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Lesson 1: Introduction to Cartographic Design

INTRODUCTION

In this lesson you will gain an understanding of the basic elements of cartographic design. In addition, you will learn about different types of maps and their applications. It is important to understand the elements needed to create an effective map and the design process involved.

LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Identify basic elements of cartographic design.
2. Describe different types of maps and their uses.
3. Create a map.
4. Explain design decisions used to create a map.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz: Introduction to Cartographic Design • Lab: Creating a Colorful Map of the United States of America

INSTRUCTION

Defining a Map

As one starts down the path to becoming cartographer, it is important to first start with the basic question of "what is a map?" Defining what a map is will provide a foundation needed to deconstruct the concept of a map into manageable pieces. A map is a graphic representation of the cultural and physical environment. The keyword here is graphic representation, as all maps are visual representations of the phenomenon to be modeled. The second definition of a map is that it is a reduced, selective, and symbolized graphical representation of an environment. This definition introduces three key terms reduced, selective, and symbolized.

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Reduced

The first term, reduced, refers to the fact that almost all maps are more useful than when they are reproduced at a smaller scale than the actual phenomenon being mapped. For example, a road map of Idaho that when unfolded is the actual size of Idaho, is not very useful to us, so instead, we reduce the size of the spatial phenomenon being represented onto a more reasonably sized piece of paper.

Selective

The second term, selective, means that maps should only include items that are directly related to the message of the map. For instance, a map designated to show where all the hospitals are located within a city should not include the location of every manhole cover in the city on the map. The reason being, the location which the manhole covers has nothing to do with the locations of the hospitals, and therefore it would be a meaningless feature on the map.

Symbolized

The third term, symbolized, refers to the idea of extracting the item being mapped by using a representative symbol. Examples of representative symbols would be a star with a circle around it that represents a state capital, or a symbol of the front of a bus that represents a bus stop.

Example: General Reference Map

Figure 1 is an example of a general reference map produced by the National Atlas of the United States of America. This map is a graphic representation of the cultural and physical environment for the area that covers the United States. The cultural items on the map include the roads, country and state outlines, river and ocean names, country names, state names, and city locations. The physical environment being represented on this map is the topography including the location of land and water masses. This map is a reduced, selective, and symbolized graphic representation of the United States.

- It is reduced because it is physically smaller than the size of the United States.
- It is selective because it does not show the relevant information to the purpose of this map.
- It is symbolized through the use of visual variables such as color, texture, size, and shape.

Figure 1 General Reference Map

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Classifying Maps

Classifying maps begins with categorizing them into mediums. The three types of map mediums are tangible, virtual, and mental.

Tangible

A tangible map is a map that you can hold in your hands such as a paper map. The nice thing about tangible maps is that they can be easily shared between users and there is no specialized hardware or software required to use them. Additionally, tangible maps are portable, and can be stored for long amounts of time without any need for maintenance.

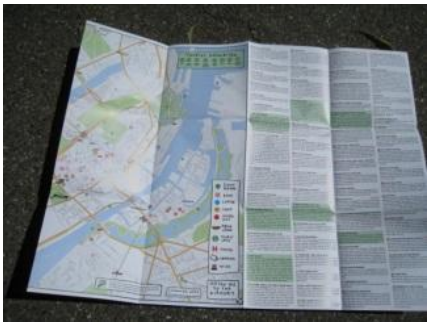

Figure 2 Tangible Map

Virtual

A virtual map is any map displayed on a computing device. Maps are now found on desktop computers, tablets, laptops, phones, GPS receivers, and many other digital devices. The great thing about virtual maps is they are easily updatable, can be dynamic, show animation, can link to large amounts of information such as documents, pictures, movies, and sounds, and can be easily shared. Negative aspects of virtual maps include: they require hardware and software to view, may require maintenance in order for the map to exist for a long time, may not intuitive to many users, and may require more training to develop.

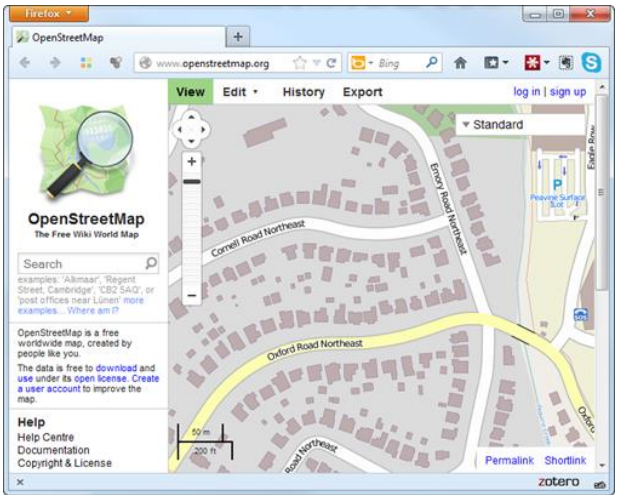

Figure 3 Virtual Map

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Mental

A mental map is a map that is stored in someone's mind and is their conceptualization of space. Mental maps do not translate exactly from person-to-person except through the conversion of the mental map to a tangible or virtual map, or to any other communication path such as speech or writing.

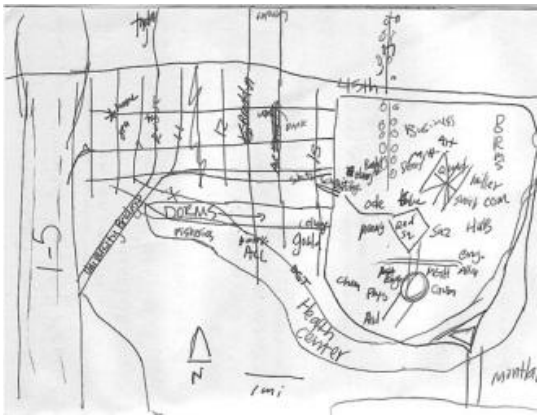

Figure 4 Mental Map

Tangible or Virtual Maps

There are two types of maps that can be tangible or virtual: general reference maps, and thematic maps. Most people are very familiar with general reference maps through their use of roadmaps, which is considered a general reference map. Thematic maps are not as familiar to as wide an audience as general reference maps however thematic maps are becoming increasingly popular and can be quite useful when you wish to create a visual representation of some aspect of a data set where you want the user to consider the spatial distribution of that information.

General Reference Maps

A general reference map emphasizes location and shows a variety of features. A general reference map primarily displays objects, their location, and identifying information. General reference maps are typically not specialized to any one particular use, but are instead meant to be used for a wide variety of activities. Displayed here are two sections of two different general reference maps. The map on the left shows a small geographic area and quite a bit of detail. On this map, we can see individual buildings, parking lots, walking paths, and detailed names. The map on the right shows a larger geographic area with less detail. On this map we can see large bodies of water, locations of public and private land, generalized building footprints, and names that apply to large geographic areas.

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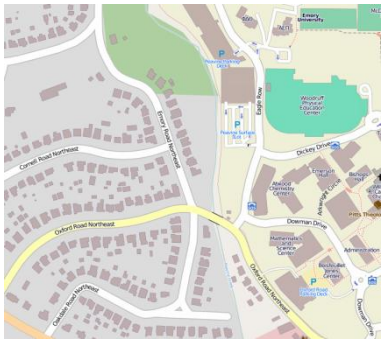

Figure 5 Close-up

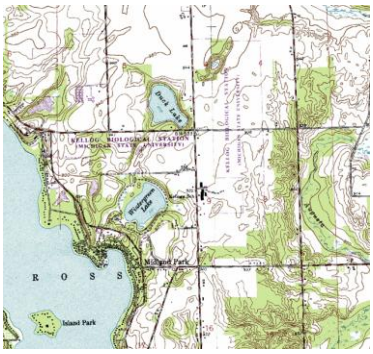

Figure 6 Wide-view

Even though these two maps are at different scales and show different amounts of detail, they have some commonalities like showing a wide variety of features, focusing on nothing in particular which makes them both examples of a general reference map. These maps were meant to be objective abstractions of reality that can be used for multiple purposes.

Thematic Maps

A thematic map emphasizes attributes related to a single subject or theme. Thematic maps typically have a very specific purpose and wish to convey a very specific message related to, typically, a single subject. Thematic maps are classified with more depth, and are not as familiar to as many people, so we will spend a little more time describing them. Thematic maps focus on a single theme which is commonly referred to as an attribute. While most thematic maps focus on a single theme it is important to note that thematic maps can also display multiple related scenes at the same time. One of the reasons thematic maps are so useful is that they display patterns of the theme across space.

If multiple thematic maps are created relating to a single, or related multiple themes, it can be very useful to compare the two maps to draw additional conclusions. Unlike general reference maps, thematic maps are typically very selective in the features that are included on the map. Only features that support the maps theme are to be included on thematic maps. Lastly, thematic maps were not widely used until the 1800s, and are considered newer map technology than a general reference map.

Qualitative

A qualitative map is one type of thematic map. The provided image is a qualitative map of the Standard Time Zones for the United States of America created by the National Atlas of the United States of America. The different time zones are considered qualitative data, and do not contain any numerical information nor does it represent a magnitude. Qualitative thematic maps show nominal data and its distribution throughout space. A qualitative thematic map does not show any quantities or data that has magnitude. This map simply shows where each time zone exists, and that the spaces the time zones cover are considered to be different time zones. No mathematical relationships can be drawn from this map, only equality and inequality between the time zones.

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Figure 7 Qualitative

Quantitative – Single Variable

A second type of thematic map is the quantitative-single variable map which shows numerical data and its variation from place to place. Typically, the numerical data is generalized so that it can produce a better looking visual product. This map represents the margin by which a presidential candidate won the county's votes in the 2008 presidential election. So, the theme of this map is the election results of the 2008 presidential election, and it uses the raw number of votes simplified, and aggregated to the county level so that it is easier to interpret the spatial distribution and patterns.

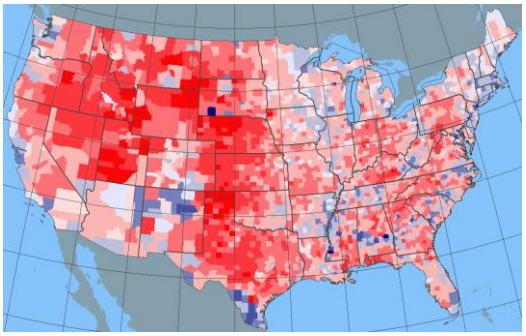

Figure 8 Quantitative – Single Variable

Categories of Thematic Maps

Thematic maps can be broken down even further into specific categories. Five common categories of thematic maps are choropleth, dot density, proportional symbol, flow, and cartogram. Let's take a look at an example of each category of thematic maps.

Qualtitative Choropleth Map

This provided image is a quantitative choropleth map that shows acres of upland cotton harvested as a percent of harvested crop on acreage in the year 2007 in the United States of America. A choropleth map, each enumeration unit, such as a county, is assigned a color that represents either a single value, or range of values that exist in that enumeration unit. This choropleth map is displaying quantitative information that is been aggregated to the county level.

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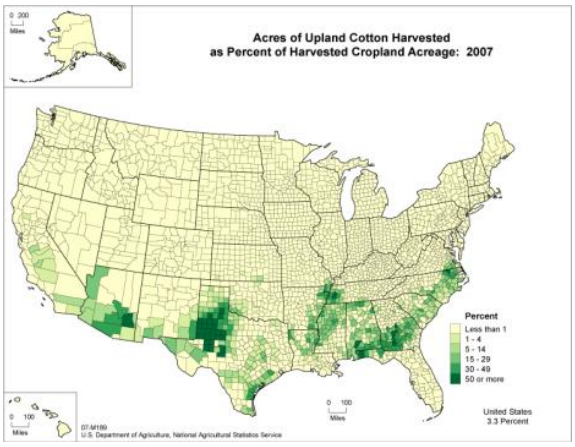

Figure 9 Choropleth Map

Dot Density Map

A dot density map shows total values of quantitative information represented by dots that are randomly placed within an enumeration unit. This dot density map shows the number of cattle and calves in the contiguous United States in the year 2002. On this map, one dot represents 20,000 cattle and calves. The data is collected at the county level, and the dots are randomly placed within each county.

