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COMPREHENSIVE GEO-DATA BASE CONTROL WITH AN ELECTRONIC COORDINATE DIGITIZER

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GEO-REFERENCED INFORMATION SYSTEMS

BACKGROUND

A need for geo-referenced data within the scientific community has led to the development of comprehensive geographic information systems. Such comprehensive systems are characterized by three fundamental attributes.[1] They possess a data organization which is indexed by using a geographic locator. They have the capability to manipulate and analyze the data base by displaying raw data, to aggregate raw data into classes, to tabulate the distribution of data within a class, and to perform arbitrary arithmetic operations on the data. They also possess the capability to prepare graphical displays of the data in the form of maps. Now that remote sensing has developed as an integral source of data for these data bases, image-based information systems need to have the capability to utilize digital image processing techniques for data entry, and to interface image format data to spatially-referenced tabular data in addition to replicating the computational steps found in the standard comprehensive systems.[2] As the complexity and sophistication of image-based information systems have developed, however, it has become difficult for users, particularly those who do not have digital image processing experience, to fully take advantage of these capabilities. Optimum use of image-based information systems will generally require an experienced user who is familiar with the user response language and syntax, who can anticipate the sequential functions of the system, and who is also familiar with the data base organization and file structure.

Some geographic information systems have been developed with the intent to simplify the use of the system for a particular type of user. These user-oriented systems attempt to "talk" the user through the functions in an interactive session with language commands that are familiar to that type of user. A common problem with this approach, however, has been the diversity of users even when the systems are designed for a specific class of users. Some users, for example, are data collectors, some are planners or analysis specialists, while others are administrators and policy-makers. Each type of user has developed a "jargon" and thought process tuned to a particular type of problem. Definition of a "jargon" as the basis for a command language is difficult under these circumstances unless decentralized information systems are designed for all possible types of users.

Alsberg has prepared a profile for the typical user which might serve as a model for the design of geographic information systems.[3] In this profile, a typical user will know a subset of the data very well. He will want access to raw data as well as the ability to develop interpretations from the data about which he is expert. He will want to derive standard interpretations, however, from the data about which he is not expert. The user will not be a computer scientist, and most likely will have little or no experience with an interactive computer terminal. Most importantly, the user will not necessarily know what questions to ask of a geographic information system, and probably won't have the computer experience to know what capabilities computer technology can support. Since the quality of the information a user can extract from an information system is, among other things, dependent upon the astuteness and creativity of the user, a geographic information system must be able to accommodate the expectations of the typical user, as well as to resolve any difficulties which develop due to his limitations.

Because there is no such thing as

"the" user response language for information systems, effective analogs need to be sought to replicate the thought processes common among the largest number of potential users. The strategy pursued in this work is based on the assumption that the visual context of data is more universal to the user community than are language command structures. Of the three primary sources of data for image-based information systems: Landsat digital image data, maps, and other digital files such as digital terrain data; maps are the single source which exploit the visual quality. Map characteristics allow an interpreter to immediately perceive spatial patterning, the very quality absent in computer data structures. Since image-based information systems are based on the digital image datatype and the associated digital image processing techniques, the user response language and data structures are oriented toward the image processing jargon and data structures. In order for map data to be compatible with these systems, they are transformed into topological data structures with the aid of electronic coordinate digitizers. Maps, therefore, normally disappear from the system until the display functions are invoked sometime during the final moments of a session.

Unless the user is familiar with the methodology by which sources of data, particularly maps, are entered into the system, it can be difficult for the user to mentally link the conceptual design of data structures with existing spatial distributions on the maps. This can especially impede the creativity of a user in developing questions and analysis procedures for the system to follow. Also, by removing the source map from the operation of the system, the user is restricted to interrogation functions only, eliminating the possibility of encoding more data, or defining irregularly shaped regions within the data base about which the user is interested. Both of these problems are related to the communication link by which a user interacts with the system, as well as performs functions to interface non-image datatypes with the digital image datatypes.

This paper reports on the progress being made to design an image-based information system which uses digital image datatype and data structures, but which emphasizes a communication subsystem that allows the user to perceive the data structures as map datatype. The subsystem as it currently stands serves as both the mechanism for communication between the user and the system, as well as the mechanism for datatype interface.

