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Abstract

This paper presents an historical analysis of the GIS industry, focusing on examples from the past twenty years, and includes an introduction on the origins of GIS. Specific topics discussed are an analysis of raster and vector processing capabilities, the integration of data base management systems (DBMS) into a GIS, digital orthophoto mapping, and raster/vector integration. The future of GIS will present a need for better user education as the capabilities of the industry grow, as data sources multiply, and as an increased number of platforms become available. The industry will face other challenges, such as the need for data compression, parallel processing, and a greater need for softcopy photogrammetry. There is definitely more acceptance by the user community of the use of raster processing than in years past, and the appreciation of the value of this technology has broadened as well. GIS is now an essential tool in resource management, forestry, global monitoring, transportation planning, mineral exploration, state and local government, and in a host of other areas.

INTRODUCTION

The advantages of geographic information systems (GIS) and image-processing (IP) techniques include statistical and spatial modeling, processing for better data sources, improved information management, the ability to perform enhanced productivity and integration, and the idea of cost-sharing capabilities between various users within an organization.

Over the past two decades, there have been numerous technological developments, including more efficient and lower cost computers, workstations with fully integrated networks, higher resolution displays approaching 2 k x 2 k, less expensive color hard copy and black and white printers, and film recording devices. There has also been the emergence of extremely large disk storage capabilities, open hardware architectures, and operating systems specifically moving toward open operating systems such as UNIX and DOS.

GIS/IP PROCESS

To conduct a project effectively today, a user needs a database, tools, and tested methodologies in place. Almost any project requires construction materials, such as raster data, vector data, and tabular data. Raster data include satellite imagery (e.g., Landsat, SPOT), scanned aerial photographs, and other types of imagery, such as digital elevation models (DEMs) and digital cartography (e.g., thematic layers of land cover, slope, aspect). Vector data are composed of points, lines, or polygons and can include such features as political boundaries, railroads, and rivers in formats such as Digital Line Graph (DLG), TIGER/Line, AutoCAD, ARC/INFO. Tabular data can include attribute information, geographic coordinates, and demographics.

Bringing all of these data types together requires computer hardware, displays, peripheral devices (such as scanners, digitizers, printers, and tape drives), and the required software to link these components. Other tools for complete support include hardware and software maintenance updates, telephone hotlines, etc. Once a system is acquired and set up, the end user must be trained to use it. Training and other professional services are in high demand. As the number of hardware and software vendors escalates, quality service programs, such as training and software support, become major selling points. This becomes critically important as GIS technology is targeted to a wider audience of "generalist" users.

TECHNOLOGICAL DEVELOPMENTS

Different "waves" or "cycles" have existed within the computer industry over the past twenty years. This started with the boom in mainframe computers, which then led into minicomputers, personal computers, and finally into open workstation systems. The cost of computing power has come down dramatically over the past couple of years, going from $1,400 per MIP in 1989 to breaking the $200 barrier in 1991. The power range has gone from five-plus MIPS in 1989, with performances in the seventy-plus MIPS range in 1991, and clearly going into the three-digit range in 1992.

There has also been a tremendous proliferation in terms of the installed base of GIS systems over the past several years. GIS systems are now on virtually every continent and are sold in greater quantities to more and more organizations. There has been an evolution in the type of users of these systems from the very technical users to what some would call the more "casual users." This trend started over the past several years and will probably grow rapidly in the upcoming years due to new developments within the industry. In 1988 the entire GIS market of services, hardware, and software was worth $550 million. By 1993 the expected value of this market is estimated to be $2.1 billion, an increase of almost fourfold.

One might wish to explore the reasons why GIS and digital remote sensing techniques are taking hold in so many diverse markets. One reason is that the population of our planet is growing at a phenomenal rate. The earth's growing population presents the distinct likelihood of a shortage of natural resources as people in different countries look for improved lifestyles and desire many of the same resources that are currently used in the United States. As the planet becomes more populated, there will be a greater need for governments and corporations to evaluate and to analyze the resources that they control; and in turn there will be a greater demand by these users for cost-efficient and friendly technologies to analyze this information.

DATA ACQUISITION

One of the many challenges facing the GIS industry is the ability to collect information in a timely and cost-effective manner. According to surveys by Daratech Inc., (Cambridge, Massachusetts), 65 to 74 percent of an organization's GIS dollars will be spent on data acquisition. If this costly and tedious process could be streamlined, it could create vast dollar savings and great financial recovery for any organization's budget. In the 1970s and probably into the 1980s, organizations spent large sums of money on hardware and software and had precious little time for actually analyzing the data and determining the implications of that analysis on the particular project at hand. However, in the 1990s as hardware and software costs drop and as organizational expertise and ease of data collection become enhanced, data and analysis will become the driving force.