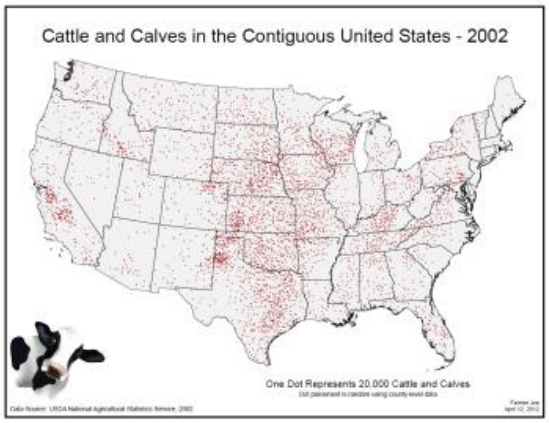

Figure 10 Dot Density Map

Proportional Symbol Map

This is an example of a proportional symbol map that shows the relative difference in total population between the 50 states in the year 2007. In a proportional symbol map, symbols, such as circles, are sized in proportion to the value of an attribute and allow for comparison of values between enumeration units.

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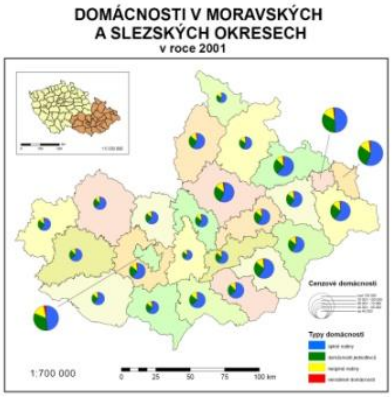

Figure 11 Proportional Symbol Map

Flow Map

A flow map shows the transport of items between one location and another. This particular flood map shows a migration of people between landmasses by using arrows of different size and color to represent different facets of the migration.

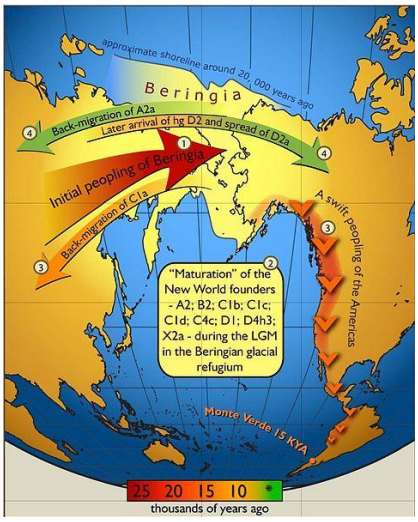

Figure 12 Flow Map

Cartogram Map

In a cartogram map, the area of the enumeration unit is sized in relation to the value of an attribute and allows the map reader to make comparisons relative to value (Figure 13). In areas where the value of the attribute is smaller than average, the size of the enumeration unit is reduced, and where the value of the attribute is larger than average, the size of the enumeration unit is enlarged. As the enumeration units are reduced or enlarged in size, the shapes of the areas can become quite distorted (Figure 14).

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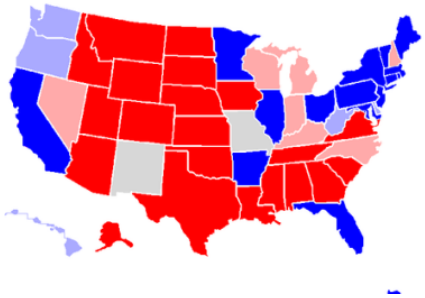

Figure 13 Cartogram Map

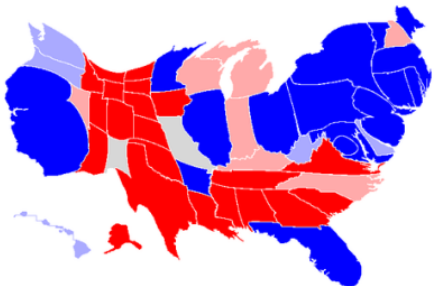

Figure 14 Cartogram Map: Distorted

Taxonomy of Maps

There are three mediums of maps: mental, tangible, and virtual and of those three mediums, we can create tangible and virtual maps using geospatial information systems (GIS). There are two types of maps that can be produced on tangible and virtual media: general reference, and thematic. Thematic maps are broken down further into two categories: qualitative thematic maps and quantitative thematic maps. A quantitative thematic map can simultaneously represent single or multiple variables. Please refer to the Taxonomy of Maps for a representation of the classification of maps (Figure 15).

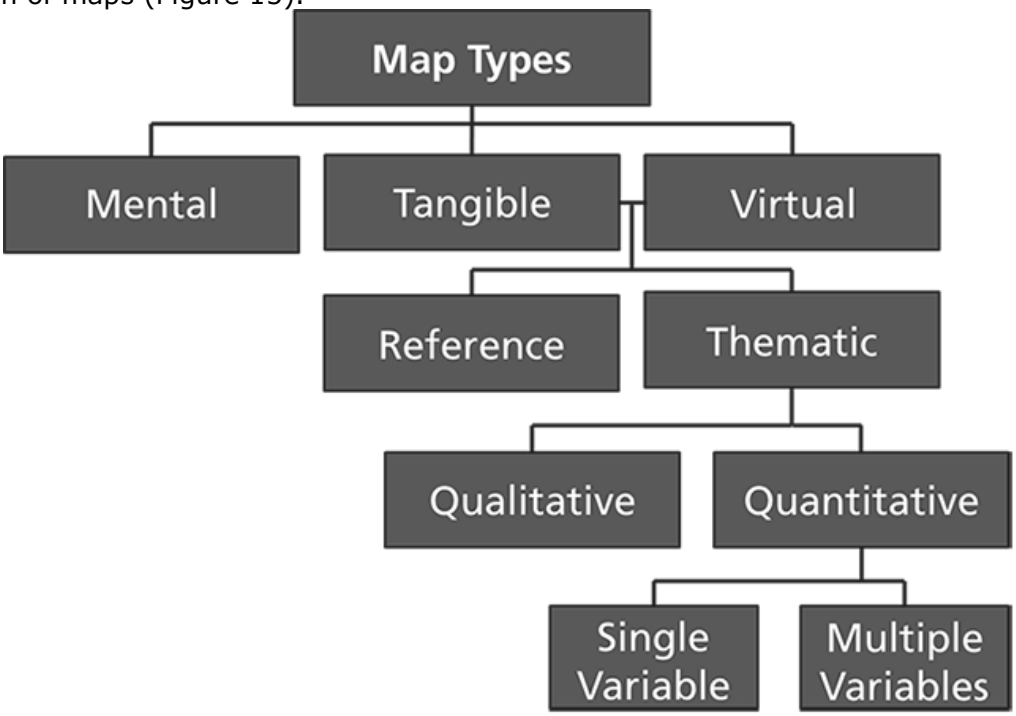

Figure 15 Taxonomy of Maps: Classification of Maps

Cartography

Cartography is the art and science of making maps. Cartography involves the process of producing a map through the philosophical and theoretical basis of map making. A cartographer is someone who designs and prepares a map for distribution. More specifically, a cartographer is someone who studies the philosophical and theoretical basis of the rules for making maps.

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Traditionally, only cartographers made maps and these cartographers were considered skilled workers that required many years of apprenticeship and practice to master. However, in recent history, cartography has been democratized and now many different groups create maps without the use of cartographers.

Cartography is seldom a stand-alone profession and is now seen as a skill set possessed by geographers, geographic information scientists, or anyone else who wishes to create a map. The profession of cartography still does exist and is important to many agencies that wish to produce high quality maps.

A Brief History of Maps

One can assume that humans have been mapping for as long as physically possible. Whether they were drawing in the dirt or sand, or chiseling into rock, maps have always been an important part of human development. Interestingly, these ancient and contemporary maps reveal more than just the geography of the people who made them.

Maps are often assumed to be reproductions of the world that are objective, accurate, and neutral mirrors. However, you must keep in mind that all maps are considered communication devices created by some person who has been influenced by their environment and culture. Therefore, maps are not neutral representations of the world, but social constructions, situated in a milieu. A milieu is a physical or social setting in which something occurs that often has an influence on the outcome. Review the following examples of ancient maps.

Çatalhöyük Map

The oldest existing map was created around 6200 BC. The map shows a town with an erupting volcano in the background and enables you to see how they perceived their surrounding environment and space. View the World's Oldest Maps – 2 Çatalhöyük – 6200 B.C. Babylonian Clay Map by going here.

Giadighe Petroglyph Map

The Giadighe map in this image is from 2500 BC. One can only guess at the milieu being mapped here, but we know that cultural symbols, ideas, and practices contribute to the form of the map and to the sense it made in 2500 BC. So what do we see on this map? Animals, perhaps being husbanded, what appears to be orchards or gardens shown as grids of dots, houses with ladders indicating perhaps the settlement was located on hilly terrain, huts between structures and enclosures, and of course people engaged in a variety of activities. It is interesting how much we can probably guess correctly at a distance of more than 4000 years.

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Figure 16 Giadighe petroglyph, Valcamonica (2500 B.C.)

Marshall Island Map

Figure 17 is a traditional Marshall Islands Sea Chart. Sticks and shells were often used to depict islands. These charts were used for navigating between landmasses and were made to be portable.

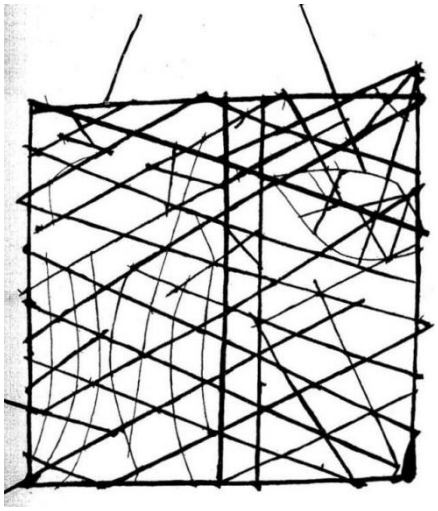

Figure 17 Marshall Island Sea Chart

Mediterranean T-O Map

This map is known as a T-O map. The T represents the Mediterranean which divides three continents: Asia, Europe, and Africa. The O represents the ocean and Jerusalem was assumed to be in the center of the circle. The earliest representation of a T-O map is attributed to an eighth century Spanish Monk.

Figure 18 Mediterranean T-O Map

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Arabia T-O Map

Take a look at an Arabia T-O Map created in a different milieu, *Mapping Universal History in the World-Map of the Rudimentum Novitorium*. Notice that the map includes Arabia as the fourth continent and the placement of the Garden of Eden at the top of the earth.

Babylonian World Map

In 600 BC, the Babylonians created their world map. In this map, the circle surrounds the land and is considered to be the end of the earth.

Figure 19 Babylonian World Map

New World T-O Map

This is a New World T-O map, created in a different milieu and with a different style. Note the inclusion of America, the New World in the lower left-hand corner of the map. Note that Jerusalem is also still located in the center of the map.

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Figure 20 New World T-O Map

Venice Map

Here is a map of Venice created in 1565. What is interesting about this map is its perspective. This map is not a bird's eye view of Venice, but a perspective map of Venice as if it were being seen by someone sitting atop a nearby mountain. This shows that even hundreds of years ago, societies were able to make advanced spatial representations even though they may have never seen Venice from this angle.

Figure 21 Map of Venice 1565

SUMMARY

In this lesson you learned about cartography and various types of maps. You were also were presented with foundational information including the definition of a map and several map types that are essential to being able to understand the map classification process.

ASSIGNMENTS

1. Quiz: Introduction to Cartographic Design

2. Lab: Creating a Colorful Map of the United States of America

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Lesson 2: Geodesy and Coordinate Systems

INTRODUCTION

In this lesson you will learn about Geodesy and Coordinate Systems. The lesson will have examples and information about the aspects that make up coordinate systems. You will learn about the determining factors to consider when creating map projections, deformation and distribution of the projection, and how to determine which map projection to use for a project.

LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Identify elements of geographic referencing systems and map projections.
2. Employ appropriate geographic referencing system parameters and base maps.
3. Explain how different projections, coordinate systems and datums can affect map design and accuracy of map products.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz: Geographic Referencing Systems and Map Projections • Lab: Exploring Coordinate Systems and Map Projections

INSTRUCTION

What is Geodesy?

Geodesy is the scientific discipline that deals with the measurement representation of the earth. Geodesists study the Earth's gravitational field, motion of the Earth's crust, tides, and the Earth's rotation. In order to do this, geodesists have built national control networks that allow them to define and assign coordinates to physical locations on earth.

