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GEOGRAPHIC INFORMATION SYSTEMS: A PRIMER

by

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Geographic information systems (GIS) offer a computer-based method for systematically recording, storing, retrieving, analyzing, and portraying geographically referenced information. In addition, new techniques for spatial analyses are provided that range from multi-layer stacking and interpretation of georeferenced data to automatic construction of new coverages (digital maps) produced by intricate analytical routines.

Developmental trends currently under way indicate that merger of computer-assisted cartography (CAC), computer aided design and drafting (CADD), and GIS technologies is taking place under the umbrella of spatial data analysis and management. With the passage of time, the segregation of the technologies is becoming less and less apparent, and the capabilities provided therein are becoming more and more interdependent. As a result, GIS is not currently unified in a well-defined disciplinary niche and presently suffers from a serious lack of definition of terminology, concepts, and standards.

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This report is intended to serve as a primer for middle and upper management personnel who may be considering applications of GIS hardware and software with intent to apply GIS technology in solution of local problems. Concepts are defined, and an attempt is made to identify some of the more generally accepted applications for GIS technology. Finally, a glossary of terms and a bibliography of relevant literature are included in an attempt to arrest some of the confusion that surrounds the GIS technology.

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PREFACE

This report was prepared by Mr. Kevin L. Schultz, Project Manager, under the direction of Dr. Bruce E. Davis of the Center for Spatial Data Research and Applications, Jackson State University, Jackson, Mississippi, under Contract No. DACW39-89-M-5054.

The work performed in connection with this contract was accomplished under the guidance of Dr. Edward E. Middleton, Chief, Computer Aided Engineering Division, and Messrs. Carl S. Stephens, Chief, and Richard Bradley, CADD Center, Information Technology Laboratory (ITL), US Army Engineer Waterways Experiment Station (WES). General supervision was provided by Dr. N. Radhakrishnan, and Mr. Paul K. Senter, Chief and Assistant Chief, ITL, respectively.

Commander and Director of WES during the conduct of this work and preparation of this report was COL Larry B. Fulton, EN. Dr. Robert W. Whalin was Technical Director.

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INTRODUCTION

GIS--Geographic Information Systems--is a relatively new information technology-oriented methodology designed to capture, store, manipulate, manage, analyze, and display both spatial and non-spatial data. It is a technology because of the innovative computer foundation, but more important, it is a methodology because a revolution based upon its techniques, procedures, and applications has become apparent. GIS is an outgrowth of numerous existing technologies, e.g., cartography, spatial analysis, remote sensing, computer mapping, and digital database management. GIS, as a modern, computerized version of old manual methods of cartographic analysis and display, is opening new paths to new types of applications. This report is a "primer", a very general introduction to GIS, discussing its foundations, rudiments, basic operations, applications, and future. As a primer, this report is not meant to be a thorough text but stands as a prologue for more detailed information.

Preface

Several points must be stressed before a detailed discussion is offered. Most of the particulars addressed are secondary to a larger understanding of GIS; nonetheless, there is a synergy involved in considering numerous small items in a novel discipline, for the basics are built from both trivial and momentous components. Also, there is no order of importance.

First, as a new field, GIS is in its relative infancy. As such, there are questions concerning the use of particular words, phrases, and ideas. The concepts and semantics of GIS are still evolving. Appendix I presents a glossary, gleaned from various sources and edited for clarity, which should help to establish some commonality.

Second, "spatial data" refers to any data or information that can be located or tied to a location, regardless of the original form (tabular, map, image, or some other form). Essentially, spatial data possess attributes or characteristics that are linked to location.

Third, originally an acronym and now a noun, the term "GIS" is transforming grammatically. The plural has not been resolved, taking the form of: GIS's, GISes, and GISs. The latter is used here because it conforms best to established grammar.

Fourth, although the "S" in GIS stands for "system(s)", it is not unusual to see or hear the term "GIS system(s)", despite its apparent redundancy. Because GIS is a noun and contexts clearly exist in which computer systems devoted to the field are considered, it is not meaningless to refer to GIS systems. Technically, it may be correct but too awkward to refer to "the computer systems supporting geographical information analysis..." For convenience, the term GIS systems is not avoided here.

Fifth, in this primer, use of the terms "small scale" and "large scale" are limited to the cartographic concepts. Large scale is the cartographically larger ratio which renders features larger as the scale increases. Conversely, smaller scale denotes smaller depictions of features as the scale decreases. The generic concepts of large scale meaning large area and small scale meaning small area or a small task are not used here in order to avoid confusion. Mixing the two concepts would be very confusing: a large scale project would use small scale cartography and a small scale project would use large scale cartography.

Sixth, a grammatical controversy lies in the use of the term "data". In a pure sense, a single bit of data is correctly referred to as "datum" and collectively they are known as "data". Therefore, it is most correct to say "datum is" and "data are". However, the phrase "data is" may be grammatically incorrect, but its increased common usage, even in prestigious journals, is establishing validity through repetition and communal understanding. The English language is dynamic and seems to accommodate comfortable terminology. Therefore, the term "data is" will not be avoided here.

Seventh, the term "methodology" is used here to encompass the set of processes that compose the operational mechanism: individual techniques, the procedures making use of the techniques, the philosophies and paradigms driving the procedures, and the overall approach and strategy program that guides the entire process. Methodology is much more than the method employed, it is the fundamental foundation of a process-oriented technology. As will be discussed, GIS is a methodology rather than an ensemble of technical hardware, software, and techniques.

Finally, basic to the implementation and utility of GIS is that it has a history of introduction and application like many other technical innovations. Essentially, all new technologies go through three phases of acceptance:

(1) **Reluctance to use:** the inertia of tradition and comfort says that the old, known ways are better than the new.
(2) **Preliminary acceptance:** once initial barriers have been overcome, the new technology is used to reproduce old products using new methods; new ways of doing old things.
(3) **Full embracement:** experience with the new technology results in comfort and enthusiasm, revealing the full capabilities of the technology; new ways of doing new things are developed.

Today, GIS technology is transitioning from stage two to stage three.

Introduction

GIS began and is still considered primarily a computerized system for spatial (geographically-referenced) data management. As this primer demonstrates, there is much that can be introduced concerning the foundation, operations, technicalities, components, applications, and future of GIS, but if a concise statement was needed, perhaps the following lists offer the most succinct and terse description. Major functions of GIS include collection, storage, retrieval, transformation, analysis, modelling, and display or output. The five major basic components of GIS include the geographic database, software, hardware, user interface, and the support for structure, e.g., organization and people. The basic functions that accompany these components are inventory, analysis, mapping, modelling, and production The central operations that accompany these functions are data capture and entry, database management, data manipulation and analysis, and reporting and map production. All of these will be described and explained in subsequent sections.

More important than the computer system and facilities comprising GIS as stated above are the approaches, operational and applications philosophies, and dynamic concepts arising from its use. GIS is much more than a spatial data management and analysis system; it is a methodology, a set of procedures and principles, based on advanced technology, to accomplish new modes of spatial analysis and map production. Initially considered a subset of remote sensing and cartography, GIS has grown sufficiently to be regarded as a discipline--an integrative system of theories, approaches, techniques, subjects, and interests, replete with a substantial and diverse literature base. New paradigms in spatial analysis, remote sensing, cartography, and geography are being produced through applications of GIS.

Typically, a GIS uses both a database and a graphics system. Although some systems do not utilize a database link, they are still referred to as GIS (discussed later). Any characteristic or attribute linked to a location can be used in a full suite of GIS routines. Further, every item need not be locational in nature, but may be simply tied to a location. For example, a building's name, color, and functions may be tagged to its address (location), allowing each attribute to be subsequently used as a query or linking element without any prior knowledge of its location. Thus, a GIS database may have numerous fields or items, yet only one field needs to be locational, with all others linked to that factor.

A GIS may perform simple tasks, such as mapping or finding specified features. Often, the most impressive and persuasive demonstrations are based upon such easily understood assignments and the basic applications are usually of this nature. However, GIS also may execute very complex tasks, such as "site suitability analysis" where numerous data files are manipulated in complicated ways to select only the best locations based upon elaborate criteria. In either case, GIS has a multitude of applications, whether relatively rudimentary or highly complex. Appendix II offers a sampling of diverse GIS applications.

GIS is a high initial investment item, yet it is extremely cost-effective and satisfying in the long run. Establishing and maintaining a GIS can be expensive, requiring dedicated facilities, equipment, personnel, and structure. More important, GIS is able to transform information flow within an organization, effectively revolutionizing the operations, but it requires new institutional paradigms for successful incorporation and implementation, dealing with activities from data entry to map production, Disruption and confusion can result from this transformation, although to overcome the change from old to new, significant conversion may be necessary for some organizations. Overcoming this initial reluctance is the first step in the acceptance of new technology. Once GIS is initiated and its capabilities are appreciated and utilized, payoffs are realized and enthusiasm is usually enhanced.

What can GIS actually do for an organization? This question is addressed in detail in this primer through discussion of the various components and relevant issues of GIS. Generally, information management will be transformed into a centralized and efficient system, resulting in enhanced productivity and innovative directions. GIS can change the way organizations think about data, produce and use data, and how they approach problems. GIS can be much more than a convenient computer system that manages information more efficiently; it can provide new approaches and directions to accomplish new things and enhance productivity.

This report discusses the various constituents, principles, and fundamentals of GIS. For the sake of brevity, this document does not attempt to be complete (nothing short of a massive tome will provide all pertinent information), however, it does attempt to be comprehensive. By nature, a primer introduces breadth and provides a sense of depth. Obviously, a wealth of literature exists behind each major component; the bibliography attempts to cover this dynamic field. Also, because of the extremely rapid pace of computer technology and GIS advancements, all information presented is subject to change. Nonetheless, we believe the fundamentals introduced here will endure, and only the technologic details and capabilities will transform.

HISTORY

Today, GIS is the modern computer version of two old methodologies: cartography and map analysis. The first computer mapping program, SYMAP, was developed in the 1960s and introduced the field of computer-assisted cartography (CAC). Output was relatively crude, e.g., line printer characters were outlined with colored pencils to highlight, or differentiate, features of interest. However, SYMAP's also provided rudimentary, but introductory, analytical functions for spatial data. Thus, computer-aided spatial analysis was born.

As remote sensing (RS) developed in the 1960s, intensive interest in spatial information and imagery emerged. Imagery from space offered the synoptic view, exhibiting multiple benefits over low altitude aerial photography. New exotic sensors presented views of the world outside of the visual spectrum. As computer technology developed, particularly the graphics and database management capabilities, and as remote sensing became more applied, computerized spatial analysis techniques undertook new importance. Therefore, the mid 1960s represented the first significant growth of digital spatial analysis technology.

During the 1960s and 1970s, these two technologies, CAC and RS, provided data and information for use in broad applications, e.g., resource assessment and land evaluation. In the late 1960s, the environmental awareness movement introduced the realization that social and physical geography of the Earth did not work independently, rather its processes were holistic. Consequently, demands arose for integrated multi-disciplinary data and information.

In the early 1970s, modern GIS evolved from developments in computer-assisted cartography and remote sensing (CAC + RS = GIS). Initially tied to cumbersome and limited mainframe systems, the technology developed at a relatively slow (but effective) pace until the advent of microcomputers in the late 1970s. Since then, GIS's development (and perhaps its actual wide acceptance) has flourished from advances in computer science.

A history of microcomputers and their impact upon technology and science is avoided here, but it is obvious that numerous advantages have resulted from the technologic innovations. Quicker, more accurate, more reliable, and more cost-efficient analyses of large data sets are afforded. Today, microcomputers rival earlier minicomputer and mainframe systems, and GIS has benefitted exceedingly well. Modern GISs often contain modules, which offer custom programming tools, to maximize flexibility and to meet users' project specific needs. Also, vendors now market systems which provide system installation, hardware and software maintenance, system security and organization, adequate documentation, and training. In effect, GIS has evolved from a mapping-based technology to a full functionality discipline.

To aid decision-makers in dealing with traditionally unstructured problem-solving, the better GISs have been integrating Decision Support Systems, Artificial Intelligence, and Expert Systems to enhance their spatial analysis capabilities. These particular areas of computer science are rapidly evolving and as a discipline, GIS is quick to exploit technologic enrichment.

Recent advances in computer technology have allowed GIS to become a standard decision-making tool for a broad range of planning and management applications. These powerful analytic tools enable users, managers, and decision-makers to deal more effectively with the complex and interrelated issues associated with, for example, natural resource management problem-solving. A direct relationship exists between data quality and the analytic tools available to decision-makers and the quality and effectiveness of decision-making. Thus, GIS promotes better decision-making, resulting in improved comprehensive management decisions, by providing flexible methods to perform unique, often previously or traditionally infeasible, analytic tasks. GIS's role in master planning will be discussed in more detail.

DATA STRUCTURE

Data Types

The primary data types used in GIS are points, lines, and polygons. (Although surfaces, or mathematical derivations of the surface configuration, can also be used, they will not be discussed here because of their relatively advanced nature and lack of common usage). All spatial features can be expressed in one of these three types. A point is a relatively dimensionless location that has attributes tagged to it. It has neither height, width, or weight (except for cartographic representation and ease of visual depiction). Generally, a point represents a location where a sub-resolution size feature exists, e.g., a house or other single element that has ground dimensions smaller than can be depicted at the viewing scale). Often points are not easily observed on a monitor or a hardcopy map and must be artificially enlarged or magnified for easier depiction.

Raster structures (discussed later; essentially a gridded arrangement of data) treat points as single cells (the smallest recognizable unit). Accordingly, depending upon the size of the cell, point location may be inaccurate. That is, the actual location may occur anywhere within the cell and the user will not know the specific site or the inaccuracy involved. Also, there are specific constraints for point data manipulations in raster systems, e.g., encoding them last in the overlay operation to avoid dominance by lines or polygons. As will be discussed, the raster structure has limitations, which are most prominent when dealing with point data.

Lines are one-dimensional depictions of linear features, e.g., transportation lines or administrative boundaries. Lines have length but no real width or depth, except for depiction purposes. Points rarely overlap, but lines can be superimposed by other lines or polygons. Line feature designation (coding or naming) must be completed for each segment if they are to retain individual identities. A single line can be broken into two portions by introducing an intersection; the part without the original label attached may become a non-entity or unidentified line, forcing post-data entry editing. Some systems have automatic means of preventing this problem through the use of internal identities of any feature regardless of subsequent use after initial entry. This is one of the more esoteric data structure qualities of good GISs that should be considered in the implementation process, though it may be apparent only to the experienced GIS operator.