Many organizations are keeping data costs low by using their data efficiently. To update a vector database quickly and accurately, users can display vector data over raster satellite data or aerial photographs. Through heads-up digitizing, new information can be entered into the database. This saves the time-consuming and expensive task of field checking information that is already outdated.

Another technique for reducing data costs involves combining data from different satellites. By performing a spectral merge of two data sets, users can derive a data set that provides new information about the study area. This data set could be considered a data fusion or the product of an analysis capability. For instance 30-meter Landsat Thematic Mapper (TM) multispectral data can be merged with 10-meter SPOT panchromatic data to produce a new file that contains the spectral diversity of the Landsat data and the cultural detail of the SPOT data. These techniques can also be applied to other data types, such as the Russian satellite, the Japanese MOS, the European ERS-1, and the Canadian Radarsat.

EARLY TWENTIETH-CENTURY GIS

GIS has much of its origin in the science of landscape architecture. Frederick Law Olmsted has long been considered the father of the landscape architectural profession. In the late nineteenth century, the landscape architectural firm of Olmsted & Associates was well known for its significant work in the design of Yosemite National Park, New York Central Park, and the Cotton States Exhibition, which later became Piedmont Park, held in Atlanta, Georgia, in 1894. In 1901 Olmsted founded the first Department of Landscape Architecture in the United States at Harvard University. It is no coincidence that the GIS industry got its start from research projects conducted in the 1960s at Harvard's Department of Landscape Architecture and at the Laboratory of Computer Graphics and Spatial Analysis.

Before going into the last twenty years of what might be considered modern GIS, it might be useful to reflect a minute on an article entitled "Hand-

Drawn Overlays: Their History and Prospective Uses" by Carl Steinitz, Paul Parker, and Lawrie Jordan, III. This article was published in *Landscape Architecture Quarterly* in July 1976. It described many of the methods used by early pioneers in this profession. For example:

1. Overlay interpretation of land data by Warren Manning in 1912 in Billerica, Massachusetts (first reported in *Landscape Architecture Quarterly* in 1913)

2. Time-series change analysis in Dusseldorf, Germany, in 1912

3. Excessibility isolines and their regional planning scheme for Doncaster, England, by Abercrombie and Johnson in 1922

The article goes on to describe studies in New York in 1923 to map economic and demographic overlays, base map underlays used in 1929 in New York, Lunding County work in the early 1940s, and many other examples of town planning in England, indicating that although the GIS technology was not present there were many examples of analytical land planning and analysis dating as early as the late nineteenth century in England.

GIS ANALYSIS: THE LAST TWENTY YEARS

1970s

During the early 1970s, there were many examples of GIS development using manual techniques to place various data sources into a digital environment. Analysts could use a mylar-drawn grid to interpret soils information or to capture data from a USGS quadrangle map, an aerial photo, or another source to produce a black and white, or gray-scale, computer generated map. Manual overlays of slope analysis for highway corridors were hand-drawn from standard data sets. Rather sophisticated analytical techniques were accomplished manually in the absence of technology to augment those analyses.

Over the next couple of years, entering the mid 1970s, there were examples of users attempting to mosaic and interpret large numbers of aerial photographs to provide a land-cover analysis of a large region. Often by mosaicking this information, the absence of some data would create voids in the data set. At this time, we also witnessed digital display systems, rather primitive by today's standards but nonetheless able to display and perform rudimentary analysis capabilities.

As GIS progressed into 1976 and 1977, some of the digital processing systems were able to display data. These systems allowed the user to interactively pick out points that closed a polygon on screen and then statistically read the information for each band of data and draw histograms. This process allowed the user to evaluate the homogeneity of the various training samples, to analyze the satellite data with high-altitude aerial photography, and to create digital cartographic maps of different vegetation themes. During this period, users were beginning to come together at large conferences to discuss GIS and remote sensing capabilities.

In 1978 and 1979, the ERDAS 400 geoprocessing system was introduced. This revolutionary system was brought out on the market at a cost of $50,000 for hardware and software. The system provided the user with 48 kb of memory; an 8-inch, single-sided, single-density, one-quarter mb floppy disk; two disk drives, A and B; a floating point processor; a display of 256 x 256 x 16 bits of data; a printer; and a display terminal. The software integrated basic image processing and raster GIS functionality in a menu-driven, user-friendly environment, allowing novice users to interact with the system in a way that was impossible before.

