# GIS from a Computer Science Perspective

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## ABSTRACT
Is GIS a tool or a science? This is a question the author would like to discuss in this paper. The question is clearly important in operations of academic institution that need to distinguish between GIS as a tool to be taught at the undergraduate level, or a science and thus a legitimate research specialty of faculty and graduate students. Is GIS a tool, involving the use of a particular class of software and associated hardware? Is GIS a tool making endeavour to advance its capability? Is it a science concern about fundamental issues?

## Keywords
GIS as Tool, GIS as a Science.

## 1. INTRODUCTION
Roger Tomlinson coined the term "geographic information system" for the Government of Canada in the early 1960s [2]. Tomlinson was clear enough in his definition of a GIS as a computer application designed to perform certain specific functions. At face value, GIS seems nothing more than a particular class of software. In that sense, "GIS research" is meaningless.

Over the years, the definition of GIS has evolved to a stage where it is not clear whether it is a tool or a science. The Wikipedia[1] Website (the free encyclopaedia) defines GIS as:

"A geographic information system (GIS) is a system for creating, storing, analysing and managing spatial data and associated attributes. In the strictest sense, it is a computer system capable of integrating, storing, editing, analysing, sharing, and displaying geographically-referenced information. In a more generic sense, GIS is a tool that allows users to create interactive queries (user created searches), analyse the spatial information, and edit data. Geographic information science is the science underlying the applications and systems, taught as a degree programme by several universities."

The question of tools or science is important. Academic institution need to know if GIS is a tool that should be taught at the undergraduate level, or a science and thus a legitimate research specialty of faculty and graduate students. Are students who "do GIS" doing substantive science? Is an association with GIS sufficient to ensure that research is substantive, or if not, what other conditions are necessary?

Someone in government or business may ask: "Why should one care whether GIS is a science or not? The technological (toolbox) personality of GIS is widely successful in government, business, and education, and it appears to have affected and improved the lives of far more people than have many theoretical advances (e.g., the theories of spatial data and of data structures, data models, and algorithms).

However, science is often held in high regard, and labelling a field as a science may sometimes help to ensure it a place in the academy or to secure it greater funding and prestige. "Science" is often used as a generic synonym for "research". Thus "science" often functions as a rather crude but convenient shorthand for academic legitimacy. If "doing GIS" is "doing science", its claim as a topic of research at graduate-level is clearly strengthened.

## 2. WHAT IS GIS?
GIS software stores the data in a 3-D database, and formats and transforms the data, sometimes even showing development over time in so-called 4-D (3-D + time) transformations.

GIS software has an enormous application range. Archaeologists use GIS to reconstruct ancient trading networks. Urban planners use GIS to model infrastructure. Environmental scientists need GIS software to model erosion in coastal areas and mountain valleys. Global-warming effects become far more apparent when visualised in GIS data viewers. Cartographers depend on GIS software to aggregate data to produce data-rich maps. GPS-enabled mobile-telephone users can use GPS and GIS software to locate the people they are talking to and, sometimes, their own position.

A GIS is most often associated with maps. A map, however, is only one way you can work with geographic data in a GIS, and only one type of product generated by a GIS. A GIS can be viewed in three ways: as a database, as a map, or as a model.

A GIS is a unique kind of database of the world, a geographic database. Fundamentally, a GIS is based on a structured database that describes the world in geographic terms (Figure 1).

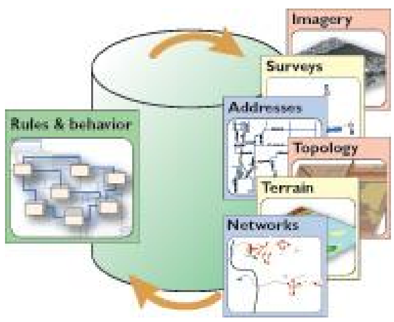


**Figure 1: GIS as a Spatial Database**

[1] http://en.wikipedia.org/wiki/Geographic_information_system

A GIS is a set of intelligent maps and other views that show features and feature relationships on the earth's surface. Maps of the underlying geographic information can be constructed and used as "windows into the database" to support queries, analysis, and editing of the information. This is called geo-visualisation (Figure 2). Geo-visualisation is about working with maps and other views of the geographic information including interactive maps, 3D scenes, summary charts and tables, time-based views, and schematic views of network relationships.

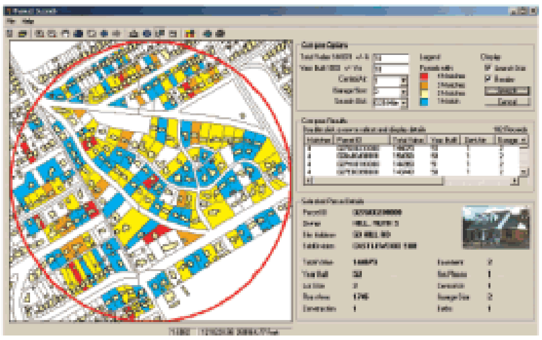

**Figure 3: GIS used for Geo-Visualisation**

A GIS is a set of information transformation models that derive new geographic datasets from existing datasets. These geo-processing functions take information from existing datasets, apply analytic functions, and write results into new derived datasets (Figure 3).