Polygons are enclosed area features having length and width, i.e., components large enough to depict 2-dimensional (2-D) spatial extent. Polygons are the most common GIS feature for most natural resource projects. Forest areas, lakes, cities, and land uses are common polygon features. Because most systems offer automatic area statistics of all features, data entry (digitizing) of polygons must be performed carefully to ensure spatial accuracy. Again, some of the less flexible GISs have data entry functions that dictate that the latest data entered dominate earlier data. For example, polygon B was entered after polygon A and their overlap area will be coded as polygon B. Some systems demand that polygons be identified upon initial digitizing, whereas other systems permit labels to be identified after all the arcs and lines have been entered. Careful digitizing is critical.

Raster and Vector Structures

Perhaps the most heavily discussed aspect of GIS data structure is the raster versus vector controversy, the two "flavors" of GIS. The choice is a major consideration in selecting which type of GIS to implement and the operating organization to be employed. Fortunately, recent advances are making the debate less relevant because more systems are capable of managing both data formats. Soon there may be "Vaster" or "Rector" formats, using both formats with effective transparency to the user.

A raster-based system uses a gridded data structure (rasters), where each grid cell is the minimum resolution area depicted, with all ground features occurring within the cell area condensed to a single cell value. A vector structure retains all features (at least at the digitized resolution) and is, in effect, a maximum resolution format. Each system has advantages and disadvantages, of course, and each section discussed below will briefly address some of the more pertinent raster versus vector concerns.

The essential advantage of a raster structure is that it can be a simplified format, saving time and storage. A disadvantage is that it generalizes reality and therefore offers particular depiction problems. That is, the ground area covered by a cell is coded as one value regardless of the diversity of features present. Various algorithms are employed, such as averaging all the features' individual values into the cell number (data generalization), choosing the center feature as the determinant (center point value to cell value), and reading the dominating feature's value (dominant value).

A vector format tends to retain the best reality, at least to the digitized resolution accuracy. Data are not generalized but retain their position accuracy and spatial dimensions. However, vector structures may require significant storage space and additional levels of data management sophistication; it is not a simple data structure.

For feature identification some, relatively simple raster systems operate on a cell coded basis (no name), particularly those lacking a database or with a limited database attached. Feature names are not used directly, only a derived code stands as a surrogate for the element. The cell value is a number that indicates the code of the class or magnitude of the theme depicted. For example, 1 = Evergreens, 2 = Conifers, etc. (names), or 1 = 100-150 population, 2 = 151-250, etc. (magnitudes). This system limits the information that can be manipulated and, as will be seen, presents problems for the operator. More powerful systems, utilizing sophisticated integrated databases (usually vector-based), avoid the indirect value coding scheme by recognizing names or direct magnitudes. The internal operations are complicated, but the input and output are very closely affiliated with, or identical to, the name and nature of the data. Advantages will become evident, particularly in the analytical discussion.

One comparative example between the two structures is the depiction and storage of a linear element, e.g., a highway. First, the raster system generalizes the road to cell width, typically making it much larger than ground reality would indicate. The vector system uses a line, which has length but no width (unless both sides of the highway are digitized). On the raster file, if the route runs either directly vertical or horizonal to the grid structure, a linear pattern of cells will be depicted, but if it tends to be in a diagonal direction, a series of stair-stepped cells will represent the feature. In contrast, the highway is unaffected by direction in the vector system. Obviously, the output device (monitor or plotter) may generalize vector data, but the data storage (the most important aspect) is not changed.

To achieve better depiction of reality in the raster format, a greater number of cells may be used to improve resolution; high density of gridding may accomplish the appearance (to the eye) of continuous lines and features. A large number of grid cells means that each cell represents a smaller area on the Earth and therefore offers a greater resolution and better representation of reality. Conversely, fewer grids obviously mean easier data management but greater generalization of reality. The higher price paid is in storage and access. Greater densities require more space and slower operations. Thus, an important consideration for a raster structure is the number of grids to be employed.

As will be discussed, images are normally a raster-based structure (due to the nature of the sensor) and therefore are usually compatible with raster GISs. This allows easy use and rapid incorporation of digital imagery with GIS coverages (digital map--see Appendix I), a particular advantage of raster systems. Nevertheless, merging images with vector systems requires either vectorization of the images or rasterization of the vector GIS file, both of which generalize the data to some degree.

Even though vectors have greater spatial integrity, the original raster data are from a cell-wide format and the vectorization algorithm "guesses" the best spot within the cell area to make the vector connection. There is a loss of spatial accuracy despite the smaller depiction of data. Conversely, when vector data are rasterized, there is the same reduction in spatial accuracy as when gridding digitized files. In either case, the basic rule of data manipulation is that there is a loss of quality with each generation of processing, regardless of appearance to the eye.

Raster data may be coded and structured in various ways, from compression (space saving) methods to quick access techniques. Explanation of the various types is too complicated for this report, but three examples are offered for illustration. The first example is run-length coding which compresses storage requirements by using a row-by-row reading of values and collecting all identical adjacent cell values into a single expression as opposed to using a cell-by-cell reading. Data storage volume is greatly reduced. The second example is quadtree format which involves recursively subdividing the coverage grid to encompass features into quarters and building a tree to represent the result.

The third example is chaincoding which reads only the nodes or turn points of a particular feature on a grid and encodes the proper raster cell. The lines needed to connect the nodes are assumed and are not needed in the description. Chaincoding can include all the nodes of a particular polygon (on a row-column description basis) or can employ a sequential list of cells that are needed in polygon definition, adding the proper polygon label with each cell description.

Although many potential users are not interested in the method of data structure coding, there is a need for basic familiarity in order to make intelligent decisions on system implementation, data quality evaluations, and production planning.

Topology

Many vector systems preserve spatial data by coordinates and some systems offer an additional data structure capability termed "topology". In effect, topology is the "intelligence" that is stored for each feature, primarily in the form of connectivity of data which defines the location of features relative to each other (yet it is independent of distance or directions). A common example of connectivity is the airline route map, where line connections functionally link cities (nodes) and are necessary to depict the entire system. Essentially, topology establishes the linkages necessary to determine where features are and how they relate spatially to other features. An associated and integrated database determines attribute relationships.

The actual computer operation for determining topology is complex, but fortunately it is transparent to the user. Simply stated, topology is the ability of a feature or arc to recognize what is to the left and what is to the right, or which features a particular arc belongs to. This is called adjacency, or contiguity. For example, when an arc is entered, it stands alone (only with coordinate information) but when the arc is a line or part of a polygon, features to each side are registered as left and right "members" or associated data.

For polygons, connectivity defines the areal extent of each adjacent polygon. If a good database structure is used, all attributes and identifications on adjacent polygons are linked to the central polygon under consideration. For example, a coverage of Africa represents each nation as a separate polygon, with the database file containing a variety of attributes for each of the countries. Topology permits the linkage of all adjacent nations from any part of the database. Querying (asking) the database for the countries connected to Kenya is relatively easy to accomplish, and displaying their capitals requires only another phrase in the query command. Therefore, spatial and thematic relationships can be determined and analyzed.

In general, raster systems do not use topology, but technology advancements may soon permit the capability. Presently, databases of raster systems do not offer good connectivity or relationship analysis (with a few possible exceptions).

DATA SOURCES

Sources of GIS data are highly varied, ranging from original ground truth information to standard digital products from federal agencies. Three basic categories of data sources exist: manual entry, digital products, and remote sensing (Appendix III). Data entry was discussed in the previous section and will be reviewed here in terms of a source of data.

Manual Entry

Manual entry is the most common form of data input in most GIS projects, consisting of manual digitizing or keyboard entry of data. Manual data entry is very slow and prone to error, although a major benefit is the control over the features entered and the coding method. Also, the area used can be controlled, with limited reliance from outside sources.

Keyboard entry of tabular data is also a very slow process and prone to error due to typing mistakes, but for many data types, this may be the only viable method of data entry. Common sources of tabular data include census tract information, city or county statistics, and lists offering a location but no numeric data as the primary form. Upon further development of optical scanning and character reading technology, entry of these data types will be greatly facilitated.

Digital Products

In the last few years several government agencies have begun producing their products in digital form. Although still in its infancy, standard digital products are beginning to make an impact in GIS, with significant advances anticipated. For example, the U. S. Geological Survey (USGS) produces Digital Line Graphs (DLGs) containing basic vector data typically present on topographic sheets--roads, rivers, streams, and administrative boundaries. While some questions regarding data quality exist, DLGs are becoming an important and expected source of land information for many GIS projects. Appendix III presents some of the more positive digital data sources and products now available, with other types forthcoming.

TIGER (Topologically Integrated Geographic Encoding and Referencing system) files are Census Bureau products meant to represent 1990 census data in digital format. Trial 1980 data files and 1987-1988 estimates have been available for testing and development, but numerous problems have been encountered, rendering the data suspect in quality and revealing a need to change data format for the 1990 data. High optimism abounds in some circles that TIGER files will become a standard source of demographic and socio-economic data for most users, yet controversy exists concerning data quality. For instance, it is not clear if the data will be consistent for all parts of the U.S. nor if all topology is to be credible.

Typically, a standard digital product is incorporated into a GIS from a purchased digital tape or a CD-ROM disk. Floppy disks of some products may also be available. Because of the wide range of GIS vendors and types of systems, standard digital data products are not universally compatible and some investigation is needed before commitment to these products. Standards and compatibility will be discussed in a later section.

Remote Sensing

As discussed, remote sensing has played a significant role in the development of GIS. Photographic data has always been a primary source of information for many disciplines but transfer of land information to digital databases has been difficult. The transition to digital formats has provided a primary stimulus for further development of digital information systems.

Remote sensing includes aerial and satellite imagery, either emulsion-based (film) or digital. Information is obtained from a wide range of the electromagnetic spectrum, from ultraviolet to microwave. When multiple bands are combined in a data set, a synergy of information is presented, e.g., several bands of visual, mid infrared, near infrared, radar, and microwave.

Imagery is manually or digitally interpreted. For GIS, images can be classified into thematic categories, rendering data into a map or into a map-based format and effectively converting data into a GIS database. Therefore, remote sensing is a substantial component of GIS, because many GIS users are proficient in remote sensing image processing and analysis. As such, remote sensing data are perceived as major sources of useful digital and photographic information for GIS projects.

INVENTORY OPERATIONS

After data have been entered and properly structured, the real work of GIS begins. There are two basic categories of functions or operations performed by the system before results are obtained: data inventory and analysis. The following presents the inventory operations and considerations, which usually precede the analytical process. It is noted that many procedures from both inventory and analysis are appropriate for each other. For example, once a file has been changed via an analytical step, it can serve as inventory data for subsequent work. Moreover, it will be seen that many of the GIS functions are performed at the database level, with graphics serving as nice, though unessential, display and "window dressing".

Data Retrieval

Efficient data retrieval is one of the basic, yet most useful operations of a GIS. Data may be called in either tabular form directly from the database or, more frequently, displayed in map form on the monitor. Further, GIS supports retrieval of selected information, e.g., ranges of data or specific items may be queried (called), without the clutter of associated data, and depicted as a thematic map.

The use of Boolean operations is a powerful tool for data retrieval. Boolean queries are composed of the logical operators AND, OR, NOT, AND/OR, and other similar requests. For instance, a range and Boolean query might consist of showing a population coverage, with urban populations between 1000 and 5000 selected AND cities of 100,000+ but NOT the city of Dallas. When combined with other inventory and analytical routines, Boolean queries offer high flexibility in data management.

One of the major advantages of computerized information systems is the ability to rapidly and accurately update information. With automatic searching and replacing of features in a database, digital information is easily managed and updated. Even the most cumbersome GIS permits direct access to and rapid change of coverage data. Updating records and databases normally is accomplished manually, either item-by-item entries or using a formula for block changes. Many GISs support the merging of newer data on a file-wide basis, essentially making updates automatic, but more often requiring some human control, making the operation semi-automatic. The wise operator updates an inventory file not by overwriting the original, but by making a second newer version, retaining the old data for possible further subsequent use (there is rarely satisfactory replacement for original data).

Data may be expressed collectively, either through listing of categories and features or by generating cumulative statistics. Some of the more basic GISs offer limited statistics, e.g., a raster-based system may provide only the number of cells contained in each category value, prompting the user to translate to real-world figures. Some of the more advanced systems offer other spatial measurements, which are automatically generated, e.g., area and perimeter of each polygon are generated as well as collective statistics of each category.

Even though good systems offer relatively complete statistics, a growing demand exists for more advanced report capabilities, such as analysis rather than just static summaries of spatial entities. For example, relationships such as how much pine forest area is included in fire protection zone A. Integrating powerful statistical package capabilities is one of the current revolutions in GIS. Output may be to the screen, file, or hardcopy.

Recoding

One of the most fundamental analytical operations is recoding. Inventory file data should be "raw", i.e., unprocessed, unclassified, and reflecting the numbers and attributes in their original form, retaining the maximum level of discrimination. These files may be too detailed for some uses, creating the need for data to be reduced or generalized. Recoding a breadth of data values to a manageable few categories may help to clarify the information. Also, because the human eye can discriminate and manage only ten to twelve variations of color or data coding, too many categories of data may be counter-productive. For "quick look" purposes, only five to seven categories may be needed.

Recoding may also be necessary for some of the analytical operations, such as Overlay. Some GISs limit the number of data values that can be combined in large data sets, requiring the recoding of file values. Obviously, the merging of files with many categories in each can result in a highly complex, overly complicated overlay coverage. Often, recoding must be applied to one or more of the files for increased manageability.

Recoding is a relatively simple process, typically operating in a logical manner for convenience and efficiency. Different GISs provide various methods of recoding. Basically, the file values are displayed, either graphically or tabularly, and then interactive changes are made. Good database systems permit block changes, e.g., data range control and sequential numbering options.

Rescale and Transform

Once data files have been properly archived and made available for retrieval, several inventory routines may be used to render data more useful for various purposes. Rescaling and Transformation of coverages are elementary and important options. In the computer, a coverage has no scale per se. Unlike a hardcopy map, the scale of display is quite fluid, permitting fast interactive magnification (zoom in) or demagnification (zoom out). Although some reference to scale may be used for convenient visual comprehension, the establishment of scale becomes functionally important only at the output (map production) stage. Consequently, two disparate scales of original data may be easily compared, for they have no size or display limitations while in the computer. Rescaling small scale to large scale is a standard operation, with a common coordinate system as the only basic requirement.