1980s

From 1980 to 1982, projects such as the mapping of New York's Adirondack Park were begun. In this project, a state jurisdiction of approximately 9,200 square miles was mapped into a GIS, using digital image-processing techniques. In other examples from this time, USGS quadrangles within an area would be integrated into a GIS, where change-detection could be performed on the digital data and various models run to perform an analysis.

In 1982 the Alaska Department of Natural Resources Geologic and Geophysical Survey Project defined several GIS improvements required for increased GIS use. These were (1) the need for floating point data to facilitate the integration of image processing with GIS systems; (2) NURE (National Uranium Resource Evaluation) data, which are published at a variety of scales. Statistical packages for variants in scaling demonstrated the need for the geochemical and geophysical data to be merged. This seems to be possible through use of a common remote sensing database; and (3) a need for techniques dealing with surfacing and kriging to be integrated into the planning process.

In 1982 the U.S. government sponsored private firms in an effort to map large areas for proposed high-level nuclear waste disposal sites. The neighborhood analysis functions of raster GIS systems provided the ability to develop models that would output maps showing only those areas that fit all of the conditions required for safe nuclear waste disposal. This was also an important step in the development of GIS technology because software packages were now being designed to perform very detailed analyses on very large areas. A high-level waste disposal project in western Texas included the mapping of entire counties that were approximately 30 by 50 miles as well as the ability to window specific areas. This provided for detailed mapping so that specific land parcels could be analyzed to determine the location of farms and historical and archaeological sites.

In 1983 the U.S. Forest Service mapped eleven counties within South Carolina to locate prime timberlands. Prime timberlands were specifically divided into two categories: (1) lands capable of producing at least 120 cubic feet of wood fiber per acre per year and (2) lands able to produce 85-120 cubic feet of wood fiber per acre per year.

For this project, the U.S. Forest Service input MIADS digital data from the USDA Soil Conservation Service as an example of soil productivity and used Landsat Multispectral (MSS) data for gathering land-cover information. This project was successfully completed by taking some ninety-five different MIADS soil conditions and recoding those into approximately five different categories of productivity. The soils data were then merged with the Landsat data, which were mapped into categories of coniferous vegetation, deciduous vegetation, areas of no vegetation, urban areas, nonforested areas, and water bodies. The sites of highest value were considered to be areas with highly productive soils that had no trees currently growing and could be planted immediately to yield a good timber product in the next twenty to thirty years.

Starting in 1983, the Army Corps of Engineers conducted research on the Tennessee/Tombigby Waterway to evaluate GIS techniques for industrial site location studies and to determine ways in which training and community involvement could be brought to the users. This was done in an innovative fashion by installing GIS technology in a mobile trailer for training and technology transfer within a four-state region.

Around 1984 and 1985, as GIS analytical capabilities were improving so were the capabilities of the hardware, with the emergence of the IBM PC/XT and the initial version of the DOS environment. Also seen was the proliferation of low-cost image displays enabling the user to have a single-vendor solution by adding a single 24-bit true-color display with various monitors, tape drives, digitizing tablets, printers, film recorders, and scanners.

During the mid 1980s, examples emerged of various image algebra functions as well as the ability to perform three-dimensional representations of the landscape. The three-dimensional capabilities were performed by merging satellite data with terrain data, warping the data sets to each other, and analyzing the landscape on the X, Y, and Z axes.

From 1986 to 1987, sophisticated techniques for image scanning were used and the initial UNIX standards through the Sun-3 Workstation emerged. The added power of the workstation environment allowed the addition of new capabilities to ERDAS Version 7.3 software:

1. *Annotation* allows the annotation of images with text, legends, borders, and graphics.

2. *Topography* allows users to create elevation contours from paper maps, to show shaded relief, and to compute aspect and slope.

3. *Three-Dimensional Analysis* allows users to create 3-D perspective views from satellite imagery.

4. *Image Algebra* allows images to be added, ratioed, transformed algebraically, trigonometrically, logarithmically, and exponentially. Image algebra allows users to perform areas-of-interest analysis by using a boundary file to define the area.

Raster/Vector Integration

Raster and vector integration techniques have allowed the user to have the benefits of both types of data sets in one GIS. Digital images like satellite data were once considered "dumb," with no real value. However, new interfaces make it possible to bring together raster satellite images and scanned aerial photography with vector GIS systems. For example, between 1989 and 1991 the Suwannee River Water Management District (SRWMD) in Florida demonstrated the power of raster/vector integration when the use of satellite imagery was introduced into the existing vector GIS. SRWMD needed up-to-date and detailed land-cover information to protect the 7,600 square miles of Florida's rivers and lakes from pollution and to ensure proper management. The integration of raster satellite imagery into the SRWMD GIS was one of the largest raster/vector conversion projects ever completed. In addition to being easily updated to provide current information, the raster/vector method proved to be cost-effective and less time-intensive; and it provided the degree of detail needed for SRWMD purposes.

