1.3 Geographic Information Systems for Today and Beyond

LEARNING OBJECTIVE

1. The objective of this section is to define and describe how a geographic information system (GIS) is applied, its development, and its future.

Up to this point, the primary concern of this chapter was to introduce concepts essential to geography that are also relevant to geographic information systems (GISs). Furthermore, the introduction of these concepts was prefaced by an overview of how we think spatially and the nature of geographic inquiry. This final section is concerned with defining a GIS, describing its use, and exploring its future.

GIS Defined

So what exactly is a GIS? Is it computer software? Is it a collection of computer hardware? Is it a service that is distributed and accessed via the Internet? Is it a tool? Is it a system? Is it a science? The answer to all these questions is, "GIS is all of the above—and more."

From a software perspective, a GIS consists of a special type of computer program capable of storing, editing, processing, and presenting geographic data and information as maps. There are several GIS software providers, such as Environmental Systems Research Institute Inc. (http://www.esri.com), which distributes ArcGIS, and PitneyBowes (http://www.pbinsight.com), which distributes MapInfo GIS. Though online mapping services and interfaces are provided by companies like Google, Yahoo!, and Microsoft, such services are not (yet) considered fully fledged GIS platforms. There are also open-source GIS options, such as GRASS (http://grass.itc.it), which is freely distributed and maintained by the open-source community. All GIS software, regardless of vendor, consists of a database management system that is capable of handling and integrating two types of data: spatial data and attribute data.

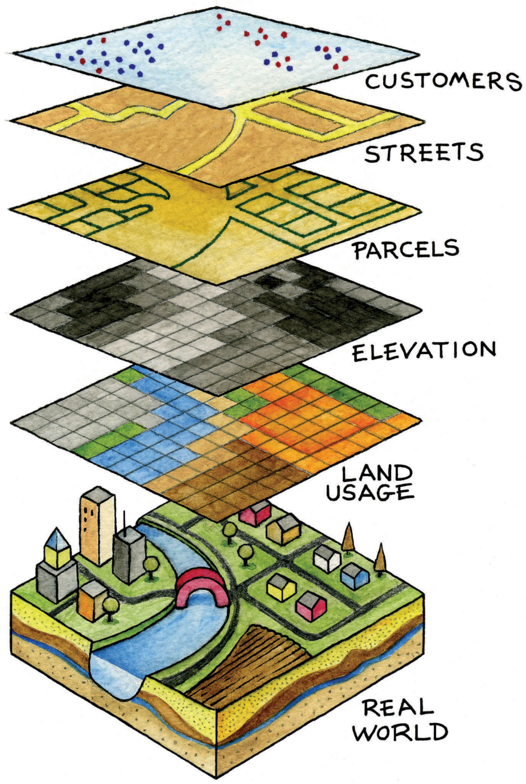
Spatial data[14] refer to the real-world geographic objects of interest, such as streets, buildings, lakes, and countries, and their respective locations. In addition to location, each of these objects also possesses certain traits of interest, or **attributes**[15], such as a name, number of stories, depth, or population. GIS software keeps track of both the spatial and attribute data and permits us to link the two types of data together to create information and facilitate analysis. One popular

14. Facts about the location and position of phenomena on the earth's surface.

15. The characteristics and qualities of features and phenomena located on the surface of the earth.

way to describe and to visualize a GIS is picturing it as a cake with many layers. Each layer of the cake represents a different geographic theme, such as water features, buildings, and roads, and each layer is stacked one on top of another (see Figure 1.8 "A GIS as a Layered Cake").

Figure 1.8 *A GIS as a Layered Cake*



As hardware, a GIS consists of a computer, memory, storage devices, scanners, printers, global positioning system (GPS) units, and other physical components. If the computer is situated on a network, the network can also be considered an integral component of the GIS because it enables us to share data and information that the GIS uses as inputs and creates as outputs.

As a tool, a GIS permits us to maintain, analyze, and share a wealth of data and information. From the relatively simple task of mapping the path of a hurricane to the more complex task of determining the most efficient garbage collection routes in a city, a GIS is used across the public and private sectors. Online and mobile mapping, navigation, and location-based services are also personalizing and democratizing GISs by bringing maps and mapping to the masses.

These are just a few definitions of a GIS. Like several of the geographic concepts discussed previously, there is no single or universally accepted definition of a GIS. There are probably just as many definitions of GISs as there are people who use GISs. In this regard, it is the people like you who are learning, applying, developing, and studying GISs in new and compelling ways that unifies it.

Three Approaches to GISs

In addition to recognizing the many definitions of a GIS, it is also constructive to identify three general and overlapping approaches to understanding GISs—the application approach, the developer approach, and the science approach. Though most GIS users would probably identify with one approach more than another, they are not mutually exclusive. Moreover, as GISs and, more generally, information technology advance, the following categories will be transformed and reshaped accordingly.

The application approach to GISs considers a GIS primarily to be a tool. This is also perhaps the most common view of a GIS. From this perspective, a GIS is used to answer questions, support decision making, maintain an inventory of geographic data and information, and, of course, make maps. As a tool, there are arguably certain skills that should be acquired and required in order to use and apply a GIS properly. The application approach to a GIS is more concerned with using and applying GISs to solve problems than the GIS itself.

For instance, suppose we want to determine the best location for a new supermarket. What factors are important behind making this decision? Information about neighborhood demographics, existing supermarkets, the location of suppliers, zoning regulations, and available real estate are all critical to this decision. A GIS platform can integrate such information that is obtained from the census bureau, realtors, the local zoning agency, and even the Internet. A suitability analysis can then be carried out with the GIS, the output of which will show the best locations for the supermarket given the various local geographic opportunities (e.g., demographics/consumers) and constraints (e.g., supply chain, zoning, and real estate limitations) that exist.

There are several professional communities and organizations concerned with the use and application of a GIS, such as the Urban and Regional Information Systems Association (http://urisa.org) and the Global Spatial Data Infrastructure Association (http://www.gsdi.org).

Unlike the previous example in which a GIS is applied to answer or solve a particular question, the developer approach to GISs is concerned with the development of the GIS as a software or technology platform. Rather than focusing on how a GIS is used and applied, the developer approach is concerned with improving, refining, and extending the tool and technology itself and is largely in the realm of computer programmers and software developers.

The ongoing integration and evolution of GISs, maps, the Internet, and web-based mapping can be considered an outcome of the developer approach to GISs. In this regard, delivering maps, navigation tools, and user-friendly GISs to people via the Internet is the central challenge at hand. The underlying, and to a large extent hidden, logic and computer code that permit us to ask questions about how to get from point A to point B on a navigation website or to see where a new restaurant or open house is located on a web-based map are for the most part the domain of GIS programmers and developers. The Open Source Geospatial Foundation (http://www.osgeo.org) is another example of a community of GIS developers working to build and distribute open-source GIS software.

It is the developer approach to GISs that drives and introduces innovation and is informed and guided by the existing needs and future demands of the application approach. As such, it is indeed on the cutting edge, it is dynamic, and it represents an area for considerable growth in the future.

The science approach to GISs not only dovetails with the applications and developer approaches but also is more concerned with broader questions and how geography, cognition, map interpretation, and other geospatial issues such as accuracy and errors are relevant to GISs and vice versa (see Longley et al. 2005).Longley, P., M. Goodchild, D. Maguire, and D. Rhind. 2005. *Geographic Information Systems and Science*. 2nd ed. West Sussex, England: John Wiley. This particular approach is often referred to as **geographic information science (GIScience)**[16], and it is also interested in the social consequences and implications of the use and diffusion of GIS technology. From exploring the propagation of error to examining how privacy is being redefined by GISs and related technology, GIScience is at the same time an agent of change as well as one of understanding.

In light of the rapid rate of technological and GIS innovation, in conjunction with the widespread application of GISs, new questions about GIS technology and its use are continually emerging. One of the most discussed topics concerns privacy, and in particular, what is referred to as locational privacy. In other words, who has the right to view or determine your geographic location at any given time? Your parents? Your school? Your employer? Your cell phone carrier? The government or police? When are you willing to divulge your location? Is there a time or place where you prefer to be "off the grid" or not locatable? Such questions concerning locational privacy were of relatively little concern a few years ago. However, with

16. The academic field that is concerned with advancing knowledge about geographic information.

the advent of GPS and its integration into cars and other mobile devices, questions, debates, and even lawsuits concerning locational privacy and who has the right to such information are rapidly emerging.

As the name suggests, the developer approach to GISs is concerned with the development of GISs. Rather than focusing on how a GIS is used and applied, the developer approach is concerned with improving, refining, and extending the tool itself and is largely in the realm of computer programmers and software developers. For instance, the advent of web-based mapping is an outcome of the developer approach to GISs. In this regard, the challenge was how to bring GISs to people via the Internet and not necessarily how people would use web-based GISs. The developer approach to GISs drives and introduces innovation and is guided by the needs of the application approach. As such, it is indeed on the cutting edge, it is dynamic, and it represents an area for considerable growth in the future.

GIS Futures

The definitions and approaches to GISs described previously illustrate the scope and breadth of this special type of information technology. Furthermore, as GISs become more accessible and widely distributed, there will always be new questions to be answered, new applications to be developed, and innovative technologies to integrate.

One notable development is the emergence of what is called the geospatial web. The geospatial web or geoweb refers to the integration of the vast amounts of content available on the Internet (e.g., text, photographs, video, and music) with geographic information, such as location. Adding such geographic information to such content is called geotagging and is similar to geocoding. The integration of geographic information with such content opens up new ways to access, search, organize, share, and distribute information.

Mapping mashups, or web-based applications that combine data and information from one source and map it with online mapping applications, are an example of the geoweb at work. There are mashups for nearly everything that can be assigned a location, from restaurants and music festivals to your photographs and favorite hikes. Several examples of such mapping mashups can be found on the Internet at sites such as http://googlemapsmania.blogspot.com.

Though the geoweb may not necessarily be considered a GIS, it certainly draws upon the same concepts and ideas of geography and may someday encompass GISs. Perhaps more important, the diffusion of GISs and the emergence of the geoweb have increased geographic awareness by lowering the barriers of viewing, using, and even creating maps and related geographic data and information. Though there are several benefits to this democratization of GISs, and more generally information and technology, it should also be recognized that there are also consequences and implications.

As with any other technology, great care must be taken in the use and application of GISs. For instance, when was the last time you questioned what appeared on a map? For better or worse, maps are among the most authoritative forms of information and are the subject of Chapter 2 "Map Anatomy". As tomorrow's GIS practitioners, you will have the ability to influence greatly how decisions are made and how others view and relate to the world with the maps that you create in a GIS environment. What and how you choose to map is therefore a nontrivial exercise. Becoming more aware of our biases, limitations, and preferences permits us to take full advantage of geographic information systems with confidence.

KEY TAKEAWAYS

- There is no single or universal definition of a GIS; it is defined and used in many different ways.
- One of the key features of a GIS is that it integrates spatial data with attribute data.

EXERCISES

1. Explore the web for mapping mashups that match your personal interests. How can they be improved?
2. Create your own mapping mashup with a free online mapping service.

Chapter 2

Map Anatomy

Maps and mapping are essential components of any and all geographic information systems (GISs). For instance, maps constitute both the input and output of a GIS. Hence a GIS utilizes many concepts and themes from **cartography**[1], the formal study of maps and mapping. Therefore, in order for us to become proficient with GISs, we need to learn more about cartography, maps, and mapping. The first part of this chapter defines what a map is and describes a few key map types. Next, cartographic or mapping conventions are discussed with particular emphasis placed upon map scale, coordinate systems, and map projections. The chapter concludes with a discussion of the process of map abstraction as it relates to GISs. This chapter provides the foundations for working with, integrating, and making maps with GISs.

1. The formal study of maps, mapping and map making.

2.1 Maps and Map Types

LEARNING OBJECTIVE

1. The objective of this section is to define what a map is and to describe reference, thematic, and dynamic maps.

Maps are among the most compelling forms of information for several reasons. Maps are artistic. Maps are scientific. Maps preserve history. Maps clarify. Maps reveal the invisible. Maps inform the future. Regardless of the reason, maps capture the imagination of people around the world. As one of the most trusted forms of information, map makers and geographic information system (GIS) practitioners hold a considerable amount of power and influence (Wood 1992; Monmonier 1996).Wood, D. 1992. *The Power of Maps*. New York: Guilford.' Monmonier, M. 1996. *How to Lie with Maps*. Chicago: University of Chicago Press. Therefore, understanding and appreciating maps and how maps convey information are important aspects of GISs. The appreciation of maps begins with exploring various map types.

So what exactly is a map? Like GISs, there are probably just as many definitions of maps as there are people who use and make them (see Muehrcke and Muehrcke 1998).Muehrcke, P., and J. Muehrcke. 1998. *Map Use*. Madison, WI: JP Publications. For starters, we can define a map simply as a representation of the world. Such maps can be stored in our brain (i.e., mental maps), they can be printed on paper, or they can appear online. Notwithstanding the actual medium of the map (e.g., our fleeting thoughts, paper, or digital display), maps represent and describe various aspects of the world. For purposes of clarity, the three types of maps are the reference map, the thematic map, and the dynamic map.

Reference Maps

The primary purpose of a **reference map**[2] is to deliver location information to the map user. Geographic features and map elements on a reference map tend to be treated and represented equally. In other words, no single aspect of a reference map takes precedent over any other aspect. Moreover, reference maps generally represent geographic reality accurately. Examples of some common types of reference maps include topographic maps such as those created by the United States Geological Survey (USGS; see http://topomaps.usgs.gov) and image maps obtained from satellites or aircraft that are available through online mapping services.