Even though scale itself is unimportant in digital form, resolution of data may present scaling limitations. For instance, it is easy to enlarge a 1:100,000 scale (original data) coverage to 1:5,000 equivalent on the monitor or hardcopy, but the magnification required is too much for credible spatial results, e.g., features may be enlarged out of proportion. More important, locations are accurate only to the original 1:100,000 scale, enlargements do not improve the accuracy despite appearances, i.e., accuracy of original data cannot be improved through artificial means.

Transformation is a series of basic operations that essentially involve redrawing the coverage to another spatial configuration. Rotation and lateral/vertical movements are easy to achieve. Projection changes usually consist of invoking the routine after selection of the desired projection. Other warping functions may be available on some systems, e.g., manual rubber sheeting (stretching) to accommodate fitting to another coverage. Because two coverages seldom match precisely, some transformation may be required.

Split and Join

Other map handling operations may be used, e.g., individual coverages can be Split or Joined. Splitting a coverage involves "cookie cutting" a section from the original coverage to make a separate smaller coverage. This may be done interactively, with a floating changeable box or configureable polygon displayed on the screen, or by keyboard entry of coordinates (though not all systems, including some of the "top end" ones, support all of these functions). All internal information is retained, although certain routines may require reestablishing topology.

Joining is the process of connecting two or more spatially adjacent coverages intc a single composite coverage (also known as "mosaicking"). Common borders may not be required in better GISs but overlapping areas may be included. Essentially, coverages are required only to share a common coordinate system and usually a common projection, although reprojection to a convenient projection could be employed. Some map transformation may be necessary, such as rotation, but the entire process is usually automatically performed. As with any of the inventory operations, the new composite may be considered another inventory file, ready for subsequent manipulation.

Each GIS offers a variety of diverse inventory options, from simple file management to exotic transformations. It is easy to become impressed with systems offering the most routines, yet only a few basic operations are used in normal, daily operations. Implementation of GISs with many exotic and seldom-used functions is not necessarily a wise move, but consideration of inventory operations is essential.

SPATIAL ANALYSIS

Thus far, discussion has focussed on inventory capabilities, but the real strength of GIS lies in its spatial analysis operations. A few of the processes mentioned in the inventory discussion can be considered analysis, e.g., Boolean selections show where particular features and characteristics occur. Also, topology offers insight to relationships without application of complex routines. For instance, adjacency, one topological component, shows spatial relationships between features of interest.

The synergetic combination of topology and Boolean queries introduces a strong analytical foundation. For example, one can select sites containing coniferous forests ten to twenty hectares in size, AND those with adjacent sites of Loblolly Pine of at least five hectares in size, but NOT areas within Scott County OR within the Bienville National Forest. Other standard GIS manipulations enhance these routines.

Overlay

Although the range of analytical possibilities is probably as great as the number of imaginative, persistent, and experienced operators, only a few of the more standard operations are discussed here. One of the principle analytical operations in GIS is Overlay, i.e., the merging of two or more coverages to construct new composite coverages. Fundamentally, Overlay involves no more than combining multiple coverages, adding THISMAP to THATMAP to make NEWMAP.

Unfortunately, even though Overlay is a standard and valuable routine, it is surprisingly limited in some GISs. A few low-end systems may allow only the domination of Cover 1 over Cover 2, requiring special steps to permit some of Cover 2 to be revealed, e.g., recoding some Cover 1 polygons to 0 (effectively making them invisible) to allow Cover 2 values to be revealed. This is particularly true in systems employing only numeric values for feature identification.

For the raster-based systems using cell values as class indicators, several Overlay options exist, each dealing with the treatment of coverage values in the subsequent generation of the new file cell codes. Overlay usually offers several basic mathematical operations, including addition, subtraction, multiplication, and division of cell values. Overlay with addition can be used to sum the values in each file's corresponding cell: the value of cell 1,1 (row 1, column 1) of Coverage A is added to the value of the same cell in Coverage B to produce the summed value in new Coverage C.

A major problem with these procedures is the intricate involvement required by the operator in order to establish a functional coding scheme. A simple raster system, in which cell values indicate specific classes or magnitudes of a given theme, may require prior knowledge of cell values before the user can predict and understand the output. Thus, the user must carefully design the end product before properly applying inventory and analysis operations. For example, if two files have codes 1 through 5 that indicate various classes of their respective themes, an Overlay with addition (addition of cell values) will result in a mix of cell values in the output files that cannot be readily understood. A resulting value of 4 may be the composite of value 1 plus 3 from each respective coverage, 2 plus 2, or 3 plus 1; there is no way of knowing which files contributed which values. Therefore, clever coding will be necessary to readily understand the origin of the new file cell value. In this case, the second file may need to be recoded as follows:

Original Value	New Value
1	6
2	12
3	18
4	24
5	30

In this way, a unique set of values will result, e.g., code 8 can only be a consequence of Cover 1 value of 2 and Cover 2 value of 6 (original value of 1).

As implied, the process is complicated, laborious, error-prone, and subject to considerable confusion. Mistakes may not be evident in the output, thereby compounding deficiencies and inaccuracies. Also, subsequent overlays, even those with minor changes, may require equal expenditures of time and effort, making the effort very slow and demanding of a user's patience and accuracy.

Better GISs allow the actual combination of coverages by identifying the superimposition of features. For example, where Soil A from Coverage 1 coincides with Vegetation X of Coverage 2, the resulting new coverage feature will be renamed SoilA-VegetationX, leaving no doubt about the identity and reason behind its value. Several options for identifying features are available in the best GISs. Each Overlay is operated from either a single command line or a menu option, requiring nothing more than the files used and a few option selections.

Vector overlays or integration of vector data files is easier for the operator but more difficult for the software than combining raster coverages. Rather than calculating cell-by-cell operations, vector systems must treat all points, lines, and polygons of each coverage and determine where each file integrates with the other and what the results will be upon combining. Therefore, the operation must address the database to read each polygon ID with any identification and compose new labels and IDs. Also, a new table is made for the new coverage. The basic task of the operator is to enter the proper command to overlay the desired files, usually nothing more. Although the operator is relieved of a great deal of tedious work, specifically in terms of prediction calculations, high demands are placed on the software to formulate the overlay results and to write new descriptions of the new points, lines, and polygons.

Additionally, sophisticated overlays are forthcoming. Boolean combinations may be in the form of feature selection, e.g., show all combinations of overlaying results but NOT polygons representing timber stands of less than five hectares if overlaid by polygons of industrial land use. Another example is the use of artificial intelligence to aid in editing, e.g., removal of small slivers and gaps currently requiring tedious manual operations. As software capabilities advance, more sophistication will be available (and expected), though basically transparent to the user, who needs only to understand what is desired.

Buffers and Proximity Analysis

Another fundamental operation found on all systems is the construction of buffers or zones of selected distances around selected features. Various names for the routine are used, such as buffer, search, and zone. Constructing a corridor five kilometers on each side of a highway is a relatively easy task, using a single command line or menu option. The first input is the desired distance, normally in real ground units but some raster systems need the number of cells, requiring the operator to calculate the ground to cell distance. Then the feature or features are selected, in terms of a broad class or specific feature. Invoking the routine builds the zone, effectively masking out the remainder of the coverage.

The buffered file then can be combined with other files using Overlay to perform further analysis. For example, land use five kilometers on each side of a selected corridor can be framed, masking out the extraneous land use data that would visually and statistically confuse the primary purpose. One potential application of this technique would be to identify those residences or businesses impacted by a flood, for example.

Moreover, Buffer can operate with Overlay to further analyze areas of influence, or connectivity, within a particular reach, i.e., proximity analysis. For instance, how many features of a particular characteristic are within a set distance of another set of features?

Proximity analysis can encompass a range of operations that show or analyze distances and numbers. For illustration, the following queries can be answered. How far is feature A from feature B? How many pine stands are within ten kilometers of a major road? Are there intermittent streams within five kilometers of a prime deer habitat area? Do proposed clearcutting areas overlap ecologically sensitive sites (e.g., red-cockaded woodpecker nesting and/or foraging habitat)?

One "exotic" analytical procedure worth mentioning is the "Field of View" or "Line of Sight" operation, which analyzes topography from a selected point to determine visual or physical obstructions. Siting of a fire tower requires a good observation point. The routine essentially asks "Which areas are within view of a 200-foot tower from this location?" or "Which site has the greatest area of view?". Extensions of this procedure would be to determine the height requirement of a fire tower to rise above the ridge to view a specific distance or selected forest site.

Numerous other routines are available on various systems. Near determines the closest feature of a selected type from a given point or other feature. For instance, where is the nearest landfall from a given oil platform in the Gulf of Mexico? The more powerful GISs have a suite of such analytical operations and the implementation process should involve close examination of the strength or weakness of capabilities.

Site Suitability

Overlay and Buffer, with their diverse derivatives, are the fundamental building blocks of spatial analysis. A primary operation using these operations is site suitability, also termed site unsuitability or sensitivity modelling when appropriate. Essentially, site suitability shows where to locate or where not to locate (unsuitability). The process involves a number of overlays, with each coverage normally having a recoded set of attributes indicating positive and/or negative criteria. When merged, the best combination of positive (or negative) locations emerges, depending on the application. The following example illustrates the process for the siting of a lake dam. The most important criteria for dam locations are:

(1) between elevations of 1000 and 4000 feet mean sea level; and
(2) on a stretch of river with a maximum bank-to-bank width of 50 meters.

Secondary criteria consist of:
(1) a potential water shed of at least 2000 hectares; and
(2) soil types A and/or B and C

Tertiary criteria are:

(1) a federal or state forest area within 10 kilometers; and
(2) a service road within 2 kilometers.

The primary criteria coverages are derived from fairly simple recodes of existing files and are assigned a relative weight of three to indicate triple importance over the tertiary criteria. That is, all data values found in these files are multiplied by three. Systems using actual names assign weights to each feature.

Similarly, this process is followed for the secondary criteria, except they are assigned a weight of two. Tertiary criteria are created from buffered new files and are not given increased weight. After all files are overlaid, the highest resulting values should be the major candidate sites for the dam location. Site unsuitability uses the lowest values to show the least suitable sites for the dam location. Because various systems treat and manage data differently, the actual steps may differ from this model.

Modelling of ecologically sensitive areas follows the same basic process to locate those sites most susceptible to damage. Whether the highest or lowest values are used to indicate sensitivity, the process is not affected; it is dependent only on how the operator wishes to construct the coding system.

Many other analytical operations could be discussed, some relatively generic and some system specific. As technology advances, new analytical developments are sure to occur. In fact, recently emerging are new types of spatial analysis, even on raster systems. More complex direct and indirect relationships may be determined. Further, the application of spatial statistical analysis is evolving, with numeric analysis and modelling of spatially-derived quantities manipulated by sophisticated programs like SAS and SPSS. Trend analysis is not far behind, e.g., merging time-oriented data into a dynamic model. Process rather than simple static description will become the expected analytical format.

OUTPUT

Most GISs generate graphic displays for a variety of output media: terminals (monitors), plotters, printers, and image film recorders. The most common output product (beside the monitor image, of course) is the hardcopy map, usually paper. These may be produced by simple pen plotters, ink jet plotters, or large electrostatic plotters. Although black and white maps are acceptable (even using patterns), most end products now are color renditions.

Some of the simple renditions of data may be page size for insertion into a report or text, but because GIS typically can produce elegant and detailed output, primary map sizes tend to be larger. Additionally, images may be directly output to film via an image film recorder or to photographic slides via a matrix camera. The latter are particularly useful for presentations.

GIS product maps usually contain all the support elements found on published commercial maps, e.g., legend, scale, north arrow, annotations, coordinates, data source, and producer. Most GISs support a full range of hardcopy production, from rudimentary "fast maps" (usually screen dumps) to automatic placement of cartographic features. For example, automated placement of legends and automatic recognition of attribute labels directly from the database are components of a high support system. Low support systems offer basic mapping, with comprehensive manual control of all cartographic output, making map production tedious and time consuming.

Desktop mapping is becoming popular, but these systems are currently better suited to small cartographic projects, not major GIS tasks. However, as the technology revolution continues, the distinction between desktop mapping and GIS production may diminish to the point of indistinction.

Another form of output includes reports, which are typically tabular accounting summaries of selective data and information. Reports may be simply down-loaded to a printer or may be configured into a more sophisticated format. Data selection flexibility is determined by the core system. Basic GISs allow output of tables directly to the printer, without adjustable formats, whereas, better systems offer a wide variety of design support.

Digital GIS products are becoming more common product types, primarily because data exchange between various systems is becoming less of a problem. Vendors have realized the importance of data compatibility and have attempted to accommodate different data exchange formats. Therefore, digital data on a tape may be incorporated directly into another database for rapid data entry or update and may be subsequently used as project inventory information.

Digital data are available in a variety of media, from standard floppy disk and magnetic reel tape to laser disk and CD-ROMS. "ROM" (Read Only Memory) will likely become obsolete in the very near future because erasable CDs are now available on the market. In fact, CD readers are becoming a standard GIS peripheral. Numerous standard digital products from federal agencies are currently available on CDs or are under development, e.g., the Defense Mapping Agency's World Vector Shoreline.

APPLICATIONS

One of the primary reasons for the popularity of GIS is its demonstrated utility for a very broad range of applications. GIS is truly holistic, integrated, and multi-disciplinary. Because GIS is not merely a computer mapping system used only for producing cartographic products, it has great value to a wide range of users. This section presents a brief idea of the breadth and depth of GIS applications with the realization that the field continues to grow, reaching into an increasing number of utilities. Any institution or arena making use of spatial data and/or its attributes can make use of the GIS. Appendix II gives an indication of the breath of potential GIS applications.

The small local government agency is one of the major types of organizations stimulating the growth and acceptance of GIS, to the degree that "local government" is a specialized field within the discipline. Many types of courthouse records, dealing with addresses, usually are catalogued by location. Tax assessor records are ideally suited for GIS. More and more data are becoming "spatialized", rendering the need for GIS as important as were computers to numeric data a few years ago.

