AUTO CARTO IV

Proceedings of the

International Symposium on Cartography and Computing: Applications in Health and Environment

Volume II

INTERNATIONAL SYMPOSIUM
ON
COMPUTER-ASSISTED CARTOGRAPHY
(AUTO-CARTO IV)

This fourth conference on automation in cartography was sponsored by the American Congress on Surveying and Mapping, and the American Society of Photogrammetry. It was held in cooperation with the National Center for Health Statistics and the National Park Service. ROBERT T. AANGEENBRUG from the University of Kansas served as the Conference Chairman. Principal liaison officer for the National Center for Health Statistics was DAVID SLABY and for the National Park Service, CABY SMITH. Executive Secretary for the conference was KAREN STOLZ from the University of Kansas. Special appreciation is given to the following conference committee members for their assistance during this symposium: MARY G. CLAWSON (DMA), THELMA FOWLER (PHS), STANLEY LEIZEAR (DMA), JACK FOREMAN (NOAA), MATTHEW TATE (USGS), KARIN BAKER (NOAA), and MICHAEL METZGAR (USGS).

The proceedings were compiled and edited by ROBERT T. AANGEENBRUG. TERRY SLOCUM of the Geography Department, University of Kansas, served as Assistant Editor, KAREN STOLZ and WENDIE FODOR provided the editorial support services.

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Volume II

Proceedings of the International Symposium on Cartography and Computing: Applications in Health and Environment

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EDITOR

Robert T. Aangeenbrug

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FOREWORD

This is the fourth conference on computer-assisted cartography sponsored by the American Congress on Surveying and Mapping, and the American Society of Photogrammetry.

In the spring of 1978, Dorothy Rice, Director of the National Center for Health Statistics, and I participated in a workshop on Automated Cartography and Epidemiology. It became clear to us that the utility of computer-assisted cartography had not been fully incorporated into the health professions and their attendant federal agencies. Mrs. Rice believed that further discussion and an exchange of information about basic methodology, applications, problems, and software and hardware in the field of computer-assisted mapping and the health planning and analysis fields, would be useful. She provided me with an excellent staff and support from the Public Health Service which enabled me to organize a symposium to meet these objectives. She was especially instrumental in supporting us with David Slaby who coordinated program advice and liaison activities for the U.S. Public Health Service.

William Riordan was instrumental in urging and executing the official co-sponsorship of the American Congress on Surveying and Mapping, and the American Society of Photogrammetry. He also provided frequent counsel to the conference chairman. Caby Smith and Ted Sudia from the National Park Service enthusiastically endorsed the conference. They were especially generous in assisting our efforts to support four sessions on natural resource systems.

The U.S. Public Health Service and the National Park Service provided contractual staff and program support.

Additional support and cooperation came from a variety of organizations; their contributions include program advice, staff support, publicity, and space, but most of all, support for the conceptual structure of AUTO-CARTO IV. These additional agencies supporting AUTO-CARTO IV include: the Defense Mapping Agency, the United States Geological Survey, the American Rural Health Association, the University of Kansas, the

National Oceanic and Atmospheric Administration, the Bureau of the Census, the Lands Directorate Environment Canada, the U.S. Army Engineer Topographic Laboratories, the International Cartographic Association, and the National Aeronautics and Space Administration.

A list of the staff and committees that assisted in pre-conference planning, registration, making local arrangements, and compiling the conference proceedings is found in the appendix. Such a list does not reflect due credit for the work of the editorial and secretarial staff. They, in addition to providing logistic support, assembled and assisted in editing the proceedings. Next time I hope AUTO-CARTO V will have a Terry Slocum, Karen Stolz, and Wendie Fodor to provide extraordinary support.

Any compliments concerning this conference should be directed to those I have named here as well as those listed in the appendix; any criticisms should be directed to me so that subsequent meetings of this type may benefit.

R.T. Aangeenbrug

PREFACE

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

A summary of each session is provided at the beginning of each section. An author index and participants' list are included in the appendix.

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PHOTOGRAMMETRY SESSIONS

PHOTOGRAMMETRY

There were two Photogrammetry sessions. The first session was chaired by Ellen Knapp of Computer Sciences Corporation, and the second session was chaired by Roy Welch of the University of Georgia.

P.F. Grosso of Image Graphics, Inc. presented the paper "High Speed, Large Format, Flatbed Photocomposition Systems". One of the major technological advancements in plotting has been the replacement of a standard optical photohead with a computer controlled cathode ray tube exposure head. This advancement has resulted in plotting capabilities 20 to 200 times faster than before. In this paper Grosso describes both the hardware and software of the system.

Jerry Robinson of the Chicago Aerial Survey presented the paper "Digital Terrain Services at Chicago Aerial Survey". Robinson describes generation of digital terrain data using the Zeiss C-100 Planicomp analytical stereo instrument; edit of the input data by computer display; edit of the computer generated contours on the M & S Interactive Graphics System; plotting of topographic maps by computer plotter; and computer output of engineering cross sections from the digital terrain model data. The ability to perform this processing on a mini-computer has allowed the Chicago Aerial Survey to implement the technology as a practical production tool.

Robert Leighty and John Benton of the U.S. Army Engineer Topographic Laboratory presented the paper, "Hybrid Digital/Optical Feature Extraction System". (Paper not included in proceedings.) This system combines the best attributes of digital and optical image/feature extraction processing. This hybrid system will use microprocessors for various control and firmware processing stages, with system management being performed by a small minicomputer. Visual interaction will be provided through both monochrome and color video monitors and manual intervention will be through a trackball or joystick. Output of the system will be identified cartographic features to be used in supporting both military and non-military sectors.

William O. Lucoff of Cal. State at Hayward presented a paper entitled "The Use of Computer Generated Maps in Interpreting Urban Forestry Data". Lucoff describes a method for digital processing of urban tree inventory data from small scale (smaller than 1:30,000) infrared aerial photography. He describes how the data was collected and processed into a form that could be used for producing contour and trend surface maps. This technique has aided planners in developing urban tree policies.

William R. Detwiler of Systemhouse Inc. presented the paper, "An Analytical Photogrammetric Solution to a Civil Engineering Problem". Detwiler describes a photogrammetric approach to assist the developer in expanding a shopping mall. To do this each surface of the structure is photographed using a 35mm camera. The results are then mapped on an analytical stereplotter. The advantages of this method are; cheap cost ($3000), little on site time (8 hours), and quick delivery of the final product (one week later).

John K. Powell, Glenn L. Osick, and Thomas G. Miller of the U.S.G.S. presented the paper "Practical Experience in Integrating Conventional Photogrammetric Compilation and Digital Mapping Techniques". They describe the use of conventional stereoplotters combined with voice entry of attributes, interactive editing, and automatic drafting techniques for the production of digital products as well as conventional topographic maps. Using the process, two major goals of the National Mapping Program have been achieved simultaneously; the processing of both a digital and a graphic format of the standard series general purpose maps.

J.E. Turek and D.J. Walker of Image Graphics, Inc. presented the paper "Large Format Laser/Scanner Plotter System". They describe a system capable of both scanning inputs in the form of opaque hard copy on photographic film and plotting positive or negative outputs on film. This system is capable of scanning an image 50" x 70" in 30 minutes with a resolution of 40 lines/mm. Details of the Laser Scanner/Plotter System hardware and software, performance level achieved and sample recordings are also included.

HIGH SPEED, LARGE FORMAT FLATBED PHOTOCOMPOSITION SYSTEM

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Fairfield, Ct. 06430

I. Introduction

The CRT Flatbed Photocomposition System was developed to produce high quality cartographic plots and color separations on film at high speeds from digital data bases. The color separations are used to prepare press-ready printing plates for conventional multicolor presses.

Replacement of a standard optical photohead on a flatbed plotter table with a computer controlled cathode ray tube exposure head dramatically improves plotting throughputs and versatility for cartographic applications.

Four CRT Flatbed Photocomposition Systems recently delivered to government agencies have demonstrated reductions in plotting times from 20-200 times depending upon the data content and format. A typical complex chart 48" X 60" can be plotted on film in less than 30 minutes.

The CRT Exposure Head may be used for the composition and placement of names data and special symbology of graphic arts quality. Characters, alphanumerics, and symbols can be recorded in a variety of font styles and sizes ranging from 4-72 points and rotated on command in 1° increments. Thousands of characters and symbols of many different styles may be put on-line. Line widths may be varied at random from .002" to .256" and vectors up to 1" long may be rotated in 1° increments.

II. System Description

A typical CRT Flatbed Photocomposition shown in Figures 1 and 2 consists of several major subsystems; a CRT Exposure Head, a Flatbed Plotter Table; a Symbol/Vector Generator; a Computer Controller and associated software. The CRT Exposure Head and its associated control electronics are mounted on the "Y" carriage of a flatbed plotter table, as shown in Figure 1.

Cartographic plot and names/symbol data are generated with a computer controlled Symbol/Vector Generator in a 2" X 2" area on the face of the CRT and imaged through a 75 mm, f/4 lens at 1:1 to expose a 2" X 2" area on a large sheet of film attached to the flatbed plotter table.

The CRT Exposure Head typically exposes each 2" X 2" area in less than 1 second and then is moved and positioned to expose an adjacent 2" X 2" area as illustrated in Figure 3. The process is repeated until the entire sheet of film has been exposed to form a latent image of a map or chart. The film sheet is then removed from the flatbed plotter table and processed using conventional film processing techniques.

Figure 4 is a block diagram of a typical CRT Flatbed Photocomposition System.

Computer Controller - The exact configuration of the Computer Controller is not critical. It usually consists of a PDP11/34 or PDP11/45 basic binary minicomputer processor with a 16 bit word and 64K words of memory; a 9 track magnetic tape input system; a magnetic disk system with adequate capacity for storing all utility and operating software programs and a font library; I/O devices such as CRT and paper keyboard consoles; an interactive graphics storage display; a direct memory access interface to the Symbol/Vector Generator and a communications interface to the Flatbed Plotter Table Control.

Symbol/Vector Generator (SVG) - The SVG converts all digital data commands from the computer controller into analog signals which operate the CRT Exposure Head.

The SVG includes all of the circuitry for: (a) character and symbol generation and placement; (b) incremental plot and stroke vector generation; and (c) X-Y random positioning. All scaling of characters and symbols from 4-72 pts; rotation of 360° in 1° increments and line width control from .002" to .256" in .001" increments is accomplished with the SVG.

CRT Exposure Head - The CRT Exposure Head, as shown in Figure 5, consists of a high resolution, 5" diameter flat face CRT with P11 phosphor assembled in a magnetic shield with its electromagnetic focus and deflection coils and its optical lens. The CRT assembly with its control electronics chassis are mounted on a mechanical structure which interfaces to the "Y" carriage of a Flatbed Plotter Table.

Flatbed Plotter Table - Flatbed Plotter Tables used in present systems have been the Gerber Model 32 and the Concord Control E-113. Any high performance plotting table may be used provided it has a positioning accuracy of better than .0005", and a table surface flatness of less than ± .005".

The computer controller transfers position instructions to the Flatbed Plotter Table Control to position the CRT Exposure Head.

System Data Flow - Data flow for the CRT Flatbed Photocomposition System is illustrated in Figure 6. Input data to the system furnished on magnetic tape may be prepared in the CRT Photocomposition format with the user's host computer or may be in the user's standard plotter production data tape format which can be converted in real time or off-line using one of the conversion software packages supplied with the system.

For names or symbol placement, the input commands call out the type of character or symbol style, which are stored as digital font representations on magnetic disk, and transfer the font data to the minicomputer memory. Relative recording parameters such as size, angle and position are assigned to the character or symbol for controlling the Symbol/Vector Generator (SVG). The Symbol/Vector Generator generates the character or symbol of proper size, angle and location on the face of the CRT using a subraster. For plotting lines, arcs, and contours, the input data files supply command codes to the minicomputer and the Symbol/Vector Generator for computing the position, the angle and width of the florescent spot on the CRT face. Line work can be plotted in incremental or stroke vectors depending upon the data content.

The Software Packages provided with a typical CRT Flatbed Photocomposition System are:
Operating System - for PDP11/34 or PDP11/45 minicomputer controllers is Digital Equipment Corporation's standard RSX11M multitasking system.

Vector/Symbol Plot (VSP) - is the principle plot program which controls all plotting; and all names and text composition and placement from input data tapes formatted in the Symbol/Vector Generator command code.

Font Library Update (FLU) - is the software package which is used to create digital font libraries on magnetic disks from properly formatted input font tapes. FLU can be used to add, delete, display or list symbol data and to perform minor editing on font data words.

Conversion Programs - Are real-time conversion programs developed for converting existing data bases in Gerber plot format into Symbol/Vector generator formats for controlling plotting.

Font Preparation - Digital Fonts are prepared with a stand-alone system from original artwork. Symbols or characters are scanned and digitized with a scanning optical beam, processed, edited and then formatted into a digital font input tape for the system. FLU is then used to develop and maintain a Font Library by storing two sizes of each font style on magnetic disk. All other sizes and orientation are produced with the Symbol/Vector Generator hardware.

Interactive Graphics Display

A Tektronix 4014-1 Interactive Graphics Display Terminal has been provided to allow viewing of the data being plotted; for software development; for previewing input data tapes and an alternate I/O peripheral for the system.

III. <u>CRT Flatbed Photocomposition Output</u>

Figures 7-12 are examples of output from the system.

Figure 7 is a recording of a typical graphic arts quality font stored on-line and used for Names Placement. Figure 8 is a recording to demonstrate the size and rotation control of the Symbol/Vector Generator. Figure 9 is a composite plot showing line work, contours and annotation.

Figure 10 is composite plot made up of vectors of different lengths and widths.

Figure 11 is a section of a 20" X 30" chart of the United States which was plotted in less than 20 minutes. Figure 12 is a section of a 48" X 60" chart which was plotted in less than 30 minutes.

The CRT Flatbed Photocomposition System output demonstrates the system's versatility and high throughput for large format charts and maps. This gives the cartographer the ability to produce complex cartographic products quickly and accurately.

IV. Acknowledgements

This work was sponsored by U.S. Army Engineering Laboratories, Fort Belvoir, Virginia, Defense Mapping Agency and the Central Intelligence Agency.

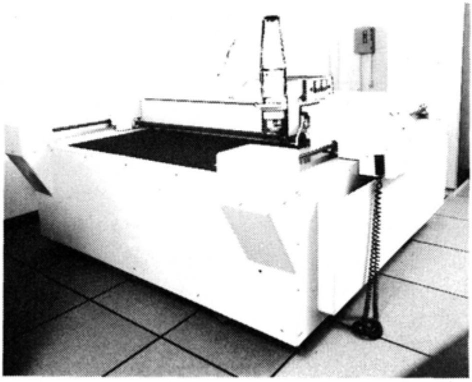

Figure 1 CRT Exposure Head Mounted on Flatbed Table

Figure 2 Computer Controller

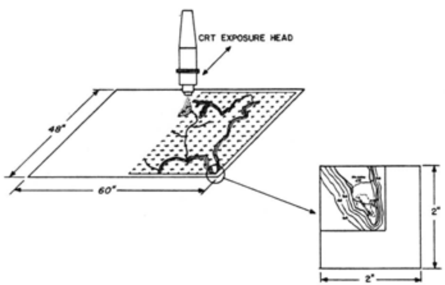

Figure 3 CRT Exposure Process

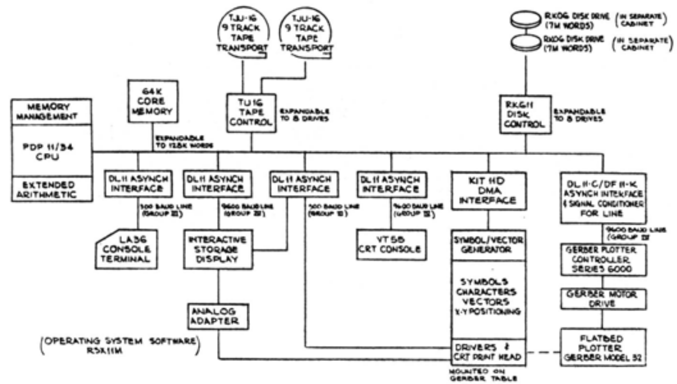

Figure 4 Block Diagram of a Typical System

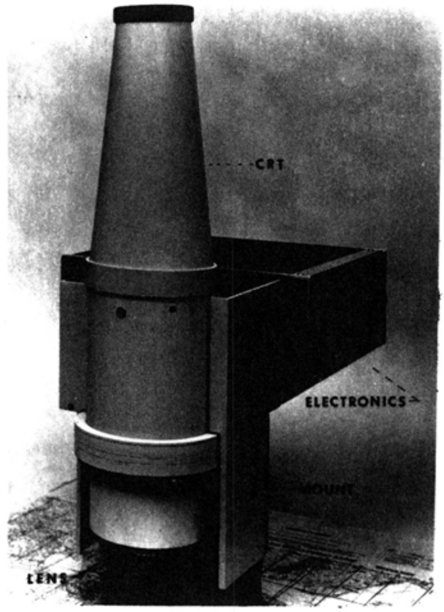

Figure 5 CRT Exposure Head

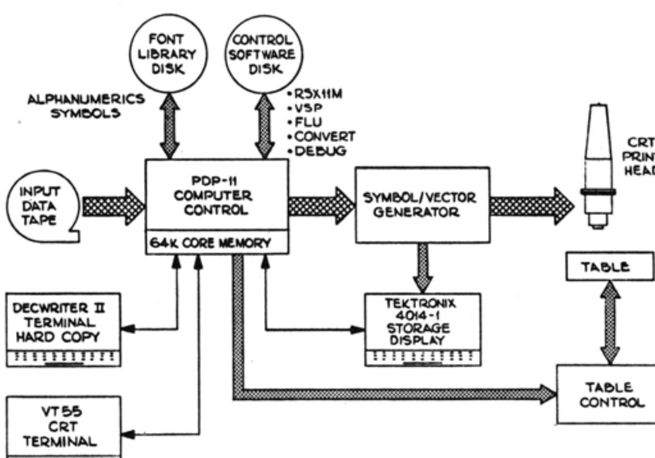

Figure 6 System Data Flow

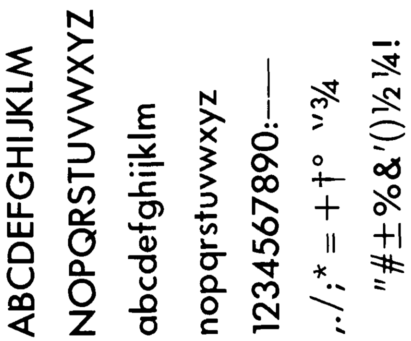

Figure 7

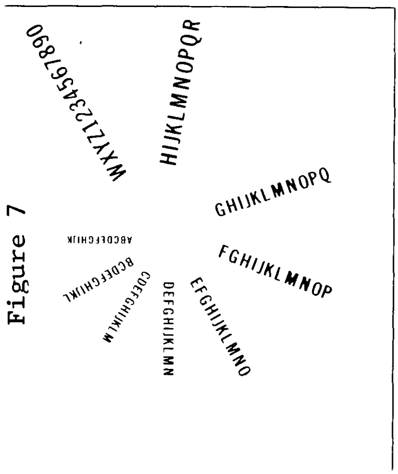

Figure 8

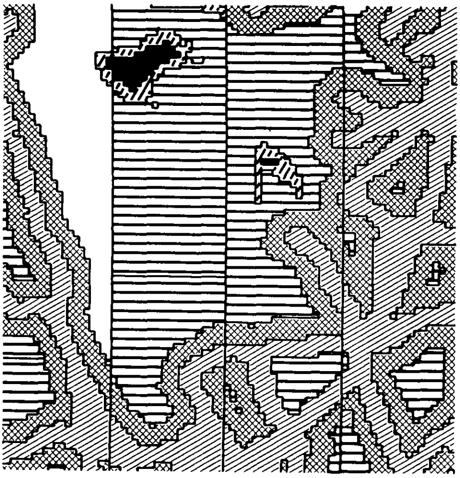

Figure 10

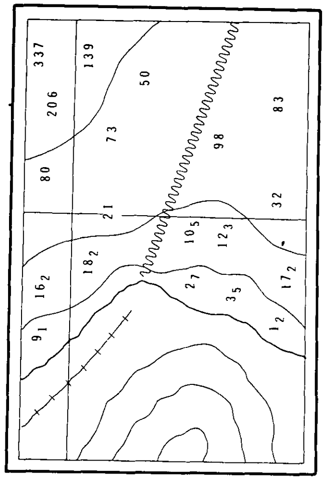

Figure 9

Examples of System Output

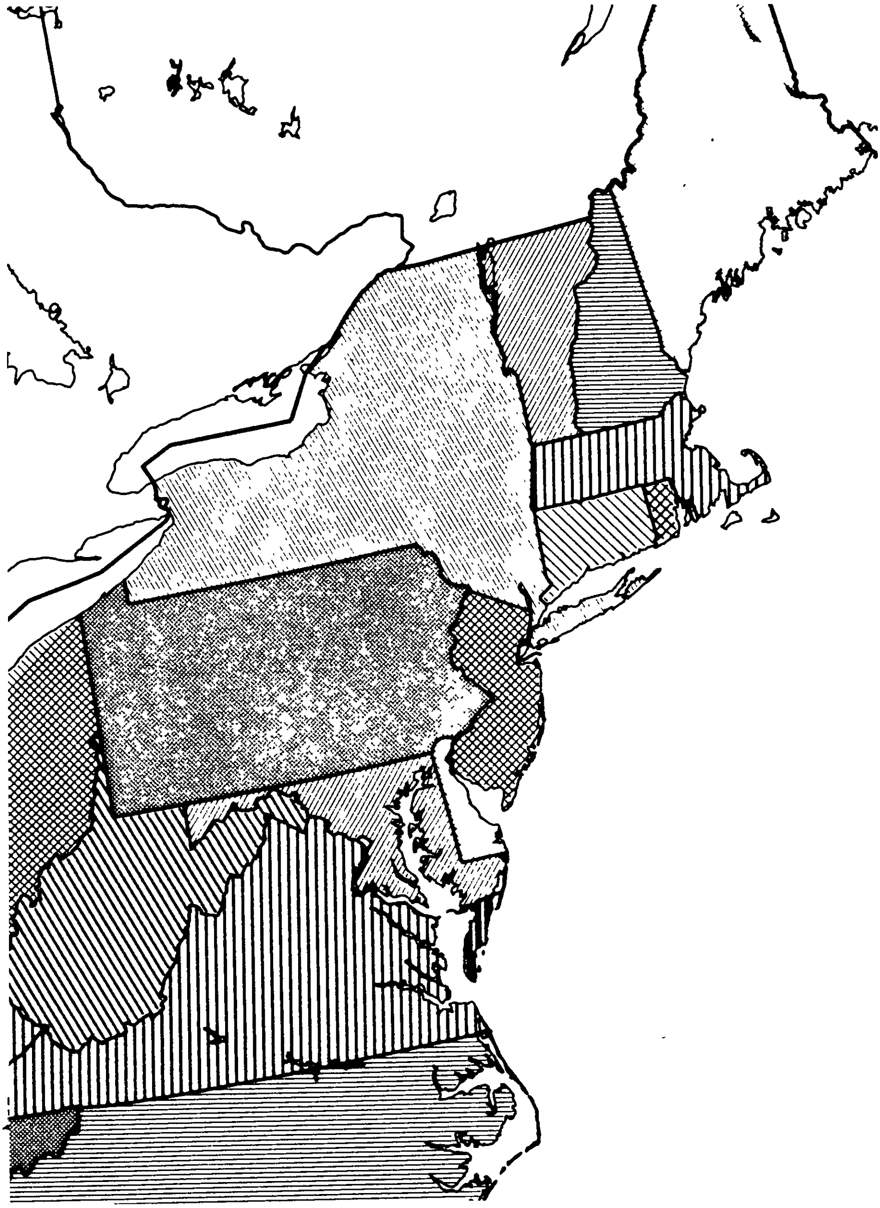

Figure 11 Portion of 20"X30" Chart

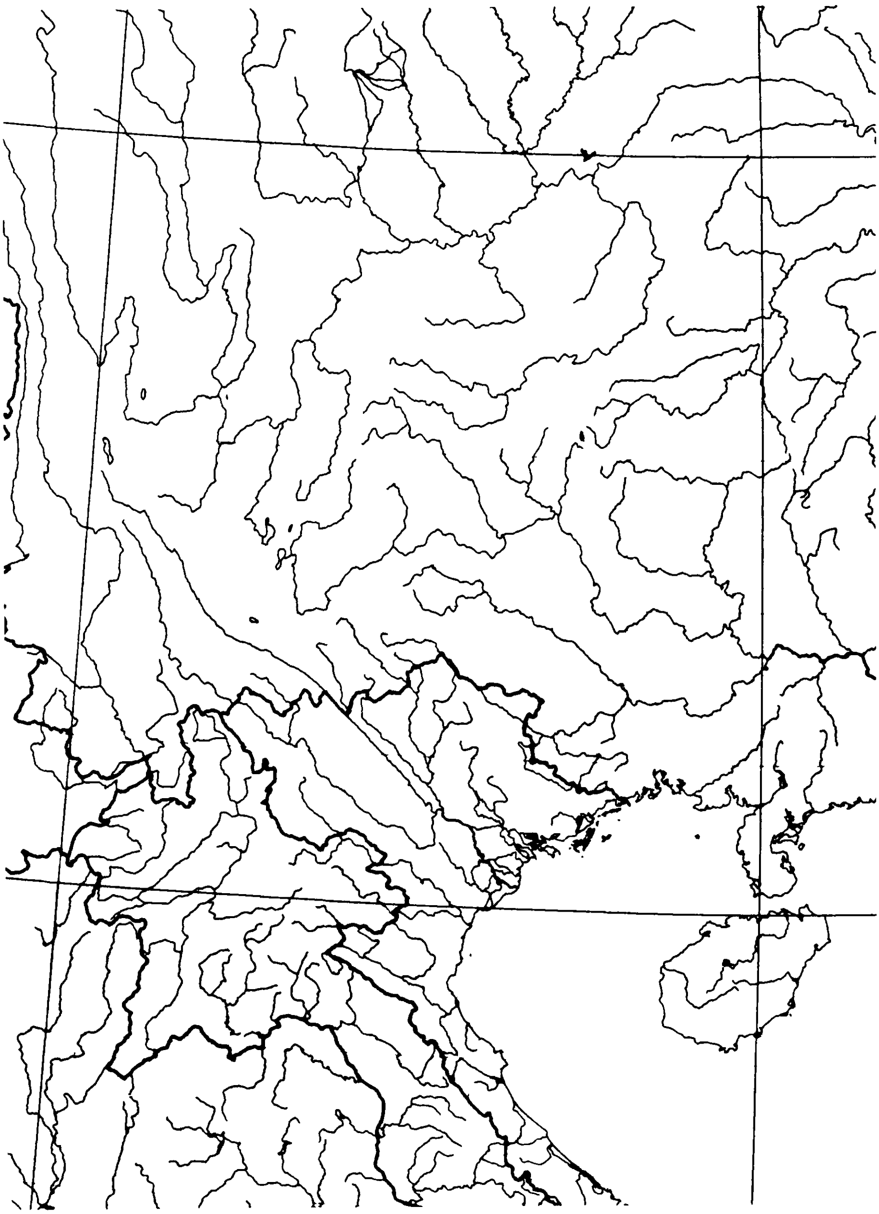

Figure 12 Portion of 48"X60" Chart

DIGITAL TERRAIN SERVICES AT CHICAGO AERIAL SURVEY

Jerry W. Robinson
President

1. INTRODUCTION

The concept of computer generating contour lines from X, Y, Z coordinate data has been studied for many years, and a number of government agencies have been computer producing contour lines from coordinate data for a considerable period of time. In the process of evaluating the introduction of computer generated contours at Chicago Aerial Survey, we determined that several deficiencies in existing systems would have to be overcome in order to use the technique for commercial applications.

2. DEFICIENCIES IN EXISTING SYSTEMS

Until now, most existing systems have not proven to be practical for commercial applications for one or several of the following reasons:

Processing Cost. The design of the software required that computer processing be performed on large computers. Since large computers are expensive to operate, the cost of data processing usually exceeded the cost of manually producing contours on stereo instruments.

Accuracy. Most programs were not designed to produce data of the accuracy required to meet civil engineering needs.

Edit Capability. In general, there was limited capability to edit the input and/or output data. Therefore, confidence in the computer generated contours was limited.

Non-Intelligent Input. Many systems required the input of hundreds of thousands of coordinate points. This approach was generally accomplished using image correlators which automatically produced a large volume of data. This required significant edit effort and still did not usually produce the results required for engineering needs.

3. THE CAS SYSTEM

Chicago Aerial Survey (CAS) has implemented technology which makes the computer generation of topographic mapping and engineering cross sections a practical production tool. At CAS, we refer to the services as, "DIGITAL TERRAIN SERVICES". Significantly, the system in use today at CAS overcomes the deficiencies which existed with most previous systems. Specifically, the CAS system has the following advantages:

Minicomputer Processing. All computer processing is performed on a minicomputer which helps make the technique cost effective.

Accuracy. The system is designed to produce contours which meet U.S. National Map Accuracy Standards.

Edit Capability. The system incorporates excellent abilities to edit (numerically and graphically) the input data, intermediate data, and final output data. The graphic data is edited at CAS on an M&S Interactive Graphics System.

Intelligent Input. Rather than generate hundreds of thousands of input coordinate points (many of which can be in error), the CAS system provides for intelligent selection of only those points which are required to accurately represent the terrain.

Accurate Input. Data input at CAS is performed on a Zeiss C-100 Planicomp Analytical Stereo Instrument and/or on analogue stereo instruments which are directly interfaced to the computer. The software is designed to also accept random field survey information.

Multiple Outputs. In addition to computer generating specified contour maps, the CAS system allows for producing other outputs from the input data. Other outputs include different contour intervals and map scales, digital data formatted to Client requirements, and computer generated engineering cross sections. We are also working on producing other outputs.

4. INPUT DATA

The CAS system allows for the input of four distinct types of information. Each type of information is coded to assure proper utilization in the computer processing operations. The four types of input information consist of the following:

General Terrain Data is input which consists of X, Y, Z coordinates in a generalized pattern covering the entire area of the stereo model. At CAS, we input evenly spaced profiles of the entire stereo model. The profile data is not recorded in a scanning mode, but rather as individual X, Y, Z spot elevations.

Linear Features such as the bottom of drains, bottom and top of banks, perimeter of enclosed lakes, and other critical features are recorded as individual X, Y, Z coordinate strings of information.

Spot Elevations are recorded as individual X, Y, Z coordinates.

Planimetric Features which are desired to be computer plotted on the map are recorded as X, Y, Z strings of information. This information will not be considered when computing contours, unless desired. The purpose of ignoring this set of data is to prevent elevation errors in the contour data which can result if planimetric features are not at ground level (such as the tops of buildings, etc.). Therefore, at CAS we do not use the planimetric data when computing contours.

5. CAS COMPUTER SOFTWARE

Software Authors. The basic CAS software was developed by Dr. Benjamin Shmutter and Dr. Y. Doytsher of Israel. Through arrangements with Dr. Shmutter and Dr. Doytsher, Chicago Aerial Survey is assigned exclusive rights to use and license the use of the software in the Western Hemisphere. CAS made the software usable in a production environment and accomplished the interface of the software to the Interactive Graphics System.

Software Design. The software is designed to process on most any minicomputer of 32K memory with a Fortran compiler and disk. The ability to process a large number of complex tasks on a minicomputer is made possible by three measures as follows:

a. Subdivision of the system into a number of individual programs which can be executed in one sequence when called up by a macro program or can be run one after the other at different points in time. The programs communicate via the computer disk.

b. Adaptation of special computational techniques and conducting most of the computations in an integer mode, making it possible to store large arrays in the memory of the computer.

c. Subdivision of the data into zones and sectors which allows the processor to only work with relevant portions of the data at any one time rather than attempting to handle all of the data at one time.

6. COMPUTER PROCESSING

The software is "human engineered" in that it performs in a tutorical mode and guides the operator through the processing. It allows the operator to select options and change general parameters as desired. The software consists of a series of basic programs which perform the following functions:

Input Edit. In order to edit the input, the original general terrain data profiles are graphically displayed on an alphanumeric CRT. The operator calls up each profile, along with the profiles in front of and behind it to view the relation of the three profiles graphically on the CRT. Erroneous points may be deleted. (See Figure 1)

Linear Feature Match. Linear feature data strings are computer matched between stereo models. (See Figure 2)

Data Subdivision. The data is analyzed by the program and, based on general parameters and the number of input points, the area of the map or model is subdivided into zones, each zone being defined by a variable number of grid lines determined by the computer memory limitations. (See Figure 3) This allows the processor to concentrate on only the data required to process each zone.

Selection of Relevant Points. The program identifies the input points which are located near each grid intersection and analyzes those points for relevance. The irrelevant points are not considered when computing the elevation of grid intersections. (See Figure 4)

a. For example, a grid intersection near the base of a cliff would be distorted if elevations at the top of the cliff were considered when computing its elevation. The use of linear feature coded data allows the program to recognize the irrelevant points. The program will not cross a linear feature line when computing grid intersection elevations. (See Figure 5)

b. The program also considers the relative distance of each point from the grid intersection and considers a point to be irrelevant should its distance be significantly greater than the other points. (See Figure 6)

Illegal Elevations. After discarding any irrelevant points, the program selects the relevant points which are to be used in computing the grid intersection elevation (usually 5 to 6 points). The program uses only those points which are close to and evenly distributed around the grid intersection. If there is insufficient data to compute an accurate elevation, the program assigns an "illegal" elevation which flags the point for edit. An "illegal" elevation is usually caused by either: (1) insufficient number of input points or (2) lack of an even distribution of points around the grid intersection. (See Figure 7)

Computation of Grid Elevations. Computation of the grid elevation is accomplished using a unique method which is not linear and which does not use polynomials. The program constructs a polygon and reduces the area of each surface of the polygon to the smallest possible size. The computation is performed by simultaneous equation, resulting in a rigid mathematical solution. This unique approach solves many deficiencies which existed with previous programs and results in accurate elevations for the grid intersections. (See Figure 8)

Processing By Sectors. In order to compute the positions of contour lines with limited computer memory, the map is divided into sectors, each sector consisting of an area covered by up to 10x10 grids. The program processes each of the grids, one at a time, in a predetermined order and establishes where each contour crosses each grid. Computation is by linear interpolation. (See Figure 9)

Subdivision of Grids. Where linear feature strings of data exist, the program divides each such grid of such sectors into smaller grids, each 10x10 in number and each meshed within the larger grids. This procedure allows for accurately representing the terrain where changes in grade slope occur. (See Figure 10)

Matching Between Models. The system performs matching between stereo models and allows for windowing-out of individual map sheets. (See Figure 11)

Numbering of Contours. Numbering of contours is accomplished by simply specifying that the index contours shall be numbered at a desired spacing (such as every eight inches, etc.). Should a contour number fall on a linear feature line, the program automatically changes the spacing so as not to overprint a contour turn-back, etc. The direction of the contour numbers is automatically determined by the direction of slope of the terrain. That is, the contour numbers are always plotted so that they are readable looking uphill. This feature makes it possible to determine the value of intermediate contours and the direction of slope by viewing only one contour number. (See Figure 12)

7. SUMMARY

The system used to produce Digital Terrain Services at Chicago Aerial Survey makes use of new, innovative technology and techniques. The system effectively combines advanced hardware and software (Zeiss C-100 Analytical Stereo Instrumentation, M&S Interactive Graphics System, and new unique software). Significantly, the process is proving to be a practical and effective production tool for generating topographic information for commercial applications.

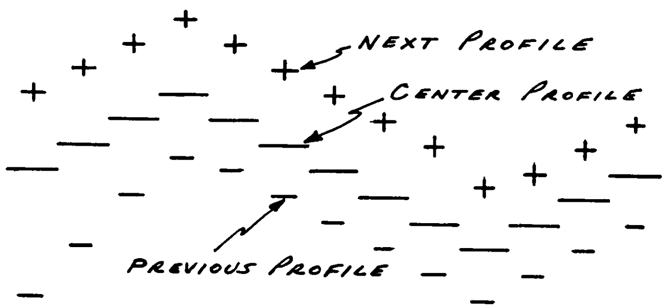

Figure 1 - Input Edit

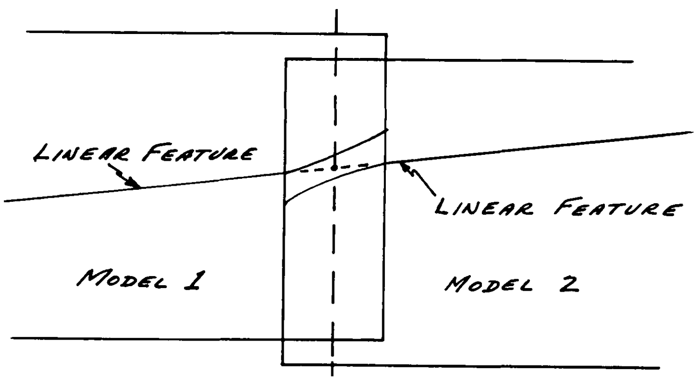

Figure 2 - Linear Feature Match

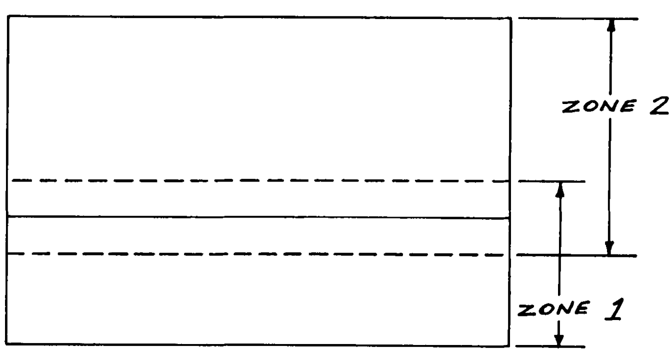

Figure 3 - Data Subdivision

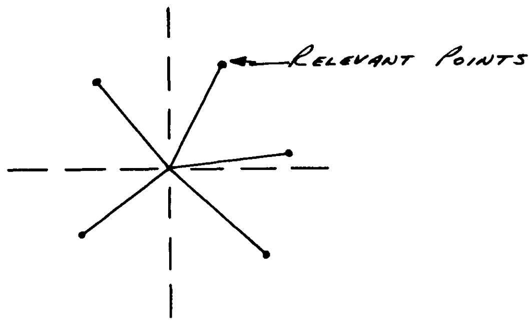

Figure 4 - Selection of Relevant Points

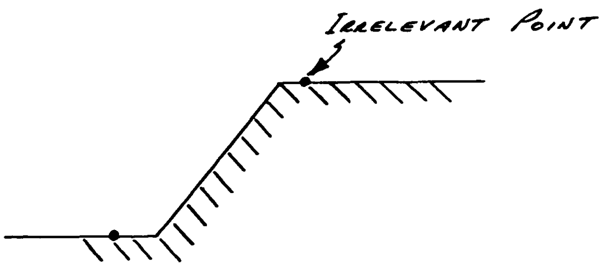

Figure 5 - Irrelevant Points

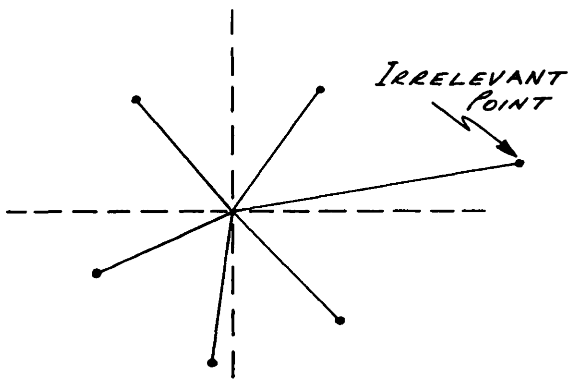

Figure 6 - Irrelevant Points

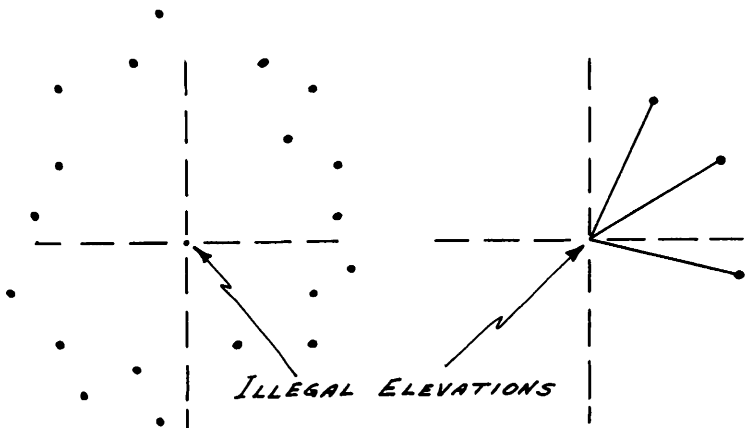

Figure 7 - Illegal Elevations

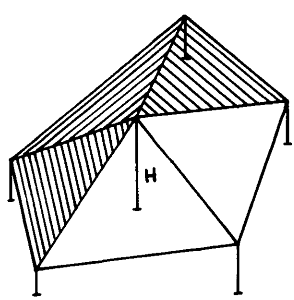

Figure 8 - Computation of Grid Elevations

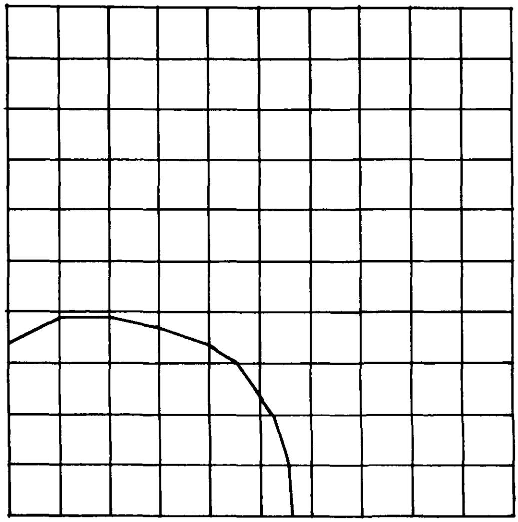

Figure 9 - Processing by Sectors

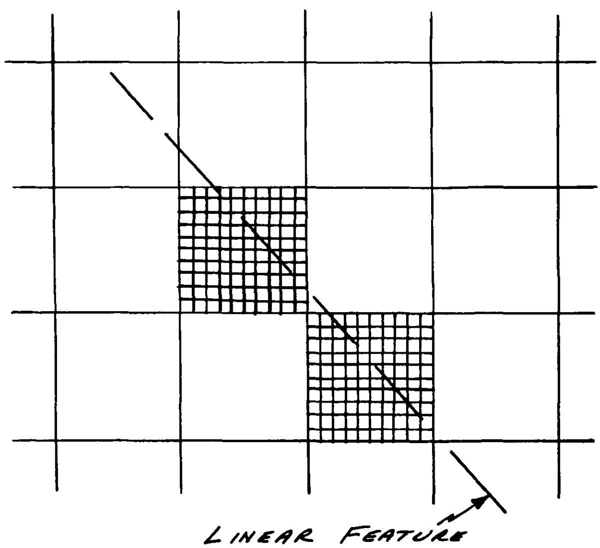

Figure 10-Subdivision of Grids

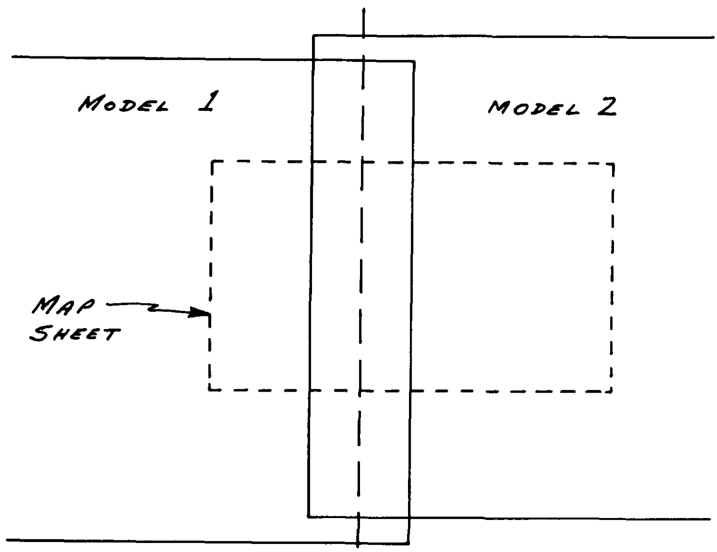

Figure 11-Matching Between Models

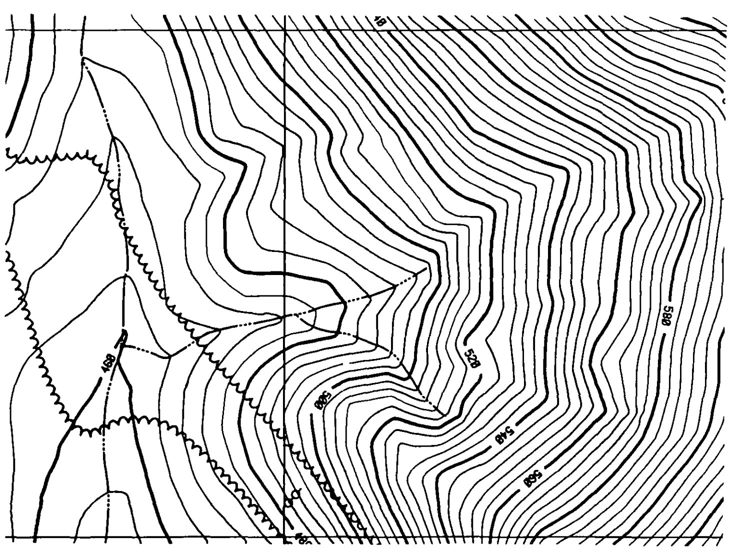

Figure 12-Numbering of Contours

THE USE OF COMPUTER GENERATED MAPS IN INTERPRETING URBAN FORESTRY DATA

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I. Introduction

The need to observe and to catalog urban tree resources for use in planning urban resources is being realized by planning agencies throughout the United States. To date, the only urban tree inventories have been on a level prohibited for large scale urban use. These surveys have been efforts to catalog specific species of flora by visiting the specific areas of the municipality included in the survey.[1] The need for small scale tree inventories can best be accomplished by extracting the data from air photos or other forms of remotely sensed data collected by a stratified random sampling technique. In this form the data can usually be converted into a computer generated statistical surface that will aid the planner, and/or agency, in developing an urban forestry resources program.

To fill this need, a method for small scale (approx. 1:32,000) tree inventories was developed at the Association of Bay Area Governments, using NASA's U2 color infrared photography of the San Francisco Bay Area. At this scale, specific species of trees could not be reliably discerned from one another, so a new classification system had to be used. Three classes of urban trees were used. These classifications were based on geographical locations rather than taxonomical considerations. The three classifications of urban trees are: street, private, and park and watershed.

1. Street trees are defined as any tree facing or situated next to a street or thoroughfare.
2. Private trees are defined as trees that are not adjacent to a street or thoroughfare.
3. Park and watershed trees are defined as any tree situated in an open area within the urban limits, but not situated in urbanized sectors of the city.

For use in this study, trees can be defined as any free standing, woody-perennial over three feet in height.

II. Methodology of Data Collection

The data was obtained by placing an inch-square grid network over a 1:32,000 scale infrared photo transparency. Each one-inch square is divided into 16 ¼" by ¼" grid cells. The area covered by each grid cell is approximately .475 of an acre, or 20,691 square feet. Each one-inch grid of the network contained approximately 7.6 acres, or 331,056 square feet. Each grid cell in every one-inch grid is numbered from 1 to 16; using a random number table, various numbers of cells out of each grid were chosen to be inventoried. The number of cells chosen depended on the area of the city that was being inventoried. A fifty percent random sample was used in areas of residential housing and large urban parks. A twenty-five percent sample was used in areas of industrial development and a fifteen percent sample was used for central business districts. These sampling densities were calculated from sample surveys which used different densities to calculate the optimal density for urban forestry resources in specific municipal land use zones.

A base map of the locations of each of the grid networks with the centroid for each of the sample cells was recorded as part of the inventory technique. The type of trees, their locations, and the number of trees for each of the sample cells were recorded on coding sheets.

Three cities were chosen as target municipalities for this study. The target municipalities were chosen on the criteria of: (1) fit the population sample derived for the study (i.e., one city of population under 5,000, one city whose population is between 10,000 and 100,000, and an urban center with a population of

100,000 plus); (2) be located in the San Francisco Bay Area.

Alameda, Brisbane, and San Francisco were the target cities chosen for the study (No. 1). The city of Alameda is situated on two man-made islands near the eastern shore of San Francisco Bay. The Alameda Naval Air Station occupies the northern end of Alameda Island. The Alameda Public Works Department has a program of urban tree planting in the newer areas of the city. In the early 1970s a ground study, similar to Schmid and Durrenbacker, was completed for Alameda's street trees. The results of this survey showed approximately 15,000[2] street trees. Alameda has continued an active policy of street tree planting.

Brisbane is a small municipality south of San Francisco with a population of 3,600. Brisbane has a concentrated urban center in the southern portion of its boundaries. The northern portion of Brisbane is predominantly industrial. The largest land user in this northern zone is Southern Pacific railroad which maintains a large rail yard. To date, no reliable ground study has been produced for Brisbane.[3]

San Francisco is the largest city in population in the San Francisco Bay Area. It is 49 miles square and has a population of 714,000. The San Francisco Urban Street Tree Department is in charge of issuing permits for street trees. Only about a quarter of the 66,000 street trees are maintained by the city. The other 44,000 have been planted by the city, but by a permit process, are maintained and owned by the residents and the businesses that the trees front. Approximately 2,500 trees a year are planted along San Francisco's streets by federally funded projects and the city's tree planting program.[4]

III. Calculations and Results

The calculations and results are divided into two parts. The first part is to estimate the numbers of trees in the various classifications from the data collected. The second part of the study was the computation of computer generated surfaces. This is accomplished by various stratified sampling techniques. In comparing the final estimations to known ground data, it is found that a twelve percent discrepancy exists between the calculated data and the ground truth data. This discrepancy does not constitute a statistically significant error in the data, at the confidence interval selected for the study. The discrepancy can be accounted for by the inclusion of multi-zonal grid cells.

The need for graphic representation of the distributional qualities of the data is assessed as the accuracy of the data becomes known. The use of computer cartographic techniques became necessary as there were a large number of data points in the study. In order to facilitate graphic representation, the centroid location and the data are smoothed, using a nearest neighbor averaging algorithm. The revised centroid location and the accompanying data are recorded on punch cards and transferred to magnetic tape. After the data has been stored, simple contour and trend surface maps, first to the sixth order, were computed using the SYMAP algorithm.

The results of the computer generated surfaces were interpreted, and likewise the correlation coefficients of the trend surfaces were calculated. The fifth order for each of the three cities were used for the interpretation. The correlation coefficients for the three cities are: Alameda, .912; Brisbane, .971; and San Fransisco, .821.

IV. Interpretations of Trend Surface

The fifth order trend surface for Alameda shows the heaviest concentration of street trees in the southern residential zones. The area of the city which shows any variations in regard to street trees is the northwestern tip of the island where the Alameda Naval Air Station and industrial zones are located.

The distribution for private trees in Brisbane demonstrates the zonation of the city. The heaviest concentration of trees are in the southern residential zone; the lightest area of concentration and the one with the most variation is the northern industrial zone and the Southern Pacific railroad yards. The central business district has a very stable number of trees. This is due to the distribution of several large parks in the downtown area.

The surface calculated for San Francisco shows the greatest amount of variability in private trees. This is due to the distribution of various civic parks and military reservations in the city. The central business district and the wharf area of the city shows a dramatic lack of vegetation. Areas of moderate income (the west central area and the southeastern area) show a slightly heavier concentration of trees. The wealthier districts show the heaviest concentration of trees. The military reserves and the civic and national parks in the northern part of the city caused the greatest amount of variation from the known data and the calculated surface.

V. Conclusions

The cartographic representations of trend surfaces produced for this study are valuable as a tool for use by the urban planner trying to cope with the problem of limited resources. These surfaces, if interpreted correctly, will aid the planner in setting specific target areas for concentration of resources in urban tree planting programs. This also will allow for a decrease in time and expenditure for overhead and planned development.

This paper proposes only one method that works for older and well established communities that have experienced maximum growth potential. The methodology needs further development if it is to meet general purpose requirements for use in rapidly developing communities or communities that have not met their maximum growth potential.

[1]William E. Darrenbacher, "Plants and Landscape: An Analysis of Ornamental Planting in Four Berkeley Neighborhoods." Unpublished Master's thesis, Univ. of California, Berkeley, 1969; James A. Schmid, "Urban Vegetation," Univ. of Chicago, Dept. of Geography Research Paper No. 161, 1975.

[2]From a conversation with Mr. Durant, City Public Works Dept., Alameda, Calif.

[3]From a conversation with Janet Kirby, Park Dept., Brisbane, Calif.

[4]From a conversation with Robert Leet of the San Francisco Street Planting Dept.

References: Dougenik, J.A. and Sheehan, D.E. SYMAP Users Reference Manual. Cambridge, Mass.: Harvard Univ. Press, 1972.

Mendenhall, William; Ott, Lyman; Scheaffer, Richard; Elementary Survey Sampling. Belmont, Calif.: Duxbury Press, 1971. pp. 31-52.

AN ANALYTICAL PHOTOGRAMMETRIC SOLUTION TO A CIVIL ENGINEERING PROBLEM

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I. The Problem

A major east coast shopping mall developer had decided to double the size of an existing mall complex. When they went to look for their twenty year old "As-Built" drawings, they found that they were not complete. In addition, over the years various superficial modifications had been made to the complex. Among those were changes such as:

- resurfacing of some of the pavement,
- construction of 50 ft. square concrete planters,
- sign relocations,
- lamp post relocations,
- increase in air conditioning capacity,
- enclosure of some of the original walkways to form a partial mall.

Obviously, these changes were made "piecemeal" by various departments, individuals and firms. To reconstruct and/or merge all of these superficial changes into one "As-Built" drawing set would be a monumental task of doubtful accuracy.

At this point they did not want to actually design the expansions, they simply wanted to determine the feasibility of such a plan. They wanted to expand on the existing architecture. They needed more than a sketch but less than a full blown structural engineering study.

II. The Alternatives

Various conventional survey and/or engineering firms were approached with the problem. Their responses were unsatisfactory. In order to accomplish a "measurement inventory" of the complex, they would have to do nearly the same amount of work as would be necessary to produce full blown final construction plans. In short, survey crew personnel would be "crawling" all over the complex for at least a month with most of the work having to be done when customers were not in the area.

One of the management group, having had some military experience in photogrammetry, thought that it might be a good idea to at least find out if it was feasible to use that method. After a cursory examination of available firms that performed photogrammetric services, he centered on one that used an analytical stereoplotter. This type of instrument would allow for extremely wide latitude in the original photography.

III The Solution

Let us digress for a moment and consider why photogrammetry is not used more often in this application, since it was in terrestrial photogrammetry that the science of photogrammetry got it's start.

Aerial photography has taken over as the major field and has dwarfed the terrestrial aspects. Because of this nearly all associated instrumentation has been designed around the parameters of aerial photography. Therefore, the only analogue instruments that can be conveniently used for compilation from other than rigorously obtained aerial photography are those which are universal in nature. These instruments cost well in excess of $100,000 and require extensive training before even minimal efficiency can be realized. Analytical instruments could be used but their cost (over $200,000) has caused them not to be economically feasible in the commercial photogrammetric engineering field. However, it has come to my attention that a new analytical instrument is now available for about $65,000 and that should change all of this.

Therefore, the factors that have been instrumental in inhibiting the use of terrestrial photogrammetry have been: a general lack of economically feasible equipment, a scarcity of trained personnel, and most importantly, a general lack of knowledge concerning the potentials of analytical stereoplotters applied to terrestrial photogrammetry.

Mapping from other than vertical aerial photography and, in this case, terrestrial or close range photography requires extensive instrument set-up procedures. The operator must first make the determination of the instrument scale and the gearbox settings. For example, with one commonly available universal analogue instrument, he must consult a table of transmission ratio settings and their relationship to the knob settings. The approximate maximum instrument scale must be determined and is derived by dividing the z range of the instrument by the difference between the greatest distance and the least distance to objects to be plotted. The instrument scale is limited by the transmission ratios available at the height counter gearbox. Yet another table must be consulted for the transmission ratios and knob settings at the height counter gearbox for instrument scales corresponding to 1 meter or 1 foot increments. The operator must then make the determination and settings of the photo tilts and base components. He must then begin on the relative orientation, which is quite a bit different in it's procedures from the normal vertical photography procedures for which the instruments are primarily designed. Absolute orientation is, to say the least, unnerving for the average stereoplotter operator especially when it comes to terrestrial photography. For example, after insertion of the photographs, introduction of all orientation data and elimination of Y parallaxes by means of relative orientation and it's arduous procedures, small errors in position and elevation may still remain in the model. The magnitude of the positional errors may be determined after connection of the coordinatograph to the plotting instrument. By setting the floating mark on the given control points in the model and checking to determine how closely the image of the reticle of the microscope placed in the pencil holder coincides with the plotted positions of those control points. Elevation errors are determined by checking model elevations of control points with their surveyed elevations.

With error correction as the final step it is no wonder that photogrammetry is not used in more instances.

Let us turn the entire situation end for end. Put three reasonably competent, reasonably well-rounded men in a van-type truck with a tripod-mounted 35mm camera, a normal 12 foot surveyors rod, a rod level and a 100 foot steel tape. No transits, no levels, no theodolites. However, we are using an analytical stereoplotter.

Controlled photography is acquired by holding the rod stationary in a plumb position using the rod level with at least it's base against the face of the structure while two overlapping stereo photographs are taken by the man on the roof of the van. The rod cannot be moved while the van is being positioned for the second of the two photographs in the stereo pair. This "set-up" is used as many times as is necessary to acquire a sufficient number of stereo pairs to cover the structure. For the shopping mall case, we used 25 of these set-ups. The total number of set-ups could have been reduced by using additional rodmen for two parallel surfaces in the same stereo pair.

The rod, in conjunction with the building face (surface) acted as all of the control necessary for set-up on the analytical stereoplotter.

Back in the office, the photographs are set up on the analytical plotter with exactly the same rapid procedures used for vertical aerial photography. No differences. As with any analytical stereoplotter, there is no "classical" error correction. There is, simply, a computer developed mathematical model produced with no real approximations made due to the instrument.

IV. Conclusion

With the advent of economically feasible analytical stereoplotters, such as the AUTOPLOT from Systemhouse, the rigorous process of controlling, acquiring and setting-up that is now associated with terrestrial photogrammetry, can be relaxed. This relaxation should not be considered sloppiness. It should, however, be viewed as an opportunity to redirect the photogrammetric community's efforts away from exotic camera and operator procedures and towards expanding the everyday applications of photogrammetry as a profitable endeavor.

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PRACTICAL EXPERIENCE IN INTEGRATING CONVENTIONAL PHOTOGRAMMETRIC COMPILATION AND DIGITAL MAPPING TECHNIQUES

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1. Introduction [1/]

Since the mid-1970's, USGS has purchased, developed, or modified various photogrammetric instruments to collect standard map data in digital form. This instrumentation includes automatic image correlation instruments such as the Gestalt Photo Mapper II (GPM-2), as well as analytical stereoplotters and conventional stereoplotters retrofitted with three-axis digitizers. Two of the latest USGS digital mapping support systems are a stereoplotter interfaced with an M&S interactive editing system and the recently acquired Sci-Tex scanning and editing system.

1/ Use of trade names or trademarks in this paper is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Digital mapping hardware and techniques offer several possibilities for the collection and processing of topographic map data. One method is to collect digital data during stereocompilation. USGS has integrated analog stereocompilation/digitization with interactive editing and automatic drafting techniques for the production of topographic maps (in digital and graphic form).

The integrated system described in this paper has been implemented as a production prototype at the Mid-Continent Mapping Center in Rolla, Missouri.

2. Objectives

There are a variety of reasons for mapping organizations to automate the photogrammetric map compilation and map production processes. Such automation:

- Provides for automatic plotting techniques.
- Accelerates the map production cycle and adds new mapping to the digital cartographic data base.
- Accelerates graphic and digital map revisions.
- Meets the increasing demand for digital data.
- Provides the data base to meet the increasing demand for special types of maps and charts.
- Enables USGS to prepare topographic maps at successively smaller scales, with a selection of features and some generalization of what shall be plotted at each stage.

The great potential for digital data lies in its flexibility either as a production tool in the generation of maps and special graphic products, or as an end product in itself.

3. Concepts

To attain the goal of integrating analog photogrammetric instruments with digital mapping techniques, a variety of offline subsystems is used. The basic input requirements are ground control data and aerial photography, and the outputs are topographic maps and digital files. The total system utilizes equipment, procedures, and a variety of computer programs to perform the following activities:

- Aerotriangulation control information entry
- Compilation/digitization
- Error detection
- Editing -- batch and interactive
- Output -- graphics or digital files

The digital output files contain cartographic features in digital representation. Each feature in the file consists of a unique feature descriptor followed by coordinate data representing the feature's position on the surface of the Earth. In addition to the feature information, the output files contain information relating to the accuracy, resolution, source of the file contents, and the method by which it was compiled.

To ensure meaningful feature identification for data recovery, the compilation subsystem uses a hierarchical classification scheme consisting of three different levels of descriptors: category, feature, and feature type. Each map feature can have up to six descriptive or attribute codes. This hierarchical classification scheme provides for rapid offline verification plots and rapid reviews on the interactive editing subsystem for selected features or categories.

It should be emphasized that the present process relies on the extensive use of offline compilation/digitization and requires operators skilled in digital compilation procedures and capable of applying sound cartographic judgment. Communication between the operator and the stereoplotter system uses appropriate functional spoken words rather than keyed entry codes. Optimum use is made of a voice data entry and response terminal to assist the operator in interfacing with the data acquisition system's various operating modes during a compilation/digitizing session. The operator is led through the operating procedure of the chosen mode, speaking the necessary commands for an appropriate action when prompted by the voice terminal.

4. Hardware

The integrated system is built around the following hardware components:

- o Analog photogrammetric data acquisition system, consisting of a Kern PG2 or Wild B8 stereoplotter, Altek AC189 digitizer, Interstate voice data entry and response terminal, and online Hewlett-Packard xy plotter.
- o M&S Computing, Inc., interactive editing system--with DEC PDP-11/70 computer (128K).
- o Gerber 4477 automatic plotter.
- o Systems Engineering Laboratories, Inc., model 86 computer (384K).

4.1 Photogrammetric digitizers

Altek AC189 data acquisition systems are activated through encoders mounted on the axial shafts of the PG2 and B8 stereoplotters. The AC189 features operator control of point and stream recording, independent scaling and translation of each axis, and both thumbwheel and keyboard entry of identification information.

4.2 Voice data entry and response terminal

The voice data entry and response terminal consists of a Data General Nova 2 minicomputer, a LINC Tape binary loader, a Votrax voice synthesizer, an output speaker, and an input microphone. The heart of the voice data entry system is the application program which allows the user to control the input and output for each specific task. The program, written in Data General machine language, permits the user to specify the vocabulary and the type of action to be taken in response to each verbal input. The program written for this application also prompts the stereocompiler, through the voice response unit, to enter the attribute codes and perform the digitizing functions in a prescribed sequence.

In operation, the stereocompiler stores his speech patterns in computer memory by voicing each word in the program vocabulary three times. The system digitizes the patterns and stores the digital representation for future reference. After training the system, the voice patterns are stored on tape so they can be read in each day rather than retraining.

During a map data digitizing session, each spoken direction is converted to digital code by the computer and compared with the stored vocabulary code for a match. When the system finds a match, it is repeated by a voice synthesizer for verification before the system responds with the appropriate output actions specified in the application program.

5. Software

The software is designed as several modular tasks, depending on the processes involved and on input and output characteristics. Basically, it can be divided into:

- Software for data collection from the stereoplotter with appropriate descriptor code assignment.

- Software for batch processing and editing: transformation of digitized xy coordinates from model-to-ground coordinate system; filtering; determination of quadrangle boundaries and fitting the cartographic features within these neat lines; partial and full-line deletions; generation of plot tapes; and model, sheet, or feature joining.

- Software for interactive graphic file design, display, and editing purposes.

6. Operational Procedures

Relative and absolute orientation of the stereomodel are performed conventionally on the stereoplotter. The xy model coordinates of aerotriangulation-established control points are then measured so that the parameters of model-to-ground transformation can be established for the recorded data. Control points are digitized in point mode. Lines are digitized in stream mode by switching the pencil switch of the stereoplotter to the down position (this switch was wired to activate the stream mode) and then the desired features are traced with the reference floating mark. Raising the pencil deactivates the stream mode. Discrete points along a line, such as the beginning and ending of straight lines, can be entered point by point with the footswitch. This facility allows considerable acceleration in operation where many straight lines and smooth curves, such as transportation systems, are digitized. To collect error-free digital data, two basic tasks are involved: the digitizing process and the editing process. Extreme care is taken to ensure that digitization from the stereoplotter follows a strict sequence. This is accomplished by the implementation of a programed menu via the voice data entry and response terminal. If the operator makes a mistake in either the descriptors or coordinate data, the data are flagged for deletion, and the computer will not process these data.

Error detection is provided during data collection via an inexpensive online coordinate plotter. Editing is performed by a combination of batch and interactive modes. Although it is possible to make all the necessary corrections at the interactive editing stage, this is a laborious and time-consuming operation. Software routines have been developed whereby most of the corrections and related processing on the photogrammetric manuscript can be performed in a batch mode. Interactive editing methods are essential for adjusting improper cartographic clearances of symbolized features to produce the final color separates.

By using the various plot specifications of the offline Gerber plotter in conjunction with the attribute codes in the data, the photogrammetric manuscript and subsequent color separates can be automatically produced with various lineweights, symbols, and text sizes. To date, no attempt has been made to automatically produce the complete map--corrections and additions made by hand play an important part in the process. In order to finish a map, it is necessary for a draftsman to place stickup type for legend and names; to perform minor additions and corrections such as depression and fill ticks, and to adjust contours for proper cartographic clearances where needed.

7. Conclusions

The integration of digital techniques into analog photogrammetric operations has the following primary advantages:

- Provides the capability to convert new map data to digital form as directly and quickly as possible for supporting requirements for digital products.

- Provides for automatic drafting techniques, which speeds up the mapmaking process.

- Eliminates separate digitization of map manuscripts.

- Coordinate data obtained directly from the stereomodel are of a higher accuracy than those obtained from the graphics.

The last point is particularly important when the ultimate objective is to create a digital cartographic data base.

Much has been learned from this production experience. First, it is a difficult task to introduce automation and new technology into a process which has been done manually, so successfully, for many years. When developing a photogrammetric digitizing system, a fundamental requirement is that the new system must be similar to and retain the ease of operation current in photogrammetric practice so that the changeover will be as easy as possible. Second, interactive editing of offline stereomodel map data is a time-consuming operation unless rigid sequential digitizing procedures are developed to minimize errors. Furthermore, many edits and related processing are semi-automatable through batch processes. Third, there are considerable time savings and increased reliability when classification codes are entered by voice for the hands-and-eyes-busy operation of stereocompilation.

On the basis of this limited experience we have been encouraged to continue the development of stereomodel digitizing as one of the primary sources of data for the digital cartographic data base. We believe that even greater success will be realized when some level of interactive data edit capability is available at the stereoplotter work station.

LARGE FORMAT LASER SCANNER/PLOTTER SYSTEM

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I. Introduction and Historical Background

Two Large Format Laser Scanner/Plotter Systems were developed for the Defense Mapping Agency's Aerospace Center, St. Louis, Mo. and Topographic Center, Washington, D.C. under the sponsorship of the Rome Air Development Center, Griffiss Air Force Base, Rome, N.Y.

The original systems were designed and assembled by CBS Laboratories, Stamford, Ct. and EPSCO Laboratories, Wilton, Ct. in 1976. Image Graphics, Inc. completed the integration, installation and testing, and introduced significant hardware and software improvements to the systems.

The Laser Scanner/Plotter is a stand alone system capable of scanning and digitizing charts or documents in the form of opaque hard copy or photographic film and plotting positive or negative output on film up to 52" x 72" (132 cm x 183 cm) in less than 30 minutes, with a basic laser spot size of .001" (.025 mm). It is currently the only available device which can both scan and plot this size format in such a short time at high resolution. In addition, the system has gray scale capability; can generate mirror images, and can accommodate variable thickness scan or plot materials.

II. System Description

Figure 1 is a photograph of the system installed at the Aeorspace Center in St. Louis, Mo. The system is composed of two main subsystems. First is the opto-mechanical section which consists of the drum-carriage assembly, all optical and laser components, and an environmental chamber. Second is the electronics control section comprised of tape drives, a dedicated mini-computer, and all electronic hardware for controls, data processing and interfacing.

The Laser Scanner/Plotter is a raster type system and utilizes a rotating drum (53" long x 25" diameter) mechanism to provide scanning in the vertical direction. Film is held on the drum by means of a vacuum system, clamps, and pressure sensitive tape. The left end of the drum contains a high resolution magnetic tachometer which encodes the drum position. Horizontal scan is provided by a lens carriage moving on a lead screw along the length of the drum. Mounted on the carriage are the laser beam focusing and deflecting optics and intensity control circuits. A stepper motor and lead screw encoder accurately position the carriage. The complete optical system is shown in schematic form in Figure 2. The light source is a Lexel Argon Ion Laser, Model 75.2 supplied with a temperature compensated wavelength selector. It has a maximum usable power output of 25 mw at 476.5 nanometers. The narrow divergence beam outputted by the laser passes through a solenoid operated shutter and is folded by two front surface mirrors into a path in line with the optical carriage motion. Stability is maintained by a feedback circuit controlling the laser power output which holds the beam intensity constant

During each drum revolution, 6 lines or channels are scanned or recorded using an acousto-optical beam deflector. This method allows the drum speed to be 1/6 that required for a single channel system to finish scanning a full size film sheet in less than 30 minutes.

The A/O modulator, an Isomet Model 1206, is driven by an IGI driver module which contains six high frequency channel outputs. The frequencies cover a range of 100-130 MHz in 6 MHz steps. A three bit spot position code received from the control logic, is demultiplexed and used to switch the output from one of the six channels into an RF balanced modulator. Each frequency may also be amplitude modulated for gray scale control. The output of the RF balanced modulator is fed to a power amplifier which drives the A/O modulator.

Laser beam modulation is achieved by placing an optical stop in the path of the undiffracted beam, and then switching on and off the acoustical excitation.

The diffracted portion of the laser beam is folded by a final mirror and focused on the scanning surface with an objective lens. The beam diameter entering the objective is approximately .9 mm, thereby producing the diffraction limited spot associated with a f/36 lens.

Spot deflection is achieved by changing the acoustical excitation frequency in steps of approximately 6 MHz from a center frequency of 110 MHz. This relatively small change in frequency alters the diffraction angle, which results in a .025 mm change in spot location.

Although the plotting density range is from 0.025 to 2; or an exposure range of less than 100:1, the static extinction ratio of the A/O modulator/deflector will be at least 1000:1 with a dynamic capability at least several hundred. This insures that the minimum fog level requirements will not be exceeded during operation.

The Raster Scanner/Plotter System uses a combination of an f/1 lens, and two mirrors to collect the light reflected from the drum surface and direct it as a collimated bundle on the photocathode of a photomultiplier tube. The first two elements of the collection optics have holes bored through them to permit the scanning beam to pass through without distortion. A 2.0 neutral density filter is placed in the optical path directly in front of the photomultiplier tube to prevent excessive light from striking the tube face and damaging the photocathode.

A self contained environmental control unit is located at the right end of the drum carriage assembly. The unit intakes room air, and ducts conditioned air to the film chamber to control the internal plotter environment $70^{o} \pm 1^{o}F$ and $50\% \pm 1\%$ RH. A return duct is located at the lower section of the equipment.

Status signals are located on the main control panel to indicate out of limit conditions for either temperature or humidity. A recorder is also provided to monitor and record the two parameters.

A simplified block diagram of the Scanner/Plotter System is shown in Figure 3. Output of the system is either digital data on magnetic tape or imagery on film. Data which has been scanned is digitized and recorded on magnetic tape. Data which has been previously digitized is supplied on magnetic tape as an input to the system and recorded on film.

Two magnetic tape drives, (Kennedy Model 9300), are located in the upper portion of Bays 1 and 2 of the raster plotter control electronics rack. The dual density formatter and the interface logic hardware are located in the computer rack. Each tape drive has its own Western Peripheral TC-130 formatter and direct memory access interface to the CPU. The magnetic tape transports have the following characteristics:

1. Tape speed 125 inches/second, and
2. Recording density of 800 NRZI/1600 PE bytes per inch, selectable.

Two transports are required in order to keep up with the high data rate associated with the system thruput.

The minicomputer controller consists of a Digital Equipment Corporation PDP 11/40 minicomputer with 32K core memory, a 30 CPS Decwriter, a TU-60 dual cassette drive for program storage, and a VT-55 Display Terminal.

The necessary data transfer rate from and to the computer is accomplished by double buffering the input tape data, and by executing core/plotter transfers simultaneously with tape reading.

The Scanner/Plotter is interfaced to the minicomputer controller through six DR11-B Direct Memory Access (DMA) units.

Each DMA channel provides the following data transfer capability:

1. High speed direct memory access to and from the PDP 11/40 core memory via 16 parallel input, and 16 parallel output data lines.
2. Programmed single word data transfer over the 16 parallel input and 16 parallel output lines.

3. Three software controlled function data lines and three software read status lines, all used for control commands.

The operation of the Scanner/Plotter System is automatically controlled using the PDP 11/40 software and special purpose logic. Data parameters such as starting point, window area, etc., are entered into the computer by means of a Decwriter or VT55 unit. The system is automatically started and data recording or scanning is initiated. During operation error checks are continually made. If any are found, operation ceases and appropriate indications are given to the operator. Otherwise scanning or recording continues until the desired window area is completed.

A raster is scanned into the Scanner/Plotter data format in the following manner:
In one revolution of the drum, the electro-optical system scans or plots six continuous lines on the periphery of the drum. At the end of the revolution, the carriage drive increments the optical carriage a distance equal to the six lines. The electro-optical system then scans or plots another six lines on the drum periphery. This continues until the desired format area has been covered.

The six continuous lines are generated in the electro-optical system by the use of an acousto-optical (A-O) modulator/deflector. At a given X coordinate, (angular position of drum rotation), the beam deflector time sequentially positions the laser beam along the Y axis (parallel to the drum axis) at a separation of a position resolution element (0.025 mm). The deflector repeats the motion along the Y axis. The action of the deflector is not that of sweeping the beam along the Y axis (and therefore smearing the beam), but is a random access type of motion, locating the beam to specific positions.

Synthesis of 0.050 mm or 0.100 mm resolution elements is accomplished by means of hard-wired high speed logic. The process involves the averaging of adjacent spot density levels.

III. System Output and Capabilities

Figure 4 is a typical example of the type of images which have been digitized and recorded on the Scanner/Plotter System. It illustrates a medium to high density image scanned and plotted in the 1 element (0.025 mm) resolution mode. High quality results can be obtained when scanning and recording in either 1, 2 or 4 element resolution modes.

Figures 5 and 6 contain the basic operating characteristics of the scan and plot modes respectively. It should also be noted that the system can scan or plot up to 16 gray shades, generate mirror images, and operate with either run-length or binary code formats.

In addition, other features presently being installed include a real-time display for both scan and plot, and the capacity to operate with a single tape drive.

IV. Applications

The Scanner/Plotter can be used for a number of automated cartography applications:

A. Preparation of raster digital data base by digitizing large format maps;
B. Input-output device for other systems;
C. Proof plotter;
D. Lineal to raster conversion by recording linear data on electron beam recorder, digitizing with a high performance raster scanner and plotting on Scanner/Plotter;
E. Image processing and enhancement of gray scale images by scanning and recording (during the same run) selective gray scale combinations; and
F. Generation of color separation plates by use of high power laser.