2. The family of maps that are used to locate features on the surface of the earth.

Figure 2.1 *USGS Topographic Map of Boulder, CO*

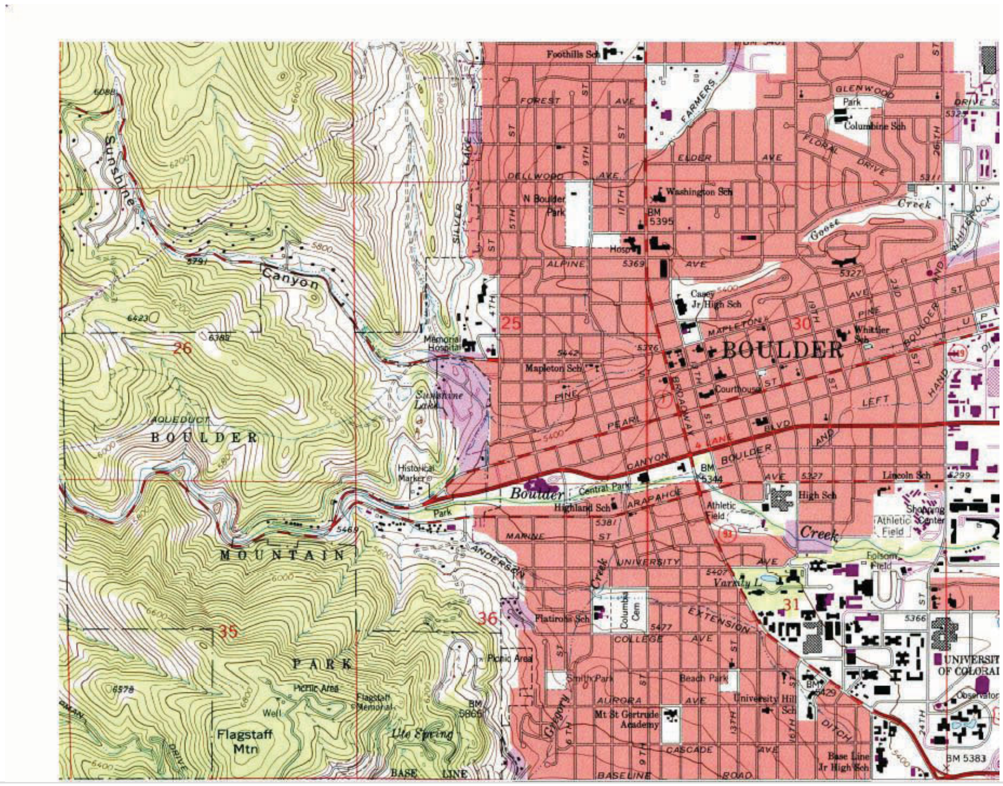


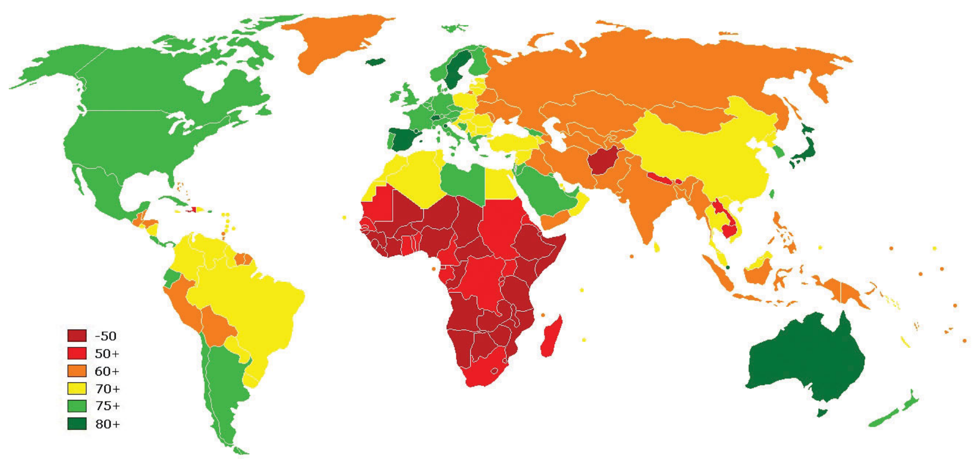
Figure 2.2 *Image Map of Palm Island, Dubai, from NASA*

The accuracy of a given reference map is indeed critical to many users. For instance, local governments need accurate reference maps for land use, zoning, and tax purposes. National governments need accurate reference maps for political, infrastructure, and military purposes. People who depend on navigation devices like global positioning system (GPS) units also need accurate and up-to-date reference maps in order to arrive at their desired destinations.

Thematic Maps

Contrasting the reference map are thematic maps. As the name suggests, **thematic maps**[3] are concerned with a particular theme or topic of interest. While reference maps emphasize the location of geographic features, thematic maps are more concerned with how things are distributed across space. Such things are often abstract concepts such as life expectancy around the world, per capita gross domestic product (GDP) in Europe, or literacy rates across India. One of the strengths of mapping, and in particular of thematic mapping, is that it can make such abstract and invisible concepts visible and comparable on a map.

Figure 2.3 *World Life Expectancies*



3. The family of maps that are about a particular topic or theme.

Figure 2.4 European GDP

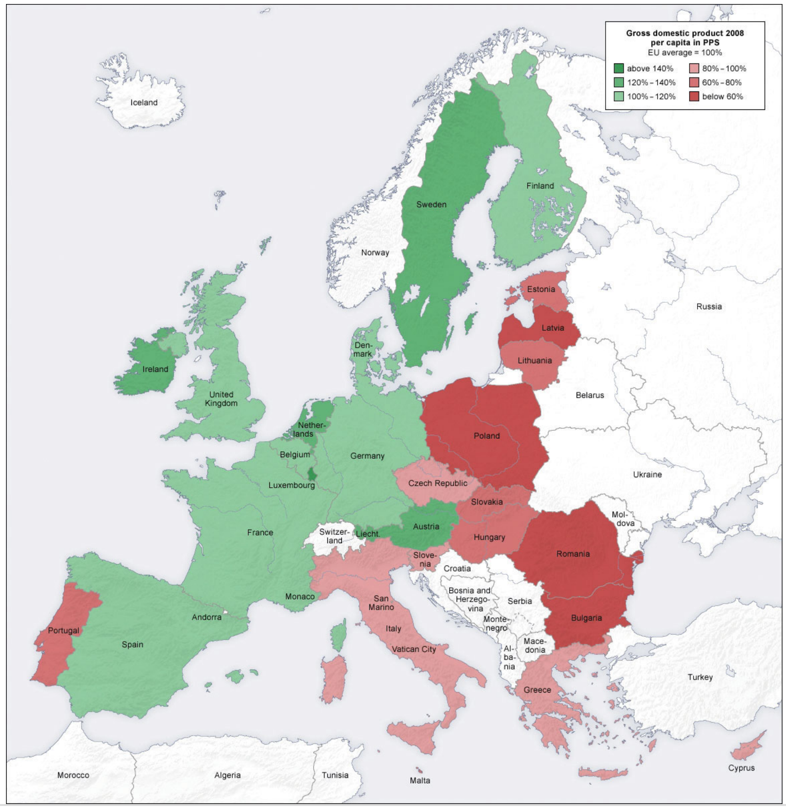
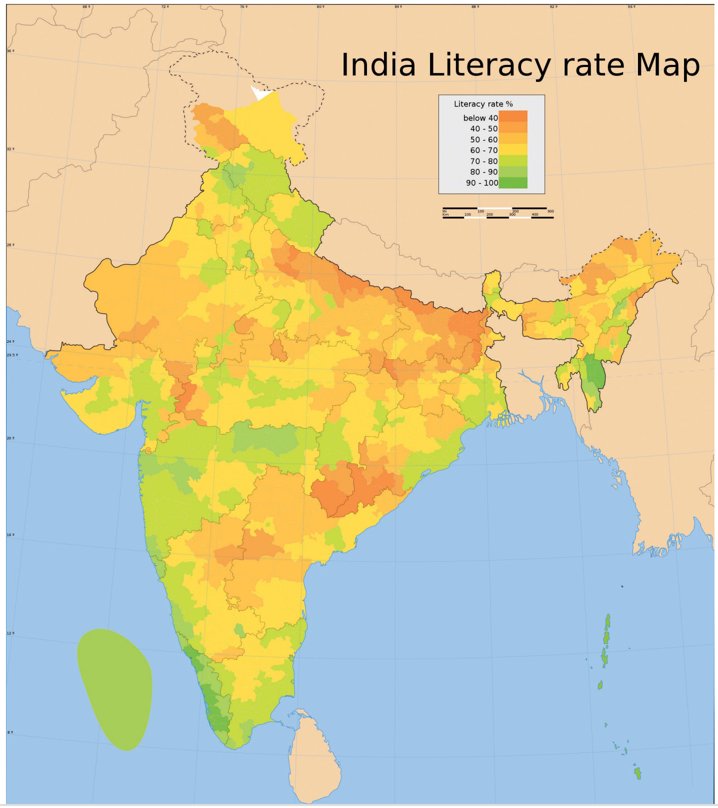


Figure 2.5 Indian Literacy Rates



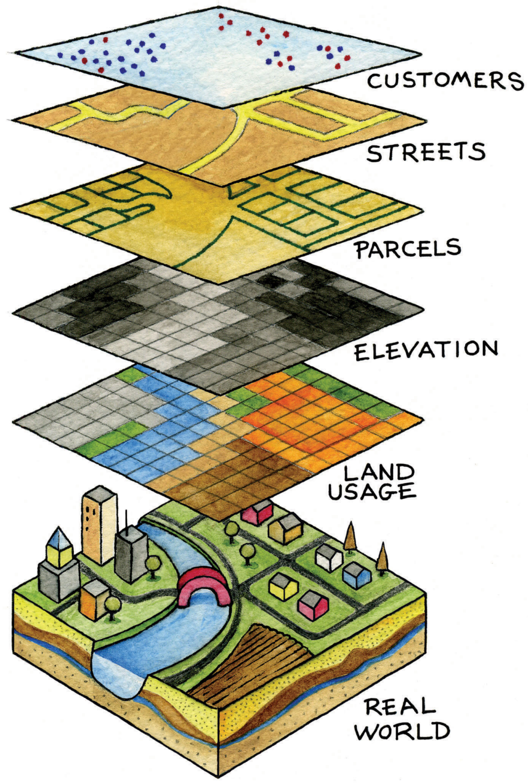
It is important to note that reference and thematic maps are not mutually exclusive. In other words, thematic maps often contain and combine geographical reference information, and conversely, reference maps may contain thematic information. What is more, when used in conjunction, thematic and reference maps often complement each other.

For example, public health officials in a city may be interested in providing equal access to emergency rooms to the city's residents. Insights into this and related questions can be obtained through visual comparisons of a reference map that shows the locations of emergency rooms across the city to thematic maps of various segments of the population (e.g., households below poverty, percent elderly, underrepresented groups).

Within the context of a GIS, we can **overlay**[4] the reference map of emergency rooms directly on top of the population maps to see whether or not access is uniform across neighborhood types. Clearly, there are other factors to consider when looking at emergency room access (e.g., access to transport), but through such map overlays, underserved neighborhoods can be identified.

4. The process of integrating two or more map layers on the same map.

Figure 2.6 Map Overlay Process



When presented in hardcopy format, both reference and thematic maps are static or fixed representations of reality. Such permanence on the page suggests that geography and the things that we map are also in many ways fixed or constant. This is far from reality. The integration of GISs with other forms of information technology like the Internet and mobile telecommunications is rapidly changing this view of maps and mapping, as well as geography at large.

Dynamic Maps

The diffusion of GISs and the popularity of online mapping tools and applications speak to this shift in thinking about maps and map use. In this regard, it is worthwhile to discuss the diffusion of dynamic maps. **Dynamic maps**[5] are simply changeable or interactive representations of the earth. Dynamic mapping refers more to how maps are used and delivered to the map user today (e.g., online, via mobile phone) than to the content of the map itself. Both reference and thematic maps can be dynamic in nature, and such maps are an integral component to any GIS. The key point about dynamic maps is that more and more people, not just GIS professionals, have access to such maps.

5. Interactive and changeable representations of the earth and its resident phenomena.

Unlike a hardcopy map that has features and elements users cannot modify or change, dynamic maps encourage and sometimes require user interaction. Such interaction can include changing the scale or visible area by zooming in or zooming out, selecting which features or layers to include or to remove from a map (e.g., roads, imagery), or even starting and stopping a map animation.

Figure 2.7 *Google Maps on an iPhone*

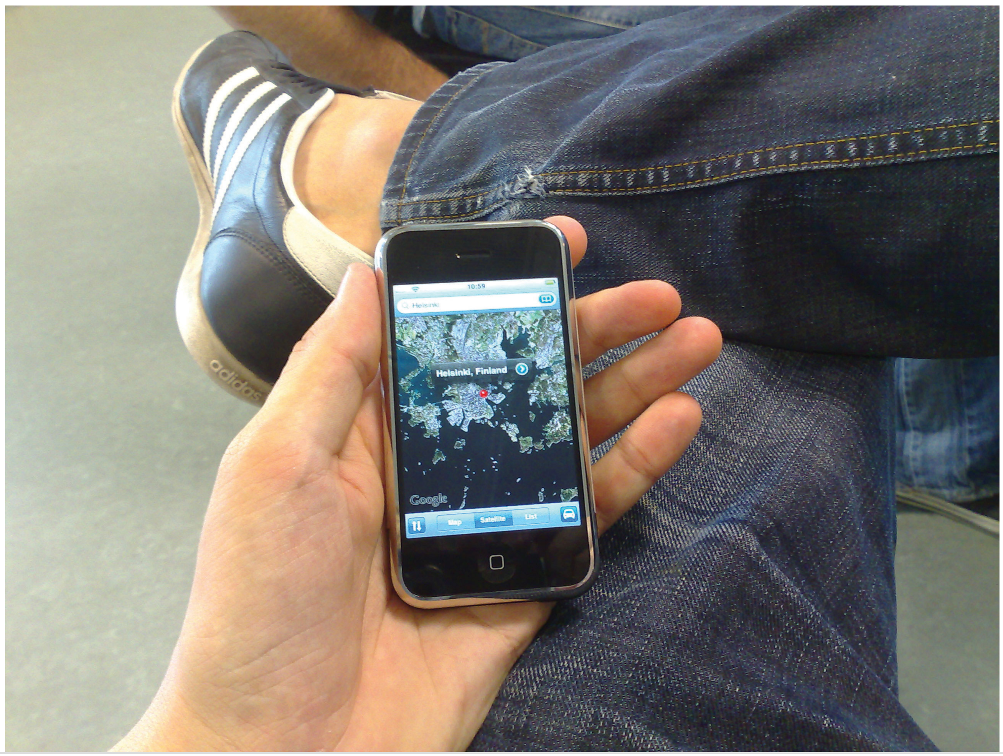
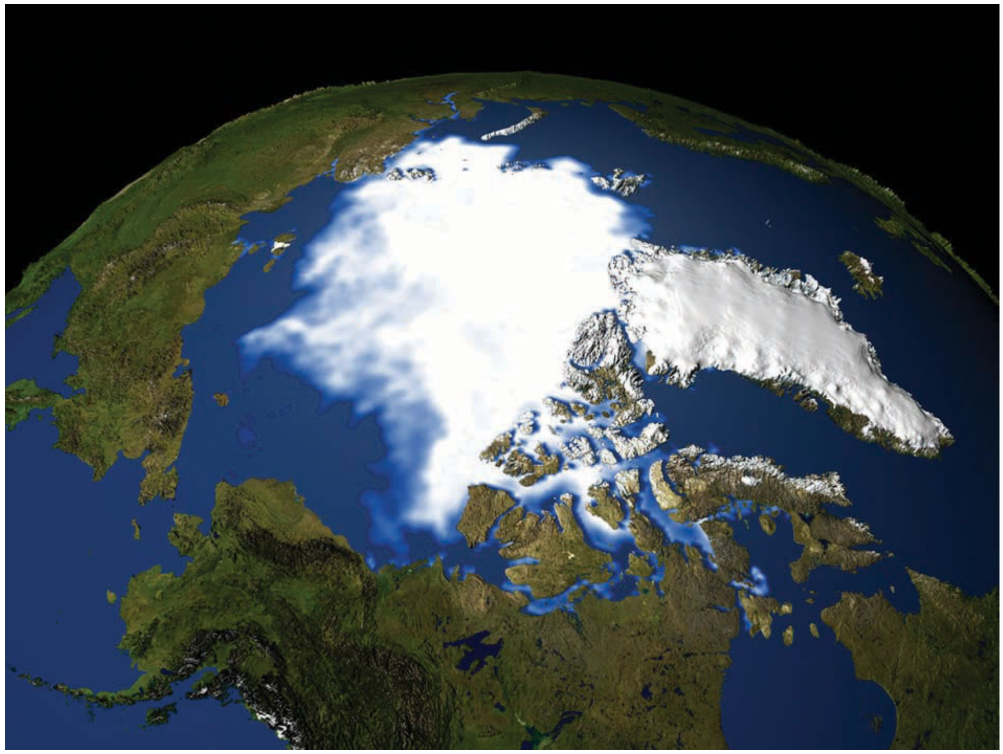


Figure 2.8 Polar Ice Cap



To see the animation, go to http://svs.gsfc.nasa.gov/goto?3464.

