

1 An Introduction to GIS

Introduction

Geography has always been important to humans. Stone-age hunters anticipated the location of their quarry, early explorers lived or died by their knowledge of geography, and current societies work and play based on their understanding of who belongs where. Applied geography, in the form of maps and spatial information, has served discovery, planning, cooperation, and conflict for at least the past 3000 years (Figure 1-1). Maps are among the most beautiful and useful documents of human civilization.

Most often our geographic knowledge is applied to routine tasks, such as puzzling a route in an unfamiliar town or searching for the nearest metro station. Spatial information has a greater impact on our lives than we realize, by helping us produce the food we eat, the energy we burn, the clothes we wear, and the diversions we enjoy.

Because spatial information is so important, we have developed tools called geographic information systems (GIS) to help us with our geographic knowledge. A GIS helps us gather and use spatial data (we will use the abbreviation GIS to refer to both singular, system, and plural, systems). Some GIS components are purely technological; these include space-age data collectors, advanced communications networks, and sophisticated computing. Other GIS components are very simple, for example, a pencil and paper used to field verify a map.

As with many aspects of life in the last five decades, how we gather and use spatial data has been profoundly altered by modern electronics, and GIS software and hardware are primary examples of these technological developments. The capture and treatment of spatial data has accelerated over the past three decades, and continues to evolve.

Key to all definitions of a GIS are “where” and “what.” GIS and spatial analyses are concerned with the absolute and relative location of features (the “where”), as well as the properties and attributes of those features (the “what”). The locations of important spatial objects such as rivers and streams may be recorded, and also their size, flow rate, or water quality. Indeed, these attributes often depend on the spatial arrangement of “important” features, such as land use above or adjacent to streams. A GIS aids in the analysis and display of these spatial relationships.

What is a GIS?

A GIS is a tool for making and using spatial information. Among the many definitions of GIS, we choose:

A GIS is a computer-based system to aid in the collection, maintenance, storage, analysis, output, and distribution of spatial data and information.

When used wisely, GIS can help us live healthier, wealthier, and safer lives.

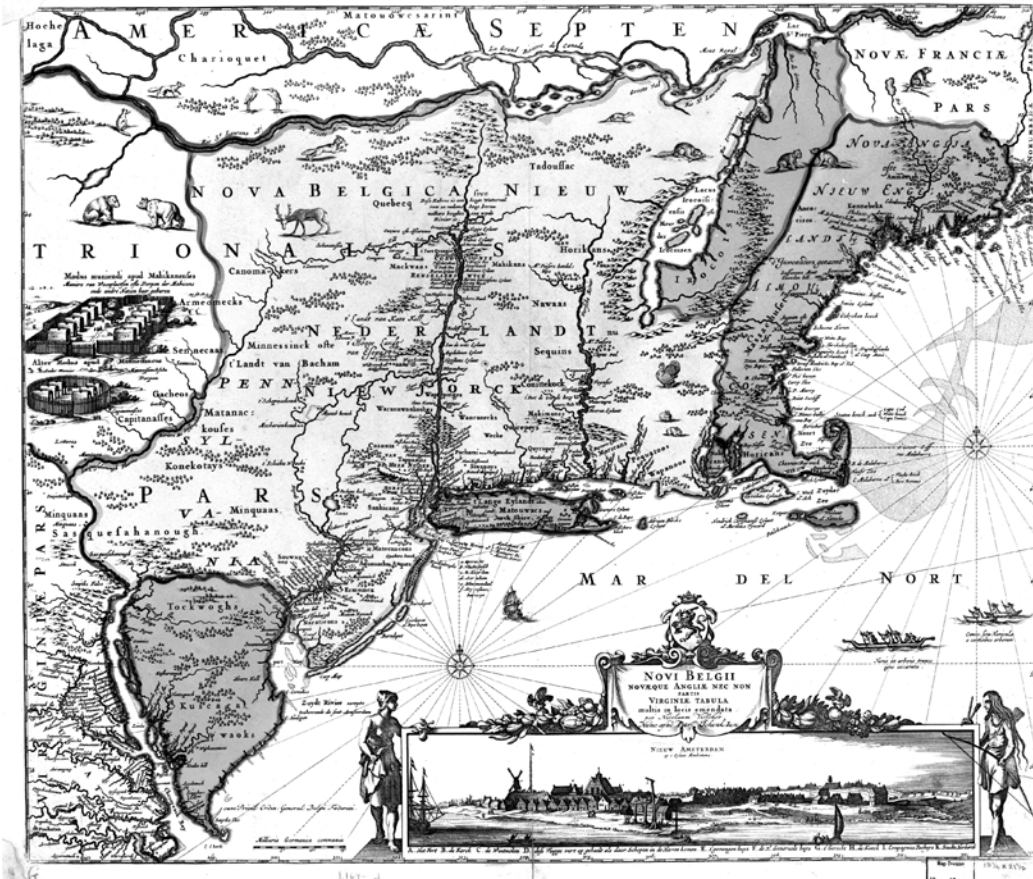


Figure 1-1: A map of New England by Nicolaes Visscher, published about 1685. Present-day Cape Cod is visible on the right, with the Connecticut and Hudson Rivers near the center of this map. Early maps were key to the European exploration of new worlds.

GIS and spatial analyses are concerned with the quantitative location of important features, as well as properties and attributes of those features. Objects occupy space. Mount Everest is in Asia, Pierre is in South Dakota, and the cruise ship Titanic is at the bottom of the Atlantic Ocean. A GIS quantifies these locations by recording their *coordinates*, numbers that describe the position of these features on Earth. The GIS may also be used to record the height of Mount Everest, the population of Pierre, or the depth of the Titanic, as well as any other defining characteristics of each spatial feature.

Each GIS user may decide what features are important, and what is important about

them. For example, forests are important to us. They protect our water supplies, yield wood, harbor wildlife, and provide space to recreate (Figure 1-2). We are concerned about the level of harvest, the adjacent land use, pollution from nearby industries, or when and where forests burn. Informed management of our forests requires at a minimum knowledge of all these related factors, and, perhaps above all, the spatial arrangement of these factors. Buffer strips near rivers may protect water supplies, clearings may prevent the spread of fire, and polluters downwind may not harm our forests while polluters upwind might. A GIS aids immensely in analyzing these spatial rela-

tionships and interactions. A GIS is also particularly useful at displaying spatial data and reporting the results of spatial analysis. In many instances GIS is the only way to solve spatially-related problems.

GIS: A Ubiquitous Tool

GIS are essential tools in business, government, education, and non-profit organizations, and GIS use has become mandatory in many settings. GIS have been used to fight crime, protect endangered species, reduce pollution, cope with natural disasters, treat the AIDS epidemic, and to improve public health; in short, GIS have been instrumental

in addressing some of our most pressing societal problems.

GIS tools in aggregate save billions of dollars annually in the delivery of governmental and commercial goods and services. GIS regularly help in the day-to-day management of many natural and man-made resources, including sewer, water, power, and transportation networks. GIS are at the heart of one of the most important processes in U.S. democracy, the constitutionally mandated reshaping of U.S. congressional districts, and hence the distribution of tax dollars and other government resources.



Figure 1-2: GIS allow us to analyze the relative spatial location of important geographic features. The satellite image at the center shows a forested area in western Oregon, USA, with a patchwork of lakes (dark area, upper left and mid-right), forest and clearings (middle), and snow-covered mountains (right). Spatial analyses in a GIS may aid in ensuring sustainable recreation, timber harvest, environmental protection, and other benefits from this and other globally important regions (courtesy NASA).

