GEOGRAPHIC INFORMATION SYSTEM (GIS) AS A TOOL FOR DEVELOPMENT

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Summary

Geographic information system (GIS) is a tool which can accept a large volume of spatial data from a variety of sources, store, manipulate, analyze and display the results according to user defined specifications. GIS technology has evolved since the 1960s, generating massive interest worldwide. GIS technology owes its phenomenal success to the advent of computer technology. There has been a rapid rate of development in GIS

theory, technology and applications due to the contributions of experts from several disciplines such as computer science, cartography, geography, mathematics, statistics, remote sensing and so on. GIS is rapidly becoming a standard tool for management of resources. It provides a spatial framework to support decisions for the intelligent use of natural resources. Applications of GIS are growing every day and it is difficult to think of a government department or an industry or an academic institute without using GIS. Theadvancements in communication and information technologies during the 1990s have made GIS a core technology in information resources management. Steps are being taken around the world towards data standards, interoperability and building spatial data clearing houses so that GIS will be cheaper to implement and easy to use. Developments in Internet technology have rapidly brought GIS to public use to query and view the results in spatial form. This article starts with an introduction followed by history of GIS and continues with spatial data concepts, data models used in GIS, methods of analysis, role of remote sensing, GPS and spatial data visualization. The accuracy aspect of spatial data has also been discussed. Attempt has been made to summarize the application areas of GIS technology. The last section discusses the current issues related to GIS implementation and the areas of research towards the growth of future GIS technology.

1. Introduction

Everyday we come across several queries such as what is the shortest route from my residence to office or what crop the farmer can cultivate in his land so that he gets better yield or what is the optimal location for building a water harvesting structure in a village etc. All these questions are concerned with geographical patterns or processes on the surface of the earth. To answer such simple questions, we need to integrate data from different sources in a consistent form. The art, science, engineering or technology associated with answering such geographic questions is called GIS. Geographic Information System (GIS) is a tool which can accept a large volume of spatial data derived from a variety of sources, store, manipulate, analyze and display the results according to user defined specifications (Figure 1). GIS is not a data bank to present results in tables or maps. It has the capability to analyze different parameters for getting solutions of variety of problems in planning and development. It can provide a range of possible scenarios and their outcomes on the landscape before taking a decision.

Figure 1. Definition of GIS

GIS has evolved since the 1960s, generating massive interest worldwide. There has been a rapid rate of development in GIS theory, technology and applications. This has been due to the interactions and contributions of experts from several disciplines such as geography, cartography, surveying, remote sensing, computer science, civil engineering, earth sciences, agriculture, economics, mathematics and statistics.

Computer based geographic information systems have been in use since mid 1960s. But their manual predecessors were in use perhaps hundreds of years earlier. The early explorers searched for new lands, new people and new resources. They investigated the spatial distribution of people, plants, animals and natural resources. They represented the spatial data in the form of maps to study the settlement patterns. General purpose maps date back centuries and focused on topography, land layout and features such as roads and rivers. In the nineteenth century, thematic maps came into use. They contained information about specific themes like land use, geology, soils, administrative units etc. Initially the maps were qualitative and the spatial distributions were not described quantitatively. The use of statistical methods for spatial analysis started during 1940s. With the availability of digital computers during 1960s, quantitative analysis of spatial data started growing and GIS evolved out as a new tool. Along with new ways to produce maps, new ways to collect and process spatial data have also emerged. These include remote sensing satellites, which provide synoptic view over large areas at frequent intervals and global positioning systems. The availability of new sources of data combined with GIS technology has opened new areas of research, development and applications.

Modern GIS owes its phenomenal success to the advent of computer technology. From a humble beginning in mid 1960s, today GIS has grown into a 12 billion dollar industry annually in terms of software, data, services, publishing and education. GIS technology has moved from the academic environment to become a part of Information Technology mainstream. Today GIS is a vibrant, active and rapidly expanding field generating considerable private and public interests. GIS technology has been quick to adopt the technological innovations such as Internet, World Wide Web, object relational data base model, global standards etc. Number of users has grown many folds. Millions are using GIS services in the Internet. The finest example is Google Earth.

1.1. Components of a GIS

The components of GIS are hardware, software, data and liveware. The hardware component can be almost any type of computer platform including high end workstations, desktop personal computers, laptop computers, hand-held palm tops, Internet based web servers and so on. The software component provides the geo processing engine of GIS. It provides functionality to capture data, store, manage, query, analyze and present the results. Based on the functionality, number of users and cost, GIS software packages can be grouped as professional, desktop, hand-held, components, viewer tool and web based GIS. The third important component in a GIS is the data. The data comprises of both spatial data and the associated attribute data. Geographical data are expensive to collect, store and manipulate. Large volumes of data are needed for a good study. In GIS, data collection cost becomes higher than the cost of hardware and software. Presently many national and global agencies are working on building spatial data infrastructure and create spatial data clearing houses. The final and most significant component is the liveware, the people responsible for designing, implementing and using GIS. GIS users can be classified as viewers, general users and GIS specialists. Viewers are the public whose need is only to browse a geographical database occasionally for getting some information. General users utilize GIS for conducting business, performing professional services and making decisions. GIS specialists are people who actually make GIS work. They include GIS managers, database administrators, application specialists, systems analysts and programmers. Efforts are being taken all over the world to generate adequate trained manpower in GIS.

