*Chapter 1*

Introducing GIS

For a long time, people have studied the world using models such as maps and globes. In the last thirty years or so, it has become possible to put these models inside computers—more sophisticated models into smaller computers every year. These computer models, along with the tools for analyzing them, make up a geographic information system (GIS).

In a GIS, you can study not just this map or that map, but every possible map. With the right data, you can see whatever you want—land, elevation, climate zones, forests, political boundaries, population density, per capita income, land use, energy consumption, mineral resources, and a thousand other things—in whatever part of the world interests you.

The map of the world, below, shows countries, cities, rivers, lakes, and the ocean.
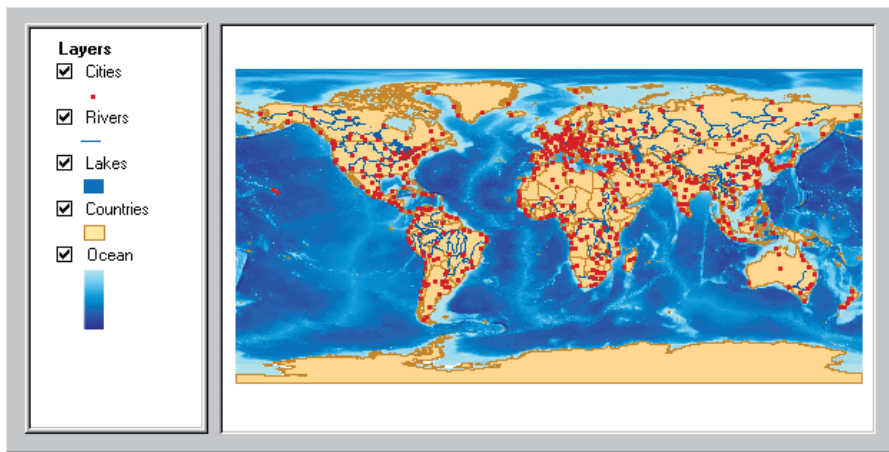
The map has a legend (or table of contents) on the left and a display area on the right.

A GIS map contains layers

On a paper map, you can't peel cities away from countries, or countries away from the ocean, but on a GIS map you can. A GIS map is made up of layers, or collections of geographic objects that are alike. To make a map, you can add as many layers as you want.
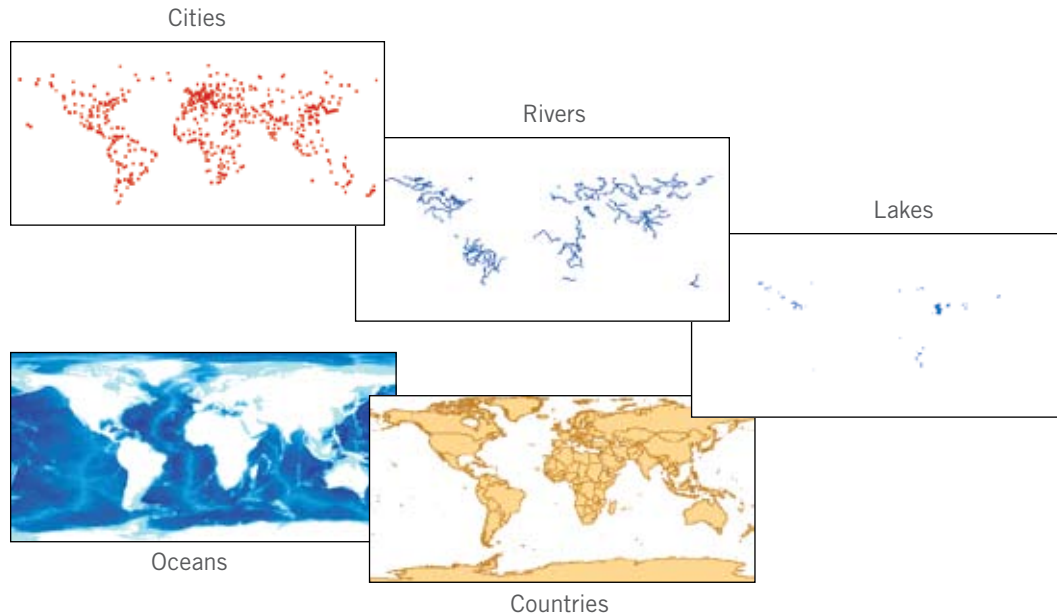
This world map is made up of five layers. It could have many more.

Layers may contain features or surfaces

In the map (page 2), the Cities layer includes many different cities and the Rivers layer many different rivers. The same is true of the Lakes and Countries layers. Each geographic object in a layer—each city, river, lake, or country—is called a feature.

Not all layers contain features. The Oceans layer is not a collection of geographic objects the way the others are. It is a single, continuous expanse that changes from one location to another according to the depth of the water. A geographic expanse of this kind is called a surface.