Why Do We Need GIS?

GIS are needed in part because human populations and consumption have reached levels such that many resources, including air and land, are placing substantial limits on human action (Figure 1-3). Human populations have doubled in the last 50 years, reaching 6 billion, and we will likely add another 5 billion humans in the next 50 years. The first 100,000 years of human existence caused scant impacts on the world's resources, but in the past 300 years humans have permanently altered most of the Earth's surface. The atmosphere and oceans exhibit a decreasing ability to benignly absorb carbon dioxide and nitrogen, two primary waste products of humanity. Silt chokes many rivers and there are abundant examples of smoke, ozone, or other noxious pollutants substantially harming public health (Figure 1-4). By the end of the 20th century most suitable lands had been inhabited and most of the Earth's sur-

face had not been farmed, grazed, cut, built over, drained, flooded, or otherwise altered by humans (Figure 1-5).

GIS help us identify and address environmental problems by providing crucial information on where problems occur and who are affected by them. GIS help us identify the source, location, and extent of adverse environmental impacts, and may help us devise practical plans for monitoring, managing, and mitigating environmental damage.

Human impacts on the environment have spurred a strong societal push for the adoption of GIS. Conflicts in resource use, concerns about pollution, and precautions to protect public health have led to legislative mandates that explicitly or implicitly require the consideration of geography. The U.S. Endangered Species Act of 1973 (ESA) is an example of the importance of geography in resource management. The ESA requires adequate protection of rare and threatened

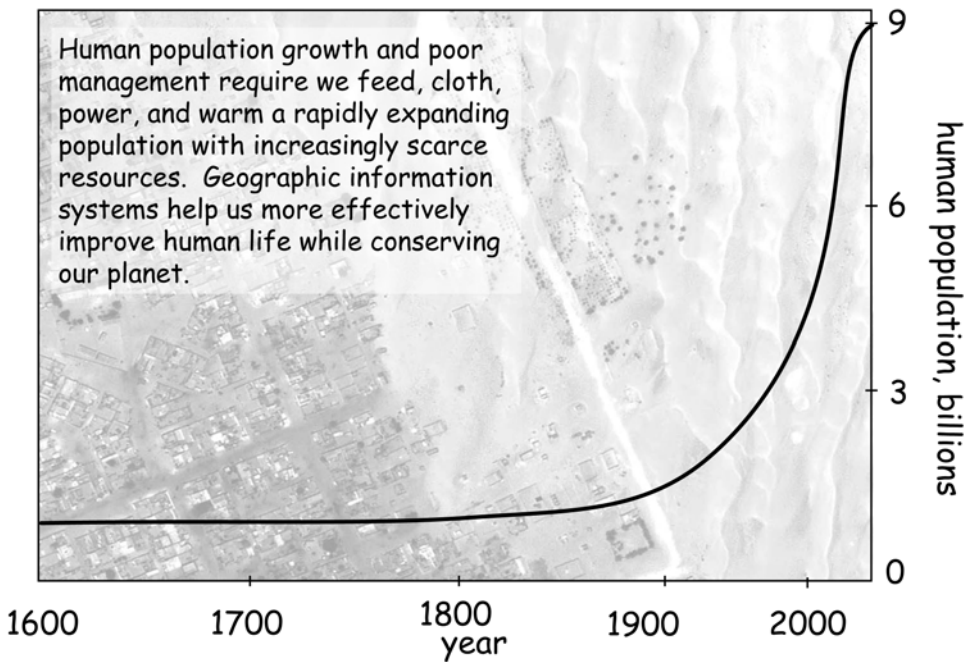


Figure 1-3: Human population growth during the past 400 years has increased the need for efficient resource use (courtesy United Nations and Ikonos).

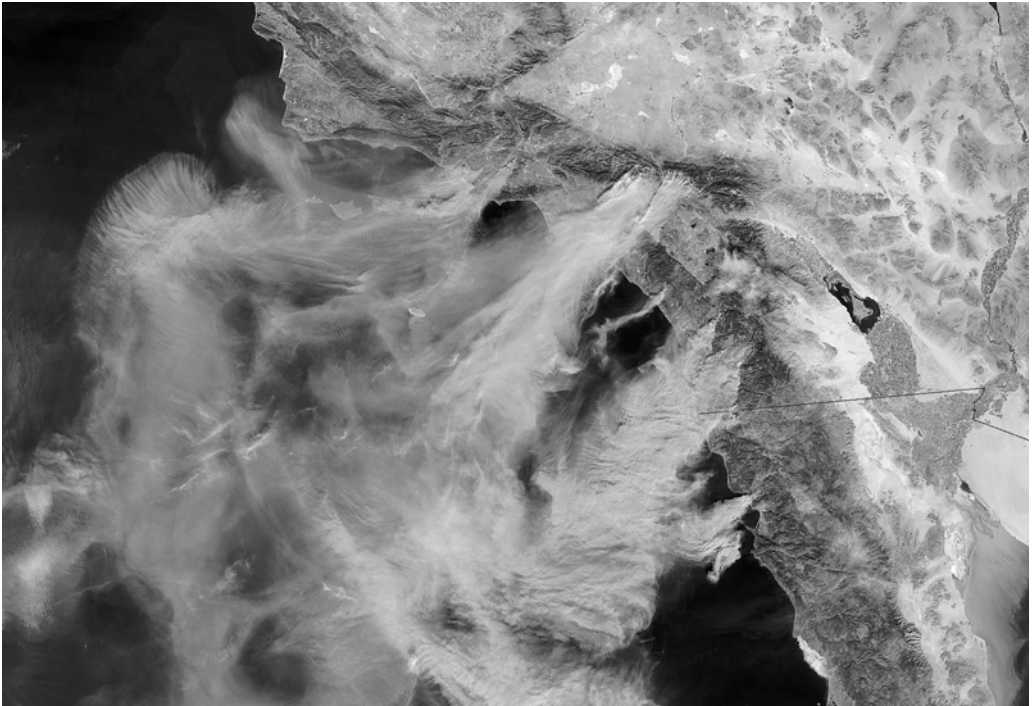


Figure 1-4: Wildfires, shown here in a satellite image of western North America, are among the human forces behind the societal push to adopt GIS. Fires surround Los Angeles, near the center of this October, 2003 image. The smoke plumes from multiple fires extend across the homes and workplaces of more than 10 million people, and out over the Pacific Ocean to the lower left. GIS may be used to help prevent, fight, and recover from such fires (courtesy NASA).

