Geographic Information Systems as an Integrating Technology: Overview, Concepts, and Definitions

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Abstract **-** Geographic Information Systems often defined as a systematic integration of hardware and software for capturing, displaying, updating, manipulating and anlysing spatial data. When GIS introduced, it was a simple software tool on a single computer. With time, GIS evolved and is being considered as a Geographic Information Science rather than a tool a system. This paper discusses components, data characteristics, constraints, conceptual data models of a GIS. It also describes standards, applications of GIS, also identifies some of the future challenges in GIS. This paper is an insight to the potential of GIS.

Keywords: *Geographic Information System, Spatial database, Open Geospatial Consortium, U.S. Federal Geographic Data Committee, International Organization for standardization, Geography Markup Language, Triangulated Irregular Networks*

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I. Introduction

GIS manages geographic data and related applications and used in areas such as environmental applications, transportation systems, emergency response systems, and battle management. GIS can also be viewed as an interdisciplinary area that incorporates many distinct fields of study such as geodesy (projects, surveying, cartography and so on), remote sensing, photogrammetry, environmental science, city planning, cognitive science, and others. As a result, GIS relies on the progress made in fields such as computer science, databases, statistics and artificial intelligence. All the different problems, and questions that arise from the integration of multiple disciplines make it much more that a simple tool.

II. COMPONENTS OF GIS SYSTEMS

An operational GIS also has a series of components that combine to make the system work. These components are critical to a successful GIS. A working GIS integrates five key components:

1. Hardware**:** Hardware capabilities affect the processing speed, ease of use and the type of output available. A GIS can run on a wide range of hardware types, ranging from desktop computers to large computer servers. It includes other hardware components also such as graphics devices, plotters, printers and P
2. Software tools: Provide the functions and tools required to store, analyze and display the spatial data. This includes the GIS software, database and drawing software.
3. Data: Is the core of any GIS. There are two types of data used in a GIS - spatial and tabular. The availability and accuracy of data will affect the results of any analysis. A GIS can integrate data from a number of different sources and store in a database management system.
4. Procedures**:** Are the defined methods used to analyze the data and produce accurate results. The procedures include access protocols, standards and guidelines.
5. People: Are responsible for the day-to-day operations of the GIS. Users include technical experts, managers, administrators and end users.

III. CHARACTERISTICS OF DATA IN GIS

There are particular characteristics of geographic data that make the modeling more complex than in conventional applications. The geographic context, topologic relations and other spatial relationships are fundamentally important in order to define spatial integrity rules. Several aspects of the geographic objects need to be considered.

1. Location: The spatial location of features is defined by coordinates in specific reference system, Theses features are represented by points, lines, or polygons. The geometry of the futures referees to the three dimensional representation in space.
2. Temporarily: The database model should consider both existence and change over time of the features. This is especially crucial with dynamic data such as land parcels, since we need to represent current, valid data.
3. Complex spatial futures: Features comprise several spatial representations that include points, lines, polygons and raster. The complex representation allows one to associate, for example, a three-dimensional object with different polygons of its facts.
4. Thematic values: The different properties and qualities of objects may be represented as attributes.
5. Fuzzy objects: Fuzziness deals with the uncertainty of the object's location and thematic classifications. The location

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of the object is presented by coordinates and is associated with a degree of error. The thematic aspect is represented by relating an object to a class with the degree or percentage of certainty.

6. Entity versus field-based data: The world can be represented as a set of discrete entities such as forests, rivers, lakes, seas, road and buildings. This is referred to as the entity-based approach. The field-based approach represents the world as a continuous function with attributes that vary in space. Natural phenomena such as air pollution distribution and terrain may be best represented using this approach.
7. Roles: An object within a data model may assume different roles according to the universe of discourse. Hence, the role is application dependent.
8. Object identification: Objects should be uniquely identified within the data model. Moreover, for data exchange purposes between organizations, universal object IDs may be necessary.
9. Data quality: Data quality refers to the credibility and accuracy of the data, or more generally how good and reliable the data is. Quantitative quality relates to measurable components such as the spatial accuracy (error in the position of the object).