Features have shape and size

Geographic objects have an endless variety of shapes. All of them, however, can be represented as one of three geometrical forms—a polygon, a line, or a point.

Polygons represent things large enough to have boundaries, such as countries, lakes, and tracts of land. Lines represent things too narrow to be polygons, such as rivers, roads, and pipelines. Points are used for things too small to be polygons, such as cities, schools, and fire hydrants. (The same object may be represented by a polygon in one layer and a line or a point in a different layer, depending on how large it is presented.)

Polygons, lines, and points collectively are called vector data.

Surfaces have numeric values rather than shapes

Unlike countries or rivers, things such as elevation, slope, temperature, rainfall, and wind speed have no distinct shape. What they have instead are measurable values for any particular location on the earth's surface. (Wherever you go, for instance, you are either at sea level or a number of meters above or below it.) Geographic phenomena like these are easier to represent as surfaces than as features.

The most common kind of surface is a raster, a matrix of identically sized square cells. Each cell represents a unit of surface area—for example, 10 square meters—and contains a measured or estimated value for that location.
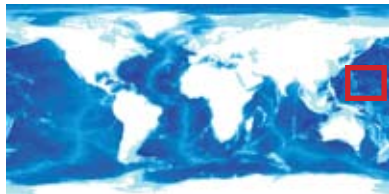

A close look at this raster of ocean depth shows that it is composed of square cells. Each cell holds a numeric value.

The world is not divided neatly into features and surfaces. Many things can be looked at either way. For example, polygons are often used to mark the boundaries of different vegetation types in a region, but this implies that the change from one type to another is more abrupt than it probably is. Vegetation can also be represented as a raster surface, where each cell value stands for the presence of a type of vegetation.

Features have locations

If you were asked to find Helsinki, Finland, on a map of the world, it probably wouldn't take you very long. But suppose Helsinki wasn't shown on the map. Could you make a pencil mark where it ought to go?

Now suppose you could lay a fine grid over the world map and you knew that Helsinki was a certain number of marks up from and to the right of a given starting point. It would be easy to put your pencil on the right spot. A grid of this kind is called a coordinate system, and it's what a GIS uses to put features in their proper places on a map.

y-axis   Helsinki

x = 2,777,281 meters
y = 6,693,532 meters
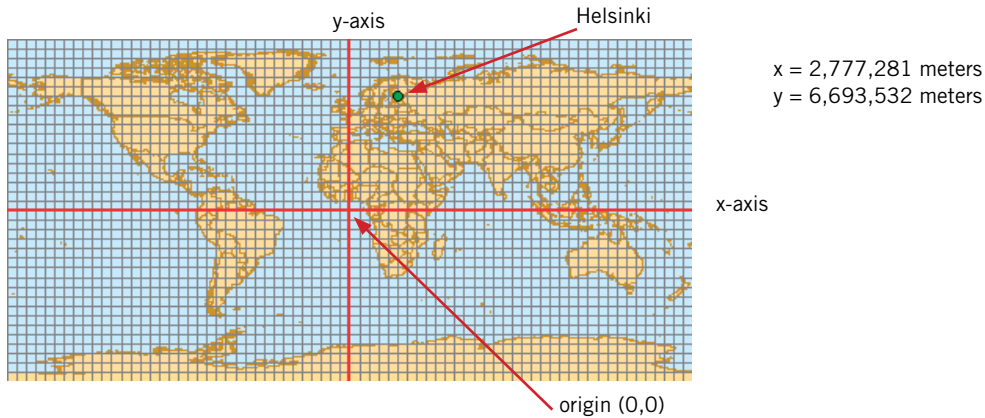
x-axis

origin (0,0)

On a map, a coordinate system has an x-axis and a y-axis. The intersection of the axes is called the origin. Feature locations are specified by their distance from the origin in meters, feet, or a similar unit of measure.

The location of a point feature on a map is defined by a pair of x,y coordinates. A straight line needs two pairs of coordinates—one at the beginning and one at the end. If the line bends, like a river, there must be a pair of coordinates at every location where the line changes direction. The same holds true for a polygon, which is simply a line that returns to its starting point.

Features can be displayed at different sizes

On a GIS map, you can zoom in to see features at closer range. As you do so, the scale of the map changes.