Just as dynamic maps will continue to evolve and require more user interaction in the future, map users will demand more interactive map features and controls. As this democratization of maps and mapping continues, the geographic awareness and map appreciation of map users will also increase. Therefore, it is of critical importance to understand the nature, form, and content of maps to support the changing needs, demands, and expectations of map users in the future.

KEY TAKEAWAYS

- The main purpose of a reference map is to show the location of geographical objects of interest.
- Thematic maps are concerned with showing how one or more geographical aspects are distributed across space.
- Dynamic maps refer to maps that are changeable and often require user interaction.
- The democratization of maps and mapping is increasing access, use, and appreciation for all types of maps, as well as driving map innovations.

EXERCISES

1. Go to the website of the USGS, read about the history and use of USGS maps, and download the topographic map that corresponds to your place of residence.
2. What features make a map “dynamic” or “interactive”? Are dynamic maps more informative than static maps? Why or why not?

2.2 Map Scale, Coordinate Systems, and Map Projections

LEARNING OBJECTIVE

1. The objective of this section is to describe and discuss the concepts of map scale, coordinate systems, and map projections and explain why they are central to maps, mapping, and geographic information systems (GISs).

All map users and map viewers have certain expectations about what is contained on a map. Such expectations are formed and learned from previous experience by working with maps. It is important to note that such expectations also change with increased exposure to maps. Understanding and meeting the expectations of map viewers is a challenging but necessary task because such expectations provide a starting point for the creation of any map.

The central purpose of a map is to provide relevant and useful information to the map user. In order for a map to be of value, it must convey information effectively and efficiently. Mapping conventions facilitate the delivery of information in such a manner by recognizing and managing the expectations of map users. Generally speaking, mapping or cartographic conventions refer to the accepted rules, norms, and practices behind the making of maps. One of the most recognized mapping conventions is that "north is up" on most maps. Though this may not always be the case, many map users expect north to be oriented or to coincide with the top edge of a map or viewing device like a computer monitor.

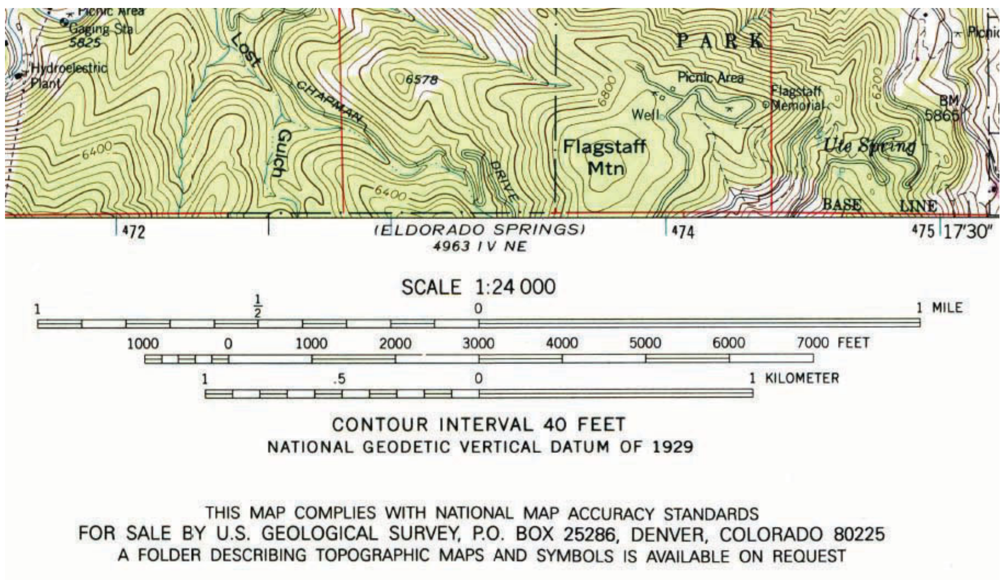
Several other formal and informal mapping conventions and characteristics, many of which are taken for granted, can be identified. Among the most important cartographic considerations are map scale, coordinate systems, and map projections. Map scale is concerned with reducing geographical features of interest to manageable proportions, coordinate systems help us define the positions of features on the surface of the earth, and map projections are concerned with moving from the three-dimensional world to the two dimensions of a flat map or display, all of which are discussed in greater detail in this chapter.

Map Scale

The world is a big place...really big. One of the challenges behind mapping the world and its resident features, patterns, and processes is reducing it to a manageable size. What exactly is meant by "manageable" is open to discussion and largely depends on the purpose and needs of the map at hand. Nonetheless, all maps reduce or shrink the world and its geographic features of interest by some factor. **Map scale**[6] refers to the factor of reduction of the world so it fits on a map.

Map scale can be represented by text, a graphic, or some combination of the two. For example, it is common to see "one inch represents one kilometer" or something similar written on a map to give map users an idea of the scale of the map. Map scale can also be portrayed graphically with what is called a scale bar. Scale bars are usually used on reference maps and allow map users to approximate distances between locations and features on a map, as well as to get an overall idea of the scale of the map.

Figure 2.9 Map Scale from a United States Geological Survey (USGS) Topographic Map



The representative fraction (RF) describes scale as a simple ratio. The numerator, which is always set to one (i.e., 1), denotes map distance and the denominator denotes ground or "real-world" distance. One of the benefits of using a representative fraction to describe scale is that it is unit neutral. In other words, any unit of measure can be used to interpret the map scale. Consider a map with an RF of 1:10,000. This means that one unit on the map represents 10,000 units on the ground. Such units could be inches, centimeters, or even pencil lengths; it really does not matter.

Map scales can also be described as either "small" or "large." Such descriptions are usually made in reference to representative fractions and the amount of detail

6. The factor by which phenomena on the surface of the earth are reduced in order to be shown on a map.

represented on a map. For instance, a map with an RF of 1:1,000 is considered a large-scale map when compared to a map with an RF of 1:1,000,000 (i.e., 1:1,000 > 1:1,000,000). Furthermore, while the large-scale map shows more detail and less area, the small-scale map shows more area but less detail. Clearly, determining the thresholds for small- or large-scale maps is largely a judgment call.

All maps possess a scale, whether it is formally expressed or not. Though some say that online maps and GISs are "scaleless" because we can zoom in and out at will, it is probably more accurate to say that GISs and related mapping technology are multiscalar. Understanding map scale and its overall impact on how the earth and its features are represented is a critical part of both map making and GISs.

Coordinate Systems

Just as all maps have a map scale, all maps have locations, too. **Coordinate systems**[7] are frameworks that are used to define unique positions. For instance, in geometry we use *x* (horizontal) and *y* (vertical) coordinates to define points on a two-dimensional plane. The coordinate system that is most commonly used to define locations on the three-dimensional earth is called the **geographic coordinate system (GCS)**[8], and it is based on a sphere or spheroid. A spheroid (a.k.a. ellipsoid) is simply a sphere that is slightly wider than it is tall and approximates more closely the true shape of the earth. Spheres are commonly used as models of the earth for simplicity.

The unit of measure in the GCS is degrees, and locations are defined by their respective latitude and longitude within the GCS. Latitude is measured relative to the equator at zero degrees, with maxima of either ninety degrees north at the North Pole or ninety degrees south at the South Pole. Longitude is measured relative to the prime meridian at zero degrees, with maxima of 180 degrees west or 180 degrees east.

Note that latitude and longitude can be expressed in degrees-minutes-seconds (DMS) or in decimal degrees (DD). When using decimal degrees, latitudes above the equator and longitudes east of the prime meridian are positive, and latitudes below the equator and longitudes west of the prime meridian are negative (see the following table for examples).

Nominal location	Absolute location (DMS)	Absolute location (DD)
Los Angeles, US	34° 3′ North, 118° 15′ West	+34.05, −118.25
Mumbai, India	18° 58′ North, 72° 49′ East	+18.975, +72.8258

7. Frameworks used to determine position on the surface of the earth.

8. The three-dimensional coordinate system commonly used to define locations on the earth's surface.

Nominal location	Absolute location (DMS)	Absolute location (DD)
Sydney, Australia	33° 51′ South, 151° 12′ East	−33.859, 151.211
Sao Paolo, Brazil	23° 33′ South, 46° 38′ West	−23.550, −46.634

Converting from DMS to DD is a relatively straightforward exercise. For example, since there are sixty minutes in one degree, we can convert 118° 15 minutes to 118.25 (118 + 15/60). Note that an online search of the term "coordinate conversion" will return several coordinate conversion tools.

When we want to map things like mountains, rivers, streets, and buildings, we need to define how the lines of latitude and longitude will be oriented and positioned on the sphere. A datum serves this purpose and specifies exactly the orientation and origins of the lines of latitude and longitude relative to the center of the earth or spheroid.

Depending on the need, situation, and location, there are several datums to choose from. For instance, local datums try to match closely the spheroid to the earth's surface in a local area and return accurate local coordinates. A common local datum used in the United States is called NAD83 (i.e., North American Datum of 1983). For locations in the United States and Canada, NAD83 returns relatively accurate positions, but positional accuracy deteriorates when outside of North America.

The global WGS84 datum (i.e., World Geodetic System of 1984) uses the center of the earth as the origin of the GCS and is used for defining locations across the globe. Because the datum uses the center of the earth as its origin, locational measurements tend to be more consistent regardless where they are obtained on the earth, though they may be less accurate than those returned by a local datum. Note that switching between datums will alter the coordinates (i.e., latitude and longitude) for all locations of interest.

Map Projections

Previously we noted that the earth is really big. Not only is it big, but it is a big round spherical shape called a spheroid. A globe is a very common and very good representation of the three-dimensional, spheroid earth. One of the problems with globes, however, is that they are not very portable (i.e., you cannot fold a globe and put in it in your pocket), and their small scale makes them of limited practical use (i.e., geographic detail is sacrificed). To overcome these issues, it is necessary to transform the three-dimensional shape of the earth to a two-dimensional surface like a flat piece of paper, computer screen, or mobile device display in order to obtain more useful map forms and map scales. Enter the map projection.

Map projections[9] refer to the methods and procedures that are used to transform the spherical three-dimensional earth into two-dimensional planar surfaces. Specifically, map projections are mathematical formulas that are used to translate latitude and longitude on the surface of the earth to *x* and *y* coordinates on a plane. Since there are an infinite number of ways this translation can be performed, there are an infinite number of map projections. The mathematics behind map projections are beyond the scope of this introductory overview (but see Robinson et al. 1995; Muehrcke and Muehrcke 1998),Muehrcke, P., and J. Muehrcke. 1998. *Map Use*. Madison, WI: JP Publications. and for simplicity, the following discussion focuses on describing types of map projections, the distortions inherent to map projections, and the selection of appropriate map projections.

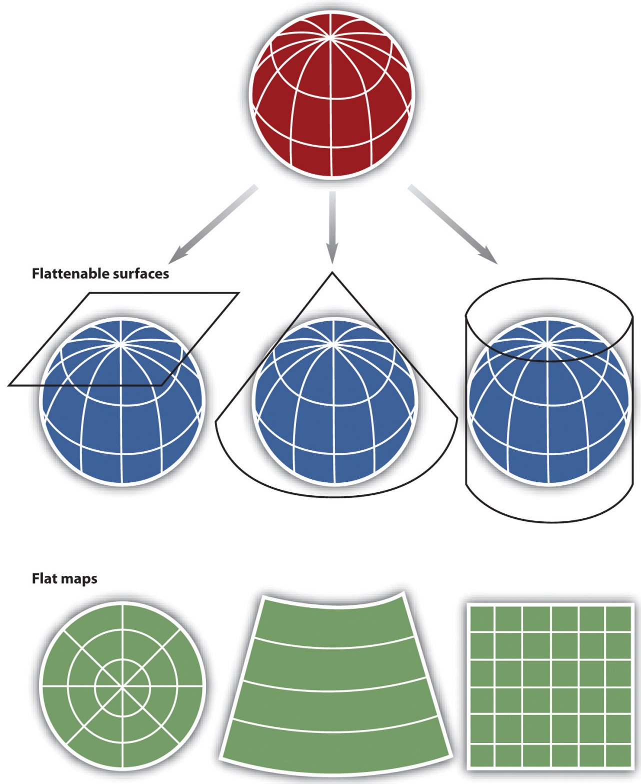
To illustrate the concept of a map projection, imagine that we place a light bulb in the center of a translucent globe. On the globe are outlines of the continents and the lines of longitude and latitude called the graticule. When we turn the light bulb on, the outline of the continents and the graticule will be "projected" as shadows on the wall, ceiling, or any other nearby surface. This is what is meant by map "projection."

Figure 2.10 *The Concept of Map "Projection"*

9. The mathematical formulae used to tranform locations from a three-dimensional, spherical coordinate system to a two-dimensional planar system.

Within the realm of maps and mapping, there are three surfaces used for map projections (i.e., surfaces on which we project the shadows of the graticule). These surfaces are the plane, the cylinder, and the cone. Referring again to the previous example of a light bulb in the center of a globe, note that during the projection process, we can situate each surface in any number of ways. For example, surfaces can be tangential to the globe along the equator or poles, they can pass through or intersect the surface, and they can be oriented at any number of angles.

Figure 2.11 Map Projection Surfaces



In fact, naming conventions for many map projections include the surface as well as its orientation. For example, as the name suggests, "planar" projections use the plane, "cylindrical" projections use cylinders, and "conic" projections use the cone. For cylindrical projections, the "normal" or "standard" aspect refers to when the cylinder is tangential to the equator (i.e., the axis of the cylinder is oriented north–south). When the axis of the cylinder is perfectly oriented east–west, the aspect is called "transverse," and all other orientations are referred to as "oblique." Regardless the orientation or the surface on which a projection is based, a number of distortions will be introduced that will influence the choice of map projection.

When moving from the three-dimensional surface of the earth to a two-dimensional plane, distortions are not only introduced but also inevitable. Generally, map projections introduce distortions in distance, angles, and areas. Depending on the purpose of the map, a series of trade-offs will need to be made with respect to such distortions.

Map projections that accurately represent distances are referred to as equidistant projections. Note that distances are only correct in one direction, usually running north–south, and are not correct everywhere across the map. Equidistant maps are frequently used for small-scale maps that cover large areas because they do a good job of preserving the shape of geographic features such as continents.

Maps that represent angles between locations, also referred to as bearings, are called conformal. Conformal map projections are used for navigational purposes due to the importance of maintaining a bearing or heading when traveling great distances. The cost of preserving bearings is that areas tend to be quite distorted in conformal map projections. Though shapes are more or less preserved over small areas, at small scales areas become wildly distorted. The Mercator projection is an example of a conformal projection and is famous for distorting Greenland.

As the name indicates, equal area or equivalent projections preserve the quality of area. Such projections are of particular use when accurate measures or comparisons of geographical distributions are necessary (e.g., deforestation, wetlands). In an effort to maintain true proportions in the surface of the earth, features sometimes become compressed or stretched depending on the orientation of the projection. Moreover, such projections distort distances as well as angular relationships.