In 1988 and 1989, ERDAS introduced several new GIS functions including GIS modeling (GISMO) and the SEED statistical classifier. GISMO is a tool to create information maps and analytical models from raster data layers. GISMO modeling techniques can be used to answer complex questions, using information about the land surface. For example, a GIS model may be used to compute the suitability of areas for urban development, to locate critical habitat types, to rank groundwater protection areas, or to calculate the economic and environmental impact of a major industrial plant on a large area. The advantage to modeling is that it allows users to change the input parameters and then create and observe an updated model on screen almost instantly.

With the SEED statistical classifier, users can pick a single pixel that is representative of the type of area to be classified, and other pixels with similar characteristics will "grow" and be automatically highlighted on the display. The resulting training samples are precise representations for the selected categories. This technique can be extremely useful for updating vector coverages and for allowing the user to quickly gain spatial knowledge of the various categories that are being mapped or evaluated.

The ERDAS Multivariate Image Analysis (MIA) module enabled users to analyze images without the use of ground-truth information or in applications such as mineral exploration where an iterative process is necessary to enhance features that are not obvious in the original imagery. Scatterplots of any band combinations are produced on the screen, showing the highest discrimination potential. The user draws boundaries around pixel values of interest, and the corresponding pixels are highlighted on the original image. This technique is also useful for determining boundary conditions such as wetlands mapping.

About this time, Global Positioning Systems (GPS) also emerged. The United States Defense Department invested $10 billion to launch a series of satellites for navigation. These satellites offer precise global navigation for land, sea, and air applications. From inexpensive receivers, processors, antennae, and hand-held devices, users can tap into the GPS satellite information (at no charge) and compute precise position, velocity, and time. The latest technology developed by Trimble Navigation, Ltd., allows both geographic coordinates and attribute information to be read into ERDAS directly.

This is extremely important information when dealing with a study area that has very old base maps or if the area has been modified. Without accurate ground control points, it is difficult to get accurate rectification results. With GPS technology, users can go to a study area and determine ground control points effectively and accurately. A second valuable use of GPS is for creating DEMs and orthophotos since the technology provides X, Y, and Z elevation values. The third valuable asset of GPS is in land-cover classification. Users can better define training samples for accuracy assessment in field verification.

1990s

In 1990 and 1991, softcopy photogrammetry gave GIS users the ability to create DEMs and digital orthophotos. Software such as the ERDAS Digital Ortho module allows users to do the following:

1. Create Digital Elevation Models (DEMs)
2. Create digital orthophotos from DEMs
3. Use DEMs with other software modules (3D, Topographic) and
4. Create 3D-perspective views, slope, aspect, contour, and shaded relief maps

Digital orthophotos are terrain-corrected images that can be used as precision base maps for GIS databases. The introduction of DEMs into a GIS adds a new dimension to many analyses whether the project involves facility siting, the delineation of wildlife habitats, or the probable location of minerals and deposits.

The next generation of GIS systems will conform to both the "casual" and the "expert" GIS user, presenting a user interface that is friendly and easy to interact with as well as technologically sophisticated, providing advanced analytical features.

The next generation of GIS and raster image-processing software will include a point-and-click graphical user interface with buttons, icons, scroll bars, and other dynamic visual aids, such as interactive histograms, color tables, function graphics, and pull-down menus. It will also include context-sensitive hypertext on-line help, editable batch-processing scripts, session histories, and a tiled file structure enabling users to roam the disk. The new GIS software will operate under a standard windowing environment, such as the X Windows OSF/Motif environment, giving users unlimited windowing ability for viewing the same area in different ways. Systems such as this give analysts the power to visualize solutions.

CONCLUSION

GIS industry has come a long way since its beginnings in landscape architecture almost 100 years ago, and the growth rate over the last twenty years has exceeded even the most optimistic expectations. The next twenty years will see the broadening of the GIS user base to include diverse disciplines, using the technology for a myriad of applications. To meet the challenges of this dynamic industry, vendors must listen to users, tailor packages for specific applications, provide powerful and user-friendly software, and offer professional services such as training. Users must continue to demand products that are well tested, well designed, and able to solve the problems they face today, as well as those they will face tomorrow. As in any technological field, there will continue to be hardware advances that necessitate equipment upgrades, but these new systems must be compatible with earlier models. GIS projects can take years to complete; therefore, continuity of data, software, and hardware must be maintained. The key to continued success in the GIS marketplace is communication and vision—the ability of users and vendors to understand the position of the other and the vision to make the decisions that will benefit the users of the future.

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