Scale 1:400,000,000
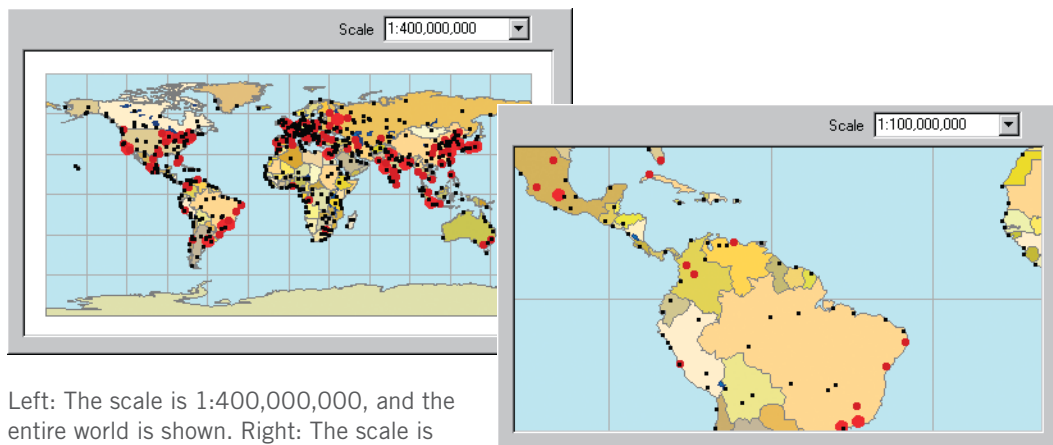
Scale 1:100,000,000

Left: The scale is 1:400,000,000, and the entire world is shown. Right: The scale is 1:100,000,000, and you see part of South America and Central America.

Scale, commonly expressed as a ratio, is the relationship between the size of features on a map and the size of the corresponding places in the world. If the scale of a map is 1:100,000,000, it means that features on the map are one hundred million times smaller than their true size.
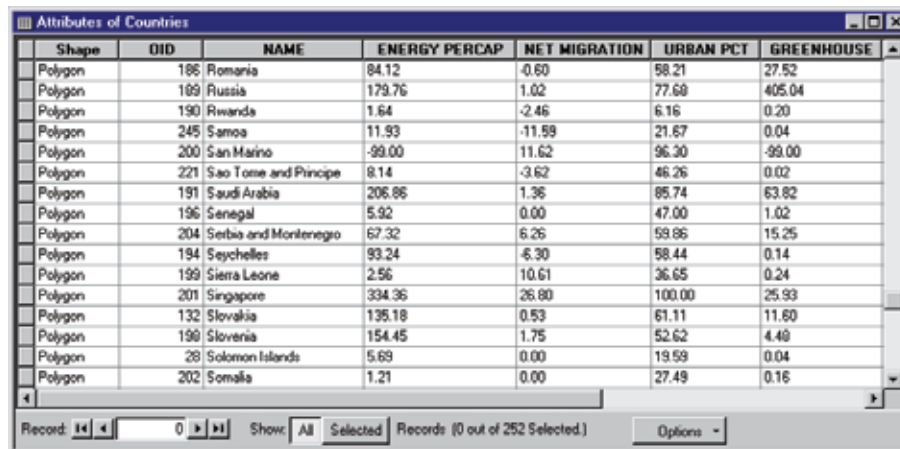
Zooming in gives you a closer view of features within a smaller area. The amount of detail in the features does not change, however. A river has the same bends, and a coastline the same crenulations, whether you are zoomed in and can discern them or are zoomed out and cannot.

How much detail features have depends on the layer you use. Just as a paper map of the world generalizes the shape of Brazil more than a map of South America does, so different GIS layers can contain more feature detail or less.

Features are linked to information

There is more to a feature than its shape and location. There is everything else that might happen to be known about it. For a country, this might include its population, capital, system of government, leading imports and exports, average rainfall, mineral resources, and many other things. For a road, it might be its speed limit, the number of lanes it has, whether it is paved or unpaved, and whether it is one-way or two-way. There is a great deal of information to be had about any feature, from a humble length of sewer pipe to an ocean.