As noted earlier, there are theoretically an infinite number of map projections to choose from. One of the key considerations behind the choice of map projection is to reduce the amount of distortion. The geographical object being mapped and the respective scale at which the map will be constructed are also important factors to think about. For instance, maps of the North and South Poles usually use planar or azimuthal projections, and conical projections are best suited for the middle latitude areas of the earth. Features that stretch east–west, such as the country of Russia, are represented well with the standard cylindrical projection, while countries oriented north–south (e.g., Chile, Norway) are better represented using a transverse projection.

If a map projection is unknown, sometimes it can be identified by working backward and examining closely the nature and orientation of the graticule (i.e., grid of latitude and longitude), as well as the varying degrees of distortion. Clearly, there are trade-offs made with regard to distortion on every map. There are no hard-and-fast rules as to which distortions are more preferred over others. Therefore, the selection of map projection largely depends on the purpose of the map.

Within the scope of GISs, knowing and understanding map projections are critical. For instance, in order to perform an overlay analysis like the one described earlier, all map layers need to be in the same projection. If they are not, geographical features will not be aligned properly, and any analyses performed will be inaccurate and incorrect. Most GISs include functions to assist in the identification of map projections, as well as to transform between projections in order to synchronize spatial data. Despite the capabilities of technology, an awareness of the potential and pitfalls that surround map projections is essential.

KEY TAKEAWAYS

- Map scale refers to the factor by which the real world is reduced to fit on a map.
- A GIS is multiscalar.
- Map projections are mathematical formulas used to transform the three-dimensional earth to two dimensions (e.g., paper maps, computer monitors).
- Map projections introduce distortions in distance, direction, and area.

EXERCISES

1. Determine and discuss the most appropriate representative fractions for the following verbal map scale descriptions: individual, neighborhood, urban, regional, national, and global.
2. Go to the National Atlas website and read about map projections (http://nationalatlas.gov/articles/mapping/a_projections.html). Define the following terms: datum, developable surface, secant, azimuth, rhumb line, and zenithal.
3. Describe the general properties of the following projections: Universe Transverse Mercator (UTM), State plane system, and Robinson projection.
4. What are the scale, projection, and contour interval of the USGS topographic map that you downloaded for your place of residence?
5. Find the latitude and longitude of your hometown. Explain how you can convert the coordinates from DD to DMS or vice versa.

2.3 Map Abstraction

LEARNING OBJECTIVE

1. The objective of this section is to highlight the decision-making process behind maps and to underscore the need to be explicit and consistent when mapping and using geographic information systems (GISs).

As previously discussed, maps are a representation of the earth. Central to this representation is the reduction of the earth and its features of interest to a manageable size (i.e., map scale) and its transformation into a useful two-dimensional form (i.e., map projection). The choice of both map scale and, to a lesser extent, map projection will influence the content and shape of the map.

In addition to the seemingly objective decisions made behind the choices of map scale and map projection are those concerning what to include and what to omit from the map. The purpose of a map will certainly guide some of these decisions, but other choices may be based on factors such as space limitations, map complexity, and desired accuracy. Furthermore, decisions about how to classify, simplify, or exaggerate features and how to symbolize objects of interest simultaneously fall under the realms of art and science (Slocum et al. 2004).Slocum, T., R. McMaster, F. Kessler, and H. Hugh. 2008. *Thematic Cartography and Geovisualization*. Upper Saddle River, NJ: Prentice Hall.

The process of moving from the "real world" to the world of maps is referred to as **map abstraction**[10]. This process not only involves making choices about how to represent features but also, more important with regard to geographic information systems (GISs), requires us to be explicit, consistent, and precise in terms of defining and describing geographical features of interest. Failure to be explicit, consistent, and precise will return incorrect; inconsistent; and error-prone maps, analyses, and decisions based on such maps and GISs. This final section discusses map abstraction in terms of geographical features and their respective graphical representation.

What Is a Forest?

One of the most pressing environmental issues facing the world is deforestation. Generally, deforestation refers to the reduction of forest area. This is an important issue because it has possible implications for climate change, global warming,

10. The process by which real-world phenomena are transformed into features on a map.

biodiversity, and the water balance of the earth, among other things. In the last century, deforestation has increased at an alarming rate and is mostly attributed to human activity. Mapping forests regularly with a GIS is a logical way to monitor deforestation and has the potential to inform policies regarding forest conservation efforts. Easy enough, so let's get started.

So what *exactly* is a forest? How do we know where a forest begins and where it ends? How can naturally caused forest fires be differentiated from those started by humans? Can a forest exist in a swamp or wetland? For that matter, what is the difference between a swamp and wetland? Such questions are not trivial in the context of mapping and GISs. In fact, consistent and precise definitions of features like forests or swamps increase the reliability and efficiency of maps, mapping, and analysis with GISs.

Figure 2.12 *Deforestation in the Amazon: 2001*

Figure 2.13 *Deforestation in the Amazon: 2009*

Within the realm of maps, cartography, and GISs, the world is made up of various features or entities. Such entities include but are not restricted to fire hydrants, caves, roads, rivers, lakes, hills, valleys, oceans, and the occasional barn. Moreover, such features have a form, and more precisely, a geometric form. For instance, fire hydrants and geysers are considered point-like features; rivers and streams are linear features; and lakes, countries, and forests are areal features.

Features can also be categorized as either discrete or continuous. **Discrete features**[11] are well defined and are easy to locate, measure, and count, and their edges or boundaries are readily defined. Examples of discrete features in a city include buildings, roads, traffic signals, and parks. **Continuous features**[12], on the other hand, are less well defined and exist across space. The most commonly cited examples of continuous features are temperature and elevation. Changes in both temperature and elevation tend to be gradual over relatively large areas.

Geographical features also have several characteristics, traits, or attributes that may or may not be of interest. For instance, to continue the deforestation example, determining whether a forest is a rainforest or whether a forest is in a protected park may be important. More general attributes may include measurements such as tree density per acre, average canopy height in meters, or proportions like percent palm trees or invasive species per hectare in the forest.

11. Phenomena that when represented on a map have clearly defined boundaries.

12. Phenomena that lack clearly defined boundaries.

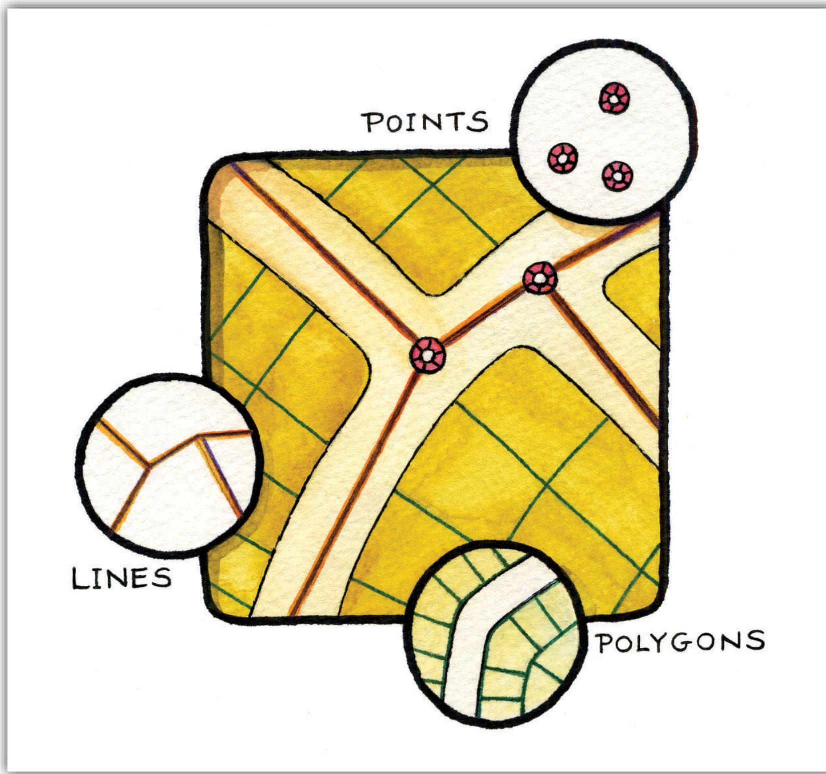
Notwithstanding the purpose of the map or GIS project at hand, it is critical that definitions of features are clear and remain consistent. Similarly, it is important that the attributes of features are also consistently defined, measured, and reported in order to generate accurate and effective maps in an efficient manner. Defining features and attributes of interest is often an iterative process of trial and error. Being able to associate a feature with a particular geometric form and to determine the feature type are central to map abstraction, facilitate mapping, and the application of GISs.

Map Content and Generalization

The shape and content of maps vary according to purpose, need, and resources, among other factors. What is common to most maps, and in particular to those within a GIS, is that they are graphical representations of reality. Put another way, various graphical symbols are used to represent geographical features or entities. Annotation or text is also commonly used on maps and facilitates map interpretation. Learning about map content and map generalization is important because they serve as the building blocks for spatial data that are used within a GIS.

Building upon the previous discussion about the geometric form of geographic features, maps typically rely on three geometric objects: the point, the line, and the polygon or area. A point is defined by *x* and *y* coordinates, a line is defined by two points, and a polygon is defined by a minimum of three points. The important thing to note is that the definition of a point is analogous to a location that is defined by longitude and latitude. Furthermore, since lines and polygons are made up of points, location information (i.e., *x* and *y*, or longitude and latitude, coordinates) is intrinsic to points, lines, and polygons.

Figure 2.14 *Geographic Features as Points, Lines, and Polygons*



Both simple and complex maps can be made using these three relatively simple geometric objects. Additionally, by changing the graphical characteristics of each object, an infinite number of mapping possibilities emerge. Such changes can be made to the respective size, shape, color, and patterns of points, lines, and polygons. For instance, different sized points can be used to reflect variations in population size, line color or line size (i.e., thickness) can be used to denote volume or the amount of interaction between locations, and different colors and shapes can be used to reflect different values of interest.

Figure 2.15 *Variations in the Graphical Parameters of Points, Lines, and Polygons*

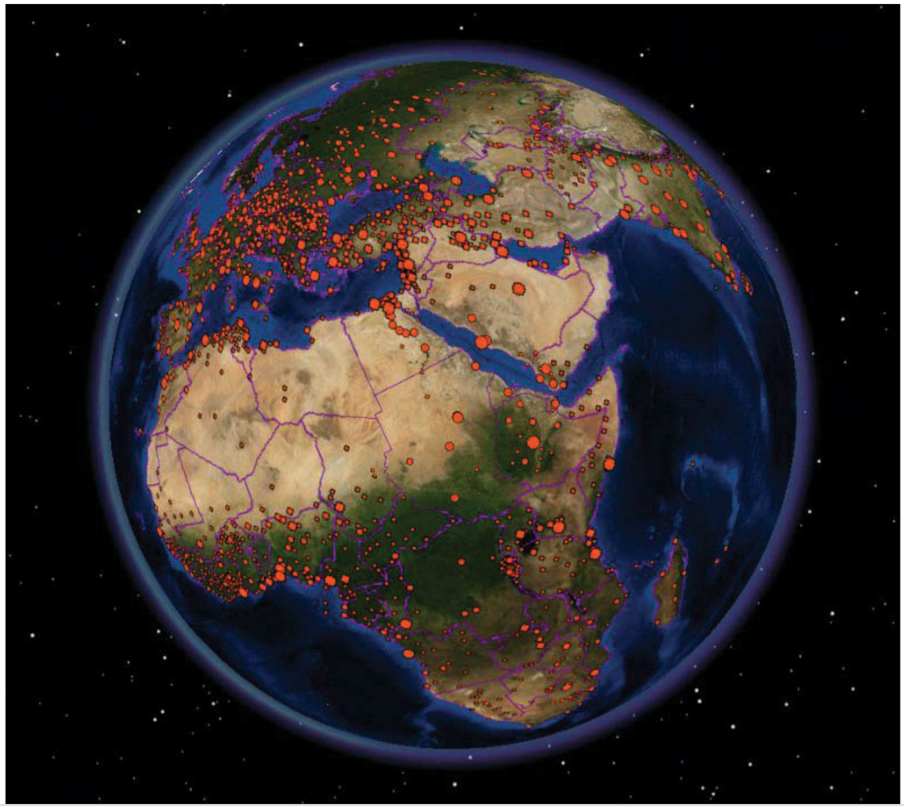
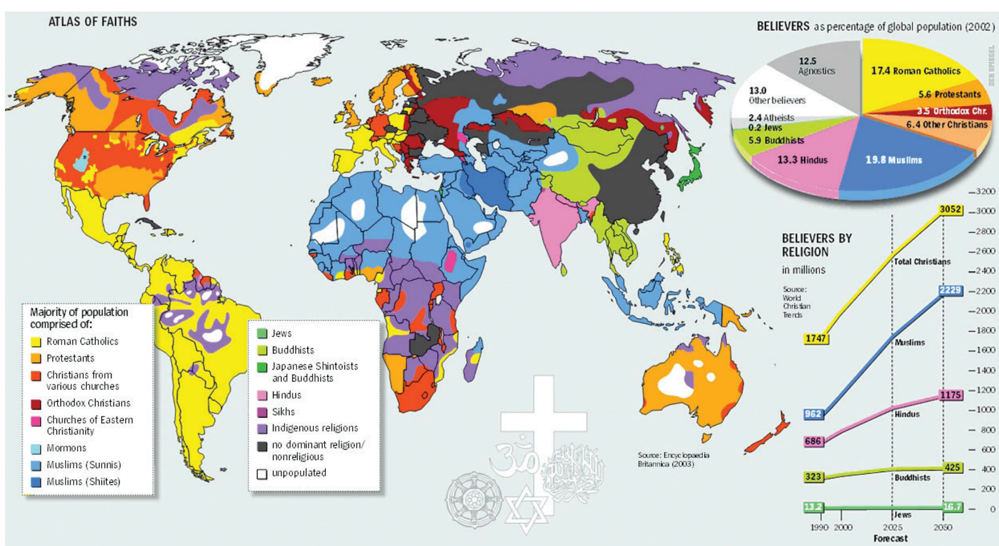


Figure 2.16



Complementing the graphical elements described previously is annotation or text. Annotation is used to identify particular geographic features, such as cities, states, bodies of water, or other points of interest. Like the graphical elements, text can be varied according to size, orientation, or color. There are also numerous text fonts and styles that are incorporated into maps. For example, bodies of water are often labeled in *italics*.

Another map element that deserves to be mentioned and that combines both graphics and text is the map legend or map key. A **map legend**[13] provides users information about the how geographic information is represented graphically. Legends usually consist of a title that describes the map, as well as the various symbols, colors, and patterns that are used on the map. Such information is often vital to the proper interpretation of a map.

As more features and graphical elements are put on a given map, the need to generalize such features arises. **Map generalization**[14] refers to the process of resolving conflicts associated with too much detail, too many features, or too much information to map. In particular, generalization can take several forms (Buttenfield and McMaster 1991):Buttenfield, B., and R. McMaster. 1991. *Map Generalization*. Harlow, England: Longman.

- The simplification or **symbolization**[15] of features for emphasis
- The masking or displacement of detail to increase clarity or legibility
- The selection of detail for inclusion or omission from the map
- The exaggeration of features for emphasis

Determining which aspects of generalization to use is largely a matter of personal preference, experience, map purpose, and trial and error. Though there are general guidelines about map generalization, there are no universal standards or requirements with regard to the generalization of maps and mapping. It is at this point that cartographic and artistic license, prejudices and biases, and creativity and design sense—or lack thereof—emerge to shape the map.