IV. CONSTRAINTS IN GIS

Constraints are an important aspect of geographic objects in GIS. Constraints can be classified in various ways:

1. Cost constraints:

Extra attention need to be paid at the financial situations of developing countries, since they do not allow expensive projects to be carried out. GIS Tools are programs which are developed and sold by developed countries. Due to currency exchange rates these products are often very expensive. The selection of the appropriate hardware and software for a GIS is a delicate matter. In the initial state it is often difficult to assess the exact functionalities required for the GIS to be used. In order to avoid unnecessary investments it would be unwise to tie the project to a completely determined GIS environment. Starting with a very basic system is usually the cheapest and most efficient way.

1.1 Software:

The most important thing to find out which software to use, is to find out which tools are needed. The appropriate technology should be low in capital costs and utilize as many local resources as possible and can be maintained without a high level of expertise. Also the range of applications should only include the ones that are efficient and entail low risk. Examples of such applications are: automated mapping, cadastral systems, natural resource management and location planning of public services.

1.2 Hardware:

Hardware is also a very cost intensive fact or, but basic GIS can also be handled with older Hardware. The goal for developing countries should be to establish a basic system as soon as possible and not to try competing with the most modern systems.

The purchase of hardware and software encompasses only a small part of the financial cost, but it is also the one that is most likely to control. Another big factor is the cost of the workforce. Due to rare availability of skilled labour, the wages for such workers are quite high. Unfortunately this is a factor, which can not be changed easily. Also housing and infrastructure often require big investment but for the protection of the sensitive and expensive hardware saving too much at this point can be dangerous.

2. Infrastructure constraints:

All electronic systems require stable power supplies and good air conditioned housing free of damp and bugs. Many developing countries cover huge areas of land yet the people may be concentrated in a few small areas around large cities. To cover the whole country at a reasonable scale is not only very time consuming and expensive, it is also a problem that many areas are very hard to access and to find appropriate conditions for data collection in such regions can sometimes be almost impossible. In addition many of those areas are too far away from commercial support services. When problems occur with the hardware or software, the companies are mostly too far away to give appropriate support.

3. Educational constraints:

In developing countries there is still a high level of illiteracy and only a few of them know how to work with computers. Although the number of computer training institutes is rapidly increasing, the number of people that have mastered computer skills is very low. This problem is handled in varies ways. In some GIS projects selected staff are sent to abroad to get training in GIS courses and in some cases on-spot training is given to staff. Both methods have the problem that they are very expensive, because it is either necessary to import skilled people which need to be paid much higher wages or pay the seminar trips to developed countries. As internet facilities become more and more available also for developing countries, there is a third way to solve this problem: online seminars.

4. Data Constraint

Very often an effective implication is hampered by the limited availability of useful data. There are two aspects to this problem. The first is the pure existence of data; the second is the accessibility of existing data (Teefelen et al, 1992, p.105).

4.1 Existence of data:

Making maps as well as updating them is a costly and time-consuming activity, therefore detailed and current maps are scarce (Teefelen et al, 1992, p.105). Often many field surveys have to be done to cover the whole area with at least a detailed topographical map. But also information about natural resources, soils and vegetation, climate and geology are often not available. Moreover, socioeconomic phenomena like population density, growth, and movement tent to be much more variable and harder to predict than in developed countries. This means that also the maintenance of a GIS might involve more work. In addition, many of those countries are or were not democratically ruled. This means that especially information about the economy, literacy and poverty might be faked, so data has to be scrutinized if there is any possibility that data is not trustworthy.

V. CONCEPTUAL DATA MODELS FOR GIS

This section briefly describes the common conceptual models for storing spatial data in GIS. Different data models are currently implemented in geographic systems. The well-known models used by the GIS community are the following:

1. Raster data model: Raster data is an array of cells. Each cell value represents an attribute. Metadata is usually stored in a file header and includes the geographic co-ordinates of the upper-left cell of the grid, the cell size and the number of rows and columns. This model is commonly used for analytical applications such modeling, map algebra and more advanced techniques of feature extraction and clustering.
2. Vector data model**:** Vector data is a discrete object representation, primarily as points, lines and polygons. The features can have a relationships defined between them and can incorporate a behavior. Spatial analysis is done using a well-known set of defined tools to analyze the spatial data and gain information for different levels of decision making.
3. Network model: Network is essentially a special type of topologic feature model that allows modeling of flow and transport of resources and services. Network topology relationship defines how lines connect to each other in point intersections (nodes). Those rules are stored in connectivity tables.
4. TIN data model: Triangulated Irregular Networks (TIN) is used to create and represent surfaces. In the TIN structure, the surface is represented as non-overlapping triangles constructed from irregularly spaced points. The density of points is determined by the relief changes of the modeled surface. The TIN data structure manages information about nodes the comprise every triangle and neighboring triangles.