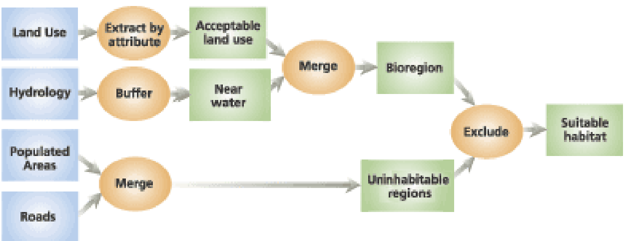


**Figure 3: GIS as a Model (Data → New Data)**

# 3. HISTORY OF GIS

A detailed history of GIS is not well understood because GIS technology evolved through multiple parallel but separate applications across numerous disciplines. The development of the GBF-DIME files by the U.S. Census Bureau in the 1960s marked the large-scale adoption of digital mapping by the government. This system led to the production of the Census TIGER files, one of the most important socio-economic spatial data sets in use today. Important geographic work was also being done at universities throughout the 1950s and 1960s. A grid-based mapping program called SYMAP, developed at the Laboratory for Computer Graphics and Spatial Analysis at the Harvard Graduate School of Design in 1966, was widely distributed and served as a model for later systems [3].

The year 1964 saw the development of the world's first true operational GIS in Ottawa, Ontario by the federal Department of Energy, Mines, and Resources. Developed by Roger Tomlinson, it was called "Canadian Geographic Information Systems" (CGIS) and was used to store, analyse, and manipulate data collected for the Canada Land Inventory (CLI)—an initiative to determine the land capability for rural Canada by mapping information about soils, agriculture, recreation, wildlife, waterfowl, forestry, and land use at a scale of 1:250,000 [3].

These early GIS packages were often written for specific applications and required the mainframe computing systems found usually in government or university settings. In the 1970s, private vendors began offering off-the-shelf GIS packages. M&S Computing (later Intergraph) and Environmental Systems Research Institute (ESRI) emerged as the leading vendors of GIS software [1].

In 1981, ESRI released Arc/Info, a standard package which ran on mainframe computers. \As computing power increased and hardware prices plummeted in the 1980s; GIS became a viable technology for state and municipal planning. In 1992, ESRI released ArcView, a desktop mapping system with a graphical user interface that marked a major improvement in usability over Arc/Info's command-line interface. By the early 1990s, GIS existed in the form of more "affordable" PC-based software.

Recently, the open source community has begun making contribution to GIS. This could be attributed to the availability of mapping and location services on the Web and mobile-phone. In the 1980s, Geographic Resources Analysis Support System (GRASS) was developed. After modification in the late 1990s, GRASS has enabled anyone with knowledge of GIS and some expertise in Linux to run a complete GIS system from the Linux command line or a graphical user interface (GUI).

Within the open source world, GRASS[2], QGIS[3], and many other GIS applications use a base library known as the Geo-spatial Data Abstraction Library (GDAL). GDAL is written in C and C++. Public domain GIS data cannot exist without some fairly sophisticated data-storage mechanism. The OpenGIS standard addresses these problems by making vector data (e.g. geometrical objects, such as points, lines, polygons, and their composites) accessible in a 3-D-enabled database called PostgreSQL. The implementation of the OpenGIS standard for PostgreSQL is known as PostGIS[4]. GIS data stored within a PostgreSQL database are fully searchable using SQL-92.

In the world of Java, a popular GIS is uDIG[5]. The uDIG is built around the concept of plug-ins to the base Eclipse Rich Client Platform. Several other well-known Eclipse plug-in are used, such as the Eclipse Modelling Framework and the Graphic Modelling Framework. Toolkits such as GeoTools[6], provide useful abstractions and data connectivity.

[2] http://grass.itc.it/

[3] http://qgis.org/

[4] http://postgis.refractions.net/

[5] udig.refractions.net/

[6] http://geotools.org/

# 4. POSITIONS ON GIS

## 4.1 GIS is a Tool

GIS a tool used to advance the investigation of a problem. Scientists use many types of tools in their research. Some tools are generic in nature, with no particular association with any discipline. Others are developed strictly for one discipline, or even for one project or for one group of scientists. GIS falls somewhere in the middle, being of interest, in principle, to any discipline dealing with the distribution of phenomena on the surface of the Earth. It seems neither a generic tool whose use is so ubiquitous that one can reasonably assume universal familiarity (i.e. word processor), nor the exclusive tool of a single discipline.

For these less-than-universal tools, the academe traditionally provides the necessary infrastructure in the form of technical courses and technical support. But in addition the academe satisfies the need for education in the associated concepts. In the case of statistics, for example, it would not be adequate to provide a laboratory of statistical tools without at the same time providing courses to ensure that students have the necessary understanding of concepts. The same distinction between technical training in the use of tools and education in the underlying concepts applies to GIS. While the concepts of GIS may be familiar to professionals, they must be taught anew to each generation of students. Without conceptual courses, the use of GIS is likely to degenerate to data management and map making, however complex the tool's capabilities for scientific analysis and modelling.

