1 The use of Geographical Information System: The user interface is the system

Andrew U. Frank

It has been observed (Albaredes 1992) that a large majority of all decisions depend on a spatial situation or have spatial effects. This should not come as a surprise given that nearly all human activities require space. Even if spatial aspects are currently not considered for many decisions where spatial distribution or interaction matters, general trends in society drive towards more exhaustive information processing before a decision can be reached. Thus the information must be analysed and presented in a spatial context and the application of Geographical Information Systems (GIS) technology is often required.

GIS are therefore useful wherever information about objects in space must be used to make a decision and when the outcome of decisions have a spatial impact. It follows that the number of applications are diverse and large in number covering simple inventory and monitoring to complex spatial modelling and analysis over all geographical scales (Maguire et al. 1991). The increasing awareness of the finiteness of earth resources and concern that human actions can affect our local or global habitat have inspired many GIS advocates.

At the global scale GIS are used to study worldwide changes in climate and how they affect different regions (Mounsey and Tomlinson 1988). GIS are also used in a regional and local context, to monitor changes and manage natural resources such as forest or grassland for multiple and long-term uses. Space itself can be viewed as a finite, non-renewable resource, whose use or uses require careful and thoughtful planning and management. Decisions to allow one use and exclude other incompatible ones can only be taken if spatial interaction with uses of adjoining pieces of land are considered. For this GIS is the appropriate technology. Other uses of GIS technology include scientific and planning applications as well as many administrative uses, such as property registration and management of public utility lines e.g. gas, water, electricity.

In many parts of the world GIS are being introduced rapidly and the rate of growth is high, however they have yet to achieve their fullest potential. There are a number of reasons for this, and these are the subject of the latter part of this chapter.

Frank, Andrew U. "The Use of Geographical Information Systems: The User Interface Is the System." In *Human Factors in Geographical Information Systems*, edited by David Medyckyj-Scott and Hilary Hearnshaw, 3-14. London: Belhaven Press, 1993.

....WHAT IS A GIS?

GISs input, store, manage, analyse and present information with respect to geographic space. Definitions as to what constitutes a GIS may differ in the stress they put on application areas, the particular users, or the different functions they must provide (Maguire 1991). Based on these definitions other terms with slightly different semantics are sometimes used. The term Spatial Decision Support System (SDSS) is used to emphasise their advanced role in decision making (see Chapter 13). Land surveyors talk of Land Information Systems (LIS) stressing the use of administrative data tied to cadastral units such as land value and ownership (National Research Council 1980), although their original scope was little more than information retrieval. Simple cadastres have evolved into the 'multi-purpose cadastre' which incorporate other related land information such as topography, hydrology and the ability to analyse information related to the cadastral unit in a similar way to a GIS (Dale and McLaughlin 1988). AM/FM (Automated Mapping and Facilities Management) refers to systems that primarily present spatial locations of facilities (e.g. gas pipelines) but may include additional analysis capabilities.

GIS AS AN INTEGRATING TECHNOLOGY

The very essence of a GIS is to bring together data from different sources which contribute to a specific decision or set of decisions and integrate this compound information on the assumption that more information and better presentation improves the decision(s) made. This is possible because spatial location acts as the common denominator that links the datasets (Figure 1.1). GIS applications often use data that are already collected for some other purpose and integrate them with other, previously unrelated datasets. Sources might include satellite images, a variety of maps and cadastral, census and environmental surveys. Thus, with little additional cost for the data processing, more and better use of available data is made.

One of the common justifications for the installation of a GIS is the observation that many different agencies collect essentially the same data. As it is well understood that the major cost of a GIS is in the collection and maintenance of the data (National Research Council 1983), considerable savings are possible if the same dataset is collected only once and maintained by one agency while providing access for other organisations. The data are presented and accessed in the customary form, but the cost of base data can be shared.