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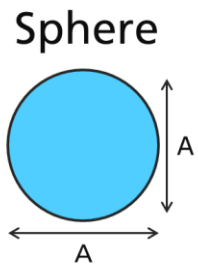
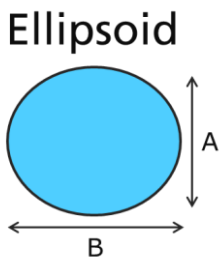
Three Approximations of Earth's Shape

There are three commonly used approximations of the shape of the earth: sphere, ellipsoid, and geoid. The sphere is the simplest approximation of the earth's shape as it is defined by a single radius. The ellipsoid is closer to the earth's shape as defined by semi-major and semi-minor axes. The geoid is the closest approximation of the earth's shape based on gravity measurements that help define global mean sea level. The reasons why the sphere and ellipsoid are still used are that they are much easier to use for calculations and when defined properly can be exceptionally accurate.





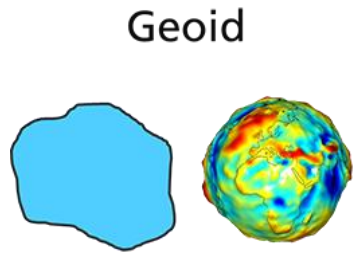


Figure 1 Sphere Figure 2 Ellipsoid Figure 3 Geoid

Ellipsoids

The ellipsoid is the most commonly used of the three approximations of the earth's shape today. There is not a single ellipsoid that fits earth well; therefore, there have been many official ellipsoids throughout the 19th and 20th centuries. Different ellipsoids were adopted because different measurements were used in different countries when defining these ellipsoids, and geodetic surveys were isolated by large bodies of water. Because of this, and ellipsoid created by one country may approximate that portion of the earth very well, but may not be a suitable approximation for another portion of the earth.

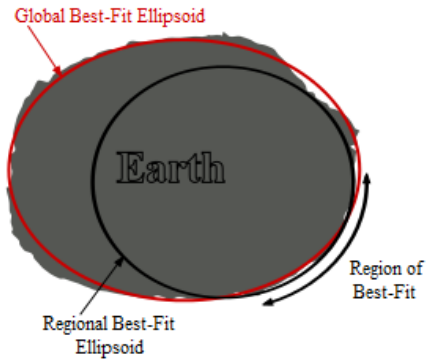


Figure 4 Ellipsoid

Datums

According to the National Geodetic Survey, a datum is a set of constants specifying the coordinate system used for calculating coordinates of points on earth. Datums serve as

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starting points of reference for surveying and mapping as they link the physical earth to a mathematical coordinate. A datum is a reference surface for measuring locations on the earth. A datum has two major components: the specification of an ellipsoid, which is an ellipsoid that has been surveyed and defines the origin and orientation of latitudes and longitude lines. We cannot assign any coordinates to a location without first specifying a datum and linking that datum to the shape of the earth through field measurements. There are three common datums that you will use in GIS: North American datum of 1927 (NAD 27), North American datum of 1983 (NAD 83), and World Geodetic System of 1984 (WGS 84).

NAD 27

The first datum we will discuss is the North American datum of 1927 also referred to as NAD 27. The NAD 27 datum is based on the Clarke 1866 ellipsoid which holds a fixed latitude and longitude in Kansas. The locations were adjusted based on about 26,000 measurements across North America. Quite a bit of GIS data is still available in NAD 27, however, more recent data should use North American datum of 1983.

NAD 83

The North American datum of 1983, or NAD 83, is the successor of NAD 27, and uses an earth centered reference ellipsoid rather than a fixed station in Kansas. Additionally, 250,000 points were measured to adjust the latitude and longitude locations.

It is worth mentioning that it is okay to use NAD 27 or NAD 83 data, however, when performing analysis you should convert all the data into a single datum for analysis purposes.

WGS 84

The third common datum is the World Geodetic System of 1984 commonly referred to as WGS 84. WGS 84 is based on satellite measurements and the WGS 84 ellipsoid which is similar to another ellipsoid named GRS 80. The major difference between the WGS 84 ellipsoid and the NAD 27 and NAD 83 datum is that the WGS 84 data has worldwide coverage, where NAD 27 and NAD 83 should only be used in North America. You should also note that the WGS 84 datum is used by the GPS system to report latitudes and longitudes.

Datums are not static and often see updates and adjustments throughout time. In fact, both NAD 83 and WGS 84 have been updated multiple times. Therefore it is very important that you read the documentation of the datasets that you are using in your GIS to determine exactly which datum was used in determining locations.

Coordinate Systems

As it pertains to Earth, we use 3-D coordinate systems which represent a sphere such as the earth. The important thing to note about the 3-D coordinate systems that we are going to discuss in this section is that it will not ignore the curvature of the earth, which makes it ideal for displaying locations, and measuring distances across long distances were the curvature of the earth will become a factor.

The 3-D coordinate system that we are going to discuss is going to use two angles of rotation commonly known as latitude and longitude, and a radius to specify the location. The angles of rotation will determine whether the location is north or south of the equator or

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east or west of the Prime Meridian and the radius will specify how far from the center of the earth that location is.

Longitude

Longitude, also known as Meridian, is the angle of rotation measured east and west around the globe. What may be confusing is that the lines of longitude run north-south from the North Pole to the South Pole. Lines of longitude will vary from positive 180° east to -180° west measured relative to the line of longitude of 0° which is known as the Prime Meridian.

The Prime Meridian runs through Greenwich, England. Lines of longitude west of Greenwich, England up to and including 180° are represented as a negative number or as a Western longitude. Lines of longitude east of Greenwich, England up to, and including 180°, is represented as a positive number or as an Eastern longitude.

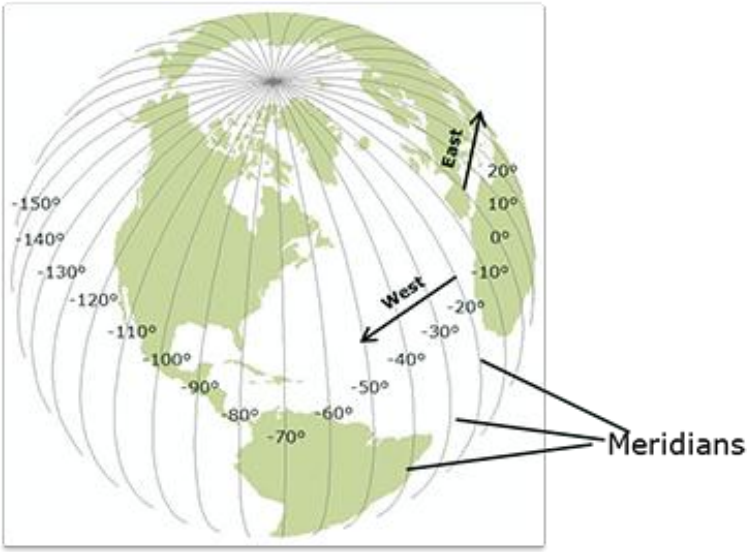

Figure 5 Example of Longitude

Latitude

The second angle of rotation is known as latitude and is also referred to as a parallel. Parallels measure north to south on the globe, and the lines run in parallel to each other east and west from the North Pole to the South Pole. The equator is the latitude of 0°. Lines of latitude measure from positive 90° north, which is located at the North Pole, to -90° south, which is located at the South Pole.

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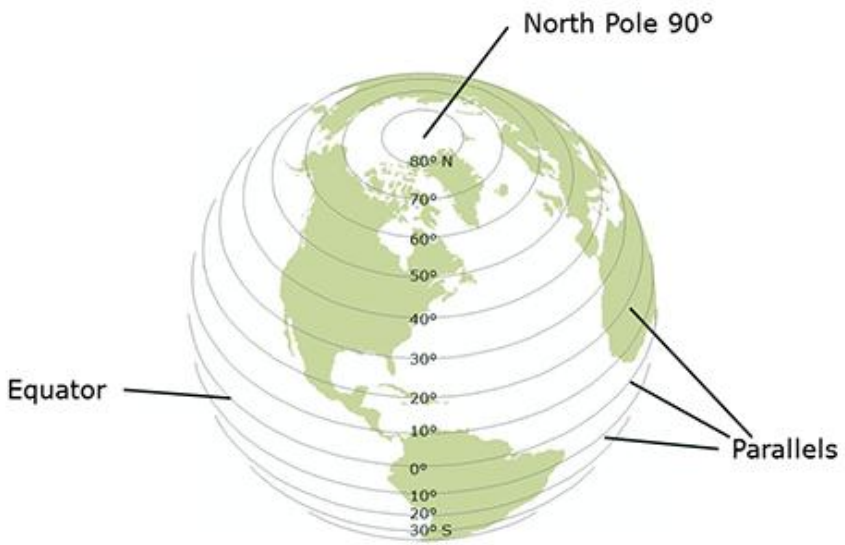

Figure 6 Example of Latitude

2D Coordinate Systems

The 2-D Cartesian coordinate can represent many possible locations at many possible scales, and it is so flexible you can even create your own. However, there are two common representations that are widely used in North America, and the world. The first is the State Plane Coordinate System and the second being the Universal Transverse Mercator Coordinate System or UTM system.

State Plane

The state plane coordinate system is a set of 126 geographic zones that cover the United States of America. Each zone is designed specifically for the region of the United States of America that it covers. It is useful because it allows for simple calculations and is reasonably accurate within each zone. In the state plane coordinate system coordinates are always positive inside each zone. The state plane coordinate system can be based off of NAD 27 and NAD 83 datums, and the coordinates are represented and measured in feet.

Each state may have multiple state plane zones but this is not required. Each zone is strategically placed to minimize the amount of error within each zone. Additionally, each zone provides a common coordinate reference for horizontal coordinates over areas such as counties while limiting error to specified maximums. Depending on the shape of the state, the state plane zone can be based on two types of map projections, the Lambert Conformal Conic, or the Transverse Mercator.

Provided below is an illustration of the state plane zones in the 48 lower contiguous states of the United States of America. Notice that most states have multiple zones and that zones typically either run north to south, or east to west. Also note that most of the smaller states, particularly in the New England area, only have one state plane zone covering the entire state, while larger states such as California and Texas, have multiple zones so that

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the error can be minimized throughout the state. A notable exception to this is Montana. It is a large state but only has a single zone. State plane zones are typically designated with the name of the state followed by a section indicator, such as North, Central, and South, or combination of those, or, West, Central, and East. A notable exception is California which specifies each zone using a different number.

Figure 7 Example of State Plane Zones

Universal Transverse Mercator Coordinate System UTMCS

The Universal Transverse Mercator Coordinate System (UTMCS) is a worldwide 2-D coordinate system that splits the world into 60 zones. The Universal Transverse Mercator Coordinate System is useful because it provides for simple calculations and manages error within each zone. Unlike the state plane coordinate system which is measured in feet, the universal transverse Mercator coordinate system is specified and measured in meters.

This is an illustration of the state plane zones covering the world from 80° South 84° north. Note the line running along the equator, which splits as zones into north, and south.

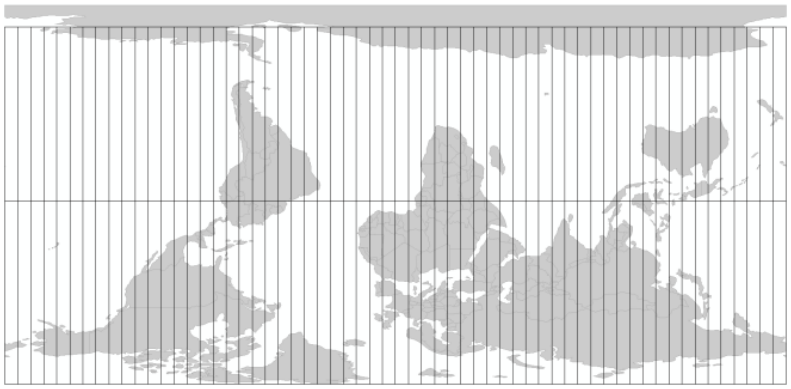

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Figure 8 State Plane Zones at 80°, 84° North

Map Projections

Defined, a map projection is a systematic rendering of locations from the curved earth surface onto a flat map surface. This allows us to flatten the curved surface onto a flat surface such as a piece of paper, or computer screen. The reason why we employ map projections is because globes are not very portable, or practical to use in some cases. Therefore we use map projections to flatten the earth into a map.

