Geographic Information Systems: The Marriage of Mapping and Computer Graphics

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One of the points of emphasis of this year's Purdue Road School is the concept of the Geographic Information System (GIS). This system, a result of the marriage between mapping and computer graphics, is growing in use throughout the world and can be used in a variety of facilities management, design and planning applications.

Geographic Information Systems are a combination of computer graphics hardware, application software and database technology that encode, analyze and display multiple data layers derived from various sources. Analyses can be expressed in tabular, graphic and, most importantly, in geographically coordinated mapping format. Information about property ownership, assessment and taxation can be directly related to water resources, soils, agricultural productivity, wildlife habitats, historic sites, property boundaries and other natural, economic and cultural attributes of the land in computer-drawn maps.

AM/FM SYSTEMS

GIS has evolved from AM/FM, or Automated Mapping/Facilities Management. In the late seventies, automated Mapping became a useful and cost-effective tool for engineers, architects and planners. Today's GIS is the descendant of years of evolution of computer science and cartography.

The typical way to produce an AM/FM system is by input of graphical data via digitizing from existing drawings. The ready prepared maps can be input in this fashion to produce an accurate landbase. However, if no existing landbase maps are available, photogrammetric mapping techniques and precise direct digitization can be used to create an extremely accurate topographic landbase. The graphics system can be designed with individual layers of graphic data for planimetric, cadastral and text features. This results in a geographical landbase which is flexible and can be displayed or plotted for reference. Various utility and attribute data layers can be overlaid and referenced to the landbase.

Around the beginning of the 1980s, it became useful to consider how the AM/FM link could be established to make facilities management possible with a graphics system. Database systems had evolved in the seventies to the point where manipulation of textual data was more efficient. Graphically, the AM/FM system could display and store lines, arcs, text, symbols and 3-D elements. In today's AM/FM systems, each of these types of graphical elements can be linked to non-graphic data types and entities. Each of these entities has a unique set of

attributes. Simply, for each graphic element, there can be an associated set of descriptive, attribute elements in the non-graphic database.

The non-graphic database is electronic and allows rapid retrieval and report generation. To explain the non-graphic database structure, one could make the following analogies. First, entities are the major descriptions of the graphical items depicted. If you have a file cabinet with each drawer relating to a separate entity, each drawer might be labeled Streets, Structures, Tax Parcels, etc. An occurrence is in each folder in the drawer. In the parcels drawer, there is a folder for each piece of taxable property.

Attributes are descriptive classifications of each entity occurrence. Some examples are: size, owner, use, location, width, and length. If street entity folders are examined, they might show a length attribute value of 5,280 feet and a material attribute value of asphalt.

The AM/FM system allows you to ask questions and have results displayed. You might ask the system to find and display the parcel at a certain address, and also display its attribute value. In a street maintenance application, a typical report might display all sections of primary thoroughfare that have not been repaired in ten years. This would tell your maintenance crew where and what to inspect. Additionally, as street lengths are attained, a cost per foot to repair can be added to produce budgeting data for maintenance.

GEOGRAPHIC INFORMATION SYSTEMS

A subtle, yet slightly different form of AM/FM system is a Geographic Information System. In a GIS, data is structured in a topological format. Within this format there are three types of elements: nodes, edges and polygons. The nodes are discrete points with x and y coordinates. The edges are the connecting lines between points, expressed in an edge table with a start node number and an end node number. Polygons are the third type of element. Polygon tables show the x-y range of a polygon. The edge tables and the polygon tables are often expanded to include attributes in a non-graphic database.

The advantage of the topological data structure is the existence of an integrated relational database. GIS systems are designed with hardware and analysis software that concentrates on specific applications of the data. This makes analysis of topologically structured data much faster, but often requires a more powerful processor. Recent developments in the speed of host processors have made GIS systems much quicker, and therefore, their use has increased. The term GIS is becoming the term used to describe all AM/FM systems, whether topologically structured or not.

CREATING A GIS LANDBASE

The creation of a digital landbase can be an expensive proposition. Millions of dollars are spent annually in the United States creating accurate, controlled landbases in digital format. However, before creating a database (whether your ultimate goal is AM/FM or GIS) you need to realize that there are several steps in its construction and that the end user must have a substantial amount of input into the process.