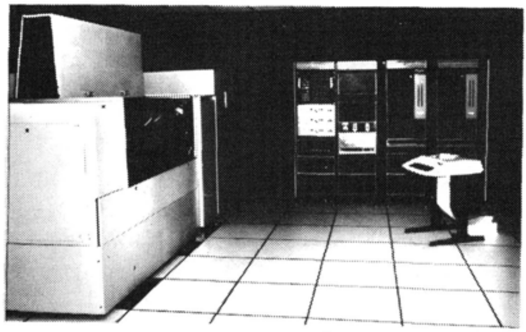

Figure 1 Laser Scanner/Plotter System

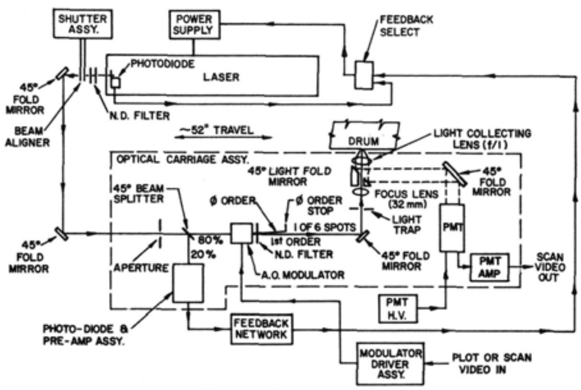

Figure 2 Optical Schematic

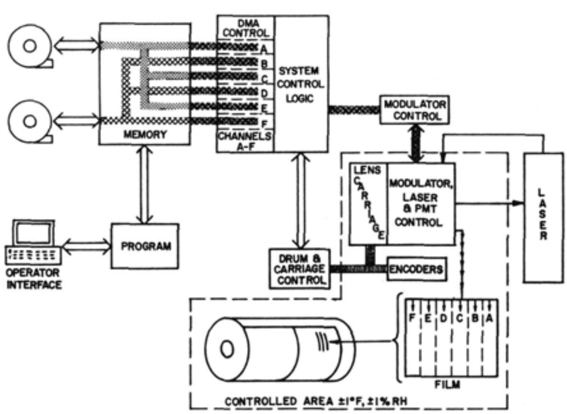

Figure 3 Block Diagram

Figure 4 Digitized/Recorded Image

SCANNER CHARACTERISTICS

CARTOGRAPHIC INPUT PRODUCTS	POSITIVE OR NEGATIVE OPAQUE, SEMI OPAQUE, TRANSPARANCIES
MAXIMUM SIZE OF INPUT	132 cm X 183 cm (52" x 72")
MAXIMUM SCAN FORMAT	127 cm x 178 cm (50" x 70")
THICKNESS OF SCAN MATERIAL	004" to 010" IN STEPS OF 0005"
SCAN TIMES	
127 cm x 178 cm (50" x 70")	30 MINUTES OR LESS
61 cm x 76 cm (24" x 30")	15 MINUTES OR LESS
RESOLUTIONS	40, 20, & 10 lp/mm
MINIMUM SPOT SIZE	025 mm (001")
POSITIONAL ACCURACY	± 050 mm (± 002")
POSITIONAL REPEATABILITY	± 025 mm (± 001")
OUTPUT	9 TRACK MAGNETIC TAPE, 800/1600 bpi IN RASTER FORMAT

Figure 5

PLOTTER CHARACTERISTICS

INPUT	9 TRACK MAGNETIC TAPES, 800/1600 bpi, 125 ips, RASTER FORMAT RUN LENGTH OR BINARY
OUTPUT	EXPOSED FILM, BLACK & WHITE, NEGATIVE OR POSITIVE
FILM TYPE	KODAK MP 2562 x MP 4562
MAXIMUM FILM SIZE	132 cm x 183 cm (52" x 72")
MAXIMUM PLOT FORMAT	127 cm x 178 cm (50" x 70")
THICKNESS OF FILM	004" to 010" IN STEPS OF 0005"
RECORD TIME	
127 cm x 178 cm (50"x70")	30 MINUTES OR LESS
61 cm x 76 cm (24" x 30")	15 MINUTES OR LESS
VARIABLE LINE WIDTHS	10 mm TO 80 mm (004" to 032") in 025 mm (001") INCREMENTS
MINIMUM SPOT SIZE	025 mm (001")
POSITIONAL ACCURACY	± 050 mm (± 002")
POSITIONAL REPEATABILITY	± 025 mm (± 001")

Figure 6

IMAGE PROCESSING SESSION

IMAGE PROCESSING

The Image Processing session was chaired by John Dalton of Goddard Space Flight Center.

Richard McKinney of the Computer Sciences Corporation presented the paper "Cartographic Considerations for the Integration of LANDSAT Digital Imagery with Existing Spatial Data". LANDSAT MSS digital imagery requires some geometric correction of data and this paper describes the cartographic problems involved in this for ten Landsat images using the Digital Rectification System.

George Kerr presented a summary of two papers that deal with the European Space Agency's METEOSAT project. "The Interactive Image System for the METEOSAT Project", by L. Fusco, G.W. Kerr, R. Powell, and J. Rupp, describes the interactive quality control of meteorological products obtained from the large-scale batch computer analysis of earth images, obtained from the METEOSAT geostationary satellite. "Image Processing and Navigation for the METEOSAT Project", by M. Jones and K.G. Lenhart deals with the preprocessing and navigation of the images produced by METEOSAT.

Frederick C. Budelman and Toini L. Figgins of the Pattern Analysis and Recognition Corporation presented the paper "Practical Application for Digital Cartographic Data Bases in Tactical Surveillance and Strike Systems". This paper describes the problems in integrating remote tactical surveillance and strike systems with digital cartographic data. The state of the art must be advanced quickly in order to meet the near-future tactical requirements for digital cartographic data bases.

Roger L.T. Cederberg of the National Defense Research Institute, Sweden, presented a paper entitled "A Data Structure for a Raster Map Data Base". In this coding scheme for raster data, the geographic entities can be accessed in line-by-line mode and as boundaries and lines (chain-coded). This Raster scan Chain code (RC-code) can be generated while scanning the map in raster code and can be extended to display a map line-by-line and column-by-column.

CARTOGRAPHIC CONSIDERATIONS FOR THE INTEGRATION OF LANDSAT DIGITAL IMAGERY WITH EXISTING SPATIAL DATA

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I. Introduction

Anyone interested in the merger of spatial data from different sources must register the various inputs to a common projection. While the registration accuracy requirements may vary from application to application, the problems associated with data integration remain -- whether the data are merged via physical overlays or combined digitally as in a digital information system.

The rectification of Landsat Multispectral Scanner (MSS) digital data to a map projection or the scene-to-scene registration of MSS digital data requires corrections not only for the new map projection, but also for a variety of distortions. MSS digital image distortions exist due to the combined effects of sensor operation, orbit and attitude anomalies, the Earth's rotation, and atmospheric and terrain effects (1).

This report describes the procedure used to overcome the cartographic problems association with the rectification and registration of Landsat digital data to USGS 1:24000 topographic maps.

II. Background

The work reported in this paper is part of an on-going joint project between Goddard Space Flight Center (GSFC) and the Bureau of the Census (2). The program goal is to develop methods for the application of major urbanized areas in the United States (3). Current research is directed toward statistical procedures for the identification of land cover change within the urban fringe. The present investigation will use data from ten different Landsat images corrected to the universal transverse mercator (UTM) map projection and registered to each other at an accuracy better than one pixel (4).

III. Study Site

The Denver study site is an area of approximately 2975 square kilometers centered on Denver, Colorado. The area is situated in the Great Plains physiographic region to the east of the Rocky Mountains at an elevation of about 1.6 kilometers. Denver is fairly dry with an average precipitation of only 36 centimeters annually. Around the city are dry land agriculture to the east, range land to the northwest and south, wet land agriculture to the northeast and southeast. The Rocky Mountains are to the west. The city has extensive older residential areas to the west and south. This combination of land usage makes Denver a study area of considerable diversity.

IV. Registration Procedure

The Digital Image Rectification System (DIRS) (5) was selected for rectification (to UTM coordinates) and registration of the MSS imagery for the Denver Study. DIRS is a collection of programs written for an IBM 360/91 computer running with an OS/MVT operating system. DIRS runs are submitted as batch jobs and do not require special image processing hardware. The programs use up to 500K bytes of memory (larger amounts are needed to do image rotation), at least five tape drives and a moderate amount of direct access (disc) storage. Run times vary from less than one minute to eight minutes or more depending on the amount of image data being processed, the number and type of shade prints and edge correlations required, and the type of resampling used.

A. Reformatting

DIRS processing begins with reformatting standard Landsat MSS Computer Compatible Tapes (CCTs). CCT data for the four image strips are reformatted to full scene scan lines in band interleaved by pixel format. Synthetic (duplicate) pixels inserted in ground processing are deleted as are the calibration data at the end of each CCT line segment. The scene identification and annotation records are copied onto the DIRS "Composite" tape to retain scene identification.

B. GCRs

The development of ground control points (GCPs) is the most time consuming phase of the procedure. In Denver, the study area covered twenty 1:24000 topographic maps. Approximately fifty locations were considered for GCPs. However, a number of points were unusable because they were not distinct either in the Landsat image or on the ground. The twenty-seven final points chosen gave a good distribution throughout the study area. A considerable amount of time was saved during this phase through the use of an interactive color graphics display and analysis system available at GSFC. The Interactive Digital Image Manipulation System (IDIMS) made it possible to approximate rapidly the position of candidate GCPs in the image. Using these approximate coordinates, subscenes were then enlarged by a 7x7 expansion using cubic convolution resampling. This magnification procedure reduces the location error and permits sub-pixel location of image control points.

The DIRS system allows for up to 10x10 cubic convolution expansion of image data before display as line printer shade prints. Line printer products, of course, do not display the information of a three color graphics terminal nor do they allow the automatic extraction of coordinates. The DIRS approach, however, avoids the requirement for an expensive graphics display device.

C. Global Mapping Function

In order to create a mapping function DIRS requires both image coordinates and easting, northing coordinates for GCPs. Fortunately our facility includes a geographic entry system which computes geographic coordinates from topographic maps. While this procedure, too, can be done manually, it would be at a cost of considerable time and an almost certain loss in accuracy.

The GCP data developed previously are used to define functions which make transformations between map and image spaces. Three types of global mapping functions are available in DIRS: affine transformation, two-dimensional least squares polynominals, and attitude model functions. The choice of the most appropriate method depends upon the number of GCPs and their distribution over the image area.

For this project the two dimensional least squares polynominal functions were used. In this method four functions are computed using a least squares fit to the GCP data. These functions are:

$$S = f_1(E, N)$$
$$L = f_2(E, N)$$
$$E = f_3(S, L)$$
$$N = f_4(S, L)$$

where S is the sample coordinate, L, the line coordinate, N, the northing coordinates, and E, the easting coordinate. These functions are polynominals in two variables and may be defined as first-, second-, third-, fourth-, or fifth-degree polynominals. The number of GCPs available determines the maximum degree of the polynominals. The polynominals have the following general form:

$$Z = C_0 + C_1X + C_2Y + C_3X^2 + C_4XY + C_5Y^2 + C_6X^3 + C_7X^2Y + C_8XY^2 + C_9Y^3 + \ldots$$

These functions are continuous and global and therefore offer advantages over the affine transformation if an entire scene or a large portion of a scene is to be rectified. However, they have inherent limitations due to the need for a large number of GCPs and the requirement that the edges and corners of an image be well covered by GCPs. Since the study area for this project is much smaller than a full Landsat scene (10%), the edge problem was avoided by use of GCPs beyond the edges of the study area. Reference (5) discusses the affine and attitude model functions.

D. Rectification

The global mapping function could be used directly to transform the image data into the desired map projection. This is not practical, however, due to the enormous amount of computation required to evaluate these functions over millions of points. The solution to this problem is the creation of an interpolation grid. The global mapping functions are evaluated at each mesh point in a grid covering the image area, and then an efficient bilinear interpolation technique is used to map points within each grid cell.

The interpolation grid is composed of approximately 20 horizontal and 20 vertical grid lines. When each mesh point is known in both UTM and image coordinates, one is ready to map the image data in an efficient manner. The mapping is actually an inverse mapping; i.e., it proceeds from the map space (output coordinate system) back into the image space (input coordinate system). This arrangement has the advantage of allowing interpolation to occur in the input (image) space instead of the output (map) space. This proves to be a much more convenient approach than forward mapping.

Prior to the generation of the mapping function used in the resampling run, a test of the GCPs was made to identify points which may be inaccurately located. Test results must be reviewed carefully because a residual in the location of a point may not mean that the point is inaccurately placed. It may indicate that the point is important in the solution of the mapping function. This occurs particularly for isolated GCPs. The test run, besides evaluating the individual GCPs, provides a measure of the suitability of the order of the polynominal mapping function. Based upon test results for second and third order polynominals the third order equation was used in the actual rectification. The size of the subscene, the number of control points and the order of the mapping equation all contribute to scene registration accuracy. This test indicates the accuracy of the combination of these parameters.

E. Resampling

With the mapping function established, resampling can proceed. Resampling refers to the determination of an image intensity value at a given location. Typically, this location falls between and not on exact pixel centers and some form of interpolation is required. Two interpolation techniques are available in DIRS. The simplest and most efficient method is nearest neighbor. In this method the pixel whose center is nearest to the resample location is used to supply the intensity value at the resample location. This method introduces up to one half sample and line of geometric error. The second resampling technique provided in DIRS is cubic convolution. This method was developed by TRW and is an efficient approximation to the theoretically optimum interpolation using sin(x)/x. (6) While cubic convolution is much more efficient than sin(x)/x, it is a great deal slower than the nearest neighbor method.

Before resampling all four bands using cubic convolution, a test run was made for MSS 5 using nearest neighbor resampling. This product displayed via a film recorder confirmed that the desired subimage area was extracted. A second resampling run using cubic convolution was made to extract a rectified and rotated image of all four MSS bands with scan lines oriented in an east/west direction.

F. Registration

A primary advantage of DIRS is a convenient edge correlation method for the registration of subsequent scenes. The labor of GCP location for image rectification to a map projection is only required for the first scene in the sequence. Subsequent scenes are then registered to the first. This means that points common to the two images must be identified but it does not require that they be located on maps. Therefore, one may use the original GCPs as possible correlation candidates and one is free to try any other features common to the images. This procedure demands little effort from the user and, thus, makes the processing of a large number of potential correlation points possible.

The correlation technique used for scene-to-scene registration was developed for NASA by the Computer Sciences Corporation for the large area crop inventory experiment (LACIE) and is a very reliable technique (7). It is based on the generally valid assumption that image edges are invariant with time.

The edge extraction process begins with the computation of a reflectance gradient value at each pixel location. This is done over the target subimage area and the search area in the second scene. A gradient histogram is then constructed for each of the subareas. The user specifies a threshold to determine the percentage of edge pixels, generally about 20 percent. The resulting edge images are then cross-correlated and the point of maximum correlation is identified. The GCP coordinates in the target subimage are then mapped into the search area and this point represents the image coordinates of the GCP in the second scene. Accuracies of plus and minus one sample and line are achieved with edge correlation. The reliability of the method is in excess of 80 percent.

The correlation points found in a pair of scenes provide a basis for creation of a mapping function just as GCPs did in rectifying the first scene. By transforming the correlation points in the subsequent scenes through the global mapping function of the first scene a relationship between image coordinates and map coordinates is established and the geometric transformation proceeds just as before.

This process produces a set of registered, rectified subscenes which can be digitally overlayed and used for change detection analysis.

V. Results

To evaluate the rectification of the scenes, shade prints scaled to 1:24000 were generated for an area of downtown Denver containing a number of prominent roads and lakes. These prints were overlaid upon the USGS topographic map for the same area. Features aligned very well over the entire area. Since the purpose of the rectification was to investigate change detection techniques and not to evaluate DIRS, a quantitative measure of rectification was not attempted.

However, scene-to-scene registration was evaluated quantitatively using a gray level correlation scheme available on the VICAR System (8) at GSFC. To test the registration sixteen points evenly distributed across the image were chosen. Except where clouds were present (or, as in one image, data was missing) each point in all of the registered scenes was correlated to the master scene which had been rectified to the map projection. Typical registration errors were less than 0.20 pixels. Several scenes had points with errors greater than 0.75 pixels. In all cases with errors over 0.70 pixels the areas contained land cover which was highly variable due to seasonal or climatic conditions. Streams or lakes were present and/or field borders were not well defined. These factors tend to affect the gray level correlation more than they would the binary edge technique used to achieve the scene-to-scene registrations. In all areas where reliable correlation features existed, the images correlated to within less than 0.70 pixels.

VI. Conclusions

Anyone working with Landsat MSS digital data generated prior to the routine geometric corrections planned for Landsats C and D must contend with various distortions in the data. If a close rectification is required, some correction will be necessary.

The Digital Image Rectification System offers a number of advantages to the user. The software is readily available at a nominal fee through COSMIC (the NASA software distribution facility at the University of Georgia). The software does not require specialized hardware such as a graphics terminal. Rectification of a scene to a map is time consuming, but subsequent scene-to-scene registrations proceed rapidly. Finally, DIRS is capable of producing images registered to subpixel accuracy as demonstrated by the Denver, Colorado, work.

Acknowledgements

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THE INTERACTIVE IMAGE SYSTEM FOR THE METEOSAT PROJECT

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1. Introduction

The Meteorological Information Extraction Centre (MIEC) of the ESA-METEOSAT Ground System at Darmstadt, West Germany, performs the extraction and dissemination of meteorological products generated from METEOSAT images.

The products (cloud displacements, sea surface temperatures, cloud top heights, radiation balance, cloud analysis, water vapour content) are generated in near real-time by automatically scheduled batch programs on a large mainframe computer. The products so calculated are then transmitted by inter-computer link to the MIEC Interactive Display System, where they are quality controlled by meteorologists before re-transmission to the mainframe for subsequent dissemination to the users.

2. Hardware Overview

The MIEC Interactive System is based upon two interconnectable mini-computers (NOVA 830), attached to three specialised meteorological display consoles and 30x64 Kbyte refreshing storages.

Each console consists of the following hardware units:
- A graphic display of 1024x1024 elements with absolute and incremental vectors, alphanumerics and 4 basic colours. This display is used for graphics and histo-

grams, and alphanumeric display of the results of MIEC processing. The display is equipped with a light pen for selection of options or picking of specific areas on the screen.

- An alphanumeric display used as a logsheet for indicating the current status of a process (image selected, coordinates of the displayed area, function in process...), and a scratch pad for all intermediate results the operator may want to keep.
- An alphanumeric keyboard for entering commands or text.
- Two function keyboards for initiating given functions
- An image display of 512 lines of 512 pixels. This display is used for image data display (with or without grids) and for software generated pseudo-images.

Each image display screen consists of a 512x512 dot matrix. Each dot is composed of 3 colours: red, blue and green. Intensity and colour are controlled independently by the values in corresponding 8-bit bytes of any two refresh memories (or by the same 8-bit byte from a single memory).

The processors for the colour and intensity channels are controlled by independent sets of operator controllable registers which allow masking, shifting, OR-ing, thresholding and scaling of the byte values from each memory.

The colour tables are 256-byte, software-modifiable, look-up tables, indexed by the digital output from the colour-channel processor.

3. Software Overview

The interactive SW is run on a NOVA 830 under the Data General multi-tasking, dual programming operating system RDOS REV.3. This operating system permits two programs to run in parallel - the foreground program, and the background program. A program may consist of a number of tasks, either resident or overlayed.

Overall system control is handled by a set of permanently resident tasks (the 'root' tasks), while each console is individually controlled by tasks loaded into fixed overlays, one overlay per console. A special task in the root (the console root task, or CRT) monitors the alphanumeric keyboard of each console.

The operator may type in commands which result in an overlay being loaded in the overlay area assigned to his console, and one task inside this overlay being executed. The procedure command language described in section 4.1 (the MIEC command language, MCL) controls this process.

The program performing this multi-task, overlayed console control is the so-called background program. In addition to the normal SW facilities available via the background program, any console operator may obtain additional SW facilities by initiating the foreground program via a task in his overlay in the background.

The foreground program is controlled by a function keyboard. The operator can continue to run tasks in his background overlay asynchronous with operation of the foreground program.

4. Design Features

The design features of most interest can be classified under 2 main headings:

- the command language,
- the picture concept.

4.1 The Command Language

Interactive processing is controlled by invoking sequences of independent, user-overlay tasks, initiated by means of language commands. The commands may be input either directly and individually via an alphanumeric console by the interactive operator, or (as for normal operational running) from indirect command files containing pre-edited chains of commands (called procedures), or both.

Processing paths through the commands in a procedure are controlled at execution time by:

(a) operator decision, via both function keyboard and/or alphanumeric input

(b) results of previous processing actions.

The command language allows many of the elements of a high-level programming language, including:

- forward and backward jumps
- variable count loops (with loop nesting)
- arithmetical and logical testing (and conditional jumps)

- procedural nesting (called sub-procedures)
- parameter passing via software registers
- indirect parameter files
- register arithmetic.

Each overlay task performs operations according to parameters and data sets supplied at run time, either directly from the operator, or from indirect files, or from SW registers (or any combination).

Tasks which require run time parameters call a resident subroutine in the root, supplying to this subroutine a list of parameter names and types, upper and lower limits of each parameter (integer parameters only), and default values, if applicable. This routine, which is part of the command language interpreter, reads parameter values from the current input device (alphanumeric keyboard, or indirect file), updating any input parameters corresponding in name to a parameter in the supplied list, until a double slash (//) is detected, after which control is returned to the user task. (The order of parameter input is unimportant. Parameters in the task list, which are not input at execution time, retain their default values.)

4.1.1 <u>Outline Structure of the Language</u>

The logical unit of input to the command language interpreter is an atom having one of the forms:

1. Command word
2. /± logical variable
3. /parameter = value
4. /parameter = \software register n

Character strings in the command line buffer are semantically interpreted according to one of these forms until a 'carriage return' is detected, after which the system determines the physical source of input for the next physical line (indirect file, or alphanumeric keyboard), and refills the command line buffer.

1. Command words may be of the form:
   - task name
   - [indirect file name
   - /*

   Logical input to a given task is terminated when the command language interpreter detects either // or a task name, as the next character string in the command line buffer. (The logic of a task may, of course, contain any number of requests for parameter

input, each request being terminated when // is encountered.)
The command word - [indirect file name - requests the system to obtain the next and subsequent lines from the corresponding ASCII file until either EOF, or /* is encountered. If EOF is encountered the next physical line is obtained from the previous source of lines (which could itself be either an indirect file, or the alphanumeric keyboard).
The command word - /* - requests the system to obtain the next logical line (to //) from the alphanumeric keyboard (valid only inside indirect files), after which return is made to the indirect command file.

2. The atom - /± logical variable - attributes the value true or false to the variable, according to the sign + or - respectively.
3. The atom - /parameter = value - sets the parameter equal to 'value', where 'value' may be numeric or string.
4. The atom - /parameter =\software register n - sets the parameter equal to 'content of SW register n'. (Software registers may be set and/or tested both inside tasks and in procedures. The registers are stored in the root area and are therefore global to all tasks. Values may be either integer or character, depending on prior definition of the register type.)

4.2 The Picture Concept

To construct a screen picture, the operator can define which memory should control picture intensity and which memory should control colour. Additionally, the operator can modify hardware parameters of the TV screen, and of both memories independently (e.g. masks, thresholds, scale factors, zoom, offset, etc.). Thus from one pair of memories, he can construct a wide variety of images on the TV screen.

The software has been designed in such a way as to remove from the operator the need to remember all the various parameter settings and refresh memory contents.

The basic concepts underlying the software design are as follows:

- any set of 256x256 - or 512x512-byte image data can be associated with an arbitrary mnemonic name, called a 'data-set' name

- any screen image can be associated with an arbitrary mnemonic name called a 'picture' name.

Pictures are in general composed either of one or two data-sets, each of which is loaded into a separate memory. All the hardware parameters associated with each picture are held on a file called the 'picture handler' file. Thus, once the operator has loaded his data-sets into memory, constructed his pictures, and saved the screen and memory parameters on the picture handler file, he can at any later time recall particular screen images simply by specifying the corresponding picture name to the task responsible for setting up the hardware registers of the display.

The physical memories used to hold the data-sets are allocated transparently to the operator, so that he need never concern himself with actual memory numbers.

The operator (or procedure writer) has a number of facilities available to simplify the task of handling images. These facilities fall into 5 main classes, as follows:

- tasks which create picture handler file (PHF) entries, allocate refresh memory and NOVA disk file space for the corresponding data-sets if required, and which generate new PHF entries from existing PHF entries
- tasks which obtain image data-sets from the mainframe and store them in pre-allocated NOVA disk image file space
- tasks which copy data-sets from NOVA disk file to refresh memory
- tasks which send data-sets from the pre-allocated image file space to the mainframe
- tasks which set up pictures on TV, according to picture definitions in the PHF.

5. Procedures

A procedure is in essence an ASCII file containing overlay task calls and parameter lists, interspersed with procedure-control commands.

Procedures can contain any number of task calls. Operational procedures typically contain 500-1000 command lines, each of which will normally initiate a 4K overlay task.

One of the major assets of the language is the ease with which large error free procedures can be developed.

The language elements invoke independent tasks which perform specific jobs of work and then terminate, and which are essentially independent of preceding task calls. Extensive trace facilities allow processing paths through the procedures to be instantly followed. Incorrect procedure logic can be corrected in minutes by on-line editing.

Each task is developed and tested as an independent entity, so that once it performs correctly, it can be used in a procedure without any possibility of interference with other tasks.

Typically, to write, edit and test a procedure of the order of 100 command lines, takes of the order of 1 to 2 days.

More than 60 independent task calls are currently at the disposal of the procedure writer, so that he can effectively develop and test programs of up to 200 Kbytes in a couple of days.

6. Application Tasks

In addition to the procedure control and picture handling tasks already mentioned, the following classes of tasks are also available:
(1) Hardware manipulation
(2) Colour table generation
(3) Animation control
(4) Array manipulation
(5) General facilities.

6.1 Hardware Manipulation

These tasks allow operator control of every hardware feature, via either keyboard, alphanumeric, potentiometer, or tracker ball input.

6.2 Colour Table Generation

These tasks supply easy to use facilities for constructing colour tables on-line according to the data types (e.g. image data or bit-planes), and dynamic ranges involved.

6.3 Animation Control

Animation consists in displaying picture sequences on a TV screen in rapid succession. Animation loops are used mainly to study short-term phenomena and for interactive quality control of the various meteorological products- for example, wind vectors, sea surface temperatures, etc.
The system has been designed to allow easy setting up and control of animation loops.

The following features are available during an animation loop:
- zoom any or all of the pictures (keyboard control)
- offset any or all of the pictures (tracker ball control)
- change speed of the animation (potentiometer control)
- change thresholds and scale factors of intensity and/or colour channels (potentiometer control)
- change direction of the loop (keyboard control)
- step backwards or forwards through the loop (keyboard control)
- change display time of each individual picture in the animation (keyboard control).

Note that offsetting can be performed on a zoomed sequence, so that the effect is similar to that of sweeping over an area with a camera fitted with a telescope lens.

6.4 Image Manipulation

A number of facilities exist for performing array manipulation on the refresh memories, including convolution on any defined area of one single data set picture, between the image data and a defined window.

6.5 General Software

These tasks may be grouped as follows:
- file handling tasks, to print, delete, change attributes, edit, list, rename, etc. standard NOVA files
- data handling tasks, to convert data from the M/F standard format to NOVA data format, and to proprocess card image files
- procedure preprocessor task, to preprocess procedures written in macro form.

IMAGE PROCESSING AND NAVIGATION FOR THE METEOSAT PROJECT

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1. Introduction

An operational system for the precision preprocessing and navigation of METEOSAT images is described. The main features of the system are that it performs the following essential functions:

- image data acquisition
- preprocessing, including such functions as inter-channel registration, line phase correction and fine gain adjustment
- navigation, involving the production of accurate image deformation models; these deformation models in effect permit transformation between image coordinates (pixel, line) and geographical coordinates (latitude and longitude), with a target accuracy of 1 IR pixel r.m.s. or better.

The image processing and navigation system forms part of a large centralised data processing system dedicated to support of the METEOSAT satellite.
Thus the user can be provided with high quality preprocessed image data and its associated navigation data; the burden of preprocessing and navigation is removed from individual users, who would otherwise need substantial facilities both in terms of hardware and software.

This paper will deal mainly with that part of the METEOSAT ground processing system dedicated to image processing/preprocessing. For a general introduction to the whole system, including discussions of the satellite, radiometer, the ground system and the various missions, the reader is referred to ref. 1.

2. Spacecraft and Radiometer

METEOSAT is a geostationary, spin-stabilised spacecraft. It rotates at 100 r.p.m. and scans spin-synchronously. A normal image scan takes 25 minutes and has 2500 lines. One of the main tasks is round-the-clock provision of weather images.

The radiometer images in three spectral bands namely infra-red (IR) 10.5-12.5 μm; visible (VIS) 0.4-1.1 μm and the water-vapour absorption band (WV) 5.7-7.1 μm. There are two visible sensors whose size, position and sampling is such that the visible resolution is twice that of the IR and WV. The pixel sizes at the subsatellite point are 5 km (IR) and 2.5 km (VIS).

3. Ground Processing Hardware

The image acquisition and preprocessing discussed in §4 is performed on a dedicated minicomputer (SIEMENS 330) with an array processor attached to handle the CPU intensive operations. This combination of hardware is known as the Front-End Processor (FEP); the processing performed on the FEP is subject to severe real-time constraints since it has to handle each line (10 Kbytes of raw image data) in 600 ms. The FEP passes each line to a large general-purpose mainframe (ICL 2980). The mainframe writes each preprocessed line to disc files thus building up complete images.

As concerns image processing, the mainframe is also used to:

(i) provide support functions for the preprocessing (e.g. preparation of fine gain adjustment factors, deconvolution kernels)
(ii) support all geometric processing (navigation)
(iii) support eventual archiving of all image and image-related data.

In order to assist image navigation, landmark consoles are attached to the mainframe via a NOVA 830 computer. Image data is transferred from the filestore of the ICL 2980 to the disc storage of the NOVA 830 or the refresh store of the display.

4. Image Acquisition and Amplitude Processing

4.1 Functional Steps

The images are acquired line-by-line, each line being sent from the ground station to the processing centre at ESOC Darmstadt over a high-speed link.
Image acquisition consists of decommutation of the raw image data to give separate lines of data for each spectral channel. This also involves expansion of the 6 bit visible and WV pixels to 8 bits (the IR image has 8 bit pixels).

Amplitude preprocessing involves the following functional steps:

(i) registration of the various channels so that the same navigation formulae can be applied to all channels

(ii) horizontal (one-dimensional) deconvolution of all channels to compensate for the transfer function of the sampling electronics

(iii) vertical (two-dimensional) deconvolution of the IR-channel to take account of the optical effects resulting from the detector size

(iv) phase correction of the line start on all channels so that the earth's disc appears in the centre of each image. This function involves as a first step computation of the times of the first sample of each line, based upon various counter values given in auxiliary data in the image stream and in the spacecraft housekeeping data. This timing data is used in subsequent deformation modelling (see §5) as well as in real-time phase correction.

(v) fine gain adjustment of the image by a linear stretching in order to compensate for changes in radiometer response.

All the above functions are performed in real-time on the front-end processor.

4.2 Support Functions for Amplitude Processing

In order to carry out the amplitude processing described in the preceding subsection, certain support functions are necessary. To make the system as flexible as possible the various parameters (e.g. registration parameters, deconvolution kernels, gain factors for on-ground gain adjustment) are sent to the preprocessor as a single parameter block before each image commences.

Whereas the registration parameters and deconvolution kernels normally remain fixed, the following data needs updating regularly:

(i) the various geometric data used in the phase correction process (principally, Earth-satellite -sun angles)

(ii) the on-ground gains used for fine adjustment of radiometer response.

For the IR channel, the on-ground gains are adjusted frequently (generally once or twice daily) based upon black-body calibrations. These calibrations involve viewing an internal 'black-body' of known temperature through part of the radiometer optics; the measured gray-level value together with the radiance of the black -body as computed from the known temperature of the black-body give a direct measure of the radiometer response. The on-ground gains can thus be computed as an inverse function of the measured radiometer response. The on-board gains can also be adjusted, but only in rather large steps. This serves to provide a coarse adjustment of the channel dynamic ranges; fine adjustment being made by ground software.

5. Geometric Processing and Navigation

5.1 General

The purpose of the geometric processing is to locate the image pixels in terms of earth coordinates. This is necessary because

- the satellite's orbit is not fixed in position with respect to the earth, although it is in a geostationary orbit;
- the attitude of the satellite does not point exactly along the normal to the orbital plane and it drifts with time;
- the process of scanning results in changes in the moments of inertia of the whole system which results in motion of the spin axis during the scan;
- there are various fixed misalignments between the radiometer axis and the satellite spin axis;
- the line start is not ideal, due to e.g. quantisation effects in the line-start electronics, finite width of the reference pulse (normally detection of the sun's

disc);
- the satellite spin-speed will normally differ from nominal; it will also vary slightly with scan step.

For these reasons, the actual imagesdiffer from the reference image, the reference image being defined as that obtained when the satellite is (a) at its reference station, (b) has attitude parallel to the Earth's polar axis, (c) rotates at a speed of 100 r.p.m. exactly and when (d) the horizontal and vertical pixel sampling rates are uniform and independent of scan step or pixel number.
The deviation of the real image from the reference image is known as the deformation; this quantity is calculated for each image from a physical model which takes into account the known orbit of the satellite, the attitude and other spacecraft dynamical characteristics.

5.2 The Dynamical Model

The dynamical model gives the direction of the radiometer optical axis in an earth-centred reference frame as a function of time.

The model is parametrised in terms of the attitude and of angles describing the other physical effects mentioned above. In effect, the model gives the direction of the optical axis as a function of time and the various adjustable angular parameters.

The dynamical model is used to compute the relationship between the scan step and geographical position for a set of sampled points in the image. Two cases can be distinguished:
- restitution, in which measured pixel scan times are substituted into the model;
- prediction, in which pixel scan times are predicted, normally for one or two slots ahead.

A sampled field of distortions can thus be computed. This field of distortion vectors can be fitted to polynomials in the image coordinates. Fifth order polynomials have been chosen since they are capable of representing the distortion over the whole image with sufficient accuracy.

5.3 Updating the Dynamical Model

The model is updated by input of measurements made upon

the image namely:
- horizon (earth-edge) detection
- landmark extraction.

The horizon detection task runs automatically and provides the addresses of the earth-edge intersections in each image line.

The landmark extraction task is interactive: the operator can display an image, or sections of an image, on a screen and can align these real data with a reference landmark template (in the form of a line graph) which is superimposed on the real data. A set of such measurements distributed over the entire disc can be made. These measurements together with the earth-edge measurements can be substituted into a set of observation equations, solution of which gives refined parameters for the deformation. This model is used to predict deformation polynomials and matrices (sampled deformations on a uniform raster), applicable to images up to two slots (one hour) ahead of the image being currently acquired. The polynomials and matrices allow the user to transform locations in the real image into geographical coordinates (direct transformation) or to find out which pixels on the real image correspond to fixed geographical locations (inverse transformations).

In practice, two principal strategies are used in updating the deformation models, namely:
(1) determination of the attitude parameters of the model by analysis of horizon data spread over a whole day;
(2) rather more frequent updating of other parameters of the model using horizon and landmark data together with precise timing data.

Separation into two strategies in this way has the advantage that the system may run using strategy (1) only; this provides an acceptable model in a completely automatic way. For refined accuracy (1 IR pixel or better) the strategy (2), involving operator interaction, must also be employed.

5.4 Maintenance of Raw Image Geometric Quality

As mentioned earlier, the deformation modelling process provides a fine determination of the attitude. This fine attitude is then used in the computation of the lowest radiometer scan step and the parameters controlling the line start. These parameters are sent to the satellite as telecommands before each image. The scan thresholds compensate for the diurnal variation in the elevation of the spin-axis above the orbital plane. Thus even in the raw image there is near-optimal centering of the earth's disc within the image frame (the centering accuracy is generally better than ± 5 IR pixels absolute and relative centering accuracy between neighbouring raw images is normally better than ± 1 IR pixel).

6. Image Products

Image products are available in three basic forms, namely:
- image data disseminated via METEOSAT
- image data archived on digital magnetic tapes or as photographic negatives
- image unit files, also on magnetic tape, providing sophisticated windowing facilities for particular chosen image areas.

6.1 Disseminated Image Data

Disseminated image data is relayed to the user community via the spacecraft. Two forms of transmission are used, namely WEFAX analogue transmissions and digital (high-resolution) transmissions. The former are compatible with the transmissions from other meteorological satellites, whereas the latter are specific to METEOSAT and give the user processed data together with all essential interpretation data (e.g. deformation models, absolute calibration coefficients). Image data is disseminated in near real-time i.e. within about half-an-hour of image reception. Images from all METEOSAT spectral channels are included in the dissemination schedule which includes formats (or image pieces) covering the entire METEOSAT field of view at least once every three hours.

6.2 Image Archiving

The archiving subsystem provides for the archiving of all image and image-related data in digital and, where appropriate, in photographic form. The storage medium of the digital archive consists of high-density digital tapes (HDTs). Digital retrievals are made by copying from the archive on to either computer-compatible tapes (CCTs) or HDTs.

The photographic archive is maintained on negative film produced by a VIZIR laser beam recorder. Retrievals are in the form of contact prints of the original negative film or specific enlargements of particular areas ('windows') in the original.

6.3 Image Unit Files (IUFs)

Image unit files are image areas, each of which consists of 256 lines of 256 pixels (i.e. 64 Kbytes). The image areas can be either full resolution or can be sampled at a lower rate. The position of the image unit in the image and the sampling rates (vertical and horizontal) are at the discretion of the user requesting a unit or sequence of units. Options exist to either (a) geographically recentre each unit (so that its centre pixel always corresponds to the same latitude and longitude as the corresponding pixel in the reference image), or (b) completely rectify each area. In the latter case, the process of rectification consists in resampling the image with the help of the deformation model so that it matches the reference image.

7. Image Quality Control

The general philosophy of quality control is to evaluate a set of quality indicators for each image received and to store these parameters for about two weeks. The quality parameters of each image received in that period can thus be dumped; operations staff can then see the evolution of the various quality parameters and can quickly detect any degradation of the system due to malfunction of any part of the image chain.
Typical examples of quality parameters computed for each image are (1) number of lines lost due to ground system problems, (2) channel-dynamic ranges and S/N ratios, (3) residual distortion after application of the deformation model to the preprocessed image.
An interactive real-time display image facility also exists and has proved indispensible for radiometer commissioning and general image quality inspection.

References

(1) Introduction to the METEOSAT System (J. Morgan, Issue 2, December 1978: ESA/ESTEC Reproduction Services)

PRACTICAL APPLICATIONS FOR DIGITAL CARTOGRAPHIC DATA BASES IN TACTICAL SURVEILLANCE AND STRIKE SYSTEMS

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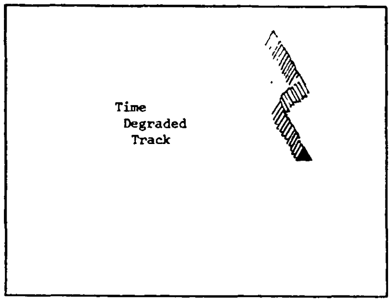
1.0. Introduction

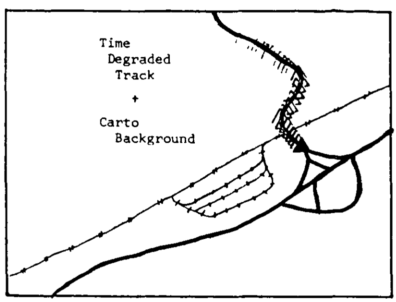
Digital cartographic data bases are becoming increasingly important in military applications for two reasons. First, radar surveillance and strike systems require cartographic data in order to place the otherwise cryptic radar-detected target symbols in a context that human operators can more easily understand. Figure 1-1 demonstrates the situation. Frame A shows a simple time-degraded target track. Notice how much more understandable the track becomes when projected against a cartographic background display in Frame B. This enhancement of symbolic radar reports is one benefit derived from tactical digital cartographic bases. In addition, accurately located cartographic features can help improve the radar's ability to find and track targets of interest.

The problems resulting from these applications will require solution by cartographic data base experts in the near future. To provide an indication of the direction solutions might take, this paper will present an overview of some applications of tactical digital cartographic data, including terrain shadowing calculations. The three types of data most used in tactical data bases are reviewed, along with their storage characteristics and current data sources. Due to space restrictions, this overview must of course be brief.

The problems described in this paper arose during work on two developmental surveillance and strike systems under research by the USAF.



A



B

Figure 1-1
Context Enhancement

2.0. Tactical Applications

The need for wide area reconnaissance in the near-real time frame of modern combat has developed out of the length of the borders that must be considered, especially in the European theater of operations, and the need for early warning of impending attack in order to expedite mobilization. As previously noted, the long range sensor reports by themselves are not sufficient to present the situation to a military analyst; they must be placed on a cartographic background to make sense tactically.

If a strike is to be called on the strength of sensor reports, the possible context of the target's movements must be examined closely. If the targets are moving into an area where the sensors will be unable to detect them, the strike must be postponed. Tracking a target accurately depends on locating it in four dimensions: x, y, z, and time. The sensors can provide accurate information on range, Doppler shift (target speed relative to the sensor), and time. This information must be correlated with the road network data in order to locate the target accurately. Thus, information about the target's location relative to bridges, rivers, railroads, and forests can be greatly helpful in planning future strikes.

By examining reports from one sensor in the context of the surrounding area, it is possible to "cue" other sensors to look at the target. This becomes increasingly important when targets have moved to areas where loss of contact is imminent due to foliage or terrain shadowing, which would not affect another sensor with different operating characteristics.

A further use for cartographic underlays involves accurate portrayal of the Ground Order of Battle (GOB), hostile anti-aircraft (AA) unit locations, and marshalling areas. This information is used to analyze and forestall hostile unit actions, and to locate safe penetration routes for strike aircraft.

In addition to actual combat applications, cartographic data is vital to realistic battlefield simulations. The prohibitively high cost of field tests has increased the importance of such simulations in recent years. Generating these simulations requires interactive access to lineal cartographic data in order to locate simulated targets realistically.

3.0. Terrain Shadowing

Terrain shadowing is the process of calculating the obstructions between a radar sensor platform and a target in order to determine if the target can be seen by the sensor. This will allow strikes to be scheduled for a time when the target is visible and will remain visible.

Shadow calculations attempt to answer one of two questions: "Given a platform position, what areas are shadowed?" and "Given a platform and a target, is the target shadowed?" Thus, terrain shadow calculations must consider the altitudes of both sensor platform and target, as well as the distance and bearing from sensor to target.

A terrain elevation model of the area being searched can be used to predict the shadows for a given platform position. For a simulation of a sensor, the terrain-model can be used to determine if the simulated target is shadowed. This terrain model is constructed from hypsographic data. The major problem with this approach is the lack of readily available data for most parts of the world.

4.0. Types of Tactical Cartographic Data

Tactical data bases use three types of cartographic data: lineal, areal, and hypsographic. These are understood in a specialized sense which probably lags behind the state of the art.

4.1. Lineal data

The term, lineal data, is used to describe those features of the earth that can be recorded as lines without losing any vital location information. These lines are actually strings of discrete cartesion coordinate points, usually recorded in terms of Lat.-Lon., x-y inches (from the lower left corner of the source material) or x-y meters (from some arbitrary position on the Earth's surface).

Lineal data is used to record features of particular tactical interest such as roads, railroads, airport and populated area outlines. Single point lineal features are used for landmarks, bridges, tunnels, and chart reference points.

In order to manipulate classes of features easily, each feature is described using a codified classification scheme, requiring about 12 bytes of encoded header information followed by 60 (or so) characters of descriptive text. The text usually contains a specific identification for the feature (such as "HUDSON RIVER", or "Route 365"). A type of single point feature called a "Graticule Point," provides the control for performing projection transformation, and registration. These are recorded in a pattern across the chart, combining the Lat-Lon or UTM grid coordinates with the Cartesian Coordinate x-y values of the digitizer.

4.2. Areal data

Areal data differs from lineal data only in the meaning of the lines, which represent the borders around features (such as swamps, lakes, and forests) rather than the features themselves. This difference presents some very difficult problems for data processing, however, since what is stored in the computer is not the feature of interest, but its outline. Although some techniques for symbolizing areal data using "Area Fill" have been developed, no work has yet been done towards developing techniques for making tactical use of this data. Figure 4-1 presents an example of symbolized areal data in order to illustrate the following discussion.

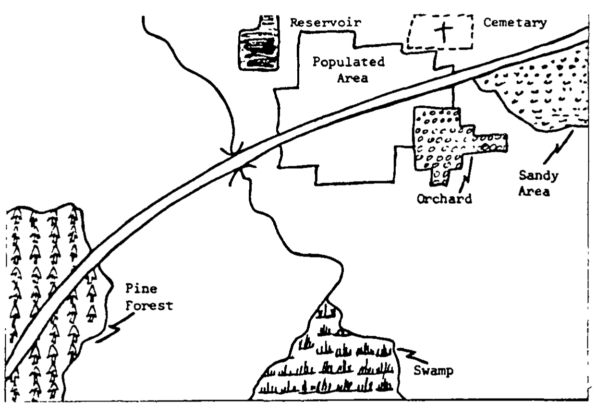


Figure 4-1
Areal Data Examples

The lack of such techniques creates several problems, which will require solutions in the near future. For example, there is a great need to be able to determine if tactical MTI (Moving Target Indicator) radars can "see" through foliated areas. Since no information is recorded inside the borders of the area, the terrain shadowing techniques described in the next section cannot be used. Instead, analysts must make a large number of assumptions about the contents of the area, including the average height of the foliage, the ratio of deciduous to coniferous trees, and the percentage of the area actually foliated.

Another difficult problem in working with areal features is deciding whether the feature is closed or not, and on which side of the line the feature exists. When the map segment under consideration contains only a portion of an areal feature, it is impossible to determine on which side of the boundary the feature lies without examining the entire feature.

4.3. Hypsographic data

Hypsographic data is useful for tactical systems in two ways: providing an elevation coordinate to improve tracking accuracy on lineal road coordinates, and provide data for terrain shadowing calculations.

The primary problem with hypsographic data is that it is largely unavailable and when obtained, in a form that is inconvienent to work with.

5.0. Data Characteristics

There is no difference between the data characteristics of areal and lineal data; both are recorded as strings of coordinate values with an attached header record describing the type of feature. The primary consideration when processing lineal data is to preserve the network continuity to allow for automated route following from node to node. Areal data, in contrast, describes not a network but a boundary. (The only areal data used so far, was the boundaries of highly populated areas, which provided a context for reports shown on the wide area display.)

The storage space needed for lineal data has little relationship to the area being covered; instead, it depends mainly on the density of features of interest and the granularity of the data. Carefully adjusting the granularity for the most accuracy with the least number of data points will permit a reasonably small area (40 km x 60 km) to be stored at an accuracy of 15-20 meters using around one million bytes for x, y, and z coordinates. Attempting accuracies of 10 meters or less can increase the amount of data dramatically. The controlling factor for accuracy in data culling is the straightness of the network segments. Very straight segments (even long ones) can be stored with only two points, while curved segments may require thousands of points to represent the same distance.

In contrast to lineal and areal data, hypsographic data is recorded as a matrix of elevations, with each elevation's position in the matrix corresponding to its position in the real world.

The storage space needed for matrix data is directly proportional to the spacing within the matrix and the size of the area it represents. Storage may vary from several thousand bytes for a small area (40 km x 60 km) with wide spacing (about one elevation value every 500 meters), to tens of millions of bytes for a large area (120 km x 240 km) with a narrow spacing (one elevation value every 30 meters).

6.0. Data Sources

Although cartographic data bases have been evolving along with computer assisted cartographic techniques, most of the research has been in support of map sheet production. In order to create a tactical cartographic data base, it is necessary to first collect the digitized data from existing charts, and then to transform this collected data into some form that will support the requirement for rapid access. Experience has shown that such diverse distributors of source materials as the USGS, DMA and New York State Department of Transportation Map Information Unit must be used in order to complete the collection process. This same experience has shown that the chart collection, digitization, transformation, and data base creation processes can require excessive expenditure of manpower and time. The problem of maintainability is compounded by the scattered sources, and overly complicated collection process.

7.0. Recommendations

The best approach to the problem of integrating cartographic data would be to maintain a single data base that could provide any of the various types of data required. This seems impossible at present, because the diverse formats used to record different data types are incompatible. Failing the development of a general purpose data base, the rule should be: "Let the form fit the function."

The requirements for accuracy, accessability and maintainability dictate that data bases for display contain more types of features, but not necessarily to a very accurate level, while tracking data bases require only one or two types of data, but must be more accurately recorded. The display requirement might easily be met by using actual images of the appropriate maps, while the tracking could be done with data recorded from aerial photos, using state-of-the-art orthophoto digitizers. Thus, the great amount of detail required for display, and the accuracy of location required for tracking could be easily provided.

8.0. Summary

Digital cartographic data bases are of increasing importance to tactical advanced sensor exploitation. The requirements for improvements in accuracy, accessibility, maintainability, and flexibility of digital cartographic data bases have been changing so quickly that they have outstripped the state of the art. Major advancements in all these areas are required in the near future.

A DATA STRUCTURE FOR A RASTER MAP DATA BASE

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Introduction

The increasing requirement for geographically referenced data in the public, private and military sectors, has led to technological advances in automated data collection, storage, manipulation and display of spatial data. A large fraction of the costs in Geographical Information Systems (GIS) can be associated with digitization, data encoding and input processing. The data encoding scheme also influences the storage efficiency and effectiveness of programs that analyse and manipulate the geographic data.

Each spatial data type (spatial data layer) has three possible types of geographic entities that must be encoded: points, lines and regions. The geographical entities are generally coded as either raster data or x, y-coordinate structures.

For raster data the entities are quantized and stored by the use of grid cells as location identifier (2). This implies that neighbourhood relationships are implicit, which facilitates analysis and manipulation. A disadvantage with raster data is the storage inefficiency due to redundancy in data.

The coordinate structures describe a point entity by its coordinate, a line by a chain of uniformly or non-uniformly spaced coordinates and a region by its boundary (lines). The coordinate oriented systems are

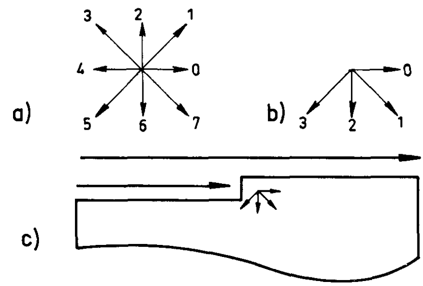

FIG.1. (a) Chain-code. (b) RC-code. (c) A contour can only be traced in four directions with the raster scan technique.

suitable for region and contour maps and have high storage efficiency.

This paper presents a data structure or encoding scheme which is intended for raster scan techniques (3). The code can be used for encoding and decoding of binary entities with high storage efficiency. The code can also be stored as a data structure, where the entities can both be accessed as raster data and as regions, boundaries and lines.

Raster-scan Chain-code

The conventional chain-code lists each object as a x, y-coordinate and a sequence of chain-links that defines the border of the object. The code contains eight directions and the entire object must be accessible during the tracing of the border. If we trace the contour stepwise in a raster-scan fashion, then only four directions can be registered for an 8-connected object (FIG.1). But more than one coordinate must normally be listed for each object. These coordinates are the first pixels that the raster-scan procedure hits in some part of the contour. Each listed coordinate, called a max-point, is connected to two R-chains (FIG.2). A min-point is the terminal of two R-chains. A number of max-points with associated R-chains define an object.

The following sections describe encoding and decoding with Raster-scan Chain-code (RC-code).

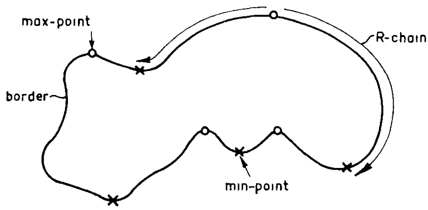

FIG. 2. A border with indicated max-points and min-points.

Coding of Regions

According to the sampling theorem the sampling interval has to be half the size of the smallest features to be encoded. Therefore the regions should not have peninsulas of one pixel width. (The preprocessing eliminates quantization noise).

The max-points can be detected either with a set of 3 by 3 templates (3) or by the use of pointers to all the R-chains of the current line. In the latter case, a max-point is registered when a border is encountered that is not marked by a chain-pointer. The attached chain-links are detected with ordinary border-following techniques. This procedure is easier to implement on conventional computers.

There are basically two methods to store the RC-code. While the extraction is strictly ordered, all the links can be stored on a stack in the same order as they are found. The max-points are stored on a separate stack. In rewriting mode, the max-point stack is poped when the coordinate given by the max-point is reached. The max-point is replaced in the image and the two links at the top of the chain-link stack is attached to the max-point. For each new generated line, the chain-link at the top of the stack is attached to the next R-chain on the line, the stack is poped and so on. We can keep track of the R-chains from line to line with pointers. Two R-chains that are meeting indicate a min-point.

To be able to access the coded image both as raster data and as regions, each R-chain must be stored as a unit. Several chains are built concurrently, so the endings of these chains must be accessible and there

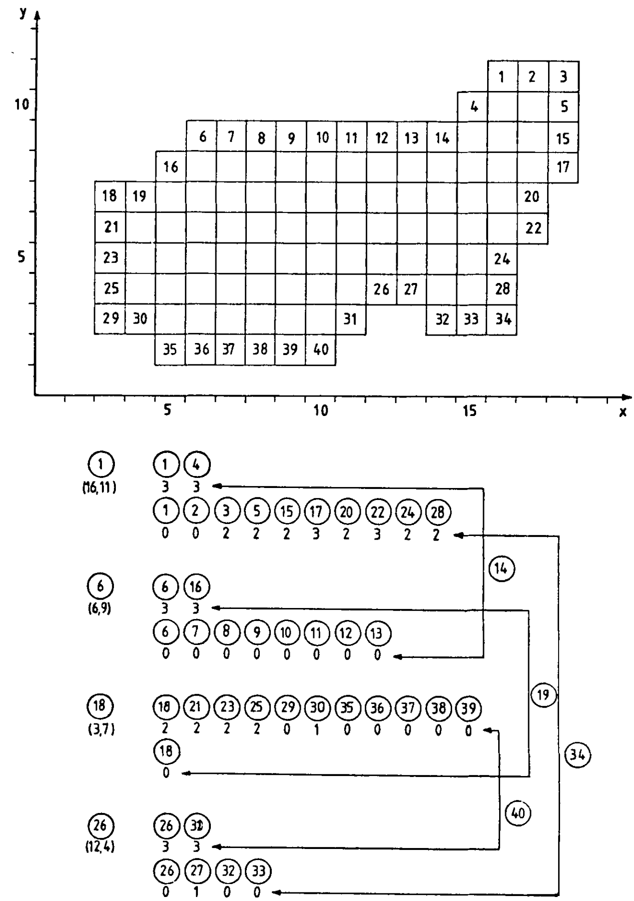

FIG. 3. Encoding of the border step by step. The numbers within rings correspond to the numbers on the border.

has to be space to append more links. Therefore, the chains are built in a buffer storage and depending on the size of the buffer, completed regions, chain-pairs or if a chain becomes extremely long, a part of a chain are transferred to secondary storage. The max-points with pointers to the R-chains are stored separately in a dictionary. In rewriting mode, the max-points are replaced as above. The chain-links must be retrieved from the list of chain-links at positions indicated by the pointers associated with the max-points. The encoding using this code is exemplified in figure 3.

The nesting of objects and holes, objects within holes and so on, can be revealed concurrently with the encoding. The principle is basically the same as for component labelling with the run-tracking method (4). The max-points introduce new possible interpretations, and min-points solve the ambiguities (3).

Coding of lines

The digitized lines are thinned to one pixel width and then encoded. The lines can be non-intersecting closed contour lines (elevation data) or a general graph with nodes and branches (region map or road map). As before, the code can be stored only for retrieval and display or stored to be accessible both as raster data and line entities. The non-intersecting closed contour lines do not change anything from the previous section except that the interior of a border is not filled with *1's* in the rewriting mode.

The general graphs are based on single lines (branches) and nodes, so we must introduce single chain max-point and min-point, called respectively start-point and end-point (FIG. 4). For the simple raster format encoding, four stacks must be stored: start-point, max-point, end-point and the stack of chain-links. The min-points are, as before, detected automatically during reconstruction. The start-point indicates the beginning of a single chain or a fork. An end-point indicates the end of a single chain or when two chains join to one.

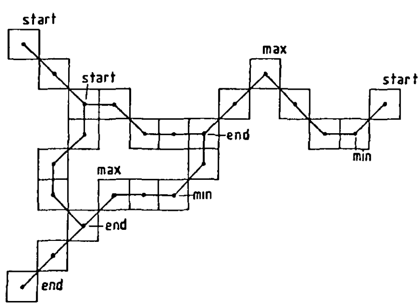

FIG.4.A unit width graph with start-points and end-points

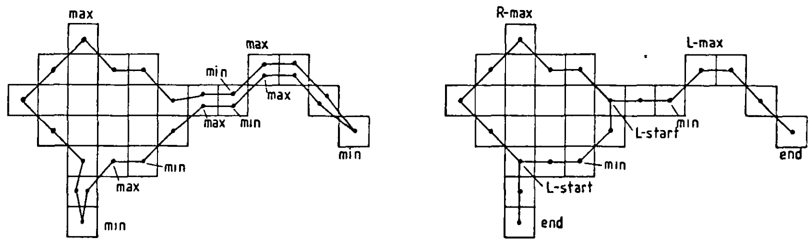

FIG. 5. The extended region encoding and the combination of region and line encoding.

To be able to access the image both as a graph and line by line in raster mode, the max-points and nodes are stored and the associated R-chains are added link by link. As before, this implies that several chains must be accessible concurrently and special routines for transfer of chains to secondary storage are needed. When a chain terminates, in a min-point or node, interconnection pointers are established.

Coding of Regions and Lines

A quantized image without preprocessing and an image with areas and thinned lines cannot be coded with the methods given above. To allow both regions and lines of one pixel width, the region encoding must be extended or combined with the line encoding. The extended region encoding assigns two R-chains to a line as if it was a region. If it is infrequent it can be accepted, but in an image composed of areas and several lines of unit width, it is better to combine the two methods. This implies that two types of max-points and start-points are involved, region max-point (start-point) and line max-point (start-point). The difference between the methods are exemplified by figure 5.

RC-code for Display

One of the encodings discussed so far can be retrieved as regions and lines or line-by-line for processing and display. The display can only be rolled in the scan direction, which makes it impossible to move the display window freely in the data base. To be able to roll the map both up, down, left and right, the RC-code can be extended. In this case, max- and min-points have to be stored for both the x and y-directions, so four co-

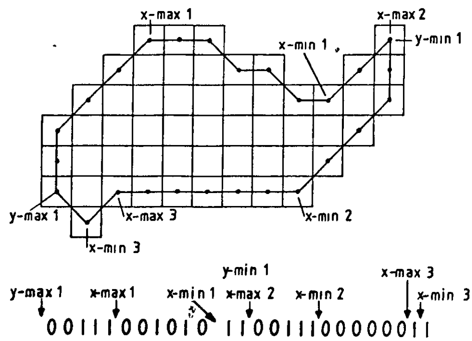

FIG. 6. RC-code for display.

ordinate lists including pointers and the chain-links are stored. This reduces the storage efficiency considerably but the situation can be improved by using relative coordinates within the x-max, x-min, y-max and y-min list for an object and because only one bit is needed for storage of the chain-links (FIG. 6). We can also transform the usual chain-code or RC-code to the display version of RC-code.

Conclusions

There are two major approaches to internal data organization in geographic information systems: raster data and x, y-cordinate/linked structures. Raster data has the advantage of direct correspondence to the format of a raster-scanner input and matrix plotter output. Processing related to distance and retrieval based on location can easily be accomplished. Software development is easier for many applications. The major disadvantage with raster data is storage inefficiency. The linked structures, on the other hand, are storage efficient and correspond directly to the format of coordinate digitizers and incremental plotters. It is suitable for processing polygonal maps and contour maps which have the property that lines do not meet. The disadvantages are difficulties of performing distance-related operations and set algebra.

The RC-code is an attempt to combine the advantages of the two schemes. RC-code corresponds to both raster and incremental input/output and it is storage efficient. The code is suitable for processing of polygonal and contour maps. One disadvantage is that, due to the data compression, processing related to distances cannot be computed directly from the storage addresses. Another minor problem is the buffer management during storage and retrieval of the code.

We are currently investigating the usefulness of the RC-code in a project where overlays from the Swedish topographical map are digitized and encoded. Encoding of region entities like lakes and forests have been implemented and we are now working with line entities.

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DIGITAL TERRAIN MODELS SESSIONS

DIGITAL TERRAIN MODELS

There were two Digital Terrain Model sessions. Both of these sessions were chaired by Raymond J. Helmering of the Defense Mapping Agency.

Thomas K. Peucker, Robert J. Fowler and James J. Little of Simon Fraser University and David M. Mark of the University of Western Ontario presented the paper "The Triangulated Irregular Network". Digital terrain models are generally developed on the basis of regular grids. The problem with this technique is the necessity for large data volumes and difficulty in the accurate determination of structural points and lines on the surface. The triangulated network has been developed over the past five years as a response to these problems. The authors describe their triangulation algorithm and some of the kinds of maps they are able to make with it.

Christopher M. Gold of the University of Alberta presented the paper "Triangulation-Based-Modelling - Where Are We Now". The focus of this paper is similar to the one by Peucker and associates, described above. Gold reviews the merits of both the triangle and square techniques and he describes some of the techniques and properties of triangulations. He indicates the appropriate model to use will depend, in part, on the nature of the data.

Gerald M. Elphingstone of the Defense Mapping Agency, presented the paper "Interactive Graphics Editing for IPIN". The IPIN system is used to edit elevation data instead of the conventional cartographic application of editing lineal strings of xy positions and intersections. The paper describes the general concepts of the system and how these concepts will be implemented into a production system.

Stanley Collins and George C. Moon of the University of Guelph presented the paper, "A Unified System for Terrain Analysis and Mapping from DEM to DTM". This paper describes the approach that is being used by the authors to analyze large amounts of terrain data, typically involving models with more than 10^6 points.

Their programs have been developed for producing thematic and engineering maps and data from the most useful data sources, polygons and grid structures.

Richard J. Heil of W.E. Gates and Associates presented the paper "The Digital Terrain Model as a Data Base for Hydrological and Geomorphological Analyses". Heil describes the advantage of the irregular triangular grid for providing a computer-compatible representation of terrain in a continuous three-dimensional surface. Using this concept enables one to perform a variety of analyses including automatic stream and basin delineation, calculation of tributary area characteristics; area, aspect, and slope.

Dennis L. White of the U.S.G.S. presented the paper "GPM-2 Digital Terrain Data Base". (Paper not included in proceedings.) This paper described the establishment of a data base for Gestalt PhotoMapper-II (GPM-2) digital elevation model data in the National Mapping Program. So far, elevation data has been processed from more than 1,100, 7.5 minute quadrangles. These data are being made available on magnetic tape and can be ordered from the National Cartographic Information Center.

THE TRIANGULATED IRREGULAR NETWORK

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Introduction

For several years, our group has developed a Digital Terrain Model based on irregularly distributed points connected into a sheet of triangular facets.

Our first motive for this research stems from problems with traditional terrain representations which were recognized as early as 1967 by Boehm. Topographic surfaces are non-stationary (Pike and Rozema, 1975), i.e., the roughness of the terrain is not periodic but changes from one landtype to another. A regular grid therefore has to be adjusted to the roughest terrain in the model and be highly redundant in smooth terrain. It is apparent that, if one is to model these non-stationary surfaces accurately and efficiently, one must use a method which adapts to this variation.
The second principal motivation came from a realization

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that the purpose of the digital terrain system is the digital representation of terrain so that "real world" problems may be approached accurately and efficiently through automated means. In response to this problem it was decided that our digital terrain system should contain those features which are the natural units of analysis for the problems to be solved. This is an important current trend in general data base construction (Mark, 1978).

These features and the boundaries between them are seen to have a higher "information content" than randomly located points on the surface. This is so both in the context of the analyses and from the standpoint of representing the surface with a minimum of storage.

Like several other researchers (Gates, 1974, Bauhuber, et.al., 1975, Gold, 1977) we realized that one simple means of meeting these specifications is to model the surface as a sheet of triangular facets. We called our implementation of this approach a Triangulated Irregular Network or TIN (Peucker, et.al., 1975).

There are two complementary approaches to the computer representation of a surface of triangular facets. One method gives primacy to the triangular facets themselves. Using that method, each triangle needs a total of six pointers to define the topology: three pointers to the nodes at its vertices (the point coordinates should be stored separately), and three pointers to the neighboring triangles. Since, by Euler's relations, there are 2N-B-2 triangular facets in a network with N nodes, B of which are on the boundary, a total of 12N-6B-12 pointers are needed.

Alternatively the nodes can be regarded as the primary entities. This is the approach that is used in the TIN data structure. The topology is captured by allowing each node to point to a list of its neighboring nodes. The neighbor list is sorted in clockwise order around the node, starting at "North" in the local Cartesian coordinate system. Applying Euler's relations, the total number of neighbor pointers will be 6N-2B-6. Thus there is about fifty percent savings in storage by representing the topology as a TIN as opposed to using its graph dual. In this implementation, the surface has been mapped onto a topological sphere by the device of adding a dummy node to represent the "outside world" or the point on the "back side" of this topological sphere.

Capturing the Phenomena: Secondary Data Structure

The TIN is conceived of as a primary data structure which contains within it a secondary data structure in which the essential phenomena and features of the terrain are represented and named as integrated, holistic objects. Different disciplines may regard different aspects of the terrain as the "essential phenomena" of the surface (Mark, 1978). We, for our own work, have adopted a set of "surface specific points and lines" to be our working, secondary, phenomenon structure. Peaks, pits and passes form the major portion of the set of surface specific points. Peaks are points that are relative maxima, i.e., higher than all surrounding neighbors. Pits, likewise, are relative minima. Passes are saddle points on the surface, relative maxima in one direction and relative minima in another.

Methods for Generating TIN's

There are two principal phases to the generation of TIN°s: the selection of the data points and their connection into triangular facets. Manual selection of the points and links which constitute the triangular network is one of the most obvious and accessible methods of creating a TIN.

Manual point selection combined with the automated triangulation is another technique which has been used. The existence of efficient programs for the triangulation of an arbitrary set of points under a variety of optimality criteria (Fowler, 1978, Gold, 1977, Shamos and Hoey, 1975) makes this approach attractive. A somewhat larger number of nodes need be recorded in order to resolve ambiguities which can be interpreted by the human operator. This is more than offset by the increased ease and speed of entry.

In light of the increasing availability of machine readable terrain data particularly in the form of very dense raster DTM's produced by automated orthophoto machines (Allan, 1978), it is becoming desirable to use automated triangulation. We have undertaken the development of a system to do this. The first requirement for such a program is that it be presented with error free input. Some automatic DTM machines produce occasional blunders or "spikes" and it is necessary that these be filtered out before the data can be presented to the TIN generation system. The first phase of generating a TIN from a very dense DTM is the extraction of the skeleton of surface specific ppoints and lines. To derive these features, we use a local geometric operator, similar to those used in picture processing, to identify possible points on ridge or channel lines (Peucker and Douglas, 1975). Subsequently, these points are linked into ridges and channels. These points are then automatically connected in a Delaunay triangulation (Fowler, 1978), the resulting model is compared with the original very dense grid, and additional support points are added at the points of worst fit until the maximum discrepancy between the TIN model and the original is within a pre-specified tolerance.

Applying the Model

Most applications of the TIN involve one or more of three basic processes:

1. Sequential element by element processes,
2. Searches - locating the closest node to a given point, or locating a point within a triangle,
3. Intersection of the terrain surface with various other surfaces by tracking their lines of intersection.

Since the nodes of a TIN refer explicitly to their neighbors, sequential element by element processes may refer to them without the penalty of having to search for them. Hill-shading and slope mapping both refer essentially only to the individual triangles on the TIN surface to obtain the location and orientation of the facets. In some cases, hill-shading will access the information about the facets which adjoin a given triangle, but this process stops at the first neighboring facet. These are the most simple methods for employing the TIN and lead to simple algorithms.

Tasks which require searching use the adjacency information in the TIN to walk through the network until a specified condition is met.
The topological structure
of the TIN makes this form of search quite efficient.

By a simple extension of this process, one can easily determine in which triangle within the TIN the given point lies.

The surfaces which are intersected with the terrain surface range from the relatively simple case of cutting the surface with vertical and horizontal planes to produce drop lines and contour lines up to the relatively complicated problem of intersecting the surface with the outlines of cast shadows or with a series of conic sections in order to simulate elipitical radar scans. In general, all of these surface intersection problems are handled by a tracking process. First, for each disconnected loop or segment of the intersection a starting point must be located. Once the line of intersection is located within any triangle it is a simple matter of deciding which of the three edges of the triangle the line crosses as it leaves that facet and enters the neighboring facet. Within each facet locating the line of intersection is the standard problem of solving for the root of a bivariate function. This can be done with numerical tracking procedures.

Automated hill shading

The TIN model of terrain representation lends itself to development of an automated method of hill shading. Because the TIN explicitly represents these surface lines as edges of facets, Yoeli's (1967) method and Brassels(1975) enhancements are simple to automate. Without perturbing the light source, structural edges aligned parallel to the light rays can vanish; in the TIN, the contrast across these edges can be examined directly and altered to improve the surface modelling.

Slope mapping

Graphic techniques similar to those used in hill shading are employed to produce maps of slope variation. Shading can be performed on a triangle by triangle basis, assigning each facet to the shading interval determined by its slope.

Contouring

The production of contour maps from the TIN is a simple procedure. The extraction of contour lines is equivalent to locating the lines of intersection between the terrain surface and a sequence of horizontal planes. The secondary data structure of ridges and channels is used as a guide in searching for the starting points for each contour loop. Once a starting point for a loop has been located, the tracking procedure as described above is used. The program contains provisions for darkening index contours and smoothing out sharp corners which are artifacts of the edges of triangles.

Profiles and hidden lines

A common method for construction of block diagrams extracts drop-lines or profiles from a gridded DTM along rows, columns, or diagonals of the height matrix. Proceeding from the profile closest to the observer, the method compares succesive profiles against a °horizon° profile, composed of the upper boundary of the region on the image converted by all preceding profiles. A scanner for the TIN extracts the profiles from the TIN, using the tracking process. By making use of the coherence of successive scan lines, i.e. the similarity in the edges crossed by adjacent scans, and the topological structure of the TIN, the process is very efficient (see Peucker, et.al., 1975). The advantage of using the TIN as the source of the profiles is twofold; first, the extraction of scans can be done at any angle through the region, without either an increase in computation or a loss of accuracy, and, second, the definition of features is not limited to the sampling interval of a grid.

Line of sight or radar maps

To determine the intervisibility of two points in a TIN, one can extract the profile of the surface along the path between the points, using a tracking procedure. To extend this technique, one can send rays out from a central location, at a fixed angular separation, and plot the sections of the rays that are visible from the central location.

Horizons

A horizon map depicts the boundary between the terrain and the space above. Construction of this image can be performed simply in a TIN, through direct extraction of all horizon lines. Any edge contributing to a horizon line must be both convex and must separate a visible from an invisible facet.

Integration of the DTM with Coverage Data

In many planning applications information about both the terrain surface and coverage of a cultural, political or ecological nature must be combined in the analysis. These coverage data are often represented by polygonal coverings of a region, linked by the adjacency relations of the regions.

One can refer simultaneously to a TIN model and a coverage network by using a tracking process to search along paths in both models. This allows comparisons to be made between models of the same region in a direct manner.

Summary

Our implemention of the TIN system is a research tool used to investigate the aplication of DTM°s based on triangular facets to a wide range of applications. Many tasks for which DTM's have been used are already implemented on the TIN model or can be demonstrated to be feasible. In addition, for certain demanding applications, such as intervisibility problems, the TIN has shown itself to be particularly well suited.

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TRIANGULATION-BASED TERRAIN MODELLING-WHERE ARE WE NOW?

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Introduction - Triangles versus Squares

In the last few years considerable effort has been expended by various individuals and organizations in the development of digital terrain modelling systems. Many different methods have been evolved, some of them better than others in technique, and some more suitable for particular data types and display requirements. Various authors have effectively surveyed the literature on the subject. Rhind (1975) divided the field into: i) zone partitioning (e.g., dividing the map area into regions whose vertices are defined by data points); ii) global fitting techniques, such as "trend surfaces"; iii) gridding methods where elevation values at nodes of an arbitrarily-defined grid are estimated by a wide variety of techniques, from rolling means to universal kriging; iv) "multi-quadric analysis" and v) contour chasing methods. Schut (1976) describes six groups: i) moving surface methods, requiring the computation of a surface at each data point, as for most weighted average techniques; ii) "summation of surfaces", in which he includes all methods involving the correlation theory of stationary random functions; iii) simultaneous patchwise polynomials, i.e. polynomials valid over "patches" of the surface, such that adjacent patches agree at their boundaries; iv) interpolation along equidistant parallel lines in a photogrammetric model; v) interpolation using a network of triangles with data points as vertices and vi) interpolation using characteristic terrain times.

It is not the intention of this paper to review further all of these techniques. Almost all of the above methods have in common an arbitrarily-defined regular grid into which are inserted the estimated elevation values prior to display by contouring or other methods. The exceptions are direct contour following, and triangulation techniques - the main subject of this paper. Consequently it is not inappropriate to make some general comparisons between "triangles" and "squares".

The general structure of the "squares" approach is clearly comprehended - which is why it has been so extensively used in a Cartesian society. The x-y values are implicit in the grid definition and only the elevations need to be stored. Indeed, using patchwise polynomials only the cofficients of each patch need be stored (e.g. Jancaitis, 1977).

Triangulation schemes, therefore, are methods that describe the relationships between the original data points. As such they are, and should be treated as, cartographic data structures. This is especially true when the data points are selected to represent features of the topography (e.g. Peucker, 1977; Males, 1977) rather than merely being randomly located. If triangles are indeed cartographic data structures then enough information should be preserved with each to permit negotiation of the network and the rapid answering of questions concerning the relationships between data points, (Peucker, 1977; Lawson, 1977). Gold et al. (1977) suggested preserving for each triangle, pointers to the three data points forming the vertices as well as to the three neighbouring triangles. This, or any equivalent scheme, permits the economical determination of any local question of relationships between neighbours by an economical <u>local</u> interrogation of the data structure. Computationally it is cheap, in storage costs it is expensive, requiring two triangles of six elements for each data point. Clearly this approach is not primarily intended for where the data point density is already too great for comfort, as in some remote sensing applications.

<u>Techniques of Triangulation</u>

In some applications (e.g. Males, 1977) the triangulation is defined manually and becomes part of the data. Usually, however, it is required that this operation be performed automatically. There are two major parts to this operation - firstly the requirements for a "good" triangulation of any point set must be defined, and secondly an efficient algorithm must be specified for the actual generation of the network.

Various criteria for a good triangulation have been defined. Most take four points forming the vertices of a quadrilateral and then decide which of the two possible internal diagonals is preferable. Criteria include maximizing the minimum height (Gold et al. 1977), maximizing the minimum angle (Lawson, 1977) and minimizing the diagonal length (Akima, 1975). Shamos (1975) mentioned that only the Delaunay triangulation (equivalent to Lawson's maximized minimum angle - see Sibson, 1978) has been shown to have a unique solution without testing every possible set of triangles. Within the last couple of years it has become accepted that this is the best criterion to use for triangle definition. This triangulation is the dual of the Theissen or Voronoi or Dirichlet tesselation in which any location on the plane is assigned to the polygon containing the nearest data point.

Having obtained a criterion for triangulation we need an algorithm to implement it. Shamos (1975) has shown that the Voronoi tesselation may be defined as O(n log n) time for n data points. Many published algorithms do not achieve this. Lewis and Robinson (1978) triangulate by splitting the plane; McLain (1976), Akima (1978) and Lawson (1977) triangulate by starting with a nucleus of points and attaching the best remaining point onto this growing network. Gold et al. (1977) start with a large enclosing triangle, locate a data point inside it, subdivide the triangle into three, find the triangle enclosing the next data point by a linear walk through the network, and repeat the process. Optimization is currently performed after each data point insertion, and is O(n) since an average of six switches of the diagonal of a quadrilateral are required for each point. Green and Sibson (1978) achieve a similar efficiency for generating a Dirichlet tesselation and claim high speed for it. Because they preserve the polygons, not the triangles, there is a potential 50% saving in pointer storage. However, the requirement for additional pointers to handle the unequal number of links to each polygon, together with the inability to preserve non-optimal tesselations / triangulations such as those formed by manual entry of surface-specific lines (Peucker, 1972) reduces this advantage.

One feature in this should be emphasized: the last two algorithms, together with a few others, produce fast triangulations. While speed comparisons between machines are difficult, a simple example should make the point clear. With the algorithm of Gold et al. (1977), the insertion of a data point into the triangulation, as well as its optimization, typically takes only 1.5 times as much computing time as the reading of the x, y, z values from punched cards or other medium. For most practical purposes, the computing time for triangulation may be ignored.

Properties of Triangulations

As already mentioned, the dual graph of the Delaunay triangulation is a Dirichlet tesselation of polygons with the properties of the "proximal map" of the SYMAP package. Thus the zone associated with each data point may readily be outlined by taking the perpendicular bisector of each triangle edge connected to the data point under consideration. This is useful for various purposes, including resource inventory based on drill hole information. The cost is clearly little more than that of generating the triangulation.