Making a map and, more generally, the process of mapping involve a range of decisions and choices. From the selection of the appropriate map scale and map projection to deciding which features to map and to omit, mapping is a complex blend of art and science. In fact, many historical maps are indeed viewed like works of art, and rightly so. Learning about the scale, shape, and content of maps serves to increase our understanding of maps, as well as deepen our appreciation of maps and map making. Ultimately, this increased geographical awareness and appreciation of maps promotes the sound and effective use and application of a GIS.

13. A common component of a map that facilitiates interpretation and understanding.

14. The process by which real-world features are simplified in order to be represented on a map.

15. The use of various text, icons, and symbols to represent real-world features.

KEY TAKEAWAYS

- Map abstraction refers to the process of explicitly defining and representing real-world features on a map.
- The three basic geometric forms of geographical features are the point, line, and polygon (or area).
- Map generalization refers to resolving conflicts that arise on a map due to limited space, too many details, or too much information.

EXERCISES

1. Examine an online map of where you live. Which forms of map generalization were used to create the map? Which three elements of generalization would you change? Which three elements are the most effective?
2. If you were to start a GIS project on deforestation, what terms would need to be explicitly defined, and how would you define them?

Waypoint: More than Just Clouds and Weather

Image maps, in large part derived from satellites, are ubiquitous. Such maps can be found on the news, the Internet, in your car, and on your mobile phone. What's more is that such images are in living color and of very high resolution. Not long ago, such image maps from satellites were the sole domain of meteorologists, local weather forecasters, and various government agencies. Public access to such images was pretty much limited to the evening news.

Technological advances in imaging technology, in conjunction with the commercialization of space flight, opened the door for companies like GeoEye (http://www.geoeye.com) and DigitalGlobe (http://www.digitalglobe.com) to provide satellite imagery and maps to the masses at the turn of the twenty-first century. With online mapping services such as Google Earth providing free and user-friendly access to such images, a revolution in maps and mapping was born.

Image maps now provide geographic context for nightly news stories around the world, serve as a backdrop to local real estate searches and driving directions, and are also used for research purposes . The popularity and widespread use of such images speaks not only to recent technological advances and innovations but also, perhaps more important, to the geographer in us all.

Figure 2.17
The Inauguration of Barack Obama from Space

GeoEye 2008.

3.1 Data and Information

LEARNING OBJECTIVE

1. The objective of this section is to define and describe data and information and how it is organized into files for use in a computing and geographic information system (GIS) environment.

To understand how we get from analog to digital maps, let's begin with the building blocks and foundations of the geographic information system (GIS)—namely, **data**[1] and **information**[2]. As already noted on several occasions, GIS stores, edits, processes, and presents data and information. But what exactly is data? And what exactly is information? For many, the terms "data" and "information" refer to the same thing. For our purposes, it is useful to make a distinction between the two. Generally, **data** refer to facts, measurements, characteristics, or traits of an object of interest. For you grammar sticklers out there, note that "data" is the plural form of "datum." For example, we can collect all kinds of data about all kinds of things, like the length of rainbow trout in a Colorado stream, the number of vegetarians in Alaska, the diameter of mahogany tree trunks in the Brazilian rainforest, student scores on the last GIS midterm, the altitude of mountain peaks in Nepal, the depth of snow in the Austrian Alps, or the number of people who use public transportation to get to work in London.

Once data are put into context, used to answer questions, situated within analytical frameworks, or used to obtain insights, they become **information**. For our purposes, **information** simply refers to the knowledge of value obtained through the collection, interpretation, and/or analysis of data. Though a computer is not necessary to collect, record, manipulate, process, or visualize data, or to process it into information, information technology can be of great help. For instance, computers can automate repetitive tasks, store data efficiently in terms of space and cost, and provide a range of tools for analyzing data from spreadsheets to GISs, of course. What's more is the fact that the incredible amount of data collected each and every day by satellites, grocery store product scanners, traffic sensors, temperature gauges, and your mobile phone carrier, to name just a few, would not be possible without the aid and innovation of information technology.

Since this is a text about GISs, it is useful to also define **geographic** data. Like generic data, **geographic** or **spatial data**[3] refer to geographic facts, measurements, or characteristics of an object that permit us to define its location on the surface of

1. Facts, measurements, and characteristics of something of interest.
2. Knowledge and insights that are acquired through the analysis of data.
3. Data that describe the geographic and spatial aspects of phenomena.

the earth. Such data include but are not restricted to the latitude and longitude coordinates of points of interest, street addresses, postal codes, political boundaries, and even the names of places of interest. It is also important to note and reemphasize the difference between geographic data and **attribute data**[4], which was discussed in Chapter 2 "Map Anatomy". Where geographic data are concerned with defining the location of an object of interest, attribute data are concerned with its nongeographic traits and characteristics.

To illustrate the distinction between geographic and attribute data, think about your home where you grew up or where you currently live. Within the context of this discussion, we can associate both geographic and attribute data to it. For instance, we can define the location of your home many ways, such as with a street address, the street names of the nearest intersection, the postal code where your home is located, or we could use a global positioning system–enabled device to obtain latitude and longitude coordinates. What is important is geographic data permit us to define the location of an object (i.e., your home) on the surface of the earth.

In addition to the geographic data that define the location of your home are the attribute data that describe the various qualities of your home. Such data include but are not restricted to the number of bedrooms and bathrooms in your home, whether or not your home has central heat, the year when your home was built, the number of occupants, and whether or not there is a swimming pool. These attribute data tell us a lot about your home but relatively little about where it is.

Not only is it useful to recognize and understand how geographic and attribute data differ and complement each other, but it is also of central importance when learning about and using GISs. Because a GIS requires and integrates these two distinct types of data, being able to differentiate between geographic and attribute data is the first step in organizing your GIS. Furthermore, being able to determine which kinds of data you need will ultimately aid in your implementation and use of a GIS. More often than not, and in the age and context of information technology, the data and information discussed thus far is the stuff of computer files, which are the focus of the next section.

4. Data that describe the qualities and characteristics of a particular phenomena.

Chapter 4

Data Models for GIS

In order to visualize natural phenomena, one must first determine how to best represent geographic space. Data models are a set of rules and/or constructs used to describe and represent aspects of the real world in a computer. Two primary data models are available to complete this task: raster data models and vector data models.

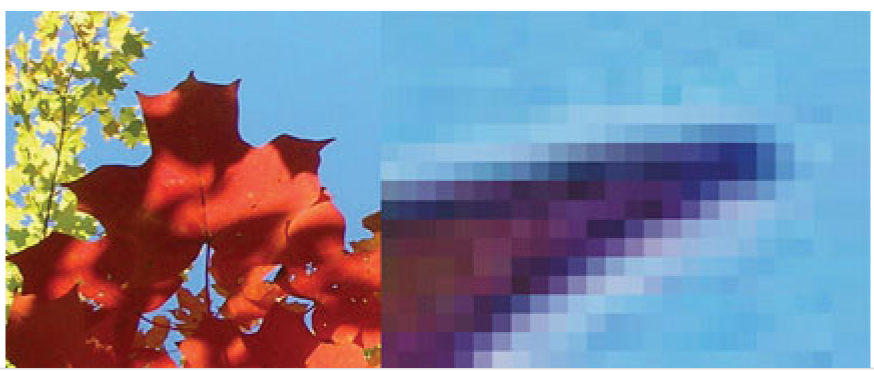
4.1 Raster Data Models

LEARNING OBJECTIVE

1. The objective of this section is to understand how raster data models are implemented in GIS applications.

The raster data model is widely used in applications ranging far beyond geographic information systems (GISs). Most likely, you are already very familiar with this data model if you have any experience with digital photographs. The ubiquitous JPEG, BMP, and TIFF file formats (among others) are based on the raster data model (see Chapter 5 "Geospatial Data Management", Section 5.3 "File Formats"). Take a moment to view your favorite digital image. If you zoom deeply into the image, you will notice that it is composed of an array of tiny square pixels (or picture elements). Each of these uniquely colored pixels, when viewed as a whole, combines to form a coherent image (Figure 4.1 "Digital Picture with Zoomed Inset Showing Pixilation of Raster Image").

Figure 4.1 Digital Picture with Zoomed Inset Showing Pixilation of Raster Image



Furthermore, all liquid crystal display (LCD) computer monitors are based on raster technology as they are composed of a set number of rows and columns of pixels. Notably, the foundation of this technology predates computers and digital cameras by nearly a century. The neoimpressionist artist, Georges Seurat, developed a painting technique referred to as “pointillism” in the 1880s, which similarly relies on the amassing of small, monochromatic “dots” of ink that combine to form a larger image (Figure 4.2 "Pointillist Artwork"). If you are as generous as the author, you may indeed think of your raster dataset creations as sublime works of art.

Figure 4.2 Pointillist Artwork

The raster data model consists of rows and columns of equally sized pixels interconnected to form a planar surface. These pixels are used as building blocks for creating points, lines, areas, networks, and surfaces (Chapter 2 "Map Anatomy", Figure 2.6 "Map Overlay Process" illustrates how a land parcel can be converted to a raster representation). Although pixels may be triangles, hexagons, or even octagons, square pixels represent the simplest geometric form with which to work. Accordingly, the vast majority of available raster GIS data are built on the square pixel (Figure 4.3 "Common Raster Graphics Used in GIS Applications: Aerial Photograph (left) and USGS DEM (right)"). These squares are typically reformed into rectangles of various dimensions if the data model is transformed from one projection to another (e.g., from State Plane coordinates to UTM [Universal Transverse Mercator] coordinates).

Figure 4.3 *Common Raster Graphics Used in GIS Applications: Aerial Photograph (left) and USGS DEM (right)*

Source: Data available from U.S. Geological Survey, Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD.

Because of the reliance on a uniform series of square pixels, the raster data model is referred to as a grid-based system. Typically, a single data value will be assigned to each grid locale. Each cell in a raster carries a single value, which represents the characteristic of the spatial phenomenon at a location denoted by its row and column. The data type for that cell value can be either integer or floating-point (Chapter 5 "Geospatial Data Management", Section 5.1 "Geographic Data Acquisition"). Alternatively, the raster graphic can reference a database management system wherein open-ended attribute tables can be used to associate multiple data values to each pixel. The advance of computer technology has made this second methodology increasingly feasible as large datasets are no longer constrained by computer storage issues as they were previously.

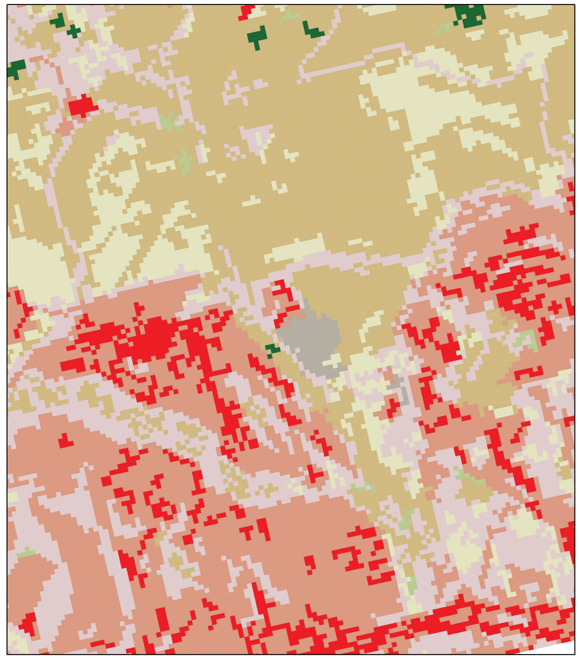
The raster model will average all values within a given pixel to yield a single value. Therefore, the more area covered per pixel, the less accurate the associated data values. The area covered by each pixel determines the **spatial resolution**[1] of the raster model from which it is derived. Specifically, resolution is determined by measuring one side of the square pixel. A raster model with pixels representing 10 m by 10 m (or 100 square meters) in the real world would be said to have a spatial resolution of 10 m; a raster model with pixels measuring 1 km by 1 km (1 square kilometer) in the real world would be said to have a spatial resolution of 1 km; and so forth.

1. The smallest distance between two adjacent features that can be detected in an image.

Care must be taken when determining the resolution of a raster because using an overly coarse pixel resolution will cause a loss of information, whereas using overly fine pixel resolution will result in significant increases in file size and computer processing requirements during display and/or analysis. An effective pixel resolution will take both the map scale and the minimum mapping unit of the other GIS data into consideration. In the case of raster graphics with coarse spatial resolution, the data values associated with specific locations are not necessarily explicit in the raster data model. For example, if the location of telephone poles were mapped on a coarse raster graphic, it would be clear that the entire cell would not be filled by the pole. Rather, the pole would be assumed to be located somewhere within that cell (typically at the center).

Imagery employing the raster data model must exhibit several properties. First, each pixel must hold at least one value, even if that data value is zero. Furthermore, if no data are present for a given pixel, a data value placeholder must be assigned to this grid cell. Often, an arbitrary, readily identifiable value (e.g., −9999) will be assigned to pixels for which there is no data value. Second, a cell can hold any alphanumeric index that represents an attribute. In the case of quantitative datasets, attribute assignation is fairly straightforward. For example, if a raster image denotes elevation, the data values for each pixel would be some indication of elevation, usually in feet or meters. In the case of qualitative datasets, data values are indices that necessarily refer to some predetermined translational rule. In the case of a land-use/land-cover raster graphic, the following rule may be applied: 1 = grassland, 2 = agricultural, 3 = disturbed, and so forth (Figure 4.4 "Land-Use/Land-Cover Raster Image"). The third property of the raster data model is that points and lines "move" to the center of the cell. As one might expect, if a 1 km resolution raster image contains a river or stream, the location of the actual waterway within the "river" pixel will be unclear. Therefore, there is a general assumption that all zero-dimensional (point) and one-dimensional (line) features will be located toward the center of the cell. As a corollary, the minimum width for any line feature must necessarily be one cell regardless of the actual width of the feature. If it is not, the feature will not be represented in the image and will therefore be assumed to be absent.

Figure 4.4 Land-Use/Land-Cover Raster Image



Source: Data available from U.S. Geological Survey, Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD.