Local government is an example of a multi-purpose user, one using diverse data for several primary purposes. In contrast, a thematic user has a narrow range of subject interest and/or a dedicated project of circumscribed scope. Petroleum companies are interested in oil exploration and thus employ GIS for specific purposes. The technology, however, is well-suited for either type of application, although the organizational procedures and system configurations may differ.

Applied research is another arena in which GIS has an important role. Applied research deals with the theory and uses of GIS. Research and development of procedures and techniques (methodologies), software design and utility, hardware design, and other aspects are pertinent research themes. Also, much effort is expended in the use of GIS to a particular application, i.e., the development of GIS technology approaches to a specific theme. Ecological modelling is a relatively new application of GIS and is a particularly valuable research item because paradigms have yet to be established. A cyclical process of applications stimulating research and research stimulating applications will continue.

Natural Resources

The analysis and management of natural resources typically is an integrated process, encompassing numerous disciplines and their methodologies, from soils and vegetation studies to economics and sociology. Before the advent of computerized GIS, resource analysts were largely confined to manual techniques of geographic information analysis, having to use mental techniques supported by maps and data laid out for visual assessment and synthesis and perhaps a few crude tools, such as planimeters for (inaccurate) area measurement and calculators. Modern GISs have overcome much of these limitations in terms of data presentation and analysis, leaving the analyst to synthesize the resource information for larger concerns such as policy formulation and economic development.

One of the primary advantages of GIS is the analytical overlay operation, where numerous data sets of divergent original scales and themes are combined into a single (or at least fewer) representation. Proximity analysis operations, for example, can be employed especially in environmental impact analysis. From the preceding discussions considering the foundations, techniques, and approaches of GIS, its utility in the analysis and management of natural resources is readily appreciated.

Most of the early GIS literature and many current publications are devoted to natural resource interests in some manner. One initial substantial publication is entitled "GIS for Resource Management: A Compendium." Its table of contents shows a wide range of applications and technical/functional capabilities. Therefore, natural resources probably will continue to be a major subject for GIS applications and methodologies development.

Master Planning

The term "Master Planning" encompasses a wide range of activities, essentially denoting a comprehensive method for the preparation of large projects. The range of potential GIS applications is very broad, from engineering of bridges and facilities development to environmental assessment and global climatic change. Landscape architecture was one of the first disciplines to incorporate the progenitors of GIS and to begin its development as a solid methodology. As such, landscape architecture directed its interest to relatively small areas, e.g., facility grounds designs and management.

Master Planning denotes a general concept of a comprehensive preparation process for large or regional projects. A master plan is the primary and encompassing guide for typically intensive and complicated activities. Upon realization that most or all of Earth's processes and cultural activities are not isolated but are integrative in nature, a need emerges for a systems approach to planning and analysis. GIS has become a very broad-based methodology and as such, is highly applicable to master planning.

Whether the master plan is for global environmental assessment, national development, regional analysis, or locally designed projects, GIS can play a primary role in accomplishing the planning process, from inventory of the necessary components to analysis of proposed scenarios. All or most of the elements and capabilities of GIS have utility in a very wide range of master planning interests.

GIS Organizations

As discussed, GIS is interdisciplinary and holistic; numerous disciplines have been involved in its development and use. Consequently, GIS may be found in many professional organizations in varying magnitudes. Because Geography is considered the "parent" of GIS, geographers and their associations seem to be the primary movers and shakers. The Association of American Geographers (AAG) incorporates GIS in a substantial manner via highly active special interest groups and it devotes several sessions to GIS in its annual international and regional meetings.

Perhaps the major GIS organization today is the American Society for Photogrammetry and Remote Sensing (ASPRS), an international organization noted primarily for remote sensing but now has taken the lead in the promotion and use of GIS (it will not be surprising if GIS is added to the organizational acronym.) Its monthly journal carries major GIS articles and newsletter information, and even devotes its October issue to the field. ASPRS also hosts and co-hosts several of the major GIS conferences each year.

The Urban and Regional Information System Association (URISA) is another major organization for GIS. Along with the AAG, ASPRS, and two other organizations (American Congress on Surveying and Mapping [ACSM] and Automated Mapping and Facilities Management International [AM/FM Intl.]), URISA co-hosts the major annual conference termed GIS/LIS '(year).

As GIS broadens in scope and its value becomes evident to more fields, additional organizations and associations are affirming their interest. The Society of American Foresters, for example, an established user of remote sensing, has a natural regard for GIS. Computer Science, an often overlooked but essential discipline, has "hidden" its interests in several of its sub-disciplines, e.g., digital image processing, graphics, and information science. The Institute of Electrical and Electronic Engineers (IEEE) offers remote sensing and GIS publications. Journals for geology, environmental science, and even mathematics are devoting more attention to GIS.

International GIS

GIS is clearly an international discipline, with extremely high value and relevance to national development interests, international problems, and global concerns. Other nations have demonstrated their devotion to the use and development of GIS. Australia, for example, has several leading centers in the field. Canada has very strong links with U.S. associations and seems to be equally committed (perhaps more so) to evolving the technology and its applications. Nations with remote sensing programs are implementing GIS as a natural corollary, e.g., Great Britain, France, Japan, India, and Brazil. The ASPRS journal has a special international GIS issue due in late 1990. Obviously, the international growth of GIS will continue.

ISSUES

As the new technology, discipline, and methodology of GIS suffers growing pains, many issues have arisen to cause concern among users. Some are controversial, others are questions to be resolved. The literature is replete with numerous deliberations pertaining to the various questions, problems, interests, issues, and concerns of GIS; a few are briefly discussed here. This discussion is by no means exhaustive, nor thorough; it is intended only to introduce the concept that there are still questions to be answered and developments to be made. Most of the considerations used here are relevant to specific operations, projects, or to the discipline at large. The major concern of standards is discussed first.

Standards

The term standards is a greatly overused concept, with different meanings to different users. As technology develops, some operators foresee common hardware and software environments and common data qualities. This, however, is not likely to occur, given the diversity of vendors and current systems (e.g. DOS, VMS, UNIX). The various manufacturers probably will not produce a common or standard environment for hardware and software in the near future.

The term "compatibility" is a better concept which will act as a surrogate standard in GIS. Practically every major GIS company either has developed or is developing data exchange and conversion routines for various common formats. Hence, data transfer between disparate systems may not be a problem in the near future. For example, ARC/INFO currently supports conversions to and from various vendors and formats, such as Intergraph, ERDAS, MOSS, SIF (Standard Interchange Format), TIGER, and AutoCAD. Therefore, data exchanges are facilitated by development of compatibility routines.

Compatibility of software operating environments is more difficult to achieve and probably is not a major concern. An insufficient need exists for Intergraph to run an ARC/INFO routine, although data may need to be exchanged. Therefore, a standard software environment is not really necessary.

Another separate issue is hardware compatibility, an on-going problem due to the myriad of vendors of various systems and peripheral devices. Ensuring easy connectivity of one product to any other may be beyond reasonable expectations and therefore, a hardware standard probably will not be established. More likely, a connection peripheral (hardware and/or software) may be developed that bridges the gaps between unlike systems and environments.

Standards in data quality and other GIS concerns are discussed below. In fact, this concept could be applied and addressed in almost every section of this primer.

Areal Coverage and Scale

Incomplete map and areal coverage is one of the major problems encountered in projects. Projects are planned for specific study areas, nevertheless, inconsistent data sets emerge during data collection. For example, complete coverage of data set A exists, but data set B has incomplete coverage. Either a reduction in the size of the study site is forced or extra effort is required to find the remainder for data set B. This is often a highly challenging and sometimes frustratingly impossible task.

Equally interruptive is the presence of inconsistent scales, though it is a common concern in most projects. For instance, data set A has a scale of 1:10,000 whereas data set B (even if areal coverage is complete) is at a scale of 1:50,000. As discussed, it is easy for GIS to merge the different scales and perhaps convenient to ignore the resolution differences, but there is disparity in data quality. Significant scale differences represent inequity in the quality, forcing the smallest scale (weakest and lowest quality) to become the base map and base data set for the project site. In effect, a database is only as strong as its weakest scale.

Classification

Another major data problem is the accuracy and validity of the classification scheme that is applied to the data. Usually, raw data must be collapsed or reduced into manageable categories by using a classification (coding) scheme. Concerns may arise regarding whether the employed scheme adequately represents the raw data. For example, the break point or division between classes can be determined in several ways, each with a particular statistical bias and each set at a different numeric level. A number near the break point in scheme A may fall in another category under scheme B. This may cause the classified data set to be too generalized and thus may not be adequately representative of reality. Consequently, the statistical treatment of data entered into a GIS database should be a major consideration.

This issue underlies a critical need for GIS users to have strong grounding in quantitative analysis, at least regarding a good background in statistical training. Computers lend a false sense of quantitative and qualitative security, leading the user to believe the analysis without question (especially true in spatial analysis and GIS). It is difficult to ascertain the credibility of results unless careful and informed examination is performed. Because such scrutiny is rarely exercised (even if time and training allow), much faith has to be extended to the GIS process and the operators in charge. A heavy responsibility rests upon the GIS operations.

Expense

Data are expensive. Regardless of the nature of data collection, whether by ground survey, remote sensing, or purchase, the initial cost of data will be high. However, if users realize the true value of data, the cost per unit area of land will be relatively inexpensive. The cost of purchased data sets may seem high, but when fully utilized in a GIS, returns are substantial.

The cost of Landsat and SPOT imagery is a controversial topic today because of their high price tag (Landsat is approximately $3,600 per scene). However, if the areal coverage is considered (some 31,450 square kilometers on Landsat), the expense is but a fraction of the comparable ground survey cost (eleven and a half cents versus untold dollars per square kilometer). Nonetheless, most GIS organizations have difficulty in securing the financial resources required for obtaining satellite imagery, despite the substantial rewards, clearly a "penny-wise, pound-foolish" perspective.

Time

Land information typically has a time attribute attached, because the date is usually very important. As geographic information becomes more social or economic in nature, the date becomes even more meaningful. Population and income data are more sensitive to time than is topographic information. Therefore, one of the critical concerns of GIS data is timeliness (or untimeliness). Untimely data can be a serious defect for many data sets, rendering them virtually useless. Consider the utility of out-dated land use data in an environmental sensitivity project, where the latest encroachment of urbanization onto wetlands is essential information. Old data are not only useless, they may be misleading and counter-productive. As noted, the smallest scale determines the base scale; similarly, the oldest date determines the base date. Hence, a database is only as timely as its oldest data.

Data Quality

One of the major topics addressed in many forms at GIS conferences and in journals is data quality, an obscure and multidimensional issue that is difficult to define and determine, but is so critical to GIS success. The quality of data creates many of the existing database problems. Attributes that have qualitative variance include spatial accuracy, coverage, data transfer method, labelling accuracy, and other elements and processes applied to the information during its journey from reality to the GIS database. Each component of data quality requires distinct treatment; it is often a highly difficult task to ensure the highest quality possible. There are always questions of data quality and therefore, questions regarding data quality and their representation of reality will always exist.

As mentioned, standard digital data sets can be purchased from various government and private agencies (also known as off-the-shelf data). However, there is limited coverage for some regions. The whimsical tenant that the area of interest falls on the corners of four maps can be modified to the corners of four data sets, two of which are unavailable. Problems in data coverage will continue to haunt GIS projects for a long time.

Despite the convenience of available data sources, questions concerning quality arise, such as spatial and thematic accuracy. For example, DLGs seem to have mosaicking problems, i.e., adjacent sets do not match or align properly. Roads do not join or connect properly from one DLG to another. Also, data within the DLGs are not perfect. A gridded street pattern may present distorted intersections as a result of smoothing algorithms, i.e., although reality conforms to right-angle connections, the smoothing attempts to spline sharp angles. Also, diagonals may be depicted as stair-steps due to a rasterization process. Moreover, there are potential problems concerning DLG accuracy; these data may not adhere to U.S. Geological Survey standards for the scales used (discussed further below). Potential users should examine data carefully, preferably before purchase, to ensure that such products are suitable for use.

Some concern has been expressed about TIGER data quality. There is incomplete address capture for many cities, making the files inconsistent in coverage and value. Also, some metropolitan areas will continue to use the Census Bureau's old standard coordinates employed in the 1980 test structure format, rendering them useless to all but a few users. Further, some TIGER files have demonstrated significant topological problems, such as fragmented streets and non-matching arcs.

Accuracy

Overall, accuracy is an often overlooked issue or at least is perceived in a rather simplistic way. There is a tendency to presume that accuracy is merely the correct placement of features; other characteristics are seldom considered. For example, the U.S. Geological Survey has established a standard of accuracy based upon scale and resolution. It is unclear whether all off-the-shelf data sets, imagery, or other data conform to these accuracy standards. Essentially, variable accuracies and variable sources of data exist; users should be wary of the inherent accuracy and quality of data being purchased and used.

Another impact on quality is the loss of accuracy caused by each data manipulation. Data change results in another generation, which usually means a loss of accuracy. This is especially evident when generalization operations are employed. The rule of quality loss per generation of data applies.

CADD vs. GIS

A primary topic in GIS today is the use of computer-aided design and drafting (CADD). Numerous articles have discussed the differences between CADD and GIS and the controversy will not be repeated here. Basically, CADD is a sophisticated set of drawing routines initially established for engineering purposes. Having migrated to map design and drafting, CADD is being promoted as an inexpensive GIS. However, the claim may be somewhat misleading.

The strength of CADD lies in its powerful drawing capabilities. As a result of its great spatial resolution and accuracy, CADD is also being used with increasing frequency as a tool for producing maps and drawings that easily approach, if not exceed, accepted map accuracy standards. New innovations in CADD technology permit queries to be invoked that overlay one or more maps in order to analyze relationships that impact upon critical engineering and environmental decisions.

GIS provides a useful augmentation to the analytical capabilities provided by CADD technology. By relying upon the spatial integrity of the CADD data and applying a topological data structure that defines relationships among arcs, nodes and polygons, analytical processes can be applied that result in creation of new spatial relationships that can be used to produce maps or map overlays, tables and graphs that show the results of analyses.

CADD and GIS are integrating, with the hybrid providing the advantages and benefits of both systems. Technological advances are making possible the consolidation of the two systems. Today, GIS vendors are beginning to provide CADD data transfer, conversion and translation routines, e.g. ARC/INFO now supports both AutoCAD and Intergraph CADD data formats.