1.2. GIS Applications

In the initial phase of GIS development, the main activity was assembling, organizing and understanding the inventory of features like forest resources maps, soil types, utility networks etc. In that phase, the systems were primarily used for simple data queries. The next phase got evolved for covering complex analytical operations. The data spread across several layers were integrated and analyzed. For example one can identify suitable areas in a village where paddy can be cultivated by combining layers such as soil, slope, rainfall, water sources, existing land use practices, socio-economic parameters and so on. The third phase is the evolution of GIS as a spatial decision support system with emphasis on spatial, analytical and modeling capabilities. Many hydrological models, transportation models, environmental models and even socio-economic models are getting integrated with GIS to develop application specific Spatial Decision Support Systems. Further, GIS software functionality are also greatly improved by providing three dimensional visualization through the addition of building heights, flying through an area by simulating the dynamic view, rendering textures of land use over the elevation to see the future appearance of landscape etc.

There is an explosive growth in GIS applications. Large number and varieties of GIS applications in use show its maturity and success. Under resources planning and management sectors, there is hardly any area where GIS is not applied. If we consider microlevel planning, the application areas are watershed delineation, micro-watershed management, ground water modeling, land suitability analysis, crop yield estimation, precision farming, land record management, infrastructure development, emergency planning, epidemiology, and so on. If fact, rural health is an area where GIS technology plays a vital role. Precision farming aims to direct the applications of seeds, fertilizers, pesticides and water within fields in such a way that optimizes farm returns and minimizes chemical inputs and environmental hazards and so on. One of the most direct applications of GIS in rural sector is participatory mapping where specialists can interact with local communities to create spatial inventories of natural resources, property status, land use practices, infrastructure availability, socio-economic conditions etc. Because local people know about their areas very well better than outsiders and they can become stakeholders in this development. Such an inventory will help to build more equitable and sustainable resources management strategies and also will help in constructive community building. Participatory mapping and GIS can bring Government closer to communities that it serves and planning can address the local characteristics and unique needs keeping in mind national priorities.

Among the numerous technologies that have impact on the development of GIS, the Internet is the most important tool. The World Wide Web is playing a dominant role for distributing and visualizing spatial information. The Internet has revolutionized the user base of GIS from a small number of sophisticated specialists to an infinitely large audience. Soon Internet is likely to become the chief mode for spatial data distribution, analysis and visualization.

2. History of GIS

There is no strictly a logical progression or evolution towards the development of GIS technology. There were many initiatives, which occurred independently in different parts of the world towards the use of automated technology for spatial data handling. The motivation for development of GIS ranged from academic curiosity to challenges faced while using the new sources of data or techniques and process with high speed and accuracy. The atlas of Great Britain and Northern Ireland in 1960 attracted criticism of being out of date and unwieldy that convinced the academic community that only computer could provide efficient and cost effective method to check, edit and classify data to model situation and produce graphical display. A calculation made in 1968 indicated the need for $ Can 8 million and a requirement of 556 technicians for 3 years in order to overlay 1:50,000 scale maps of the Canada land inventory and this unacceptable level of resources acted as an incentive to develop a more automated approach. The Canadian government sponsored the development of the first industry scale computer based GIS, knows as the Canadian Geographical Information Systems or CGIS in 1966. For the first time, the term “Geographic Information System” became well known. Many have recognized the CGIS as representing the single most important program responsible for launching of many today’s successful GIS enterprises. In the United States, Transportation Engineering Dept., University of Washington, developed quantitative methods in transportation studies in 1950s, which extended to spatial analysis further. In 1964, IBM introduced 360/65 systems. Government agencies in U.S. thought of using computer technology to handle census data, land ownership etc. Software for address matching, computer mapping and small area analysis was developed in 1967. Dual Independent Map Encoding (DIME) scheme was developed to describe the urban street network with simple topological relationships. This research gave a lead for the development of topology theory in GIS. During 1960s, the computers were affordable only by major national agencies and defense departments. Some of the universities attempted to work on automated cartography and produced line printer maps.

