Space Opera–GIS Basics

Paul H.J. Hendriks
Radboud University Nijmegen, The Netherlands

INTRODUCTION

The term "Geographical Information Systems", commonly abbreviated to GIS, is an umbrella term covering a class of computer based information systems that are typified by their focus on geographical or spatial data and information. The basic notion underlying a GIS is that every object present on the earth can be "geo-referenced", which refers to defining the spatial location of objects by referencing systems (e.g. latitude/longitude or postal zones). The key to specific GIS functionality is that GIS allow connection of geo-referenced data to attribute or non-spatial data of geographical objects. In varying ways and to varying degrees GIS facilitate the steps necessary for acquiring both classes of data and turning them into geographical information, including input (e.g. via GPS or scanning of maps), data processing and analysis (e.g. overlay analysis or shortest path calculation) and display (e.g., on maps).

The history of GIS spans roughly four decades, bringing a story that springs from many origins, and mingles many disciplines. GIS finds its roots in public administration domains and military applications, but has fanned out to many commercial, non-profit and academic areas. From its origins in the nineteen sixties, GIS has grown in size and stature, building on diverse influences concerning concepts and principles, data and issues of spatial infrastructure, software and software vendors, application areas, etc. The GIS landscape contains a multitude of proprietary and public domain GIS software packages (most notably Autodesk's AutoCAD Map, Erdas's Imagine, ESRI's Arc/Info, Intergraph's GeoMedia, Maplnfo and Smallworld). From its ongoing development history GIS emerges not as one sharply delineated concept or class of computer systems. The GIS landscape is as diverse as the multitude of roots from which it originated and the throng of influences that shaped its development.

BACKGROUND

GIS as an umbrella term covers various types of technology, ranging from relatively simple mapping facilities to advanced environments supporting spatial analysis. What combines different manifestations of GIS is that they all draw their operability from functionalities around spatial information, or geoinformation (Goodchild, 2003; Konecny, 2003). Developing an understanding of what distinguishes GIS from other information systems can be achieved by looking at GIS through four windows. Firstly, GIS can be defined through a *database window*, which involves exploring the alternative data models used in GIS and the principles and technical issues involved in defining and linking spatial and attribute data (including temporal data) based on these models. Secondly, an important distinction between different GIS refers to the types of spatial and non-spatial analysis they support, which involves looking at these systems through a *geographical analysis window*. Thirdly, applying a *visualization window* allows to assess the functionality of GIS for making the contents of their database and analysis outcomes visible, in which maps and computer cartography play an important role. Fourthly, GIS can be looked at through a *relevance window*. This fourth perspective, which involves looking at the context of system usage, is crucial for understanding GIS as information systems instead of data systems, as it should allow to understand how and when geographical analysis may make geographical data meaningful, how and when their presentation on maps will be useful, and how and when specific functionalities of GIS are necessary elements for defining GIS.

A DATABASE WINDOW ON GIS

Looking at GIS through a *spatial database* window shows GIS as a dedicated system for acquiring, storing and processing data with a spatial component (Haining, 2003; Shekhar & Chawla, 2003). Building a spatial database requires spatial data modeling and processing. Spatial modeling involves several steps. Firstly, it concerns developing a spatial understanding by distinguishing and relating the elements that define "spatiality", such as "location" or "distance". Secondly, it involves building a *conceptual spatial data model* by translating the spatial perspective into formalized data elements. Thirdly, a *logical spatial data model* must be built, which involves representing and formalizing the elements of the conceptual model in a univocal manner so that these can be entered into an automated system. Fourthly, the logical spatial data model has to be translated into the actual data storage, which refers to choosing a *physical data model*.

As the first two steps most specifically enter the spatial perspective in data modeling, we will focus on these.

Building a conceptual spatial data model consists of identifying spatial objects and characterizing these. Five aspects describe spatial objects:

1. These are objects that are in a certain place or location (aspect: *where* or *absolute location*),
2. with a certain spatial size, appearance, etc. (aspect: *spatial form*),
3. at a certain distance from other spatial objects and in a certain relationship with these (aspect: *spatial relationships* or *relative location*),
4. at a certain moment in time or during a certain period, and possibly subject to change (aspect: *when*), and
5. with other characteristics than spatial and temporal (aspect: *what*).

A basic distinction between conceptual spatial data models is whether they represent spatial objects in 2D or 3D. Commonly, four basic types of two-dimensional spatial objects are distinguished: points, lines (or specific collections of points), areas (objects identified by lines beginning and ending in the same point) and surfaces. Combinations of these basic classes and their characteristics may produce new types of spatial objects, such as spatial patterns, spatial structures, or spatial networks. For instance, a spatial network such as a road network or a network of pipelines, results from understanding points as nodes and lines as connections between nodes, and may be expanded to include areas and surfaces as well. Data models for representing these objects can be distinguished into raster models (based on fixed units of space) and vector models (based on combinations of points and lines). Three-dimensional spatial data models or geomorphometrical models, which are less common in GIS, aim to represent the height dimension of space in a more sophisticated form than by using contour lines. The most commonly used models are the triangulated network (TIN) and the digital elevation model (DEM).