GIS DEAL WITH DATA IN GEOGRAPHIC OR LARGE-SCALE SPACE

Any GIS manages spatial data, in particular data that describe some property of geographic space or objects in geographic space. They are thus different from other spatial information systems. Kuipers and Levit (1990) have defined geographic or large-scale space as:

> a space whose structure is at a significantly larger scale than the observations available at an instant. Thus, to learn the large-scale structure of the space, the traveler must necessarily build a cognitive map of the environment by integrating observations over

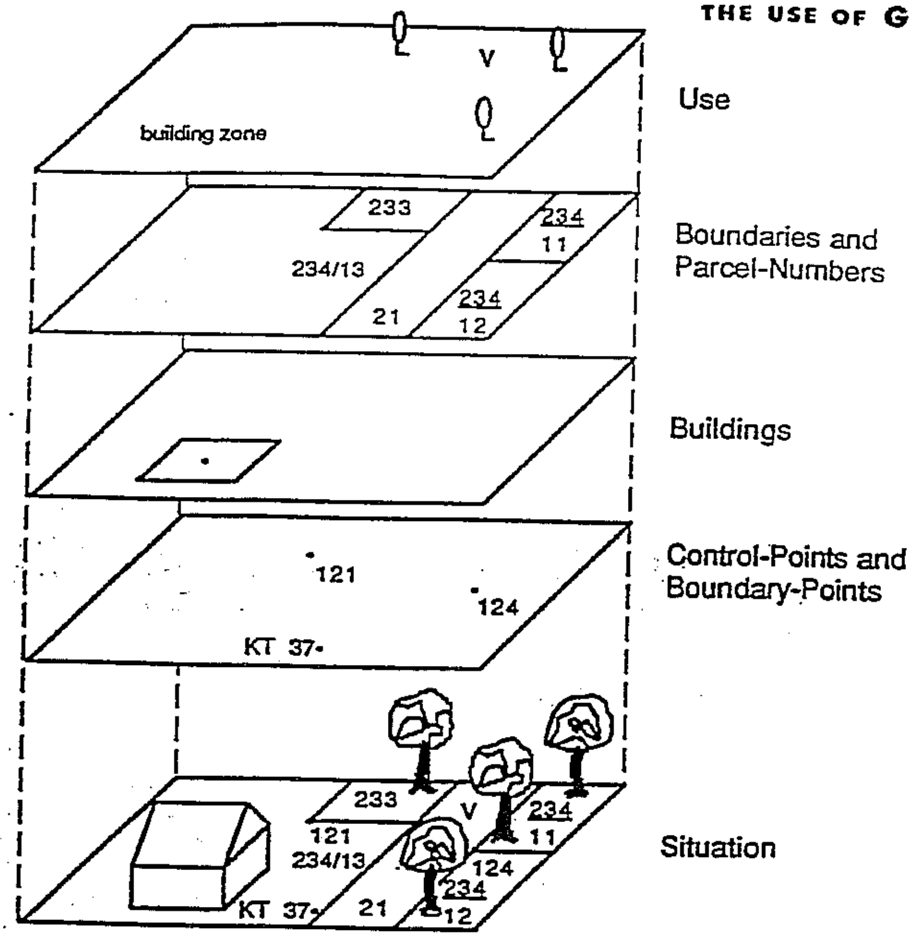

Figure 1.1 The spatial integration of different data in a GIS

> extended periods of time, inferring spatial structure from perceptions and the effects of actions. (p. 208)

Maps show geographic space in the same way we think of small-scale objects. Cartography uses our ability to apply concepts learned in one situation – namely the manipulation of small-scale objects on a table-top – to another one, for example, navigation in a city. This metaphorical transformation, in the terminology of Lakoff (1987), is useful because it translates from geographic space, which is more difficult to understand, to the small-scale space of the table-top, which is easier to grasp. All the analytical tools developed for the small-scale space, e.g. Euclidean geometry, become applicable to the large-scale space (see Chapter 4).

These metaphorical mappings between different realms of experience need to be understood by the designers of user interfaces (Kuhn and Frank 1991). A GIS may invoke the experience of road navigation and orienteering in geographic space, the experience of small physical objects which can be moved on a table-top, and the specific experience of cartographic techniques. For each of these contexts, different types of everyday experiences are evoked and influence what system behaviour the users expect. This multiplicity indicates why interfaces for full functional GIS are very complex.

GIS AND MAPS

A GIS uses cartographic methods extensively and may even use maps and cartographic operations as user interface metaphors. Maps are the only tools in common use for spatial analysis, for navigation and any other form of spatial thinking. Therefore users and designers of GIS have most often thought and communicated about GIS in terms of maps and operations on maps.

