RESEARCH PROJECT TECHNICAL COMPLETION REPORT

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Project Title Use of Interactive Computer Graphics in Water Resources Planning and Management

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Project Began July, 1971 Project Ended December, 1974

PROJECT OBJECTIVES

1. To find a computer-graphics-oriented method for studying the dynamic effects of geometric configurations on the interconnecting networks relevant to water resources planning and management.

2. To determine a possible means for evaluating the impact of an interactive computer system on the water resources development process.

ACHIEVEMENT OF OBJECTIVES

A limited graphics system was developed during the first phase of the project. The system allows the user to describe, specify and manipulate 2-dimensional configurations that might exist in a typical interconnecting network. The second object was achieved by experimenting with the ideas and facilities developed in phase 1 using a set of realistic water data. However, only a limited amount of evaluation of these experiments was made.

RESEARCH PROCEDURES USED

Our research has been carried out in three stages. In the first stage, the main goal was to come up with an analytic scheme that would allow us to describe and store graphical data pertinent to water resources problems through interactive means. This is the problem of information representation and organization within a computer. A conceptual data base, called the "Relationship Matrix" (R-matrix), which is particularly suitable for describing and organizing data of 2-dimensional forms (e.g. geometrical configuration of such water-related objects as rivers, lakes, and reservoirs), has been developed. This data base has been found to have many desirable properties that would facilitate the organization and analysis of graphical data in a man-machine environment. In particular, it can be used as a unified data format to allow the active participation of multiple users in the data management process.

In the second stage of the project, our major efforts were directed toward implementing the ideas and techniques developed in Stage I on our PDP-9 computer system. The interactive environment was provided by the
simultaneous use of two graphical terminals - a DEC 339 graphical display and a Tectronix Storage scope - and a Teletype terminal. This implementation involved the development of computer programs that would accept, monitor, and display the graphical data in various forms at user's command.

The final stage of the project was carried out primarily to test and evaluate the concepts and techniques developed using a set of real data relating to water resources. The data set selected for our experimentation was the remotely sensed multispectral imagery from the NASA Earth Resources Technology Satellite (ERTS-1). This data base was made available to this investigator in connection with a Civil Engineering Department research contract with the New England Corps of Engineers. Digitized earth imageries are stored on computer tapes which are believed to contain unique information relating to such earth surface features as water, vegetation and soils. These tapes provide "pictures" of an earth scene at four different spectral bands. A complete scene is about 100 nautical miles square, and is represented at each band as a set of (usually) 2340 lines of 3240 points each, where each point may take on one of 128 different (gray level) values. For purposes of our experimentation, each point was coded to assume either a hexadecimal scale (0 to 9, A to F) sufficient for internal computer processing, or in a 5-level gray scale ('Y', '-', '=', '$', '#'), convenient for human viewing. The computer printout of a scene near the Cape Cod canal and the adjacent land is shown in Figure 2a (Hexadecimal) and in Figure 2b (5-level). A 30-element section for each of the four spectral bands corresponding to the portion enclosed by 4 dots (see Figure 2a) is shown in Figure 3. These imageries, when properly interpreted, can provide accurate, timely information for water resources planners and management.

A prototype interactive system (see figure 1 for a block diagram) which combined the intelligence of the planners (human users) with the speed capabilities of the computer, was attempted. Because of the nature of the data available (on magnetic tapes compatible with large-scale computers), the system was implemented on the IBM 360/65 and on the IBM 2250 graphical terminal at the University Computer Center. The system was designed to operate in the following manner: A user works at the graphical terminal which has displayed on it sections of an imagery to be investigated. These may be seen for any of the four bands. The user has the capabilities of moving the image, changing sections, changing bands, or getting "closeups" on the display screen. A light pen (a device which may be used as a pointer input to the IBM 2250) can then be used to roughly outline hydrological features of interest. Names and conditions associated with the features may be inputted through a keyboard.

Computer programs and routines that would allow much of the operation described above have been developed. Additional computational techniques that would facilitate the interactive processing of imagery have also been investigated.

RESULTS AND CONCLUSIONS

The phase I (stages 1 and 2) of the project resulted in a working system for interactively inputting, monitoring, and otherwise manipulating the
graphic data. A complete description of the design and capabilities of the system is given in [6]. Some of the system's capabilities are:

1) Accept and transform the graphical data in a descriptive form into a computer manipulative form (R-matrix).

2) Display the input data in the original form as described by the user or in the form of an equivalent R-matrix as stored within the computer.

3) Perform mathematical operations as defined by the user on the input data and display the intermediate as well as the end results of the operations performed.