Information about the features in a layer is stored in a table. The table has a record (row) for each feature in the layer and a field (column) for each category of information. These categories are called attributes.
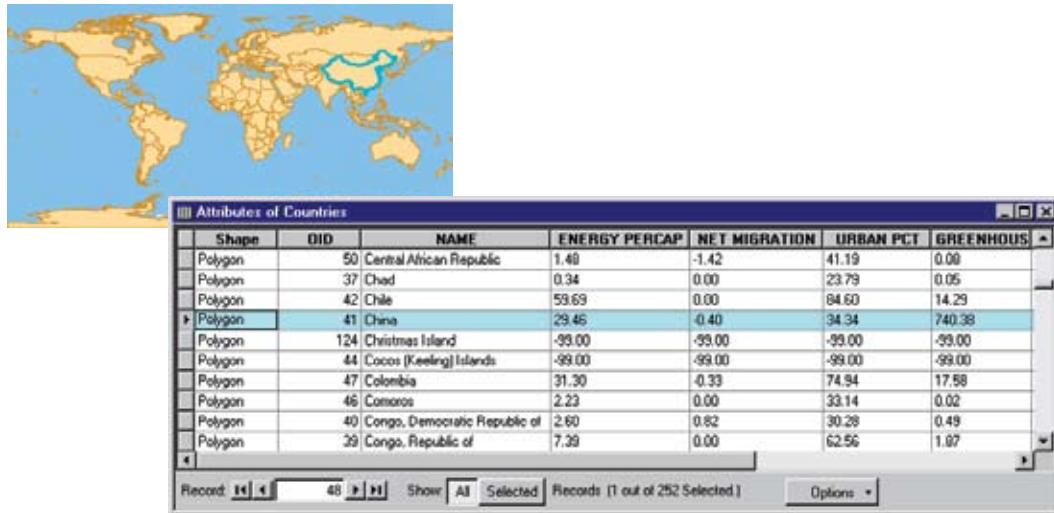
Shape	OID	NAME	ENERGY PERCAP	NET MIGRATION	URBAN PCT	GREENHOUSE
Polygon	186	Romania	84.12	-0.60	58.21	27.52
Polygon	189	Russia	179.76	1.02	77.69	405.04
Polygon	190	Rwanda	1.64	-2.46	6.16	0.20
Polygon	245	Samoa	11.93	-11.59	21.57	0.04
Polygon	200	San Marino	-99.00	11.62	96.30	-99.00
Polygon	221	Sao Tome and Principe	8.14	-3.62	46.26	0.02
Polygon	191	Saudi Arabia	206.86	1.36	85.74	63.82
Polygon	196	Senegal	5.92	0.00	47.00	1.02
Polygon	204	Serbia and Montenegro	67.32	6.26	59.86	15.25
Polygon	194	Seychelles	93.24	-6.30	58.44	0.14
Polygon	199	Sierra Leone	2.56	10.61	36.65	0.24
Polygon	201	Singapore	334.36	26.80	100.00	25.93
Polygon	132	Slovakia	135.18	0.53	61.11	11.60
Polygon	198	Slovenia	154.45	1.75	52.62	4.49
Polygon	28	Solomon Islands	5.69	0.00	19.59	0.04
Polygon	202	Somalia	1.21	0.00	27.49	0.16

Record: ◄ ◄   0 ► ►I   Show: All Selected   Records (0 out of 252 Selected.)   Options ▾

The attribute table for a layer of countries includes each feature's shape, ID number, and name, among other things.

Features on a GIS map are linked to the information in their attribute table. If you highlight China on a map, you can bring up all the information stored about it in the attribute table for countries. If you highlight a record in the table, you see the corresponding feature on the map.

Shape	OID	NAME	ENERGY PERCAP	NET MIGRATION	URBAN PCT	GREENHOUS
Polygon	50	Central African Republic	1.48	-1.42	41.19	0.08
Polygon	37	Chad	0.34	0.00	23.79	0.05
Polygon	42	Chile	59.69	0.00	84.60	14.29
Polygon	41	China	29.46	-0.40	34.34	740.38
Polygon	124	Christmas Island	-99.00	-99.00	-99.00	-99.00
Polygon	44	Cocos (Keeling) Islands	-99.00	-99.00	-99.00	-99.00
Polygon	47	Colombia	31.30	-0.33	74.94	17.58
Polygon	46	Comoros	2.23	0.00	33.14	0.02
Polygon	40	Congo, Democratic Republic of	2.60	0.82	30.28	0.49
Polygon	39	Congo, Republic of	7.39	0.00	62.56	1.97

Record: 48   Show: All Selected   Records (1 out of 252 Selected.)   Options

The link between features and their attributes makes it possible to ask questions about the information in an attribute table and display the answer on the map.

Which cities are national capitals?

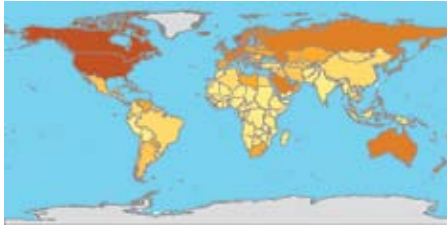Which cities have populations over five million?

Which countries are net importers of goods?

Which countries are net importers of goods and have per capita GDP of $10,000 or more?

Similarly, you can use attributes to create thematic maps, maps in which colors or other symbols are applied to features to indicate their attributes.

Energy consumption per capita

The darker the shade of brown, the more energy is used per person in each country.
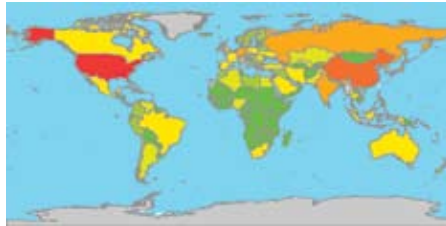
Migration

Red countries have net emigration, blue countries have net immigration. Light yellow countries have little or no change.

Urban population by percentage

Darker shades of purple show countries where a higher percentage of the population lives in cities.

