Geographical Information Systems – An Overview

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Abstract

Although many GIS have been successfully implemented, it has become quite clear that two-dimensional maps with most complex contours and color schema cannot precisely present multidimensional and dynamic spatial phenomena. Most GISs in use today have not been designed to support multimedia data and therefore have very limited capability due to the large data volumes, very rich semantics and very different modeling and processing requirements.

This paper discusses some of the features of a GIS, the general trends in this field and the technology behind it. It also describes the advantages of using multimedia to implement a GIS by extending its capabilities of presenting geographic and other information*. Then the main subsystems of a GIS have been presented. This paper also identifies some of the key areas where Multimedia GIS systems could be very useful.*

1 Introduction

Geographical Information Systems (GIS) are computer-based systems that enable users to collect, store, process, analyze and present spatial data.

It provides an electronic representation of information, called spatial data, about the Earth's natural and man-made features. A GIS references these real-world spatial data elements to a coordinate system. These features can be separated into different **layers**. A GIS system stores each category of information in a separate "layer" for ease of maintenance, analysis, and visualization. For example, layers can represent terrain characteristics, census data, demographics information, environmental and ecological data, roads, land use, river drainage and flood plains, and rare wildlife habitats. Different applications create and use different layers. A GIS can also store attribute data, which is descriptive information of the map features. This attribute information is placed in a database separate from the graphics data but is linked to them. A GIS allows the examination of both spatial and attribute data at the same time. Also, a GIS lets users search the attribute data and relate it to the spatial data. Therefore, a GIS can combine geographic and other types of data to generate maps and reports, enabling users to collect, manage, and interpret location-based information in a planned and systematic way. *In short, a GIS can be defined as a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information.*

GIS systems are dynamic and permit rapid updating, analysis, and display. They use data from many diverse sources such as satellite imagery, aerial photos, maps, ground surveys, and global positioning systems (GPS).

2 Types of GIS

The following GIS types are not necessarily mutually exclusive and a GIS application can be always classified under more than one type.

2.1 Four-dimensional GIS

While spatio-temporal geo-representations can handle two dimensions of space and one of time, four-dimensional GIS are designed for three dimensions of space and one of time.

2.2 Multimedia/hypermedia GIS

Multimedia/hypermedia GIS allow the user to access a wide range of georeferenced multimedia data (e.g., simulations, sounds and videos) by selecting resources from a georeferenced image map base. A map serving as the primary index to multimedia data in a multimedia geo-representation is termed a hypermap. Multimedia and virtual geo-representations can be stored either in extended relational databases, object databases or in application-specific data stores.

2.3 Web GIS

Widespread access to the Internet, the ubiquity of browsers and the explosion of commodified geographic information has made it possible to develop new forms of multimedia geo-representations on the Web.

Many current geomatics solutions are Web-based overtaking the traditional Desktop environment and most future ones are expected to follow the same direction.

2.4 Virtual Reality GIS

Virtual Reality GIS have been developed to allow the creation, manipulation and exploration of geo-referenced virtual environments, e.g., using VRML modelling (Virtual Reality Modelling Language). Virtual Reality GIS can be also Web-based. Applications include 3D simulation for planning (to experiment with different scenarios).

3. Multimedia and Geographical Information System (GIS)

3.1 Multimedia

Multimedia is a technology that encompasses various types of data and presents them in an integrated form. There are several types of data that are used by the technology, including text, graphics, hyperlinks, images, sound, digital and analogue video and animation.

Although many GIS have been successfully implemented, it has become quite clear that two-dimensional maps cannot precisely present multidimensional and dynamic spatial phenomena. Moreover, there is a growing need towards accessing spatial data. It seems that merging GIS and Multimedia is a way to deal with these issues.