SYSTEM CONTROL

In order to enhance the visual interaction between the user and the image-based information system, an electronic coordinate digitizer serves as the primary communication mechanism. With this approach, the digitizer tablet is partitioned into two main compartments. One compartment serves as a location for mounting a base map of the area stored in the data base, while the other compartment contains an instruction menu. The user's view of the entire system, therefore, is focused on the digitizer tablet. (see figure 1)

Digitizers can operate in many different ways, but they have in common the function of recording the Cartesian coordinates of a point on the digitizer tablet relative to some origin. When a map is mounted on the digitizer surface, the Cartesian coordinates can be obtained for a single point, a line segment, or the perimeter of a polygon.[4] If the digitizer is connected directly to the host computer, this data can be communicated immediately to the system in an interactive session. Since map coordinate systems (e.g., Universal Transverse Mercator, latitude and longitude, etc.) often serve as the geographic indexes of geo-data base systems,

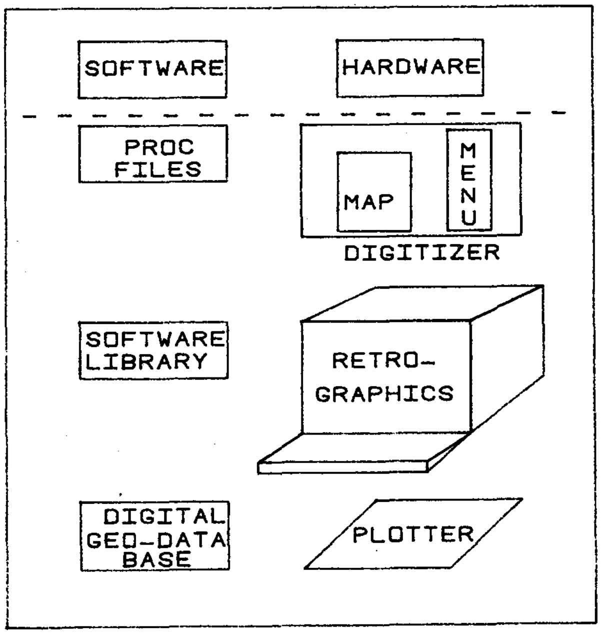

FIGURE 1. USER'S VIEW OF SYSTEM

a direct link exists between the map and computer data structures. Data base software can translate the digitizer coordinates into computer addressable data base coordinates.

In much the same manner, an instruction menu can be mounted alongside the map. The menu can be used as a mechanism for the user to select functions and send instructions to the system. Instruction menus are designed by partitioning one compartment of the digitizer surface into discrete areal units. (see Figure 2) Each unit has a predefined instruction label assigned to the Cartesian coordinates bounding the area. Instructions are communicated to the information system by digitizing a location within any menu unit. Data base software can translate the menu commands into executable functions by a simple search routine applied to a menu command dictionary.

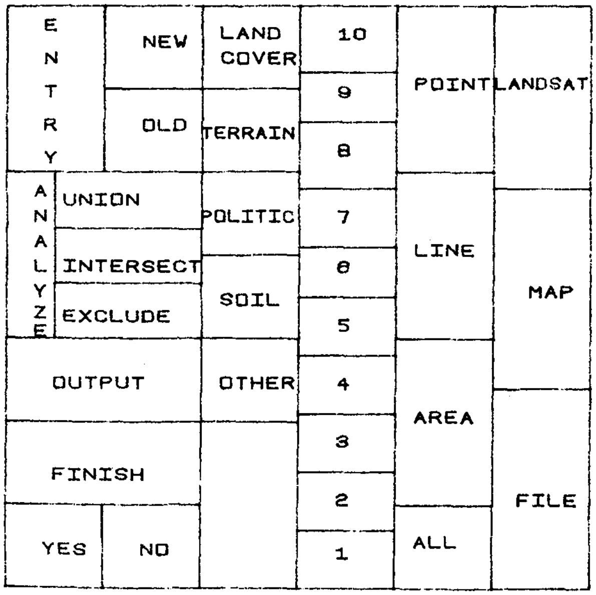

FIGURE 2. SAMPLE INSTRUCTION MENU

By focusing the user's attention on a base map and instruction menu which are both mounted on a single communication device, the user can apply maximum concentration toward what that user wants to extract from the data base. The system can be extremely flexible. A user can choose to perform only interrogation functions on the entire data base by digitizing the appropriate menu commands. A more creative user, however, can use the system to define regions within the data base about which he is interested, at the exclusion of the remainder of the data base. New patterns can be entered into the system during any session since the system is designed to read and translate map coordinates into computer addressable coordinates. Any user can be a data collector, analyst, or policy-maker with no restrictions on the sequence of the operations generally performed by each type of user.