The reasons for this are partly historical. Some of the first GIS were designed to maintain large collections of maps and engineering drawings. They were therefore in a very restrictive sense not properly GIS, but only cartographic databases (Frank 1991). Users soon discovered the potential of GIS and demanded more powerful applications. Analytical functions were added to the cartographic ones. Multiple thematic maps were organised as layers. Unfortunately, when operations in a GIS are designed and presented in the context of a map metaphor, they tend to inherit the limitations from the metaphor which the technology alone would not impose.

....BASE GIS ARCHITECTURE

GIS are customarily divided into two major classes, namely those which originate from the remote sensing and image processing tradition and deal with space in a 'raster' (gridcell) structure, and those which started with a cartographic tradition of encoding geometry using points and lines, often called 'vector based' GIS. These systems differ in more than their application area and implementation details. Obviously there is the difference in the organisation of data storage, but they also differ in the spatial concepts they provide for the user to model his application (Frank 1992) and in some of the functions they provide.

DIFFERENCES IN THE SPATIAL CONCEPTS

One tradition of understanding the world is to assume that for each point in space there exists, for a given time, a value for every attribute. Goodchild's abstract model of 'geographic reality' (Goodchild 1990), posits an 'observation function' f which for any point in space and time (x, y, t) returns a vector with a specific value for each of n attributes a_1 to a_n. One can then conceptualise these attributes as 'thematic maps' which lay on top of each other. This can be written as:

$$f(x, y, t) = (a_1, a_2, a_3, \ldots a_n)$$

The other tradition understands the world as a collection of objects, which fill space and have particular properties. Each of these objects, O, has an identity (represented by an identifier i), a spatial location, l, a boundary, b, and the additional non-spatial attributes $a_1 \ldots a_n$. An 'object map' can be written as

$$O_i = (l, b, a_1, a_2, \ldots a_n)$$

REGULAR AND IRREGULAR SUBDIVISIONS

There are two major architectures which implement Goodchild's abstract model of 'geographic reality'. Each uses different geometric data models. One divides space in regular raster cells with a single value for each attribute for each cell (Figure 1.2) and the other collects data as the largest area of uniform value represented by a boundary polygon (Figure 1.3). The raster architecture is popular with applications that use data originally collected as a raster image, primarily remote sensing data. The polygon architecture is often used with natural resources data, that is typically collected as areas of uniform value for land use, soil type, etc.

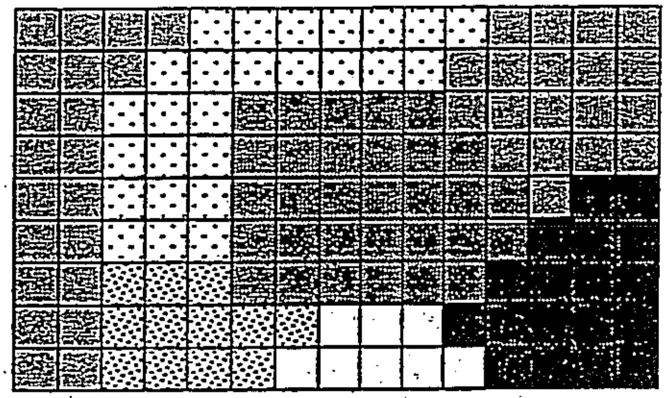

Figure 1.2 A regular subdivision of space (raster)

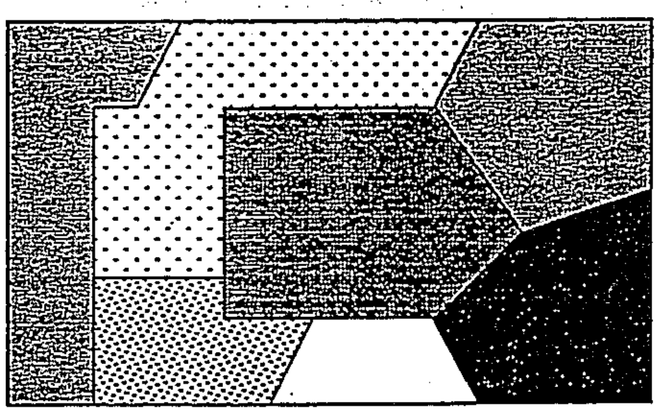

Figure 1.3 An irregular subdivision of space (coverage)

OBJECT-BASED GIS

Here each object has a unique identifier. This is necessary for most administrative applications, where one might deal with the land parcel 'number

'9401/5' owned by 'Tom Miller', rather than with areas that have 'Tom Miller' as an owner (there may be several parcels). Operations can be applied to these specific objects, not only to whole layers of cell values. The geometry of the objects may be an area, but lines and points can also be objects. Typically communication and transportation applications require graph-like structures of lines and points to represent the road network or the electricity lines. These structures seem straightforward to implement but, as yet, no consistent comprehensive base theory exists. A contribution to this problem has been made by Gueting and Schneider (1992).