Computer-Assisted Cartography (CAC)

CAC was actually a precursor to GIS, but contemporary technology has diminished it to near non-recognition. The first computer mapping programs, e.g., SYMAP and SYMVU, were used to produce cartographic renditions from digital data and were not capable of analysis beyond simple line measurements. Later developments added a few more capabilities, such as area measurements. Because of such limited capabilities, CAC was eventually superseded by GIS. GIS includes most or all CAC capabilities. Today, the latter is seldom referred to as a separate technology. Consequently, CAD, CAC, and GIS (as well as remote sensing) are becoming a single comprehensive methodology from which users can choose specific functionality for specific tasks.

Many other issues exist within GIS and others are sure to emerge in light of developing technology and methodologies. As will be seen in "Trends" at the end of this primer, rew paradigms in the operation and use of GIS are under formation and important questions and needs surely will arise. For example, the arrival of true three-dimensional GIS (solid cubic format) will make demands on data standards, from simple nomenclature to accuracy and quality. As GIS stands on the threshold of maturity, its accompanying issues will continue to grow in numbers and importance.

SYSTEMS

When discussing the various GIS systems, hardware must be separated from software considerations, although both are required for a complete system. Questions often arise in terms of hardware requirements and expenses. A GIS requires a minimum of one computer and a few support items, called peripherals. The computer may be as basic as an IBM PC/AT (or equivalent), operating a relatively simple floppy-based software package or may be a clustered mainframe system running a networked GIS to numerous powerful workstations.

Expectations about low-end systems should be kept very low. Several microcomputer GIS learning packages are available, but they are not suggested for applications. Realistically, the minimum microcomputer hardware setup for a small GIS application probably would be:

* 80386 Math Coprocessor
* 640K RAM
* 30 Megabyte (MB) Hard Disk Drive
* 1.2 MB Floppy Disk Drive
* Color Graphic Monitor (at least EGA) and Adaptor Board
* High Quality Dot Matrix Printer
* Small Digitizing Tablet (24" x 36" active surface)

Implementation

A wealth of literature exists on GIS implementation, from user needs and cost/benefit analysis to commencement of operations. In GIS conferences, entire sessions have been devoted to systems implementation. Essentially, successful implementation involves careful examination of organization missions, goals, needs, capabilities, and available resources. Such factors are highly variable and no blanket guidelines can be offered that will satisfactorily support a given agency's concerns and questions. Therefore, this discussion is relatively brief and does not attempt to cover any comprehensive issues or considerations involved in implementation. Rather, this focusses on the highlights of immediate concern and presents only a rough outline of the necessary components of a system. Further, at this stage of the report, many of the elements mentioned here have been addressed elsewhere, and thus, repetition will be avoided.

GISs typically are expressed as either vector or raster systems, and sometimes as raster-vector, meaning that the basic format has a convertible routine to integrate the two different structures. Most systems are structured as either raster- or vector-based, with or without an internal database (something besides minimum attributes and ID tagging). Databases may be hierarchical or relational, the former being a relatively simple structure but with limited query capabilities, whereas, the latter is more complex and capable, yet more expensive. The strongest system seems to be the vector relational database format.

The necessary features for a GIS, providing full functionality is desired, include digitizing capabilities, an internal database, preferably relational, and output support in the form of export and printing capabilities. Data input requires the inclusion of something more than an import routine. The number of low-end systems that do not support active digitizing is surprising, though it should be a standard item among all GISs. Further, linkage to several standard or major digitizing systems is usually desireable. However, it is possible to utilize a GIS that supports only one digitizing system, providing all the special digitizing peripherals are to be included. This, of course, means dependence upon a single product line and forces full system configuration prior to purchase. With such a system, growth may be limited because of inflexibility.

Anticipating all operational problems and all growth needs is a very difficult task. A good GIS offers easily operated inventory and analysis routines. Extreme caution must be exercised in evaluating inventory and analysis capabilities, despite the claims that strong and perfected proficiencies exist for a given system. There is no substitute for consultation with existing users of the vendors under examination.

Most of the standard operations discussed in this report should be standard elements of a good GIS; separate modules for normal features should be viewed with suspicion. Worse, when standard operations are billed as specialized features (often in additional and expensive modules), radical skepticism should be exercised. Moreover, the modules for any operation should be carefully assessed, not only for expense but for compatibility and ease of integration. The use of modules in a system may afford custom design flexibility, but also may introduce problems of comprehensive use. If the modules have been developed by a separate vendor or do not support full integration with the essential system, problems may be encountered.

Output capabilities may also be limited to a specific vendor or other type of product. As above, the single vendor approach may or may not present difficulties, but output limitations are certain to cause questions and concerns in the future. For example, a single vendor may have limited hardcopy sizes for production or may be restricted to a specific type of production, such as pen plotters or ink jet systems. Growth into higher output capability is a common evolution as a GIS operation matures. However, if the system does not support the desired needs, then either more expense is required or custom programming may be necessary for the reconfiguration. Neither of these may be necessary if the initial system design is considered carefully.

Pen plotter devices range from pagesize for less than $1000 to very large and sophisticated devices costing thousands of dollars. The new color electrostatic plotters, priced up to a hundred thousand dollars, are superb machines but are not always supportive. As laser printers become more standard and as color laser developments occur, even more sophisticated output may be desirable. However, growth ambitions should be tempered with realities.

As a GIS becomes more flexible and more widely supportive of peripherals, an increase in cost and involvement is needed. For example, color electrostatic plotters require sophisticated and demanding environmental controls (e.g., temperature and humidity systems), which can add significant cost to overall system support. Also, plotter supplies, such as ink and paper, become more expensive.

Maintenance

Both the essential GIS and the peripherals have maintenance costs, primarily in the form of annual support fees, which insure the repair, consultation, and upgrades as they develop. Obviously, the user will pay all of these costs, making the annual operations budget much larger than with simple systems. This means that the cost of a GIS is well beyond the initial price tag of the central system.

Peripherals should not only be carefully considered, but maintenance, supplies, and growth factors must be incorporated also. Too many nearsighted GIS users are shocked and financially distressed upon learning the real cost of a functional and productive operation. Such special considerations are inherent in any computer operation, not just GIS.

Extras

Additional components beyond the required core may be desirable (or sometime, even necessary). Numerous extras (often referred to as "bells and whistles") are usually available to enhance core systems and capabilities. Sophisticated digitizers may be one of the more exotic desirables, particularly after intense and tedious involvement with manual digitizers. Video and line following digitizers costs range from $20,000 to $100,000+ (not to mention maintenance and support). No one likes mundane and manual work, and certainly such digitizers are desirable, but much care must be exercised to assess the real need for such automation. The standard perception is that high capacity data input may be justified in a large corporation, but small agencies probably will not need such high cost items. Also, video digitizers are limited to the type of data that are easily read (simple graphics, sometimes text, but never topology and GIS specifics) and practically all systems require human intervention for operation, i.e., they are not automatic.

One of the more common and affordable types of extras are the enhanced computer capabilities, such as faster operating speed and higher memory capabilities. Faster speeds allow more rapid and efficient operation, of course, but also may permit some highly sophisticated routine to be incorporated. Increased memory, both RAM and disk storage, are usually highly desirable because graphics data files normally consume large amounts of storage. Enhanced RAM memory allows the user to invoke other support software, such as an advanced statistical package like SAS, in addition to the GIS software. Also, the extra RAM allows increased processing capabilities.

Magnetic memory devices are available, containing up to several hundred megabytes for PC systems and a few gigabytes or even terabytes in the near future for mainframes. The industry, however, seems to be moving toward the development of other types of storage devices. Compact laser disk systems are becoming more popular, flexible, and affordable, although they still seem to be relatively slow in terms of access. Computer science literature is heavily focussed on future developments, but the present reality is that most of us are still dependent upon disk and laser drives.

Minimum Configuration

Many organizations desire to incorporate GIS but are unsure of the necessary requirements beyond the purchase of software. The following is a suggested minimum configuration that may be termed a GIS operation. Although there are a few free or very low cost GIS software packages available, running on a two-floppy drive 640K memory system and requiring little more than an inexpensive dot matrix printer for support, a valid GIS facility has much larger requirements for productive and quality work.

One PC-styled computer with EGA graphics, operating at 15 megahertz, with one megabyte RAM memory and 50 megabyte hard disk storage is suggested. Because map graphic files require large storage space, the 50 megabyte hard disk storage may be a debatable minimum; perhaps 100 megabytes would be a better suggestion for truly functional operations that do not wish to invest hours each day trading data between the computer and floppy disks. Support items include:

1 24" x 36" digitizing tablet
1 color ink jet or pen plotter
1 dedicated office and equipment space
1 dedicated person

The last two items frequently are under-represented and seldom given full attention. The GIS implementation design process typically focusses on hardware and software issues, usually doing a poor job of incorporating people and space. However, people and facilities are perhaps the most important components in GIS operations and will be discussed in the next section.

SUPPORT: PEOPLE, FACILITIES, MANAGEMENT

GIS is a technology used to provide efficient, accurate, and rapid spatial data management, but it does not exist alone. A functional system requires support and a formal structure. Often overlooked, the support items are critical for successful implementation and use of GIS. Without support, a GIS becomes little more than a seldom used computer system in a corner of an office. Several critical primary components of the support are needed: people, facilities, and management.

Support fundamentally consists of people and facilities. Few operations have readily available human, hardware, or space resources for allocation to a new technology. Serious GIS implementation requires reassignment and re-dedication of resources. First and foremost, a dedicated staff is necessary.

Staff

Some administrations perceive GIS to be merely a word processor for map data and consequently, devote inadequate resources. Many new agencies attempting GIS implementation for the first time are not ready to dedicate reliable human resources. e.g., they assign the system to an existing staff person as an additional task or responsibility. Administrators typically perceive the implementation to be a prolonged process that can and will arise slowly from a gradual increase of use and will be one that is efficiently facilitated by a gradual incorporation into the current office process and structure with minimum interference to and from other operations. This is a penny-wise, pound-foolish solution perception, which can lead to failure and a waste of time, money, and effort.

Worst, the administratively-heavy bureaucracies of the public and private world often need proof of utility and value before commitment to full operations, thus personnel are not hired and space is not allocated until there is proven success and a proven need. An obvious tenet arises from this situation that unless given adequate resources, a GIS is likely to be less successful than originally anticipated. This is somewhat of a self-fulfilling prophecy of failure: "it probably will fail, therefore, we should not devote significant resources."

Experience and research have shown that successful GIS implementation requires the dedication of at least one knowledgeable staff person. However, upon successful activation many organization realize the full inherent potential of GIS and find that at least two people are needed, one who is systems-oriented for maintenance and programming and an applications person for making appropriate use of the GIS. Therefore, the best recommendation is to have two dedicated people to the system.

A less-desirable but potentially acceptable situation is to have at least one full-time applications person and one half-time systems person. Dedication is emphasized even for part-time help, rather than GIS being an additional responsibility of some already overworked technician. However, GIS should not be perceived as a part-time or extra duty technology that eventually will mature and then deserve adequate resources.

The user capabilities or primary talents of the GIS staff should be carefully considered. Three primary skills are necessary for proper system operation. The first is the technical facility or computer ability. This means the operator should be sufficiently proficient in the use and maintenance of computers to be relatively independent in this operation. A keyboard operator, such as a typist, may manage to enter data or to perform basic input operations, but higher skill levels are needed in a one- or two-person operation.

The second primary skill required is scientific knowledge, especially in the type of data used. This need not be a ranking scientist or a senior staff person, but the GIS operator must know the contents or themes being employed. Without such knowledge, there is a potential for the established computer principle GIGO: "Garbage In, Garbage Out."

The third fundamental skill needed is a blend of the first two, the ability to integrate the knowledge under study and the system operation; a synthesizer. This person must be aware of the broad applications as well as specific operations. Fortunate is the organization that finds in one person all three required proficiency levels. The suggested minimum of a two-person operation has better chances of one of the staff developing into the synthesizer. It is possible that in a small organization a sufficiently adaptive and bright person possessing either of the first two skill requirements may develop into the third type of operator.

Facilities

A second critical support item is facilities, which come in many forms and may have numerous components, but the primary objective is to provide for the GIS a dedicated place within the structure. All too often failure may be insured by perceiving the GIS to be just another computer that can be placed on some available corner. Normally, GIS operations involve map handling and production (use of plotters and printers) and thus require considerable elbow room. Adequate space should constitute a separate room or substantial work area.

Other support equipment is used, such as filing cabinets, map drawers, and light tables. Where GIS is treated as a major component of operations and given appropriate space, success is facilitated. System characteristics, (e.g., size, host environment, and peripherals) determine the minimum area requirements.

The psychological aspect of dedication should not be ignored. It is difficult to generate organizational excitement about a few pieces of computer equipment jammed into a corner, indicating that there is insufficient importance to warrant more functional attention. But when provided with special and dedicated facilities, the understanding that the equipment deserves distinctive regard is achieved. Staff will react accordingly.

Management

Pages, even volumes, could be written concerning the management of GIS operations and applications but this report introduces only a few considerations. For many GIS organizations the issues and demands of management do not become apparent during the initial phases. For most GIS projects (other than the most simple) success requires a dedicated and thoughtful management strategy. Even if all the physical support elements are incorporated (e.g., adequate staff, space, and facilities), it must be realized that GIS will be implemented successfully only within a proper organizational framework. Management must include GIS into the overall operations and ensure that all aspects of the organization are linked to the GIS (a two-way integration).

As discussed in the paragraphs above, the organization of people, space, hardware, software, and other components is not to be taken lightly. Even the minimum organizational structure comprising a single computer, single operator, and minimum space needs good management. Therefore, management must be an important element at the implementation design stage and should be a major item that is included in initial planning.

Unfortunately, many organizations react to events and processes rather than taking the time to design a strategic plan (Reactors versus Planners). This management approach is highly dangerous in that if the GIS becomes successful (despite the lack of strategic planning), it may not be able to handle the increased demands that are sure to follow. Once the operation begins failing because of overload, the entire GIS approach may be perceived as a failure to the organization. It may be very difficult to convince the administration that initial success can be maintained only if increased administrative attention is given and if adequate management is applied.

Data organization is a critical management component, from very simple concerns to the very complex. As trivial and mundane the naming of files may seem, it may be an element that determines the efficiency of data file use. Anyone experienced in word processing understands that files must have appropriate names and must be kept in logical directories and subdirectories if they are to be properly used. GIS data are no less important and in fact, are more difficult to manage because there is seldom sufficient identifying information in file labels. Careful naming and ordering of files is essential, however simple the task may seem.

