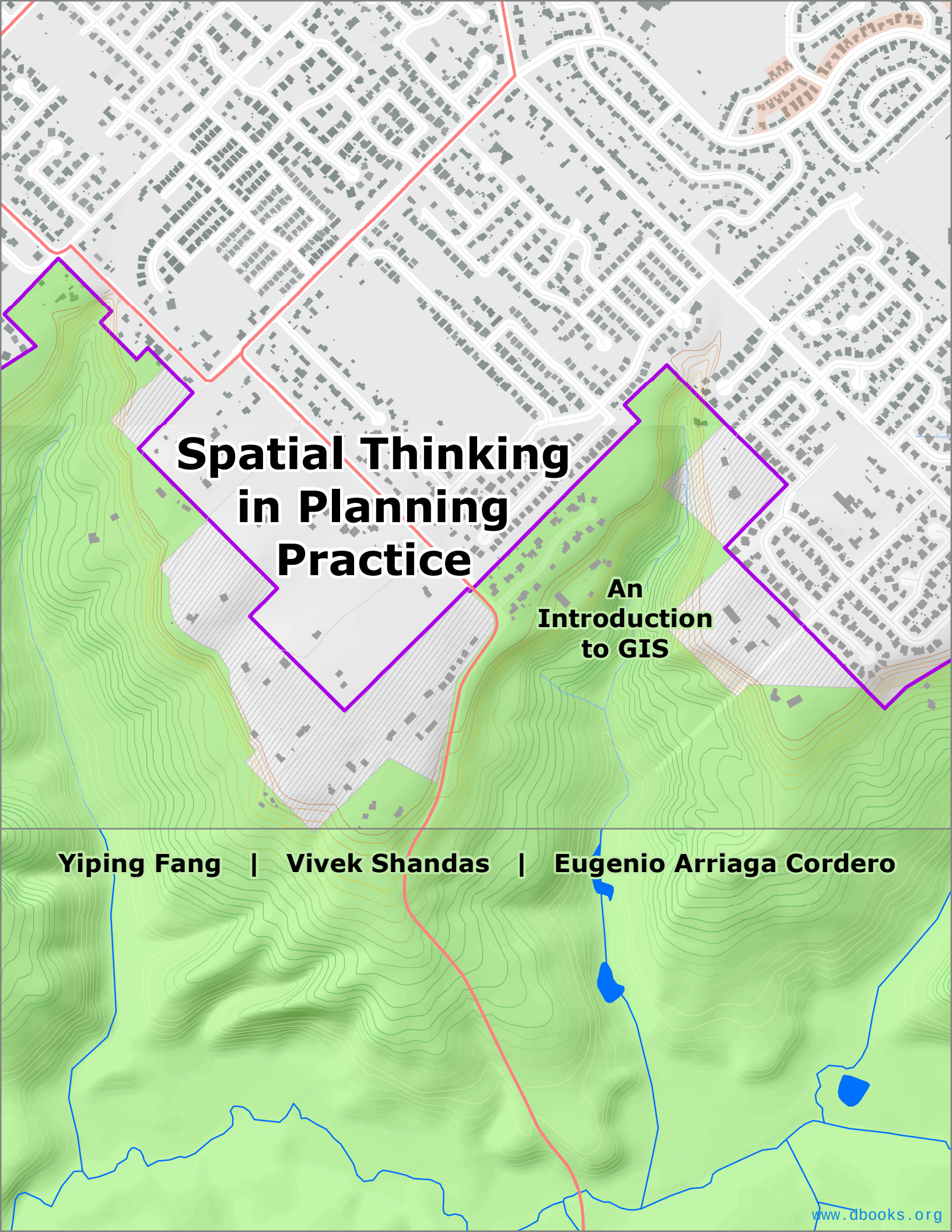


Spatial Thinking in Planning Practice

An Introduction to GIS

Yiping Fang | Vivek Shandas | Eugenio Arriaga Cordero

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Spatial Thinking in Planning Practice: An Introduction to GIS

By

Yiping Fang, Vivek Shandas, & Eugenio Arriaga

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PREFACE

THE EMERGENCE OF GIS IN URBAN AND REGIONAL PLANNING PRACTICE

During the last 20 years, geographic information systems (GIS) have transitioned from scientific laboratories into the heart of conventional planning practice. During this period, planners have been aggressive adopters and adapters, and strong advocates for local governments deploying GIS. This is true in part because GIS provides a platform for collecting and organizing spatial data, along with analyzing and manipulating capabilities that align closely with the professional needs of urban and regional planners.

When facilitating GIS courses in the field of urban and regional planning, we have observed a deficit of introductory textbooks specifically written for planning students, whose career paths may require a certain set of GIS skills that differ from those taught in geography or other departments. This textbook is our first effort to compile a series of readings that we find compelling and relevant for planning graduate students to explore spatial thinking and application, which will support a spatially informed future in the profession.

The goals of this textbook are to help students acquire the technical skills of using software and managing a database, and develop research skills of collecting data, analyzing information and presenting results. We emphasize that the need to investigate the potential and practicality of GIS technologies in a typical planning setting and evaluate its possible applications. GIS may not be necessary (or useful) for every planning application, and we anticipate these readings to provide the necessary foundation for discerning its appropriate use. Therefore, this textbook attempts to facilitate spatial thinking focusing more on open-ended planning questions, which require judgment and exploration, while developing the analytical capacity for understanding a variety of local and regional planning challenges.

While this textbook provides the background for understanding the concepts in GIS as applicable to urban and regional planning, it is best when accompanied by a hands-on tutorial, which will enable readers to develop an in-depth understanding of the specific planning applications of GIS. Chapters in this text book are either composed by the editors using Creative Common materials, or linked to a book chapter scanned copy in the library reserve. In the end of each chapter, we also provided several discussion questions, together with contextual applications through some web links.

CHAPTER 1: DEFINING A GEOGRAPHIC INFORMATION SYSTEM

Although GIS has been around since the 1970s, the concepts surrounding GIS are old, and even the practice of doing GIS began before computers. The difference today is that GIS is computerized. By computerizing GIS, we have taken the processes away from our hand-drawn depictions, which tend to require extensive time, money, training, and energy. Computers process numbers and mathematical equations far quicker than people. Yet, before the concepts behind GIS were transferred to computers, people were doing manual GIS by combining spatial and attribute data on various types of media including hard-copy maps, hard-copy overlays (acetate or vellum), aerial photographs, written reports, field notebooks, and—of course—their eyes and minds.

With manual GIS, a large base map was often placed on a tabletop, and a series of transparent overlay maps, drawn at the same scale, were placed on top of the base map. One would then look for relationships among the base map and the features on the transparent overlays. Frequently, spatial data were copied from one map (or aerial photograph) to another. This took time, and because of it, many great ideas about the relationships of the Earth's features (both physical and human) were not analyzed. These ideas were constrained by the amount of time it took to do the analysis. Still, some impressive manual GIS projects did occur. The much-repeated example of Dr. John Snow's Cholera map is a great example of manual GIS (Figure 1.1).



Figure 1.1. Dr. John Snow's Cholera Map of London's Soho. Source: Wikipedia http://en.wikipedia.org/wiki/Geographic_information_system

In the 1840s, a cholera outbreak killed several hundred residents in London's Soho section. Snow, a physician, located the address of each fatality on a hand-drawn base map and soon a cluster of cases was visible. Then, on the base map, over the streets and fatalities, he drew the locations of water wells. Familiar with the idea of distance decay, he knew that people might go a far distance to purchase a product that was cheaper, but they would go to the nearest well because water was free and heavy to carry. Snow could see that the fatalities clustered largely among those who lived near the Broad Street water well. He and his students took the handle off the water pump, and new cholera cases dropped rapidly. By disabling the pump, Snow demonstrated the spatial relationship between cholera fatalities and the Broad Street water well, and, more importantly, he established the relationship between cholera and drinking water.

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Even with the advent of computers, GIS applications to several decades to transform to the personal computer that we use today. Originally, the largest and most powerful computers were mainframes that were available to some academics and government officials. In the 1980s, most GIS applications ran on workstation computers tied to mainframe computers because the early microcomputers (IBM, Apple, etc.) did not have enough memory, storage capacity, or processing ability. Today's personal computers, however, are fast, capable of storing and processing large datasets, and can process multiple tasks simultaneously. This enables many academics, government agencies (from local to federal), organizations, and small and large businesses to use GIS. Computer-based GIS has its advantages, but requires trained users.

GIS DATA MODELS

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

VECTOR DATA MODEL

An introductory GIS course often emphasizes the vector data model, since it is the more commonly used in the planning professions. Vector data models use points and their associated [X and Y] coordinate pairs to represent the vertices of spatial features, much as if they were being drawn on a map by hand (Aronoff 1989)1. The data attributes of these features are then stored in a separate database management system. The spatial information and the attribute information for these models are linked via a simple identification number that is given to each feature on a map. Three fundamental vector types exist in GIS: points, lines, and polygons, each of which we define below (and illustrate in Figure 1.2):

- Points are zero-dimensional objects that contain only a single coordinate pair. Points are typically used to model singular, discrete features such as buildings, wells, power poles, sample locations, and so forth. Points have only the property of location. Other types of point features include the node and the vertex. Specifically, a point is a stand-alone feature, while a node is a topological junction representing a common X, Y coordinate pair between intersecting lines and/or polygons. Vertices are defined as each bend along a line or polygon feature that is not the intersection of lines or polygons. Points can be spatially linked to form more complex features.

- Lines are one-dimensional features composed of multiple, explicitly connected points. Lines are used to represent linear features such as roads, streams, faults, boundaries, and so forth. Lines have the property of length. Lines that directly connect two nodes are sometimes referred to as chains, edges, segments, or arcs.

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

1 Aronoff, S. 1989. *Geographic Information Systems: A Management Perspective*. Ottawa, Canada: WDL Publications.

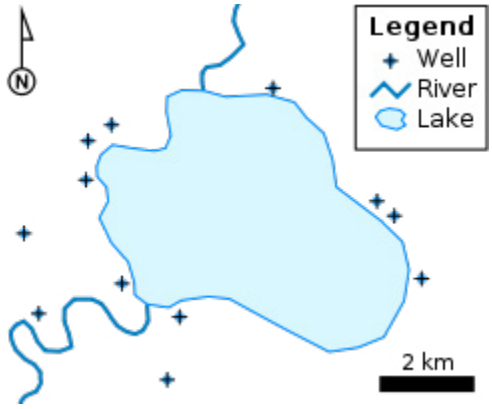


Figure 1.2. A simple vector map, using each of the vector elements: points for wells, lines for rivers, and a polygon for the lake. Source: Wikipedia. http://en.wikipedia.org/wiki/GIS_file_formats

RASTER DATA MODEL

The raster data model is widely used in applications ranging far beyond geographic information systems (GISs). Most likely, you are already very familiar with this data model if you have any experience with digital photographs. The raster data model consists of rows and columns of equally sized pixels interconnected to form a planar surface. These pixels are used as building blocks for creating points, lines, areas, networks, and surfaces. Although pixels may be triangles, hexagons, or even octagons, square pixels represent the simplest geometric form with which to work. Accordingly, the vast majority of available raster GIS data are built on the square pixel. The contrast between raster and vector model reflect the 'pixilization' of a raster, which would be points, lines and polygons in a vector data model (Figure 1.3). The raster data model is a part of a later chapter.

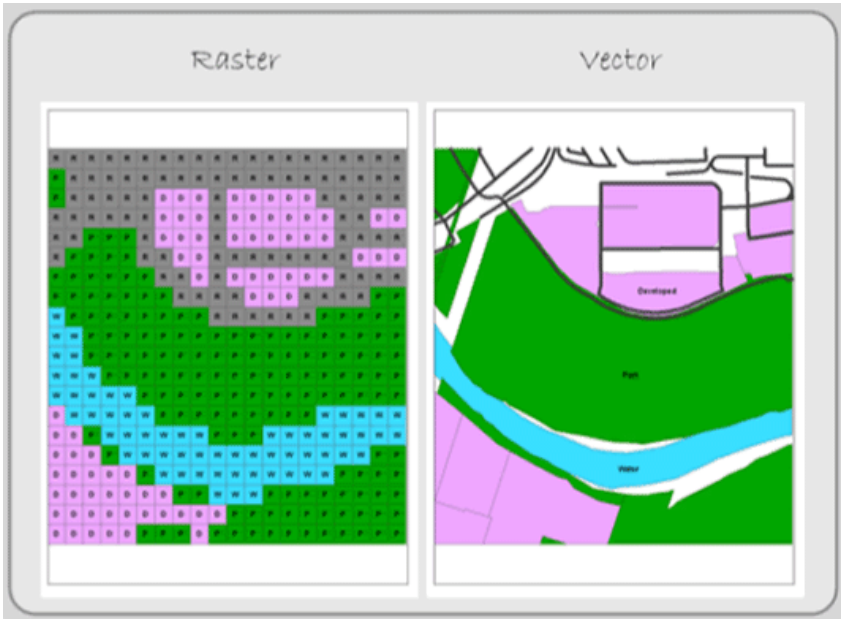


Figure 1.3. Visual depiction of the difference between a raster (left) and vector (right) data model. Source: GIS Commons. http://giscommons.org/introduction-concepts/

VECTOR VS. RASTER

Which is better? Although GIS users have their own personal favorite data model, the question of which is "better" is an incomplete question. There are advantages and disadvantages to both data models, so a better question is which is better for particular applications or datasets. Some in the GIS industry use the slogan "Raster is faster, but vector is corrector." While this is a good starting point, it conceals the details. Yes, your computer can process raster data quicker, but today computer processors are so fast the difference may be negligible. Yes, vec-

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tor output looks more accurate, but you can increase pixel resolution to something resembling vector resolution (this, however, greatly increases the database size). In the following we try to list the advantage and disadvantages of vector and raster file.

VECTOR ADVANTAGES:

1. *Intuitive*. In our minds, we picture features discreetly rather than made up of contiguous square cells.

2. *Resolution*. If the locations of features are precise and accurate, you can maintain that spatial accuracy. The features will not float somewhere within a cell.

3. *Topology*. Although the raster data model preserves where features are located in relation to one another, they do not represent how they are related to one another. This complex form of topology can be constructed in most vector systems, so you can track the connections in a municipal water network between pipe and valve features and thus track the direction and flow of water.

4. *Storage*. Vector points, lines, and simple polygons use little disk space in comparison to raster systems. This was once a major consideration when hard-disk storage was limited and expensive.

VECTOR DISADVANTAGES:

1. *Geometry is complex*. The geometrical algorithms needed for geoprocessing, for example polygon overlay and the calculation of distances, depending on the projection/coordinate system used, require experienced programmers. This is not usually a problem for most GIS users since most functions are directly coded in the software.

2. Slow response times. The vector data model can be slow to process complex datasets especially on low-end computers.

3. Less innovation. Since the math is more complex, new analysis functions may not surface on vector systems for a couple of years after they have debuted on raster system.

RASTER ADVANTAGES:

1. *Easy to understand*. Conceptually, the raster data model is easy to understand. It arranges data into columns and rows. Each pixel represents a piece of territory.

2. *Processing speed*. Raster's simple data structure and its uncomplicated math produce quick results. For example, to calculate a polygon's area, the computer takes the area contained within a single cell (which remains consistent throughout the layer) and multiples it by the number of cells making up the polygon. Likewise, the speed of many analysis processes, like overlay and buffering, are faster than vector systems that must use geometric equations.

3. *Data form*. Remote sensing imagery is easily handled by raster-based systems because the imagery is provided in a raster format.

4. *Some analysis functions* (surface analysis and neighborhood functions) are only feasible in raster systems. In addition, many new analysis functions appear in raster systems before migrating to vector systems because the math is simpler.

RASTER DISADVANTAGES:

1. *Appearance*. Cells "seem" to sacrifice too much detail (Figure 1.9). This disadvantage is largely aesthetic and can be remedied by increasing the layer's resolution.

2. *Accuracy*. Sometimes accuracy is a problem due to the pixel resolution. Imagine if you had a raster layer with a 30 by 30 meter resolution, and you wanted to locate traffic stop signs in that layer. The entire 30 by 30 meter pixel would represent the single stop sign. If you converted this raster layer to vector, it might place the stop sign at what was the pixel's center. Sometimes problems of accuracy (and appearance) can be resolved by selecting a smaller pixel resolution, but this has database consequences.

3. *Large database*. As just described, accuracy and appearance can be enhanced by reducing pixel size (the area of the Earth's surface covered by each cell), but this increases your layer's file size. By making the resolution 50 percent better (say from 30 to 15 meters), your layer grows four times. Improve the resolution again by halving the pixel size (to 7.5 meters) and your layer will again increase by four times (16 times larger than the original 30-meter layer). The layer quadruples because the resolution increases in both the x and y direction.

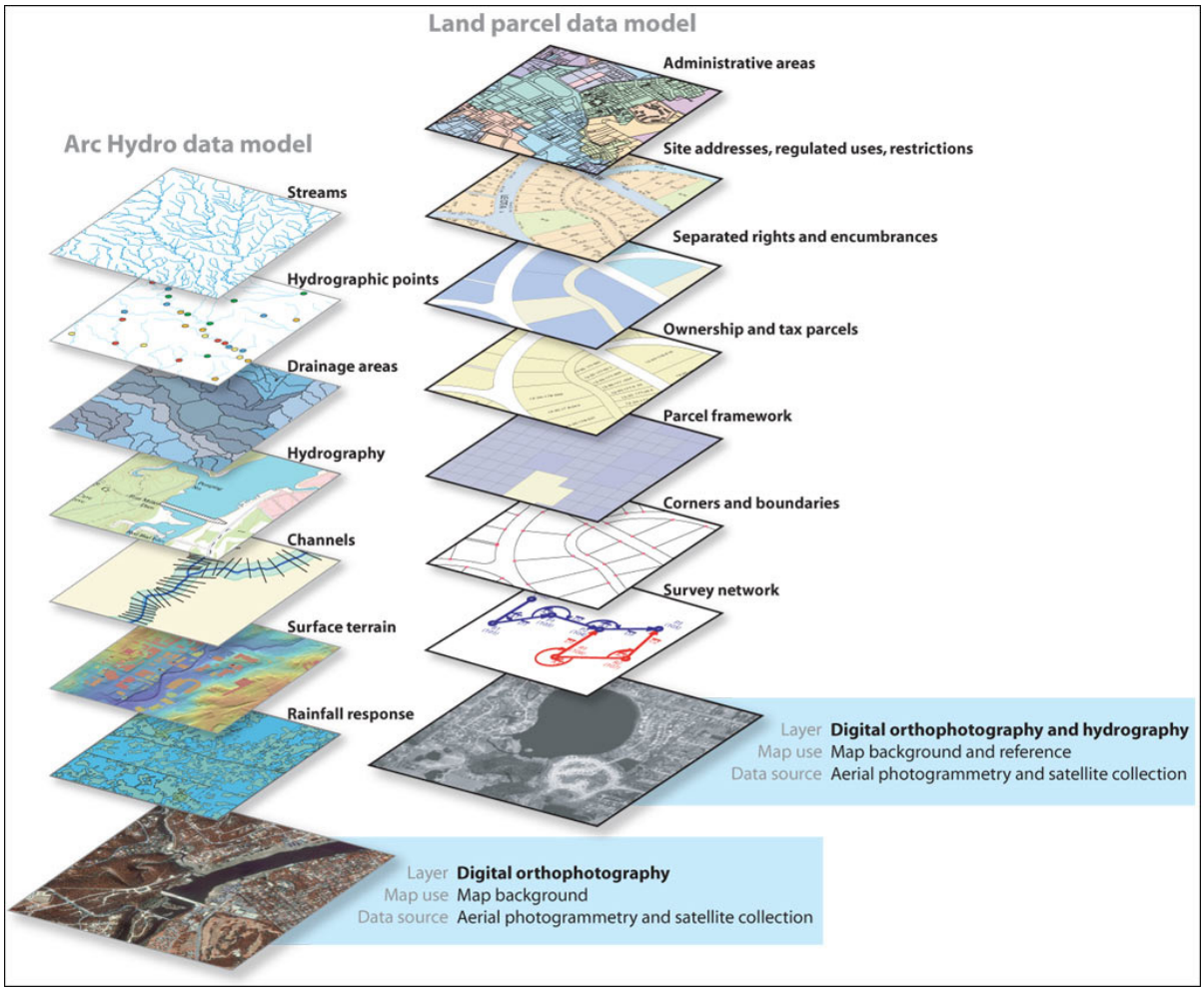


Figure 1.4. Visual depiction of overlay analysis. Source: ESRI. http://www.esri.com/news/arcnews/fall04articles/arcgis-raster-data-model.html

MORE ON VECTOR DATA MODELS

The real world is too complex and unmanageable for direct analysis and understanding because of its countless variability and diversity. It would be an impossible task to describe and locate each city, building, tree, blade of

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grass, and grain of sand. How do we reduce the complexity of the Earth and its inhabitants, so we can portray them in a GIS database and on a map? We do it by selecting the most relevant features (ignoring those we do not think are necessary for our specific research or project) and then generalizing the features we have selected. The image above shows the real world is selectively represented by different features that we are interested in. They are also called map layers in GIS.