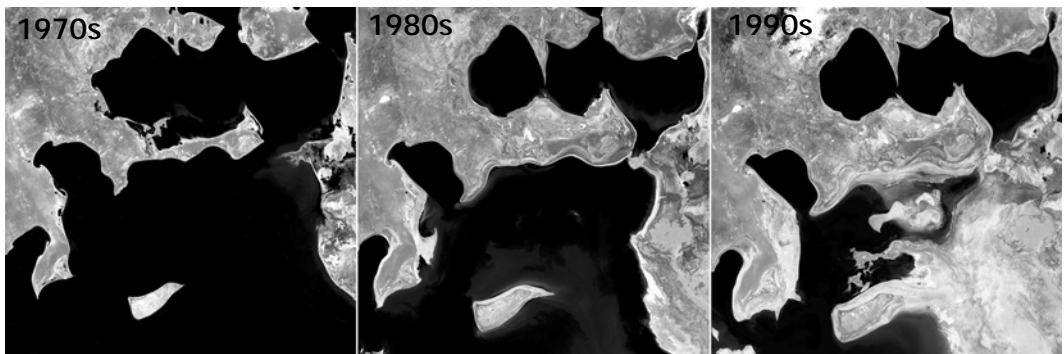


Figure 1-5: The environmental impacts wrought by humans have accelerated in many parts of the world during the past century. These satellite images from the 1970s (left) to 1990s (right) show a shrunken Aral Sea due to the overuse of water. Diversion for irrigation has destroyed a rich fishery, the economic base for many seaside villages. GIS may be used to document change, mitigate damage, and to effectively manage our natural resources (courtesy NASA).

organisms. Effective protection entails mapping the available habitat and analyzing species range and migration patterns. The location of viable remnant populations relative to current and future human land uses must be analyzed, and action taken to ensure species survival. GIS have proven to be useful tools in all of these tasks.

Legislation has spurred the use of GIS in many other endeavors, including the dispensation of emergency services, protection from flooding, disaster assessment and management (Figure 1-6), and the planning and development of infrastructure.

Public organizations have adopted GIS because of legislative mandates, and because GIS aid in governmental functions. For example, emergency service vehicles are regularly dispatched and routed using GIS. Callers to E911 or other emergency response

dispatchers are automatically identified by telephone number, and their address recalled. The GIS software matches this address to the nearest fire, police, or ambulance station. A map or route description is immediately generated by the software, based on information on location and the street network, and sent to the appropriate station with a dispatch alarm.

Many businesses have adopted GIS because they provide increased efficiency in the delivery of goods and services. Retail businesses locate stores based on a number of spatially-related factors. Where are the potential customers? What is the spatial distribution of competing businesses? Where are potential new store locations? What is traffic flow near current stores, and how easy is it to park near and access these stores? Spatial analyses are used every day to answer these questions. GIS are also used in



Figure 1-6: GIS may aid in disaster assessment and recovery. These satellite images from Banda Aceh, Indonesia, illustrate tsunami-caused damage to a shoreline community. Emergency response and longer-term rebuilding efforts may be improved by spatial data collection and analysis (courtesy DigitalGlobe).

hundreds of other business applications, such as to route delivery vehicles, guide advertising, design buildings, plan construction, and sell real estate.

The societal push to adopt GIS has been complemented by a technological pull in the development and application of GIS. Inter-continental mariners were vexed for more than four centuries by their inability to determine their position. Thousands of lives and untold wealth were lost because ship captains could not answer the simple question, “Where am I?” Robust nautical navigation methods eluded the best minds on Earth until the 18th century. Since then there has been a continual improvement in positioning technology to the point where today, anyone can quickly locate their outdoor position to within a few meters. A remarkable positioning technology, known as the global positioning system (GPS), was originally developed primarily for military applications. Because this positioning technology is available, people expect to have access to it. GPS is one of several Global Navigation Satellite Systems (GNSS) now incorporated in cars, planes, boats, and trucks. GNSS are indispensable navigation and spatial data collection tools in government, business, and recreation. GNSS and other GIS-related technologies contribute to commerce, planning, and safety.

The technological pull has developed on several fronts. Spatial analysis in particular has been helped by faster computers with more storage. Most real-world spatial problems were beyond the scope of all but the largest government and business organizations until the 1990s. The requisite computing and storage capabilities were beyond any reasonable budget. GIS computing expenses are becoming an afterthought, as computing resources often cost less than a few months salary for a qualified GIS professional. Costs decrease and performance increases at dizzying rates, with predicted plateaus pushed back each year. Computer capabilities have reached a point that computational limits on most spatial analysis are minor. Powerful field computers are lighter, faster, more



Figure 1-7: Portable computing is one example of the technological pull driving GIS adoption. These hand-held devices substantially improve the speed and accuracy of spatial data collection (courtesy Compaq Computer Corp.).

capable, and less expensive each year, so spatial data display and analysis capabilities may always be at hand (Figure 1-7). GIS on rugged, field-portable computers has been particularly useful in field data entry and editing.

In addition to the computing improvements and the development of GNSS, current “cameras” deliver amazingly detailed aerial and satellite images. Initially, advances in image collection and interpretation were spurred by World War II and then the Cold War because accurate maps were required, but unavailable. Turned toward peacetime endeavors, imaging technologies now help us map food and fodder, houses and highways, and most other natural and human-built objects. Images may be rapidly converted to accurate spatial information over broad areas (Figure 1-8). A broad range of techniques have been developed for

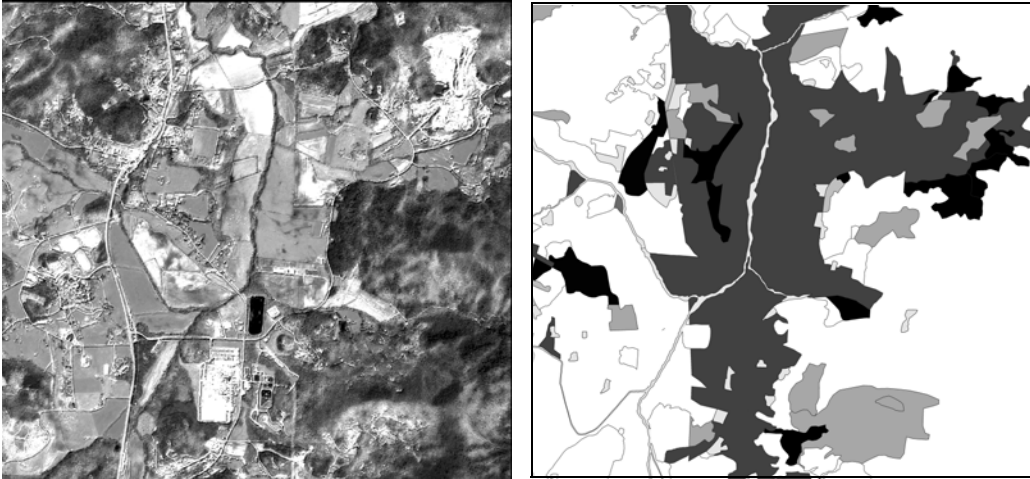


Figure 1-8: Images taken from aircraft and satellites (left) provide a rich source of data, which may be interpreted and converted to information about landcover and other characteristics of the Earth surface (right).

extracting information from image data, and ensuring this information faithfully represents the location, shape, and characteristics of features on the ground. Visible light, laser, thermal, and radar scanners are currently being developed to further increase the speed and accuracy with which we map our world. Thus, advances in these three key technologies -- imaging, GNSS, and computing -- have substantially aided the development of GIS.

GIS in Action

Spatial data organization, analyses, and delivery are widely applied to improve life. Here we describe three examples that demonstrate how GIS are in use.

Marvin Matsumota is alive today because of GIS. The 60 year-old hiker became lost in Joshua Tree National Park, a 300,000 hectare desert landscape famous for its distinct and rugged terrain. Between six and eight hikers become lost there in a typical year, sometimes fatally so. Because of the danger of hypothermia, dehydration, and death, the U.S. National Park Service (NPS) organizes search and rescue operation that

include foot patrols, horseback, vehicle, and helicopter searches (Figure 1-9).

