voice input for cartographic applications; some experimental work that has been accomplished and published; a brief description of the ongoing current work at RADC; and some plans for the future.

Automatic speech processing is actually a three-pronged development undertaken by RADC: message monitoring, voice control systems, and speaker verification. These three lent themselves to the idea that we could take this technology and apply it to cartography. With the advent of voluminous cartographic data becoming available and the fact that we had a technology available, we decided to marry the need with the technology.

Many of you are familiar with bathymetric data. There seems to be, for a simple system using a very limited vocabulary, an area that would benefit mostly by this, and that is the area of multiple, limited vocabulary, sounding information that needed to be put into digital form such that software could operate on it to produce a series of bottom contours.

The existing cartographic or bathymetric input that we decided to operate on had to do with a digitizing table and a keyboard entry system that generated a set of cards that were then run to provide the information in a digital form. We decided to introduce the system at the Hydrographic Center of the Defense Mapping Agency. These are the experimental hardware units that were involved with the system that we evolved. I will describe each of them in detail but I would just like to give them all a name right now. We have the word recognition module, voice input headset, and an IBM card punch. There we have a Sony tape recorder that we are using to pick up the spoken words that we can do a statistical analysis. Here we have a Bendix digitizing table.

Basically we have here a voice input remote control unit, an alphanumeric display, pre-processor, Nova 1200 mini-computer, a tape unit, and a digitizer interface. In the voice input remote control unit shown here in detail we have the capability of selecting the operator, the word we wish to train, (and a gain control for various types of voice), a training mode, and a prompting or displaying unit, which also allows for viewing several of the past entries. The training procedures that are used are speaker dependent using unconnected speech. We use a limited vocabulary, in this case, the digits zero through nine, and five control words. The unique part about the system is that it can be re-trained instantly such that if there are speech difficulties due to colds, or tonal differences, you will get a re-training indication through the error button. During the training mode the word that we wish to train is displayed on the console, and then, through a preset number of repetitions, is entered into the pre-processor where a template is electronically formed, the template will be stored and used to match the speaker's voice with the stored template during an operational mode.

Here is the cursor that was used in the experimental work. You will notice one of the important things we did here (to provide ourselves an instant edit capability) is that we employed a visible feedback on the cursor, a light emitting diode unit. As the speaker speaks the words into the boom microphone, this system automatically, visually feeds it back to the operator, thus allowing him a complete concentration on the work area. Errors or misrecognitions are easily backstepped through a single word voice control, thus allowing proper numerical entry to occur.

This is a slide showing one of the operators that took part in our experimental work and the method of data entry. In the foreground you see, again, the keyboard that used to be used in the manual mode of digitizing. Here we move into our current outgoing work. This is a slide showing the hardware components of the system that is called the bathymetric data reduction system. The experimental work that was done was statistically analyzed and gave forth results that, while not absolutely conclusive as to certain size, numerical groupings, (as far as whether they are more rapid by input or not than the manual input), led us to believe that the results merited further investigation, particularly from a production environment point of view. We therefore went under contract to provide this bathymetric data reduction system in two phases, using both manual and voice input. The first phase hopefully should be concluding within the next couple of months and is called the basic operating capability, which would: create for us a data base in our data management system for both voice and manual input capabilities and yeild several algorithms operating on various types of input. The final phase of the program would then be to convert several other existing algorithms that are running on a large computer to a smaller system. For the experimental work we discovered that certain modifications to the cursor would prove to be useful from an operator point of view. Consequently, the cursor was modified. It is lighter weight, somewhat smaller, and still gives us the capability for a rapid visual feedback of the spoken word. Where do we go from here? Plans for the future include connected speech. Experimental systems under development now at Rome Air Development Center have provided 600-word vocabularies. These are node structured, and allow very rapid entry through high speed techniques that have recently been developed. We will be addressing even larger word vocabularies. A thousand words does not seem unreal at this point in time. Areas that are being in our advanced development model include digital radar landmass simulation, where highly structured feature analysis data tables will be used to describe certain characteristics of cultural features that are then fed verbally through the system to be stored on tape; and in flight information production program, again, where we have a very highly structured data input format. Let me just summarize where we have been, why we got there, and where we are going. The technology that we are applying here for voice and cartographic entry was developed from ongoing programs at Rome Air Development Center in automatic speech processing. This work was done under the auspices of Dr. Bruno Beek, Captain Bob Curtis, and Mr. Dick Vonusa. They are taking it from the very basic stages to the areas where the applications could be transferred to our systems. I mentioned some experimental work that we did. The results of that work were published in the fall 1977 proceedings of the ACSM. Currently, we are under development with a bathymetric data reduction system. This system will provide an on-line operational use of a voice technology. Our plans for the future include larger vocabularies, connected speech, and possible applications areas that use highly structured data format for input. Thank you for your attention. (Applause.)

DR. BOYLE: Thank you very much indeed. I will now ask Mr. Walko to tell us a little bit about the speech output and some of the interesting new developments are being done. Incidentally, I would say that this area around Palo Alto, Menlo Park and these places is a very exciting area for me to go around and to see many small companies doing a great deal of work on optical character recognition, audio input, audio output and so on. The excitement of the development in these areas is very real. These are companies you may not have heard about, but if we serve as a little bit of an introduction to their names I think it is serving a useful purpose. We always like at these meetings to bring in local companies around an area of a meeting, and I think that the optical and audio input we have not at this conference on hardware talked about optical character recognition at all. It is one of the things we ought to have done, really, but it was too much to try to get in. But the audio one is quite an exciting part of this area. So, we have given you a few introductions. If you want to hear more about them, well, get in touch with them yourselves. Mr. Walko, will you please tell us a little bit about your work.

MR. WALKO: Thank you Dr. Boyle. This should be rather interesting in two respects. First of all, Telesensory Systems has nothing to do with cartography at all, not anywhere close to it. Second, I was not supposed to speak today, as Dr. Boyle mentioned. Dr. Obester was to speak. I will give you some of the highlights the way I know them. My position at Telesensory Systems is Speech Products Manager. I have been developing marketing strategies for new developments that we have in devices that are of interest to original equipment manufacturers. I would just like to give you a little description of the company and the background.

The company started around a product called the Optacon, which stands for optical to tactile converter. All the products that Telesensory makes are for the handicapped, and especially the blind. Now the Optacon was developed with the help of OE grant to Stanford University and SRI to develop a reading system for the blind. What the Optacon does is to take a printed material and convert it to a tactile reproduction. A blind person would have in his hand a small camera bout the size of a pocketknife. He would then scan print with this camera. As he does so, he has a device with him about the size of a cassette player with a small array of 144 pins in it. As each character is scanned, there is no character recognition but simply a reproduction in vibrating pins. So under his index finger, as he scans the page, if he covers the "C," a "C" will be reproduced in the pins. In reading letter to letter he is able to develop words and develop reading rates of between 40 and 60 words per minute. That was the device that started the company. The whole reason behind Telesensory was to take the Optacon from the university atmosphere out into the marketplace so that the maximum number of people could benefit from the device.

With the profits made from the Optacon, we began to look into other areas, other products for the handicapped. One thing that we discovered that was a real need for the blind was some type of calculator. Up until the point that we developed our calculator, most blind people would be using an abacus to do their mathematics. We searched the market and found there were a number of calculators already available that had Braille outputs and some printed outputs but nothing was really useful for the blind. So we began to see that the only thing that would really be useful would be if the calculator could talk. We began doing research into speech technology and the development of our own speech technology. At that time a professor at Berkeley, Dr. Mozer, was doing some work, and we joined forces with him and developed the first use of custom LSI, or large scale integration, for generation of speech. So, the calculator, when it came out in 1976, was a first in two respects. It was the first use of a microprocessor in a calculator, and it was also the first use of a customer LSI to develop.

I have the SPEECH PLUS Calculator with me right now. This is a small, hand-held unit. It works on rechargeable betteries, and it is a six-function calculator, similar to any standard electronic calculator that you can find on the market right now. The difference between this one and the one which you might buy is the fact that this one is able to talk. I will give you an example of how it sounds when it is turned on. (Demonstrating). This is a sample of a calculation. So, in fact, the calculator speaks on every key entry and every function entry, and then will repeat the answer at any time. Whatever is in the display you can read out again. (Demonstrating.) After the development of the English vocabulary, we went into a second language, which was German. (Demonstrating.)

When the calculator was first developed we thought there would probably be a sighted market for it also, and it was on display in Neiman-Marcus in New York and in a couple of other large department stores. While it was on display at Neiman-Marcus -- it was kind of funny the way this happened -- an Arab sheik and his entourage came walking through the store and saw the calculator and just fell for it as a novelty item, and decided that they had to have some themselves. So they bought a few English models. The sheik decided it would be really something if he had an Arabic model. (Laughter.) So he assisted Telesensory by putting up some of the development money for a new vocabulary, which runs somewhere around $10,000, and bought quite a large number of these calculators to disseminate in his country. Later, I should explain, he did find out it did have a good use in the blind community, and it turns out he was quite a benefactor in his country. The name of the family is Binladen. They bought these calculators to disseminate to the blind, so it was not just a frivolous type of thing. But it is kind of interesting the way it came about. That was the calculator development. By the way, the calculator sells for $395, if you might be interested in the price of something like that. When we came out with the calculator, and since it was a first in speech technology, many companies were interested in the use of the technology in their own products to make their products speak also. At that time our company charter was such that since we were interested only in products for the handicapped and especially the blind, we really did not want anything to do with any outside manufacturers, even though we had something that was quite unique and something other people were interested in. Since then our attitude has changed greatly, basically because we need more and more money for development of new products for the blind. One way to generate profits would be to sell this technology to other manufacturers for use in their product.

This is a module right now that is available in two 64-word vocabularies. This sells for around $179. Two modules are available with fixed vocabularies. One of them is an ASCII vocabulary, so it is capable of doing the alphanumerics of the keyboard. The other one is a standard vocabulary of 64 words. It can count up to a million, and also has the capability of saying some measurement terms like "second," "degrees," "pound," "ounces," things like that. We also have the capability of custom programming any vocabulary that is necessary. Just a short explanation of what is on here: There is a microprocessor we developed, a ROM, read only memory. The microprocessor takes information from the memory as to what full names to string together, how long to say them, the duration of the word, and then send signals through the audio filtering circuit to the audio circuit for the speech.

When the Optacon was first conceived, the idea even at that time was that the ideal thing for it to do, instead of just reproducing a letter, would be to actually speak. This system is now under development at our company, and it is pretty well developed at this point in a PDP 11 computer. Work is being done to reduce it to micro circuits to produce what we term "the spoken word output accessory to the Optacon." This right now is being billed as probably the most sophisticated consumer product ever developed. What it will do is, as you scan the page of printed material or numbers, use a text to speech machine to actually read to you. I have an example of the speech quality. We are also developing a new method of speech synthesis in conjunction with MIT. Professor Allen is doing a lot of work there in speech synthesis. I have an example of it. It is a more natural sounding speech, and puts intonation in, and it has a little bit of an Irish brogue to it. It is very clear. Let me play it for you. (Demonstrating.) This was done by just scanning a typed page with those words on it, and the computer spoke as it was hand-scanned.

There is one last tape I would like to play for you, and it will give you an idea of how speech is built up. It is a very interesting presentation that was done recently at a news conference that we had. This is the voice of Jim Caldwell, one of our scientists who is doing a lot of work in speech synthesis. It is a very good explanation, and I wanted to play that for you. (Demonstrating.) That is about all I have to tell you. If you have any questions you may ask me later. I would like to thank you for the opportunity to speak, and I hope that you might see some use for our speech generation in the type of products you are interested in. I thank you for your attention. (Applause.)

DR. BOYLE: Thank you very much. I find these sorts of developments very exciting ones. You just try to think how you apply these to the sorts of problems you have.

Are there any questions on either of these audio output aspects? No questions? No comments about any other audio systems that may be in use which might be helpful to people?

SMALL OPERATIONAL SYSTEMS

DR. BOYLE: We change over now to the second part of the panel. Thank you, Major Broglie, Mr. Walko. We are going to talk about small systems. First of all, I am going to ask Efraim Arazi to tell you a little bit about editing in the raster mode. Christian Hoinkes, from Switzerland, is going to tell you a little about editing in the vector mode.

I think this is bringing us back to the present day. I think that this session right from yesterday morning has been rather like the Enterprise taking off on the back of the mother ship. We got to, I think, about maximum altitude and parted company with a sort of solid base of the 747 when Harry Heard came on, and since then we have been gradually coming back to earth, and we are going to slide to a stop in the future. Before we do, I want to ask Efraim to tell us a little about editing in the raster mode and as he sees how it must be useful in cartography, bearing in mind some of the things that were said by the group speaking about raster programming on Tuesday.

MR. EFRAIM ARAZI: In the first session today you saw the Sci-Tex movie. I apologise for the fact that it did not deal with cartographic material. The equipment is usually used for textile printing, packaging, decorative printing and the like. I want to take one minute to explain to you briefly the operation of this graphic design equipment that we have developed. Just to familiarize you with it, (because that movie was kind of running along), I would like to show you a couple of slides, just to acquaint you briefly with the equipment. Then we will show you how to use it. Now, this is a more formal picture. In the movie you saw the equipment in color, the scanning unit, the computer disc memory that goes with each editing station. This is the color television of the editing station.

Next slide please. Very quickly, there is not much to it. The editing stations are fairly independent, and many users have one scanner, one laser plotter, and several editing stations. You can increase your productivity fairly rapidly because one scanner and one laser plotter can support several interactive editing stations, about which we are going to amplify.

Next slide. This will give you a closer view. I am sorry I do not have good photographs of the screen itself. But let me drive home one point about the design philosophy behind this equipment. As I mentioned yesterday during the panel discussion on mass digitization, we are aware of the fact that scanned data -- including cartographic base data -- whether it is obtained from manuscripts or maps, involve alot of editing, inspection and revision, which may be due to mistakes or artifacts in the incoming art material or problems that have to do with autimatic scanning. We have always paid tremendous attention to speeding up the man-machine interface of the people who operate the console.

Now, the update time of the television screen is a fraction of a second. By pressing buttons on this little function box over here we do what normally people might do when they select things from the menu in automatic drafting systems that operate in vector mode, those that are in the hardware display over there, except, notice the very important differences:

The person operating the equipment can run the stylus with his right hand and with his left hand he can very quickly decide what he is doing; assign colors, draw vectors, draw different colors, change the size of the drawing points, zoom in, zoom out, magnify, minify the picture, display on the screen the location where he is, zoom down to see the entire picture so he can go and work and zoom up on some detail. All together, the raster editing station is fairly optimized for man-machine interface.

The last two slides will be just a quick look at the laser plotter. This particular plotter is pushing the state of art in hardware in several respects. To the engineers amond you I want to mention two interesting points. The heart of the plotter is this drum. The axis of the drum is going this way. The drum weighs 500 pounds. It is rotating 1,000 revolutions per minute. The surface is going at a hundred miles per hour, and the surface acceleration is 200G --i.e., 200 times the pull of gravity. A sheet of film which is lying on the surface of the plotter basically has to be held as if it was 200 layers of seven mil or four mil film. The film is held by vacuum from the inside. While the drum is turning, the laser light is coming out of this traversing head and is switched on and off at the rate of one million times per second. We now have developed a continuous tone modulator whereby we can also change the intensity of the light so that we can use continuous tone films.

Now, when you have the film turning with 200 G acceleration on the outside and vacuum on the inside, we obtain absolutely perfect films from the equipment. There are no pin holes if you plot negatives, for instance. So, one more advantage of plotting on a photo plotter of this kind of performance is that the users practically do not spend any time inspecting the film. The films are almost perfect. If something was right on the color television, the likelihood of getting it right on the film is great.

Computers have a way of either completely scrambling the data or you will have it right. The laser plotter is also doing electronic screens for those that print half tones, and you can assign different shapes, angles and percentage transmissions, if you wish. While the laser camera is rotating, we are generating the screen electronically.

Now, if we may have the lights back on, I will discuss for a moment the editing capabilities of this raster design system. Most cartographic problems have, by tradition or by complexity of the data, to do with having several layers of information which are superimposed on one another. If you spend enough time looking at the vector design systems, you will see that they have some intrinsic advantages, except that in terms of comprehending what is going on when you have several layers of lines lying on top of the other, you begin to have problems finding out who is doing what to whom.

Raster base systems are displaying areas. They are not displaying lines. We can very quickly assign a tint or color or shade to any polygon, or to any other zone, island or area in the picture. The rater systems are instrinsically capable of dealing with the more common cartographic material.

The vector systems, of course, have their backgrounds in two origins which should be remembered. Twenty years ago when they were being initially developed, one did not have the micro-electronic memories which are so essential to buffering and refreshing one screen worth of data, which is the heart of the whole raster display screen. Those memories did not exist. The only way then to display graphic data was by deflecting an electron beam on a CRT and addressing different places on the screen. These deflections were analog. I was involved at that time at MIT in the early stages og project MAC, which was one of the first graphic systems of this kind. Also, the plotting systems which were available at the time were Calcomp or Gerber or other flatbed or drum plotters, which are also by definition vector type systems. They have one pen which can go from one place to another.

Those were the technologies which were available for input and for display. The digitizers were also targeted toward manual driven "do some interpolation, of some thinking" as you scan. That is how the whole world of vector design equipment was developed.

This equipment is, of course, very efficient for mechanical design, for zoning, for tax applications, for two-dimensional overview of things, but they do not handle areas.

Handling areas is the thing we do so much better than those raster systems.

One last point. We now have scanned many cartographic source materials, and we are beginning to see that the amount of data which you need to store is definitely within the realm of currently available storage devices. Can you flash on the topographic map? What you see on the screen now is about 8 megabytes worth of data due to the specific encoding method we now employ. The system is now equipped with a 300 megabyte disc which can take care of an entire topographic quad map. Three hundred (300) megabyte is not like the mass storage that was spoken of yesterday. Those are mass produced discs which are available from IBM, and other manufacturers. By the way, I am talking about storing all the layers together. You can have a composite of the map. Can you put on a hydrographic map? This is a hydrographic map. It is a three-color map with all the tints in it. This is the black printer. Here we can show you a quick example of an editing operation. The map is a little bigger than what the overhead projector can handle. In dealing with other people's maps, you may have the requirement to delete some unwanted details, such as writing in it. You may want to change some of the symbols, so you want symbology. This is a patch that was later drafted into the main map. Basically, you can go up with your pen on your color television screen and wipe out the unrequired writing. Ilan, you can now lift the different layers. Can you just move the film a little bit? As you can see, we are dealing with several layers of data.

A typical editing job can be to either correct graphics that are in the map or to change the symbols. You can very rapidly use your cursor to indicate a point and say, "Please lay over Symbol No. so-and-so, Angle so-and-so," and bingo, it is in. It pops up on the screen and you have verification. If you make a mistake, you can step back a couple of steps.