FEATURES AND FEATURE CLASS

In ArcGIS, map layers are also called shape files, or feature classes. Conceptually, there are two parts of a shape file: a spatial or map component and an attribute or database component. Features have these two components as well. They are represented spatially on the map and their attributes, describing the features, are found in a data file. These two parts are linked. In other words, each map feature is linked to a record in a data file that describes the feature. If you delete the feature's attributes in the data file, the feature disappears on the map. Conversely, if you delete the feature from the map, its attributes will disappear too.

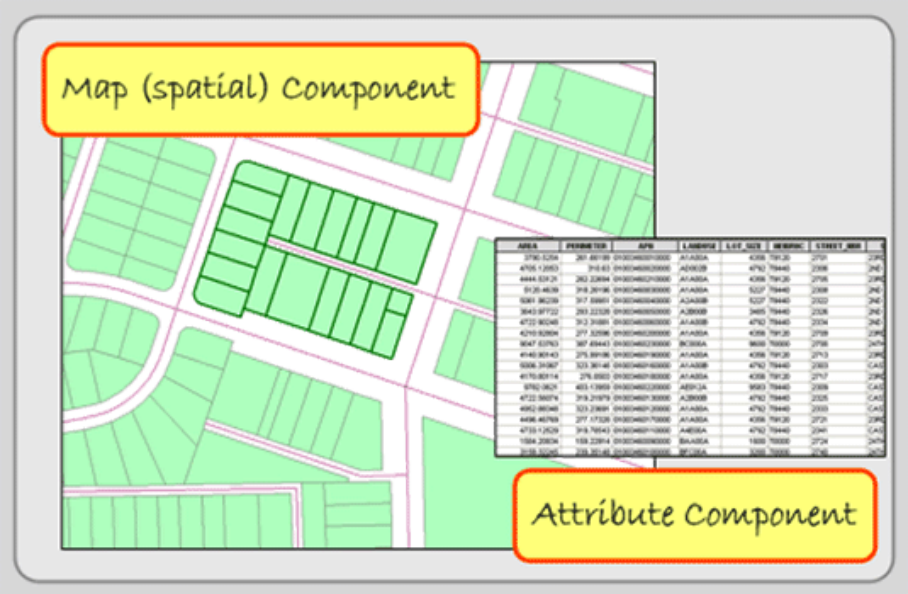


Figure 1.5. Spatial and attribute data. GIS Commons. http://giscommons.org/introduction-concepts/

Features are individual objects and events that are located (present, past or future) in space. In the above Figure, a single parcel is an example of a feature. Within the GIS industry, features have many synonyms including objects, events, activities, forms, observations, entities, and facilities. Combined with other features of the same type (like all of the parcels in Figure), they are arranged in data files often called layers, coverages, or themes.

In the Figure below, three features—parcels, buildings, and street centerlines—of a typical city block are visible. Every feature has a spatial location and a set of attributes. Its spatial location describes not only its location but its extent.



Figure 1.6. Each feature in the layers above has a spatial location and attribute data, which describes the individual feature. GIS Commons. http://giscommons.org/introduction-concepts/

Besides location, each feature usually has a set of descriptive attributes, which characterize the individual feature. Each attribute takes the form of numbers or text (characters), and these values can be qualitative (i.e. low, medium, or high income) or quantitative (actual measurements). Sometimes, features may also have a temporal dimension; a period in which the feature's spatial or attribute data may change. As an example of a feature class, think of a streetlight. Now imagine a map with the locations of all the streetlights in your neighborhood. In Figure 1.5, streetlights most are depicted as small circles. Now think of all of the different characteristics that you could collect relating to each streetlight. It could be a long list. Streetlight attributes could include height, material, basement material, presence of a light globe, globe material, color of pole, style, wattage and lumens of bulb, bulb type, bulb color, date of installation, maintenance report, and many others. The necessary streetlight attributes depends on how you intend to use them. For example, if you are solely interested in knowing the location of streetlights for personal safety reasons, you need to know location, pole heights, and bulb strength. On the other hand, if you are interested in historic preservation, you are concerned with the streetlight's location, style, and color.

Now continue thinking about feature attributes, by imagining the trees planted around your campus or office. What attributes would a gardener want versus a botanist? There would be differences because they have different needs. You determine your study's features and the attributes that define the features.

ATTRIBUTE DATA TABLE

Once you have decided on the features and their attributes, determine how they will be coded in the GIS database. There are multiple ways to code features in different scale and circumstance. For example, schools can be coded as a point in large scale maps, and a polygon of their campus in small scale maps. You can decide whether to code each feature type as a point, line, or polygon. Together you also need to define the format and storage requirements for each of the feature's attributes.

While thinking about your attribute values, consider where it fits in the "levels of measurement" scale with its four different data values: nominal, ordinal, interval, and ratio. Stanley S. Stevens, an American psychologist, developed these categories in 1946. For our purposes, these categories are useful way to conceptualize how data values differ, and it is an important reminder that only some types of variables can be used for certain mathematical operations and statistical tests, including many GIS functions. The different "levels" are depicted in the

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following table and demonstrated using an example of a marathon race:

Nominal	**Ordinal**	**Interval**	**Ratio**
Runner ID	Order finished	Time of day finished	Total race time
238	1	10:10am	2:30
143	2	10:11am	2:31
14	3	10:13am	2:33
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
301	450	18:10pm	10:30

Figure 1.7. Levels of Measurement. Adopted from GIS Commons. http://giscommons.org/chapter-2-input/

Nominal data use characters or numbers to establish identity or categories within a series. In a marathon race, the numbers pinned to the runners' jerseys are nominal numbers (first column in the figure above). They identify runners, but the numbers do not indicate the order or even a predicted race outcome. Besides races, telephone numbers are a good example. It signifies the unique identity of a telephone. The phone number 961-8224 is not more than 961-8049. Place names (and those of people) are nominal too. You may prefer the sound of one name, but they serve only to distinguish themselves from each other. Nominal characters and numbers do not suggest a rank order or relative value; they identify and categorize. Nominal data are usually coded as character (string) data in a GIS database.

Although census data originate as individual counts, much of what is counted is individuals' membership in nominal categories. Race, ethnicity, marital status, mode of transportation to work (car, bus, subway, railroad...), and type of heating fuel (gas, fuel oil, coal, electricity...) are measured as numbers of observations assigned to unranked categories. Using nominal data we can use the Census Bureau's first atlas to depict the minority groups with the largest percentage of population in each U.S. state (Figure 1.8). Colors were chosen to differentiate the groups through a qualitative color scheme to show differences between the classes, but not to imply any quantitative ordering. Thus, although numerical data were used to determine which category each state is in, the map depicts the resulting nominal categories rather than the underlying numerical data.

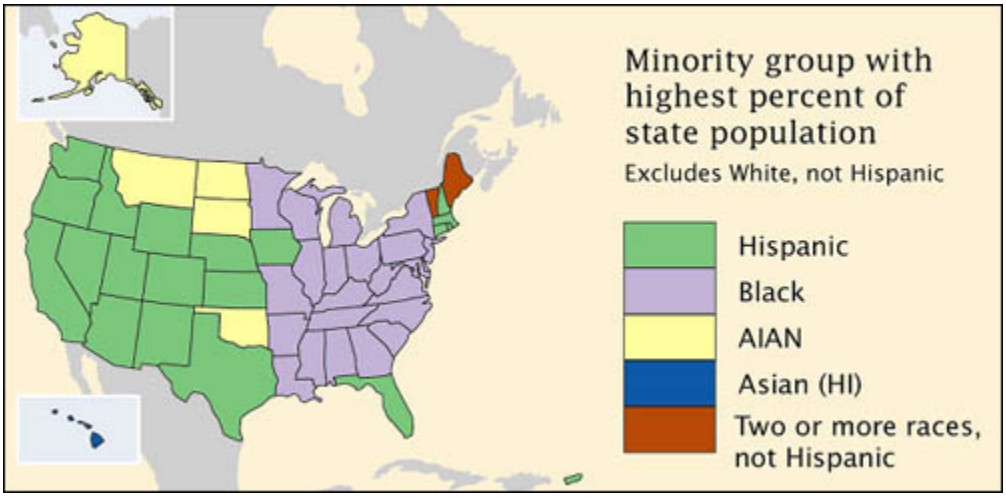


Figure 1.8. Highest percent minority group by state. Source: US Census (2000).

Ordinal datasets establish rank order. In the race, the order they finished (i.e. 1st, 2nd, and 3rd place) are measured on an ordinal scale (second column in Figure 2.5). While order is known, how much better one runner is than the other is not. The ranks 'high', 'medium', and 'low' are also ordinal. So while we know the rank order, we do not know the interval. Usually both numeric and character ordinal data are coded with characters because ordinal data cannot be added, subtracted, multiplied, or divided in a meaningful way. The middle value, the "median", in a string of ordinal values, however, is a good substitute for a mean (average) value.

Examples of ordinal data often seen on reference maps include political boundaries that are classified hierarchically (national, state, county, etc.) and transportation routes (primary highway, secondary highway, light-duty road, unimproved road). Ordinal data measured by the Census Bureau include how well individuals speak English (very well, well, not well, not at all), and level of educational attainment (high school graduate, some college no degree, etc.). Social surveys of preferences and perceptions are also usually scaled ordinally.

Individual observations measured at the ordinal level are not numerical, thus should not be added, subtracted, multiplied, or divided. For example, suppose two 600-acre grid cells within your county are being evaluated as potential sites for a hazardous waste dump. Say the two areas are evaluated on three suitability criteria, each ranked on a 0 to 3 ordinal scale, such that 0 = completely unsuitable, 1 = marginally unsuitable, 2 = marginally suitable, and 3 = suitable. Now say Area A is ranked 0, 3, and 3 on the three criteria, while Area B is ranked 2, 2, and 2. If the Siting Commission was to simply add the three criteria, the two areas would seem equally suitable (0 + 3 + 3 = 6 = 2 + 2 + 2), even though a ranking of 0 on one criteria ought to disqualify Area A.

The Interval scale, like we will discuss with ratio data, pertains only to numbers; there is no use of character data. With interval data the difference—the "interval"—between numbers is meaningful. Interval data, unlike ratio data, however, do not have a starting point at a true zero. Thus, while interval numbers can be added and subtracted, division and multiplication do not make mathematical sense. In the marathon race, the time of the day each runner finished is measured on an interval scale. If the runners finished at 10:10 a.m., 10:20 a.m. and 10:25 a.m., then the first runner finished 10 minutes before the second runner and the difference between the first two runners is twice that of the difference between the second and third place runners (see third column 3 Figure 2.5). The runner finishing at 10:10 a.m., however, did not finish twice as fast as the runner finishing at 20:20 (8:20 p.m.) did. A good non-race example is temperature. It makes sense to say that 20° C is 10° warmer than 10° C. Celsius temperatures (like Fahrenheit) are measured as interval data, but 20° C is not twice as warm as 10° C because 0° C is not the lack of temperature, it is an arbitrary point that conveys when water freezes. Returning to phone numbers, it does not make sense to say that 968-0244 is 62195 more than 961-8049, so they are not interval values.

Ratio is similar to interval. The difference is that ratio values have an absolute or natural zero point. In our race, the first place runner finished in a time of 2 hours and 30 minutes, the second place runner in a time of 2 hours and 40 minutes, and the 450th place runner took 10 hours. The 450th place finisher took over five times longer than the first place runner did. With ratio data, it makes sense to say that a 100 lb woman weighs half as much as a 200 lb man, so weight in pounds is ratio. The zero point of weight is absolute. Addition, subtraction, multiplication, and division of ratio values make statistical sense.

The main reason that it's important to recognize levels of measurement is that different analytical operations are possible with data at different levels of measurement (Chrisman 2002). Some of the most common operations include:

- Group: Categories of nominal and ordinal data can be grouped into fewer categories. For instance, grouping can be used to reduce the number of land use/land cover classes from, for instance, four (residential, commercial, industrial, parks) to one (urban).

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- Isolate: One or more categories of nominal, ordinal, interval, or ratio data can be selected, and others set aside. For example, consider a range of temperature readings taken over a large area. Only a subset of those temperatures are suitable for mosquito survival, and health officials can select and isolate areas based upon a specific temperature range that is likely there to take action in order to reduce the threat of a West Nile Virus or Dengue Fever outbreak from these mosquitoes.

- Difference: The difference of two interval level observations (such as two calendar years) can result in one ratio level observation (such as one age). For example, in 2012 (a year is an interval level value), someone born in 2000 (also interval level, of course) is 12 years old (age is ratio level, since it has a definite zero).

- Other arithmetic operations: Two or more compatible sets of interval or ratio level data can be added or subtracted. Only ratio level data can be multiplied or divided. For example, the per capita (average) income of an area can be calculated by dividing the sum of the income (ratio level) of every individual in that area (ratio level), by the number of persons (ratio level) residing in that area (a second ratio level variable).

- Classification: Numerical data (at interval and ratio level) can be sorted into classes, typically defined as non-overlapping numerical data ranges. These classes are frequently treated as ordinal level categories for thematic mapping with the symbolization on choropleth maps, for example, emphasizing rank order without attempting to represent the actual magnitudes.

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http://giscommons.org/introduction-concepts/

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http://giscommons.org/chapter-2-input/

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http://2012books.lardbucket.org/books/geographic-information-system-basics/s08-02-vector-data-models.html#

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https://www.e-education.psu.edu/geog160/c3_p8.html

Discussion Questions

1. In what ways would John Snow's mapping process differ given the GIS technologies available today? How would his results be different or the same?

2. How do the differences between discrete and continuous attribute data impact the selection of using vector and/or raster data models?

3. Find an internet source that contains an interesting map that visualizes data from two of the different attribute measurement scales: nominal, ordinal, interval, and ratio. How do the different measurement scales reflect the type of data provided?

Contextual Applications of Chapter 1

All Cities Are Not Created Unequal (Brookings)

American Migration

CHAPTER 2: COORDINATE SYSTEMS AND PROJECTING GIS DATA

A coordinate system is a way to reference, or locate, everything on the Earth's surface in x and y space. The method used to portray a part of the spherical Earth on a flat surface, whether a paper map or a computer screen, is called a map projection. Each map projection used on a paper map or in a GIS is associated with a coordinate system. To simplify the use of maps and to avoid pinpointing locations on curved latitude-longitude reference lines, cartographers superimpose a rectangular grid on maps. Such grids use coordinate systems to determine the x and y position of any spot on the map. Coordinate systems are often identified by the name of the particular projection for which they are designed. Because no single map projection is suitable for all purposes, many different coordinate systems have been developed. Some are worldwide or nearly so, while others cover individual countries (such as the United Kingdom's Ordnance Survey's coordinate system), and others cover states or parts of states in the U.S.

This chapter begins with concepts that define the geographical referencing standards of the Earth. Topics include latitude and longitude, projections, coordinate systems, and datums.

GEOGRAPHIC COORDINATE SYSTEM- LATITUDE AND LONGITUDE

Any feature can be referenced by its latitude and longitude, which are angles measured in degrees from the Earth's center to a point on the Earth's surface (see Figure 2.1). Across the spherical Earth, latitude lines stretch horizontally from east to west (left image in Figure 2.2), and they are parallel to each other, hence their alternative name, parallels. Longitude lines, also called meridians, stand vertically and stretch from the North Pole to the South Pole (center image in Figure 2.2). Together these "north to south" and "east to west" lines meet at perpendicular angles to form a graticule, a grid that encompasses the Earth (right image in Figure 2.2).

Latitude can be thought of as the lines that intersect the y-axis, and longitude as lines that intersect the x-axis. Think of the equator as the x axis; the y axis is the prime meridian, which is a line running from pole to pole through Greenwich, England. Just as the upper right quarter in the Cartesian coordinate system is positive for both x and y, latitude and longitude east of the prime meridian and north of the equator are both positive. Europe, Asia, and part of Africa – which have positive latitudes and longitudes – correspond to the upper right quarter of the Cartesian coordinate system. With the exception of some U.S. territories in the Pacific and the westernmost Aleutian islands, all of the United States is north of the equator and west of the prime meridian, so all latitudes in the U.S are positive (or north) while almost all longitudes are negative (or west).

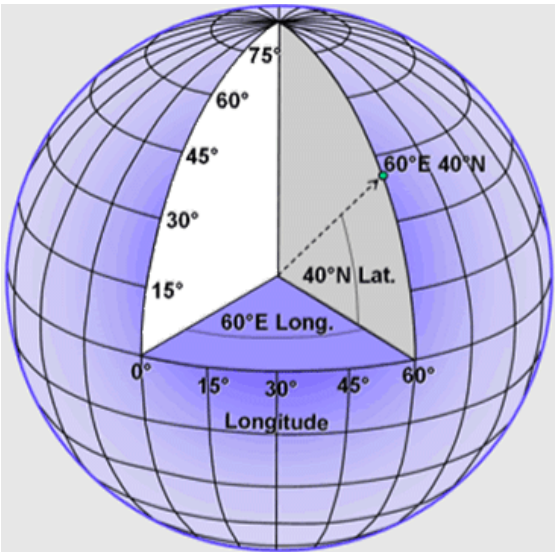


Figure 2.1: Latitude and longitude are angles measured in degrees from the Earth's center to a point on the Earth's surface. GIS Commons. http://giscommons.org/earth-and-map-preprocessing/

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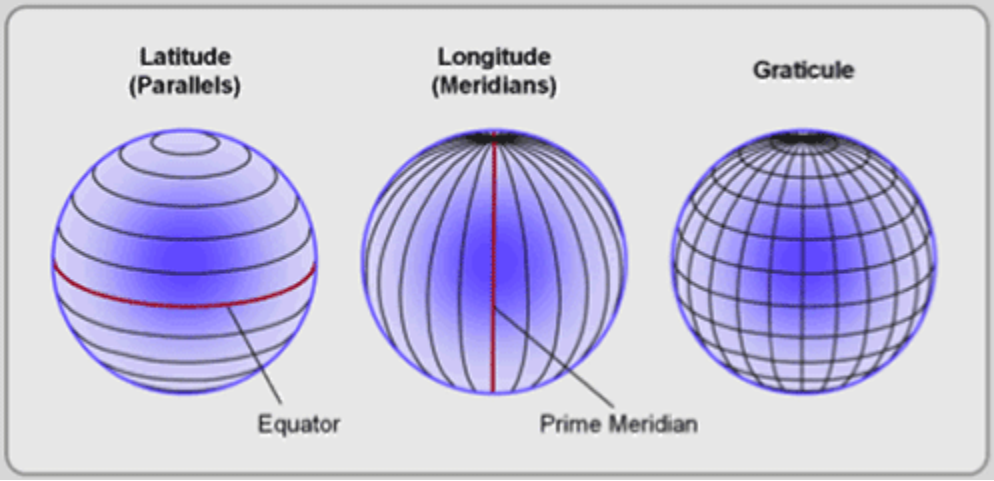


Figure 2.2: Latitude, longitude, and the Earth's graticule. GIS Commons. http://giscommons.org/earth-and-map-preprocessing/

Midway between the poles, the equator stretches around the Earth, and it defines the line of zero degrees latitude (left image in Figure 2.2). Relative to the equator, latitude is measured from 90 degrees at the North Pole to -90 degrees at the South Pole. The Prime Meridian is the line of zero degrees longitude (center image in Figure 2.2), and in most coordinate systems, it passes through Greenwich, England. Longitude runs from -180 degrees west of the Prime Meridian to 180 degrees east of the same meridian. Because the globe is 360 degrees in circumference, -180 and 180 degrees is the same location.

PROJECTION - TRANSFORMATION OF GEOGRAPHICAL COORDINATES TO CARTESIAN COORDINATE SYSTEMS

While the system of latitude and longitude provides a consistent referencing system for anywhere on the earth, in order to portray our information on maps or for making calculations, we need to transform these angular measures to Cartesian coordinates. These transformations amount to a mapping of geometric relationships expressed on the shell of a globe to a flatten-able surface -- a mathematical problem that is figuratively referred to as Projection.