Figure 9 is a basic illustration displays the concept of a map projection. The map projection is broadly composed of three parts, the ellipsoid, which models the shape of the earth, a light source which is used to project features on the earth surface, and a developable surface commonly a flat piece of paper onto which the Earth's features are projected, and flattened to be used as a map.

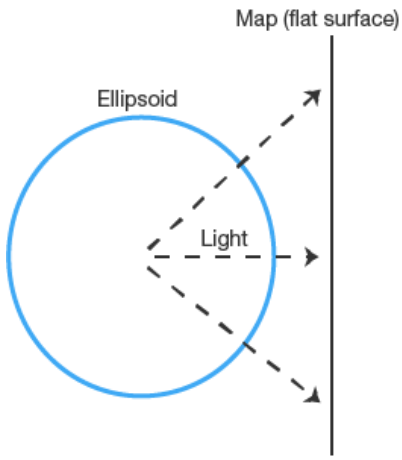

Figure 9 Basic Example of Map Projection

Developable Surfaces

A developable surface is a geometric surface on which the curved surface of the earth is projected; the end result being what we know as a map. Geometric forms that are commonly used as developable surfaces are planes, cylinders, cones, and mathematical surfaces.

No matter which developable surface is used to create a map the basic idea remains the same. The features of the curved earth are projected onto one of the four geometric forms to produce a flat map.

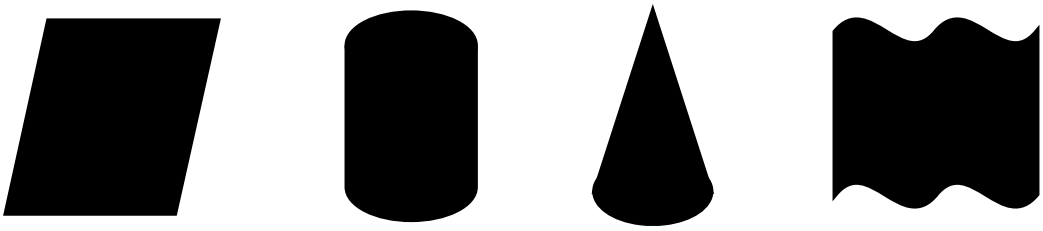

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Figure 10 (left to right) Examples of Plane, Cylinder, Cone, and Mathematical

The way in which an ellipsoid and developable surface interacts with each other is to place the ellipsoid in different locations and different rotations is to gain a desired view at map properties. In the Figure 11 illustration the blue circle is an ellipsoid representing the earth. The triangle represents a cone although we are representing it in 2-D. The idea is that the developable surface can be placed on top of the ellipsoid as a hat, or pulled down through the surface of the earth, and even rotated side to side, or forwards and backwards to create the desired view that we are looking for in a flat map.

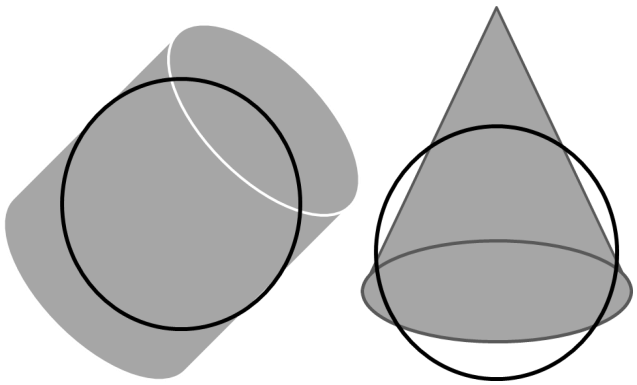

Figure 11 Developable Surface Examples

Interaction

These developable surfaces will interact in a few different ways with the ellipsoid. Generally, the developable surfaces will touch the ellipsoid in either two places which creates two secant lines or at a single location and creates a single tangent line. In the illustration shown the tangent line is touching the ellipsoid of the South Pole which should give us a polar view of the earth.

The secant intersection is intersecting the earth at two locations which provides us with an abnormal view of the northern portion of the ellipsoid. Both types of interactions are correct as they depend on the purpose of the map and the way in which we want to portray the earth on a flat map.

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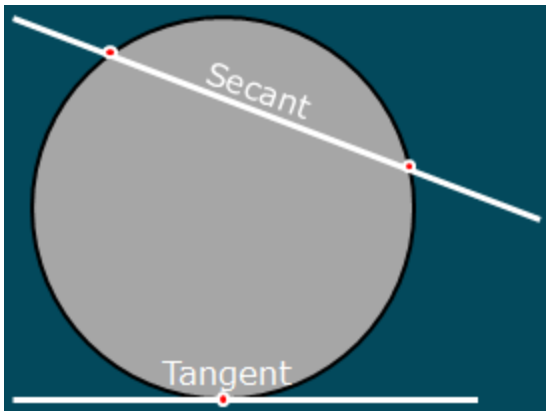

Figure 12 Two secant lines, one point or tangent line

To further illustrate the idea of a tangent and secant intersection, two more illustrations are provided. For the tangent interaction there is a line that can be drawn around the earth at its widest point that is perpendicular to the point tangents. This is known as the tangent line. For secant interactions two lines are drawn following the earth's curvature between the secant intersection points.

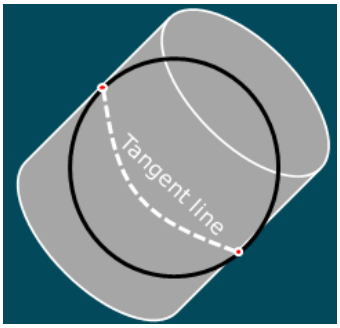

Figure 13 Tangent Interaction

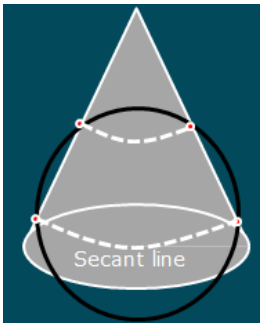

Figure 14 Secant Interaction

Map Projection Parameters

There are five map projection parameters that are going to be discussed in this section. They are: standard points and lines, projection aspect, central Meridian, latitude of origin, and light source location. Together these five map projection properties allow an individual to selectively display and distort the earth to create a map that is suitable based on need. The lesson will start with standard points and lines and continue on with details covering each of the additional four map projection parameters.

Standard Points and Lines

Defined, a standard point and line is a point or line of intersection between the developable surface and the spheroid or ellipsoid. In the case of a secant intersection, there will be two standard lines that would define where the developable surface intersects with the spheroid.

If the developable surface happens to intersect the spheroid along a line of latitude it is known as a standard parallel. Additionally if a standard line falls on a line of longitude exactly it is known as a standard Meridian. When defining a map projection you must define

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the standard points and lines. It is not uncommon to have a map projection follow a standard parallel or standard Meridian.

In this illustration the cone is in a normal aspect and with the secant intersection, the secant intersecting lines follow parallels. Therefore they are both known as standard parallels.

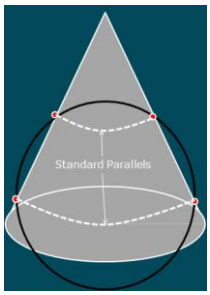

Figure 15 Standard Parallels

Importance of Standard Points and Lines

The reasons why standard points and lines are important are because the corresponding places act or along the standard point to lines will have no scale distortion. That means that where the developable surface intersects with the spheroid there is little to no distortion on our flat map. The further away from the standard point or lines the greater the distortion or deformation that will occur on the map. Secant intersection between the developable surface and the spheroid can help minimize distortion over a large area by providing more control than a tangent intersection at a single point or line. Therefore placement of standard points and lines is one of the most important parameters to consider when defining a map projection.

Project Aspect

The next projection parameter to discuss is the projection aspect. A projection aspect is the position of the projected graticule relative to ordinary position of the geographic grid on earth. What that means is that if the developable surface's vertical axis coincides with the vertical axis of the earth this defines a normal aspect. Should the vertical axis of the developable surface differ from the vertical axis of the earth this would be an abnormal aspect. Figure 16 displays the normal axis of the globe, which runs from the North Pole through the center of the Earth to the South Pole.

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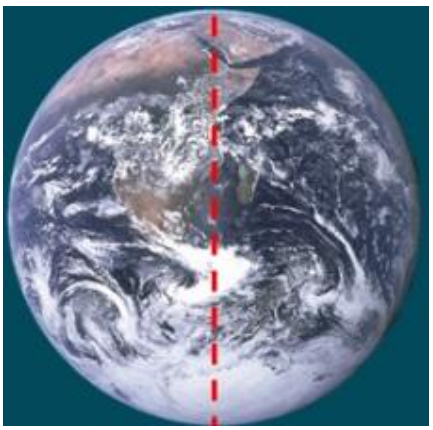

Figure 16 Globe Normal Axis

Figure 17 shows a cone developable surface at a secant intersection with the earth. The vertical axis of the cone, displayed as a blue line, coincides with the vertical axis of the earth displayed as a red dotted line which is considered a normal aspect.

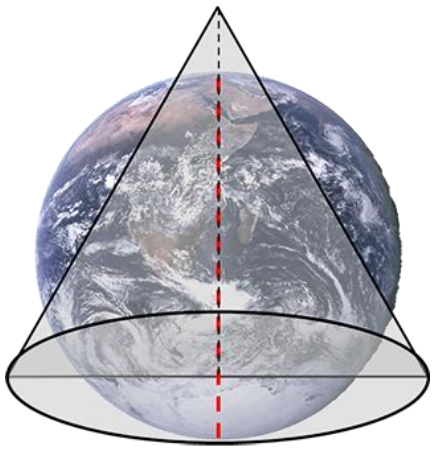

Figure 17 Normal Aspect

Figure 18 is an illustration that shows a non-aspect. Note that the vertical axis of the cone does not coincide with the vertical axis of the earth thus creating a non-aspect.

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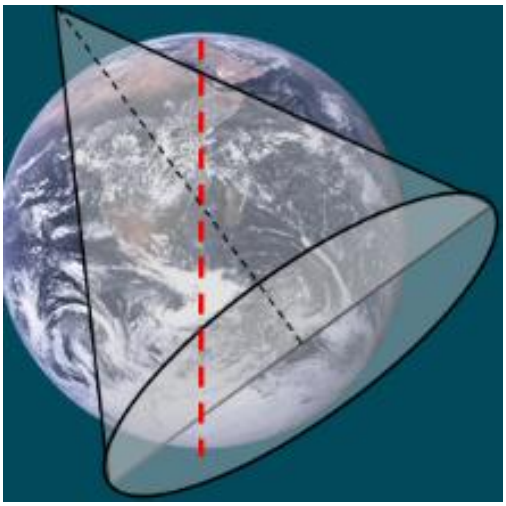

Figure 18 Non-Normal Aspect

Central Meridian

The next projection parameter to discuss is the Central Meridian. The Central Meridian defines the center point of the projection. That means that this is the Meridian, or longitude line, that displays in the center of the map. Essentially this allows you to rotate the earth about the vertical axis to determine what portion of the earth you want to have in the center of the map.

Latitude of Origin

Related to the Central Meridian is latitude of origin. Latitude of origin is the latitude that defines the center of the projection. That means that this is the latitude that will be in the center of the map projection. Changing the latitude of origin moves the projection about the horizontal axis to determine which portion of the earth will be shown in the middle the map.

Light Source Location

The light source location map projection parameter is the location of the hypothetical light source in reference to the globe being projected. Remember that there are three parts of a map projection: ellipsoid, the light source, and the developable surface. The light source is what projects the surface of the earth onto the developable surface and there are three primary positions in which we can place the light source.

The three primary positions of light sources are gnomonic, stereographic, and orthographic.

Gnomonic

In the gnomonic light source position the light source is placed at the center, or core, of the earth. The light is then projected through the earth's surface and projects the landmasses onto the developable surface. In the illustration, the earth is the bottom circle, the lines are the light source, and the solid white line is the developable surface, in this case a plane. The top circle and the dotted lines represent where the earth will be compressed, or stretched, based on the position of the light source. In the case of the gnomonic light source, looking

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at a polar projection, locations at the center of the earth are held closer to true. However the locations towards the extremities are elongated as they are stretched out to meet the developable surface.