A very useful property of any triangle in any triangulation is that it may be the basis of a three-parameter homogeneous coordinate system (Gold et al. 1977). If linear interpolation is a sufficient approximation to a terrain surface then the elevation of any internal x-y location is obtained by weighting each of the elevation values of the data points at the triangle vertices with the appropriate area coordinate, and summing.

The ability to process map elements in some sequential order is of considerable value with current computer equipment. A triangulation may be treated as a binary tree structure with respect to any arbitrary direction ("north"). Any triangle must have either one or two south or downwards facing edges (ignoring the neutral case of a vertical edge). Thus, if triangles are to be processed from north to south the initial triangle must be followed by either one or two neighbours to the south. The second one, if present, is put on a stack for later retrieval and processing continues with the other neighbour. The end result is a triangulation "cut" along various edges to form a tree structure (Gold and Maydell, 1978). Triangles are processed in swathes and pen movement is greatly reduced for any drafting (e.g. contour lines) required in each triangle. The order is such that, looking from the north, frontmost triangles are always processed prior to those behind them. This is valuable in some forms of terrain display. In addition, at any stage in the map generation, the southern boundary of the completed portion of the map is monotonic in the east-west direction. This has proven to be valuable in the construction of contour lines that may take any path through the triangular mesh.

Interpolation Within Triangles

For purposes of contouring, it is usual to subdivide the triangle into a regular grid of subtriangles, (Gold et al., 1977), estimate elevations at each grid node and then trace the contours through the grid. This is similar to contouring a rectangular grid, but without the ambiguities due to interpolating between four corners.

As mentioned above, linear interpolation within each triangle is very rapid and economical. Where a "smooth" surface (continuous in the first derivative) is required, rather elaborate interpolation functions are needed. This is the most important field of current research, and is where most of the computing time is spent. The method used by Gold et al. (1977) is relatively economical but may be rather "stiff" for some applications. Akima (1975) uses a bivariate fifth degree polynomial, Lawson (1977) uses Clough & Tocher piecewise polynomials in each triangle. Powell and Sabin (1978) use a piecewise quadratic approach. Very little difficulty arises in defining a mathematical function to agree with elevation and slope values at the vertices, and these functions have surface continuity between adjacent triangles. The difficulty comes in obtaining continuity of slope between adjacent triangles at the mid-point of the sides. Further work will undoubted clarify the preferred methods to be used.

One marked difference between triangulation techniques and grids is that smoothing is an inevitable product of gridding, and is normally not a product of triangulation. This is basically an advantage in triangulations, but there is no doubt that where there is an appreciable error component in the x, y or z observations at each data point an unsmoothed map is unattractive to many users. Gold (1979) has used neighbouring data points to estimate a mean and standard deviation at a central data point and from this to perform various types of controlled smoothing and examination of residuals. The presence of a high standard deviation means that the neighbours do not agree well among themselves. This may be due to measurement error, inadequate sampling frequency or real slope discontinuities such as ridges or cliffs.

The Topographic Model

This phrase has been widely, and perhaps loosely, used. Most often it is considered to be a fine grid of elevation data - primarily because that is where most of the computational effort went. What happens in the case of triangulation techniques? As has been mentioned, the cost of triangulation is little more than the cost of reading the data unless manual triangulation is used to define certain features.

In computer terms at least, a topographic model should be distinguished from a topographic map. As with the balsa-wood or styrofoam model, it should be viewable in many ways - from any orientation, by slicing it, etc. A contour map is merely one way of displaying the topographic model. The primary requirement for any display of the model is that it may be interrogated to obtain the elevation at any x-y location, and that this value should be obtained in some reasonably efficient manner. Since there will not usually be a data point precisely at each desired location, a topographic model should be defined as a set of data points plus the required algorithms to obtain any requested elevation.

Gold (In Press) describes problems encountered in obtaining reasonable zero-thickness contours on isopach maps and concludes that, rather than contouring the value "thickness", isopachs should be considered as the difference between two distinct topographic models. He states:

"Two important conclusions may be derived from this example, and in the opinion of this writer they hold true for all map types - whether topographic or thematic. The first is that a model consists of an attempt to generate a space-covering map of a single parameter only. It should conform as closely as possible to the original data and avoid synthetic devices such as grids. The second point is that grids or rasters should be display devices only, to be used as needed to compare and display models. Ideally they should not be preserved or used again to make subsequent comparisons."

Conclusions

Where are we now with triangulation-based terrain modelling? Current techniques are less appropriate for very dense, noisy data than some of the available gridding techniques. However, where data storage is not a problem - either with large computers or smaller data-sets - triangulation techniques can provide a flexibility of use not readily available where grids have to be generated, preserved and compared. It is to be hoped that the next few years will bring further understanding of the potential of relational cartographic data bases of this type.

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INTERACTIVE GRAPHICS EDITING FOR IPIN

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INTRODUCTION

The digital terrain matrix will be the final product resulting from a number of collection, processing, and editing steps. The approach within IPIN will be to reduce the amount of required editing of the digital terrain matrix by editing the raw collected data before it contributes to the interpolation process. This implies it will be edited as close to its collection source as possible, such as the geomorphic and epipolar edit. The edit procedure will be a compromise between completely off-line editing and completely on-line editing. Each new data set will be plotted at a common scale and compared to existing maps, photo source, and other plots to determine which areas of data must require additional analysis. These areas will be marked on the initial plot and eventually windowed at the Interactive Graphics terminal of the Edit Station. The plot will be aligned with the data base through the data tablet associated with each terminal to assist the operators in windowing portions of the data base. All routines of the Edit Station operate on an area basis instead of a single point. This reduces the number of commands and the time required to complete the overall editing process.

Editing will be divided into five major modules corresponding to the steps in the production cycle that generates new data files. These modules will include Geomorphic Edit, Epipolar Edit, Matrix Edit, Fill-in Edit, and Edit of Model Joins. The following sections describe the basic operations that will occur within each module and a general description of the hardware components.

EDIT SYSTEM HARDWARE

The IPIN Edit System is composed of a central processor called the Edit Processor and several intelligent satellite terminals. It is designed to handle all the editing and plotting functions required for IPIN. A diagram of the hardware is shown in Figure 1.

Edit Processor

This processor is a ModComp II/45 mini-computer which acts as host processor to the Edit Stations and XY plotter. Its primary task is communications processing, but it is also available for background processing such as plot generation and some computations associated with terrain editing. It contains large scale disk storage for active edit files and high-speed communications link to the file manager.

XY Plotter

This is a high-speed flatbed plotter and controller and will function on-line to the Edit Processor. Plot files will be generated by the edit processor and plotted on a real-time basis or be spooled on a disk file for later retrieval by the plotter controller.

Edit Station

This is a collection of hardware and software to perform the actual editing. It contains a general purpose mini-computer, graphics controller, two data tablets, and two CRT display terminals. Each CRT display terminal and data tablet is considered as one edit terminal. Therefore, each edit station is composed of two independent edit terminals.

The general purpose mini-computer is a 16 bit system that will be time shared by two CRT display terminals through a graphics controller. It will have a minimum of 64K core and 10 million words of disk storage. It will be used for program development and in supporting the edit terminals.

The graphics controller will have computer graphics hardware/firmware designed to perform windowing, clipping, zooming, transformations, and vector/character generation. It will contain a 32K refresh buffer memory to be shared by the two CRT display terminals.

The edit terminal will be a high performance display CRT interfaced to the graphics controller. There will be two display CRT's per controller and the operation of each will be independent. The display CRT will have a minimum diagonal of 53 centimeters and a maximum spot size of .25 millimeters. The operator's interface to the terminal will be through a joystick, function switches, control dials, or keyboard.

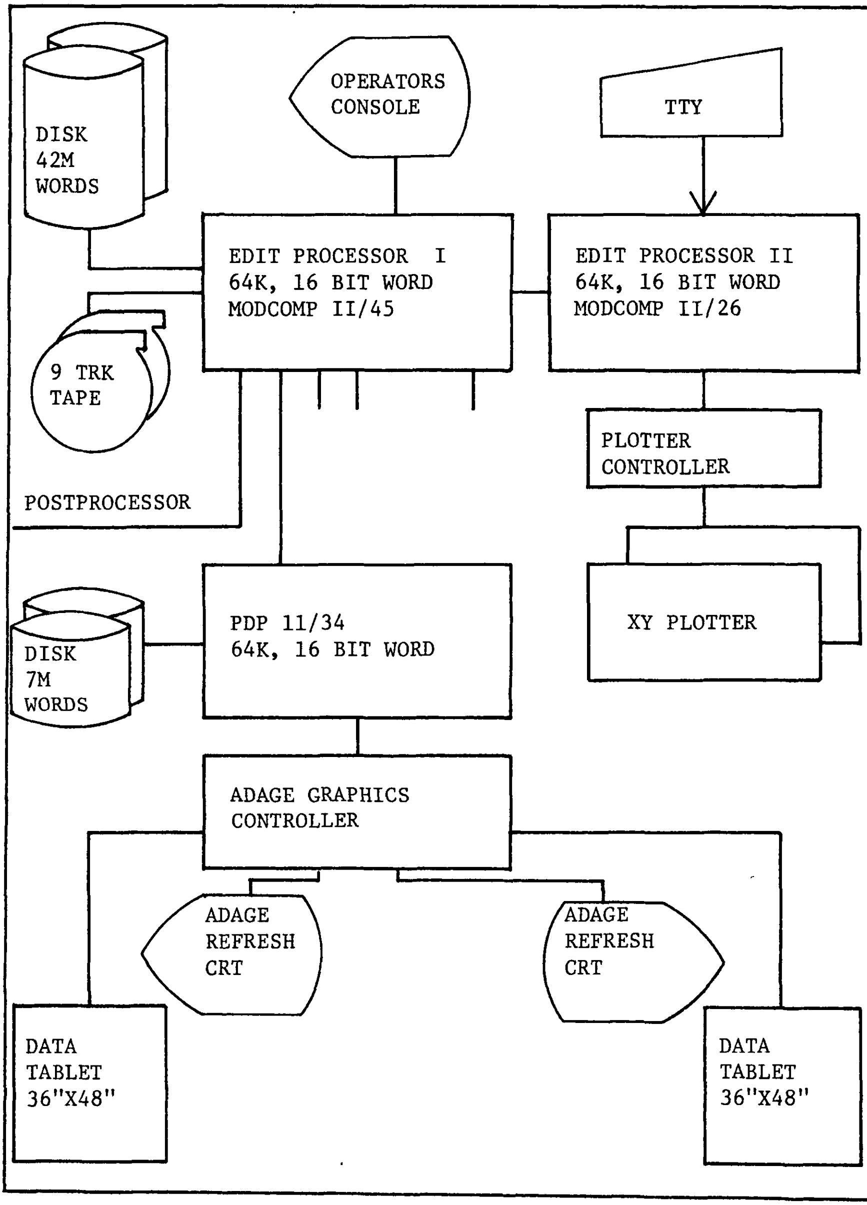

FIGURE 1. EDIT SYSTEM HARDWARE

Each edit terminal will also contain at least a 76 by 100 cm data tablet. Each data tablet will be interfaced to an edit terminal for operator interaction. A plot of the complete model data base and the operator's menu will be located on the data tablet.

EDIT PROCEDURES

The basic steps have been defined by the experience of DMAAC personnel in generating digital terrain data for the last three to five years. These anticipated edit steps, along with the volume of data and expected throughput helped to define the requirements for the Edit System hardware presented in the previous section. The software to execute each edit step is being designed and coded by DMAAC and the initial system is expected to be operational by July of 1980.

Edit of Geomorphic Data

Geomorphic data consists of natural features such as drainage patterns, lakes, ridges, cliffs, etc., and may contain some manmade features such as roads, railroads, canals, dams, etc. These features are compiled from aerial photography using X, Y and Z motions of an AS-11 Analytical Stereoplotter. The X and Y motions are controlled by handwheels to guide the floating mark and the Z motion is controlled by a footwheel to keep the floating mark on the ground. The primary source of errors that can be detected for the X and Y motions are procedural blunders, such as overshooting an intersection, placing incorrect labels on features, recording information while searching for features, etc. The primary editing of the X, Y elements of the lineal strings will be the deletion of the blunders without any attempt at smoothing features or performing any cartographic type corrections to lineal features, such as separating contours from lineal features or clipping intersections.

The footwheel controlling the Z motion of the stereoplotter is used to keep the floating mark on the model surface while following some feature. The footwheel requires a touch that is difficult to maintain. Hence, instead of a continuous decline or increase in the motion of the floating mark it is incremented in small steps. This vertical stepping is the primary source of error in the geomorphic data. The operator attempts to keep the floating mark on the surface but he continually overcorrects and undercorrects as he digitizes. The AS-11 stereoplotter records X, Y and Z coordinates of all collected data using an equal distance algorithm. Hence, if a drain or ridge line is considered as a straight line and each point were plotted on that line as a function of distance, then the plot would consist of a profile of the drain with equally spaced points. This information is used in the numerical smoothing algorithms to remove blunders and incremental steps of the X coordinate.

The numerical smoothing or editing of the data will occur at the collection devices before the photographs are removed.

Procedures at the edit stations will involve correcting the remaining anticipated geomorphic errors such as, assigning the correct elevation to lakes and shoreline points, correcting double line drains so that opposite shorelines are at the same elevation and the drain flows in the correct direction with the appropriate slope, and finally that the intersections of all drains are approximately at the same elevation.

A sample plot of geomorphic data is shown in Figure 2. This plot contains several lakes and the drainage patterns of the area. The grid network represents the basic definition of the data storage cells within IPIN. Each square represents the ground area covered by sixty intervals of matrix data.

Edit of Epipolar Data

Epipolar data is collected by the Advanced Compilation Equipment (ACE) Epipolar Plotter and is output in X, Y and Z model coordinates. The postprocessing component of IPIN converts this data to geographics and separates it into two files dependent upon each collected points figure of merit. The figure of merit is provided by the ACE and represents some degree of confidence in the correlated data. All points below an acceptable level are separated and plotted on the XY plotter and are used to show the areas of the model where the ACE has trouble correlating. A sample of this type of plot is shown in Figure 3. When two or more points are deleted in sequence, they are represented by a straight line. The actual flagging of the data has been accomplished at its source hence, the edit station is used to define the model areas that must be recollected. The edited geomorphic plot and unacceptable epipolar plot are superimposed and then a boundary file is generated to designate the fill-in areas. A sample plot of these fill-in areas is shown in Figure 4. The large void area in the lower right hand corner of the plot is not designed as a fill-in area since it falls within the large lake shown in Figure 2.

The operators will have the capability to review all or part of the acceptable epipolar data at the edit station, but this is not recommended due to the large volume of data.

Edit of Matrix Data

The matrix data is interpolated from edited geomorphic and epipolar data, hence, it is assumed that this data will be very close to being a final product. The first step after the matrix interpolation is the generation of a contour plot of the complete model referenced to the data base coordinates of latitude and longitude. A sample plot of this data is shown

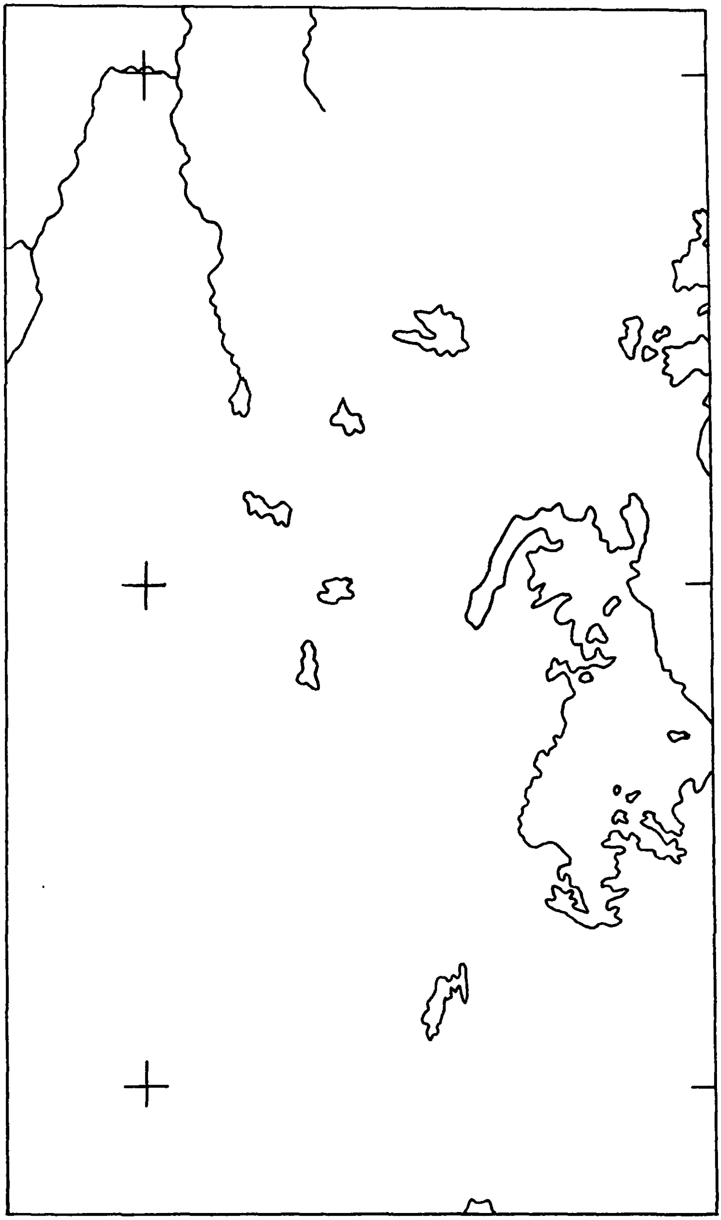

FIGURE 2. PLOT OF GEOMORPHIC DATA

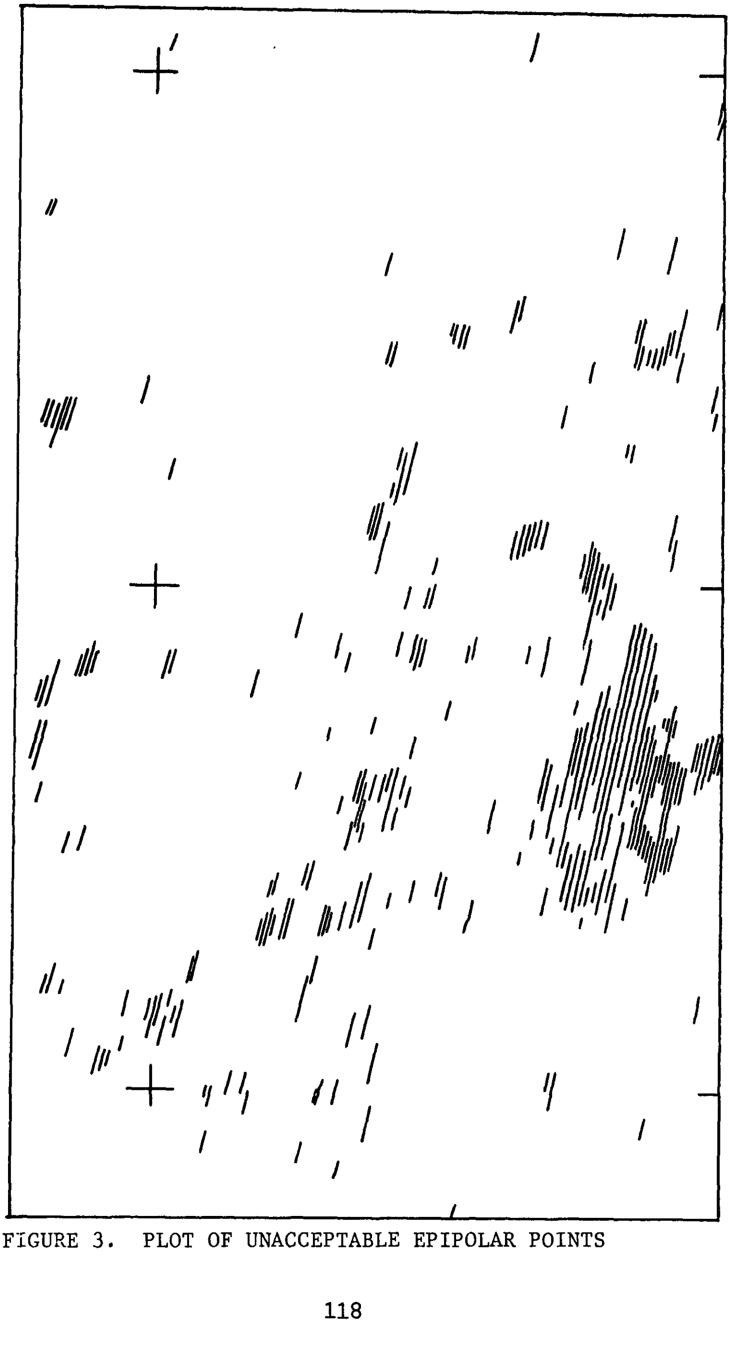

FIGURE 3. PLOT OF UNACCEPTABLE EPIPOLAR POINTS

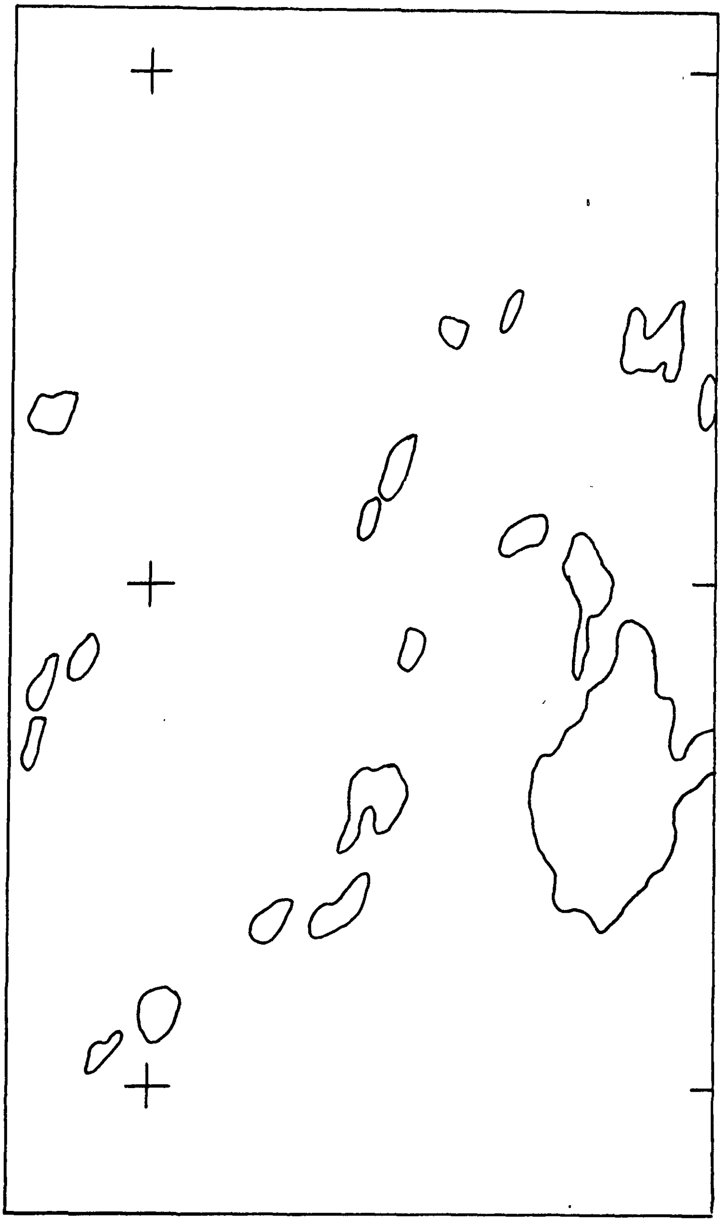

FIGURE 4. SELECTED EPIPOLAR FILL-IN AREAS

in Figure 5. The interpolation routine does not attempt to fill-in void areas. This is the reason the areas marked by the fill-in boundaries contain contours that are left hanging. The contour algorithm used for this plot is a simple linear routine to avoid misrepresenting the actual matrix.

The operator at the edit station will use the plot and all previous plots to locate areas outside the fill-in areas already defined that require his attention. He will have available most of the matrix edit routines that are currently being used to improve the aesthetic quality of the data or to designate additional fill-in areas. These routines include profile plots; polynomial smoothing by row and column or by area; deletion of data; interpolation routines; spike detection; etc. All of the routines are based on an area edit instead of single points.

Edit of Fill-in Data

Fill-in data is collected on the AS-11 Analytical Stereoplotter using the epipolar and matrix fill-in boundary files. These files are expanded by five rows and five columns to provide an overlap with the interpolated matrix data. The data is collected using a precise point matrix collection technique. The operator is directed to profile by the AS-11 Stereoplotter along meridians within the fill-in boundaries and the system records a point at every matrix interval. This matrix data is smoothed in the direction of collection on the AS-11 Stereoplotter and perpendicular to that direction at the edit station. The first step of the fill-in edit is the generation of a contour plot and then the comparison of this plot with all the previously generated plots. Next, each fill-in area is numerically compared to the interpolated matrix and is transformed using two rotations and a Z translation for each area to fit the interpolated matrix data. The operator at the edit station can use the derived statistics and elevation difference plots to determine if additional smoothing is required. He will be able to choose the common boundary of the two files, the method of data integration, (overlay, underlay, average of feather), and the acceptability of the completed matrix files. He also has all of the matrix edit functions available to correct any problems with the merged data sets. An example of the contour plots of the fill-in areas is shown in Figure 6.

Edit of Model Merge

The most time consuming operation at an edit station is the merging of geographic matrix data derived from two photogrammetric models. A major assumption of this process is that the control for each model is derived from the same photogrammetric block adjustment and that orientation and Z adjustment of each model is based solely on that control. This implies that any problems with model joins must be

FIGURE 5. CONTOUR PLOT OF INTERPOLATED CONTOUR DATA

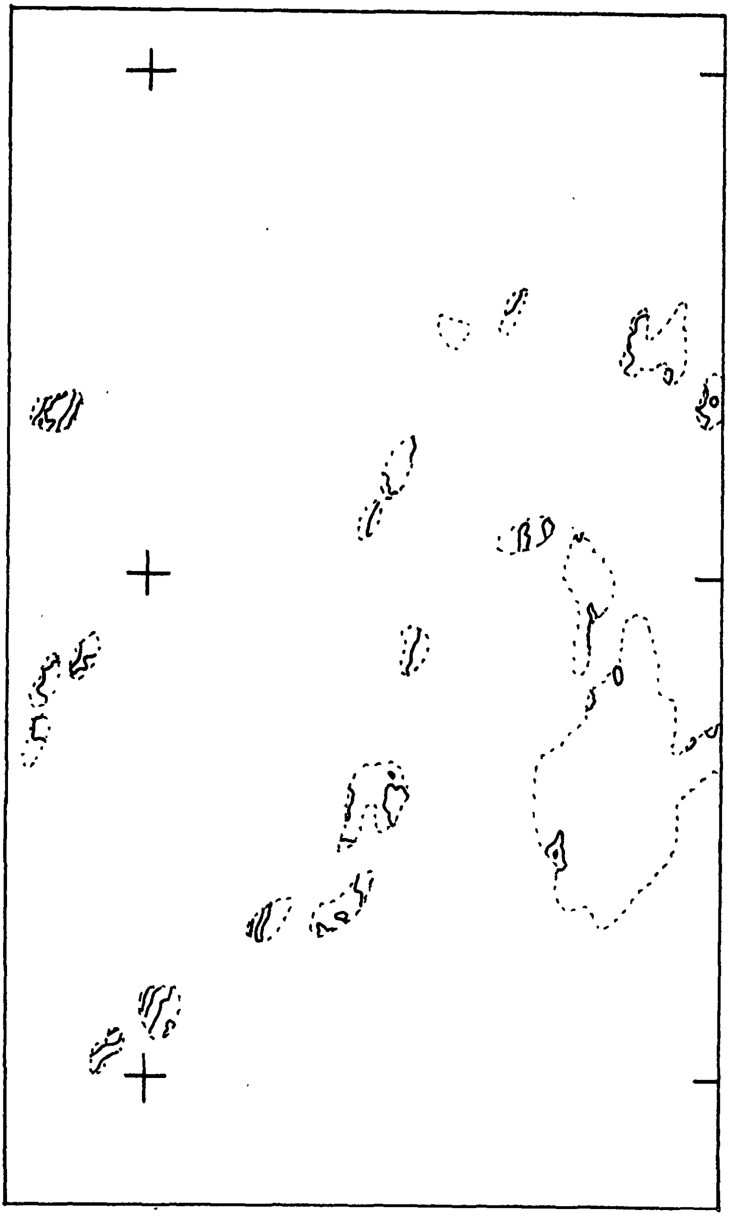

FIGURE 6. CONTOUR PLOT OF MATRIX FILL-IN AREAS

absorbed in the merger if the differences are within the predicted error of triangulation. The only type of merging that is allowed is for the common data sets to be averaged or feathered across the model join lines.

The procedure at the edit station is for the operator to load the matrix data in the overlap areas of both models and to compare common storage cells on each end and middle of the overlap region. These three areas are used to determine what technique and how many points should be used for this merger. The edit station will provide statistics, difference plots, and profile plots to assist the operator. Once the merge parameters are determined, then the complete overlap area is merged numerically and the statistics of each storage cell are computed. The operator has the same edit routines to correct or plot the merged matrix data as the matrix edit module.

All the models from a common photogrammetric strip are merged first. The matrix data for one model is then unique along that strip. Next, the overlap between adjoining strips are merged and this then generates a unique matrix file for each model. The last step of the process is the generation of a composite one degree square of information or submatrix that is not based upon model definitions, but data base areas. The basic area is a one degree square, which can vary according to matrix interval. Therefore, the basic matrix output file contains matrix data with a maximum of 1200 columns of elevations data and 1201 elements per column. The southwest corner of each submatrix is always a multiple of 1200 intervals times the matrix interval.

SUMMARY AND CONCLUSIONS

The Edit System has been defined for IPIN and its software development is well underway. It was designed to handle large volumes of data and to meet a stringent production schedule. There are several cartographic edit systems available, but this is the first system that attempts to operate in the realm of digital terrain matrices and pushes the state-of-the-art in interactive graphics.

A UNIFIED SYSTEM FOR TERRAIN ANALYSIS AND MAPPING FROM DEM AND DTM

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Computer technology was originally introduced into terrain analysis and mapping in two distinct developments. In one of these, map production units adopted digitization of terrain features and computer graphics to reduce the costs of production. This development is now proceeding at a very high rate, and has already resulted in some maps that are completely computer-drawn. Engineering plans and cadastral maps have also been completely computerized by a few institutions. The other line of development was inaugurated by geographers, whose original goal was to derive numerical parameters to characterize and describe various terrain types. For this purpose, much work was done on fitting analytical surfaces to digital elevation data, and in such exercises as cluster analysis and trend analysis of thematic data. It now seems reasonable to say that analytical surface-fitting is dead, except perhaps for local smoothing operations. The statistical techniques have some value in mapping such variables as population, traffic patterns and the like, but seem inappropriate for deriving physical terrain properties or combinations of properties.

To an every-increasing degree, the computer is now being used to provide direct and quantitative answers to simple but important questions such as the ones described in this paper. Most of the change in emphasis has arisen from the advance of digital electronic techniques, including more rapid and accurate data capture as well as the tremendous increase in capacity and speed of the computer itself. The present authors happened to adopt this approach from the outset (Collins, 1975), and the result has been the development of a powerful series of programs. All of them are intended for economical processing of terrain information, and some of them produce terrain parameters that are unique and highly useful. (Collins and Moon, 1978; Collins, Moon and Fetter 1979). This paper will describe in a more complete form the approach that is being used by the authors for analysing large amounts of terrain data, typically involving models with 10^6 or more points.

Methods of Data Storage and Analysis

There are two methods of data capture which lead directly and naturally into two different methods of data storage. There has been a tendency to preserve this differentiation into the data-analysis stage. One method of data capture, exemplified by contouring, profiling, and outline drawing in photointerpretation, is the polygon method. Terrain information is digitized in continuous or discontinuous strings of points, each with x and y coordinates and one coded attribute. The other method is the grid-cell method. Coarse grid-cell techniques have been used for many years by geographers, hydrologists and others to record and combine broad terrain features. More recently, remote sensing with its many forms of digitized images has provided new data in a dense-grid form, and dense grids of elevations have been provided by the Gestalt orthophoto system (Brnjac et al, 1976).

Storage in polygon (and isolated single point) form is inherently economical, because it involves storing only the data that are essential to describe each significant terrain feature. Some terrain analyses have been carried out by working directly from the polygon structure, but generally speaking it is difficult to derive terrain descriptions from combinations of several types of data stored in polygon form. In addition, while polygonal and grid data can be mapped on one base easily enough, there are computational difficulties in combining information from the two types of data source.

Storage of data in grid-cell form provides a simple means of stacking many pieces of coded information on each point, and thus allows the application of simple and very fast programs for producing derived thematic maps. In fact, digital image processing and thematic map derivation take on similar characteristics as the grids on which the terrain data are stored are increased in density. Some suggestion will be made in this paper of the speed and power of the programs that can be used for manipulating gridded terrain data.

The obvious drawback of handling terrain data in grid form is the storage problem. The approach used by the authors has nullified this problem for project-sized operations, involving up to one million grid points, but storage in direct grid form for large geo-referencing systems is out of the question. For a single project area, the grid that is fine enough to allow accurate representation of the terrain may be redundant over sections where there is little variety, but the redundancy is not significant compared to the extreme speed of data processing. For large geographic areas the redundancy factor increases rapidly, even though somewhat coarser grids may be used.

About two years ago, it became evident to the authors that the strengths of the polygon and the grid system would have to be united into one comprehensive terrain analysis and mapping system. The examples following will show the steps that have been taken to effect this unification and the potential value of the approach.

Analysis of Dense Digital Elevation Models (DEM)

Dense digital elevation models in grid form (primarily from the Gestalt orthophoto system) have been used to extract quantitative information for hydraulic and hydrologic applications. Watershed analyses have been carried out to quantify the number, areas and potential storage volumes of depressions on scales ranging from small test plots up to very large hydro-electric head lakes. The programs for these purposes have been derived largely from the algorithms described first by one of the authors in 1972 at the Fall Convention of the ASP and published later (Collins, 1975). Only the reservoir storage volume and area program system has been completely developed in fast languages for commercial application (Collins, Moon and Fetter, 1979).

In this system, polygons were added to the grid data to delimit specific areas of interest in order to save computer time and also to represent specific dam sites (Figure 1). The Gestalt data have a spacing at the original photo scale of 0.1816 mm, giving a ground spacing of about 5.5 m at the 1:30,000 scale of the photographs used for this project. The valley chosen for the project was extremely deep with side-slopes up to 70^{o}, and the Gestalt data showed some imperfections. But a comparison with conventionally-plotted contours showed that the grid data represented the terrain very well, and the resulting computations of area and volume were of high precision. The complete process of plotting contours from the DEM, delimiting the study area and including the dam site, computing the flooded volumes and areas for many stages, and plotting the flooded areas at each stage, required just 5 minutes of CPU time on an Amdahl V5 computer. Within the delimiter, about 250,000 points were processed.

It is interesting to note that, using Gestalt data and the present program system, it is reasonable to derive stage-volume data at much closer stage intervals than can be used for contour plotting. The computation time is almost independent of the number of stages that is called up, and the precision of the Gestalt data would permit an interval of about 5 m, much closer than the contour interval that might be used in such mountainous terrain.

Thematic Mapping from DTM

The well-known advantages of using a grid base for the extraction of interactions among several layers of thematic data has led the authors to create fast programs for this purpose. The natural ease of data capture and storage in polygonal form, and the desirability of being able to map the outlines of derived features made it necessary to write programs for converting polygons to grids and vice versa.

The program adapting polygon data for use in grid-cell analysis is especially interesting. Any data source capable of generating closed strings of points in cartesian coordinates may be used. The program creates grid points from the strings, and identifies all interior grid points with the strings. The software carries out this identification without regard to the order in which the string points were digitized, and will handle highly convoluted and multiply-connected strings. This simplifies the process of digitizing because it is not necessary to supply an identifier for the interior of the string or for the direction of digitization.

First Version of THEMAPS

For areas of 'project' size, it is efficient to use the conversion program above to attach all thematic data to every point of a dense grid. Thus each point carries a stack of data cells which carry coded values of the input themes. The process of selection is then, in principal, similar to the common methods where attributes are manually coded to a coarse grid of terrain cells. The selection may be carried out either by logical algebra, which is very fast, or by arithmetic functions which are more flexible but which may take somewhat more computer time.

As an example of the speed of this first version for work on a project scale, five different photointerpreted overlays, some of them highly complex, were combined into a grid data base of 500,000 points. Using logical algebra, any combination of the properties from the overlays could be derived in less than 10 seconds of CPU time on an Amdahl V5 computer. (One combination, for example was: Slope from 15 to 20%, Soil type sand, Vegetation trees $>$ 5', Tree spacing 3', Moisture conditions wet). A shaded plot in black and white or in colour can be drawn of the selected areas. A fast program is also available for drawing outlines of the selected areas.

Second Version of THEMAPS

The second version is one that has important implications for the creation and use of large amounts of geographically-based information. It may be called a 'virtual-grid' method, and it combines the important qualities of the polygon and the grid into a unified system. The input data is stored in the original polygon form or in the form connected to the grid, and can quickly be converted from one to the other. The storage requirements may be one tenth or less than those for the complete grid data base.

The selection process, whether by logical or arithmetical algorithms, proceeds directly from the stored polygons, which are called up only as needed by the selection algorithm. The program will economically select combinations of features from up to 300 polygon files at a time, using less than 64K bytes of main memory. It is thus usable on any minicomputer. The value of this great competence for calling up and combining data will not be realized in most single projects, but will be fully appreciated when large data banks are to be used.

Nobody is going to want to derive thematic maps from 300 data sources for any one job, but the power of this program allows the simultaneous derivation of many thematic maps from such a large data base, at one pass through the computer.

As an example of the economy of the programs of Version 2, multiple derivations have been made in 10 to 20 seconds of CPU time on an Amdahl V5 computer, for the equivalent of an 800,000-point grid data structure.

Display Techniques

A tektronix 4027 colour terminal has been used to display some of the results obtained from the programs above. Individual themes derived from a common data base are displayed in different colours, and it is possible to use special colours where conflicting themes overlap. The instrument allows the operator to modify the colour selection after the display is complete, without replotting, in order to accent the most important features that are shown. The final results can be photographed, recorded on video-cassette, or plotted in continuous-tone or in outline mode.

Comments on Terrain Data Storage

In the light of these developments, it may be instructive to look again at the basic methods of data storage. In most grid cell techniques, the data are stored 'vertically' as a list of attributes attached to each cell. This method was and is used effectively in the first version of Themaps. The amount of data to be stored on every point is determined by the total number of classes of input data, and is thus highly redundant in two senses. Firstly, the terrain variability may be high over part of the area, and low over most of it. Secondly, many of the decision functions to be applied will require only a few classes of information from the data base. Both of these factors mean that most grid cells are loaded with far more data than are required for deriving any one combination.

Storage of features in polygonal form can be considered as 'horizontal' storage, in which each terrain classification can be called up independently. The second version of THEMAPS has this advantage, and only the classes of data or 'overlays' that are necessary for one computer run (which may involve many different derivations) will be addressed.

Summary

Program systems have been developed for producing thematic and engineering maps and data from the most useful data sources, polygons and grid structures. The programs combine the advantages of economical data storage with very high processing speeds, and permit the parallel derivation of several or many types of thematic maps from the same large polygonal data files.

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THE DIGITAL TERRAIN MODEL AS A DATA BASE FOR HYDROLOGICAL AND GEOMORPHOLOGICAL ANALYSES

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Introduction

All land based activities, natural and those performed by man, are influenced by the geomorphology of the area in which they occur. Geomorphologic or terrain characteristics such as slope, aspect and elevation influence a number of natural processes including soil formation, floral development, erosion-sedimentation and hydrology. The same parameters are important considerations in the location and modification of man's structures and activities on the land surface; as an example, the internal and external costs/impacts for man's activities increase directly with slope. Despite the obvious influence of terrain characteristics on process response systems that man is interested in managing to his advantage, e.g., soil erosion, nonpoint source pollution, stormwater runoff, little has been done in determining the causal relationships involved.

Much of this lack of understanding can be attributed to a lack of technology to aid in defining these relationships. The technology required must be able to both define the terrain characteristics of an area in unambiguous and spatially unique terms and utilize these data as data inputs to process-response models for analysis. Such an approach implies that the process-response models must be sensitive to not only the terrain parameters of interest but also the unique spatial location in which they occur. The latter consideration is particularly important to allow both location and terrain characteristics to be independent variables in analyses. Relationships derived under these conditions are, then, transferable to any other terrain. The nature of the technology required to bring about such understanding is simulation modeling, in this case, the simulation of terrain.

Conceptually, the terrain model must attain two special conditions: 1) provide a continuous surface and 2) define the spatial/locational relationships of the surface. The former condition is necessary to provide model continuity; the latter defines model connectivity. To date only one conceptual model has been developed for terrain representation that meets both these conditions: the triangulated irregular network (TIN). The TIN concept has been used to develop digital terrain models (DTM's) as part of the ADAPT system, which is a computer-based geomodeling technology developed by W. E. Gates and Associates. The ADAPT system has utilized the terrain simulation provided by TIN to produce sophisticated engineering and planning information both rapidly and at low cost. (An example ADAPT system application, a hydrologic study conducted in northeast Ohio, is presented in another paper in these proceedings. Reference 1.) The subsequent sections of this paper are intended to describe the TIN concept and its applicability as a data base for terrain and hydrologic analyses.

The TIN Concept

The triangulated irregular network concept is based on the surveying technique of triangulation in which uniformly sloping triangular areas are defined by lines of constant slope. The three vertices of a triangle are assigned unique locations in space-latitude, longitude and elevation-which in turn define a uniquely oriented triangular plane in space (see Figure 1). In order to prevent warping or discontinuities in the surface between triangles the network design process allows a maximum of one adjacent triangle along any triangle side (see Figure 2). The triangular network, then, provides the basis for a continuous surface representation and an appropriate DTM.

Perhaps the best feature of the TIN and, at the same time, the least liked by many professionals in the DTM field is the manual design of the DTM which is a

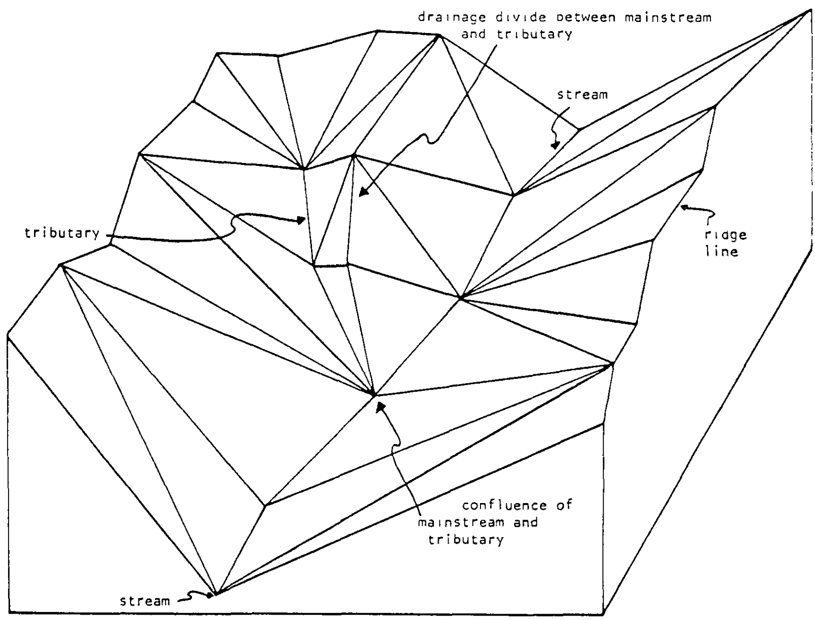

Figure 1. An Example of Triangulation Representing Terrain.

requirement and not an option. There are no random points or lines in a TIN; each vertex location is a high information point, e.g., a stream confluence or ridge intersection, and each line is a high information line, e.g., a stream segment or a slopebreak. In addition, because triangles can vary in size and shape there are no inherent constraints imposed by the TIN in the degree of terrain representation possible. (Generally speaking, the more detailed a terrain representation is the easier it is to design; however, the incurred production and operating costs per unit area go up dramatically with increased detail.) As a result, a DTM designer must not only be skilled at perceiving terrain in three dimensions from elevation contour maps but must be able to perceive the level of surface abstraction appropriate for the purposes the DTM is intended to serve. These design requirements, although somewhat demanding, are necessary to produce a TIN

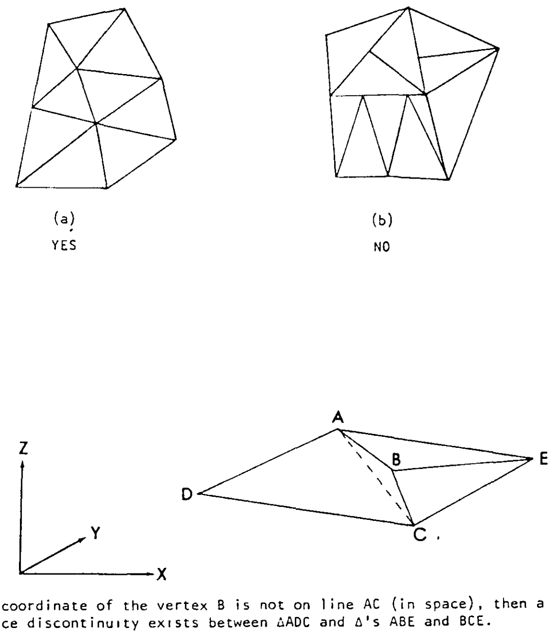

Figure 2. The Surface Continuity Solution for a TIN

which does in fact represent an actual terrain surface. A TIN DTM is by design an intelligent (i.e., nonrandom) network and because of this feature allows for computer software to be developed which automatically defines the spatial and locational character (i.e., connectivity) of the DTM.

Development Of A DTM Data Base

There are a number of ways to set up a DTM data base from a TIN. The ADAPT approach, which is the one most familiar to the author, creates a triangle (i.e., cell) file and a vertex file from the TIN. Each triangular cell is uniquely numbered as is each vertex by ADAPT software. The latter specification enables adjacent triangle pairs to be identified by software, thus, establishing the neighborhood relationships or topology of the DTM. In addition, the latitude and longitude for each vertex and triangle centroid is calculated and stored. This specification enables the DTM to be geodetically correct as to spatial location as well as providing an absolute coordinate system. This unambiguous and geodetically-correct topologic system provides the framework for both surface continuity and connectivity.

The fundamental topographic data for each cell, i.e., area, slope and aspect, are calculated from the vertex coordinates and stored in the triangle file. In conjunction with the DTM topology the topographic data define in digital format the three-dimensional character of the terrain surface.

Some Applications Of A DTM Data Base

As an example of how this DTM data base can generate terrain information, ADAPT software has been developed which automatically defines the stream and overland flow networks embedded in the DTM from the stored topologic and topographic data in the triangle file. Additional software uses this information to partition the DTM into any hydrologic unit specified. Thus, the hydrologic connectivity of a TIN DTM is automatically derived from the digital format.

A series of computer derived graphics are presented in Figure 3 which display alternative characteristics of the same DTM. The watershed modeled is a headwater portion of the Silver Creek basin in Madison County, Kentucky with a total area of 28.5 square miles. The two-dimensional projection of the DTM, which was drawn from a 1:24000 scale U.S.G.S. topographic map, is presented in Figure 3a. The overland flow and stream networks which are generated automatically from stored slope data are presented in Figure 3b. An elevation contour map of the DTM, generated by easily attainable software, is presented in Figure 3c. Contour maps have not been found to be a particularly useful analytical product but they have proven to be a convenient means for the DTM designer to verify the desired accuracy of the terrain model. Figure 3d is a shaded plot display of the aspect (i.e., orientation) of each triangular cell within the watershed. These same characteristics can be analyzed by software to provide statistical data such as the basin average value for slope, area-frequency analyses (e.g., histograms) for aspect or

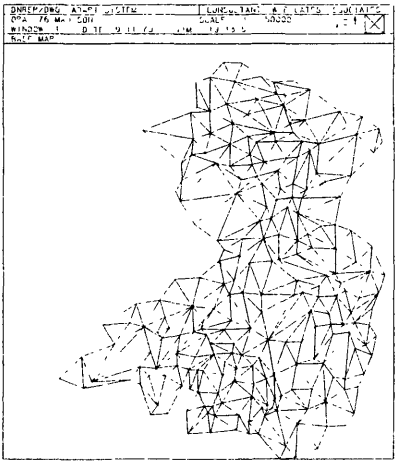

Figure 3a. TIN DTM Projection

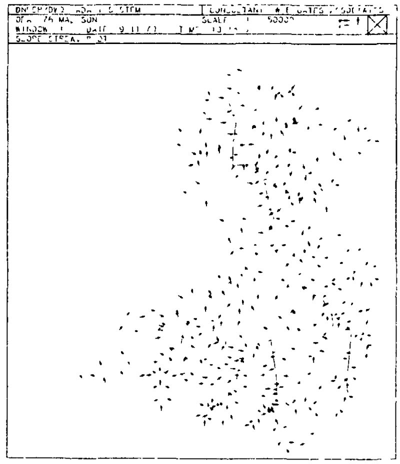

Figure 3b. DTM Overland Flow and Stream Plot

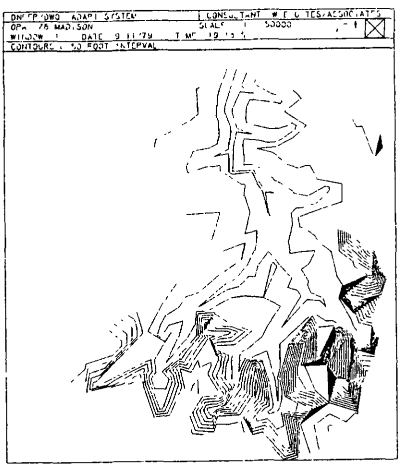

Figure 3c. DTM Contour Plot

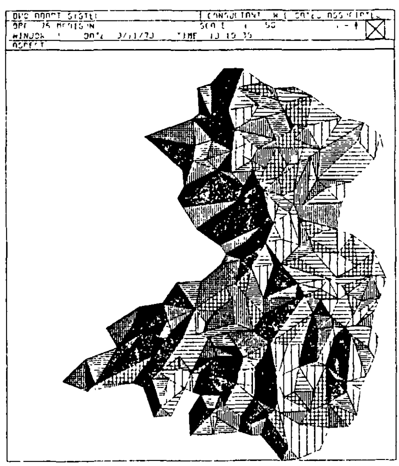

Figure 3d. DTM Aspect Plot

Figure 3. Example Computer Plot Displays of DTM Data Base for Silver Creek, Madison County, Kentucky

total length of streams. The DTM data base can be and has been used as input data for process-response models such as rainfall-runoff and erosion-generation models. With the unique spatial location characteristic of the DTM, it is possible to define the impact of individual land parcels on unit hydrographs or sediment loadings predicted by the models.

Conclusion

Much of the effort currently being devoted to the new and rapidly evolving field referred to as digital terrain modeling focuses on the need of mapping agencies to quickly and accurately produce elevation contour maps using low and high altitude photography as a data base. That one cannot produce a DTM without an accurate elevation contour map should not obviate the fact that a contour map is the starting point, i.e., the data base, for a terrain model. This could explain to a large degree why terrain specialists such as geomorphologists and hydrologists have not participated in the evolution of the field up to this point. The TIN concept, however, provides both a data base consistent with the needs of terrain specialists and a means to utilize the cost-effectiveness of the computer in analyzing the significance of terrain characteristics on processes such as erosion-sedimentation, hydrology and land stability.

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URBAN MAPPING SESSIONS

URBAN MAPPING

There was a total of three urban mapping sessions. John Lay of Fairfax County, Virginia and Ron Domsch of Wyandotte County, Kansas, co-chaired these three sessions.

John Lay gave a paper entitled "Mapping Services in Fairfax County Virginia". In this paper Lay describes the land parcel based mapping system of Fairfax County. In this system the individual land parcels can be combined to form a property identification map. These latter maps can then be mosaicked to form the base data for the street location map. Finally, the street location map becomes the base for the overprinting of information related to the entire county.

Ron Domsch have a paper entitled "Urban Mapping Applications: Census Tracts Through Ownership Parcels". Domsch reviews some of the earlier applications of geographic base files for Wyandotte County. He also describes the more recent developments in the area of parcel level mapping. Domsch foresees a productional mode level of applications in this area in about 2 years.

James Wray of the U.S.G.S. presented a paper entitled "Examples of Automated Cartography in Presenting Land Use and Land Cover Maps and Data". (Paper not included in proceedings.) Illustrated examples included maps for the cities of Pittsburg, Atlanta, Wichita, Kansas City, Washington, Seattle-Tacoma, San Fransisco and Alaska's National Petroleum Reserve. Since these maps were not all produced in an identical manner, a comparison provides some interesting ideas for map presentation format. In particular, these maps provided insight into the preparation of thematic Earth Science data for video display and for publication in an updated National Atlas.

Leonard J. Simutis and Todd Scott of Virginia Polytechnic Institute presented the paper "Interactive Computer Mapping Applications in Criminal Justice Planning in Three Virginia Cities". This paper describes research in criminal detection at the local level in Portsmouth, Norfolk, and Hampton Virginia. Particular emphasis is placed on the use of interactive mapping as a heuristic device in problem recognition and discovery. Also included are examples of the use of exploratory data analysis techniques.

Thomas K. Peucker of Simon Fraser University and Andrew Clement of Vancouver City College presented the paper, "Interactive Computer Mapping". This paper describes a project for the interactive analysis of spatial data via the thematic map. The advantage of this system is the speed with which a query can be answered. The system also has a very flexible data structure which the authors feel could be an example for similar studies.

Richard Lycan of Portland State University presented a paper entitled "Alternatives to the Population Pyramid for Mapping Age Sex Characteristics of Metropolitan Census Tracts." Two types of maps are typically used to display data on the age and sex of residents for use in the planning of health care and other social service programs. Seventeen choropleth maps and twenty-one multiple population pyramids were superimposed on a base map. The author describes several alternatives to these techniques including 1) a typology of pyramids for use in the legend to facilitate reading an age-sex pyramid map, 2) a process color map, and 3) a polar coordinate type symbol. These alternatives are based in part on a factor analysis that reduces the number of categories to be mapped.

Eugenia Calle of Oakridge National Laboratory presented a paper entitled "Computer Mapping of Cancer Mortality by Census Tract: Columbus, Ohio 1956-1974". This paper offers a geographic description of cancer mortality at the intracommunity level using the census tract as the basic unit of allocation and comparison. A statistical analysis is based on the use of the Poisson distribution to determine the significance of age, sex, and race adjusted Standard Mortality Ratios. The results show that it is possible to detect certain "high risk" areas using this technique.

Joel Orr presented a paper entitled "Urban Uses of Geo-Based Data: Getting the Technician out of the Way". Orr considers one of the major problems of geoprocessing projects to be the satisfaction of technical considerations at the expense of the user. To solve this problem he recommends an intensive design procedure, wherein the user makes his needs known to the technical team in progressively greater detail, while the technical team concurrently works with the user to give him a progressively better understanding of the limitations and capabilities of the technology with respect to the user's needs.

MAPPING SERVICES IN FAIRFAX COUNTY, VIRGINIA

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Trying to maintain a series of 446 Property Maps for Fairfax County is no small chore. About 9,000 new parcels of land are added to the tax rolls each year Most of the additions come from formal dedicated subdivision. The subdivision may consist of as few as two lots or as many as two thousand lots. Many of the lots are just simple divisions of land put record. Then again there is the planned development community such as Reston which encompassed 7,400 acres and was designed to house 75,000 residence and to support its own population through industry, employing Reston residents in research, development and governmental installation within the various industrial complexes.

Whether it is the recorded subdivision or a simple lot division the change has to get to the map. Most subdivisions are straight forward drafting changes as the bounds are in fair order on the Property Identification Map. This is because there has usually been significant activity in the area. The survey for the land title transfer and rezoning action are compared to the Property Identification Map long before the subdivision goes to record. Any change in bounds are researched and corrected as they are found.

Often a parcel of land is divided without the benefit of a survey. Descriptions such as the East half, all that portion north of the creek, one acre wide etc., don't help in the least to update the map and correct errors that have been carried for years. Fortunately most deeds now are prepared from rather good surveys and present no problem in transfering them to the map.

Property Identification Map numbers are shown on the deeds now recorded in Fairfax County. This aids greatly in location of the land parcel on the map particularly when rather sketchy descriptions are used. This is a direct result of the action taken by the Fairfax County Board of Supervisors to have the number shown on deeds of record.

The Property Maps are continually in a stage of update. Revisions for the maps are abstracted from the deeds recorded in the Clerks Office. A special section is set up in the Assessors Office which reads each deed put to record, about seven hundred pages a day, and makes appropriate transfers as needed. Transactions which require property map revisions are identified and as the Assessment Office provides the information to the Mapping section on a Land Record Card, it is researched, if necessary, and drawn on the work sheet set of maps. The new parcel is identified with a unique map number and the Land Record Card is returned to the Assessors Office where it is entered into the Master Land Data Bank.

The final drafting on the mylar original map might not be done immediately. The revision of the originals is usually done in sequence twice a year or so. This is done to eliminate excessive handling of the originals and it also helps to be certain that no minor corrections are overlooked.

Subdivisions usually get on the maps sooner. They are laid out on the work sheet first and then drafted onto the original.In an effort to reduce manhours required for the drafting of subdivisions only the exterior of the area subdivided is platted to scale. This plat is then compared to the Property Map. If the limits on the Property Map agree with the subdivision limits then a photographically reduce to scale copy of the subdivision is traced directly onto the mylar.

If errors are detected they are resolved prior to putting the subdivision on the map from the time that the subdivision is put to record and it appears on the final map. This process is stepped up to provide for the demand that is made for the revised map by the Real Estate Appraisers.

The preparation of the Zoning Maps for Fairfax County is probably the most important project of the Mapping Section after the production of the Property Identification Map.

An average of one hundred and seventy rezoning cases are considered by the Board of Supervisors each year. Using the Property Identification Map as a base an overlay is prepared to reflect the status of any zoning case from the time that it is filed until it is final by the Board of Supervisors. The average rezoning case takes about eighteen months to complete. The complete annotation of all zoning cases since 1941 are reflected on the overlays. This is done to allow the staff and other interested persons a ready means of running a zoning history on any given parcel of land.

The Zoning Overlay worksheets are updated on a weekly basis after each Board meeting. There in excess of thirty zoning catagories for Fairax and they are continually being added to.

The Zoning Maps are designed for Ozalid printing for maximum convenience. To provide a better presentation of land use density a projectable color transpariency is also provided. The standard land use colors are used as much as possible. The projection transpancy is maintained at a scale of 1"=1000'. All of the transparancies are trimmed at the neat line to allow them to be mosaicked for projection of areas which span more than one map.

The Property Identification Map and the Zoning Map series are published each year in book form at a reduced scale of 1"=500'. These complete sets are of a convenient scale for desk top or automobile use. These reduced scale maps are also used for developing a base map to add specific information for a particular project.

The Property Identification Map is the source data for the preparation of the County Street Map at 1"= 2000'. Once a year all of the Property Maps are printed for the purpose of picking up new streets. The new streets are marked over with a magic marker to make them readily identifiable. The full scale map is then reduced to 1"=2000' through the use of a digitizer and plotting board. The neat line of the map is plotted and all new streets are plotted. Often one or two of the major roads are plotted to assure better control of the new streets on the overall county street map at 1"=2000'.

These reductions are controlled to proper location by aligning them with existing street patterns.In areas of all new development the index grid is used for control. This grid was prepared with the use of a Computer Plotter to gain as much accuracy as possible. This grid is established on a geodetic projection and each intersection represents a base map sheet corner.

The new streets are scribed on the original scrib coat street map base. The street names are then transferred to the street name overlay and positioned for best readability.

The street map base is divided into four quads at the scale of 1"=2000'. The full county map would be seven and a half feet square. By dividing it into the quads it is made easier to work with. The old street base map was scribed on a 1"=4000' base and it was found to be much to tedious to work with.

The complete process for the preparation of the street map is done in-house. When the package goes out to the printers it is camera ready. Most of the maps printed in color are done using flat inks. Some of the maps, the County Wide Land Use Map for example, have so many zones that process colors are used.

For most map production the 1"-2000' scale base is mosaicked and reduced to 1"-4000'. Overlays for information data are overprinted on the base map. The annual map printing for the County of Fairfax is about twelve different maps with a total of 7000 maps more or less. Not all maps are printed every year.

Some are only printed as the stocks run out, such as the Watershed Map or the Planning District Map. Other are printed every year to reflect the most recent change. These are the maps which show Park Lands, School Locations, Police Patrol Areas and the like.

Special purpose maps are made on request and are individually prepared on preprinted base maps. If there is a need for quick turn around maps an overlay is made on clear film and registered to a clear film map base. This combination can then be made into a sepia for additional Diazo printing or photographed for offset printing.

Should the request for a color map be placed on the Mapping Section and sufficient time is not available to prepare the proper art work for printing the color separation plates are prepared with a camera from hand colored maps. The printing of the maps is then accomplished with process inks. It is not a very high quality production but it does put a product on the street fast.

To facilitate the delineation of data for the 1"-2000' base a mosaic of the property map has been prepared. This is done every two or three years as needed for current information. It is a very simple process. The 1"-200' scale Property Identification Maps are photograpically reduced to 1"-2000'; reverse reading, positive image. These reductions are trimmed at the neat line and mosaicked together. An index grid is used to control the mosaic which is put together on a clear Mylar base. The images are held in place with double sided clear tape. We have also used rubber cement with good success. The advantage of the double sided tape is that if the image has to be shifted it can be done with little trouble.

As I said in the begining maintaining the maps for Fairfax County is not a small chore. The demand for services must be met with adequate funding and personnel. The Mapping and Graphics support personnel number twenty-three positions and in excess of $380,000 per annum funding. There is plenty of room for improvement and I welcome comments on our Mapping Services in Fairfax County, Virginia.

URBAN MAPPING APPLICATIONS
CENSUS TRACTS TO OWNERSHIP PARCELS

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Introduction

Geoprocessing is a production mode function in Wyandotte County and Kansas City, Kansas. Geoprocessing applications utilize one or more of three geographic base files: ACG/DIME, parcel, and sanitary sewer network. The uses of these base files and their derivatives fall generally into three categories: computer mapping, base file for data, and analytic tool. A chart has been provided which categorizes the applications mentioned in this paper. This paper will provide a synopsis of the development of our local geoprocessing capabilities, discuss two recently initiated urban mapping applications (the Wyandotte County land data system and a parcel level land use system), and finally make some suggestions regarding the building of geographic data bases.

Development of Local Geoprocessing Activities

The nature of urban mapping applications in Wyandotte County is partly attributable to a decision by the Board of Public Utilities and Kansas City, Kansas in 1965 to begin the acquisition of large scale topographic base maps[1]. This base map series has been maintained with funds from a consortium of City, County, and public utility departments. The decision to acquire these maps was made without consideration of any geoprocessing capabilities that were to develop six years later.

URBAN MAPPING AND RELATED AUTOMATED APPLICATIONS
WYANDOTTE COUNTY AND KANSAS CITY, KANSAS

CATEGORY OF USAGE	GBF/DIME	PARCEL GBF	SANITARY SEWER GBF
Analytic Tool	- ADMATCH - Intersection matcher - Computation	- UNIMATCH* - Computation	- Capacity and flow modeling - "Address-to-pipe" linker* - Computation
Computer Mapping	- Choropleth - Dotmap - Network display - Incidence mapping	- Choropleth - Street right-of-way* - Parcel display with LANDS data* - Incidence mapping*	- Network display
Base File for Data	- Street inventory - Street sign inventory - Address file	- LANDS - Land use* - Zoning* - Address file	- Maintenance data* - Complaint data*

* Planned application

Local geoprocessing began with the development of a GBF/DIME file by the City in 1972. The DIME file was constructed from topographic base maps with a superimposed network. Street name and address information for each structure was acquired in the field by Post Office mail carriers and placed on the maps by planning department personnel. Once all DIME file coding was complete, the nodes were digitized. A system for added shape or "contour" points between the nodes for a single segment was developed and these points were also digitized. The result, after a great deal of editing, was a highly accurate DIME file with very precise coordinates.

The implementation of ADMATCH provided the ability to geocode and then summarize local data by geographic area. The first major geocoding application was a population migration study of Kansas City, Kansas. Post Office change-of-address records for a two-year period were geocoded to census tract and the summarized results used as the basis of the study. The study was a success and provided impetus for the development of additional capabilities.

Confidence in the quality and usefulness of the DIME file coupled with a lack of confidence in the integrity of local computerized land records prompted County officials to create the Base Mapping Program in 1973 and charge it with the development of a system for land ownership parcels.[2] Work began immediately with research into County records to determine and draw parcel boundaries on a set of topographic base maps. This endeavor proved to be a very time-consuming and exhausting task. Original estimated completion dates were grossly underestimated. Work on the maps, the coding of a basic parcel record, and initial digitizing of boundary points was not finished until mid-1978. It was during this time, however, that a computer mapping capability was developed.

The County acquired a plotter in late 1973 and development of computer graphic software began as a joint effort between the City and County.[3] Choropleth, dot map, and network mapping software was written and was soon being used by the City in a production environment. Local data files were routinely geocoded to census tract and summary data mapped. Several series of thematic maps were produced of both locally coded files and published 1970 census summary data. An intersection matching program was written. An incident mapping program was written which plots the street network with street names from the DIME file and plots various symbols representing incidents. (Coordinates are assigned to address data by first assigning the data record to a DIME record and then using from and to address with from and to X and Y coordinates to interpolate along a segment. Parity is used to determine an offset from the segment either to the left or the right. Matched intersection data is identified and coordinates assigned around the intersection.) The incident mapping software has been particularly useful to the police department in the display of traffic accident and crime data.[4]

The computer mapping applications made an immediate positive impact on local officials. Computer generated maps were soon incorporated into reports and studies and it became standard procedure to geocode and map data from local files. With local urban mapping gaining momentum, the decision pending regarding the digitizing of parcels was made easier. It was decided that parcels would be digitized and furthermore that complete boundaries would be digitized rather than just centroids. A digitizer was acquired and a method of topologically encoding points was developed.[5] Some aspects of the method follow. Each parcel boundary point is encoded at digitizing time with the ordered list of parcels incident to the point. Node numbers are not used and complications attendant to their usage are avoided. Software for topologically editing the points similar to DIME topological editing is used to test the completeness and accuracy of the parcel points file. The software will produce ordered boundary lists for each parcel as well as DIME encoded parcel boundary segments. (All of the County has been digitized as of this writing and the coordinates and encoding are in the final stages of editing. It is expected that a current parcel map of Wyandotte County will be plotted by mid-1980.)

Construction of the sanitary sewer geographic base file[6] began in 1976. The file consists of node records which represent manholes, pump stations, treatment plants, etc., and segment records which represent pipes between nodes. The file will be used for record keeping of maintenance and complaint data, mapping, and for flow and capacity modeling. Present mapping applications plot map features from all three geographic base files. Segments and nodes are drawn from the sewer network file. Parcel boundaries are drawn from the parcel points file (with parcel addresses from the parcel file). Street names are determined and plotted from the DIME file. One of the important features of the sanitary sewer system is the linkage between the parcel file and the sewer network. Individual parcels which connect or would be connected to a particular pipe segment are coded to that segment record. This linkage will provide a two-way path between sewer network data and detailed parcel data. For example, sewer complaints by address can be address matched to a parcel and that parcel number used to determine pipe and manholes affected by the complaint. Going the other way, given a piece of sewer network for a modeling problem, it will be possible to extract detailed information about all parcels connected to that network.

Two major applications involving the parcel file have begun in the last eighteen months. One is a parcel level land use system and the other is the Wyandotte County land data system.

Parcel Level Land Use System

The City and the County both have an interest in parcel level land use data. The County's interest lies in the potential usage of the classifications in a computer assisted appraisal system, as a key in accessing both a real estate sales history file and data in the LANDS data base, and to help satisfy state reporting requirements regarding real estate assessment data. The City's interest lies in the use of the file by the Economic Development Department in working with existing and potential business, by the Physical Planning Department in neighborhood planning, and by the Water Pollution Control Department for sewer planning and as input to flow and capacity analysis programs.

The City and County are currently working with the USGS Program for Technical Assistance in the Analysis of Land Resources through the Ozark Regional Commission to select coding schemes, identify and evaluate data sources, and develop procedures for data collection. The results will be used initially to code a test area containing approximately fifteen square miles with five thousand parcels.

The selection of coding schemes will be done carefully. SIC (Standard Industrial Classification) codes are prevalent in economic and business data but are not very useful for non-business land uses. A land use coding scheme, such as the Bureau of Public Roads Standard Land Use Code (SLUC), covers a wide spectrum of land uses but is not used in economic data or business applications. It is likely that translation tables for SIC to SLUC and SLUC to SIC will be developed and both codes stored in the file.

It is felt that land use is most useful to local government when collected at the parcel level because it is only at that level that it can serve the operational needs. If it successfully serves the operational needs, then it at least stands a chance of being properly maintained.

LANDS - Wyandotte County Land Data System

When the parcel maps for the County were completed, the Base Mapping Program began matching the newly developed parcel numbers to existing real estate records and resolving differences in the two files. A new land data system has been designed to take advantage of the map-based parcel system. The design concept of LANDS[7] is centered around the ownership parcel. County land records organize themselves quite well by legal description and while various account numbering schemes, assessor's numbers, clerk's book and reference numbers, and other varied and assorted identification numbers for land records will come and go, the heart of the identity for any land record is its legal description. We have based our parcel numbers on legal descriptions.

LANDS will consolidate at least five separate computer systems dealing with land records in its initial implementation. It will eventually encompass all land record systems. The consolidation alone will solve many of the problems which currently exist in local land record keeping systems. The consolidation of systems, the new parcel base maps, and an automated mapping capability represents a massive jump in technology to those working on land data (many of whom were here when the records were manual!).

A parcel level mapping capability has been eagerly awaited for several years. Software and hardware technology have been available to do the graphics but data other than for small test areas has not been available for practical applications. The next year will see many parcel level urban mapping applications emerge. In two years from now, it will reach a production mode level and a real time graphics capability will follow that.

Summary Remarks

The chronology of local geoprocessing development demonstrates a methodical approach to implementing geographic information systems. Each development followed successful applications of previous systems and was in response to a particular need. The complexity of the geographic base files and the applications increased as the level of involvement in geoprocessing escalated.

Although the scope of this paper did not allow for the development of specific methodology for building geographic base files and developing urban mapping applications, a few suggestions based on local experiences can be given.

1) Geographic base files should be designed utilizing data structures that conform to the natural structure of the phenomenon that is being represented, that is to say, it should be a virtual map. If the data structure is properly designed, then it can be edited for completeness and consistency; if not, it will have a short and inglorious life. The success of the DIME method lies in the ability to topologically edit a file so encoded. A properly designed data structure stands an excellent chance of being appropriate for applications which will arise in the future.
2) There is no short cut in building a geographic base file which will stand the test of time. Time, effort, and considerable resources must be expended to obtain a quality product with long term payoffs.
3) Application software should be written in a modular and generalized fashion so as to be useful in future applications. A glance at the chart provided demonstrates that many applications are listed for more than one base file.

Kansas City, Kansas and Wyandotte County have benefitted from the technology of geoprocessing and automated cartography and are firmly committed to the utilization of those tools in the implementation of information systems to which they are applicable.

NOTES

[1] 655 sheets cover Wyandotte County at a scale of 1:1200. All planimetric features and two-foot contour intervals are produced using steriophotogrammetric methods. Kansas plane coordinates are indicated at 500 foot intervals. The maps are produced by M.J. Harden Associates of Kansas City, Missouri.

[2] Thomas M. Palmerlee and Ronald E. Domsch, "A Parcel Identification and Data System", Papers from the Eleventh Annual Conference of URISA, (1973), pp. 393-407.

[3] Ronald E. Domsch and Kenneth D. Mai, "Computer Mapping and its Impact on Kansas City, Kansas and Wyandotte County", Proceedings of the International Symposium on Computer-Assisted Cartography (Auto-Carto II), 1975, pp. 469-481.

[4] Rick Holloway, "Police Dispatch Reporting and Analysis System", Papers from the Fourteenth Annual Conference of URISA, (1976), pp. 115-126.

[5] Ronald E. Domsch, "A Topological Encoding of Points in a Cadastral Mapping System", Papers from the Fifteenth Annual Conference of URISA, (1977), pp. 176-184.

[6] Thomas M. Palmerlee and Jaye Brake, "Sanitary Sewer Computer File", Department of Information and Research Reports, 1978.

[7] Steve Hall, "The Wyandotte Land Data System - LANDS System Proposal", 1979.

EXAMPLES OF AUTOMATED CARTOGRAPHY IN PRESENTING LAND USE AND LAND COVER MAPS AND DATA

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Summary - *

The development and analysis of land use and land cover information is one of the responsibilities assigned to the U.S. Geological Survey. The task embraces a range of activities and products. Among the products already created by this first-time nationwide land use and land cover inventory, and continuing research and development in the techniques involved, are area data sets and map manuscripts in a variety of forms--more than can be formally published. This variety is illustrated by eight maps recently published or in advanced stages of production. The demonstration areas include Pittsburgh, Atlanta, Wichita, Kansas City, Washington, Seattle-Tacoma, San Francisco, and Alaska's National Petroleum Reserve.

A matrix of map feature combinations is arranged by demonstration area, content feature, and/or format feature. Despite the common theme (land use and/or land cover), and common reproduction process (four-color lithography), each map poses a unique challenge that is being met with an innovative solution. Description of these challenges and solutions is the

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* - Summary of oral-visual presentation at International Symposium on Computer-Assisted Cartography: Auto-Carto IV, Reston, Virginia, November 4-8, 1979.

main purpose of this paper. Five of the maps demonstrate some recent developments in automated cartography. The three others are unique in other respects. Brief comparisons among the four pairs offer further insight as to some of the benefits and costs of selected design or reproduction features, including those resulting from automation.

A second purpose is to suggest that preparation of even these experimental maps for publication samples a range in alternatives in the design and presentation of many thematic maps in general. One by-product is new insight in preparing thematic Earth science data for video display and for publication in an updated National Atlas.

Examples of Automation in Land Use and Land Cover Maps

Map subject, and theme format		Main theme	Scale range	Major classes	Geo-info system	Repro-duction	Distinction, with respect to automation
Polygonal (air photos)	Pittsburgh	All land use and land cover inventory	All between 1:100,000 and 1:250,000	Similar, based more on land cover than use-*	Data adaptable for storage, retrieval	All by four-color offset lithography	None. Color scheme; gazetteer in UTM; land use conversion matrix.
	Atlanta						Laser scanned, -measured -plotted films by class; theme accuracy; no labels.
	Wichita						Black-White Level II; 2-color litho in lieu of open file distribution.
	Kansas City						Level I color; Level II; computer-scribed, hand-peeled; polygon labels.
Digital (Landsat)	Washington						Computer-aided classes; scene overlays; tables; folds; small laser plots.
	Seattle-Tacoma						Computer-aided classes; data tables; quality map base; accuracy statement.
	Meade River						Computer digital mosaic to stand. topo map; laser plots, area measurements.
	San Francisco						Atlas of sectional maps at tabulator page size; laser plots; data tables.

*-Some class differences are significant, but less so in the context of this discussion.

INTERACTIVE COMPUTER MAPPING APPLICATIONS TO CRIMINAL JUSTICE PLANNING IN THREE VIRGINIA CITIES

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The analysis of crime in local communities, and the administrative responses to crime problems, have evolved into a fairly predictable set of descriptions and procedures. The deficiencies in current approaches to dealing with crime and its causes, particularly in terms of useful and reliable data about the social and economic characteristics of high crime areas, have led to the view that significant advances in understanding the causes of crime, and dealing with its consequences will only come about if analysts undertake exhaustive data collection, sophisticated research designs, and clever data analysis.

The project described in this paper works from a substantially different set of premises:

1) that intuition and judgment based on local knowledge and experience are far more important than sophisticated data analysis
2) that no amount of number-crunching will ever unearth the elusive "causes" of crime, particularly if deterministic approaches to data analysis are employed
3) that there are ways in which data display and analysis using heuristic approaches can influence the local decision-making process in dealing with crime problems in local communities.

The project was undertaken specifically to explore the ways in which heuristic approaches to problem definition and data analysis could be applied to the problem of crime in local communities. The project is funded by the Virginia Division of Justice and Crime Prevention, and is being conducted through the Center for Urban and Regional Studies at Virginia Tech, with Professors Sara Rosenberry and Beverly Yanich serving as principal investigators. Initially, the project has been based in Portsmouth, Virginia, but recently the project has been expanded in scope to include the cities of Norfolk and Hampton as well.