Globes do not need projections, and even though they are the best way to depict the Earth's shape and to understand latitude and longitude, they are not practical for most applications that require maps. We need flat maps. This requires a reshaping of the Earth's 3-dimensions into a 2-dimensional surface.

To illustrate the concept of a map projection, imagine that we place a light bulb in the center of a translucent globe (Figure 2.3). On the globe are outlines of the continents and the lines of longitude and latitude called the graticule. When we turn the light bulb on, the outline of the continents and the graticule will be "projected" as shadows on the wall, ceiling, or any other nearby surface. This is what is meant by map "projection." The term "projection" implies that the ball-shaped net of parallels and meridians is transformed by casting its shadow upon some flat, or flatten-able, surface. In fact, almost all map projection methods are mathematical equations.

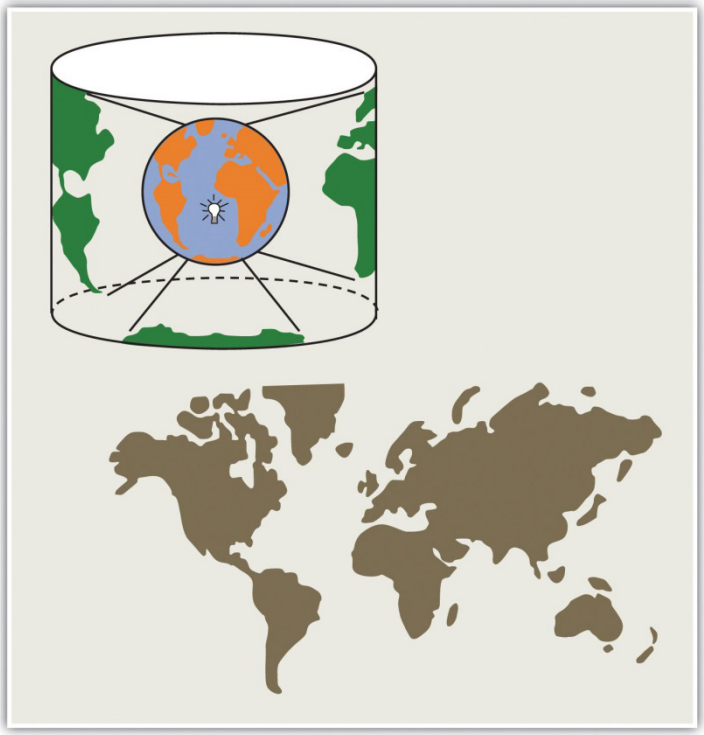


Figure 2.3. The concept of Map Projection as illustrated using a spherical globe and a flat map. http://2012books.lardbucket.org/books/geographic-information-system-basics/s06-02-map-scale-coordinate-systems-a.html

Within the realm of maps and mapping, there are three surfaces used for map projections (i.e., surfaces on which we project the shadows of the graticule). These surfaces are the plane, the cylinder, and the cone (Figure 2.4).

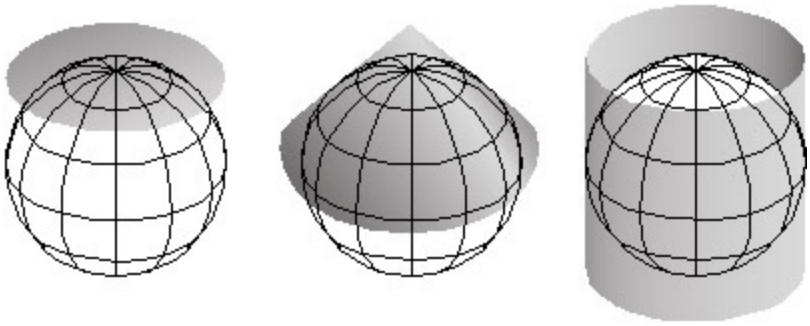


Figure 2.4. Three types of "flattenable" surfaces to which the graticule can be projected: a plane, a cone, and a cylinder. https://www.e-education.psu.edu/geog482fall2/c2_p30.html

As you might imagine, the appearance of the projected grid will change quite a lot depending on the type of surface it is projected onto, and how that surface is aligned with the globe. The three surfaces shown above in Figure 2.4 -- the disk-shaped plane, the cone, and the cylinder--represent categories that account for the majority of projection equations that are encoded in GIS software. The plane often is centered upon a pole. The cone is typically aligned with the globe such that its line of contact (tangency) coincides with a parallel in the mid-latitudes. And the cylinder is frequently positioned tangent to the equator (Figure 2.5).

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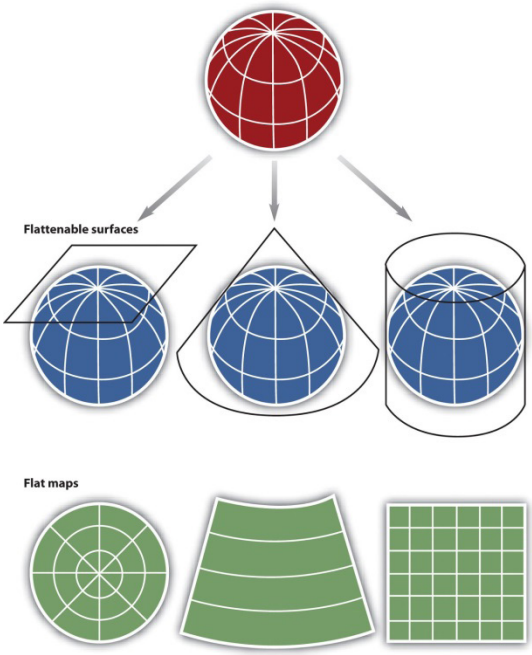


Figure 2.5. The projected graticules produced by projection equations in each category – plane, cone, and cylinder. http://2012books.lardbucket.org/books/geographic-information-system-basics/s06-02-map-scale-coordinate-systems-a.html

Referring again to the previous example of a light bulb in the center of a globe, note that during the projection process, we can situate each surface in any number of ways. For example, surfaces can be tangential to the globe along the equator or poles, they can pass through or intersect the surface, and they can be oriented at any number of angles. The following figures shows how these projections can vary.

PROJECTION AND DISTORTION

Flattening the globe cannot be done without introducing some error, and some distortion is unavoidable. Any projection has its area of least distortion. Projections can be shifted around in order to put this area of least distortion over the topographer's area of interest. Thus any projection can have an unlimited number of variations or cases that determined by standard parallels or meridians that adjust the location of the high-accuracy part of the projection.

If the geographic extent of your project area was small, like a neighborhood or a portion of a city, you could assume that the Earth is flat and use no projection. This is referred to as a planar surface or even a planar "projection," but with the understanding that it does not use a projection. Planar representation does not significantly affect a map's accuracy when scales are larger than 1:10,000. In other words, small areas do not need a projection because the statistical differences between locations on a flat plane and a 3-dimensional surface are not significant.

For small-scale maps one must consider the Earth's shape. Our assumption that the Earth is round or spherical does not accurately represent it. The Earth's constant spinning causes it to bulge slightly along the equator, ruining its perfect spherical shape. The slightly oval nature of the Earth's geometric surface makes the terms ellipsoid and spheroid more accurate in describing its shape, but they are not perfect terms either since differences in material weights (for instance iron is denser than sedimentary deposits) and the movement of tectonic plates makes the Earth dynamic and constantly changing. The Earth is a geoid with a slight pear shape; it is a little larger in the southern hemisphere and includes other bulges. The difference, however, between the ellipsoid and the geoid is minor enough that it does not affect most mapping. Until recently, projections based on geoids were rare because of the complexity and cost of collecting the necessary data to create the projection, but satellite imagery

has helped with measurement and geoid projections are now more common.

Projections are abstractions, and they introduce distortions to either the Earth's shape, area, distance, or direction (and sometimes to all of these properties). Different map projections cause different map distortions.

One way to classify map projections is to describe them by the characteristic they do not distort. Usually only one property is preserved in a projection. Map projections classified based on the preserved properties include:

- Conformal - Preserves: Shape, Distorts: Area
- Equal Area - Preserves: Area; Distorts: Shape, Scale or Angle (bearing)
- Equidistant - Preserves: Distances between certain points (but not all points); Distorts: Other distances
- Azimuthal (True Direction) - Preserves: Angles (bearings); Distorts: Area and shape

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

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

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

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

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

Within the scope of GISs, knowing and understanding map projections are critical. For instance, in order to perform an overlay analysis, all map layers need to be in the same projection. If they are not, geographical features will not be aligned properly, and any analyses performed will be inaccurate and incorrect. If you want to con-

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duct a measurement of land parcel size, you need to use a projection that does not distort area space. Most GISs include functions to assist in the identification of map projections, as well as to transform between projections in order to synchronize spatial data. Despite the capabilities of technology, an awareness of the potential and pitfalls that surround map projections is essential.

ON-THE-FLY PROJECTION

Creating map projections was extremely challenging, even just 30 years ago. And now we can project and unproject massive quantities of coordinates, transforming them backward and forward from Latitude and Longitude (assuming this or that earth model) to overlay precisely with data that are stored in some other coordinate space. It is truly amazing that humans have perfected a rich library of open-source software that can Forward Project geographic coordinates (latitude and longitude, + earth model) to any projected system; and also backward project) from any well described projected coordinates back to geographic coordinates -- all in the wink of an eye. We can be thankful for that. But there are still some details that we have to understand.

Automatic transformation of coordinate systems requires that datasets include machine-readable metadata. In about 2002, the makers of ArcMap added one more file to the schema of a shape file. The .prj file contains the description of the projection of a shape file, and if it exists, it is always copied with the shape file or dlements that are exported from it. This is the machine-readable metadata that allows ArcMap to know how to handle the dataset if any transformation (reprojection) is required. There are plenty of datasets that do not include such machine readable metadata. This includes data that are not created with ArcMap since 2002 and even some that are. So we should get used to understanding map projections and their properties. If you need to learn to set the coordinate system for a dataset, use ArcCatalog - as explained in the The ArcMap Projections Tutorial.

UNIVERSAL TRANSVERSE MERCATOR

The first coordinate system we want to introduce here is the Universal Transverse Mercator grid, commonly referred to as UTM and based on the Transverse Mercator projection. Universal Transverse Mercator (UTM) is a coordinate system that largely covers the globe. The system reaches from 84 degrees north to 84 degrees south latitude, and it divides the Earth into 60 north-south oriented zones that are 6 degrees of longitude wide (Figure 2.6). Each individual zone uses a defined transverse Mercator projection (See Figure). The UTM system is not a single map projection. The system instead has 60 projections, and each uses a secant transverse Mercator projection in each zone.

The contiguous U.S. consists of 10 zones (Figure 2.7). In the Northern hemisphere, the equator is the zero baseline for Northings (Southern hemisphere uses a 10,000 km false Northing). Each zone has an arbitrary central meridian of 500 km west of each zone's central meridian (called a false Easting) to insure positive Easting values and a central bisecting meridian. In UTM, the CSUS Geography Department is located at 4,269,000 meters north; 637,200 meters east; zone 10, northern hemisphere. UTM zones are numbered consecutively beginning with Zone 1. Zone 1 covers 180 degrees west longitude to 174 degrees west longitude (6 degrees of longitude), and includes the westernmost point of Alaska. Maine falls within Zone 16 because it lies between 84 degrees west and 90 degrees west. In each zone, coordinates are measured as northings and eastings in meters. The northing values are measured from zero at the equator in a northerly direction (in the southern hemisphere, the equator is assigned a false northing value of 10,000,000 meters). The central meridian in each zone is assigned an easting value of 500,000 meters. In Zone 16, the central meridian is 87 degrees west. One meter east of that central meridian is 500,001 meters easting.

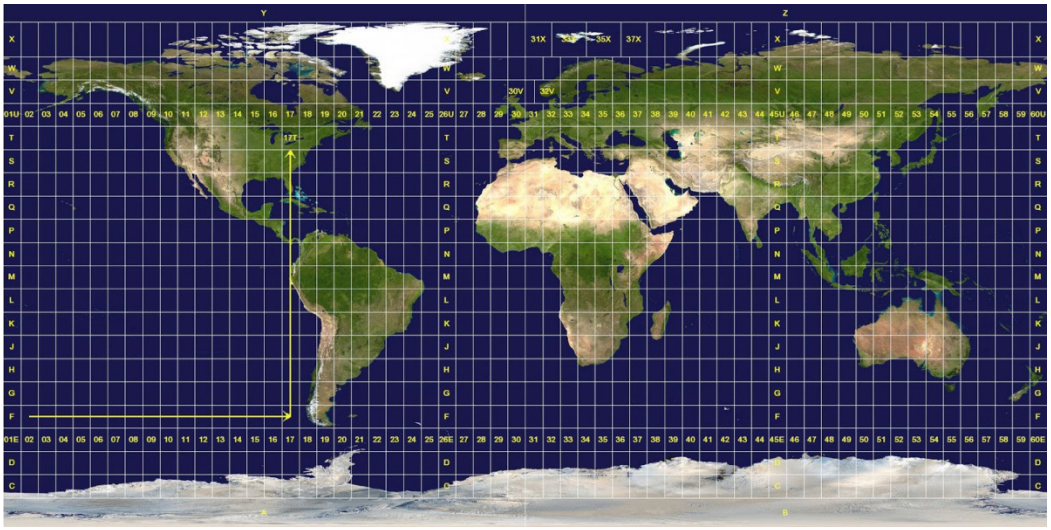


Figure 2.6. Visual depiction of the Universal Transverse Mercator project system. http://en.wikipedia.org/wiki/Universal_Transverse_Mercator_coordinate_system

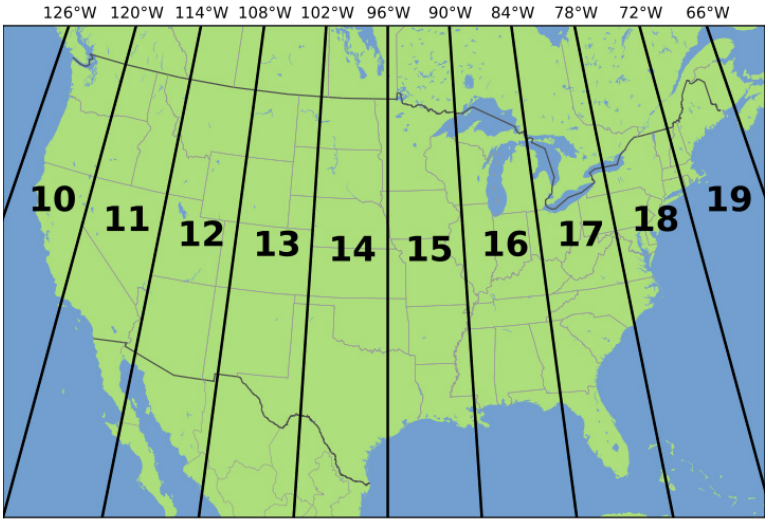


Figure 2.7. The zones of the Universal Transverse Mercator system as displayed over the United States. http://en.wikipedia.org/wiki/Universal_Transverse_Mercator_coordinate_system

STATE PLANE COORDINATE SYSTEM

A second coordinate system is the State Plane Coordinate System. This system is actually a series of separate systems, each covering a state, or a part of a state, and is only used in the United States. It is popular with some state and local governments due to its high accuracy, achieved through the use of relatively small zones. State Plane began in 1933 with the North Carolina Coordinate System and in less than a year it had been copied in all of the other states. The system is designed to have a maximum linear error of 1 in 10,000 and is four times as accurate as the UTM system.

Like the UTM system, the State Plane system is based on zones. However, the 120 State Plane zones generally follow county boundaries (except in Alaska). Given the State Plane system's desired level of accuracy, larger states are divided into multiple zones, such as the "Colorado North Zone." States with a long north-south axis (such as Idaho and Illinois) are mapped using a Transverse Mercator projection, while states with a long east-west axis (such as Washington and Pennsylvania) are mapped using a Lambert Conformal projection. In either case, the projection's central meridian is generally run down the approximate center of the zone.

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A Cartesian coordinate system is created for each zone by establishing an origin some distance (usually 2,000,000 feet) to the west of the zone's central meridian and some distance to the south of the zone's southernmost point. This ensures that all coordinates within the zone will be positive. The X-axis running through this origin runs east-west, and the Y-axis runs north-south. Distances from the origin are generally measured in feet, but sometimes are in meters. X distances are typically called eastings (because they measure distances east of the origin) and Y distances are typically called northings (because they measure distances north of the origin).



Figure 2.8. Visual depiction of the State Plane project system as displayed over the United States. http://gis.depaul.edu/shwang/teaching/geog258/Grid_files/image002.jpg

DATUMS

All coordinate systems are tied to a datum. A datum defines the starting point from which coordinates are measured. Latitude and longitude coordinates, for example, are determined by their distance from the equator and the prime meridian that runs through Greenwich, England. But where exactly is the equator? And where exactly is the Prime Meridian? And how does the irregular shape of the Earth figure into our measurements? All of these issues are defined by the datum.

Many different datums exist, but in the United States only three datums are commonly used. The North American Datum of 1927 (NAD27) uses a starting point at a base station in Meades Ranch, Kansas and the Clarke Ellipsoid to calculate the shape of the Earth. Thanks to the advent of satellites, a better model later became available and resulted in the development of the North American Datum of 1983 (NAD83). Depending on one's location, coordinates obtained using NAD83 could be hundreds of meters away from coordinates obtained using NAD27. A third datum, the World Geodetic System of 1984 (WGS84) is identical to NAD83 for most practical purposes within the United States. The differences are only important when an extremely high degree of precision is needed. WGS84 is the default datum setting for almost all GPS devices. But most USGS topographic maps published up to 2009 use NAD27.

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http://giscommons.org/earth-and-map-preprocessing/

http://2012books.lardbucket.org/books/geographic-information-system-basics/s06-02-map-scale-coordinate-systems-a.html

https://www.e-education.psu.edu/geog482fall2/c2_p30.html

http://www.gsd.harvard.edu/gis/manual/projection_fundamentals/

http://gis.depaul.edu/shwang/teaching/geog258/Grid.htm

http://en.wikipedia.org/wiki/Universal_Transverse_Mercator_coordinate_system

http://resources.arcgis.com/en/help/main/10.1/index.html#//003r0000000r000000

Discussion Questions

1. Describe the general properties of the following projections: Universe Transverse Mercator (UTM), State plane system.

2. Discuss the following concepts: Geographic Coordinate System, Projected coordinate system, Datums.

Contextual Applications of Chapter 2

An Anti-Poverty Policy that Works for Working Families (Brookings)

U.S. Women Are Dying Younger Than Their Mothers, and No One Knows Why

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CHAPTER 3: TOPOLOGY AND CREATING DATA

GEOMETRIC PRIMITIVES

Topology is the subfield of mathematics that deals with the relationship between geometric entities, specifically with properties of objects that are preserved under continuous deformation. A GIS topology is a set of rules and behaviors that model how points, lines, and polygons share coincident geometry. The concepts of topology are very useful for geographers, surveyors, transportation specialists, and others interested in how places and locations relate to one another. We have learned that a location is a zero-dimensional entity (it has no length, width, height, or volume), locations alone are not sufficient for representing the complexity of the real world. Locations are frequently composed into one or more geometric primitives, which include the set of entities more commonly referred to as:

1. Points;

2. Lines; and

3. Polygons (or Areas).

In the field of Topology, we can expand them to:

1. Nodes: zero-dimensional entities represented by coordinate pairs. Coordinates for nodes may be *x,y* values like those in Euclidean geometry or longitude and latitude coordinates that represent places on Earth's surface. In both cases, a third *z* value is sometimes added to specify a location in three dimensions;

2. Edges: one-dimensional entities created by connecting two nodes. The nodes at either end of an edge are called connecting nodes and can be referred to more specifically as a start node or end node, depending on the direction of the edge, which is indicated by arrowheads. Edges in TIGER have direction so that the left and right side of the street can be determined for use in address matching. Nodes that are not associated with an edge and exist by themselves are called isolated nodes. Edges can also contain vertices, which are optional intermediate points along an edge that can define the shape of an edge with more specificity than start and end nodes alone. Examples of edges encoded in TIGER are streets, railroads, pipelines, and rivers; and

3. Faces: two-dimensional (length and width) entities that are bounded by edges. Blocks, counties, and voting districts are examples of faces. Since faces are bounded by edges and edges have direction, faces can be designated as right faces or left faces.