Several methods exist for encoding raster data from scratch. Three of these models are as follows:

1. **Cell-by-cell raster encoding**[2]. This minimally intensive method encodes a raster by creating records for each cell value by row and column (Figure 4.5 "Cell-by-Cell Encoding of Raster Data"). This method could be thought of as a large spreadsheet wherein each cell of the spreadsheet represents a pixel in the raster image. This method is also referred to as "exhaustive enumeration."
2. **Run-length raster encoding**[3]. This method encodes cell values in runs of similarly valued pixels and can result in a highly compressed image file (Figure 4.6 "Run-Length Encoding of Raster Data"). The run-length encoding method is useful in situations where large groups of neighboring pixels have similar values (e.g., discrete datasets such as land use/land cover or habitat suitability) and is less useful where

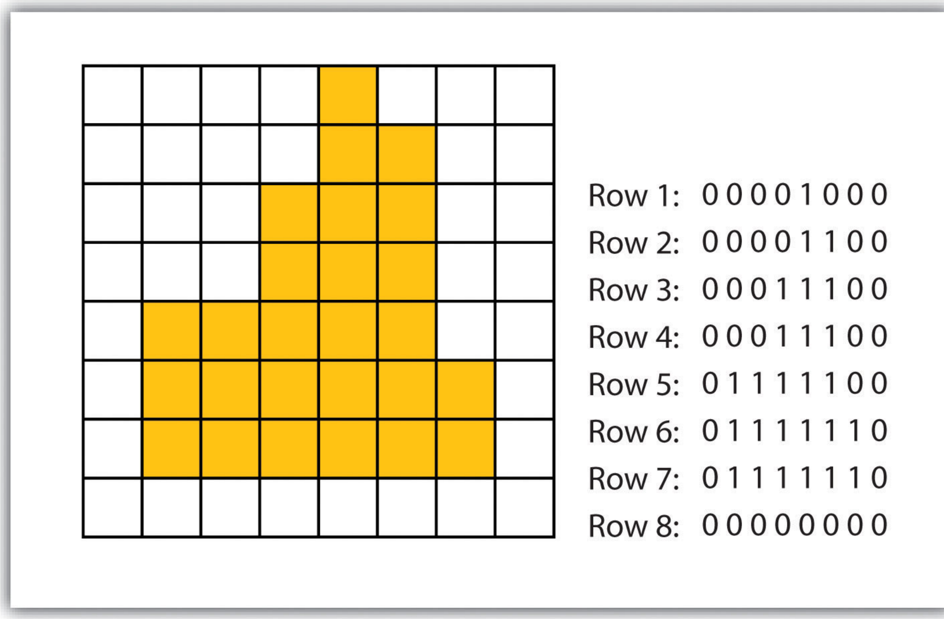
2. A minimally intensive method to encode a raster image by creating unique records for each cell value by row and column. This method is also referred to as "exhaustive enumeration."

3. A method to encode raster images by employing runs of similarly valued pixels.

neighboring pixel values vary widely (e.g., continuous datasets such as elevation or sea-surface temperatures).

3. **Quad-tree raster encoding**[4]. This method divides a raster into a hierarchy of quadrants that are subdivided based on similarly valued pixels (Figure 4.7 "Quad-Tree Encoding of Raster Data"). The division of the raster stops when a quadrant is made entirely from cells of the same value. A quadrant that cannot be subdivided is called a “leaf node.”

Figure 4.5 *Cell-by-Cell Encoding of Raster Data*



4. A method used to encode raster images by dividing the raster into a hierarchy of quadrants that are subdivided based on similarly valued pixels.

Figure 4.6 Run-Length Encoding of Raster Data

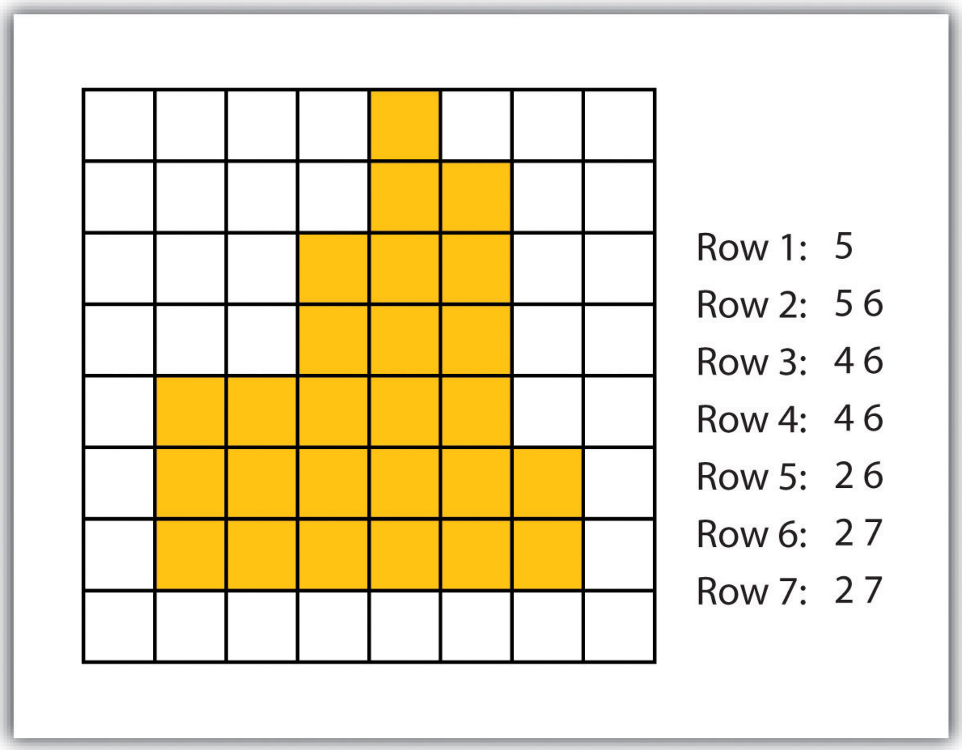
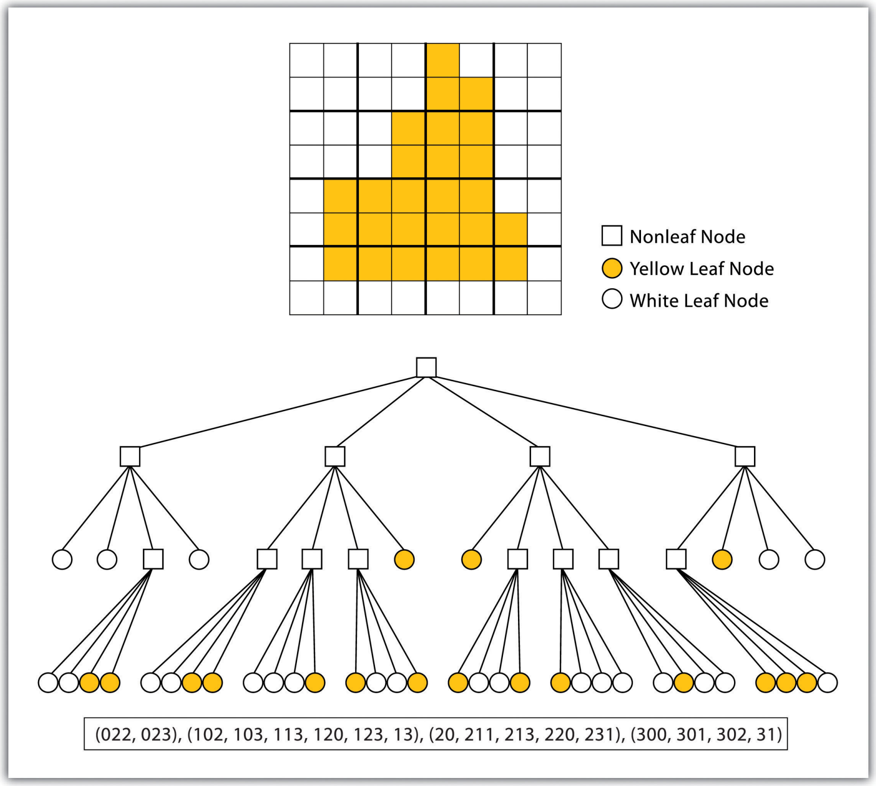


Figure 4.7 *Quad-Tree Encoding of Raster Data*



Advantages/Disadvantages of the Raster Model

The use of a raster data model confers many advantages. First, the technology required to create raster graphics is inexpensive and ubiquitous. Nearly everyone currently owns some sort of raster image generator, namely a digital camera, and few cellular phones are sold today that don't include such functionality. Similarly, a plethora of satellites are constantly beaming up-to-the-minute raster graphics to scientific facilities across the globe (Chapter 5 "Geospatial Data Management", Section 5.3 "File Formats"). These graphics are often posted online for private and/or public use, occasionally at no cost to the user.

Additional advantages of raster graphics are the relative simplicity of the underlying data structure. Each grid location represented in the raster image correlates to a single value (or series of values if attributes tables are included). This simple data structure may also help explain why it is relatively easy to perform overlay analyses on raster data (for more on overlay analyses, see Chapter 7 "Geospatial Analysis I: Vector Operations", Section 7.1 "Single Layer Analysis"). This simplicity also lends itself to easy interpretation and maintenance of the graphics, relative to its vector counterpart.

Despite the advantages, there are also several disadvantages to using the raster data model. The first disadvantage is that raster files are typically very large. Particularly in the case of raster images built from the cell-by-cell encoding methodology, the sheer number of values stored for a given dataset result in potentially enormous files. Any raster file that covers a large area and has somewhat finely resolved pixels will quickly reach hundreds of megabytes in size or more. These large files are only getting larger as the quantity and quality of raster datasets continues to keep pace with quantity and quality of computer resources and raster data collectors (e.g., digital cameras, satellites).

A second disadvantage of the raster model is that the output images are less "pretty" than their vector counterparts. This is particularly noticeable when the raster images are enlarged or zoomed (refer to Figure 4.1 "Digital Picture with Zoomed Inset Showing Pixilation of Raster Image"). Depending on how far one zooms into a raster image, the details and coherence of that image will quickly be lost amid a pixilated sea of seemingly randomly colored grid cells.

The geometric transformations that arise during map reprojection efforts can cause problems for raster graphics and represent a third disadvantage to using the raster data model. As described in Chapter 2 "Map Anatomy", Section 2.2 "Map Scale, Coordinate Systems, and Map Projections", changing map projections will alter the size and shape of the original input layer and frequently result in the loss or addition of pixels (White 2006).White, D. 2006. "Display of Pixel Loss and Replication in Reprojecting Raster Data from the Sinusoidal Projection." *Geocarto International* 21 (2): 19–22. These alterations will result in the perfect square pixels of the input layer taking on some alternate rhomboidal dimensions. However, the problem is larger than a simple reformation of the square pixel. Indeed, the reprojection of a raster image dataset from one projection to another brings change to pixel values that may, in turn, significantly alter the output information (Seong 2003).Seong, J. C. 2003. "Modeling the Accuracy of Image Data Reprojection." *International Journal of Remote Sensing* 24 (11): 2309–21.

The final disadvantage of using the raster data model is that it is not suitable for some types of spatial analyses. For example, difficulties arise when attempting to overlay and analyze multiple raster graphics produced at differing scales and pixel resolutions. Combining information from a raster image with 10 m spatial resolution with a raster image with 1 km spatial resolution will most likely produce nonsensical output information as the scales of analysis are far too disparate to result in meaningful and/or interpretable conclusions. In addition, some network and spatial analyses (i.e., determining directionality or geocoding) can be problematic to perform on raster data.

KEY TAKEAWAYS

- Raster data are derived from a grid-based system of contiguous cells containing specific attribute information.
- The spatial resolution of a raster dataset represents a measure of the accuracy or detail of the displayed information.
- The raster data model is widely used by non-GIS technologies such as digital cameras/pictures and LCD monitors.
- Care should be taken to determine whether the raster or vector data model is best suited for your data and/or analytical needs.

EXERCISES

1. Examine a digital photo you have taken recently. Can you estimate its spatial resolution?
2. If you were to create a raster data file showing the major land-use types in your county, which encoding method would you use? What method would you use if you were to encode a map of the major waterways in your county? Why?

4.2 Vector Data Models

LEARNING OBJECTIVE

1. The objective of this section is to understand how vector data models are implemented in GIS applications.

In contrast to the raster data model is the vector data model. In this model, space is not quantized into discrete grid cells like the raster model. Vector data models use points and their associated X, Y coordinate pairs to represent the vertices of spatial features, much as if they were being drawn on a map by hand (Aronoff 1989).Aronoff, S. 1989. *Geographic Information Systems: A Management Perspective*. Ottawa, Canada: WDL Publications. The data attributes of these features are then stored in a separate database management system. The spatial information and the attribute information for these models are linked via a simple identification number that is given to each feature in a map.

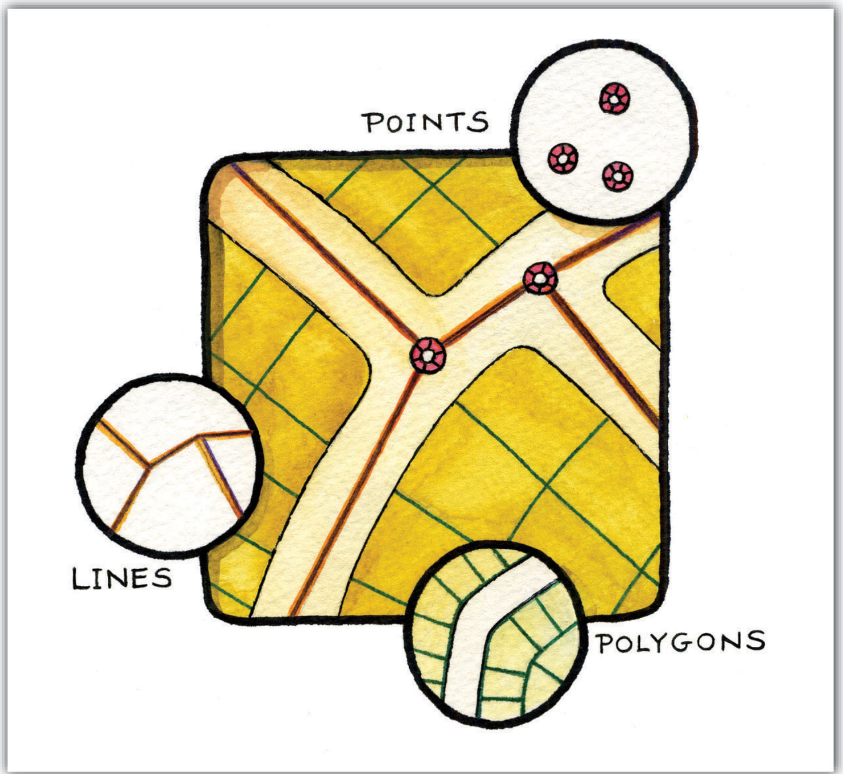
Three fundamental vector types exist in geographic information systems (GISs): points, lines, and polygons (Figure 4.8 "Points, Lines, and Polygons"). **Points**[5] are zero-dimensional objects that contain only a single coordinate pair. Points are typically used to model singular, discrete features such as buildings, wells, power poles, sample locations, and so forth. Points have only the property of location. Other types of point features include the **node**[6] and the **vertex**[7]. Specifically, a point is a stand-alone feature, while a node is a topological junction representing a common X, Y coordinate pair between intersecting lines and/or polygons. Vertices are defined as each bend along a line or polygon feature that is not the intersection of lines or polygons.

5. A zero-dimensional object containing a single coordinate pair. In a GIS, points have only the property of location.

6. The intersection points where two or more arcs meet.

7. A corner or a point where lines meet.

Figure 4.8 Points, Lines, and Polygons



Points can be spatially linked to form more complex features. **Lines**[8] are one-dimensional features composed of multiple, explicitly connected points. Lines are used to represent linear features such as roads, streams, faults, boundaries, and so forth. Lines have the property of length. Lines that directly connect two nodes are sometimes referred to as chains, edges, segments, or **arcs**[9].

Polygons[10] are two-dimensional features created by multiple lines that loop back to create a "closed" feature. In the case of polygons, the first coordinate pair (point) on the first line segment is the same as the last coordinate pair on the last line segment. Polygons are used to represent features such as city boundaries, geologic formations, lakes, soil associations, vegetation communities, and so forth. Polygons have the properties of area and perimeter. Polygons are also called **areas**[11].