The initial step in creating a digital database is to obtain existing records (tax maps, public works maps, USGS maps, etc.) to see if they contain enough

information to develop the structure of the database. The next step is to design what you want to see on the landbase (streets, rights-of-way, structures, hydrography information, etc.). The digital landbase must then be designed with the structure, line codes and the non-graphic attributes you wish to track. Data is captured by digitizing, scanning or choosing another form of input such as acquiring existing digital data from the source who has it. After capture, manipulation will be required to accommodate design changes that will occur during the process.

If you decide to map physical features in your landbase, you may wish to photogrammetrically map the area. Stereoplotters can be directly interfaced to CAD systems, allowing for direct creation of graphic design files. (As stereoplotters are quite expensive, it's best to contract this work out to qualified firms.) A stereoplotter is a device which takes pairs of overlapping aerial photos, allowing the operator to see a stereo image which can be used to accurately trace topographic images and create a map.

Forsaking the physical features and showing only parcel and right-of-way types of land features results in a cadastral map or a tax map. These maps are usually input through compilation of existing tax deed records, repeatedly controlled to induce more accuracy. This results in a continuous map layer of parcel information controlled over a large area. The large cadastral map used as a landbase is often referred to as a multi-purpose cadastre.

DATABASE ACCURACY

Accuracy should not be confused with precision. Accuracy is the quality of the result, in this case how close to the exact coordinate position will each of these lines be placed. Precision is the quality of the maps. The accuracy of the photogrammetrically produced map is effected as the altitude of the airplane is increased or decreased. Both accuracy and cost go down as the altitude goes up.

Accuracy is a relative term, therefore one person's needs are not always the same as another's. Defraying the cost to each user by bringing multiple users on board means greater accuracy can be afforded. The accuracy should be designed into the alternate landbase and should meet the design needs of the most stringent participant. Accuracy is also affected by the survey control used. Many mapping projects use Global Positioning survey (GPS) techniques to establish control points. GPS uses a receiving stations and signals received from satellites revolving around the earth. These satellites establish extremely accurate coordinate values for discrete locations. At the other end of the accuracy spectrum, digitizing existing schematic maps results in poor accuracy in the resulting landbase.

GIS APPLICATIONS

Once you have developed your GIS system, what are the applications? One major application is in land use planning for urban or regional planners. A map can be produced very quickly to show population, housing starts, crime statistics, or property tax values. GIS data is useful for route optimization for Emergency 911 dispatch. Yet another application of a GIS database is the inventory of utility systems. The utility pipe layers can show the total lengths of all pipes in any section chosen. Other GIS uses are listed below.

GIS APPLICATIONS IN VARIOUS AREAS

Federal, Regional and Local Government Agencies

By storing data such as land parcel ownership, zoning regulations, land use and natural hazards on a GIS, officials can improve the efficiency with which services can be allocated and regulations enforced.

Public Safety

Determining the quickest route for fire engines, squad cars and ambulances can be done automatically on current GIS systems. Such systems can also help law enforcement agencies identify shifts in criminal activity so they can allocate their resources most efficiently.

Utilities

By recording the location and characteristics of assets such as transformers, poles, pipes and transmission lines in a GIS format, utilities have been able to improve their ability to quickly restore service following an accident and to automate the replacement of aging equipment.

Environmental Problems

GISs are a vitally important tool in tackling some of the global issues that are emerging, such as the greenhouse effect and the ozone hole. A GIS allows the entire globe to be viewed at any scale, and lets the user superimpose a variety of different variables and directly see the manner in which they interact.

Natural Resource Management

Forest management agencies use GIS technology to map and inventory timber resources and to plan annual harvests. Because GIS systems can examine the complex relationships between different resources, they vastly improve the land manager's ability to balance the demands of conflicting uses. For instance, they make it possible for a forest manager to compare the impact that different types of timber harvesting will have on wildlife habitat.

Site Development

Companies can utilize GIS technology to accurately determine the best locations for public and private site development.

Other Uses

Mapping, hazards mitigation, weather prediction, tax assessment and a number of other areas are using GIS technology to reduce costs while maintaining or improving output or performance.

Finally, the concept of raster imagery has great potential for GIS. A drawing or photo can be optically scanned to produce a raster image of the original. Some GIS systems will allow the raster image to be rectified by controlling it with some known coordinates for reference. These known values are used to "warp" the photo image and display a somewhat sealed, superimposed photo. A polygon from the GIS system could then be overlaid to produce professional exhibits.

Geographic Information Systems have a vast array of uses. And the number of uses is growing on a daily basis. Their capacity to maintain, integrate and

graphically manipulate thousands of bits of information make them an effective tool in comprehensive facility and land management.