Figure below shows an example of these geometric primitives in a realistic arrangement. In this example, note that:

1. Nodes N14 and N17 are isolated nodes;

2. N7 and N6 are the start and end nodes of edge E1; and

3. Due to the directionality of edges, face F2 is on the left of edge E8.

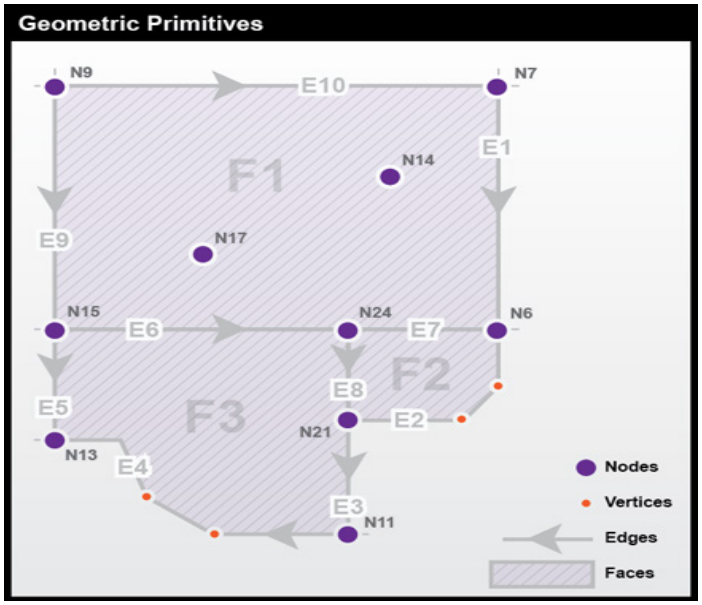


Figure 3.1. The geographic primitives include nodes, edges, and faces. Source: Department of Geography, The Pennsylvania State University. Adapted from DiBiase (1997).

The following illustration shows how a layer of polygons can be described and used:

- As collections of geographic features (points, lines, and polygons)
- As a graph of topological elements (nodes, edges, faces, and their relationships)

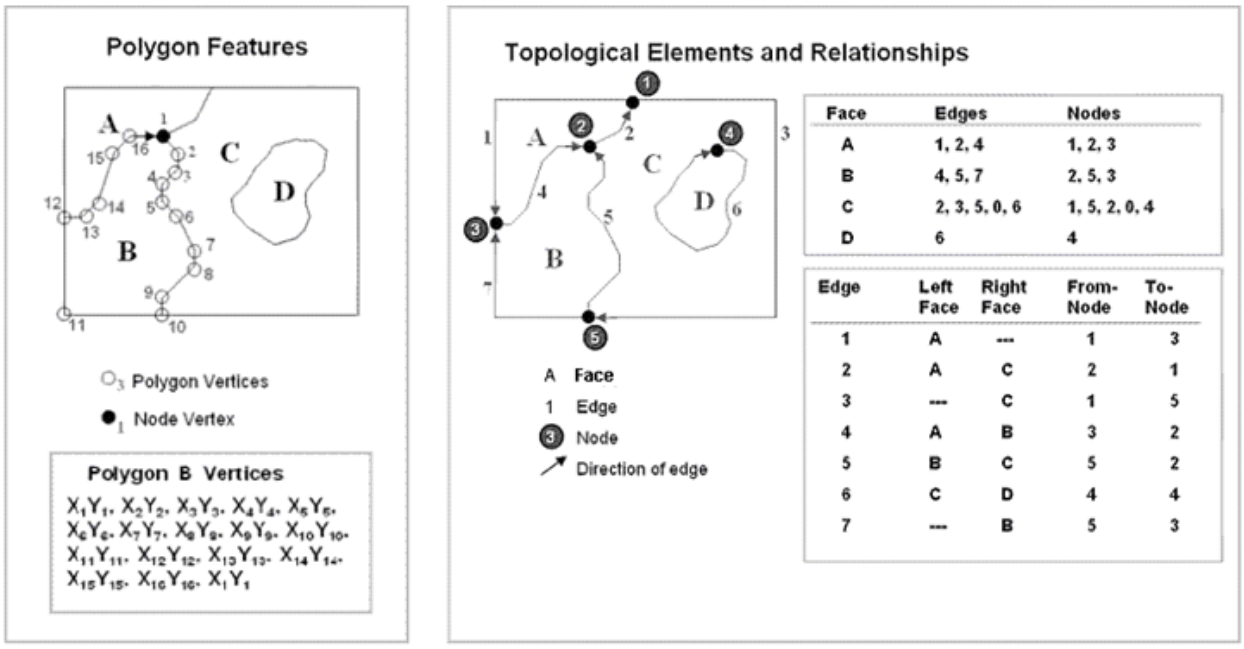


Figure 3.2. Relationship between geographic feature and the topological elements. Source: ESRI Help: http://webhelp.esri.com/arcgisserver/9.3/java/index.htm#geodatabases/topology_basics.htm

TOPOLOGICAL RELATIONSHIPS

We have learned how coordinates, both geometric and geographic, can define points and nodes, how nodes can build edges, and how edges create faces. We will now consider how nodes, edges, and faces can relate to one another through the concepts of containment, connectedness, and adjacency. A fundamental property of all topological relations is that they are constant under continuous deformation: re-projecting a map will not alter

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topology, nor will any amount of rubber-sheeting or other data transformations change relations from one form to another.

Containment is the property that defines one entity as being within another. For example, if an isolated node (representing a household) is located inside a face (representing a congressional district) in the database, you can count on it remaining inside that face no matter how you transform the data. Topology is vitally important to the Census Bureau, whose constitutional mandate is to accurately associate population counts and characteristics with political districts and other geographic areas.

Connectedness refers to the property of two or more entities being connected. In Figure 2.1, Topologically, node N14 is not connected to any other nodes. Nodes N9 and N21 are connected because they are joined by edges E10, E1, and E10. In other words, nodes can be considered connected if and only if they are reachable through a set of nodes that are also connected; if a node is a destination, we must have a path to reach it.

Connectedness is not immediately as intuitive as it may seem. A famous problem related to topology is the Königsberg bridge puzzle (Figure 3.3).

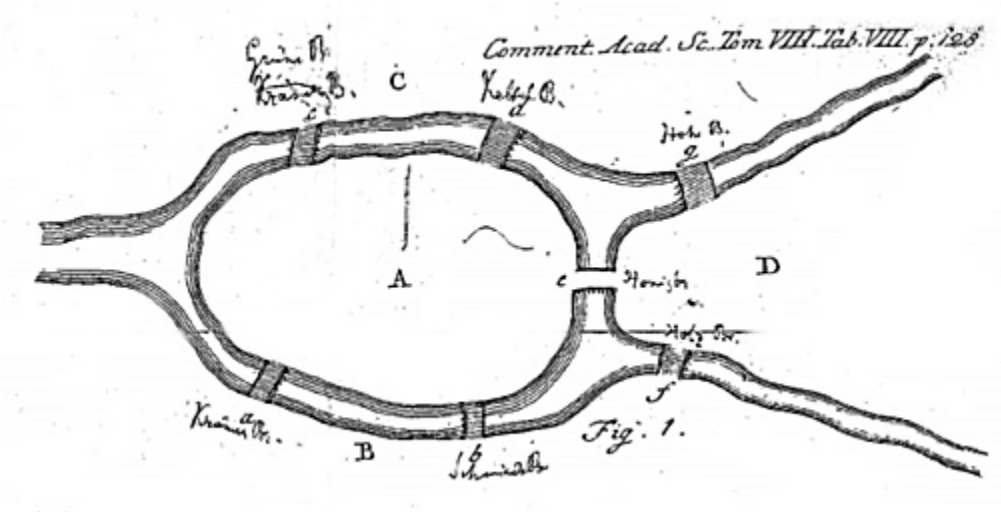


Figure 3.3. The seven bridges of Königsberg bridge puzzle. Source: Euler, L. "Solutio problematis ad geometriam situs pertinentis." Comment. Acad. Sci. U. Petrop. 8, 128-140, 1736. Reprinted in Opera Omnia Series Prima, Vol. 7. pp. 1-10, 1766.

The challenge of the puzzle is to find a route that crosses all seven bridges, while respecting the following criteria:

1. Each bridge *must* be crossed;

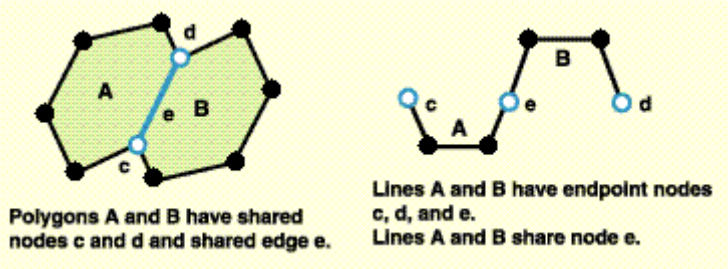
2. A bridge is a directional edge and can only be crossed once (no backtracking);

3. Bridges must be fully crossed in one attempt (you cannot turn around halfway, and then do the same on the other side to consider it "crossed").

4. *Optional:* You must start and end at the same location. (It has been said that this was a traditional requirement of the problem, though it turns out that it doesn't actually matter – try it with and without this requirement to see if you can discover why.)

The right answer is, there is no such route. Euler proved, in 1736, that there was no solution to this problem.

WAYS THAT FEATURES SHARE GEOMETRY IN A TOPOLOGY

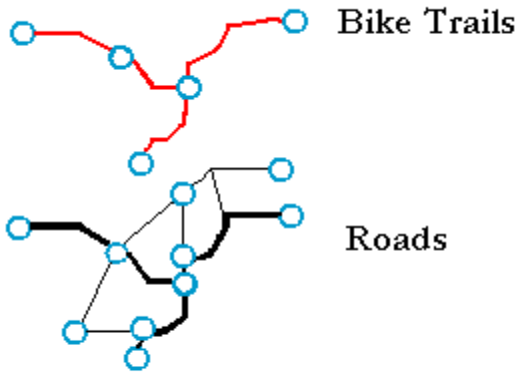


Features can share geometry within a topology. Here are some examples among adjacent features. Source: ESRI Help http://webhelp.esri.com/arcgisserver/9.3/java/index.htm#geodatabases/topology_basics.htm

- Area features can share boundaries (polygon topology).
- Line features can share endpoints (edge–node topology).

In addition, shared geometry can be managed *between* feature classes using a geodatabase topology. For example:

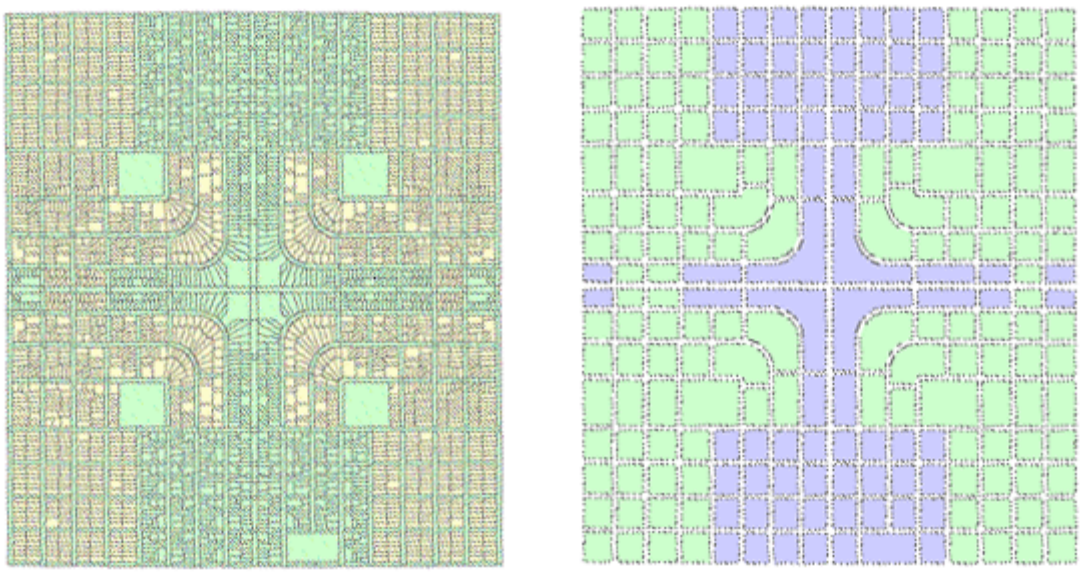
- Line features can share segments with other line features. For example, parcels can nest within blocks:
- Area features can be coincident with other area features.
- Line features can share endpoint vertices with other point features (node topology).
- Point features can be coincident with line features (point events).



The shared geometry between Roads and Bike Trails are shown as thick lines.

Source: ESRI Help: http://webhelp.esri.com/arcgisserver/9.3/java/index.htm#geodatabases/topology_basics.htm

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Source: ESRI Help: http://webhelp.esri.com/arcgisserver/9.3/java/index.htm#geodatabases/topology_basics.htm

Galdi (2005) describes the very specific rules that define the relations of entities in the vector database:

1. Every edge must be bounded by two nodes (start and end nodes).
2. Every edge has a left and right face.
3. Every face has a closed boundary consisting of an alternating sequence of nodes and edges.
4. There is an alternating closed sequence of edges and faces around every node.
5. Edges do not intersect each other, except at nodes.

Compliance with these topological rules is an aspect of data quality called logical consistency. In addition, the boundaries of geographic areas that are related hierarchically — such as blocks, block groups, tracts, and counties - are represented with common, non-redundant edges. Features that do not conform to the topological rules can be identified automatically, and corrected.

Topology is fundamentally used to ensure data quality of the spatial relationships and to aid in data compilation. Topology is also used for analyzing spatial relationships in many situations such as dissolving the boundaries between adjacent polygons with the same attribute values or traversing along a network of the elements in a topology graph. Topology can also be used to model how the geometry from a number of feature classes can be integrated. Some refer to this as *vertical integration* of feature classes. Generally, topology is employed to do the following:

- Manage coincident geometry (constrain how features share geometry). For example, adjacent polygons, such as parcels, have shared edges; street centerlines and the boundaries of census blocks have coincident geometry; adjacent soil polygons share edges; etc.
- Define and enforce data integrity rules (such as no gaps should exist between parcel features, parcels should not overlap, road centerlines should connect at their endpoints).

- Support topological relationship queries and navigation (for example, to provide the ability to identify adjacent and connected features, find the shared edges, and navigate along a series of connected edges).

- Support sophisticated editing tools that enforce the topological constraints of the data model (such as the ability to edit a shared edge and update all the features that share the common edge).

- Construct features from unstructured geometry (e.g., the ability to construct polygons from lines sometimes referred to as "spaghetti").

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https://www.e-education.psu.edu/geog160/node/1948

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http://webhelp.esri.com/arcgisserver/9.3/java/index.htm#geodatabases/topology_basics.htm

Discussion Questions

1. How does the topology change as you change the features of a map – for example, when you introduce a road into a landscape?

2. Consider the role of the planner in understanding topology. In what ways does the concept of topology apply to the practice of planning?

3. What are examples of topological errors that may be present in a dataset, perhaps one that you received second-hand?

Contextual Applications of Chapter 3

Metropolitan Jobs Recovery? Not Yet (Brookings)

Job growth

www.dbooks.org

CHAPTER 4: MAPPING PEOPLE WITH CENSUS DATA

WHY CENSUS?

Some of the richest sources of attribute data for thematic mapping, particularly for choropleth maps, are national censuses. In the United States, a periodic count of the entire population is required by the U.S. Constitution. Article 1, Section 2, ratified in 1787, states (in the last paragraph of the section shown below) that "Representatives and direct taxes shall be apportioned among the several states which may be included within this union, according to their respective numbers ... The actual Enumeration shall be made [every] ten years, in such manner as [the Congress] shall by law direct." The U.S. Census Bureau is the government agency charged with carrying out the decennial census.


We the People of the United States, in order to form a more perfect Union, establish Justice, insure domestic Tranquility, provide for the common defence, promote the general Welfare, and secure the Blessings of Liberty to ourselves and our Posterity, do ordain and establish this Constitution for the United States of America.

Article. I.

Section. 1. All legislative Powers herein granted shall be vested in a Congress of the United States, which shall consist of a Senate and House of Representatives.

Section. 2. The House of Representatives shall be composed of Members chosen every second Year by the People of the several States, and the Electors in each State shall have the Qualifications requisite for Electors of the most numerous Branch of the State Legislature.

No Person shall be a Representative who shall not have attained to the Age of twenty five Years, and been seven Years a Citizen of the United States, and who shall not, when elected, be an Inhabitant of that State in which he shall be chosen.

Representatives and direct Taxes shall be apportioned among the several States which may be included within this Union, according to their respective Numbers, which shall be determined by adding to the whole Number of free Persons, including those bound to Service for a Term of Years, and excluding Indians not taxed, three fifths of all other Persons. The actual Enumeration shall be made within three Years after the first Meeting of the Congress of the United States, and within every subsequent Term of ten Years, in such Manner as they shall by Law direct. The Number of Representatives shall not exceed one for every thirty Thousand, but each State shall have at least one Representative; and until such enumeration shall be made, the State of New Hampshire shall be entitled to chuse three, Massachusetts eight, Rhode-Island and Providence Plantations one, Connecticut five, New-York six, New Jersey four, Pennsylvania eight, Delaware one, Maryland six, Virginia ten, North Carolina five, South Carolina five, and Georgia three.

Figure 4.1: A portion of the Constitution of the United States of America (preamble and first three paragraphs of Article 1). Credit: Obtained from: http://www.archives.gov/exhibits/charters/charters_downloads.html

The results of the U.S. decennial census determine states' portions of the 435 total seats in the U.S. House of Representatives. Thematic maps can show states that lost and gained seats as a result of the *reapportionment* that followed the 2000 census (Figure 4.2). By focusing on the U.S. state-by-state, we develop a variant on a choropleth map. Rather than using color fill to depict quantity, color depicts only change and its direction, red for a loss in number of Congressional seats, gray for no change, and blue for a gain in number of Congressional seats. Numbers are then used as symbols to indicate amount of change (small -1 or +1 for a change of 1 seat and larger -2 or +2 for a change of two seats). This scaling of numbers is an example of the more general application of "size" as a graphic variable to produce "proportional symbols" – the topic we cover in detail in the section on proportional symbol mapping below.

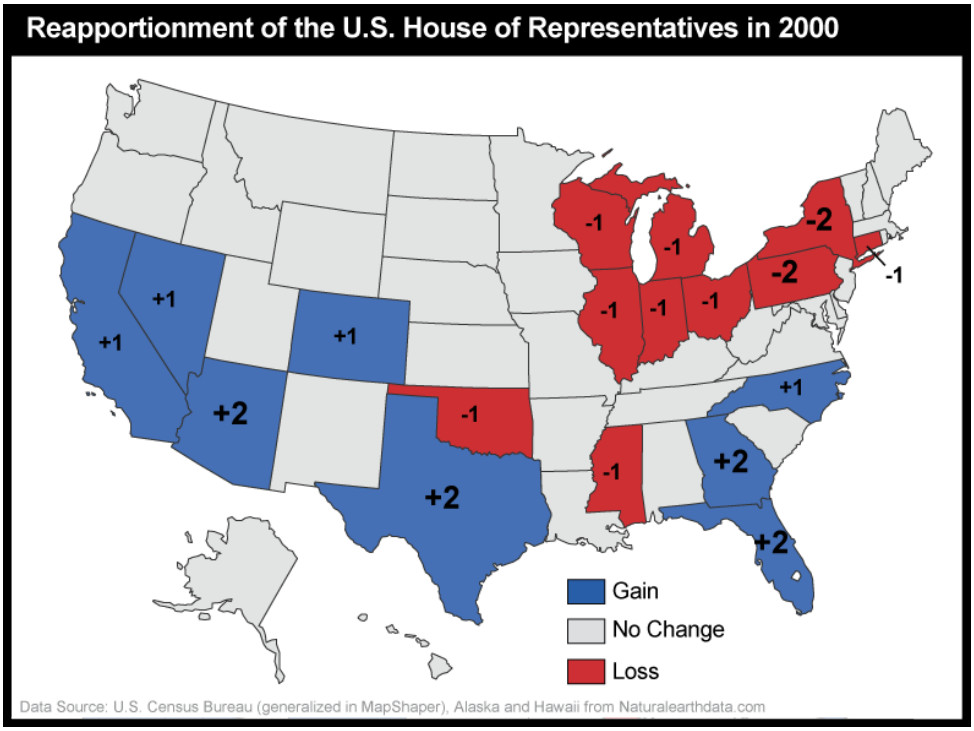


Figure 4.2: Reapportionment of the U.S. House of Representatives as a result of the 2000 census. Source: Smith, JM., 2012. Department of Geography, The Pennsylvania State University; After figure in Chapter 3, DiBiase.