Greenhouse gas emissions

Greenhouse gas emissions are lowest in green countries, higher in yellow and orange countries, and highest in red countries.

Features have spatial relationships

Besides asking questions about the information in attribute tables, you can also ask questions about the spatial relationships among features—for example, which ones are nearest others, which ones cross others, and which ones contain others. The GIS uses the coordinates of features to compare their locations.

Which cities are within 50 kilometers of a river?

Which countries have a river that crosses their border?

Which countries share a border with China?

Which countries contain a lake completely within their borders?

## New features can be created from areas of overlap

Questions about attributes and spatial relationships identify existing features that do or do not have certain qualities. To solve some geographic problems, however, a GIS must create new features. Suppose you want to find suitable places for growing amaranth, a nutritious grain originally grown by the Aztecs. You know that in Mexico amaranth is grown in areas of moderate elevation (1,000 to 1,500 meters) that have an average yearly rainfall of 500 to 800 millimeters and loam or sandy-loam soil. You also know that the plant requires a fairly long growing season, at least 120 days without frost.

You have layers of elevation, rainfall, growing season, and soil type for North and South America.
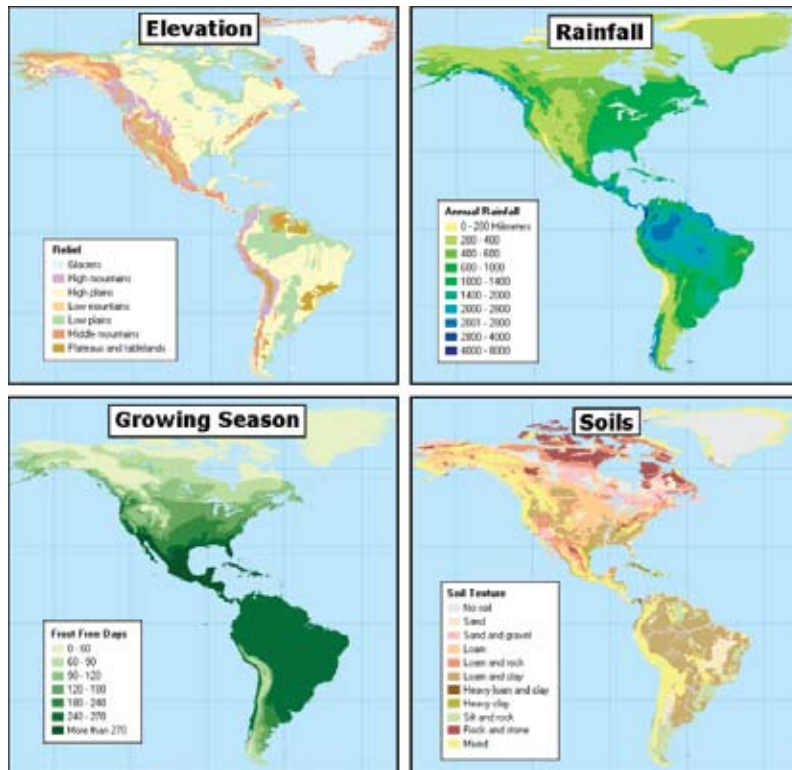
To find places that meet the specified conditions, the GIS looks for areas of overlap among features in the different layers. Wherever there is overlap between four features with the right attributes—the right elevation, the right amount of rainfall, the right growing season, and the right kind of soil—a new feature is created. The new feature's boundary is the area of overlap, which is different from the boundaries of each of the four features it was created from.

The result of the analysis is a new layer that shows where amaranth can be grown.

New layer
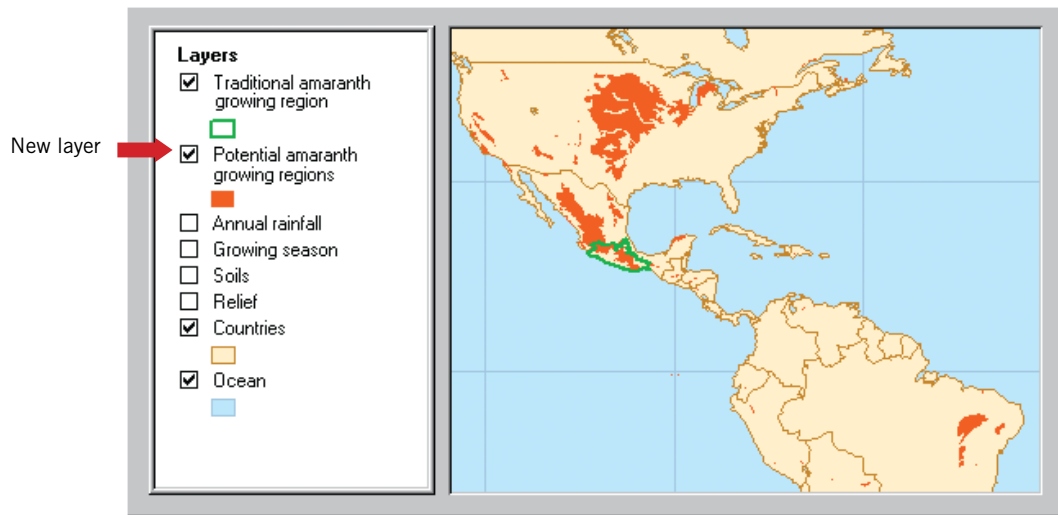
You now have some idea of what a GIS is and what it can do. In the next chapter, you'll learn a little about ArcGIS Desktop, the latest GIS software from ESRI.