There are numerous data access issues, e.g., security measures, ease of extraction, and storage. For instance, security denotes levels of access. The GIS manager should have complete access to all files and the ability to make changes, whereas student workers should have read-only capabilities. Data may be stored in the central memory in a logically structured directory and subdirectory system or they may be kept on disk or tape. Storage data media then becomes a management item.

The need to manage facilities, both space and equipment, rapidly becomes a central need as the GIS operations begin. Questions arise dealing with all aspects, such as who has access to the computer and who is to maintain stored data? Other demands relate to maintenance of the machines, e.g., sufficient lead time for ordering supplies and insuring that all equipment runs properly. Maintenance contracts and other administrative duties are also needed. In essence, the management requirements of a GIS operation can be almost overwhelming to a small agency, but they must be a primary component of the commitment.

Making GIS fit into the overall organization can be difficult. Because it is a new technology and new methodology, there may be aversion to incorporating GIS into departmental operations, particularly by "old-timers" who seem to be stuck at the first stage of technologic acceptance, i.e., reluctance to use it in favor of traditional time-tested (albeit slow and inefficient) methods. This is not an unusual circumstance, especially among larger organizations where department heads make the final technologic and operational decisions.

Further, because GIS is relatively new, only a "new guard" of recently educated or atypically progressive older staff may hoist the banner for innovation. Convincing established management that new management approaches will ultimately accomplish the major organizational responsibilities can be a supremely difficult charter. In effect, the new guard is trying to convince the old guard, while the middle guard stands by in a neutral position awaiting further proof.

In effect, proper support for GIS is an essential management responsibility. People, space, and management are needed to support the "gee-whiz" hardware and software. There are other deliberations and issues that have not been discussed, but may be equally important, such as marketing of the GIS products, generating external funds, and the like. GIS is much more than a machine; it is a methodology and an organizational way of life, fraught with high initial costs, hidden costs, and difficult management concerns. Administration must recognize that GIS implementation may not be inexpensive but if utilized correctly, it will become an efficient, productive, and profitable investment.

REVIEW OF MAJOR VENDORS AND SYSTEM EVALUATION

Major Vendors

Nothing short of a massive tome will adequately discuss the world of GIS vendors. Each vendor obviously has a particular strength upon which it bases its product (otherwise it would duplicate other systems and not be sufficiently unique to be competitive). A review of each vendor and its strengths and weaknesses is far beyond the purpose of this report; only a few generalities are discussed. GIS World, a monthly journal, produces an annual survey that presents excellent information on the breadth and specifics of GIS vendors.

Vendors and systems are highly dynamic--developing, evolving, and dying. What is said about a particular system or vendor today may be modified tomorrow. Technology is highly evolutionary and almost obsolete by the time it is available to customers. Frustrating as that may be, there is comfort in knowing that the technology and the discipline will continue to grow. Some vendors are able to adapt, even lead, whereas others collapse and disappear. Following are brief comments on a few of the outstanding GIS vendors and their role or position in the field today. The discussion certainly is not meant to promote or support selected vendors over others, but the major players in the field are obvious and can be considered surrogates for their imitators, regardless of weaknesses or strengths of any one of them.

There is little controversy in noting that Environmental Systems Resource Institute's (ESRI) ARC/INFO is the leading GIS today. It is a vector-based, topological, and relational database system that has been installed in several thousand sites internationally in the past ten years. It is available on a variety of levels, from mainframe to microcomputer, and is compatible with numerous corporate hardware and software products. Like all major vendors, ARC/INFO is continually evolving and developing. Depending upon individual appraisal, ARC/INFO will continue to lead or at least be a major GIS player.

Several other vendors, most notably Intergraph Corporation, are pressing hard in the competition for sales and development. Intergraph has risen from a troubled GIS (but outstanding CAD system) to a potentially leading vendor. Similar to ARC/INFO, it also uses a vector-based relational data model and is available on both mainframe and microcomputer. Both corporations, as well as many others, are trending towards the workstation environment configuration. Other major vendors include Synercom, Tydac, System 9, and GeoVision.

Basically, because of its more simple format and the limited processing capabilities of the earlier computers, the first GIS data structures were raster-based. In recent years, however, with advanced computing power, vector systems have dominated the high-end markets for most GIS users and probably will continue to dominate. Contemporary technologic advances are making raster-based systems, with attached relational databases, foreseeable and feasible competitors. Some users prefer the raster-based system for many reasons and a new and viable market may redevelop.

Several raster vendors still have a survivable market share. ERDAS (Earth Resources Data Analysis Systems) Corporation established early preeminence in the market, but with the advent and expectations of integrated relational databases, it has become secondary. However, ERDAS is still a leading image processing system. Realizing the new developments, ERDAS is planning renewed leadership in the new raster-RDBMS field. Other competitive raster-based vendors include GRASS and EPPL7.

ERDAS has retained a good reputation in GIS, basically because of its superb image processing (IP) capabilities. Helping to set the pace in image processing developments, ERDAS has been adapted and integrated by its GIS competitor, ARC/INFO. The major GIS vendor has incorporated a major IP system to offer the user most of the capabilities usually demanded. In response to stiff competition, Intergraph developed its own GIS-IP integration. Tydac is another relatively new and competitive image processing vendor offering some new analytical capabilities.

As discussed, CAD is becoming part of the GIS world. AutoCad has enhanced its mapping capabilities and now has data conversion and integration capabilities with several major GIS vendors. Several other major vendors are becoming constituents in the GIS field, such as DigiCad. These and other CAD systems may be worthy of inclusion into any major GIS operation, not only because of their unique drawing capabilities, but because of their enhanced integration with GIS today.

System Evaluation and Selection

GIS implementation has received much attention in various publications and has been discussed in various parts of this primer. System evaluation and selection can be an intimidating and complex processes, particularly for the inexperienced. It is extremely difficult for new users to know exactly what is needed and what will be needed in their near future. Obviously, experience is the best guide and should be a resource exploited by potential customers from the outset. Several organizations exist for that specific purpose, notably PlanGraphics, Inc. which assists organizations and governments in the selection of GIS. Their basic approach is to evaluate the need first and then to consider the economic capabilities of the customer before actual system assessment. Obviously, system evaluation is based upon the need and resources of the customer.

This primer does not intend to offer specific suggestions for the evaluation process. Other publications provide excellent guidelines (Appendix IV, Bibliography). Although comments about the aforementioned vendors may be debatable, the typical suggestion today is to select a vector-based and relational database system, preferably with some image processing capabilities. Many considerations are involved in system evaluation, including basic elements such as cost, market share, and corporate stability, as well as such esoteric considerations as data format, data integration capabilities, data management philosophy and techniques, and supported peripherals. Because each customer has unique circumstances and needs, any one or more vendors may be ideal.

GISs are considered to be useful and viable for five years, without requiring major upgrades, and for 10 years with support by major advancements. Databases may have a useful lifetime of 20 to 50 years. Consequently, the primary system should be selected with a perception of present and future needs. Established major vendors have distinct advantages, but convincing cases may also be made for the struggling and new systems.

Again, although GIS is expensive, usually more so than originally anticipated, the payoffs can be greater. Implementation of specific vendors and the myriad of support elements are perhaps the major decisions to be made concerning GIS. A wealth of intangible returns may be realized, also, e.g., satisfaction among personnel and customers, establishment of new directions, and a feeling of technologic and production advancement. It is not easy to choose a vendor and even more difficult to dedicate the resources necessary for proper implementation, but for most users the basic choice would be to avoid underestimation of GIS's potential and to allocate even more support from the beginning.

GIS TRENDS

Much has been published and discussed concerning the trends of GIS, far too much to present here, so a brief synthesis is offered. There is no doubt that GIS is advancing at a very rapid rate, primarily as a result of developments in computer technology. Therefore, the initial driver of GIS developments seems to be the hardware technology advances, soon followed by software improvements and innovations, and the subsequent establishment of new paradigms that reach beyond technology.

Chips are becoming faster and all the elements affiliated with them are becoming more sophisticated, both hardware and software developments. Computing speeds are increasing at phenomenal rates, with measurements now in MIPS (millions of instructions per second) for microcomputers. This means that more advanced operations can be accomplished in shorter time. Storage devices and routines are being enhanced almost exponentially, permitting the use of very large spatial databases and increasingly complex data sets. Parallel and distributed processing routines are opening new directions in digital spatial data management. More realistic graphics, including solid 3-D display and analysis, have arrived. Holographics and laser technology are beginning to present new modes of visualization.

GIS will continue to be easier to learn and to operate. The use of icons and friendly menu systems already allow users to concentrate more on the use of the technology rather than on the operations. Users are also becoming more sophisticated. As human resource capabilities increase, new expectations are established. Simple map production will no longer be adequate, systems will be expected to perform highly advanced analyses and intricate presentations. The use of Artificial Intelligence and Expert Systems will revolutionize GIS to remarkable magnitudes.

Currently, GIS is confined to using two-dimensional data sets (with simulated 3-D) and static time-frame analysis. In the next few years, cubic volumes will be standard display and analysis formats. The application of sophisticated trend analysis programs will aid the incorporation of various time periods into a single database for backward and forward temporal analysis. The current use of X-Y-Z coordinates will be expanded to a new nomenclature of X-Y-Z locational coordinates, T for time data, and A for attribute characterization.

Revolutions in data are occurring continually. Off-the-shelf data sets will contain more detail and will become standard, with world-wide information available through global networks and high capacity centralized file servers. Practically all types of land information will be available for almost all parts of the world, with frequent updates accomplished via satellite data. Universal compatibility will be achieved, probably through the use of data transformation routines that automatically read and accommodate the receiving system. Standards for data accuracy, resolution, and other measures of quality will be established, with nearly global adherence to *common expectations*.

Even today, more applications for spatial data are occurring. An increasing number of organizations are "spatializing" data, with the realization that location can be a primary and highly valuable attribute. GIS implementation becomes a logical step for these organizations. As a result, GIS will soon become so entrenched into a myriad of systems and applications that it will become largely "invisible", much in the same way that computers today are accepted and expected tools for a plethora of applications. Hence, the discipline of computer science is more of a development and support foundation rather than the driver of computer technology utilization. GIS will be a success when we no longer perceive it as a distinct entity outside of the core discipline.

In effect, new paradigms in all aspects of GIS are being developed. New methods of doing new things with the technology are occurring continually, causing expectations to increase. This is already somewhat of an unrecognized paradigm today. No doubt the rate of change will increase and the revolutions that await the field may be nearly incredible to today's users.

Conclusion

Only a fraction of the GIS topics and considerations have been discussed here, practically all incompletely and perhaps inadequately. As a primer, it was intended to present the breadth of the field, with some indication of depth. The field is so new that established paradigms are only beginning, but soon to be surpassed by revolutions in technologic developments. As a discipline, GIS is only beginning to be recognized, yet as a methodology it is being incorporated in an increasing number of applications.

GIS is not a "flash in the pan" but will survive, eventually to evolve into a largely unrecognizable entity. If successful, it may disappear into the mainstream of technologic support. Thus, it is hoped that the primary message delivered by this primer is that while GIS is only beginning to mature, now is the time for involvement and for assimilation. It is an exciting, dynamic, and highly productive field. GIS is here to stay.

APPENDIX I

GLOSSARY

ABSOLUTE COORDINATE SYSTEM - A geographic coordinate system based on an established system such as latitude-longitude, Universal Transverse Mercator, State Plane, etc.

ACCURACY - The degree to which a measured value is known to approximate a given value, or the degree of conformity with a standard. Accuracy relates to a result's quality; it is distinguished from precision which is related to the quality of the operation by which the result is obtained. In terms of mapping, for example, "accuracy" is the completeness and correctness of illustrating an aspect of the landscape for a specific purpose.

ACCURACY STANDARDS - A composition of specifications constituting minimum levels of accuracy, or standards, to which the finished product (desired results) must adhere.

ADDRESS - An identification, represented by a group of characters, that specifies a register or computer memory location. An address is also the x,y location of a square or a rectangular grid cell.

AGGREGATION OPERATIONS - Process of grouping together many distinct parts or categories of data into one category, usually as a composite display.

ALGORITHM - A finite set of instructions which, if followed, accomplish a particular task such as solving a problem.

AM/FM - Automated mapping/facilities management systems used for managing spatially distributed facilities, including utilities, roads, and property and tax assessment records. These systems are primarily database mangement systems.

ARC - A vector segment composed of a series of points that start and end at a node.

ARC DATA - Data which represent the borders of polygon features or the location of linear, or curvilinear, features.

AREA - A level of spatial measurement representing a two-dimensionally defined space. For example, a polygon on the earth projected onto a horizontal plane.

ASPECT - The horizontal direction in which a slope faces. Aspect is commonly expressed as the direction clockwise from north.

ATTRIBUTE - A non-spatial label, descriptive characteristic, or feature quality. An attribute value is a measurement assigned to an attribute or a feature. On parametric maps, attributes are the map unit labels. On an integrated map, an attribute is the subject heading.

ATTRIBUTE TAGGING - Assignment of attributes to particular features.

AUTOMATIC CLIPPING/JOINING - A capability of some systems for copying, moving, and placing small portions of a database elsewhere in the database, without operator intervention.

AUTOMATIC POLYGON CENTROID CALCULATION - A system capability for center determination of a polygon area, without operator intervention. Usually, this capability is associated with automatic label placement.

AUTOMATIC SNAPPING - A capability for completing a vector whose end approaches a predefined closeness threshold to a node or an intersection, without any operator intervention. It is a part of the "cleaning" or editing process.

BASE DATA - Basic level of map data on which other information is overlain for comparing and analyzing spatial relationships.

BATCH PROCESSING - A computer processing mode which processes instructions and data as a complete package.

BOOLEAN OPERATIONS/RETRIEVALS - A strategy for searching, selecting, and retrieving information (features of interest) based on criteria specified by logical operators, such as AND, OR, and NOT, to represent symbolic relationships.

BROWSING - A system capability used to find, or locate, an undefined feature or set of features in a database.

BUFFER - An internal, temporary memory used to provide intermediate storage between the central processing unit (CPU) and the disk or printer.

BUFFERING/BUFFER GENERATION - A typical inventory and analytical operation in which zone polygons or buffers are created, each zone is a corridor of a specified width that circumscribes a geographic feature. It includes the determination of spatial proximity or nearness of features.