The latest advances in computer industry especially in hardware have led to the development of the Multimedia and Geographical Information System (GIS) technologies. Multimedia provides communications using text, graphics, animation, and video. **Multimedia GIS systems** is a way to overcome the limitations displayed by the technologies when they are used separately. Multimedia can extend GIS capabilities of presenting geographic and other information. The combination of several media often results in a powerful and richer presentation of information and ideas to stimulate interest and enhance information retention. They can also make GIS more friendly and easier to use. On the other hand, multimedia can benefit from GIS by gaining an environment which facilitates the use and analysis of spatial data. The result is a system, which has the advantages of both worlds without retaining most of their disadvantages.

4 GIS Subsystems

A GIS has four main functional subsystems. These are:

4.1 Data Input Subsystem

A **Data Input** subsystem allows the user to capture, collect, and transform spatial and thematic data into digital form. The data inputs are usually derived from a combination of hard copy maps, aerial photographs, remotely sensed images, reports, survey documents, etc.

4.1.1 GIS Data Types

These data will contain maps of different detail levels (maps of the county, its main cities and villages, maps of the archaeological and historical sites etc.), photos of places and monuments, video images, text (in many languages), music and sound.

For more complex applications, multimedia data can be remotely sensed imagery, scanned maps, digitized video clips, DTMs, one or more dimensional measurements, simulation model outputs and others. Most of them are complicated objects, which have large data volumes, intensive processing requirements and rich semantics.

The basic data types in a GIS reflect traditional data found on a map. Accordingly, GIS technology utilizes two basic types of data. These are:

4.1.1.1 Spatial data

Spatial data describes the absolute and relative location of geographic features.

4.1.1.2 Attribute data

Attribute data describes characteristics of the spatial features. These characteristics can be quantitative and/or qualitative in nature. Attribute data is often referred to as tabular data.

The coordinate location of a forestry stand would be spatial data, while the characteristics of that forestry stand, e.g. cover group, dominant species, crown closure, height, etc., would be attribute data. Other data types, in particular image and multimedia data, are becoming more prevalent with changing technology. Depending on the specific content of the data, *image data* may be considered either spatial, e.g. photographs, animation, movies, etc., or attribute, e.g. sound, descriptions, narration's, etc.

4.1.2 Sources of Data

A wide variety of data sources exist for both spatial and attribute data. The most common general sources for spatial data are:

- Hard copy maps
- Aerial photographs
- Remotely-sensed imagery
- Point data samples from surveys
- Existing digital data files

This spatial data is usually in analog form and needs to be converted to digital form before it can be used. Maps can be digitized, or hand-traced with at computer mouse, to collect the coordinates of features.

Attribute data has an even wider variety of data sources. Any textual or tabular data than can be referenced to a geographic feature, e.g. a point, line, or area, can be input into a GIS. Attribute data is usually input by manual keying or via a bulk loading utility of the DBMS software.

4.1.3 Data Editing and Quality Assurance

Data editing and verification is in response to the errors that arise during the encoding of spatial and non-spatial data. The editing of spatial data is a time consuming, interactive process that can take as long, if not longer, than the data input process itself.

Several kinds of errors can occur during data input. They can be classified as:

- **Incompleteness of the spatial data:** This includes missing points, line segments, and/or polygons.
- **Locational placement errors of spatial data**: These types of errors usually are the result of careless digitizing or poor quality of the original data source.
- **Distortion of the spatial data:** This kind of error is usually caused by base maps that are not scale-correct over the whole image, e.g. aerial photographs
- **Incorrect linkages between spatial and attribute data:** This type of error is commonly the result of incorrect unique identifiers (labels) being assigned during manual key in or digitizing. This may involve the assigning of an entirely wrong label to a feature, or more than one label being assigned to a feature.
- **Attribute data is wrong or incomplete:** Often the attribute data does not match exactly with the spatial data. This is because they are frequently from independent sources and often different time periods. Missing data records or too many data records are the most common problems.

4.2 Data Storage, Editing and Retrieval Subsystem

The second necessary component for a GIS is the data storage and retrieval subsystem. The **Data Storage** and retrieval subsystem organizes the data, spatial and attribute, in a form, which permits it to be quickly retrieved by the user for analysis, and permits rapid and accurate updates to be made to the database. This component usually involves use of a database management system (DBMS) for maintaining attribute data. Spatial data is usually encoded and maintained in a proprietary file format.