4) Respond to changes and modifications of the input data as initiated by the user.

5) Contain software facilities that can be easily controlled by the user to solve large scale network problems through his interaction with the computer.

In the second phase (stage 3) of the project, a limited interactive graphical system was realized on the IBM 360/65 computer. It consisted of two types of computer programs: the utility programs and the computational programs. These programs were developed in conjunction with the NASA ERTS data described above although they could be easily adapted to other types of data.

The utility programs were written primarily for the purpose of accepting, storing, retrieving, displaying and many other forms of manipulating the data. These programs were necessary to put the data, result of analysis and various other types of information in a form suitable for computer display and human observation. The information to be displayed usually involved several (more than 2) channels such as the 4 spectral bands of the ERTS imagery. Thus, our problem was to transform data of high dimensionality into a 2-dimensional space ready for display. This type of transformations must satisfy the following requirements:

1) must preserve the intrinsic characteristics of the imagery.

2) must be computationally fast to avoid any excessive idle time on the part of human observers while engaging in man-machine interactive analysis.

A set of computational programs were then developed to achieve the requirements above. The transformations were obtained by a class of nonlinear mappings. By iterative means, a nonlinear mapping transforms each of the 4 dimensional points (4 spectral bands) into a 2-dimensional point on the display. An example of such a transformation for the 30 4-dimensional points (Figure 3) is shown in Figure 5 after 10 iterations.

A similar display showing the transformational mapping to be applied after 20 iterations is shown in Figure 6. Three distinct groups of points (water, land and uncertain) were identified on both figures. The performance of these nonlinear mappings was usually measured by the error curve associated with each mapping. These curves measure the errors, resulting from
transforming higher-dimensional data into 2-dimensional, as a function of the number of iterations required. A typical error curve is shown in Figure 10.

Figure 4 shows an experimental comparison of three different nonlinear mappings as applied to a section of the ERTS data (Figure 2 and 3). The Sammon's algorithm was found to be the slowest algorithm but required the least storage. The Chang-Lee algorithm was the fastest but required the most storage. A compromise algorithm - the speedy Sammon's - was developed by this investigator as a variation of the Sammon's algorithm (see details in [3,7]).

In another set of computational programs, the nonlinear mapping algorithms were extended to include the option of recursive applicability. Recursive mapping algorithms (see details in [3]) were found to be faster when the algorithms must be repeatedly applied to expanding data bases. An example of expanded data base, including 60 4-dimensional points in a section of the Cape Cod Canal and its adjacent land, is shown in Figure 7 after 10 iterations of a nonlinear mapping algorithm. Figure 8 shows the same data but after 20 iterations. A comparison of recursive and non-recursive algorithms is shown in Figure 9.

In conclusion, the results of a limited experimentation with the NASA ERTS data indicate that:

1) With the aid of a computer display, the human operator can play a direct and immediate role in selecting the spectral bands that will describe certain hydrological features in the most informative way.

2) Speedy display and user's interaction of information may be achieved by putting transformational algorithms in a recursive structure. This will allow the user to apply the algorithms to various portions of the imagery for repeated analysis without introducing excessive calculations.

LIST OF PUBLICATIONS


ACKNOWLEDGEMENT

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ABSTRACT

An experimental graphics system was developed to evaluate its usefulness in the area of water resources planning and management. The system included a conceptual model and a large number of computational techniques, operational programs, and utility routines. A class of display-oriented transformational algorithms were studied in relation to the NASA ERTS imagery. By combining several spectral bands of information, the possibility of delineating various classes of hydrological events (water, land, etc.) in a man-machine environment was examined. The results of a limited experimentation with a section of the Cape Cod Canal and its adjacent land indicate that (a) with the aid of a computer display, the human operator can play a direct and immediate role in selecting and analyzing the portions of the data of particular interest, and (b) Speedy display and user's interaction may be achieved by putting the transformational algorithms in a recursive structure. This recursive applicability will allow the algorithms to be applied to expanded data bases without introducing excessive calculations.

KEYWORDS

ERTS Imagery Coded in Hexadecimal

Band 7

C C D E F F F D D C C
C C D F F F E D C C C
C C E F F F D D C C C

Water

Land

Band 6

A A A B E D B A A 9
A A A D E C A A A A
A A C E E B A A A A

Band 5

D D C D E E D D D D
E D C E E D D E E E
E D D E E D D D E E

Band 4

C C C C D D D C C C C
C C C C D D D C C C C
C C C C D D D C C C C

FIGURE 3
FIGURE 4
**Figure 6**

- **O**—Land
- **△**—Water
- **○**—Uncertain