Department of Agriculture, Canada initiated a project for planning a Canada Land Inventory using computer based techniques. This work with Department of Agriculture and IBM resulted in the first operational successful GIS, the development of drum scanner, digitizer and Morgan data indexing system. A topological coding of boundaries involving the use of link/node concept of encoding lines was evolved. Two international conferences were organized in Ottawa in 1970 and 1972 in GIS.

In the U.K. need for computer in land use planning was observed in 1960s and officials of central and local governments in 1972 released a report on Information System for Planning. A project by Oxford system of Automated Cartography led to the development of first free cursor digitizer and the high precision plotting table. National Environmental Research Council (NERC) funded a research unit in automated cartography. Experimental Cartographic Unit in Royal College of Art in London focused on production of high quality digital maps. In 1975, NERC unit for Thematic Information System was established. It assisted Ordnance Survey to build a digital spatial atlas in the U.K. A report on spatial data handling for implementation was prepared in 1987. Two GIS tutors were developed in the U.K.

The Harvard Laboratory for Computer Graphics was established in 1965 in Graduate School of Design at Harvard University, U.S.A. SYMAP, the first GIS package to handle geographic data was developed and it used liner printer for printing isoline, choropleth and proximity maps. SYMAP was distributed in North America and U.K. GRID, a cell based package for multiple overlay of data was also developed. A symposium on topological data structures was organized in 1977. It attracted talented individuals who contributed in many ways to the development of computer mapping and its extension to Geographic information systems. ODYSSEY, a prototype vector GIS package was developed.

In academic and research front, universities across the world started teaching computer cartography and GIS in the early 1980s. SYMAP GIS package developed in Harvard Laboratory was used for training. Urban and Regional Information Systems Association (URISA) formed in U.S. started holding annual meetings. AUTOCARTO series began and symposiums on computer-assisted cartography were held annually. International Journal of Geographical Information Systems edited in U.K and U.S.A. started and the journal was later renamed as International Journal of Geographic Information Science. During 1980s, National Center for Geographic Information Analysis (NCGIA) funded by National Science Foundation, USA was established in Universities of California, Maine and New York.

In commercial sectors, Harvard Laboratory of Computer Graphics graduates started GIS commercial units. In 1969 Environmental Systems Research Institute (ESRI) was started as a nonprofit organization for environmental consultancy with emphasis on computer graphics. ESRI launched the first version of Arc/Info, a vector based GIS package in 1982 and became a profit enterprise. ESRI has started publishing Arc News letters regularly and holds annual GIS users conferences in various parts of the world. Today GIS software industry has grown into multi-billion dollar industry with many commercial off-the-shelf GIS software packages. In addition to major GIS software vendors like ESRI, Intergraph, Map Info etc., the software giants like Microsoft and Oracle have also entered into GIS market.

In the early stages, GIS software was providing a large number of functions to operate and analyze spatial data layers and also the tools to input the maps, store and display the results. The map data was stored in layers and associated attributes were handled using DBMS tool. Today this approach has changed. Both geometric and non-geometric data are stored in an Object-Relational DBMS model. Also the users want to customize their applications buying the necessary GIS components rather than working on a full-fledged GIS package. Open Geospatial consortium has taken the lead to formulate common standards and emphasizes on the interoperability among various GIS data formats. Open

Geospatial Consortium (OGC) has been established in 1994. In the early years, UNIX operating systems were predominantly used to run GIS software. Since the 1990s Windows has become a widely adopted platform to run GIS applications because of its low cost and ease of use. With the advent of Internet technology, web based GIS applications have grown many fold. The focus is on simple query, display and data publishing. Some observers opine that Internet may become the principal platform for GIS. One of the reasons for GIS growth is the development in remote sensing technology. Since 1960s, remote sensing satellites data became a source to provide repetitive data about the Earth surface in digital images. While processing these data, GIS techniques are used to combine these images with other ancillary information. Today many GIS software packages provide extensive functionality to process remote sensing images. Today there are over two million professional users of GIS around the world and the total global expenditure towards GIS may be around U.S. $ 25 billion annually. GIS is playing a central role in many of the e-government initiatives. GIS is used to manage the assets, namely, land ownership, natural resources, human resources, infrastructure, utilities etc. Open storage of GIS features and availability of core GIS tools in standard programming languages have made GIS a part of Information Technology. GIS has moved from a departmental tool to enterprise solution.

