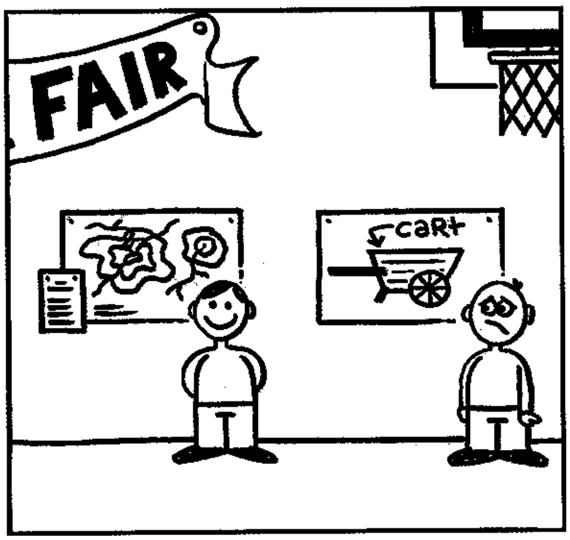
CHAPTER 2

GIS's Roots in Cartography

Blow winds, and crack your cheeks! rage! blow!
You cataracts and hurricanoes, spout
Till you have drenched our steeples, drowned the cocks!
Your sulphurous and thought-executing fires,
Vault couriers to oak-cleaving thunderbolts,
Singe my head white! And thou, all-shaking thunder,
Strike flat the thick rotundity o' the world!
—Shakespeare, King Lear, *act 3, sc. 2.*

It was difficult to understand exactly what was happening, but the general impression was favourable, and I remember being struck by a message from a young officer in a tank of the 7th Armoured Division, "Have arrived at the second B in Buq Buq." —Sir Winston Churchill, The Second World War, Vol. 2, Their Finest Hour, *1949.*



Completely due to a lack of attendance in "Introduction to GIS" lectures, Bradley's science fair project enters the school "Cartography Hall of Shame."

2.1 MAP AND ATTRIBUTE INFORMATION

Information permeates our society, but fortunately, it takes on only a few tangible forms. Without the preordering of information, much of it would not be usable by humans raphy

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in their everyday lives. Among these are the everyday methods for organizing information, visible by everyday examples such as the Yellow Pages, baseball box scores, magazines, or the television listings. Most information is usually preordered into lists, numbers, tables, text, pictures, maps, or indexes. Clusters or chunks of similar information, usually numbers and text, are called *data*. When data are entered into the computer, we store them as *files* and refer to them collectively as a *database*. In database language, the items that we gather information about are referred to as *attributes*, and individual data items as *records*. For example, we may have a shoebox filled with baseball cards. On each card (record) in the *database* (shoebox) we have a picture and some *values* for the attributes. The attributes may be the player's name, team, batting average, or the years playing on which teams in the major leagues. Values of the attributes could be "*Jason Giambi*," "*The New York Yankees*," *0.3084*, and *2001–02* (Figure 2.1).

A basic difference between these types of information and the information that is collected into geographic information systems is that GIS information has associated with it an underlying *geography*, or descriptions of *locations* on the face of the earth. This means that pictures and especially maps can be a database, too. A link to the earth must somehow be placed into the GIS database, so that we can refer to the data by the location—and the location by the data. With this feature comes the fact that we can now manage the data using the underlying geography, the attributes, or both.

This is possible for our baseball card example. On each card we have the name of the team and the city where the team plays. If we went to an atlas and looked up the *latitude* and *longitude* of the city, we would be *geocoding* the baseball cards. If we then entered the latitudes and longitudes in pencil on each card, we would have a geographic information system of sorts, although we would have to enter the cards into a computer to really have a GIS. The data are now more usable, because if we have the capability of mapping in our GIS, we can place any baseball card information on a map. Later, we will see that this is only the first of many new abilities that georeferencing the data brings. For now, however, location is everything!

The power of the GIS is in allowing the attribute and the geographic or map information to be linked together in a useful way. For example, we can search the data both by the attributes (find all players with a batting average over 0.300) and by using the map (find all the players who play within 200 miles of Yankee Stadium). Obviously, if the two sorts of information are linked, we can use either one to search the other, or we can use them together. So we could ask the GIS, for example, to select from the database all players who bat left-handed, have better than a 0.300 average, and play no more than 200 miles from New York. Furthermore, as we have locations, we can answer the query about the data with a map rather than a list.

Central to this map and attribute data use is finding a way to *link* the map with the attributes. As we are using a computer, obviously the link should be in the form of numbers. When we locate people and houses, we usually use street addresses rather than numbers. Later in the book, we will see that a GIS gives us the power to move from one to the other of these descriptions of location with numbers. For now, however, we need a simple number description for a location. In the example here, we used

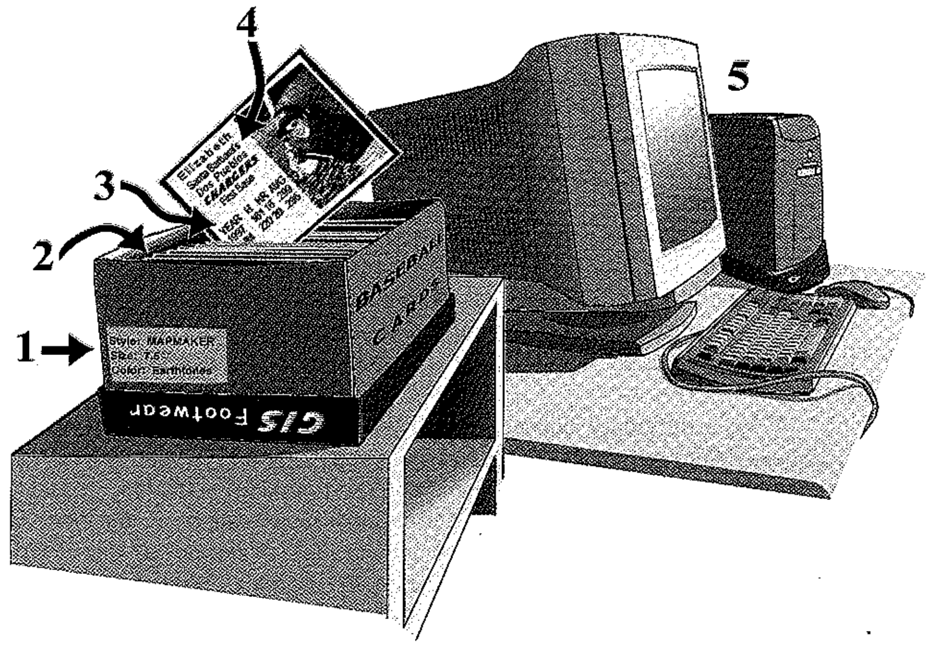

FIGURE 2.1: The elements of a GIS. (1) the database (shoebox); (2) the records (baseball cards); (3) the attributes (the categories on the cards, such as a batting average, (4) the geographic information (locations of the team's stadium in latitude and longitude); (5) a means to use the information (the computer).

latitude and longitude. Many GIS packages use latitude and longitude, so this is quite appropriate.

Before we move on, however, it is important to get a feel for what these geographic numbers mean and how they correspond to places on both the earth and the map. It is a little more complex than it first seems, but with a little digression, we can quickly come up to speed, and even be experts. This means that to understand GISs, we need to know a little *cartography*, which is the science that deals with the construction, use, and principles behind maps and map use. The basics here go back a long way, to the work of the ancient Greek Ptolemy, the father of latitude and longitude and of map projections. A little digression, therefore, is called for on the way that we "strike flat the thick rotundity o' the world."

2.2 MAP SCALE AND PROJECTIONS

2.2.1 The Shape of the Earth

A rather astounding fact, and a true one, so I am told, is that there are many more members of the Flat Earth Society than of the American Cartographic Association (now the Cartography and Geographic Information Society). Nevertheless, it would be hard to maintain that the earth is flat, appearances aside. A trip to the beach to observe a ship sailing into the distance reveals not a visible dot that gets smaller and smaller, but a

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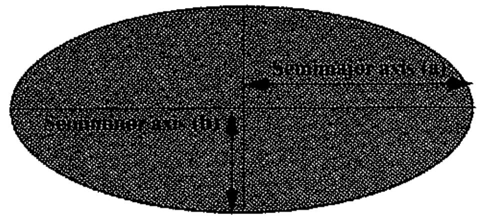
dot that eventually just disappears over the curve of the earth. When high in a plane at cruising altitude, hold a ruler at arm's length up to the horizon and judge for yourself whether the horizon line is straight. Two issues suggest themselves if the idea is to "contain" the earth, or parts of its surface, onto a map inside a GIS. First, how big is the earth? Second, how can a flat map (and simple numbers) be used to describe locations on the earth's surface?

First of all, how big? This question becomes one of what shape we use as a description of the earth. Although for many mapping applications the earth can be assumed to be a *perfect sphere*, there is a small but significant difference between the distance around the earth pole to pole (39,939,593.9 meters) versus the distance around the equator (40,075,452.7 meters). This is because the earth resembles more closely than the sphere a figure called an *oblate ellipsoid* or *spheroid*, the three-dimensional shape you get by rotating an ellipse about its shorter axis (Figure 2.2).

There have been many attempts to measure the size and shape of the earth's ellipsoid. In 1866 the mapping of the United States was based on the ellipsoid measured by Sir Alexander Ross Clarke, which had a basis in measurements taken in Europe, Russia, India, South Africa, and Peru. The Clarke 1866 ellipsoid had an equatorial radius of 6,378,206.4 meters and a polar radius of 6,356,538.8 meters. This gave a "flattening" of the ellipsoid of 1/294.9787 (Figure 2.3). In 1924, a simpler measure of 1/297 with a longer radius of 6,378,388 was adopted as an international standard. As mapping had already begun in the United States, the older values were used, adopted as the North American Datum of 1927 (NAD27).

The satellite era has brought with it more accurate means of measurement, including the global positioning system (GPS). An estimate of the ellipsoid allows calculation of the elevation of every point on earth, including sea level, and is often called a *datum*. Recent datums have been calculated using the center of the earth as a reference point instead of a point on the ground as was the case before. In 1983 a new datum was adopted for the United States, called the North American Datum of 1983 (NAD83), based on measurements taken in 1980 and accepted internationally as the geodetic

FIGURE 2.2: Sphere and ellipsoid (or spheroid). Earth's ellipsoid is actually only about 1/300 off from the sphere.



$$f = 1 - \frac{b}{a}$$

For the WGS84
$a = 6{,}378{,}137$
$b = 6{,}356{,}752.3$, so $f = 1/298.257$

FIGURE 2.3: The ellipsoid. The long axis is the major axis, the short the minor axis. Half of each of these lengths is used to calculate the flattening of the ellipsoid.

reference system (GRS80). Efforts have been under way since then to make the slight necessary corrections to maps of the United States, which amount to about 300 meters in places.

The U.S. military has also adopted the GRS80 ellipsoid but refined the values slightly in 1984 to make the world geodetic system (WGS84). It is important that when maps are to be used that the datum and ellipsoid reference information be known, as at large scales there can be major differences, especially in elevations (Figure 2.4). The datum and ellipsoid are also essential to know when using a GPS receiver, as coordinates will be different in each, sometimes by a significant distance.