## 4.2 GIS is a Science

Two terms have evolved to describe the emergence of a science based on GIS. The first is Geomatics, a term favoured in many countries because of its simplicity and its ease of translation into French. The second, geographic information science is a term that is well-known in the English-speaking world.

Geographic information science, the science of GIS, is concerned with geographic concepts, the primitive elements used to describe, analyse, model, reason about, and make decisions on phenomena distributed on the surface of the earth. These range from the geometric primitives of points, lines, and areas to the topological relationships of adjacency and connectivity.

GIS research will most likely deal with issues such as recognition and measurement in the field; the choice between alternative representations; the roles of generalization and multiple representations; the representation of uncertain information; methods of analysis and modelling; problems of describing the content of geographic data and evaluating its fitness for use; and methods of visualization. These sorts of issues underscore the multidisciplinary nature of geographic information science. It includes such traditional geographic information disciplines as geography, geodesy, surveying, cartography, photogrammetry, and remote sensing along with the spatially oriented elements of such other disciplines as information statistics, cognitive science, information science, library science, and computer science.

## 4.3 GIS is Toolmaking

Along the continuum between "GIS is a tool" and "GIS is a science" is a middle position. That is GIS is toolmaking. Typical users of GIS often lack the necessary technical skills to build GIS software. Developers of GIS tools have backgrounds in many disciplines, including computer science, engineering, design, and mathematics. Most current GIS originated in the private sector, with GRASS and Idrisi[7] as notable exceptions.

The toolmaking position confers a more significant status on GIS. In this case, GIS includes case studies that demonstrate the methodology and the development of software. Toolmaking will remain more akin to engineering than to science. An academic department adopting the toolmaking position would probably offer a range of undergraduate and graduate courses in GIS. The faculty would regard GIS as a research specialty and encourage students to make significant contributions as toolmakers.

# 5. GIS AND COMPUTER SCIENCE

From a computer science perspective, GIS is concerned with:

- Data structures and access method
- Representations and Algorithms
- Architectures
- Interfaces

GIS: A Computer Science Perspective is an appropriate text book for this topic [6].

GIS courses are offered in several universities. In Australia, James Cook University in Queensland offers a bachelor degree in Computer Science (GIS Strand)[8]. A typical study program can include the following subjects:

Level 1
- Introduction to Computer Science 1
- Introduction to Database Principles
- Introduction to Multimedia
- Introduction to Computer Science 2
- Computing Mathematics

Level 2
- Data Structures and Algorithms
- Internetworking 1
- Object Oriented Programming with Java
- Operating Systems and Architectures
- Electives (Advanced Database, Computer Graphics)

Level 3
- Information Technology Project 1
- Fundamentals of Software Engineering
- Information Technology Project 2
- Principles of Data Communications
- Object Oriented Software Engineering

GIS at all levels (BSc, MSc and PhD) is offered with the Faculty of Engineering at the University of Melbourne. Similarly, the Spatial Information and Engineering Department of the University of Maine (USA) offers GIS degrees at all levels.

In Europe, GIS research is strong at the Swiss Federal Institute of Technology (Zurich) and at Deft University of Technology (Netherlands).

[7] www.clarklabs.org

[8] srvcns.it.jcu.edu.au/flyers/BIT_Geographical_Information_Systems.html

IT graduates with a major in Geographical Information Systems (GIS) use expertise in IT and practical experience analysing 'real world' situations to creatively adapt state of the art GIS tools for new uses. They become GIS systems administrators, applications developers, and software engineers in government, mining, agriculture and other industries.

### 5.1 Data Structures and Access Method

Data structures and access method is concerned with efficient data storage and retrieval. It includes from general purpose databases (relational and object-oriented) to specialised data structures such as region and point quad-trees. The book Spatial Databases: A Tour provides a suitable text for a course on spatial databases [5].

### 5.2 Representation and Algorithms

A geometric algorithm operates upon geometric or spatial objects. Geometric algorithms have some special features. Consider the classical "point in polygon" decision problem. It is easy for humans to determine the answer visually but much more difficult to write a computer program that solves the problem. This property of geometric algorithms is in stark contrast to arithmetic algorithms that may be difficult to manually solve but quite easy and fast using computers.

Note that the manner in which spatial data is represented will impact on the required algorithm and its efficiency. Issues such as time and space complexity, intractability, correctness and completeness are important.

A classic book in this field is that of Preparata and Shamos [4].

## 6. CONCLUDING REMARKS

Is GIS a tool or a science? From a computer science perspective, the middle position that GIS is a tool making discipline seems more appropriate. As a toolmaking discipline, GIS is more akin to engineering than to science. In that sense, it is comparable to software engineering discipline. Hence, it is justifiable to offer a degree in computer science major in GIS as it is acceptable to offer a major in software technology within a computer science degree.

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