This is how in cartographic terms one sees those editing activities, some of which were shown in this jazzy movie that we played in the first part of the session. I think the best thing for me to do now is wait for the question period for any questions that may arise with regard to the matter of editing data. So, I will yield the microphone.

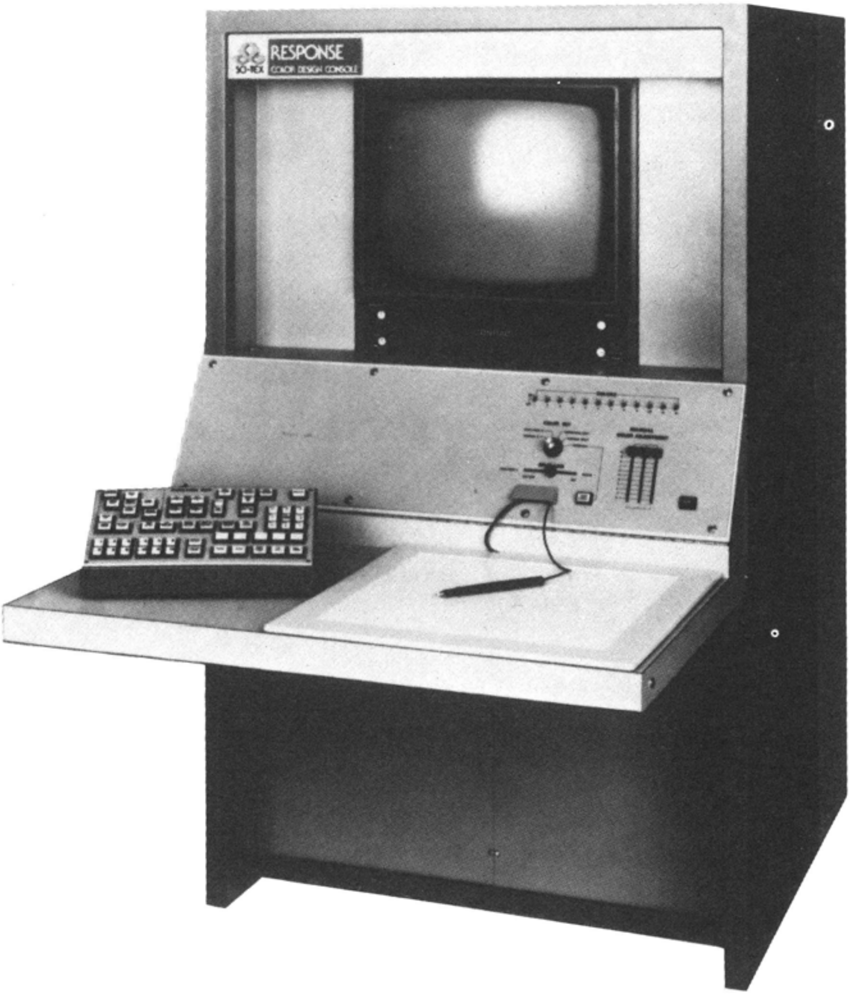


Fig. 2 The SCI-TEX RESPONSE Raster Editing Station

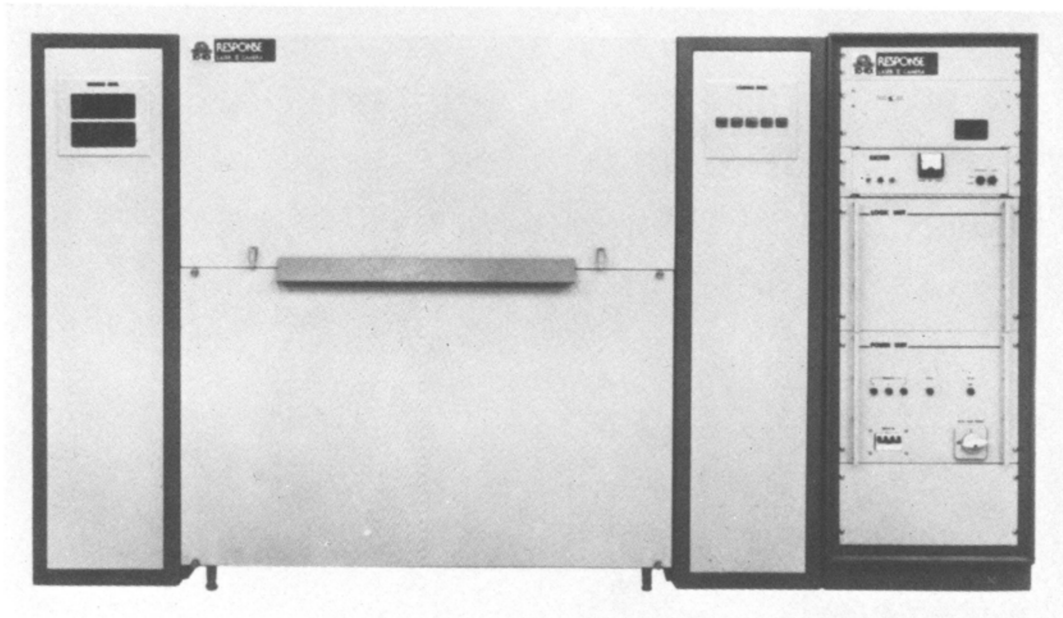


Fig. 3 The SCI-TEX Electronic Laser Plotter

DR. BOYLE: Thank you very much. (Applause). Christian Hoinkes is at the ETH at Zurich in Switzerland, and has come over to tell us about some of his work that he has been doing over there.

MR. CHRISTIAN HOINKES: Thank you for the invitation to come here. It is a pleasure for me to talk about something that we have done for the last couple of years. I will try to fulfill my role at the end of this hardware session, to land you smoothly down on earth again, so nobody will be knocked over by a car when coming out of the building and figuring out what ten to the 16th really is, or getting afraid of talking computers, and so on. We have nothing of this kind, rather something we can call "smallware" or even "oldware", because all the technology used is five to ten or even more years old. Also, we think in terms of classical map production. It has been our main aim to produce something on the plotter that can be printed in maps the standard way. In Switzerland we have a big challenge there because of the high graphic quality of the maps, and the intensive use of maps too. People walk around with them and read them. I think we have to continue to produce something like that.

To go back to the beginning, briefly. It was about 1971 when we started our computer project, with something like half a million dollars endowment, to spend on something like digitizing and precision plotting. It was our task then to get a system together for this amount of money and try to do something useful with it. We first had to find out what was existing then, and how this fit into our aims and objectives. What we actually did was something mentioned earlier during this week, we tried to take cartographic thinking to the manufacturers. We wrote out specifications and talked to them on our needs.

So, what are these main demands of cartography? First of all, we looked for a high quality output, as I mentioned earlier, which should come at least close to what human cartographers can scribe. In Switzerland, at least, that is so good that I have not yet seen any automated output that is really as good. It may come close, but I have not seen anything quite as good as a manually scribed line. So that was quite a task already. Then secondly, we looked for precision digitizing, because we thought we would have a cartographer sitting there, and his hand movement should be digitized, and we still trusted in that because all the maps so far are produced that way, one to one with printing scale. So we did not think there was any trembling or shaking in the hand. We wanted the precise movement of him to be digitized. Then, certainly some other digital inputs were necessary, because one main problem we were facing generally was the fact that digital data had to be mapped, so that had to be one of the main functions of such a system. In those two cases, digitizing and digital input for a map, we felt a very strong need for immediate graphic verification and feedback to the operator. He should see what he does graphically and not work blind. Then, after this sort of quick verification, we thought he needed some good hard copy output also, because from the traditional technology we knew that it is really necessary to look at the various parts which are generated for a printed map in close detail, to determine whether it is all right, and to mark corrections, and so on.

Finally we always pointed out to the manufacturers the importance of human engineering factors, because we wanted the cartographer to be the most important part of the system, and he should not be bored or be bothered by the computer, he should be assisted. With these ideas in mind we evaluated things about two years or so. And in late 1973 we were ready to place an order. We had about one year delivery time, since we also ordered some special hardware and software. The system went into operation in 1975. So, from then on we have worked now for three years, roughly.

The first Vu-Graph (Figure 1) will show you roughly what we got. The system basically fell apart into two halves. First, an interactive graphic system, including the digitizing work station, editing, and verification plotting. Off-line from this a precision plotting system, a Ferranti master plotter with light spot projector. We were looking for a photo plotter from the very beginning, besides other possibilities like scribing and cut and peel work and even pen and ink. But we felt the light spot projector had certain advantages. Coming back to this part, the system you see there consists of several work stations on-line on one mini-computer, and quite a bit of storage, nearly 50 megabytes, which was not small then, but it seems to be very small now. We had quite some trouble to convince manufacturers that we needed that much storage on such a small system. However, the amount of data worked with interactively is certainly only a small fraction of this. One drawing that is to be edited may contain up to maybe one megabyte, not more than that.

This operation of several stations on one mini-computer and interactive work called for a lot of software, which we were in no position to develop ourselves. So,the main thing was to find a software company doing this for us, or having done most of it already. So, although we are on a hardware panel, I shall show you something of the software in the next Vu-Graph (Figure 2). AGS, by the way,

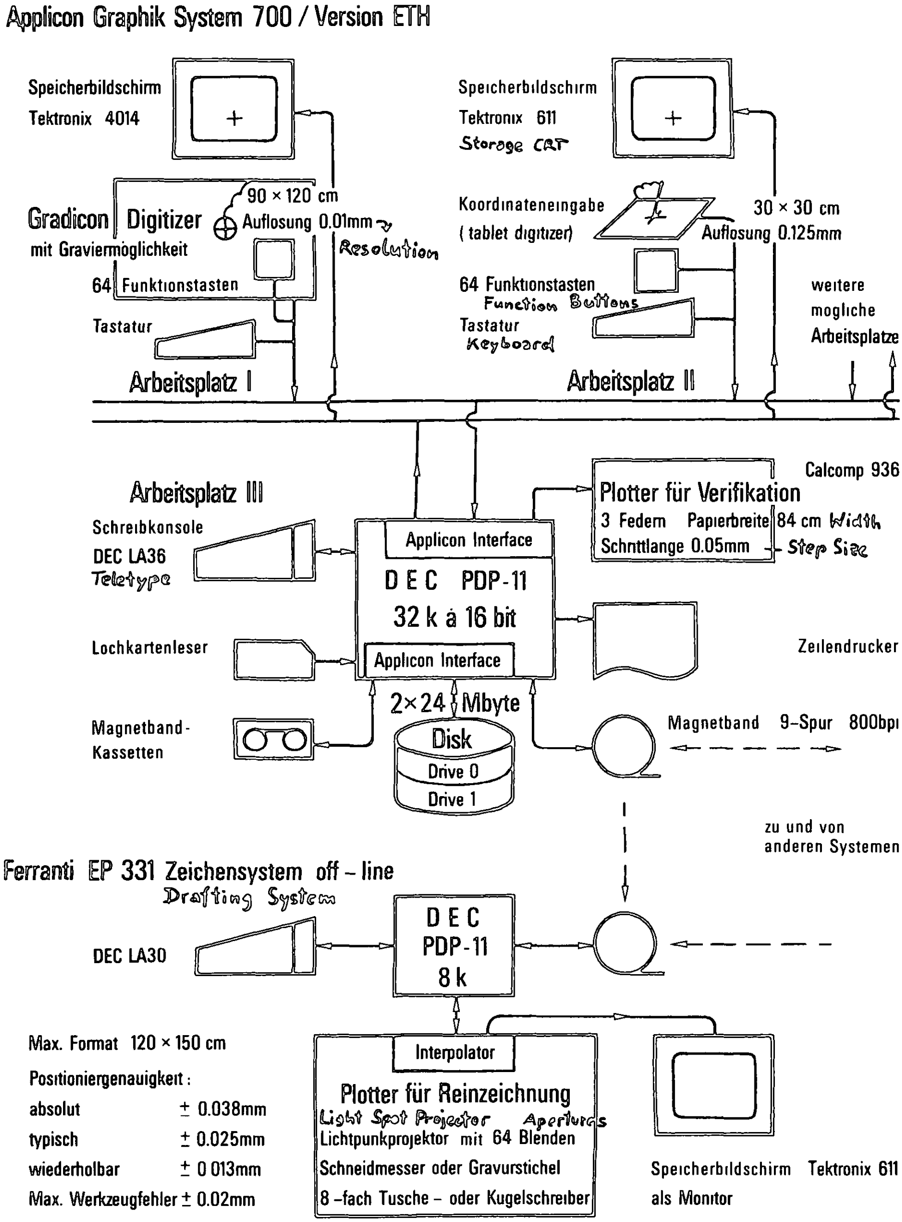


Figure 1 ETH Zurich Computer Assisted Cartographic Design and Drafting Unit (CACADU), Hardware Configuration

AGS/ETH SOFTWARE

-- Real-Time Multi-User Operating System for up to 5 Work Stations

-- Specialized Graphic Data Base Management System for Data Description and Manipulation by Means of a Comprehensive Command Language, which Includes:

  - Graphic Symbol Recognition for Command Input from Tablet
  - Menu and Function Button Definition and Decoding
  - File Management with Access Control and Accounting
  - Interface Software to the Data Base System for MACRO Assembler and FORTRAN

-- Standard DOS/BATCH Software from DEC for Single User Program Development

-- ETH Custom Software Package for Cartographic Applications

-- Library of ETH-Programmed "User Commands", which is Growing Constantly According to Production Requirements

ALL SOFTWARE STRICTLY SYSTEM DEPENDENT, i.e. Useful only for other AGS 700 Installations

Figure 2 Applicon Graphic System Software Summary means Applicon Graphics System. It contains a whole lot of software. I had difficulty to get it down on one Vu-Graph, and it still could be done in much more detail. First of all, there is a real time multiuser operating system which was developed by Applicon, not using DEC's, because that did not exist in the late '60's and '70's when they developed their system. It has a data base management system, but not a general one, a very highly specialized one. But this allows, by means of a command language, to manipulate the data.

It also includes certain nice things like graphic symbol recognition on the tablet. That is something very handy to input commands graphically, like define a window just by a graphic symbol, nothing typed, no buttons pushed at all. Also menu and function button decoding, so these techniques can be used. We use much more the functions buttons, you will see later, than the menu. A file management system. This is in contrast to data base management. While we work interactively, the data of a file reside within the data base system. After manipulation the changed data are taken out again by a store manipulation and stored as a file, but filed with access control and accounting information, et cetera. This is meant by "file management". So, for this file storage we use a lot of disk space, which allows us to keep quite a lot of data on-line. Archival storage is then off-line on mag tape.

Then, very important, too, the system has a software interface for data base input-output operations. So, by Assembler and even FORTRAN programs we were able to expand the systems capabilities. Such programs are developed with the standard DOS/BATCH software from DEC in a single user mode.

This facility to access the data base was quite an important criterion for the decision of what to buy. However, it is important to realize that all this software is hardware dependent, and this is mainly because of the speed that is the main issue in interactive editing. So, the system makes use of special hardware for interfacing displays and digitizers. Thus the software is not only PDP 11 dependent, it is really system-dependent.

There is no code for the operating system and the data base management system available, but we were not really interested in that. We were just interested in learning basically how it works, and we succeeded in that. But I think the code would not have been much help to us. Important is this data base interface. Since we have this we can access the data base and do anything to the data in an interactive mode. Now, I show this in such length on the hardware panel because I got the feeling here during the last week that the software going with the various available interactive graphic systems off the shelf is somewhat underestimated. There is such a lot in our system that I would think no university department could develop that on its own, not even in years. So, why not take advantage of what these companies did? Although, as I said, it needs some modification to be used in cartography. All these systems are developed for quite different purposes, for which they are used economically,and that is why you can buy the software together with the hardware so cheaply. These systems are sold by the hundreds for layout of integrated circuits, and things like that. I think we will have to ride on the back of others in this case.

Now, let me show you some slides to bring this a little bit to life. The first one gives you an overall impression of the interactive system without the precision plotter, which is off-line. Here, the PDP 11. One graphic work station has a 611 Tektronix with a digitizing tablet, the other one the 4014, and the GRADICON digitizer (See Figure 3). In the foreground here, the disk drive, one at that time, we ordered a second one a little later. The Calcomp 936 drum plotter for verification, which we find does a very good job very cheaply. It is our sort of hard copy device,by a software program, certainly, but it allows us to verify map data full size. In the background, mainly for programming, also a printer. Here, a card reader. This, a little bit more closely, the two graphic work stations. From the software point of view they are pretty much alike. They both have a digital tablet input, this one small, this one big, for precise work, and a CRT output.

Figure 3

View of the Two Graphic Work Stations, Large Tektronix 4014 with Digitizer in Background, Smaller Tablet Station with Card Reader and Cassette Tape in Foreground

The next slide shows the digitizing station in more detail. We use two types of cursor, cross-hair with magnification or a scribing cursor. Quite important is this device here, a function button array. It is made up that way, so you can easily write in here to specify what the buttons are defined to mean, and that is user definable, certainly. You can take this sheet out and use it as a menu in digitizing, but we found that very, very impractical as compared to this way of operation, pushing the button with the finger and keeping the cursor in place, maybe with the other hand; you do not have to move the cursor back and forth all the time.

Next slide. This shows something on CRT (Figure 4). It is quite a good example for a practical application. It is an aeronautical chart overlay done for real production purposes. It is printed, and it will go to the second print now, and will be updated every year and reprinted every year -- on top of a topographic map that is still manually produced. The next shows the windowing, or zooming-in capability, which is very fast. I cannot really show the editing here without having a film to show, because otherwise you do not get the impression of time. But you have seen something like that-I hope-in the exhibition, so you can imagine. It is important that these things work pretty fast, in a matter of seconds, because an operator waiting there really wastes his time if he has to wait for minutes just to look at another section of the map, which he could do in a manual process very, very quickly. But, at least with sort of a limited amount of data we have here, although there are continuously digitized lines with thousands of points (but not more than, say, 50 000), this works very well.

Pressing one function button we get the same display on the plotter, but certainly at defined scale, with one of three pens, and, also, if we like, full symbolization. For verification that is quite important. That was stressed earlier today. This shows one of these plots. One important thing for verification is also that we use output sort of "sliced" by feature, so we plot only one kind of feature at a time, and then another and another, or maybe three different colors on top of each other, so three, then the next three, so that the feature code assignment can also be verified. After verification a tape is made and this goes to this photo plotter, or light spot projector, as it is called, very accurately I would say, by Ferranti, with a disk of 64 apertures, of which we have two. This is purely used to play back what is on the tape. Not even scale changes are possible, although a computer is used to control it, but this has to control other things, like speed, light intensity along the path, and so on.