As a final complication, the science of geodesy, which measures the earth's size, shape, and gravitational fields exactly, has mapped out all of the local variations from the ellipsoid and calls the resultant surface a *geoid*. Only under highly demanding circumstances would a geoid be used in a GIS. In fact, in cartography, a common reference base is the sphere. The ellipsoid becomes necessary when we deal with finer, more detailed, or "large" map scales, and differences caused by not using it can become significant at scales coarser (smaller) than about 1 : 100,000 but are noticeable even at scales less detailed than 1 : 50,000.

2.2.2 Map Scale

All maps, whether on a sheet of paper or inside a computer, are reductions in size of the earth. A map at one-to-one scale (1 : 1) would be virtually useless; you would barely be able to unfold it. In cartography, the term *representative fraction* is used for the amount of scaling. A representative fraction is the ratio of distances on the map to the same distances on the ground. A model airplane or train is usually at about a 1 : 40 scale. This means that every distance on the model is one-fortieth of its size on the real object. The world is so big that for maps we often reach some pretty small values for the representative fraction. Just a couple of examples will show why this is necessary.

First, let's use the WGS84 numbers for earth's size. The two ellipsoid distances average to 6,367,444.65 meters. To calculate the circumference of a circle of this size, we multiply by two times Π.

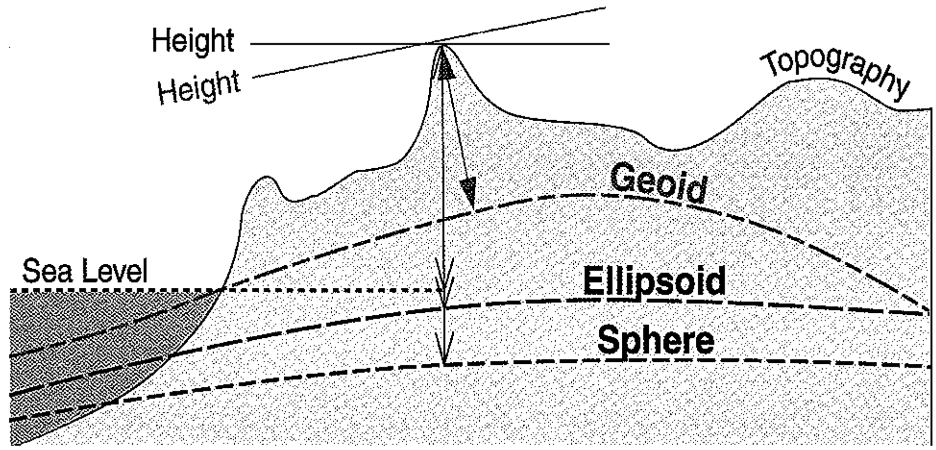


FIGURE 2.4: Elevations defined with reference to a sphere, ellipsoid, geoid, or local sea level will all be different. Even locations as latitude and longitude will vary somewhat. When linking field data such as GPS with a GIS, the user must know what base to use.

This gives a distance "around the average world" of 40,078,346.23 meters. Table 2.1 shows what this number becomes when multiplied by various representative fractions to give map distances associated with the earth's circumference. A quick look at Table 2.1 reveals a suspicious number. At 1 : 40,000,000 the earth's circumference maps onto a meter almost exactly. This is because the original definition of the meter was one ten-millionth of the distance from the equator to the north pole measured along the meridian passing through Paris, France. It is fairly obvious that the metric system makes these computations far easier, as we don't have to convert feet to inches and miles.

Over the range of scales shown in Table 2.1, the earth's equator would map onto about the circumference of a gumball at 1 : 400,000,000, (Figure 2.5) a baseball at 1 : 177,000,000, a basketball at 1 : 40,000,000, but at 1 : 50,000 would map onto about 10 Manhattan city blocks! At 1 : 1,000, a very detailed scale used in engineering and construction maps, the earth's equator would map onto twice the length of Manhattan Island. A convenient scale to hold in mind is 1 : 40,000,000, with the equator mapped across a 1-meter poster-size world map. Obviously, we don't use all scales in cartography. Most national mapping for GIS use is between 1 : 1,000,000 and 1 : 10,000. In the United States, key scales are 1 : 100,000 and 1 : 24,000, at which national coverages are available.

Another important factor to keep in mind is that a GIS is largely *scaleless*. The data can be multiplied up or reduced to any size that is appropriate. However, as we get farther and farther from the scale at which a map was made before it was captured into the GIS, problems of scale appear. As we enlarge maps, detail does not appear as if by magic. A smooth coastline, for example, remains smooth and imprecise as we enlarge it. On the other hand, if we keep reducing the scale of a map without eliminating detail, the map becomes so "dense" with data that we cannot see the forest for the trees. The proper presentation of information at a particular scale is one of the most important goals of cartographic design.

A last point to keep in mind as we finish this short discussion of map scale is that only on a globe is a scale constant. As we move the map from the curved surface of the

TABLE 2.1: Lengths of the Equator at Different Map Scales

Representative Fraction	Map Distance (m)	Distance in Feet (approx.)
1 : 400,000,000	0.10002	0.328 (3.9 inches)
1 : 40,000,000	1.0002	3.28
1 : 10,000,000	4.0008	13.1
1 : 1,000,000	40.008	131
1 : 250,000	160.03	525
1 : 100,000	400.078	1,312
1 : 50,000	800.157	2,625
1 : 24,000	1,666.99	5,469 (1.036 miles)
1 : 10,000	4,000.78	13,126 (2.486 miles)
1 : 1,000	40,007.8	131,259 (24.86 miles)

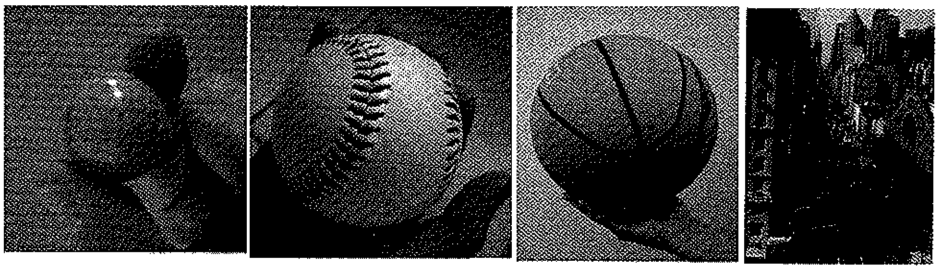


FIGURE 2.5: Assuming a sphere, the earth maps onto a gumball at 1 : 470,000,000; a baseball at 1 : 177,000,000 and a basketball at 1 : 40,000,000. At 1 : 50,000 the earth's circumference maps on 10 city blocks.

sphere or ellipsoid to the flat surface of paper or the computer screen, we necessarily have to distort the map in some way. The part of cartography that deals with this problem of putting a round earth onto flat paper is called *map projections*.

2.2.3 Map Projections

Given that the earth can be approximated by a shape like the sphere or the ellipsoid, how can we go about converting data in latitude and longitude into a flat map, with x and y axes? The simplest way is to ignore the fact that latitude and longitude are angles at the center of the earth, and just pretend that they are x and y values. Figure 2.6 shows this arrangement. Obviously, the map will range from 90 degrees north to 90 degrees south, and from 180 degrees east to 180 degrees west.

The corresponding (x, y) values are from $(-180, -90)$ to $(+180, +90)$. This map is now a *map projection*, because the earth's geographical (latitude and longitude) coordinates have been "mapped" or projected onto a flat surface. Obviously this can be done in many ways. We can "project" the sphere (or the ellipsoid) onto any of three flat surfaces and then unfold them to make the map. These can be the plane (as previously), the cylinder, or the cone. Projections onto these three surfaces are

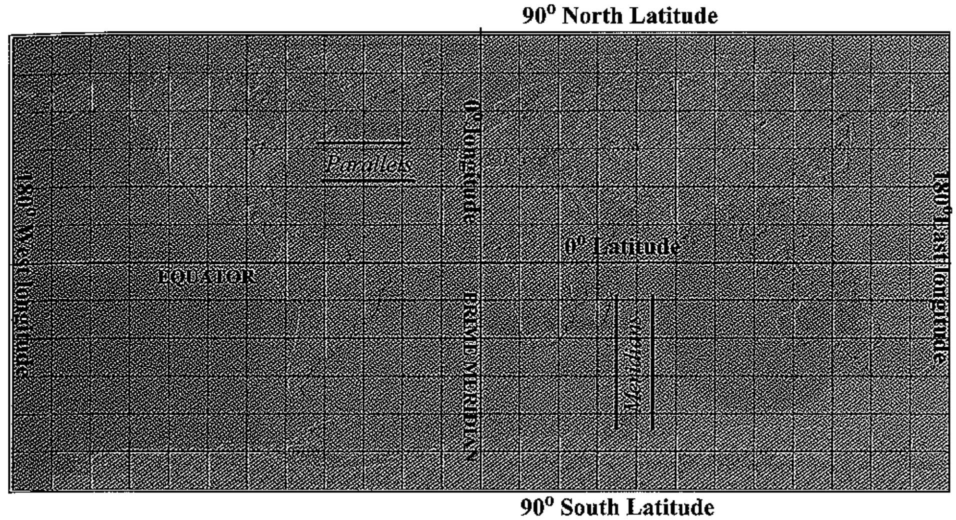


FIGURE 2.6: Geographic coordinates. The familiar latitude and longitude system, simply converting the angles at the earth's center to coordinates, gives the basic equirectangular projection. The map is twice as wide as high (360° east-west, 180° north-south).

called *azimuthal*, *cylindrical*, and *conic*, respectively. Examples of each are shown in Figure 2.7.

We can also choose how the mapping takes place with relationship to earth's surface. We can have the figure, such as the cone or the cylinder, "cut" through the earth. The resulting projection, shown in Figure 2.8, is called *secant*. So, for example, if a cone cuts the earth we would have a secant conic projection. The line on the map where the "cut" falls on the projection is important because it is a line along which the earth and the map match exactly, just as on a globe at the same scale, with no distortion. If this line coincides with a parallel of latitude, it is often called a *standard parallel*. Figure 2.8 shows a secant conic projection with two standard parallels. On or near these lines the map is most accurate. Similarly, there is no hard-and-fast rule that we have to orient the figure we are using in the projection with the earth's polar or rotation axis. If we align instead to a line at 90 degrees to this axis, we call the projection *transverse*. If we orient the projection axis at another angle, we call the projection *oblique* (Figure 2.9).