4.2.1 Organizing Data for Analysis

Most GIS software organizes spatial data in a thematic approach that categorizes data in vertical *layers*. The definition of layers is fully dependent on the organization's requirements. Typical layers used in natural resource management agencies or companies include forest cover, soil classification, elevation, road network (access), ecological areas, hydrology, etc.

4.2.2 Editing and Updating of Data

Perhaps the primary function in the data storage and retrieval subsystem involves the editing and updating of data. Frequently, the following data editing capabilities are required:

- Interactive editing of spatial data
- Interactive editing of attribute data
- The ability to add, manipulate, modify, and delete both spatial features and attributes (independently or simultaneously)

- Ability to edit selected features in a batch-processing mode.

4.2.3 Data Retrieval and Querying

The ability to retrieve data is based on the unique structure of the DBMS and command interfaces are commonly provided with the software. Most GIS software also provides a programming subroutine library, or macro language, so the user can write their own specific data retrieval routines if required.

Querying is the capability to retrieve data, usually a data subset, based on some user-defined formula. These data subsets are often referred to as *logical views*. Often the querying is closely linked to the data manipulation and analysis subsystem. Querying can be either by example of by content.

4.3 Data Manipulation and Analysis Subsystem

The **Data Manipulation and Analysis** subsystem allows the user to define and execute spatial and attribute procedures to generate derived information. This subsystem is commonly thought of as the *heart of a GIS*, and usually distinguishes it from other database information systems and computer-aided drafting (CAD) systems.

4.3.1 Manipulation and Transformations of Spatial Data

The maintenance and transformation of spatial data concerns the ability to input, manipulate, and transform data once it has been created. Some specific functions are:

- Coordinate thinning: involves the reduction of the coordinate pairs (X and Y) from arcs.
- Geometric Transformations
- Map Projection Transformations
- Edge Matching
- Interactive Graphic Editing

4.3.2 Analytical Functions in a GIS

The primitive analytical functions that must be provided by any GIS are:

- Retrieval, Reclassification, and Generalization
- Topological Overlay Techniques
- Neighbourhood Operations
- Connectivity Functions

4.4 Data Output and Display Subsystem.

The **Data Output** subsystem allows the user to generate graphic displays, normally maps, and tabular reports representing derived information products. This subsystem conveys the results of analysis to the people who make decisions about resources. Wall maps and other graphics can be generated, allowing the viewer to visualize and thereby understand the results of analyses or simulations of potential events.

5 Applications of Multimedia GIS

5.1 Education

Education is a field where integration of multimedia and GIS can bring enormous benefits. Students will learn faster and more efficiently. In addition, it will be possible to individualize learning and tune it to particular preferences of each student. In this model a teacher becomes a guide rather than a repository of facts. It is the computer that takes on a role of "an infinitely patient teacher."

5.2 Mapmaking

GIS can use and combine all layers that are available for an area, in order to produce an overlay that can be analyzed by using the same GIS. Such overlays and their analysis radically change decision-making process that include, among others:

- Site selection
- Simulation of environmental effects (for example, creating perspective views of a terrain before and after mining)
- Emergency response planning (for example, combining road network and earth science information to analyze the effects of a potential earthquake)

5.3 Land Information

GIS has aided management of land information by enabling easy creation and maintenance of data for land records, land planning and land use. GIS makes input, updates, and retrieval of data such as tax records, land-use plan, and zoning codes much easier then during the paper-map era. Typical uses of GIS in land information management include managing land registry for recording titles to land holdings, preparing land-use plan and zoning maps, cadastral mapping etc. Input of data into a land information GIS includes: political and administrative boundaries, transportation, and soil cover.