The project provides two kinds of technical assistance to local governments. The first relates to interactive computer display and analysis of crime-related data. The second is in problem definition and group problem-solving techniques which focus the utilization of local resources and knowledge in the definition and understanding of crime-related problems in the community. In order to carry out the technical assistance, the first phase involves the creation of a data base to describe the community, working from existing sources of information normally collected and tabulated for use by operating public agencies. The data base is made available through time-sharing computer terminals using commonly available statistical analysis procedures--SPSS--for statistical purposes and data management capabilities. The data analysis capabilities include computer-generated polygon displays and overlays, selective data retrieval and analysis, and a subset of the exploratory data analysis techniques developed by John Tukey. While most of these analysis capabilities are not currently available to most local governments, it can be anticipated that they will become widely available during the next decade.

In addition to the creation of a data base and analysis techniques, the project's procedures also include an analysis of the community's decision-making environment as it relates to crime control. This aspect of the approach is particularly concerned with the various public and private institutions responsible for dealing with crime-related problems, identifying the patterns of interaction among those institutions, and creating mechanisms for exchanging information about decisions which may affect the character of the community. The intent, over time, is to develop not only a shared data base, but also a shared recognition of a problem and an awareness of the variety for institutional responses developed to deal with crime in communities.

Heuristic Approaches and Exploratory Data Analysis

The operational mechanisms for conducting the project are derived from heuristic approaches to problem recognition and data analysis. The term "heuristic" is based on the Greek word for discovery. Heuristic approaches are meant to be inference-aiding, a way of testing hunches. They rely primarily on a process of conjecture -test: the search for possible solutions to a problem within existing limitations of knowledge and data, but without any formal decision rules based on statistical inference. Rather than relying on elaborate research designs and exhaustive data collection, heuristic approaches depend on the insight and judgment of the analyst when applied to a limited set of data and observations.

Heuristic approaches work from the unfashionable premise that judgment is important, that insight is something to be nourished, nurtured, and rewarded, and that local knowledge and sensitivity derived from experience are valuable and essential elements in any decision-making process. While deterministic approaches try to control for the bias that might be introduced by the analyst, heuristic approaches depend on the analyst bringing prior experience to a problem which constructively contributes to finding a solution.

Heuristic approaches do not rely on formal tests of statistical significance. Rather, they depend on methods for verifying or refuting the judgments and hunches brought to the particular problem. Recently, methods for dealing with data in a heuristic fashion have been greatly improved by the work conducted by John Tukey of Princeton University. Under the title of "exploratory data analysis," Tukey describes a series of data display and analysis procedures which are quite useful in discerning underlying trends or patterns in data distributions without having to rely on more traditional, formal tests of statistical significance.

Tukey's methods are designed to be employed using manual techniques, but the methods are greatly facilitated by employing interactive computing versions of data display and analysis. By breaking from formal decision rules derived from levels of statistical significance, and relying instead on inspection and judgmental interpretation of data, Tukey has made a major conceptual and analytical contribution which extends the applicability of heuristic approaches to a wide range of social problems.

Project Procedures

The major focus for carrying out project activities is the organization of task forces from the community to define the problem, and to establish the decision rules for data analysis. The task force approach is based on heuristic techniques of inquiry and discovery, drawing on local knowledge and perceptions of the problem. Where possible, data are derived from existing sources as suggested by task force participants. In some instances, special tabulations may be required, but these are normally discouraged. The effort is to make full use of existing data sources, rather than falling back on the excuse of data unavailability to avoid dealing with certain issues.

The major intent is to have local decision-makers actively involved in selecting the data for analysis generating the analysis framework, and interpreting the findings using their insight and experience based on local knowledge. In this way, the technology of interactive computer graphics and data analysis is a way of enhancing rather than replacing local decision-making capability.

Once the data have been coded and stored, it is a relatively simple matter to generate displays of individual variables or to create composite overlays using computer graphics. The graphics displays are used initially to ascertain visually whether there are spatial clusterings of particular community characteristics which may be related to crime. The visual inspection becomes one way in which the insights or prior knowledge of decision-makers may be supported or refuted, and provides a basis for defining further inquiries of the data base.

The displays then, provide both a reconnaissance function and a filtering one, since the inspection of the displays often leads to the focus on a particular area or subset of neighborhoods in the city. The techniques associated with exploratory data analysis also provide a powerful mechanism for focusing and filtering the spatial patterns which may exist in the community. Of course, such displays have applicability in areas other than criminal justice planning, and have served a useful role in other aspects of community planning.

Subsequent phases of the analysis are focused on specific problems in the community identified by local decision-makers. There is no presumption that analysts from outside the community can go much beyond descriptive statements about the community. Instead, by placing reliance on heuristic approaches, local knowledge and experience can be the basis for refining the questions to be examined and in formulating the hypotheses to be explored in more detail. In Portsmouth, for example, detailed studies are being conducted of the occurrence of crime in selected public housing communities in which there are clusters of crime problems, and social service programs designed to deal with community dysfunctions.

Computer-Based Procedures

Just as there was a reliance on utilizing existing approaches to data collection when initiating the project, there was a similar reliance on modifying the existing computer software for the project, rather than undertaking significant software development. As a consequence, the major software development activity focused on linking together the SPSS package of statistical routines with the CALFORM program for shaded polygon mapping.

This was accomplished by creating a pseudo-interactive environment by linking the two software packages together with minor modifications to their batch versions. The pseudo-interactive environment was relatively easy to create, given the computing environment at Virginia Tech. The hardware configuration is in IBM 370/158 with either Tektronix 4010 family graphics terminals or Hewlett Packard 2648 graphics terminals as the primary output medium. Graphics displays may also be produced on either a Calcomp or a Versatec plotter at the main computing center, or on a Tektronix 4662 plotter tied to a terminal. Installation of a Tektronix 4027 terminal later this fall will allow for color graphic output as well.

The operating system environment is VM370 using CMS time-sharing facilities. VM is itself a pseudo-interactive environment, so in reality the programs are twice-removed from any true interactive computing environment. However, because of the speed of software execution, and the luxury of relatively high transmission rates between the graphics terminals and the host computer (either 2400 or 1200 baud), the process appears transparently to the user as an interactive one. For all standard statistical operations, SPSS is used both for analysis and as a crude data base management system. SPSS is used to generate the necessary input data for CALFORM (using the WRITE CASES option). CALFORM is used, then, only for graphic output generation, and some of the analysis capabilities inherent in CALFORM are currently employed.

Through a series of prompts executed in a conversational mode, the user specifies the data variables to be included in the analysis, the statistical procedures to be employed, and legends and output medium for the graphics displays. For other than trivial tasks, a knowledge of SPSS is essential, and an understanding of the purposes of descriptive and deterministic statistical approaches is assumed. So while the program sequence is meant to be conversational, some intelligence is necessary to make it a meaningful dialogue! Employing a widely known statistics package like SPSS increases the likelihood that the analyst will be comfortable with the processing environment.

The computer procedures for using the exploratory data analysis routines, such as box-plots, stem and leaf plots, and scattergrams all are based on refinements to the algorithms prepared by Donald R. McNeil, Interactive Data Analysis (New York, 1977). Currently, the routines are not tied to graphic displays of the spatial distribution of the results from the exploratory data analysis algorithms; however, it is anticipated that this capability will be available in the near future.

The analysis framework had been applied to a variety of social, economic, land use and criminal justice data using different levels of aggregation in each of the three cities - census tracts in Portsmouth, traffic zones in Hampton, and neighborhood areas called "planning districts" in Norfolk. The results to date have been most encouraging, and we anticipate being able to continue to refine the heuristic approaches developed to date, as well as the graphics routines, to modify the ways in which crime-related problems are described and analyzed at the local level. Detailed information about the project and computer programs, as well as a project summary report, is available from the authors.

INTERACTIVE COMPUTER MAPPING*

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For two decades computer scientists have developed interactive systems and computer graphics researchers have followed suit very quickly. Systems which produce maps are somewhat more recent (Phillips and Geister, 1972; Deeker and Penny, 1972). This paper presents the results of some research on the Interactive Map of Urban Research, a system developed by the authors (Clement, 1973 b).

We may distinguish between four classes of interactive operations on maps:

1. Interactive maps can be useful for EDITING SPATIAL INFORMATION. In preparation for the production of a final hardcopy map and for the clean-up of digitized data sets. The operations would be performed on the pictorial elements such as boundary outlines, map symbols, place names and titles and would be typically line smoothing, data reduction, correction, name attachment, name placement and image composition.

2. With the addition of CONTENT INFORMATION to the spatial information, the data bank would be built up with the aid of interactive editing. Since there are

* This project has been supported by a grant of the Canada Council (now Social Science and Humanities Council of Canada).

often logical connections between content information, especially the topological information (i.e. in relationships between neighboring elements) certain control functions can be implemented to test the consistency of the data set.

3. An interactive map can also be a valuable tool for INVESTIGATING A LARGE SPATIAL DATA BASE. By displaying

data sets with varying symbolism, different classes, changing windows in a data set, etc., the user can get a very quick overview of the variables and their spatial distributions and plan his subsequent analysis or the graphic display of the data in a hardcopy accordingly.

4. With the incorporation of more computational power, together with structural relations between the spatial data and a more advanced query language the interactive map can become a powerful tool for DATA ANALYSIS. One can relate data sets and study the resulting spatial distributions immediatly on the display distribution. Also, route selection, network flow analysis, and spatial simulation become possible within the same system.

The INTURMAP System.

The INTURMAP system was developed to facilitate these four types of operations (Nake and Peucker, 1972; Clement, 1973a; Peucker,1973). The data and command structures are flexible enough to enable most of the possible applications, however, only a subset has been implemented:

- The editing of spatial data is performed through the deletion, creation and redefinition of graphic objects. One specific editing feature is the selective deletion of points along arbitrary lines. The system stores the operator´s decisions and developes a strategy for "generalization" which can be used for subsequent generalisations (Clement, 1973a).

- Content information can be edited through the correction, redefinition and regrouping of adjectives. A specifically powerful feature is the definition of sets of objects which in turn can be treated as single objects.

- By displaying variables in map form, a quick overview can be achieved since maps can be produced in quick succession, combining two variables through statistical or graphical combinations, the user realizes very quickly in which direction a more sophisticated data analysis has to be pushed.

-There are only few statistical techniques which are not so complex that their application in an interactive environment would slow down the process to a point where interactive work would be possible. We have therefore restricted our development to combinations of pairs of variables through simple arithmetic operations and regression analysis with the mapping of the predicted values and their residuals.

The development was based on a series of objectives, usefulness, flexibility and extensibility, and machine independence. These objectives were approached through a series of developments: 1. Query language. 2.Interactive display. 3. Flexible data storage and retrieval. 4. The possibility of data editing and input.

1. Query language.

The query language has been designed to be be as easy and natural to use as possible. Thus the commands are sufficiently English-like that the expected action is fairly clear. Equally the system is fairly compromising with respect to errors in the user´s interaction. Although it does not independently correct errors or guess the right answer, it indicates exactly where it had difficulties understanding.

The chief entities that are referenced by the query language are "geographical objects". A geographical object can represent anything that has a well defined locational description (boundaries, regions, points, etc.). It has associated with it content information (names, population, size, etc.) which is referred attribute-object pairs as keys in a hash table (Rovner and Feldman, 1968), and locational information, (i.e. point, line or region, boundary, etc.). Sets of geographical objects can be assembled directly

(CREATE WEST END_FROM CT001 CT002 CT003 CT004)

through a logical predicate that every object of the set must satisfy

(INCOME > 10,000 and (POPULATION/AREA) > 4.5)

or using a light pen to select objects displayed on the screen of the CRT. In addition, algebraic variables can be declared and manipulated with the same algebraic power as FORTRAN or PL/1.

The complete language is defined by means of a formal grammar. The production rules of this grammar are supplied to a parser-generator that produces parse-tables (Wales and Thomson, 1974). These are used to drive the parser to analyze input command. The advantage of this parser approach is that once the initial overhead has been assumed, the language can be extended very easily. Thus the query language constitutes a geographic programming language in its own right.

2. Interactive Display.

The display component of the system consists of two quite distinct parts. The part that the user deals with is called the Virtual Graphics System, and is not linked to a particular application such as mapping (Meads, 1972). It relieves an applications programme from being concerned with the details of the user interaction by letting the high level programme draw segmented images on a number of "virtual" screens that are potentially infinite in extent. The user determines the portion(s) of the image that he wants to look at. This is done by defining a number of "windows" of varying size into the "virtual" screen. This makes it possible to start with a general view of a large area and then gradually "zoom" in on a particular feature.

3. Data Storage and Retrieval.

The retrieval of statistical and locational information is handled separately, because of the different characteristics of these two sets of data. The three types of entities in the location data structure are points,boundary segments ("snakes" or curved lines with a start - head- and an end -tail) and lines (sequences of snakes). Geographical objects are assembled from these entities and combined with the statistical objects. In this way space is saved and and the property of spatial relationships (eg. adjacency) maintained in a flexible way.

The statistical values are stored in a table which is referenced by object-attribute pairs as keys to a hash function. When a command is given which requires some statistical data, space in core is acquired and the hash table is brought in.

4. Data Editing and Input.

The system allows for the transformation of data from one structure into the other. For the digitizing and editing of line data some previously developed programmes are used for the logical and geometrical improvement of the data (Douglas and Peucker, 1973).

Experience with the system

The system has shown to be highly flexible and extremely expandable. However, one has also to admit that the system had some serious faults. Some of these faults were brought about through the changes in the conditions around the development during the time of active work. Others were caused by misjudgment in the planning process.

One problem was that we had based the development on a graphics instrument which as of today has to be considered outdated for the purpose of cartographic design, but could not be replaced because of its high costs. The ADAGE graphics terminal allows very immediate interactive work but with roughly 6,000 vectors is too restrictive for cartographic work. The parser chosen (Wales and Thomson, 1974)) and the basic language (ALGOL-W) were highly unportable which caused some organizational problems when the research administration had to be moved from one university to another.

One serious organizational problem was our inability to attract users who would apply the system to real problems and suffer with us through some of the difficulties of a system in the development. Today we know that in order to get proper applications of such a system one actually has to pay users to work with the developers through the development stages and apply their practical knowledge for the improvement of the system.

There is no doubt that an interactive system can help very much the production and the usage of maps. There are in the meantime several attempts to develop such systems. With improvements in hardware ,especially interactive graphics, and in software, especially languages with more powerful data and command structure we can be confident that more interactive mapping systems will be developed and made available to interested users.

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ALTERNATIVES TO THE POPULATION PYRAMID FOR MAPPING AGE-SEX CHARACTERISTICS OF METROPOLITAN CENSUS TRACTS

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I. Introduction

Data on the age and sex of residents are extensively used in the planning of health care and other social services programs. This information must be available for small geographic areas, such as metropolitan census tracts, when planning facility locations or designing service delivery systems. Often it is desirable to utilize maps showing age-sex characteristics of tracts, either as a tool to help the planner visualize possibilities or to communicate alternatives to interested groups. Two types of maps are typically utilized to display such information: (1) choropleth maps for individual age-sex groups (eg: males 65 years or older) or (2) multiple population pyramids superimposed upon a base map. The choropleth map suffers by requiring as many maps as age-sex groups, making intergroup comparisons difficult. The use of pyramids permits a single map, but is visually so complex that comprehension of spatial patterns is difficult.

This paper describes and graphically displays several alternative approaches for mapping age-sex characteristics of metropolitan census tracts. These alternatives are based in part on a factor analysis that reduces the numbers of categories to be mapped from approximately 30 age-sex groups to two to four derivative components and permits the use of simpler mapping symbology than the age-sex pyramid. The alternative displays include: (1) a typology of pyramids for use in the legend of age-sex pyramid maps which facilitates reading this complex type of map, (2) a process color map, which can be computer produced, showing areas of particular types of age-sex characteristics, and (3) a polar coordinate type symbol which may better allow the viewer's eye to detect qualitative differences in age-sex characteristics of metropolitan area tracts. Analyses carried out for two cities (Madison, Wis. and Portland, Ore.) suggest that these techniques can be generalized.

II. Conventional Displays for Age-Sex Data

The most common form for the graphic display of age-sex information is the population pyramid, illustrated here for a major part of a metropolitan area (Figure 1). Population experts can look at the profiles of such pyramids and recognize the effects of the "great depression", the "post World War II baby boom" and even events unique to the local area. Two pyramids can be compared by superimposing them or simply viewing them adjacent to each other. However, when a large number of pyramids are simultaneously displayed, even a trained demographer has difficulty making sense of the geographic patterns. There are two main reasons for this confusion: (1) When many pyramids must be presented in a small space, as on a book page sized map, the legibility of the labeling of the age groups cannot be preserved. The reader can easily identify the youngest and oldest age groups at the upper and lower extremes of the diagram, but must count lines or make rough intuitive judgments of the vertical position for the intermediate age groups. These processes are slow, frustrating and error prone. (2) When pyramids are used to show census tract age-sex characteristics, tracts are usually chosen which highlight the phenomena being illustrated. The population pyramids for skid row tracts, tracts including college dormitories, or tracts of newly built suburban housing are easy to recognize. However, most metropolitan census tracts are heterogeneous due to aggregation of two or more dissimilar areas or to changes occurring over time, such as the gradual resettlement of older neighborhoods by younger families. Where such heterogeneity exists, the resultant pyramids can be difficult to interpret.

Spatial patterns can be seen better in chorpoleth maps of individual age groups (Figure 2). Where the age group under consideration is clearly defined, such as

FIG. 1
POPULATION PYRAMIDS

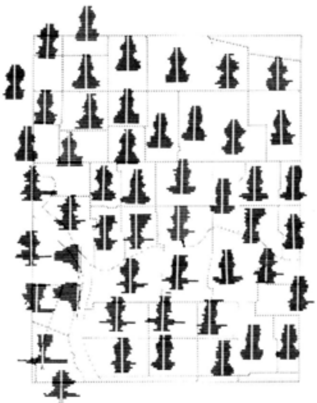
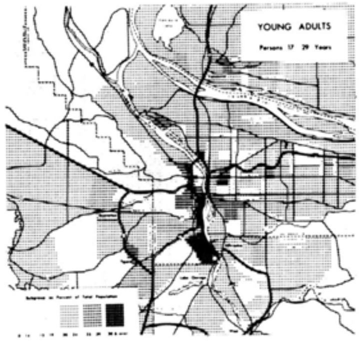
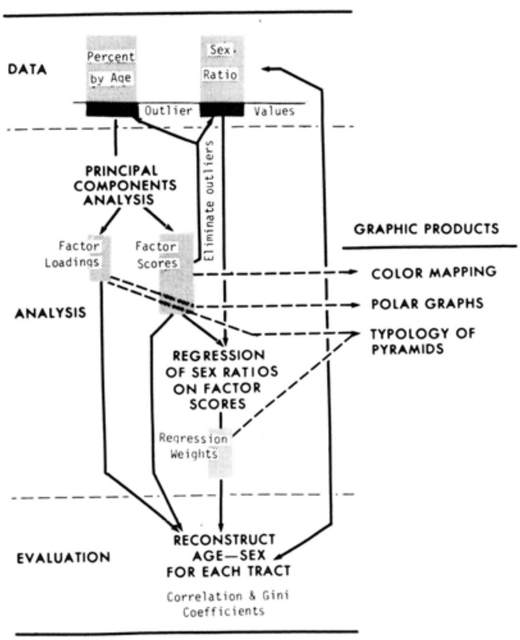


FIG. 2
CHOROPLETH MAP
FOR AGE GROUPS



F1G. 3 FLOW CHART FOR MODEL



by a law pertaining to persons 65 and over, such a map may adequately depict the geographic distribution. However if the reader needs to comprehend information about and relations between several age groups the limitations of the human eye and mind make it difficult for the reader to utilize the information displayed simultaneously on maps of several age groups. There also can be a problem in the aggregation of various ages into a single age group. For example, a map of the five year age group 15 to 19 can be somewhat confusing because it includes both persons living at home with parents and those who have established separate households.

III. The Model Employed for Data Reduction

Age-sex data for census tracts for Madison, Wisconsin and Portland, Oregon were Factor analyzed in order to reduce the complexity of the data and thus allow the use of simpler maps to display complex data. The model utilized is diagramed in Figure 3 and the results are graphically displayed in Figures 4 and 5. Interested persons may contact the author for a more detailed discussion of the methodology or a copy of the computer program used in the analysis.

The data analyzed is the same as that displayed on a population pyramid (Figure 1). Age composition and sex composition are analyzed separately (Figure 3) as "percent by age" and "sex ratio", the number of males per female. The percent by age data were transformed by means of a square root transformation to reduce skewness and a small number of outlier values, such as skid row and student dormitory areas, were eliminated.

The percent by age data were subjected to a principal components type of factor analysis in order to produce factor loading and score matrices. The eigenvalues (Figure 4) indicate that the first four and especially the first two factors account for most of the variation in age structure. The factor loading diagrams (Figure 5) are quite similar for the two cities. Those groups found near each other on the diagrams tend to be co-located in actual city space as well. The third and fourth factors are smaller and result mainly from a few concentrations of young adult populations, such as those clustered around college campuses.

Table 1. Example of Data for One Tract

Tract 1.00

	Age Group										
	00-04	05-09	10-14	15-17	18-24	25-34	35-44	45-54	55-59	60+	Total
Males	143	141	158	91	228	226	155	167	66	107	1482
Females	115	161	136	83	195	219	170	178	55	142	1454
Persons	258	302	294	174	423	445	325	345	121	249	2936
% by age	.088	.103	.100	.059	.144	.152	.111	.118	.041	.085	-
$\sqrt{\%\text{ by age}}$	.296	.321	.316	.243	.380	.389	.333	.343	.203	.291	-
Sex ratio	1.24	0.87	1.16	1.10	1.17	1.03	0.91	0.94	1.20	0.75	-

FIG. 4 EIGENVALUES FOR PERCENT BY AGE DATA

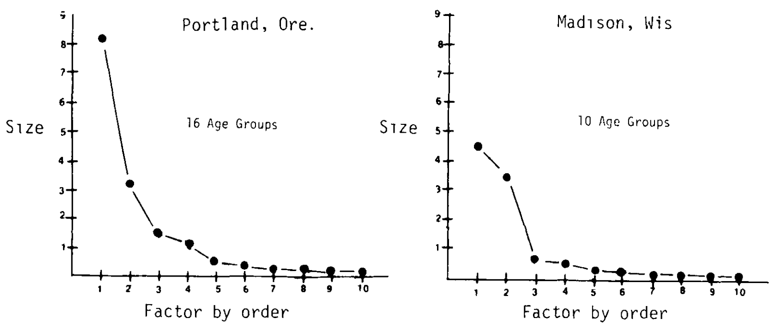
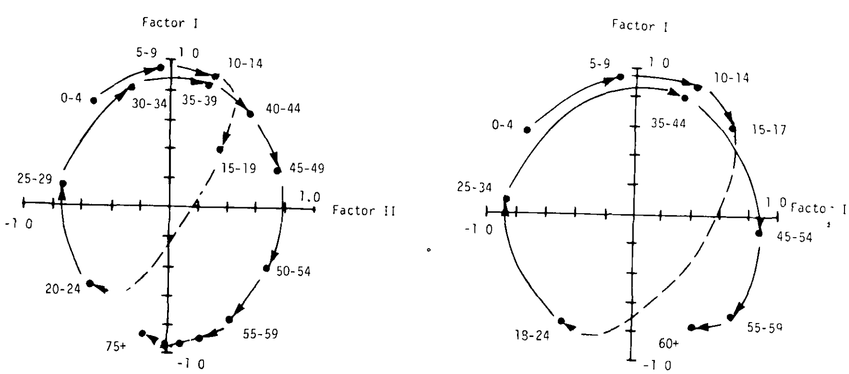


FIG. 5 FACTOR LOADINGS FOR PERCENT BY AGE DATA



So far the analysis has been concerned only with age distributions, not the varying proportions of males and females. A regression analysis was performed to find out whether it would be reasonable to view geographic sex ratio variations as largely explained by geographic age variations. The results suggest this to be true to some extent, but multiple correlations are not high.

As a check on the model the factor scores and loadings (for age factors I-IV) and regression weights for sex ratios were used to reconstruct the pyramids for each tract. The results were highly encouraging for the age data with about half the correlations between actual and estimated percent by age over .99. The results for sex ratios were not as good as shown by the correlation coefficients, but the errors as measured by Gini coefficients, were about equal in absolute terms to those for percent by age.

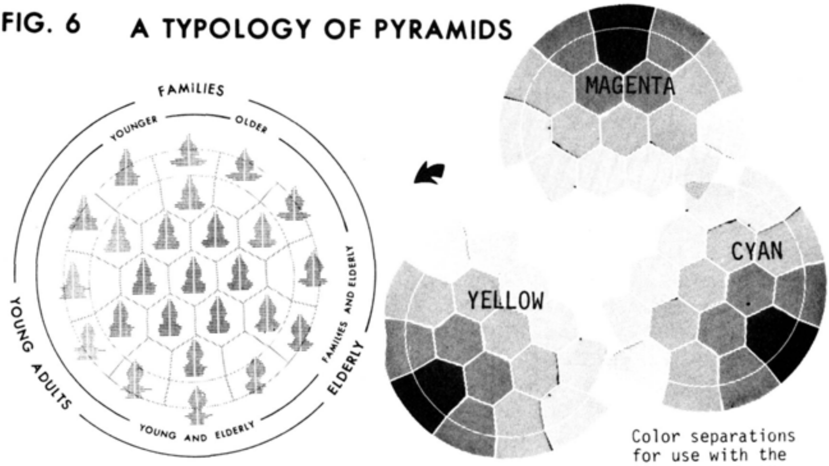
IV. Alternative Graphic Displays

The analysis described above allows a considerable reduction in complexity of the age-sex data. Several examples of maps stemming from this analysis are discussed below.

The first example is a legend intended to assist the reader in interpreting maps which are composed of "synthesized" population pyramids (Figure 6). This diagram provides the reader with a visual crutch which can help make sense of the sometimes bewildering variety of pyramids that appear on the map. These legend pyramids were constructed from the model's factor loadings and regression values.

The second example is a map composed of color tones (Figure 7) which also are used in the map legend and are intended to allow the reader's eye to scan the map more rapidly. This color coding should aid the map reader in such tasks as (1) finding areas with certain types of population structures; (2) comparing areas; and (3) making general statements about regional trends and differences. Population pyramids (as in Fig. 1) can be printed over these tones, as could dots or other point or line symbols. The values for the color separations are factor scores for factors I and II from the age analysis, color standardized to key the mag-

FIG. 6 A TYPOLOGY OF PYRAMIDS



Color separations for use with the diagram to left.

FIG. 7 SEPARATIONS FOR COLOR MAP

Age pyramids (Fig. 1) may be overprinted on three color age map.

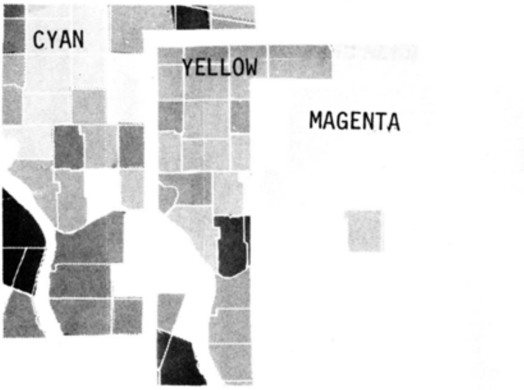
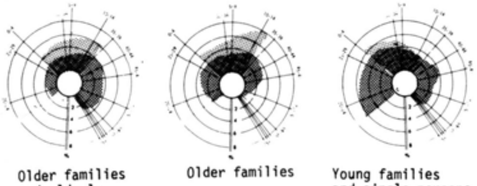


FIG. 8 POLAR DIAGRAM FOR AGE



Older families and elderly

Older families

Young families and single persons

enta separation to the family age groups.

The third example is a polar coordinate graph which displays age structure, but not sex composition differences (Figure 8). The order of the age classes used in this display is the same as their location on age factors I and II. The logic of this placement is that groups which tend to be co-located in the city are placed in adjacent positions on the diagram. This diagram may be preferable to the population pyramid because (1) on a small symbol the reader can better identify individual age groups, (2) the qualitative distinctions between areas with differing age structures may be enhanced, and (3) spatially associated age cohorts are grouped together.

Whether these experimental diagrams are as effective as the traditional use of population pyramids on maps may be difficult to determine because the pyramid is so widely used and accepted. Nevertheless, the author is presently attempting to arrange for such testing. Efforts are also underway to carry out the data reduction analysis for additional cities in order to better evaluate the model's generality.

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COMPUTER MAPPING OF CANCER MORTALITY BY CENSUS TRACT:

COLUMBUS, OHIO 1956-1974*

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Introduction

A phenomenon of considerable epidemiologic interest in cancer research is the pronounced effect of geographic location on cancer mortality. Most cancer rates vary markedly by country and within regions of the same country. These differences have given rise to national and international research in an attempt to identify the environmental and demographic factors associated with high risk areas.

The technique of mapping provides a most effective means of describing the geographic differences in cancer rates, identifying patterns of elevated mortality, and generating etiologic hypotheses.

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**Operated by Union Carbide Corporation under contract W-7405-eng-26 with the U.S. Department of Energy.

Mortality maps have been widely used to display cancer frequency at varying geographic scales of analysis (Dunham and Bailar, 1968; Burbank, 1971; Mason et al., 1975). While the majority of studies have employed fairly large areal units of comparison (e.g. countries, states, counties), some have focused on the intracommunity variations in cancer rates within an urban area (Cohart, 1954; Greenburg et al., 1967; Pyle, 1971; Henderson et al., 1975).

The present study examines the geographic variation of cancer mortality in Columbus, Ohio using the Poisson distribution to judge the significance of standard mortality ratios adjusted for age, sex, and race. Total Columbus age, sex, and race-specific rates for a variety of cancer sites are used to generate expected numbers of deaths. The census tract serves as the basic unit of analysis and comparison of intracommunity risk.

Methodology

Mortality tapes from the Ohio Department of Health (ODH) provided the main data source for the study. The tapes document all deaths which occurred in Ohio during the 19-year period 1956 to 1974; each mortality record (for Franklin county) also includes the census tract of residence at the time of death. The causes of death considered were limited to 16 of all the most common individual cancers and the combined category of 'all malignant neoplasms'. Cancers less common than these would yield (over the 19-year period) too few cases in each census tract to allow for any meaningful description or analysis.

Because three revisions of the International Classification of Disease (ICD) were used to code cause of death on the ODH tapes, the more specific seventh and eighth revisions were converted to the less specific sixth revision. Following conversion of ICD codes, the mortality tapes yielded number of deaths from each cancer in each census tract stratified by race (white, nonwhite), by sex, and by 10-year age groups.

Population data by census tract are available on summary tapes for the 1960 and 1970 censuses and in printed form for the 1950 census. Intercensal values were estimated by linear interpolation and estimates for the years after 1970 were derived by extrapolation based on the growth rate of the 1960's. Total population at risk values for each tract in each age and race-sex group were then computed by summing across all 19 years.

Three types of situations required some modification to correct for changes in census tract boundaries over the three censuses. The first, and the easiest to remedy, results from simple population growth and consequent subdivision of already existing tracts. To achieve comparability, any tracts that were subdivided in 1960 or 1970 were recombined and assigned to the original 1950 tract number. All mortality and population data from these subdivided tracts were also combined and assigned to the larger 1950 tract.

The second situation arises due to changes in individual tracts lying inside (i.e., not on the periphery of) the study area. Changes in census tract boundaries occur between each census for a variety of reasons and to varying degrees. Block maps and block statistics were used to make rough estimates of the degree of geographic and population changes that resulted from boundary changes. In most cases, tract boundary changes inside the study area involved only one or two blocks and less than 10 percent of the population. However, where changing boundaries between tracts shifted at least 10 percent of the tract's population, these contiguous tracts were combined into larger tract groups, thus maintaining stable geographic units across the three census periods.

The third, and most troublesome, situation results from changes in the outer boundaries of tracts that lie on the periphery of the study area. Because these tracts delineate the external borders of the study area, they could not be combined with other tracts to compensate for boundary changes. Major boundary changes occurred for three border tracts between the 1960 and 1970 censuses. In each case, these tracts became much larger (geographically) with the 1970 census, encompassing land lying outside of the study area. The problem lies in estimating the 1970 population values of the original tract area, i.e., the change that would have occurred in the tract's population between 1960 and 1970 if the tract had not experienced such a large geographic addition. The 1970 Census of Population values cannot be used directly; presumably these values are too large. In order to estimate the

1970 population values, growth rates for each race, sex, and age group that can then be applied to the 1960 population values are needed. For each tract, these growth rates were derived from an average of the growth rates in the five closest neighboring tracts.

Many previous studies (Cohart, 1954; Greenburg, et al., 1967; Henderson et al., 1975) aggregated census tracts according to some predefined criteria of homogeneity (socioeconomic status, air pollution, demographic factors). While grouping on a certain factor facilitates correlation of cancer rates with that factor, it also tends to obscure other relationships that might exist. Grouping was not attempted in this study because hypotheses relating cancer to specific geographic or demographic influences were not being tested. This study is, rather, a descriptive study, and as such, attempts to disclose any geographic patterns in cancer mortality that are present in the study area. Consequently, no grouping of census tracts has been done other than the aggregation necessary to insure equivalent units of study between the three census periods.

From the ODH mortality data and the population data, age-specific mortality rates were computed for the study area as a whole (all tracts combined) for each of the 17 cancer sites and each of the four race-sex groups. These age-specific mortality rates were then applied to the population values in each individual tract to arrive at an expected number of deaths for each of the race-sex groups in each tract and for each cancer site. The entire study area thus served as the standard for each individual census tract. These unexpected deaths were totalled across the race-sex groups so that, ultimately, one age, sex, and race-adjusted standard mortality ratio (SMR) was computed for each tract and each cancer site.

In an attempt to reveal geographic variation in cancer mortality between census tracts, the tracts were grouped into five classes according to their SMR's: higher and lower than the entire study area at $p \leq 0.05$; higher and lower than the entire study area at $0.05 < p \leq 0.2$; and no different from the study area. The choice of a significant level $p \leq 0.05$ is dictated by convention while the less conservative level of $p \leq 0.2$ is used to highlight geographic clusters or patterns that might exist. Attention is thus focused on a tract significant at the $p \leq 0.2$ level if it borders or is surrounded by tracts significant at the $p \leq 0.05$ level. These five classes are represented visually by five different shading schemes on maps produced of the study area. All maps were computer generated and produced by a light pen plotting on film, and then printed following photographic processing.

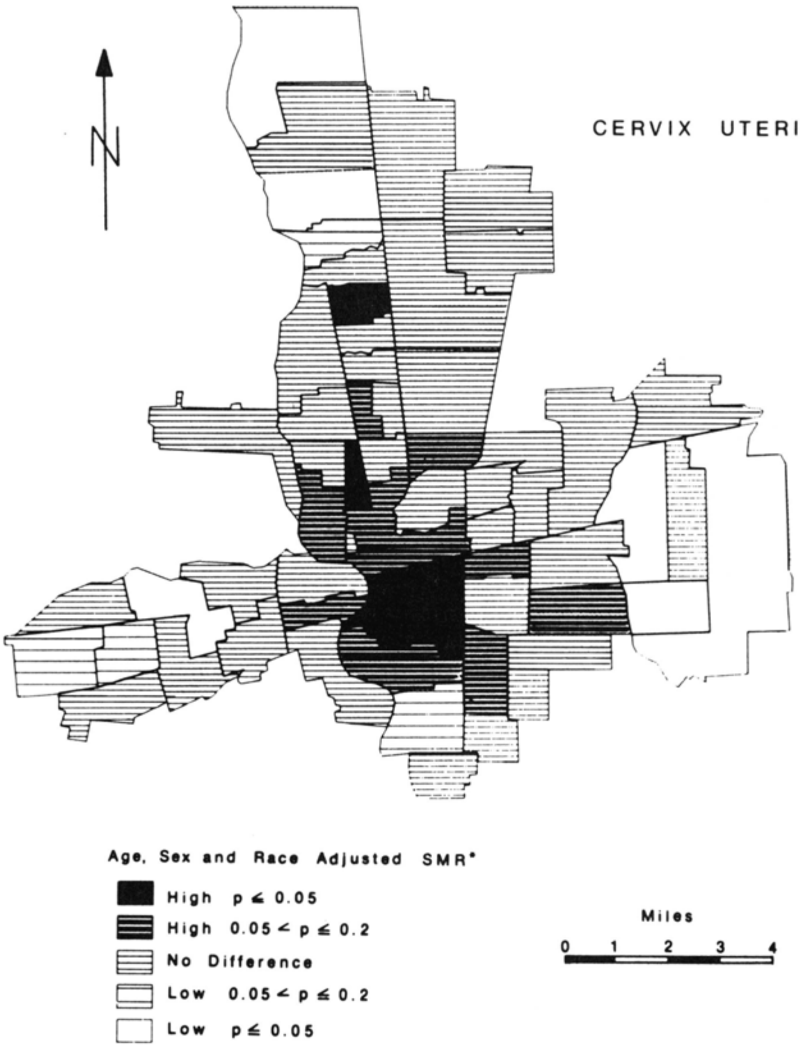
Results and Conclusions

The finished maps provide a visual indication of variation between census tracts for each individual cancer site and for 'all malignant neoplasms'. A number of sites form what might be called a central city pattern, displaying high SMR's in the centrally located tracts and low SMR's in the outlying areas. Cervical cancer (Figure 1) is the best example of this type of pattern; others are stomach, liver, lung, and 'all malignant neoplasms'. This particular type of geographic variation is quite probably the result of the negative relationship between socioeconomic status and certain cancers since central city residents are of lower socioeconomic status (as indicated by median incomes). A marked association exists between low socioeconomic status and cancer of the cervix, stomach, lung (Levin, et al., 1974), and liver (Hoover et al., 1975). Two cancers show an opposite type of pattern, that is low SMR's in the center of the city with higher SMR's in the outlying areas. Both of these cancers (large intestine, lymphosarcoma and reticulosarcoma) have shown a positive association between socioeconomic status and mortality (Hoover et al., 1975), which may be reflected in the Columbus distribution. No obvious city-wide patterns appear for cancers of the rectum, pancreas, breast, uterus, ovary, prostate, kidney, bladder, brain, or leukemia.

A second method of examining variation among the census tracts is to note those tracts that have SMR's significantly high or low for a number of cancer sites. Most Columbus tracts having high SMR's are similar in terms of socioeconomic status, percent foreign stock, and types of cancer for which mortality is elevated. Four of these tracts form a geographic block around the Scioto River in south central Columbus. Residents of these four low income inner city tracts are at high risk of mortality for cancers of the lung, cervix, liver, and 'all malignant neoplasms'.

CANCER MORTALITY BY CENSUS TRACT: 1956 — 1974

COLUMBUS, OHIO



*Standard Population is Columbus, Ohio

Figure 1

The most remarkable census tract in Columbus, in terms of cancer mortality, is tract 91. This tract is significantly high (p 0.05) for seven individual sites and for "all malignant neoplasms'. It is quite dissimilar from the other high mortality tracts, displaying a greater percentage of foreign stock, a much higher median income level, and a different group of cancer sites for which mortality is elevated (large intestine, breast, ovary, kidney, brain, leukemia). The tract has a sizable Jewish population, many of them foreign born or of foreign stock from the U.S.S.R., Germany, and Poland. People of foreign stock comprised 25.2 percent of the population in 1960 and 24.4 percent in 1970. These people may experience genetic and/or cultural influences that predispose them to increased risk of mortality from certain cancers.

This study offers one application of mapping techniques to the investigation of disease and illustrates large differences in risk between census tracts within an urban area. These differences may be due to differences in local exposure to carcinogenic influences or to differences in the social, cultural, and demographic risk profiles of the local populations. Describing the variation in cancer mortality within the population is the first step toward interpreting patterns, increasing current knowledge of the disease, and suggesting theories of etiology.

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URBAN USES OF GEO-BASED DATA:
GETTING THE TECHNICIAN OUT OF THE WAY

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The Problem

Geo-based data is absolutely essential to the functioning of a municipality; it is its very lifeblood. Research has revealed that over 90% of the documents handled within most municipalities contain some form of geographical identification. It is therefore not surprising that cities are users and producers of many different types of maps. In fact, a recent study performed by the City of Philadelphia enumerated over 70 different series of maps being simultaneously maintained by various City departments. These included maps at a variety of scales and sizes, with different updating cycles and different combinations of features.

Unhappily, no convenient way was ever found to interrelate non-graphical geo-based data with maps - until the advent of computer graphics. Manually, maps and non-graphical collections of data are simply too different in their essential natures to tie together easily. Lists are one-dimensional, while maps are inherently two-dimensional. And, while it is not totally impossible to construct indexes and numbering schemes for cross-referencing between the two data formats, it is extremely cumbersome. Municipal users of geo-based data always want more maps, of all kinds; but these are so expensive to produce and to update that they are used only when absolutely necessary.

Computer graphics is changing all that. By having the ability to represent two-dimensional objects within the computer, techniques of information management that are not manually feasible become extremely useful. In particular, computer graphics makes it possible to use the map as an index to geo-based information. It is almost as if we can pin strings to locations on a wall map that are attached to individual geo-based records in our files, and retrieve the files, record by record, by pulling on the strings attached to them. Actually, computer graphics offers us superior techniques: We don't have to get tangled up in string (although that capability is also available...).

Maps are entered into the computer through a technique called "digitizing". This usually means using an "electronic drafting table" to enter into the computer system the end points of all the lines that make up the map, and critical points defining curves. (Automatic digitizing is almost, but not quite, commercially practical at this time.) Lines and areas are identified in the computer system's database by their usual geographic identities - e.g., streets, parcels, etc. - and can thus be linked to corresponding identifiers in other files. For instance, it is usually possible to identify a correspondence between parcel numbers and street addresses. Since lines and areas in the database are named, they can be called by name, rather than having to be identified by the coordinates of their boundary points.

Once the graphical database is constructed (with appropriate identification of lines and areas), it is relatively simple to write programs to link existing computer-resident geo-based data files - such as the tax rolls, which usually have both parcel numbers and street addresses; school board files, which have street addresses; police files, which define reporting areas in terms of bounding streets; and so on - to the maps for inquiry and display purposes. The computer graphics system then allows us to make requests like, "Show me the parcels owned by parents of children in Public School 94 that lie in Police Reporting Areas 352 and 456." The system responds by drawing an appropriate map on its graphic display; we can then request a "hard copy" of it. We can also ask that those parcels be listed and counted, rather than drawn.

The same computer system that can perform these amazing feats of informational prestidigitation is also well-suited for automating the map-making chores of the municipal engineers and other mapmakers. It is fairly well-established that the production of maps by using a computer graphics system is at least three times as efficient as doing it manually, and that the updating of maps is more than five times as efficient with a system as without.

Furthermore, engineering tasks such as road design, generation of planimetric maps from surveying notes and cut-and-fill computations can all be performed more effectively through the use of computer graphics than without.

All in all, computer graphics seems like a useful technology for municipalities. It would appear that, if the proper funding and political arrangements could be made, this is a technology that could be pursued by almost any city, to its gain. And in fact, that is the author's opinion. However, the purpose of this paper is not to convince the reader regarding the potential benefits of computer graphics, but rather to point out a major pitfall of introducing this set of techniques into municipalities. But, if reading this far has convinced you that your city should embrace computer graphics as the solution to most of its problems, beware! You are dangerously near the edge of the pit! The paragraphs that follow make the danger - and how to avoid it - abundantly clear.

The nature of the problem is fairly simple: The only people in a municipal government likely to be able to understand the potential of computer graphics well enough to define and purchase a system are the people currently involved with computers - the DP/MIS gang. These people usually know little or nothing about mapping and graphics in general, let alone the specific policies and procedures of their own city's mapmakers. Furthermore, as the opening paragraphs above indicate, it is easy for such technology fans to be so impressed with the potential benefits of the technology that implementation details lose their proper weight in decisions about such projects. On the other hand, the noble mapmakers typically know next to nothing about computer systems of any sort, least of all computer graphics systems.

The problem emerges when the city is getting ready to actually implement computer graphics technology in some way. The city fathers and the line managers are sold on the potential benefits; money has been set aside for the equipment, based on vendors' price estimates; it is now time to define the uses to which the system will be put, in detail, and to come up with a functional system specification. Who will do this work? That is the issue wherein lies the pitfall mentioned above. Three rather obvious answers to this question present themselves:

1. The DP/MIS people should do it, because they are trained problem-solvers and know about computers.

2. The user departments should do it, because they know what their needs are better than anyone else;

3. A committee should be formed with representation from both departments, to get the benefit of both 1 and 2.

The project initiators seldom pick answer number three; everyone knows that committees never get anything done. My purpose is to show that number three is indeed the best choice.

Experience Speaks

Several years ago, I directed the planning and implementation of a computer graphics project for the Metropolitan Government of Nashville and Davidson County, Tennessee. I was associated with Data Processing. Although it was our desire to involve the users in every phase of the project, to ensure that their needs were being met, we went a little too fast for them in the selection of a system output device.

This is what happened: Having established that we needed computer graphics to cope with a number of problems - lack of drafting personnel because of Metro's wage scales, lack of a geocoding framework for traffic accident reporting, lack of certain kinds of planning maps - we wrote a functional system specification in terms of what we knew about systems available at the time. When it came to the output device, we reasoned as follows: While pen plotters come closest to reproducing the then-current graphics products of the various Metro departments, they are counter-technology devices, in two senses: The development direction of all computer technology is toward less mechanical motion and more compact means of storage. Pen plotters are complex mechanical devices, and they would tend to produce more large sheets of paper and mylar than were being produced manually.

We, therefore, decided that a graphical computer-output microfilm (COM) unit would be the best choice of output device. COM units have few moving parts, and have as their output small, inexpensive pieces of film, that are produced two to three orders of magnitude more quickly than pen plots. We knew that the engineers were used to microfilm, as all their drawings were archived on 35 mm aperture cards. So - we bought a graphical COM unit, and no pen plotter. We also purchased an aperture card "blow-back" unit, to provide us with occasional paper copies.

A few months after the system was installed and working satisfactorily, we added a pen plotter. Why? Not being mapmakers, we had neglected to take into account the need for accurately-scaled large hard-copy output; nor had we properly communicated to the mapmaking users the limitations of the COM output subsystem.

Another municipal computer graphics geo-data system was being implemented at about the same time, in another southeastern city. A consortium of users from different public and private organizations overcame tremendous political and organizational obstacles, and was well on its way to producing a system specification, when an objection was raised by the drafting manager of one of the participating organizations. He insisted that the system output device had to be capable of plotting on linen (an outmoded drafting medium, even at that time), no matter what else it was to do. No amount of arguing or reasoning swayed him, and plans were changed to include a device - a large flat-bed pen plotter - that could plot on linen. And a question was left in the minds of all observers as to whether the organization whose drafting manager had insisted on linen-plotting capabilities had any idea of the function and potential capabilities of a computer graphics geo-data system, which they were helping to finance.

A couple of years later, I was principal consultant for a similar type of project for the City of Milwaukee. Once again, the project was being initiated by a department other than the ultimate user department; this time, it was the Community Development Department, with the cooperation of the Central Electronic Data Services group. We worked with the Department of Public Works (DPW) to produce a functional system specification, doing most of the design work ourselves, but checking with DPW from time to time. At a point when we thought we had a complete understanding of the user's needs - the system design was virtually complete - we had a meeting with the City Engineer. The system was to contain all the City's quarter-section maps; we were going to resolve "edge-matching" discrepancies on input. We proudly told the City Engineer how all the maps would thenceforth fit perfectly together along their boundaries. "Forget that!" was his somewhat-less-than-pleased response. He then told us how many functions (including engineering and assessment tasks) depended on the measurements of the maps just as they were, with their inaccuracies. He also pointed out that the current referencing schemes worked, inelegant as they might seem to us. We beat a hasty retreat, regrouped, and returned to assure him that the existing inaccuracies would be preserved in the computerized system.

The Solution

None of the three situations described above turned out poorly, in the long run. However, in each there was an element of unproductive activity - "wheel-spinning" - that could have been avoided, had the proper approach to the implementation process been taken. In Nashville, in spite of everyone's good intentions, the fact that the project initiative and leadership were in the data processing department led to an improper system specification. In the other southeastern city, control by an unenlightened user led to a distorted system specification. Total failure of the Milwaukee project was narrowly averted through a barely-adequate system of project designer/user communication. All three problems were caused by the user not having been properly educated by the computer people - a result of the computer people being so involved with the technology that they did not see that proper attention was not being given to implementation details.

Through these and other experiences, I have come to some simple conclusions regarding the implementation of computer graphics geo-data systems in municipalities. I have formulated them as guidelines, below, that tend to compensate for the razzle-dazzle effect of the technology on the technicians and the innocent users.

1. Project control should not be entirely in the hands of the DP/MIS group. With the best of intentions, this group will tend to be prejudiced by technological considerations, and will tend to overlook user department needs, through ignorance of the actual nature of user activities.

2. Project control should not be entirely in the hands of the user department. The users' ignorance of computer and computer graphics technology make it very difficult for them to appreciate the full potential of automation as applied to their activities.

3. A small committee - having at most, say, five members - should be formed, with roughly equal representation from the users' departments and the DP/MIS group. This committee should be charged with producing a system design. The system design should be as detailed and formal as possible, with heavy management participation and "signed-off" documents at the end of each design phase. The design process should begin with the users educating the DP/MIS people regarding their needs, and should proceed with the computer group educating the users in applicable aspects of computer technology. Only after the educational phase should an initial system design be attempted.

   Provision should be made for the design process to be iterative. That is, at each stage of its development, the design should be submitted to a review cycle that includes both user and DP/MIS management. The final design should be agreed upon and accepted by all parties at a meeting of top-level management, to insure proper initial support for the project.

If the recommended process seems cumbersome, remember that it has evolved as the result of experience. Before attempting short-cuts in the interests of saving time, remember, "There's never time to do it right, but there's always time to do it over!" is a saying that has come into currency because of the human tendency to want to finish things as quickly as possible, often with no regard for long-term consequences. I'll risk a homily: "An ounce of prevention is worth a pound of cure."

There is no formula that can guarantee the success of any project - because formulas must be followed in order to work, and people are not always totally dependable followers. However, my experiences since I adopted these guidelines have borne out their usefulness. I trust that they will be useful to you, the reader, as well.

EXPLORATION AND UTILITY SYSTEMS SESSION

EXPLORATION AND UTILITY SYSTEMS

Henry A. Emery, the chair of this session, presented the paper "Automated Mapping and Facilities Management". The Kellogg Corporation assists utilities and local governments in planning and managing automated mapping projects. These project costs can often range from 3 to 30 million dollars.

D.R. Johnston of Gibbs & Hill presented a paper entitled "CADAE: Computer Aided Design and Engineering". In this paper, Johnston describes the tremendous benefits which have accrued to the Gibbs & Hill firm by automating the engineering design process. Automation has resulted in a four-fold increase in efficiency over traditional methods and has encouraged the firm to expand their efforts in the graphics area toward the development of a geo-based information system.

"'Landform' Land Analysis and Display for Mining", was presented by Richard O. Mahan of the U.S. Forest Service. Landform is a system for analyzing and displaying digital data, collected in both surface and subsurface form. One advantage of using the system is the ability to depict what a proposed development will look like before any land is disturbed.

Douglas M. Isbell and William H. Young of Riverside County, California presented the paper "Engineering Applications of Digital Terrain Maps". A major breakthrough in the use of digital ground information occurred in 1976, with the development of a procedure to produce engineering quality orthophoto-contour maps from Digital Terrain Models. Some of the uses of the DTM are for extracting cross sections along any prescribed boundary for stockpiles, and determining flood plain limits.

James P. Corbett gave a paper entitled "Topological Models for Architectural and Engineering Projects". The purposes of the mathematical model are to provide facilities for efficiently evoking selected images and detecting structural or geometric anomalies.

AUTOMATED MAPPING AND FACILITIES MANAGEMENT

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Most utilities and local governments have drawn maps for as long as these organizations have been in existence. These maps are usually large-scale, 1"=100', 1"=200', sometimes 1"=50'. They show varying degrees of land or geography, generally referred to as planimetric and topographic features. Utilities use this as a background for showing plant - generally referred to as facilities - information. Facilities/plant information is shown on different map sets for electric, gas, water, wastewater, steam and any other utility systems in a combined locational and schematic manner. Local government engineering and public works departments have map sets that contain more geographic detail while tax assessor departments have parcel boundaries and tax identification items on their map sets.

The mapping systems for most communities and utilities have been developed and are maintained independent from each other. They have evolved over 50, 100, or more years as communities and utilities have grown. Usually the maps in the system have been created, one or a few maps at a time. They do not necessarily accurately tie together from map to map. In many cases they follow the U.S. land system and each map covers a quarter section or a section. Since it is universally recognized that sections are not exactly one mile square, it is difficult if not impossible to have a continuous mapping system. In years past, monumentation was not nearly as good as it is today. Many times in the past, developers, subdividers and land surveyors laid out developments starting from a known monument which may or may not have been accurate. This worked out well until a second development occurred near or adjacent to the first one. In these cases a new development survey could have very well started from a different monument. As you can expect, the surveys of the two developments may or may not have met. Thus, the map makers were required to make adjustments which were probably not accurate. Thus, today, utilities and local governments find that their existing manual mapping system does not truly represent what is on the ground.

You have undoubtedly noted that this discussion has not been confined to utilities but has included local governments. This may be considered an infringement on discussions on Urban Mapping. However, utilities and their facilities reside in communities which are, for the most part urban and the urban mapping, in most cases is controlled and perpetuated by local governments. In any one community the utilities and local governments are concerned about the same geography. Granted, each organization may require different levels of accuracies and different levels of information on their maps, and they may use the information on the maps for different purposes. However, this is still the same geographic territory and should be mapped once, and maintained once for the benefit of all the organizations in the community. Unfortunately, there are minimal examples of this having been successfully accomplished. To create one manual mapping system that would serve all of a community's needs has not been economically, technically, and politically feasible until recently. Although it is feasible today to use computers for a community system, the fact that it has not been successfully done indicates that it may be a few or several years before it becomes a reality.

Some events have occurred over the past ten years that provide the foundation for community and utility mapping systems and data bases. For years the aerospace industry, architects and academicians have been developing and using graphics, computers, and programs for design and modeling purposes. However, until about ten years ago, the cost was prohibitive, except for very specialized projects. In the late 1960's and early 1970's a phenomenon occurred unrelated to mapping, which has turned out to be a boon for automated mapping and facilities management. With the development of the so-called minicomputer, several companies put together turnkey systems called interactive graphics systems (IGS). These were developed and have been sold extensively to fill a need in printed circuit board design, engineering and architectural drafting, and other graphic applications. They were generally marketed as computer-aided drafting (CAD) systems. These systems centered around stand-alone minicomputers and included digitizing boards, cathode ray tubes, keyboards, tape and disk storage, and mechanical/electronic plotting devices.

In the early 1970's a few people who had previous associations with utilities began to recognize that these interactive graphics systems could be adapted for computerized mapping. Prior to that time, work on automated utility mapping had been done on large host computers and required the development of large, complex computer programs. The interactive graphics systems provided the breakthrough that was needed. Albeit, the software at that time was not sophisticated enough to satisfy the mapping needs. However, a few groups began to expand, evolve and refine the software to address the ultimate needs. As the power/cost ratio of minicomputers improved and the software sophistication evolved, these systems became very usable for automated mapping. Along with the mapping system developments it became evident that facilities/plant management systems were as needed as was drawing maps. And thus, today, automated mapping is a product of facilities management and facilities/land data bases.

As is generally the case in our society, the economic and political development has not kept pace with the technical development. There have been a few examples of successful utility automated mapping and facilities management projects. There are minimal examples of successful local government projects. Perhaps the one factor having the biggest influence on this process is what is termed "conversion." In order to have a successful project the massive amount of geographic and facilities/plant information contained in the manual system must be converted into the computer system. This is a large resource-consuming, time-consuming and extremely expensive process. Very few utilities and local governments have been able to convince management that these large expenditures are justified.

Fortunately, today there are some subtle, and not so subtle events occurring in society that are tending to change the situation. Utilities and local governments are facing external pressures to a degree that has not been felt before. The energy crisis, taxpayers' revolts, environmental impacts, opposition to rate increases, proliferation of government regulations, inflation and difficulties in financing, are prompting an introspective look by management on how to cut operating costs and still maintain the expected level and reliability of service. Stated another way: How can organizations more efficiently manage their operations? In general, these organizations have done a good job in improving the engineering of the components of their services. And there appears to be minimal opportunity to achieve savings by improving equipment engineering.

However, there is one basic resource that has had only limited attention. As a matter of fact, until recently, this area has not really been considered as a resource. This resource is "information." As we all know, most organizations are paper mills. The amount of required information for efficient operation is minimal as compared to the total information maintained. And, yet, all departments and all individuals within an organization must have certain amounts of quality information in order to effectively perform their functions. A large portion of the required information in a utility is contained on maps and in facilities records. The availability, the accuracy, and the quality of this information is highly important to successful operation. In varying degrees a similar statement could be made about local governments.

The amount of information that is maintained in a utility almost defies one's imagination. Very little thought has been given to controlling and managing this vital resource. The required information as maintained on the maps and facilities records of a utility is extremely important to the organization. It is so important that they each spend sizable sums, perhaps $1 million or more a year, to maintain this information. However, duplication, lack of timeliness, and the quality of the information is a very serious problem. The redundant files, nonagreement between files, and the perceived lack of reliability by the users, has created immeasurable problems.

As an example, one utility had five card files, in five different departments, consisting of information about 700,000 customer connections. All five card files were being maintained independently while getting their change and update information from the same source. The information in these five card files did not agree from file to file. You can imagine the time spent in reconciling the differences. The files were used by many, frequently, and continuously. The same situation can be applied to local governments. For example, any resemblance between engineering deparment maps and records and assessors maps and records may be purely coincidental. If the time spent resolving the differences was measurable, automated mapping and facilities management projects would be much easier to justify. In terms of usability, if one were to do a thorough investigation, maps and records in utilities and local governments in this country are probably not serving their perceived purpose. And, the sad thing about this is that many - the creators, maintainers and users - don't realize it. There are many examples of redundant, out-of-date, unreliable information that the users in the field do know about but are powerless to change. Therefore, they find expensive, time-consuming ways to get around the problems.

Another aspect of this is that planning departments, the census bureau, and other government agencies, have come up with methods and shortcuts to serve their needs. However, they have avoided the real issue. They have not encouraged local governments to go back to ground zero and remap, starting with aerial photography - tie all the maps together creating a continuous mapping system in the computer - resolve the differences and inaccuracies, and provide this base map to utilities, planners, police and fire departments, election commissions, and all the other organizations in the community. Yes, the cost for the total project would be high, but if it was split between fifty or more organizations in the community, the cost would be very minimal for each organization. In lieu of attempting to solve the fundamental problem, someone created the Dime File resulting in the expenditure of unbelievable sums of money.

On the other side of the coin, a few utilities have faced the task head-on and have attempted to do it right. They have gone back to the basics, acquired aerial photography, tied maps together into a continuous system, used coordinate systems and put this into a computer. They have placed their facilities and plant on this accurate land base. Over a period of years they will save their organizations sizable sums of money because the changes will be input once, all departments in the organization will be utilizing the same geography, the same coordinate values for the intersection of the streets, and will be communicating accurately with each other.

As was stated earlier, the conversion from manual maps and records to computer, which results in automated mapping and facilities management, is expensive. Projects can run from $1 million to $30 million, or more, depending on the geographic size, density of the area, amount of detail required, amount of storage required, and source document conditions. One utility company has budgeted $3.5 million for a pilot to convert one of its operating districts, a district consisting of 400 square miles. If the pilot is successful the utility anticipates it will cost in the neighborhood of $50 million to convert the land and facilities records into the computer for their total service area. This service area obviously is extremely large. The impetus behind this pilot and conversion is the Public Utilities Commission of the state that they reside in. The PUC has, in essence, said: You have computers and we don't think you are getting reasonable benefit out the the money you are spending for maintaining your maps and facilities management. One could reasonably expect that other state commissions could say similar things to the utilities under their jurisdiction.

Automated mapping and facilities management projects are not only costly but they are extremely complex. Perhaps it's the other way - they are extremely complex and thus expensive. There are 1,000, 5,000, 10,000 items that must be understood, defined, coordinated, specified and managed in a project. One must have a working knowledge of aerial photography, photogrammetry, mapping, grid systems, geography, utility operation, engineering, accounting, customers, energy flow, computer hardware, computer software, human relations, management, organization, planning, and a myriad of other skills. The magnitude and complexity of projects make it almost imperative that experienced, expert help be obtained.

Kellogg Corporation, located in Littleton, Colorado, a suburb of Denver, is a group of engineering management professionals doing many things, one of which, the one that I represent, is consulting with utilities and local governments on how to put together an automated mapping and facilities management project from inception to implementation. We provide history, background and understanding. We recommend and assist in maps and records audit of the existing manual system. We help define the needs of the organization. We help prepare the specifications and translate those into requests for proposals. We help justify the economics of projects. We provide a systematic approach for the evaluation of hardware, software and conversion services. We help negotiate contracts. Perhaps, above all else, we help to plan, organize, coordinate and manage the project. I personally have been involved in automated mapping and facilities management for over eleven years - that is about as long as anyone has been involved. We have a good understanding of most of the projects that occurred in the past, including those that were less than successful. We know about most of the hardware and software systems which are available. We know about most of the conversion services that are available. We are involved in, or know about most of the projects that are in progress today. We know what stages they are in and in what direction they're going, and we have a good understanding of why they're going in these directions. We have a good understanding of why they may be successful and why they may not be successful.

The Kellogg Corporation has recognized a need in the automated mapping and facilities management industry for the transfer of experience and understanding between utilities, local governments and the providers of services. In an attempt to address this need we publish a bimonthly AUTOMATED MAPPING CHRONICLE which is distributed to over 1200 individuals.

We plan, coordinate and sponsor annually the Keystone Automated Mapping Workshops. The recent Keystone II was attended by 80 individuals from 46 different organizations. Highlights of the workshops are panels on timely subjects and discussions on currently active projects. The panels and project discussions are led by the utility and local government project managers who are in the process of making their projects work.

Kellogg Corporation provides a one-day seminar titled

BOAMAP (Basics of Automated Mapping Projects) which is designed as an overview for management, engineers, operators, analysts and others who need to know.

Finally, the Kellogg Corporation is perhaps the only non-affiliated group providing consulting services in automated mapping and facilities management directly to utilities and local governments. Our only interest is to assist these organizations in achieving the most beneficial results from their project.

In summary, automated mapping and facilities management for utilities and local governments is a fledgling industry. Tremendous progress has been made in its ten plus year history. Much still remains to be accomplished. However, today there are far more projects either in progress or being considered than ever before.

The future looks extremely bright!

CADAE*
(COMPUTER AIDED DESIGN & ENGINEERING)

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Introduction

Gibbs & Hill is a large engineering and design organization headquartered in New York City. Beginning at the turn of the century as a pioneer in electrical transportation systems the company now provides a complete range of engineering/architectural services. These activities include: the design of major power generation facilities (including nuclear, fossil, hydro and solar power) planning, development and construction of new communities, urban and regional systems, industrial facilities, transmission and transportation systems siting and environmental studies, water and waste treatment systems and constructions services.

CADAE

As with most engineering firms Gibbs & Hill was faced with an ever-higher level of demand for design output. This traditional problem coupled with the increasing complexity of projects and new requirements imposed by stringent environmental, government regulations, and siting demands posed an increasingly serious production question. In 1972 the development of the CADAE system was initiated as a possible solution to some of these more obvious problems.

*Illustrations available from the author.

CADAE was desinged as a completely interactive system that could be used by the whole engineering staff. It is based on descriptive geometry. Complex shapes are readily constructed from baseic elements: angular lines, rectilinear lines, points, circles, ellipses, and irregular curves are called up and manipulated by keyboard and light pen. Views can be manipulated in any direction. The designer sees the results of any action immediately. Design changes previously requiring days of redrafting effort may be made on CADAE in a matter of minutes.

Gibbs & Hill have now had an opportunity to test and refine this capability on a variety of projects over a period of many months and preliminary experience indicates that CADAE is a significant breakthrough in the methodology of designing and enineering of large projects. The system frees the designer of much of the mechanical burden, and enables the design and engineering team to solve many communications problems inherent in traditional design methods. It provides a designing tool that can keep pace with the increased requirements of today's engineers.

The fundamental architecture of the CADAE System is based on bounded numeric geometry and employs the methodology of classical descriptive geometry. All geometry elements in CADAE are two-dimensional. Each element lies in a "view" - a plane oriented arbitrarily in space. Internally, CADAE handles geometry using the techniques of modern linear algebra. The user constructs views by indicating lines-of-sight and base points. They are converted to the equivalent matrix form. Projection of elements between views is accomplished using edge lines, just as a draftsman would. The projection of elements between views always utilizes these matrices. The drawings are created on a cathode ray tube (CRT) graphic display screen sensitized to a light pen that is used to develop the drawings.

Views are displayed to the user as if they were located on a piece of paper. The user is free to move, rotate, and scale each view and to add, change, or remove elements from them. All of these operations merely change the image; none of them alters the three-dimensional relationship between views. Thus, the tedious work involved in orthogonal/isometric view construction and projection on the drafting board is eliminated when using CADAE, but the convenience and ease of visualization of objects attendant with the use of descriptive geometry techniques remains.

The system installed at the company's New York headquarters on an IBM 3033 C.P.U. permits the storage of an enormous inventory of engineering detail. With the large memory available, CADAE can store many thousands of typical engineering drawings ranging from the most simple elements to highly complex modules (Figure 1). Once stored, the drawings, geometry, and alphanumeric data may be shared among an unlimited number of users. This sharing of data among users not only eliminates the need to duplicate drawings within engineering disciplines, but greatly reduces the margin for error as an increasing number of drawings circulate. The designer is always assured of having available the latest version of any drawing. Computer response time to a user request is less than one-half second for normal operations.

The designer/draftsman has instantaneous access to standard details, symbols, and drawings stored in the CADAE System by simply depressing a key on the terminal keyboard. Changes to drawings, previously requiring days of redrafting effort, are made directly on the display screen in minutes. The System automatically accommodates all changes made to a drawing. Electrostatic hard copy reprodution that incoporates changes can be obrained at a scale defined by the user within 3 to 10 minutes after the drawing has been stored. Other reproduction options avilable with CADAE are wet ink on film plots (produced on a flatbed plotter) with a quality surpassing that of hand-drafted ink drawings (at a fraction of their cost) and the reproduction of drawings either on microfilm or with microfiche techniques (Figure 2).

In using CADAE, any drawing detail need be constructed only once. Thereafter, it can be positioned and replicated on a single drawing or a group of drawings as needed. The replicated item is sized automatically without distortion to suit the scale and unit of measurement of each drawing.

During the creative process CADAE logic inhibits human and construction errors. If a syntactic or geometrically impossible error is made, a message to that effect appears on the screen so that it may be corrected immediately.

CADAE's data base provides the capability of duplicating portions of drawings or entire drawings stored by the System, thus minimizing new drawing development from project to project or from discipline to discipline within any given project. Using the building block approach, a plant physical arrangement developed by one design discipline may then be displayed on several terminals simultaneously and independently. Other disciplines may then work with a copied version, as required, while remaining independent of the master drawing. The copied version may be used by each design discipline as a basis for that discipline's portion of design responsibility. Such a feature greatly reduces the time formerly required for individual background creation and ensures uniformity of all drawing development.

One feature which has a direct analogy in environmental/planning applications is the ability to composite a multiplicity of elements. In engineering, there are always various disciplines which must be accommodated within the same space. The structural detail relates to the piping which in turn must relate to electrical, mechanical and so on. All activities must be reconciled within a certain floor or structure space. CADAE permits the user to composite multi-layers of detail within the same drawing. If there is a conflict or interference between structural and piping this is quickly evident and the necessary revisions can be made with a light pen. Seperate engineering disciplines can continue to work independently on a large project and still resolve the interdisciplinary conflicts by compositing any two or more elements on the screen at the same time.

One simple but time consuming task in any engineering detail is the need to change scale or dimension. CADAE provides a user-defined unit-of-measure option including English or metric, scale, and displayed-size capability accommodating variations in any scale and size. Drawings may be developed in first- or third-angle projection (American or European). The system will automatically calculate and display dimensions simultaneously in English or metric units. Dimensions may also be displayed in feet, inches, and fractions of an inch to 1/64 or in excess of 6 decimal places. Geometry chosen in a given scale can be subsequently converted to any other scale or unit of measure as required.

An increasing number of analytical functions are available on the system including: calculations of volume, area and weight, beam analysis, structural sections and properties, hydraulic circuit properties, fluid line analysis, individual geometric element analysis, etc.

Use of CADAE

As an operational tool CADAE has been available since 1977 and has been used on a number of projects already underway. Based on these successes we are now initiating large projects on CADAE, where all drawings will be developed on the system. Preliminary experience has shown that the first and obvious advantage has been the time saving over conventional drafting and design methods. Design efficiencies appear to be at least 4 times as fast as an average designer and for tedious repetitive tasks the ratio has been as high as 20:1. As an increasing number of the design/engineering staff have gained experience with the system, efficiencies in a number of different areas have become evident: time spent in checking drawings has been reduced by 25%, errors in accuracy have been reduced by 90%. Interaction among various engineering disciplines is now a very simple procedure. Once the basic design standards and functions have been established for a project all users can operate from the same data base.

Various disciplines can composite their individual design units to ensure all components are compatible and that there are no conflicts. A complex project can go forward on several fronts simultaneously with complete control over the technical interrelationships. Improvements in project coordination is approximately 60%. Coordination is accomplished by providing General Arrangement drawings to all disciplines. Each layout has the same plotting reference and can be overlaid precisely on any discipline drawings of the same area. Although each designer is working from the same data base he has complete freedom to select any scale, or choose as required any number of symbols or details from the library. This freedom and flexibility greatly reduces research and production time and enhances the creativity of the operator.

Training

CADAE has been designed to be completely user-oriented so that a minimum of training time familiarizes all levels of the engineering staff with the system.

Training programs entail 10 periods of 3 hours each for a total of 30 hours training for new designer/engineer users. At the end of the 30 hours the trainee has a good working knowledge of the system and can begin using CADAE on regular production work. Levels of skill and sophistication increase quickly so that by the end of the first 30 days of user experience, the operator is competent in all facets of CADAE's application.

The Gibbs & Hill program has completed the training of over 200 of its staff on the use of the system and by the end of 1979 expects to have 60 terminals in use.

CADAE Future

During the 1980's the engineering profession will be facing an increasing shortage of engineers. Of the students entering college, less are entering engineering schools. Even today we are experiencing a shortfall of 11,000 engineering graduates. CADAE will aid in easing the burden of the existing engineers, reduce the tedium, and enable them to be more productive professionals. Recent experience with CADAE suggests that it will aid greatly in this task and indirectly assist in alleviating another persistent problem - paperwork. In recent years the flow of paper has increased exponentially. More regulations, more codes, increased standards, more people active in projects that were not previously involved. The result has been that the designer/engineer is awash in paper. He spends more of his time in "busy" work. Paper shuffling, forms, correspondence, and general communication between project participants consumes a significant portion of the creative time available. CADAE has proven to be a significant aid in reducing this problem. The alternative would be a substantial reduction in the companies productive efficiency in the next five years.

Now that the viability of CADAE has been established in the engineering field the company has expanded its efforts into the area of computer mapping to include urban and regional planning, environmental and economic considerations and the total field of spatial data analysis for resource and land planning projects.

Now that the viability of CADAE has been established in the engineering field the company has expanded its efforts into the area of computer mapping to include urban and regional planning, environmental and economic considerations and the total field of spatial data analysis for resource and land planning projects.

During the coming months Gibbs & Hill will expand their capabilities in this area as a logical complement to its engineering/design activities. The vehicle for this expansion is the newly formed department - Geographic Information Services (GIS). The primary focus of the new department will be the use of computer graphics as a supporting service for existing Gibbs & Hill applications in energy generation, natural resource development, mining, transportation, planning and real estate development.

The function of GIS is the development and management of project data bases and its most visible application as in CADAE, is in the storing, display and analysis of information.

As a purely graphic tool we see GIS as one of the most direct and effective means of communication with the client throughout the life of a project. As a management tool it provides a means of organizing data and aids in the simplification of the project methodology. Being involved in a large number of complex projects, both domestic and foreign, we are always aware of the need to maintain a high level of communication with the client and to ensure he has a full understanding of every facet of the project. The maxim: "a client would rather live with a problem he cannot solve than accept a solution he does not understand", is still very true. Gibbs & Hill views the GIS capability as a mechanism to expand client participation and thereby enhance his project perception.

The final contribution of the GIS will be in the broad range of analytical and modeling applications that are possible. As a computer based device it brings to the project manager the luxury of being able to explore all the "what if" options that might influence the project.

The R & D required to develop this new capability necessitates considerable committment, consequently a commercial enterprise such as Gibbs & Hill must weigh the implications of the R & D effort, and ensure that the development exercise does not lose sight of the eventual corporate requirement, that the effort results in a contribution to net earnings. To this end, the development is directed to facilitate as broad a system application as possible. The system will incorporate Fortran language in a mini/micro configuration that is as transportable as possible and also compatible with our IBM 3033 central processor.

With this type of configuration we hope to be able to develop large spatial data bases within the system and also use the increasing number of public sector digital inventories already available from such agencies as the Bureau of the Census and U.S.G.S.

There are two main reasons that have encouraged us to pursue the development of GIS: The near-miraculous advancements in hardware have reduced the cost of highly sophisticated components to a level which makes them available to a much larger segment of the user population. At the same time, both the hardware and software have become more familiar and user-friendly to all participants. The other component essential to the expansion of this new capability is the sharply inreased user awareness. We have growing evidence from departments within our own firm who, having seen some colorful output products on a project, suddenly become enthusiastic users of the system's graphic capabilities. The highest confirmation of our decision to expand in this area came when a young engineer said, upon receiving the first output from the plotter - "hey, this is okay!"

"LANDFORM" LAND ANALYSIS AND DISPLAY FOR MINING

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Landform - A Computer-Aided Planning and Design Process

What is landform?

Landform is an acrononym for Gathering and Organizing, Displaying, and Processing data to assist the planner and designer in doing a thorough job and reaching timely decisions which are based on more facts.

The process was developed under the Forest Service Surface Environment and Mining program and is being demonstrated in a cooperative effort with J. R. Simplot Company in the phosphate area of southern Idaho.

The Surface Environment and Mining (SEAM) program was a special Research, Development, and Application program established by the Forest Service. The program got underway in 1974 and was given a five-year charter to examine the potential environmental effects of surface mining in the west. This entailed doing the necessary research and developing technology to minimize any adverse effects or to hopefully enhance the environment. This entire effort, of course, was underscored by the need to get the knowledge used or applied to the problems. The program is closing down at the end of September, in about a week, with the objectives initially established met. The cooperation and assistance by the minerals industry has been tremendous, is appreciated, and we would like to take this opportunity to say thanks.

Why landform?

In recent years, there has been a significant public awareness and concern for environmental conditions and especially possible environmental degradation. This environmental concern, as well as legal and economic constraints, has made minerals development expensive. Ways of handling the necessary planning and design have become quite sophisticated.

In examining the ways minerals development was being planned, it seemed there was a real need for a more comprehensive approach to minerals development. For example, a few years ago reclamation was considered the action that was taken after mining was completed. Now, I believe, most people in the business realize that proper development includes adequate consideration of all phases of mining, from exploration through post reclamation.

At the same time that there was recognition of the need for more comprehensive planning, it was also recognized there was a need for better methods and tools to do the job. There were a number of computer programs in use both inside and outside the Forest Service which could be applied to the task of doing a better planning and design job. Landform is the result of the effort to bring existing and new computer programs into a system that can be applied to minerals development, planning, and decision. It brings together digital modeling, information display techniques, and engineering design programs into a single, integrated process.

Over the past few years, technology has advanced significantly, and methods have now been developed to collect both surface and subsurface data in digital form so that, with the aid of computers, it can be rapidly manipulated and displayed. In addition, program and processes have been developed to use digital data for planning and designing many different types of landform changes, including those resulting from such activities as surface mining, timber harvest, transportation facilities construction, and ski area development. Visual display and simulation capabilities have been developed, which can be used to depict what a proposed development will look like before any land is actually disturbed.

How is landform organized?

Landform is divided into three primary phases. These are:

(1) Data Gathering and Organizing

(2) Information Display

(3) Design and Plans

I would like to discuss each of the three phases.

Data gathering and organizing.

In the first phase, Data Gathering and Organizing, we are collecting data sufficient to define the surface of the ground, the subsurface geology, man-made improvements, and other information needed for planning.