Cartographers have devised thousands of different map projections. Fortunately, they all fall into a set of "types" that are quite easily understood. The simplest way to evaluate a projection is by how it distorts the earth's surface during the transformation from a sphere or ellipsoid to a flat map. Some projections preserve the property of local shape, so that the outline of a small area like a state or a part of a coastline is correct. These are called *conformal* projections. They are easily identified, because on a conformal projection the lines of the latitude and longitude grid (called the *graticule*) meet at right angles, the way they do on a globe, although not all right-angle graticules mean conformal projections. Conformal projections are employed mostly

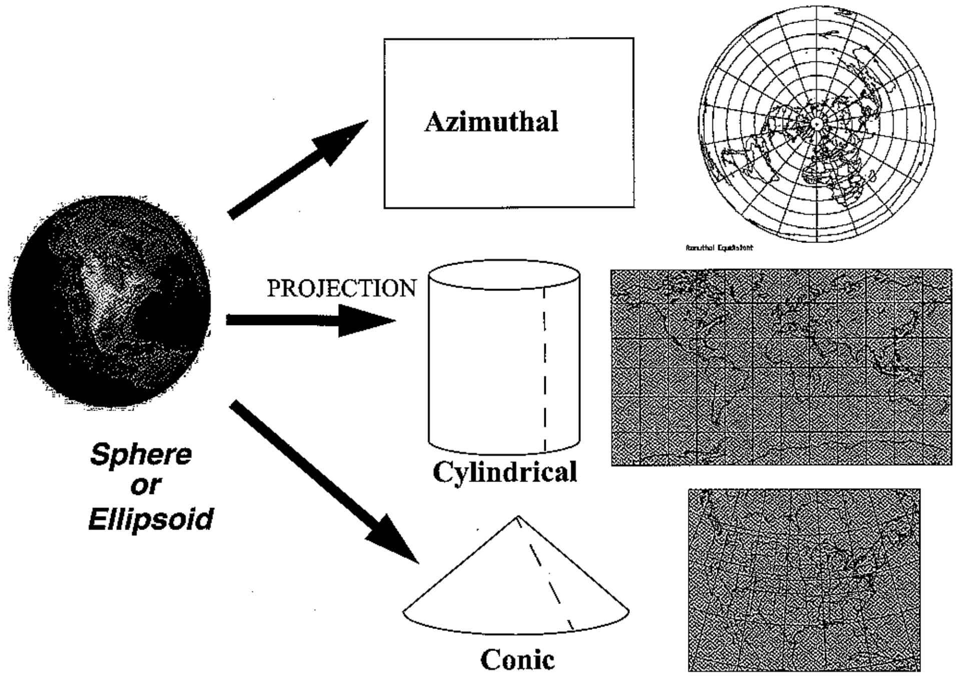


FIGURE 2.7: The earth can be projected in many ways, but basically onto three shapes that can be unrolled into a flat map: a flat plane, a cylinder, and a cone.

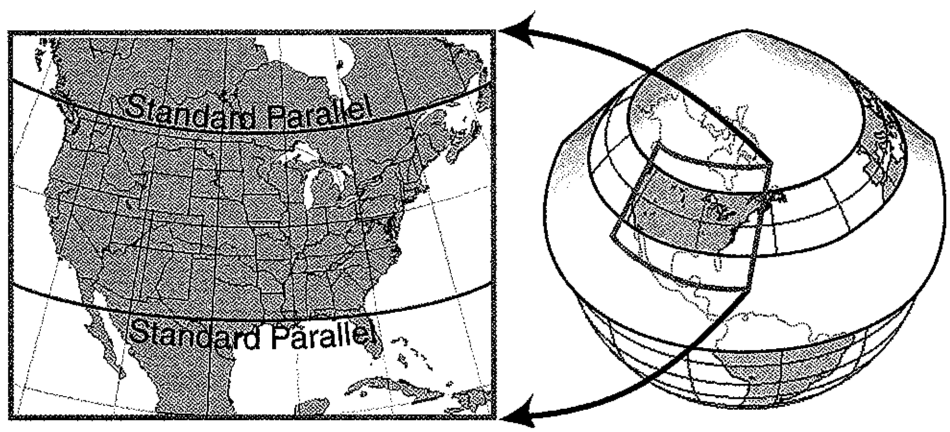
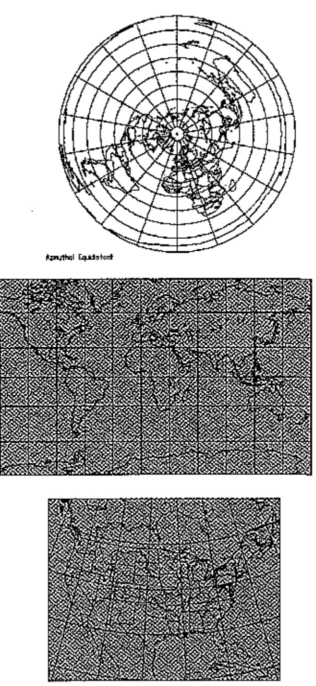


FIGURE 2.8: The projection in this figure is a secant conic projection. The figure also illustrates standard parellels. The conic projection cuts through the globe, and the earth is projected both in and out onto it. Lines of true scale, where the cylinder and sphere touch, become standard parallels. If the touching is along one line, the projection is tangent and has one standard parallel.



to three shapes that can be unrolled

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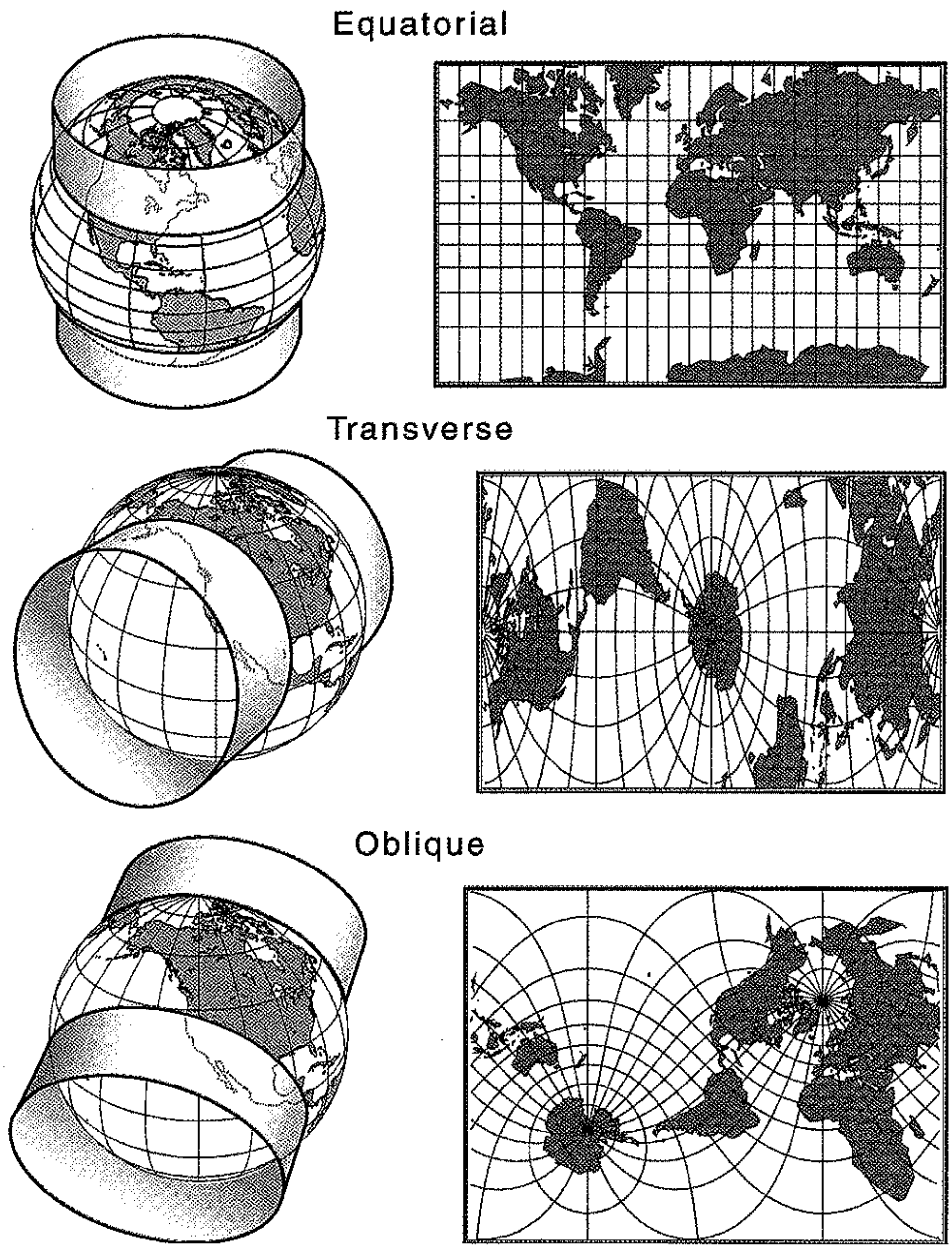


FIGURE 2.9: Variations on the Mercator (pseudocylindrical) projection shown as secant.

for maps that must be used for measuring directions, because they preserve directions around any given point. Examples are the Lambert conformal conic and the Mercator projections.

At the other extreme are projections that preserve the property of area. Many GIS packages compute and use area in all sorts of analyses, and as such must have area mapped evenly across the surface. Projections that preserve area are called *equal area* or *equivalent*. On an equivalent projection, all parts of earth's surface are shown with their correct area, as on the sphere or ellipsoid. Examples are the Albers equal area and the sinusoidal projections.

A third category of projections is the set that preserves distances but only along one or a few lines between places on the map. The simple conic and the azimuthal equidistant projections are examples. These projections are useful only if distances are critical, and are infrequently used in GIS. A final category is that of the miscellaneous projections. These are often a compromise, in that they are neither conformal nor equivalent, and sometimes are interrupted or broken to minimize distortion. Similarly, projections are sometimes the average of two or more similar projections. Examples are the Goode's homolosine (made by patching different projections together) and the Robinson projection (Figure 2.10).

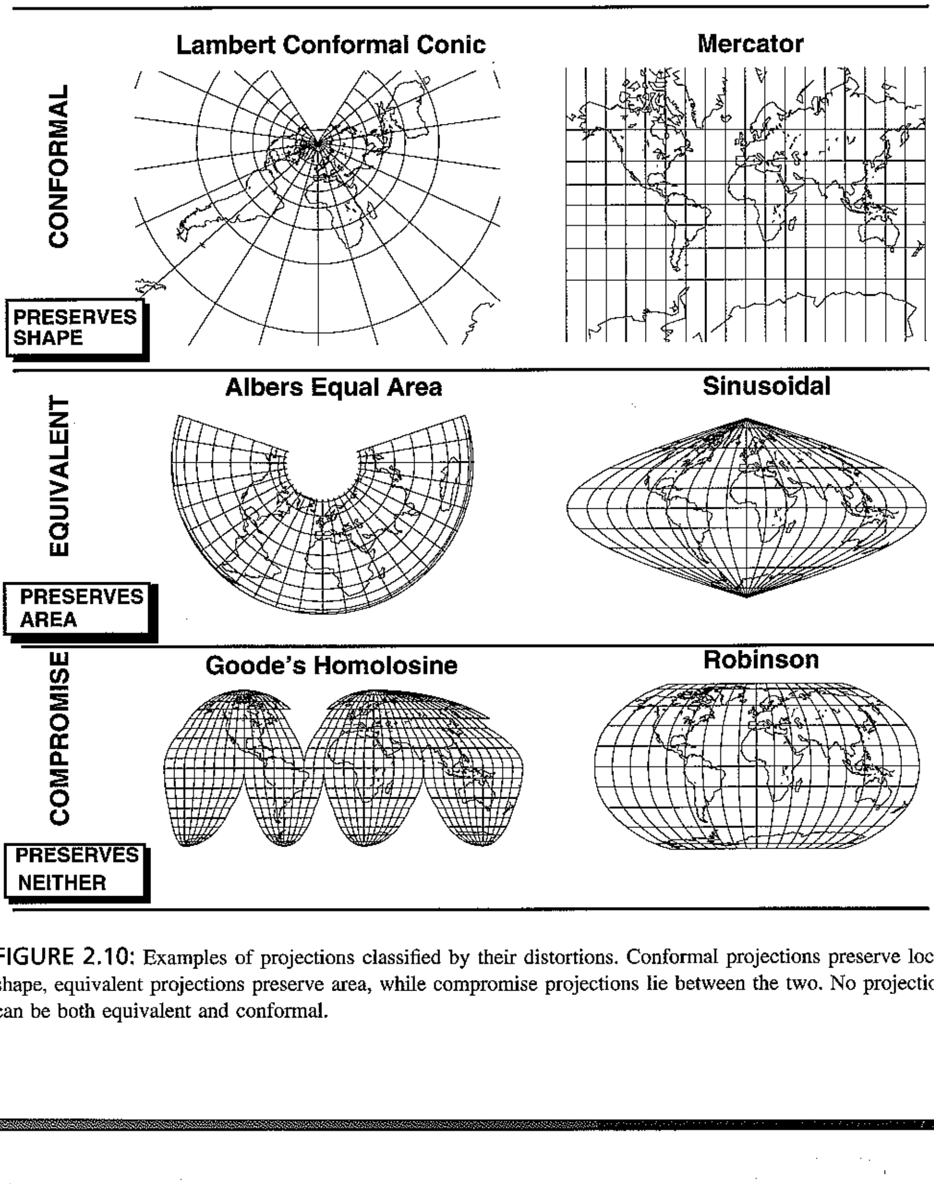
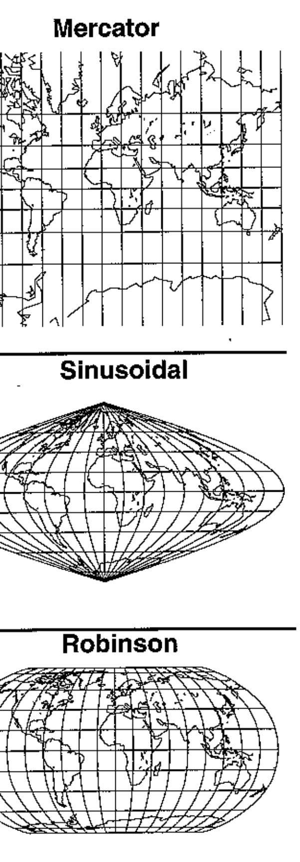