Congressional voting district boundaries must be redrawn within the states that gained and lost seats, a process called *redistricting*. Constitutional rules and legal precedents require that voting districts contain equal populations (within about 1 percent). In addition, districts must be drawn so as to provide equal opportunities for representation of racial and ethnic groups that have been discriminated against in the past. Further, each state is allowed to create its own parameters for meeting the equal opportunities constraint. Whether districts determined each decade actually meet these guidelines is typically a contentious issue and often results in legal challenges.

Beyond the role of the census of population in determining the number of representatives per state (thus in providing the data input to reapportionment and redistricting), the Census Bureau's mandate is to provide the population data needed to support governmental operations, more broadly including decisions on allocation of federal expenditures. Its broader mission includes being "the preeminent collector and provider of timely, relevant, and quality data about the people and economy of the United States". To fulfill this mission, the Census Bureau needs to count more than just numbers of people, and it does.

THEMATIC MAPPING

Unlike reference maps, thematic maps are usually made with a single purpose in mind. Typically, that purpose has to do with revealing the spatial distribution of one or two attribute data sets. In this section, we will consider distinctions among three types of ratio level data, counts, rates, and densities. We will also explore several different types of thematic maps, and consider which type of map is conventionally used to represent the different types of data. We will focus on what is perhaps the most prevalent type of thematic map, the choropleth map. Choropleth maps tend to display ratio level data which have been transformed into ordinal level classes. Finally, you will learn two common data classification procedures, quantiles and equal intervals.

MAPPING COUNTS

The simplest thematic mapping technique for count data is to show one symbol for every individual counted. If

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the location of every individual is known, this method often works fine. If not, the solution is not as simple as it seems. Unfortunately, individual locations are often unknown, or they may be confidential. Software like ESRI's ArcMap, for example, is happy to overlook this shortcoming. Its "Dot Density" option causes point symbols to be positioned randomly within the geographic areas in which the counts were conducted (Figure 4.3). The size of dots, and number of individuals represented by each dot, are also optional. Random dot placement may be acceptable if the scale of the map is small, so that the areas in which the dots are placed are small. Often, however, this is not the case.

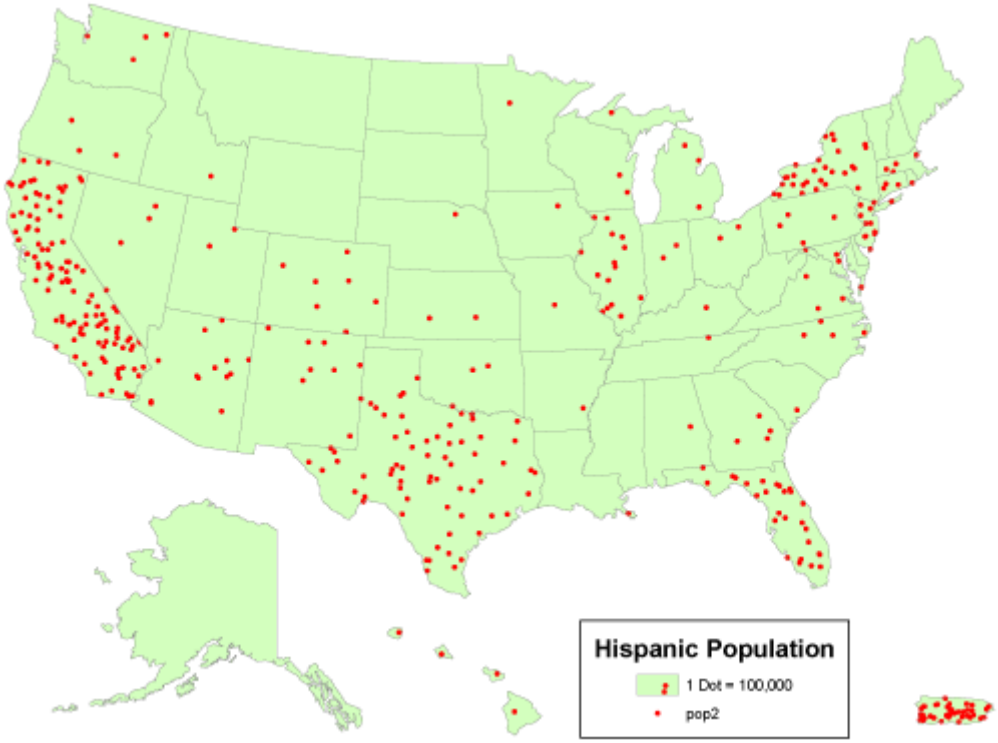


Figure 4.3. A "dot density" map that depicts count data. Source: G. Hatchard. https://www.e-education.psu.edu/geog482fall2/c3_p17.html

An alternative for mapping counts that lack individual locations is to use a single symbol, a circle, square, or some other shape, to represent the total count for each area. ArcMap calls the result of this approach a Proportional Symbol map. When the size of each symbol varies in direct proportion to the data value it represents we have a proportional symbol map (Figure 4.4). In other words, the area of a symbol used to represent the value "1,000,000" is exactly twice as great as a symbol that represents "500,000." To compensate for the fact that map readers typically underestimate symbol size, some cartographers recommend that symbol sizes be adjusted. ArcMap calls this option "Flannery Compensation" after James Flannery, a research cartographer who conducted psychophysical studies of map symbol perception in the 1950s, 60s, and 70s. A variant on the Proportional Symbol approach is the Graduated Symbol map type, in which different symbol sizes represent categories of data values rather than unique values. In both of these map types, symbols are usually placed at the mean locations, or centroids, of the areas they represent.

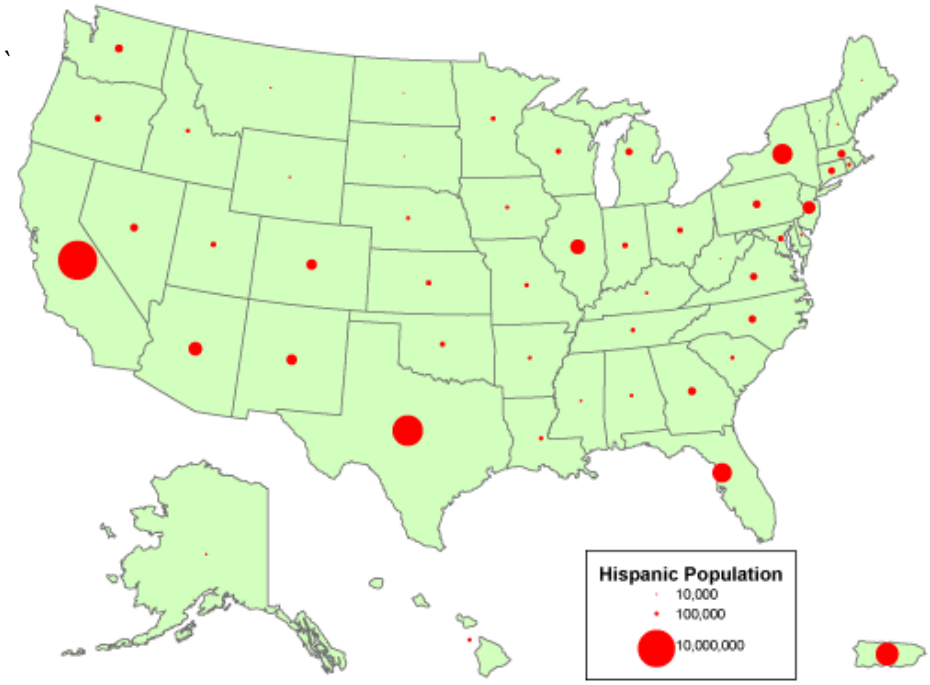


Figure 4.4. A "proportional circle" map that depicts count data. Source: G. Hatchard. https://www.e-education.psu.edu/geog482fall2/c3_p17.html

MAPPING RATES AND DENSITIES

A rate is a proportion between two counts, such as Hispanic population as a percentage of total population. One way to display the proportional relationship between two counts is with what ArcMap calls its Pie Chart option. Like the Proportional Symbol map, the Pie Chart map plots a single symbol at the centroid of each geographic area by default, though users can opt to place pie symbols such that they won't overlap each other (This option can result in symbols being placed far away from the centroid of a geographic area.) Each pie symbol varies in size in proportion to the data value it represents. In addition, however, the Pie Chart symbol is divided into pieces that represent proportions of a whole (Figure 4.5).

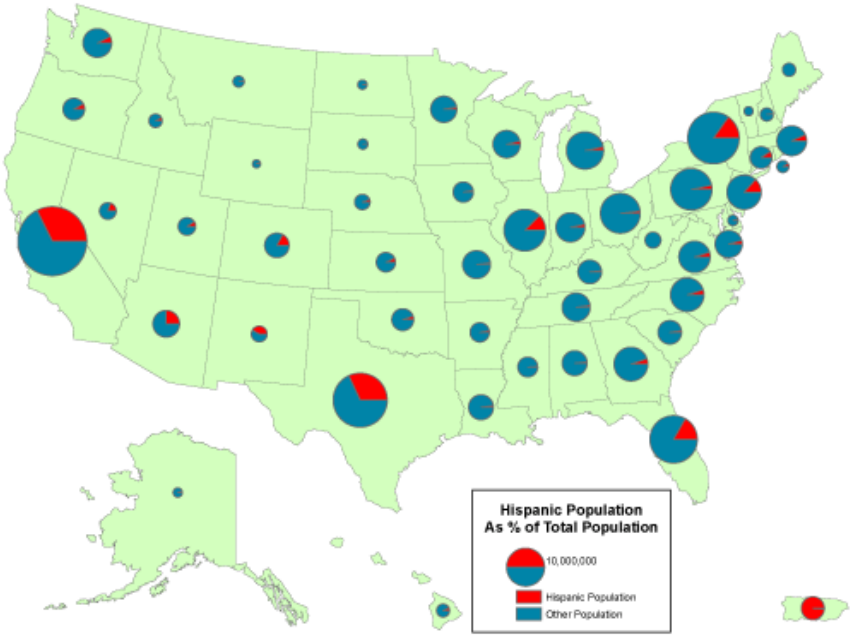


Figure 4.5. A "pie chart" map that depicts rate data. Source: G. Hatchard. https://www.e-education.psu.edu/geog482fall2/c3_p16.html

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Some perceptual experiments have suggested that human beings are more adept at judging the relative lengths of bars than they are at estimating the relative sizes of pie pieces (although it helps to have the bars aligned along a common horizontal base line). You can judge for yourself by comparing the effect of ArcMap's Bar/Column Chart option (Figure 4.6).

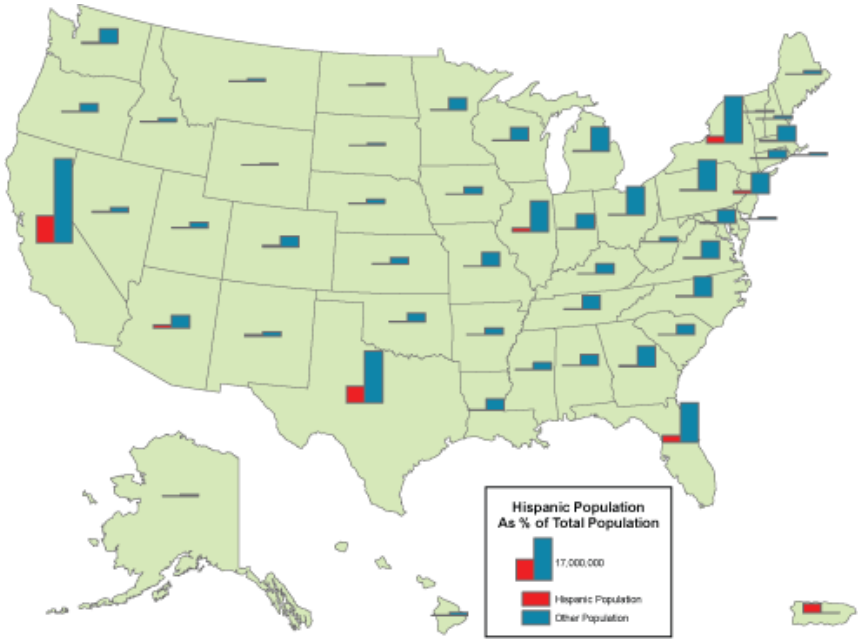


Figure 4.6. A "bar/column chart" map that depicts rate data. Source: G. Hatchard. https://www.e-education.psu.edu/geog482fall2/c3_p16.html

Like rates, densities are produced by dividing one count by another, but the divisor of a density is the magnitude of a geographic area. Both rates and densities hold true for entire areas, but not for any particular point location. For this reason, it is conventional not to use point symbols to symbolize rate and density data on thematic maps. Instead, cartography textbooks recommend a technique that ArcMap calls "Graduated Colors." Maps produced by this method, properly called choropleth maps, fill geographic areas with colors that represent attribute data values (Figure 4.7).

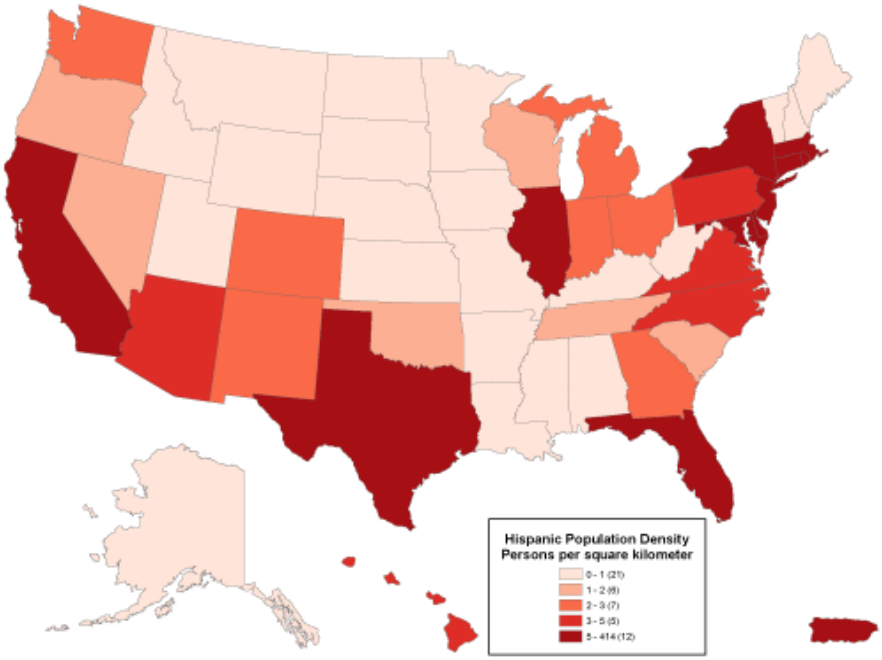


Figure 4.7. A "graduated color" (choropleth) map that depicts density data. Source: G. Hatchard. https://www.e-education.psu.edu/geog482fall2/c3_p16.html

Because our ability to discriminate among colors is limited, attribute data values at the ratio or interval level are

usually sorted into four to eight ordinal level categories. ArcMap calls these categories classes. Users can adjust the number of classes, the class break values that separate the classes, and the colors used to symbolize the classes. Users may choose a group of predefined colors, known as a color ramp, or they may specify their own custom colors. Color ramps are sequences of colors that vary from light to dark, where the darkest color is used to represent the highest value range. Most textbook cartographers would approve of this, since they have long argued that it is the lightness and darkness of colors, not different color hues, that most logically represent quantitative data.

Logically or not, people prefer colorful maps. For this reason some might be tempted to choose ArcMap's Unique Values option to map rates, densities, or even counts. This option assigns a unique color to each data value. Colors vary in hue as well as lightness. This symbolization strategy is designed for use with a small number of nominal level data categories. As illustrated in the map below (Figure 4.8), the use of an unlimited set of color hues to symbolize unique data values leads to a confusing thematic map.

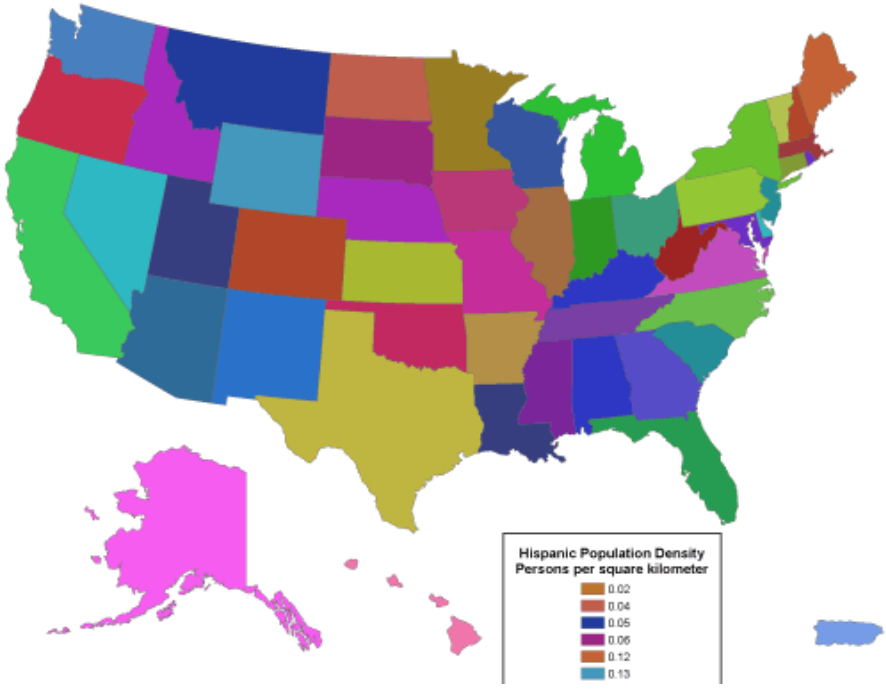


Figure 4.8. A "unique values" map that depicts density data. Note that the legend, which in the original shows one category for each state, is trimmed off. Source: G Htchard. https://www.e-education.psu.edu/geog482fall2/c3_p16.html

DATA CLASSIFICATION

As discussed earlier, all maps are abstractions. This means that they depict only selected information, but also that the information selected must be generalized due to the limits of display resolution, comparable limits of human visual acuity, and especially the limits imposed by the costs of collecting and processing detailed data. What we have not previously considered is that generalization is not only necessary, it is sometimes beneficial; it can make complex information understandable. Consider a simple example. The graph below (Figure 4.9) shows the percent of people who prefer the term "pop" (not soda or coke) for each state. Categories along the x axis of the graph represent each of the 50 unique percentage values (two of the states had exactly the same rate). Categories along the y axis are the numbers of states associated with each rate. As you can see, it's difficult to discern a pattern in these data; it appears that there is no pattern.

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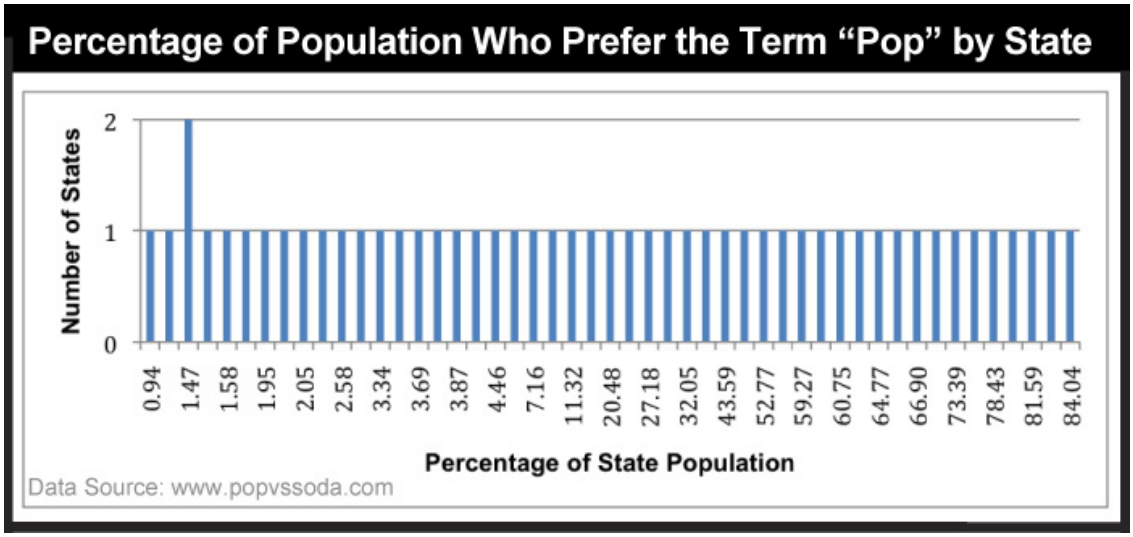


Figure 4.9: Unique percentage values for people who use the term "pop" by state. Source: JM Smith, Department of Geography, The Pennsylvania State University.