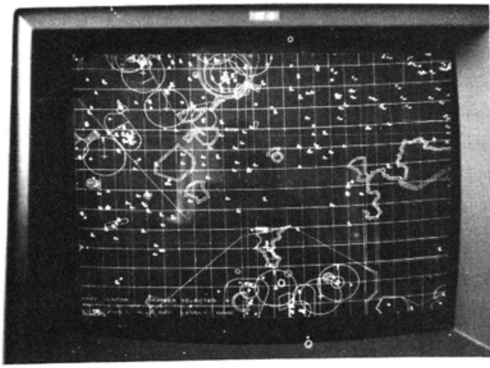
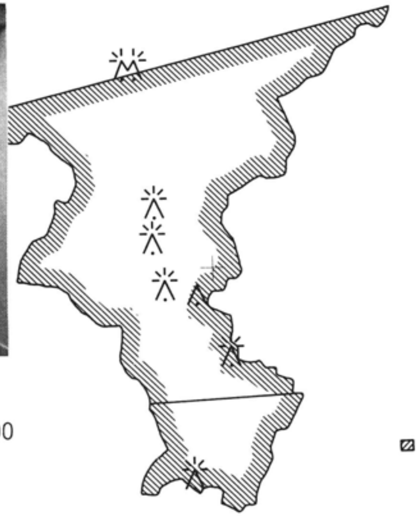


Figure 4

A Section of the ICAO Chart 1 : 500 000 on Display during Editing



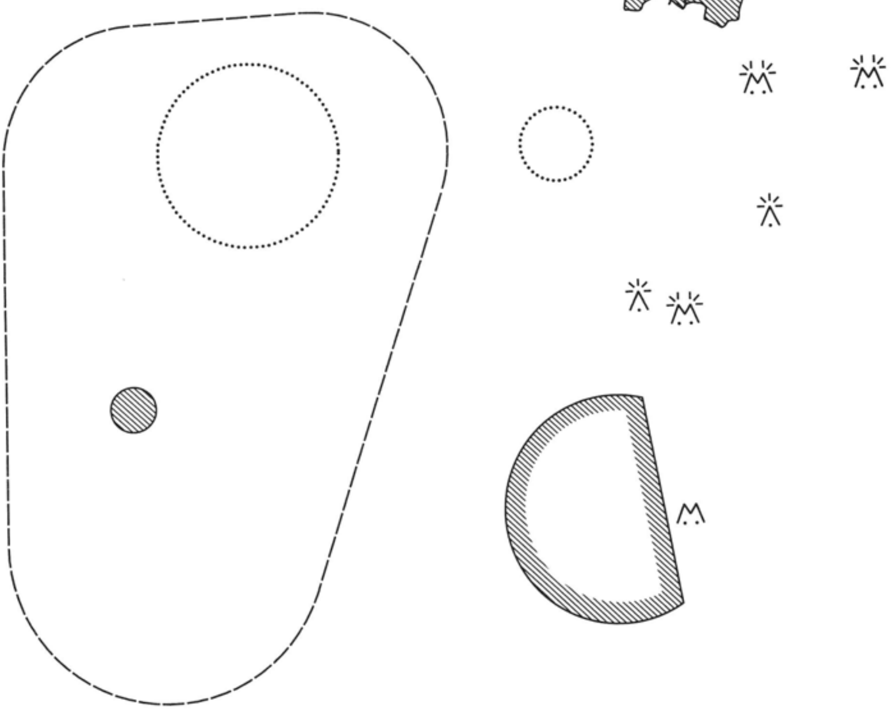


Figure 5 A Section of the Printing Masters for the ICAO Chart without any Manual Touch-up

Now, this is the output we get on the film, for example, after development (Figure 5). You see also these continuous lines, which consist of short straight segments, about three points a millimeter, come out rather nicely, constant line width, depending on the aperture. And we have practically all necessary apertures to compete with everything that is scribed manually. Even these line symbolizations are generated automatically by flashing dots along the line or making breaks at regular intervals. Also, the cross-hatching is done automatically. However, for this, we prefer to cut masks and copy this in manually, like a standard screen is copied in, but the lines themselves were produced by the plotter on a big sheet to generate exactly that kind of screen which was required for this map.

This procedure illustrates one important thing. We always felt that these plotting capabilities are one additional capability to all the other, the reproduction and manual techniques, and that they should fit together. In this case they do. For example, as I mentioned earlier, the base map for this map, all the topography, is done manually in the National Topographic Mapping Center on glass plates, absolutely accurate and stable in dimension. The plotted overlay sheets have to fit these plates precicely, and they did, even though the map is more than a meter wide.

Here you see dashed and dotted lines, cross hatching and even some symbols, like these obstacles, which were plotted at printing scale, and the result is satisfactory for even the most critical Swiss cartographers.

Now, this is another example of an area we are going into, thematic maps for the "Atlas of Switzerland". This is a simple example where we used the standard system capabilities, just placing various sized symbols at centers of villages, at Zurich, for example (see Figure 6). We are now working on additional software (called DIAMANT) to process directly the statistical data, like population counts, and generate things like pie diagrams and other kinds of diagram maps at the interactive system. The output should be film masters directly for printing, but there may still be some other lines on the map (e.g. topographic base) which have been generated manually. Also the lettering we leave out because we did not find the capabilities of a light spot projector good enough to generate cartographic style lettering. Some experimental work is also done in the field of topographic mapping. We are digitizing sample areas, but are experiencing the limits of such an interactive system there. To find these was one of the objectives of our research, to show what can be done and what cannot yet be done.

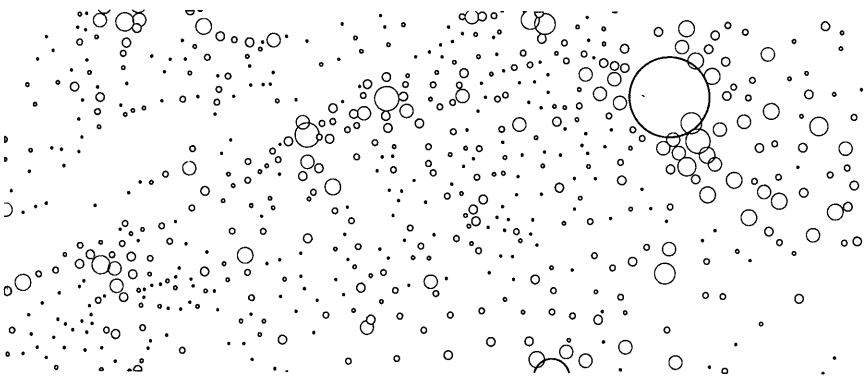


Figure 6 Section of a Light Spot Projector Plot as Used for Printing of the "Atlas of Switzerland"

This brings me to the end of my presentation. I just want to say something more about the economic aspects. Although our main interest is research and education, (also for visitors, not only for our students, so you are welcome to do the same as many others did before, if you have a chance to visit us we will be glad to show you the system), we have tried to use the system also - part-time - for production, in applications as you have just seen. Although being part of a university, we will try to run something like a service for automated plotting, especially for other government agencies, but also for private companies. So we have to figure out quite well the cost of our work, because these people actually pay. The aeronautical chart office paid our effort in full and found it actually cheaper than what they would have had to pay to do this manually, and it was faster. So, we arrived at cost figures per system hour. This means one hour on one of the two interactive terminals, which can be used simultaneously, or one plot hour. So, on the whole, there are three things that can go on together, and each of them costs anywhere between $ 30 and $ 50 an hour. It depends mainly on how many productive hours you count. We found this figure quite low. It comes close to the cost for manual labor hours which in Switzerland is about $ 25. So, we found that cost-effective applications can be found for such a system already now, if there would be enough volume of work. That is one problem in Switzerland, where just one sheet like this aeronautical chart covers the whole country. It is only a part-time job for us to do that, but I would think in your country that there are very good application areas for systems like that in cartography. Thank you. (Applause).

HARDWARE SUMMARY

DR. BOYLE: Thank you very much, Christian. I am afraid we are running rather late, and there will not be time for any questions at this point.

I would now like to recapitulate what we have tried to do in this session.

On this Enterprise operation, we have now skidded to a halt. We have brought together for you some of the best people that are available in the world. I think that much of this will only come through when you read it again in the report, which, I hope, can be made available as soon as possible. I believe it will be a very valuable document of the state of the art in hardware, which, as I said at the beginning of this period, may be at a peak in its development. From now on we shall be getting to much more straightforward engineering.

I think you may be getting worried in case this juggernaut of technical advance is really a juggernaut. And believe me, it is. North America has chosen to go to advancing technology and, it is moving very, very quickly. You, in cartography, are at the convergent point of a number of juggernauts coming down the roads towards you. If you are not careful you might become just part of the graphics art operation, and, along with design of dress fabric, cartography might be an auxiliary art.

I have had great fun over the last few years riding, on a little white horse, ahead of the juggernauts and beckoning to them and pretending I am doing a bit of leading. In fact, it is not that at all. As I get older and more experienced I know which wheels will speed up and which ones will slow down. I am able to see which way they are going to turn, and can pretend I am guiding them. I am not, of course, from my position, and just purely as an individual.

However, you have to be prepared to learn to get into the driving seat of these juggernauts and you have to do a lot of work to get to this stage. If you do not, you will get -- I was going to say a "dumb engineer" sitting in the seat, driving along, because, if he does not, he will get a parking ticket from some office of budget or finance. He has to move on, and you are going to be taken along in the wash. I do strongly suggest that you get into the driving seat.

This raises the problem of education. How are you going to get education? The universities have a part to play. They are not going to do it unless they get some financial support from your government organizations. I believe one way might be to give a contract to an appropriate university near a large organization, to do some research in methods of teaching advanced cartography, automated cartography, and so on.

I would also like to see the aspect of service bureaus advanced. In my opinion there has been too much of the large government departments keeping the black boxes to themselves; it is then very difficult for anyone outside to get in and use them. I would much prefer to see the departments now supplying some support money, some bread and butter money, to operations outside, so that these operations gain some background, knowing that they are going to get so much a month to do certain basic work; not impossible work, but just straightforward work. They can get some of their jam and cake doing work for other people.

I would like to see this approach in the area of mass digitizing. I would like to see it in precision drafting. I would also like to see it in the area of mass storage recording. I think that most people will want somebody else to do their recording as it will be an infrequent operation. Even a large amount of digitizing would only require that one of these optical disks be made once every six months or maybe once a year.

These are all philosophies, and maybe we will have a little time to talk about them this afternoon in the overall wrap-up session. However, I wanted to bring them to you because they are part of hardware and part of hardware development.

I have had the opportunity of working with Dean this summer to sort out the people we wanted to invite. We chose people who were not only leaders but could confer their knowledge in plain English to you. Believe me, most of these people could have spoken to you in a language, which, without going back to a university for a number of years, you would not have been able to understand. But they were all people who could translate into, I believe, a language that you understand. You have had a packed session and you have had a lot of information. I have been very thrilled with the quality of the information and I think that it will make an excellent report when it appears.

Would you like to finish off, Dean, with any final announcements? (Applause).

MR. EDSON: I would like to thank Ray for all that he has done in bringing this hardware session to us. We had to bring him in from somewhere on the other side of the world, and we are going to be returning him, I believe, to someplace on the other side of the world. It certainly is inconvenient for him, but it was great for us. Thank you, Ray.

DATA EDITING

MR. DEAN EDSON: I identified the data editing as a topic unto itself because of the extensive work that is going on in this field and the impact it ultimately will have on the usefulness of digital cartographic data.

To lead the discussion for this important subject, Harvard Holmes has traveled from the Lawrence Berkeley Laboratory, just on the other side of the Bay Bridge, and is the leader of the computergraphics group at this particular laboratory. Harvard's group has been involved in thematic mapping efforts for a number of federal agencies over the last five years, and is one of the largest general purpose computer centers in the federal government. They have specialized in the use of very large data bases such as census and so forth, which are on-line at the computer center at Cal Berkeley. Without further ado, then, I now introduce Harvard Holmes who will lead the discussion concerning data editing.

MR. HARVARD HOLMES: I will start with a few words of what data editing is all about. It includes the original data capture, with perhaps the exception of some mass digitization efforts. It includes the correction of mistakes and perhaps more importantly it includes alterations and additions to the original data base. I would like to just describe the areas of work that are going on at Lawrence Berkeley Laboratory and then summarize what we have learned from these projects. The largest project to date has been the Urban Atlas project in cooperation with the Department of Labor and the Census Bureau. This project required digitizing about 35,000 polygons. That is where we got our experience.

The editing that we did used a refresh terminal. In our case, it was connected to a large general purpose time sharing system. That leads to problems, problems in the area of response time, primarily. I guess the two things that we did to get good response time were, first, we worked at night. That always helps. Secondly, we made some deals with the computer operators. Anyway, what did we learn from all of this? We were involved in the Census Bureau project with mass digitization, and we had a very early version of a line following digitizer. We learned a very painful lesson, which was "get it right the first time." It is far easier to lavish a great deal of care and attention on a high quality base map and digitizing operation than it is to go back and fix it up later. The second thing that we think we learned, and I know at least one panel member wil disagree with me, is that BATCH editing is a drag. We feel that interactive editing is the only hope of correcting the errors and keeping track of what is right and what is wrong. Apropos of that, we discovered that interactive editing can generate very high interaction rates. Over a two-hour period we have measured interaction rates as high as one operator input every six seconds. And on every operator input, the computer system must respond with some response. On every third or fourth input, there is a significant graphic output to go along with that. We think that only a mini-computer can keep up with the need for this kind of responsiveness. Finally, we discovered that subsequent uses of the base file map, especially aggregations, disaggregations, modifications and so forth, demand a fairly sophisticated file structure like the DIME structure or the chain structure, which you will be hearing about. Finally, we discovered that we should use the same file structure throughout. In an early part of the project we were converting a file structure to use an existing graphic editor. That killed us. That was a very expensive, very frustrating period. We discovered that every time we had one minor bug, we were going to spend five minutes of computer time converting the file to the edit format, fixing this one thing, five minutes changing it back, and then retry your program. That is just not going to work. So if you possibly can, you should keep the same file structure throughout.

I would like to introduce our first speaker, Marv White, who is from the Census Bureau. He is in the Statistical Research Division. He has been concerned for a number of years with ARITHMICON, which is a project to exploit the topological aspects of cartographic data bases for editing and verification.

A Geometrical Model for Error Detection and Correction

Marvin S. White, Jr.

INTRODUCTION

Practitioners of automated cartography are well aware of the inevitable intrusion of errors into their maps and of the tenacity that these errors exhibit. Errors seem to have a survival instinct. To combat these intruders and to provide a sound foundation for automated cartography, we turn to the mathematics of maps.

The maps we have been concerned with all represent the surface of the earth and so the appropriate mathematics is the geometry of 2-dimensional surfaces. By studying the geometrical character of 2-dimensional surfaces, we can understand map phenomena from a mathematical point of view. This understanding provides the basis for encoding and decoding maps for automated cartography and subsequently for detecting and correcting errors in the encoding.

The model described below is a topological model which is the basis for the well known DIME map encoding method. The DIME edits are also well known but their mathematical foundations and fundamental nature are not widely understood. These edits are not *ad hoc* tests, rather they are questions about the fundamental properties of the encoded map.

Mathematical Character of a Map

A map may be regarded as an assembly of elements of dimension 0, 1 and 2. This is a combinatorial view of maps, which is illustrated in Figure 1. The elements are points, called 0-cells, line segments, called 1-cells, and areas, called 2-cells.

The elements of a map are called n-cells after Poincare, who invented the terms. A 0-cell is merely a point; a 1-cell is a line segment stretched and formed to the desired shape but not crossing itself; and a 2-cell is a disk stretched and squeezed to the necessary shape but neither torn nor folded onto itself. Figure 2 illustrates 0-, 1- and 2-cells.

Dual Independent Map Encoding (DIME)

An automated map consists of numerical representations of the 0-, 1-, and 2-cells and their interrelations. The fundamental relations are the incidence relations, viz., which cells touch which other cells. In DIME we code the incidence relations for each 1-cell, i.e., the pair of 0-cells that bound the line and the pair of 2-cells that the 1-cell separates, as shown in Figure 3.

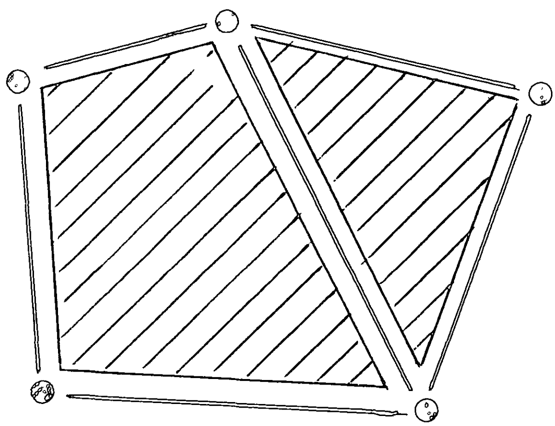
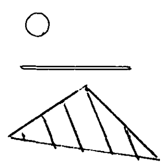
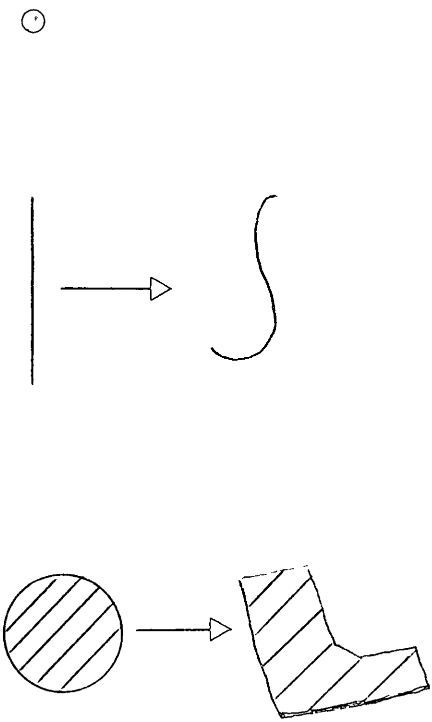


FIGURE 1. A MAP MAY BE REGARDED COMBINATORIALLY AS AN ASSEMBLY OF

POINTS
LINES
AREAS





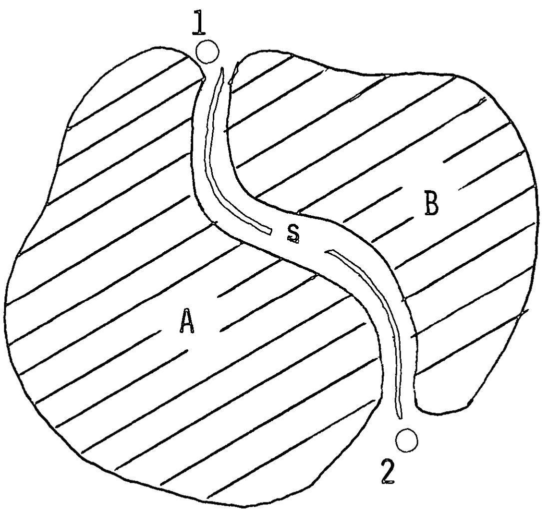
A 0-CELL IS A POINT

A 1-CELL IS A LINE SEGMENT STRETCHED AND FORMED

A 2-CELL IS A DISK STRETCHED AND FORMED

FIGURE 2.