Any point, line, or surface can be described in a numerical way by coordinates so computers can be used to manipulate the data. This digitized data in an XYZ coordinate system can be gathered in a number of ways. It may be collected from aerial photography using what we call the Mahan Breakline Method. With this procedure, a digitizer-equipped stereo plotter such as a KERN PG2 or TOPOCART is used to digitize the drainage bottoms and ridge lines. If the terrain is uniform, this is the minimum amount of data that will adequately describe it. However, the ground is seldom uniform or seldom has a constant slope between the ridges and drains. Therefore, additional data is collected along what we call "form lines" to define additional breaks in the terrain. This method is designed to allow the definition of the terrain within specified limits of accuracy with a minimum amount of data.

Recently, it has become possible in certain areas to get terrain data tapes from the U. S. Geological Survey. These data tapes are collected as a byproduct of their normal process of developing orthophotos and mapping. We have tested the data to a very limited extent and have found that a 40-foot contour level of resolution is reasonable. This would be very suitable data which could provide useful information for broad area planning.

Terrain data can also be collected by digitizing the XYZ coordinate data from contour maps. In some cases, suitable data can be obtained from on-the-ground surveys.

We believe that use of the Mahan Method is efficient and effective, and it does allow the user to statistically evaluate the accuracy of the terrain data. We believe this is important, because it tells one how closely the terrain model represents the actual ground.

Subsurface data can be developed using drill hole logs, information from seismic or resistivity surveys, or other valid geologic data sources. I would like to point out that the geologist or mining engineer must specify and systematically identify the encoded information. The subsurface data will normally be much sparcer than the surface data. The system is developed so that machine extrapolation beyond known data is not allowed. We have found that considerable interaction between the user (geologist or mining engineer) and the system is necessary to properly develop subsurface information.

Other resource information is also needed to do an adequate job of planning. Such information as property boundaries, existing transportation facilities, vegetative types, and wildlife habitats can be incorporated into the system by using either an XY digitizer, or a stereo digitizer. The information can be taken from maps, photos, or surveys.

The Landform system is designed to operate on mini computers as well as large systems. Therefore, organizing the data takes on special significance. First, all data is oriented or tied to a uniform coordinate system. All data is sorted by location in a series of grid blocks. These blocks of data are addressed and can be selectively retrieved. In that way, the entire file does not have to be searched in order to call out some specific data.

The data is stored in either a random or gridded format so that advantage can be taken of either or both, as appropriate. As was mentioned earlier, the data is compartmentalized so that it is useable on small systems which will support random access files and where core storage is limited. All programs are written in Fortran language so they can be more universally applied.

The system as it presently exists is organized in a matrix with nine programs. There are an average of about six (6) subprograms in each program. The system is modularized, and we foresee the addition of other programs and subprograms in the future. Many of the programs have been developed on an IBM 1130 mini computer, but also operate on the large Univac 1100 system. Some of the programs have also been put on the Data General Eclipse and Nova mini computers in our office. The rest of the programs are currently being put on the Eclipse system.

Information displays.

One of the advantages of having a digital data bank that a computer can use with a machine plotter is that contour intervals, scales, and perspective views can be rapidly changed to meet the user's needs. It also allows the overlaying of the different information layers.

The initial output of the Landform process is the production of a number of displays or plots of the existing conditions. These displays are useful to the planner or designer, because it provides a visual representation and enhances understanding of the site. They can also be used for actual planning and designing activities such as laying out road grade lines using topographic plots. Examples of plots which can be produced using surface data are: perspective views of topography, perspective fishnet grids, slope and aspect, or profiles at any location selected by the user. These plots can be registered to vertical or oblique photography as desired.

The subsurface data can also be represented in various ways. In addition to the drill hole locations, structural contours or cross-sections showing the various strata or layers can be plotted. These can also be turned and viewed in perspective from any position. We believe, for example, that perspective plots of the underground surfaces are very useful in locating and analyzing faults or other discontinuities.

These informational displays can be supplemented and overlayed with any number of other resource or physical feature plots, such as property boundaries or existing roads.

Designs and plans.

Computations - With the above information available and easily accessible, the designer has products which he can use. To further assist the designer, the system includes programs which provide compuation of plan areas, such as the area disturbed and needing revegetation. Cross-sectional areas and the volumes of overburden and ore, for example, can also be computed. These computations are all provided in a systematic tabular format. Once the location and volume of material is known, haul quantities and costs can be computed. Road design processes are included so that the geometry, such as the centerline alignment, is calculated and tabulated. Cross-sections and profiles are plotted and areas and earthwork volumes computed.

Plans - Finally, the result of the design process needs to be represented as plans with drawings and/or models. Again, using the display capabilities of the system and alternative designs of the transportation system, pit or waste disposal areas can be produced in plan views, perspective views, or as cross-sectional views. These plots can be used by themselves or registered to vertical or oblique photography to accurately depict what the proposed development will look like. With a minimum of artistic enhancement, the proposed development can be accurately portrayed. This gives both the designer and the public a better understanding of just what the proposed development will look like before any ground is disturbed.

Applications.

Development and assembly of the system has been undertaken during the past year in cooperation with the J. R. Simplot Company and the Forest Service Regional Office in Ogden, Utah. The system, as it presently exists, is documented in a draft User's Manual. The Forest Service will continue testing and application of the system at the regional headquarters in Ogden. The programs will be available at reproduction costs to those who want them. These will be provided within the constraints of the time available by the two-man project staff.

ENGINEERING APPLICATIONS OF DIGITAL TERRAIN MAPPING

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The Riverside County Flood Control and Water Conservation District has taken the pragmatic approach to Digital Terrain Modeling beginning approximately ten years ago with the District's engineers using photogrammetric equipment to capture digital information to describe the surface of the ground. Initially this involved the extraction of cross sections along a prescribed alignment through the use of a stereo plotter. This experience lead to the construction of simple Digital Terrain Models of borrow areas and sanitary landfills for the purpose of volume computations.

A major breakthrough in the use of digital ground information occurred in 1976, with the development of a procedure to produce engineering quality orthophoto contour maps from Digital Terrain Models. Unlike earlier Digital Terrain Models generated from cross sections, the mapping D.T.M. had to represent the ground surface within the relative accuracies of the aerial photography from which it was derived. This was accomplished by recording numerous ground elevations (40,000 per stereo model) during the production of the orthophotograph. An orthophotograph is a true scale photograph that is used in place of the traditional hand drawn planimetric data as the base for the contour map. The digital elevation data is converted into a D.T.M. using sophisticated computer programs and a finished orthophoto-contour map is produced on a high speed flatbed plotter. This process not only produces maps that meet U.S. Map Standard Accuracy, but also provides the engineers with a D.T.M. of the same accuracy.

A closer look at this Automatic Orthophoto-Contour Mapping procedure will illustrate the precision with which the digital elevation data is collected. The process begins with the set-up of a stereo model within the Santoni IIC Orthophoto Plotter. The digitizing procedure starts with the recording of all horizontal and vertical control points. The stereo model is then scanned for the production of the orthophoto in a series of vertical profiles. As mentioned earlier, relative coordinates and elevations of more than 40,000 points for a single model are recorded in terms of X, Y, and Z. When the scanning is complete, spot elevations are read and recorded at normal locations: the hilltops, saddles, culverts, street intersections, and most importantly, where scanning of the vertical profile might have lost contact with the ground. These spot elevations replace data obtained from the vertical profile scan. When the digitizing is completed the data tape is fed into the computer where the scan data are rotated and translated into a uniform elevation grid based on the State Plane Coordinate System. Several models are processed and held in the computer's disk storage until an area larger than the defined limits of the desired map sheet is processed. Contour mapping begins by defining the limits for each map sheet in terms of the California Coordinate System. The computer extracts all survey data and elevation grid values falling within these limits to produce a Map Grid. Overlapping grid values for common points from various stereo models are converted to single values. In addition, an extra one-inch strip of vertical data is extracted for the area immediately outside the limits to insure proper edge matching of adjoining models.

Once the Map Grids are complete, the engineer may elect to produce a contour map to a specific scale and contour interval or he may utilize the D.T.M. data for engineering computations. If a contour map is desired, it is constructed using a Contouring Program that outputs a magnetic tape used to draw and label the contours on the flatbed plotter. At the same time another tape is prepared to plot the survey data, State Plane Grid, spot elevations, and title information. Meanwhile, the orthophoto conforming to the previously defined map limits is enlarged, screened, and photographically printed on a title block.

After the orthophoto is printed on stable base material for processing on a Diazo White Printer, the finished orthophoto transparency is placed on the CalComp 748 Flatbed Plotter and registered to the ground control, then all the data stored on the two plot tapes are plotted directly on the orthophoto in ink. Currently, inking and labeling of the contours is done on the reverse side, while control points, grid, borders, title, spot elevations and control descriptions are drawn on the right side. This technique permits correction to be made to contours without disturbing grid values or control point information and vice versa.

The D.T.M. is available for use by the engineers once the Map Grids are complete. The engineers access D.T.M.'s through computer terminal, a series of computer programs that provide for computation of volumes, extraction of cross sections and alignment profile plots.

Cross sectioning is by far the most prevalent method of volume computations. With the D.T.M. the engineer can evaluate alternate alignments by merely inputing the coordinates and curve data that describe the alignments, the cross sectioning frequency and the left and right limits of the sections. The computer program computes elevations for each cross section and stores this data in a computer cross section file which may be utilized by the earthwork computer program as well as the cross-section plot program.

An alternate method of volume computation, now available to the engineers, is grid to grid computations within a prescribed boundary. This process utilizes two D.T.M.'s representing the before and after conditions and is well suited for stockpiles, borrow pits, reservoirs and land fills. The D.T.M.'s can either be produced by the Automatic Orthophoto-Contouring procedure or through contour tracing of existing and design maps or from cross sections. The engineers have found that this method of volume computation provides accuracies comparable with traditional methods and are using this method for final payment quantities.

Through the use of the D.T.M., the engineer is able to display his design through the use of perspective views. This method of conveying the visual effects of a project has been found to be invaluable when interfacing with the general public.

In conclusion, the District has found that the Automatic Orthophoto Contour Maps using D.T.M.s is a cost effective alternative to traditional line mapping and the engineers have found the use of D.T.M.'s an exciting new approach to solving traditional problems.

TOPOLOGICAL MODELS FOR ARCHITECTURAL AND ENGINEERING PROJECTS

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I. Introduction

The model presented here is intended for the interactive use of architects and engineers. The effective use of the model requires adequate computer support. In particular, it is desirable that adequate computer graphics facilities are in place so that selected structural elements may be displayed. A comprehensive system for projective geometry is also desirable. The purpose of the model is to provide facilities for the efficient evoking of selected images, and for the detection of structural or geometric anomalies. These anomalies will be of two kinds. First, there may be topological anomalies, whose presence makes consistent detailing impossible, and second there may be metrical anomalies arising from metrical inconsistencies with the topological structure. Such anomalies should be detected before fabrication is begun.

The model is a framework for organizing the project. It is constructed according to the principles of combinatorial topology. Here, a geometric object is considered as being a synthesis of elementary objects, cells, according to a specified scheme of interconnection. The cells and their connections are not to be regarded as representations of material objects, but rather as abstract geometric references to which the individual details are required to conform. The important property of this frame of reference is that it may be established at the outset as a self-consistent geometric object, before any detailing is begun. It thereby becomes a powerful tool for controlling the mutual consistency and self-consistency of the details of the structure.

II. Combinatorial Topology in Three Dimensions

Combinatorial topology deals with elementary geometric objects, cells, and a single binary relation on pairs of cells. This relation is known as incidence. In principle, a list of incident pairs of cells provides a complete and unambiguous description of a method of assembling cells into an integral structure. Cells are endowed with a property, dimension, specified by an integer, 0, 1, 2, or 3; and hence we speak of cells as 0-cells, 1-cells, 2-cells and 3-cells. We refer to cells by the symbols, c^k, in which the super-script denotes the dimension of the cell. The relation of incidence is expressed by the symbols,

(2:1) $$I(c^k, c^{k+1})$$

Note that the cell of lower dimension appears first in the pair. The first cell of the pair is said to bound the second, and the second cell is said to co-bound the first.

The term, cell, is quite a useful one. Although the intended interpretation is that 0-cells are points, 1-cells are arcs, 2-cells bounded simple two-dimensional manifolds, the term itself carries no connotation of a metrical nature, such as position, curvature, torsion, length, area or volume.

There is a second point of view from which the term is useful. Much of a designer's work is synthetic, connecting simple elements (cells), or modules (collections of connected cells), in particular ways to form integral structures. On the other hand a designer may begin with a single amorphous cell, and procede to create a structure by subdividing the space, using the separation properties of cells of lower dimension.

III. Relations of Order and Orientation

There are certain important properties of cells and their incidence relations that are most simply expressible in topological terms. The most important of these properties is orientation. Every cell, of whatever dimension, may be oriented in two ways, referred to as positive and negative. Orientation depends on order relations. For the 0-cell, which is intended to represent a point, one arbitrarily associates with each 0-cell a positive or negative algebraic sign.

For a 1-cell, we establish an orientation (direction) by ordering the pair of bounding 0-cells. The first 0-cell is taken as negative, the second, positive. The negative of this 1-cell is defined by reversing the order of the bounding 0-cells, and therefore the direction of the 1-cell. This relation with the bounding 0-cells is often referred to as the "from-to" relation.

Analogously, the 2-cell is oriented by establishing an order on its bounding 1-cells. The poitive 2-cell is taken to be that version for which the cell lies to the left of each bounding 1-cell. Obviously, this may require that some, or all, of the bounding 1-cells are negative. We will refer to this scheme of order and orientation as the near side view of the cell, and the opposite view as the far side.

Finally, the 3-cell is oriented in terms of oriented 2-cells on its boundary. The positive version of a 3-cell is that for which the cell lies on the far-side of each bounding 2-cell. Thus, it is possible to think of the positive version of a 3-cell as that seen from without, looking in, and conversely, the negative version as the same cell from the inside, looking out.

The method of orienting the 2-cell is in agreement with a convention for which a positive traverse of the boundary is taken in the anti-clockwise direction.

IV. Duality, Boundary and Coboundary Operators

The duality of a topological structure is a form of abstract symmetry. The concept is of extreme importance to the model. The scheme known as Poincare duality is used. Dual concepts are listed as pairs in the following table.

0-cell -------	3-cell
1-cell -------	2-cell
boundary------	boundary

In the sequel many definitions will occur for which dimension numbers and the terms "boundary" and "co-boundary" appear. Any set of statements of this kind is related to a dual set of statements formed by replacing the dual elements from the table.

We now give definitions of the two most important algebraic operators associated with a topological structure the boundary and coboundary operators. It will turn out that these operators are dual to each other. The boundary operator will be denoted by the symbol, B, and the co-boundary operator, by the symbol G.

The boundary operator is defined in stages. The first step is to define the operator on the domain, c^k, the set of k-cells. The domain of the operator is c^k, and its co-domain the power set of c^{k-1}.

For any cell, c^k, $B(c^k)$ is the set of all (k-1) cells for which the relation

$$I\ (\ c^{k-1},\ c^k\ )$$

holds.

This operator is extended to the domain consisting of the power set of c^k simply by taking set theoretic unions.

In practice the operator is realized as follows: For each cell of the argument set, the set B(c) is constructed. The signs of the occurrences of individual cells are retained. The union of all such boundary sets is then reduced to an unduplicated list of cell names, in which positive and negative occurrences of the same cell are distinguished. Each cell is associated with an integer denoting the multiplicity of its occurrences in the amalgamated set of boundaries.

The coboundary operator is defined by a set of statements dual to the set defining the boundary operator above.

V. The View and the Section

We are now in a position to relate the formalism of combinatorial topology to engineering drawing practice. The view, illustrated in Figure 1, represents a 2-cell, and its complete boundary, that is, the set of bounding

1-cells, and the 0-cells on the boundary of these 1-cells.

The section, illustrated in Figure 2, represents a section through a 1-cell, its cobounding 2-cells, and the 3-cells cobounding this set of 2-cells.

The view and the section are therefore dual structures. We further annotate the view with the names of the 3-cells on the near and far sides of the cell, and similarly, annotate the section with the names of the "from" and "to" 0-cells on its boundary.

VI. Circuits and cocircuits

A set of k-cells for which the bounding (k-1)-cells each occur exactly twice and with opposite orientation is a k-circuit. The term cycle is often used in place of circuit, and in some branches of topology, the term, loop, is used.

The set of all k-circuits will be denoted by the symbol Z^k, and the set of all k-cocircuits, by Y^k.

A convention is required for 0-circuits, and the usual one defines a fictitious boundary, the sum of the coefficients of the 0-cells. Thus pairs of oppositely oriented 0-cells are 0-circuits, and pairs of oppositely oriented 3-cells are 3-cocircuits.

In some of the analytical procedures it will be required to identify the non-bounding circuits (and their dual structures). When this is required, the bounding circuits will be denoted by Z_B^k and the cobounding cocircuits by Y_G^z.

VII. The Algebraic Structure and its Model

We have now reached the final step in the description of the topological framework, the construction of the algebraic model. This model will provide for an efficient storage structure for the necessary data, and a natural and convenient language, L, for evoking images of particular designated structures.

The model is the algebraic structure, consisting of the elements,

(6:1) (C^k, Z^k, Y^k, B, G)

The symbols of the structure are incorporated into a logical language as an extension. In this extension one can express all of the necessary conditions to be satisfied by the model, and all of the necessary practical descriptions of cells, cell-modules, and extended structures that may be required.

VIII. Examples of terms in the language, L

The operator, $(1 - B)^{-1}$, will represent the Neuman series, $1 + B + B^2 + \ldots..$ When operating on cells this operator is always truncated, since c^{-1}, and c^4 are taken to be null sets.

To evoke the image, the view of a 2-cell, the term is

(7:1) $$(1 - B)^{-1} c^2$$

To evoke the section of a 1-cell,

(7:2) $$(1 - G)^{-1} c^1$$

The duality of these two structures, already remarked, is evident from this pair of formulae.

To annotate the 2-cell with its pair of cobounding 3-cells, the required algebraic term is

(7:3) $$G\ c^2$$

To annotate the 1-cell with its pair of cobounding 0-cells the term is

(7:4) $$B\ c^1$$

The conditions that must be satisfied for each cell of the model are,

(7:5) $$(c^k)\ B(c^k)\ e\ Z^{k-1}$$ (e denotes set membership)

and the dual condition

(7:6) $$(c^k)\ G(c^k)\ e\ Y^{k+1}$$

These examples illustrate the fact that all of the necessary terms and sentences can be expressed in standard mathematical terms within the language, L.

IX. One and two-dimensional structures

Many substructures in a complex project are most conveniently abstracted as one and two-dimensional geometric objects. Piping, electrical conductors, partitions, decks, etc. are obvious examples. Such structures are embedded in three-dimensional space, but are themselves abstracted to one and two-dimensional form.

The Poincare duality scheme in two dimensions differs from that for three dimensions. The dual pairs are listed in the following table.

0-cell ------ 2-cell
1-cell ------ 1-cell
boundary ---- boundary

For a one-dimensional object the table is

0-cell ------ 1-cell
boundary ---- boundary

The model for the one-dimensional case is trivial, but the model for the two-dimensional case is determined by the same algebraic structure as that constructed for three-dimensions. The difference is that the value of k, the dimension numbers are restricted to 0, 1, and 2. Thus although the structures are formally similar, the two dimensional model is simpler. These models are displayed as tableau in Figures 3 and 4.

X. Metrical descriptions

Each cell requires a metrical description. It is assumed that this set of algorithms, $A(c_i^k)$ is provided for each cell of the structure.

There are two general conditions that must be satisfied by these descriptions; 1) The non-intersection condition for pairs of cells, 2) The continuity condition between a cell, its boundaries and its coboundaries.

These conditions may be verified algorithmically, and even approximate interfaces discovered.

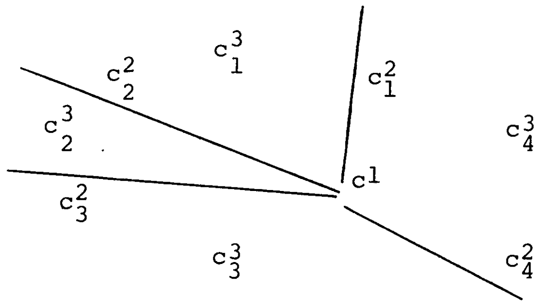
XI. The data storage structure

The data storage structure is shown schematically in Figures 3 and 4. Structures for both two-dimensional and three-dimensional manifolds are shown. It is evident that these storage structures are simple maps of the algebraic structure.

Seperate lists of the algorithms defining the shapes and sizes of the individual cells are provided. These are entered with the cell name as a key.

It is an absolute necessity that this structure be edited both topologically and metrically. The topological editing consists of verifying that the model satisfies the cyclic and cocyclic conditions for a boundary and a coboundary respectively. The metrical edit consists in verifying the continuity conditions for a cell, its boundary, and coboundary, and the non-intersection condition for all pairs of cells.

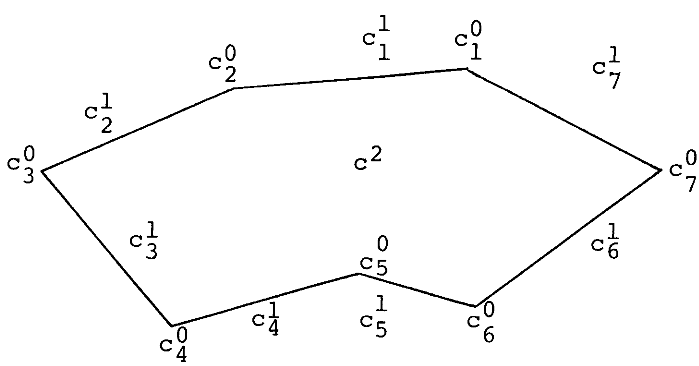
A data structure that passes these editing tests is necessarily self-consistent both metrically and topologically. The importance of conducting these tests interactively cannot be overestimated.
This form of correction permits re-editing of alterations immediately upon data entry. In fact, it is possible for a designer to create the entire structure under this discipline, so that no inconsistent data is ever accepted into the model at all.



looking from c_1^0 to c_2^0

Section through a 1 - cell

Figure 1



near side c_1^3
far side c_2^3

View of a 2-cell

Figure 2

C^0 $\quad$ Y^1 $\quad$ C^1 $\quad$ Z^1 $\quad$ C^2

$$(c^0 : y^1) \overset{G}{-----} y^1 ------ (c^1 : c^0_1, c^0_2, c^2_1, c^2_2) ----- z^1 \overset{B}{-------} (c^2 : z^1)$$

Note that the elements, c^1, are self dual. The sets c^0, Y^1, are dual to the sets c^2, Z^1.

There are three entry points.

File Layout for Model of a Two-Dimensional Manifold

Figure 3.

C^0 $\qquad\qquad Y^1 \qquad\qquad C^1 \qquad\qquad Y^2$

$(\ c^0:\ y^1)\overset{G}{\text{---------}}\ y^1\text{--------}(\ c^1:\ c^0_1, c^0_2,\ y^2)\ \overset{G}{\text{-------}}y^2\text{----------}C^2$

C^3 $\qquad\qquad Z^2 \qquad\qquad C^2 \qquad\qquad Z^1$

$(\ c^3:\ z^2)\overset{B}{\text{---------}}\ z^2\text{--------}(\ c^2:\ c^3_1,\ c^3_2,\ z^1)\ \overset{B}{\text{------}}\ z^1\text{---------}\ C^1$

Note that the data storage structure is an exact map of the data structure.
The sets, C^0, Y^1, C^1, Y^2 are dual to the sets, C^3, Z^2, C^2, Z^1.
A symbol followed by the symbol, ":", is an entrance key; there are four such keys in all.

<u>File Layout for Model of a Three-Dimensional Manifold</u>

Figure 4

DATA BASES, SMALL SYSTEMS SESSIONS

DATA BASES, SMALL SYSTEMS

There were two Small Data Base sessions, both chaired by Carl Youngmann of the University of Washington. In the first session, Youngmann demonstrated his CAC/APPLE system. (Paper not included in proceedings.) His system consists of a set of computer-assisted cartography programs for the APPLE II computer. Although the resolution of the APPLE system is not particularly high, Youngmann considers it good enough to use for demos and community groups. The APPLE also has three basic advantages: speed of computation, ease of use, and interactive capabilities. Youngmann has implemented a statistical graphics package and discontinuous mapping procedures for choropleth maps on the APPLE. He also intends to implement simple continuous mapping procedures and interactive geographic entry.

In the latter part of the first session Richard Phillips of the University of Michigan described an emulator which he is running on the APPLE II computer. This emulator emulates Tektronix type vector graphics on the raster style APPLE. Output which normally would appear on a Tektronix can thus be shown on the APPLE by feeding it through the emulator. He indicated the basic limitation of the APPLE for this purpose is its low resolution. However, the distinct advantages of the APPLE are: fast area filling capabilities, color, and the ability to connect a plotter to get hard copy output.

Marvin White and Patricia E. Griffin presented a paper entitled "Coordinate Free Cartography". In this paper it is demonstrated that by using coordinate free cartography, one can test a network for topological correctives without attaching x and y coordinate values.

Paul M. Wilson and Donald A. Olmstead presented a paper entitled "The Data Structure of BASIS". BASIS is a grid cell system containing data about the San Fransisco Bay region. Wilson and Olmstead discuss some of the efficient coding strategies used to implement this large data base on a mini computer.

COORDINATE FREE CARTOGRAPHY

Marvin S. White, Jr. and Patricia E. Griffin
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Introduction

There are three famous characterizations of planar graphs [1]. Kuratowski's identifies forbidden subgraphs K(5) and K(3,3). Whitney's demands a combinatorial symmetry called duality, and MacLane's requires the existence of a vector space of circuits with a particular algebra.

Although none of the three provides a construction of a planar representation of a graph, MacLane's is the foundation for Tutte's algorithm [3,4] and some later algorithms [1] for embedding a graph in the plane. These algorithms are used both as a test for planarity and as a means for drawing a graph that is planar.

Lefschetz [2] has proven MacLane's Theorem much more simply via recourse to algebraic topology. The algebra required by the theorem is quite easily understood topologically.

We proceed as Lefschetz did to greatly simplify Tutte's algorithm. This new algorithm is applied to a topological encoding of a map known as the Dual Independent Map Encoding (DIME) invented by Corbett [5].

The DIME scheme for maps is in widespread use throughout the world. In this scheme, incidence relations are explicitly coded and coordinates are associated with points and lines. The encoding of a line written as [from node, to node, left block, right block] may be tested for consistency.

The consistency requirements are severe enough that they can be used to guess coordinate values where they are in error or even where they have never been measured. The guessed coordinate values are useful for interactively presenting a display of a small portion of a map with erroneous coordinates. The clutter is eliminated and the console operator may proceed directly to the business at hand, e.g., locating street addresses or correcting errors.

Our Algorithm Applied

Our algorithm for drawing a map given only a DIME description without any coordinates produces a representation that is topologically consistent with the actual map (Figure 1). The guessed coordinates will be a rotation and/or translation of the original map, but they will allow for a consistent and uncluttered display that can be altered with a small amount of effort. Points can be relocated so that their position is closer to that of the original map. Using the coordinates of the relocated points and computing coordinates for all other points results in a likeness of the original map (Figure 2).

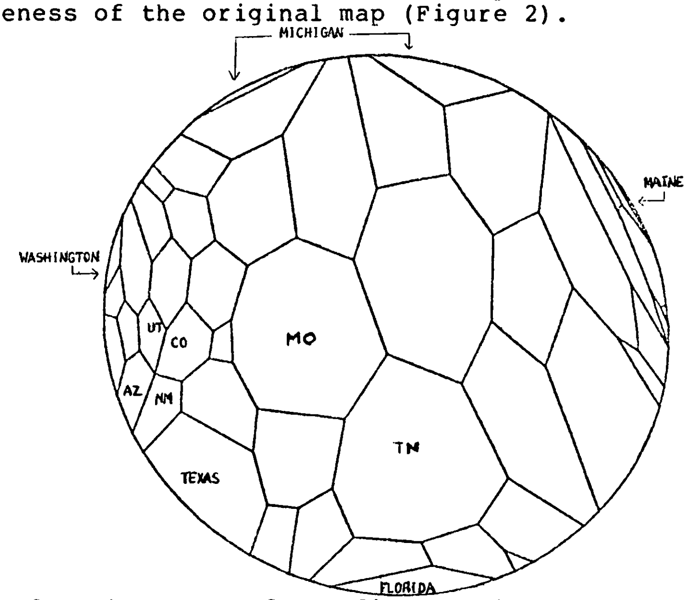


Figure 1. The computed coordinates yield a map topologically consistent with the original.

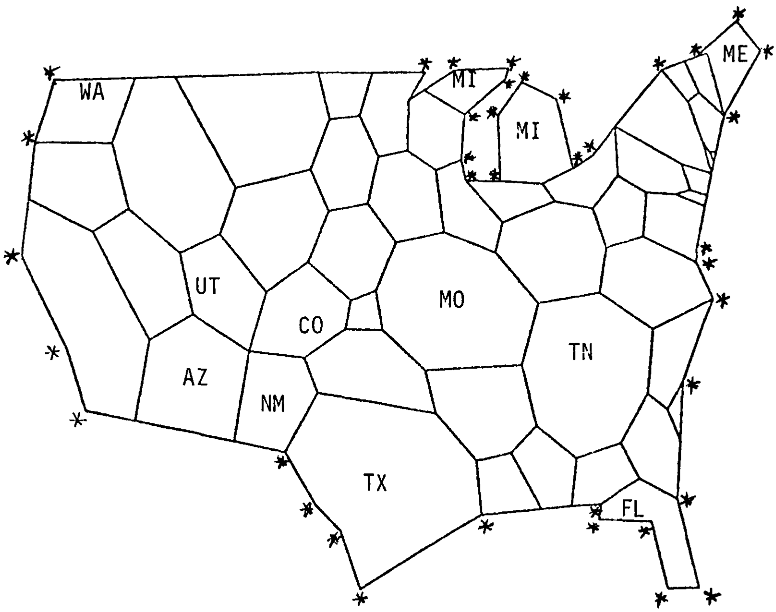


Figure 2. Repositioning boundary points (indicated by "*") produces a map similar to the original.

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. The elements are points, called 0-cells, line segments, called 1-cells, and areas, called 2-cells (Figure 3).

A 0-cell is a point

A 1-cell is a line stretched and formed, but not crossing itself

A 2-cell is a disk stretched and formed, but not torn or folded

Figure 3. 0-, 1-, and 2-cells

<u>The Algebra of Maps</u>

An algebra of maps is obtained from the elements of a map, the 0-, 1-, and 2-cells with coefficients from the field of integers. The interrelations among the dimensions is expressed in the boundary and coboundary operators.

A chain of 1-cells is written formally as

$$\sum_i c(i)\ b(i),$$

where c(i) is a coefficient and b(i) is a 1-cell. The boundary of 2-cell A in Figure 4 is:

$$\partial A = a + b + c$$

The boundary of B is:

$$\partial B = d + f + g - c,$$

the -1 coefficient indicates negative orientation, i.e., opposite to the the direction of the arrows.

Chains of 2-cells can be similarly expressed. The sum of A and B is just A + B. Notice that the boundary $\partial(A+B) = \partial A + \partial B$ is just the boundary of $A \cup B$.

$$\begin{aligned} \partial A + \partial B &= a + b + c + d + f + g - c \\ &= a + b + d + f + g \\ &= \partial (A \cup B) \end{aligned}$$

Note that the interior 1-cell c has coefficient zero in the sum. This algebra is the foundation of MacLane's Theorem and Tutte's algorithm interpreted topologically.

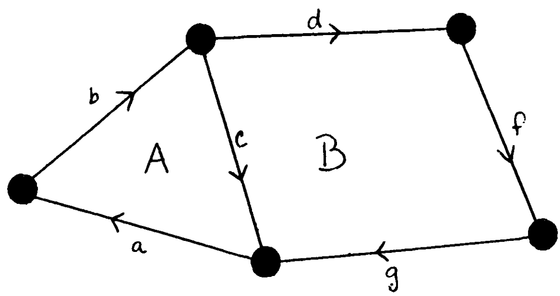


Figure 4. The algebra of maps

MacLane's Theorem

Theorem of Sanders MacLane [2, p.91]: Let G be connected and inseparable with Betti number R. A necessary and sufficient condition in order that G may be represented as a spherical graph is that it possess a set of R+1 loops L(1), L(2), ..., L(R+1) such that

I. Every branch of G belongs to exactly two loops L(h).

II. With a suitable orientation of the loops L(h), the only independent relation which they satisfy is $\sum_1^{'} L(h) = 0$.

The statement of this theorem is combinatorial and without reference to topology. A spherical graph is also planar and visa versa, since the sphere may be projected into the plane stereographically [2, p.90].

Condition II implies that any R of the L(h) form a basis for a vector space of cycles in G. Condition I implies that the coefficients may be taken from the field of integers mod 2, ignoring orientation. The sum of two loops, L(h) and L(j), is then a single loop with the common branch of L(h) and L(j) omitted, or it is just the two loops again if they do not intersect.

Despite the lack of topology in the statement of the theorem, Lefschetz proves it topologically. He shows that each of the loops L(h) is the boundary of some 2-cell. Property I implies that the complex thus formed is a 2-dimensional surface, and property II implies that the surface must then be a sphere. Conversely, a spherical graph by definition has an embedding in the sphere. The Jordan Curve Theorem and results concerning the Betti numbers imply that there must be R+1 loops L(h) with properties I and II. For details the reader is referred to Lefschetz [2].

The important point about the topological proof is that it is very direct and appeals to one's geometrical intuition. If property I failed, as in Figure 5, we would not have a 2-dimensional surface. Rather we would have the intersection of two surfaces.

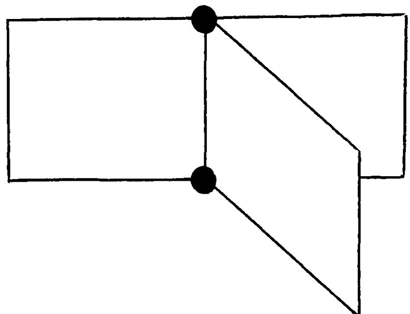


Figure 5. Intersecting surfaces fail to have property I

Tutte's Algorithm

This brings us to Tutte's algorithm. We quote his definition of "planar mesh," which is fundamental to the algorithm:

> A planar mesh of G is a set M=[S(1), S(2),..., S(k)] of elementary cycles of G not necessarily all distinct, which satisfy the following conditions:
>
> (i) If an edge of G belongs to one of the sets S(i) it belongs to just two of them.
>
> (ii) Each non-null cycle of G can be expressed as a mod 2 sum of some members of M.
>
> Condition (i) implies that no elementary cycle of G can appear more than twice as a member of M. Further, the mod 2 sum of all members of M is null.

Therefore, a planar mesh is just the graph specified in MacLane's Theorem but with orientation ignored.

The elementary cycles (also "peripheral polygons") of a planar mesh are the loops of MacLane's Theorem and boundaries of the 2-cells of Lefschetz's proof. In the span of two long and complicated papers, Tutte proves combinatorially that the planar mesh of a graph G may be identified, and presents his algorithm for drawing a graph using the planar mesh. Furthermore, he shows that for a nodally 3- connected graph there is a unique barycentric representation [3, p.759].

Tutte realizes the function mapping the graph into the plane as one that assigns cartesian coordinates to the nodes, and maps the edges to straight lines connecting the nodes [3, p.752]. The outer boundary is one of the elementary cycles; in fact, any one will do. The nodes of that cycle are assigned the coordinates of the vertices of a regular n-gon in the plane so that their cyclic order is preserved. The other nodes are interior to the n-gon and are assigned coordinates so that each node is at the center of mass of its adjacent nodes (see Figure 6). For a nodally 3-connected graph there is a unique assignment of coordinates satisfying those criteria. They are also determined by the following:

$$\sum_j{}' c(ij)\ x(j) = 0$$

$$\sum_j{}' c(ij)\ y(j) = 0 \text{ for } n < i \leq m, \text{ where}$$

$$c(ij) = \begin{cases} -\text{ number of edges joining nodes } i \text{ and } j, \\ \quad \text{for } i \neq j \\ +\text{ valency of node } i \text{ for } i=j. \end{cases}$$

The coordinates for nodes v(i), $1 \leq i \leq n$, are already known, as these are the vertices of the n-gon.

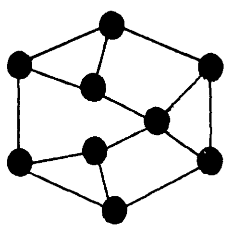


Figure 6. Barycentric representation of a graph

Our Algorithm

From the topological viewpoint, Tutte's algorithm is building a larger and larger disk rather than adding loops to form one large loop, which is the graph theoretical interpretation. A disk may be constructed vertex by vertex as well as block by block since the open neighborhood of a 0-cell is topologically equivalent (homeomorphic) to an open disk and a 2-cell is homeomorphic to a disk. The union of two overlapping disks is again a disk, as shown in Figure 7.

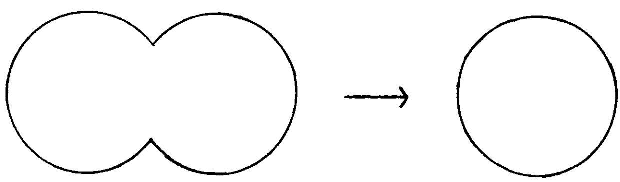


Figure 7. The union of two overlapping disks is equivalent to a disk

Disk construction continues merging overlapping disks until the entire graph is covered (Figure 8).

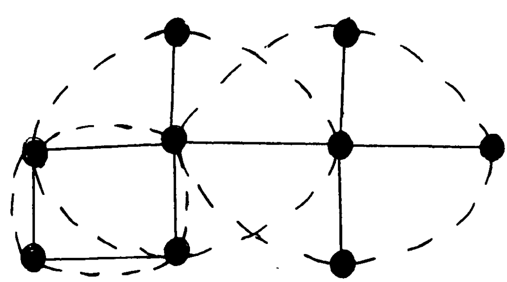


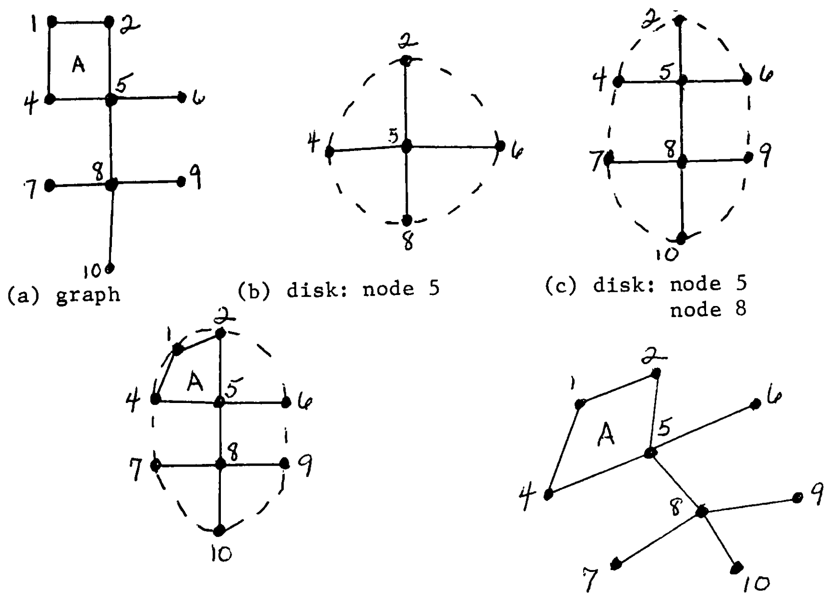
Figure 8. Disk construction

Tutte's algorithm and MacLane's Theorem both have restrictions on the connectivity of the graph. As our algorithm uses the topological equivalence between the open neighborhood of a vertex and a disk to allow the addition of nodes to the disk, the restrictions are not needed.

The two ways of building a disk, point by point and 2-cell by 2-cell, are combined in our algorithm. We proceed point by point as much as possible, since this simplifies identifying interior nodes. When an inconsistently coded vertex is encountered, it must be on the boundary, and incident 2-cells are then considered. The algorithm then continues point by point.

Given a segment list for a graph, the algorithm constructs disks and their boundaries, assigns coordinates for disk boundary nodes, and computes coordinates for disk interior nodes. Disk construction begins by identifying a consistently coded 0-cell as an interior node and its adjacent nodes as disk boundary nodes, or if there are not any consistent nodes in the graph, by identifying the boundary nodes of a consistently coded 2-cell as disk boundary nodes. The algorithm continues adding to the disk by examining disk boundary nodes in counter-clockwise traversal of the boundary. A consistent boundary node is replaced by its adjacent nodes, and added to the interior of the disk. If the boundary node is not coded consistently, then adjacent blocks are examined. Nodes on a consistent block boundary are added to the disk boundary, and the process continues by examining the next disk boundary node. The entire disk has been constructed when all disk boundary nodes have been examined, and the algorithm iterates to build any remaining disks for the graph.

Additions to the disk boundary occur in a manner which insures that the counter-clockwise traversal of the boundary is not disrupted. Thus, the disk grows in an orderly fashion, examining every disk boundary node exactly once. Node additions to the disk boundary are always inserted after the current disk boundary node and are ordered to maintain the counter-clockwise traversal. Additions to the disk boundary occur in two cases: the replacement of a consistent disk boundary node by its adjacent nodes, and the addition of boundary nodes of a consistent block. The node and block edit routines facilitate the maintenance of the counter-clockwise order of the disk boundary, as they chain the node co-boundary and the block boundary in counter-clockwise order. Figure 9 displays disk additions as the result of node and block edits, and shows the barycentric representation of the graph.



(a) graph (b) disk: node 5 (c) disk: node 5 node 8

(d) disk: node 5,8 block A (e) barycentric representation

Figure 9. Disk additions

Once a disk and its boundary have been constructed, coordinates are determined as in Tutte's algorithm. Coordinates of a regular n-gon are assigned to the disk boundary nodes, and are computed for disk interior nodes such that they are located at the center of mass of their adjacent nodes.

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THE DATA STRUCTURE OF BASIS

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1. Background: Small Systems, Big Applications

Small computer systems, as they have increased in power and decreased in cost, are being widely used for handling geographic data. Small systems have severe limitations, however, when the area to be covered is a large and complex region. This paper will focus on the issue of data structure - the arrangement of data in the data base and its correspondence to the geography of the region - since this element of system design is especially critical when constrained by the limitations of a small computer.

2. A Bay Area Example

An example of a minicomputer-based geoprocessing tool is the Bay Area Spatial Information System (BASIS), an automated geographic data base for the 7000-square mile San Francisco Bay region. Built over the last three years, it was designed to serve as a common data base for planning decisions in the Bay Area. Although created primarily for regional applications, it contains enough detail to be useful in some county and city level problems. It has been used in projects such as earthquake damage assessment, location of hazardous solid waste disposal sites, airport noise mitigation, and an industrial lands inventory.

BASIS is a grid cell system; space is represented by an array of one-hectare cells. Coverage of the region (including land, Bay, lakes, and parts of the ocean important for coastal planning) requires over two million of these cells. (Figure 1 shows parts of the BASIS area plotted at different scales.)

Cell size is clearly a critical design decision in a system of this nature; the tradeoffs are between level of detail (where smaller cells imply the ability to capture and maintain data with finer grain) and cost (smaller cells mean more total cells to cover a given area, which means higher costs for storage and processing). The hectare cell size used in BASIS was chosen after much discussion, and reflected consideration of the detail v. cost tradeoff as well as anticipation of probable applications.

3. Hardware Configuration

BASIS runs on a medium-scale minicomputer system. It is built around a Univac V76 processor, and utilizes a large (88mb) disk for data storage. Two peripheral devices are included specifically for geoprocessing applications: a digitizer is used to encode mapped data and an electrostatic plotter is the graphic output device.

These peripheral devices are connected to the computer through hardwired lines. This direct connection enables high speed transmission of data and eliminates the need for manual transfer of cards or tape. It also permits an interactive approach to the data entry process, so that potential errors can be flagged for immediate attention by the digitizer operators.

4. Data Management Software

Grid cell structures have been extensively used for many years to handle geographic data bases. The concept of a cell as storage location for data is easy to understand, and software for analyzing cell-based

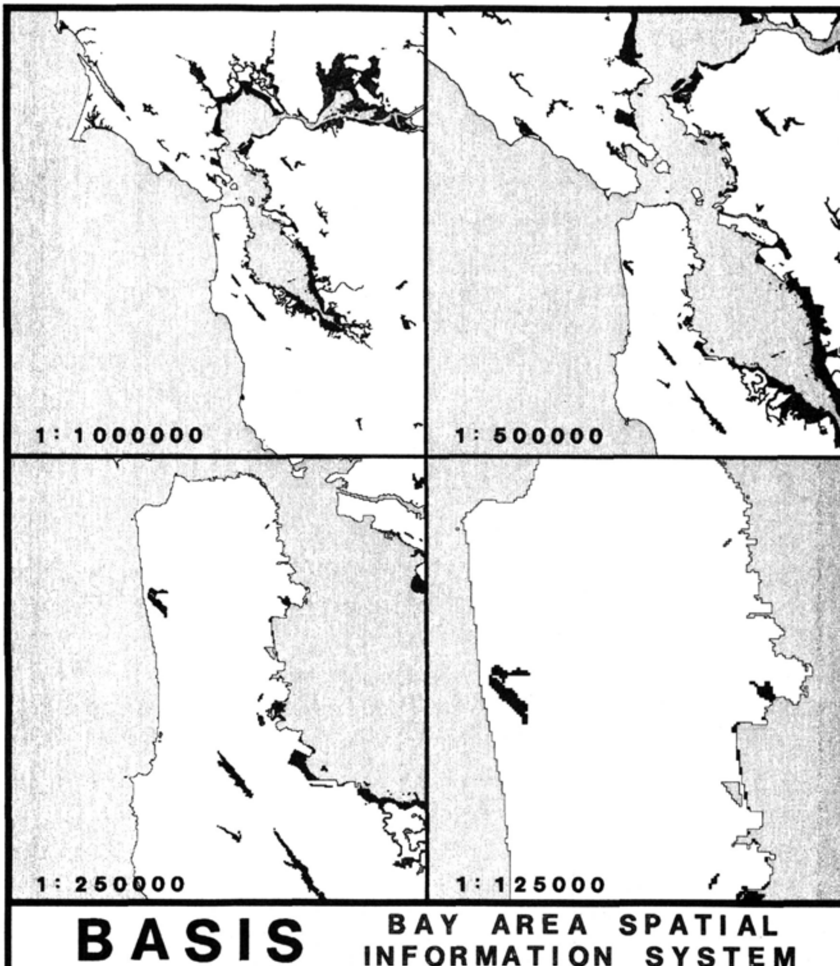

FIGURE 1 - Plot of coastal features in a portion of the area covered by BASIS, shown at four different scales (original plot has been photographically reduced so scales are no longer correct).

data is relatively simple. Problems arise with size, however: a combination of factors such as a large region, small cells, and many data types lead to large storage requirements.

Storing up to eighty separate data items for each of two million grid cells - and being able to quickly access any one of those cells - is a considerable task on any size computer system. It is made even more difficult on a small system with limitations in memory size, disk capacity, and I/O speed. Operating a large geographic data base on a relatively small computer system, then, requires considerable attention to the design of data management structure.

Design of the structure for BASIS had, as a major objective, on-line access to the entire data base. This type of access is essential for efficient updating and editing. Also, access to only part of the data base (some data types for the entire region or all data for a part of the region) would be inadequate for many applications.

Two major elements in the structure of a grid cell data management system are the location of the data for any specified ground location and the arrangement of the data base on some mass storage mechanism such as a disk. The BASIS approach to this problem of data management relies on two key concepts: direct access to data grouped by kilometer cell, and bit plane coding.

Direct access techniques

The first concept deals with the relationship of data space and "ground" space; that is, how to establish the correspondence between a given location on the earth (a defined grid cell) and the space on the disk (file name and record number) where data concerning that location on earth is stored. This correspondence is, of course, fundamental to any geoprocessing system. The linkage should, if possible, support direct access; that is, the data for a cell anywhere in the region should be accessible without having to search.

This relationship is established in BASIS by using a lookup table, which is arranged so that table position corresponds directly to ground position (e.g., the location of the data for the cell at Row 126, Column

240 in the ground coordinate system is contained the same row and column of the lookup table). Each element of the table points to the disk location (file designation and record number) of the data for the corresponding grid cell. Figure 2 diagrams this method.

To minimize the size of this lookup table, the hectare cells are grouped by square kilometer. Since each kilometer cell can be viewed as a ten by ten array of hectare cells, the location of each hectare within the kilometer space is implicit. Some entries in the lookup table will be blank; those positions which correspond to grid cells for which there is no data (cells outside the region or in the ocean) will have no pointer. This way, only areas of interest occupy storage space. By having the disk file designation in the lookup table, all references to different files can be invisible to the applications programmer. The entire data base can be viewed as one logical disk file; the table handles the correspondence between this single logical file and multiple physical files.

Bit plane coding

A second major consideration in data management structure is the question of storage efficiency. For most applications, it is desirable to have the entire data base accessible at any time; this becomes difficult when the data base is large and the amount of on-line storage is relatively small. In BASIS, where there are over two million spatial units and up to eighty data items for each cell, the problem becomes one of storing 160 million units of data on a device (disk drive) with a capacity of 44 million words.

BASIS uses a method of data compaction called bit plane coding to reduce space requirments. Instead of each separate data value occupying one full word (16 bits) of storage, it is assigned the minimum number of bits needed to retain the full range of that variable. For example, a data value that is strictly in/out, such as the delineation of a flood plane, can be coded with only one bit. Similarly, many of the data types used in this type of system require only a few bits for complete encoding. The result is more types (or planes) of data packed into the same storage space.

In theory, the structure of such a data base is not very different from the usual approach: it can be viewed as a three-dimensional array, where rows and columns represent two dimensions and different types of data are stacked vertically. (Figure 3.) The essential difference in bit plane coding is that each vertical element, instead of being a constant size in bits, has a height (i.e., number of planes) which differs according to its requirements.

The relative efficiency of this technique in minimizing storage space is dependent on the nature of the data; types with large ranges require many bits, and will therefore approach the "natural" encoding scheme where each data item occupies one word. The greatest gain is, of course, for those types of data where the coding can be accomplished with only one bit. Many types of spatial data do fit under this heading; any data with an on/off, in/out, present/not present character can be coded this way, and with good data definition other (and not so obvious) types can be fit into a few bits.

Use of the bit plane technique does require care, however. Considerable thought must be given to the definition of each data type and its range of potential values. And additional software, probably in assembly language, will be required. The additional machine operations required to pack and unpack the bit planes will increase execution time. Overall, the added work required to implement this type of coding scheme is worthwhile only if there is a severe constraint on the amount of on-line disk storage available and immediate access to all data is important.

5. Operational Environment

Creating an operational system is very different from designing an equivalent system in a research setting. Solving the technical problems - the selection of hardware, design of data base structure, development of software - does not ensure that the system will be used, or that it will receive the support necessary to maintain it. Institutional factors, such as funding and management responsibility, are also part of the overall system design.

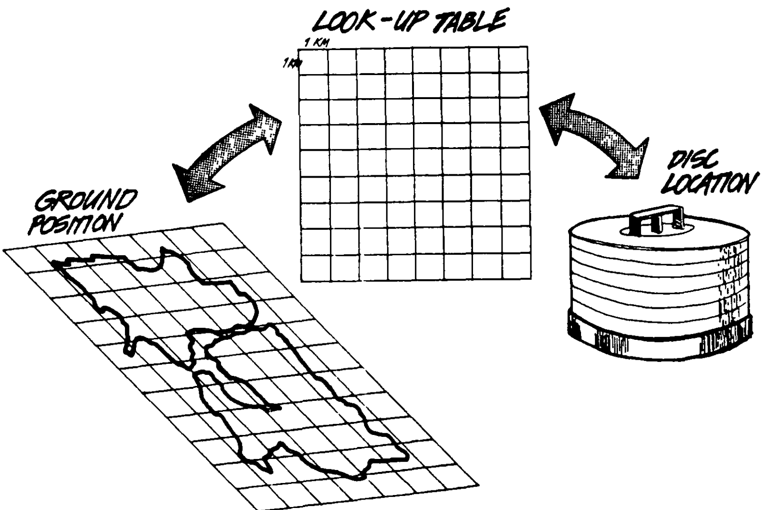

FIGURE-2

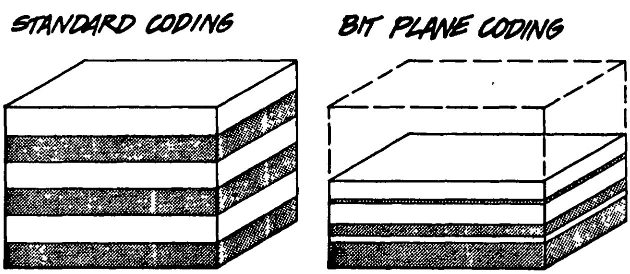

FIGURE-3

BASIS resides on a minicomputer operated by ABAG (the Association of Bay Area Governments), the regional planning agency for the Bay region. Since the computer is used for other ABAG computing functions BASIS must compete for use of system resources. This results in a very different operational environment from a system dedicated to the geoprocessing function. The data management design is based on these constraints; for example, the absence of personnel to handle media transfers (such as loading the disk from tape) is an added motivation for having the entire data base on a single disk pack.

6. Conclusions

BASIS has confirmed that a very large geographic data base system can indeed be based on a minicomputer system. This is demonstrated by the projects to which the system has been successfully applied.

The process of designing BASIS has also yielded insight into the problems of data structure in grid cell systems. The techniques of direct access and bit plane coding have been important in building the system in a way that is understandable and responsive to the user.

Finally, it is important to recognize the nontechnical aspects of system design. While this paper has concentrated on technical factors, it should not be assumed that these considerations are sufficient to build a successful system. A solid technical design is essential if the system is to be useful, but technical excellence by itself is not enough. Unless the organizational environment has been designed with equal care, the system is unlikely to be a success.

References

A discussion of bit plane coding is contained in J.L. Pfaltz's paper "Representation of Geographic Surfaces within a Computer" in John C. Davis and Michael J. McCullagh (eds.), Display and Analysis of Spatial Data (London: John Wiley and Sons, 1975).

Further discussion of BASIS applications is contained in several publications available from ABAG.

DATA BASES, LARGE SYSTEMS SESSIONS

DATA BASES, LARGE SYSTEMS SESSIONS (cont.)

DATA BASES, LARGE SYSTEMS

There were three Large Data Base sessions. Dave Holland of the Defense Mapping Agency chaired all three sessions.

Kenneth Gordon of Western Washington University presented the paper "Computer-Assisted Environmental Data: Issues and Implications". Gordon discusses a survey of computer-assisted spatial data handling systems. The survey covered a variety of federal, state, regional, municipal, and corporate systems. It demonstrated that different types of applications require different systems configurations, software, and data characteristics and that geographic information systems are not being utilized to their full potential.

Ray E. Moses of NOAA and James L. Passauer of the Information Sciences Company presented a paper on the "National Ocean Survey - Automated Information System". This is a system developed by the Planning Research Corporation, Information Sciences Company to provide on-line storage for the features of nautical charts published by the National Ocean Survey. The main advantage of this system is its extensive interactive capabilities.

Jay R. Baker of the U.S. Bureau of the Census presented the paper "GEOMODEL - Integrated Data Structures for Representing Geographic Entities". The foundation of GEOMODEL is a non-redundant encoding of 0-cell (point), 1-cell (line), and 2-cell (area) topological atoms with appropriate linkages to represent their boundary/co-boundary relationships. An important point discussed in the paper is the transformation of a GBF/DIME file into the GEOMODEL representation.

David P. Bickmore of the Royal College of Art, London, and Graham J. Witty of the Experimental Cartography Unit gave a paper entitled "Ecobase of Britain: Status Report on a Digital Data Base of Britain". The digital data base of Britain is currently being digitized at scales of 1:50,000 and 1:200,000. A description of the system indicates the digital data base can not be as efficiently used as was hoped for.

Robert Haralick and Linda Shapiro of the Virginia Polytechnic Institute presented a paper entitled "A Data Structure for a Spatial Information System". Haralick and Shapiro present a detailed description of a data structure for a spatial information system. One advantage of their structure is that it can be used for both raster and vector format data. They describe ways the data structure can be used to do inferential reasoning with spatial data and they indicate the system can be used to logically store any of the spatial information in maps, line drawings, region adjacency graphs, or other geographic entities.

James Dougenik of the Harvard Laboratory for Computer Graphics and Spatial Analysis presented the paper "WHIRLPOOL: A Geometric Processor for Polygon Coverage Data". The primary purpose of WHIRLPOOL is to overlay two polygon coverages. It serves other purposes, including creating polygon identifiers for unlabelled (digitized) lines, determining point-in-polygon for large numbers of location points, and calculating polygon areas. Also, it is able to filter out unwanted data.

Timothy Nyerges of Ohio State University presented a paper entitled "A Formal Model of a Cartographic Information Base". Nyerges indicates map description analysis and generation can be considered a subset of a larger class of problems generally treated in picture processing. A linguistic approach is seen as a general method for organizing cartographic data with a conceptual hierarchy of information. The basis of this linguistic approach is a web grammar.

Scott Morehouse and Geoffrey Dutton presented a paper entitled "Extraction of Polygonal Information from Gridded Data". Basically, this paper describes an algorithm for converting from gridded (raster type data), to polygonal (vector type data).

Kenneth Duecker of Portland State University presented the paper "Land Resource Information Systems: Spatial and Attribute Resolution Issues". This paper describes the variety of land resource information systems which have been developed. It is noted that the single most important issue in developing such a system is the determination of the appropriate level of spatial and attribute resolution. System designers are also concerned with the extent to which imaged data should be processed prior to capture and the amount of reduction and editing subsequent to data capture.

Robert T. Pelletier of the USDA Forest Service presented a paper "RIDS - Current Technology in Resource Management". RIDS is an overlay processing system that has been adopted for service-wide use by the Forest Service. The paper describes how RIDS is used in the collection, digitization, manipulation, and display of data for the management of natural resources.

Malcolm J. Stephens, Michael A. Domaratz, and Warren E. Schmidt of the U.S.G.S. presented the paper, "The Development of a National Small-Scale Digital Cartographic Data Base". This paper deals with the implementation of a national digital data base at a scale of 1:2,000,000.

COMPUTER-ASSISTED ENVIRONMENTAL DATA HANDLING: ISSUES AND IMPLICATIONS

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Introduction

This paper is a report of a study of computer-assisted spatial data handling systems. The study's focus is upon systems which store, manipulate, or display topographic, land resources, or similar environmental data in digital form. The study seeks answers to questions which would be of greatest interest to users of environmental data, especially those considering the use of computer-assisted techniques or the use of computer-stored data from other sources. Issues for spatial data handling and system design are identified based upon an observation of the collective data handling and data use requirements of different user groups and the potential applications and limitations of different types of spatial data handling systems. Data handling encompasses the following operations: 1) data acquisition; 2) changing data to useful formats; 3) storing data in or on some medium; and 4) retrieving and manipulating data for display and analysis. Spatial data handling systems include data-base management systems, cartographic systems, geographic information systems, and various special hardware and software configurations (e.g., for Landsat data processing). The common characteristic is the capability of the system to store and process spatial data in a manner that both the data attributes and their geographic location can be retrieved.

Many public agencies, research institutions, and private corporations are experimenting with and utilizing computer-assisted spatial data handling technology. The inventory of what applications may be performed, what problems may arise, and what is desired by the user are basic preliminary steps for information system design. This paper briefly describes a research study designed to answer these and other similarly important spatial data system design questions, and reports some of the findings of the investigation (1).

Research Technique

A survey of system users was conducted during the summer of 1978. Its population was limited to spatial data handling systems operating in or supplying data for the Pacific Northwest states of Washington, Oregon and Idaho (2). The investigation was designed to be both descriptive and analytical. Many aspects of data handling were queried in the survey: system application; data handling capability (software); method of data acquisition; data storage, manipulation, and display. Many characteristics of the data were also of concern. These included scale, coordinate reference, precision and resolution, source, and form of location identification. Other important issues included: data and software transferability; factors inhibiting the wider application of systems; differences between actual and desired data types, software, and applications; and the extent and characteristics of digital data coverage. A mailed questionnaire, followed by in-person or phone interviews, was the method chosen to conduct the survey (3).

The survey population consisted primarily of planning, natural resource, and environmental agencies, and the spatial data processing systems of the agencies. Data was acquired from thirty-nine federal systems, ten state systems, five regional systems, four municipal systems, and six corporate systems. The chosen sample of fifty responses was quite diverse. Some of the agencies and systems included in the survey were the following: Environmental Protection Agency - STORET; Soil Conservation Service - Advanced Mapping System and Natural Resources Data System; Geological Survey - Digital Mapping Systems, Computerized Resources Information System (CRIB), Geographic Information Retrieval and Analysis System (GIRAS), and WHATSTORE; Washington State Department of Natural Resources - Gridded Inventory Data

System (GRIDS) and Calma Mapping System; Oregon Department of Revenue - Computer-Assisted Mapping System (CAMS); and many municipal government, and corporate systems - Puget Sound Council of Governments, Lane County, Oregon, City of Tacoma, Battelle Northwest Laboratories, Boeing Computer Services, and Weyerhaeuser Corporation.

More than thirty individual characteristics of the systems, the data, and the agencies' use of the systems were recorded from the questionnaire. The responses were coded and keypunched and then tabulated, using the CROSSTABS option of the Statistical Package for Social Sciences. The program counts the number of pair-wise comparisons between selected variables, and prints out tables of the frequency and percentage of correlation. Thus, for example, the number of times respondents reported both aerial photography as a data source and a particular size of coverage could be tabulated. Cross-tabulation was performed on twelve data characteristics such as source, precision, resolution, scale, and location identifier. Significant correlations were found between many of these variables, and many expected correlations were not observed. The sample also could be sorted by any other chosen descriptor. A profile, albeit from a limited sample, was thus developed for the characteristics of the total sample, federal versus non-federal systems, eleven different system types, and eight different system applications. It was thus possible to differentiate the data use, geographic referencing, or data handling capabilities and perceived needs of regional planning agencies from municipal planning agencies, of environmental protection from natural resource management agencies, of data-base management systems from true geographic information systems, or grid referenced systems from point, line, or irregular polygon referenced systems.

A sample tabulation is included. It portrays the desired data handling capabilities of groups of system users. Comparison with a similar tabulation of the operating characteristics of the systems facilitates the assessment of unmet user need. This type of assessment provides, by empirical description, an overview of the limitations and potentials of different types of systems, and of the preferences and unmet needs of different types of data users.

COMPARISON OF THE DATA HANDLING SOFTWARE DESIRED BY EACH TYPE OF SYSTEM USER

KEY

- — None Reported
- • Less than 25%
- ▲ 25% to 49%
- ■ 50% to 74%
- ● 75% or Greater

(Note: Sample size in parentheses)

	Editing				Spatial Rectification						Measurement				Sorting/Merging					Comparison							Graphic Output					Other		
BASIC RESPONSIBILITY OF RESPONDENT: / SOFTWARE	Identify and Correct Closure	Identify and Correct Slivers	Data File Update	Labeling	Removing Map Distortion	Line Generalization	Modify Alignment	Scale Change	Projection Change or Coordinate Conversion	Location Identifier Coversion	Linear Measurement	Area Measurement	Direction Determination	Centroid Determination	Selective Retrieval - Geographic	Selective Retrieval - Descriptor	Edge Matching	Create New Files	Integrate from Remote Files	Contouring	Overlay - Union	Overlay - Intersection	Value Weighting	Modeling	Statistical Analysis	Extreme Value Search	Zooming	Diagram and Chart Display	Lettering	Shading	3D	Digital Relief Analysis	Landsat Data Analysis	Not Reported
Metropolitan Land Use Planning (4)	▲	▲	●	■	●	■	■	■	●	●	●	●	■	●	●	●	●	●	▲	●	●	●	■	■	●	▲	■	●	●	●	▲	●	▲	0
Regional Land Use Planning (5)	▲	•	■	▲	▲	•	•	■	■	■	■	●		▲	●	●	●	●		▲	●	●	■	▲	■	•	■	▲	●	▲		■		0
Land Management (5)	■	▲	●	■	▲	■	▲	■	■	●	■	●		▲	●	●	■	▲		●	■	■			▲			▲	■			▲		1
Mapping (6)	●	▲	●	■	●	■	■	●	●	▲	■	■	▲		●	■	●	●		●	●	■		•	■	▲	■	■	■	▲		▲		0
Environmental Protection (3)	●	▲	▲	■			▲	■	■		▲	▲		▲	●	●				▲	▲	▲			▲		■	▲	■	▲	▲			0
Resource Planning and Management (14)	•	▲	▲	▲	▲	▲	•	■	■	▲	▲	■	▲	▲	●	●	▲	■	▲	■	■	▲	▲	▲	■	▲	▲	■	▲	▲	▲	■	•	2
Special Area Planning (2)	●	●	●	●		●	●	●	●	●	●	●	■	●	●	●	●	●	●	■	●	●	●	●	●	■	●	■	●	■	●	●	■	0
Other (11)	▲	▲	■	■	▲	•	▲	■	■	▲	▲	■	•	▲	●	●	▲	●	▲	▲	■	▲	•	•	■	▲	▲	•	■	▲	•	•	•	0
Total (50)	▲	▲	■	▲	▲	▲	▲	■	■	▲	▲	■	•	▲	●	●	■	■	•	■	■	■	•	▲	■	▲	▲	▲	■	▲	•	▲	•	3

Results

Space does not permit the reporting of the findings of the research at the level of comparative detail of the system and use profiles. However, some significant insights were developed based upon analysis of the responses from the total population. Also reported are some observations based upon a comparison of the tabulated responses for federal and non-federal systems.

General observations

A number of empirical, analytical, and deductive observations were made in the course of this study. They reflect some of the problems and potentials of the use of computer-assisted spatial data handling systems, and provide comment upon the status of geoprocessing in this country.

Stage of Development - The systems are in various stages of development. Most are operational, but still improving their data handling capability. The systems built around particular data storage and retrieval functions are least likely to be considering new applications.

In-House Programming - A very high percentage of the respondents reported that the data handling capabilities were developed in-house. This procedure is especially true of the non-federal systems, and has caused problems of lack of documentation and lack of concern for data or software transferability. Vendor-supplied software is available for nearly every data handling task, but few agencies take advantage of this source of software. The only software which was nearly universally supplied by the vendors was the graphics component.

Limited Application - Most systems are dedicated to the performance of very specific applications and are constructed around the performance of these tasks. Though many systems seem to have the software to perform more sophisticated data analysis and display, there are few reports of systems being used to their potential.

Data Accuracy and Data Documentation - There is a noticeable lack of concern for data accuracy and data documentation. Less than 15 percent of the respondents were aware of the precision of their data, and most do not maintain descriptions of the basic characteristics of the data necessary to assess its utility. The lack of data documentation is alarming. Access to and analysis of the data are thus limited by the lack of general knowledge of where the data came from, how recent is its vintage, who collected it and how, to what degree it is generalized, and how it is interpreted.

Data Integration - Systems are able to store many different types and formats of data, each uniquely referenced by geographical location. Most respondents report that they can and do commonly store environmental data with non-environmental data such as land use, census, facilities, political boundaries, etc. The extent of logical integration of the different data files is not known. Half of the respondents report the ability to change scale, change projection, and convert between different encoding formats.

Diversity of Design Options - The characteristics of the systems and the way in which data are handled in the systems are very different even among respondents with similar administrative responsibilities and data handling needs. There are therefore many different system design options which may satisfy similar user needs.

Most Desired Software - The greatest proportion and frequency of unmet spatial data handling needs are reported for the following: Landsat data use and analysis, value weighting, direction determination, shading, overlay, projection change, centroid determination, edge matching, and statistical analysis. The most common types of data handling software include these: selective retrieval of geographic and attribute descriptors, creation of new files, lettering, overlay, scale change, coordinate conversion, area measurement, and contouring.

Factors Limiting Expanded System Use - Limited mandate, budget, and time are reported to be the predominant factors restricting the greater application of systems. Data availability, accuracy, and reliability are not perceived to be very limiting. There is greater desire indicated for more hardware and software to process data than to improve the data itself. The lack of trained personnel is also a significant deterrent.

Interrelationships of Data Characteristics - The data descriptors which were found to be related to one another, and therefore factors which deserve added attention for system design, are the following: data type and data source, resolution and size of coverage, location identifier and size of coverage, scale and resolution, scale and size of coverage, and scale and precision. The size of the area and the scale of the encoded data appear to be very significant. The factors for which correlations are implied by deduction, but for which analytical examinations failed to show correlation, are these: data type and location identifier, resolution and data source, data source and size of coverage, precision and size of coverage, and location identifier and resolution.

Comparison of Federal and Non-Federal Systems

The federal systems normally are designed around large data bases of primary data. Some include applications programs to assist the data users, while others are simply designed for data storage and retrieval. Non-federal systems are usually designed around broader data use objectives and can handle ad hoc inquiry. Federal systems are more likely to be developed by vendors, while non-federal systems are likely to be in-house programmed. The size of the area of coverage, and the primary nature of the data in the federal systems has a significant bearing upon the characteristics of the data within the system's data base. This may influence the ability of the federal systems to supply useful data to other digital data users and accounts for the perceived need for data conversion software. An assessment of the characteristics of the data shows, for example:

1. Original data sources are very different. Federal systems contain data primarily from field monitoring stations and field surveys. Non-federal systems contain data primarily from published surveys and maps, conventional aerial photography, and from pre-encoded data sources;
2. The predominant encoding scale of data from federal systems is 1:62,500 to 1:1,000,000. The predominant scale of data in non-federal systems is 1:24,000 or larger;
3. The predominant location identifier of data in federal systems is coordinate point. The predominant location identifier of data in non-federal systems is irregular polygon, with significant percentages of coordinate point and grid identifiers as well;
4. The predominant coordinate reference for federal systems is latitude and longitude, while the predominant coordinate reference for non-federal systems is State Plane Coordinates;
5. The predominant map projections for federal systems are Transverse Mercator and Lambert Conformal Conic, while the predominant map projection for non-federal systems is Polyconic.

Conclusion

There is a time in the evolution of any new technology when it is appropriate to step back and look critically at the experience to date. In this case, a research technique was designed to benefit from the recording and comparison of the unique characteristics of systems designed to date for handling environmental data. The intent was to provide aggregated assessments of various characteristics for future reference. The sample was small, but the results are believed to be representative. The research resulted in the recording of many illuminating observations about geoprocessing systems and their use. A researcher can only make these observations, pointing out areas which seem to deserve attention. The responsibility for using the results of these and similar research efforts in a constructive manner rests with the people making data handling decisions.

Notes

1. The study was performed as a master's thesis at Western Washington University.

2. The survey coincided with other studies of the Land Resources Inventory Demonstration Project, a program of data and technology application involving federal, state, and local agencies in the Northwest. Partial funding was granted under University Consortium Interchange No. NCA2-OR862-801 from the NASA-Ames Research Center.

3. Documentation of the survey content and conduct are contained in a report prepared for NASA entitled, "An Investigation of Digital Geographic Data Handling Activities and Digital Environmental Data Coverage in the Pacific Northwest States," 1978.

NATIONAL OCEAN SURVEY--AUTOMATED INFORMATION SYSTEM*

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Introduction

The Marine Data Systems Project (MDSP) of the National Ocean Survey (NOS), National Oceanic and Atmospheric Administration (NOAA), was formed in 1970 to design, develop and transition to operational use a balanced, computer-assisted nautical charting system. The system development was designed to minimize impact on concurrent production activities, and to arrive at a system which could reduce or eliminate the steadily increasing backlogs of unprocessed data while responding in a timely manner to dynamic charting requirements. Incremental transition of the various subsystems to operational use was planned as they became operational. The various subsystems of the computer-assisted NOS Nautical Charting System are: (Slide 1)

- -Data Acquisition and Processing
- -Evaluation, Storage, and Compilation
- -Automated Graphics
- -System Management

1. The Data Acquisition and Processing Subsystem includes basic hydrographic and photogrammetric surveys and subsequent processing of collected survey data

*For information about the slides, please contact the author.

through such steps as smooth-plotting, editing, and verification. The hydrographic surveys are conducted primarily by ships and launches based at the Atlantic Marine Center (AMC) in Norfolk, Virginia, and the Pacific Marine Center (PMC) in Seattle, Washington.

The field Data Acquisition Subsystem includes more than 30 HYDROPLOT units and the survey processing subsystems which are operational at both AMC and PMC. The PMC subsystem, operational since 1975 with a Harris computer and stand-alone Xynetics Plotter, has a newer Calma Digitizing System. This System allows production of complete hydrographic survey tapes which can be readily entered as new data into the central data base. At each of the marine centers there is also a Wild B-8 stereo photogrammetric plotter for compilation of digital topographic information from aerial photographs.

Data preparation and graphic conversion for other source input to the data base is accomplished at NOS Headquarters in Rockville on a five-table digitizing system. Also accomplished at Rockville, Maryland, is an analysis of tidal and lake level data collected during survey operations which is used to correct depth soundings at the marine centers before data is entered into the data base.

2. The Evaluation, Storage, and Compilation Subsystem provides quality control of NOS conducted surveys, evaluates nautical chart data from other sources, reformats data as necessary, stores, retrieves, and updates both NOS-originated data and other source data, and compiles nautical charts. Recently established quality control procedures will be consistent with the system final configuration and will require little or no modification.

3. The Automated Graphics Subsystem produces nautical chart drawings as well as negatives used to produce printing press plates. Automated graphics products are produced at NOS Headquarters on two Calcomp flatbed plotters, as well as on the one-of-a-kind laser raster production plotter built by MB Associates. This plotter produces reproduction quality full size chart negatives or positives for direct printing plate production. (Slide 2)

4. The Management Subsystem includes such activities as planning, scheduling, budgeting, management information, system logistics, training, etc. This system is

centered at NOS Headquarters, but responsibility for portions of it is delegated to the marine centers. It is an integrated management system managed by NOS Headquarters.

The Automated Information System

The Automated Information System (AIS) is a system implemented by the Planning Research Corporation/Information Sciences Company (PRC/ISC) under contract to the U.S. Department of Commerce, NOAA, in response to NOS design requirements. The primary objective of the system is to provide nautical chart cartographers with a computer assisted chart compilation and maintenance capability. Two basic concepts in the development of the AIS are the universal, geographic feature oriented data base and the concept of continual update and maintenance. (Slide 3) All incoming source material is evaluated for entry into the data base as soon as possible after it is received. Since there is only one record per feature, all charts displaying that feature are corrected at the same time. Different levels of density are selected for large, medium or small scale charts. The source material is handled only once with application and review for all affected charts at the same time, by the same cartographers. (Slide 4) The AIS data base contains the following four types of data:

1. New data--from a new source document.
2. Published data--depicted on a published chart
3. Non-published data--not on a published chart
4. Archival data--superseded data

New, Published, and Non-published data reside on disks, but archival data are on magnetic tapes. For purposes of automated nautical chart production, areas of production responsibility within NOS are divided into seven geographic areas of approximately equal chart revision activity in terms of number of changes to charts per unit of time:

1. Northeast Atlantic coast
2. Mid-Atlantic coast
3. South Atlantic coast and Caribbean
4. Gulf of Mexico
5. Pacific coast
6. Alaska and Pacific
7. The Great Lakes

The six basic types of overlays can be selected for compilation:

1. Base Control 2. Waterway 3. Navigation
4. Topography 5. Labels 6. Special Overlay

Data Base

By law, Federal Government publication of a nautical chart makes it a legal document, and if the omission of known hazards contribute to an accident, the Government may become liable. This puts NOS/AIS data base access in a unique category. No changes may be entered without a supervisory review. As a means of ensuring that only valid changes are made, a separate work file is created for the cartographer, which is manipulated, edited, and/or changed. A supervisory cartographer is required to validate changes prior to the data base entry. The security provisions are incorporated into the AIS system software.

The pacing element of the NOS AIS is the arrival at NOS Headquarters of new source documents such as new NOS Hydrographic Surveys, U.S. Army Corps of Engineers blueprints, Notices to Mariners, Chart Letters, etc. The document may or may not be in digital form, and may require digitization. A report is then generated to notify the cartographer that new data is available. The cartographer initiates a work file request for the new data, as well as any published, non-published, or even archival data to which the cartographer may wish to refer. Necessary changes are made to this data base work file, interactively. After supervisory review, the data base is updated, and the data awaits a chart printing cycle or more new data. When a chart is due for printing, the digital representation of the chart can be retrieved and input into a graphics program to produce the chart negatives. This also provides the flexibility to custom design or reformat existing or new charts and other products which are not tied to an existing graphic. (Slide 5)

AIS Site

The NOS/AIS is located in NOS facilities in Rockville, Md., and, when completed, will have data storage, central computer processing, and 10 cartographic work stations (Slide 6). The central site computers and two work stations are installed in the completed site. Central site data base managment and work station software were provided under contract. The central site contains two Varian V-76 computers, each with 128K bytes of memory, interfaced to work as either master-slave or separately. There are also five of the 16 planned 300-megabyte data base Eagle disks containing 128.9 million words of on-line memory. An intercomputer link (ICL) provides direct memory-to-memory transfer between the central and the work station computers. Each work station consists of a Varian V-76 computer with 96K words of memory, a Calcomp T-50 work station disk, a Bendix Datagrid DTS1.04, and two CRTs. One station has two Sanders SA 900 color graphic refresh CRTs, while the second has one Sanders color refresh CRT and one Tektronics 4014 graphic storage CRT. Each station has a hard copy device (one is a Varian STATOS 4122HS, and the other is a Tektronics 4631).

