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NARAYAN PANIGRAHI

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To

my father, Shri Raghu Nath Panigrahi and
mother Mrs Yasoda Panigrahi who brought me up with dedication and placed education second to none despite their modest means

Foreword

Over the last decade GIS (geographical information systems) has established itself as a collaborative information processing system. The vast domain of information it can process is ever increasing and so is its popularity. Yet this interdisciplinary field of knowledge is not readily available to the large community of students and academicians as a subject of study.

Traditionally, GIS is looked upon as a processor of geo-spatial information. With the advent of space imaging systems, remote sensing and carto-satellites, the capturing and processing of spatial data temporally has become important. Hence GIS has embarked upon the new role of spatio-temporal data analysis and visualization. Of late, records of various objects can be stored in relational databases and processed using GIS. With the success of GPS (global positioning system), real time tracking of objects and visualizing the dynamics of moving objects on the map has widened the scope of GIS. Therefore, GIS is emerging as a platform for collaborating information from various walks of life having geo-spatial data. GIS gives a unified picture of any operation under consideration.

The author's earnest endeavor to present the subject lucidly and cover the various aspects of GIS from different perspectives is laudable. The IPO (input, processing and output), MVC (model, view and control), and DIKD (data, information, knowledge and decision) models have been used to illustrate the different perspectives.

In my view the author's experience in analysis, design, development and testing of different commercial GIS during his professional career spanning over a decade has been used effectively to compile this text. I believe that this book will kindle the interest of the community of GIS users and readers to further enhance their geo-spatial knowledge.

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Director
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Preface

GIS (geographical information system) has established itself as a popular and effective collaborative information processing system. The input domain of GIS is ever increasing and so is its processing capability and user domain. The scientific concepts behind GIS, known as geographical information science (GISc), are fast emerging as a separate field of study—though an interdisciplinary one.

This book intends to address the GIS user domain encompassing students, users and engineers. Efforts have been made to capture the basics of GIS from the point of view of a student. The requirements of GIS have been explained keeping in mind the general user's level of knowledge. The processing capability of GIS along with the mathematics and formulae involved in arriving at a solution are explained for students and cartographers. The work flow of the whole system, its output and applications are illustrated from an engineer's point of view.

I have tried to present the subject lucidly and cover the various aspects of GIS from different perspectives using the IPO (input, processing and output), MVC (model, view and control), and DIKD (data, information, knowledge and decision) models.

This book may not have had the same impact as it does without the large number of illustrations in the form of figures, tables, block diagrams and references interspersed within the text. These illustrations help in explaining the concepts clearly and are an outcome of a set of trial data prepared particularly to technically evaluate GIS software. Hence in a way they are generic without infringing upon the copyright of any organization or person. I have used many equations, illustrations and references from varied sources and agencies. I have tried to trace the owners of the copyright materials and duly acknowledged the same in the book.

Organization of this book

This book has been organized into fifteen chapters. In order to make the subject simple and lucid to the readers, a systematic approach has been adopted. Each chapter is organized in the form of dialogues, answering the more common questions asked by a reader. Further, each chapter shapes the subject matter to fit the pattern of an 'input–processing–output' model, a 'model–view–control' process, and a 'use case of information' function.

Sometimes the GIS function is compared with traditional cartographic or geographic processes so as to bring out the true advantages and guiding principles of the GIS function. Each chapter is supplemented with work flows and numerous figures illustrating the processes and outputs. Relevant references are added to further the knowledge of the reader. To help in recapitulating the material, pertinent questions are asked at the end of each chapter.

Therefore each chapter in the book is organized in the following patterns.

1. The descriptive GIS functions
2. The GIS function as used by the user (use case view)
3. The IPO (input–processing–output) view

4. The MVC (model–view–control) perspective of the GIS function
5. Comparison with the traditional system and procedures
6. Work flow and process flow as applicable in GIS

One more perspective of GIS as an EIS (enterprise information system) has been discussed as the process of evolving EIS. Microscopically each section of the book explains both the IPO and MVC paradigms consistently.

Acknowledgements

This book is an outcome of my association with various GIS intensive projects of the Defence Research and Development Organization (DRDO). These projects involved rich spatial data processing, analysis and visualization functions. The experience gained during analysis, design, development and testing of these projects concerning geo-spatial functions were quite educational and unique. Hence I am very grateful to DRDO as an organization.