FIGURE 2.10: Examples of projections classified by their distortions. Conformal projections preserve local shape, equivalent projections preserve area, while compromise projections lie between the two. No projection can be both equivalent and conformal.



The most important implications of map projections for GIS are the following. First, the larger the area involved, the more important the mapping errors due to the projection become. At 1 : 24,000 scale, the errors are already significant, and at smaller scales like 1 : 1 million they are major. Second, the projection used should suit the GIS application. If directions or bearings from point to point are important, obviously a conformal projection is called for. If the analysis within the GIS consists of comparing or calculating areas or values based on areas, such as densities, then an equivalent projection is essential. Finally, to overlay or edge-match any two maps, they must be on the same map projection.

Many GIS packages have the ability to convert geographic coordinates to several different map projections. Some allow conversion backwards, from map coordinates in a projection to latitude and longitude. Obviously, this ability is rather important to the power and capability of a GIS, because usually GIS maps come from many different sources.

Finally, certain countries, and especially certain coordinate systems, rely entirely on the ability to work in a particular map projection, with a particular ellipsoid or a specific datum. In the United States, for example, the bulk of the 1 : 24,000 topographic map series of the US Geological Survey uses a polyconic projection, the Clarke 1866 ellipsoid, and the NAD27 datum. The recent movement to the NAD83 datum and its corresponding ellipsoid the GRS80, have "moved" features by as much as 300 meters on the ground or 12.5 millimeters (0.49 inch) on a 1 : 24,000 map. If the GIS user makes a basic mistake in comparing or assembling maps on different projections, based on different ellipsoids, and with different datums, many complex errors can result. This is especially important when data are to be captured from a map into the computer, as we will see in Chapter 3.

2.3 COORDINATE SYSTEMS

When we describe where we are, we usually give the place with reference to somewhere else. Giving directions, for example, we would say, "Go down to the second traffic light, turn right, then continue until you see the diner on the left, then take the second right." When we describe the location of a house or business, we might give the street address, "695 Park Avenue," for example. A *street address* is also a reference to another place, simply saying "Go to the street named Park Avenue and find the building labeled 695." Geography calls such references to locations *relative location*, because they give locations with respect to some other place. Later we will see that a GIS *can* handle some relative locations, such as street addresses. It can only do it, however, by fixing locations with respect to the earth as a whole. This is called an *absolute location*, because it is fixed with respect to an origin, a "zero point." For latitude and longitude, we use the earth's *equator* and the *prime meridian* as the system's origin. The location of the point, actually in the ocean off West Africa, is not critical, but locations fixed using the origin are indeed important.

Converting maps into numbers requires that we choose a standard way to encode locations on the earth. Maps are drawn (whether by computer or not) on a flat surface such as paper. Locations on the paper can be given in *map millimeters* or inches starting at the lower left-hand corner. A computer plotter or a printer can understand these dimensions also, and usually requires that the locations be given in (x, y) format; that is, an east-west distance or *easting*, followed by a north-south distance or *northing*. This pair of numbers is called a *coordinate pair* or, more usually, a *coordinate*. Standard ways of listing coordinates are then called *coordinate systems*. Maps on common coordinate systems are automatically aligned with each other.

A significant problem with coordinates is that while the map dimensions are simple and the (x, y) axes are at right angles to each other, locations on earth's surface are not so simply derived. The first and foremost problem is that a flat map of all or part of earth's surface is necessarily on a map projection. Something has been distorted to make the surface flat, usually scale, shape, area, or direction. On our flat map, we would like all of the earth's curvature removed. Just how this is done depends on which of the various coordinate systems we use, how big an area we seek to map, and what projection the system uses.

We consider four of the systems in common use in the United States in more detail in this section. As we cover each of the systems, take note of what projections are used and relate them back to the categories of projections introduced in Section 2.2. As you will quickly see, none of the coordinate systems in regular use is really ideal for computer mapping. Considering how complex a shape the earth is, however, many of the systems are perfectly adequate—indeed—extremely well suited for work with GIS.

The four systems we cover are the *geographic* coordinates themselves; then the worldwide *universal transverse Mercator* (UTM) coordinate system favored in many mapping efforts; the *military grid* system, an alternative form of the UTM that has been adopted in many countries outside the United States and for world mapping; and the *state plane* system, the basis of most surveying practice in the United States. Finally, we consider what other systems might be encountered in the GIS world and the implications of using these systems.

2.3.1 Geographic Coordinates

Many GIS systems store locations as numbers using latitude and longitude or geographic coordinates. This system was standardized by the International Meridian conference, held in Washington, D.C. in 1884. At this conference, it was decided to establish the origin for longitude for the earth at the Greenwich Observatory in England (Figure 2.11). In a GIS, latitude and longitude are almost always geocoded, or captured from the map into the computer, in one of two ways. These are degrees, minutes and seconds (DMS) and decimal degrees (DD). In both cases, latitudes go from 90 degrees south (-90) to 90 degrees north ($+90$) (Figure 2.6). Precision below a degree is geocoded as minutes and seconds, and decimals of seconds, in one of two formats: either in DMS as plus or minus DD.MMSS.XX, where DD are degrees, MM are minutes, and SS.XX are decimal seconds; or alternatively, in DD as DD.XXXX, or decimal degrees. Just as with time, a degree consists of 60 minutes, each with 60 seconds. Longitudes are the same, with the exception that the range is -180 to $+180$ degrees. In the second format, degrees are converted to radians and stored as decimal numbers with the appropriate number of significant digits.

For example, the file listed in Figure 2.12 is part of the World Data Bank, a listing of coordinates of the world's coastlines, rivers, islands, and political boundaries. The coordinates are decimal degrees, rounded to the nearest 0.001 degree. At the equator, one degree is about 40,000 km per 360 degrees = 111.11 km; 0.001 degree is then 111 meters. So, these data have a resolution of 111 meters on the ground. Their accuracy is determined by how well the line actually represents the real coastline of Africa (Figure 2.12).

aps on common coordinate

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minutes and seconds (DMS)
m 90 degrees south (−90) to
egree is geocoded as minutes
ats: either in DMS as plus or
nutes, and SS.XX are decimal
al degrees. Just as with time,
ongitudes are the same, with
n the second format, degrees
ith the appropriate number of

he World Data Bank, a listing
and political boundaries. The
01 degree. At the equator, one
001 degree is then 111 meters.
. Their accuracy is determined
of Africa (Figure 2.12).