The following graph (Figure 4.10) shows exactly the same data set, only grouped into 10 classes with equal 10% ranges). It's much easier to discern patterns and outliers in the classified data than in the unclassified data. Notice that people in a large number of states (23) do not really prefer the term "pop" as they are distributed around 0 to 10 percent of users who favor that term. There are no states at the other extreme (91-100%), but a few states whose vast majority (81-90% of their population) prefer the term pop. Ignoring the many 0-10% states where pop is rarely used, the most common states are ones in which about 2/3 favor the term; looking back to `Figure 3.13, these are primarily northern states, including Pennsylvania. All of these variations in the information are obscured in the unclassified data.

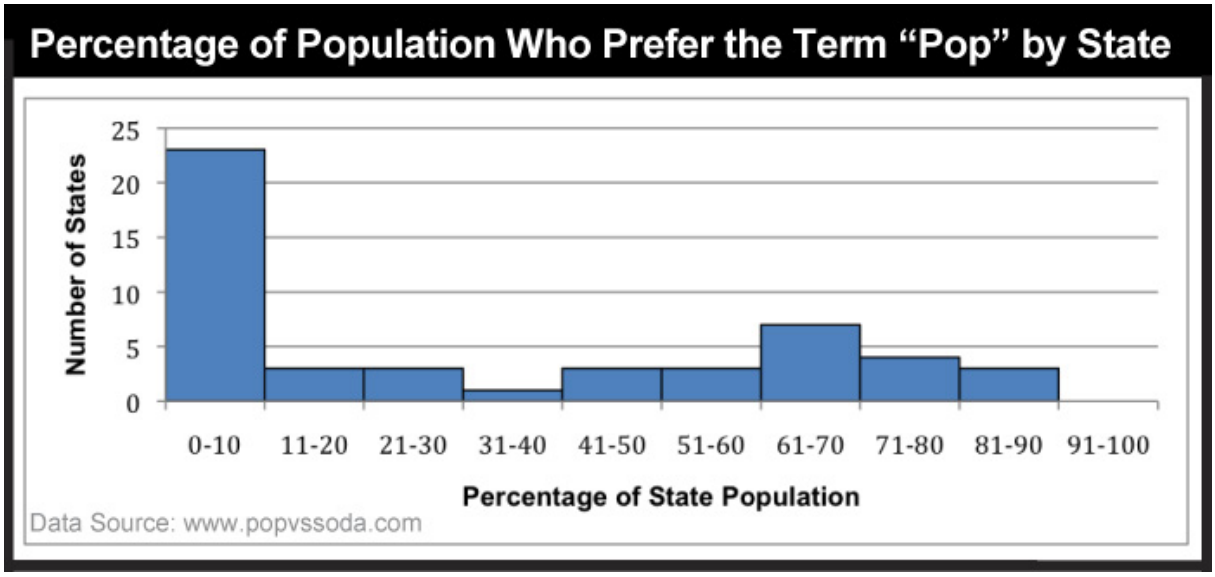


Figure 4.10: Classed percentages of people who use the term "pop" by state. Source: JM Smith, Department of Geography, The Pennsylvania State University.

As shown above, data classification is a generalization process that can make data easier to interpret. Classification into a small number of ranges, however, gives up some details in exchange for the clearer picture, and there are multiple choices of methods to classify data for mapping. If a classification scheme is chosen and applied skillfully, it can help reveal patterns and anomalies that otherwise might be obscured (as shown above). By the same token, a poorly-chosen classification scheme may hide meaningful patterns. The appearance of a thematic map, and sometimes conclusions drawn from it, may vary substantially depending on the data classification scheme used. Thus, it is important to understand the choices that might be made, whether you are creating a

map or interpreting one created by someone else.

Many different systematic classification schemes have been developed. Some produce mathematically "optimal" classes for unique data sets, *maximizing the difference between classes and minimizing differences within classes*. Since optimizing schemes produce unique solutions, however, they are not the best choice when several maps need to be compared. For this, data classification schemes that treat every data set alike are preferred.

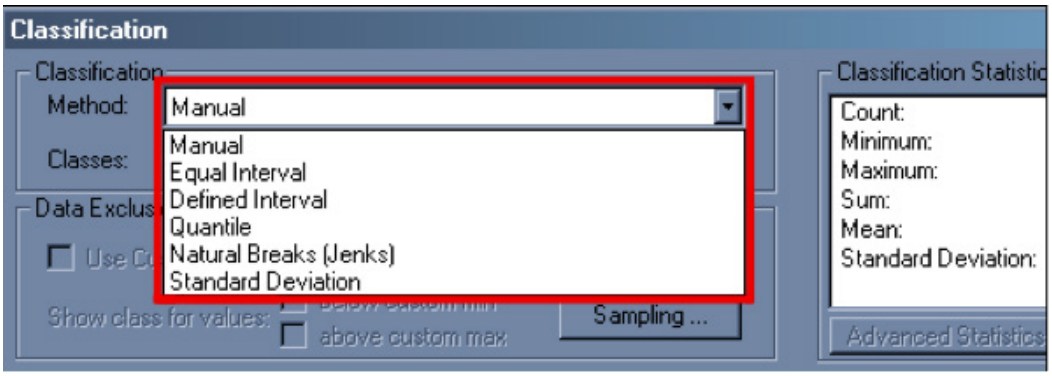


Figure 4.11. Portion of the ArcMap classification dialog box highlighting the schemes supported in ArcMap 8.2. Source: Department of Geography, The Pennsylvania State University.

Two commonly used classification schemes are quantiles and equal intervals. The following two graphs illustrate the differences.

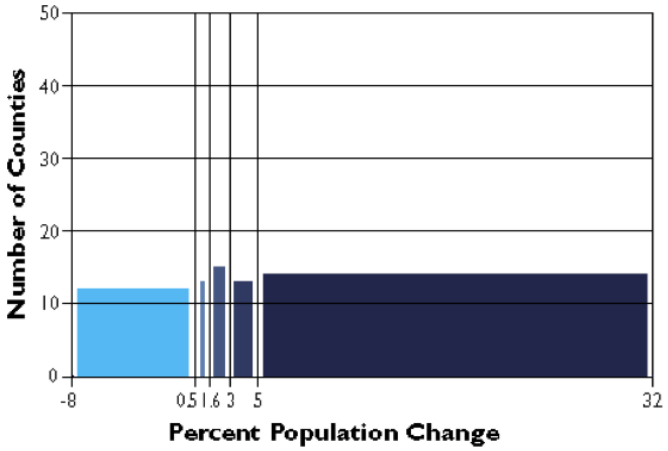


Figure 4.12. County population change rates divided into five quantile categories. Source: Department of Geography, The Pennsylvania State University.

The graph above groups the Pennsylvania county population change data into five classes, each of which contains the same number of counties (in this case, approximately 20 percent of the total in each). The quantiles scheme accomplishes this by varying the width, or range, of each class. Quantile is a general label for any grouping of rank ordered data into an equal number of entities; quantiles with specific numbers of groups go by their own unique labels ("quartiles" and "quintiles," for example, are instances of quantile classifications that group data into four and five classes respectively). The figure below, then, is an example of quintiles.

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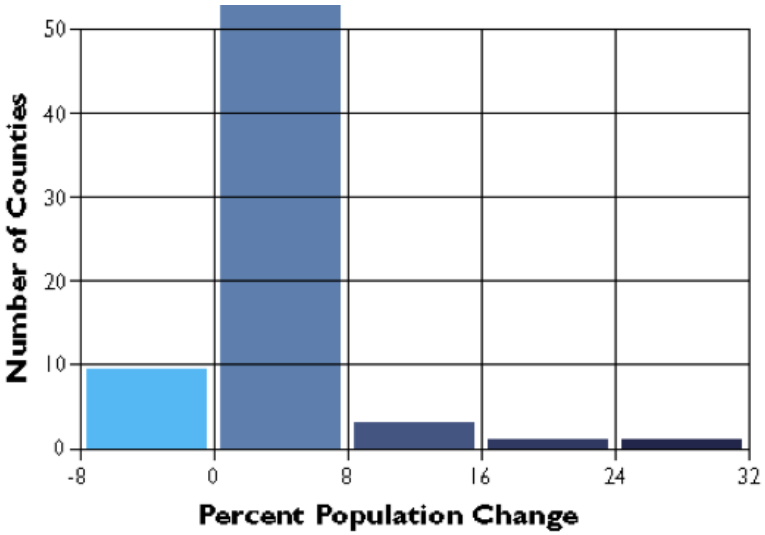


Figure 4.13. County population change rates divided into five equal interval categories. Source: Department of Geography, The Pennsylvania State University.

In the second graph, the data range of each class is equivalent (8.5 percentage points). Consequently, the number of counties in each **equal interval** class varies.

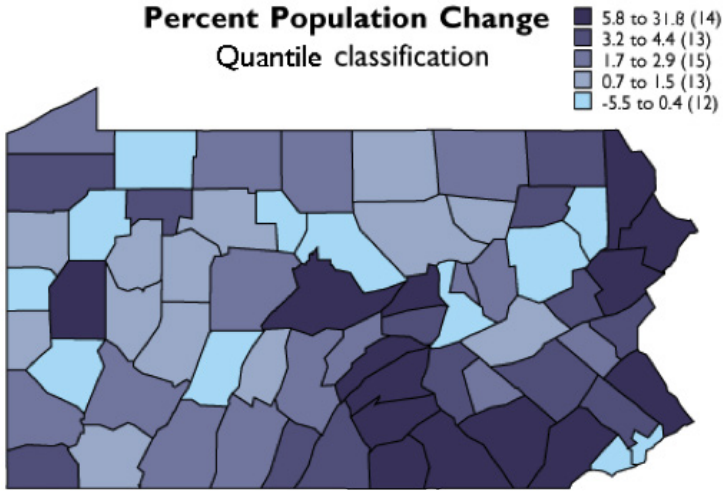


Figure 4.14. The five quantile classes mapped. Source: Department of Geography, The Pennsylvania State University.

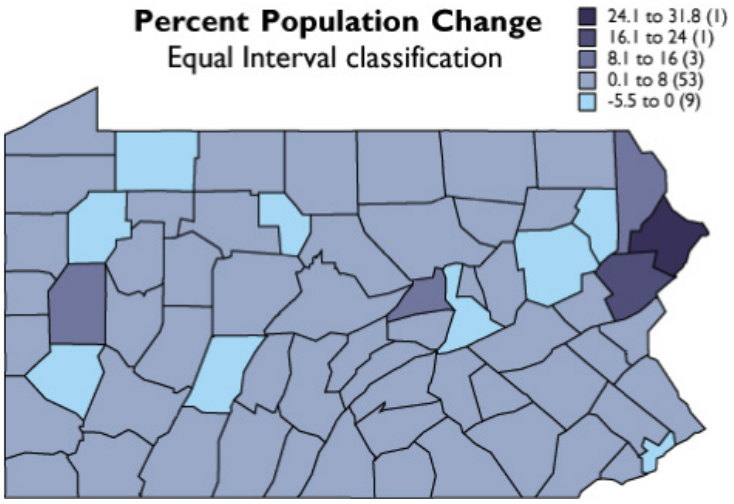


Figure 4.15. The five equal interval classes mapped. Department of Geography, The Pennsylvania State University.

As you can see, the effect of the two different classification schemes on the appearance of the two choropleth maps above is dramatic. The quantiles scheme is often preferred because it prevents the clumping of observations into a few categories shown in the equal intervals map. Conversely, the equal interval map reveals two outlier counties that are obscured in the quantiles map. Due to the potentially extreme differences in visual appearance, it is often useful to compare the maps produced by several different map classifications. Patterns that persist through changes in classification schemes are *likely to be more conclusive evidence* than patterns that shift. Patterns that show up with only one scheme may be important, but require special scrutiny (and an understanding of how the scheme works) to evaluate.

AGGREGATED DATA: ENUMERATION VERSUS SAMPLES

Quantitative data of the kinds depicted by the maps detailed in the previous section come from a diverse array of sources. In the U.S., one of the most important sources is the U.S. Bureau of the Census (discussed briefly above). Here we focus in on one important distinction in data collected by the Census and by other organizations, a distinction between complete enumeration (counting every entity) and sampling.

Sixteen U.S. Marshals and 650 assistants conducted the first U.S. census in 1791. They counted some 3.9 million individuals, although as then-Secretary of State Thomas Jefferson reported to President George Washington, the official number understated the actual population by at least 2.5 percent (Roberts, 1994). By 1960, when the U.S. population had reached 179 million, it was no longer practical to have a census taker visit every household. The Census Bureau then began to distribute questionnaires by mail. Of the 116 million households to which questionnaires were sent in 2000, 72 percent responded by mail. A mostly-temporary staff of over 800,000 was needed to visit the remaining households, and to produce the final count of 281,421,906. Using statistically reliable estimates produced from exhaustive follow-up surveys, the Bureau's permanent staff determined that the final count was accurate to within 1.6 percent of the actual number (although the count was less accurate for young and minority residences than it was for older and white residents). It was the largest and most accurate census to that time. (Interestingly, Congress insists that the original enumeration or "head count" be used as the official population count, even though the estimate calculated from samples by Census Bureau statisticians is demonstrably more accurate.) As of this writing, some aspects of reporting from the decennial census of 2010 are still underway. Like 2000, the mail-in response rate was 72 percent. The official 2010 census count, by state, was delivered to the U.S. Congress on December 21, 2010 (10 days prior to the mandated deadline). The total count for the U.S. was 308,745,538, a 9.7% increase over 2000.

In the first census, in 1791, census takers asked relatively few questions. They wanted to know the numbers of free persons, slaves, and free males over age 16, as well as the sex and race of each individual. (You can view replicas of historical census survey forms at Ancestry.com) As the U.S. population has grown, and as its economy and government have expanded, the amount and variety of data collected has expanded accordingly. In the 2000 census, all 116 million U.S. households were asked six population questions (names, telephone numbers, sex, age and date of birth, Hispanic origin, and race), and one housing question (whether the residence is owned or rented). In addition, a statistical sample of one in six households received a "long form" that asked 46 more questions, including detailed housing characteristics, expenses, citizenship, military service, health problems, employment status, place of work, commuting, and income. From the sampled data the Census Bureau produced estimated data on all these variables for the entire population.

In the parlance of the Census Bureau, data associated with questions asked of all households are called 100% data and data estimated from samples are called sample data. Both types of data are aggregated by various enumeration areas, including census block, block group, tract, place, county, and state (see the illustration below). Through 2000, the Census Bureau distributes the 100% data in a package called the "Summary File 1" (SF1) and the sample data as "Summary File 3" (SF3). In 2005, the Bureau launched a new project called American Com-

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munity Survey that surveys a representative sample of households on an ongoing basis. Every month, one household out of every 480 in each county or equivalent area receives a survey similar to the old "long form." Annual or semi-annual estimates produced from American Community Survey samples replaced the SF3 data product in 2010.

To protect respondents' confidentiality, as well as to make the data most useful to legislators, the Census Bureau aggregates the data it collects from household surveys to several different types of geographic areas. SF1 data, for instance, are reported at the block or tract level. There were about 8.5 million census blocks in 2000. By definition, census blocks are bounded on all sides by streets, streams, or political boundaries. Census tracts are larger areas that have between 2,500 and 8,000 residents. When first delineated, tracts were relatively homogeneous with respect to population characteristics, economic status, and living conditions. A typical census tract consists of about five or six sub-areas called block groups. As the name implies, block groups are composed of several census blocks. American Community Survey estimates, like the SF3 data that preceded them, are reported at the block group level or higher. The unit types are organized with each higher type composed of some number of the lower type as outlined above for blocks, block groups, and census tracts (Figure 4.16).

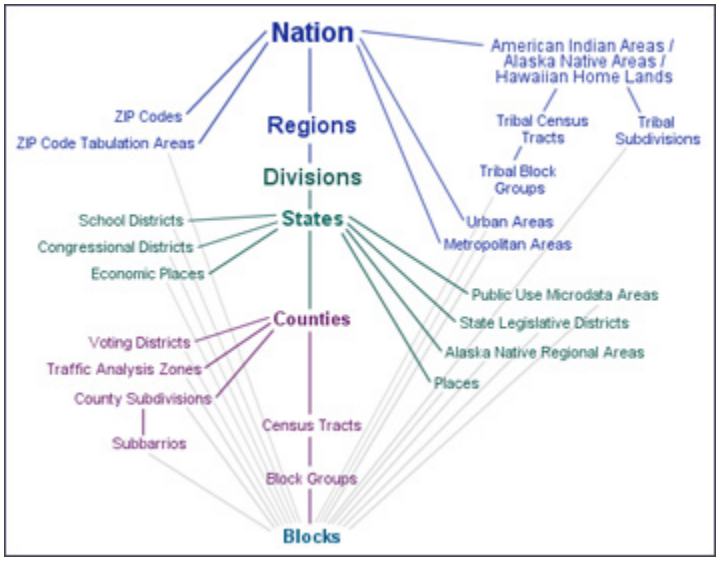


Figure 4.16 Relationships among the various census geographies. Source: U.S. Census Bureau, American FactFinder. http://factfinder2.census.gov/faces/nav/jsf/pages/using_factfinder5.xhtml

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https://www.e-education.psu.edu/geog160/c3_p14.html

https://www.e-education.psu.edu/geog482fall2/c3_p16.html

https://www.e-education.psu.edu/geog482fall2/c3_p17.html

Discussion Questions

1. In what ways do local planners rely on US Census data?

2. How does a pie chart and a bar/column chart differ? What are their visual advantages and disadvantages

when depicting quantitative data?

3. How could you use longitudinal US Census data to address a pressing challenge in the field of urban and regional planning?

Contextual Applications of Chapter 4

The Metropolitan Geography of Low-Wage Work (Brookings)

New Data Illustrate Local Impact of Tax Credits for Working Families

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CHAPTER 5: LYING WITH MAPS

When you understand the technique of making maps in general, it is time to realize that how maps finally look like to a great extent depends on how you present your data. Especially in choropleth map, how do you define the data breaking points, and varied choices on symbology lead to different looking maps which might hide part of the information what the real data truly present.

This piece by Mark Monmonier warn us not only to be careful in designing maps, but also to be critical in reading maps, and promoting a healthy skepticism about these easy-to-manipulate models of reality. Monmonier shows that, despite their immense value, maps lie. Statistics of any kind can be manipulated. For professionals working in the planning field, who rely on lots of data to make public decisions, it is especially important to be skeptical about what you are presented.

To show how maps distort, Monmonier introduces basic principles of mapmaking, gives entertaining examples of the misuse of maps in situations through progressively more subtle treatments of data, each misleading, some innocent and others malicious, until you begin to question all map abstractions entirely. It covers all the typical kinds of distortions from deliberate oversimplifications to the misleading use of color.

Read the book chapter

Mark Monmonier. 1996. 'Data Maps: Making Nonsense of the Census'. in Mark Monmonier (1996) 2nd edition. *How to Lie with Maps?* Chapter 10. University Of Chicago Press

Discussion Questions

1. What are ways that a map-maker (cartographer) has control of the displaying spatial data?
2. What are examples of ways that planners can use maps to persuade city council members with a decision about a proposed change in zoning or land use designation?
3. How can a planner ensure that they are not being seduced by the spatial information they review?

Contextual Applications of Chapter 5

The 5 U.S. Counties Where Racial Diversity Is Highest—and Lowest

Exposed: America's Totally Inconsistent Minimum Parking Requirements

CHAPTER 6: TO STANDARDIZE OR NOT TO STANDARDIZE?

The idea of data quality and standards are important especially in the urban planning field because we make decisions based on data collected from different institutions. If there is not a common standard to follow, it will be frustrating to work if these data came with different quality. Besides, using low quality data might lead public officials and researchers to wrong conclusions, affecting the decision-making process. This chapter by Yeung explains the importance of data quality and data standards, and their inter-relationships. There are ways to quantitatively assess the positional and attribute accuracy of geo-spatial data. If you are interested, you can explore census TIGER file to see how the1990 files differ from thee 2000 dataset.