DIFFERENCES IN THE FUNCTIONS OF GIS PACKAGES

IMAGE PROCESSING ORIENTED GIS Some GIS have their roots in systems built to use the images acquired from satellite platforms. Remote sensing systems record intensity of reflected electro-magnetic radiation (EMR) from an area of the surface of the earth. Commonly used wavelengths of EMR are those in the visible light and infra-red regions of the electro-magnetic spectrum, each wavelength showing a different surface characteristic (for example near infra-red indicates the health of vegetation well). Resolution is today between 1 sq. km and 100 sq. m (pixel area) and full images contain several million pixels. Within each wavelength region (or band) the intensity for each pixel is typically represented as an integer between 0 and 255 (8 bit). Such images are quite large but simply structured raster datasets (American Society for Photogrammetry and Remote Sensing 1983).

Images are first radiometrically and geometrically corrected, to counter systematic errors in the sensor. Typically the sensors register the intensity in different parts of the electromagnetic spectrum and composite images of multiple 'channels' are produced, assigning each channel a colour. This assignment can be designed to produce either images close to 'natural' colours or special colour assignments which clearly differentiate land use categories. Using various methods information may be extracted from satellite images: by enhancing the visual appearance of the image (e.g. contrast enhancement); by feature extraction (e.g. edge enhancement); by classification of the intensity values into similar groups. Classification methods use the typical reflections of known land uses to estimate the land use of an unknown area. There are several methods in use, some require the user to indicate areas for which he knows the true value (ground truth). Last, but not least, there is a need for data compression methods to reduce the large datasets to manageable quantities. These functions apply specifically to raster or grid-based GIS.

LAYER-ORIENTED GIS FUNCTIONS Land use planning has used sets of maps drawn on transparent material, each showing different aspects of the problem to be treated, which are then overlaid to produce composite layers. With a set of simple base maps, one identifying all areas that are zoned 'residential' and the other walking distance to public transportation, it is possible, by overlaying the two maps, to locate those residential areas within, for example, 5 minutes walk of public transport.

The underlying logic, when extended to GIS, is still very simple: the values at the same location are combined using some simple algebraic formula. Tomlin

(1990) described the applicable operations and classified them, coining the term 'map algebra'. Functions include operations to:

- change the classification of attribute values;
- compute logical and arithmetic values from attribute values for corresponding areas in different layers;
- combine values from adjoining areas, which allow averaging over a neighbourhood, or the determination of distances between points and regions.

These operations form an algebra for layers, such that a combination of two or more layers produces another layer. This new layer can then again be used as an input to another combination operation. These operations are theoretically the same for both regular and irregular subdivisions (raster and vector/polygon systems). Unfortunately, the operations in a GIS are only approximations for the mathematically exact operations the user conceptualises and these shortcomings may occasionally be significant.

CARTOGRAPHIC FUNCTIONS OF A GIS Computerised systems can be used effectively to produce maps. A computer based editing system can produce changes in a map relatively easily, and a new edition can be created on a computer-controlled high precision drawing system. Such functions are not only used by the national mapping agencies for maintenance of topographic map series, but also by public utilities, such as power suppliers, to maintain their very large collections of drawings showing utility lines.

Cartographic use of a GIS requires operations to identify a single graphical element of a map, to delete, translate or copy such an element and also operations to construct new parts of a drawing (see Chapter 9).

ADMINISTRATIVE FUNCTIONS OF GIS Where a GIS is used to maintain a database for administrative purposes, it must provide operations to access individual records in the database quickly and support the easy change of attribute values, often by many users at the same time. Administrative uses of GIS cover a range of applications, from property registration and taxation, routing of vehicles, from rubbish (trash) collection to school buses, and management of emergency vehicles.