FIGURE 2.11: The author standing on the prime meridian in Greenwich, England at the Royal observatory, Longitude 0°0′0″, Latitude 51°28′38″. Photo by Raymond H. Clarke.

```
....
0.215 9.297
0.166 9.319
0.050 9.340
0.055 9.324
0.006 9.324
-0.022 9.308
-0.105 9.286
-0.243 9.281
-0.530 9.270
-0.640 9.276
....
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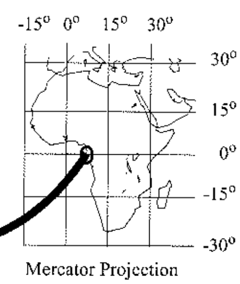

FIGURE 2.12: Part of the World Data Bank I listing of the coordinates of the coastline of Africa. Format is geographic coordinates in decimal degrees.

The advantage of using geographic coordinates in a GIS is that all maps can be transformed into a projection in the same way. If maps captured on a variety of projections are reprojected into geographic coordinates, there is some room for error. For example, the points in Figure 2.12 can never achieve a resolution better than 111 meters, regardless of the projection. If, however, the GIS does not support transformations between projections, then working in a common coordinate system such as the UTM or state plane system is very important if the maps are expected to overlay each other.

2.3.2 The Universal Transverse Mercator Coordinate System

The UTM coordinate system is commonly used in GIS because it has been included since the late 1950s on most USGS topographic maps. The choice of the transverse Mercator, probably now used more than any other projection for accurate mapping, has an interesting history. The story begins with the observation that the equatorial Mercator projection, which distorts areas so much at the poles, nevertheless produces minimal distortion laterally along the equator.

Johann Heinrich Lambert modified the Mercator projection into its transverse form in 1772, in which the "equator" instead runs north-south. The effect is to minimize distortion in a narrow strip running from pole to pole. Johann Carl Friedrich Gauss further analyzed the projection in 1822, and Louis Kruger worked out the ellipsoid formulas in 1912 and 1919 adjusting for "polar flattening." As a result, the projection is often called the Gauss conformal or the Gauss–Kruger, although the name *transverse Mercator* is used in the United States. Rarely, however, was the projection used at all until the major national mapping efforts of the post–World War II era.

The transverse Mercator projection, in various forms, is part of the civilian UTM system described here, the state plane system, and the military grid. It has been used for mapping most of the United States, many other countries, and even the planet Mars. The first version is the civilian UTM grid, used by the U.S. Geological Survey on its maps since 1977, and marked on many maps since the 1940s as blue tic marks along the edges of the quadrangle maps or grids over the surface. In 1977 the transverse Mercator projection replaced the polyconic for large-scale U.S. mapping.

The UTM capitalizes on the fact that the transverse Mercator is accurate in north-south strips by dividing the earth up into 60 pole-to-pole zones, each 6 degrees of longitude wide, running from pole to pole. The first zone starts at 180 degrees west (or east), at the international date line, and runs east, that is, from 180 degrees west to 174 degrees west. The final zone, zone 60, starts at 174 degrees east and extends east to the date line. The zones therefore increase in number from west to east. For the coterminous United States, California falls into zones 10 and 11, while Maine falls into zone 19 (Figure 2.13).

Within each zone we draw a transverse Mercator projection centered on the middle of the zone oriented north-south. Thus for zone 1, with longitudes ranging from 180 degrees west to 174 degrees west, the central meridian for the transverse Mercator projection is 177 degrees west. Because the equator meets the central meridian of the system at right angles, we use this point to orient the grid system (Figure 2.14). In reality, the central meridian is set to a map scale of slightly less than 1, making the projection for each zone secant along two lines at true scale parallel to the central meridian.

To establish a coordinate system origin for the zone, we work separately for the two hemispheres. For the southern hemisphere, the zero northing is the South Pole, and we give northings in meters north of this reference point. As the earth is about 40 million meters around, this means that northings in a zone go from zero to 10 million meters.

The numbering of northings starts again at the equator, which is either 10 million meters north in southern hemisphere coordinates or 0 meters north in northern hemisphere coordinates. Northings then increase to 10 million at the north pole. As we approach the poles, the distortions of the latitude-longitude grid drift farther and farther from the

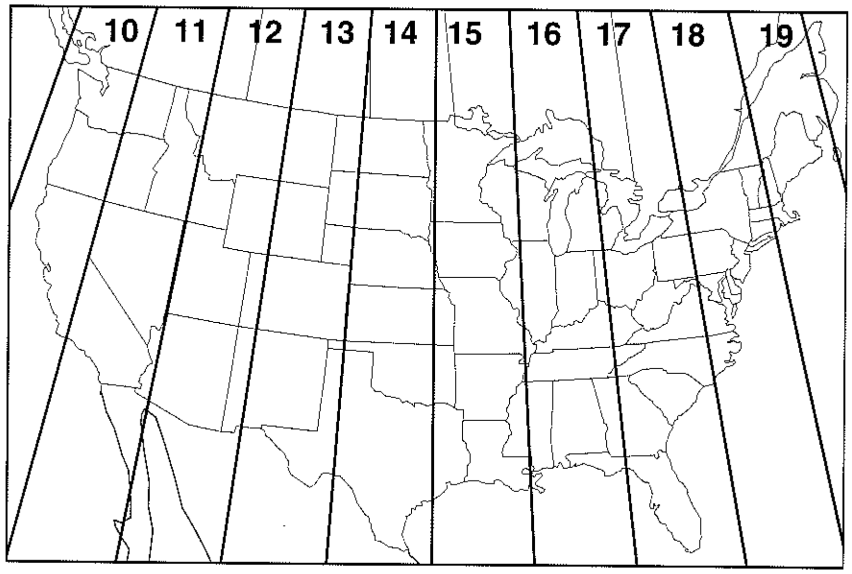

FIGURE 2.13: Universal transverse Mercator zones in the 48 contiguous states.

UTM grid. It is customary, therefore, not to use UTM beyond 84 degrees north and 80 degrees south. For the polar regions, the universal polar stereographic coordinate system is used.

For eastings, a false origin is established beyond the westerly limit of each zone. The actual distance is about half a degree, but the numbering is chosen so that the central meridian has an easting of 500,000 meters. This has the dual advantage of allowing overlap between zones for mapping purposes and of giving all eastings positive numbers. We can tell from our easting if we are east or west of the central meridian, and so the relationship between true north and grid north at any point is known. To give a specific example, Hunter College in New York City is located at UTM coordinate 4,513,410 meters north; 587,310 meters east; zone 18, northern hemisphere. This tells us that we are about four-tenths of the way up from the equator to the north pole, and are east of the central meridian for our zone, which is centered on 75 degrees west of Greenwich. On a map showing Hunter College, UTM grid north would therefore appear to be east of true north.

The variation from true scale is 1 part in 1000 at the equator. As a Mercator projection, of course, the system is conformal and preserves the shape of features such as coastlines and rivers. Another advantage is that the level of precision can be adapted to the application. For many purposes, especially at small scales, the last UTM digit can be dropped, decreasing the resolution to 10 meters. This strategy is often used at scales of 1:250,000 and smaller. Similarly, submeter resolution can be added simply by using decimals in the eastings and northings. In practice, few applications except for precision surveying and geodesy need precision of less than 1 meter, although it is often used to prevent computer rounding error and is stored in the GIS nevertheless.

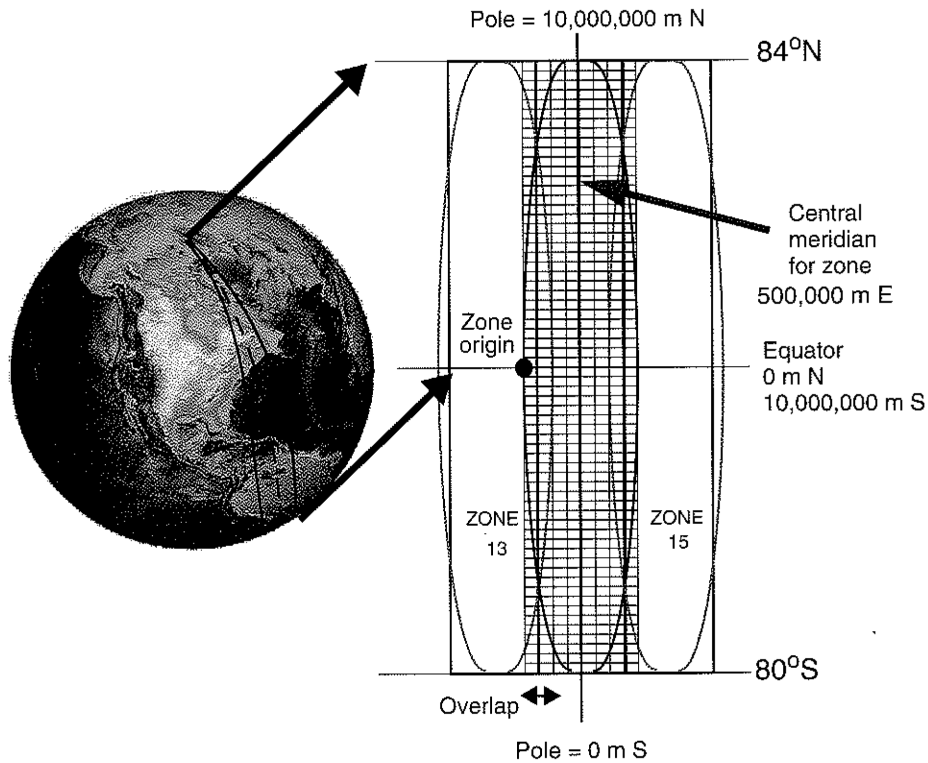

FIGURE 2.14: The Universal transverse Mercator coordinate system.

2.3.3 The Military Grid Coordinate System

The second form of the UTM coordinate system is the *military grid*, adopted for use by the U.S. Army in 1947 and used by many other countries and organizations. The military grid uses a lettering system to reduce the number of digits needed to isolate a location. Zones are numbered as before, from 1 to 60 west to east. Within zones, however, 8-degree strips of latitude are lettered from C (80 to 72 degrees south) to X (72 to 84 degrees north: an extended-width strip). The letter designations A, B, Y, and Z are reserved for Universal Polar Stereographic designations on the poles. A single rectangle, 6-by-8 degrees, generally falls within about a 1000-kilometer square on the ground. These squares are referenced by numbers and letters; for example, New York City falls into grid cell 18T (Figure 2.15).

Each grid cell is then further subdivided into squares 100,000 meters on a side. Each cell is assigned two additional letter identifiers (Figure 2.16). In the east-west (x) direction, the 100,000-meter squares are lettered starting with A, up to Z, and then repeating around the world, with the exception that the letters I and O are excluded, because they could be confused with numbers. The first column, A, is 100,000 meters wide and starts at 180 degrees west. The alphabet recycles about every 18 degrees and includes about six full-width columns per UTM zone. Several partial columns are given designations nevertheless, so that overlap is possible, and some disappear as the poles are approached.

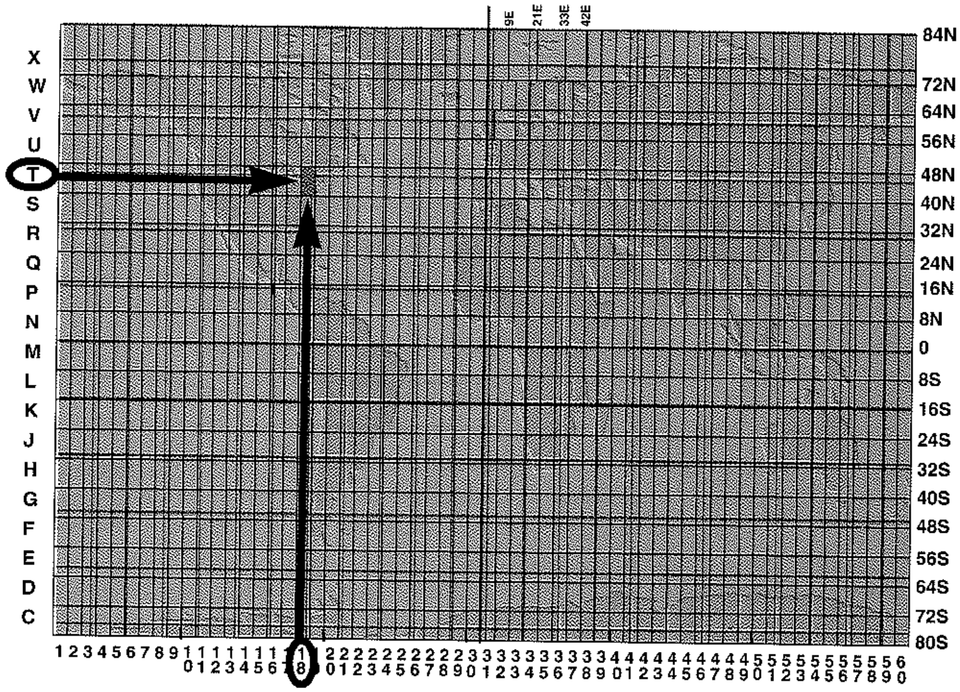

FIGURE 2.15: Six-by-eight-degree cells on the UTM military grid.

In the north-south (y) direction, the letters A through V are used (again omitting I and O), starting at the equator and increasing north, and again cycling through the letters as needed. The reverse sequence, starting at V and cycling backward to A, then back to V, and so on, is used for the southern hemisphere. Thus a single 100,000-meter grid square can be isolated using a sequence such as 18TWC. Within this area, successively accurate locations can be given by more and more pairs of x and y digits. For example, 18TWC 81 isolates a 10,000-meter square, 18TWC 8713 a 1000 meter square, and 18TWC 873134 a 100-meter square. These numbers are frequently stored without the global cell designation, especially for small countries or limited areas of interest. Thus WC873134, two letters and six numbers, would give a location to within 100-meter ground accuracy. Finally, the polar areas are handled completely separately on a different (UPS) projection.

2.3.4 The State Plane Coordinate System

Much geographic information in the United States uses a system called the *state plane coordinate system* (SPCS). The system is used primarily for engineering applications, especially by utility companies and local governments that need to do accurate surveying of facilities networks such as power lines and sewers, or for property designation. The SPCS is based on both the transverse Mercator and the Lambert conformal conic projections with units in meters (previously feet). The SPCS, which has been used for decades to write legal descriptions of properties and in engineering projects in many states, is based upon a different map of each state, except Alaska. States that are elongated north

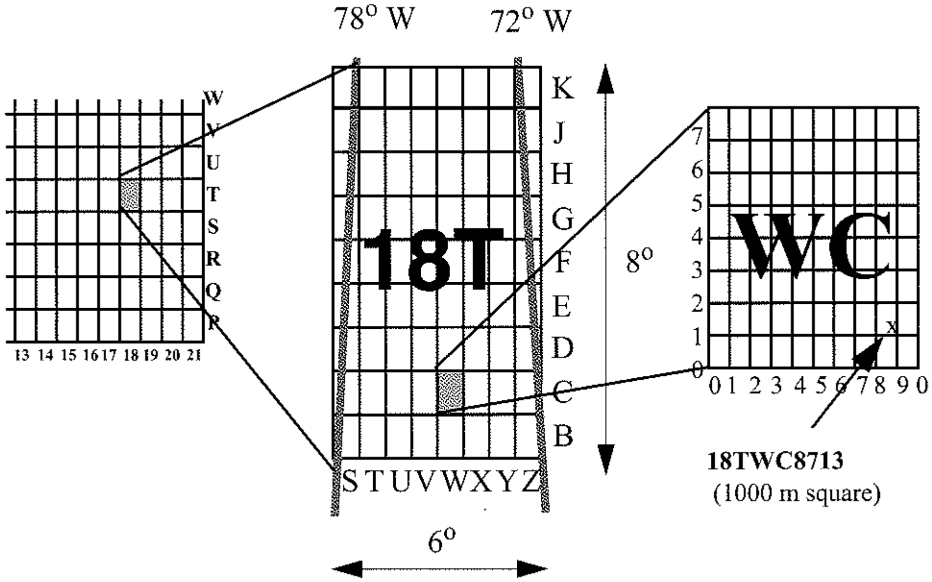

FIGURE 2.16: Military grid cell letters.

to south, such as California, are drawn on a Lambert conformal conic projection. States that are elongated east to west, such as New York, are drawn on a transverse Mercator projection, because the zones are divided into north-south strips.

The state is then divided up into zones, the number of which varies from small states, such as Rhode Island with one to as many as five zones. Some states have special case zones; for example, the state of California has one zone that consists of Los Angeles County alone. Some have more logic; for example, Long Island has its own zone for the state of New York. Because there are so many projections to cover the land area, generally the distortion attributable to the map projection is very small, much less than in UTM, where it can approach 1 part in 2000.