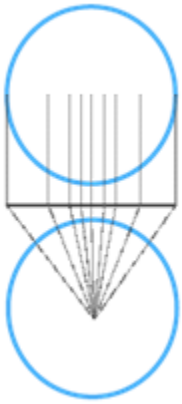

Figure 19: Gnomonic Light Source

Stereographic

In the stereographic projection the light sources are placed at the opposite side of the earth from where the developable surface has its secant or tangent intersection. In this case we see a less severe differential between where the earth is compressed and elongated, but no location is clearly free from distortion.

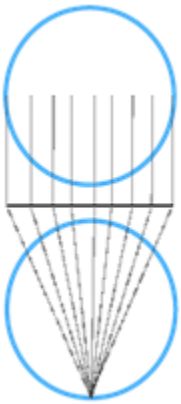

Figure 20: Stereographic

Orthographic

In the orthographic position the light is placed at a theoretical infinite distance from Earth opposite from the point of intersection or tangency. This allows formidable distortion in the center the projection however there is significant compression at the extremities of the map.

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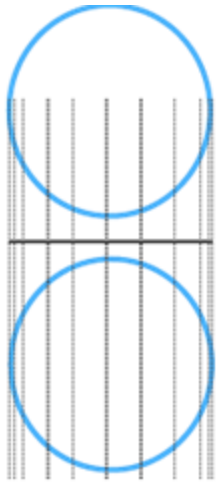

Figure 21: Orthographic

Great Circle

A great circle is a circle that results when a plane intersects the earth going through the center effectively dividing the earth into two equal parts. Based on this definition, all meridians and the equator are considered to be great circles as they all divide the earth into two equal halves. An arc segment of a great circle is the shortest path between two points on a spherical surface. Therefore, to determine the shortest distance between two points on earth you would first construct a great circle and then calculate the distance along that segment.

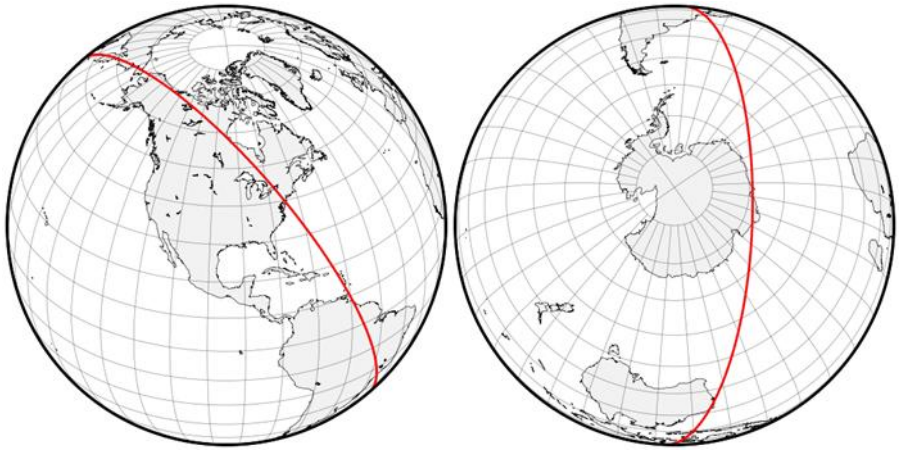

Figure 22 Examples: Great Circle

Small Circle

A small circle is a circle the results when a plane intersects the earth but does not go through the center effectively dividing the earth into two equal parts. Based on this definition of a small circle, all parallels, except the equator, and other lines that do not pass

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through the center of the earth are small circles. A small circle is not the shortest distance between two points on the spherical surface even though it may appear to be.

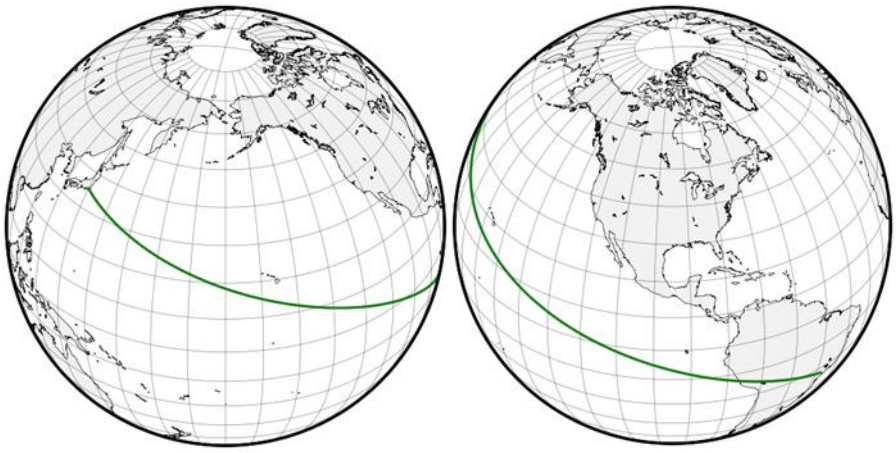

Figure 23 Small Circle

Rhumb Line

A Rhumb Line is a curve that crosses each Meridian at the same angle. This is also known as a loxodrome. Rhumb lines are useful because they are easier for navigation because a rhumb line follows a constant bearing or azimuth. While the Rhumb line is easy to use for navigation it does require that you follow a longer distance in the shortest possible distance which would be a great circle.

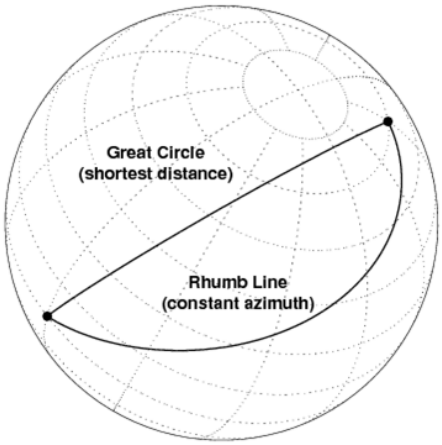

Figure 24 Rhumb Line

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Importance of Great and Small Circles

There are three important reasons that you should know about circles. First, on an azimuthal projection all lines drawn through or to the center of the projection are great circles. Second, on an azimuthal projection all lines not drawn to the center are considered small circles. And third on a gnomonic azimuthal projection all lines drawn are great circles.

These three points illustrate that even though the map user may draw a straight line on a map projection, it may not represent the shortest distance between two points. Therefore it is important that you consider how different map projections portray small and big circles and what implications that will have for your map user.

Map Projection Families

The azimuthal map projection family, also known as the Planar or Zenithal map projection family is when a spheroid is projected onto a flat plane. Based on this interaction between the spheroid and a developable surface we see deformation outward a series of concentric bands from the center. The azimuthal family of map projections is commonly used to display larger scale maps and Polar Regions of the earth. The azimuthal map projection family has three aspects: polar, which is considered the normal aspect, oblique, and equatorial. Figure 22 is an illustration of an azimuthal map projection with a polar aspect. The plane's pointed tangency is the North Pole, and the earth is then unfolded onto the plane which causes deformation in a radial pattern way from the North Pole.

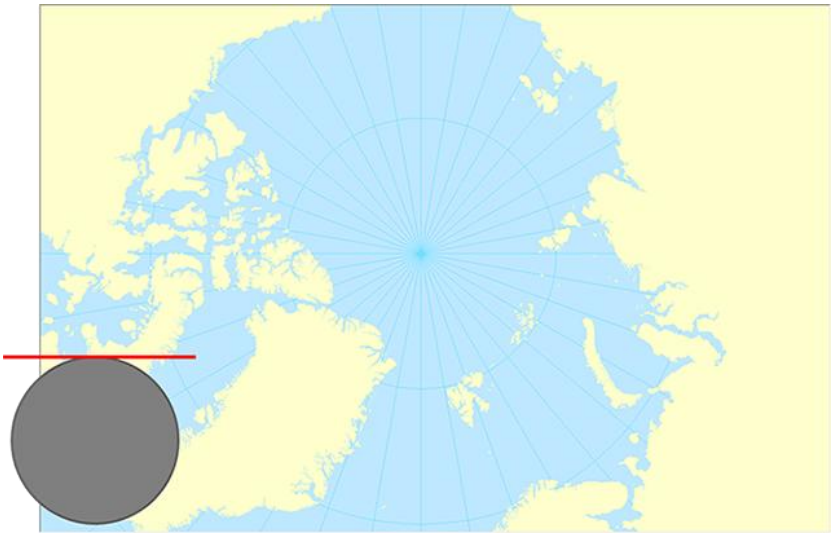

Figure 25 Polar Aspect

Figure 26 is an illustration of an azimuthal map projection with an oblique aspect along the mid-latitudes of earth centered over Europe. Here, the developable surface's pointed tangency is centered over Europe, and the earth is folded out onto the plane.

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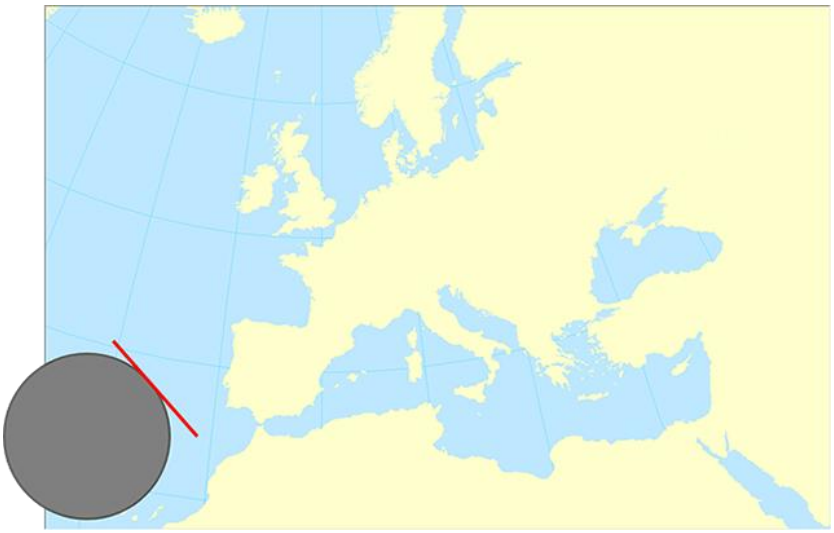

Figure 26 Oblique Aspect (Mid-Latitudes)

Figure 27 is an illustration of an azimuthal map projection within equatorial aspect. The developable surface's pointed tangency is on the equator.

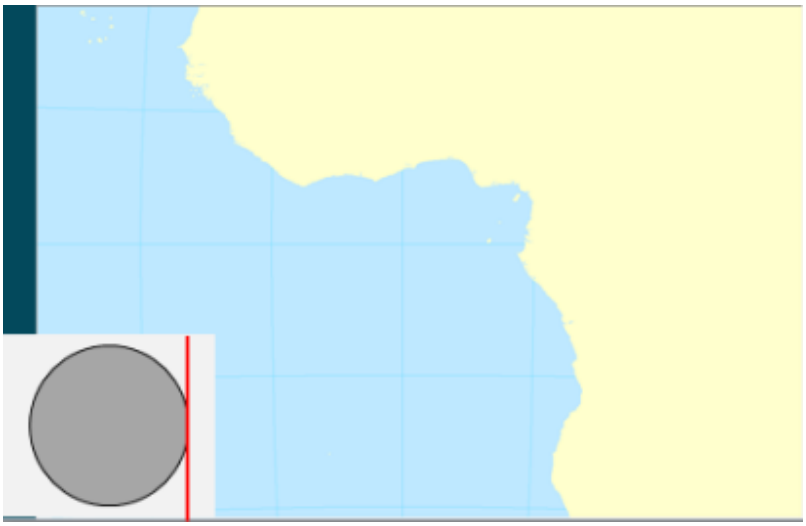

Figure 27 Equatorial

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Cylindrical Family

The second map projection family we will discuss is the cylindrical family. The cylindrical family projects the spheroid onto a cylinder. The spheroid is deformed and increasing bands of exaggeration towards the outer edges of the map plane. The cylindrical map projection family is commonly used to display the entire world, or medium and large scale mapping. One unique characteristic of the cylindrical family is that all parallels and meridians intersect at 90° angles. Figure 28 is an illustration of the Miller cylindrical projection. In this projection, the center of the cylinder touches the equator.