Chapter 2

Introducing ArcGIS Desktop

When you shop for a car, a cordless vacuum, or a credit card, you often choose among different models in a product line. The models do essentially the same thing, and usually look similar—the difference is in the extras that come with the medium or high-end models.

ArcGIS Desktop is a GIS software product line. The entry-level model is ArcReader, a product that comes with every ArcGIS installation or can be downloaded for free from the ESRI Web site. ArcReader lets you view and print digital maps created by others, navigate to different parts of the map, and zoom to various levels of detail.

ArcView makes the maps and data that ArcReader can only view and print. With ArcView, you can also query data; analyze spatial relationships like distance, intersection, and containment among map features; and overlay layers to discover how different types of data are interrelated at particular locations.

ArcEditor gives you complete ArcView functionality and has additional data creation and editing tools. Other features include versioning, which allows multiple users to edit data simultaneously, and disconnected editing, which allows data to be checked out of a database, edited in the field, and then checked back in.

At the top of the line, ArcInfo gives you complete ArcEditor functionality plus a full set of spatial analysis tools. ArcInfo also comes bundled with ArcInfo Workstation, a parallel, self-standing GIS software product.

ArcView, ArcEditor, and ArcInfo share a common user interface and can freely exchange maps and data.

The ArcMap and ArcCatalog applications

GIS tasks can be broadly divided into two categories. One includes mapmaking, editing, and spatial analysis; the other includes database design and data management. This division is reflected in the ArcMap and ArcCatalog applications of which ArcView, ArcEditor, and ArcInfo are composed.