A DIME file contains one record for each 1-cell in the map, which contains the incidence relations for the 1-cell and from that information alone, all topological relations can be computed. For example, the set of 1-cells incident to a particular 0-cell can be assembled by searching the file for all references to that 0-cell (this is called the coboundary of the 0-cell). Similarly, the set of 1-cells bounding a 2-cell can be constructed by searching the file. The neighborhood of a 0-cell is constructed in stages, as shown in Figure 4.



	From	To	Left	Right
s:	2	1	A	B

FIGURE 3. IN DUAL INDEPENDENT MAP ENCODING (DIME) THE INCIDENCE RELATIONS BETWEEN A 1-CELL AND ITS ASSOCIATED 0-CELLS AND 2-CELLS ARE CODED.

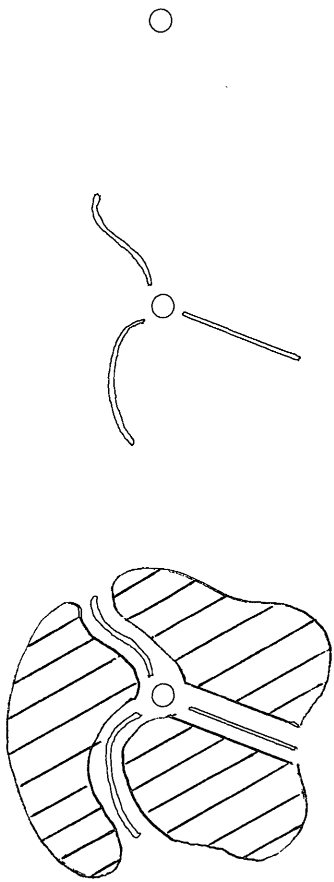


FIGURE 4. CONSTRUCTING THE OPEN NEIGHBORHOOD OF A 0-CELL. THE 0-CELL, 1-CELLS AND 2-CELLS TAKEN TOGETHER FORM A LARGER 2-CELL.

Error Detection and the Mathematical Model

The mathematical model of a map provides a simple but telling question to be asked of files allegedly representing maps: can this file possibly represent a smooth 2-dimensional surface? If not, the allegation is false, because maps are drawn on spheres or planes, which are smooth 2-dimensional surfaces. Corbett ("Topological Principals in Cartogtaphy," 1976) has shown that this question can be answered by a series of easy questions about parts of the file.

The questions are:

1. Is every 1-cell incident with exactly two 0-cells or for a loop incident twice with a single 0-cell?
2. Is every 1-cell incident with exactly two 2-cells or for interior segments, incident twice a single 2-cell?
3. Is each 2-cell bounded?
4. Does each 0-cell have a neighborhood equivalent to a disk?

If the answer is 'yes' in every case, i.e., for every 1-cell for questions 1 and 2 and for every 2-cell for question 3 and for every 0-cell for question 4, then the file can be interpreted without contradiction to be a smooth 2-dimensional surface. Otherwise the file must represent some torn, folded or higher dimensional or higher genus surface, if it is to be interpreted as a geometrical object at all. Figure 5 illustrates affirmative and negative answers to each of the questions.

For a DIME file, questions 1 and 2 are automatically answered affirmatively. Every DIME record represents a 1-cell and gives the two bounding 0-cells and the two cobounding 2-cells. Questions 3 and 4 are answered via the DIME block and vertex edits. To determine whether a particular 2-cell is bounded, all the incident 1-cells must be assembled and chained together on their bounding 0-cells. If they form a single closed chain, the 2-cell is bounded and the condition for a smooth 2-dimensional surface is satisfied. This bounding test is illustrated in Figure 6 (this figure and several of the following figures are taken from the file correction of the Washington, D.C. GBF/DIME file using ARITHMICON, a

1. Is every 1-cell incident with two 0-cells?

2. Is every 1-cell incident with two 2-cells?

3. Is every 2-cell bounded?

4. Is the neighborhood of a 0-cell equivalent to a disk?

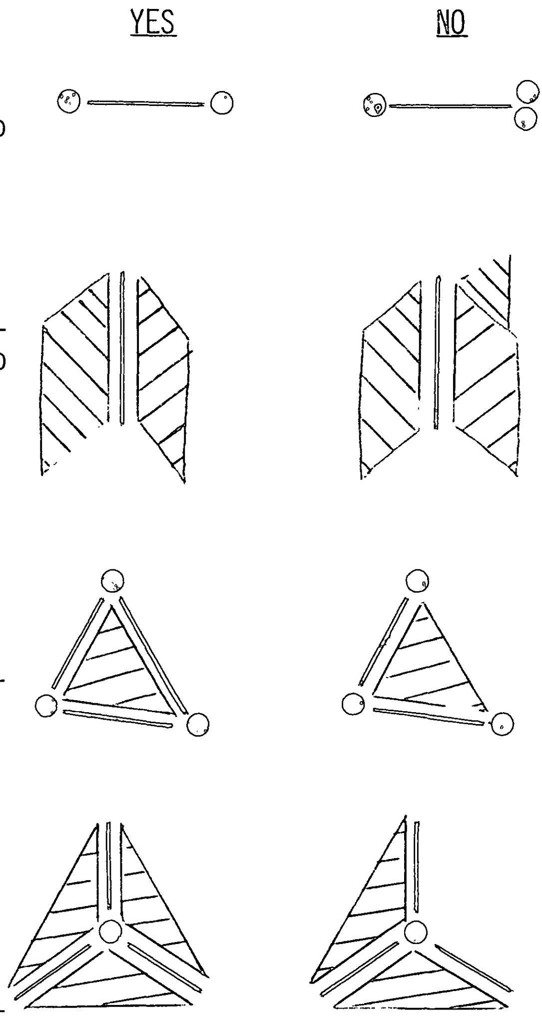


Figure 5. For a smooth 2-dimensional surface, the answer to questions 1 - 4 is always 'yes'. If any answer is 'no' the surface is not smooth.

research system developed at the Census Bureau).

Question 4 is the dual of question 3. It is answered in exactly the same way but with 0-cells and 2-cells interchanged. All of the 1-cells incident to a particular 0-cell must be assembled and chained together on their cobounding 2-cells. If they form a single closed chain, then the neighborhood of the 0-cell is equivalent to a disk. The vertex edit is illustrated in Figure 7.

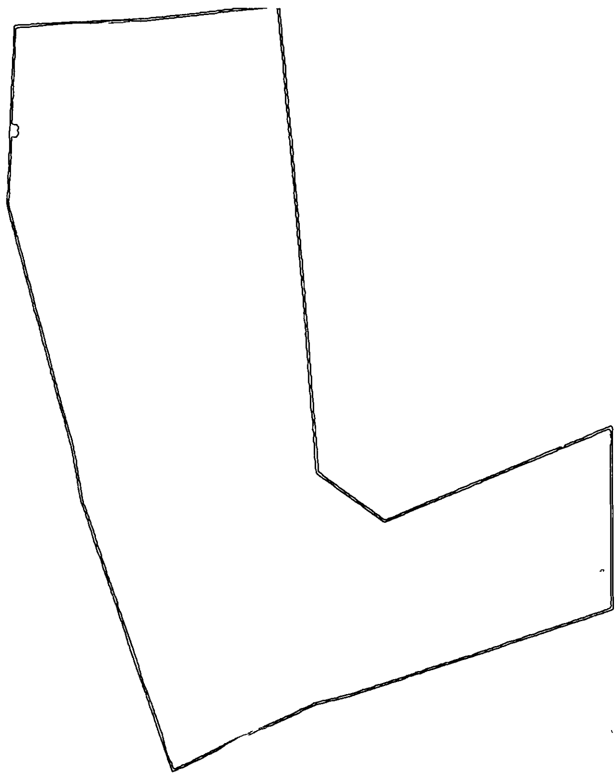


FIGURE 6. THE BOUNDARY OF A 2-CELL IS A CLOSED CHAIN OF 1-CELLS. THIS 2-CELL IS THE NEIGHBORHOOD OF A PARTICULAR 0-CELL.

Duality

The symmetry between 0-cells and 2-cells mentioned above is worth further study. The symmetry between questions 3 and 4 is clearer in a reformulation of the questions: 3' Is each 2-cell bounded by a chain of 1-cells; and 4' Is each 0-cell bounded by a chain of dual 1-cells (a dual 1-cell intersects with the primal 1-cell but connects the two 2-cells that the primal 1-cell separates --- the dashed line in Figure 7 is composed of dual 1-cells).

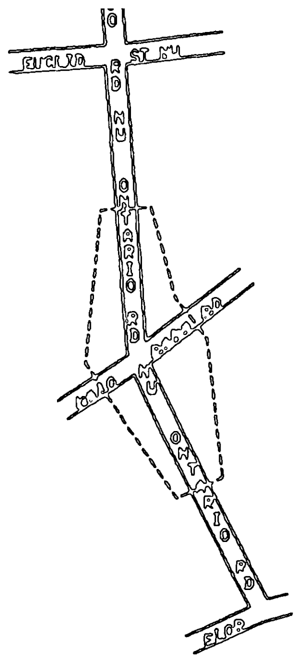


FIGURE 7. THE 1-CELLS INCIDENT TO A 0-CELL MUST CHAIN IN A LOOP, AS INDICATED BY THE DASHED LINE. THIS IS EQUIVALENT TO THE NEIGHBORHOOD OF THE 0-CELL BEING A 2-CELL.

Questions 1 and 2 exhibit the same symmetry --- the questions themselves are interchanged by merely interchanging 0-cells and 2-cells.

This symmetry is called duality and appears in graph theory as well as in topology. The 0-cells and 1-cells of our map form a graph, which is a set of points and a set of edges, in which each edge is terminated by points in the set. The circuits in a graph may be regarded as boundaries of regions and the dual graph is formed by interchanging the roles of the regions and points. It is the dual graph that is the subject of the four color theorem, which states that every map may be colored with no more than four colors so that no two adjacent regions have the same color.

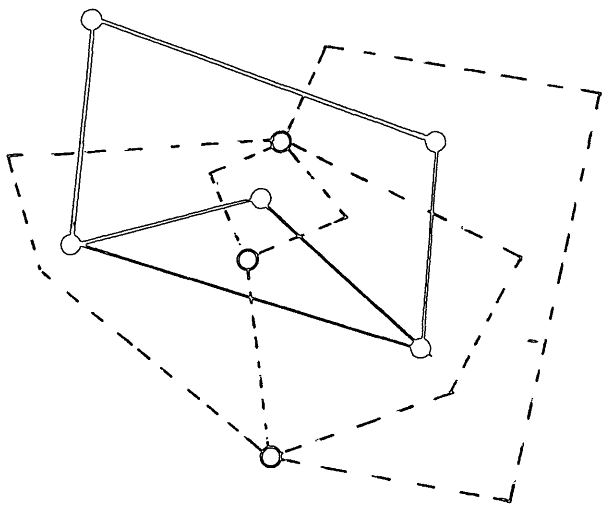


FIGURE 8. A GRAPH (○═══○) AND ITS DUAL (○- - -○):
EACH 0-CELL IN THE GRAPH IS A 2-CELL IN THE DUAL;
EACH 1-CELL IN THE GRAPH HAS A CORRESPONDING 1-CELL IN THE DUAL;
EACH 2-CELL IN THE GRAPH IS A 0-CELL IN THE DUAL.

Figure 8 illustrates a graph and its dual. Each region in the primal graph is represented in the dual by a vertex and each vertex in the primal is contained in a unique region in the dual. This symmetry appears in other places in both graph theory and topology, such as the question of planarity, but a discussion of those topics would be too lengthy for this paper.

Planarity and Orientability

Once we have determined that a file represents a 2-dimensional smooth surface, we may ask further whether it is orientable and if so whether it is a plane (or equivalently a sphere). An orientable surface is one on which left and right may be assigned consistently over the entire surface. It is surprising that there are surfaces on which left and right make no sense, the non-orientable surfaces. However, there are such surfaces and map files frequently represent them, albeit inadvertently. The simplest example is the Moebius strip shown in Figure 9.

When we code a DIME file, we distinguish between left and right --- we code the oriented incidence relations. To answer the question about orientability, we merely ask whether the assignment of left and right is

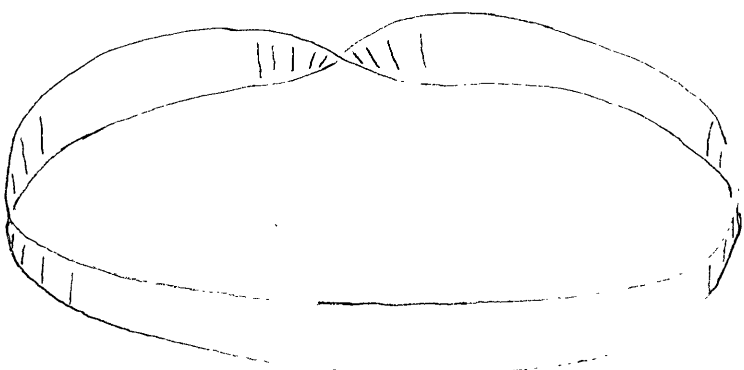


FIGURE 9. A MOEBIUS STRIP IS A SMOOTH 2-DIMENSIONAL SURFACE BUT IT IS NOT ORIENTABLE.

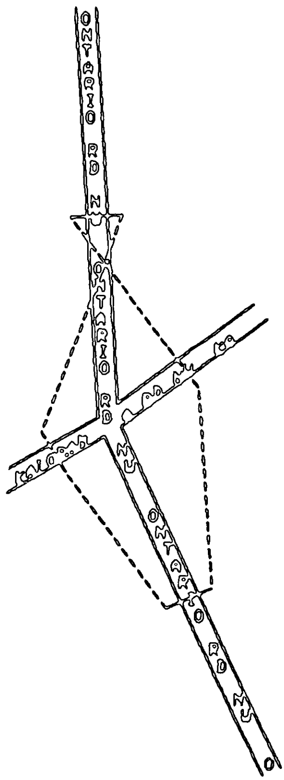


FIGURE 10. THE VERTEX EDIT DETECTS AN ORIENTATION ERROR.

consistent throughout the map, which is easily incorporated into the DIME block and vertex edits. Rather than asking whether there is a chain of 1-cells, we ask whether there is a chain of 1-cells that maintains the encoded orientation. For the block edit this consists in keeping the block being edited on the left while chaining and for the vertex edit keeping the vertex in the "from" position. Figure 10 illustrates the vertex edit in the case of an orientation error.

The question of planarity is answered by a straightforward computation of what is called the Euler characteristic. This tells us the genus of the surface, i.e. how many handles, like handles on a coffee cup, the surface has. For zero handles we have a sphere, which is the very thing we hope for. A handle may be inadvertently created in a DIME file by mislabelling a vertex so that it is identified with another distant vertex. This is equivalent to grasping the map at the mislabelled vertex, pulling and stretching that portion of the map and attaching it to the map at the distant point. Figure 11 illustrates how a mislabelled vertex may be interpreted as a handle on the map.

<u>The Department of Redundancy Department</u>

It has been suggested that the DIME edits are merely redundancy tests and thus we might, by abandoning the tests, actually encode less information but still encode a map. However, these tests are consistency tests that apply to any coding scheme, not only DIME. No matter how we code a map, we can ask whether the code can possibly represent a smooth 2-dimensional surface and further whether it is planar. To illustrate, two different schemes are described below with a discussion of how the consistency tests are applied.

A very popular scheme is the polygon encoding method in which the ordered list of vertices on the boundary of the polygon is coded. This amounts to encoding the incidence relations for 1-cells and 0-cells in pairs along with one of the incidence relations for 1-cells with 2-cells -- we have a DIME segment without the left 2-cell. Each DIME segment is indicated by a pair of vertices in succession. Figure 12 illustrates this encoding of a map. To recover the missing incidence relation, i.e. which 2-cell is on the other side, we can match 1-cells (vertex pairs) occurring in the file

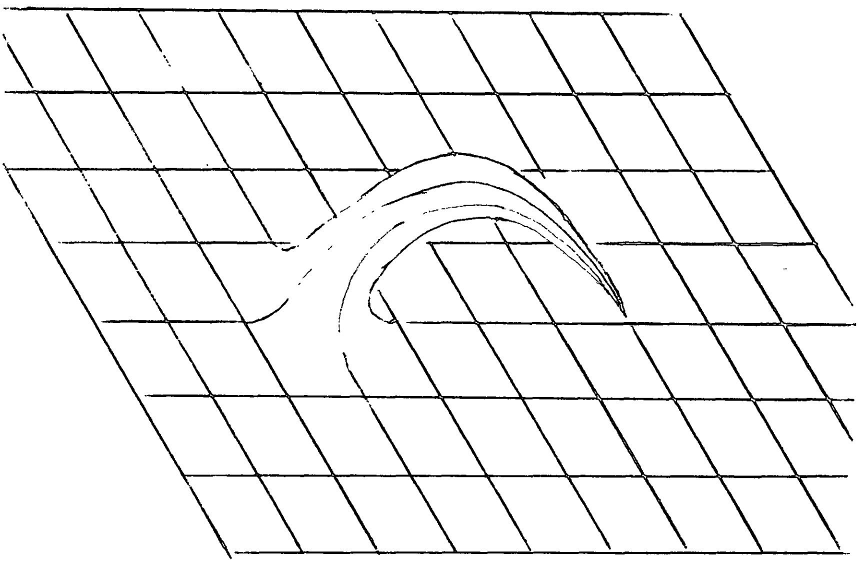
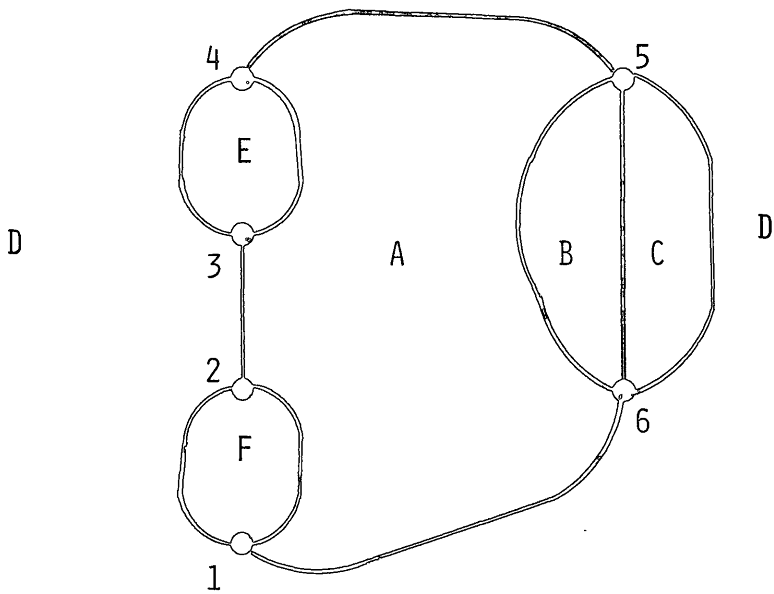


FIGURE 11. A MIS-IDENTIFIED 0-CELL MAY CREATE A HANDLE IN THE MAP. THIS CONDITION IS DETECTED BY COMPUTING THE EULER CHARACTERISTIC.