The search and rescue operation for Mr. Matsumota was organized and guided using GIS. Search and rescue teams carried field positioning devices that recorded team location and progress. Position data were downloaded from the field devices to a field GIS center, and frequently updated maps were produced. On-site incident managers used these maps to evaluate areas that had been searched, and to plan subsequent efforts in real time. Accurate maps showed exactly what portions of the park had been searched and by what method. Appropriate teams were tasked to unvisited areas. Ground crews could be assigned to areas that had been searched by helicopters, but contained vegetation or terrain that limited visibility from above. Marvin was found on the fifth day, alive but dehydrated and with an injured skull and back from a fall. The search team was able to radio its precise location to a rescue helicopter. Another day in the field and Marvin likely would have died, a day saved by the effective use of GIS. After a week in the hospital and some months convalescing at home, Marvin made a full recovery.

GIS are also widely used in planning and environmental protection. Oneida County is located in northern Wisconsin, a forested area characterized by exceptional scenic beauty. The County is in a region with among the highest concentrations of freshwater lakes in the world, a region that is also undergoing a rapid expansion in the permanent and seasonal human population. Retirees, urban exiles, and vacationers are increasingly drawn to the scenic and recreational amenities available in Oneida County. Permanent county population grew by nearly 20% from 1990 to 2000, and the seasonal influx almost doubles the total county population each summer.

Population growth has caused a boom in construction and threatened the lakes that draw people to the County. A growing number of building permits are for near-shore houses, hotels, or businesses. Seepage from septic systems, runoff from fertilized lawns,

or erosion and sediment from construction all decrease lake water quality. Increases in lake nutrients or sediment may lead to turbid waters, reducing the beauty and value of the lakes and nearby property.

In response to this problem, Oneida County, the Sea Grant Institute of the University of Wisconsin, and the Land Information and Computer Graphics Facility of the University of Wisconsin have developed a Shoreland Management GIS Project. This project helps protect valuable nearshore and lake resources, and provides an example of how GIS tools are used for water resource management (Figure 1-10).

Oneida County has revised zoning and other ordinances to protect shoreline and lake quality and to ensure compliance without undue burden on landowners. The County uses GIS technology in the maintenance of property records. Property records

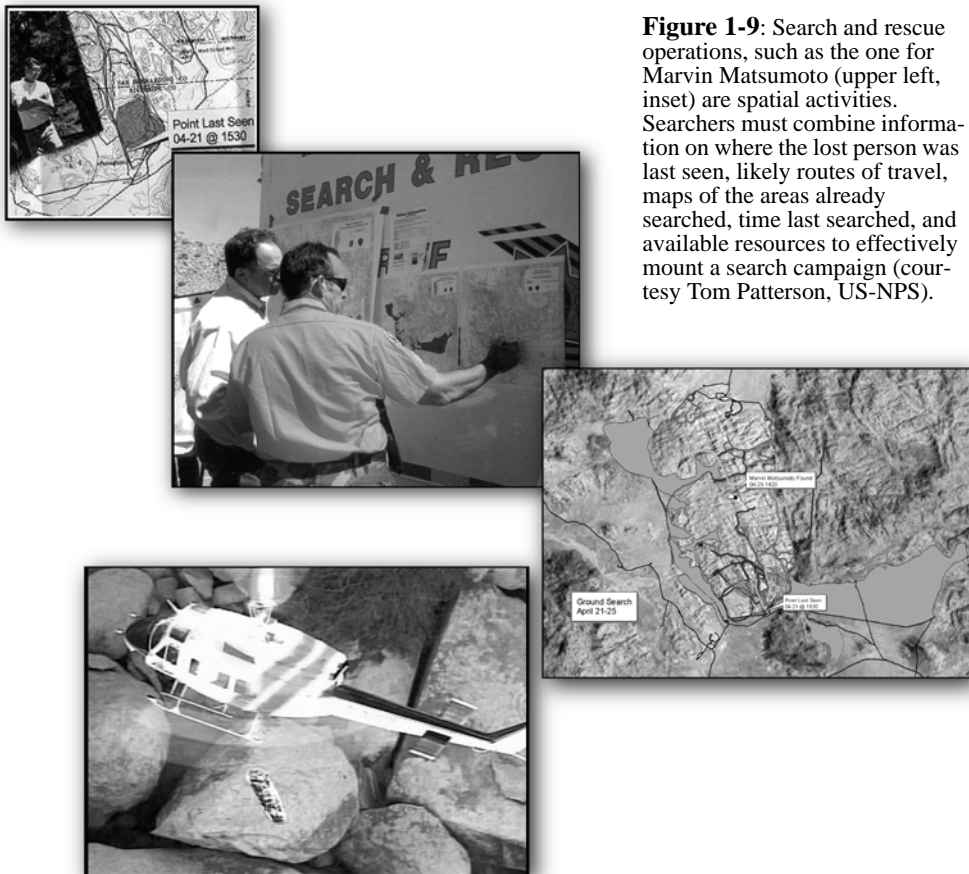


Figure 1-9: Search and rescue operations, such as the one for Marvin Matsumoto (upper left, inset) are spatial activities.

Searchers must combine information on where the lost person was last seen, likely routes of travel, maps of the areas already searched, time last searched, and available resources to effectively mount a search campaign (courtesy Tom Patterson, US-NPS).

include information on the owner, tax value, and any special zoning considerations. The county uses these digital records when creating parcel maps, processing sale, subdivision, or other parcel transactions, and when integrating new data such as aerial or boat-based images to help detect property changes and zoning violations.

GIS may also be used to administer shoreline zoning ordinances, or to notify landowners of routine tasks, such as septic system maintenance. Northern lakes are particularly susceptible to nutrient pollution from near-shore septic systems (Figure 1-11). Frequent, verified maintenance of each septic system is required. A GIS may be used to automatically generate notification of non-compliance. For example, landowners may be required to provide proof of septic systems maintenance every three years. The GIS can automatically identify owners

not in compliance and generate an appropriate notification.

Our third example illustrates how GIS helps save endangered species. The black-footed ferret is a small carnivore of western North America, and is one of the most endangered mammals on the continent (Figure 1-12). The ferret lives in close association with prairie dogs, communally-living rodents once found over much of North America. Ferrets feed on prairie dogs and live in their burrows, and prairie dog colonies provide refuge from coyotes and other larger carnivores that prey on the ferret. The blackfooted ferret has become endangered because of declines in the range and number of prairie dog colonies, coupled with ferret sensitivity to canine distemper and other diseases.