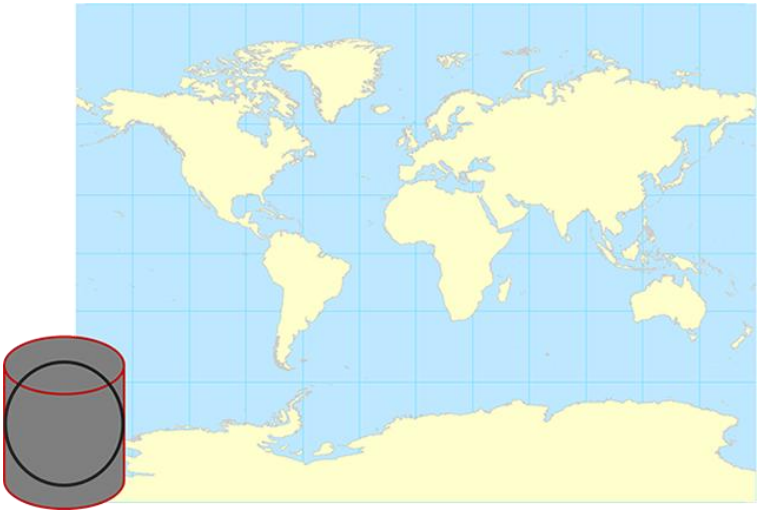

Figure 28 Miller Cylindrical Projection

Cylindrical Aspects

There are three cylindrical aspects: equatorial, just consider this the normal aspect, transverse, which is also known as the polar aspect, and the oblique aspect. Figure 29 is an illustration of the equatorial aspect for the cylindrical family of map projections. For this aspect, the line of tangency follows the equator.

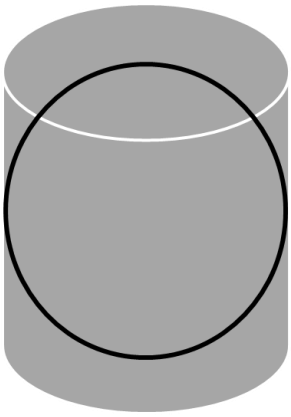

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Figure 29 Equatorial (normal)

In Figure 30 you can see the transverse, or polar, aspect for the cylindrical projection. In the case of the transverse aspect, the cylinder can have a single line of tangency following a Meridian from North to South Pole, or a secant intersection for the cylinder is still centered over the pole.

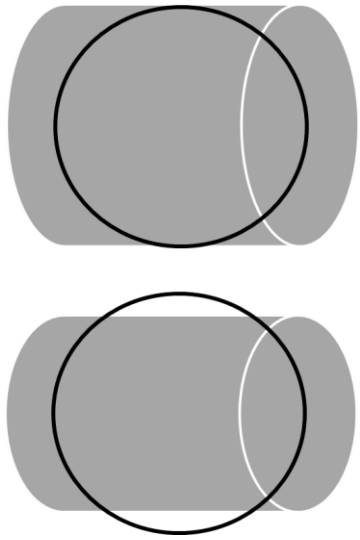

Figure 30 Transverse (polar)

In the oblique aspect, shown in Figure 31, the line or lines of intersection between the developable surface and the spheroid touch the Earth between the equator and the poles.

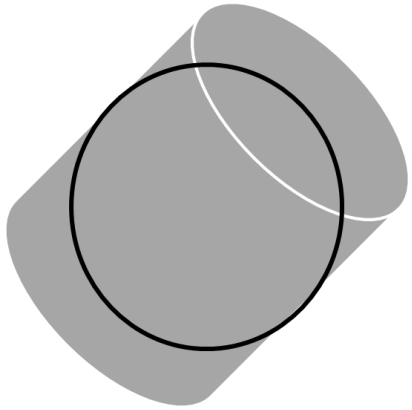

Figure 31 Oblique

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Conic Family

The third map projection family is the conic family. In the conic family the developable surface is a cone onto which the spheroid is projected. We see deformation and concentric bands parallel to the standard parallels of the map projection. The conic family is commonly used to display areas of earth having a greater east-west extent. Figure 32 is an illustration that shows how the cone developable surface interacts with the spheroid. In this case, the cone is pushed through the surface of the earth so that it has two secant lines of intersection. The lines of intersection follow parallels which reduce distortion in the east-west direction.

Figure 32 Conic Projection

With respect to aspects, the conic map projection family is typically presented in the normal aspect where the axis of the cone is in line with the axis of the spheroid as shown in Figure 33.

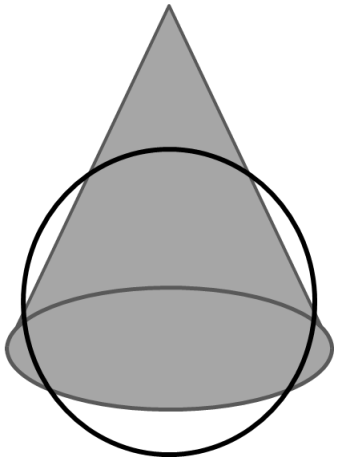

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Figure 33 Conic Aspects

Mathematical Family

The final map projection family we will discuss is the mathematical family. To create a map projection of the mathematical family the spheroid is projected onto a mathematical surface that is not a cone, plane, or cylinder. Deformation can vary quite widely depending on the shape of the developable surface.

Additionally, since the developable surfaces in this mathematical family can vary so greatly, there is no common map purpose that is used with the mathematical family of map projections. In some cases developable surfaces in the mathematical family of map projections may resemble cylinders, cones, or planes that have been slightly deformed or warped for a specific need. In these cases the developable surfaces may be referred to as pseudo-cylindrical, pseudo-conic, or pseudo-azimuthal.

Figure 34 Sinusoidal

Figure 35 Hammer-Aitoff

Map Projection Properties

A map projection property is an alteration of area, shape, distance, and direction on a map projection. These map projection properties exist because the conversion from a three dimensional object, such as the earth, to a two-dimensional representation, such as a flat paper map, requires the deformation of the three-dimensional object to fit onto a flat map. The three-dimensional spherical surface is torn, sheared, or compressed to flatten it onto a flat developable surface.

Four Map Projection Properties

These map projection properties are area, shape, distance, and direction. These four map projection properties described for facets of a map projection that can either be held true, or be distorted.

Area and Shape

Area and shape are considered major properties and are mutually exclusive. That means, that if area is held to its true form on a map, shape must be distorted, and vice versa.

Distance and Direction

Distance and direction, on the other hand, are minor properties and can coexist with any of the other projection properties. However, distance and direction cannot be true everywhere on a map.

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Equal Area Map Projection

The equal area map projection, also known as the equivalent map projection, aims to preserve the area relationships of all parts of the globe. You can easily identify most equal area map projections by noting that the meridians and parallels are not at right angles to each other. Additionally, distance distortion is often present on equal area map projections and the shape is often skewed.

Even with the distortion of distance and shape, equal area map projection is useful for general quantitative thematic maps when it is desirable to retain area properties. This is especially useful for choropleth maps, when the attribute is normalized by area. Holding area properties to be true allows for an apple to apple comparison of density between different enumeration units such as counties. Two types of equal area map projections include: Cylindrical Equal Area and Hammer-Aitoff.

Cylindrical Equal Area

The cylindrical equal area map projection is an example of an equal area, or equivalent map projection, which aims to keep the areal relationships of all parts of the globe correct.

Figure 36 Cylindrical Equal Area

Hammer-Aitoff

A second example of an equal area projection is the Hammer-Aitoff map projection. Again, like the cylindrical equal area projection, this map projection aims to hold areas true. Also note that on this map projection, the parallels and meridians do not intersect at 90° angles, which is a hint that lets us know that this may be an equal area projection.

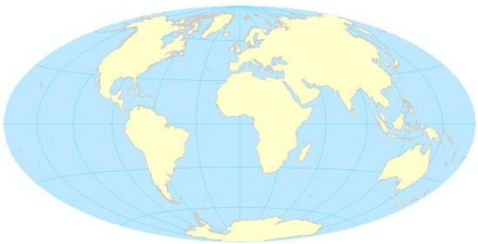

Figure 37 Hammer-Aitoff

Conformal Map Projections

Conformal map projections, also known as orthomorphic map projection, preserves angles around points and shapes of small areas. Additionally it allows for the same scale in all directions to or from a single point on the map. Conformal map projections can usually be

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identified by the fact that meridians intersect parallels at right angles, areas are distorted significantly, its' small scales, and the shapes of large regions may be severely distorted. Even with the potential for large shape distortion conformal map projections are useful for large scale mapping and phenomena with circular radial patterns such as radio broadcasts for average wind directions.

The Mercator projection, perhaps the most famous of all map projections, is a conformal map projection that preserves shape. However notice the massive amount of distortion in the lower latitudes towards the South Pole and the northern latitudes near the North Pole. Also note that the parallels and meridians intersect at 90° angles.

Figure 38 Conformal Map Projections

Equidistant Map Projection

The third map projection family is the equidistant map projection which aims to preserve great circle distances. That means a distance can be held true from one point to all other points or from a few select points to others but not from all points to all other points. It is also important to note the scale is uniform along these lines a true distance from the select points on the map. Identifying marks of the equidistant map projection are that they are neither conformal nor equal area, and look less distorted. Equidistant map projections are useful for general purpose maps and Atlas maps.

An example of an equidistant map projection is this equidistant cylindrical map projection. Notice that compared to the conformal map projection there is less distortion at the North and South Poles, and the shapes do not look overly distorted.

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Figure 39 Equidistant Cylindrical

Azimuthal Map Projection

The azimuthal map projection, also known as the true direction map projection, preserves direction from one point to all other points in the map. It is important to note that direction is not true between non-central points. Direction is only true when measured to or from the specific points chosen to have true direction. Azimuthal map projection is most useful for preserving direction two or one from point, often used for navigation.

The azimuthal equidistant map projection is an example of a true direction map projection that also holds distance to be true. While not all azimuthal map projections look like this, this particular map projection allows you to measure across the poles and around the world to determine true distance and direction from a single point.

Figure 40 Azimuthal Equidistant

Combined Map Projections

As seen on a few example map projections previously we can combine map projection properties onto a single projection. For example an equal area map projection can also combine parts of it azimuthal map projection. Conformal can combine with azimuthal, equidistant can combine with azimuthal, and azimuthal can combine with equal area, conformal, and/or equidistant.

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Note: Yes denotes map projections can be combined. No denotes that map projections cannot be combined.

	Equal Area	Conformal	Equidistant	Azimuthal
Equal Area	--	**No**	**No**	**Yes**
Conformal	**No**	--	**No**	**Yes**
Equidistant	**No**	**No**	--	**Yes**
Azimuthal	**Yes**	**Yes**	**Yes**	--

Compromise Map Projection

There is another map projection family that does not try to hold a single map projection property true. This map projection family is known as the minimum error, or compromise map projection. The goal of the compromise map projection is to simultaneously minimize all for map projection properties, but may not hold any of the four map projection properties as true. The compromise map projection is useful for general geographic cartography.

Robinson Map Projection

An example of a compromise map projection is the Robinson map projection. It does not greatly distort any of the four map projection properties nor does it hold any of the four properties true. However what is nice about the Robinson map projection is that it does a reasonable job of showing the true shape, distance, direction, and size of the features of the earth.

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Figure 41 Robinson Map

Determining Deformation/Distribution over the Projection

A common method used to determine deformation on a map projection is called Tissot's indicatrix. As we know all flat maps distort shape, area, direction, or length when displaying features of a three-dimensional object such as the earth. Tissot's indicatrix helps to quantify the distortion and projection properties shown on the map projection.

Tissot's indicatrix is composed of infinitely small circles centered at points on the earth. The earth is then projected onto a map using a map projection and we consider the shape of the circles after projecting the map to determine the deformation and distribution of error throughout the map.

To gain a better understanding of of Tissot's indicatrix look at the image with five map projections. Remember that the circles were all originally the same size and were perfect circles. We will interpret Tissot's indicatrix by seeing what happens to the circles when the earth is projected.