A: 1 2 3 4 5 6 1
B: 5 6 5
C: 5 6 5
D: 1 6 5 4 3 2 1
E: 1 2 1

POLYGON ENCODING

1: A F D A
2: A D F A
3: A E D A
4: A D E A
5: A B C D A
6: A D C B A

VERTEX ENCODING

FIGURE 12

with the negatively oriented version, which should also be in the file, ultimately constructing a DIME file. We pay for not encoding all the incidence relations in doing the match.

The same questions can be asked of a file constructed by the polygon method: Does it represent a smooth 2-dimensional surface? Is it orientable? What is its genus? The first question again becomes the four: 1. Is every 1-cell incident with exactly two 0-cells? (Yes, the coding forces it). 2. Is every 1-cell incident with exactly two 2-cells? (This question is answered in the match). 3. Is each 2-cell bounded? (Yes, the coding forces it) 4. Does each vertex have a neighborhood equivalent with a disk? (This is answered with the vertex edit).

Note that two of the questions (1 and 3) are automatically answered affirmatively and that two (2 and 4) must be answered by computation, as for DIME encoding. Whatever savings might have been achieved in encoding did not affect the nature of the edit, only the details. We did not sacrifice the edit; satisfying the edit means exactly the same thing, viz., the file represents a smooth 2-dimensional surface.

Even if the coding had been perfect, the matching of 1-cells for the map in Figure 12 would have been ambiguous. It is impossible to determine from the polygon encoding whether the 2-cell B is between A and C or between C and D. This ambiguity will arise whenever a pair of 0-cells are connected by several 1-cells, i.e. when they occur in several ordered lists. This ambiguity arises only because the necessary information was not encoded.

Another interesting encoding method is the vertex method, which is just the dual of the polygon method. The dual graph around each vertex is coded, rather than the bounding graph around each 2-cell. So for every 0-cell, the list of regions incident to the point are named in the order that they would be seen in a counter-clockwise sweep. Each pair of regions implies a 1-cell separating them and the 1-cells must be matched to determine 0-cell adjacencies. Figure 12 also shows this encoding for the example map. Now ambiguities arise when 2-cells are adjacent several times, as for regions A and D. Of course, questions 2 and 4 are automatically answered by the form of the encoding and questions 1 and 3 must be answered by computation. But the consistency test remains the same.

The vertex encoding allows one to implicitly label 0-cells rather than explicitly labelling them on the source map. The numerals identifying the 0-cells in Figure 12 were unnecessary; they could have been automatically generated and never have appeared on the map. This is a great advantage, since node numbering is an expensive manual process. Polygon encoding allows 2-cells to be named implicitly, but this is not much of an advantage, since we generally wish to maintain common names for regions. In any case, one must weigh the cost of resolving ambiguities and matching 1-cells against the advantages in these encoding methods to decide on the least expensive approach.

Controlling Error Correction and Updating

The DIME edits discover the existence of errors and even localize them very well. The geometrical theory also helps in controlling the correction of errors and the introduction of new information into the file. The remarkable tenacity of errors is in part due to lack of control over the correction process. It is a common practice to stop entering corrections when some small percentage of the file seems to be in error, because the marginal cost of correcting the errors is high and avoiding the intrusion of new errors is very difficult.

File correction and editing in general can be controlled in an interactive system so that the cost of making the last correction is no worse than for the first correction and so that the introduction of new errors is immediately discovered and can be reversed. This is the case in the ARITHMICON system. The question also arises whether file correction is a finite process --- does it ever end? This is a serious matter and should give one pause before undertaking the correction of a map file.

Whether the correction process terminates depends on whether corrections force changes in parts of the file that have already passed the test. In testing orientation on a Moebius strip, one would eventually discover an inconsistency and correct it. But this would lead to further inconsistencies finally forcing changes in portions of the file already tested. The conclusion is that the surface is not orientable and the so-called correction process would never terminate. Fortunately, few maps are coded on Moebius strips or other non-orientable surfaces but even so, we can detect such a condition and know that 'correction' is impossible.

Correcting for a smooth surface does however finally cease, provided the corrector is not perverse. Controlling the correction process so that it does cease may be accomplished in more than one way. In ARITHMICON, the system we have developed at the Census Bureau, we maintain a check list of 0-cells to be edited and remove them from the list individually as they pass the vertex edit. Whenever a change is made to a 1-cell (all changes in ARITHMICON are made to 1-cells), its bounding 0-cells and all the adjacent 0-cells are pushed back into the check list, so that they are retested. So the check list shrinks and grows as the edit proceeds but the overall effect is that it shrinks. The size of the list gives us a good indication of the remaining work. The file is declared consistent only when the check list is empty.

The check list does finally empty and the corrections cease, provided the person making the corrections always makes changes so that the file corresponds to the source map after the change. Our confidence that the process terminates comes from our confidence that the source map is a smooth 2-dimensional surface.

Summary

A geometrical model provides the foundation for understanding maps and the automation of maps. The topological tests that determine whether a file could possibly represent an orientable smooth 2-dimensional surface are the DIME edits. This topological test is appropriate even for files not encoded directly as DIME files and gives us the same assurances of consistency. Finally, the geometrical model is the basis for controlling the correction and update processes so that they may ultimately terminate.

MR. HOLMES: Our next speaker, Robin Fegeas, is with the U.S. Geological Survey in Reston, Virginia. He will describe his work with automatic digitizing and how to incorporate that data into a chain file structure. Robin?

MR. ROBIN FEGEAS: Thank you, Harvard. To clear up a small point right off the bat. We not only have experience with automatic digitizing, but manual tables as well. The system I wish to describe can be called an operational system. We have been using it for four years to generate data and convert data from graphic form to a data base.

Could I have the first slide. This shows the status map of the work that the U.S. Geological Survey is doing in land use mapping. We are trying to map the entire country by 1982. As I said, we started three, four years ago. This slide was made two years ago and shows status at that time. The red was what was completed then. The blue, what was in production. Today, the blue is pretty much completed except for around here. The West Coast, north of Los Angeles is all that is not completed. By the end of this year we hope to complete approximately 23 states and much of the coastal areas.

This shows the classification scheme used (table 1). I will not go into it too much except to say that it is based on using high-altitude aerial photographics and some Landsat imagery as well as medium-altitude photography to compile the maps at the regional scale of 1:250,000. For those of you interested in the classification scheme, there is a Geological Survey Professional Paper, 964, which may be purchased for 75 cents.

This is an example of one of our land use sheets. This is from the West Palm Beach 1:250,000 quadrangle showing an area around Fort Lauderdale, Florida (see figure 1). This shows about four percent of a total 1:250,000 quad.

Since we are talking about in excess of 400 of these quads, and this is only less than one-twenty-fifth of that, you can see how much data we are talking about. This is a blow-up of the center portion of that last slide. This covers an area roughly equivalent to a 7½-minute quadrangle.

This indicates that data volumes by overlay. I forgot to mention that--along with the land use, we are compiling political boundaries--in other words, county boundaries, census tracks and minor civil divisions, hydrological units, and federal land ownership. As you see, the land use is the predominant data type. Once again, this slide was made two years ago, and you can increase the volume per map by about 50 percent.

1 URBAN OR BUILT-UP LAND

11 Residential
12 Commercial and Services
13 Industrial
14 Transportation, Communications and Utilities
15 Industrial and Commercial Complexes
16 Mixed Urban or Built-up Land
17 Other Urban or Built-up Land

2 AGRICULTURAL LAND

21 Cropland and Pasture
22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
23 Confined Feeding Operations
24 Other Agricultural Land

3 RANGELAND

31 Herbaceous Rangeland
32 Shrub and Brush Rangeland
33 Mixed Rangeland

4 FOREST LAND

41 Deciduous Forest Land
42 Evergreen Forest Land
43 Mixed Forest Land

5 WATER

51 Streams and Canals
52 Lakes
53 Reservoirs
54 Bays and Estuaries

6 WETLAND

61 Forested Wetland
62 Nonforested Wetland

7 BARREN LAND

71 Dry Salt Flats
72 Beaches
73 Sandy Areas Other than Beaches
74 Bare Exposed Rock
75 Strip Mines, Quarries, and Gravel Pits
76 Transitional Areas
77 Mixed Barren Land

8 TUNDRA

81 Shrub and Brush Tundra
82 Herbaceous Tundra
83 Bare Ground Tundra
84 Wet Tundra
85 Mixed Tundra

9 PERENNIAL SNOW OR ICE

91 Perennial Snowfields
92 Glaciers

For definitions of Level I and Level II categories see U.S. Geological Survey Professional Paper 964, *A Land Use and Land Cover Classification System for Use With Remote Sensor Data*, 1976, by Anderson, J R., E E. Hardy, J. T. Roach; and R. E. Witmer. Minimum mapping units are: 4 hectares (10 acres) for Level II categories 11-17, 23-24, 51-54, 75, and urban occurrences of 76; and 16 hectares (40 acres) for all other Level II categories.

Table 1.--U.S. Geological Survey Land Use and Land Cover Classification System

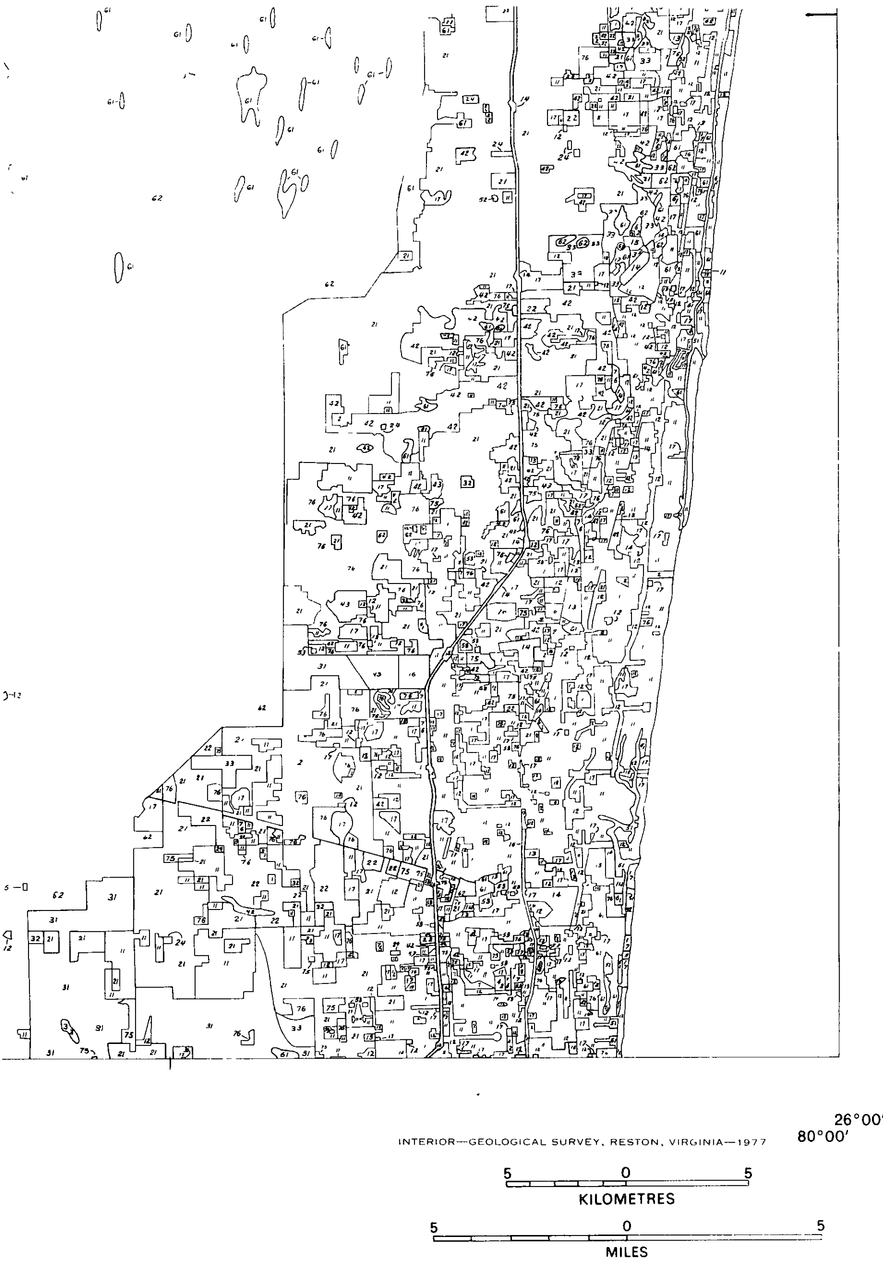


Figure 1.--A Portion of the West Palm Beach 1:250,000 Land use and Land Cover Map

To follow up on some of Marv's discussions, we use a similar structure to DIME, one based on the polygon boundaries, which we call arcs (see figure 2). An arc begins a node, must begin a node, must end in a node, and never pass through a node. A special case is an island, simple island completely enclosed by a larger island. In this case an arbitrary point is chosen to be the beginning and ending point. The final data that we generate from the graphic maps consists of both arc records and polygon records.

This is a depiction of a fixed portion of an arc record (see figure 3). It gives the unique identification number and a pointer to the number of coordinates which make up that arc, that is, the variable portion of the record, plus the indication as to polygon left, polygon right; attribute left, attribute right; a window; length; beginning node and the ending node. For each polygon we also end up with a unique sequence number, a pointer to its variable length portion, which gives the numbers of the arcs which make up the boundary of the polygons (see figure 4). There is a code that points to its descriptive information, the attribute code. Then there is area information, the window, perimeter length, whether it is an island or not, number of islands within it.

This is what our final output is. This input procedure is only part of a larger information scheme, information system that we are working on. We call it GIRAS, geographic information retrieval and analysis system. There is another professional paper just out, which I have some copies of up here. You can get a copy of it after the session, which describes GIRAS see figure 5).

Today I will only be talking about the first four boxes, from source material to the simple data base. In detail, the input procedure consists of the steps you see here (see figure 6). First, the source material is digitized. Then the data is converted to a standard format, and that is what the "read" data box is meant to say. The data is then compacted, and then coordinate transformations are done. For large data sets, data is split up and segmented into manageable spatial sections. There is an automatic edit and error detection performed, and then a manual edit of the arc data. Once the arc data are clean, they are combined with polygon attribute data to form the final files. If necessary, the polygon files, polygon information may also be edited.

As I indicated at the beginning, in the initial digitization stage we have used many separate hardware devices. The methodology we chose has allowed us this flexibility. We have used very simple manual tables, blind tables such as the Bendix Datagrid and Wang table, and also tables which have an interactive system associated with them so you can do some editing while you are digitizing, onto

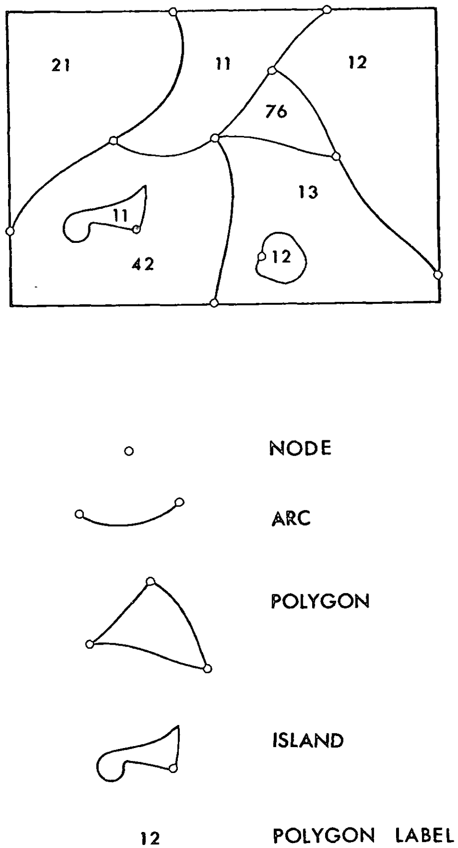


Figure 2.--Elements of a Polygon Map

ARC RECORD

AID	PLC	PL	PR	PAL	PAR	XMNA	YMNA	XMXA	YMXA	ALEN	SN	FN

Name	Description
AID	Arc number.
PLC	Position of last arc coordinate in COORD file.
PL	Polygon number of polygon to left of arc.
PR	Polygon number of polygon to right of arc.
PAL	Attribute of polygon to left of arc.
PAR	Attribute of polygon to right of arc.
XMNA, YMNA	Minimum x,y coordinates in arc.
XMXA, YMXA	Maximum x,y coordinates in arc.
ALEN	Arc length in coordinate units.
SN	Node number at beginning of arc.
FN	Node number at end of arc.

Figure 3

POLYGON RECORD

PID	PLA	CX	CY	ATT	AREA	XMNP	YMNP	XMXP	YMXP	PERL	NIW	NIP

Name	Description
PID	Polygon number.
PLA	Position of last arc number of polygon in FAP file.
CX,CY	Coordinates x,y of an interior point.
ATT	Polygon attribute.
AREA	Area of polygon.
XMNP, YMNP	Minimum x,y coordinates of polygon.
XMXP, YMXP	Maximum x,y coordinates of polygon.
PERL	Perimeter length of polygon.
NIW	Number of islands contained within polygon.
NIP	Number of the polygon containing this polygon, if it is an island.

Figure 4

INFORMATION SYSTEM FLOW

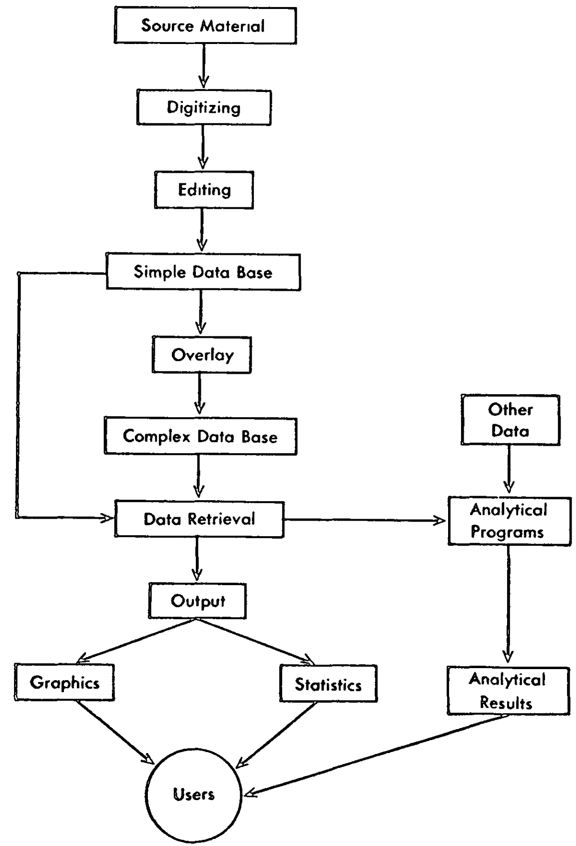


Figure 5

automatic line following, done by I/O Metrics Corporation, now IOM - Towill in California. Broomall Industries is now raster scanning our data and then converting it to vector before sending it to us. Of course, with the many sources that we have, the first step has to be the conversion to standard format. Once the data is delivered to us in Reston, Virginia, all the steps from the conversion to the standard format through final file formation are done on an IBM 370. All the modules used were developed in-house, coded in FORTRAN. They operate in anywhere from 72K bytes to 360K bytes of core memory.