The U.S. Fish and Wildlife Service (USFWS) has been charged with preventing the extinction of the blackfooted ferret. This

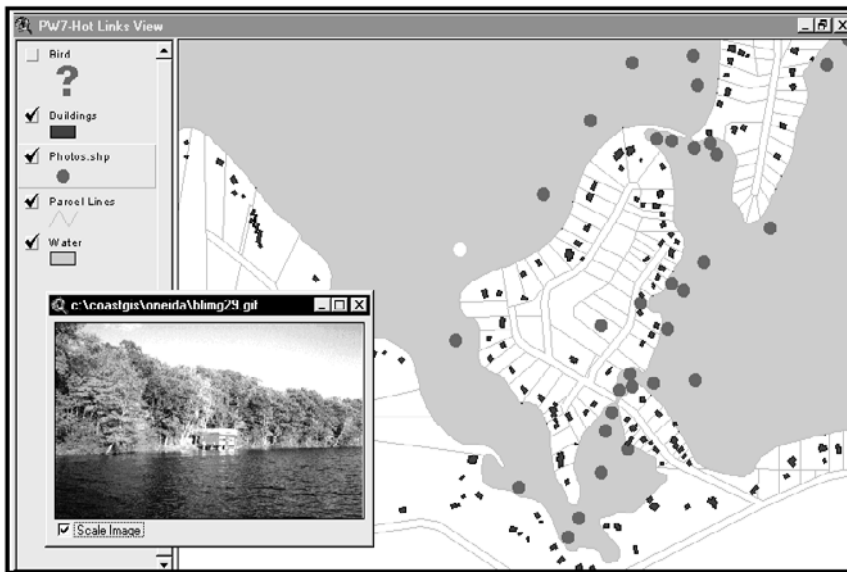


Figure 1-10: Parcel information entered in a GIS may substantially improve the maintenance and evaluation of county government. Here, images of the shoreline taken from lake vantage points are combined with digital maps of the shoreline, buildings, and parcel boundaries. The image in the lower left was obtained from the location shown as a light dot near the center of the figure (courtesy Wisconsin Sea Grant and LICGC).

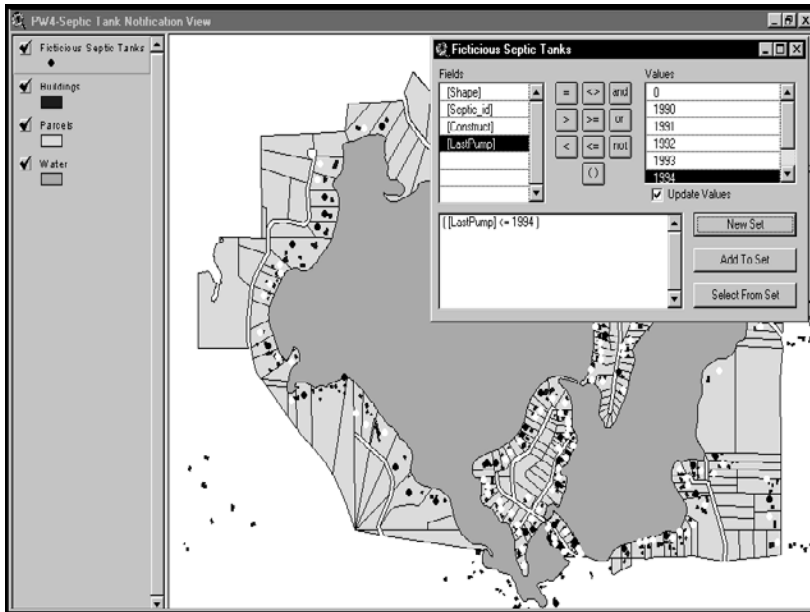


Figure 1-11: GIS may be used to streamline government function. Here, septic systems not compliant with pollution prevention ordinances are identified by white circles (courtesy Wisconsin Sea Grant Institute and LICGC).

entails establishing the number and location of surviving animals, identifying the habitat requirements for a sustainable population, and analyzing what factors are responsible for the decline in ferret numbers, so that a recovery plan may be devised.

Because blackfooted ferrets are nocturnal animals that spend much of their time underground, and because ferrets have always been rare, relatively little was known about their life history, habitat requirements, and the causes of mortality. For example, young ferrets often disperse from their natal prairie dog colonies in search of their own territories. Dispersal is good when it leads to an expansion of the species. However, there are limits on how far a ferret may successfully travel. If the nearest suitable colony is too far away, the dispersing young ferret may likely die of starvation or be eaten by a larger predator. The dispersing ferret may reach a prairie dog colony that is too small to support it. Ferret recovery has been hampered because we don't know when prairie

dog colonies are too far apart, or if a colony is too small to support a breeding pair of ferrets. Because of this lack of spatial knowledge, wildlife managers have had difficulty selecting among a number of activities to enhance ferret survival. These activities include the establishment of new prairie dog colonies, fencing colonies to prevent the entry of larger predators, removing predators, captive breeding, and the capture and transport of young or dispersing animals.

GIS have been used to provide data necessary to save the blackfooted ferret (Figure 1-12). Individual ferrets are tracked in nighttime spotlighting surveys, often in combination with radiotracking devices. Ferret location and movement are combined with detailed data on prairie dog colony boundaries, burrow locations, surrounding vegetation, and other spatial data (Figure 1-13). Individual ferrets can be identified and vital characteristics monitored, including home range size, typical distance travelled, number of offspring, and survival. These data are



Figure 1-12: Specialized equipment is used to collect spatial data. Here a burrow location is recorded using a GPS receiver, as an interested black footed ferret looks on (courtesy Randy Matchett, USFWS).

combined and analyzed in a GIS to improve the likelihood of species recovery.

Geographic Information Science

Although we have defined GIS as geographic information *systems*, there is another GIS: geographic information *science*. The abbreviation GIS is commonly used for the geographic information systems, while GIScience is used to abbreviate the science. The distinction is important, because the future development of GIS depends on progress in GIScience.

GIScience is the theoretical foundation on which GIS are based. GIS research is typically concerned with technical aspects of GIS implementation or application. GIScience includes these technical aspects, but also seeks to redefine concepts in geography and geographic information in the context of the digital age. GIScience is concerned with how we conceptualize geography and how we collect, represent, store, visualize, analyze, use, and present these geographic concepts. The work draws from many fields, including traditional geography, geodesy, remote sensing, surveying, computer science, cartography, mathematics, statistics, cognitive science, and linguistics. GIScience investigates not only technical questions of interest to applied geographers,

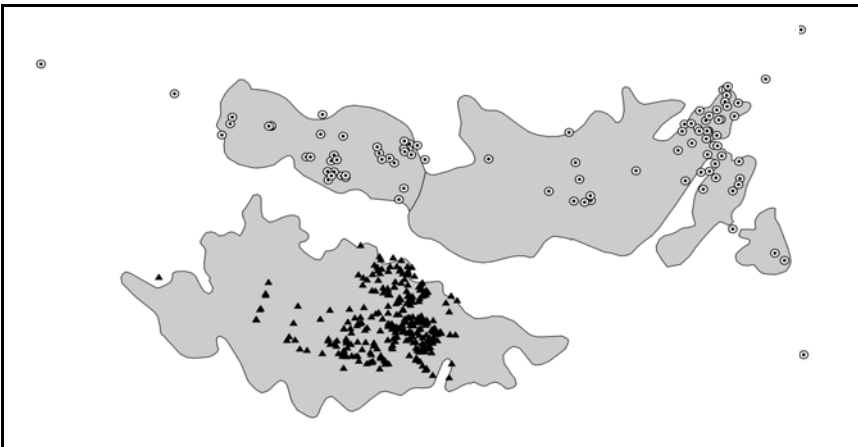


Figure 1-13: Spatial data, such as the boundaries of prairie dog colonies (gray polygons) and individual blackfooted ferret positions (triangle and circle symbols) may be combined to help understand how best to save the blackfooted ferret (courtesy Randy Matchett, USFWS).

business-people, planners, public safety officers, and others, but GIScience is also directed at more basic questions. How do we perceive space? How might we best represent spatial concepts, given the new array of possibilities provided by our advancing technologies? How does human psychology help or hinder effective spatial reasoning?