- Work Station #1--A five color Edit CRT (KRATOS) with a sufficiently rapid refresh rate that the display appears stable.

  --A monochrome storage tube CRT (Tektronix 4014) is used as a reference screen, for textual communications with the operator, to display data base records, for on-line prompting, and operator responses.

  --A Tektronix plotter provides a scaled reproduction of the Tektronix CRT image without computer intervention.

  --A Bendix digitizing table is used for chart registration and to define data sets for display. The cursor has two operating functions, one of which is an internal reset or "clear" and the other a "set" command which records the cursor position.

  --A keyboard is used for cartographer communications with the system. There are also two sets of 16 keys which serve as a function control devices. One set of keys is back-lighted under program control.

  --A teletype terminal is used for system startup, shutdown, computer system logging, etc.

- Work Station #2--Essentially the same as #1 but with two KRATOS five-color CRTs and a STATOS 4122/45 plotter.

- AIS Work Station Operation A cartographer begins an editing session with a Log-On sequence by entering the number of the request that generated the Work File, employee number and security identifier. Data can be selected from the Work File for display on the work station CRTs by compilation overlay, data type, display area, cartocode, and chart-inset-extension number. Menus to support the cartographers selection process are displayed on the Reference CRT.

The cartographer's work file is retrieved from the data base in a 60 by 60-inch grid. This is further segmented into 2-inch-square work blocks for data organization and display. Latitude and longitude coordinates of features are converted to cartesian grid X-Y coordinates in units of scaled inches, based on the scale of the retrieval.

The cartographer normally manipulates only the keyboard and cursor. To display data on the screen, the digitizing table must be registered to the work file coordinates. The projection type and retrieval scale are established by the original request. The first step in registering is to clear the table by positioning the cursor at the lower left corner of the digitizing table using the "L" shaped template as a guide. Depressing the red cursor button causes a prompt for latitude coordinates to be input from the keyboard, followed by longitude coordinates. The cursor is now placed on the chart point corresponding to the entered geographic coordinates and the blue button on the cursor is depressed. A second point is entered in the same manner, and NEW LINE is selected, which completes the registration. After the table has been registered, any point on the table can be located and associated data displayed by placing the cursor on the desired point. The data is retrieved from the work file, with data density related to the zoom factor. At this point, the display is directed to either the Edit or Reference CRT, which causes a prompt for the types of data desired on the display. Any number of the following types of data which correspond to those previously described, but with a finer breakdown, may be selected:

1. Published
2. Unpublished
3. New
4. Transactions
5. Suppressed
6. Selected
7. Pre-selected

Up to ten specific types of cartographic features may be displayed simultaneously. This allows control of the relative density of features to minimize clutter during editing. Overlays such as navigation, waterway, topographic, chart base, and labels may be selectively displayed or deleted.

• Editing Functions The basic cartographic action in editing is to locate a feature on the display screen, perform an operation on it, such as MOVE, ROTATE, etc., and then change its status, e.g., from non-published to published. The cartographer may select hardcopy of the CRT displays, intensity, color, and listings of data or charts affected by the displayed data. The basic available functions are:

--FIND POINT--correlates the point designated by the cursor with the same point on the display screen. The located feature blinks on the CRT display. End points of lines can be located and edited as point features. Once a point is identified, the cartographer has the following options:

RELEASE	PUBLISH	NEW CARTOCODE
ROTATE	SUPERSEDE	PUBLISH NOMENCLATURE
TEXT	MOVE	NON-PUBLISH

Depressing FIND POINT a second time will exit from this function. If no other features can be found, exit is automatic.

--RELEASE is used in conjunction with FIND POINT, FIND LINE, FROM/TO, and TEXT. Depressing RELEASE causes a new search to find and blink another feature within the search tolerance.

--MOVE S/N is used in conjunction with FIND POINT to move a blinking feature on the screen display by use of the four arrow directional keys on the keyboard. The feature is not moved in the work file until it is PUBLISHED.

--ROTATE permits CLOCKWISE, COUNTERCLOCKWISE or ROTATE HOME functions to be used in conjunction with FIND POINT, but only when a blinking feature is displayed on the CRT. One depression of the key will rotate the feature by two degrees and holding the REPEAT key down will cause continuous rotation. Activation of the ROTATE HOME key will return the feature to its original position. The feature is not rotated in the work file until it is PUBLISHED.

--NEW CARTOCODE permits the cartographer to interactively change the chart symbols of a feature.

--FIND LINE functions for lines the same as FIND POINT.

--FROM/TO is used for editing line features in conjunction with FIND Line. In response to an audible signal, the cartographer places the cursor on the position where the line is to terminate, and the coordinates are entered by depressing the blue push button. The selected location is shown by a blinking symbol which may be input by depressing the FROM/TO key a second time. It is now possible to activate the PUBLISH, NON-PUBLISH, SUPERSEDE, or RELEASE functions.

--TEXT is used in conjunction with FIND POINT or FIND LINE, and is valid only when there is a blinking feature on the display screen. Selection of the TEXT function results in all GP BASE records associated with the selected feature being displayed on the Reference screen for review.

--PUBLISH NOMENCLATURE allows publication of only the nomenclature associated with a point feature.

Summary

The NOS AIS, developed by PRC/ISC, is an interactive cartographic production system which supports continual data base update so cartographic products may be produced when they are required, without the time delays normally associated with chart production. The data base integrity is protected to ensure that the legal status is not subject to erroneous factors by creation of a work file for the cartographer's use. The final output product of the AIS is a completely laser-plotter-produced set of color separation negatives/positives which are used directly to make the final lithographic printing press plates for nautical charts. In addition, the AIS is capable of providing other products such as management information, plots and data listings to support bathymetric mapping, custom designed plots, tapes and data listings for outside users, and products to aid the hydrographer. NOS began using the AIS test data base for charts in the Gulf of Mexico in March 1978. As a result of this contract NOS now has an operational central site data base system and two operational prototype work stations. NOS plans to begin loading the entire Gulf of Mexico data file on the AIS Data Base in November 1979.

GEOMODEL - INTEGRATED DATA STRUCTURES FOR REPRESENTING GEOGRAPHIC ENTITIES

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Introduction

GeoModel is a system of data structures and access software providing a geographic base for a wide variety of planning functions. GeoModel consists of a data storage system with various input, manipulation, and output or display subsystems managed under the umbrella of a control language and special-purpose application packages. This paper will discuss the objectives, philosophical considerations, theoretical underpinnings, and implementation of the system. Not all of the ideas presented here are new, but the unique combination of elements in the design of GeoModel has led to a highly useful system.

Design Philosophy

The design philosophy of GeoModel includes a commitment to draw from mathematical disciplines for suitable models of geographic relationships, to provide a system which does not get in the planner's way, to generate spin-off products throughout the course of the project and to create machine-independent systems, while always striving to avoid complexity in the implementation.

The use of existing mathematical tools is motivated by the consistency and depth which mathematics provides. Ad hoc alternatives to a mathematical design often have some intuitive appeal and may provide expedient implementations, but must eventually lead to patches in the design, further resort to ad hoc approaches, and ultimate lack of generality or integration. By faithfully building on a mathematical base, however, generality and extensibility are assured to the extent to which the mathematical theory has been developed.

A major consideration in designing a system is to decide what it is to be able to do. Systems are often designed by making an inventory of the services and options the user may want, choosing among these as to which are feasible to implement, and then providing the user a menu of commands to the system. To the extent that a system provides off-the-shelf facilities, it also delineates what the user is permitted to do, and channels the planner's intentions into the designer's image of planning. The planning system, in effect, defines what planning is.

Our approach is to <u>not</u> anticipate what the user will want to do, but to provide a means to combine primitive access functions in a great number of ways. Implemented as a language which is extensible and recursive, this facility would permit the planner to build complex access, edit, and display functions. Use may then be made of the system in ways which the designer never anticipated. In short, rather than identifying high-level services to provide, we have tried to identify low-level barriers to access which can be removed.

An important goal of GeoModel is to insulate the planner, to whatever extent desired, from census-defined geography and to operate exclusively in the units which the planner finds most useful. Data access is dictionary-based so that the user need never become familiar with actual record layouts. A planner may define traffic zones, school districts, or police precincts as sets of tracts, zips, or any other geographic entities already defined in GeoModel. Once the planner has described the relationship of his real-world planning zones to the census geography, he will immediately have access to aggregated population, race, income, miles of bus-lines, or any user-defined attributes in terms of the planning zones.

Mathematical Foundations

Fundamental mathematical contributions to GeoModel are found in topology and graph theory, as developed by Corbett (1) and White (2). Topology tells us that a line is bounded by exactly two nodes and is cobounded by exactly two areas. These are abstract relationships for which a great body of mathematical analysis has been developed. In spite of some obvious real-world entities which are related in this manner, the topological relationships are not a description of any particular physical structure, but rather serve to describe inherent properties of any system which can be modelled in terms of nodes, lines, and areas.

DIME is a well known topological model which encodes city streets as lines between street intersections (the nodes), with blocks represented as the cobounding areas. Within the topological constraint of planarity, which is satisfied in a general way by local patches on the earth, it is clear that a street segment always has exactly two sides and extends between exactly two points. (Of course, the Capitol Beltway is nowhere simply a line with two sides, and streets do not intersect at a point, but the model which makes this assertion is useful and powerful.) DIME thus represents a physical situation which is ideally suited for a topological model.

Any computer-based implementation of the DIME model must support algorithms which operate on the topological and graph theoretic relationships. At some basic level, the following four operations must exist:

1. Given a line, compute its bounding nodes;
2. Given a node, compute its cobounding lines;
3. Given a line, compute its cobounding areas;
4. Given a area, compute its bounding lines.

Planning zones are comprised of sets of atomic areas. Lattice theory is well suited to representing the overlapping and nonhierarchical nature of various administrative areas by their set relationships. For instance, the boundaries of ZIP codes and tracts seldom correspond. A lattice relates any two such zones covering some common area on the basis of set inclusion and partial ordering rather than any predefined precedence between all tracts and zips.

Data Structures

A GBF/DIME file from the Census Bureau carries all the necessary information to support the four topological operations listed above. However, its sequential structure, oriented around the line or street segment, causes the second and fourth to cost several orders of magnitude more than the other two. Each GBF/DIME record carries the complete set of 0-, 1-, and 2-dimensional information associated with a street segment, making any segment-based access very straightforward, indeed. The drawbacks of this layout, however, include the lack of control between records which carry the same information in several places, such as street names and coordinates, and the difficulty of updating such information. Edit operations using such a structure typically involve reformatting the file into a more suitable form, performing the operation, and restoring the data to its original format.

GeoModel stores the GBF/DIME information in a direct-access form which makes the four operations listed above all cost the same. This requires three basic record types, called 0-cells, 1-cells, and 2-cells, containing 0-dimensional, 1-dimensional, and 2-dimensional data, respectively.

The 1-cells are the keystone of the topological data structures. Each 1-cell record corresponds to a street segment record in the original GBF/DIME file and relates the segment to its bounding nodes and cobounding areas (henceforth to be called 0-cells and 2-cells). They are split into two parts, a topological relations part, and a features part.

Figure 1a. 1-cell Record

from 0-cell	to 0-cell	left 2-cell	right 2-cell

Figure 1b. 1-cell Feature Record

phrase pointer	non-street code	GBF/DIME id	left addresses	right addresses

GeoModel reduces the costs of computing 1-cells (the second and fourth operations mentioned above) by copying the relation information contained in the 1-cell records and grouping it by 0-cell and 2-cell. That is, a 0-cell record references all 1-cells which cobound it, and a 2-cell record references all 1-cells which bound it.

Any other information about a particular 0-cell or 2-cell on the GBF/DIME is stored only on the 0-cell or 2-cell record. Therefore, the latitude/longitude coordinates and census node number for a 0-cell are recorded only once, on a 0-cell record, rather than on each 1-cell which refers to it. So when a coordinate changes, it is updated in only one spot in the data base, with all references to that 0-cell implicitly corrected at no cost. Likewise, 2-cell records contain any 2-dimensional codes from the GBF/DIME such as state, county, tract, and block.

Figure 2a. 0-cell Record

GBF/DIME id	lat/long	count of 1-cells	list of 1-cells

Figure 2b. 2-cell record

pointer to CITY file	tract	block	ED	ZIP	count of 1-cells	list of 1-cells

The CITY file is an interim form of the 2-dimensional set descriptions which will later be converted to a lattice.

Figure 2c. CITY Record

state	place	county	SMSA	MCD	CD	area	postal state	city name

After GeoModel has been initialized, the files have the following relationships:

Figure 3.

```
+----------+
|          |
| 0-CELLS  |<---------+
|          |          |
+----+-----+          |
     |                |
     |          +----+-----+  +----------+
     +--------->|          |  |          |
                | 1-CELLS  |<->| 1-CELLS  |
     +--------->|          |  | FEATURES |
     |          +----+-----+  +--+-------+
     |               |           |    A
+----+-----+         |           |    |
|          |         |           V    |
| 2-CELLS  |<--------+        +-------+--+
|          |                  |          |
+----+-----+                  | PHRASES  |
     |                        |          |
     |                        +--+-------+
     V                           |    A
+----------+                     |    |
|          |                     V    |
|   CITY   |                  +-------+--+
|          |                  |          |
+----------+                  |  WORDS   |
                              |  HASH    |
                              +----------+
```

Implementation

The development plan calls for a series of products to be released throughout the course of the project. While only about one-third of the entire system has been implemented to date, there is already a stable and useful data base with several spin-off application packages and independent software tools. These include a data retrieval and manipulation language called L; the Basic Access Method (BAM); GMLOAD, a series of programs to restructure a GBF/DIME file into a set of GeoModel files; WORDED, a program to search and edit street names; and ADMATCH'80, an interactive address matching system. Two of these, BAM and L, are crucial to the implementation of GeoModel.

Early in the design of GeoModel it became clear that many files were going to be needed, and that the ultimate number of files was unknown. In the interest of portability (and hopefully, ease of use), the interface of GeoModel with the operating system had to be as simple as possible. This led to the design of BAM, the Basic Access Method, which stores all files used by GeoModel in a single direct-access file (called the "library") partitioned into any number of sub-files (called simply "files"). Records are then referenced by file name and record number, and may be read or written in any order. Records within a file must all be of the same length, but each file may have a different record length. BAM has the added benefits of centralized I/O handling, a reduced number of file handling tasks such as opens and closes, and a data access technique which is invariant throughout the system.

A language called L is being developed to access GeoModel. It is composed entirely of functions which may be built-in primitives or user-defined combinations of other functions. Any operand of a function may itself be another function. This allows pipelining of the results of one function into another. Every data item in GeoModel may be accessed by name and record key through a primitive called GM. Other primitives provide IF/ELSE structuring, iteration, and address matching.

New applications may be implemented by the planner at the terminal. As an example, suppose it were necessary to find the nearest cross street to a particular house address. The address must be matched to a particular 1-cell to make a 0-cell available. From the 0-cell, the intersecting streets are available, so via 1-cell and phrase (street name) pointers, the cross street may be found. Two lines of L can do this as follows:

```
PRINT GM 'PHRASE' GM 'C1P' GM 'C01' GM 'FROM0'
    HN01 '202' PMT 'HAWAII AV NE'
```

Executing from right to left, PMT returns a phrase record key, HN01 returns 1-cell record key, GM returns first a 0-cell, then a 1-cell, then a phrase record key, and finally the phrase itself. PRINT displays the street name on the terminal. While L requires a certain amount of training to use, it allows the composition of functions by the planner which the designer never could have foreseen. Some special-purpose applications of GeoModel have session control commands which are more user oriented, but less versatile than L.

GeoModel is being developed as part of an interagency agreement between the Census Bureau and the Urban Mass Transportation Administration (UMTA) to enhance the planner's interface to census data. It is implemented in portable COBOL, and both the software and the data files have been designed to allow transporting them from one computer to another. All functions supported by GeoModel can be executed in either interactive or batch mode. GeoModel is to be distributed by UMTA as part of the Urban Transportation Planning System (UTPS) to 300 planning agencies nationwide.

References

1. Corbett, James P., "Topological Principles in Cartography," to be published as a Census Bureau Technical Paper.

2. White, Marvin S., "The Cost of Topological File Access", Harvard Papers on Geographic Information Systems, 1978

ECOBASE OF BRITAIN: status report on a digital data base of Britain

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1. The Experimental Cartography Unit (ECU) is part of the British Natural Environment Research Council - an official body which embraces a number of internationally known institutes concerned with geology, hydrology, oceanography, ecology, etc. This particular project was initiated in 1976 by the Institute of Terrestrial Ecology (ITE) who required ECU to digitise the 1:250,000 Ordnance Survey map of the country. In doing so, they stated:

2. "Basically the requirement is a simple one. We expect increasingly to be concerned in ITE in the characterisation of the ecological resources of Britain for a variety of customers. Much of this characterisation will be on a national or regional scale rather than a purely local scale, and we will need to present the results of the surveys and analyses of existing information in a cartographic format which is both convincing and flexible. Furthermore, it is almost impossible to predict the regions for which characterisation will be required. We believe, therefore, that first priority should be given for a national coverage at 1:250,000 scale with about as much detail as is currently given in OS maps at that scale.

Certainly this complete coverage should be available within two to three years if we are to meet the requirements of our customers."

"We readily concede, of course, that it would be nice to have more detail than can be obtained at the 1:250,000 scale, but we do not want a situation in which the time for completion of the survey disappears over the horizon - excellent though the few maps produced may be. We would prefer a complete coverage with a limited amount of detail and precision."

"Our need for this digitisation is becoming urgent. Not only are we concerned with the ecological survey of Britain, but we have extensive studies of the land use of the uplands, and of coppice woodlands in the south of England. Our pollution studies will require cartographic presentation and we are currently planning a project on energy production of ecological systems."

3. At this same time ECU was already engaged in another large digitising operation for the Institute of Geological Sciences (IGS) in order to produce a series of Geochemical atlases at 1:250,000 scale. This project started in the north of Scotland: it is proceeding southwards at a somewhat slower rate than that envisaged by the ecologists on account of the massive amount of sampling data involved. The geochemical project also required that topographic base map information should be digitised at 1:50,000 scale. In addition, updated geological compilations were made at 1:50,000 scale and these were also digitised.

4. Under these circumstances ECU argued that Ecobase should consist of material derived from the 1:50,000 scale as that came into existence; the rest of the country should be digitised at 1:250,000 scale being replaced, bit by bit, as further 1:50,000 data became available. The present coverage of the two scales is shown (fig. 1) with the larger scale over most of the Highlands and Islands of Scotland - circa 20% of Britain. Thus, digital data covering the whole of Britain has been available since mid-1979.

5. It must be emphasised at once that this digital data does not represent the totality of the published OS maps either at 1:50,000 or 1:250,000 scales. The objectives of Ecobase are manifestly different from those of topographic maps which anyhow exist as printed maps already and obviously do not require reconstituting digitally at substantial extra cost.

The maps elements that have been digitised for Ecobase are:

1. Coastlines (high water mark) including islands.
2. Rivers, canals and lakes.
3. Motorways, A class and B class roads.
4. Railways.
5. Woodlands.
6. Urban areas.

Additionally, ECU is "importing" digital data from other government agencies for:

7. Contours (at 100m interval)
8. Administrative boundaries (to ward/parish level).

Note that items 1-6 are broadly common as between 1:50,000 and 1:250,000, though the larger scale gives a positional accuracy of +/-10m against +/-75m for the smaller scale.

6. The following notes illustrate some of the issues involved in such an exercise.

(a) Coastlines We plan to use the same coastline data throughout relying on software (program REDUCE) to smooth data and get rid of intermediate co-ordinates within each line segment that are visually "unnecessary" for smaller scale plots. However, the smaller islands are still left with some line segments and are liable to show up, if only perhaps as dots, at smaller scales. The only solution here seems to be that of measuring the areas of every island and sieving out the smaller ones as appropriate for the scale - and for the purpose - of the map. This area measurement is a somewhat tedious and lengthy process even when run in batch mode.

(b) River classification Initially all rivers and lakes at both scales were tagged with single feature codes. However, to enable a coherent 1:250,000 water pattern to be produced from a data base which has topographic input at variable scales, a recoding exercise has been necessary. Table 1 below gives details of this.

(c) Roads Each class of road carries a feature code which distinguishes it so that the selection of particular classes for particular scales is straightforward. In a few selected areas we have also digitised minor roads, tracks and "rights of way": these lower categories may have some value in themselves and they have also been used to identify areas of inaccessibility (e.g., 500 metres from any track or road) a factor which may have ecological significance.

(d) Railways These have been treated as a single class of feature (though "disused railways" are also separately digitised). We are aware that smaller scale maps may make it necessary to add a code to those lines which, on operational grounds; are of greater importance.

(e) Woodland This is an undifferentiated category with no reference to species at this stage. Obviously those areas where the source material was at 1:50,000 scale will, in general, show more small bits of woods: however, woods are relatively infrequent in Highland Scotland and this geographical fact balances the smaller scale source used so far for the rest of Britain. The problem of selecting woods at smaller scales is that of selecting any other "islands" and will probably have to depend on area measurement.

It is worth noting that woods adjoining roads or rivers have been digitised by a single line segment carrying feature codes for both.

(f) Urban areas OS maps show a tint that defines built-up areas and it is the outline of this that has been digitised: this tint obviously does not cover isolated buildings. The problem of selecting only major built-up areas for showing on small scale maps is very similar to those of selecting woods and islands.

(g) Contours The imported data set for contours was originally prepared more as input for a digital terrain model than with the intention of providing, for example, complete sets of closed polygons representing, say, the 100m contour. Thus, the digital contours stop at cliffs and have small gaps and discontinuities which have need of repair before being incorporated in Ecobase. The data base as well as providing a set of contours at 100m interval also includes some form lines at 50m interval where the relative flatness of slope makes this desirable, as well as a liberal scatter of spot heights. To edit this data set - topologically as well as topographically - is a long and expensive task under the ECU system, taking some 30%-50% of the time of redigitising de novo.

It has to be noted that Ecobase contours will, when tidied up, deal only with the land area and have not so far been extended below the zero-contour; nor do they portray the depths of lakes, etc.

(h) Administrative Boundaries This data set is also an imported one (from the Dept. of the Environment): it shows boundaries down to parish/ward level and was originally digitised at one-inch-to-the-mile scale and in relation to boundaries as used in the 1971 population census. Since much statistical data, e.g., from the population census is published in terms either of these boundaries or of centroids based on them, this boundary data, once incorporated into Ecobase, consequently provides a key for computer mapping of demographic, medical, sociological data, as may be wished.

However, before this data can be properly incorporated into Ecobase two editing functions are necessary on it. The first of these requires the elimination of duplicated boundaries so that the file contains only a single digital record of any line segment but tags common boundaries with the codes of the relevant contiguous areas. It is estimated that this editing process will reduce the size of the data sets by 40%. Secondly, editing is necessary to ensure that where these imported boundaries are coincident with parts of topographical lines, like rivers that are already in the data base, one or other line segment is deleted and the archive appropriately updated so that both/all feature codes are alloted to the particular segment. This is, again, a job for interactive editing, and a long one.

7. While it is not clear whether Ecobase, as it now stands, is a large system or a small one - and perhaps judgements on that will alter over time - it is clear that we have more data than can be accommodated on the 80 megabite disk pack on the ECU's PDP-11/34 computer. This means that fast interactive interrogation of any of the data of all the area is not possible - at least at the resolution of digitising. This is not very surprising but is disappointing. The attractiveness of Ecobase is partly related to the concept of instant retrieval of any area and any combination of features.

8. The 1:250,000 part of the data (1) (water pattern, communications, woodlands and urban areas) occupies 66% of an 80 megabyte disc-pack and comprises 100,870 line segments with a total line length of 554 metres (2). The 1:50,000 part of the data (1), which covers approximately 20% of the land area, occupies a whole 80 megabyte disc and comprises 136,650 line segments with a total line length of 1,012 metres (2). The administrative boundaries and contours to cover the whole area at present occupy a further $1\frac{1}{2}$ disc-packs, although this figure will be reduced when line duplication within the administrative boundary data-set is eliminated.

---

(1) See Figure 1

(2) At 1:250,000 scale

Table 1

Categories of rivers and lakes as shown on Ordnance Survey 1:50,000 maps and as used in Ecobase.

> Feature codes 4 or 5 in position 1 denote river or lake respectively.
> Feature codes in position 2 give categories of river or lake.

(a) Rivers shown by double lines which are non-parallel.	Both banks plus islands within river are digitised (Code 4,28). Centre lines also entered by eye during interactive editing (Code 4,27).
(b) River shown by double parallel lines.	Centre lines are digitised (Code 4,26).
(c) Thick lines.	Centre lines are digitised (Code 4,29).
(d) Thin lines constituting all other rivers, drains etc.	Lines are digitised (Code 4).

NB By running program LINKER any combination of the above may be selected.

(e) Lakes within a category (a) river system.	Digitised as mapped (Code 5,58).
(f) Ditto for category (b) rivers.	Digitised as mapped (Code 5,56).
(g) Ditto for category (c) rivers.	Digitised as mapped (Code 5,59).
(h) Ditto for category (d) rivers.	Digitised as mapped but excluding those estimated as below 25 square kilometres on ground (ie $10mm^2$ at 1:50,000) (Code 5,50). Remainder as mapped (Code 5).

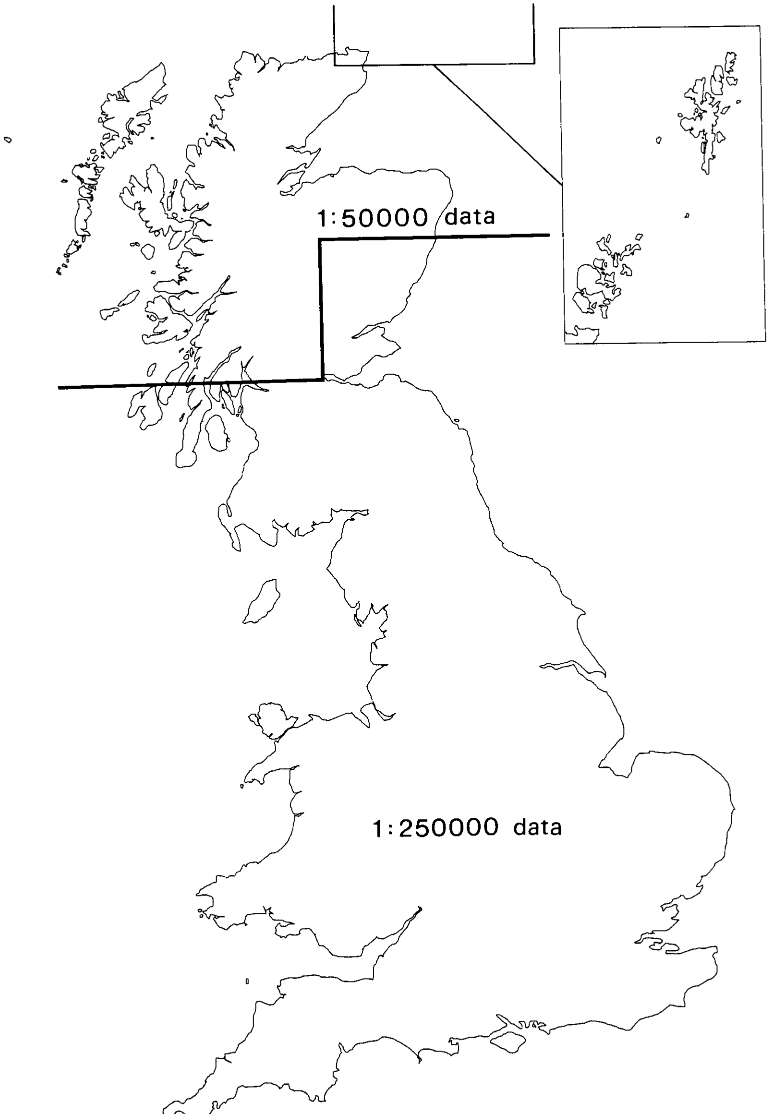


Figure 1
Scale of digitisation of planimetric data

<u>DIRECT PLOTS OF ECOBASE</u>

Figure 2(a)

<u>At 1:2.000.000</u>

Showing coast major rivers and lochs as digitised at 1:50.000

Area of figs 2(b) and 2(c) indicated.

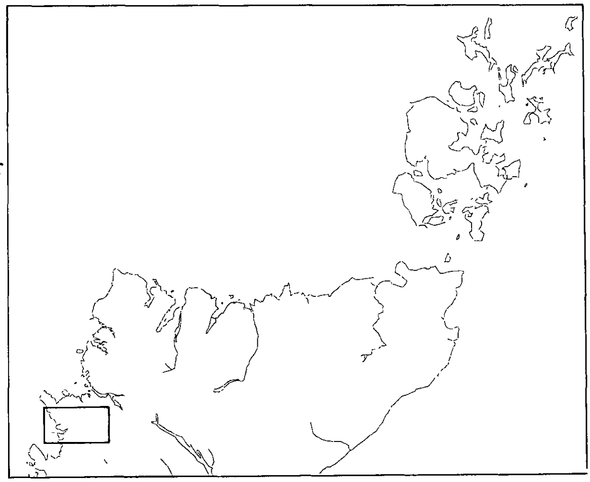


Figure 2(b)

<u>At 1:250.000</u>

Showing coast & three out of four (width) categories of rivers, lochs etc

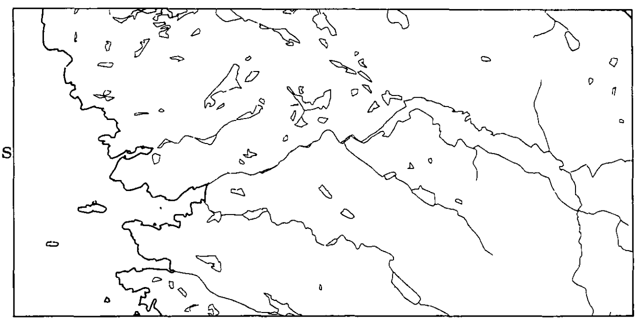
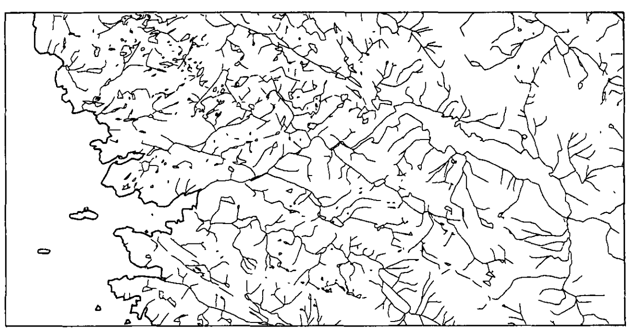


Figure 2(c)

<u>At 1:250 000</u>

Showing coast all rivers and lochs as digitised at 1:50 000



A DATA STRUCTURE FOR A SPATIAL INFORMATION SYSTEM

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I. Introduction

We consider maps to be a visual representation of spatial data. We call the formal organizational structure by which we may represent spatial data in the computer a spatial data structure. In this paper we give a definition of spatial data structure and some examples illustrating its use in raster format data, in vector format data, and in procedures which do inferential reasoning with spatial data. The structure is rich, flexible, and efficient enough to logically store any of the spatial information in maps, line drawings, region adjacency graphs, and other geographic entities that we might desire to represent.

II. A Spatial Data Structure

An atom is a unit of data that will not be further broken down. Integers and character strings are common examples of atoms. An attribute-value table A/V is a set of pairs A/V = {(a,v) | a is an attribute and v is the value associated with attribute a}. Both a and v may be atoms or more complex structures. For example, in an attribute-value table associated with a structure representing a person, the attribute AGE would have a numeric value, and the attribute MOTHER might have as its value a structure representing another person.

A spatial data structure D is a set D = {R1,...,RK} of relations. Each relation Rk has a dimension Nk and a sequence of domain sets S(1,k),...,S(Nk,k). That is for each k = 1,...,K, Rk c S(1,k) X ... X S(Nk,k). The elements of the domain sets may be atoms or spatial data structures. Since the spatial data structure is defined in terms of relations whose elements may themselves be spatial data structures, we call it a recursive structure. This indicates 1) that the spatial data structure is defined with a recursive definition (and not that the information stored in it is infinitely recursive), and 2) that it will often be possible to describe operations on the structure by simple recursive algorithms.

A spatial data structure represents a geographic entity. The entity might be as simple as a point or as complex as a whole map. An entity has global properties, component parts, and related geographic entities. Each spatial data structure will have one distinguished binary relation containing the global properties of the entity that the structure represents. The distinguished relation is an attribute-value table and will generally be referred to as the A/V relation. When a geographic entity is made up of parts, we may need to know how the parts are organized. Or, we may wish to store a list of other geographic entities that are in a particular relation to the one we are describing. Such a list is just a unary relation, and the interrelationships among parts are n-ary relations.

For example, we may represent the state of Virginia by a spatial data structure. In this case, the A/V relation would contain global attributes of the state such as population, area, boundary, major crop, and so on. The values of most of these attributes (population, area, major crop) are atoms. The value of the boundary attribute is a spatial data structure defining the boundary.

One obvious division of the state is into counties. A list of counties could be included as one of the relations, or it might be more valuable to store the counties in a region adjacency relation, a binary relation associating each region (county) with every other region (county) that neighbors it. Counties, of course, would also be represented by spatial data structures.

Some other geographic entities that are related to a state are its highways, railroads, lakes, rivers, and mountains. Some of these entities will be wholly contained in the state and others will cross its boundaries. One way to represent this phenomenon is to use a binary relation where the first element of each pair is a geographic entity, and the second element is a code indicating whether the entity is wholly contained in the state. The spatial data structures representing the geographic entities themselves would contain more specific information about their locations. Figure 1 illustrates a simplified spatial data structure containing an attribute-value table, a county adjacency relation, and a lakes relation for the state of Virginia.

Comparison to Other Geographic Data Structures

The spatial data structure defined in this paper can easily store the spatial data used in well known vector based spatial systems such as the Canada Geographic Information System (Tomlinson, 1967), the U.S. Census DIME files (Cooke and Maxfield, 1967), and POLYVRT (Harvard Laboratory for Computer Graphics and Spatial Analysis, 1974). We illustrate this by defining a system with similar characteristics. In our system, a point is an atom consisting of an ordered pair (X,Y) where X represents latitude and Y longitude. A chain C is a spatial data structure C = {A/VC, LP}. LP is an ordered list (unary relation) of points that define the chain. The attribute-value table A/VC of a chain contains the attributes LEFT_POLYGON, RIGHT_POLYGON, NEXT_CHAIN_LEFT, and NEXT_CHAIN_RIGHT whose values correspond to the pointers in Tomlinson's system. The attribute-value table can also contain such global information as the length of the chain or a function to be used to interpolate between the points.

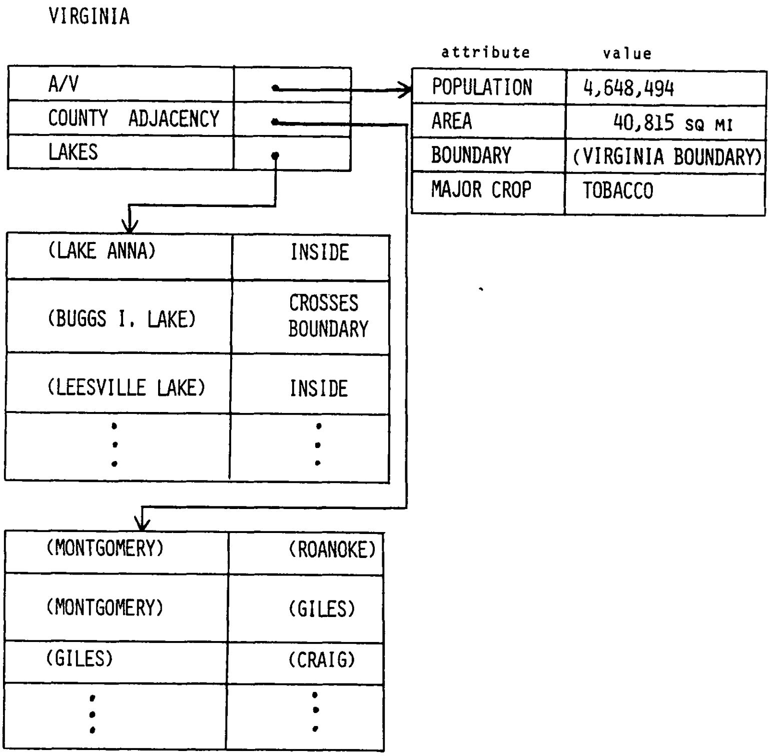


Figure 1 illustrates a spatial data structure representing the state of Virginia. The A/V relation is an attribute-value table. The COUNTY ADJACENCY relation contains pairs of adjacent counties. The LAKES relation contains pairs consisting of a lake and an indication of whether it lies inside or on the boundary of the state.

A polygon P is a relatively simple spatial data structure P = {A/VP}. In this case, the attribute-value table contains the attributes FIRST_CHAIN and POSITION. The value of FIRST_CHAIN is the first chain of the polygon, and the value of POSITION is LEFT or RIGHT depending on whether the polygon lies to the left or to the right of the first chain. Such global attributes as AREA and CENTROID can also be stored in the attribute-value table.

Figure 2 illustrates this structure for a simple 'map' of two regions P1 and P2. In this example, we have chosen the chains to be the longest sequence of points that have exactly one region to their right and one region to their left. The directions of the chains

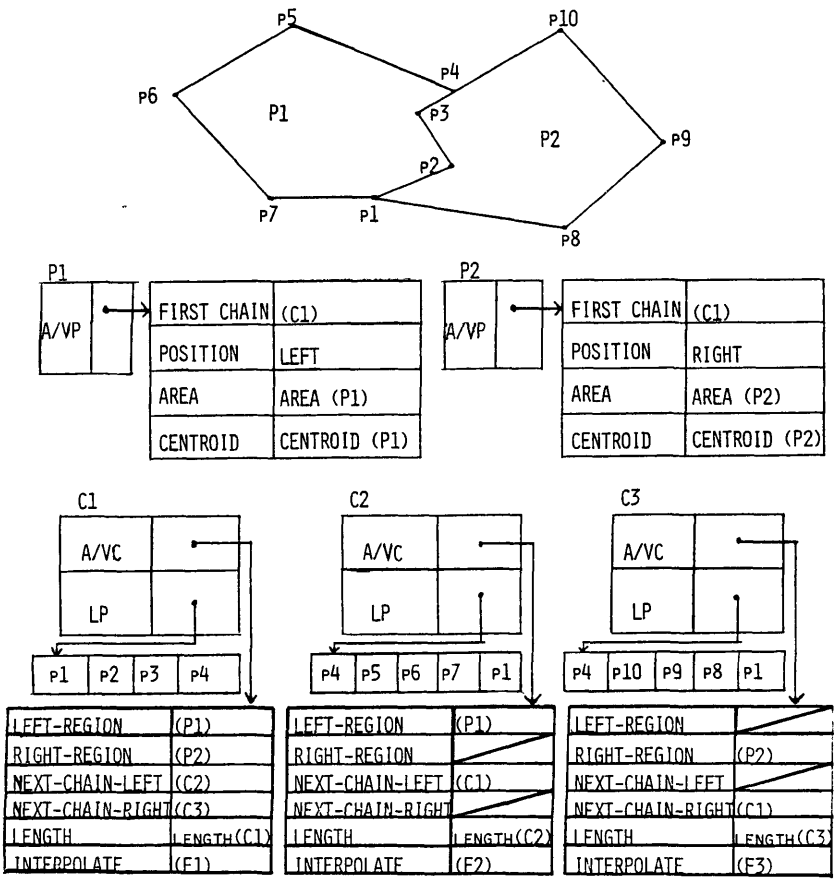


Figure 2 illustrates a spatial data structure for a simple map that encompasses the structures used in the Canada Geographic Information System, the DIME system, and the POLYVRT system.

were chosen arbitrarily. We do not mean to suggest that the points in a chain be stored sequentially as (X,Y) condinates. Instead, we are leaving the physical storage mechanism open. In some applications, storing differences or using Freeman chain codes (Freeman, 1974) might be appropriate. In other applications, storing the chain in a parametric functional form might be appropriate. Regardless of the physical form of storage, the structural aspect of the representation is the same.

Because the spatial data structure is a recursive structure, it can naturally handle the hierarchy of a region and its holes. We define the boundary of a region as follows. A boundary is a polygon plus a (possibly empty) list of boundaries of interior polygons. Thus a boundary can be represented by a spatial data structure B = {A/VB, LB} where A/VB contains the attributes FIRST_CHAIN and POSITION, and the unary relation LB is a list of boundaries. As before, FIRST_CHAIN is the first chain of the polygon, and POSITION indicates whether the bounded region lies to the left or the right of the first chain.

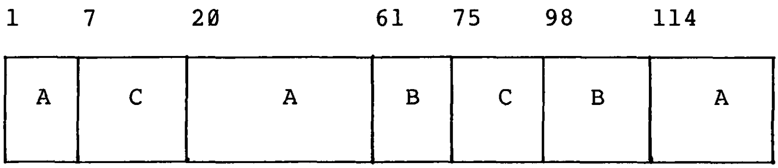
When LB is empty, B is a polygon or simple boundary. When LB is not empty, then B has holes in it. Each of these holes is also a boundary, so it may also have holes. Thus this spatial data structure handles the hierarchical polygonal data structures. Other hierachic structures such as Edwards, Durfee, and Coleman's (1977) and Brassel's hierarchically organized spatial data base of Thiessen polygons can be handled similarly by our spatial data structure.

In the triangle data structure (Gold, 1976; Males, 1977), each triangle points to its vertices and adjacent triangles. Thus a triangle is a spatial data structure T = {LV, AT} where LV is a list of three vertices, and AT is a list of adjacent triangles. Each vertex V is a spatial data structure V = {A/VV} where the attribute-value table A/VV contains the attributes SLOPE, ELEVATION, and other information.

The systems just described all store their geographic data in vector form. Vector form is only one form of spatial data. It represents areas by their boundaries and has the advantage of a very compact representation.

Raster or grid form is another form of spatial data. In this form areas are represented by the grid cells that cover them. The advantage of raster format data is the simplicity of performing certain tasks such as map overlay. Our spatial data structure can handle raster form data just as easily as it handles the vector form.

Consider, for example, storing an entire map of regions in a run length encoded form of raster grid cell data. Shown below is one row of such map data.



In the row shown, there are seven intervals, each one of which belongs to one of three regions: A, B, or C. Each interval is specified by a beginning pixel, an ending pixel, and an interval label. By grouping together all intervals of the same label we may represent this row by the following table.

		Internal List Name	
A:	(1,6),(20,60),(114,130)	IL47A	Partition
B:	(61,74),(98,113)	IL52D	List
C:	(7,19),(75,97)	IL36E	PL81B

In this case, the row points to the partition list (Merrill, 1973) PL81B which contains the interval lists IL47A, IL52D, and IL36E, each of which contains a set of intervals for some region in the row.

Grid cell data structures explicitely represent areas. We will call the entities employing this representaion 'map areas'. Thus, the entity 'map area' is a spatial data structure MA = {A/VMA,PLR}, where the attribute-value table A/VMA has the attribute THEME with values such as 'soil type' or 'land use'. PLR is the partition list binary relation. It consists of a set of ordered (row,partition list) pairs. The entity 'partition list' is a spatial data structure PL = {A/VPL,ILS}, where the attribute-value table A/VPL has the attribute ROW whose value is the number of the row being divided up by the partition list. ILS is the set of interval lists composing the partition PL. Finally, the entity 'interval list' is a spatial data structure IL = {A/VIL,HS}, where the attribute-value table A/VIL contains the attributes NAME and ROW. The attribute NAME takes on a value which is the name of the region to which the intervals in IL belong. The attribute ROW has as its value the row number. HS is the ordered list of horizontal strips (intervals) in the interval list. Each strip in HS is an ordered pair whose first component is the beginning pixel and whose second component is the ending pixel of the strip.

All of the fast geometric distance, region editing, point in polygon, and line intersection algorithms in vector format or in raster format have data structure requirements that are easily and naturally fulfilled by the general spatial data structure. In the next section we illustrate that the general spatial data structure can handle the data for inferential reasoning required by the intelligent query capability that we desire a spatial information system to have.

III. Design of a Spatial Information System

We are currently involved in the design and implementation of an experimental spatial information system using the spatial data structures concept of Section II. The system will answer user queries and solve problems presented to it in a subset of English. In this section, we describe some of the important features of the proposed system.

Major Data Structures

The spatial data structure is the primitive or building block of the system. A finite number of spatial data structure types will be allowed. For instance, the system might include spatial data structures representing the high-level entities states, cities, counties, highways, rivers, lakes, and mountains and the lower-level entities boundaries, simple boundaries, and chains. Thus the system might contain a spatial data structure whose name is MONTGOMERY and whose type is COUNTY.

For each type of spatial data structure, the system will keep a prototype structure. The prototype will indicate what attributes are found in the attribute-value relation of this type of spatial data structures and what relations besides the A/V relation comprise the data structure. Similarly a finite number of relation types will be allowed, and the system will keep prototypes of the allowable relations. Thus the STATE prototype might indicate that all spatial data structures of type STATE have a COUNTY_ADJACENCY relation. The COUNTY_ADJACENCY prototype would indicate that this is a binary relation and that both components of each pair in the relation are spatial data structures of type COUNTY. (See Figure 3 in the section entitled Primitive Operations.) A user query might involve a specific spatial data structure or a specific type of spatial data structure. For fast access in either case, the system will include a spatial data structure name dictionary that maps a name to a spatial data structure and a spatial data structure type dictionary that maps a type to a list of all spatial data structures of that type. Similarly a relation type dictionary will map a relation type to a list of all relations of that type. We are planning to implement relations as relational trees (Shapiro, 1979). Note that all of these structures can be represented by spatial data structures, unifying the whole system.

Primitive Operations

The spatial data structure is a relational structure. Because of this, the spatial database system shares many characteristics of relational database systems. In particular, all of the primitive operations used in relational database systems are applicable to the relations of a spatial data structure. We will use a small example database to motivate the use of these and other primitive operations.

Figure 3 illustrates a set of prototypes for spatial data structures and their relations that might be found in a spatial information system. The STATE prototype indicates that STATE is a type of spatial data structure having an A/V_STATE relation, a COUNTY_ADJACENCY relation, and a RIVERS relation. The A/V_STATE relation has four attributes: NAME, whose

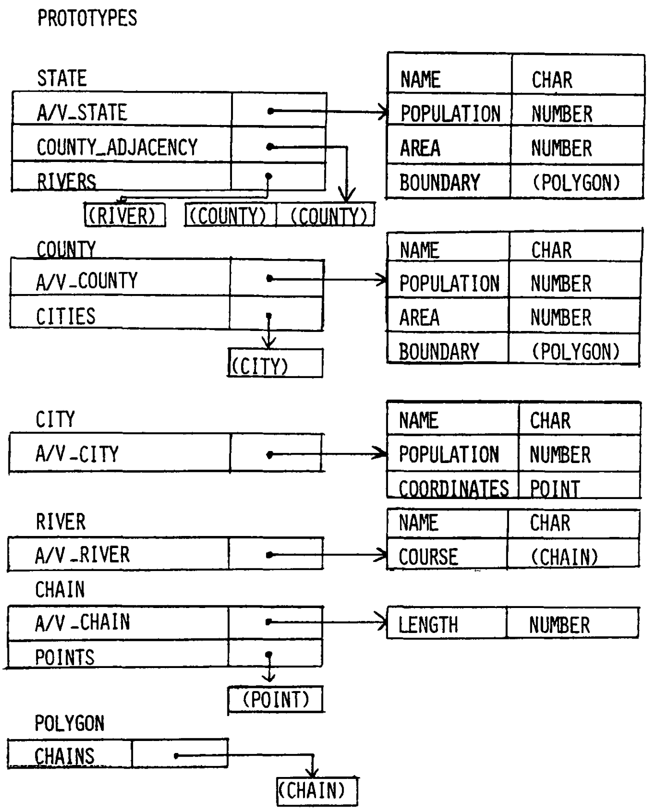


Figure 3 illustrates a set of prototypes for the spatial data structure types STATE, COUNTY, CITY, RIVER, CHAIN, and POLYGON and the relation types COUNTY ADJACENCY, RIVERS, CITIES, POINTS, and CHAINS.

value is a character string, POPULATION and AREA whose values are numbers, and BOUNDARY whose value is a spatial data structure of type POLYGON.

The COUNTY_ADJACENCY relation is a binary relation, and each member of each pair is a spatial data structure of type COUNTY. The RIVERS relation is a unary relation, and each element is a spatial data structure of type RIVER. The other prototypes convey similar information.

The following questions are possible queries to a spatial information system having the prototypes of Figure 3. Under each question, we suggest a sequence of operations that might be performed to answer the query.

1) What cities are in state X ?

    A. Locate state X.
    B. Perform a projection operation on COUNTY ADJACENCY(X) to obtain a list of counties.
    C. For each county Y in the list
       For each city C in CITIES(Y)
        1. Look up N = NAME(C).
        2. Add N to the relation being created.

2) What cities lie on rivers in state X?

    A. Locate state X.
    B. Perform a projection operation on COUNTY ADJACENCY(X) to obtain a list of counties.
    C. For each county Y in the list
       For each city C in CITIES(Y)
       For each river R in RIVERS(x)
       if
       POINT_CHAIN_DISTANCE(COORDINATES(C), COURSE(R))=Ø
       then add C to the relation being created.

3) What counties in state X does river R flow through?

    A. Locate state X.
    B. Perform a projection operation on COUNTY ADJACENCY(X) to obtain a list of counties.
    C. For each county Y in the list
       if CHAIN_INTERSECTS_POLYGON(COURSE(R), BOUNDARY(Y))
       then add Y to the relation being created.

From these and other sample queries, we find the following operations are necessary: projection in the relational database sense, selection in the relational database sense, intersection or join in the relational databases sense, look up the value of an attribute, call on geometric or distance functions, create a list, add elements to a list, comparison, determine if an N-tuple is a member of a relation, create a new relation, and create a new spatial data structure.

IV. Summary

We have defined a general spatial data structure to be used as the building block in a spatial information system. The structure is general enough to represent all the data structures used in previous systems without changing their logical structures and can handle vector or raster data with equal use. We have discussed the major data structures needed for a spatial information system. Finally we have presented a set of possible queries, described the sequence of operations needed to answer them, and used these sequences to motivate the primitive operations required for the spatial information system.

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WHIRLPOOL:
A GEOMETRIC PROCESSOR FOR POLYGON COVERAGE DATA

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I. Introduction

WHIRLPOOL is one of the family of ODYSSEY programs developed for the manipulation and display of polygon coverage data. Together these programs have a broad range of capabilities from creation of cartographic base files to interactive display of thematic maps. (Dutton 1977) (Teicholz 1979).

By itself WHIRLPOOL has a variety of functions. In the creation of new base files, the program can plan an important role, automatically correcting some common digitizing errors and detecting others. Another important function is the geometric overlay of polygon coverages to produce a combined coverage for further use in modeling and analysis.

The program has other useful capabilities which are necessary to perform geometric polygon overlay and can also be used alone. It can calculate polygon areas and produce a file containing the area and perimeter of each polygon. The technique is applicable even for highly complex coverages whose polygons may be too complicated for other programs. A list of location points can be processed producing a file containing, for each point, the polygon identifier of the polygon within which the point is located. The base file can also be generalized to remove excess detail points.

The program was written in FORTRAN by James Dougenik and Nick Chrisman. It has been installed on a PDP-10 and on an IBM 370 with the CMS operating system, and is currently being installed on other systems.

Polygon Coverages

One of the unifying concepts underlying the ODYSSEY family of programs is that of a common cartographic file organization. Called a "chain file", it is an abstract representation of the network of boundaries present in a polygon coverage. (Puecker and Chrisman 1975).

In a polygon coverage, the area of interest is partitioned into non-overlapping polygons using nominal (or numerical) categories. Examples are governmental jurisdictions such as municipalities or states, land use categories, or zoning classifications. The "chain" abstraction represents the boundaries between polygons as sequences of line segments approximating the true boundary to the accuracy necessary. The lists of boundary segments are often referred to as chains or arcs, and where they meet are called nodes or junctions.

The chain file consists of all the chains for a study area. Each chain consists of a list of its segments and the names or identifiers of the two polygons of which it is a boundary and the two nodes at which it begins and ends. The node identifiers allow easy assembly of the network again (Puecker and Chrisman 1975) (Corbett 1975).

II. <u>Major</u> <u>Functions</u>

Polygon Overlay

The statement of the problem of polygon overlay is deceptively simple. Given two polygon coverages of the same study area, make them into one polygon coverage. Its solution is a powerful tool. It gives the information necessary to answer specific questions such as "What regions possess a certain combination of proper ties?", or "What combinations of properties does this region possess?" and more general questions such as "What properties are commonly (rarely) present together?".

When performing polygon overlay, certain major tasks can be identified. (White 1977). To make the two coverages into one, geometrically, requires finding all the locations where polygon boundaries from one coverage intersect the other. Finding the intersections is not too difficult, but finding them efficiently is challenging, and is the key to an efficient polygon overlay program. Shamos and Hoey (1976) describe some techniques applicable to finding intersections efficiently.

To answer the questions about the combined coverages, the correspondences between the polygons of the combined coverage and the separate coverages must be established. Some created polygons contain boundaries from both original coverages; the correspondences here are immediately available. Some original polygons are not intersected by the other coverage; more complicated techniques are necessary to find within which polygon of the other coverage they lie.

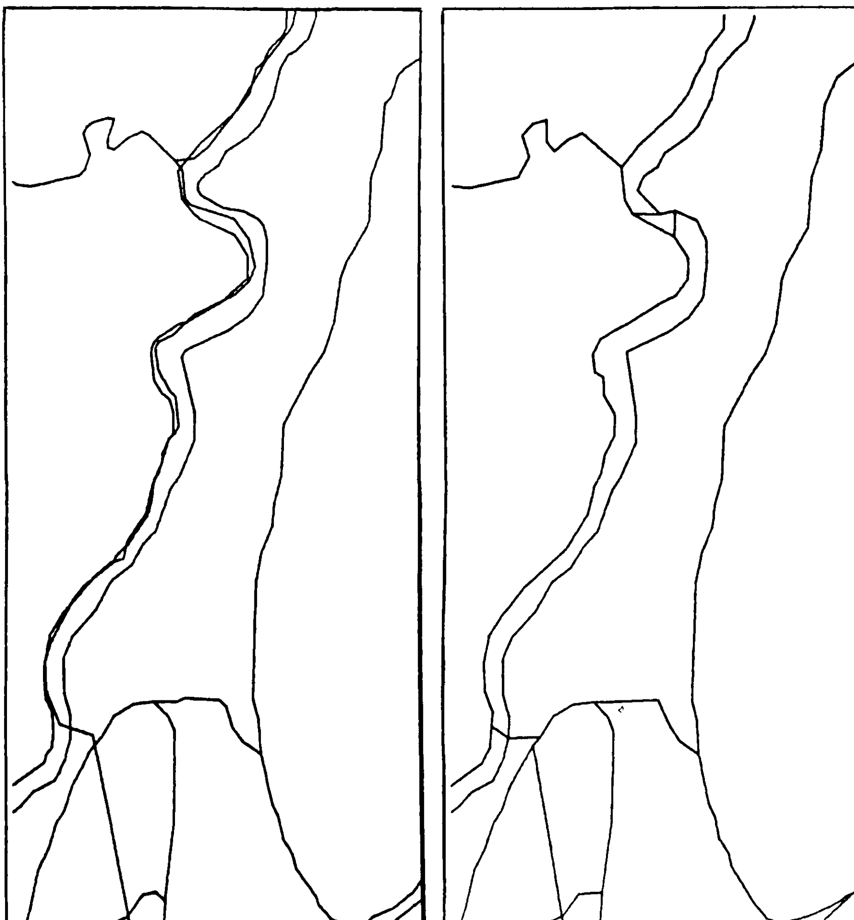
The great difficulty that is encountered when attempting to solve the polygon overlay problem is not at all obvious. This is because it is really the separate problem of data error. The polygon boundary locations are not exact. Errors in surveys, the source maps, the digitizing process all combine to make the boundaries only approximate locations. The difficulty arises when the same boundary is represented slightly differently in the two different coverages. The result is "sliver" polygons, small areas resulting from where the two descriptions do not match. (Goodchild 1977) They are small in area, yet can greatly increase the size of the combined coverage file. Also, the more detailed the boundary descriptions the more slivers are produced.

WHIRLPOOL can solve this problem by using its error distance, which is described in more detail later. This distance is used as the maximum distance which any location can be moved. By giving the program the freedom to move coordinates, it can remove many sliver polygons because they are narrower than the error distance. See Figure I.

Digitizer Data

An important function in any polygon coverage manipulation system is the creation of polygon coverages. A digitizer will record the coordinates of the polygon

Figure I. On the left, a map of zoning classifications has been overlayed with a map of soil types. A boundary from the zoning map closely follows the west bank of a river from the soils map, producing numerous sliver polygons. On the right, WHIRLPOOL has removed the slivers using an appropriate error distance. The triangular polygon in the river results from where the zoning boundary was closer to the other bank of the river, due to digitizing error. The procedure cannot handle errors which are larger than the error distance.



boundaries, but the polygon identifiers have to be entered and the boundary endpoints at the same junction coerced to the same coordinate location before a correct coverage has been created. When digitizing manually, segments are sometimes duplicated, and boundaries are occasionally digitized without stopping at junctions resulting in errors which must be corrected.

There are many approaches to these problems. A common solution is that boundary endpoints are given numbers and all endpoints with the same number can then be given the same location. The two polygon identifiers are also entered when the polygon boundary is digitized. This type of solution has the drawback that each time a number or identifier has to be entered more than once the chance of making a mistake increases.

A different technique is as follows. After digitizing the boundaries, a point is digitized for each polygon and the identifier is entered with it. A point can then be used to name a polygon in the coverage by finding within which polygon it is located. The boundary endpoints can be rectified if the different digitized locations fall within an error distance of each other. This process removes the necessity of specifying identifiers multiple times and eliminates node number entirely. Digitizing operations must then be aware of the error distance when preparing highly detailed maps.

Digitized data can be processed through WHIRLPOOL using this technique. Errors in digitizing such as forgetting to stop at boundary endpoints, and digitizing segments more than once are automatically corrected by finding intersections and eliminating sliver polygons.

Implementing the Error Distance

The error distance plays a major role in the polygon overlay and digitizer input processes of WHIRLPOOL. First, the basic concept of intersection is generalized to that of extended intersection or "fuzzy" intersection. Basic intersections occur if two line segments share a common point. Extended intersections occur if a point from each line is within the error distance of each other. A basic intersection is the special case of an extended intersection with the error distance at zero. Segments are then broken at their point of intersection.

The other important role the error distance plays is when the boundary endpoints are coalesced. The error distance is used to find endpoints which are closer than this distance. These are collected together and a clustering analysis is performed. This process selects which points are moved and which stay fixed. These clusters can get quite complicated if the error distance is relatively large. Then a point can be close to a point which is close to another point, and so on. As points are moved, checks are made to determine when two boundary segments have become identical.

Spatial Filter

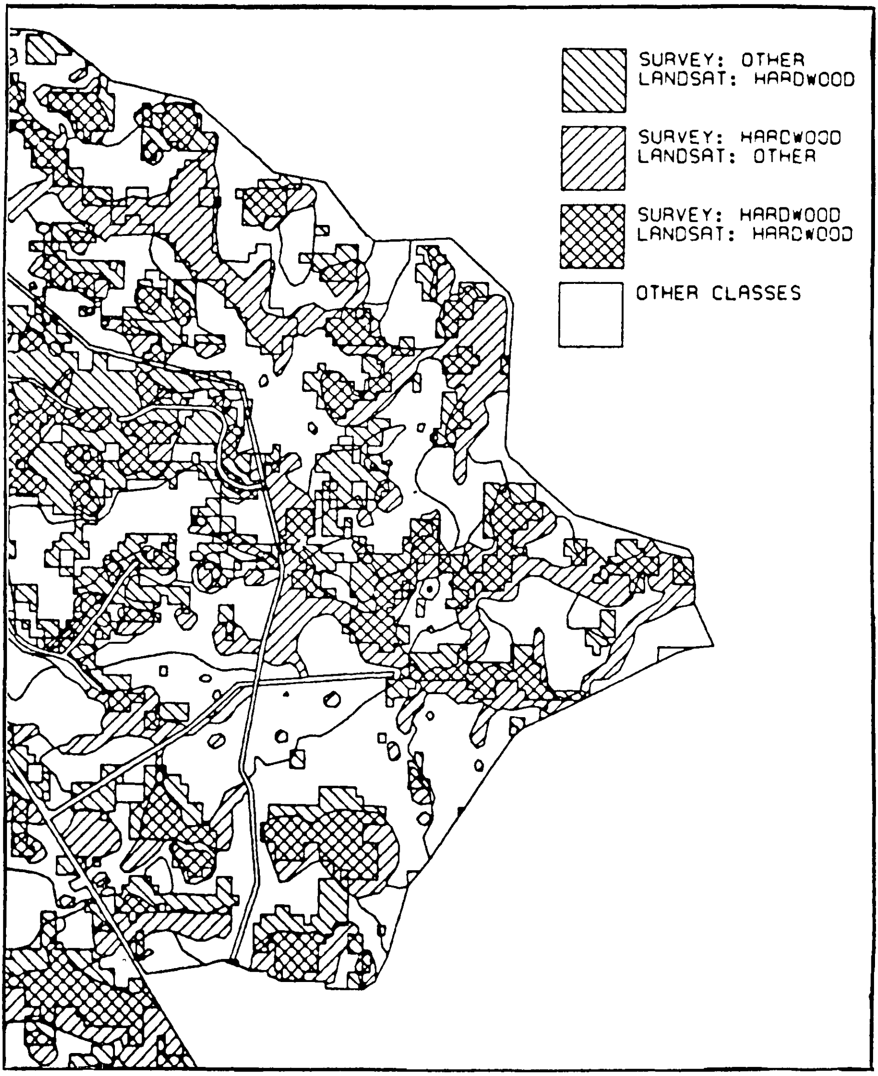
A byproduct of the implementation of the error distance is its use as a spatial filter. By making the error distance larger when processing a digitized file, two things happen. Detail is reduced along boundary lines and closely packed features begin to coalesce. The properties of this filter technique are largely unexplored but its results to date have been pleasing for removing excessive detail and numerous small polygons.

III. Applications

The program has been used in a number of test and practical applications. A file of census tracts for Montreal was digitized and processed by WHIRLPOOL to create the base file used for an epedemiological study. (Nisen and Hunt 1979)

An important application was a test project sponsored by a lumber company. (Morehouse and Dougenik 1979) A polygon coverage classified by forest types was digitized from maps compiled by traditional survey methods of ground survey and aerial photographs. This was overlaid with a classified LANDSAT matrix which had been converted to a polygon coverage. The results were then analyzed for agreement of forest types. The results were very interesting with many large areas of agreement. Some major areas of disagreement were explained through lack of map updating to reflect recent harvests of hardwood trees. An example of this is found in the upper portion of Figure II.

Figure II. An example from an overlay of a LANDSAT derived polygon coverage and a similarly classified coverage digitized from survey maps.
(The shaded map was produced by the POLYPS program.)



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A FORMAL MODEL OF A CARTOGRAPHIC INFORMATION BASE

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Introduction

A hierarchical web grammar for a cartographic information base combines a web grammar (graph grammar) introduced by Pfaltz and Rosenfeld [6] with a phrase structure grammar discussed by Youngman [9]. A web grammar is appropriate because of its natural two-dimensional character; and a phrase structure grammar is appropriate because it conveys conceptual notions about internal cartographic structure. The combination of these grammars provide a linguistic formalism for a cartographic information base. An information base is an extended notion of the data base concept; it integrates conceptual information and program modules into a data base to increase data processing flexibility.

Data Base Models

The three types of data base models are: hierarchical, network and relational [3;4]. The hierarchical model is a subset of the network type, and can be formulated as if it is a directed network. The relational model has been shown to be relationally equivalent to the network model under certain transformations. That is, when the relational model is inverted so that an attribute, rather than a relation, is a primary key a psuedo-pointer structure is set up. This pointer structure is similar to that in a network model [1;5].

The fundamental building block of a data base is a record type. A record type consists of one or more data items. The data items name actual data in a record occurrence of a given record type. A one-to-many relationship defined between two record types is called a set. One of the record types is declared the owner of the set and the other the member. Each record occurrence of the owner record type "owns" zero, one or more record occurrences of the member record type.

The schema of a data base consists of data items, record types and set relationships between record types. Actual data is related to the schema through the data item names and record types. The schema, depicted by a graph, is thus a logical description of the actual data occurrences.

Two properties of a data base can be characterized by a linguistic model: (a) the structure of the data base and (b) the storage and retrieval capabilities of the data base. It must be emphasized that a grammar derived for a data base does not necessarily describe a data base in a unique manner, but what is important is that it is a formal characterization.

<u>Linguistic Models and Data Bases</u>

A linguistic model for a hierarchical data base is a context free grammar [1;9]. The grammar G_H is a triple: $G_H = (V,I,R)$, where V is a set of vocabulary elements; $I = 1$ is an initial symbol; and R is a set of production rules. The set V is composed of two, non-empty, finite, disjoint subsets; $V_N = \{1,2,3,4,5,6\}$ is the set of non-terminal labels denoting record types; and V_T is the set of terminal elements representing data. The symbol I initiates a set of productions which generate a schema for a hierarchical data base (See Figure 1).

The drawbacks to the hierarchical model are obvious. There is no provision for sharing data elements between records, thus redundancy may occur. The network model ameliorates this problem because it provides for a relationship whereby data can be shared. Consequently, the primary difference between the hierarchical model and the network model is that a member of a set may have only one owner in the hierarchical case, but a member record may have more than one owner record in the network case.

A grammar for directly modelling a network data base is context sensitive because two different record types may own the same member record. This situation produces a particular context of ownership, hence a production of record types transpires only in this context. The formulation of such a context sensitive grammar would require a different rule for every set relationship. However, an alternative way of viewing a network data base is as the intersection of one or more hierarchical data bases. This viewpoint has an historical basis. Since sequential file processing is a form of hierarchical storage processing, a collection of interrelated sequential files constitute a network data base. Therefore, given a data base it is sufficient to find a group of hierarchical structures of which the network data base is the intersection (See Figure 2). If a hierarchical data base is described by a context free grammar then an interrelationship of hierarchies (which is a network) is capable of being described by an interrelationship of context free grammars. Thus, to represent the network structure as a hierarchical structure a transformation is required. This transformation is simply the computation of all maximal hierarchical paths through the network as is performed in Figure 2b. It should be emphasized that the hierarchical form produced in Figure 2b is accomplished through a process of path determination, and not by storing the data in this manner. A drawback in this model of a network data base, as pointed out in the grammar, is that it is a single level network, i.e. the productions of the grammar only generate relationships on a single conceptual level. A single conceptual level is inappropriate for a cartographic data base because it limits the potential of utilizing "conceptual information" for query processing.

A Cartographic Information Base

Two features added to a network data base extend it into an information base: (a) the introduction of conceptual levels and (b) the ability to handle the integration of programs into its logical structure (only the former is discussed in this paper, see [2]). With the introduction of conceptual levels to a data base, a new type of set relationship is added. This relationship is called a "vertical set". A vertical set relationship is different from the set relationships discussed in the previous sections. Those discussed previously are of the CODASYL set type, and refer to what will now be called a "horizontal set" relationship. These horizontal set relationships occur on a single, conceptual level of a network. The vertical set is used to identify a relationship between one conceptual level and another (higher to lower). A horizontal set is a functional relationship whereas the vertical set is more like a mathematical set. In a vertical set an owner is a record type while a member is a data item occurrence. These vertical sets become the production rules of the linguistic model (discussed in the next section).

A different notation, i.e. different than the schema graph, is utilized to simultaneously display vertical and horizontal set relationships in an information base (See Figure 3). The nested boxes represent vertical sets of an information hierarchy. Each set is an information parcel. In each parcel a record type encloses the data item occurrences which are related to that record type on a given conceptual level. In turn, each of the data item occurrences may become a record type on the next lower conceptual level (lower in a sense of being closer to primitives). The horizontal set relationships are denoted by the dotted-line arrows, with the tail emanating from the owner and the head pointing at the member. The portion of the information base shown is that which directly concerns cartographic entities. However, a dummy record, labelled "Thematic Identification", is included to incorporate thematic data from another data base. This is accomplished by using a horizontal set relationship.

A Grammar for a Cartographic Information Base

A hierarchical web grammar serves as a formal linguistic model for a cartographic information base. The grammar generates a multi-level, network structure of cartographic information. Webs represent the levels in the derivational process of the information hierarchy. A web W on a vocabulary V of labelled elements is a triple: $W = (N_W, A_W, f_W)$, where N_W is a set of nodes in W; A_W is a set of arcs that represent relationships between unordered pairs of distinct nodes; and f_W is a function from N_W into V which labels each node of N_W as a record type. A web $\alpha = (N_\alpha, A_\alpha, f_\alpha)$ is a subweb of W if: N_α is a subset of N_W; A_α is a subset of A_W; and f_α is the function f_W restricted to N_α into V. This notion of subweb is crucial to the production of web nodes (record types) in the grammar.

An underlying graph which carto-graphically depicts a web W is defined by the pair (N_W, A_W); hence a web is a graph with labels. If a pair of nodes (m,n) is in A_W, the pair forms a horizontal set relationship. These pairs are usually defined only in the terminal web of the hierarchy because nonterminal, conceptual elements are only weakly related through a process of cartographic inference. The terminal web becomes a general spatial data structure which allows spatial-query processing (See [7;8]).

Formally, the grammar is a triple G = (V,I,R). The set V is a vocabulary consisting of two, finite, non-empty subsets: V_N, the set of labels for nodes, and V_T, the set of data. The symbol I initiates the productions in the grammar. The set R is composed of production rules which rewrite the subwebs, i.e. generate the host web W. A production rule is a quadruple: $R = (\alpha, \beta, C, E)$, where α and β are the subwebs of W (β is to replace α in the rewrite operation), C is a logical function acting as a contextual condition for replacing α with β in W, and E is an embedding function which specifies the linkage of nodes N_β in the subweb β to nodes $N_{W-\alpha}$ in the subweb $W-\alpha$, the complement of α. These neighboring nodes become members of A_W.

Productions are documented in two ways: (a) by an ordered listing of the production rules which are employed (See Table 1); or as a tree diagram (See Figure 4). The nonterminal elements of the production rules are record types in the information base. Primitive object-types are the record types associated with occurrences of primitive objects. These occurrences are the terminal elements of the grammar. It is the primitive object occurrences which are manipulated in a cartographic query and viewed as the cartographic objects on a cartographic display (See Table 2).

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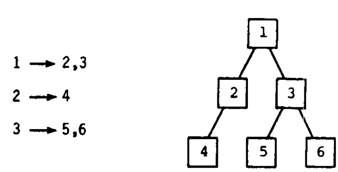

Figure 1. Production Rules and a Hierarchical Schema

Table 1

Subweb Production Rules

	α *		β **		α *		β **
(1)	I (Initial Element)	→	R M	(9)	Sc (Scale)	→	Sym
(2)	R (Reference Base)	→	Gb Rl	(10)	Mb (Map Border)	→	Li
(3)	M (Message Theme)	→	T S	(11)	Ll (Lat./Long.)	→	Sym
(4)	Gb (Geographic Base)	→	Fo Sc	(12)	Tm (Tic Marks)	→	Sym
(5)	Rl (Reference Lines)	→	Mb Gl	(13)	T (Title)	→	Nd
(6)	S (Symbolization)	→	L D	(14)	L (Legend)	→	Sym Nd
(7)	Gl (Grid Lines)	→	Ll Tm	(15)	D (Data Domain)	→	Sym Nd Ch Li Po
(8)	Fo (Feature Objects)	→	Sym Nd Ch Li Po				

*Definition of nonterminal node labels given in parentheses.

**Definition of primitive object-types given in Table 2.

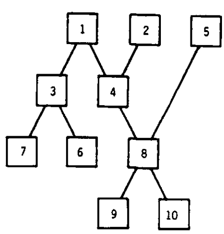

Figure 2a. Network Schema

Table 2

Primitive Object-Types

Label:	Object-Type*	Attributes
Nd	Node	Pt,L
Sym	Symbol	Pt,T,V,L
Ve	Vector	Pt,Rho,D,V,L
Ar	Arc	Pt,Pt,Rad,V,L,
Sec	Sector	Pt,Rad,Rho,Theta,V,L
Ch	Chain	Nd + Str + Nd
Li	Line	Ch + Ch + Ch ...
Po	Polygon	Pt,V,L,Li

where the attributes are defined as:

- Pt (point) : an x,y coordinate pair
- Str (string) : a list of coordinate pairs
- V : a numeric value
- L : a text label
- T : a symbol prototype
- RHO : an angle of rotation
- Theta : an angle of openning
- D : a distance
- Rad : a radius

*Based on Bracchi and Ferrari, 1971 and Youngman, 1977

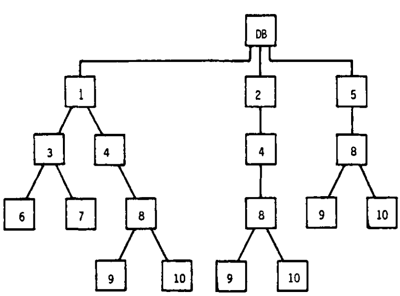

Figure 2b. Transformed Network Schema

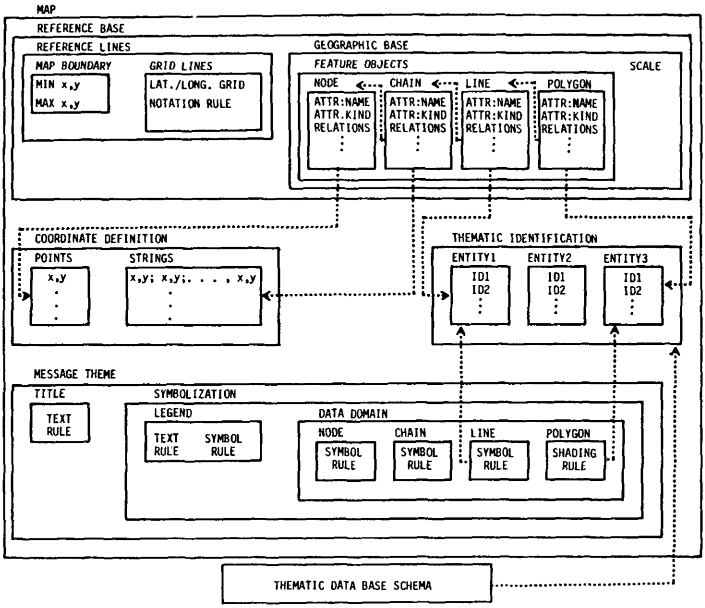

Figure 3. Information Base Schema

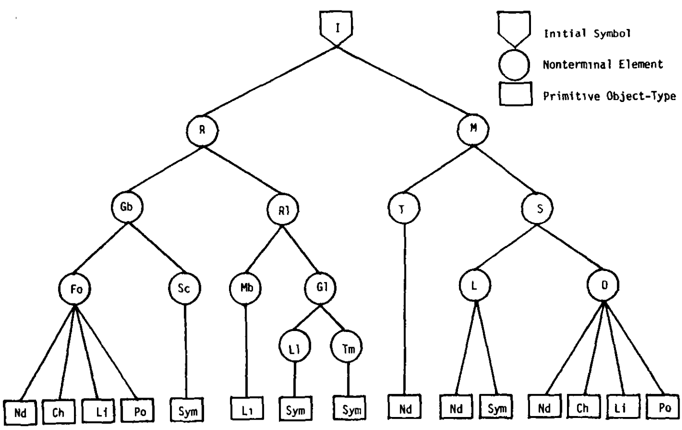

Figure 4. Hierarchical Web Marker

EXTRACTION OF POLYGONAL INFORMATION FROM GRIDDED DATA

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Introduction

Rectangularly sampled, or gridded, spatial data such as classified LANDSAT imagery and Digital Terrain Models (DTM's), are increasingly ubiquitous sources of cartographic information. For environmental analysis, gridded data must be related to point, line, and polygon descriptions of phenomena, such as highway networks and soil zones. In combining such disparate forms of data, analysts must convert the irregular data structures to regular ones (or vice versa). That is, either points, lines and polygons describing objects may be gridded , or objects may be extracted from gridded representations of phenomena. This paper discusses integrating such data sources. Principally, issues involved in extracting polygonal features from grids will be addressed.