After the data have been converted to standard format they are compacted, the arc data are compacted merely by eliminating points unnecessary to define the lines within a given spatial tolerance. I will not go into the algorithm used. We feel it is a very efficient one. It has allowed us to compact data that has been initially defined by about 200 points per inch down to 30 points per inch, and still retain an accuracy of five mils. That is about an 85 percent reduction. I will not mention too much about the conversion and splitting. That is a very minor operation.

The first step in assuring a clean data set, at least clean arc data, is an automatic edit and error detection routine which is basically an arc end-point matching routine. I am not sure I mentioned it, but the flexibility that we have attained in allowing different hardware to digitize our data is because of the limitations or the limited amount of information we require from the digitizers. We do not require the digitizer operator or device to code the arcs in any way. All they are is just a bunch of spaghetti at this point. A separate file of polygon information is digitized, consisting merely of a polygon label with an arbitrary point within the polygon. At this stage all we are dealing with is unlabeled arc data.

I will not read the slide (see table 2). I think you should be able to read it. It is very elementary editing. What error resolution the program cannot do, it lists errors for the manual editors to then take and perform corrections.

Now, to help us in our work we have acquired a stand-alone mini-computer system developed at the University of Saskatchewan. Many of you have heard of it. It is Cart/8. It is now called Intermap, developed under the direction of Ray Boyle. This shows the digitizing table (see figure 7). Anytime we have to add data into the files, we must, of course, go to the digitizing table.

The rest of the system is shown here, consisting of a small PDP 8 mini-computer, a couple of Tektronix display tubes. The system

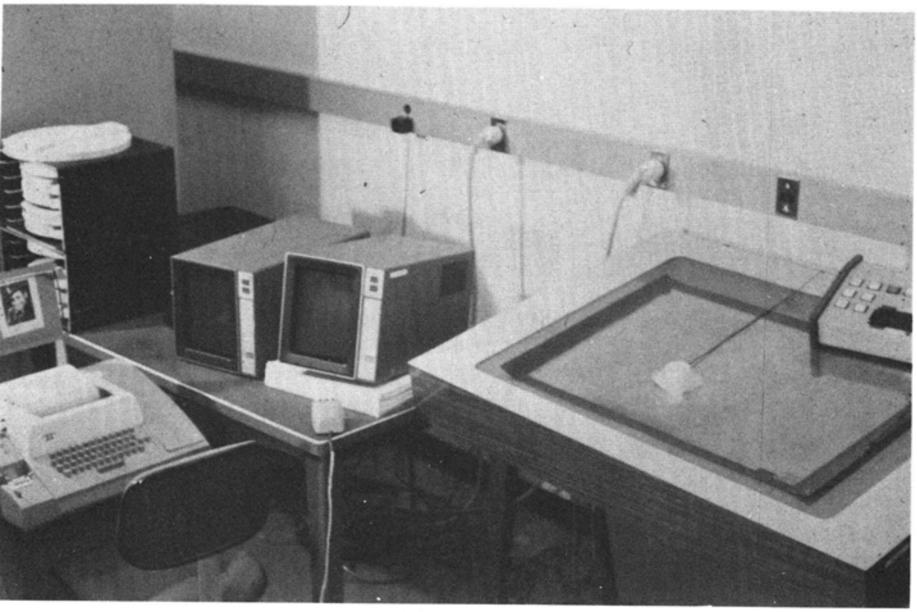
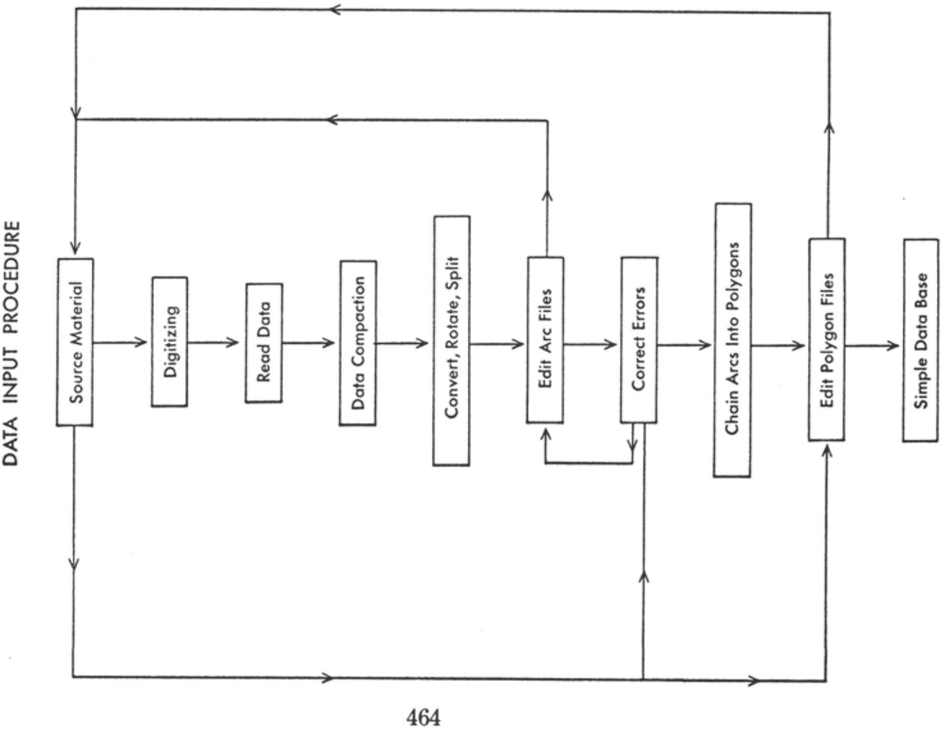


Figure 7


DATA INPUT PROCEDURE
Source Material
Digitizing
Read Data
Data Compaction
Convert, Rotate, Split
Edit Arc Files
Correct Errors
Chain Arcs Into Polygons
Edit Polygon Files
Simple Data Base

AUTOMATIC EDITING AND ERROR DETECTION

An arc end-point matching routine forms the basis of first step toward ensuring a 'clean' or logically correct data files. As part of the routine the following editing is performed:

1. Deletion of one point arcs.

2. Deletion of arcs of length shorter than an allowed tolerance;

3. Deletion of duplicate arcs (duplicate arcs are defined as those whose end-points match and whose bounded area to length ratio is less than an allowed tolerance);

4. Adjustment of arc end-points to meet exactly at nodes; and

5. Deletion of arc points within positional accuracy tolerance of nodes.

Since not all errors can be automatically corrected, the node matching routine detects and lists the following errors:

1. An end-point of an arc matches no other end-point;

2. Only two arcs meet at a node; and

3. One and only one arc end-point matches the node of a one-arc island (this is actually a special case of the second error called "apple in a window").

Table 2.

can also perform a wide range of interactive editing. However, we do not use the system for that because of the volume of data we must process. The system is a one-user station only, and most of the time it is being used for digitizing. We do some in-house digitizing as well as error addition digitizing. Just to give you an example of what can be seen on the screen, this is the land use of a portion of Louisiana shown on the screen (see figure 8), just the arc data again.

This is a blow-up of around Ferriday, Louisiana (see figure 9). This is a portion of a land use sheet from Florida (see figure 10). There are polygon labels also displayed here. You cannot read them very well, but they are there. As I say, we do not use the system much. We are forced to use what we have, and that is an IBM 370, which has limited us to BATCH editing. Therefore, practically all of the editing we do is in a BATCH environment.

We give the error listings and listings of data plus the plots of the data. That is the simple Calcomp drum plotter we use to plot the data. This is a sample plot. We give these to our manual editors to then determine what kinds of corrections are to be made to the data. The errors introduced in data may come from two sources, the digitizing or the original compilation of maps. Digitizing errors introduced, of course, depend greatly on the device used. There are more errors introduced in manual editing than in automatic scanning. Since most of the data that we have processed so far--and I believe I am safe in saying this--has been digitized by I/O Metrics, using their automatic line following scanner, digitizing errors have been reduced considerably. We are left with compilation errors which, becuase of the large amount of data and complex data, are considerable, and we spend a lot of time doing our edit because of compilation errors. I will echo a previous statement made that the more editing you can do before you perform your initial digitization, the better off you are. Right now, once the data is in digital form, it is expensive and time consuming to edit, especially in a BATCH environment. Regardless of whether you edit in a BATCH environment or interactive environment, these are the kinds of options available to our editors. I will not read them (see table 3).

Sometimes we are forced to perform a massive update of our data because of a map being sent out for digitizing before a field check has been made. This slide represents a large amount of updating that was necessary because of field checking. The red represents additions to be made. The blue, deletions. In this case we are forced to go to interactive editing. This (figure 11) shows on the interactive screen the additions that were digitized on the Intermap system for the last area shown, the previous slide.

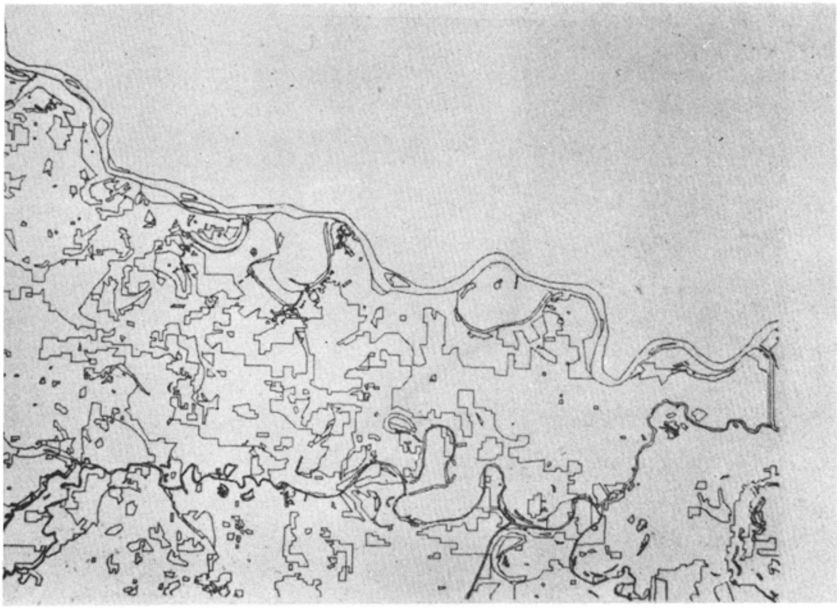


Figure 8

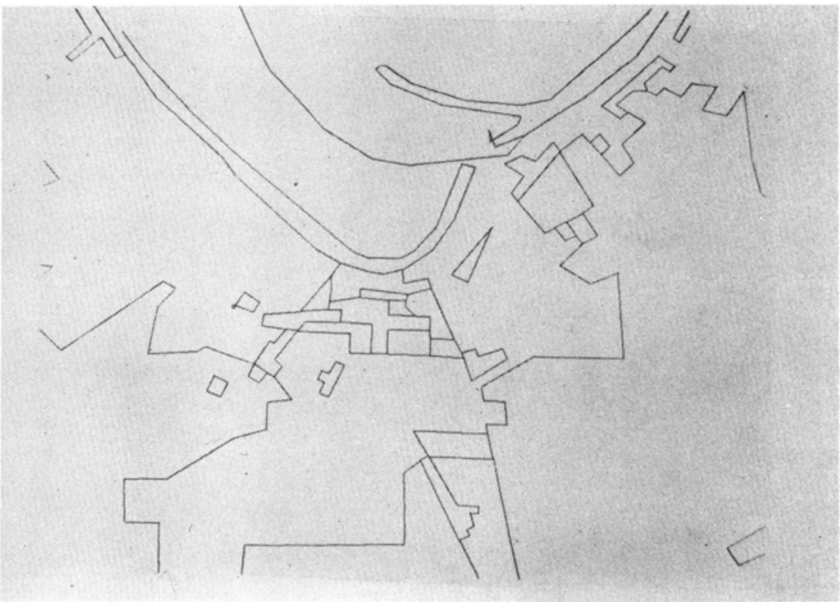


Figure 9

The following commands are available to correct the arc data:

1. Join two arcs into one;
2. Divide one arc into two;
3. Delete an arc;
4. Add an arc;
5. Delete a segment of an arc;
6. Add a segment to an arc; and
7. Translate, rotate and/or stretch/compress an arc.

The arc data are again checked for node errors and the editing process continues until no futher errors are found.

Table 3

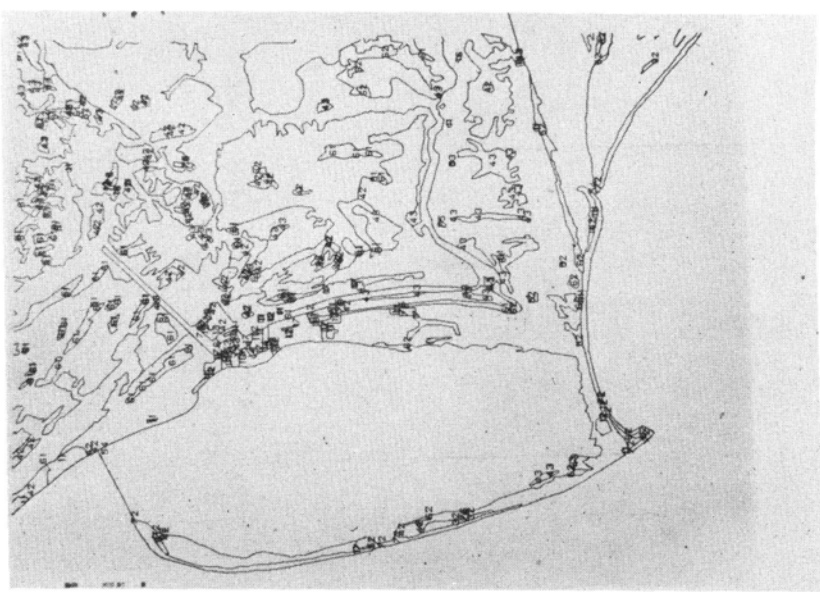


Figure 10

Figure 11

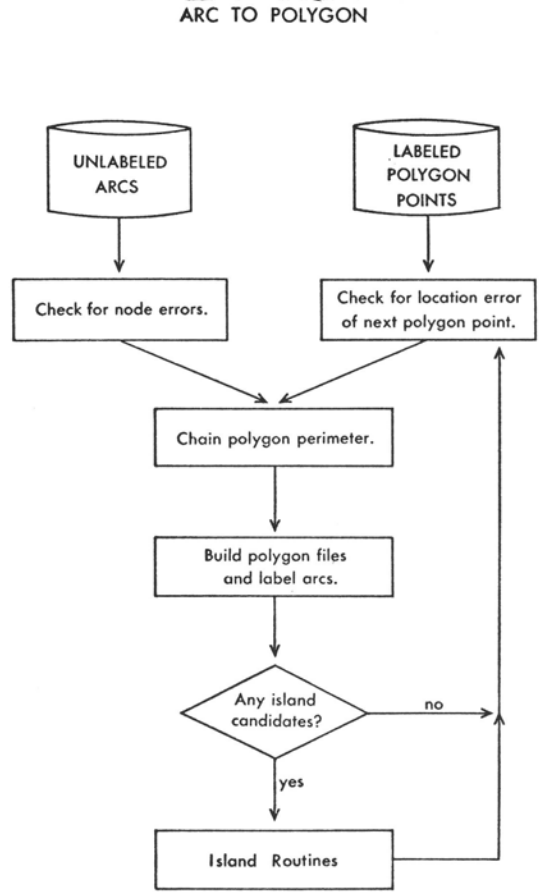


Figure 12

Once the arc data have been cleaned, they can then be merged with the polygon label data to form the final clean files (figure 12). This basically consists of taking each polygon label point and chaining a polygon around it, then labeling the arcs as to right and left. By the way, the arcs have already been labeled as to beginning node and ending node at this point. However, a check is made again to make sure this is correct.

Special routines must handle islands (see figure 13). If any islands are found within a given polygon, this information is also added to that polygon's file, and the arcs are also coded as to left and right. In this method we also can check for identification conflict within one polygon if it is identified by more than one label. Finally, the arc-to-polygon step forms the last topological edit check (see figure 14). Once all the polygons have been chained for those labeled polygon points input, then a check is made to make sure that all arcs are labeled as to right and left, and if that arc is labeled by the same label, same polygon label right and left, the polygon does not necessarily have to be the same, but the labels which are not necessarily unique may be the same. That is an error. Areas are totaled.

As a topological check, this process assures topologically error-free data, but not necessarily attribute error-free data. We must also use procedures to make sure the polygon labels are correct. We can do this by summarizing and seeing if the area summaries look right. We can also plot out selective uses. Here is an area around Little Rock showing urban and water.

You can also then compare the data that we just edited with data that is already in the file. This is a plot of the entire State of Kansas, consisting of 12 separate sheets. So we check the edge information. I think I will end there. I will show a sample of a graphic map that can be produced from the data in publication form.

ISLAND ROUTINES WITHIN ATP

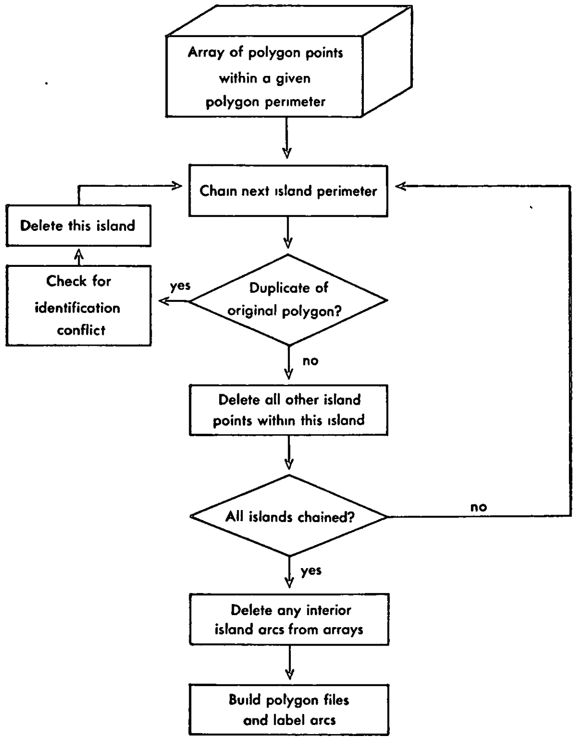


Figure 13

FINAL ATP ERROR CHECKING

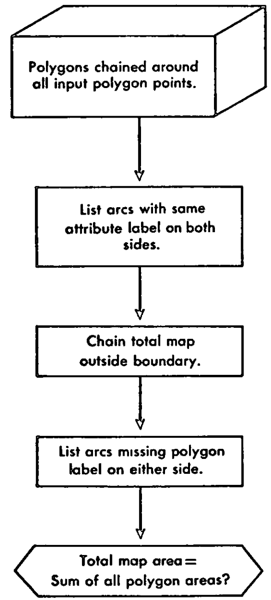


Figure 14

MR. HOLMES: Our next speaker is Marv Grimes. He is Project Manager for the County Mapping Project for the Alameda County Assessor's Office. I think he has developed some unique approaches to urbanized mapping projects. Marve?