I duly acknowledge the constant inputs from my research and development team, which has enhanced the readability of this text. This book would not have been possible without the active help of some enthusiastic individuals.

The academic criticisms of my scientist wife Smita were of great help in structuring the book. My son Sabitra was a source of motivation throughout this project, boosting my enthusiasm every time I felt low. My cute little daughter Mahasweta deserves a mention because I have spent the time, which is rightfully hers, in compiling the book. Subhalaxmi deserves a mention for her witty and critical comments.

My sincere thanks to Mr. V. S. Mahalingam, Scientist-G, Divisional Officer, B Command and Control Division of the Centre for Artificial Intelligence and Robotics (CAIR)—it was he who kindled the very thought of writing this book. His constant guidance and valuable advice were a source of great inspiration.

Finally, I thank Mr. N. Sitaram, Distinguished Scientist and Director, Centre for Artificial Intelligence and Robotics, Bangalore, for his advice and support.

For suggestions/feedback to improve the book you can reach the author at

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1

Introduction

This chapter introduces geographical information science (GIS) to a first time reader of the subject. It opens with the first question that would occur to the reader— 'What is GIS?' This is followed with some basic definitions and the genesis of the subject with a historical review explained from various perspectives. In order to generate further enthusiasm in the reader, this chapter is supplemented with workflows, process flow and an information perspective of 'how GIS is evolving'.

1.1 What is GIS?

Geographical information system or geographic information system is an interdisciplinary field of knowledge, comprising geography, digital cartography, computer science, mathematics, image processing, pattern recognition, digital photogrammetry and remote sensing. It is more popularly called GIS.

In another sense, GIS is an information processing system, which is an embodiment of information pertaining to objects on, above and under the earth's surface. GIS primarily processes data which are geographic in nature associated with reference coordinates (latitude, longitude and height). Such data which has reference coordinates associated with it are called spatial data.

1.2 Definition of GIS

To formally define GIS, we must know a little bit about information. Generally, information has three main components—the location (spatial) it is associated with, the time of its happening (temporal) and the contents (what) of the information itself. Any information can be analyzed into its spatial, temporal and non-spatial components by answering fundamental queries such as, where it has occurred? when it has occurred? and what the information is about?

GIS can be defined as a system of systems collecting, processing and analyzing spatio-temporal information regarding earth features. It involves the people preparing the data, the system (input and output devices, computing platforms and networking) and the users using the system.

An alternative definition would be: An information system exploiting spatial, temporal and non-spatial data pertaining to terrain objects. Hence, GIS is an information system capable of answering the following queries:

1. Given the coordinates of an object, what is the object about?
2. Given the description of the object, where is the object located on the earth?
3. Given the location and characteristics, where and when does the object occur on the Earth (time of occurrence)?

Collating all these statements, we can define GIS as an information processing system, collaborating data and information from various walks of life, giving a unified visual representation of the process under consideration with a digital map in the background. Depicted in Fig. 1.1 is an ortho-photo with typical earth features like roads, buildings, trees etc. in it. Also attached to these features are the spatial and non-spatial data corresponding to them.

Road junction at:	Lat, Long, Alt: 12:58:21,77:38:11,846
Road names:	Ring Road and Peripheral Road
State:	Northern Province
Road width:	100 meters
Bi-lane:	Y
All weather:	Y
Date of survey:	07-06-1996

Fig. 1.1 Examples of spatial, non-spatial and temporal data

The data record in Fig. 1.1 constitutes three parts. The first field of the record gives a series of coordinates in the form of latitude, longitude and altitude, describing the physical location of the object and is called the spatial information, because it is related to the object in space. The rest of the data fields barring the last field describe various attributes of the object and are known as non-spatial information or aspatial information. The last field of the record gives us the date and time at which the information is recorded or surveyed. This gives the temporal dimension to the geo-spatial information.

The corresponding visual representation of this geo-spatial information can be found in the digital ortho-photo. This is captured in the form of a digital line feature in a digital vector map and finally as a line with particular colour, line style, font and width in a paper map as depicted in Fig. 1.1.