Science has been described as a handmaiden of technology in the applied world. A more apt analogy is perhaps that science is a parent of technology. GIS, narrowly

defined, is more about technology than science. But since GIS is the tool with which we solve problems, we are mistaken if we consider it as the starting and ending point in geographic reasoning. An understanding of GIScience is crucial to the further development of GIS, and in many cases, crucial to the effective application of GIS. This book focuses primarily on GIS, but provides relevant information related to GIScience as appropriate for an introductory course.

GIS Components

A GIS is comprised of hardware, software, data, humans, and a set of organizational protocols. These components must be well integrated for effective use of GIS, and the development and integration of these components is an iterative, ongoing process. The selection and purchase of hardware and software is often the easiest and quickest step in the development of a GIS. Data collection and organization, personnel development, and the establishment of protocols for GIS use are often more difficult and time-consuming endeavors.

Hardware for GIS

A fast computer, large data storage capacities, and a high-quality, large display form the hardware foundation of most GIS (Figure 1-14). A fast computer is required because spatial analyses are often applied over large areas and/or at high spatial resolutions. Calculations often have to be repeated over tens of millions of times, corresponding to each space we are analyzing in our geographical analysis. Even simple operations may take substantial time on general-purpose computers, and complex operations can

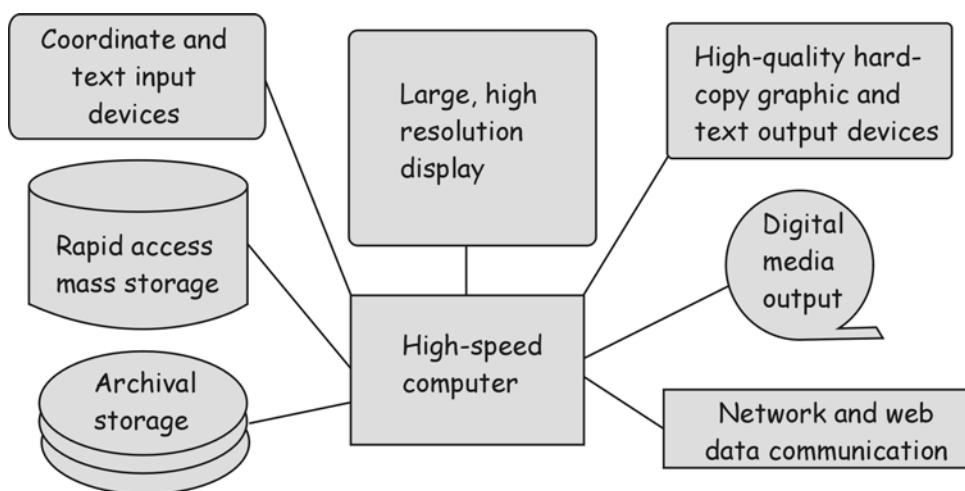


Figure 1-14: GIS are typically used with a number of general-purpose and specialized hardware components.

Data entry

- manual coordinate capture
- attribute capture
- digital coordinate capture
- data import

Editing

- manual point, line and area feature editing
- manual attribute editing
- automated error detection and editing

Data management

- copy, subset, merge data
- versioning
- data registration and projection
- summarization, data reduction
- documentation

Analysis

- spatial query
- attribute query
- interpolation
- connectivity
- proximity and adjacency
- buffering
- terrain analyses
- boundary dissolve
- spatial data overlay
- moving window analyses
- map algebra

Output

- map design and layout
- hardcopy map printing
- digital graphic production
- export format generation
- metadata output
- digital map serving

Figure 1-15: Functions commonly provided by GIS software.

be unbearably long-running. While advances in computing technology during the 1990s have substantially reduced the time required for most spatial analyses, computation times are still unacceptably long for a few applications.

While most computers and other hardware used in GIS are general purpose and adaptable for a wide range of tasks, there are also specialized hardware components that are specifically designed for use with spatial data. While many non-GIS endeavors require the entry of large data volumes, GIS is unique in the volume of data that must be entered to define the shape and location of geographic features, such as roads, rivers, and parcels. Specialized equipment, described in Chapters 4 and 5, has been developed to aid in these data entry tasks.

GIS Software

GIS software provides the tools to manage, analyze, and effectively display and disseminate spatial data and spatial information (Figure 1-15). GIS by necessity involves the collection and manipulation of the coordinates we use to specify location. We also must collect qualitative or quantitative information on the non-spatial attributes of our geographic features of interest. We need tools to view and edit these data, manipulate them to generate and extract the information we require, and produce the materials to communicate the information we have developed. GIS software provides the specific tools for some or all of these tasks.

There are many public domain and commercially available GIS software packages, and many of these packages originated at academic or government-funded research laboratories. The Environmental Systems Research Institute (ESRI) line of products, including ArcGIS, is a good example. Much

of the foundation for early ESRI software was developed during the 1960s and 1970s at Harvard University in the Laboratory of Computer Graphics and Spatial Analysis. Alumni from Harvard carried these concepts with them to Redlands, California when forming ESRI, and included them in their commercial products.

Our description below, while including most of the major or widely used software packages, is not meant to be all-inclusive. There are many additional software tools and packages available, particularly for specialized tasks or subject areas. Appendix B lists sources that may be helpful in identifying the range of software available, and for obtaining detailed descriptions of specific GIS software characteristics and capabilities.

ArcGIS

ArcGIS and its predecessors, ArcView and Arc/Info, are the most popular GIS software suites at the time of this writing. The Arc suite of software has a larger user base and higher annual unit sales than any other competing product. ESRI, the developer of ArcGIS, has a world-wide presence. ESRI has been producing GIS software since the early 1980s, and ArcGIS is its most recent and well-developed integrated GIS package. In addition to software, ESRI also provides substantial training, support, and fee-consultancy services at regional and international offices.

ArcGIS is designed to provide a large set of geoprocessing procedures, from data entry through most forms of hardcopy or digital data output. As such, ArcGIS is a large, complex, sophisticated product. It supports multiple data formats, many data types and structures, and literally thousands of possible operations that may be applied to spatial data. It is not surprising that substantial training is required to master the full capabilities of Arc/Info.

ArcGIS provides wide flexibility in how we conceptualize and model geographic features. Geographers and other GIS-related

scientists have conceived of many ways to think about, structure, and store information about spatial objects. ArcGIS provides for the broadest available selection of these representations. For example, elevation data may be stored in at least four major formats, each with attendant advantages and disadvantages. There is equal flexibility in the methods for spatial data processing. This broad array of choices, while responsible for the large investment in time required for mastery of ArcGIS, provides concomitantly substantial analytical power.

GeoMedia

GeoMedia and the related MGE products are a popular GIS suite. GIS and related products have been developed and supported by Intergraph, Inc. of Huntsville, Alabama, for over 30 years. GeoMedia offers a complete set of data entry, analysis, and output tools. A comprehensive set of editing tools may be purchased, including those for automated data entry and error detection, data development, data fusion, complex analyses, and sophisticated data display and map composition. Scripting languages are available, as are programming tools that allow specific features to be embedded in custom programs, and programming libraries to allow the modification of GeoMedia algorithms for special-purpose software.

GeoMedia is particularly adept at integrating data from divergent sources, formats, and platforms. Intergraph appears to have dedicated substantial effort toward the OpenGIS initiative, a set of standards to facilitate cross-platform and cross-software data sharing. Data in any of the common commercial databases may be integrated with spatial data from many formats. Image, coordinate, and text data may be combined.