In order for this communication subsystem to work effectively, efficient data structures and analytical methods need to be incorporated which are compatible with the command structure of the instruction menu.

SYSTEM CHARACTERISTICS

DATA STRUCTURES

The image-based geographic information system described in this paper uses a hierarchical data organization to interface Landsat digital image data with other sources of mapped data and digital files; to enhance the communication link between the user and the system; and to perform data base analysis functions. Data are stored in three types of files, referred to as "raw" data structures, geo-referenced attribute structures, and bitplane data structures. (see Figure 3)

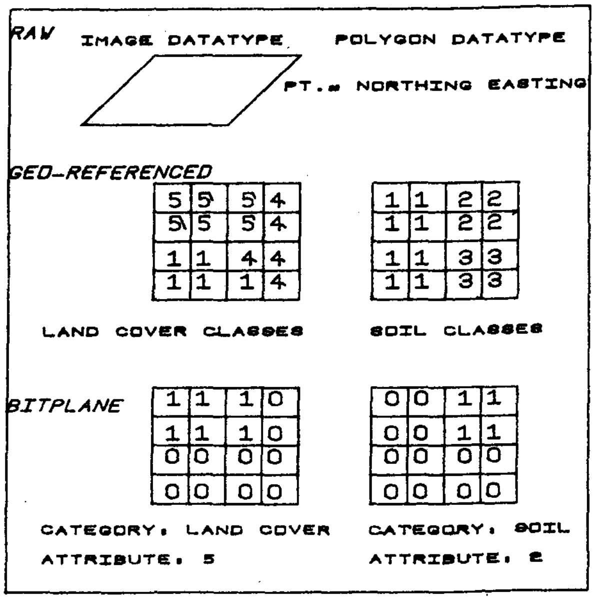

FIGURE 3. DATA FILE STRUCTURES

Raw data structures record the original measurement values or class values, and the locational references of the data for each category in the data base. File structures are dissimilar since different sources of data arrive in various formats, i.e. image data type and polygon datatype. (see Table 1)

A common data structure for the system is supplied by the geo-referenced attribute data structure. An attribute file contains the data value or class for a variable size grid cell which is registered to UTM coordinate location. In essence, the data base boundaries are defined by UTM coordinate minima and maxima for both the northing and easting, and the interior of the data base is divided into cells of a user-defined dimension. Each cell is referred to as an "element" of the data base. The elements are encoded with the corresponding numerical data for that UTM location. One geo-referenced attribute file is stored for each category.

Bitplane data organization records only the presence or absence of a particular attribute.[5] An element of the geo-referenced data structure is encoded with a "one" or a "zero" to indicate the presence or absence, respectively, of the attribute in that element. One bitplane is stored for each data value or class for each category. Although a relatively large number of individual bitplane files might be required for a large number of categories and classes, the small size of each file makes an efficient data organization (binary data structures can be stored as one-bit bytes).

Table 1.
Data Organization and File Structure

Source	Category(s)	File structure
Landsat MSS	Land Cover	Image datatype
Maps	Physical Characteristics (soil, political boundary, etc.)	Polygon datatype
Digital files	Digital terrain data	Source dependent

DATA ENCODING

Landsat digital data. Landsat digital image data is registered to the UTM coordinate system with two transformation equations:[6]

$$x'=p(x,y) \qquad (1)$$

$$y'=q(x,y) \qquad (2)$$

where x' and y' are the scanline and sample in the Landsat image domain, respectively; and x and y are the UTM easting and northing coordinate locations respectively, of the elements in the attribute data structure. The mapping is achieved with a least-squares estimation based on the selection of control points, i.e., scanline, sample, northing, and easting coordinates for a number of identifiable locations on both the Landsat image and base maps:

$$\text{scan} = a_1 + a_2N + a_3E \qquad (3)$$

$$\text{sample} = b_1 + b_2N + b_3E \qquad (4)$$

Inherent distortions in the image geometry; such as caused by earth rotation during the scanning process (image skew), increased scan angle away from the nadir on a scanline, and the inconsistent mirror velocity across a scanline, are corrected prior to computation of the mapping coefficients.[7] Although some error will occur using this method, the amount and location will depend upon the accuracy and distribution of control points, and the element resolution of the data base.