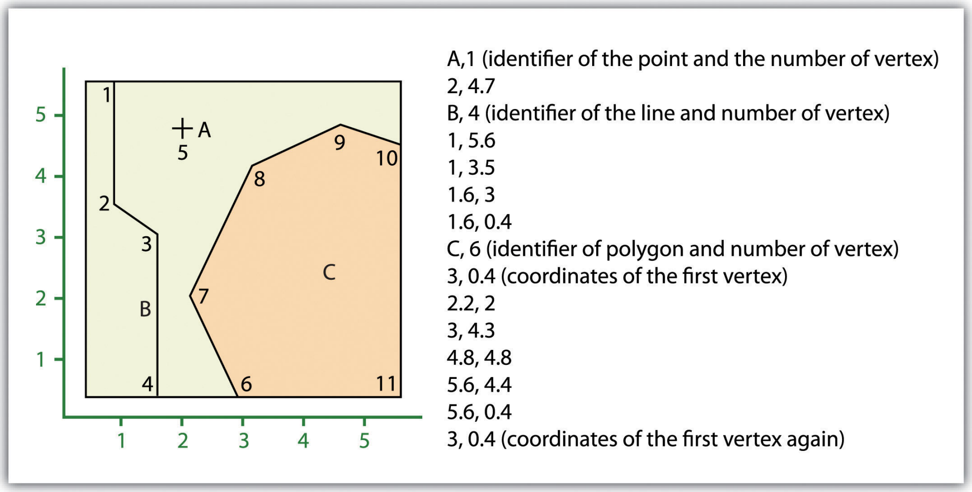
Vector Data Models Structures

Vector data models can be structured many different ways. We will examine two of the more common data structures here. The simplest vector data structure is called the **spaghetti data model**[12] (Dangermond 1982).Dangermond, J. 1982. "A Classification of Software Components Commonly Used in Geographic Information

8. A one-dimensional object composed of multiple, explicitly connected points. Lines have the property of length. Also called an "arc."
9. A one-dimensional object composed of multiple, explicitly connected points. Lines have the property of length. Also called a "line."
10. A two-dimensional feature created from multiple lines that loop back to create a "closed" feature. Polygons have the properties of area and perimeter. Also called "areas."
11. A two-dimensional feature created from multiple lines that loop back to create a "closed" feature. Areas have the properties of area and perimeter. Also called "polygons."
12. A data model in which each point, line, and/or polygon feature is represented as a string of X, Y coordinate pairs with no inherent structure.

Systems." In *Proceedings of the U.S.-Australia Workshop on the Design and Implementation of Computer-Based Geographic Information Systems*, 70–91. Honolulu, HI. In the spaghetti model, each point, line, and/or polygon feature is represented as a string of X, Y coordinate pairs (or as a single X, Y coordinate pair in the case of a vector image with a single point) with no inherent structure (Figure 4.9 "Spaghetti Data Model"). One could envision each line in this model to be a single strand of spaghetti that is formed into complex shapes by the addition of more and more strands of spaghetti. It is notable that in this model, any polygons that lie adjacent to each other must be made up of their own lines, or stands of spaghetti. In other words, each polygon must be uniquely defined by its own set of X, Y coordinate pairs, even if the adjacent polygons share the exact same boundary information. This creates some redundancies within the data model and therefore reduces efficiency.

Figure 4.9 *Spaghetti Data Model*



Despite the location designations associated with each line, or strand of spaghetti, spatial relationships are not explicitly encoded within the spaghetti model; rather, they are implied by their location. This results in a lack of topological information, which is problematic if the user attempts to make measurements or analysis. The computational requirements, therefore, are very steep if any advanced analytical techniques are employed on vector files structured thusly. Nevertheless, the simple structure of the spaghetti data model allows for efficient reproduction of maps and graphics as this topological information is unnecessary for plotting and printing.

In contrast to the spaghetti data model, the **topological data model**[13] is characterized by the inclusion of topological information within the dataset, as the name implies. **Topology**[14] is a set of rules that model the relationships between

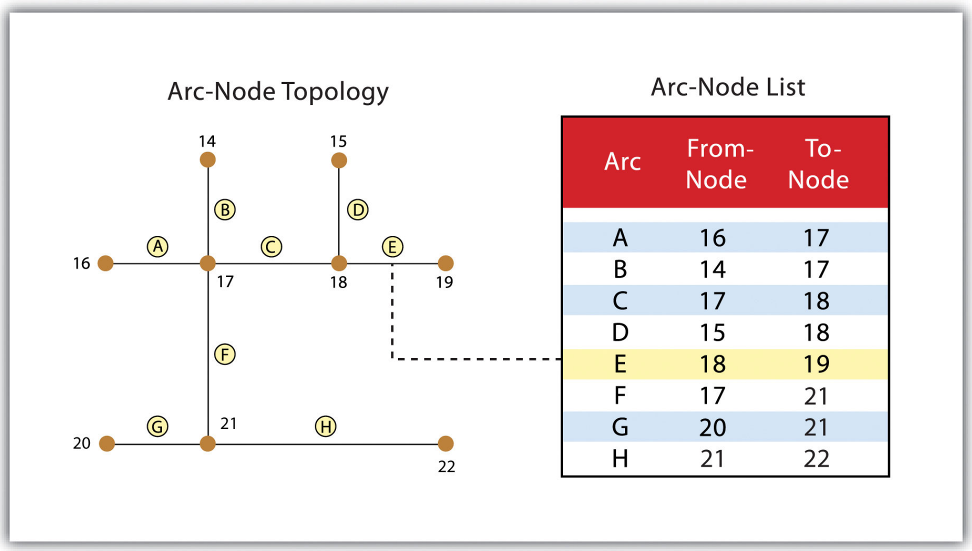
13. A data model characterized by the inclusion of topology.

14. A set of rules that models the relationship between neighboring points, lines, and polygons and determines how they share geometry. Topology is also concerned with preserving spatial properties when the forms are bent, stretched, or placed under similar geometric transformation.

neighboring points, lines, and polygons and determines how they share geometry. For example, consider two adjacent polygons. In the spaghetti model, the shared boundary of two neighboring polygons is defined as two separate, identical lines. The inclusion of topology into the data model allows for a single line to represent this shared boundary with an explicit reference to denote which side of the line belongs with which polygon. Topology is also concerned with preserving spatial properties when the forms are bent, stretched, or placed under similar geometric transformations, which allows for more efficient projection and reprojection of map files.

Three basic topological precepts that are necessary to understand the topological data model are outlined here. First, **connectivity**[15] describes the arc-node topology for the feature dataset. As discussed previously, nodes are more than simple points. In the topological data model, nodes are the intersection points where two or more arcs meet. In the case of arc-node topology, arcs have both a from-node (i.e., starting node) indicating where the arc begins and a to-node (i.e., ending node) indicating where the arc ends (Figure 4.10 "Arc-Node Topology"). In addition, between each node pair is a line segment, sometimes called a link, which has its own identification number and references both its from-node and to-node. In Figure 4.10 "Arc-Node Topology", arcs 1, 2, and 3 all intersect because they share node 11. Therefore, the computer can determine that it is possible to move along arc 1 and turn onto arc 3, while it is not possible to move from arc 1 to arc 5, as they do not share a common node.

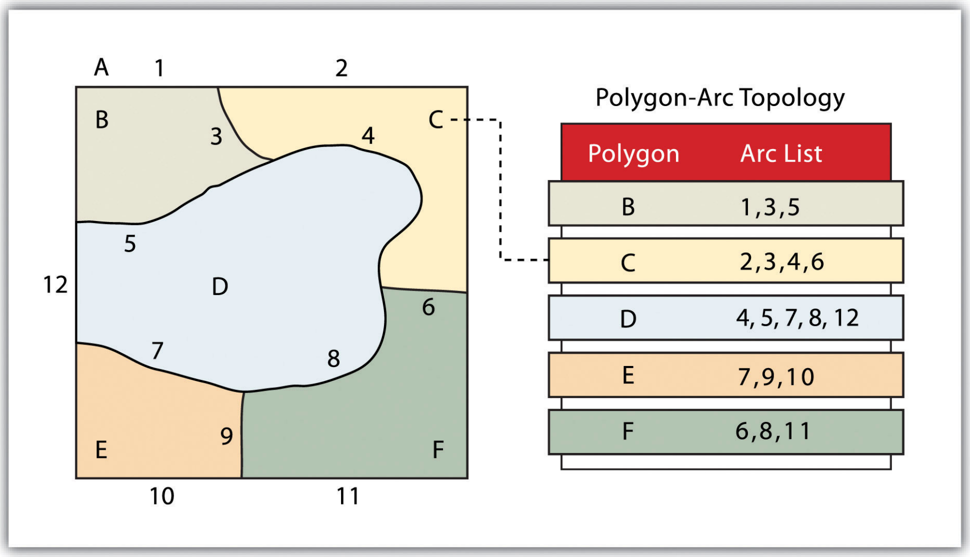
Figure 4.10 *Arc-Node Topology*



15. The topological property of lines sharing a common node.

The second basic topological precept is **area definition**[16]. Area definition states that an arc that connects to surround an area defines a polygon, also called polygon-arc topology. In the case of polygon-arc topology, arcs are used to construct polygons, and each arc is stored only once (Figure 4.11 "Polygon-Arc Topology"). This results in a reduction in the amount of data stored and ensures that adjacent polygon boundaries do not overlap. In the Figure 4.11 "Polygon-Arc Topology", the polygon-arc topology makes it clear that polygon F is made up of arcs 8, 9, and 10.

Figure 4.11 *Polygon-Arc Topology*

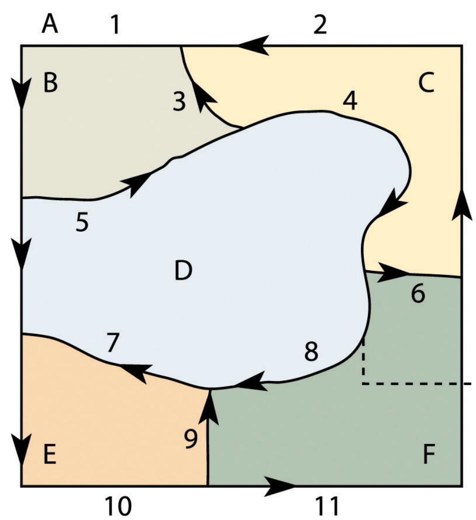


Contiguity[17], the third topological precept, is based on the concept that polygons that share a boundary are deemed adjacent. Specifically, polygon topology requires that all arcs in a polygon have a direction (a from-node and a to-node), which allows adjacency information to be determined (Figure 4.12 "Polygon Topology"). Polygons that share an arc are deemed adjacent, or contiguous, and therefore the "left" and "right" side of each arc can be defined. This left and right polygon information is stored explicitly within the attribute information of the topological data model. The "universe polygon" is an essential component of polygon topology that represents the external area located outside of the study area. Figure 4.12 "Polygon Topology" shows that arc 6 is bound on the left by polygon B and to the right by polygon C. Polygon A, the universe polygon, is to the left of arcs 1, 2, and 3.

16. The topological property stating that line segments connect to surround an area and define a polygon.

17. The topological property of identifying adjacent polygons by recording the left and right side of each line segment.

Figure 4.12 Polygon Topology



Left-Right Topology

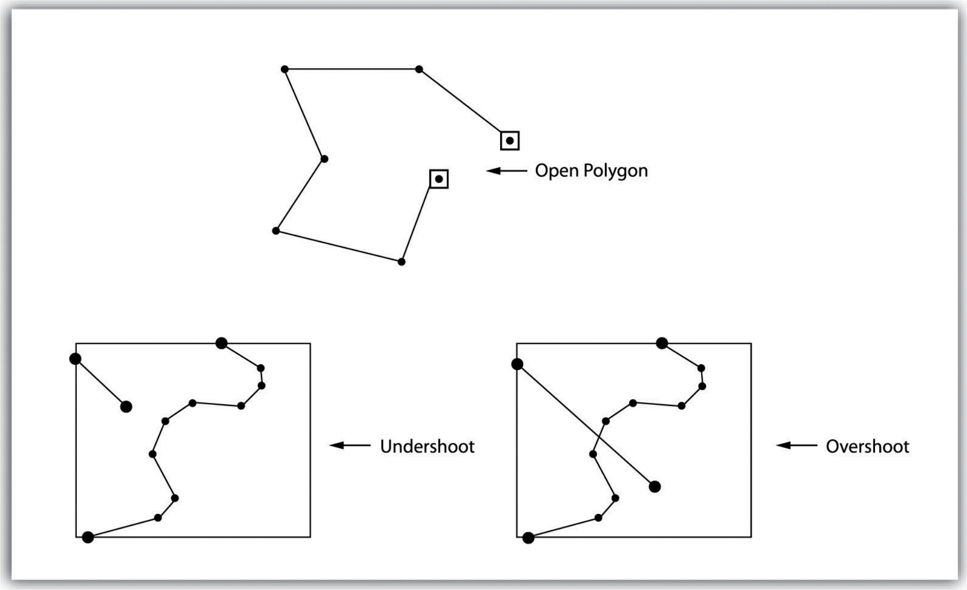
Arc	Left Polygon	Right Polygon
1	A	B
2	C	A
3	B	C
4	C	D
5	B	D
6	C	F
7	E	D
8	F	D
9	E	F
10	E	A

Topology allows the computer to rapidly determine and analyze the spatial relationships of all its included features. In addition, topological information is important because it allows for efficient error detection within a vector dataset. In the case of polygon features, open or unclosed polygons, which occur when an arc does not completely loop back upon itself, and unlabeled polygons, which occur when an area does not contain any attribute information, violate polygon-arc topology rules. Another topological error found with polygon features is the **sliver**[18]. Slivers occur when the shared boundary of two polygons do not meet exactly (Figure 4.13 "Common Topological Errors").

In the case of line features, topological errors occur when two lines do not meet perfectly at a node. This error is called an "undershoot" when the lines do not extend far enough to meet each other and an "overshoot" when the line extends beyond the feature it should connect to (Figure 4.13 "Common Topological Errors"). The result of overshoots and undershoots is a "dangling node" at the end of the line. Dangling nodes aren't always an error, however, as they occur in the case of dead-end streets on a road map.

18. A narrow gap formed when the shared boundary of two polygons do not meet exactly.

Figure 4.13 *Common Topological Errors*



Many types of spatial analysis require the degree of organization offered by topologically explicit data models. In particular, network analysis (e.g., finding the best route from one location to another) and measurement (e.g., finding the length of a river segment) relies heavily on the concept of to- and from-nodes and uses this information, along with attribute information, to calculate distances, shortest routes, quickest routes, and so forth. Topology also allows for sophisticated neighborhood analysis such as determining adjacency, clustering, nearest neighbors, and so forth.

Now that the basics of the concepts of topology have been outlined, we can begin to better understand the topological data model. In this model, the node acts as more than just a simple point along a line or polygon. The node represents the point of intersection for two or more arcs. Arcs may or may not be looped into polygons. Regardless, all nodes, arcs, and polygons are individually numbered. This numbering allows for quick and easy reference within the data model.

Advantages/Disadvantages of the Vector Model

In comparison with the raster data model, vector data models tend to be better representations of reality due to the accuracy and precision of points, lines, and polygons over the regularly spaced grid cells of the raster model. This results in vector data tending to be more aesthetically pleasing than raster data.