VI. GIS STANDARDS AND OPERATIONS

The need for standards and policies within the GIS community that defines the data types and methods has been addressed by several organizations. Different standards organizations, such as the Open Geospatial Consortium (OGC), the U.S. Federal Geographic Data Committee (FGDC), and the International Organization for Standardization (ISO) started to define standards in order to enable spatial data sharing. In 1999, OGC defined the core data types and methods that should be supported by GIS systems. The proposed schema was designed to be accessed though SQL. In 2003, OGC defined the GML (Geography Markup Language), which is an XML coding for geographic information. It enables the transport, modeling and storage of spatial information, including the geometry and properties of geographic features. With the proliferation of Web services, the OGC defined the OGC Web Services Common (WSC), which specifies how requests and responses handle geographic features and objects such as bounding box.

VII. GIS APPLICATIONS

The implementation of a GIS is often driven by jurisdictional (such as a city), purpose, or application requirements. Generally, a GIS implementation may be custom-designed for an organization. Hence, a GIS deployment developed for an application, jurisdiction, enterprise, or purpose may not be necessarily interoperable or compatible with a GIS that has been developed for some other application, jurisdiction, enterprise, or purpose. GIS provides, for every kind of location based organization, a platform to update geographical data without wasting time to visit the field and update a database manually. GIS when integrated with other powerful enterprise solutions like SAP, helps creating powerful decision support system at enterprise level.

Many disciplines can benefit from GIS technology. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS, and usage in the fields of science, government, business, and industry, with applications including real estate, public health, crime mapping, national defense, sustainable development, natural resources, climatology, landscape architecture, archaeology, regional and community planning, transportation and logistics. GIS is also diverging into location-based services, which allows GPS-enabled mobile devices to display their location in relation to fixed objects (nearest restaurant, gas station, fire hydrant) or mobile objects (friends, children, police car), or to relay their position back to a central server for display or other processing.

VIII. FUTURE CHALLENGES IN GIS

The GIS field has developed rapidly in the last decade. Developments in database technologies and the growing interest in GIS by many new disciplines have developed new questions and problems. Some of the challenges are:

1. Data sources: Frequently new methods to collect the data are introduced to the GIS community. New satellites, aerial cameras, and GPS must be incorporated into the system efficiently. Merging new technologies with different accuracies is a constant challenges faced by the community. The diversity of data sources results in the challenge of integration.
2. Data models: The two commonly used models are vector and raster. A major practical issue is that the GIS systems today deal primarily with only one model. Merging and utilizing both vector and raster models remains challenging.
3. Standards: The GIS community needs to enforce global or at least national standards. The recommendations of ISO, OGC, and FDGC should be addressed, considered and used by private and public sectors. This will allow better information sharing among the different organizations around the world.
4. New architectures: GIS applications will need a new client/server architecture that will benefit from existing advances in RDBMSs and OODBMSs and expanded relational database technology. Appropriate models are required handle both spatial and non-spatial data. Also appropriate tools for data transfer, change management and workflow management are generally required.
5. Mobile GIS and location-based services (LBS): The mobile which holds geographic information, receiving online updates and querying a database while on the road is a major application area. With the advent of GPS-enabled cell phones, location-based applications are immanent. Mobile GIS will be an extremely important topic with major payoffs in research. Indoor location services that cannot rely on GPS use Wireless Positioning Systems (WPS).

IX. SUMMARY AND CONCLUSIONS

A GIS is a computer based tool for geographical analysis of information. It holds a database of spatial data and attribute. The information in a GIS describes entities that have a physical location and extent in some spatial region of interest, while queries involve identifying these entities based on their spatial and temporal attributes and relationships between entities. Although a GIS can offer great flexibility in how data can be used and manipulated, it can only do what it is designed to do with the information it has.

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