GeoMedia also provides a comprehensive set of tools for GIS analyses. Complex spatial analyses may be performed, including queries, for example, to find features in the database that match a set of conditions, and spatial analyses such as proximity or overlap between features. Worldwide web

and mobile phone-based applications and application development are well supported.

MapInfo

MapInfo is a comprehensive set of GIS products developed and sold by the MapInfo Corporation, of Troy, New York. MapInfo products are used in a broad array of endeavors, although use seems to be concentrated in many business and municipal applications. This may be due to the ease with which MapInfo components are incorporated into other applications. Data analysis and display components are supported through a range of higher language functions, allowing them to be easily embedded in other programs. In addition, MapInfo provides a flexible, stand-alone GIS product that may be used to solve many spatial analysis problems.

Specific products have been designed for the integration of mapping into various classes of applications. For example, MapInfo products have been developed for embedding maps and spatial data into wireless handheld devices such as telephones, data loggers, or other portable devices. Products have been developed to support internet mapping applications, and serve spatial data in worldwide web-based environments. Extensions to specific database products such as Oracle are provided.

Idrisi

Idrisi is a GIS system developed by the Graduate School of Geography of Clark University, in Massachusetts. Idrisi differs from the previously discussed GIS software packages in that it provides both image processing and GIS functions. Image data are useful as a source of information in GIS. There are many specialized software packages designed specifically to focus on image data collection, manipulation, and output. Idrisi offers much of this functionality while also providing a large suite of spatial data analysis and display functions.

Idrisi has been developed and maintained at an educational and research institution, and was initially used primarily as a teaching and research tool. Idrisi has adopted a number of very simple data structures, a characteristic that makes the software easy to modify in a teaching environment. Some of these structures, while slow and more space-demanding, are easy to understand and manipulate for the beginning programmer. The space and speed limitation have become less relevant with improved computers. File formats are well documented and data easy to access and modify. The developers of Idrisi have expressly encouraged researchers, students, and users to create new functions for Idrisi. The Idrisi project has then incorporated user-developed enhancements into the software package. Idrisi is an ideal package for teaching students both to use GIS and to develop their own spatial analysis functions.

Idrisi is relatively low cost, perhaps because of its affiliation with an academic institution, and is therefore widely used in education. Low costs are an important factor in many developing countries, where Idrisi has also been widely adopted.

Manifold

Manifold is a relatively inexpensive GIS package with a surprising number of capabilities. Manifold combines GIS and some remote sensing capabilities in a single package. Basic spatial data entry and editing support are provided, as well as projections, basic vector and raster analysis, image display and editing, and output. The program is extensible through a series of software modules. Modules are available for surface analysis, business applications, internet map development and serving, database support, and advanced analyses.

Manifold GIS differs from other packages in providing sophisticated image editing capabilities in a spatially-referenced framework. Portions of images and maps may be cut and pasted into other maps while maintaining proper geographic alignment.

Transparency, color-based selection, and other capabilities common to image editing programs are included in Manifold GIS.

AUTOCAD MAP

AUTOCAD is the world's largest-selling computer drafting and design package. Produced by Autodesk, Inc., of San Rafael, California, AUTOCAD began as an engineering drawing and printing tool. A broad range of engineering disciplines are supported, including surveying and civil engineering. Surveyors have traditionally developed and maintained the coordinates for property boundaries, and these are among the most important and often-used spatial data. AUTOCAD MAP adds substantial analytical capability to the already complete set of data input, coordinate manipulation, and data output tools provided by AUTOCAD.

The latest version, AUTOCAD MAP 3D, provides a substantial set of spatial data analysis capability. Data may be entered, verified, and output. Data may also be searched for features with particular conditions or characteristics. More sophisticated spatial analysis may be performed, including path finding or data combination. AUTOCAD MAP 3D incorporates many of the specialized analysis capabilities of other, older GIS packages, and is a good example of the convergence of GIS software from a number of disciplines.

GRASS

GRASS, the Geographic Resource Analysis Support System, is a free, open source GIS that runs on many platforms. The system was originally developed by the U.S. Army Construction Engineering Laboratory (CERL), starting in the early 1980s, when much GIS software was limited in access and applications. CERL followed an open approach to development and distribution, leading to substantial contributions by a number of university and other government labs. Development was discontinued in the

military, and taken up by an open source "GRASS Development Team", a self-identified group of people donating their time to maintain and enhance GRASS. The software provides a broad array of raster and vector operations, and is used in both research and applications worldwide. Detailed information and the downloadable software are available at <http://grass.itc.it/index.php>.

MicroImages

MicroImages produces TNTmips, an integrated remote sensing, GIS, and CAD software package. MicroImages also produces and supports a range of other related products, including software to edit and view spatial data, software to create digital atlases, and software to publish and serve data on the internet.

TNTmips is notable both for its breadth of tools and the range of hardware platforms supported in a uniform manner. MicroImages recompiles a basic set of code for each platform so that the look, feel, and functionality is nearly identical irrespective of the hardware platform used. Image processing, spatial data analysis, and image, map, and data output are supported uniformly across this range.

TNTmips provides an impressive array of spatial data development and analysis tools. Common image processing tools are available, including ingest of a broad number of formats, image registration and mosaics, reprojection, error removal, subsetting, combination, and image classification. Vector analyses are supported, including support for point, line, and area features, multi-layer combination, viewshed, proximity, and network analyses. Extensive online documentation is available, and the software is supported by an international network of dealers.

ERDAS

ERDAS (Earth Resources Data Analysis System), now owned and developed by Leica Geosystems, began as an image pro-

cessing system. The original purpose of the software was to enter and analyze satellite image data. ERDAS led a wave of commercial products for analyzing spatial data collected over large areas. Product development was spurred by the successful launch of the U.S. Landsat satellite in the 1970s. For the first time, digital images of the entire Earth surface were available to the public.

The ERDAS image processing software evolved to include other types of imagery, and to include a comprehensive set of tools for cell-based data analysis. Image data are supplied in a cell-based format. Cell-based analysis is a major focus of sections in three chapters of this book, so there will be much more discussion in later pages. For now, it is important to note that the “checkerboard” format used for image data may also be used to store and manipulate other spatial data. It is relatively easy and quite useful to develop cell-based spatial analysis tools to complement the image processing tools.

ERDAS and most other image processing packages provide data output formats that are compatible with most common GIS packages. Many image processing software systems are purchased explicitly to provide data for a GIS. The support of ESRI data formats is particularly thorough in ERDAS. ERDAS GIS components can be used to analyze these spatial data.

This review of spatial data collection and analysis software is in no way exhaustive. There are many other software tools available, many of which provide unique, novel, or particularly clever combinations of geoprocessing functions. GRASS, PCI, and ENVI are just a few of the available software packages with spatial data development or analysis capabilities. In addition, there are thousands of add-ons, special purpose tools, or specific modules that complement these products. Websites listed in Appendix B at the end of this book will provide more information on these and other GIS software products.

GIS in Organizations

Although new users often focus on GIS hardware and software components, we must recognize that GIS exist in an institutional context. Effective use of GIS requires an organization to support various GIS activities. Most GIS also require trained people to use them, and a set of protocols guiding how the GIS will be used. The institutional context determines what spatial data are important, how these data will be collected and used, and ensures that the results of GIS analyses are properly interpreted and applied. GIS share a common characteristic of many powerful technologies. If not properly used, the technology may lead to a significant waste of resources, and may do more harm than good. The proper institutional resources are required for GIS to provide all its potential benefits.