Each zone then has an arbitrarily determined origin that is usually some given number of feet west and south of the southwesternmost point on the map. This again means that the eastings and northings all come out as positive numbers. The system then simply gives eastings and northings in feet, often ending up with millions of feet, with no rounding up to miles. The system is slightly more precise than UTM because coordinates are to within a foot rather than a meter, and it can be more accurate over small areas. A disadvantage is the lack of universality. Imagine mapping an area covering the boundary between not only two zones, but two states. This means that you could be working with data that fall into four coordinate systems on two projections. Any calculation, such as computing an area, on that basis becomes a set of special-case solutions. On the other hand, SPCS is used universally by surveyors all over the United States.

A sample set of zone information is shown in Figure 2.17. New York State is somewhat of an exception. The bulk of the state, being east-west in extent, is divided into three north-south zones called "east," "central," and "west." Each of these three

New York State (3 zones on Transverse Mercator, 1 on Lambert Conic)
Based on NAD83

		Central Meridian	Origin	Scale reduction at Central Meridian	Easting at Origin
East	TM	74 30	40 00	1 in 10,000	150,000 m
Central	TM	74 30	40 00	1 in 10,000	250,000 m
West	TM	74 30	40 00	1 in 10,000	350,000 m
Long Island	LC	40 40 N 41 02 N	74 00W 40 10N		300,000 m

FIGURE 2.17: Statistics for New York State's state plane zones.

zones is drawn on a single transverse Mercator projection with a central meridian at 74°30′ West, with the scale factor at the center set at 0.9999, making the "cylinder" secant to the projection. Each zone then has an origin of zero meters (or feet) set at the northing of the origin (40° N) and at the easting given in Figure 2.17.

Coordinates in each zone are then numbered off in meters (or feet, without aggregation beyond feet). New York's Long Island zone uses a Lambert conic projection. For this one zone, the origin is a point and the standard parallels are given. For example, a position could have the following state plane coordinates:

870, 432 feet North; 730, 012 feet East, New York, Central Zone

Maps often show one or more of these coordinate systems, often by overprinted grids, and showing tic marks along the edges to show the coordinates. These are essential if the map data are to find their way into the GIS. Complicating the process are zone boundaries, and the fact that abbreviations of coordinates often look similar across coordinate systems (Figure 2.18).

2.3.5 Other Systems

There are, in addition, many other coordinate systems. Some are standardized, but many are not. Most countries have their own, although many use UTM or the military grid. The national grid of the United Kingdom uses the lettering system of the military grid but different-sized zones. In a few cases—Sweden, for example—the national census and other data are tied directly into the coordinates. Within the United States, many private companies and public services use unique systems, usually tied to specific functions such as power lines, or a specific region such as a municipality, or even a single construction project. There is also a tendency, especially when a base map is of unknown origin or when the map must be captured quickly, to throw away coordinates and just use "map millimeters" or "tablet coordinates." In this instance, unless we have the critical spatial fact of knowing at least two and preferably more points in both this and an accepted coordinate system, the map will be useless for matching with others or for overlay and analysis.

When using a coordinate system for geocoding in a GIS, we should be sure to remain consistent within that system and to record the relationship between the system and latitude and longitude or some other recognized system. Two points will suffice if

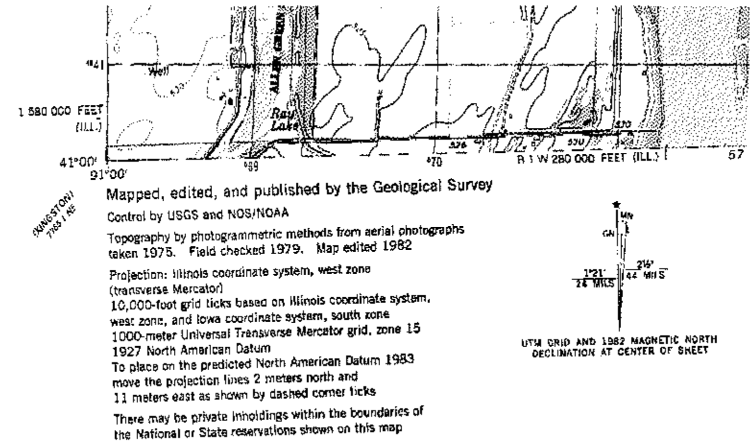

FIGURE 2.18: Map collar annotation from the Keithsburg USGS 7.5 minute Quadrangle (Illinois-Iowa). Note the grid systems in use are Geographic, UTM, and the intersection of two zones of the State Plane system. Note also the NAD27 to NAD83 correction. Note that UTM grid north is 1 degree 21 minutes east of true north (from the declination diagram lower right), implying that we are east of the central meridian for zone 15, and that UTM eastings should be greater than 500,000.

the spatial extent is perfectly aligned and north is the same on both maps, but different projections and other differences make this a rare occurrence. Also, we should be sure to use precision and numbers that make sense. Can we really measure distances over entire states down to the micrometer level or below? And even if we can, is this efficient to use in the GIS? In contrast, there is also a tendency to throw away precision needlessly.

Finally, while coordinates are the way that a GIS records information about location, location is just one of the many facets of geographic data. In the following section, we take a look at the full set of properties. Many of these become important to understand as we move into analysis and description of geographic features using a GIS.

2.4 GEOGRAPHIC INFORMATION

The purpose of geocoding is to encode the fundamental characteristics of geographic data in a digital form recognized by the GIS. Obviously, the most basic geographic characteristic is location. In a GIS, location is described by coordinates as numbers—and occasionally as letters. Obviously, just as a map contains many features, a map inside a GIS must contain a complete digital description of the features as coordinates. This means that a typical GIS database, especially the map component, is very large, especially if the coverage is detailed and the area large. Fortunately, the cost of storing data has decreased dramatically. Even on small computers, new storage methods have increased available memory from kilobytes to gigabytes within only a decade. The rapid growth of GIS has been heavily dependent on computer storage systems getting bigger and bigger over time.

Another basic characteristic of geographic data is *dimensionality*. Traditionally, cartography has divided data into *points*, *lines*, and *areas*. Basic to understanding how a GIS structures information is the idea that complex map features can be built up from simple ones. So a line can be constructed connect-the-dots style from a set of points.

Then an area or region can be made up of connected lines. This truly important concept is illustrated in Figure 2.19.

The attributes associated with a geographic feature are also important geographic information and can be categorized by their *level of measurement*. Levels of measurement are divided into *nominal*, *ordinal*, *interval*, and *ratio*. *Nominal* data are those that simply assign a label or class to a feature, such as a mine shaft or a ski resort. *Ordinal* features have a rank assigned to them, such as the sequence used for highways on maps of Jeep trails, unsurfaced roads, single-lane roads, two-way roads, state highways, and interstate highways. *Interval* values are those measured on a relative scale, such as elevations on a datum (based on mean sea level, an arbitrary zero point) or survey locations measured by pace and compass without a geodetic control. *Ratio* values are measured on an absolute scale, such as coordinates on a standard system or computed measures such as total precipitation. This division allows us to group features into classes, point-nominal, for example, or area-ratio. We return to this grouping system as a way of deciding what type of map to use in Chapter 7.

Another major characteristic of geographic information is *continuity*. Some types of maps, such as contour maps, assume a continuous distribution sometimes called a field, while others, such as choropleth maps, assume a discontinuous distribution. This distinction is made in detail in Chapter 7. Continuity is an important geographical property. The best example of a continuous variable is probably surface elevation. As we walk around on the earth's upper surface, we always have an elevation; at no point is elevation undetermined.

Continuity does not always apply to statistical distributions. For example, tax rates are a discontinuous geographic variable. A resident of New York has to pay the state personal income tax, but by living just 1 meter inside Connecticut, a person will not pay the New York tax. Geographic continuity is an important property. GIS coverage must be exhaustive for continuity; that is, there should be no holes or unclassified areas. Continuous variables in GIS, often called *field variables*, are most appropriately manipulated with raster (grid-based) GIS systems.

Once geographic features are built up from points, lines, and areas, their collective description can consist of measurements of the feature's size, distribution, pattern, orientation, neighborhood, contiguity, shape, and scale. Each of these properties defines

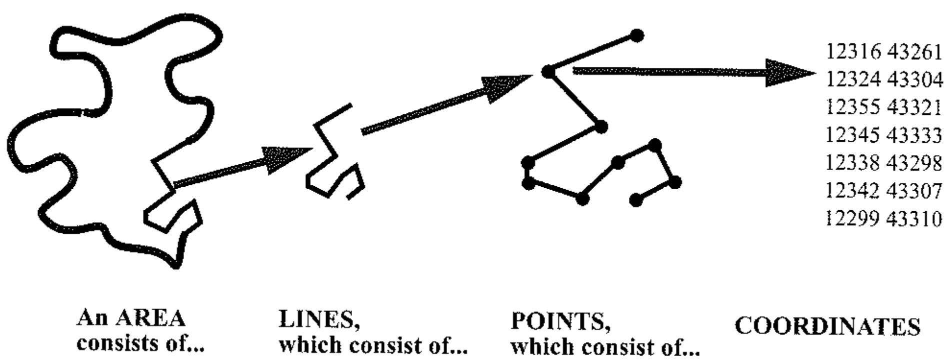

FIGURE 2.19: Geographic information has dimension. Areas are two-dimensional and consist of lines, which are one-dimensional and consist of points, which are zero-dimensional and consist of a coordinate pair.

the character of a feature and can usually be measured by the tools within a GIS and used for analysis. Usually, these higher-level descriptions are what prompted the use of a GIS in the first place. For example, we can measure the areas (size) of land parcels, or the orientation of highways, or the distribution of flora and fauna in a state park. The basic properties are summarized in Figure 2.20. Even though the GIS will directly hold only the coordinates and some additional information such as contiguity, information about every one of these properties will be available by using the tools within the GIS for higher-level analysis. Part of what the GIS user does is to coax descriptions of these properties out of the data that are available in the particular GIS in use. How well you can do this will depend on your skills as an intelligent GIS user.

Our digression on the cartographic roots of GIS is now complete. As we have seen, there are numerous important considerations to bear in mind that are directly related to the geometry of the map and the geometry of the features that we will store in the GIS. We are now ready to move on and begin covering GIS concepts proper. Step one is to cover how the map is structured as sets of digits inside the computer. Step two is to examine how to get the data from the map into the computer. As we will find out, this is another basic but overridingly important step in getting started with GIS.

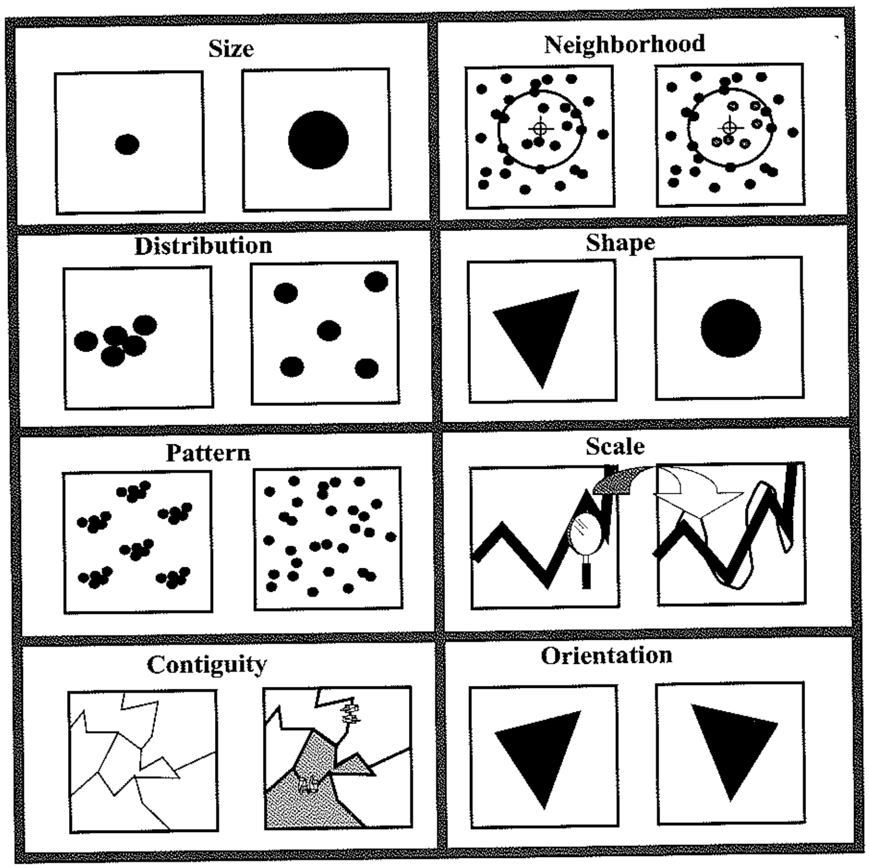

FIGURE 2.20: Basic properties of geographic features.

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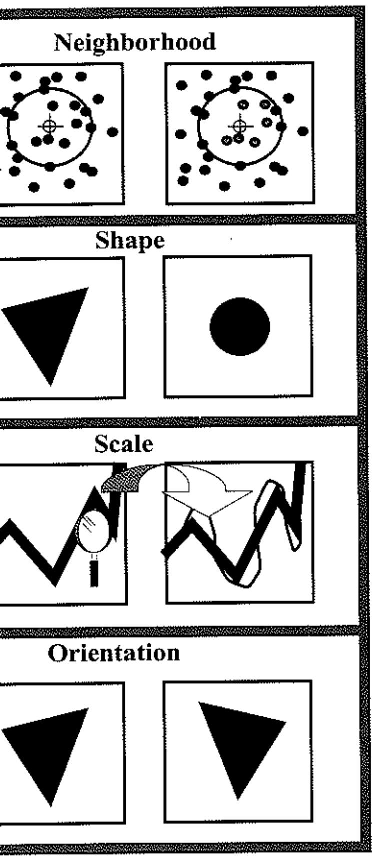

of geographic features.

2.5 STUDY GUIDE

2.5.1 Summary

CHAPTER 2: GIS's Roots in Cartography

Map and Attribute Information (2.1)

- **Information can be organized as lists, numbers, tables, text, pictures, maps, or indexes.**
- **Clusters of information called data can be stored together as a database.**
- **A database is stored in a computer as files.**
- **In a database, we store attributes as column headers and records as rows.**
- **The contents of an attribute for one record is a value. A value can be numerical or text.**
- **Data in a GIS must contain a geographic reference to a map, such as latitude and longitude.**