CADASTRAL - A geographic coordinate system based on fixed monuments whose locations are defined by ground survey. This term is generally used for mapping landownership and other legally defined boundaries.

CAC - Computer-assisted cartography systems are very similar to CAD systems; they emphasize final graphic products.

CAD/CAM - Computer-aided design or drafting/computer-aided mapping or manufacturing. These systems differ from a GIS because only displays can be created; they cannot be used to analyze or process the database, nor can they be used to create new spatial databases or relationships.

CARTESIAN COORDINATES - A coordinate system in which points in space are located and expressed by reference to three planes, called the "coordinate planes" (X,Y, and Z), no two of which are parallel.

CELL - A defined geometric shape which stores data or defines a labeled area. The most common mapping cell size is a square.

CENTROID - The mathematical center point of a polygon or the midpoint of a line. The centroid is described as an X,Y coordinate.

CHARACTER - A letter, number, or symbol used to represent information.

CLASSIFICATION - In general, a systematic arrangement of objects into a logical structure or hierarchy. In image processing, classification is the process of assigning individual pixels of an image to categories.

CLUSTER - Any configuration of elements (pixels or cells) occurring closely together in n-dimensional (spectral) space.

CLUSTERING OPERATIONS - Routines allowing users to agglomerate (cluster) individual items or features into groups of similar value.

COGO - Essentially, coordinate geometry systems are CAD systems, designed specifically for public land survey data entry and transformation.

COMMON SCALE - A single mapping scale which is used for spatial (geographic) analysis. Maps which are not at the common scale are rescaled prior to processing.

COMPOSITE MAPPING - The process of, or a system for, overlaying maps to locate specified combinations of features. Generally, this is required for spatial analysis.

COMPRESSION - A series of techniques used to reduce the space, band-width, cost, transmission, generating time, and storage of data. These techniques are designed to eliminate repetition, remove irrelevant data, and employ special coding techniques, such as run-length encoding.

COMPUTER-COMPATIBLE FORMAT - A data format which can be readily entered into a computer and usually referred to in magnetic media terms, e.g., CCT or computer-compatible tapes.

COMPUTER MAPPING - The linkage existing between an attribute database and graphical display system, facilitating the automatic assignment of symbology to spatial entities based on data values.

CONNECTIVITY ANALYSIS - An analytical technique used to determine whether a set points (nodes) or lines are connected to each other.

CONTIGUITY ANALYSIS - An analytical technique used to determine whether a set of areas (polygons) are adjacent. Sometimes this technique is referred to as adjacency analysis.

CONTOUR - An imaginary line on the ground, all points of which occur at the same elevation above or below a specified datum reference surface (usually mean sea level).

CONTROL POINT - Any station in a horizontal or vertical control network identified in a data set, or photograph, and used to correlate the data shown in that data set of the database.

COORDINATE - The relative location of a point in a right angle axis. On line maps, the coordinate is expressed as the horizontal (X) and vertical (Y) distance from the axis (origin). In grid cell maps, the coordinates represent row and column intersection.

COORDINATE PAIR - A set of Cartesian cordinates describing the two-dimensional (2-D) location of a point, line, or polygon (area) feature in relation to the common coordinate system of the database.

COVERAGE - A digital version of a single map sheet layer. It generally describes one type of map feature (e.g., roads, soil units, or forest types).

CURSOR - A marker that specifies an X,Y coordinate in the computer. A screen cursor marks the position of a character. A digitizer cursor defines a coordinate that will be transmitted to the computer.

DATA - Factual or assumed material used as input for analysis. "Raw" data are used as original input. Plural for datum.

DATABASE - An organized collection of data that is automated (computerized) for manipulation and related by a common fact, element, or purpose. A geographic (spatial) database is generally organized according to area and may consist of several scales linked, or related, by a hierarchical classification system.

DATA CAPTURE - A series of operations required to enter data in a computer-readable digital format. Digitizing is the most common form of data capture.

DATABASE DEVELOPMENT - A process of determining which elements to include in a database and identifying their internal relationships.

DATABASE MANAGEMENT SYSTEM (DBMS) - A systematic approach using software to structure, maintain, access, and manipulate a database and its files. A DBMS may consist of a single program or a collection of task-specific programs.

DATA ELEMENT - A basic unit, or specific item, of information which forms a portion of a set of data. Also called a data item, attribute, feature, variable, or observation.

DATA ENCODING - A process of applying a code, frequently one consisting of binary numbers, to represent individual data or groups of data. Sometimes it refers to data capture.

DATA ENTRY - A process of loading data directly into a database, either manually or automatically, in a computer-compatible format.

DATA FILE - An organized group of related data, e.g., results of a soil sample analysis for a particular study area. A data file may contain one or more data sets.

DATA LAYER (CATEGORY) - This term refers to data, with similar characteristics, being contained in the same data set and portraying a particular theme on a map, e.g., transportation maps include roads, railroads, and airfields. Usually, information in one data category is associated and designed to be used with other data categories.

DATA MANIPULATION - Refers to those data processing tasks common to most users, such as sorting, filing, managing, maintaining, updating, and generating reports.

DATA QUALITY - Refers to the degree of excellence exhibited by data and their portrayal of the actual phenomena.

DATA REDUCTION - A process of transforming large amounts of raw data into useful, ordered, or simplified intelligence. It may also refer to data compression.

DATA RETRIEVAL - The process of retrieving data from databases resident in the system and summarizing, reporting, or otherwise displaying the information.

DATA SET - A group of related data elements. The data set may be contained in one or more data files processed in a single session.

DATA STRUCTURE - The organizational scheme for a data file. Also referred to as the data format.

DATA TOPOLOGY - Refers to the order or relationship of specific data items to other data items.

DECOMPRESS - A process which compresses and expands data to its former file size.

DEFAULT VALUE - An option selected by the computer or program if no alternative is specified.

DIGITAL DATA - Refers to data in the form of numbers. In geographic processing and spatial analysis, both the X,Y coordinates of lines and label characteristics are represented by numbers.

DIGITAL DATA SET - A collection of similar and related data records stored and maintained for subsequent use by a computer.

DIGITAL ELEVATION MODEL (DEM) - A file with terrain elevations recorded at the intersections of a fine grid and organized by quadrangle. DEMs are the digital equivalent of elevation data on a topographic base map.

DIGITAL IMAGE - A numerical representation of an object or scene.

DIGITAL TERRAIN MODEL/MODELING (DTM) - A digital representation of a land surface using an elevation grid or lists of 3-dimensional coordinates. DTM systems are concerned with analyzing and displaying surface data, regardles of whether actual terrain is represented.

DIGITIZER - A device which converts maps or graphics into a digital X,Y format. Also, a person operating such a machine.

DIGITIZING - The process of converting map or graphic data to digital form.

DISPLAY - A display (usually CRT) attached to a computer for the visual depiction of information as either maps, text, or tables. Also, the visual image of data and analytical results.

DISSOLVE - Refers to the removal of shared common attributes by the elimination of the shared boundaries during the merger of two or more polygons.

DISTANCE MEASURE - A system capability for measuring the distance between selected locations or points. This measurement may include perimeter, path length, nearest neighbor distances, or search distances.

DISTORTION - Any shift in the position of an image which alters the desired spatial characteristics of the image.

DISTRIBUTED DATABASE - A database with unique components in geographically dispersed locations physically linked via a telecommunications network.

DOUBLE DIGITIZING - In digitizing a map unit using a raster-based system, each polygon is stored as a complete unit. As a result, lines shared by adjoining polygons are digitized twice in raster systems.

EDGE MATCHING - The process of comparing and graphically adjusting features to obtain agreement along the edges of adjoining map sheets.

EDITING - The process of inserting, deleting, and changing attribute and geometric elements to correct and/or update a model or database.

ENCODING - The process of transforming, or converting, either spatial or non-spatial data from its original form to a computer-usable format, usually a digital format. In geographic data processing, encoding means to translate locations, boundaries, and labels into numerical representations.

ERROR ANALYSIS - An analytical technique used to determine the amount of deviation from a standard or specification.

FEATURE - An object or aspect of the earth's surface, or a set of phenomena with common attributes and relationships, such as a road, vegetation, or townsite. This concept encompasses both entity and object.

FEATURE ATTRIBUTE - An element used to represent the non-positional aspects of an entity. Also, it refers to a feature object.

FIELD - A group of characters or words treated as a unit of data.

FILE STRUCTURING - The logical form of a file resulting from the application of a particular file organization and layout to a group of records.

FORMAT - The predetermined arrangement of data, i.e., characters, fields, lines, etc., in a record or file. Also, the type of geographic representation depicted, e.g., a polygon for lines or a grid for grid cells.

GEOCODING - The process of translating geographic coordinates for map sites, lines, and points into X,Y digits or grid cells.

GEODETIC REFERENCING - Use of latitude and longitude as a geographic reference.

GEOGRAPHIC(AL) INFORMATION SYSTEMS (GIS) - An information technology (computer hardware and software) and systematic approach designed to capture, manage, manipulate, analyze, model, and display both spatially referenced and non-spatial data. Often, GISs are used as a decision support tool for complex planning and management problem-solving. The term is generally applied to automated systems.

GEOPROCESSING - The automated manipulation and/or analysis of geographic data.

GEOREFERENCE SYSTEM - An X,Y or X,Y,Z coordinate system that locates points on the surface of the earth as a reference to points on a map. Systems include latitude-longitude, Universal Transverse Mercator, State Plane Coordinate, and Cadastral.

GRID - A network of uniformly spaced horizontal and perpendicular lines which enclose an area or a cell with an associated assigned value.

GRID FORMAT - A data structure in which data are encoded and stored as regular areal units, usually square or rectangular in shape, and called grids or cells. Data are somewhat generalized.

HARD COPY - A printed paper or film copy of a computer file, the results of processing, or other digital data.

HIERARCHICAL - A classification scheme that includes general and specific labels. Often, it is used in multiple-scale mapping systems in which the labeling system for each scale can be generalized or subdivided into the labeling system for a different scale.

IMAGE PROCESSING - Encompasses a variety of operations that can be applied to digital image data. Generally, these include the preparation of a raw image for presentation and the set of computer manipulations for extracting data from an image.

INTEGRATED MAP - A natural features map in which each map unit has multiple labels addressing a variety of geographic subjects. For example, one map unit may contain bedrock geology, soil type A, vegetation type 1, Slope 5%-10%, etc.

INTEGRATED SYSTEM - A geographic database structure in which the spatial data (cells, polygons, lines, and points) and the attribute data (feature labels) are stored in separate files. The spatial data are stored as manuscripts in which each map unit has multiple labels.

INTERNAL DATA STRUCTURE - The organization and reference linkages among data elements within the data system.

ISLANDS - Refers to polygons enclosed entirely within another polygon.

JOIN - The area in which two or more adjacent maps or images are combined or merged to form a continuous model.

LABELLING - The process of assigning attributes to polygon, line, and point coverages.

LANDSAT - A series of unmanned Earth-orbiting NASA satellites used to gather multispectral data.

LAYERS - Refer to the various "overlays" of data. Each overlay normally deals with one thematic topic, with each registered to the others by a common coordinate system of the database.

LINE - A level of spatial measurement referring to a one-dimensionally defined object having length, direction, and connectivity in at least two points. Examples are roads, railroads, telecommunication lines, streams, etc.

MAP - In GIS, it is the hardcopy version of a coverage.

MERGE - To combine items from two or more similarly ordered sets into one set that is arranged in the same order. In a GIS, this means to splice separate but adjacent mapped areas into a single, coherent map, database, or data set, without retaining redundant information.

MODEL/MODELING - A model is an attempt to duplicate nature to simulate, predict, or provide new information about the situation being analyzed. It is an analogy of the real world system. The nature of a GIS lends itself well to the modeling process.

NEAREST NEIGHBOR ANALYSIS - An analytical technique used to determine relationships between point locations and their n-th order neighbors.

NETWORK ANALYSIS - An analytical technique concerned with the relationships between locations on a network. For example, the calculation of optimal road network routes, capacities of network systems, or best locations for facilities along networks.

NODE - A point which is common to two or more line segments.

OPTICAL SCANNER - A light sensitive device used for reading lines and symbols for computer input. Often used for mapping.

OVERLAY - The superimposition of two or more maps or digital images to determine data combinations or intersections. A common coordinate system is used to register overlays to the base data.

PARAMETRIC MAP - Refer to thematic map.

PERSPECTIVE VIEW - A three-dimensional representation generated with reference to a specific viewer location on or above the portrayed surface.

PIXEL (PICTURE ELEMENT) - The unit of resolution, storage, and retrieval for a digital raster image. The smallest discrete element making up an image.

POINT - A level of spatial definition referring to an object having no dimension. Examples include wells, weather stations, and navigational lights.

POLYGON - A geographical area defined by a boundary; a basic map unit.

POSITIONAL ACCURACY - A term used to evaluate the overall reliability of a cartographic feature's position relative to its true position, or to an established standard, such as a geographic coordinate system.

PROJECTION - A systematic drawing of lines of a plane surface to represent Earth's parallels of latitude and meridians of longitude.

PROJECTION CHANGE - A procedure for transferring features from one projection surface to their corresponding position on another projection surface by either graphical or analytical methods.

PROXIMITY - A measure of closeness to a user-defined specified point.

PROXIMITY ANALYSIS - An analytical technique used to determine the existing relationships between a selected point and its neighbors.

PROXIMITY SEARCH - An analytical procedure used to identify occurrences of predefined data elements in a selected point's neighborhood.

RASTER - A pattern of horizontal and parallel scan lines comprising the image on a CRT screen. Each scan line consists of segments varying in intensity.

RASTER SCAN - A method of generating or recording an image in which a line by line sweep across a display surface is performed.

RECTIFICATION - The process of removing the effects of tilt, relief, or other distortions from imagery, photographs, or maps by correcting small, independent portions of the image or map. Also, the process of projecting these tilted or distorted images onto a reference plane.

RELATIVE POSITION - A registration approach used to refer to the locations of features relative to other features.

REPEATABILITY - A system capability to obtain the same results consistently when conducting the same operation.

RESCALE - An adjustment of values or parameters which represent magnitudes or intensity, causing data to reflect an aspect more suited to the user.

RESOLUTION - A measure of the ability of an imaging system, such as LANDSAT, to separate the images of closely adjacent objects. Also, the smallest area identified as a separate mapping unit.

RUBBER SHEETING - A type of registration operation analogous to stretching one data layer to fit another, as if it were a rubber sheet.