Characteristics of Gridded and Polygonal Data

Gridded data results from a systematic sample of a study area. Within a rectangular array of sample points (cells), the values of a geographic variable (such as terrain elevation or soil characteristics) are sensed and/or calculated for each cell.

Polygon data, in contrast, results from an exhaustive partitioning of a study area into discrete zones according to natural or administrative criteria (Peucker and Chrisman, 1975). The zones can either be defined *a priori*, or deduced from the distribution of phenomena under study. Frequently both types of polygons are of interest (e.g., county and soil zone boundaries). In either case, a patchwork of irregular zones will completely cover the study area. Each zone is regarded as internally homogeneous, with discontinuous transitions between zones. Within a computer, polygons are normally represented as strings of x,y boundary coordinates, using as many coordinates as one is willing or able to capture to characterize the behavior of the boundaries.

Despite the fundamental differences between them, gridded and polygonal data representations are interchangable, though not necessarily equivalent. The conversion of information from a grid cell system to polygonal representation involves several operations (Rosenfeld 1978).

Classification is required because in a data grid cell values can be measured on a continuous scale, and can represent samplings of a continuous data distribution. Terrain elevation data immediately comes to mind, but other continuous surfaces (such as proximity fields or rainfall measurements) are widely studied. To segment a continuous surface into subsets, each cell can be classified into one of a discrete number of data classes (as when employing a contour interval).

Once a classification has been defined, borders between unlike classes must be located. A number of assumptions can be made about the spatial behavior of the phenomena sampled. The first is that the value of the geographic variable varies continuously from place to place. This is a natural assumption for a variable such as terrain elevation. An alternative assumption is that there are discontinuities between places. This is always the case where data are collected in nominal categories, as are soil types.

This choice of assumptions will influence how polygon borders are located. If the variable is nominal or discrete, it is appropriate to locate boundary lines along cell boundaries; with continuous data, however, boundaries can be interpolated which cut through grid cells.

The third and final task is to assemble boundary segments into a polygonal representation. This involves identifying all polygons formed, smoothing or filtering borders, and ensuring that each polygon has proper closure in the face of boundary and resolution constraints.

<u>Cell Classification versus Contour Interpolation</u>

Two basic strategies are available for converting grids to polygons. In cell classification, each cell is assigned to a class based on its value. This classified matrix is then scanned and a border generated whenever a cell's value differs from a neighbor's. In this method, all elevation class boundaries follow cell borders.

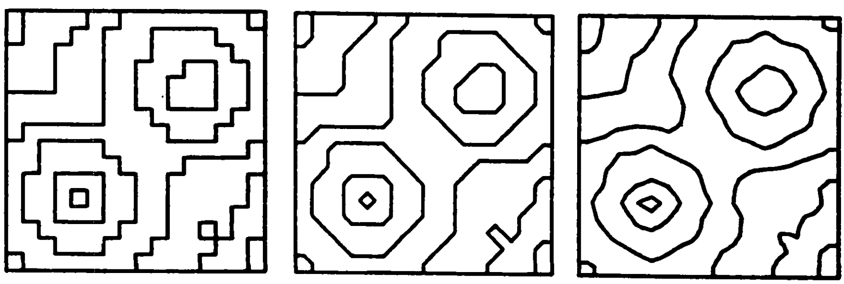

Fig. 1: (a) Cells Classified; (b) Edges Smoothed; (c) Interpolated Contours

This technique is satisfactory when the spatial resolution of the grid is fine enough. 'Staircase' lines resulting from following cell borders can then be smoothed.

When the spatial resolution of the grid is poor, additional height values can be interpolated within each cell. These heights can be used to locate borders with finer resolution than the original cell possessed. This interpolation may involve resampling the grid with finer resolution, using a distance weighted average to interpolate values for the new cells. This new matrix can then be classified and processed.

An alternative to grid resampling is to interpolate the position of borders within the original cells. As grids tend to be large (and redundant) , resampling adds further bulk (hence processing effort) to the data. By allowing contours to pass through cells, smooth borders can be produced without resampling.

A Conversion Algorithm

Many algorithms for generating contours exist (see, for example, Calcomp 1968; Dayhoff, 1968; Murray, 1968; Coulthard, 1969). Most existing algorithms follow contours throughout a data grid (or randomly accessable subsets of a data grid). While this directly produces the desired result -- contour lines in the form of strings of coordinates -- random access memory requirenments may be burdensome. As contour lines may start and end anywhere in the grid, large sections of the grid must be available for processing in random access memory for the contour following approach to be efficient. Since all cells of the grid must be scanned for possible contours anyway, it seems sensible to minimize random access memory requirements by separating the segment generation process from the segment linking process. With such a strategy, each process can be performed using sequential scans of the data.

The conversion algorithm has two principle steps -- contouring and structuring. In the first step, the data grid is scanned and processed to generate a contour segment file. For each segment, the elevation class on the left and right sides of the segment are recorded as well as the endpoints of the segment. In the second step, structuring, the segment file is processed to generate a polygon boundary file. This involves linking together segments to form borders and identifying the polygons thus created.

Contouring Phase

Contour segments are generated on a row by row basis using the grid values in the current row and the the two ajacent rows. within each row, each cell is processed independently to locate and output contour segments. All such segments which fall in the cell will be identified before passing on to the cell in the next column. Segments are derived by decomposing the rectangular cell into eight triangles:

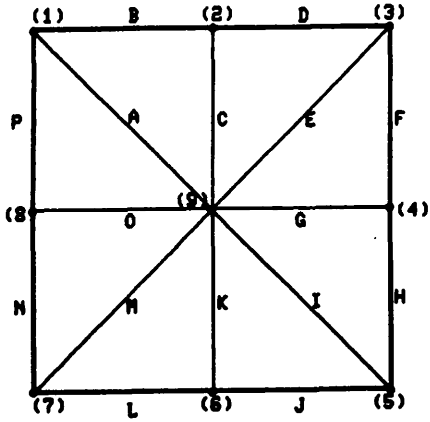

Fig. 2: Triangulation of a Grid Cell with Nodes numbered (1) - (9) and Edges Labelled A - P

The network of triangles imposed on the cell has nine nodes, interconnected by sixteen edges. Each of the nodes is assigned a z-value which is the average of the classified values of all cells touching that node. Thus, in the above figure, node 9 is assigned the value of the cell , nodes 2,4,6 and 8 are assigned averages of the cell with values in the top, right, bottom and left cell neighbors, respectively, and nodes 1,3,5 and 7 are assigned z-values averaged using the cell and the 3 other cells touching each node. Cells with missing values are excluded from this averaging process.

First, the minimum and maximum z-values are checked to determine if they fall into different classes. If both are in the same class (which will normally be true), no contours exist in the cell, and the next cell in the row is processed. Otherwise, a scan of the 16 edges is performed, referencing a table of the z-values of the nodes bounding edges A through P. Should both nodal values for an edge lie in the same contour interval, the edge has no contours crossing it, and the next edge can be inspected. Otherwise, the intersection of the contour with the edge is interpolated. The resultant coordinate marks the location where the contour crosses into a triangle. Each such intersection is entered in a table with the identifier of the edge and the class break involved.

Should this table already contain an entry for the same class break, a contour segment may have been found. Whether the current intersection is linked to the prior intersection, depends on whether both intersections are located in the same triangle. If the edge index for the prior intersection is either (a) one less than the current one or (b) two less than the current one (for interior edges), then a contour segment exists and is output. In any case, the table is updated, replacing the prior intersection's coordinates with those of the current one. Although no search of the table is necessary, the number of contours allowed to cross an edge is limited by the table's length. A 100-word table is sufficient to index up to 33 countours intersecting a cell.

Edges are examined in clockwise sequence around the cell, ending by processing the first edge once again. The procedure ensures that all segments of contours which are within the cell will be identified, located, and output. Correct "left" and "right" class identifiers are also output with each segment's coordinates. The six-word-long segment records (x1,y1,x2,y2,left,right) are accumulated in an output file as the grid is scanned. This file is then processed in the concatenation phase, in which polygon boundaries are constructed from the segments.

Structuring Phase

The concatenation of contour line segments was performed by the WHIRLPOOL program of Harvard's ODYSSEY family of geoprocessing modules (Dutton, 1978; Dougenik, 1979). This program, although designed to perform overlay of polygon coverages, is also capable of finding intersections of a single coverage with itself. That is, given a minimal amount of topological information (in this case, the left and right elevation classes of each contour segment), WHIRLPOOL can link segments, as well as discover errors in topological and geometric descriptions. In addition to serving the present purpose, this capability allows manually-digitized coverages to be verified as planar graphs, making automatic adjustments for small discrepancies in coordinates (part of the so-called "fuzzy overlay" problem). Not all of WHIRLPOOL's power is required to link segments, although one portion of the problem would have been been troublesome without it. This has to do with contours which, instead of forming closed loops, simply disappear at the edge of the grid. In order to form polygons, such contours must be connected to one another at the points where they terminate. This was approached by generating a "rim" contour, by writing out the coordinates of the cell edges at the border of the study area. Because of the nature of the contour generation algorithm, contours can cross cell edges at any point. All such intersections must be found with the rim contour in order to ensure that all contours are part of some polygon, and that all polygons are completely and consistently described. While a much simpler program could accomplish this limited objective, WHIRLPOOL performed the task without any modification, using about as much computation time as the contour generation phase preceeding it. The resultant contour polygons are then available for plotting contour maps in which elevation classes can be shaded, and for overlay with other kinds of data zones for analytic purposes.

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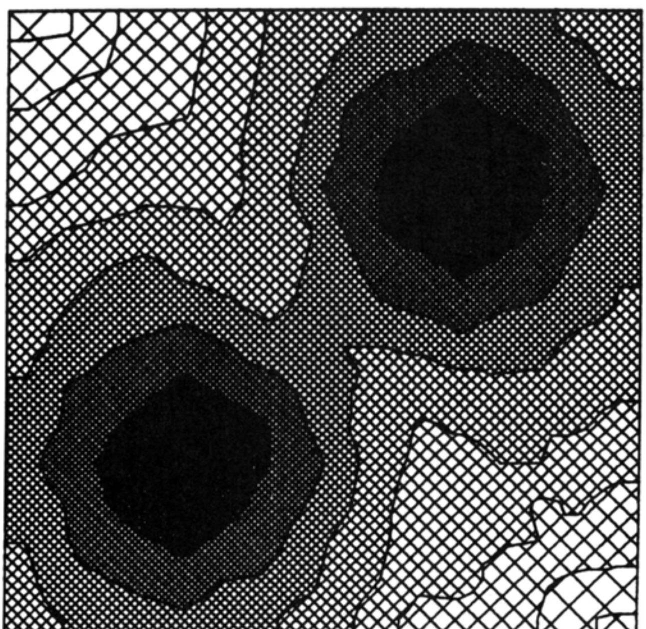

Fig. 3. Shaded Map of Polygons Extracted from a Coarse (16x16 cells) Digital Terrain Matrix

LAND RESOURCE INFORMATION SYSTEMS: SPATIAL AND ATTRIBUTE RESOLUTION ISSUES

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I. Introduction

The tasks of inventory of land uses and the reconaissance of resources for large regions has resulted in the need for and the development of a variety of computer data-base systems. When data bases are organized to handle non-routine analyses stemming from land planning and management questions, the data base and its computerized and procedural environment may be termed a land resource information system.

Land resource information systems stem from diverse origins, disciplinary orientations, and purposes. This diversity makes comparison and analysis of systems difficult, but it is important to compare systems so as to understand better the different approaches to land resource information systems.

The single most important issue in designing a land resource information system is the determination of the appropriate level of spatial and attribute resolution. Other kinds of information systems have discrete basic data such as transactions, persons, or events, whereas geographic space is continuous and choices must be made how to classify activities in that space to manageable categories and how to partition the space into observable spatial units. In addition, the observable spatial units must describe the extent and character of features as well as maintain spatial relationships between units, and thereby features. The choice of spatial and attribute resolution is interrelated. The size of areal unit and the number of categories for a characteristic are interdependent and together determine the volume of data, which in turn is the most important determinant of the hardware and software requirements of the information system.

The spatial and attribute resolution of land data in a land resource information system is crucial to the kinds of questions that can be addressed. It is easy to claim the need for the greatest detail possible, but the volume of data may become overwhelming. Yet, there exists little knowledge as to tradeoffs between detail and volume in terms of cost and use of information for management and planning. Often users of information cannot wait or pay for detailed data and more aggregate data are used. The more aggregate data may be used because the value of more detailed data is not well known in terms of the decision to be made.

Purpose

This presentation serves to illustrate the linkage between alternative ways of capturing and encoding spatial data, levels of spatial and attribute resolution, and uses of the data. An interpretive comparison and assessment of land resource information systems is employed to highlight the linkages. Early rather than current systems are compared because they provide a broader range of approaches that were largely uninfluenced by one another. These early systems are: The Canada Geographic Information System (CGIS), the Polygon Information Overlay System (PIOS), the Minnesota Land Management Information System (MLMIS), the Land Use and Natural Resources Inventory of New York State (LUNR), and the Oak Ridge Regional Modeling Information System (ORRMIS). These systems are described and examined in Tomlinson, Calkins, and Marble (1976). These systems will be reexamined in a framework utilizing a communications system model for geographic data that allows comparison of approaches for data capture and illuminates choices made for spatial and attribute resolution. There has been a considerable amount of learning from early experience and convergence on system design approaches that is discernable and is documented more fully (Dueker, 1978).

A Framework for Comparison

To compare systems, a communications model is employed. This enables explicit recognition of data capture and spatial and attribute resolution choices made by systems (Dueker, 1976).

A generalized communications system is comprised of elements: 1) a data source from which a message is encoded, 2) a transmitter from which a signal is emitted, 3) a channel for communicating the signal, and 4) a receiver for receiving the signal and converting it back to a message at the final destination. This problem of sending and receiving messages through a communications system which is constrained by channel capacity and the presence of perturbances (noise and distortion) is analogous to the capture and encoding of spatial data.

A geographic information system has an attribute message for each spatial unit that derive from a source, are captured, transmitted, communicated, and decoded and received. The problems of channel capacity and transmission cost may be considered as analogous to computer storage size and machine processing cost. In the generalized communication system, information theory is used to measure the amount of information (in units called "bits") that is contained in the data being transmitted and this theory aids in the evaluation of alternative encoding schemes to eliminate redundancy through efficient coding.

Comparison of Early Systems

Although technology has advanced, system designers are faced with making choices as to the extent of preprocessing image data prior to capture in machine records versus the amount of data reduction and editing subsequent to data capture. But foremost, designers must make choices with respect to spatial and attribute resolution in conjunction with the data capture technology.

To illuminate the data capture and resolution interactions, Table 1 provides in a comparative format the five early geographic information systems. Using the communications model analogy, these systems are compared with respect to the process used to prepare, capture, encode, reduce, edit, format, and retrieve geographic data.

In interpreting Table 1, one observes that two systems (CGIS and PIOS) generate vector data and the other three (MLMIS, LUNR, ORRMIS) generate grid data. Two systems (CGIS and ORRMIS) capture data with scanners, PIOS employs a digitizer, and MLMIS and LUNR rely on manual encoding. Although one normally thinks of scanners as generating grid data, the CGIS vectorized grid data is a data reduction process, wherein ORRMIS maintained a grid format but aggregated the fine grid mesh of the scanner to larger geodetic grid units.

With respect to spatial resolution and attribute resolution, the systems again vary considerably. The spatial resolution of CGIS and PIOS depend on the data; that is, the size of the polygons, which is a consequence of the number of attribute levels and the diversity of the study area. Although CGIS and PIOS are theoretically limited by the precision of the hardware, the ability to draw small polygons on source maps and the number of attributes rarely resulted in the hardware resolution as being a constraint as more aggregate data resulted from the process. The spatial resolution of MLMIS, LUNR and ORRMIS were direct consequences of the grid size selected. In MLMIS and LUNR, a single grid size was imposed on all data entered into the system, whereas in ORRMIS one could capture data for several size grid units, depending on the size needed to capture the complexity of data on the source map.

The attribute resolution depends on the nature of data represented. Land use and soils are two difficult data types to classify, map, and capture. Land use is used to illustrate attribute resolution choices made by the five systems and how attribute resolution interacts with spatial resolution. CGIS had a 14-category system for land use and PIOS 20 categories. In diverse areas, this level of attribute resolution resulted in small polygons to capture and process. A finer attribute resolution (or more categories) would have required mapping at a smaller scale, and consequently more data for the same study area.

MLMIS used nine categories of land use encoded to 40-acre units. This coarse level of land use was apparently selected so that predominant (or single users)

Table 1. Comparison of Early Systems

PROCESS \ SYSTEM	CGIS The Canada Geographic Information System	LUNR The New York Land Use and Natural Resource Information System	MLMIS The Minnesota Land Management Information System	PIOS The Polygon Information Overlay System	ORRMIS The Oak Ridge Modeling Information System
Date Initiated	1964	1967	1969	1971	1972
Basic Technology					
Data Capture	drum scanner	manual	manual	digitizer	flying spot scanner
Encoding	fine polygon	large grid	medium grid	polygon	small grid
Graphic Data					
Pre-processing	scribe polygon boundaries, number polygons and mark centers	air photo interpret, compile on quad maps	none	polygons and classifications drawn on stable base mylar	polygon, linear, and point data from source map are transferred to a mylar, category by category, and the mylar is photographed each step
Data Capture Techniques	scan for presence of line segment, digitize polygon centers	manual coding to UTM (1 km^2) grid and keypunch	mark sense card	digitize polygon boundaries	scan to detect darkened areas, each darkening representing a category
Encoded Data					
Data Reduction	vectorization of bits indicating presence of lines or boundaries between areas	none	none	sliver and gap removal	reduction of sum cells to 3.75 second or larger grids
Mode	vector; polygon, distance-direction notation	grid, percentages of each grid in particular land uses	grid, predominant use	vector, polygon chain of x, y coordinates	geodetic hierarchal grid, predominant or percentage
Editing	gap and spike removal, edge matching	sample field check	redundant interpretation, machine echo plot of coding	delete, change, rotate, shift polygons	quick look plots

could be assigned to each 40-acre grid.

The LUNR system employed 130 land use categories for larger, 1 km^2 (247 acres), grids. Consequently, predominant assignment of land use to grids was inappropriate and the amount or area of land uses in each grid was encoded. This disparity between attribute resolution and spatial resolution results in a loss of information because the land use detail inherent in a detailed classification is lost when aggregated to a 1 km^2 grid. This loss takes a form where one cannot determine where within a grid unit the different uses occur and how they are related spatially.

ORRMIS utilized both a hierarchy of categories for land use and a hierarchy of geodetic grid cells. A grid cell size of 7½' is used in conjunction with nine categories of land use, 2½' grid cell size with 46 categories, and 30' grid cell size corresponds to 235 categories.

If the technology employed captures a large part of the graphic content of maps or photos, there is an associated and large problem of data reduction, editing, aggregation and formatting. On the other hand preprocessing of map data and/or abstracting (or recording only part of the map content, say by imposing a large grid) simplifies the amount of reducing or processing of encoded data to develop formatted data for use. CGIS is an example of a system which requires preprocessing of map data because of strict input requirements, considerable data reduction software, and severe editing requirements to insure quality data. PIOS requires considerably less pre-processing and data reduction, although the edit requirements are again severe, so severe that strict polygon systems (those that maintain vector data throughout overlay) are rarely used now. MLMIS and LUNR require little pre-processing, reduction, or editing because of the level of abstraction inherent in those systems; they are for coarse level inventories of large regions. ORRMIS, like CGIS, requires considerable pre-processing to prepare for scanning and data reduction to translate an extremely fine mesh of scan line cells to the geodetic grids. Another complication of the ORRMIS is the merging of separate scan data, a separate scan for each land use category, into a single data set containing all land uses. The ORRMIS data capture technology works well when there are few categories (low attribute resolution) per map coverage, but when encoding a high attribute resolution, each category requires a separate scanning process. This is particularly burdensome when inputting a set of unique areas, such as census tracts, counties, traffic zones; each unique areal unit must be transferred to the mylar, photographed, and scanned.

Lessons from Experience

None of the systems is functioning today as described here. CGIS relies more on digitizer data entry; PIOS on single line digitizing and generating polygons rather than double digitizing of lines inherent in direct polygon digitizing, greater attention to preparing higher quality input maps, and conversion to grid prior to overlay analysis; MLMIS on interactive data entry and retrieval; LUNR is not functioning with respect to new data entry; and ORRMIS relies on digitizer input of data. Nevertheless, comparison of the original systems is instructive in gaining an appreciation of approaches to encoding geographic data, especially the interrelatedness of data capture technology, the character of source data, spatial and attribute resolution, and data reduction and editing. To a great extent the designs of current systems have integrated knowledge gained from these earlier experiences. Each of these early efforts contributed knowledge to current approaches. In effect, we have modularized our successes in terms of sub-routines or hardware, and discarded (or postponed subject to further research and development) the less successful features of these early systems.

But most importantly, system designers have learned better through these experiences the appropriate functions to be performed by man or machine. For example, the current version of PIOS requires more carefully controlled source maps and utilizes grid data structures where gridded data are more cost-effective (Dangermond, 1978). Dangermond (1976) posits that manual compositing of slope, soil, vegetation, and geology is necessary due to limitations inherent in the individual source maps; man's judgement is needed to resolve inconsistencies. He calls polygons created in this compositing "integrated terrain units" and argues that they have greater validity than a computer overlay of the separate coverages would provide. PIOS also relies more on chain encoding rather than polygon encoding so as to avoid the "sliver and overlap" problem that occurs when digitizing adjacent polygons, which results in two lines which do not match exactly.

For natural resource applications, polygon encoding is giving way to a streamlined creation of topological data which links "all the segments which constitute a curvy boundary into a list, and to assign to this whole chain of points the topological properties which all the segments have in common...The more irregular the geometry of the network being represented, the more efficient chaining becomes." (Dutton and Nisen, 1978, p. 140).

These early experiences also identified areas needing greater computerization. For example, many of the early systems relied on sequential data stored on cards and tape, which have given way to more complex, but realistic, data structures that are stored in more efficient forms. Originally, CGIS, PIOS, and ORRMIS relied too heavily on the computer and have had to modify some procedures, whereas LUNR and MLMIS found it necessary to augment some procedures with more computer assistance. Gradually a clearer understanding of man-machine roles is emerging.

Examination of both early and current experience with geographic information systems documents the importance of the classic criteria for information systems--timeliness, accuracy, flexibility, reliability, etc. In addition to these, spatial and attribute resolution are important determinants of utility of geographic information systems. Resolution that is too fine usually results in violating one or more of the classic criteria, usually cost or time overruns. Too coarse spatial or temporal resolutions do not allow addressing questions with enough precision to be telling.

In sum, what appear to be pragmatic and straightforward decisions concerning spatial and attribute resolution turn out to be the most crucial decisions concerning system utility. Spatial and attribute resolution decisions are usually a result of data volume or system constraints, rather than a direct result of application requirements. Yet there is little guidance or experience in relating system resolution to application requirements. This relationship needs further development.

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RIDS-CURRENT TECHNOLOGY IN RESOURCE MANAGEMENT*

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Introduction

Resource managers of the Forest Service are entrusted with the stewardship of nearly 187 million acres (74,800,000 hectares) of public land throughout the United States. Most of the land is managed for multiple use--recreation, timber, grazing, watershed, wildlife, etc. Some land is devoted to a specific use--ski developments, water storage, power transmission or pipelines, etc. Other land is dedicated by law to remain in wilderness status. Decisions affecting the use of this land are difficult and the impacts on the environment are of vital interest to managers and users alike. It is incumbent on all resource managers to take advantage of as much data as possible when making these decisions. The fact that much of the terrain is mountainous and scenic further restricts the options available in the decisionmaking process. If we are to survive on this earth, we must learn to effectively manage the use of earth's resources.

Forest Service resource managers have been collecting spatial information from inventory maps and aerial photographs for many decades. Since the late 1960's, numerous computer mapping or Resource Information Display Systems have been developed within the Forest Service in an attempt to automate some of the most tedious tasks in the collection, data manipulation, and display processes. As a result of the developmental activities by various field units, several systems evolved that performed similar functions. To avoid further duplication of development effort, the Resource Information Display System (RIDS) has been adopted for Service-wide use. In doing this the Forest Service is assured of (1) a standard technology transfer package with user guides, (2) a Service-wide system with program documentation which is being maintained and supported, (3) a system that promotes, on a national basis, data standardization, and (4) user continuity. A Service-wide system also reduces the need for constant training and retraining of users due to changes that result from user mobility and reassignments.

This paper is a brief explanation on what the RID system is and examines the means being used by the resource managers to assist them in managing the earth's resources.

Development

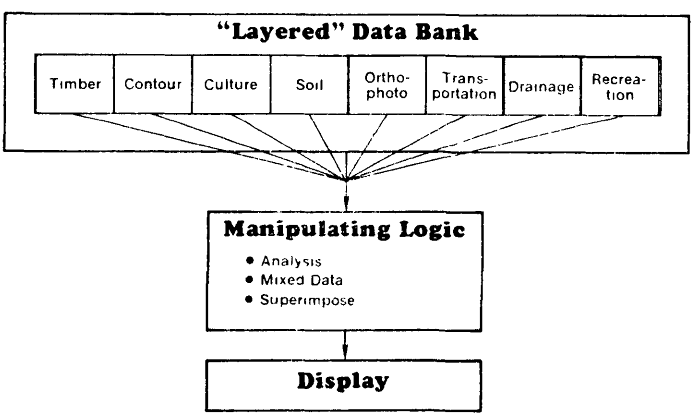
RIDS is an overlay processing system which uses the computer to derive, summarize, and display layered information digitized from maps and aerial photographs. Input to the system can be either in the form of "grid" (cell) or polygon. The system is geographically referenced, that is, cellular and polygon data are keyed to longitude and latitude. Therefore, any data that is similarily referenced can be input into RIDS.

Resource information such as vegetation types, soil classes, land forms, etc., are interpreted and delineated on maps or photos then digitized as input to the RID system. Digitized planimetric features such as political boundaries, land net, transportation facilities, etc., are also input. Slope and Aspect zones may be obtained by processing topographic data in the Topographic Analysis System (TOPAS), which is another Service-wide system. The processed data then can be used as additional layers of information in the digital data bank.

The RID system is designed to overlay various layers of data to produce responses to resource managers' requests. For example, a manager would like to know how many hectares of hardwoods there are in a certain planning unit which are in soil classes XG on slopes between 20-30 percent, outside delineated recreation areas and dedicated wilderness areas. The output from such a query would be a statistical listing of the hardwood in hectares and a graphical representation either in the form of line printer output, a cathode ray tube (CRT) image and hard copy or plotter output which could be registered to a map base.

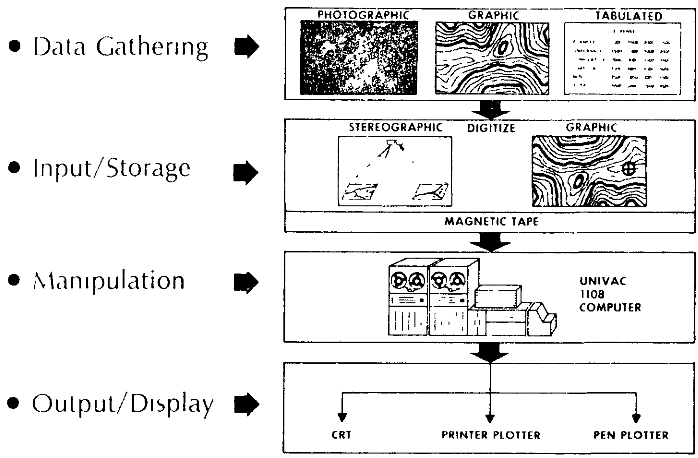
The system utilizes the tremendous storage and manipulating capacity of advanced computer technology to generate and display the information that is required in the decisionmaking process. The Forest Service has a central high capacity UNIVAC computer system located at Fort Collins, Colorado. It serves all Forests on a time and cost-sharing basis. The data is collected and stored separately, by layers, so that it can be called upon an "as required" basis. Individual layers of information can then be overlayed and displayed as computer generated multi-layer maps.

Computer Based Multi-Layer Mapping



The RID system can be divided into four basic phases. First, relevant source data is gathered, either by photographing or scanning imagery, by field tabulation, or from existing maps. This data is entered and stored in computer memory by digitizing with either a two dimensional graphic or a three dimensional stereoscopic system. This source data is then manipulated by the UNIVAC 1108 to generate the output displays used in decisionmaking. And finally, the computer drives a variety of output devices which draws the displays.

Major Subsystems



Data Gathering

Over the years, resource specialists have been organizing data on maps and aerial photographs and cross-referencing to statistical data. Identification codes have been devised to describe the data in legends on maps. This information also can be digitized and recorded on magnetic tapes with existing tools. However, most data collection has been accomplished independently by each resource specialist. Little consideration was given to any standard, scale, accuracy, or systematic process for later combining the results of each individual's effort. Today, it is vital to collect data in each of the soil, geology, and vegetation categories in a standard, coordinated, systematic manner to avoid later duplication of effort. Data can be collected from any scale source material for input to the RID system.

Data Input

Once the relevant data has been gathered, it is then entered into the computer memory. Data can be hand coded by placing a grid over a map and identifying the data by row/column, digitized with either a two or three axis digitizer or use automated scanning techniques.

Controlled aerial photography provides the initial stereo pairs that can be photogrammetrically scanned in a systematic manner, recording spatial data (x, y, z positions) in known increments. These data are automatically recorded and stored on magnetic tape. At the Forest Service computer center in Fort Collins, Colorado, software programs convert spatial data to map products depicting slope, aspect, elevation, contours, seen areas, perspectives, and many others.

The same aerial photographs also serve as the basic tool for collecting and recording resource data (x, y positions) pertaining to soils, geology, and vegetation. Data recorded on the photos are classified by the resource specialist then transferred manually, sometimes with the aid of stereo-plotters, to base maps.

Data Storage

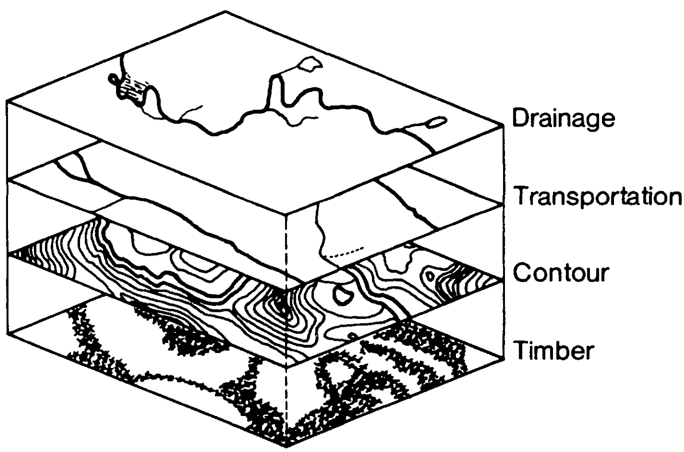
Each data type, whether it be terrain, drainage, soil, timber, transportation, or ownership, is stored as a separate layer in the data base. This means that the resource managers can obtain specific information on an individual resource type or overlay the data using the system to derive a composite multilayer map containing the exact information required for a specific management situation.

Data Storage

Timber	Contour	Culture	Soil	Ortho-photo	Trans-portation	Drainage	Recrea-tion

Computer Magnetic Tape

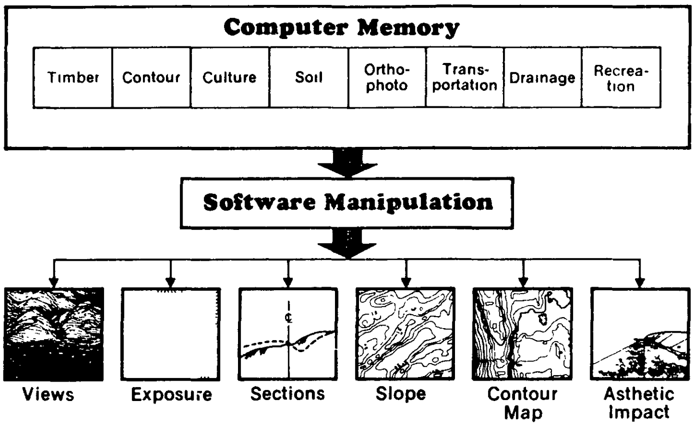
Multi-Layer Maps



Data Manipulation

But even more importantly, RIDS software routines can manipulate this basic "layered" data and generate additional information to aid the user in decision-making. For instance, the computer can determine capability areas based on the resource managers' overlaying of selective vegetation, soils, and land forms combinations.

Data Manipulation



Output and Display

Output devices which visually display the information generated by RIDS constitute the final component of our system. Because the display requirements may vary over a considerable range, from coarse resource plots for initial planning to detailed perspective drawings for public display, several output options are available. These options present the user with wide choices in speed, accuracy, and cost. And they enable the user to tailor the output displays for specific managerial situations.

The basic display option is a low-cost printer-plot with its rapid output capability. The display is a variety of type-like symbols each having specific value or meaning associated with it. Because printer-plot displays are relatively coarse, they are most useful for displaying information where high accuracy is not important.

If a higher degree of accuracy is needed then a plot output tape can be obtained from RIDS and a plot generated on a line plotter. At present, only the Regional Offices have line plotters. Each National Forest has the capability to access the Fort Collins Computer facility and receive a line printer output.

In addition to obtaining plots, various statistical reports are available including frequency distribution, multivariate linear regression, and multiple stepwise regression. The user has the option to suppress the map outputs and obtain statistical outputs alone.

<u>Summary</u>

Making the right decisions for managing the earth's resources depends, to a great extent, on the correct interpretation of data which has been collected. However, knowing which data to collect to respond to critical needs may be most important. Also it is vital that the right data is available at the right time in the decisionmaking process. Consequently, accelerating the processes from collection of data to the decision point is an important step. The use of modern photogrammetric tools combined with computer assisted systems assures accurate timely information for today's resource managers.

The RID system, briefly described in this paper, is not the ultimate answer to effective decisionmaking. However, it does represent a quantum step from the way data was collected, stored and retrieved, manipulated and displayed only a few years ago. With this system, resource managers are able to explore alternatives, modeled with the computer, to an extent unknown previously. Computer generated graphic displays give the manager the opportunity to share with the public the options he must contend with in managing the resources. Hopefully, with the assistance of current technology better decisions on the use of the earth's resources can be a reality.

<u>Bibliography</u>

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THE DEVELOPMENT OF A NATIONAL SMALL-SCALE DIGITAL CARTOGRAPHIC DATA BASE

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I. Introduction

The United States Geological Survey has identified an urgent multi-user requirement for a national small-scale digital cartographic data base. To satisfy the expressed needs of both the USGS and other user agencies, it was concluded that the data base had to be current, topologically structured, no smaller in scale than 1:2,000,000, and sufficiently flexible to permit the generation of smaller-scale maps, thematic overlays, and other graphic products. Existing data bases, software, and hardware were investigated, but all had limitations. After considerable study and planning, a series of tasks directed toward the generation of a comprehensive national data base was defined. These tasks involved primarily the modification and linking of existing software systems, the development of some new programs, and the acquisition of additional digitizing hardware. The project was initiated in June 1979, with sample products for a selected test area planned for September. Early in 1980, a digital cartographic data base covering a major portion of the nation will be available at a scale of 1:2,000,000 and, with it, the capability to automatically display a host of new base, reference, thematic, and index maps.

In an attempt to respond to growing user demands for up-to-date cartographic data and products on a nationwide basis, the Geological Survey has been increasingly looking toward the application of numerical techniques to the cartographic and geographic sciences to help meet these needs. This approach offers the attractive features of reduced manual effort, quick response, high precision, and versatility (i.e., the means for generating products of various scales, projections, feature combinations, and output media). These advantages do not, however, come without some problems; one of the major problems is the lack of suitable data sets for the applications identified.

II. Existing Digital Cartographic Data Bases

Among the current data sets which include the United States are World Data Bank I, World Data Bank II, and the DIMECO files.* Some of the limitations related to these data sets are; the scale of the source material used for the original digitization, the limited range of features digitized, the currency of information, the accuracy of source documents, and the flexibility of merging these files with thematic data (such as socio-economic factors) available in digital form from various organizations. Using World Data Bank II as an example, source documents were digitized at scales of 1:1,000,000 to 1:4,000,000; digitizing was performed from 1973 through 1977; and only coastlines, islands, lakes, rivers, and international and State boundaries are available for the U.S. Our past experience with these data bases has shown that, while they most likely met the objectives for which they were designed, their content is not sufficiently comprehensive for many common cartographic applications.

* See Appendix for examples of WDB I, II data.

III. The National Small-Scale Data Base Project

The current effort, toward generating a nationwide small-scale digital data base, is intended to address several of these shortcomings. The source materials used for the digitizing, the General Reference Maps of The National Atlas of the United States of America, are at a scale of 1:2,000,000--the only exception being Alaska drainage (originally compiled at 1:1,000,000). The content of the final data base will include political boundaries (State and county level), Federal lands, transportation network (roads and railroads), hydrographic features (streams and water bodies), populated places, miscellaneous cultural features (airports, etc.), and hypsography. The source material is to be updated immediately before the digitizing phase, thus providing the most current information available. The data is structured to provide the adaptability required for plotting general-purpose base maps for use in portraying thematic data as well as singular-purpose base maps for scientific investigations. The coding system used is intended to allow the production of a variety of smaller scale products with varied content using minimal manual interaction.

Plans are to produce the data in two formats. The first will be a topologically-structured data set which will provide a useful geographic reference system for displaying a wide range of thematic data, allow for various types of spatial analysis, and furnish a means of automatically producing patterned or solid-fill plates for reproduction. The second is to be a graphically-oriented data set which will be compatible with the Cartographic Automatic Mapping (CAM) program. Although the final data base organization is yet to be decided, it is intended that both data sets will be as machine independent as possible.

IV. The Approach

The coding scheme used in the project is organized to allow the selection of certain classes of features appropriate for a map given its scale and intended use and/or purpose. The various features are assigned a numerical rank based on the significance of that feature relative to other features of similar type. The evaluation of a feature's significance is based on criteria established for a given set of features; the criteria varies between different sets of features. For example, railroads are classified by annual tonnage; roads by designation (Interstate, U.S., etc.).

The work flow for the project is shown in figure 1. All steps in the flow are based on digitizing on a sheetwide, rather than state-by-state, basis in order to minimize edge join problems and other complications. The process begins with the gathering of pertinent source documents used in the compilation process. The digitizing source is then updated using traditional cartographic techniques. Following an edit of the updated compilation, the features on the source documents used for digitizing are submitted for ranking and coding. After an edit of the codes to insure uniformity across the entire data base, the features are digitized in a topological fashion indicating nodes, areas and lines. As the digitization of an overlay of features is finished, the data is processed through the USGS Topographic Division's topological data-structuring program, UCLGES (Unified Cartographic Line Graph Encoding System). Through a combination of computer printouts and plots, the attributes and alignments of various features are checked for accuracy and correctness. After the data has been captured, an automatic check is performed to assure that all indicated topological relationships among the data are correct. Corrections are made when errors in the topology are found, and the topological file is archived. The final step is the conversion of the archived file x-y coordinates to geographic coordinates in a format compatible with CAM. It is intended that topological files for the individual sheets will eventually be joined into one master data base. The target completion date for the individual sheet files is April 1980. It is intended that both the topological and the graphical files will be available through the National Cartographic Information Center.

V. Concluding Remarks

The task of creating a nationwide digital cartographic data base, as presented, is singular in its attempt at completeness, flexibility and independence of application. Moreover, a precise system of attribute codes related to basic cartographic data has been defined, and will be offered as a standard to the user community. The development of software to process, merge and transform digital cartographic information into a topologically-structured data base is underway, and the successful completion of this project will demonstrate the capability for developing a truly comprehensive digital cartographic data base.

Continuing research in the design of data base structures and the development of additional software for off-line processing are needed to establish a system that can provide an effective means for updating existing maps and digital data bases, as well as to facilitate the production of a broad range of thematic maps/graphics. A number of government and other institutions have identified their requirements for digital cartographic support for several time-critical applications related to their resources management programs. The ability to effectively administer the increasing array of projects related to the development and prudent use of our nation's natural resources appears to pivot on the availability of accurate, current, and complete base map information.

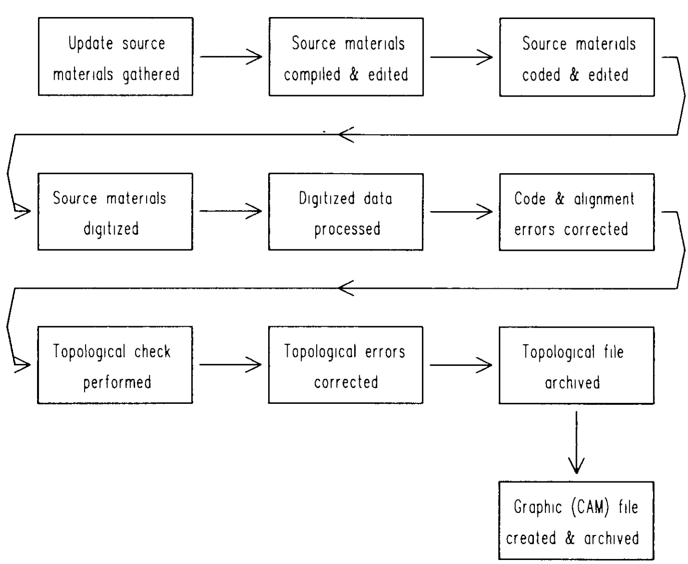
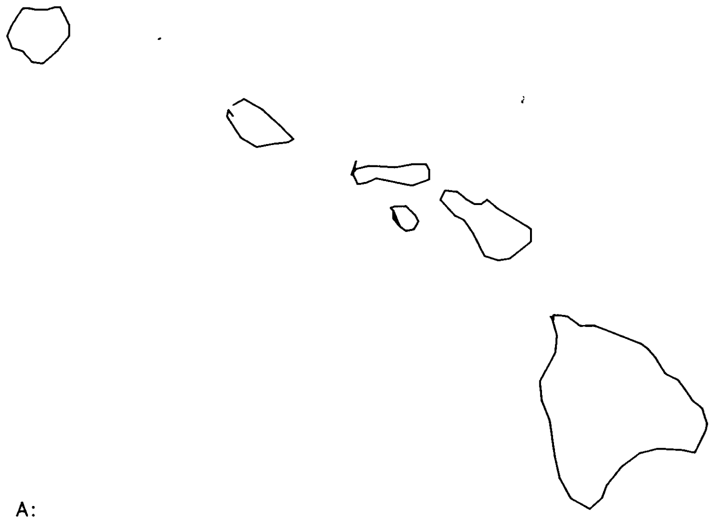
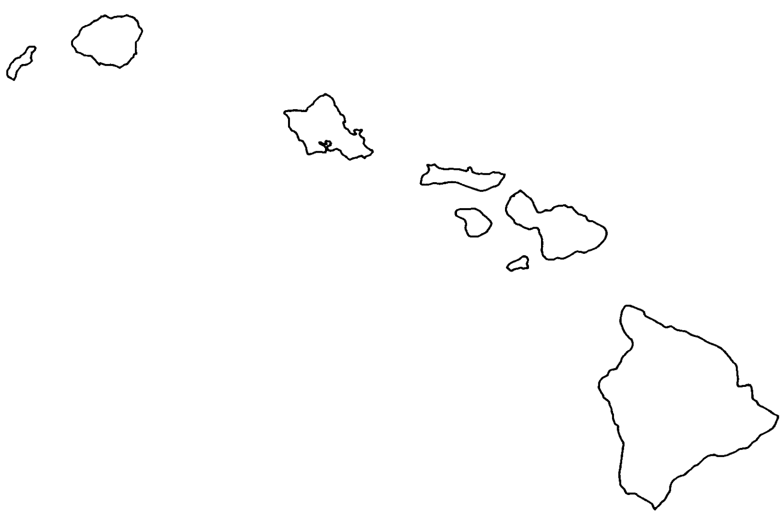


Figure 1



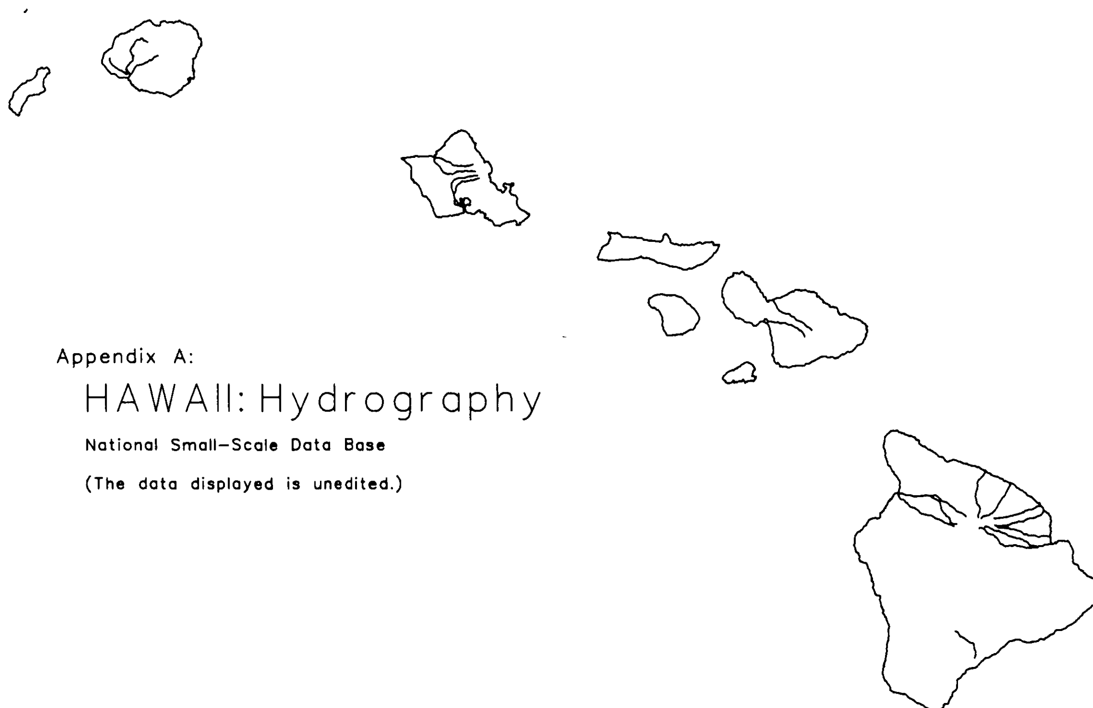
Appendix A:

HAWAII: World Data Bank I



Appendix A:

HAWAII: World Data Bank II



Appendix A:

HAWAII: Hydrography

National Small-Scale Data Base

(The data displayed is unedited.)

Appendix A:

HAWAII: Roads

National Small-Scale Data Base

(The data displayed is unedited.)

INTERACTIVE CARTOGRAPHY, SMALL SYSTEMS SESSIONS

INTERACTIVE CARTOGRAPHY, SMALL SYSTEMS

There were two Interactive Cartography, Small Systems sessions. Both of these sessions were chaired by Howard Carr of the U.S. Army Engineering Topographic Laboratory and James Carter of the University of Tennessee.

Charles H. Alvord and Stephen L. Morgan of HRB-Singer Inc., presented the paper "Recent Advances in GIS Processing Techniques Using Color Graphics and Mini-computer Technology". In their paper they describe an HRB-Singer independent research and development effort to exploit the areas of automated cartography, digital remote sensing, color graphics, and digital processing for the purposes of developing system specification for an image processing and analysis facility. They describe a prototype geographic information system, the role of interactive display in this system, and some of its data base limitations.

In the talk "Field Exploitation of Elevation Data (FEED)", Howard Carr described the activities of the U.S. Army Engineer Topographic Laboratory in interactive computer cartography. During the past five years, ETL has developed software and use techniques on a DEC PDP-11/45 minicomputer, that has demonstrated the feasibility of producing good quality 3-D terrain graphics in near real time. With rapid advances in technology it is now possible to move 'ruggedized' equipment into a mobile unit that can be transported to participate in military field tests at remote sites. This advance will enable one to perform the field exploitation of elevation data (FEED). FEED data will be useful for a variety of military situations including fire control, communications and mission control.

James Carter of the University of Tennessee presented the paper "The Cartographic Potential of Low-Cost Color Computer Graphics Systems". Carter describes both the uses and limitations of color graphics systems. A variety of color systems are currently available at a relatively cheap cost. Carter describes some possible applications on his own color graphics system. He closes his paper with an important point: "the availability of colors extends our range of options but it also extends our responsibilities".

Peter Van Demark of the Center for Governmental Research presented the paper "Color Mapping on a Raster Graphic Terminal". (Paper not included in proceedings.) Van Demark described some mapping he has done on a RamTek using a color copier (Xerox) as an output device.

Charles Ross of the Kansas Geological Survey described "GIMMAP: A (Mini)Computer-Assisted Cartography System". This system has been developed jointly by KGS and the Bureau de Recherches Geologiques et Minieres, France. It is designed to process geologic and geographic spatial data extracted from standard U.S.G.S. quadrangle maps. Current developments include an attribute data base, display interface, and graphical query language. Surprisingly, the system is implemented on a minicomputer having only 32k words of memory and random access files.

Michael Dolan and Leonard J. Simutis presented the paper "Interactive Mapping of Environmental Data Analysis Using a Modified Grid Technique". (Paper not included in proceedings.) One major limitation of using grid based approaches has been the poor quality of line printers. Dolan and Simutis described several techniques for employing raster graphic terminals for generating interactively grid-based results. The discussion was based on the Hewlett Packard family of raster terminals.

The final Interactive Cartography, Small Systems paper was by Albert Yen, Harvard Holmes, and Peter Wood of Lawrence Berkeley Laboratory. In their paper "Moving Interactive Thematic Mapping from Mainframe to Mini: Some Design Possibilities and Development Experience", they describe CARTE, a thematic mapping program which produces annotated choropleth, line, and point symbol displays of data on a variety of interactive terminals and hardcopy plotters. The advantage of CARTE is its simplistic design for the novice user and a wide range of options for the advanced user.

RECENT ADVANCES IN GIS PROCESSING TECHNIQUES USING COLOR GRAPHICS & MINICOMPUTER TECHNOLOGY

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A. Introduction

Advances in the collection of geographic information have resulted in the requirement for more sophisticated processing techniques. Specific technological improvements have been made in the areas of: automated cartography, digital remote sensing, color graphics and digital processing. These advances have given impetus to a HRB-Singer independent research and development effort to exploit these areas for purposes of developing system specification for an image processing and analysis facility (IPAF). A multi-year effort has been planned. This paper addresses the salient features of efforts to date and presents a functional description of a prototype geographic information system (GIS).

The prototype system being developed combines machine-readable representations of thematic maps and remote sensor data with cartographic display software and remote sensor data analysis routines, and with applications oriented analysis software for decision making/ planning utilization. This prototype is an attempt to merge information contained in a multitude of thematic maps and remote sensor media into a coherent data base and from this data base to extract (via digital analysis techniques) information not present in any particular input.

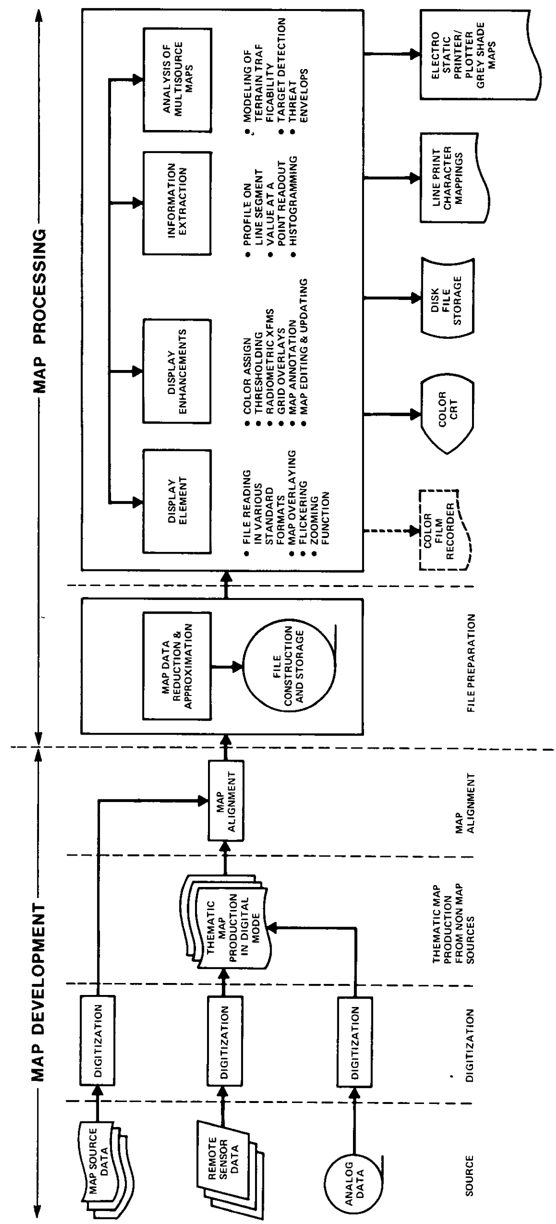
This prototype system is attempting to address a number of problems in the handling of large volumes of map data. A number of data reduction techniques are being explored, e.g., two dimensional surface approximations and the use of polygon storage techniques. This paper will later address the trade-offs between display speed, accuracy, and storage. The polygon storage mode requires less storage and preserves accuracy reasonably well. The existing prototype system hardware configuration is one to two orders of magnitude slower at construction of polygon based displays vis-a-vis raster displays. In addition to exploring the trade-offs involved in data handling, the use of color is being exploited. Color has the impact of adding another dimension to cartographic displays and greatly augments display flexibility, but the use of color introduces questions of user perception of color in mapping. The alignment and rescaling of multiple map bases onto a standard base for analysis presents a computation problem in the 32K of the host's memory. The use of relative ground control points and least squares polynomial curve fitting is being examined as a possible solution to the alignment and rescaling problem. It is our expectation that the resolution of these, and other problems will result in a IPAD which presents the user with an extremely powerful analysis and decision making tool, all in a compact computing environment.

B. The Prototype GIS Processing System

The present in house capability for exploiting geographic information is centered about a DEC PDP-11/45 processor and a I^2S model 70 image analysis terminal. On/Off line storage is facilitated via RP-03 MHD disk, RK-05 disk cartridge, and 7 or 9 track magnetic tape. Present hard-copy output is limited to either line printer/plotter which is useful for grayshade image output (limited to 16 level at present).

Functionally, the prototype system can best be described as is illustrated in Figure 1. This overview describes the system from the top level as being map development or map processing based. There are four phases of map development, these are: source, digitization, thematic maps, and map alignment. The source

FIGURE 1- FUNCTIONAL DIAGRAM OF THE PROTOTYPE GEOGRAPHIC INFORMATION SYSTEM



media forming input to the system is raw map data, remote sensed data or analog tape data originating from some line scan system. A digitization phase is included to transform analog input to a digital format. At present, digitization is tedious since the appropriate capital equipment has yet to be procured. The third phase of map development is termed thematic map production. Thematic maps represent an invaluable input source for use in generating graphic overlays. This capability will be described in more detail later on. The final phase of map development, map alignment, addresses the very real issue of registering multisource geographic information. The second major function of the prototype system is that of map processing. Here it is assumed that the final phase of map development has resulted in a file entry in the data base. In certain cases, a map product will be reduced via a suitable approximation technique. This will also be the subject of a later discussion in this paper. Map processing, for purposes of this effort, is grouped into one of four categories. These are: a display element; display enhancement; information extraction; and analysis of multisource maps. These features are enabled via analyst interaction with the I^2S model 70 electronics and color CONRAC monitor which permit processing of 512x512 arrays of 8 bit data. The display element permits: the retrieval and subsequent display of various data formats; map overlaying; flickering and roam, to name but a few features. Display enhancement features include routines to change color assignments; threshold images; alter images radiometrically; overlay with grid registration points; annotate map; or edit and update. Another major attribute of map processing is termed statistical information extraction. Routines to assess the spatial content of the image or map are provided. These include techniques to profile amplitude of a user selected line segment; to obtain digital amplitude readouts of a user defined target or target region, etc. A histogram capability is provided to accomplish the latter. The analysis segment is tailored to special applications in the military and nonmilitary sectors. Terrain trafficability, target detection, and threat modelling have been identified as special applications for this prototype GIS, based upon a series of potential customer contracts.

In general, the application for the GIS steers the type of input and output media the GIS will need and create.

The prototype system includes, at present, input sources of two types: traditional base maps and remotely sensed photogrammetric material. The remotely sensed data includes both satellite multi-spectral scanner and return beam vidicon outputs. Data from traditional base maps include elevation, soils, highway networks, and hydrogeologic characteristics. Intermediate level processing products are computed from input data, e.g., land-use maps from remotely sensed data and gradient maps derived from elevation data. Outputs from the prototype system include new maps generated by fusion of the intermediate and primary map sources, maps of the occurrence of user specified features, decision making/planning aids and application oriented thematic maps, e.g., isochrones of travel time for a particular vehicles specifications given a set of weather, congestion, and time of day parameters.

C. The Role of Interactive Display in Computer Based Geographical Information Systems

The importance of the interactive capability in the prototype system can not be understated. Present capabilities include the ability to interactively overlay, sum, difference, transform, make nominal comparisons, histogram, profile, and zoom. These constitute prerequisites to more sophisticated modelling. Modelling and/or decision making from the analysis of multiple map bases can be enhanced by the execution time introduction of dynamic data, e.g., climatological parameters or other rapidly changing variables. If one were interested in terrain trafficability modelling, the static map based information would not be sufficient for decision making and/or planning purposes. Terrain trafficability is a function of both slow-changing or static variables (for which base maps can be made) and rapidly changing variables (for which no base map will exist). One parameter of such a terrain trafficability model, soil bearing capacity, is a function of soils information and local weather conditions for which no apriori map exists. In addition to the upgrade in modelling flexibility, the interactive capability permits the user to update base map information when changes have been observed. The flexibility of interactive display manipulation of static and dynamic data is a very desirable element in the prototype system and augments the information extraction and analytic capabilities inherent in the system.

D. GIS Data Base Limitations

There are a number of problems associated with the implementation of multi-source geographic information in a minicomputer environment: however, the large volume of data, limitations of display size, and hardware transfer speed limitations seem to be the most significant. Imagery products and related map data sets tend to be described quantitatively as constituting megabits of information. It is a small wonder that minicomputer implementation in conjunction with GIS is lagging. Given that small scale systems architecture reduces the flexibility of large data set handling, the question might be raised rather justifiably then why adapt such technology to this problem. There are solutions, namely mathematical modelling. A variety of approximation techniques serve as useful data reduction devices. The trend seems to favor the use of polynomial approximation where coefficients and degree of fit are key design parameters. There are, of course, a set of conflicting system objectives which need to be reconciled prior to the utilization of such techniques. For the purpose of our effort, the following have been established:

(1) maximize restoration while minimizing information loss
(2) minimize storage requirements (i.e., maximize degree of reduction)
(3) minimize computation and display execution times.

Obviously, these aspirations are conflicting and trade-offs become necessary, since the best solution to (1) involves no approximation while (2) requires some approximation. We have established a few design criteria which incorporate relative degrees of attainment for all three goals.

The polynomial approach provides the capability to approximate all elevations within a square of terrain via a low-order mathematical function. Given that the input map is represented by 512 x 512 8 bit values and there exist conflicting design parameters, the search for an optimal solution focuses in on the degree of partitioning of the matrix and the manner of sampling. (i.e., whether we under sample or not.) Table 1 summarizes the partition sizes, number polynomials needed per partition size, and the storage requirements. As an example, if we were to partition the

n, (nxn)	#POLYNOMIALS	# COEFFICIENTS FOR Kth ORDER POLYNOMIAL (K=1,2,3...6)					
		1st ORDER	2nd ORDER	3rd ORDER	4th ORDER	5th ORDER	6th ORDER
1	262,144	U	U	U	U	U	U
2	65,536	192K	U	U	U	U	U
4	16,384	48K	96K	160K	240K	U	U
8	4,096	12K	24K	40K	60K	84K	112K
16	1,024	3K	6K	10K	15K	21K	28K
32	256	768	15K	2.5K	3.8K	5.4K	7.2K
64	64	192	384	640	960	1.3K	1.8K
128	16	48	96	160	240	336	488
256	4	12	24	40	60	84	112

TABLE 1: COEFFICIENT STORAGE AS A FUNCTION OF POLYNOMIAL ORDER & SAMPLING INTERVAL
(NOTE: U = UNDEFINED FOR PARTITION SIZE ''n'')

input space into a set of 8 x 8 submatrices, we would need to store off 4096 polynomials and 40 K coefficients, assuming a third order fit. That is to say, $\frac{(P+1)\,(P+2)}{2}$ coefficients per polynomial. The derivation of coefficient values can be accomplished by trend surface analysis wherein all the values of the submatrix are used to define the coefficient set. An alternate approach is to select candidate points within the submatrix according to some sampling scheme. This obviously produces a larger residual error than does trend surface but has the advantage of not being quite so compute bound. Our efforts to date suggest that a random sampling scheme for selection of points and a submatrix size of 8 x 8, using a 3rd order fit, provides a good tradeoff between execution time, storage and residual error measured against observed values. Work continues in this area and our results are still not conclusive.

E. Concluding Observations

Future plans call for the acquisition of a digitizer and array processor to finalize the system implementation for the IPAF at HRB-Singer's interactive computer facility. A conversion over to the VAX 11/780 processor will also be accomplished to permit remote usage and take advantage of the 32 bit work size and virtual memory of that machine.

The array processor will be used to download the data reduction algorithms from the PDP-11/45 initially and the VAX 11/780 later. Future endeavors also call for the development of special purpose software applications packages for both military and non-military interest areas.

THE CARTOGRAPHIC POTENTIAL OF LOW-COST COLOR COMPUTER GRAPHICS SYSTEMS

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For most cartographers the direct view storage tube (DVST), as in the Tektronix 4010 family of terminals, is the basic unit of graphic display. The storage tube displays only monochromatic vectors and shades or tones can only be created by drawing patterns of lines. The resolution of these tubes is usually 760 by 1024 addressable positions which has become accepted as the standard of graphics quality. Because the screen displays everything written on it, a display cannot be erased selectively. Displays can be documented with hardcopies using special photocopiers or plotters. A variety of storage tube systems are now available from simple terminals to integrated graphic systems with multiple work stations. Prices range from $4,000 upward into six figures. A sizeable body of software is available, including many mapping programs and subroutines.

Now another form of graphic display has been developed as an alternative or complement to the DVST. The world of microprocessors has led to the development of the low-cost, color CRT display, which in its cheapest form sells for less than $2,000. Some of these low-cost color systems are employed as intelligent terminals while other systems are self-contained microprocessors with more than 40K of memory and peripheral storage devices. Pictures are refreshed (recreated) at least 30 times a second so that displays can be modified or selectively erased as desired. The resolution of the system and the number of colors and shades that can be created is related to the memory dedicated to refreshing the image and thus to the cost.

To date, three low-cost, low-resolution color CRT systems are known to the author, but other systems may and probably do exist. The Cromemco Dazzler is a microprocessor that displays a 64 by 64 pixel array in 15 colors on a TV set. The 8 basic colors are shown in either low-intensity and high-intensity: black, white, red, blue, green, magenta, cyan, and yellow. The low and high intensity blacks are the same, thus the 15 colors. The Apple II is advertised as a personal computer and is marketed primarily to those who want to use it as a stand alone microprocessor system. This system can generate a 40 by 48 pixel array in the same colors on a TV set. It can also be used at a higher resolution to generate a 280 by 192 pixel array in 4 colors. The third unit is called the Compucolor when packaged as the personal computer and is known as an Intecolor when configured as a business/scientific package. These units can display the basic 8 colors at one intensity in a 25 by 80 or a 48 by 80 array and can be operated at a higher resolution in 8 colors in a 100 by 160 array or a 192 by 160 array.

Perhaps the newest development is the announcement by Texas Instruments of a color video graphics chip to plug into a microprocessor to generate a 15-color display at 256 by 192 levels of resolution. The chip will sell for under $50 in batches of 100 units. (1) ABW Corporation has come out with a chip to let the Apple II emulate a Tektronix terminal, but at a much lower level of resolution. Announcements of this type will probably become more common in the next couple of years. What is really missing at this time is software--programs to do something useful with the color systems. However, software will be forthcoming and we will soon see organizations devoted to the sharing of programs of all types. Certainly, some of these programs will be cartographically oriented.

What can these low-cost, low-resolution systems do for cartography? The low resolution of these systems makes them quite limited for line-drawing. Their strength lies in the ability to produce a variety of tones, or colors, which can be quite dramatic. For the most part, these systems are comparable to the image processing systems used by our colleagues in remote sensing. The refresh nature of the tube permits the image to be changed and modified in real time. This attribute should permit the development of dynamic cartography, where a series of map patterns evolve before our eyes. A real disadvantage of these low-cost color systems is that there is no convenient way to make colored hard copies, other than taking a photograph of the screen. But even if you could get a colored hard copy, what can you do with it? If you want slides you are in good shape, but the costs of printing color makes it unlikely that colored maps will soon be reproduced in most journals or books. The photographs in this paper illustrate this problem. In spite of the problems of getting hardcopies and the lower resolutions, some new dimensions in thematic cartography are opened with these systems.

The Intecolor Experience

Four years ago my department purchased an Intecolor CRT intelligence terminal, a forerunner of today's low-cost color systems. The unit is a 25 line by 80 column alphanumeric terminal with the graphics option to break each alphanumeric cell up into a 2 by 4 array of smaller cells so that an array of 100 by 160 cells can be addressed and displayed in a saturated color. Another option allows the full range of 8 colors to be displayed as foreground or background. The display screen is a 19-inch TV tube. The terminal is connected to a DEC10 with a KL10 processor by a 300 baud dial-up modem.

We soon found that using the terminal in the graphics mode with the 100 by 160 cells was of no benefit to our mapping applications. This resolution was too coarse to use for line drawings. Where detailed lines were required to enhance a map we found they could be added by inking on an acetate overlay and attaching it to the screen. Further, in the graphics mode the terminal is limited in the number of colors that can be combined. A red line drawn to cross over a blue line on a white background will result in part of the blue line being changed to red. This characteristic kept us from using the terminal for dot maps because the color of a dot might be determined by the sequence of plotting rather than by its value. The problem also makes it impractical to use this terminal for the processing of remote sensing imagery.

The strength of this terminal lies in the ability to display a broad palette of rather brilliant colors. By writing any alphnumeric character in one color on a different background color, combinations of colors may be created. In this way graded series can be constructed as: solid red, yellow colon on red, yellow X on red, red X on yellow, red colon on yellow, solid yellow. This sequence could be expanded or contracted as well as be continued by going from yellow into blue or black. Such color sequences are appropriate for map situations where the data have a numerical range, be it ordinal, interval or ratio data. If the data being mapped are nominal values, then the color terminal provides enough distinct hues to distinguish between a number of non-related classes.

On the 25-line terminal the alphanumeric display cells are much taller than they are wide. Text can be written horizontally for titles and legends but is limited to one size. Because of the very low resolution (25 by 100) and the non-square nature of the cells, it seemed practical to base the mapping programs on the scan-line algorithm used in CMAP (2). In CMAP a map of a fixed size and scale is defined line by line. Each line is specified in terms of how many display positions are allocated to each polygon or choropleth area. Text or titles are assigned to particular rows and columns. This technique works well for choropleth maps on the color CRT and was incorporated into other mapping programs. In a contour program the data points are specified as row and column positions on the screen, the outlines of the study area are specified row by row and the map is at a fixed scale. With the low resolution no attempt has been made to incorporate variable scaling into the programs.

Last year my colleagues in engineering purchased a 48 line by 80 column Intecolor terminal with a floppy disk drive. Because of my experience with the 25 line unit, I was called in to help develop some programs for mapping data output from a simulation study. Although this terminal was a more advanced intelligent terminal with BASIC and usable memory, it was used as a display device attached to the DEC10.

Four basic mapping programs and a set of utility subroutines have been written at Tennessee for use on the Intecolor terminals. Each program is unique to one of the terminals and the mapping problem. Listings of the programs and subroutines are available from the author. All programs are written in FORTRAN IV for a DEC10.

A choropleth mapping program designed around a scan-deck for the counties of Tennessee gets the most use. Interactively, the user has to select the data set to be mapped, set the number of class intervals and the class limits, specify the colors for the highest class, lowest class, the background area and the titles and give a title. Colors for intermediate classes are put together in the program by combining the colors from the highest and lowest classes. The characters forming the symbols are fixed within the program. A variation of the Tennessee choropleth map employs two variables for a cross-correlation display, similar to the maps from the U.S. Bureau of the Census (3).

In a study of the changing patterns of moisture conditions in the southeastern United States, the author designed an isoline mapping program specific to the task but containing subroutines that could be adapted easily to other mapping situations (Fig. 1). Data for the program consist of values for 54 climatic divisions. A 25 x 80 grid of the character blocks was overlaid on an outline map of the southeastern United States and the centers of the climatic divisions were selected as data points specified in terms of character block coordinates. The outline of the study separating it from the surrounding land and ocean was specified as a scan-deck file similar to that used in the choropleth program. Values for display positions in the study area are determined by interpolation.

Thirteen classes are displayed in a graded series ranging through three colors. A good color combination was found to be red-yellow-blue, where red is used for the lowest class (dry), yellow for the intermediate class, and blue for the highest class (wet); shadings for the second through sixth lower classes employ yellow characters on a red background and the second through sixth higher classes are displayed as yellow characters on blue. Cyan identifies the Atlantic and Gulf of Mexico, and green for the outside land areas, and heat from power plants into water bodies (5). Input data were matrices of concentration values. In a preprocessing program the values were transformed into a matrix of color patches and symbols. This matrix was then fed to the display program where the rectangular set of values is centered on the screen. A white outline was drawn around the study area, tick marks and scaling were added to the outline and the title and legend were printed. The white outlines and tick marks on these maps are the only use in all of the programs of the graphics mode. After making a particularly revealing map, the terminal was put into local mode, the map was enhanced with embellishments like a blinking X at the site of the discharge, and the image was transferred to a floppy disk. Images stored on a disk can be recreated in seconds.

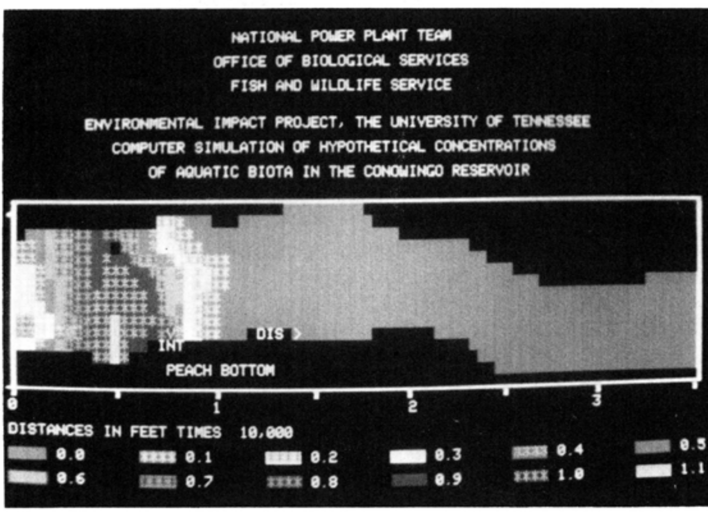

Fig. 2-Simulated concentrations of biota in the Conowingo Reservoir displayed on a 48-line Intecolor terminal. This black and white copy was made from a color print in which the central point is magenta and the colors grade from magenta-red-yellow-green cyan-blue. The outline and tick marks are drawn with the graphic plot mode. Data are a matrix of values for every print position.

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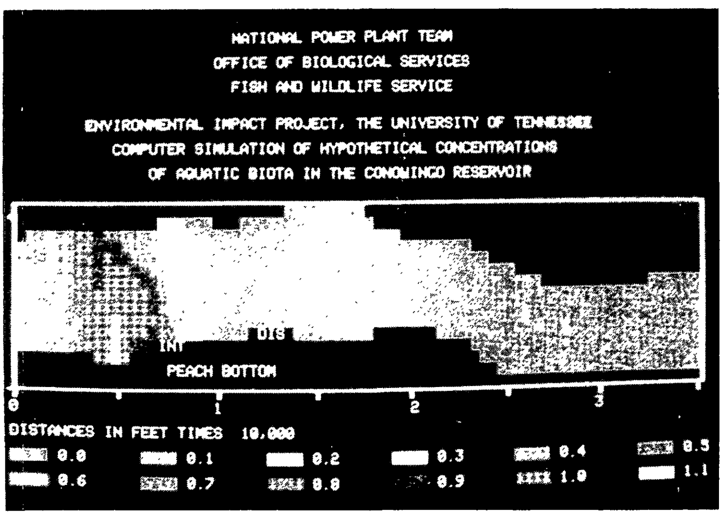

Fig. 2-Simulated concentrations of biota in the Conowingo Reservoir displayed on a 48-line Intecolor terminal. This black and white copy was made from a color print in which the central point is magenta and the colors grade from magenta-red-yellow-green cyan-blue. The outline and tick marks are drawn with the graphic plot mode. Data are a matrix of values for every print position.

The present and future

Low-resolution color CRT terminals cannot produce the detailed drawings we normally look for in cartography, but these terminals can be used to make some rather dramatic and effective maps. Coarseness need not be of much concern; of all of the people I have observed using the choropleth mapping program for Tennessee, no one has really complained about the coarse resolution used to define the counties.

What can be done with low-resolution color? Not much if you need multiple copies at a low price, but if you can live with slides, videotapes, a few color prints or a temporary picture on a CRT, these graphic systems may be of great service to you.

As interactive color systems proliferate, our concern should be that good cartographic design is incorporated into software we develop. Just because we can display 3, 8, 16, or 64 colors does not mean we should do it. Numerical data that are to be displayed in a gradation from low to high should be assigned colors that convey that trend. With the ability to select a number of colors with the push of a button, we must make people aware that color on a map is a symbol and conveys meaning by itself and in combination with other colors. The availability of colors extends our range of options but it also extends our responsibilities.

Footnotes

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3. Meyer, M.A., F. R. Broome and R. H. Schweitzer, Jr., "Color Statistical Mapping by the U. S. Bureau of the Census," Am. Cart., Vol 2, No 2 (Oct 1975), pp. 100-17
4. Johnson, P. E., "The Diffusion of Commercial Fertilizer in the Corn Belt," M.S. Thesis, Geog. Dept., Univ. of Tennessee, June 1978.
5. Eraslan, Arsev, "Environmental Impact Project," for the U. S. Department of the Interior, Univ. of Tennessee, Eng. Sci. and Mech. Dept.

GIMMAP: A (MINI)COMPUTER-ASSISTED CARTOGRAPHY SYSTEM

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The University of Kansas
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Introduction

The Kansas Geological Survey requires a general-purpose, computer-assisted cartography system for construction and maintenance of a state-wide cartographic data base. The purpose of this data base is to support production of single copies of specialized working maps; for production of general-purpose maps that will be published; and for resource analysis in the State of Kansas. The system being developed is called GIMMAP, for Geodata Interactive Management, Map Analysis, and Production. It is designed to operate in a minicomputer environment, a constraint which has promoted the development of an efficient, compact, and modular system. GIMMAP is written in FORTRAN, contains no module in excess of 32K (16-bit) words, and relies on random-access disk files. At the Kansas Geological Survey, the system operates with a manual digitizing table, a minicomputer, a vector display device, a flatbed plotter, and a printer-plotter with hard-copy unit.

The design of GIMMAP began with Dr. Tho Trang Cao at the Bureau de Recherches Géologiques et Minières (BRGM) in Orléans, France. Graph-theoretic techniques were employed to implement the initial system, which was based on topological data structures parallel to those of Peucker and Chrisman (1975) and others. These initial experiments resulted in the production of color-separation materials for two high-quality geologic maps of areas in France (Cao, 1974, 1976).

Development of GIMMAP at the Kansas Geological Survey began in 1977, when Cao served as Visiting Research Scientist at the Survey. In collaboration with this author, Cao produced the present extended design and began implementation of the basic computer-aided cartography system. An experimental geologic map of the Lawrence West 7.5 minute quadrangle is currently in press. At the present time, the logical and physical extension of the GIMMAP system, as described in this paper, continues in parallel as a cooperative effort between BRGM in France and the Kansas Geological Survey.

Current Capabilities

GIMMAP currently includes facilities for data input, data base construction, interactive editing, and data retrieval for a single document (Fig. 1 and Fig. 2). Standard 7.5 minute US Geological Survey topographic quadrangle maps are used as the basic input source for the geographic base. The extended data structure (Cao, 1978) employs a topological approach similar to one developed independently at the US Geological Survey by Mitchell and others (1977).

GIMMAP uses a simple format for the input of data (Cao, 1978). The suggested digitizing procedure eliminates unnecessary practices required in other systems, such as the entry of header information, line or node numbers, and left-right codes. It also eliminates the digitizing of zone identification marks, and multiple digitizing of zone boundaries.