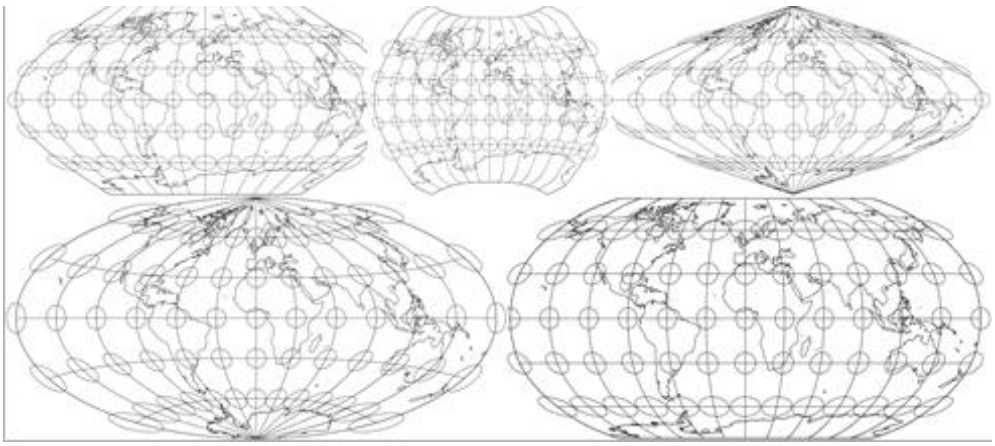

Figure 42 Tissot's Indicatrix

Interpreting Tissot's Indicatrix

As you learn how to interpret Tissot's indicatrix consider how the circles change on an equal area and conformal map projection. On an equal area map projection the circles will be

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transformed into ellipses but the area of the ellipses will be the same as the area of the original circles. That means although they will change shape they will not change in size. On a conformal map projection the circles will continue to be perfect circles but their size will vary over the map.

Conformal Projection Property

Here are a few common map projections so you can see how Tissot's indicatrix performs. Figure 40 is a Mercator map projection which is a conformal map projection the perfect circles would continue to remain circular however they will be larger or smaller than the original circle size. This is due to fact that the conformal map projection property keeps shape true but must distort size as shape and size are two major map projection properties, and are mutually exclusive.

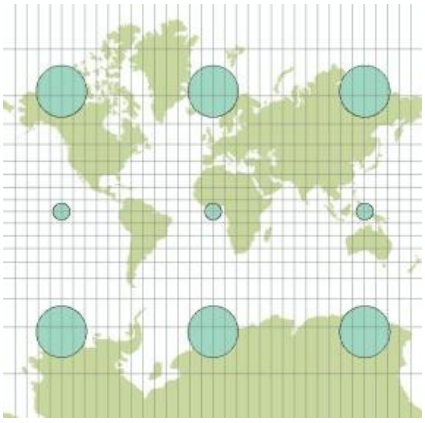

Figure 43 Mercator Map Projection

Equal Area Projection Property

Consider the flat polar quartic projection and how Tissot's indicatrix performs on it. As the flat polar quartic projection is an equal area projection circles will not have the same shape as a perfect circle; however, they will have the same area as the original circle. As we see on this map projection the circles roughly have the same size although we are still seeing some areal distortion towards the North and South Poles.

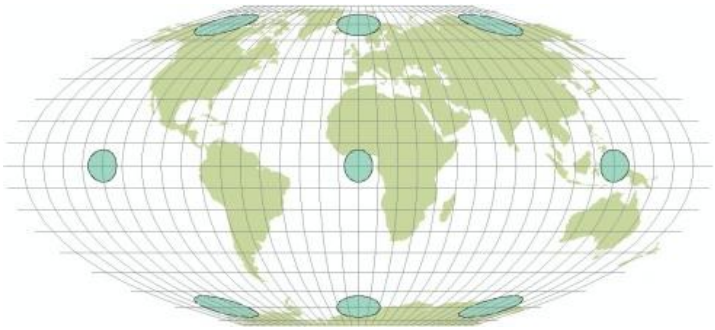

Figure 44 Flat Polar Quartic Projection

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Equidistant Map Projection

On an equidistant map projection such as the equidistant cylindrical projection, where distances are true between two points, the circles are formed into different shapes throughout the map projection. This tells us that this map projection distorts both shape, and size, however, we are not able to immediately tell that this is an equidistant map projection based solely on the size and shape of the circles.

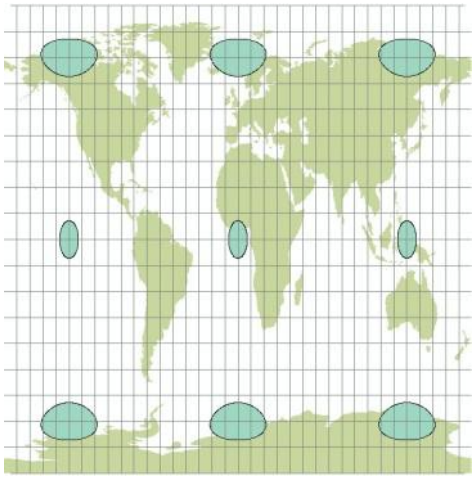

Figure 45 Equidistant Cylindrical Projection

Aphylactic Map Projection

On an aphylactic map projection, which is another way of referring to a compromise map projection, we do not have perfect circles anywhere on the map; however, the distortion is not severe anywhere on the map. Again this is because the aphylactic map projection distorts all four properties but no one property is distorted much greater than the other.

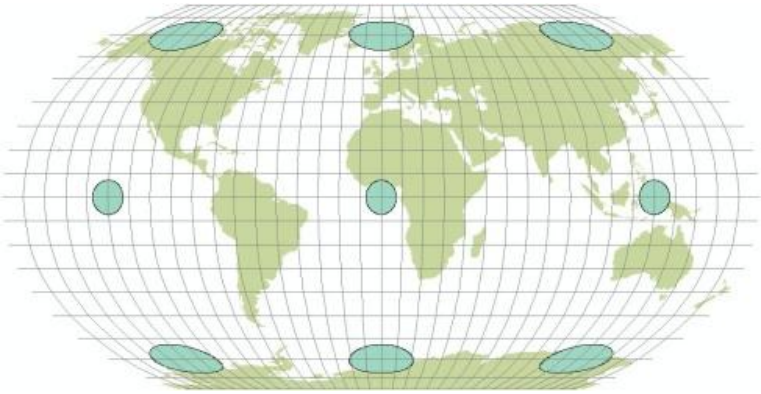

Figure 46 Robinson Projection

Map Projection Types

In order to choose the optimal map projection for your map there are many things that you must consider.

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1. **Projection Properties:** You must consider the projection properties and whether those properties are compatible with the purpose of your map. For instance, if you want users to compare density across the globe you would want to choose an equal area map projection so that areas are kept true allowing users to do a true comparison with respect to density.

2. **Deformational Patterns:** You also need to consider the deformation patterns of the map projections. Some spatial phenomena are better represented using certain deformation patterns.

3. **Projection Center:** You will need to consider where you wish to center the projection. Typically you center the projection over the area that is of interest to the map user.

4. **Familiarity:** You should also consider how familiar your map users are to the map projection. Depending on your audience they may have a preconceived notion of what a map looks like. Then if you show them a complex mathematical map projection it may confuse the user too much and they may not be able to utilize your map to its fullest.

5. **Software Support:** You should consider software support if you are making a virtual map. Not all GIS and mapping software support the same map projections; therefore, if you are sharing your produced map you should make sure that the recipient has access to software that supports the same map projection of your map. If your map is part of a larger map series then the map projection you choose for your map should allow the map to have the same look and feel of the other maps for continuity and ease of use.

Note: The rest of this lesson will discuss broad recommendations for what types of map projections you should use for particular situations. The discussion will not be exhaustive, nor must it be followed exactly. It is a good exercise and is often expected for a cartographer to render the map using many different map projections including changing properties to suit their needs before choosing the final map projection.

Recommended Map Projections for World Projections: Equivalent

Equivalent map projections are recommended for world projections. Review the following types of equivalent map projections to become familiar with what their map projections entail.

Mollweide

The Mollweide map projections are useful for mapping world distributions as it does a good job of keeping relative sizes in check about the equator and mid-latitudes, however does distort greatly at the poles as can be seen with Tissot's indicatrix.

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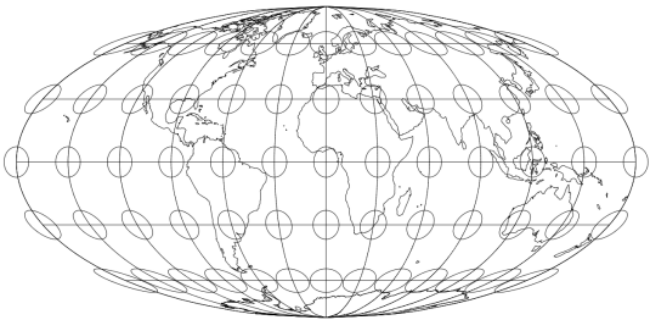

Figure 47 Mollweide

Sinusoid

The sinusoid all map projection is also useful for mapping world distributions. Like the Mollweide map projection it too does a reasonable job of keeping relative size intact around the center of the map and between the middle latitudes. However, as you approach the extremities of the map, distortion becomes quite great.

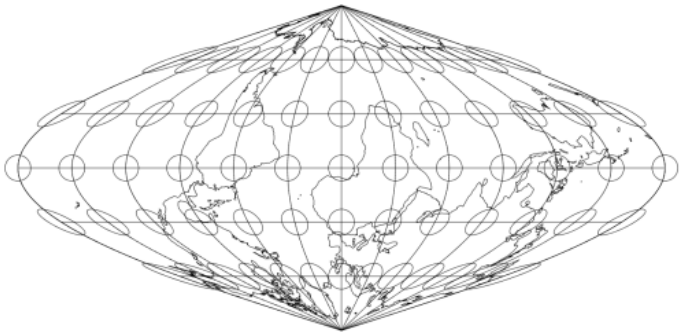

Figure 48 Sinusoid

(Aitoff-) Hammer

The Aitoff-Hammer map projection is useful for mapping world distributions and excels at reducing the shape distortion at the extremities. The trade-off is that it does not hold the shape as well across the entire projection as the previous two map projections.

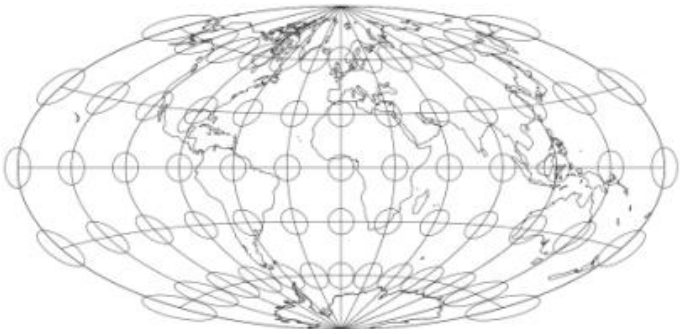

Figure 49 (Aitoff-) Hammer

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Goode's Homolosine

The Goode's Homolosine map projection is interesting because it is an interrupted map projection that maximizes distortion over bodies of water and minimizes distortion over landmasses. One of the most negative aspects of using a good small sign map projection is that it is unfamiliar to many users and may confuse them.

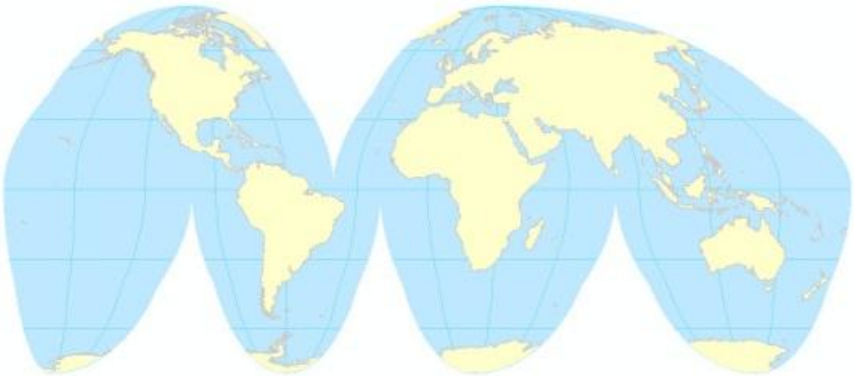

Figure 50 Goode's Homolosine

Recommended Map Projections for World Projections: Minimum Error

Minimum error map projections are also recommended for world projections. This section will focus on the various types of minimum error map projections.

Robinson

The Robinson map projection is a good choice for mapping the world. It does a reasonably good job of maintaining equal area and equal shape across the earth but it does distort once you reach the extremities especially at the North and South Pole.