5.4 Infrastructure and Utilities

GIS technologies are also widely applied to the planning and management of public utilities. Typical uses include management of the following services: electric, gas, water, roads, telecommunication, storm sewers, TV/FM transmitting facilities, hazards analysis, and dispatch and emergency services. Typical data input includes street network, topographic data, demographic data and local government administration boundary.

5.5 Environmental

The environmental field has long used GIS for a variety of applications that range from simple inventory and query, to map analysis and overlay, to complex spatial decision-making systems. Examples include: forest modeling, air/water quality modeling and monitoring, environmentally sensitive zone mapping, analysis of interaction between economic, meteorological, and hydrological & geological change. Typical data input into an environmental GIS include: elevation, forest cover, soil quality and hydrogeology coverage.

5.6 Archaeology

Archaeology, as a spatial discipline, has used GIS in a variety of ways. At the simplest level, GIS has found applications as database management for archaeological records, with the added benefit of being able to create instant maps. It has been implemented in cultural resource management contexts, where archaeological site locations are predicted using statistical models based on previously identified site locations. It has also been used to simulate diachronic changes in past landscapes, and as a tool in intra-site analysis

5.7 Natural Hazards

Areas vulnerable to earthquakes, floods, cyclones, storms, drought, fire, volcano, land slides, soil erosion can be used to accurately predict future disasters.

5.8 Forestry

GIS has been emerging as a strong tool for many areas of forestry, from harvesting schedules to urban forestry.

5.9 Military GIS

GIS offers a virtually unique ability to aggregate, automate, integrate and analyze geographical data, which further enhance the intelligence base for defense operations

5.10 Oceanography

GIS enables study of sea level change, marine population, sea surface temperature, and coral reef ecosystem

5.11 Water Resources

GIS enables spatial representation of ground water resources, waste quality, watershed management, surface water management, and water pollution.

5.12 GIS in agriculture and soil

Data includes information on the country's land resources including physiography, soils, climate, hydrology, cropping systems and crop suitability.

6 Currently available GIS software

Some of the big players providing GIS software are:

- **ESRI's ArcGIS:** ArcGIS is a scalable system for geographic data creation, management, integration, analysis, and dissemination.
- **Autodesk's AutoCAD Map:** This software is for precision mapping and geographic information system (GIS) analysis in the AutoCAD environment. It has the special tools needed to create and produce maps and geographic information—plus all the underlying functionality of AutoCAD.
- **Autodesk's GIS design overlay:** Autodesk GIS design overlay combines powerful server technology with the mapping and design capabilities of AutoCAD Map®, enabling access to enterprise geographic and design data via desktop, web, and mobile client technology.
- **Intergraph's GeoMedia Transportaion:** It provides dynamic segmentation and linear analysis capabilities for roadway, railway, waterway, pipeline, and transit system networks. The software can retrieve business and project data required for analysis from virtually any Geographic Data Objects (GDO)-compliant data server within the enterprise, including

Oracle, Microsoft Access, Microsoft SQL Server, MGE, ArcInfo coverages, and ArcView shape files.

7 Future of GIS

As discussed above, many disciplines can benefit from GIS techniques. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS. These developments will, in turn, result in a much wider application of the technology throughout government, business, and industry.

It is quite likely that the future GIS systems of the future will include the additional dimension of time, giving researchers the ability to examine the variations in Earth processes over days, months and years.

The advances in computer hardware, software and remote sensing technology will lead to more and more GIS adopting multimedia to represent data. These GIS systems coupled with the multimedia technologies will result in a powerful and richer presentation of information and ideas to stimulate interest and enhance information retention. The GIS of the future will also be more user friendly and accessible to the common man.

8 Summary and Conclusions

GIS in essence is an applied science, and I believe that while the GIS vendor community, hardware and software vendors, provide us with newer, better and faster technological tools, it is in the end, the domain specialists applying the tool that define state-of-the-art. The heartbeat of GIS still lies in the field and district offices, the logging divisions, the engineering offices, and with the small GIS entrepreneurs in offices everywhere who will be applying this technology in their field of work.

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