The graphical data base is created primarily in batch mode. A small amount of operator interaction is required for syntax editing. Duplicate-node detection and resolution, and duplicate-arc detection are automatic, but are guided by operator-selected thresholds.

The data base is edited interactively by means of a graphical display device and a software module which provides the following capabilities:

1. Deletion or addition of points, arcs, and zones.
2. Node matching (connection of arcs).
3. Selective display by feature type.
4. Positional correction of nodes or interior points.

5. Splitting an arc at any interior point (node creation).
6. User-selected, scanning, zoom window.
7. Rotation, translation, or scaling of arcs.
8. Multi-level operator error protection.

The treatment of zones such as geologic formations includes the automatic assembly of boundaries (Cao, 1978). The zone treatment facility also provides for:

1. Zone coding (coloring) and linkage for efficient retrieval.
2. Labelling and marking for symbology.
3. Generation of left-right codes for boundary arcs.
4. Calculation of perimeter lengths, areas, and minima and maxima.

A recent extension provdes for the grouping of features by graphically connected components or by arbitrary, user-selected collections. Such collections may be based on feature type, location, name, code, or other attribute values. This extension includes updating capabilities analogous to those for zones.

A retrieval facility for the production of maps or the creation of "clean" digitized data files allows multiple selection by feature type, collection, name, location, code, or attribute value. This facility provides options for scaling, translation, and addition of fiducial marks and map titles. Options will soon be available for projection, shading, symbolization, contouring, and selection of line type, color, and width.

Current Developments

In the effort to extend GIMMAP to provide a flexible and comprehensive retrieval package from the user viewpoint (Fig. 3), current developments are concentrated in three areas. The first is to provide software for the construction of higher level, graphical data bases, such as county and state maps, from the primary data base. Such a facility will accommodate efficient, multi-level input and retrieval, and will include intermap editing, latitude-longitude conversion, feature generalization, and inter-map patching (concatenation) of features.

The second area of development is a facility for the capture of data from non-standard documents, and incorporation of this data in all levels of data bases. Such a facility is essential since most geologic and resource maps are not generally available on the standard quadrangle map bases.

The third area of development is in the construction of a relational data base system for cartographic attribute data. The data base will be accessed with a graphical query language founded on the "Query-by-Example" language developed by Zloof (1977), providing the full capabilities of relational calculus. This relational system will provide feature or attribute retrieval for analysis or map production with selection by relation, attribute, attribute values, multi-relation manipulation, or statistical evaluation of graphical or attribute data.

Conclusions

GIMMAP is designed to meet the requirements of a comprehensive cartographic system, as detailed in the recent survey by Nagy and Wagle (1979), with additional facilities for attribute data and analysis. GIMMAP is modular, is written in FORTRAN, and unlike many other systems, is designed for operation on a minicomputer.

The basic system has been implemented and successfully tested on a limited production basis at the Kansas Geological Survey and at the Bureau de Recherches Géologiques et Minières. A GIMMAP user's manual is being prepared for publication in the Series on Spatial Analysis of the Kansas Geological Survey.

Current extensions of the system include construction of multi-level data bases, incorporation of non-standard data, and a graphical, relational data base system for cartographic attribute data. Completion of these goals will provide a general-purpose, computer-assisted cartography system for the minicomputer environment.

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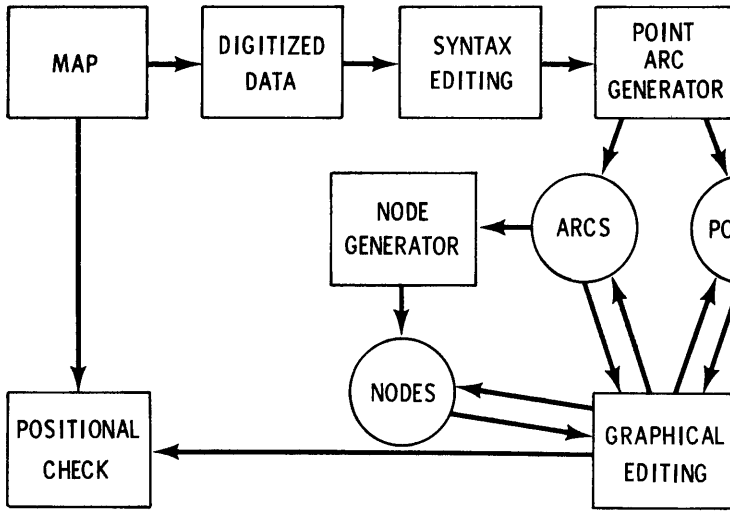
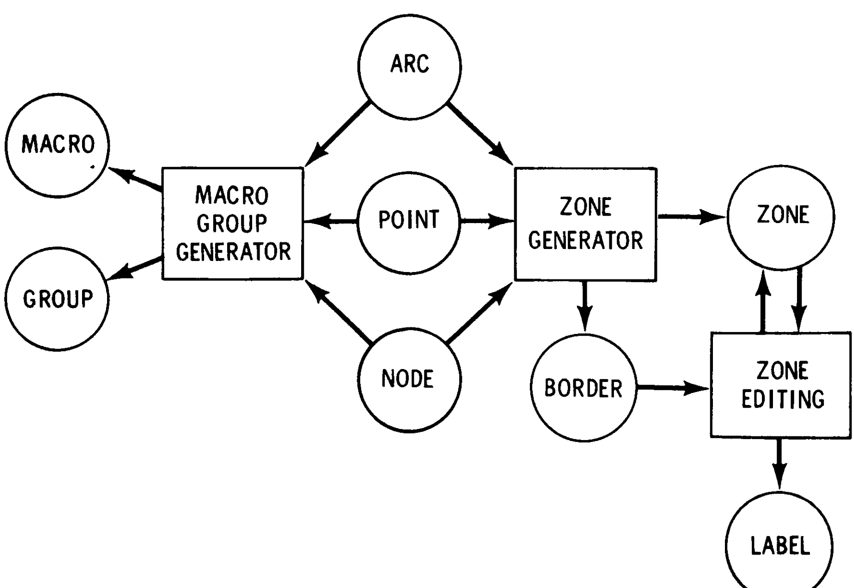


MAP
DIGITIZED DATA
SYNTAX EDITING
POINT ARC GENERATOR
NODE GENERATOR
ARCS
POINTS
NODES
POSITIONAL CHECK
GRAPHICAL EDITING

Fig. 1



ARC
MACRO
MACRO GROUP GENERATOR
POINT
ZONE GENERATOR
ZONE
GROUP
NODE
BORDER
ZONE EDITING
LABEL

Fig. 2

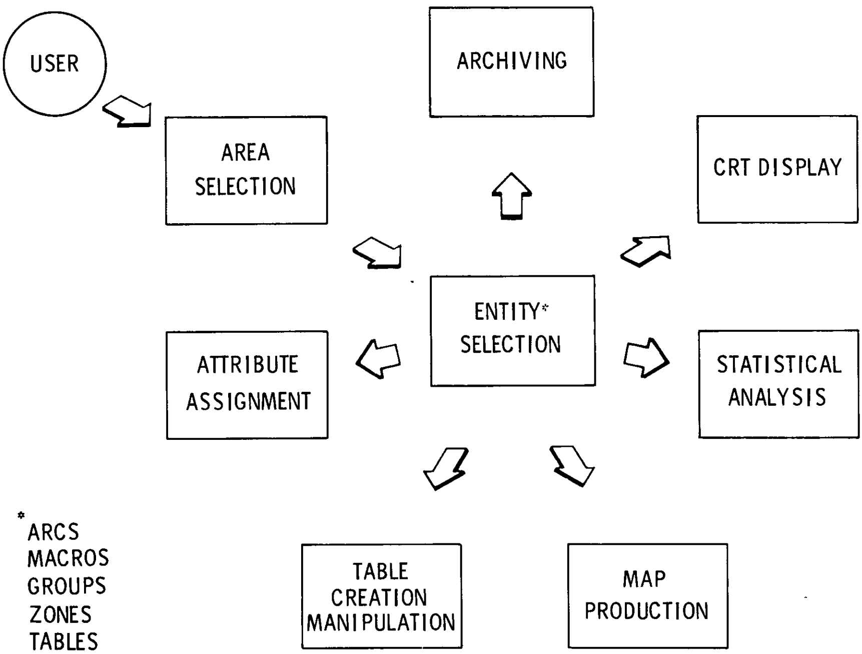

USER
ARCHIVING
AREA SELECTION
CRT DISPLAY
ENTITY* SELECTION
ATTRIBUTE ASSIGNMENT
STATISTICAL ANALYSIS
TABLE CREATION MANIPULATION
MAP PRODUCTION
*ARCS
MACROS
GROUPS
ZONES
TABLES

Fig. 3

MOVING INTERACTIVE THEMATIC MAPPING FROM MAINFRAME TO MINI:

Some Design Possibilities and Development Experience

Albert Yen, Harvard Holmes, and Peter Wood
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Lawrence Berkeley Laboratory
Berkeley, California

1. Introduction

The analysis, interpretation and assimilation of geographically referenced data often requires that it be presented in the form of maps and other graphic displays. CARTE is a thematic mapping program which produces annotated chloropleth, line or point-symbol displays of socio-economic, energy, or other data on a variety of interactive terminals or hardcopy plotters.

CARTE is designed primarily for interactive use and provides both simplicity for the novice and a wide range of options for the advanced user. Script or command files provide a convenient facility for setting defaults and other parameters from a monitor program as well as providing for non-interactive operation. CARTE has the ability to write a script which will reproduce the current map display. This frees the interactive user to concentrate on the map design without concern for keeping track of the commands issued, and also allows him to produce a series of similar maps with a common layout.

The goal of CARTE is to provide thematic maps to a broad user community. This software is a part of SEEDIS

(Socio-Economic-Environmental-Demographic Information System) [1], a broadly-based set of data bases and software which includes 100 million data items and a wide variety of analytic and display tools.

We know that displays such as CARTE are indispensable to our users and we feel that as the state of the art is advanced it will become possible and economical to supply the general public with these kinds of graphic displays. This will allow citizens to participate in decision-making with the same access to data that only a few lucky administrators now have.

2. Software Organization

SEEDIS, including CARTE, has been under development since 1972 (see [2] for an overview of an earlier version of CARTE), but the recent acquisition of a Digital Equipment VAX-11/780 prompted us to do a complete redesign. An overview of CARTE program structure is given in Figure 1.

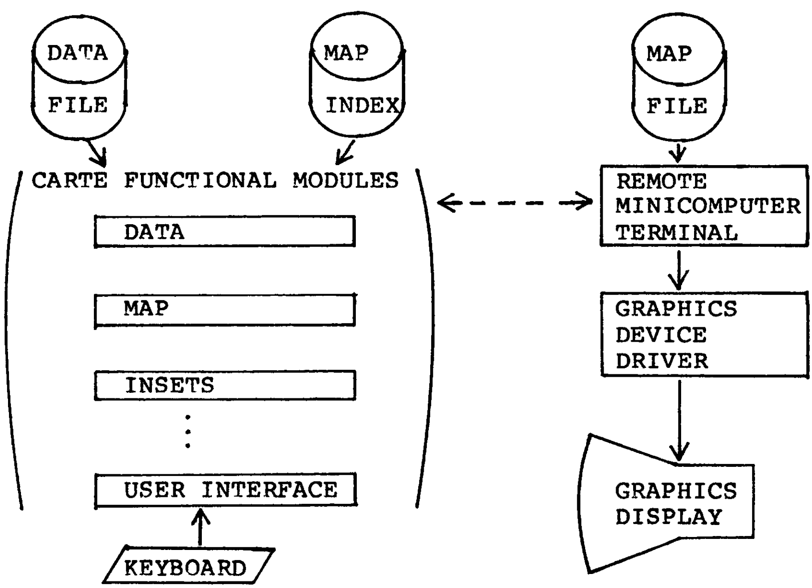

Figure 1. CARTE Functional Overview

As shown, input comes from three sources: geographic base (map) file, thematic data file and user directives. Both map and data files for use in CARTE are prepared by other modules in the SEEDIS system. Map files are organized by polygon, with each record containing an array of geocodes as well as a list of boundary points. No other topological information is maintained in the map file. Data files are also keyed using geocodes, so that map records and data records may be presented in any order.

Output from CARTE is mainly in the form of maps, but it can also display tables and histograms of data items for exploratory purposes. Another form of output is the script file, by which a user can save and recall the design of a map. The script file is in the form of CARTE directives, so that it may be modified with a text editor and reprocessed in CARTE to produce a corrected map design.

3. Using Intelligent Terminals

To support the possible use of intelligent terminals in map-making we have divided CARTE conceptually into two parts: host- and (potentially) terminal-resident. The philosophy behind the division is this: Basic graphic display functions must be performed by the terminal, while manipulation of items from a large data base can only be done by the host. For rapid response, the map itself is stored at the terminal. In order to make a map, certain information must be passed from the host to the terminal. The exact division between the parts was chosen to minimize the amount of this information.

With the separation of control and graphics generation, CARTE can use a unique graphics portion for each graphics device. This allows wide variations in strategy for controlling these devices. Even the map files can be different for differing terminals, since they are unique to each terminal. With raster devices, we would expect to store the image in raster form and manipulate the color look-up table to achieve the desired display [3]. This approach promises extremely fast graphic generation for many types of maps.

The terminal functions include the geographic base file interface plus routines to display symbolism and annotation. The remainder of the program (about 90% of the code), is the host portion. It includes the control program, data base interface and user input analysis and semantic routines. The host computer does not access the map file directly, but instead uses a map index (essentially the geocode portion of the geographic base file) to correlate the data and map.

To make a map, the terminal first receives from the host a list describing the types of symbolism desired. A symbolism description denotes whether polygon outlines and labels are to be drawn as well as the type of area fill (crosshatch, solid color, etc.). Furthermore, the description contains a list of graphic attributes such as vector color, line style and character size. These attributes are identified mnemonically so that they can be passed directly to the device driver without further processing by the terminal. Since graphic attributes can be applied to annotation as well as to the display of polygons, we have introduced the term "display style" to denote this wider use of symbolism.

In addition to the style definitions, the terminal receives the name of the map file, the limits of the geographic area to be displayed and the area of the screen to contain the display. To produce the map, the terminal receives a vector giving for each geoarea, the index of the corresponding display style. Finally, the terminal receives graphic primitive instructions for drawing any necessary annotation.

4. User Interface

Like many other large software systems, CARTE employs a centralized user interface. Our particular implementation somewhat resembles GPIS [4], which is used in GIMMS. Our design goals were: flexibility, ability to prompt the user, and ease of use not only from the user's standpoint but from the implementor's as well.

A typical CARTE command begins with a keyword or verb, and continues with one or more parameter lists. Within a list, parameters are separated by commas, and the lists themselves are separated by spaces. Each call on the scanner processes one list, so that the applications program can perform any necessary intermediate semantic processing. A command can be implicitly continued to more than one line by terminating the previous line with a comma, equals-sign or (within an expression) an operator.

Parameters are commonly of the form "keyword=value", though a value alone may appear in selected cases where no ambiguity results. The following is a typical example:

```
TITLE   1   STRING="text", XY=(.3,.3), MODE=CENTER
```

which specifies a text string, centered about the screen coordinates (.3,.3). As evidenced, parameters can have several kinds of values, including numbers, expressions, character strings, or other keywords. Since the XY parameter specifies a graphic location, its value could have been input by positioning a graphic cursor. However, only locators can be input in this way.

The user interface incorporates three settable prompting modes: "beginner", "familiar" and "expert". In all three modes, the user may enter a command as in the example above. If the prompt mode is "expert", no prompting is done; default values are supplied for omitted parameters. In "beginner" mode, the system prompts for all omitted parameters; the user may still decline to enter a value for any of them. "Familiar" mode is a hybrid of the other two; there is no prompting unless the user requests it by omitting parameters from the command line. The prompts themselves are very simple: a keyword followed by one or two words describing the type of value desired. We are considering the possibility of incorporating the on-line help information, which is organized by command and parameter, into the prompts. Below is a sample dialog in "beginner" mode (user inputs are in lowercase):

```
title
INDEX?
1
STRING? (Character string)
"text"
XY? (Coordinates)
(.3,.3)
MODE? (LEFT, RIGHT, or CENTER)
center
```

5. Use of VAX/VMS System Features

In moving CARTE to the VAX, we have been able to take advantage of some special features offered by this machine. One such feature is virtual memory. With virtual memory program organization is simplified since there is no need for explicit overlays. Dynamic paging ensures that main memory is occupied only by program segments which are actually being used. CARTE also allocates virtual memory itself when convenient. This enabled us to remove explicit limits, for example, on the number of geographic areas and on the number of points per polygon which can be plotted.

Another important feature used in CARTE is the condition handling facility. CARTE uses the condition handling facility to process all abnormal conditions, including user input errors and user interrupts. When a signaled condition is too serious for execution to continue, program flow is unwound to the main control program, which reads the next user command. Thus, the user can continue after any error, even coding errors provided he avoids the failing module. We believe this to be very important in an interactive system.

6. Unresolved Issues

A number of issues have been left unresolved by our conversion. Among these are:

- Base map organization.
  Map files represent each polygon as a list of points and do not store any higher level topological information. While this structure makes assembling of polygon outlines very efficient, there are some drawbacks. For example, interior boundaries are drawn twice.

- Terminal hardware dependencies.
  CARTE does not make use of information about graphics terminal characteristics. For example, it would be nice to know the possible character sizes in order to place the default title and legend; or, it would be nice to use the output resolution in order to optimize polygon outlining and shading.

- Base map preparation.
  CARTE can only operate with one base map at a time and does no cartographic processing. If the user wishes to combine two maps, or otherwise edit the map file, a separate processing step is necessary.

7. Conclusions

In the six months CARTE has been operational on the VAX, it has been used to prepare over 150 maps for presentation, plus an uncounted number for experimental or exploratory purposes. These included:

- o A series of maps of energetics data for the U.S. by state and Federal Region IX by county.
- o A series of maps of air quality statistics and cancer mortality data for the Populations at Risk to Air Pollution project.
- o Other maps dealing with economic and demographic data (Figure 2).

Our users are more than pleased with the rapidity and quality with which maps can be composed and produced. They believe, as we do, that such graphical displays can be a great aid in developing and presenting new knowledge.

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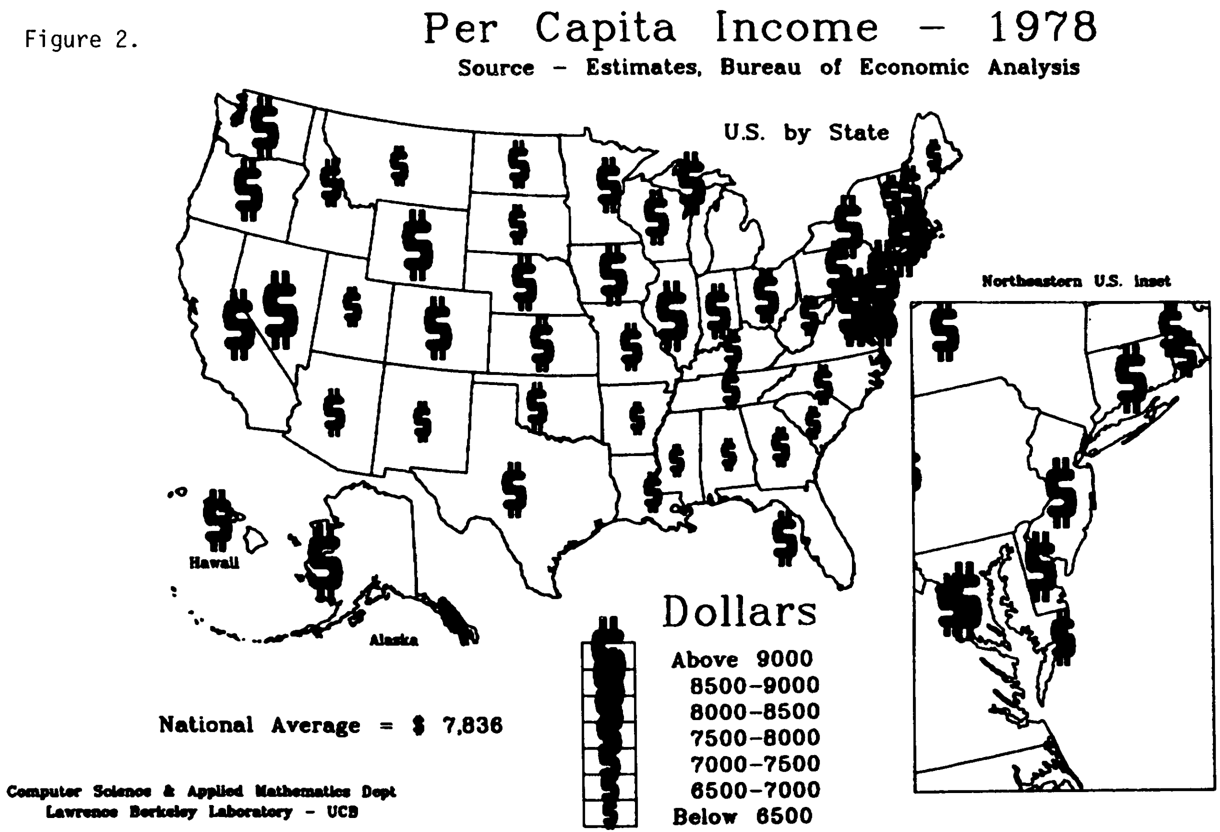
Figure 2.


Per Capita Income - 1978
Source - Estimates, Bureau of Economic Analysis
U.S. by State
Northeastern U.S. inset
Hawaii
Alaska
Dollars
Above 9000
8500-9000
8000-8500
7500-8000
7000-7500
6500-7000
Below 6500
National Average = $ 7,836
Computer Science & Applied Mathematics Dept
Lawrence Berkeley Laboratory - UCB

INTERACTIVE CARTOGRAPHY, LARGE SYSTEMS SESSIONS

INTERACTIVE CARTOGRAPHY, LARGE SYSTEMS

There were two Interactive Cartography, Large Systems sessions. Bryce Schrock of the U.S. Army Topographic Laboratory chaired both sessions.

James B. Campbell of the Virginia Polytechnic Institute presented the paper "Automated Production of a Large Scale Thematic Atlas". This atlas deals with a portion of a U.S.G.S. 7.5 minute quadrangle and was produced jointly by the Kansas Geological Survey, Lawrence, and the Experimental Cartography Unit, London. Maps portrayed in the atlas include the topics of slope, topography, soil and depth to bedrock.

M. Mosaad Allam, of the Department of Energy, Mines and Resources, Canada, presented the paper entitled "Multiple System Interactive Compilation with Distributive Computer Network". His paper presents a brief description of the configuration of the interactive map compilation system of the Topographical Survey. Experience using the present system for digital topographic mapping is described and suggestions regarding future systems development are given.

A third paper entitled "MOSS/WAMS - Conceptual and Photogrammetric Discussion of a Large Scale Geographic Information System" was presented by Carl Reed of the U.S. Fish and Wildlife Service.(Paper not included in proceedings.) MOSS and WAMS are the display and analysis and digitizing systems respectively within the geographic information system, EIDA. Reed described the design and use of these two subsystems and presented several example products of the system. Also, some philosophical remarks were made regarding the use and acceptance of large scale geographic information systems.

Mark Henriquez of Lawrence Berkeley Laboratory presented the paper, "Energy Analysis by Means of Computer Generated Interactive Graphics". This paper describes a joint effort by two LBL departments to assess the impacts of environmental residuals resulting from proposed alternatives in energy production activities within Federal Region IX. A new graphics system being developed at LBL has been particularly advantageous in this attempt.

P.F. Grosso and A.A. Tarnowski of Image Graphics presented a paper, "Electron Beam Recorders for Automated Cartography". Their paper deals with a technical description of an electron beam recorder system for producing aerospace, topographic, and hydrographic charts, and other cartographic products.

Bryce Schrock presented a talk entitled "Large Interactive Cartographic Systems". (Paper not included in proceedings.) In this talk, Schrock described the interactive systems of the U.S. Army Topographic Laboratory.

AUTOMATED PRODUCTION OF A LARGE SCALE THEMATIC ATLAS

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I. Introduction

Users of large scale maps are frequently faced with the problems of comparing and interpreting data from several maps representing different characteristics of the same area. For example, a given area in the United States might be covered by a topographic map at 1:24,000, a soil map at 1:20,000, and a geologic map at 1:48,000. The person who must integrate information from such diverse documents must contend not only with differences in scale, but also with varied map sizes, coverages, accuracies, and symbols. The usual optical and manual methods of changing scale, registering maps, then resolving differences in generalization and symbolization are often so tedious and expensive that it may be impractical to make full use of even the most commonplace data. The atlas described here illustrates how computer graphics can be applied to the presentation and interpretation of map information acquired from varied cartographic sources.

This atlas consists of a set of thematic maps of a single area in eastern Kansas; each map depicts one or more aspects of the physical environment. A total of twelve atlas maps were generated from three source maps by means of changes in scale, superpositioning of two or more maps, generation of new distributions, and other operations completed entirely by means of digital computers. The final products are four-color maps, printed at a common scale and format, with detail, legibility, and accuracy comparable to high-quality conventional maps generated by manual methods. Although map topics focus upon needs of local planning officials, the techniques described here could equally well serve the needs of others.

This work is a joint effort of the Kansas Geological Survey (KGS), Lawrence, Kansas, and the Experimental Cartography Unit (ECU), London, England, organizations that both have long histories of applying automated cartography to mapping the environment. The KGS selected the study area, supplied the source materials and designed the content and general format for the atlas maps. The ECU was responsible for production of the maps.

II. Atlas Map Area

The atlas map area shows the northern half of the Wakarusa, Kansas U.S. Geological Survey 7.5 Minute Quadrangle, an area measuring approximately 8 by 11 kilometers (about 5 by 6.5 miles) covering about 88 square kilometers (33 square miles). Located just south of the city of Topeka, the area has experienced numerous changes in land use during recent years. Development has been greatest along the northern edge of the map area, and along the main highways. Land use in most of the remaining portion of the area has been changing from agricultural land to suburban residential housing.

III. Source Maps

Information for the atlas is derived from three source maps. The Wakarusa, Kansas 7.5 Minute Topographic Quadrangle was the source for topographic, hydrographic, and cultural detail. Because of its high planimetric accuracy, this map was selected as the base for all of the atlas maps. The Wakarusa Quadrangle was first published in 1955 by the U.S. Geological Survey (USGS) at a scale of 1:24,000; it was later revised to update cultural information.

The second source map is the Geologic Map of Eastern Shawnee County Kansas and Vicinity (Johnson and Adkison, 1967), and the corresponding report published by the U.S. Geological Survey. In the atlas map area 13 geologic mapping units are shown at a scale of 1:48,000.

The geologic map uses a USGS topographic base, so its locational accuracy is roughly comparable to that of the topographic map.

The third source map is the soil map published as part of a county soil survey by the U.S. Soil Conservation Service (Abmeyer and Campbell, 1970). This map shows boundaries between soil mapping units plotted on a 1:20,000 base derived from aerial photographs.

This soil map is the source not only for soil information, but also for engineering interpretations of each soil unit. These interpretations provided information concerning a variety of potential uses, ranging from suitability for foundation support for low buildings to suitability for septic tank waste disposal. As a result, the soil information forms the base not only for the soil information itself but also for other maps based upon interpretations of the soil information. Although 33 categories are shown on the original soil map, the atlas soil map (published at much smaller scale) was generalized to show only 15 categories. However, all 33 categories were digitized to permit all of the original categories to be used for generating other distributions.

IV. Atlas Maps

The atlas contains 12 map plates (Table 1); these are best described in groups organized according to the manner in which they were generated from the source maps.

The first group consists of those atlas maps generated by a simple change of scale, accompanied by appropriate generalization, and changes in symbolization. Information for Maps 1 and 2, for example, has been simply selected and generalized from the topographic source map. Likewise, Map 4 -- Soils -- is generalized from the soils source map. And Map 3 -- Geology -- presents essentially the same information presented on the geology source map. For the latter, no change in scale was necessary, although the map was slightly generalized.

Table 1.--List of atlas maps

	Title	Computer Operations	Source Maps
1.	Cultural features	selection and generalization	topography
2.	Elevation	selection and generalization	topography
3.	Geology	generalization	geology
4.	Soils	scale change, generalization	soil
5.	Soil capability	interpretation of source map	soil
6.	Slope	new map generated from source map	topography
7.	Land surface elements	visual overlay	soil, geology, topography
8.	Depth to bedrock	interpretation of source map	soil
9.	Suitability for recreational land use	interpretation of source map	soil
10.	Permeability of surface materials	interpretation of source map	soil
11.	Foundation support	interpretation of source map	soil
12.	Suitability of surface materials for road fill	logical overlay	soil, geology

A second category consists of those maps generated by transforming data presented in the original source maps. An example is Map 6 -- Slope. Topographic elevations, digitized as a series of discrete values from the contour map, were gridded to form a regular array; this array was then used to calculate slope values. Slope data were generated at the Department of Geography, University of Nottingham, using the department's PDP-11 computer and the MAPCAT mapping and data analysis system (McCullagh, 1977). Slope information was then supplied to the ECU to generate final masters for the atlas map.

The third group consists of maps created by combining information from two or more maps. Map 12 -- Suitability of Surface Materials for Road Fill -- is an example of taxonomic addition of information selected from the soil and geology maps. Another example is Map 7 -- Land Surface Elements -- formed by the visual addition of information from topographic, soil, and geology maps. The complex symbolization on this map required publication at a scale of 1:24,000, rather than the 1:48,000 scale used for the other atlas maps.

The last group consists of interpretations of data presented on the source maps. Each of the general purpose mapping units on the soil map can be interpreted with respect to engineering properties important in low or medium density commercial and residential development. These interpretations have been published as a portion of the original soil survey (Abmeyer and Campbell, 1970) and therefore are readily available in a form keyed to the soil mapping units. Map 10 -- Permeability of Surface Materials -- is simply a plot of each soil mapping unit in respect to permeability. In this instance, permeability is represented by quantitative values (inches per hour), but other interpretations could be qualitative ratings of each mapping unit in respect to certain uses. For example, Suitability for Foundation Support for Low Buildings (Map 12), consists of mapping units defined as "good," "excellent," "poor," and so on.

V. Production Sequence

The most important steps in the production sequence can be outlined as follows.

The first step was the generation of a preliminary list of map topics using information presented on the source maps and a knowledge of information requirements of planners. This list was further modified after consultations with the ECU to eliminate maps that present difficulties in legibility or symbolization. Legibility of some of the proposed maps was tested by manual and photographic compilation at the KGS. This provisional compilation approximated the visual complexity of each map, and provided a guide to the amount of generalization required to produce legible maps. During this phase it became clear that it would not be practical to publish maps at the planned scale of 1:24,000 without using either foldout pages or an impractically large format. Therefore it was decided to print each atlas map at a 1:48,000, and reserve the centerfold for a single map (Map 7) at 1:24,000.

At the conclusion of this phase, the ECU was supplied with a list of the atlas maps, with complete descriptions of legend items, titles, map detail, and all data to appear on completed map sheets. This information was keyed to the source documents. For example, category "A" on the atlas map might be formed from categories "1" and "4" from specified source maps.

The second step was the acquisition of source maps. The atlas area was selected partially on the basis of the availability of up-to-date source maps, so this step did not present significant problems. Because of the requirement for accurate digitization and registration, it was necessary to procure stable-base copies to be sent to the ECU for digitization. During digitization, each class of map feature, and each form of line symbol, was separately coded to permit selective recall of each kind of feature on the map.

Following preliminary editing and checking by the ECU, proof copies of the digitized point and line data were shipped to the KGS. These proofs were separate plots of the source data plotted on transparent plastic material at a common scale of 1:24,000. Errors were marked on copies returned to the ECU for correction.

The ECU then began production of Cromalin color proofs for each atlas map. These proofs included complete map data, legend and title information, as well as the assignment of colors to each mapping unit. Following acceptance of the color proofs, the final masters were shipped to the KGS, where the map sheets were printed, integrated with the text, then bound.

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MULTIPLE SYSTEM INTERACTIVE MAP COMPILATION WITH DISTRIBUTIVE COMPUTER NETWORK

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1. Introduction

The use of digital photogrammetric map compilation systems with interactive display and editing capabilities is providing an unprecedented opportunity for achieving new levels of efficiency, cost effectiveness and improved responsiveness in the production of topographic maps, charts and related data.

During the last decade, there has been a noticeable acceptance of the advantages of map data in digital form. This change is due to several reasons, which include:

- the ability to create a digital cartographic data base;
- the increased demand for digital map data from users for computation, geographic modelling and geographic information systems;
- the rapidly improving technological methods for digitization display, edit and drafting;
- the increased demand for special types of maps and charts;
- the possibility of preparing maps at successively smaller scales, with a selection and generalization of what shall be represented at each scale;
- the elimination of the re-digitization of substantial amounts of the plot inherent in the generation of maps at larger scales;
- the elimination of manual drafting and scribing work;
- the speeding up of the map-making process;
- the possible acceleration of map revision;

- the present availability of software for display, edit and data base manipulation.

In the Topographical Survey Division, the development of a digital compilation system was started in 1972 to digitize photogrammetric measurements from stereo-plotters and record data. This system was developed in 1975 and had no display or editing capabilities, and the operator had limited control over the recorded information.

In 1976 the first experimental interactive digital map compilation system with display and editing capabilities was developed in the Topographical Survey Division by integrating our data collection system with the Interactive Graphic Design System (IGDS) developed by M&S Computing (Huntsville, Alabama, U.S.A.).

Based on the experience gained from the experimental system, two interactive mapping systems were installed in the Topographical Survey in 1978.

2. System Configuration

With regard to the way and extent of involvement of digital computers and peripheral units in automated photogrammetric systems, several feasible configurations can be drawn up. In principal they can be classified according to one or more of the following options:

a. single or multiple station;
b. capabilities for interactive display and editing;
c. uni-directional or bi-directional communication.

In addition to the hardware configuration of the system, the capabilities of the software used adds another factor to the complexity of the desired system. In addition to the basic requirement for cartographic digitization and recording of data, the options for extensive display and editing functions, data processing, system intelligence and degree of operator control or interaction, and the capabilities for data base management must be considered.

The experience of the Topographical Survey Division with digital map compilation using analog photogrammetric instruments is best illustrated with the various configurations of the systems developed since early 1972.

2.1 Multiple Station Digital Compilation (1972-1975)

This system was developed for the digitization of photogrammetric measurements during map compilation and the recording and storing of data as represented in figure 1.

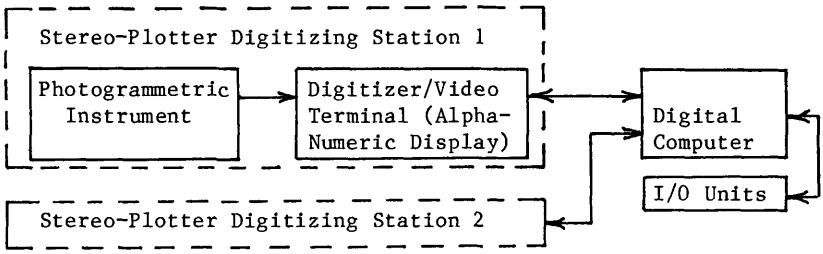

Figure 1. Digitizing/Recording System

The measuring device of the photogrammetric instrument was modified by adding a tri-axis locator with optical incremental encoders for the measurement of the X,Y and Z coordinates in model space. A digitizer video terminal with alpha-numeric display and keyboard was developed in-house to serve as a link between the stereoplotter and the computer. A bi-directional communication existed between the digitizer/video terminal and the computer; thus providing a limited closed-loop system. The stored information consisted of cartographic codes and X,Y coordinates in ground units for the digitized features.

With this system, the operator has no control over the digitized information except for very simple operations provided by the digitizer/video terminal and the software. For example, it is possible to "backspace" any feature and write over old information in a time-shared environment.

2.2 Multiple Station Interactive Map Compilation (1976)

From the experience gained from the previous system and due to the nature of photogrammetric compilation, where a map consists of several models, it was absolutely necessary to provide the operator with complete control over the digitized data. Display and editing capabilities were needed for error detection and editing during the compilation of features in a model and to join models. The configuration of this system is represented in figure 2.

In this configuration each stereo-plotter station is interfaced to the front-end computer (PDP-11/T10) using a digitizer/video terminal as in figure 1. The front-end computer is interfaced to a main computer (PDP-11/45) using a standard Digital Equipment interface. Each stereo-plotter station is equipped with a dual graphic CRT display terminal.

The control over the digitization is provided by the closed-loop between the digitizer/video terminal and the front-end computer (selection and assignment of cartographic codes, digitizing X and Y coordinates and end-of-feature). The control over the display and editing functions is provided by the CRT graphic terminal and the main computer.

The CRT graphic terminal has a data tablet with a menu of commands. A free cursor is used to select the desired design, display or edit function.

In this configuration, a large surface digitizer table with CRT terminal is used for cartographic editing and a CalComp pen plotter for the production of hard copy proof plots.

2.3 Modified Multiple Station Interactive Map Compilation (1978)

This configuration is represented in figure 3. The main differences between this system and the 1976 system represented in figure 2 are:

- the front end computer and the digitizer/video terminals were eliminated;
- each stereoplotter is interfaced to the computer using a microprocessor.

This system consists of six stereoplotter stations, a large surface digitizing/editing station, and a Calcomp 960 pen plotter.

In this system the computer directly affects the operation of the individual microprocessors and the CRT graphic terminals. The microprocessors have no storage capabilities for the digitized data and are used for the transformation of digitized data from model to ground coordinate system. Bi-directional communication exists between the microprocessors and the computer and between the computer and CRT graphic terminal.

In all these systems a uni-directional communication exists between the stereoplotter and the interface to the digitization system.

3. Software

The main components of the software system for interactive photogrammetric map compilation are:

- Software for data collection from the photogrammetric instrument

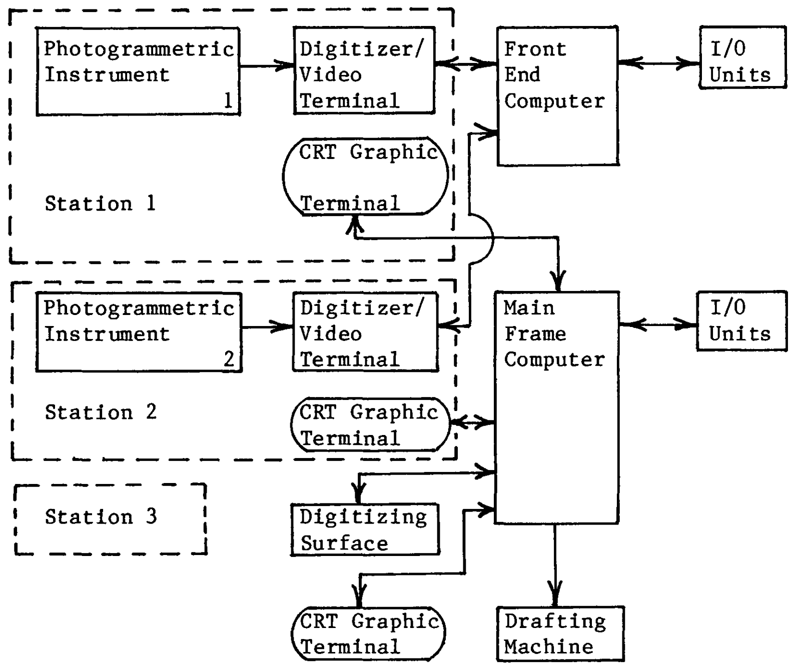

Figure 2. Multiple Station Interactive Map Compilation (1976)

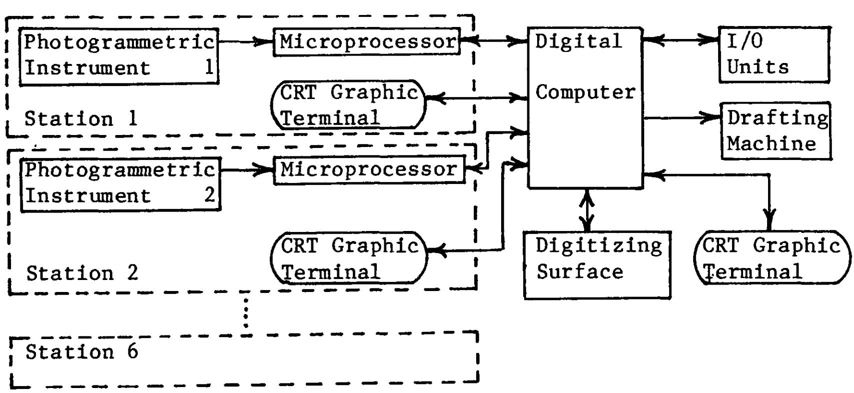

Figure 3. Modified Multiple Station Interactive Map Compilation (1978)

with appropriate cartographic code assignment; and the transformation of digitized X,Y, and Z coordinates from model to ground coordinate system.
- Software for interactive graphic file design, display, and editing purposes.

It is essential that the software be designed as several modular tasks communicating with the user on a real-time, event-driven (user request), priority structured basis.
The interactive graphic programs should be made accessible through the menu and keyboard, or they might be addressed directly by application programs. The main features of the interactive graphics software include:
a) Placement, deletion, modification, and movement of design elements, such as lines, polygons, arcs, circles, ellipses, text and curves.
b) On-line user definition of any combination of design elements as a cell to be added to a cell library; placement, manipulation and scaling of any cell.
c) Storage and retrieval of intermediate and final designs.

4. <u>Operational Procedures: Interactive Display and Editing</u>

Editing can be done during data collection, after the completion of some compilation or after the data have been plotted and reviewed. Editing and graphical display are closely related. The following are some of the combinations that can be graphically shown on the interactive storage display system.
- display one or more overlays in combination with the class of data as identified by association code such as roads, railroads, rivers, etc.
- display with or without: a pattern (e.g. railroad). a symbol (e.g. marsh, building, etc.), a line type (e.g. solid line, dash, dotted, etc.) and line weight.

Also related to editing is the measurement of data. It is possible to measure the distance between graphical elements, the angle between lines or the area bounded by a polygon. Equally important is the precision and exact location and placement of data, e.g. placing a geodetic monument exactly on the map.

The editing, like the display function, is controlled by a menu command. This includes the classical editing capabilities such as add, delete, modify, and smooth data. It is possible to add line data, text data symbols and so on. Part or all of a data element can be deleted. Two segments of data can be joined into one continuous smooth curve. It is possible to modify data such as in the case of road intersections or contour and stream intersections.

These are a few examples of the numerous combinations that can be performed while editing. It is possible to use automatic dimension to place a name between two specified points. Another useful editing function is the processing of fence content. We can define an area which encompasses some data as a fence and move, rotate, delete, copy, etc. the contents to another location in the design file. The editing functions are interactive and highly responsive. While editing there exists a constant dialogue between the operator and the computer ensuring maximum interaction.

5. Conclusions

The recent progress in computer technology, peripheral units and graphic display terminals promotes increasingly new developments in the field of digital photogrammetric map compilation. Although microprocessors are important as an interface between the photogrammetric instrument and the minicomputer, microcomputers will be used to increase the capabilities of the digitizing station and to reduce the load on the main frame computer. Microcomputers with I/O peripheral units will be used for the recording and storage of data and perhaps for the control of the CRT graphic terminal. In multiple station systems, microcomputers will play the full role of a distributive computer network. In this case, a bi-directional communication between the microcomputers will exist in addition to the bi-directional communication between the main frame and each microcomputer.

For the last few years, the majority of the CRT graphic terminals used with interactive systems are of storage tube type. Vector refresh terminals with excellent brightness, small spot size and large display area are currently available and will be used to increase the system performance by having the capability to erase any displayed feature and to display the modifications without rewriting the entire screen.

6. References

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ENERGY ANALYSIS BY MEANS OF COMPUTER GENERATED INTERACTIVE GRAPHICS

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Introduction

In an age where resolution of complex technical questions is characterized by the use of large data sets, informational display in the term of interactive computer graphics has become an increasingly valuable research tool. The advantages of cartographic output over alternatives such as a tabular format have increasingly become clear to our research group At the time we were involved in the early stages of a study conducted by the Energy Analysis (EAP) Group of LBL, on behalf of the Department of Energy.

Our work which is known as Technological Assessment of Solar Energy Characterizations, (TASE) is a project in which we participated with other national laboratories. It is designed to evaluate the potential of alternative energy systems to displace a given fraction of conventional oil based fuels, identify potential applications and to develop engineering specifications of specific technologies for which potential sites are identified on a county-by-county basis within Federal Region IX. This includes California, Nevada, Arizona and Hawaii.

A number of factors are examined in the execution of this task; these include county population and demographic trends, ambient air quality, land and water use patterns, to name a few. By displaying base case (existing) and scenario specific (proposed) data sets in cartographic form, the geographical distribution of many variables is available at a glance even to those who are neither familiar with nor involved in the original research.

This is not to suggest that the use of maps has totally eclipsed tabular or graphical displays. On the contrary, for any hand manipulation of data or in other cases where absolute values are described, tables are inherently superior to maps. However, by making use of both options, we have developed a more comprehensive picture than the use of either option alone would allow.

General Process Description

A collaborative effort by the Energy Analysis Program and the Computer Science and Applied Mathematics Group at the Lawrence Berkeley Laboratory has resulted in the completion of a new method for producing computer generated graphics. The software necessary for implementation has been undergoing various stages of development by CSAM over a period of years. The author, on behalf of EAP modified and perfected this technique and was the first to successfully apply it to an actual research task.

The heart of the new system is a VAX 11/780 computer operated for DOE and the Department of Labor by the Computer Science and Applied Mathematics Department at Lawrence Berkeley Laboratory. This computer has stored on line a portion of the Socio-Economic Environmental Demographic Information System, or SEEDIS, data base. Because the fraction of SEEDIS stored on the VAX is a subset of a much larger version which resides on the laboratory's separately administered BKY computer network, we were initially faced with a choice as to which system to use. The BKY system, which consists of a ODC 6400, 6600 and 7600 computers, had a cartographic/graphics software package (13) already up and running. But because the VAX offered a less saturated user environment and lower job costs, it was felt that these advantages outweighed the developmental effort required to produce VAX color cartography. But since the VAX lacked a color hardcopy device, methods were devised to access and manipulate data on the VAX, write it on tape, and process the tape, i.e., draw the maps, elsewhere. From an applications point of view, this approach has enabled us to undertake runs consiting of up to 23 separate Federal Region by County maps at once, in a fraction of the time and cost that would have resulted from conventional methods.

At this point, it may be helpful to examine, from an applications point of view, the steps necessary to produce a color map by this new system. To begin, one enters the interactive SEEDIS monitor of the VAX to select the area and geographic level desired. The result of this step is a geocode file, which is used in subsequent steps to automatically extract the data and interface the selected information with previously created base maps which reside in the system. Possible choices for areas include one or more Federal Regions, Standard Metropolitan Statistical Areas, Census Tract, Counties or Water Quality Control regions, to name a few. Population limits on the desired area may be set at this time. In terms of data for our chosen areas, it is possible to use either packaged data already installed on line as part of the SEEDIS monitor or to insert our own original data. Examples of installed data bases developed by Ray Tessmer at BNL, the Federal Energy Regulatory Commission Electrical Generating Unit Reference File or, what we will use to illustrate the procedure, the Populations at Risk to Air Pollution (PARAP) file developed by L. Belo and the School of Public Health at the University of California at Berkeley. We may for example, select data on the concentrations of specific airborne pollutants for the counties of California, along with information of death rates due to various forms of cancer for a given segment of the population. In some cases it is desirable to determine the ratio of two variables, and straightforward arithmetic subroutines are available for this purpose.

Having assembled the desired information, we proceed to create maps within SEEDIS, using the CARTE program developed by CSAM. The graphic files thus created are saved for additional processing, and the resulting file is recorded on tape. The maps themselves are drawn by a Zeta plotter which currently is an output peripheral on the BKY system. Alternatively, the tape may be processed in such a way as to allow for cartographic output in the form of Dicomed transparencies. These transparencies are available in a variety of formats and are characterized by intense color saturation and high resolution. Samples of graphic output for the cancer mortality information described in our example are presented in this report.

Process Applications

This process has demonstrated its usefulness in applications where a number of variables interact in a complex or synergystic manner. One example is in the case of certain water quality treatment problems which are usually impacted by energy projection technologies. Previous work by the author, (Refs. 2, 14, 15) has shown one such interaction involving the degree to which a given waste stream can be treated, the cost of treatment and the size of the treatment facility. For any given treatment system, there will be a specific number of plants which may be located in a county to meet a given level of treatment. In evaluating the applicability of a given treatment technology to a county, it is helpful to know the number of separate plants that such a county can support. Competing factors in the selection of plant sites include population trends, land use patterns and ambient environmental quality. Cartographic displays are one ideal way to present this information.

The relationship of cost, degree of treatment, and size of plant may be displayed as a two-dimensional representation of the relationship between these three variables and would take the form of Figure 1. Now if we were to superimpose a three-dimensional matrix on the design envelope shown in Figure 1, it would be possible to define equi-distant points within our matrix through or near which descriptive curves for any treatment system must pass. (see Figure 2) Each point may be identified by a code specific to its location in the matrix. Each location specific code also identifies several frames of cartographic output which were constructed using data values valid for that point in the design space. By inputting two or more of the desired parameters (cost, degree of treatment, plant size), into a separate FORTAN program, points in the matrix corresponding to points in the design curve are identified and the graphical information corresponding to the number of plants per county can be easily extrapolated.

For example, consider a specific treatment technology

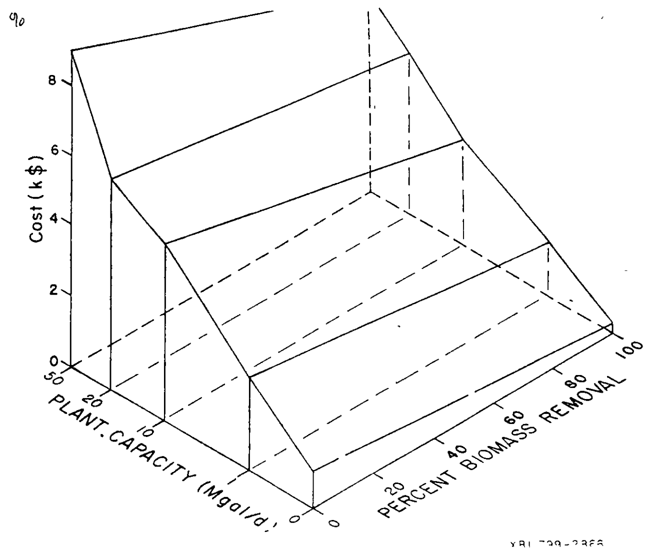


Figure 1

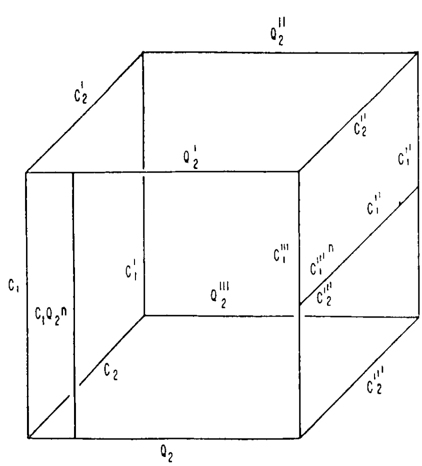
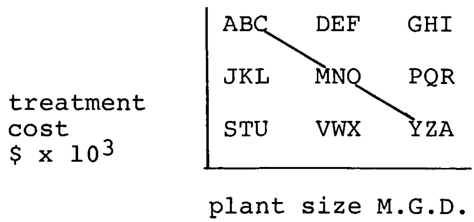


Figure 2

for which a linear relationship exists between the size of the plant and the cost of treatment over the interval of interest. Such a relationship may look like the curve described below and is shown in two dimensions for clarity. By superimposing a matrix in the form of:



on resulting design space we can identify three points, namely, ABC, MNO and YZA, which are at or adjacent to the cost/size function. Location ABC may serve as the address for one or more frames of cartographic output which show the number of treatment plants per county which may be sited if each of the plants operate within the extreme low range of plant size and the high range of treatment cost. The system may be expanded for the three dimensions.

Our new technique allows up to twenty separate frames to be stored per design point with the option of having each frame represent a multiple of the basic design space units. It is interesting to note that when the graphics data quantities are consistant with the operational characteristic equations identied for a given system, proportionality between the graphics and engineering data results. Because the maps themselves have been previously prepared, this system, which has been developed by the author for the Energy Analysis Group, has applications in instances where users are lacking sophisticated computer skills.

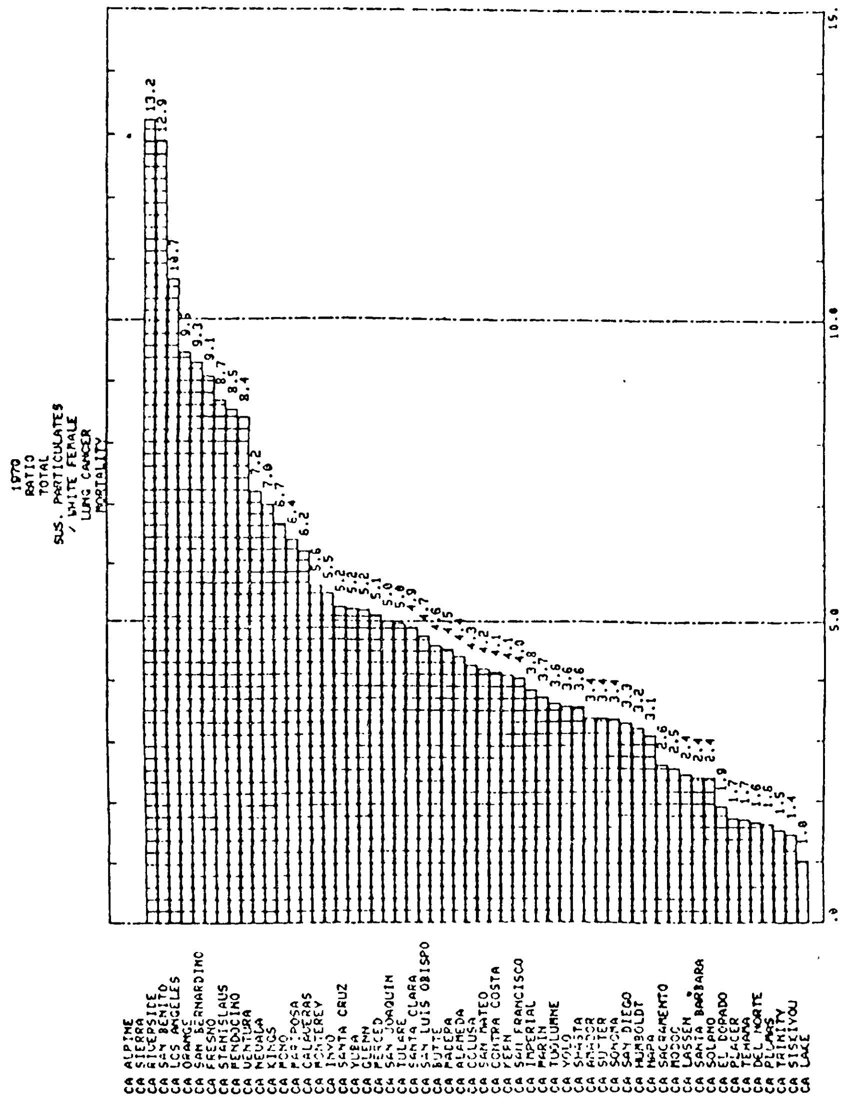
Methods of this type are not restricted either to water quality or energy related applications. Many fields, including aeronautical mechanical structural engineering, law enforcement, marketing and remote sensing to name a few, can benefit from interactive graphics. The reasons for the increasing popularity of interactive graphics can be largely attributed to decreasing hardware costs and the emergence of application techniques such as the one described above which seek to incorporate powerful tools into a format which is both accessible and comprehensible to the naive user. There is always the potential for a problem however, when sophisticated techniques are used by unsophisticated users.

We may take, as an illustration, our initial example of cancer mortality with respect to air pollutant concentration. Becasue both cancer and air pollution are rightly topics of public concern, there may be a tendency because of this concern to draw conclusions from existing data which may not be justified. The following example will show how the use of graphical display options may in some cases facilitate this process.

Cancer mortality data is summarized on a county base from death certificates made available from the National Center of Health Statistics. This data was manipulated to include a calculated function for the annual age adjusted rate. The result is to translate the mortality rate into the number of standard deviations above or below the mean rate for the entire U.S. This was done to equalize statistically death rates in counties of different sizes.

For example, if no deaths occur in the California counties of Alameda or Alpine the resulting zero cancer mortality rates do not accurately reflect the respective risks. This is becasue the population of Alameda is about 2×10^3 times as large as Alpine County. Thus zero deaths in Alameda County will be a number of standard deviations from the U.S. mean for most sites. While the number of standard deviations for a given cancer are near to zero for the entire U.S. and if even a single death resulting from this cancer is reported in Alpine county the result would be a substantial increase in death rate from the national mean - again due to the size of Alpine's population.

Other factors unrelated to statistical considerations may also mislead the researcher. For instance, cancer is characterized by long lead times between contracting the disease and succumbing to it. Given the mobility factor which characterizes human populations in this country, it is not possible at this time to determine where individuals who do succumb, initially contracted the disease. Finally, a coincidental relationship between a given pollutant and a given mortality rate does not prove a cause and effect relationship between the two.



ELECTRON BEAM RECORDERS FOR AUTOMATED CARTOGRAPHY

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I. Introduction and Historical Background

Electron Beam Recorders have been developed for the Defense Mapping Agency to produce aerospace, topographic and hydrographic charts and other high resolution imagery and cartographic products.

A computer controlled electron beam recorder (EBR) delivered to the Aerospace Center, St. Louis, Mo. in May, 1978 by Image Graphics, Inc., under a subcontract with the Synectics Corporation is the principal cartographic output device of the Charting, Publishing and Air Facilities subsystems of the Automated Air Information Production System (AAIPS).

Two other cartographic electron beam recording systems which will be delivered to the Hydrographic/Topographic Center, Washington, D.C. and the U.S. Army Engineering Laboratories, Ft. Belvoir, Va. early next year will be used to produce a variety of master recordings in either lineal or raster data formats for the production of maps, charts, text and high resolution continuous tone imagery.

II. System Description

A typical computer controlled electron beam recorder (EBR) system developed for automated cartography is shown in Figure 1. The Cartographic EBR is a complete stand-alone electronic recording system which can produce high quality imagery, graphics and text on film from raster or lineal digital data on magnetic tape. The system is capable of generating graphic arts quality alphanumerics and symbols from a digital font library stored on-line and plotting lines, arcs and contours of variable widths at high speeds. Line widths, character styles, sizes, angles and positions can be rapidly changed upon command. High resolution imagery or graphics can also be recorded in raster format as black and white or continuous tone gray levels using either binary or run length encoded data.

Input data is rapidly composed and recorded directly on film. The latent images generated in the EBR are processed into visible images using conventional film processing techniques. These master recordings and color separations are then used to prepare press-ready printing plates for conventional multicolor printing presses or to prepare high resolution black and white or color composite photographs.

Functional Sections

There are five functional sections of a Cartographic EBR System as shown in Figure 2.

The Input Section consists of a 7 or 9 track magnetic tape system which accepts industry standard ½" magnetic tape with data densities of 800 or 1600 bpi and operates at 45, 75 or 125 ips, and a keyboard console. Input data stored on magnetic tape as data files call out the commands needed to generate each of the cartographic products or high resolution imagery.

For names or symbol placement, the input commands call out the type of character style or special symbol which are stored on-line as digital representations on a magnetic disk and transfers the characters or symbols into computer memory. The input tape also provides recording parameters such as size, angle and position for controling the Symbol/Vector Generator.

For plotting lines, arcs and contours of variable widths, the input data files supply command codes to the minicomputer and Symbol/Vector Generator for computing position of the electron beam and variations in angle and line width.

For high resolution imagery or raster data, the input data files are supplied as an 8 Bit code to the minicomputer for controlling the Raster Scan Translator. The raster data may be binary or run length encoded for recording either black and white or grey level data.

The keyboard console is used as an auxillary input/output (I/O) communications line with the minicomputer.

The Control Section consists of a Digital Equipment Corporation PDP11/34 or PDP11/45 basic binary minicomputer processor with a 16 bit word and 64K words of memory. The minicomputer transfers operating data and plotting instructions to the Data Translator Section to generate and position characters, symbols, vectors or rasters.

In addition, the Control Section contains magnetic disk storage for storing the operating software package and other utility software programs which control lineal or raster recording; and a digital font library for characters and symbols.

The Data Translator Section consists of two major subsystems; (a) a Symbol/Vector Generator (SVG) for lineal and character/symbol data and (b) a Raster Scan Translator (RST) for raster plot and image data.

The SVG and RST convert digital data from the computer controller into analog signals which drive the EBR. The SVG includes all of the Circuitry for:
(a) Character and symbol generation with variable size and orientation control.
(b) Vector generation in incremental and stroke vector modes with variable line width control.
(c) Automatic intensity control.
(d) X - Y random positioning.
(e) Other controls and interfaces for the EBR.

All scaling of character and symbol sizes and positioning of characters with the proper orientation and exposure level; all line work and map features with the proper line width, orientation and exposure level; and all random positioning, is accomplished with the SVG.

The RST includes all of the circuitry for:
(a) Recording a variety of raster formats from 500 to 32,000 elements per line in one axis and 500

to 32,000 lines in the other axis.
(b) Automatic intensity control.
(c) Other controls and interfaces for the EBR.

The Software programs provided with the Cartographic EBR are:
Operating System - for PDP11/34 or PDP11/45 mini-computer controllers is Digital Equipment Corporations standard RSX11M multitasking system.

Vector/Symbol Plot (VSP) - is the principle plot program which controls all plotting; and all names and text composition and placement from input data tapes.

Font Library Update (FLU) - is the software package which is used to create digital font libraries on magnetic disks from properly formatted input font tapes. FLU can be used to add, delete, display or list symbol data and to perform minor editing on font data words.

Raster Scan (RS) - this is a software package which controls the raster plot data supplied to the Raster Scan Translator.

Conversion Programs (CV) - are real-time conversion programs developed for converting existing data bases in Gerber or Calcomp plot formats into Symbol/Vector Generator formats for controlling plotting.

Font Preparation - Digital Fonts may be prepared with a stand-alone system from original artwork of symbols or characters which are scanned and digitized with a scanning optical beam. The digitized symbols and characters are processed and edited and then formatted into a digital font input tape for the Cartographic EBR. FLU is used to develop and maintain the Font Library. Two sizes of each font are stored on magnetic disk. All other sizes and orientation are produced with the Symbol/Vector Generator hardware.

A Graphics Display Terminal has been provided to allow viewing of the data being plotted by the EBR during the recording process. The display is a Tektronix 619 storage display which is interfaced directly to the SVG and the RST.

The Recording Section uses an Electron Beam Recorder (EBR) which is an instrument that converts electrical signals representative of map features, alphanumeric characters, graphic plots or variable density pictures into latent images on electron sensitive film. The latent image is formed by exposing the film with a precisely controlled, finely focused electron beam. An EBR may be regarded as analogous to a cathode ray tube (CRT) recorder where the lens and the phosphor faceplate have been removed and the recording medium placed in the vacuum.

An EBR, consists of a high resolution electron gun, an electromagnetic system for focusing, deflecting and controlling the electron beam, a film transport mechanism for handling various film media, a fully automatic vacuum system which maintains suitable vacuum in various parts of the recorder and a number of highly regulated power supplies, electronic circuits and monitors. Operation control functions of the EBR have been kept to a minimum and are readily accessible to provide the operator with convenient control and ease of operation. Modular construction provides ease of maintenance, trouble-shooting and repair.

Recording Media - various recording media may be used in Electron Beam Recorders; (a) high resolution fine grain silver halide electron sensitive film which is processed by conventional wet chemistry after exposure to electrons (b) dry silver which forms visible images by heat after exposure to electrons and requires no processing whatsoever; (d) electrostatic films and papers which are processed with toner solutions; and (e) electron resists which can be developed by conventional means.

A typical recording film selected for the Cartographic EBR is Kodak Direct Electron Recording Film, Type SO-219 which has a very fine grain emulsion and can be enlarged over 30X without graininess.

III. Performance Characteristics

Table I lists some of the performance characteristics of a typical Cartographic EBR System.

IV. Cartographic EBR Output

Figures 3- 8 are typical examples of output and applications of Cartographic EBR Systems. Figure 3 is a

TABLE I - TYPICAL CARTOGRAPHIC EBR SYSTEM PERFORMANCE CHARACTERISTICS

Film Sizes	140, 127, 105, 70 and 35 mm
Film Transports	Single frame pull down (pin registration or registration punches available)
Maximum Image Size	8¼" X 5"
Minimum Line Width	6 µm
Maximum Vector Length	1024 elements (250 mil-inches)
Line Widths	6 to 261 µm with 8 bit (256 levels) control, in 1 µm increments
Character Sizes	8-250 mil-inches
Character Rotation	1^{o} Increments
Addressable Positions	32,768 X 19,859 address matrix over a 8¼" X 5" format area
Congruity of Sequential Images	± .003%
Geometric Fidelity	± .01% (with software correction ± .05% (without software correction)
Maximum Optical Density	2.35+
Density Range	64 Levels for graphics 256 Levels for imagery
Background Density	0.1 density units
Video Bandwidth	DC - 10 MHz
Lineal Data Recording	
Random Points	40,000 points/sec
Adjacent Points (IVP)	125,000 points/sec
Stroke Vectors (1024 points)	1,000,000 points/sec
Character/Symbol Recording	20-2000 Characters/sec depending upon style, size and quality
Raster Data Recording	
Elements/Scan	500 - 32,000 computer selectable
Lines/Raster	500 - 32,000 computer selectable
Scan Rates	50 - 2000 lines/sec continuously variable

composite photograph prepared to show samples of the Automated Air Information System cartographic products produced by the AAIPS Cartographic EBR System.

Figure 4 is a standard Instrument Approach Chart which is presently recorded at full scale (8¼" x 5") with the AAIPS Cartographic EBR. A contact negative is made from the EBR positive, from which press ready printing plates are made.

Figure 5 is a master recording with Instrument Approach Charts recorded at 4:1 reduction. This recording can be subsequently enlarged to produce a 16 up film flat which can be used to produce a press-ready printing plate containing 16 full size pages (8¼" x 5").

Figure 6,a,b, c are three color separations recorded at 1/6 scale with the AAIPS Cartographic EBR. The color separations are enlarged to full size (20"x45") film flats from which printing plates are produced for a color press. The final product is a color Enroute Chart.

Figure 7 is an example of high resolution raster imagery. This aerial photograph has been recorded at different sizes and different density levels to enhance the input image data using the gamma enhancement circuits in the Cartographic EBR.

Figure 8 is another example of high resolution raster imagery. This satellite image was made from LANDSAT computer compatible input tapes. The data was recorded at different sizes and density levels to enhance the input data.

The Cartographic EBR output clearly illustrates the systems capability of recording both lineal and raster data. The system offers the cartographer the ability to intermix both lineal and raster data bases on the final cartographic product.

V. Acknowledgements

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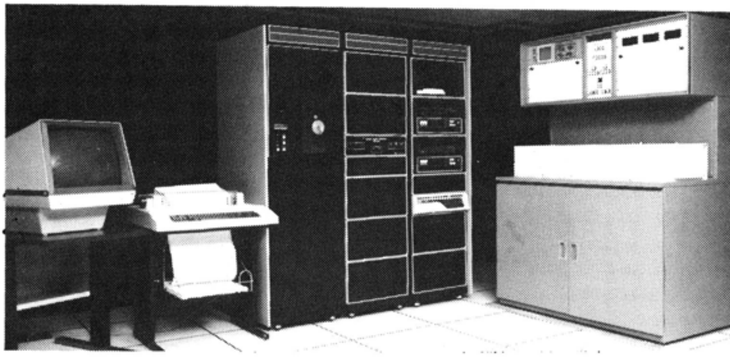

Figure 1 Cartographic EBR System

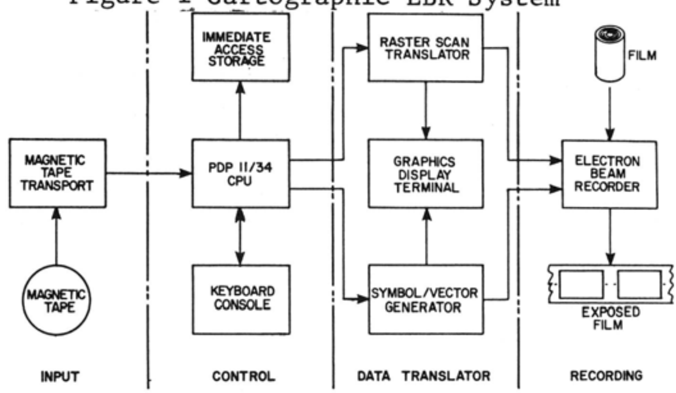

Figure 2 Functional Sections

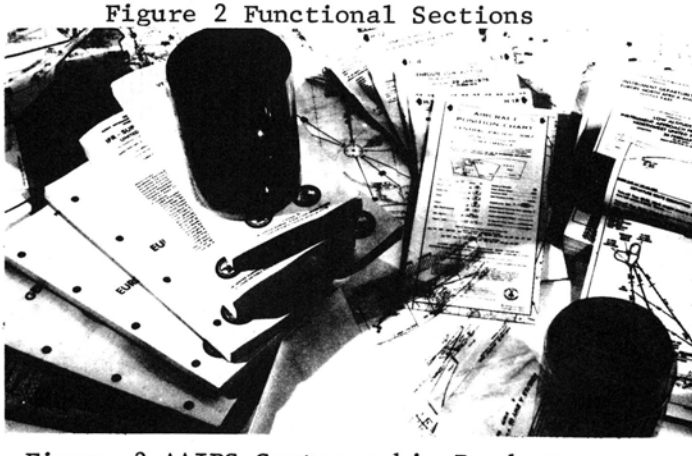

Figure 3 AAIPS Cartographic Products

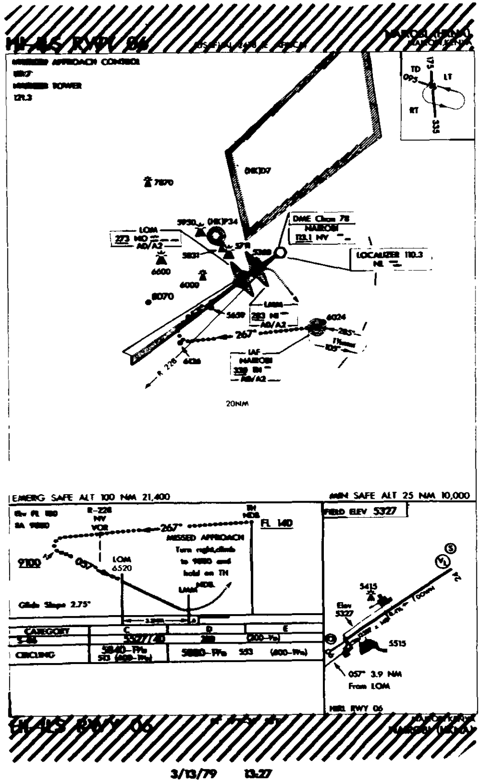

Figure 4 AAIPS Instrument Approach Chart Recorded at Full 5"x8" Scale

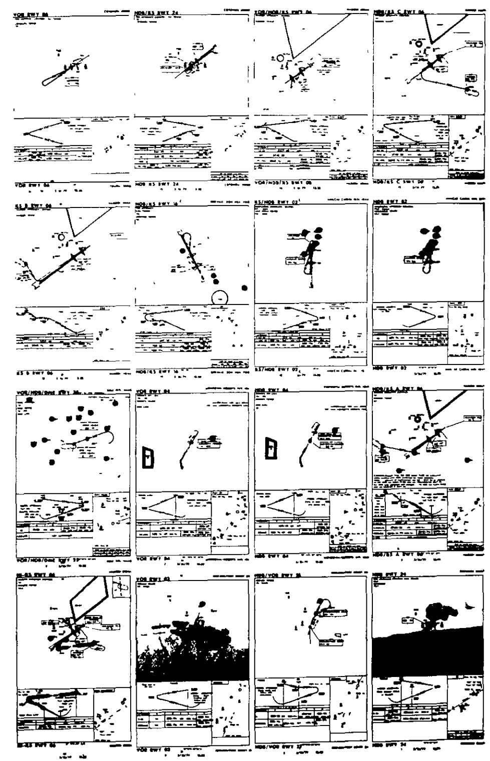

Figure 5 16 AAIPS Approach Charts Recorded at ¼ Scale

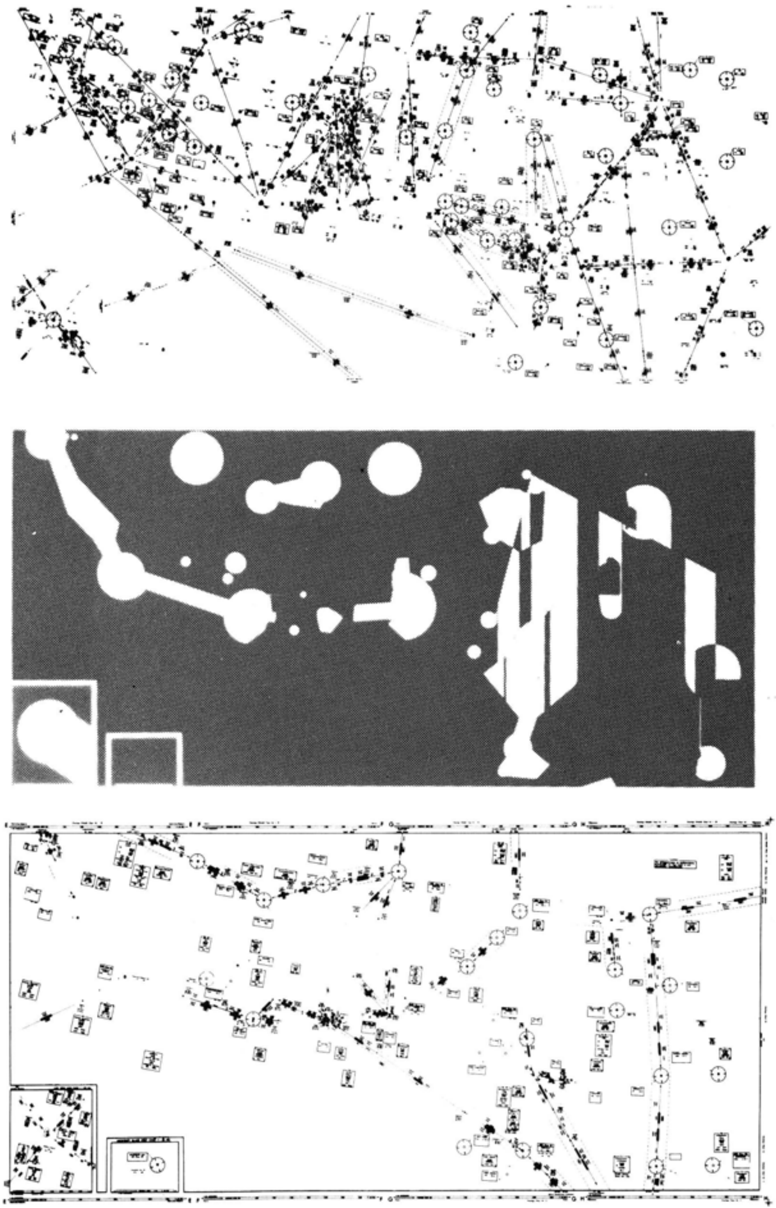

Figure 6a, b and c Enroute Chart Separations (1/6 scale)

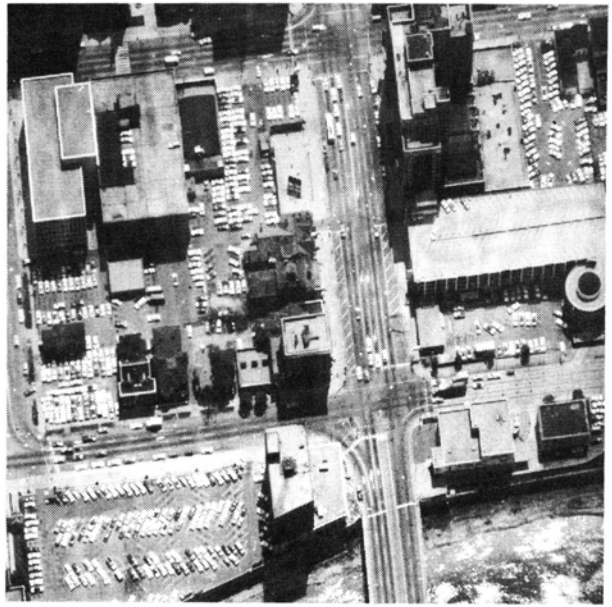

Figure 7 - High Resolution Aerial Photograph Recorded in Raster Format

Figure 8 - LANDSAT Image Recorded in Raster Format

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