Map data sources. Map data sources are entered into the attribute files in much the same manner. For these data, however, the transformation equations are used to translate the Cartesian coordinates from the digitizer into UTM northing and easting coordinates.[8] Two control points are selected near opposite corners of the map. For each point, the northing and easting coordinates are read directly from the map and are entered into the system through an interactive computer terminal. Each point, in turn, is digitized. The x,y coordinate pairs are adjoined to the northing and easting coordinates of the respective points. Two mapping equations are computed:

$$\text{northing} = a_1 + a_2\, x + a_3\, y \qquad (4)$$

$$\text{easting} = b_1 + b_2\, x + b_3\, y \qquad (5)$$

where, x and y are the Cartesian coordinates, and a and b are the mapping coefficients.

Inherent distortions are also introduced in this method. Corrections are applied to the data for scale:

Scale =

$$(n_1-n_2)^2+(e_1-e_2)^2/(x_1-x_2)^2+(y_1-y_2)^2 \qquad (6)$$

where, n and e are the UTM coordinates, and x and y are the Cartesian coordinates. Map rotation, r, measured clockwise in degrees relative to the two dimensional plane of the Cartesian coordinate system is also corrected, where;

$$270° < r < 90° \qquad (7)$$

Once the transformation equations are established, any point on the digitizer surface can be translated into UTM coordinates. Data base software can round each coordinate pair to an equal interval of the element dimensions, and encode elements with a standard polygon to grid cell conversion.

COMMUNICATION SUBSYSTEM

Now that the data structure and encoding techniques have been defined, it should become apparent why an efficient instruction menu can be designed. Basically, the only inputs which the user needs to communicate to the system are function type: data entry, analysis, or output; category name: land cover, soil, terrain, etc.; class value; and source of the datatype. Depending upon the source, the system can determine the appropriate file structure, i.e., image datatype or polygon datatype.

In an interactive session, the user can respond to the system prompts for inputs. For example, if the user selects the analysis option, the system will prompt the user with

<enter analysis function>

The user responds by digitizing union, intersect, or exclude (refer Figure 2). The system will then prompt the user with,

<enter category, enter finish when complete>

to which the user's response should be to select and digitize a single category. The system will next request the user to digitize a class value for that category. The system will then search a system file dictionary to locate a bitplane file for that category, class combination. If a bitplane is not located, the system will automatically construct one, and record its presence in the dictionary. This procedure is repeated until the user completes the selection of category/class files. Users then have the option to select a region of the data base for which the analysis is to be performed. For example, if area is selected, the system invokes the map registration subroutine to establish the transformation equations from Cartesian coordinates to UTM coordinates. The user should proceed to digitize the perimeter of the region, and the system automatically constructs a bitplane file for the area within the data base.

Other data base functions are performed in much the same manner. The system prompts the user according to the previous user response selection, and automatically performs the necessary file maintenance procedures. Since all user responses are entered from the digitizer, the user can perform both analysis functions and data interface functions during any session. The added flexibility for defining regions during the analysis phase also increases the interaction a user is allowed to have with the data base.

DATA ANALYSIS

The rationale for encoding large amounts of data into a geographically referenced information system is to provide quantitative analysis capabilities for spatial distributions which might not otherwise be available, or will be impractical from a map handling, data interface framework. An example of these functions is the calculation of the areal overlap (intersection) of two or more distributions, such as land cover type on a particular soil type. Basic to these kinds of analyses are a capability to calculate and map the intersection, union, or exclusion of two or more distributions, simultaneously. (see Figure 4)

Since the data within this information system which are acted upon by analysis functions are limited to bitplane organization structures, binary set theory provides rules for the rapid interrogation by these three types of functions. For example,

Let: A and B represent the bitplane matrices for any two Category, class combinations.