DIFFERENCES IN DATA STORAGE

Current GIS software vary in the organisation of data storage. While systems have developed technically far from the prototypical cases described here, these roots still have an influence, primarily at the user interface level, in the conceptualisation of operations and the objects to which these operations are applied.

FILE ORIENTED STORAGE Storing each layer of data (sometimes called a 'coverage') as a file is the most direct implementation. Effective use of the directory structure of the operating system can be made, with the organisation of layers that belong to the same area, or the same project, in a single directory. This works well both for systems which store data in a raster format, and for systems that store polygons of equal value.

Cartographic systems often inherit the data organisation from the manual cartographic production process: data are grouped in map sheets, which are stored, manipulated and drawn individually. A map sheet consists of graphical map features, which are sometimes grouped in thematic layers, this reflecting the colour separation of the printing process. Typically a map sheet is stored and manipulated as a single file.

DATABASE-ORIENTED GIS In order to support objects with unique identifiers and to provide rapid access to them, the database concept was introduced in GIS (Frank 1988). Database management systems (DBMS) are tools created to store and protect a collection of data and make it available for many different applications. They are widely used for storage of alphanumeric data, but are not yet optimised for the storage of geometric data (see Chapter 10).

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IMPEDIMENTS IN THE USE OF GIS

Considering today's technology and its extensive and rapid diffusion, it is worthwhile to analyse what are the major obstacles to the best use of the technology. Understanding the impediments may provide guidance for the research and development work necessary today. We will see that the limiting factor is not the hardware but data issues, organisational issues and the usability of the systems, in particular the user interface.

AVAILABILITY OF BASE TECHNOLOGY

In the early days of GIS, computer technology was very limited and not widely available. Hardware to process and store spatial data were expensive and it was often found not to be cost effective to use systems with limited capabilities when compared with the traditional methods. This situation has changed completely. Hardware and software for GIS are widely available at prices which are very low when compared with the cost of training users and data collection (Dillon et al. 1990). There are hardly any practical limitations for using a GIS imposed by the hardware, indeed the hardware is usually more advanced than what the software is capable of using.

DATA ISSUES

Collecting or acquiring the data is a major expense in setting up a GIS. Data maintenance is also therefore a crucial problem for all systems that require long-term usage of their data. Data capture often starts with a current collection of data, which pre-exists the GIS. Data capture from paper maps can be done through manual digitising or by scanning and vectorization; tools are now available at competitive prices for doing this. The major cost is not the conversion itself, but the need to correct errors found in currently held data which, although they do not disturb manual processing, cannot be tolerated in

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a computerised system. With the growth of GIS, another source of data is from those organisations who have already computerised their records and are willing to sell them to others.

When building a database for a GIS, the quality of the data must be carefully monitored. Data from different sources will vary in spatial and attribute precision, level of update and spatial, temporal and categorical resolution (Goodchild and Gopal 1989). The means for assessing the effects of data quality of individual components on the outcome of analysis are not widely available. Facilities for the user to assess these effects through, for example, visualization methods (Beard and Buttenfield 1991) are needed. Generally, the cost of data acquisition, and errors in data, are impediments to the effective use of GIS.

Other impediments created by data problems include liability for errors in products derived from purchased data, protecting confidentiality of those to whom the data refer, copyright and patent of derived datasets, data security (Blakemore 1991) and data pricing (Rhind 1992).

PERSONNEL AVAILABILITY

A number of differently trained people are required to introduce and run a GIS, e.g. systems manager, analyst, database expert. Because of the rapid growth of the GIS area, the market for GIS specialists is currently very competitive. Despite warnings some time ago that this problem would occur (e.g. Department of the Environment 1987), the introduction of GIS in many organisations is still 'personnel limited' and this is impeding the successful uptake of the systems (see Chapter 18).

TRAINING TO USE GIS

Given the difficulty in finding GIS personnel to employ, it is often the case that the people who operate the GIS come from within the organisation. This has the advantage that such people already know the organisation, its tasks and procedures, etc. Training itself is expensive, not only in terms of the fees asked for by training organisations (frequently the GIS vendor) but also in unproductive time whilst the new system is learnt—attending courses, time spent experimenting with the system and so on. Organisations have a tendency to underestimate these training costs which may be of the same order of magnitude as the cost of GIS hardware and software. Training is definitely a major cost when introducing a GIS and any means by which the cost can be reduced will be welcomed.