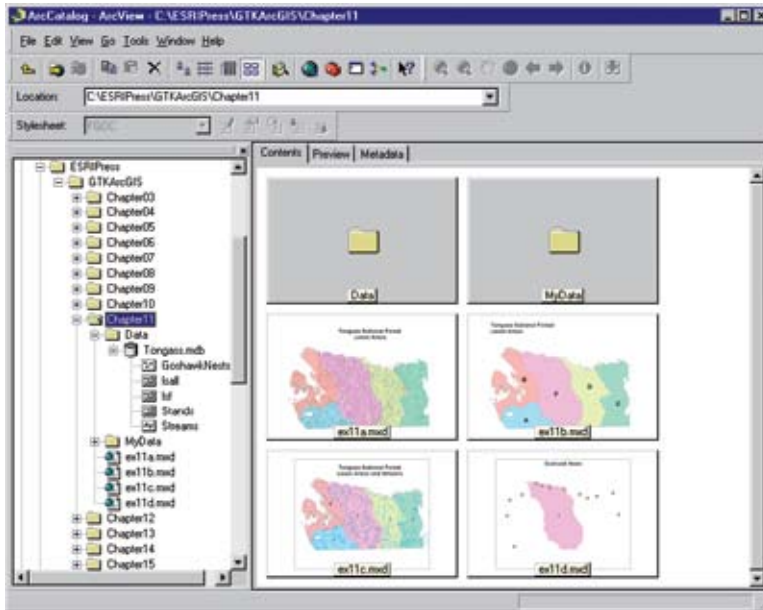ArcMap is the application for making maps and analyzing data.
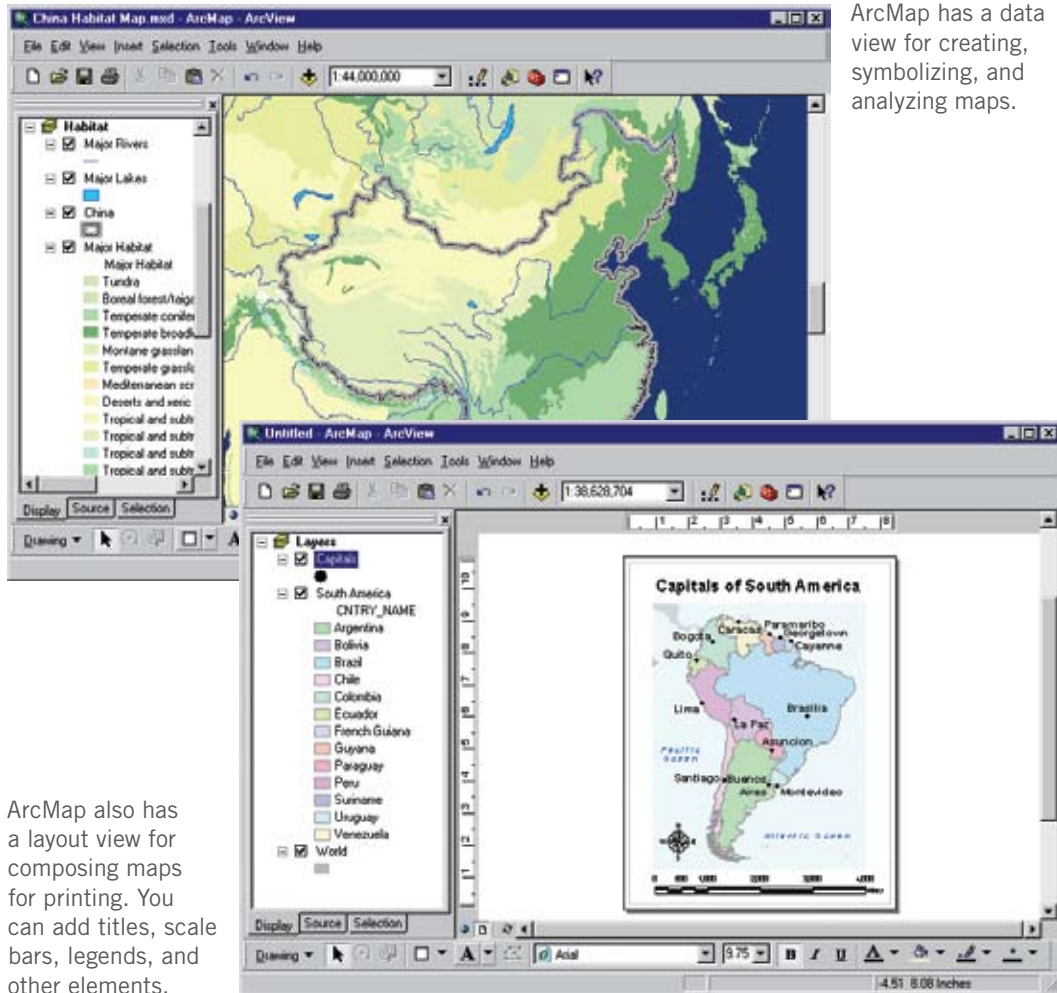
ArcMap has a data view for creating, symbolizing, and analyzing maps.

ArcMap also has a layout view for composing maps for printing. You can add titles, scale bars, legends, and other elements.

ArcCatalog is the data management application.

With ArcCatalog, you organize, browse, document, and search for spatial data. ArcCatalog also has tools for building and managing GIS databases.

Extending ArcGIS Desktop

You can augment the capabilities of ArcGIS Desktop with specialized extension products that are fully integrated with ArcView, ArcEditor, and ArcInfo. ArcGIS Spatial Analyst, ArcGIS 3D Analyst, and ArcGIS Geostatistical Analyst, described below, along with several other extension products are included on the demo CD that comes with this book. The book does not teach you how to use them, but you can explore them on your own using the on-line help and the ArcGIS Tutorial data that is also on the CD. Like ArcView, the extensions are good for 180 days.

ArcGIS Spatial Analyst maps and analyzes measured data like elevation, rainfall, or chemical concentrations. By dividing geographic space into a matrix of square cells that store numbers, ArcGIS Spatial Analyst allows you to represent, query, and statistically summarize this kind of data. You can also estimate values at unmeasured locations through the mathematical interpolation of known sample values.

ArcGIS 3D Analyst gives you the ability to see spatial data in three dimensions. You can "fly through" terrain and examine it from any height or angle. You can model cities and neighborhoods by drawing buildings at their correct heights. Analysis tools let you solve visibility, volume, and downhill path problems. (Which areas can be seen from the mountaintop?

Can Tower 1 be seen from Tower 2? How much earth is in the hill? Which course will water follow down a surface?)