Connecting the five aspects specified above with spatial objects involves three issues: firstly, defining the spatial data (aspects 1, 2, 3); secondly, defining the non-spatial data (aspects 4 and 5); and thirdly, linking spatial and non-spatial data. The non-spatial are typically called the attribute data in GIS, which include temporal data (see Christakos, Bogaert, & Serre, 2001). Describing absolute location (aspect 2) is called georeferencing. A basis distinction is between continuous (e.g., LATLONG) and discrete (e.g., postal zones) georeferencing.

Working with spatial data in GIS presumes a choice of spatial data model, facilities for getting data into the system based on that data model, and functions for processing data. Some GIS have chosen one spatial data model as the basis of their functionality for handling spatial (e.g., leading to a distinction between raster and vector GIS); others offer combinations of models and facilities for linking these. As to data input GIS users no longer need to collect all data themselves because many commercial datasets are available (e.g., based on postal zones or road networks), as well as spatial data sets built in academic or other public domain projects (see Rigaux, Scholl, & Voisard, 2002; Walford, 2002). Data input has been revolutionized by the Global Positioning System (GPS), which allows inputting both 2D and 3D spatial data from satellite data (e.g., Konecny, 2003). GIS typically contain functions for additional processing of data input from external data sets or from input devices (GPS, digitizers, etc.), such as geometric transformation (translating among methods of map projection), edge matching (ensuring that features crossing adjacent map sheets have the same edge locations, attribute descriptions and feature classes), and standard attribute editing functions (e.g., reclassifying objects based on their attribute data).

A GEOVISUALIZATION WINDOW ON GIS

The window of *visualizing spatial information* shows GIS as a system to present spatial data and information, e.g. via maps (Cartwright & Hunter, 2001). Geovisualization, and therefore also the use of maps in GIS, can refer to GIS output or input. Geovisualization as input refers to taking the visual form as the starting point for communication with GIS or further analysis steps within or outside of GIS (Maceachren & Brewer, 2004). For instance, maps can be used as interactive devices for defining queries for showing and exploring the contents of the database, e.g., to detect errors (Andrienko, Andrienko, & Gitis, 2003), or for starting a new geographical analysis. Using maps in GIS in an interactive sense presumes that the map is linked with a set of controls (e.g., it can be made clickable) allowing to change the content of the map or to take the content of the map as a step toward building a new map (e.g., Cartwright & Hunter, 2001).

Geovisualization as output refers to showing the GIS's contents, such as the data contained in the spatial databank, or the outcomes of spatial analysis. GIS can be used for producing, showing and interpreting maps and other visualizations. Producing maps involves generating data with a spatial footprint, and showing these in a new or updated map. Producers of atlases and road maps use GIS to facilitate updating the frequent changes in the location of objects (e.g., changes in the street networks, or the usually less frequent changes in the boundaries between administrative units). Geographical analysts that perform their analysis in analysis modules linked to GIS and show the analysis outcomes in GIS are another class of GIS map producers.

AN ANALYSIS WINDOW ON GIS

Through a *spatial analysis window* GIS appears as a system that offers possibilities for processing spatial and non-spatial data so that new spatial and non-spatial data and information can be inferred. GIS are best understood as toolboxes of operations that may be combined in multiple ways, guided by specific analysis needs. Additionally some GIS offer a (mostly modestly filled) spatial model base coupled to standard spatial analysis functions or offer functions for linking to external model bases (DeMers, 2002; Haining, 2003).

Typical analysis-related functions in GIS include retrieval, classification, overlay, neighborhood and connectivity operations. Such GIS functions may lead to GIS-based spatial analysis when applied and combined in different ways. Firstly, the analysis may involve generating new attribute data from existing attribute data of known spatial objects, while not affecting the location data of these objects. An example that fits within this class of spatial analysis is the overlay of two maps (e.g., private-public ownership and land use classes of lots) to produce a characterization of the areal units on the map in a third map (e.g., conveying an insight into the connections between ownership and land use of lots).

Secondly, GIS may support forms of analysis that deduce attribute properties from location data of known spatial objects. As an example consider combining network and aspect operations to assess whether a particular location is likely to run the risk of pollution in the case of a toxic spillover, because of how the downhill path runs from the spillover location (e.g., Rodriguez-Bachiller & Glasson, 2004).