Then, define A U B as the union of A and B, and A Ω B as the intersection of A and B. The operation A + B, the matrix elements summed, e.g.,

$$C(1,1) \leftarrow A(1,1) + B(1,1) \qquad (8)$$

results in the union of A and B. A x B, the dyadic product of the elements, not the matrix product, e.g.,

$$C(1,1) \leftarrow A(1,1) \times B(1,1) \qquad (9)$$

results in the intersection of A and B.

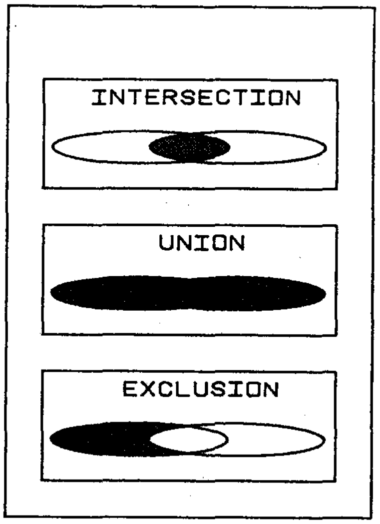

FIGURE 4. ANALYSIS FUNCTIONS

Since binary representations of the data are stored in the data base, simple decision rules must be established to preserve the binary results. The following rules govern the calculations.

For A U B (union):

0 + 0 = 0 cell is in neither region
0 + 1 = 1 cell is in either region
1 + 1 = 1 cell is in both regions

For A Ω B (intersection):

0 x 0 = 0 cell is in neither region
0 x 1 = 0 cell is in only one region
1 x 1 = 1 cell is in both regions

For A - (A x B) (exclusion):

0 - 0 = 0 cell is in neither region
1 - 0 = 1 cell is in exclusion, A but not AxB
1 - 1 = 0 cell is in both regions
0 - 1 = 0 cell is in AxB but not A

More complex calculations are possible by embedding the computations within parenthetic rules. For example, the elements which are in the union of two bitplanes, but are not in the intersection, can be found by (A + B) - (A x B). In a similar fashion multiple bitplanes can be analyzed simultaneously, for example, (A x B) x C; or (A + B) - (B x C). Since more than a single question is likely to be asked of the data base system within any single session, the combinatorial problem demonstrated with the parenthetic calculations is trivial with bitplane structures. The product or sum of any bitplane analysis can be retained for subsequent use in the calculation of a more advanced computation.

DEMONSTRATION

A natural heterogeneity of land cover usually occurs in mountainous terrain. Vegetation cover type and density are affected by complex interactions of climate, topography, and edaphic conditions. Slope, aspect, and elevation of the terrain influence the characteristic vegetation. As such, it is possible to define floristic-physiognomic vegetation belts with these characteristics. When vegetation patterns are being analyzed through remote sensing, these characteristics become a useful added dimension.[9]

In this study, the relationship between vegetation patterns and elevation are evaluated for a location in the Crazy Mountains, Montana. A corrider aligned east to west across the Crazy Mountains encompasses all elevations and slope aspect characteristics. Eighteen spectrally unique land cover classes were derived from a July 25, 1978 Landsat III MSS scene with an unsupervised clustering algorithm. (see Table 2) An area from 530,000 to 570,000 meters east, and 5,110,000 to 5,100,000 meters north in the UTM coordinate system were classified with a maximum likelihood technique. 100 x 100 meter cells were encoded with land cover data from this classification.

Table 2
Land Cover Classification

Class	Frequency	Name
1	344	Water
2	3325	Forest 1
3	1783	Forest 2
4	2101	Forest 3
5	1957	Forest 4
6	1143	Forest 5
7	645	Forest 6
8	720	Forest 7
9	1833	Riparian
10	1637	Brush
11	1301	Bare 1
12	2143	Bare 2
13	690	Bare 3
14	553	Bare 4
15	1136	SNOW
16	1014	Ag 1
17	2986	Ag 2
18	2483	Ag 3

In order to create matching bitplane files for elevation zones, the 5600', 7520', and 9520' contours were delineated on USGS 7 1/2 minute quadrangles. The resulting polygons were composited into four bitplane files. The four elevation bitplane files represent: (1) less than 5600', (2) 5600 - 7520', (3) 7520 - 9520', and (4) greater than 9520'. (see Figure 5)