Vector data also provides an increased ability to alter the scale of observation and analysis. As each coordinate pair associated with a point, line, and polygon represents an infinitesimally exact location (albeit limited by the number of significant digits and/or data acquisition methodologies), zooming deep into a vector image does not change the view of a vector graphic in the way that it does a raster graphic (see Figure 4.1 "Digital Picture with Zoomed Inset Showing Pixilation of Raster Image").

Vector data tend to be more compact in data structure, so file sizes are typically much smaller than their raster counterparts. Although the ability of modern computers has minimized the importance of maintaining small file sizes, vector data often require a fraction the computer storage space when compared to raster data.

The final advantage of vector data is that topology is inherent in the vector model. This topological information results in simplified spatial analysis (e.g., error detection, network analysis, proximity analysis, and spatial transformation) when using a vector model.

Alternatively, there are two primary disadvantages of the vector data model. First, the data structure tends to be much more complex than the simple raster data model. As the location of each vertex must be stored explicitly in the model, there are no shortcuts for storing data like there are for raster models (e.g., the run-length and quad-tree encoding methodologies).

Second, the implementation of spatial analysis can also be relatively complicated due to minor differences in accuracy and precision between the input datasets. Similarly, the algorithms for manipulating and analyzing vector data are complex and can lead to intensive processing requirements, particularly when dealing with large datasets.

KEY TAKEAWAYS

- Vector data utilizes points, lines, and polygons to represent the spatial features in a map.
- Topology is an informative geospatial property that describes the connectivity, area definition, and contiguity of interrelated points, lines, and polygon.
- Vector data may or may not be topologically explicit, depending on the file's data structure.
- Care should be taken to determine whether the raster or vector data model is best suited for your data and/or analytical needs.

EXERCISES

1. What vector type (point, line, or polygon) best represents the following features: state boundaries, telephone poles, buildings, cities, stream networks, mountain peaks, soil types, flight tracks? Which of these features can be represented by multiple vector types? What conditions might lead you choose one vector type over another?
2. Draw a point, line, and polygon feature on a simple Cartesian coordinate system. From this drawing, create a spaghetti data model that approximates the shapes shown therein.
3. Draw three adjacent polygons on a simple Cartesian coordinate system. From this drawing, create a topological data model that incorporates arc-node, polygon-arc, and polygon topology.

4.3 Satellite Imagery and Aerial Photography

LEARNING OBJECTIVE

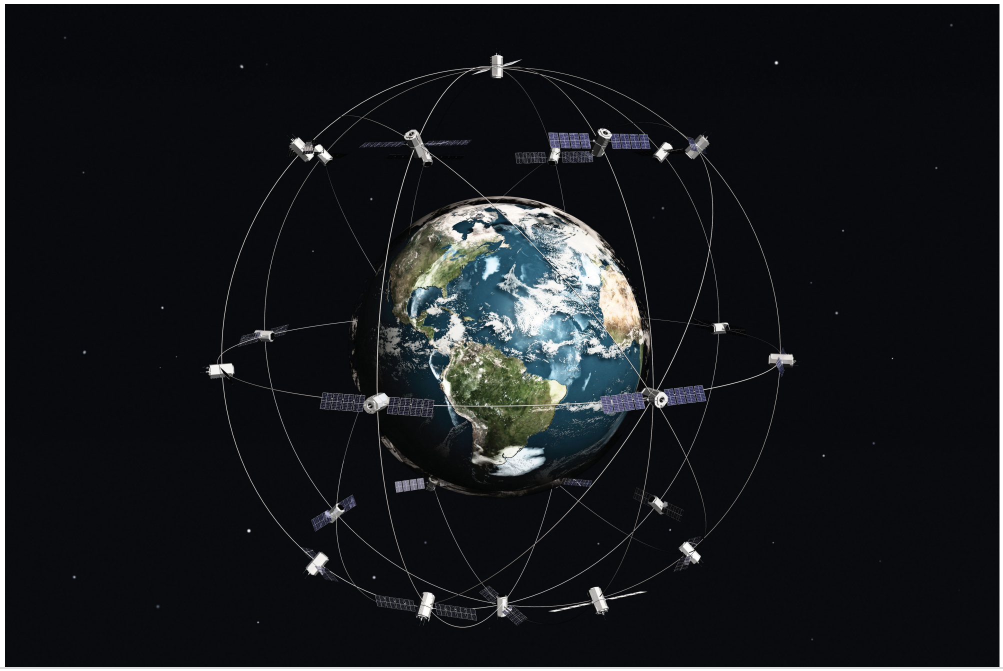
1. The objective of this section is to understand how satellite imagery and aerial photography are implemented in GIS applications.

A wide variety of satellite imagery and aerial photography is available for use in geographic information systems (GISs). Although these products are basically raster graphics, they are substantively different in their usage within a GIS. Satellite imagery and aerial photography provide important contextual information for a GIS and are often used to conduct heads-up digitizing (Chapter 5 "Geospatial Data Management", Section 5.1.4 "Secondary Data Capture") whereby features from the image are converted into vector datasets.

Satellite Imagery

Remotely sensed satellite imagery is becoming increasingly common as satellites equipped with technologically advanced sensors are continually being sent into space by public agencies and private companies around the globe. Satellites are used for applications such as military and civilian earth observation, communication, navigation, weather, research, and more. Currently, more than 3,000 satellites have been sent to space, with over 2,500 of them originating from Russia and the United States. These satellites maintain different altitudes, inclinations, eccentricities, synchronies, and orbital centers, allowing them to image a wide variety of surface features and processes (Figure 4.14 "Satellites Orbiting the Earth").

Figure 4.14 Satellites Orbiting the Earth



Satellites can be active or passive. **Active satellites**[19] make use of remote sensors that detect reflected responses from objects that are irradiated from artificially generated energy sources. For example, active sensors such as radars emit radio waves, laser sensors emit light waves, and sonar sensors emit sound waves. In all cases, the sensor emits the signal and then calculates the time it takes for the returned signal to "bounce" back from some remote feature. Knowing the speed of the emitted signal, the time delay from the original emission to the return can be used to calculate the distance to the feature.

Passive satellites[20], alternatively, make use of sensors that detect the reflected or emitted electromagnetic radiation from natural sources. This natural source is typically the energy from the sun, but other sources can be imaged as well, such as magnetism and geothermal activity. Using an example we've all experienced, taking a picture with a flash-enabled camera would be active remote sensing, while using a camera without a flash (i.e., relying on ambient light to illuminate the scene) would be passive remote sensing.

The quality and quantity of satellite imagery is largely determined by their resolution. There are four types of resolution that characterize any particular remote sensor (Campbell 2002).Campbell, J. B. 2002. *Introduction to Remote Sensing*. New York: Guilford Press. The **spatial resolution**[21] of a satellite image, as described previously in the raster data model section (Section 4.1 "Raster Data Models"), is a

19. Remote sensors that detect reflected responses from objects that are irradiated from artificially generated energy sources.

20. Remote sensors that detect the reflected or emitted electromagnetic radiation from natural sources.

21. The smallest distance between two adjacent features that can be detected in an image.

direct representation of the ground coverage for each pixel shown in the image. If a satellite produces imagery with a 10 m resolution, the corresponding ground coverage for each of those pixels is 10 m by 10 m, or 100 square meters on the ground. Spatial resolution is determined by the sensors' instantaneous field of view (IFOV). The IFOV is essentially the ground area through which the sensor is receiving the electromagnetic radiation signal and is determined by height and angle of the imaging platform.

Spectral resolution[22] denotes the ability of the sensor to resolve wavelength intervals, also called bands, within the electromagnetic spectrum. The spectral resolution is determined by the interval size of the wavelengths and the number of intervals being scanned. Multispectral and hyperspectral sensors are those sensors that can resolve a multitude of wavelengths intervals within the spectrum. For example, the IKONOS satellite resolves images for bands at the blue (445–516 nm), green (506–95 nm), red (632–98 nm), and near-infrared (757–853 nm) wavelength intervals on its 4-meter multispectral sensor.

Temporal resolution[23] is the amount of time between each image collection period and is determined by the repeat cycle of the satellite's orbit. Temporal resolution can be thought of as true-nadir or off-nadir. Areas considered true-nadir are those located directly beneath the sensor while off-nadir areas are those that are imaged obliquely. In the case of the IKONOS satellite, the temporal resolution is 3 to 5 days for off-nadir imaging and 144 days for true-nadir imaging.

The fourth and final type of resolution, **radiometric resolution**[24], refers to the sensitivity of the sensor to variations in brightness and specifically denotes the number of grayscale levels that can be imaged by the sensor. Typically, the available radiometric values for a sensor are 8-bit (yielding values that range from 0–255 as 256 unique values or as 2^8 values); 11-bit (0–2,047); 12-bit (0–4,095); or 16-bit (0–63,535) (see Chapter 5 "Geospatial Data Management", Section 5.1.1 "Data Types" for more on bits). Landsat-7, for example, maintains 8-bit resolution for its bands and can therefore record values for each pixel that range from 0 to 255.

Because of the technical constraints associated with satellite remote sensing systems, there is a trade-off between these different types of resolution. Improving one type of resolution often necessitates a reduction in one of the other types of resolution. For example, an increase in spatial resolution is typically associated with a decrease in spectral resolution, and vice versa. Similarly, **geostationary satellites**[25] (those that circle the earth proximal to the equator once each day) yield high temporal resolution but low spatial resolution, while **sun-synchronous satellites**[26] (those that synchronize a near-polar orbit of the sensor with the sun's illumination) yield low temporal resolution while providing high spatial resolution.

22. The ability of a sensor to resolve wavelength intervals, also called bands, within the electromagnetic spectrum.

23. The amount of time between each image collection period determined by the repeat cycle of a satellite's orbit.

24. The sensitivity of a remote sensor to variations in brightness.

25. Satellites that circle the earth proximal to the equator once each day.

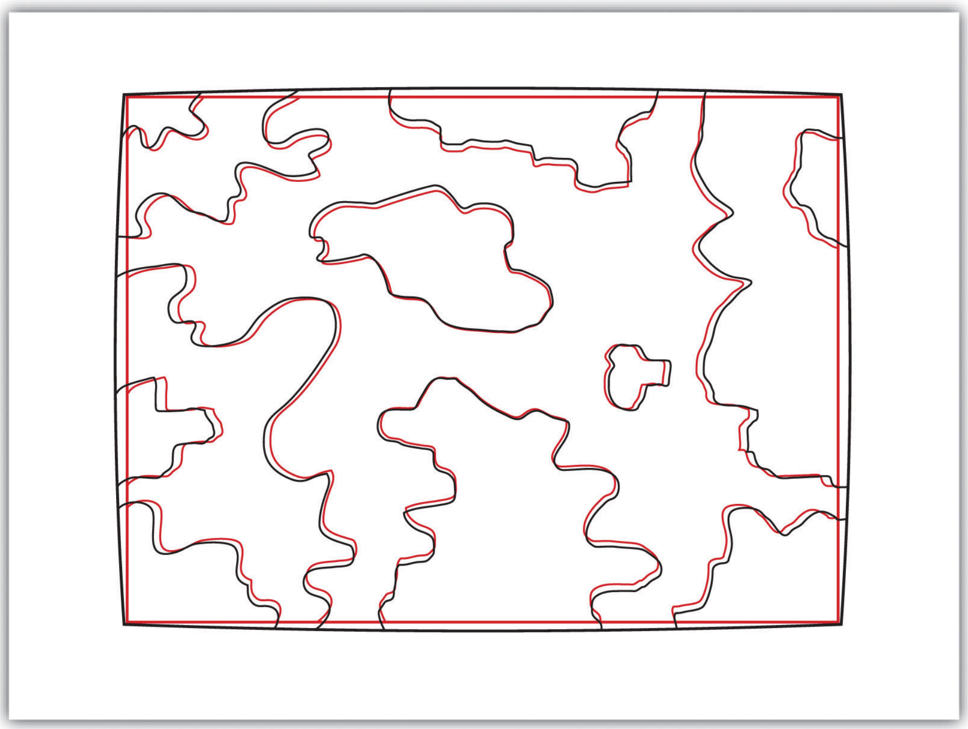
26. Satellites that synchronize a near-polar orbit with the sun's illumination.

Although technological advances can generally improve the various resolutions of an image, care must always be taken to ensure that the imagery you have chosen is adequate to the represent or model the geospatial features that are most important to your study.

Aerial Photography

Aerial photography, like satellite imagery, represents a vast source of information for use in any GIS. Platforms for the hardware used to take aerial photographs include airplanes, helicopters, balloons, rockets, and so forth. While aerial photography connotes images taken of the visible spectrum, sensors to measure bands within the nonvisible spectrum (e.g., ultraviolet, infrared, near-infrared) can also be fixed to aerial sources. Similarly, aerial photography can be active or passive and can be taken from vertical or oblique angles. Care must be taken with aerial photographs as the sensors used to take the images are similar to cameras in their use of lenses. These lenses add a curvature to the images, which becomes more pronounced as one moves away from the center of the photo (Figure 4.15 "Curvature Error Due to Lenticular Properties of Camera").

Figure 4.15 Curvature Error Due to Lenticular Properties of Camera



Another source of potential error in an aerial photograph is relief displacement. This error arises from the three-dimensional aspect of terrain features and is seen as apparent leaning away of vertical objects from the center point of an aerial photograph. To imagine this type of error, consider that a smokestack would look like a doughnut if the viewing camera was directly above the feature. However, if this same smokestack was observed near the edge of the camera's view, one could observe the sides of the smokestack. This error is frequently seen with trees and multistory buildings and worsens with increasingly taller features.

Orthophotos[27] are vertical photographs that have been geometrically "corrected" to remove the curvature and terrain-induced error from images (Figure 4.16 "Orthophoto"). The most common orthophoto product is the digital ortho quarter quadrangle (DOQQ). DOQQs are available through the US Geological Survey (USGS), who began producing these images from their library of 1:40,000-scale National Aerial Photography Program photos. These images can be obtained in either grayscale or color with 1-meter spatial resolution and 8-bit radiometric resolution. As the name suggests, these images cover a quarter of a USGS 7.5 minute quadrangle, which equals an approximately 25 square mile area. Included with these photos is an additional 50 to 300-meter edge around the photo that allows users to mosaic many DOQQs into a single, continuous image. These DOQQs are ideal for use in a GIS as background display information, for data editing, and for heads-up digitizing.

27. Vertical photographs that have been geometrically "corrected" to remove the curvature and terrain-induced error from images.

Figure 4.16 Orthophoto

Source: Data available from U.S. Geological Survey, Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD.

KEY TAKEAWAYS

- Satellite imagery is a common tool for GIS mapping applications as this data becomes increasingly available due to ongoing technological advances.
- Satellite imagery can be passive or active.
- The four types of resolution associated with satellite imagery are spatial, spectral, temporal, and radiometric.
- Vertical and oblique aerial photographs provide valuable baseline information for GIS applications.

EXERCISE

1. Go to the EarthExplorer website (http://edcsns17.cr.usgs.gov/EarthExplorer) and download two satellite images of the area in which you reside. What are the different spatial, spectral, temporal, and radiometric resolutions for these two images? Do these satellites provide active or passive imagery (or both)? Are they geostationary or sun-synchronous?