MR. MARV GRIMES: Thank you, Harvard. Good afternoon. It is a pleasure to be here. I would like to give you a little history of our automated mapping project, and then get into more of the data characteristics of the system.

In March of 1973, Mr. Hutchinson, the Assessor of the County of Alameda, attended a symposium and was made aware of the possibilities of a computerized mapping system and its application to the mapping of the County of Alameda.

The concept and supporting data for the automated mapping program were presented to Mr. Loren Enoch, County of Alameda Administrator. The Board of Supervisors gave support, and funding was provided subject to annual progress reviews. The actual beginning of the automated mapping project began with my hiring in April of 1975.

I should like to take a minute of your time to present some of the problems in developing this mapping system. May I have the first slide, please.

How does the property on the assessor's map relate to the property as it actually exists on the ground?

How to develop a system to capture for the computer, data from the 1890's to the present for over 300,000 parcels?

How to create an accurate mapping system to ensure the complete inventory of all the land in the County of Alameda?

Finally, how to develop a system that has the flexibility and accuracy to satisfy requirements of today and in the future?

The project was divided into two sections:

<u>Section I</u> - <u>The establishment of monuments to control map data.</u>

The accuracy of our mapping system is based on knowing exactly where the property is located on the face of the earth. The problem in the development of a horizontal control network was to produce accurate state plane coordinates for monuments within the budgeted time and cost parameters.

In order to achieve this objective, an extensive analysis was conducted of technologies to provide adequate ground control monumentation. These methods included satellites, photogrammetry, field survey teams, and inertial guidance systems.

As a result of our research, we selected the auto-surveyor system. This is a picture of the system. This system incorporates inertial measurement techniques similar to those employed in guided missiles, satellites, airplanes and submarines.

The auto-surveyor system's outstanding features include speed, mobility and precision, greatly reducing the time, manpower and expense required in more conventional surveying methods.

The auto-surveyor is completely self-contained:

- no signals are transmitted or received.
- no angles or distances need to be measured.
- neither weather nor temperature retards its operation.
- surveys can be accomplished day or night.

The precision operation is executed by

- the use of gyros that sense the earth's rotation;
- accelerometers that measure the acceleration to as small as 1 part in 10 million;
- a computer that instantly indicates the distance travelled.

To maximize the use of this highly sophisticated system, routes were prepared prior to its arrival. Here is an example of a route.

We prepared the routes to begin and end with a first or second order United States Coast and Geodetic Survey monument. Within each route was a United States Coast and Geodetic Survey monument. This monument allowed us to check the accuracy of the system while it was in operation. Cadastral control monuments were marked by the auto-surveyor, and each of our routes was run in a forward and reverse direction.

Here is a picture of the vehicle shown on one of its routes. There was a total of 1,045 monuments marked by the auto-surveyor. Our average accuracy for all the routes was one foot error in 60,000 feet. The time to accomplish this survey was one calendar month.

Section II - The gathering of map information and the production of finished maps.

This is pretty hard to see, but on the next slide, it will be better.

In Step 1, the map information from the assessor's map, filed maps and recorded documents is input to a micro-processor by clerks. This machine is made up of a screen, a tape cartridge holder, keyboard and memory. The screen allows the clerk to see a picture of the map as it is being input into the system. The clerks do not need prior mapping experience. They are only required to have average typing skills.

Using this methodology, we are able to train clerks in a week and a half, and they become proficient in their input. As you can see in this slide, the input is tutorial. The clerk is asked to enter the book number, page number, block, street address and parcel number. Then metes and bounds information is input into the system.

This is what the input clerks actually see as the map data is input into the system. Now, as you can see, as they put in the metes and bounds information, the actual parcel is being drawn on the screen, so visually the input clerks can actually see what they are doing. This information is collected on a tape cassette.

Once the clerk has input all of the map information, we go to the next step.

At this step, the mapping supervisor views the information on the map. We do this on a block-by-block basis by parcel outline only. The mapping supervisor can visually confirm that the map data have been input correctly by the clerk.

The clerks are able to pick up errors rapidly while they are inputting the map data, and this becomes quite a challenge to them.

When the information has been visually checked, the information is transferred to a mini-computer. Mapping engineers check the map pages and make the necessary adjustments and corrections. Once the mapping supervisor has certified that the information is complete, the computer generates the information to produce the map by a plotter.

This is a picture of our communicator. It is the one on the left. We labeled it "DH" or the Don Hutchinson unit, because it has to communicate. We take the information off the tape cassette and transfer it to a magnetic tape. This is all done off-line. We are able to capture a number of tape cassettes on one magnetic tape.

From that point, the information is put into our computer. There you see a picture of our computer. We use 80 megabyte disks, and we have three of them on this particular computer. We use an interactive terminal, the 4014 by Tektronix. This is a picture of the data from the mini-computer on the display CRT as actually received from the clerks.

This picture does not look too good as you can see letters upside down, so we want to clean up the map. We may want to delete these two; we may want to move this down here some place; we may want to take and flip some of these over; we may want to put our addresses on these two points right here. Almost instantaneously, as you can see, we do that on the next slide.

Now, we may want to make a picture of this map. We take that picture right off the tube.

This is a view of the completed map. The map is ready to be plotted. This is a picture of our plotter in operation. We are able to give the scaling, the paper size, the position that we want the map on the paper. This is a completed map.

This is just to demonstrate that we can put in a series of scale maps on the same plot output. It is a very simple thing to do by just changing the scaling size.

In summary, I should like to point out a few of the highlights of the system:

- metric to English conversion is instantaneous.
- we have perimeter and area information.
- we can blank, delete, change, move data, and obtain plane coordinates instantaneously for any part of the map.
- translation and rotation of map data.
- the whole map is constructed by metes and bounds information.
- we do not use any digitizer in our system.
- we use basic geometry and mechanical drafting and geometric analysis techniques.

This is a very fast, thumbnail sketch of what we have in our system. We have over 175 different things we can do to a map.

This concludes our presentation of the mapping system for Alameda County. Thank you. (Applause).

MR. HOLMES: Next is Tom Patterson from the Southeastern Wisconsin Regional Planning Commission. Tom is going to describe the mini-computer system which they use. Tom?

MR. TOM PATTERSON: The Southeastern Wisconsin Region is a seven-county planning unit. Its 2,700-square-mile area comprises about five percent of Wisconsin's total land area, but its resident population of 1.8 million people is about 40 percent of the state's population. It also contains about 40 percent of the state's employment and about 40 percent of the state's equalized valuation of property. So, in a very real sense, it is a major portion of the state. The Planning Commission has been in existence since 1961, and is a long-range physical facilities planning agency operating in the areas of land use, transportation, housing, air quality, water quality, waste water collection and treatment systems, and public water distribution systems.

In addition to the specialized engineering and planning data necessary for the individual planning programs, the Commission also acquires and analyzes large quantities of demographic and economic information about the Region. The end result of almost two decades of detailed planning work has been the emergence--not too surprisingly--of a large data management problem. This problem has been attacked in a number of ways, including microfilming, acquisition of larger and more powerful mainframe computers, use of interactive remote entry terminals for program and data set editing and updating, and the use of a digitizing table for conversion of information contained on maps and aerial photographs directly into machine-readable data for analytical and modeling uses. The digitizing hardware itself was acquired and installed during the fall of 1976. The initial purpose for acquisition of this hardware was to convert, directly into machine-readable form, land use information coded directly onto prints of low-flight aerial photography taken in the spring of 1975.

Analysis of the situation prior to system acquisition indicated that there might be a slight cost advantage in the use of a digitizer, even including the hardware and software acquisition costs, as opposed to the manual measurement of land use parcels by polar planometer or dot screen, entering the data by hand on coding sheets, and keypunching. This slight cost advantage was not sufficient in and of itself, however, to tip the balance in favor of acquisition of a digitizing system. There were four additional considerations, however, that made acquisition of such a digitizer quite attractive. These were: ease of update; computation of polygon intersections; the scale independence of the collected data; and the ability to measure areas as part of the data collection procedure. The primary advantages to acquisition of digitizing capability were perceived to be long-term rather than short-term.

As finally configured, the system has a data input and editing station. This consists of a free cursor digitizing table and cathode ray tube display device. The processing station consists of a mini-computer, a disk storage unit, and a tape drive. Communication with the mainframe computer is by tape, and the digitizing system has software to generate plotting tapes for the Commission's off-line drum plotter. An interactive configuration was obtained in the expectation that data could be collected and edited as a single operation. Experience has shown, however, that this was not a good assumption. The reason, however, cannot be attributed to either hardware or software shortcomings, but turned out to be inadequate quality control operations on the interpreted manuscripts or, in other words, a management shortcoming.

At least in our experience, "data editing" is at least of equal magnitude a management function as it is a hardware or software function. Over a period of time, and utilizing experience gained on two short data collections projects, a data editing system has evolved. It begins before a manuscript is ever mounted on the digitizing table. Hand-coded aerial photograph prints are received in batches of about a dozen at a time. They are reviewed by the lead digitizer operator for logical consistency and completeness. Any questions are referred back to the person who has prepared the print and may result in a revision to the coded manuscript. After passing this initial review, a record form is attached to the document, and it is assigned to an operator for digitizing. All operations performed on the document and its image are logged on the form.

After the document has been digitized, the operator will carefully review its image on the CRT and make any necessary changes before placing the image in storage. After digitization is complete, the lead operator will recall the image from storage, review the image against the document, make any additional revisions as necessary, and will then generate a check plot of the image and a summary report of the coded information. These items are returned to the originating division where the plot is checked against the coded document for a third time. Any desired changes are annotated on the plot, and the material is returned to the digitizing personnel. The image is recalled from storage and revised, plotted, and returned again with the document for another review. This sequence is repeated until the image is approved. When the image is finally approved, it is placed on tape for long-term storage. A final summary report of the coded information is also generated on tape for use on the mainframe computer. These summary tapes represented the total end product under our previously existing manual inventory system.

Through this new system, in addition to obtaining the summary report of land use categories and areas contained within categories, we now have an image of that information in machine readable form. There are several advantages that have accrued to us because of that. One is that we can replot those images back at requested scales. This has proven to be quite valuable. The data, once collected, are scale independent. Secondly, ease of update as the result of future inventories seems assured. The present inventory of land use that is being coded is the fourth such inventory and a fifth is scheduled to begin in 1980 at the same time as the federal census.

The digitizing operation has given us some additional analytical capabilities. I mentioned before the possibility of computing polygon intersections. We have attempted this on some initial data sets and it has been successful. It does not work well yet, but we can do it, and we can do it on a small mini system as opposed to a mainframe computer. We are quite excited about the information system possibilities that this and some other "problem areas" that we are working on will give us. But there are also some disadvantages, or, if you want to look at them that way, opportunities, for the acquisition of this type of equipment. For a small agency such as ours, staffing poses a severe problem, particularly in that is required a minimum of one or two people who are very well grounded in systems programming, geographic information systems, and state-of-the-art hardware technology.

It can also cause environmental problems or problems in the operating environment which, again, for small agencies is something that may not be considered in the original acquisition. The hardware itself throws off heat like a small furnace, which has to be dissipated, and can result in expensive air conditioning requirements. We have also found that the operating environment can be quite noisy, particularly in small areas, and may require sound deadening and/or protective earplugs for operators.

In summary, then, while we have gained some initial advantages from switching to this type of an operation, we feel that the long-term payoffs, if they finally come about, will be far more substantial than originally anticipated and in the end will probably be the only justification for small agencies to ever embrace technologies of this type. Thank you.

MR. HOLMES: We can open the floor for questions.

MR. TONY VAN CURREN: Tony Van Curren, San Bernardino County. I think this panel has pointed up a very important controversy among small governmental agencies that perhaps the rest of the audience should be explicitly aware of, and that is the relative requirements for accuracy in building a virtual map. The Alameda County project is obviously one in which cadastral locations are considered to be of prime importance. I presume they are paying a price in dollars for that accuracy. The Wisconsin project is one in which the acquisition of data and its manipulability seems to be uppermost in the minds of the users. This divergence of user philosophy is something that the purveyors should keep in mind. I have one question I would like to ask Mr. Grimes, and that is: Have you any estimate what your cost per parcel is going to be by the time you develop your entire data base: And, a somewhat separate question, if you could elaborate somewhat on the uses you hope to put this data base to.

MR. GRIMES: We do not have it down to the price per parcel on putting the information in. We have a bogey figure we are shooting for, which is $1,600,000 for the whole thing, including the equipment. As far as other applications are concerned, it has all the engineering standards. Right now we are going from one inch equals one foot up to one inch equals 2,000 feet, but these are variable. We can go out to double precision of 64 bits. It just depends on how much people want to utilize them.

CONCLUDING SUMMARY: WHERE DO WE GO FROM HERE?

MR. EDSON: As the "summary session" implies, we are here to have a parting glimpse of where we have been during the last few days, and, as the program states, perhaps a few comments on where we might appropriately go. I would not continue with that one with a three-meter poll. (Laughter). But the nice thing about a summary session is that it is sort of like celebrating the 4th of July: You save your biggest, finest skyrockets for the final five minutes of the skywork display, light the fuse and stand back. It is always exciting. We have, I think, seen the results of a lot of hard work on the part of our panelists here, and I have asked them to take this opportunity to present any additional thoughts that they have concerning this meeting. I would expand the title from "Where do we go from here" to perhaps "What is missing? What should we include in any future meetings?"

With that, we are going to just sit down, relax and let it all hang out. So, do not expect anybody to stand up here and give a formal talk. We will start off with Jon Leverenz, who had the economics panel.

MR. JON M. LEVERENZ: Thank you, Dean. Good afternoon. It certainly is nice to surface. I came up on Monday, and now I am surfacing again after the Ray Boyle show, and that is quite an act to follow, but I do have a few comments to make. First of all, in our economics panel we attempted to put together sort of overall costs on a cross-section of various groups concerned with automated production systems. As you remember, we had the large federal system, we had a specialized university, and then I talked about a very small segment, and maybe I did not make that clear, very small segment of the commercial map making industry in the United States.

Now, unfortunately, we did not have a representative from the group of map makers or maybe a number of representatives from the group of map makers concerned primarily with, say, public utility maps, aerial surveys, the map companies and public utilities that usually produce large scale one-color highly specialized maps for maybe in-house use or for a relatively small special interest market. That is unfortunate, and someone brought that point up. I hope for the next panel or even before, we can make sure that a representative from that group is on the panel and, certainly any other groups that are interested in automation and automated systems.

When we presented our talks, each of us, I think as I looked at it, did try to define the particular needs of each group or agency or firm. I think that was very important. That is, 1.) the purpose must be well defined before we can begin to develop methods of a achieving that purpose as far as automated cartography is concerned, 2.) defining the detail we need in the data bank and the detail of output and the particular needs of the market that we service, 3.) we also talked about special factors which affect the choice of equipment. Then we did, finally, furnish some documentation of the dollars necessary to implement this system. I feel that as far as I can recall, Dean, that this was one of the first attempts to really try to get out some real good costs, overall costs, on what it would take to get a good automated system going. Because it was the first, it certainly was not complete. But we did attempt to address the dollars and cents aspect.

I think that in the future we need figures, detailed figures, much more detailed figures so that we can better evaluate methodology, equipment, the efficiency, etc. I think that these are some of the things that we should be looking at and be cognizant of as we spend these large sums of money in experimental work. We should be gathering much more detailed information on developmental costs, not just running costs and equipment costs, but how much does it take to set up a file system? What is the structure of the file system? How much does it cost to develop? And determine these costs from the very beginning of the automated adventure, not try to file back through a bunch of figures and hours and contracts, and come up with something, but use some type of structure to keep track of costs from the beginning.

The second thing I think is that we ought to look a little bit more carefully and define overhead costs. What is the real downtime on existing systems in the federal government or in other activities. How much maintenance is there? That gets into manpower and downtime again. Also, I might mention, what are the failure rates? We very seldom hear anything on the failures.

The third thing, I think this would be good for establishing credibility within the cartographic community, and that is that the federal agencies, because, of course, they are spending most of the money, should really set the pace for more explicit, detailed, yet simple total costing on developing structures, file systems, as well as the other things that they seem to have done like digitizing times and equipment costs, et cetera. I think there is a real need for this.

The fourth thing is, I think, we should begin to place a dollar figure on that old heavily weighted reason for going into automation given by many military agencies, and that is speed, or "our mission." There should be something placed upon that, some dollar figure or some time figure or what it means, so that after the system is initiated, we can go back and evaluate it more effectively as far as the cost-benefit is concerned.

Fifth. I think we have to get some real good feedback now that we have operational systems going from these users of production line systems concerning the real output of these systems so that we can evaluate that against what the suppliers have stated the maximum output or minimum output is, so we therefore can make better evaluations about the systems that we install. I think it is very important. And, then, finally -- I mentioned this once before -- I think we should have a session sometime on failures. With that, I will conclude my remarks.

MR. EDSON: Thank you, Jon. I am sure that in the future we will be seeing a lot of well bitten bullets. The economic impact is here now, and the whole usefulness has to be justified in terms of dollars. The bottom line is important. In fact, this is the first time that I can recall ever publicly trying to stir up that hornet's nest.

Next, Waldo Tobler, who is the chairman of our panel on display requirement. Waldo?

MR. WALDO TOBLER: Thank you, Dean. I do not have any rockets, because I did not know I was going to be on this panel until the final program. But I did make out a wish list, and made some speculations on what we might talk about at AUTO CARTO IV. I have no official connection with AUTO CARTO IV, and I do not even know if there is one planned, but first of all let me give you some of my biases. I am in a university and I do teaching and research. That means I have no operational responsibilities, essentially no budget, and the market I service is students. Therefore, I do not have any systems, and I hope I never do have a system.

In terms of research, again, I am not very interested--this is a strong bias of my own--in large amounts of data, but I am interested in very carefully selected data, and I do fairly refined analyses of this data. I do not think Newton had very much data when he came up with the law of gravity. Well, I do not expect to come up with the law of gravity or anything like it, but it is a bias in that direction. On the other hand, the operators, the people with operational responsibilities typically use large amounts of data, but do very simple analyses. Somebody commented, for example, one could use a computer to change map scale. Well, as far as I am concerned, changing scale is a simple multiplication, and that is something one learns in the third grade. I cannot get too excited about things like that.

In terms of hardware, hardware tends to get obsolete very quickly. In some ways I think I am fortunate in not being able to buy any, because then I would wish I had the best all the time, and I never will. A $2 Etch-A-Sketch works very well to teach computer graphics. (Laughter.) For $20 you can get a little more elaborate toy. But, there are some devices I would like to see.