In this rapidly expanding information age, a plethora of information systems are emerging. The sole driving force behind this information explosion is 'How easily can we provide processed information to the user, so that he or she can make effective decisions'. Most information systems are oriented and developed to address the contents of the information in various ways pertaining to a particular domain. But of late, there is a growing demand to address the spatial and temporal occurrence of the information along with the information itself. Some operation information systems OIS have more need for real-time spatial information, for example, the fleet management system; the tactical command, control and communication system; and the battle field management system etc. Whereas, in some operational information systems such as the urban planner, agriculture and land management systems etc. the spatio-temporal data collected over a period of time is required to be processed. These systems do not exploit the time criticality associated with the spatial data. GIS has emerged as a reliable provider of this kind of spatial information, which need to be processed (Longley et al. 1999, pp. 8–13).

1.3 Genesis and Historical Perspective of GIS

GIS emerged due to a number of operational necessities arising from the usage of digital maps in civil and military applications. Some prominent applications, which also had a profound impact on its evolution, are operation planning, situation representation and terrain feature measurement. The motif force which spurred the development of GIS as an information system was thematic cartography i.e. composition of maps according to a particular theme, collaborative visualization of operation information and application-specific map generation e.g. communication map, soil map etc.

Cartography is the art and science of map-making. It involves surveying objects or features on, above and under the earth's surface e.g. land survey, aerial survey and survey of coastal zones etc. Traditionally, the surveyed features were then represented with appropriate graphic symbols in a paper format such as maps. The graphic symbols representing the surveyed features with specific fonts, colour and styles were collectively called cartographic symbology. The process of surveying and then engaging in the painstaking task of drawing the symbols was human-intensive and carried out by a specialist team of professionals called field surveyors and cartographers. As the need of application-specific maps increased, there was a growing demand for a flexible library of digital cartographic symbols (symbology) for representation of spatial features and a process to prepare application-specific maps. The characteristics of the symbol library are listed in Table 1.1.

Table 1.1 Characteristic requirements of a symbol library

Characteristic	Cartographic requirement of symbol library
Uniqueness	Unique and unambiguous representation of surveyed data in different formats e.g. paper map, sand model, globe or digital graphic display etc. This is achieved through the assignment of a unique combination of colour, line style, font and width or thickness to each set of digitized features.
Scale independence	The symbols can be scaled up or down so as to preserve the relative position of the features on the terrain. That is, the line and area symbols should get appropriately scaled up or down to fill the corresponding space in the map, whereas the point symbols should maintain the location accuracy of the features they represent.
Updatable	The symbology library can be updated from time to time to incorporate new spatial features. To take care of new natural or man-made features, cartographers modify and update the symbol library from time to time.
Temporal change	Random and periodic change in terrain surface is inevitable. The symbol library needs to cater and represent temporal changes effectively. It also needs to be updated from time to time to incorporate such temporal changes or new spatial features.
Application-specific symbol library	The symbology can represent features specific to a particular application such as defense application, civil application, cadastral application etc.
Overlay representation	Man-made features or the operations carried out by an organization need to be depicted on a map. The symbol library should effectively represent the operations without affecting the background map.

As mentioned before, the traditional cartographic processes were quite human-intensive, inflexible and error-prone. With the advent of digital processing technology, the traditional cartographic processes were replaced by digital cartographic processes, which were simple and less error-prone. When remote sensing and satellite photography developed, the manual survey data were supplemented by satellite images which could reflect recent terrain changes and thus were more authentic. The actual survey itself was augmented by a combination of digital cartographic processes such as, survey using GPS (global positioning system), aerial photography and photogrammetric interpretations of remotely sensed satellite images and aerial photographs for accurate representation of earth features.

The whole idea of graduating from the manual cartographic process to the digital cartographic process was to reduce the dependency on human skill, thus removing the errors caused due to this; and accurately representing spatial information in a composite manner.

Earth features are digitized from the satellite image and after due interpretation, are assigned an appropriate symbol, colour, font and style (symbology) to give a visual representation to the feature. Further, these features are categorized according to the common major and minor characteristic they possess (theme-wise). The categories of symbols along with their spatio-temporal information are stored in various data organization methods (formats) so that they can be modified and retrieved from the digital database with ease. The process flow in Fig. 1.2 describes the various stages of thematic cartography. The various modules of thematic cartography are realized in the form of software, hardware or a combination of both. Geographical information systems has emerged as an embodiment of all these digital cartographic modules.