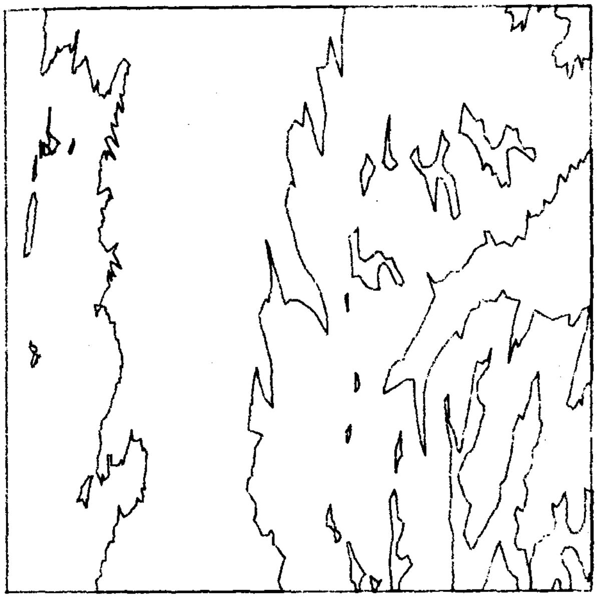

FIGURE 5. SLOPE POLYGONS

The intersection of each land cover class and each elevation zone illustrates the spatial relationship between land cover pattern and elevation zone. Theoretically, each vegetation class should be contained within a single elevation zone. Practically, however, the relationships aren't that clearly defined. (see Table 3) More than one slope and aspect can occur within a given elevation zone, resulting in the conditions necessary for different vegetation patterns.

The apparent distinction between the four forest classes in the Landsat classification can't be made solely on the basis of elevation. Further investigation could be accomplished with this system, however, by subdividing the elevation zones into slope and aspect divisions. The new bitplane files constructed from these polygons could then be intersected with the bitplane files previously constructed from the intersection of land cover and elevation.

Table 3
Class Occurrence by Elevation Interval

	Elevation Interval (j)							
	>5600'		5600-7520'		7520-9500'		<9500'	
CLASS$_i$	17.1% area		38.3% area		39.0% area		6.5% area	
	$\%_i$	$\%\Sigma_j$	$\%_i$	$\%\Sigma_j$	$\%_i$	$\%\Sigma_j$	$\%_i$	$\%\Sigma_j$
1	.0	.0	15.1	.4	70.9	2.2	14.0	2.8
2	36.9	25.9	22.3	6.9	41.5	12.7	.8	1.6
3	13.2	5.0	37.1	6.2	49.9	8.2	.0	.0
4	.0	.0	56.7	11.1	43.2	8.3	.0	.1
5	.0	.0	58.7	10.7	41.2	7.4	.0	.1
6	1.0	.3	9.8	1.0	76.9	8.1	12.4	8.2
7	.0	.0	10.2	.6	82.0	4.9	7.6	2.8
8	.0	.0	29.4	2.0	70.4	4.7	.0	.0
9	33.2	12.9	62.2	10.7	6.6	1.1	.0	.0
10	3.3	1.1	83.6	12.8	13.2	2.0	.0	.0
11	2.3	.7	3.3	.4	64.3	7.7	29.9	22.4
12	21.1	9.5	.1	.2	59.0	11.6	19.1	23.5
13	.0	.0	3.0	.2	84.3	5.4	12.6	5.0
14	.0	.0	1.8	.1	83.7	4.3	14.3	4.5
15	4.2	1.0	.0	.0	53.5	5.6	42.1	27.5
16	25.7	5.5	17.6	1.7	54.6	5.1	2.5	1.4
17	35.3	22.3	64.7	18.1	2.6	.7	.0	.0
18	29.8	15.6	72.4	16.8	.0	.0	.0	.0

CONCLUSIONS

The importance of interactive geographic information systems will surely increase as more inexperienced users require georeferenced data. The system described in this paper is an initial attempt to meet these projections in the State of Illinois. Although this system will undoubtedly evolve, the current success has demonstrated that a communication subsystem can be incorporated into image-based information systems that can provide effective datatype interface and data analysis for a wide range of users and applications.

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