SCALE - A ratio or fraction between the distance on a map, chart, or photograph and the corresponding distance on the Earth's surface.

SCANNING - A process of using an electronic input device to convert analog information, such as maps, photographs, or overlays, into a computer-usable digital format.

SINGLE LINE DIGITIZING - A vector digitizing process in which a polygon is defined by a series of separate line segments. Boundaries between polygons are digitized once, with the polygon identifier carried to the right and left sides of the line.

SITE SUITABILITY ANALYSIS - An analytical technique used to select the most or least suitable mapped characteristics (or a hierarchy of suitabilities), to assign weights to some of these characteristics, and to perform multiple overlays of interrelated information to see which sites have the best qualities for a specific purpose. Thus, a coherent picture is presented for assessing suitability.

SLIVERS - Refer to polygons formed when two adjacent polygons do not abut on a single common line (border), leaving a small area polygon between the larger two polygons.

SPATIAL ANALYSIS - Analytical techniques associated with the study of locating geographical entities and their spatial dimensions. Also, this is referred to as quantitative analysis.

SPATIAL (GEOGRAPHICALLY REFERENCED) DATA - Data which pertain to the location of geographical entities or which are tied to a location. Spatial data types include point, line, area (polygon), and surface.

SPATIAL DATABASE - A collection of spatial information related by a common fact or theme.

SPATIAL DATA SET - A collection of similar and related spatial records stored for subsequent computer use.

STANDARDS - Refer to an exact value, a physical entity, or an abstract concept, established and defined by authority, custom, or common consent to serve as a reference, model, or rule in measuring quantities or qualities, establishing practices or procedures, or evaluating the results. It is a fixed quantity or quality.

SURFACE - A level of spatial measurement which refers to a three-dimensionally defined space. For example, contours, isolines, bathymetry, etc.

TERRAIN ANALYSIS - Analytical techniques used to determine the effect of terrain on a particular operation, usually involving slope, soil types, and vegetation.

THEMATIC MAP - A map related to a topic, theme, or subject of discourse. Also called geographic, special purpose, distribution, parametric, or planimetric maps. Thematic maps emphasize a single topic such as vegetation, geology, or landownership.

THINNING - A process in which a linear feature is generalized by using a series of rules to reduce the number of data points and maintain the basic shape of the feature.

THREE DIMENSIONAL (3-D) DATA - Volumetric data representing measurements in three dimensions. These dimensions can be angular or linear measures such as phi-lambda-kappa or latitude-longitude-elevation.

TOPOGRAPHIC ANALYSIS - Surface configuration analysis which includes its relief and the position of streams, roads, cities, etc. Usually, it is subdivided into hypsography (relief features), hydrography (water and drainage features), cultural (man-made features), and vegetation.

TOPOLOGICAL - Refers to the properties of geometric figures, such as adjacency, connectivity, and containment, which are not altered by distortion as long as the surface is not broken.

TOPOLOGY - It is a mathematical procedure for explicitly defining the spatial relationships between features. Topology defines three spatial relationships: containment (area definition), contiguity (adjacency), and connectivity.

TOPOLOGICAL RELATIONSHIPS - Refers to how data elements relate to each other within the data base. In particular, how a change to one element affects other elements.

TOPOLOGICAL STRUCTURING - Process of organizing data topologically to specify the relationships and reference linkages.

TRANSFORMATION - Conversion of coordinates between alternative georefencing systems.

TRIANGULAR IRREGULAR NETWORK - A data structure which describes a three-dimensional surface as a series of irregularly shaped triangles. The term is usually used in connection with terrain modeling.

TWO-DIMENSIONAL (2D) DATA - Areal data specified in two dimensions, such as northing-easting or latitude-longitude.

UPDATING - Refers to the capability to make changes or add new information to existing data.

VECTOR - A data organization in which lines representing pictorial or graphical information are quantified into a series of X,Y coordinates describing the vertices (endpoints) of the small line segments making up the graphic.

WEIGHTED AVERAGE - An arithmetic mean of a numerical series adjusted to give appropriate significance to each item in relation to its importance.

WINDOW - Rectangular frame with a specified aize and location on the screen of an interactive graphics systems, and within which a rectangular portion, or window, of the map is displayed.

WINDOWING - A method of designating and separating out a particular area of map data for presentation on a display or for analysis. Also used to enlarge a portion of a geographic database.

APPENDIX II

SAMPLE GIS AND REMOTE SENSING APPLICATIONS

Thematic Application	Examples
Agriculture	Irrigable lands identification & monitoring Regional soil and ecology evaluation Crop type mapping and yield assessments Soil erosion assessments
Archaeology	Site relationships of a discovery and surroundings Site suitability for potential excavation sites of interest Spatial analysis of dig site findings Cultural resource management
Demographic & Socioeconomic	Redistricting/reapportionment Voting pattern trend analysis Population density estimation Quality of life analysis Market research analysis
Engineering	Viewshed/visual impact analysis Reservoir site suitability Hydrologic/groundwater modelling Hazardous waste disposal site assessment Digital terrain analysis
Forestry & Wildlife	Ecological simulation modelling Fire behavior assessment and modelling Timber harvest yield assessment Operational planning of timber harvests Insect damage assessment and monitoring Cumulative environmental impact analysis
Geology	Topographic relationships with various features - e.g., vegetation, soils Site suitability for mineral exploration Locational analysis of proposed well sites Regional landscape analysis Lineament identification and spatial analysis using AI/ES
Global	Acid rain impact assessment Biosphere reserves assessment Climatic change analysis and monitoring

	Deforestation assessment and monitoring Desertification hazard trend analysis
Land Use	Land use/cover change detection and analysis Environmental sensitivity assessment Openlands determination Land use trends analysis and predictions Industrial site suitability analysis Landfill suitability Conflict resolution
Transportation	Highway planning and regional site analysis Emergency vehicle response routing Analysis of frequency and location of emergency events Optimal route analysis for public transportation and school buses Prediction of airport noise levels
Urban	Regional site planning and analysis Urban growth analysis and sensitivity modelling Urban thermal heat island analysis Urban heat loss and trend analysis Urban development trends analysis Facilities management
Water	Water quality/pollution measurement and monitoring Wetlands identification and monitoring Groundwater flow sensivitiy analysis Water well contamination from underground gas storage tanks

APPENDIX III

DIGITAL DATA SOURCES

DIGITAL DATA SOURCES | **POINT OF CONTACT**

US Bureau of Census — Fred Broome
Customer Services Branch
Data Users Services Division
Washington, DC 20233
(301) 763-4100
(301) 763-7662
DATA: TIGER (Topologically Integrated Geographic Encoding and Referencing System)
GBF/DIME (Geographic Base File/Dual Independent Map Encoding System)
Census Attribute Data Sets

Canada Centre for Remote Sensing
2464 Sheffield Road
Ottawa, Ontario KIA 0Y7
(613) 952-2171
DATA: LANDSAT
SPOT

Canada Centre for Remote Sensing
Prince Albert Receiving Station
Prince Albert, Saskatchewan S6V 5S7
(306) 764-3602
DATA: LANDSAT
SPOT

CanSIS Project Leader
Land Resource Research Centre
Agriculture Canada, Research Branch
K.W. Neatby Building
Ottawa, Ontario KIA 0C6
(613) 995-5011
DATA: Canada Soils Information System

ContiTrade Services Corporation — Dr. V. Minshew
2000 South Main
Fort Worth, TX 76110
(817) 923-8301
(800) 343-8650
DATA: Soviet Satellite KFA-1000 Imagery (5m)

Defense Mapping Agency (DMA) Aerospace Center   Kathleen Durako
3200 South Second Street
St. Louis, MO 63118-3399
(314) 263-3901
DATA: Digital Elevation Models (DEMs)
Digital Terrain Elevation Data (DTED)
Digital Feature Analysis Data (DFAD)
World Vector Shoreline (WVS) Data
Digital Bathymetric Sounding Data (BDB)
Digital Bathymetric Gridded Data (DBDB-5)
Digital Point Positioning Data Base (DPPDB)
ARC Digitized Raster Graphics (ADRG)

Ducks Unlimited, Inc.   Dr. Gregory Koeln
One Waterfowl Way
Long Grove, IL 60047
(312) 438-4300
DATA: Wetlands

Earth Observation Satellite Co. (EOSAT)   Judy Collins
4300 Forbes Boulevard
Lanham, MD 20706
(301) 552-0500
(800) 344-9933 Ext. 537
DATA: LANDSAT Thematic Mapper (TM)
LANDSAT Multi-Spectral Scanner (MSS)

Topographic Surveys Division
Surveys and Mapping Branch
Energy, Mines, and Resources Canada
615 Booth Street
Ottawa, Ontario KIA 0E9
(613) 992-0924
DATA: Digital Topographic Data

Environmental Information Systems Division
State of the Environment Reporting Branch
Environment Canada
Ottawa, Ontario KIA 0H3
(613) 997-2510
DATA: Canada Land Data System (Canada Geographic Information System)

US Environmental Protection Agency (EPA)
Office of Water and Hazardous Materials
401 M Street, SW
Washington, DC 20460
202-426-7792
DATA: STORET (Water Quality)

US Environmental Protection Agency (EPA)
Remote Sensing Branch
P. O. Box 15027
Las Vegas, NV 89114
(702) 798-2100
(702) 798-2476
DATA: Daedalus 2600 ATM

ETAK, Inc.
Map Product Group
P. O. Box 2148
Menlo Park, CA 94026
(415) 328-3825
DATA: Etak MapBase - Topological Digital Map Data Base

Geographic Data Technology, Inc. (GDT) — Molly Hutchins, Katesel Strimbeck
13 Dartmouth College Highway
Lyme, NH 03768-9713
(603) 795-2183
DATA: GBF/DIME
TIGER
DYNAMAP/USA DATABASES:
- Street Network File
- Administrative Boundary File
- Census Block/Tract File
- 5-Digit Zip Codes
- Metropolitan Statistical Areas (MSAs)

National Aeronautics and Space Admininstration (NASA) — David DeBlanc, Richard Galle, Dale Quattrochi, Julius Baham
Stennis Space Center (SSC)
Space Technology Laboratory
Stennis, MS
(601) 688-1931
DATA: Daedalus 2600 ATM (5m and 10m)
Calibrated Airborne Multispectral Scanner (CAMS)
Thermal Infrared Multispectral Scanner (TIMS)

National Cartographic Information Center (NCIC)
US Geological Survey (USGS)
User Services Section
507 National Center
Reston, VA 22092
(703) 860-6045
DATA:
- GIRAS format:
  - Political Units
  - Census County Subdivisions
  - Land Use/Land Cover
  - Hydrological Units
  - Composite Theme Grid
- Digital Line Graphs (DLGs):
  - Political Units
  - Census County Subdivisions
  - Land Use/Land Cover
  - Hydrological Units
  - Composite Theme Grid
- Digital Elevation Models (DEMs)
- Geographic Names Information System:
  - National Geographic Names Database
  - USGS Topographic Map Names Database
  - National Atlas Database
  - Board on Geographic Names Database
- Digital Terrain Models (DTMs)

National Climatic Data Center (NCDC)
Federal Building
Asheville, NC 28801
(704) CLIMATE
(704) 259-0871
DATA:
- AVHRR (Advanced Very High Resolution Radiometer)
- Seasat Altimeter and SAR (Synthetic Aperture Radar)
- Sea Surface Temperature
- TIR OS-N
- Surface Marine & Air Obs.
- Hourly Precipitation
- Lightning Statistics
- Soil Temperatures

National Geophysical Data Center (NGDC) Jason Maddox
325 Broadway
Boulder, CO 80303
(303) 497-6474
(303) 497-6376
DATA:
- Aurora
- GOES/VISSR (Geostationary Operational Environmental Satellites)
- LANDSAT
- MAGSAT

National Geodetic Survey (NGS)
Rockville, MD 20852
(301) 443-8631 (Geodetic Data)
(301) 443-8136 (Digital Data Catalog)
DATA: Geodetic Control Information

National Oceanic and Atmospheric
Administration (NOAA)
National Environmental Satellite Data
and Information Service
National Climatic Center
Satellite Data Services Division
Washington, DC 20233
(301) 763-8111
DATA:
- AVHRR (Advanced Very High Resolution Radiometer)
- Nimbus-7 Satellite/Coastal Zone Colour Scanner (CZCS)
- GOES
- Seasat Data

National Oceanographic Data Center (NODC)
ATTN: Albert Bargeski
Page Building 1
2001 Wisconsin Ave., N.W.
Washington, DC 20235
(202) 673-5594
DATA:
- Physical
- Biological
- Chemical

National Technical Information Service (NTIS)
US Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650
DATA:
- World Data Bank I
- World Data Bank II
- Small Scale World Boundaries, Major Rivers

Oak Ridge National Laboratory (ORNL) — R. J. Olson, C. J. Emerson, M. K. Nungesser
Oak Ridge, TN 37830
(615) 576-5454
DATA: County Level Data in SAS tabular format

Agriculture	Vegetation
Base Data	Forestry
Climate	Air Quality

National Stream Quality Accounting Network (NASQAN)

Soil Conservation Service (SCS) Richard Folsche
National Cartographic Center
South Technical Service Center
P. O. Box 6567
Fort Worth, TX 76115
(817) 334-4685
DATA: Soils

SPOT Image Corporation
1897 Preston White Drive
Reston, Va 22091-4368
(703) 620-2200
DATA: SPOT HRV (High Resolution Visible) Panchromatic (10m)
SPOT HRV (High Resolution Visible) Multispectral (XS) (20m)

Geocartographics Division
Statistics Canada
Ottawa, Ontario KIA 0T6
(613) 951-6980
DATA: CARTLIB Files

Geography Information Services
Geography Division
Statistics Canada
Ottawa, Ontario KIA 0T6
(613) 951-3889
DATA: Area Master File (AMF) Data

User Summary Tapes
Electronic Data Dissemination Division
Statistics Canada
9th Floor, R.H. Coates Building
Ottawa, Ontario KIA 0T6
(613) 951-8200

Atlantic Region	(800) 565-7192
Quebec Region	(800) 361-2831
Ontario Region	(800) 268-1151
Prairie Region	(800) 282-3907
Pacific Region	(800) 663-1551
Northwest Territories	(403) 495-3028
Yukon & Northern British Columbia	Zenith 08913

DATA: Census Related Data

APPENDIX IV

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