Digital cartography emerged during the 1960s. Many basic concepts in digital cartography (spatial data, map layers, topological structure etc.) can be traced back to work done in the land inventory branch of the Canadian Government or the Harvard Laboratory for Computer Graphics and Spatial Analysis. Some of the first GIS systems for mapping and spatial analysis were put into operation by the Environment Systems Research Institute Inc. (ESRI). ESRI launched its commercial GIS ARC/INFO® at the same time Intergraph's Geomedia® suit of solutions came to be considered as the first generation GIS. These popular commercial GIS systems (Goodchild et al. 2001) owe their origin to Harvard laboratory technology.

GIS systems were first used in the armed forces because there was a felt need for an operation information system (OIS) which could depict the deployment of forces on a thematic map as an information layer. This kind of a system would help commanders to assess the deployment of their own forces with respect to the enemy deployment.

1.4 Process Flow of GIS

The block diagram shown in Fig. 1.2 depicts various processes generally followed in a digital cartographic system. Almost all GIS systems perform some or all of these steps in different ways. The block diagram clearly describes the various stages that geo-spatial data undergoes in a typical GIS system before it can be used as geo-spatial information by the end user.

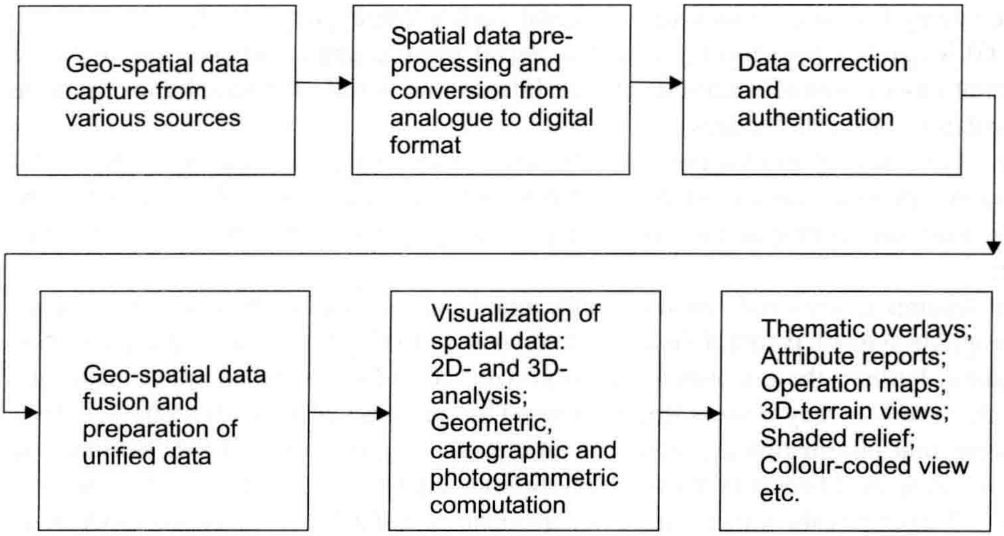

Fig. 1.2 Different stages of processing geo-spatial data

STEP 1 Spatial data can be obtained from various sources e.g. manual survey, scanned paper maps or photos, survey data obtained from global positioning systems (GPS), satellite images, ortho-photos obtained by air-borne surveillance platforms etc.

STEP 2 Some of the spatial data obtained in STEP 1 are analog data and need to be converted to digital form by digitization. Some data do not have geo-reference information i.e. the information required to refer them to a particular patch of earth. Hence STEP 2 involves pre-processing the spatial data obtained in STEP 1 i.e. converting them to digital form, imparting uniform coordinate information and register to the earth surface it belongs to.

STEP 3 The data obtained after pre-processing sometimes has some spatial error due to registration. This needs correction. The spatial data also needs to be validated using ground truthing of a candidate sample before analysis.

STEP 4 The geo-coded, geo-referenced spatial data, obtained after validation and verification through the above steps represents different aspects of terrain viz. two-dimension spatial features, three-dimension spatial features and attributes of different features. Hence to provide a comprehensive view to the user, the spatial data need to be fused for a unified representation of the terrain. This is not a mandatory step in all GIS.

STEP 5 The spatial data obtained in the above steps can be visualized and analyzed in various ways e.g. 2D-digital map, 3D-terrain model etc. Geometric and cartographic computations to measure the spatial features and derive further meaning can be performed on these data.

STEP 6 By applying different processing tools and algorithms provided in GIS, the user can derive many specific spatial information and outputs.