Thirdly, analyzing attribute data of spatial phenomena may form the basis of the detection and subsequent characterization of new spatial objects. As an example consider a shop that is interested in what typifies its service area, to assess possibilities for adapting its range of goods. GIS allows to establish this neighborhood if customer trip data are available and to analyze prevailing demographic properties of residents within the window by connecting the spatial object with external attribute data as are available for postcode zones (e.g., Kidner & Higgs, 2003; Miller & Shaw, 2001).

Fourthly, spatial analysis may involve detecting new spatial characteristics of objects, by examining their spatial properties alone or in conjunction with associated attribute data. A GIS analyst may, for instance, perform a combined contiguity and network analysis based on address and routing information to determine how close residents are to a service such as an ambulance post or community service, to define the catchment areas of these services (e.g., Kidner & Higgs, 2003; Miller & Shaw, 2001).

A RELEVANCE WINDOW ON GIS

The *relevance window* concerns the objective for which the information stored in GIS and generated by GIS is used. A GIS is more than a collection of hardware and software. It is a specific aspect system of a larger system, namely the organization within which GIS data is managed and processed.

A view through this fourth window shows the classes of GIS applications and users (individuals, groups, departments, organizations, networks, etc.). Looking at typical GIS applications reveals a broad spectrum of uses and users (e.g., see Geertman & Stillwell, 2003; Grimshaw, 2000; Kidner & Higgs, 2003). Important business users of GIS include owners of large physical distribution networks, such as utility companies, for example gas, phone, electric, water, cable TV companies, the telecommunication industry, the transportation sector (including government transportation departments who use GIS, for instance, to store information on the state of pavement on the highway network, maintain an inventory of all highway signs, and analyze data on accidents). This sector also includes delivery companies that use GIS technology to keep track of shipments, know where they are, and plan efficient delivery routes (e.g., Miller & Shaw, 2001). GIS is also being used for siting facilities such as retail shops and warehouses, by analyzing demographic data of customer populations, access routes for customers, delivery routes for suppliers, etc. Large-scale GIS users also include farmers and foresters who increasingly use detailed maps for planning, analyzing and evaluating land use.

If we try to define GIS through a relevance window in more general terms their multicolored nature becomes even more apparent. GIS can be defined as dedicated spatial object and spatial network management tools as is customary in the AM/FM (automated mapping/facilities management) domains. GIS can be looked at as spatial decision support systems, when we see them as tools for supporting decision makers making choices that involve spatial elements, such as solving routing problems, connected location-allocation problems, or problems of service area development (e.g., Clarke & Madden, 2001; Grimshaw, 2000). GIS appear as organizational learning systems when their presence in organizations and functionalities are assessed from the perspective as to whether and when using spatial categories supported through GIS makes the organization smarter

(Hendriks, 2000, 2004). GIS can be tools in the hands of spatial scientists, including geographers, physical planners, forestry students, environmental students, and geologists, that support them in their research activities.

FUTURE TRENDS

In recent decades several developments have resulted in moving GIS from the outskirts of eclectic computing by geographical pioneers to mainstream data and information processing in private and public companies, in academia and even in private households (e.g., car navigation systems or route planners on the Internet). Many trends have supported this move. More data is available for GIS, via commercial datasets with spatial footprints and via new data collection techniques. Among these, Global Positioning System (GPS) has become a major source of new GIS data, and new GIS data comes increasingly from integrated GPS/GIS systems. The mobility of portable GIS and GPS systems has revolutionized GIS use. As GIS have been recognized for their integration facilities for databases of different kinds, GIS has quickly incorporated distributed systems and databases. Improvements in the software installation facilities user interface, improved interoperability of proprietary GIS packages, etc. have substantially altered how GIS "look and feel". National geographical data infrastructures are being built and expanded, combining the datasets and knowledge of various agencies involved in spatial data handling (e.g., land register offices, spatial planning departments). GIS education has done its part in lowering some thresholds for recognizing the potential value of GIS, and in raising the critical awareness using GIS without profound geographical insight has limited value.

It can be expected that new developments will build on such existing trends. In the short run the further integration with GPS technology, and the development of national and transnational spatial infrastructures may be expected. In the longer run we may anticipate an increasing integration of scientific visualization and computer graphics with GIS capabilities. An increased integration of GIS with advanced modules for geographical analysis can also be foreseen. The use of animated and interactive maps, whether delivered via the Internet or not, holds much promise for enhancing the approachability of such spatial analysis modules.