ArcGIS Geostatistical Analyst lets you evaluate measured spatial data according to statistical principles. You can explore the value distributions of datasets, compare them to normal (bell-shaped) distributions and to each other, and look for correlations between different types of data. As with ArcGIS Spatial Analyst, you can make maps of predicted values at unmeasured locations. ArcGIS Geostatistical Analyst, however, gives you a wider choice of predictive models, more control over their parameters, and statistical techniques for assessing the quality of the results.
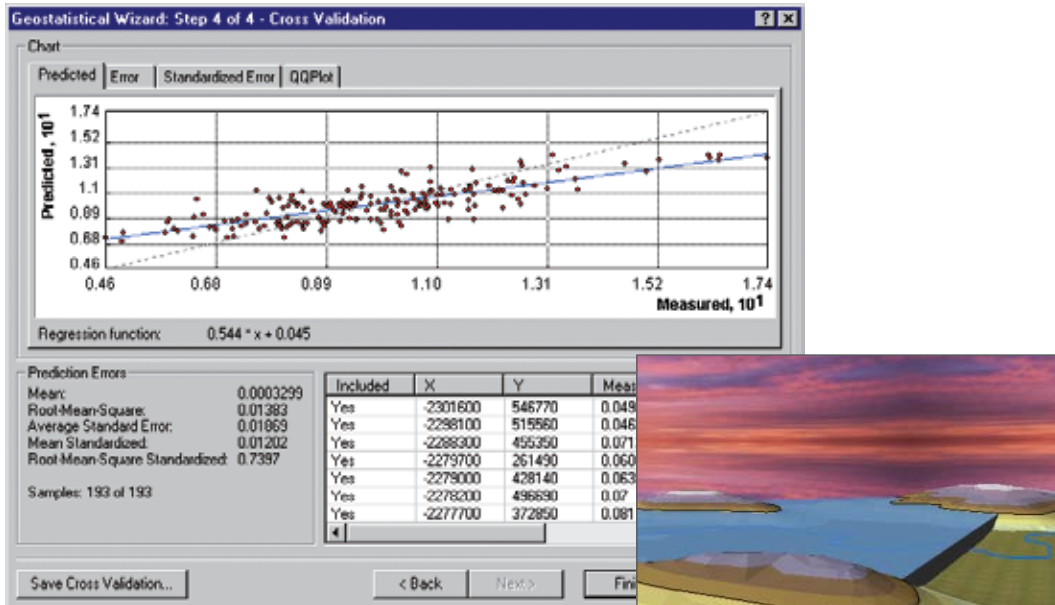
Top: ArcGIS Geostatistical Analyst uses cross-validation to assess the quality of ozone level predictions for California. Upper right: ArcGIS 3D Analyst draws a map of a dam in Kansas. Lower right: ArcGIS Spatial Analyst represents distances to the nearest airport (green points) with graduated colors. (Only airports serving more than 25,000 passengers annually are shown.)
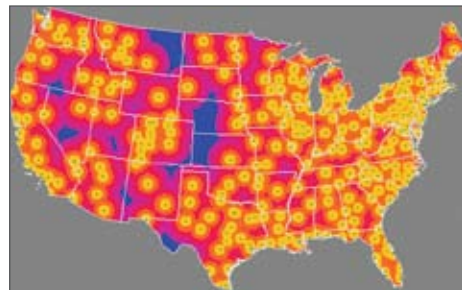
The ArcGIS system

ArcGIS Desktop is just one of five parts of the ArcGIS system, which also includes mobile GIS, online GIS, server GIS, and ESRI Data.

Mobile GIS goes into the field

For people who record and use geographic data in the field—for example, surveyors, field technicians, delivery people, public service and utility workers—ArcGIS Mobile enables organizations to deliver GIS capabilities and data from centralized application servers, providing access to GIS services over wireless networks to a range of mobile devices. ArcPad is an out-of-the box solution that provides essential GIS functions on pocket computers.

Online GIS goes to digital worlds

ArcGIS Online is a family of Web-based products and resources that enhance and extend the ArcGIS user experience. ArcGIS Online Content, hosted by ESRI and powered by ArcGIS Server, provides ready-to-use content and capabilities for ArcGIS users including 2D map and 3D globe services as well as tasks that can be executed directly from ArcGIS Desktop, ArcGIS Server, and ArcGIS Explorer.

Server GIS goes over the Internet and through the enterprise

ArcGIS Server is used to build Web sites that deliver maps, data, and information—like driving directions or ATM locations—over the Internet. They bring GIS to people who don't have GIS software themselves.

ArcSDE (Spatial Database Engine) manages the exchange of information between ArcGIS and relational database management systems, such as Microsoft SQL Server, IBM DB2, Informix, and Oracle. It enables users throughout an enterprise to share and edit centrally stored geographic data.

ESRI Data goes to work for you

ESRI Community Data encompasses a variety of datasets that help companies and organizations analyze markets, profile customers, evaluate competitors, and more.

ESRI's StreetMap Premium and StreetMap Premium Europe are enhanced street datasets that provide routing, geocoding, and high-quality cartographic display for the entire United States, Canada, and Europe.

ESRI Data & Maps is a set of annual map data that is included at no additional cost with ArcGIS software and preconfigured to work with ArcGIS products.

In this book, you will learn the basics of ArcView, ArcEditor, and ArcInfo. To find out more about ArcGIS Desktop extensions, or about mobile GIS, online GIS, server GIS, or ESRI Data, visit the ESRI Web site at www.esri.com.