- **The GIS cross-references the attribute data with the map data, allowing searches based on either or both. The cross-reference is a link.**
- **Understanding the way maps are encoded to be used in GIS requires knowledge of cartography.**
- **Cartography is the science that deals with the construction, use, and principles behind maps.**

Map Scale and Projections (2.2)

- **The earth can be modeled as a sphere, an oblate ellipsoid, or a geoid.**
  - **The sphere is about 40 million meters in circumference.**
  - **An ellipsoid is an ellipse rotated in three dimensions about its shorter axis.**
  - **The earth's ellipsoid is only about 1/297 off from a sphere.**
  - **Many ellipsoids have been measured, and maps have been based on each. Examples are WGS83 and GRS80.**
  - **An ellipsoid gives the base elevation for mapping, called a datum. Examples are NAD27 and NAD83.**
  - **The geoid is a figure that adjusts the best ellipsoid and the variation of gravity locally. It is the most accurate, and is used more in geodesy than in GIS and cartography.**
- **Map scale is based on the representative fraction, the ratio of a distance on the map to the same distance on the ground.**
- **Most maps in GIS fall between 1 : 1,000,000 and 1 : 1,000.**
- **A GIS is scaleless because maps can be enlarged and reduced and plotted at many scales other than that of the original data.**
- **To compare or edge-match maps in a GIS, both maps MUST be at the same scale and have the same extent.**
- **The metric system is far easier to use for GIS work.**
- **Geographic coordinates are the earth's latitude and longitude system, ranging from 90 degrees south to 90 degrees north in latitude and 180 degrees west to 180 degrees east in longitude.**
- **A line with a constant latitude running east to west is called a parallel.**

- **A line with constant longitude running from the north pole to the south pole is called a meridian. The zero-longitude meridian is called the prime meridian and passes through Greenwich, England.**
- **A grid of parallels and meridians shown as lines on a map is called a graticule.**
- **A transformation of the spherical or ellipsoidal earth onto a flat map is called a map projection.**
- **The map projection can be projected onto a flat surface or a surface that can be made flat by cutting, such as a cylinder or a cone.**
- **If the globe, after scaling, cuts the surface, the projection is called secant. Lines where the cuts take place or where the surface touches the globe have no projection distortion.**
- **Projections can be based on axes parallel to the earth's rotation axis (equatorial), at 90 degrees to it (transverse), or at any other angle (oblique).**
- **A projection that preserves the shape of features across the map is called conformal.**
- **A projection that preserves the area of a feature across the map is called equal area or equivalent.**
- **No flat map can be both equivalent and conformal. Most fall between the two as compromises.**
- **To compare or edge-match maps in a GIS, both maps MUST be in the same projection.**

Coordinate Systems (2.3)

- **A coordinate system is a standardized method for assigning codes to locations so that locations can be found using the codes alone.**
- **Standardized coordinate systems use absolute locations.**
- **A map captured in the units of the paper sheet on which it is printed is based on relative locations or map millimeters.**
- **In a coordinate system, the x-direction value is the easting and the y-direction value is the northing. Most systems make both values positive.**
- **Some standard coordinate systems used in the United States are geographic coordinates, the universal transverse Mercator system, the military grid, and the state plane system.**
- **To compare or edge-match maps in a GIS, both maps MUST be in the same coordinate system**
- **A GIS package should be able to move between map projections, coordinate systems, datums, and ellipsoids.**

Geographic Information (2.4)

- **Geographic information has the characteristics of volume, dimensionality, and continuity.**
- **Simple geographic features can be used to build more complex ones. Areas are made up of lines, which are made up of points represented by their coordinates.**
- **Geographic features collectively have the properties of size, distribution, pattern, contiguity, neighborhood, shape, scale, and orientation.**

- **Much of GIS analysis and description consists of investigating the properties of geographic features and determining the relationships between them.**

2.5.2 Study Questions

Map and Attribute Information

Define the following: *data*, *attribute*, *record*, *value*, and *database*. Using as an example the Yellow Pages part of a telephone directory for your town, discuss how you would build a database to hold the list information. What parts of the Yellow Pages attributes are geographic references?

Map Scale and Projections

Using an atlas, make a list of as many map projections as you can find. Are any of the atlas maps not annotated with their projection? Make a table listing the properties of each of the projections, plus any other information you can find out—for example, whether the projection is secant, transverse, based on an ellipsoid, conformal, and so on. In a final column, state what properties are distorted on the map; for example, "Map distorts area increasingly as one moves north and south."

Consult one of the sources listed in the References and try to find the sizes of as many ellipsoids as possible. Are any of them more or less suitable for foreign countries? Select a country, for example, Egypt or Australia, and research what ellipsoids have been used and whether any particular projection is favored for that country. Why would one projection be better than another?

Find the regulation sizes of either a baseball diamond or a soccer field. Draw maps of the fields at the following scales: 1 : 1000, 1 : 24,000, 1 : 100,000, and 1 : 1,000,000. What problems do you run into? What would be the effect of mapping both a winding river and an irregular patch of forest at these scales?

Coordinate Systems

The chapter covers several different coordinate systems. Determine which coordinate systems are shown on a map of your local area.

For a single location, such as your house or school, try to find the coordinates of the position in as many coordinate systems as possible. How might you make sure that your result from the map is correct?

Geographic Information

Make a table of levels of measurement versus dimension. In each cell of the table, write in as many types of geographic data or features as you can think of.

Using the example of a lake, write out sample measurements that might describe each of the major geographic properties covered in Figure 2.20. For example, the size of the lake is its area in square meters. For which properties is it most difficult to think of representative numbers? (*Hint*: Can a single number describe the shape?)

FIGURE 2.21: Mercator projection of North America secant at 40°N overlain with a Lambert conformal conic with standard parallels at 30°N and 45°N.

2.6 EXERCISES

1. *Use the manual that came with your GIS software package to see what map projections the software can support and whether it is possible to transform between map projections and from geographic coordinates into a map projection. For any digital map, ideally at a smaller scale such as 1 : 1 million, plot the same map in two map projections one on top of the other. What magnitude of error do you see?*
2. *Again, using your GIS package, draw a map of a small feature such as a lake. Manipulate the scale of the feature on the plot so that the same feature is plotted at a number of different map scales. How might the GIS deal with the small scales when the feature is too detailed? How might the GIS deal with the feature when it is enlarged beyond its ability to "look" like a map feature?*
3. *Using the database component of your GIS package and an existing database such as the tutorial data set that came with the software, list all the attributes for one or more records. Which are numerical attributes? What are the ranges and legal values for the attributes values? How would the GIS detect a value that was out of bounds? (Try it!) How does the GIS software allow you to change the value for an attribute for one or more records? (Hint: You will have to dig into the documentation for this.)*
4. *Use your GIS package to print out the location of a feature in its raw coordinates. What is the coordinate system in use? What is the map projection? What ellipsoid and datum were used? Does the software (or documentation) supply any information about the accuracy of the data? Using the printed coordinates, give a numerical estimate of the precision of the data. How might the accuracy and precision be improved?*
5. *Using a GIS map showing a polygonal feature such as a lake, a city boundary, or a soil or land-cover polygon, think of three different ways to quantify the orientation of the feature. (Hint: What "line" best represents the polygon?)*

2.7 BIBLIOGRAPHY

Campbell, J. (1993) *Map Use and Analysis*. 2nd ed. Dubuque, IA: William C. Brown.

Clarke, K. C. (1995) *Analytical and Computer Cartography*. 2nd ed. Upper Saddle River, NJ: Prentice Hall.

Department of the Army (1973) *Universal Transverse Mercator Grid*, TM 5-241-8, Headquarters, Department of the Army. Washington, DC: U.S. Government Printing Office.

Snyder, J. P. (1987) *Map Projections—A Working Manual*. U.S. Geological Survey Professional Paper 1396. Washington, DC: U.S. Government Printing Office.

2.8 KEY TERMS AND DEFINITIONS

absolute location: A location in geographic space given with respect to a known origin and standard measurement system, such as a coordinate system.

accuracy: The validity of data measured with respect to an independent source of higher reliability and precision.

attribute: A numerical entry that reflects a measurement or value for a feature. Attributes can be labels, categories, or numbers; they can be dates, standardized values, or field or other measurements. An item for which data are collected and organized. A column in a table or data file.

azimuthal: A map projection in which the globe is projected directly on a flat surface. Only one "side" of the globe can be shown at a time.

cartography: The science that deals with the principles, construction, and use of maps.

compromise: A map projection that is neither area preserving nor shape preserving. An example is the Robinson projection.

conformal: A type of map projection that preserves the local shape of features on maps. On a conformal projection, lines on the graticule meet at right angles, as they do on a globe.

conic: A type of map projection involving projecting part of the earth onto a cone-shaped surface that is then cut and unrolled to make it flat.

continuity: The geographic property of features or measurements that gives measurements at all locations in space. Topography and air pressure are examples.

coordinate pair: An easting and northing in any coordinate system, absolute or relative. Together these two values, usually termed (x, y), describe a location in two-dimensional geographic space.

coordinate system: A system with all the necessary components to locate a position in two- or three-dimensional space: that is, an origin, a type of unit distance, and axes.