CONCLUSION

Combining the four windows specified above – or adopting a more GIS-like terminology: overlaying these windows – allows drawing the contours of what GIS are. The four windows show Geographical Information Systems as sets of software tools and associated guidance principles that are based on insights as to how using spatial categories can further our understanding of phenomena and that allow the further development of such a spatial understanding through instantiations of combined spatial data, analysis and visualization models. History has moved GIS from the backwaters of pioneering academics and some individual public institutions into the floodlights. The story of GIS is an ongoing story of success, notwithstanding the critical comments GIS has received and is receiving (e.g., Sheppard, Couclelis, Graham, Harrington, & Onsrud, 1999). It presents GIS viewers with a space opera in which the acts they have seen so far have done everything to arouse the attention of what the future will hold for GIS and its users.

REFERENCES

Andrienko, G., Andrienko, N., & Gitis, V. (2003). Interactive maps for visual exploration of grid and vector geodata. *ISPRS Journal of Photogrammetry and Remote Sensing, 57*(5-6), 380-389.

Cartwright, W. E., & Hunter, G. J. (2001). Towards a methodology for the evaluation of multimedia geographical information products. *Geoinformatica, 5*(3), 291-315.

Christakos, G., Bogaert, P., & Serre, M. L. (2001). *Temporal GIS: Advanced functions for field-based applications*. Berlin: Springer.

Clarke, G., & Madden, M. (2001). *Regional science in business*. Berlin: Springer.

DeMers, M. N. (2002). *GIS modeling in raster*. New York: Wiley.

Geertman, S., & Stillwell, J. (2003). *Planning support systems in practice*. Berlin: Springer.

Goodchild, M. F. (2003). The nature and value of geographic information. In M. Duckham, M. F. Goodchild & M. F. Worboys (Eds.), *Foundations of geographic information science* (pp. 19–32). New York: Taylor and Francis.

Grimshaw, D. J. (2000). *Bringing geographical information systems into business* (2nd ed.). New York: Wiley.

Haining, R. (2003). *Spatial data analysis:Ttheory and practice*. New York: Cambridge University Press.

Hendriks, P. H. J. (2000). An organizational learning perspective on GIS. *International Journal of Geographical Information Science, 14*(4), 373-396.

Hendriks, P. H. J. (2004). Intelligence from space; Using geographical information systems for competitive intelligence. In D. J. Vriens (Ed.), *Information and communications technology for competitive intelligence* (pp. 194-226). Hershey, PA: Idea Group Publishing.

Kidner, D., & Higgs, G. (2003). *Socio-economic applications of geographic information science*. London: Taylor & Francis.

Konecny, G. (2003). *Geoinformation: remote sensing, photogrammetry and geographic information systems*. London: Taylor & Francis.

Maceachren, A. M., & Brewer, I. (2004). Developing a conceptual framework for visually-enabled geocollaboration. *International Journal of Geographical Information Science, 18*(1), 1-34.

Miller, H. J., & Shaw, S.-L. (2001). *Geographic information systems for transportation: principles and applications*. New York: Oxford University Press.

Rigaux, P., Scholl, M., & Voisard, A. (2002). *Spatial databases: With application to GIS*. San Francisco, CA: Morgan Kaufmann.

Rodriguez-Bachiller, A., & Glasson, J. (2004). *Expert systems and geographic information systems for impact assessment*. London: Taylor & Francis.

Shekhar, S., & Chawla, S. (2003). *Spatial database: A tour*. Upper Saddle River, NJ: Prentice Hall.

Sheppard, E., Couclelis, H., Graham, S., Harrington, J. W., & Onsrud, H. (1999). Geographies of the information society. *International Journal of Geographical Information Science, 13*(8), 797-823.

Walford, N. (2002). *Geographical data characteristics and sources*. Chichester, UK: Wiley.

KEY TERMS

Geographical Analysis Model: A model to derive new spatial information by combining existing spatial and attribute data sources as appears useful for a given research goal (e.g., route selection, service area definition).

Geographical Information System (GIS): Computer system for acquiring, storing, processing, analyzing and displaying combined spatial and non-spatial data for academic, societal or organizational purposes.

Georeferencing: Identifying the geographic location of features and their boundaries on the Earth surface, e.g., derived from GPS, remote sensing, mapping, and surveying technologies.

Geovisualization: Data representation using more than one dimension to convey meaning, including animation and dynamic cartography, and spatialization (using geographic metaphors to generate georeferenced displays of nonspatial data such as text, image or sound archives).

Global Positioning System (GPS): A system of determining the absolute location of features by calculating x, y, z coordinates of ground locations from the signal of satellites orbiting the Earth.

Spatial Data Model: Set of principles and concepts for describing spatial objects and associated characteristics in a formal, univocal way, at the conceptual, logical or physical level.

Spatial Decision Support System: System built on the integration of spatial database management systems, geo-analytical models, geovisualization models, and the expert knowledge of individuals and organizations facing spatial decision problems.