3. Concepts of Spatial Data

Geography of the real world is infinitely complex. It varies continuously without distinct boundaries. When we describe what we observe over an area, we try to simplify the inherent complexity by abstraction of key features and develop a conceptual model. The geographical features are described in terms of building, road, lake or hill and how they are spatially related like in front of, to the right of etc. These conceptual models are converted into digital form with the help of spatial data models such that the data are communicated effectively without any ambiguity. In fact, the real world phenomenon is converted into database using the representations based on these spatial data models. We view the real world through the medium of the database. For example, to describe a building, we first refer to its location (where it is) and then its characteristics (e.g. name, address, commercial, residential etc.). The location represents the spatial data and the characteristics are the attribute data. The database contains the digital representation of discrete objects such as lakes, contours, buildings etc. The spatial features like buildings, roads, lakes and wells are real objects and can be represented as point features (wells), line features (roads) and area features (building boundaries). Some spatial features exist everywhere and vary continuously over the earth’s surface (e.g. elevation, atmospheric temperature, natural vegetation). These features are represented by taking measurements at sample prints by dividing the area into zones and assuming the variable is constant within each zone or by drawing contours connecting points of equal values with lines.

3.1. Spatial Objects

Spatial entity also known as spatial object or geo-object refers to a phenomenon that cannot be subdivided to like units. An object is referred by a single identifier. The object may be readily mappable like a building or not readily mappable like land use boundary. The indivisibility is based on the properties used in the definition. There need not be complete homogeneity within the spatial extent. A spatial object can be defined by an identifier (name), position on the earth's surface (location), character and function of the object and spatial properties. For example, a school can have a name, its position in terms of x, y coordinates, number of students in the school, its distance from another school etc. The attributes characterizing an entity can be organized in a single attribute table or multiple tables.

There are three types of spatial objects used for digital representation of spatial features. A point is an object that has a position in space and no length and has zero dimension. A point can represent the location of a feature like a well, a building, a tower etc. A point can also be a node or vertex. A point layer is made up of one point or a set of separate points. A line is a one-dimensional object and has the property of length. A line has two end points and points in between to mark the shape of the line. A line can represent a feature like road or contour. It can also be an edge or link or chain. A line layer is made up of lines like road network, drainage network, contours etc. An area is a two-dimensional object and has the properties of length and width. An area is bounded at least by three line objects (Figure 2). An area may be alone or share boundaries with other areas. An area may contain hole. The existence of holes means that the area has both external and internal boundaries. An area is normally called as polygon. An area layer is made up of polygons like village boundaries, land parcels, water bodies, soil types etc.

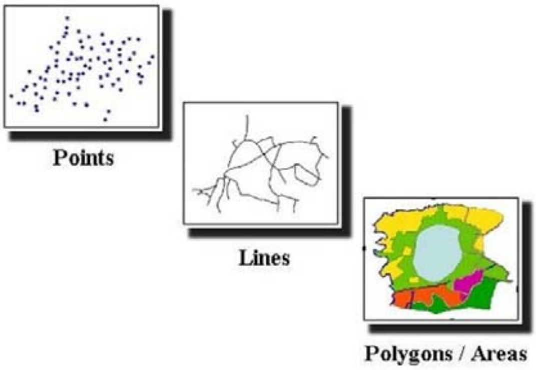

Figure 2. Representations of Spatial Objects

The representation of spatial features using point, line and area depends on scale, purpose and other factors. For example, a city may be represented as an area on 1:25000 scale map. A stream may appear as a line on a small scale map while it may appear as an area with width on a large scale map. Map scale of source document is very important to decide the level of detail represented in a database.

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Biographical Sketch

Parvatham Venkatachalam was born in Tirunelveli, Tamil Nadu, India on 18.11.1949. She obtained M.Sc. degree in Mathematics from IIT, Bombay, India in the year 1972 and Ph.D. degree in Applied Statistics from the same institution in the year 1978.

Currently she is a Principal Research Scientist in the Centre of Studies in Resources Engineering, Indian

Institute of Technology, Powai, Bombay, India. Previously she held the positions of Research Scientist and Senior Research Scientist in the same organization. She has to her credit 80 technical publications in International and National Journals and Conference Proceedings. She is the author of 12 technical reports. Her areas of research are development of GIS for natural and human resources applications, digital image processing of remote sensing satellite data, development of spatial decision support systems, data structure in spatial databases, spatial data mining and ware houses. She has undertaken several consultation and research projects funded by National and International agencies. She has built an indigenous GIS software, GRAM++ with the financial support from UNDP and Department of Science and Technology, Government of India. The software is being widely used by academia, government departments and industries. She has visited several universities and national organizations abroad and delivered lectures. She has conducted over 25 training programs in the area of GIS and its applications towards capacity building. She received gold award (1^{st} prize) for the development of E -Tutor for GIS at the Fourth Computer Assisted Teaching Contest organized by International Society for Photogrammetry and Remote Sensing (ISPRS) Technical Commission – VI at the International Symposium on "E-Learning and the Next Steps for the Education" held at Tokyo during June 27 – 30, 2006.

Dr. Venkatachalam is a Founder Member of Indian Society of Geomatics, Life Member of Indian Society of Remote Sensing and Life Member of Indian National Cartographic Association.