The chapter starts discussing concepts of geospatial data quality such as accuracy (degree to which data agree with the description of the real world that they represent); precision (how exactly are measured and stored); error (a measure of the deviation between the measured value and the true value), and uncertainty (lack of confidence in the use of the data due to incomplete knowledge of the data). All these concepts are related to the description and evaluation of data quality. Yeung also discusses the sources and types of errors in geospatial data (inherent and operational errors), which are almost impossible to avoid.

In sum, Yeung describes seven dimensions of geospatial data quality: (i) lineage (document the sources from which data is derived), (ii) positional accuracy (it is defined as the closeness of values in the database to the true positions of the real world), (iii) attribute accuracy (closeness of descriptive data to the assumed real world values), (iv) logical consistency (describes the fidelity of the relationship between real world and encoded data), (v) completeness (refers to whether the data exhausts the universe of all possible items), (vi) temporal accuracy (refers to the representation of time in geospatial data), and (vii) semantic accuracy (measures how correctly spatial objects are labeled in the data set). The positional and attribute accuracy are the most relevant.

The presence of errors is a norm rather than an exception. Thus spatial errors need to be managed to reduce uncertainty. There are three perspectives to effect the management of spatial data errors: (i) data production (control de data quality during the data acquisition), (ii) data use (related to errors when data is used), and (iii) communication between data producer and data user (evaluating the quality of the data so that users are aware of the level of uncertainty).

To make sure the quality assurance and quality control of geospatial data is the expected the process of data collection needs to be monitor because is the greatest source of errors in digital geospatial data. During the process of geographic analysis there might be an accumulation of the effects of errors. This is known as the error propagation. Managing errors requires a pragmatic approach through, for example, sensitivity analysis, which is a modeling technique to assess the subjectivity and variability in the parameters of spatial problem-solving model. The purpose of the sensitivity analysis is to test the model for output over a range of legitimate uncertainties. Another relevant aspect is the reporting data quality: information need to be effectively communicated in the form of 'accuracy indices' and maps to all potential users. Geospatial data standards can provide a yardstick -- created by consensus by a recognized organization -- against which quality can be evaluated, through the provision of rules for common and repeated use. Yueng offers four categories of standards: (i) application standards, (ii) data standards –the most important-, (iii) technology standards, and (iv) professional practice standards. In general geospatial data standards provide the means of communication between suppliers and users. These are made up of one or more of these four components: (a) standard data products, (b) data transfer standards, (c) data quality standards, and (d) metadata standards. The development and acceptance of data standards was crucial not only for allowing sharing data but most important, it helped to develop 'open GIS'.

Read the book chapter

Albert Yeung. 2007. "Geospatial Data Quality and Standards" in Albert Yeung 2007 Concepts and Techniques in Geographic Information Systems. pp 108-42.

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Discussion Questions

1. Why does standardization provide a means for assessing data quality?
2. What problems can standardization of spatial data create?
3. IN what ways might you evaluate a dataset for possible errors?

Contextual Applications of Chapter 6

Nine cities that love their trees

The Map That Reveals 5,900 Natural Gas Leaks Under Washington, D.C.

CHAPTER 7: GEOGRAPHIC CONSIDERATIONS IN PLANNING PRACTICE

This chapter is composed of two sections, a book chapter by O'Sullivan and Unwin on the Pitfalls and Potential of Spatial Data, and a small compiled session on geo-coding. The book chapter identifies major problems in the analysis of geographic information and statistical analysis of spatial data, related to spatial autocorrelation, modifiable area units, the ecological fallacy, scale, and non-uniformity of space and edge effects. It also discusses relevant geographic concepts central to spatial analysis such as, of distance, adjacency, interaction (first law of geography), and neighborhood. Finally, it discusses proximity polygons and shows how variogram clouds are used to analyze relationships between data attributes and their spatial location, through matrices.

Spatial data require special analytic techniques thus standard statistic methods have significant problems to analysis spatial distributions. There are five major problems. First, spatial data tend to violate assumption that samples are random because in geography phenomena do not vary randomly through space, leading to the given problem of spatial autocorrelation (data from locations near to one another in space are more likely to be similar than data from locations remote from one another), which introduces the problem of redundancy due to biased samples. Second, the modifiable areal unit problem (when aggregation units used are arbitrary with respect to the phenomena under investigation) tends to affect the 'coefficient of determination, R square. Third, the ecological fallacy (when statistical relations observed at one level of aggregation are assumed to hold because the same relationship holds when we look at more detail level). In this case the thread is that statistical relations may change at different levels of aggregation. The fourth problem is related to scale, which might affect spatial analysis based on the geographic scale at which the phenomenon of interest is analyzed. Lastly, another problem distinguishing spatial analysis from conventional statistics is the non-uniformity of space**.** This issue refers to the fact that analysis might find patterns –thus clusters-, simply as a result of where people live and work. An example is the "edge effect" (it emerges when artificial boundary is imposed on a study).

Although geospatial referencing provides ways to look at data. There are four useful concepts to analyze the spatial distribution of associated entities and spatial relationships: (i) distance (it can be measure as the simple crow's flight distance between the spatial entities of interest, though it can be measured in more complex ways). (ii) Adjacency (it is of the thought as the nominal, or binary, equivalent of distance. It is argued that two spatial entities are either adjacent or they are not: there is not a middle ground). (iii) Interaction (it is considered a combination of distance and adjacency and rests on the ideas that nearer things are more related than distant things: first law of geography). And (iv) neighborhood (there are many ways to conceptualize it (e.g., with respect to sets of adjacent entities, a region of space defined by distance from an associated entity, etc.). One way of pulling these four concepts together is to represent them in matrices.

Lastly, the chapter discusses the proximity polygons, a tool used to specify the spatial properties of a set of objects through partitioning a study region into proximity polygons. The proximity polygon of an entity is the closest region to the entity. The variogram cloud is an exploratory tool (though difficult to interpret) that offers a general picture of relationships between the spatial locations of objects and the other data attributes. It does it by plotting the differences in attribute values for pairs of entities against the differences in their location.

Read the book chapter

O'Sullivan, David, and David John Unwin. Geographic information analysis. John Wiley & Sons, 2003. The Pitfalls and Potential of Spatial Data. Chapter 2

CREATING DATA THROUGH GEOCODING

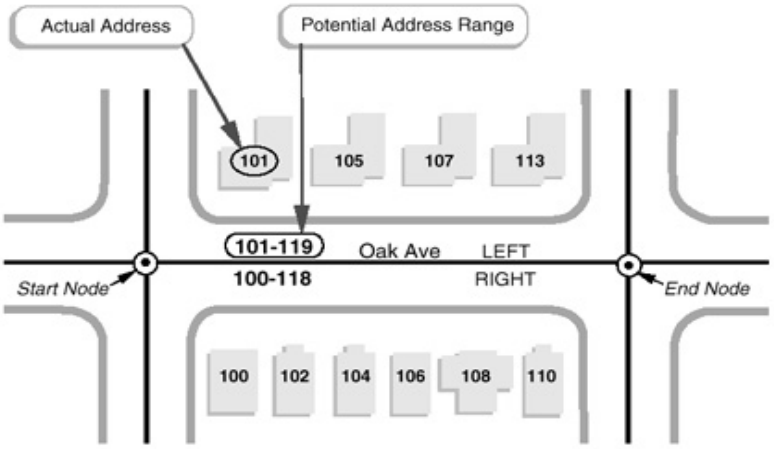
Geocoding is the process used to convert location codes, such as street addresses or postal codes, into geographic (or other) coordinates. The terms "address geocoding" and "address mapping" refer to the same process. Geoc-

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oding address-referenced population data is one of the Census Bureau's key responsibilities. However, as you may know, it is also a very popular capability of online mapping and routing services. In addition, geocoding is an essential element of a suite of techniques that are becoming known as "business intelligence." We will look at applications like these later in this chapter, but, first, let's consider how the Census Bureau performs address geocoding.

ADDRESS GEOCODING AT THE US CENSUS: PRE-MODERNIZATION

Prior to the MAF/TIGER modernization project that led up to the decennial census of 2010, the TIGER database did not include a complete set of point locations for U.S. households. Lacking point locations, TIGER was designed to support address geocoding by approximation. As illustrated below, the pre-modernization TIGER database included address range attributes for the edges that represent streets. Address range attributes were also included in the TIGER/Line files extracted from TIGER. Coupled with the Start and End nodes bounding each edge, address ranges enable users to estimate locations of household addresses (Figure 7.1).



Record Type 1 contains separate data fields for both the start and end of each address range.

Record Type 1				Address Range			
				Left side		Right Side	
				Start	End	Start	End
RT	TLID	FENAME	FETYPE	FRADDL	TOADDL	FRADDR	TOADDR
1	0007654320	Oak	Ave	**101**	**119**	**100**	**118**

Figure 7.1: How address range attributes were encoded in TIGER/Line files. Address ranges in contemporary TIGER/Line Shapefiles are similar, except that "From" (FR) and "To" nodes are now called "Start" and "End". Souce: U.S. Census Bureau 1997.

Here's how it works. Figure 7.1 highlights an edge that represents a one-block segment of Oak Avenue. The edge is bounded by two nodes, labeled "Start" and "End." A corresponding record in an attribute table includes the unique ID number (0007654320) that identifies the edge, along with starting and ending addresses for the left (FRADDL, TOADDL) and right (FRADDR, TOADDR) sides of Oak Avenue. Note also that the address ranges include potential addresses, not just existing ones. This is done in order to future-proof the records, ensuring that the data will still be valid as new buildings and addresses are added to the street.

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https://www.e-education.psu.edu/geog160/node/1941

Discussion Questions

1. In what ways can spatial autocorrelation impact your interpretation of spatial patterns, including changes in demographics or land use patterns?

2. If land use practice occurs at a parcel (or tax lot) scale, then how and why are other scales relevant?

3. What are pitfalls of the computerized geocoding process that may lead to a misinterpretation of spatial phenomena?

Contextual Applications of Chapter 7

People of Color Are Disproportionately Hurt by Air Pollution

Seattle's Hilly Neighborhoods Could Slide Into the Water During the Next Earthquake

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CHAPTER 8: MANIPULATING GIS DATA

Before today, we have been mainly working on data that we downloaded from certain sources, or creating new GIS shapefiles. We basically present whatever we have, and we haven't taken advantage of the greatest strength of a geographic information system (GIS), notably the explicit spatial relationships. Spatial analysis is a fundamental component of a GIS that allows for an in-depth study of the topological and geometric properties of a dataset or datasets. Geoprocessing is to provide tools and a framework for performing spatial analysis and managing your geographic data. This chapter by Longley et al (2001) first discusses what is spatial analysis, and continued two major spatial analysis, one based on location, and the other based on distance.

While knowing geo-processing refers to tools that allow one to perform GIS tasks that range from simple buffers and polygon overlays to complex regression analysis and image classification, spatial analysis refers to efforts that turns data into information: making what is implicit explicit, and what is invisible visible. This is especially true for urban planners, whose needs require decisions to be based in data and from different disciplines. The kinds of tasks to be automated can be mundane—for example, to collect different data and transform it from one format to another. Or the tasks can be quite creative, using a sequence of operations to model and analyze complex spatial relationships—for example, calculating optimum paths through a transportation network, predicting the path of wildfire, analyzing and finding patterns in crime locations, predicting which areas are prone to landslides, or predicting flooding effects of a storm event.

One point to be highlighted is that, spatial analysis open the door for a lot of more sophisticated GIS tools to us. This does not underestimate the power of map making. The design of a map can be very sophisticated and that maps provide a means of conveying geographic information and knowledge by revealing patterns and processes. Map making itself, can be one way of conducting spatial analysis.

Read the book chapter

Longley, Goodchild; Maguire, and Rhind. Geographic Information Systems and Science. Hoboken, NJ: John Wiley & Sons, 2001. Spatial Data Analysis. Chapter 14.

Discussion Questions

1. What geo-processing tasks may be most useful for GIS analysis in your planning interests (e.g. environment, transportation, community development, etc.)?

2. How might we use geo-processing to find patterns of development that have unintended consequences on the quality of life for residents?

3. As spatial analysis becomes more complex, what are ways for communicating your spatial analysis to non-technical audiences?

Contextual Applications of Chapter 8

The 5 U.S. Counties Where Racial Diversity Is Highest—and Lowest

The Number of Americans Living in High-Poverty Neighborhoods Is Still on the Rise

CHAPTER 9: RASTER DATA MODELS

We have learned that there are two major ways how GIS model the real world. Both the vector and raster approaches accomplish the same thing: they allow us to represent the Earth's surface with a limited number of locations. What distinguish the two is the sampling strategies they embody. The vector approach is like creating a picture of a landscape with shards of stained glass cut to various shapes and sizes. The raster approach, by contrast, is more like creating a mosaic with tiles of uniform size. Neither is well suited to all applications, however. Several variations on the vector and raster themes are in use for specialized applications, and the development of new object-oriented approaches is underway.

Although our course has mainly focused on the vector data model, raster data analysis presents the final powerful data mining tool available. Raster data are particularly suited to certain types of analyses, such as basic geoprocessing, surface analysis, and terrain mapping. Some of them are very closely related to planning needs, such as terrain analysis to identify buildable land in a county. While not always true, raster data can simplify many types of spatial analyses that would otherwise be overly cumbersome to perform on vector datasets. Some of the most common of these techniques are presented in this chapter. First, we want to summarize the advantages and disadvantages of the raster model.

ADVANTAGES/DISADVANTAGES OF THE RASTER MODEL

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

Additional advantages of raster graphics are the relative simplicity of the underlying data structure. Each grid location represented in the raster image correlates to a single value (or series of values if attributes tables are included). This simple data structure may also help explain why it is relatively easy to perform overlay analyses on raster data. This simplicity also lends itself to easy interpretation and maintenance of the graphics, relative to its vector counterpart.

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

A second disadvantage of the raster model is that the output images are less "pretty" than their vector counterparts. This is particularly noticeable when the raster images are enlarged or zoomed. Depending on how far one zooms into a raster image, the details and coherence of that image will quickly be lost amid a pixilated sea of seemingly randomly colored grid cells.

The geometric transformations that arise during map reprojection efforts can cause problems for raster graphics and represent a third disadvantage to using the raster data model. We know that changing map projections will alter the size and shape of the original input layer and frequently result in the loss or addition of pixels (White 2006)[2]. These alterations will result in the perfect square pixels of the input layer taking on some alternate rhom-

2 White, D. 2006. "Display of Pixel Loss and Replication in Reprojecting Raster Data from the Sinusoidal Projection." *Geocarto International* 21 (2): 19–22.

www.dbooks.org

boidal dimensions. However, the problem is larger than a simple reformation of the square pixel. Indeed, the reprojection of a raster image dataset from one projection to another brings change to pixel values that may, in turn, significantly alter the output information (Seong 2003)[3].

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

SINGLE LAYER ANALYSIS

Reclassifying, or recoding, a dataset is commonly one of the first steps undertaken during raster analysis. Reclassification is basically the single layer process of assigning a new class or range value to all pixels in the dataset based on their original values. For example, an elevation grid commonly contains a different value for nearly every cell within its extent. These values could be simplified by aggregating each pixel value in a few discrete classes (i.e., 0–100 = "1," 101–200 = "2," 201–300 = "3," etc.). This simplification allows for fewer unique values and cheaper storage requirements. In addition, these reclassified layers are often used as inputs in secondary analyses.

In vector analysis, buffering is the process of creating an output dataset that contains a zone (or zones) of a specified width around an input feature. In the case of raster datasets, these input features are given as a grid cell or a group of grid cells containing a uniform value (e.g., buffer all cells whose value = 1). Buffers are particularly suited for determining the area of influence around features of interest. Whereas buffering vector data results in a precise area of influence at a specified distance from the target feature, raster buffers tend to be approximations representing those cells that are within the specified distance range of the target (Figure 9.2).

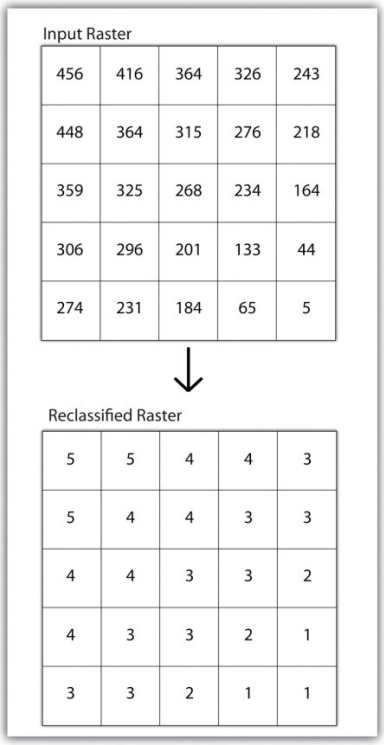


Figure 9.1 Raster Reclassification. http://2012books.lardbucket.org/books/geographic-information-system-basics/s12-geospatial-analysis-ii-raster-.html

3 Seong, J. C. 2003. "Modeling the Accuracy of Image Data Reprojection." *International Journal of Remote Sensing* 24 (11): 2309–21.

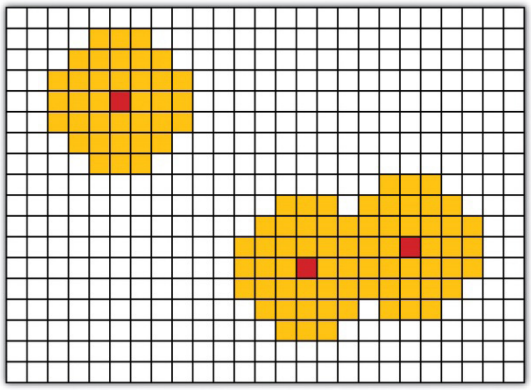


Figure 9.2 Raster Buffer around a Target Cell(s). http://2012books.lardbucket.org/books/geographic-information-system-basics/s12-geospatial-analysis-ii-raster-.html

MULTIPLE LAYER ANALYSIS

A raster dataset can also be clipped similar to a vector dataset. Here, the input raster is overlain by a vector polygon clip layer. The raster clip process results in a single raster that is identical to the input raster but shares the extent of the polygon clip layer.

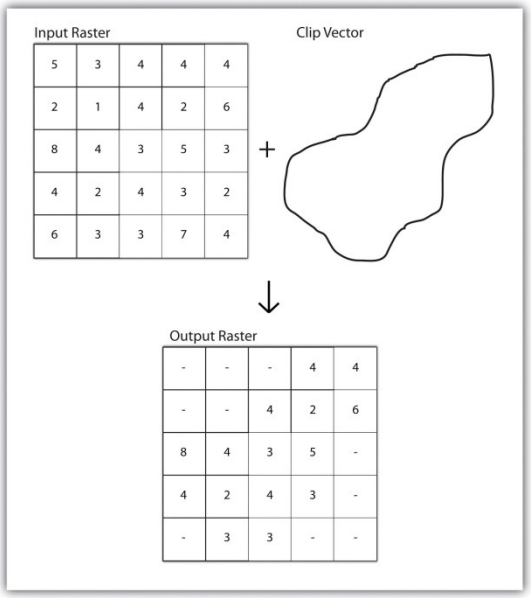


Figure 9.3 Clipping a Raster to a Vector Polygon Layer. http://2012books.lardbucket.org/books/geographic-information-system-basics/s12-geospatial-analysis-ii-raster-.html

RASTER OVERLAYS

Raster overlays are relatively simple compared to their vector counterparts and require much less computational power (Burroughs 1983)[4]. Raster overlay superimposes at least two input raster layers to produce an output layer. Each cell in the output layer is calculated from the corresponding pixels in the input layers. To do this, the layers must line up perfectly; they must have the same pixel resolution and spatial extent. Once preprocessed, raster overlay is flexible, efficient, quick, and offers more overlay possibilities than vector overlay.

Despite their simplicity, it is important to ensure that all overlain rasters are coregistered (i.e., spatially aligned), cover identical areas, and maintain equal resolution (i.e., cell size). If these assumptions are violated, the analysis will either fail or the resulting output layer will be flawed. With this in mind, there are several different method-

4 Burroughs, P. 1983. *Geographical Information Systems for Natural Resources Assessment*. New York: Oxford University Press.

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ologies for performing a raster overlay (Chrisman 2002)[5].

Raster overlay, frequently called map algebra, is based on calculations which include arithmetic expressions and set and Boolean algebraic operators to process the input layers to create an output layer (Figure 9.4). It is often used in risk assessment studies where various layers are combined to produce an outcome map showing areas of high risk/reward. The most common operators are addition, subtraction, multiplication, and division. In short, raster overlay simply uses arithmetic operators to compute the corresponding cells of two or more input layers together, uses Boolean algebra like AND or OR to find the pixels that fit a particular query statement, or executes statistical tests like correlation and regression on the input layers.