One longstanding one that I would like to see is the wrist watch latitude-longitude indicator. I do not know if I will live to see that or not, but it will probably come sooner than most people think. The other one that I have thought about, and have actually tried to write a program for, although the device does not yet exist, is the pocket calculator with a little LED screen, two inches by two inches, that can do contour maps. The reason for this is, as a scientist I often get not very much data, but I want to look at it quickly and think about it, sort of the back of the envelope kind of calculation. A little pocket calculator with which I could do contour maps very quickly would be a very useful thing to have.

The mass storage devices and the high speed processors, and so on, are all right, for operations, but I am not so sure that they are going to be so interesting to me for research. In terms of firmware I have a few other items on my wish list. I would like to see a hard device, for example, that one could plug in the back of a Tectronix 4051 that does geometry and topology. Example, line intersection and distance between points, area of polygons, intersections of polygons, polygon overlays, polygon shading and that sort of thing would probably be very useful. I think there are some possibilities here, and I think Ray's panel did not address that very directly. Another wish list would be in the area of data. Each of us, I think, could come up with some. One set of data would seem to me to be very useful in this field is some statistics on what is going on. For example, I would guess, and I would be willing to bet on this, that the number of nodes in a city is a log-linear function of the population with an R square of at least .8, probably higher than that. It would seem very useful for the profession to have a number of rules of thumb like that on which we could make judgments of what costs and so on are going to be.

Another thing in the area of data. As you all know, the most rapidly growing sector of the computer industry is word processing. That is because people use words, not data and not numbers. I expect that within a very short time most electrical typewriters will be equipped with a plug where you can pull the phone jack out that put the typewriter plug in, and you will essentially have a termainal at home. Technologically that seems very simple. You would dial up by typing the numbers on the keyboard. This means that virtually everybody in the country would have a computer terminal. Now, the question then becomes, what is the data base--for example, in the last session we heard that some California county had put the Assessor's records in the computer. Now, that is public information. Am I going to be able to tap into that data directly from home, from my office, find out what my neighbor's house is assessed at? Presumably, I can do that now. But could I do it from a terminal at home? Again, I do not think that the hardware people address that question directly. That is partly not an equipment question but it is really a policy question, which is going to become more severe I think.

Finally, in the area of software. One can easily think of such things as device-independent software, software certification and publication, software standards and so on. It is also pretty obvious that most of the software is oriented at doing the things that we have been doing in the past, not taking advantage, really, of the technology to do new kinds of things. For example, I notice the people who have the Assessor's files in the system do not normally make contour maps of assessed value. I have seen two such maps done by computer. Nor, for example, are the people who are putting population density in the computer doing the second derivative population density maps, probably because it has only rarely been done before.

Another area of particular interest to me personally was covered in one of the panels on Monday; Harry Andrews gave the work they are doing with picture processing. This all operates essentially on pixels, picture elements. These are little square polygons, each of which has four neighbors. Now, I would like to generalize some of those operations to census data. As you know, the census gives us a very blurred picture of the United States. That is because they have these little polygons in which they aggregate data. I would like to sharpen up those pictures in the way that Harry sharpens up conventional pictures.

The easiest way I find to explain the difficulty is to notice that all of those operations essentially work on neighborhood relations, and every picture element has four neighbors. It is just like a chess board. Now, you can image trying to invent a game of chess to be played on the county board of Virginia Counties, for example. Take counties in an Eastern state, any one. Imagine that it is a chess board; color it red and black. Now, devise a set of rules to play chess on that board. You have to generalize the conventional rules of chess, which are very simple rules. Playing chess is difficult, but the rules themselves are simple. A somewhat comparable operation would be to feed two pictures into the computer, taking two time slices, that is, you could take two pictures of a chess game at two different times during the play. Now compute the rules of chess from the pictures.

Well, I would like to compute the rules of land use change from two land use maps at different times by feeding them into a computer. I have actually had a student (S. Guptill) write a thesis on this soft of thing. That is what I meant by more a refined type of analysis. Again, the natural way for a scientist to compare two maps is to do cross-spectral analysis. Well, how do you do cross-spectral analysis when the data are given in the form of polygonal census data?

Also very interesting to me is the work on things like the algebra of qualitative data. The algebra of non-numerical data. These are the kinds of things I find interesting. But, thinking a little further ahead in terms of software and what one might do at AUTO CARTO IV, I asked myself, do there exist problems that I do not know how to solve today? Are there any problems I can think of that I couldn't figure out some way to solve? I find it very difficult to think of such a problem. The question is really trickier than it seems, because we really have to talk about problems which are solvable, and you have to define what you mean by "solvable" in a rather extensive way. But this leads directly into what computer scientists call the study of algorithms and it relates to the question of algorithmic complexity. For example, just as a simple study of algorithms, everybody knows you can convert from polygons to grids and back. Right? Well, let us do it again. Let us go back from the new set of polygons to grids and back and back and back and back and back and back--and what happens in the limit? I do not think that kind of question has been studied very much. It really relates to the inverse of some of the algorithms that we have worked with. For example, there are street address to state plane coordinate programs. I do not know of anybody who has a state plane coordinate to street address program. There are all sorts of things one can imagine along these lines. But that is still a very simple problem. Polygon overlays is often considered a complicated problem in this field. Now, I think--I am not sure about this--but it seems to me that the polygon overlay problem goes up as the square of the number of polygons. You have N polygons times M polygons, and if you increase those two numbers you simply multiply the problem. That suggests that it is a polynomial problem. Now, it is well known in the computer field that polynomial problems are solvable. They are not like what is known as exponential problems, which are essentially impossible to compute. So, it seems to me you have been talking mostly about solvable problems here. But there are interesting geographical problems which do fall in other classes. This relates to theoretical work on algorithms. For example, it is well known that the best possible algorithm to do sorting will take N log, N time. There is no possible algorithm that can beat that in time, and if you have an algorithm that does it in that time you have the best possible time algorithm.

There are some problems that are even more difficult. These are generally called NP complete problems, and, somewhat crudely stated, you can prove that there are no efficient ways of solving them. One of the ones that comes up in cartography is to program a plotter to minimize the plotter movement. That is essentially the same as the traveling salesman problem. It is now believed that there is no efficient way of doing it. The only way of finding the optimal path is testing every possible path. I think we can ask if several people have polygon overlay problems what is the theoretical minimum time that that should take, and how close do these algorithms come to it? It is a little more complex, because you have to worry about storage trade-offs, too, and so on. My point here is that there is a whole class of things that we did not talk about at this conference, and they might be topics for next year's conference. Thank you.

MR. EDSON: Thank you, Waldo. I did recall that, I believe, it was at AUTO CARTO I that Waldo appeared in fact with a $20 Etch-A-Sketch and appeared on the hardware panel. (Laughter.) Duane Marble, as the moderator of our software panel, I am sure has a few concluding remarks. Duane?

DR. DUANE F. MARBLE: Thank you, Dean. The software area is a rapidly developing one. Many of the comments that I would like to have made have already been made by Waldo. So, I will content myself with making some general statements in this area.

There is a lot of software out there, and a lot of it is very poor, and we really do not know very much about the operations we are undertaking. Sit down and ask yourself, if you were to undertake a sequence of cartographic operations and you wanted to write computer code to do these, how would you find out the most efficient way to do this? At the present time there is no good answer to this question. This leads us into the area of what Waldo was talking about -- that is, algorithms. We do not know enough about the algorithms or, to use an alternate word, the procedures that are necessary for development of cartographic software. I talked to you earlier about the IGU/USGS inventory of computer software. These programs in and of themselves may perhaps be useful to individuals, but the most useful thing in them is the ideas, the algorithms that underlie them, the ways of doing things. In many cases, the statement that, "I don't really want your lousy code, what I want to do is steal your ideas," is an appropriate one. But at the presnt time we do not have a library of cartographic or spatial data handling algorithms. I think this is something that we need to undertake as a critical research area. This involves a lot of things, some of which we find it difficult to do because most of us are basically cartographers or geographers and have not really been trained to think in computer science terms. This is a problem that is going to have to be overcome. We need to pay a great deal more attention to algorithms and we must do it in a formal

Sense. We have to start worrying about some of the algorithmic problems that Waldo discussed.

Two of the sessions in the software day were oriented toward problem areas. One dealt with raster processing of cartographic data. The other dealt with the handling of large volumes of spatial data using data base management system technoloty. Both of these areas need a great deal more examination. I think the raster approach is an example of one of the things Waldo was talking about, and that is trying to find new ways of thinking about things. I do not think we should constrain ourselves to trying to automate existing techniques. I guess for that reason I find myself a little uneasy with the term "computer-assisted" cartography that was used in the opening day's session, because it has the implication, at least in my own mind, of using the computer to do just the things we are already doing. The computer is a new tool. There are new things that we can do with it, and we must search these out.

The comments that were made about costs are also important. In the software area we have the ability to do a great deal to influence the economic viability of these operations. But at the present time we do not know anything about the cost functions. The IGU Commission tried to do a study on comparative digitizing operations. So did the Corps of Engineers, the Forest Service, and for all I know, some other people have as well. Most of these studies have not produced what we really need in an operational sense. I sit here, for example, with two maps. I can say this is a simple map, and you will say, "Yes, that is a simple map, it doesn't really have very much on it." I say this other one is a complex map. You'll say, "Yes, that is a complex map because it is the Grand Canyon topographic plate," or something like that. Obviously, there is a difference between these two maps and the effort that is going to be needed to encode them. What an operational manager needs is a digitzing cost function that will enable him to take a given set of map data, either in archival form, which we have been talking about implicitly, or direct digital capture form, which is something else, and say how long is it going to take to do this, to create the data base, and how much is it going to cost? You cannot very well go to a board of supervisors or the Federal Bureau of the Budget and say, "I think the project is going to cost somewhere between 60 and $600 million, and we will let you know exactly when it's done." The way we should do this is to find out what are the appropriate measures of information on the map, which of the measures are important factors in the cost function, how do the cost functions differ for the different digitizing technologies -- the table digitizers, scanners, automatic line followers -- each one of which will have a different cost functic One should be able to go through, take the maps, take the spatial data set, devise a sampling scheme to measure the parameters, insert the parameters into the cost functions, and come out with an estimate as well as a variance measure. Until we can do this, it is going to be a very risky operation building a large spatial base.

The same thing occurs when we start getting into operational software. If we do not know about algorithm efficiency, if we do not know about efficient data organization and management, then we cannot translate these into dollars and cents and days and weeks and years of time. This means we are not going to have economically viable operations. The development of this economic information is very difficult at the present time. We have to do our homework in other areas first, not only in the hardware characteristics but in how we measure spatial data and how we manipulate it and store it.

This brings me to two concluding topics that I would like to pose as questions. First, there seems to me to be a need for a substantial amount of cartographic research, applied research or day-to-day engineering problems. But there is a great deal of work to be done out there. Some of these things will be done by operational agencies under the pressure of their line responsibilities. Other portions of it will not get done that way. I worked in the urban transportation field for many years. There was a constant problem of who was to fund the needed research. The things that agencies like the Department of Transportation felt were blue-sky basic research, in the eyes of many academic researchers appeared to be quite applied.

Many agencies are unable to fund things that cannot be directly related to their day-to-day operations. But someone, at some time, is going to have to start worrying about integrated research programs in cartography and the provision of financial and manpower resources for carrying them out. At the present time I think, for example, the National Science Foundation would be hard pressed to fund things in the software area. They have a division that deals with computer science. We have no credibility in that area. We are not computer scientists. They have a program that deals with geography and regional science which funds no work in cartography. The engineering division, I do not really know about, but I doubt their interest as well. There is a very real problem with funding and organizing basic research. I think the people working in cartography and geographic information systems are going to have to worry about this.

The problem is not only that of funding; there are questions of manpower -- manpower for research and manpower for development work, and manpower for carrying out day-to-day operational responsibilities. I think that, again, we must ask ourselves what are we doing in terms of training programs? Again and again, during the meeting and other times, people come up to me and ask do I know anyone with thus-and-such a set of characteristics. Most of the time I say, "Yes, but they are already gainfully employed." They ask about students who are trained, for example, in cartography and computer science. There are very few of these that are coming out. I think we in the universities have to look at our training programs and see what we can do to restructure them to try to start solving some of these problems. We also need large scale training programs to upgrade skills of existing staff. There are a lot of people that are working in the area of computer cartographic today that came into it with no formal training. I am one of them.

The things that are learned on your own sometimes sink in deepest, but they are also very hard to come by. There is no effective program of in-service training on either the Federal, state, or local level. I feel things have to be done in this direction as well.

We have a number of things to do in the next few years, a number of problems to attack on both an operational and sort of basic research and training areas. I would certainly hope that we can meet them efficiently and not just stumble ahead into the future. With that I will pass it back to Dean. Thank you. (Applause.)

MR. EDSON: Thank you very much, Duane. Perhaps in the next couple of years before AUTO CARTO IV, we will have to consider a new term, perhaps "computer-biased" cartography or something like that would be better.

DR. MARBLE: I would like to suggest "cartography."

MR. EDSON: That sounds super to me. Next, Ray Boyle, who has held forth yesterday and part of today on hardware. I am sure Ray has some concluding remarks. Ray?

DR. RAY BOYLE: I think I did most of them this morning, and Duane has done quite a number for me where I was going to touch into the software area. It is very difficult to in fact separate software and hardware. The two go along together.

One of the things that I noticed in my travels and in talking with people about programs, I have not yet come across a program that has been put out as a job to be done that specified it had to have a certain run cost. Nobody seemed to worry about how much it costs to run their program when it came back. I think that cost-effectiveness should be in every contract for programming. Hardware, particularly, and software as well, are entirely dependent for their application on their economics. We are no longer at a stage where it is possible to just buy a toy to play with. It has to do work and it has to do it efficiently and economically.

We are starting to get the feel, if not all the information we need -- and we tried to bring some of that out in the hardware panel. I feel confident that scan digitizing can meet the economic requirements that are needed. I also feel that the smaller optical disk memory will be able to meet the necessary economics of storage and transmission of data. I would like to feel that these will be used because I believe that they are an essential part of cartography in the future.

Somebody remarked to me that it seemed to them from the meeting that the poor old vector is dead and now we have only to work in raster scan and think only in raster scan. This was no intention of mine in the hardware part. I do not think it was any intention in the software part either. However, there has been a stress in this presentation of scan methods. I think in some areas they are better; I think in some areas they are worse. Perhaps, because we are presenting new things at this meeting, there has been a slight overaccentuation of the word "scan." The vector is there, and it is good, and we have got a lot of use to come from the vector method. I think so myself for cartography, for cartographic storage. But I am prepared to be argued out of this. There are arguable matters in both directions.

The audio aspect of hardware I think is important, and I think will be used more and more. It is getting to be very low cost; it is simple and good.

When I talk about the small optical disks for memory, I am trying to avoid LANDSAT imagery, storage and ideas. I am treating those as outside automated cartography. I think that for ordinary cartography something of the order of 10^{10} bits is good storage. As I said this does mean that you can store about a thousand topographic quad sheets on one rotating disk. Quite a nice handeable amount and good quality data that will be with sufficient redundancy checking so that there will be no problem of errors.

With regard to the question of large displays, in my travels I have certainly found that in presenting the results of geographic information systems to politicians, they demand the large display, as Dean Edson said in his final remarks. I am not certain whether it is wanted in editing work in cartography, and we did not get a clear answer in our panel meeting. The question was left in the air. Maybe that is where it should be until we see the costs of these larger screens and how we can use them effectively.

I was extremely happy, and I would very much like to thank all the members on the hardware panel. We did explain to them how we wanted their ideas put over. They were going to talk to cartographers, cartographers who knew their subject well, but would not understand jargon in some of these areas. I do compliment them on doing an extraordinarily good job. There was never any question of my going to sleep in any of the discussions. I was enthralled, although these were things I had heard before. I think that the written account will be a very valuable document for people outside this room as well as to you, because I am certain some of the things you will read again to take them in. Ideas came thick and fast. They were all good. I shall be very happy to read the report when it comes through, and I know I will be meeting a lot of people who will be asking for it. I hope that many copies will be made available, Dean; we ought not to have such a limited number that it goes out of print one month after the first issue.

I still go back, I think, to my original comments, that I am not certain that this is not going to be the peak of hardware developments. I think that most of the things I want to be answered are being answered and are being answered by engineering hard work, not by a new vital breakthrough. We did not cover every subject, but we covered a lot of the subjects; we had to be selective.

I would also like to repeat the comments that I made, the summary remarks this morning, that I do believe that there has to be a greater effort at getting good education to cartographers, updating the thinking in these areas. It is a new type of cartography. You do not have to learn programming, but you have to learn a new way of thinking. I hope that the universities can perform this teaching job for you as on-line working people, and that departments will support this development and implementation of in-service training.

I also hope that the government will support the idea of service bureaus. There are a lot of people who want to use these facilities. They are not going to be able to run them 24 hours a day or even one minute a day. But they still want to use them occasionally. So, please, do, as government administrators, please think of this need from outside.

I am very happy with the state of hardware as it is, both with the manufacturers who are showing here and things that I have heard have been done. I hope that you also feel the same way. That is all I want to say. (Applause).

MR. EDSON: Thank you, Ray. I am very pleased that you altered your position slightly from your opening remarks, because I feel I am almost looking forward now to the next couple of years, because I am almost positive we will see new inventions, new thinking in the hardware front. It just cannot help but be that way.

Finally, the panel on data edit, headed by Harvard Holmes, the cleaner of the non-clean data.

Harvard, what can you tell us?

MR. HARVARD HOLMES: I guess I will start by answering Ray. Our editors would like a large screen, as large as possible. We also have to show that data to politicians. I think we have to realize that politicians do make decisions, and there is a lot of worth in showing the data to politicians. I guess as a computer scientist and not a cartographer at all, my real interest in cartography is as an information transfer mechanism. So, my real interest in looking toward the future is in tapping some of the very large data bases that have been collected and using cartography and mapping to convey that information to the analysts, the planners, the politicians, the people who need to understand what that data says.

I guess I, too, would be very encouraged by the current state of affairs in cartography. I sort of get the feeling that for my needs, pretty much everything is there. I can get it. I can get the hardware, I can get the software for the cartography aspects of what I am doing. What I cannot get is the mass storage system yet. I have hope for those. What I have a little less hope, at least for the present, is for the software, to access these map data bases. It is still not clear to me if one has ten billion characters of census data exactly how a naive user can sit down at a terminal and discover what is in those ten billion characters of data, and how to get out the 500 characters that he would like to have and get those characters out in ten seconds or so, and then in another 15 seconds have a map put on his graphic terminal so he can begin to understand what that means. I think the challenge for the next few years, at least for me, lies there.

MR. EDSON: Thank you, Harvard.

(The meeting was then formally concluded, with remarks by Mr. Edson and Mr. Chamberlain.)

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