GIS are often employed as decision support tools (Figure 1-16). Data are collected,

entered, and organized into a spatial database, and analyses performed to help make specific decisions. The results of spatial analyses in a GIS often uncover the need for more data, and there are often several iterations through the collection, organization, analysis, output, and assessment steps before a final decision is reached. It is important to recognize the organizational structure within which the GIS will operate, and how GIS will be integrated into the decision-making processes of the organization.

One important question that must be answered early is “what problem(s) are we to solve with the GIS?” GIS add significant analytical power through the ability to measure distances and areas, identify vicinity, analyze networks, and through the overlay and combination of different information. Unfortunately, spatial data development is often expensive, and effective GIS use

requires specialized knowledge or training, so there is often considerable expense in constructing and operating a GIS. Before spending this time and money there must be a clear identification of the new questions that may be answered, or the process, product, or service that will be improved, made more efficient, or less expensive through the use of GIS. Once the ends are identified, an organization may determine the level of investment in GIS that is warranted.

Summary

GIS are computer-based systems that aid in the development and use of spatial data. There are many reasons we use GIS, but most are based on a societal push, our need

to more effectively and efficiently use our resources, and a technological pull, our interest in applying new tools to previously insoluble problems. GIS as a technology is based on geographic information science, and is supported by the disciplines of geography, surveying, engineering, space science, computer science, cartography, statistics, and a number of others.

GIS are comprised of both hardware and software components. Because of the large volumes of spatial data and the need to input coordinate values, GIS hardware often have large storage capacities, fast computing speed, and ability to capture coordinates. Software for GIS are unique in their ability to manipulate coordinates and associated attribute data. A number of software tools

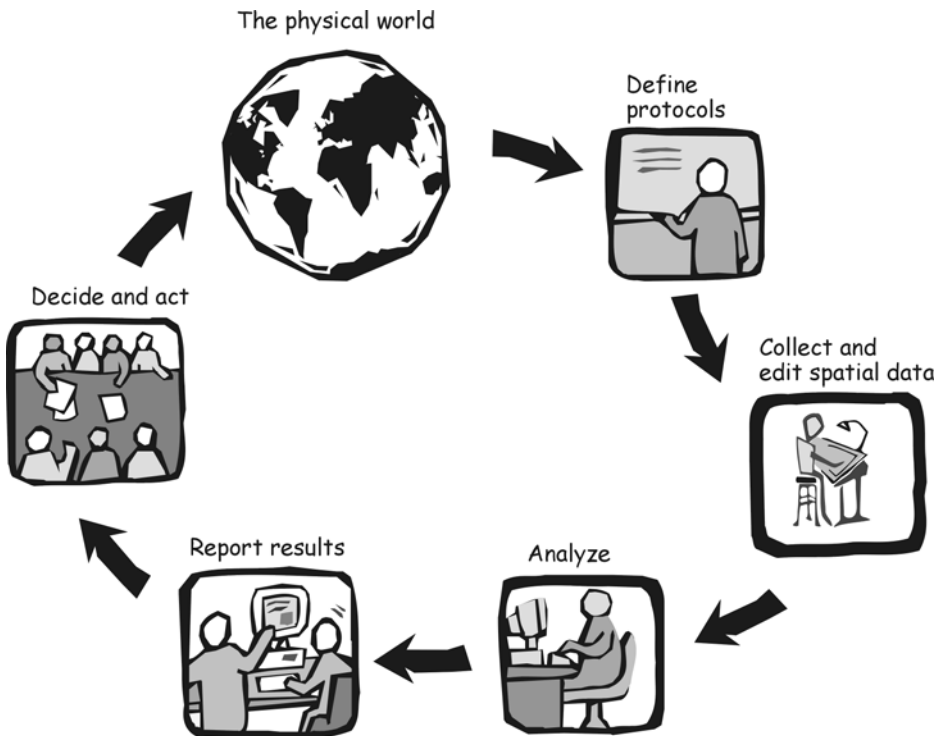


Figure 1-16: GIS exist in an institutional context. Effective use of GIS depends on a set of protocols and an integration into the data collection, analysis, decision, and action loop of an organization.

and packages are available to help us develop GIS.

While GIS are defined as tools for use with spatial data, we must stress the importance of the institutional context in which GIS fit. Because GIS are most often used as decision-support tools, the effective use of GIS requires more than the purchase of hardware and software. Trained personnel and protocols for use are required if GIS are to be properly applied. GIS may then be incorporated in the question-collect-analyze-decide loop when solving problems.

The Structure of This Book

This book is designed to serve a semester-long, 15-week course in GIS at the university level. We seek to provide the relevant information to create a strong basic foundation on which to build an understanding of GIS. Because of the breadth and number of topics covered, students may be helped by knowledge of how this book is organized. Chapter 1 (this chapter), sets the stage, providing some motivation and a background for GIS. Chapter 2 describes basic data representations. It treats the main ways we use computers to represent perceptions of geography, common data structures, and how these structures are organized. Chapter 3 provides a basic description of coordinates and coordinate systems, how coordinates are defined and measured on the surface of the Earth, and conventions for converting these measurements to coordinates we use in a GIS.

Chapters 4 through 7 treat spatial data collection and entry. Data collection is often a substantial task and comprises one of the main activities of most GIS organizations. General data collection methods and equipment are described in Chapter 4. Chapter 5 describes Global Navigation Satellite Systems (GNSS), a relatively new technology for coordinate data collection. Chapter 6

describes aerial and space-based images as a source of spatial data. Most historical and contemporary maps depend in some way on image data, and this chapter provides a background on how these data are collected and used to create spatial data. Chapter 7 provides a brief description of common digital data sources available in the United States, their formats, and uses.

Chapters 8 through 13 treat the analysis of spatial data. Chapter 8 focuses on attribute data, attribute tables, database design, and analyses using attribute data. Attributes are half our spatial data, and a clear understanding of how we structure and use them is key to effective spatial reasoning. Chapters 9, 10, 11, and 12 describe basic spatial analyses, including adjacency, inclusion, overlay, and data combination for the main data models used in GIS. They also describe more complex spatio-temporal models. Chapter 13 describes various methods for spatial prediction and interpolation. We typically find it impractical or inefficient to collect “wall-to-wall” spatial and attribute data. Spatial prediction allows us to extend our sampling and provide information for unsampled locations. Chapter 14 describes how we assess and document spatial data quality, while Chapter 15 provides some musings on current conditions and future trends.

We give preference to the International System of Units (SI) throughout this book. The SI system is adopted by most of the world, and is used to specify distances and locations in the most common global coordinate systems and by most spatial data collection devices. However, some English units are culturally embedded, for example, the survey foot, or 640 acres to a Public Land Survey Section, and so these are not converted. Because a large portion of the target audience for this book is in the United States, English units of measure often supplement SI units.

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Exercises

1.1 - Why are we more interested in spatial data today than 100 years ago?

1.2 - You have probably collected, analyzed, or communicated spatial data in one way or another during the past month. Describe each of these steps for a specific application you have used or observed.

1.3 - How are GIS software different from most other software?

1.4 - Describe the ways in which are GIS hardware different from other computer hardware?

1.5 - What are the limitations of using a GIS? Under what conditions might the technology hinder problem solving, rather than help?

1.6 - Are paper maps and paper data sheets a GIS? Why or why not?