The Boolean connectors AND, OR, and XOR can be employed to combine the information of two overlying input raster datasets into a single output raster. Similarly, the relational raster overlay method utilizes relational operators (<, <=, =, <>, >, and =>) to evaluate conditions of the input raster datasets. In both the Boolean and relational overlay methods, cells that meet the evaluation criteria are typically coded in the output raster layer with a 1, while those evaluated as false receive a value of 0.

The simplicity of this methodology, however, can also lead to easily overlooked errors in interpretation if the overlay is not designed properly. Assume that a natural resource manager has two input raster datasets she plans to overlay; one showing the location of trees ("0" = no tree; "1" = tree) and one showing the location of urban areas ("0" = not urban; "1" = urban). If she hopes to find the location of trees in urban areas, a simple mathematical sum of these datasets will yield a "2" in all pixels containing a tree in an urban area. Similarly, if she hopes to find the location of all treeless (or "non-tree," nonurban areas, she can examine the summed output raster for all "0" entries. Finally, if she hopes to locate urban, treeless areas, she will look for all cells containing a "1." Unfortunately, the cell value "1" also is coded into each pixel for nonurban, tree cells. Indeed, the choice of input pixel values and overlay equation in this example will yield confounding results due to the poorly devised overlay scheme.

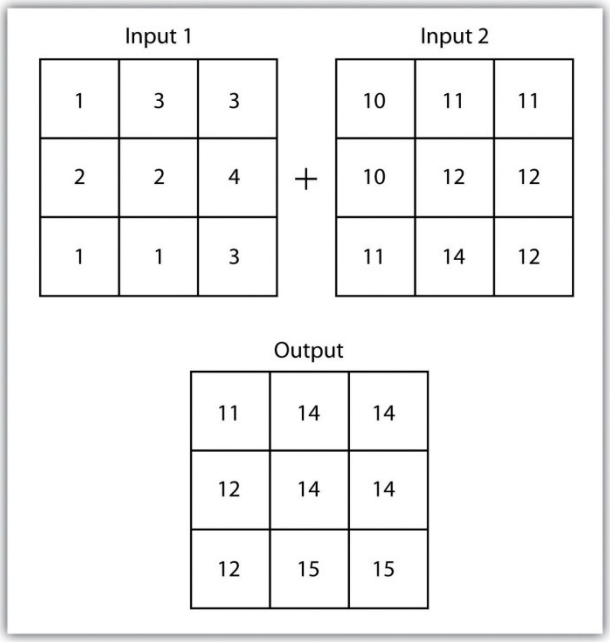


Figure 9.4 Mathematical Raster Overlay. http://2012books.lardbucket.org/books/geographic-information-system-basics/s12-geospatial-analysis-ii-raster-.html - Two input raster layers are overlain to produce an output raster with summed cell values.

THE DIGITAL ELEVATION MODEL (DEM)

The United States Geologic Survey's DEM is a popular raster file format due to widespread availability, the simplicity of the model, and its extensive software support. Each pixel value in these grid-based DEMs denotes

5 Chrisman, N. 2002. *Exploring Geographic Information Systems*. 2nd ed. New York: John Wiley and Sons.

spot elevations on the ground, usually in feet or meters. Care must be taken when using grid-based DEMs due to the enormous volume of data that accompanies these files as the spatial extent covered in the image begins to increase. DEMs are referred to as digital terrain models (DTMs) when they represent a simple, bare-earth model and as digital surface models (DSMs) when they include the heights of landscape features such as buildings and trees.

From the elevation data in each pixel of the raster DEM layer, you are able to produce output layers to portray slope (inclination), aspect (direction), and hillshading (Figure 9.5). These topographic functions are typical neighborhood processes; each pixel in the resultant layer is a product of its own elevation value as well as those of its surrounding neighbors.

- *Slope* layers exhibit the incline or steepness of the land. It is the change in elevation over a defined distance.
- *Aspect* is the compass direction in which a slope faces. From north, it is usually expressed clockwise from 0 to 360 degrees.
- *Hillshading*, which is cartographically called shaded relief, is a lighting effect which mimics the sun to highlight hills and valleys. Some areas appear to be illuminated while others lie in shadows.

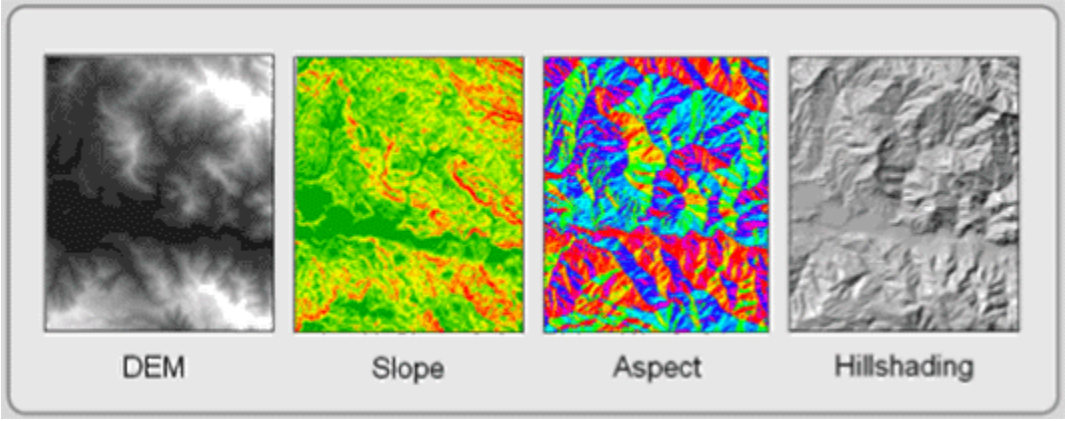


Figure 9.5. Topographic Functions. The DEM creates the slope, aspect, and hillshading layers.

While these functions are raster processes, most can be mimicked in a vector environment by Triangulated Irregular Networks (TIN). In addition, topographic functions can derive vector isolines (contours). Source: GIS Commons (http://giscommons.org/analysis/)

CONNECTIVITY ANALYSIS

Connectivity analyses use functions that accumulate values over an area traveled. Most often, these include the analysis of surfaces and networks. Connectivity analyses include network analysis, spread functions, and visibility analysis. This group of analytical functions is the least developed in commercial GIS software, but this situation is changing as commercial demand for these functions is increasing. Vector-based systems generally focus on network analysis capabilities. Raster-based systems provide visibility analysis and sophisticated spread function capabilities.

SPREAD FUNCTIONS (SURFACE ANALYSIS)

Spread functions are raster analysis techniques that determine paths through space by considering how phenomena (including features) spread over an area in all directions but with different resistances. You begin with an origin or starting layer (a point where the path begins) and a friction layer, which represents how difficult—how much resistance—it is for the phenomenon to pass through each cell. From these two layers, a new layer

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is formed that indicates how much resistance the phenomenon encounters as it spreads in all directions (Figure 9.6).

Add a destination layer, and you can determine the "least cost" path between the origin and the destination. "Least cost" can be a monetary cost, but it can also represent the time it takes to go from one point to another, the environmental cost of using a route, or even the amount of effort (calories) that is spent.

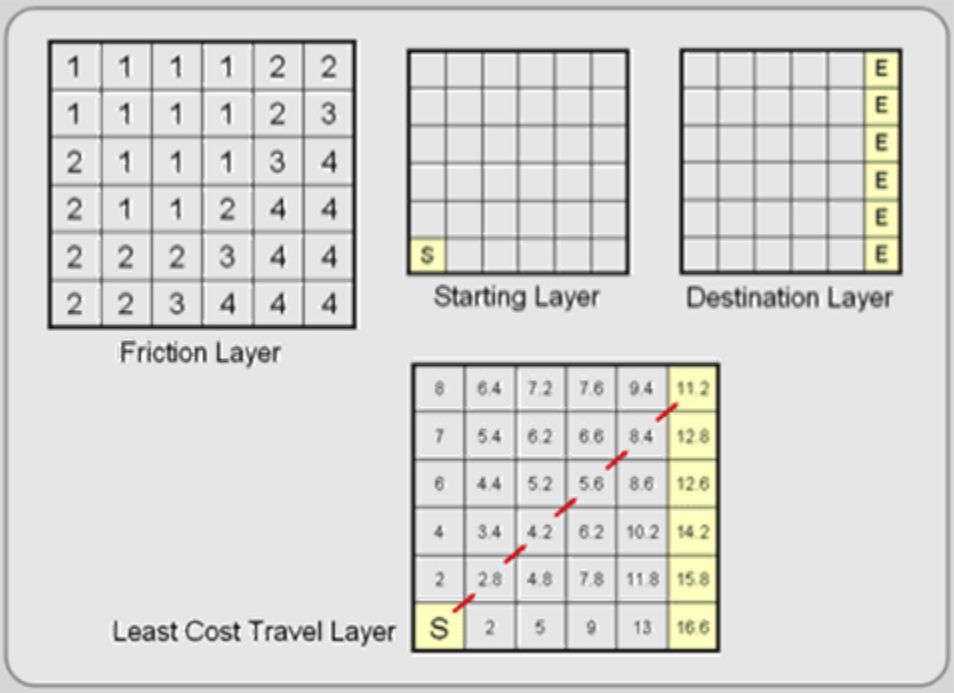


Figure 9.6. Spread Functions. This example shows that the shortest distance is not always the least cost distance. Source: GIS Commons. http://giscommons.org/analysis/

VIEWSHED MODELING (INTERVISIBILITY ANALYSIS)

Viewshed modeling uses elevation layers to indicate areas on the map that can and cannot be viewed from a specific vantage point. The non-obscured area is the viewshed. Viewsheds are developed from DEMs in raster-based systems and from TINs in vector systems. The ability to determine viewshed (and how they can be altered) is particularly useful to national and state park planners and landscape architects (Figure 9.7).

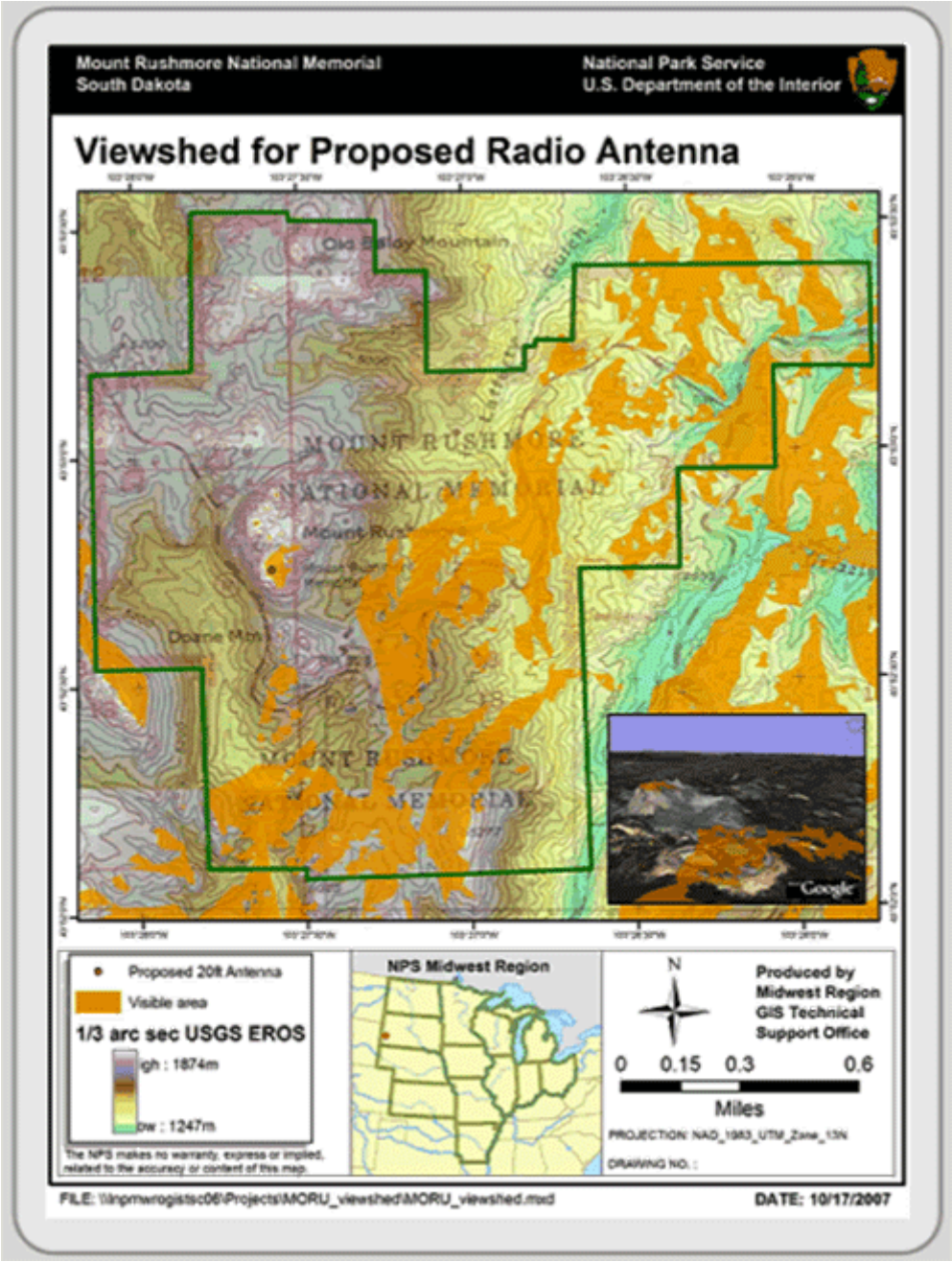


Figure 9.7 Viewshed Analysis depicting the areas within a park where a proposed radio antenna can be seen. Map courtesy of the National Park Service, Department of Interior, 2007. Source: GIS Commons. http://gis-commons.org/analysis/

CORRELATION AND REGRESSION

Correlation and Regression are two ways to compute the degree of association between two (or sometimes more) layers. With correlation, you do not assume a causal relationship. In other words, one layer is not affecting the spatial pattern of the other layer. The patterns may be similar, but no cause and effect is implied. Regression is different; you make the assumption that one layer (and its variable) influences the other. You specify an independent variable layer (sometimes more than one) that affects the dependent variable layer (Figure 9.9).

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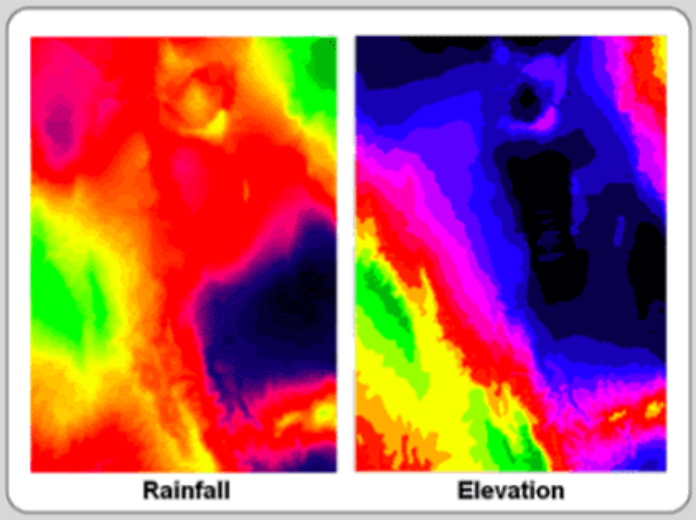


Figure 9.9. Is there a spatial relationship between these two layers? Source: GIS Commons. http://giscommons.org/analysis/ - Correlation and regression tests allow you to overlay layers to test their spatial relationship.

With both statistical tests, you compute a correlation coefficient, which ranges from -1 to +1. Positive coefficients indicate that the two layer's variables are associated in the same direction. As one variable increases, the other variable increases (both can simultaneously decrease too). The values closer to +1 describe a stronger association than those closer to zero. A negative coefficient depicts two layer's variables that are associated but in opposite directions. As one variable increases, the other variable decreases. Values closer to -1 have a strong negative association. If the correlation coefficient is near zero, there is little to no association. Both of these processes are raster based.

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http://giscommons.org/analysis/

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http://2012books.lardbucket.org/books/geographic-information-system-basics/s08-01-raster-data-models.html

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https://www.e-education.psu.edu/geog160/node/1935

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http://2012books.lardbucket.org/books/geographic-information-system-basics/s12-geospatial-analysis-ii-raster-.html

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Discussion Questions

1. In what ways does a raster analysis provide insights that may not be available through the vector data model?

2. What is an urban and regional planning application where map algebra could provide insights helpful for characterizing a location?

3. As a practicing planner, how might you integrate the advantages of vector and raster data models when engaging the public?

Contextual Applications of Chapter 9

Why Drivers Should Pay to Park on Residential Streets

The Difficulty of Mapping Transit 'Deserts'

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CHAPTER 10: THE FUTURE OF GIS

Planning support systems (PSS) emerged in the 1980's to include a widely set of computer-based tools providing 'strategic support' to urban planners. By the 1990's with the availability of GIS PSS displaced the more rigid "systems planning approach" and were widely used in most of the stages of the technical planning processes. Currently PPS are applied to several and diverse planning proposes mostly because of three aspects related to the transformation of the urban planning field: (i) into a more fragmented and pluralistic field; (ii) from a rigid professionalism to collective negotiation, where the processes of communication to inform has become crucial; and (iii) widely access to a diverse and constantly evolving computer technologies, through the internet and the open source movement.

Among these new generic (GIS software, build in modules) and specialized 'planning tools' technologies are: (i) hardware able to process increasing amounts of data; (ii) convergence of computers and communications; (iii) new powerful microprocessors; (iv) computer simulation models (agent-based, disaggregated) with three dimensional visualization displays; (v) ability to communicate and interact among computers and participants using visualization technologies (e.g. virtual reality theaters allowing public interaction).

Visualization and communication technologies revolve around interactivity using the Web. The Web is organized into four general styles: (i) vanilla-style Web pages that present information to users with no interactivity other than hyperlinking; (ii) Web pages that enable users to download data and software to their desktops; (iii) Web-pages enabling users to run software within their own Web; and (iv) Web-pages enabling users to import their own data and run software remotely. There are also 'collaboratories' (online systems remotely linked that enable users to communicate with one another and run software jointly), which are growing in popularity.

Although we are in the midst of a fragmentation of PSS tools, we can classify them into: (i) those serving the technical planning process (e.g., problem identification, goal setting, etc.); (ii) processes focus on providing opportunities for public participation (e.g. PP-GIS, 3-D virtual city models); (iii) those related to tasks (observing, measuring, predicting, etc.) related to how the city system is represented and manipulated (e.g., modeling and simulation). Among the computer packages developed to do it are: GIS, land use transportation models (LUTM), multi-criteria analysis (MCA), What if/; (iv) fine scale disaggregated models (agent based); (v) tools focus on either spatial/non-spatial analysis or general/specialist tasks; (vi) GIS toolbox (e.g., free mapping and visualization software on the Web).

Authors used three examples to illustrate many of the features and characteristics of the PSS: (i) long term forecasting: visualizing land use and transportation scenarios in the Greater London, through modeling (ii) Immediate forecasting at the local level: visualizing the impact of air pollution using a virtual city model for the Greater London; and (iii) Describing and exploring spatial data: tools to enhance the understanding of urban problems.

Planning support systems (PSS) usually refers to a computer-based system that can integrate spatial mapping, analysis and visualization, and further lead to operational and meaningful public decision making. This introduction chapter in the book, which originated from a conference on PSS organized by Lincoln Institute of Land Policy, provide an overview of planning and decision support system. This chapter highlights the movement of urban planning over the past decades from a top-down, 'professionals know best' attitude to a participatory approach involving a broad spectrum of citizens, interest groups, and public officials. Today planners and public officials interact with multiple communities and increasingly do so with digital technology. Therefore, the visualization of models and processes becomes the central part of planners' toolbox.

Read the book chapter

Batty, Michael (2008) Planning support system, Progress, prediction, and speculations on the shape of things to come, in Brail, R. K. eds. Planning support systems for cities and regions. Cambridge, MA: Lincoln Institute of Land Policy.

Discussion Questions

1. Does the planning profession need to keep up with the transformation and proliferation of GIS technologies? If so, how? If not, why not?

2. What does the 'democratization of GIS' mean for the expert planner?

3. Can planning support systems become a tool that enables the public to participate in decision-making? If so, how? If not, why not?

Contextual Applications of Chapter 10

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