EASE OF USE

Even experienced users of word-processing software, currently the most widely used software, know only a small number of the functions available and use an even smaller one. Some reports in trade journals quote figures as low as 10 per cent. Whiteside et al. (1982) found that people used perhaps 5 per cent of the functions available in text editors and that everybody used a *different* 5 per cent.

Introspection as well as observation confirms a similar level of use for GIS. Thus much of what is in principle available to the user is actually not used, because the user:

- never finds out about it;
- does not understand that it could be helpful in a particular task;
- does know about it and wants to use it, but cannot find out how it works;
- does know about the functionality in principle, but it seems too complicated to use.

This partial use of the GIS may produce ineffectiveness and inefficiency.

USE OF GIS INTERMEDIARIES

The complexity of operating a GIS has led to a situation where the application specialists (the planners, the tax assessors, the foresters, etc.) do not use the GIS themselves but rely instead on a GIS specialist for interacting with the system. These specialists become the bottlenecks: not only is it difficult to hire people with the necessary skills but the arrangement itself impedes the innovative use of the GIS.

Unless the application specialists themselves understand what the system can do for them, they will not be able to ask other than the standard questions. Compare the situation with the new computers for financial planning. Before spreadsheets were available, senior personnel used computers only for the large, but routine, efforts. With the introduction of spreadsheet programs on personal computers, all this has changed. Because they can use the spreadsheets, managers can use the computer for many commercial calculations themselves. They are no longer dependent on the specialists to operate the computers and they can get results immediately, before a decision has already been made.

THE USER INTERFACE IS THE GIS

GIS are only as useful as the information which users can gain from them. The user interface is the part of the system with which the user interacts. It is the only part directly seen and thus 'is' the system for the user. This illustrates the crucial importance of the user interface for the usability of a GIS. This importance extends to both the value of the GIS as a system and the value of the data which have been costly to collect. In early GIS software the user interface was nothing more than a method to call the operations in the system, and provide the necessary parameters. The user interface showed directly the structure of the program and, in order to succeed, the user had to be familiar with the way the operations of the system were programmed. Over time GIS software has become more versatile and general purpose. Commercial GIS have different user interfaces, and many functional extensions have been added, each increasing the complexity of the interface. Functional generality in the software has had a price, namely a more complex user interface and a bigger manual. This translates directly to higher costs for learning and using the system.

It is beneficial at this point to consider the experience gained with accounting software on mainframes and spreadsheets on personal computers, or to study the evolution of the user interfaces of word processing software. Only when the user interfaces became simpler did wider usage of computers become practical. Wide use led to increased sales, higher volumes of production and reduced prices. This applies now to GIS. Only if it is easy to learn how to use a GIS (and there is a large group of users that could, at most, spare twenty minutes to learn it) will the number of users increase. However, it is not just a 'quick fix' that will achieve these benefits. Changing from a textual user interface to a menu-driven one, or a graphical one, does not alone substantially improve the usability of a system if the command set is still using baroque terminology. The user interface is much more than meets the eye!

A difficult problem remains to be addressed, namely the inclusion of 'usability' and 'user interface' quality in the GIS selection process. GIS selection is guided by a long list of functional requirements and performance comparisons. It is often only after selection and installation of the GIS that users, who may not have been consulted in the process of choosing the GIS, then observe that the GIS would perform very quickly, if only somebody knew the commands to type!

Unfortunately, this insight comes too late. There is a need for research into developing methods for formally assessing usability so it can be introduced into the selection process, thus forcing GIS vendors to pay attention to this aspect of their products.

The user interface is therefore much more than just the colours and fonts that appear on the screen (Samuelson 1992). It includes all the concepts that the user needs to understand the system and to communicate effectively with it. Studying these concepts and reducing the plethora of ideas found in today's GIS should be a priority. In particular, we must weed out all the remnants of past hardware limitations that still confuse today's users. A serious study of the feasibility of a 'core' GIS interface, with a restricted set of concepts, based on a convincing metaphor and appropriately visualized, could yield large benefits. It would not only make GIS more 'friendly' to the non-specialist, but would also speed up the task of learning a new system for the application specialist, and allow simplification of the training of GIS users.

This book addresses, then, the gap in much GIS research between the rapid advances in technology and the human factors considerations of how those advances can best be used.

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