cylindrical: A type of map projection involving projecting part of the earth onto a cylinder-shaped surface that is then cut and unrolled to make it flat.

data: A set of measurements or other values, such as text for at least one attribute and at least one record.

database: A collection of data organized in a systematic way to provide access on demand.

datum: A base reference level for the third dimension of elevation for the earth's surface. A datum can depend on the ellipsoid, the earth model, and the definition of sea level.

dimensionality: The property of geographic features by which they are capable of being broken down into elements made up of points, lines, and areas. This corresponds to features being zero-, one-, and two-dimensional. A drill hole is a point, a stream is a line, and a forest is an area, for example.

distortion: The space distortion of a map projection, consisting of warping of direction, area, and scale across the extent of the map.

easting: The distance of a point in the units of the coordinate system east of the origin for that system.

edge matching: The GIS or digital map equivalent of matching paper maps along their edges. Features that continue over the edge must be "zipped" together and the edge dissolved. To edge-match, maps must be on the same projection, datum, ellipsoid, and scales and show features captured at the same equivalent scale.

equal area: A type of map projection that preserves the area of features on maps. On an equal-area projection, a small circle on the map would have the same area as on a globe with the same representative fraction. See also **equivalent**.

equatorial radius: The distance from the geometric center of the earth to the surface, usually averaged to a single value for a sphere.

equirectangular: A map projection that maps angles directly to eastings and northings. A cylindrical projection, made secant by scaling the height-to-width ratio. The nonsecant or equatorial version is called the Plate Carree. Credited to Marinus of Tyre, about A.D. 100.

equivalent: A type of map projection that preserves the area of features on maps. On an equal area projection, a small circle on the map would have the same area as on a globe with the same representative fraction. See also **equal area**.

field variable: A geographic value that is continuous over space.

file: Data logically stored together at one location on the storage mechanism of a computer.

flattening (of an ellipsoid): The ratio of the length of half the short axis of the ellipse to half the long axis of the ellipse, subtracted from 1. The earth's flattening is about 1/300.

geocode: A location in geographic space converted into computer-readable form. This usually means making a digital record of the point's coordinates.

geodesy: The science of measuring the size and shape of the earth and its gravitational and magnetic fields.

geographic coordinates: The latitude and longitude coordinate system.

geographic property: A characteristic of a feature on earth, usually describable from a map of the feature, such as location, area, shape, distribution, orientation, adjacency, and so on.

geography: (1) A field of study based on understanding the phenomena capable of being described and analyzed with a GIS. (2) The underlying geometry and properties of the earth's features as represented in a GIS.

geoid: A complex earth model used more in geodesy than cartography or GIS that accounts for discrepancies over the earth from the reference ellipsoid and other variations due to gravity, and so on.

globe: A three-dimensional model of the earth made by reducing the representative fraction to less than 1 : 1.

GPS (Global Positioning System): An operational, U.S. Air Force–funded system of satellites in orbits that allow their use by a receiver to decode time signals and convert the signals from several satellites to a position on the earth's surface.

graticule: The latitude and longitude grid drawn on a map or globe. The angle at which the graticule meets is the best first indicator of what projection has been used for the map.

GRS80 (Geodetic Reference System of 1980): Adopted by the International Union of Geodesy and Geophysics in 1979 as a standard set of measurements for the earth's size and shape. The length of the semimajor axis is 6,378,137 meters. Flattening is 1/298.257.

information: The part of a message placed there by a sender and not known by the receiver.

interval: Data measured on a relative scale but with numerical values based on an arbitrary origin. Examples are elevations based on mean sea level, or coordinates.

latitude: The angle made between the equator, the earth's geometric center, and a point on or above the surface. The south pole has latitude −90 degrees, the north +90 degrees.

level of measurement: The degree of subjectivity associated with a measurement. Measurements can be nominal, ordinal, interval, or ratio.

link: The part or structure of a database that physically connects geographic information with attribute information for the same features. Such a link is a defining component of a GIS.

location: A position on the earth's surface or in geographic space definable by coordinates or some other referencing system, such as a street address or space indexing system.

longitude: The angle formed between a position on or above the earth, the earth's geometric center, and the meridian passing through the center of the observing instrument in Greenwich, England, as projected down onto the plane of the earth's equator or viewed from above the pole. Longitudes range from −180 (180 degrees West) to +180 (180 degrees East).

map: A depiction of all or part of the earth or other geographic phenomenon as a set of symbols and at a scale whose representative fraction is less than 1 : 1. A digital map has had the symbols geocoded and stored as a data structure within the map database.

map millimeters: A coordinate system based on the dimensions of the map rather than those of the features represented on the earth itself, in metric units.

map projection: A depiction of the earth's three-dimensional structure on a flat map.

mean sea level: A local datum based on repeated measurements of sea level throughout all of its normal cycles, such as tides and seasonal change. The basis for elevations on a map.

meridian: A line of constant longitude. All meridians are of equal length on the globe.

metric system: A system of weights and measures accepted as an international standard as the Systeme International d'Unites (SI) in 1960. The metre (meter in the United States) is the unit of length.

military grid: A coordinate system based on the transverse Mercator projection, adopted by the U.S. Army in 1947 and used extensively for world mapping.

mosaicing: The GIS or digital map equivalent of matching multiple paper maps along their edges. Features that continue over the edge must be "zipped" together and the edge dissolved. A new geographic extent for the map usually has to be cut or clipped out of the mosaic. To permit mosaicing, maps must be on the same projection, datum, ellipsoid, and scale, and show features captured at the same equivalent scale.

NAD27 (North American Datum of 1927): The datum used in the early part of the national mapping of the United States. The Clarke 1866 ellipsoid was used, and locations and elevations were referenced to a single point at Meade's Ranch in Kansas.

nominal: A level of measurement at which only subjective information is available about a feature. For a point, for example, the name of the place.

northing: The distance of a point in the units of the coordinate system north of the origin for that system.

oblate ellipsoid: A three-dimensional shape traced out by rotating an ellipse about its shorter axis.

oblique: A map projection in which the centerline of the map is not at right angles to the earth's geographic coordinates, following neither a single parallel nor a meridian.

ordinal: A level of measurement at which only relative information is available about a feature, such as a ranking. For a highway, for example, the line is coded to show a Jeep trail, a dirt road, a paved road, a state highway, or an interstate highway, in ascending rank.

origin: A location within a coordinate system where the eastings and northings are exactly equal to zero.

parallel: A line of constant latitude. Parallels get shorter toward the poles, becoming a point at the pole itself.

perfect sphere: A three-dimensional figure traced out by all possible positions of an arc of a fixed radius about a point. A good approximation of the shape of the earth.

polar radius: The distance between the earth's geometric center and either pole.

precision: The number of digits used to record a measurement or which a measuring device is capable of providing.

prime meridian: The line traced out by longitude zero and passing through Greenwich, England. The prime meridian forms the origin for the longitude part of the geographic coordinates and divides the eastern and western hemispheres.

ratio: A level of measurement at which numerical information is available about a feature, based on an absolute origin. For land parcels, for example, the assessed value in dollars would be an example, the value zero having real meaning.

record: A set of values for all attributes in a database. Equivalent to a row of a data table.

relative location: A position described solely with reference to another location.

representative fraction: The ratio of a distance as represented on a map to the equivalent distance measured on the ground. Typical representative fractions are 1 : 1,000,000, 1 : 100,000, and 1 : 50,000.

scale: The geographic property of being reduced by the representative fraction. Scale is usually depicted on a map or can be calculated from features of known size.

scaleless: The characteristic of digital map data in abstract form of being usable and displayable at any scale, regardless of the scale of the map used to geocode the data.

secant: A map projection in which the surface used for the map "cuts" the globe at the map's representative fraction. Along this line there is distortion-free mapping of the geographic space. Multiple cuts are possible, for example, on a conic projection.

standard parallel: A parallel on a map projection that is secant and therefore distortion-free.

state plane: A coordinate system common in utility and surveying applications in the lower 48 United States and based on zones drawn state by state on transverse Mercator and Lambert conformal conic projections.

transverse: A map projection in which the axis of the map is aligned from pole to pole rather than along the equator.

UTM (Universal Transverse Mercator): A standardized coordinate system based on the metric system and a division of the earth into sixty 6-degree-wide zones. Each zone is projected onto a transverse Mercator projection, and the coordinate origins are located systematically. Both civilian and military versions exist.

value: The content of an attribute for a single record within a database. Values can be text, numerical, or codes.

WGS84 (World Geodetic Reference System of 1984): A higher precision version of the GRS80 used by the U.S. Defense Mapping Agency in world mapping. A common datum and reference ellipsoid for hand-held GPS receivers.

zone (of a coordinate system): The region over which the coordinates relate with respect to a single origin. Usually, some part of the earth or a state.