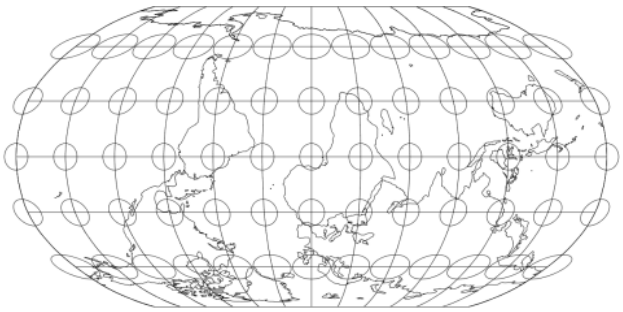

Figure 51 Robinson

Winkel Tripel

The Winkle Tripel map projection is another good minimum error map projection choice when you want to map the entire world. Some consider this to be the best compromise map projection yet for world projections as it does a reasonably good job of minimizing distortion across the entire globe without any one area being distorted significantly more than other areas.

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Figure 52 Winkel Tripel

Cylindrical

Cylindrical map projections are recognized as a recommended map projection type for world projections. Cylindrical maps are popular and commonly used although these map projections are not appropriate when mapping the entire Earth.

Mercator

The Mercator map projection was originally developed for navigation. It is an important and useful map projection because lines of constant bearing are shown as straight lines of a map projection. The downside is there is extreme distortion at high latitudes which unfortunately has imbued a massively distorted mental map of the world in many people's minds. Figure 53 is an illustration of the Mercator map projection, perhaps the most famous map projection of all. Note the significant distortion as you move north or south away from the equator which causes significant distortion in the northern and southern latitudes.

Figure 53 Mercator

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Gall-Peters

The Gall-Peters projection was made to counteract the Mercator projection. The problem is this projection distorts third world areas thus rendering the map not useful because the shape distortion is simply too great.

Figure 54 Gall-Peters

Map Projections Recommended for Continental Areas

There are two types of map projections that are recommended for Continental areas: Lambert Azimuthal Equal Area, and Bonne.

Lambert Azimuthal

The Lambert Azimuthal equal area map projection is quite versatile as the standard point can be placed anywhere. If you are mapping a hemisphere then the equatorial aspect will be your best choice. For this map projection, distortion is radial. Figure 54 is the Lambert Azimuthal Equal area map projection centered over the North America region of the world.

Figure 55 Lambert Azimuthal Equal Area Map Projection

Bonne

The Bonne map projection is an equal area conical projection. Scale is true at the central Meridian and each parallel. However shape distortion is severe in the northeast and northwest corners of this map projection. This map projection is best for mapping compact areas on one side of the equator.

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Figure 56 Bonne Map Projection

Map Projections for Multiple Size Countries at Mid-Latitudes

There are three types of map projections recommended for multiple size countries at mid-latitudes: Lambert Azimuthal Equal Area, Albers Equal Area Conic, and Lambert Conformal Conic.

Both the Albers Equal Area Conic and Lambert Conformal Conic map projections are great for entities that have a pronounced east-west orientation. Remember that the conic family of map projections in the normal aspect minimizes distortion of the east-west directions. Since the continental United States has a pronounced east-west orientation, the Albers Equal Area Conic map projection is great for mapping the continental United States.

In general, conic projections are adequate for mapping large entities within east-west orientation. As areas being mapped become smaller, selection of a map projection becomes less critical as the curvature of the earth is less of a factor. Review Figures 56-58. Figure 56 is an example of the Lambert Azimuthal Equal Area map projection is great for groups a small countries as well as a single medium-size country. It excels at keeping distortion in check for countries of expand in all directions. Figure 57 is an illustration of the Albers equal area conic map projection. It is similar to the map scratch that is similar to the next map projection. Figure 58 is an example the Lambert Conformal Conic map projection is similar to the previous Albers equal area conic map projection and is also useful for mapping countries at mid-latitudes.

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Figure 57 Lambert Azimuthal Equal Area Map Projection Figure 58 Albers Equal Area Conic Figure 59 Lambert Conformal Conic

Map Projections Recommended for Low Latitudes

There are there types of map projections that are recommended for low latitudes.

- The Lambert azimuthal equal area map projection is great for mapping low latitudes.
- A Cylindrical projection with the standard parallel at the equator is also a good choice.
- The Mercator map projection is great if the focus is on and around the equator.

Projected Coordinate Systems

For zones within the state plane coordinate system each zone uses either the Lambert conformal conic map projection or the transverse Mercator map projection. The only exception is that Alaska uses the oblique Mercator for one of its zones. Since one of the desires of creating the state plane coordinate system was that if you work within a single zone all coordinates are in the first quadrant and positive, the y-axis false origin is typically placed 600,000 m, or 2,000,000 feet, west of the zones central Meridian.

The placement of the x- axis false origin is more arbitrary and may change from zones. You may run into a situation where the area that you are mapping crosses multiple state plane coordinate system zones. There are two common solutions to this problem. One is to use the most central zone if the zones are prominently east-west in orientation. The second option is to choose one north-south zone and adjust the central Meridian to provide a balanced look.

Figure 59 is an illustration of all of the state plane coordinate system zones of the contiguous United States. The zones that have a predominant east-west orientation are mapped using the Lambert conformal conic map projections is that map projection minimizes distortion in the East and West directions. The zones that have a prominent north-south orientation are mapped using the transverse Mercator map projection as that map projection minimizes distortion in the North and South directions.

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Figure 60 State Plane Coordinate System

Universal Transverse Mercator (UTM)

The Universal Transverse Mercator (UTM) coordinate system is generally not as accurate as a state plane coordinate system. This coordinate system uses the transverse Mercator projection with the central Meridian running through the center of each zone. The y-axis false origin is placed 500,000 m west of the zone central Meridian. The x-axis false origin for each zone is at the equator for North Hemisphere and 10,000,000 m south of the equator for the southern hemisphere.

Figure 60 is an illustration showing the universal transverse Mercator map projection. There are 60 zones that start at zone one which is at -180° longitude and heads East 360° around the earth. The zones are split into North and South about the equator.

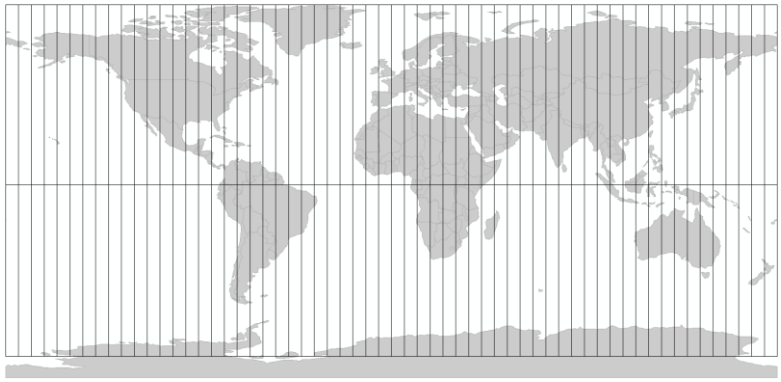

Figure 61 Universal Transverse Mercator Coordinate System

Map Projection Reference Websites

Here are three recommended map projection reference websites.

1. USGS Map Projections Poster: The USGS map projections poster provides illustrations and information about many common map projections, and useful matrices to show when the use of a particular map projection is appropriate.

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2. Radical Cartography Projection Reference: The radical cartography projection reference also shows helpful illustrations, and information about when to use certain map projections.

3. Flex Projector: Flex projector is a free piece of software that allows you to create your own map projections, and export them into projection files for use elsewhere.

SUMMARY

This lesson provided examples and information about Geodesy and Coordinate Systems. The lesson identified the determining factors one should consider when creating map projections, deformation and distribution of the projection, and how to determine which map projection to use for a project.

ASSIGNMENTS

1. Quiz: Geographic Referencing Systems and Map Projections
2. Lab: Exploring Coordinate Systems and Map Projections

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Development was funded by the Department of Labor (DOL) Trade Adjustment Assistance Community College and Career Training (TAACCCT) Grant No. TC-22525-11-60-A-48; The National Information Security, Geospatial Technologies Consortium (NISGTC) is an entity of Collin College of Texas, Bellevue College of Washington, Bunker Hill Community College of Massachusetts, Del Mar College of Texas, Moraine Valley Community College of Illinois, Rio Salado College of Arizona, and Salt Lake Community College of Utah.

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Lesson 3: Map Elements and Design Principles

INTRODUCTION

In this lesson the content will focus on map elements and design principles. The cartographic process will be covered which explains why one would want to create a map and for what purpose. In this process the lesson will identify and explain elements that should be considered and added when creating a quality map. Planar and Hierarchical organization are outlined and to aid in understanding how to organize a map. The lesson concludes with an example map critique which highlights issues and identifies solutions to make the map sound.

LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Identify map elements and design principles.
2. Employ appropriate map elements and design principles for different types of maps and audiences.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz: Map Elements and Design Principles • Lab: Map Elements and Design

INSTRUCTION

The Cartographic Process

The Cartographic process is the process you should follow when you want to go from unmapped data to a map form. The cartographic process is not a rigid processing you need to follow step-by-step, however, it is a recommended set of steps that you should follow in order to properly create a map.

The Cartographic process is composed of five steps. Step one is to define purpose and meaning of the map. Step two is to choose the scale of the map. The third step is to

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determine the map format, printing limitations you may have, and the economics of production and reproduction of the map. Step four is to abstract and generalize the data. And finally step five is the design and the layout of the map.

Once you reach step five you will often need to make changes, evaluate those changes, and possibly start one of the previous steps in the cartographic process. Also note that the cartographic process does not need to be followed in this particular order. Designing a map is often a dynamic and iterative process which requires you to bounce back and forth between steps in order to produce a cartographically sound map. We will now go over each one of the five steps in the cartographic process in more detail.

Step 1: Define Purpose and Meaning

The first step in the cartographic process, define purpose and meaning, means that you should interpret the requirements of the user when you're thinking about the design of the map. You need to answer two important questions.

The first question is "what needs to be communicated?" In order to answer this question you need to make sure you have a thorough understanding of what you want to convey to the map user, who is a map user is going to be, and what you expect the map user to gain from viewing your map.

The second question to answer is "how to best facilitate the communication of ideas?" Once you determine what needs to be communicated you can then determine the best way to communicate that information. Things to think about here are if you're going to make a tangible or virtual map, what category of map you will create, and how you will produce and deliver the map.

Step 2: Choose Scale

The second step in the cartographic process is to choose the scale of the map. Defined, map scale is the ratio of map distance to earth distance. In other words it is the ratio at which the earth has been reduced to fit on the map. Map scale operates along a continuum from large-scale too small scale.

There are no hard rules for exactly what constitutes a large scale, medium scale, or small scale map. Therefore we will present the rules of thumb for determining which category of scale your map falls within. A large scale map is a map it is produced at 1 to 0 all the way through 1 to 600,000. A medium scale map is a method is produced from one to 600,001 through 1 to 2,000,000. A small scale map is a map that is produced from the scale 1 to 2,000,001 through 1 to infinity. A large scale map shows a very small geographic area while a small scale map shows a very large geographic area. While this may seem counterintuitive, we call a large scale map a large scale map because of the relative size of the fraction. For instance the fraction 1/600,000 is a significantly larger number than 1/2,000,000, therefore, the scale 1:600,000 is considered to be a large scale compared to 1:2,000,000.

Because scale is going to have such a bearing on the look of your map, what data will be required, and how much detail you can show on the map, selection of scale is possibly the most important decision a cartographer makes. If you choose the correct scale at the beginning it will make your life quite a bit easier when you run to the iterative cartographic

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process. However, it is common to slightly change the scale as you work through the map design process, but it is best if you try to decide if you are making a small, medium, or large scale map early.

Step 3: Format, Printing, and Economics

The third step in the cartographic process is considering the format, printing, and economics of map production. There are three questions you must answer in this step: The first question is what kind of map will you create a reference or thematic map? If you decide to make a thematic map, what type of thematic map will it be?

The second question to answer is how will the map be displayed? Will the map be printed on 8.5 inch by 11inch piece of paper? Will the map be viewable on a mobile device? Will the map be viewed by a pilot in the cockpit of a helicopter? Answering this question will help determine the options you have for producing the map.

The third question to answer in this step is how much will it cost to create the map? Depending on your format restrictions, whether you are going to use color or not, and many other decisions, these all factor into the cost of creating a map you should check this cost against your budget.

Step 4: Abstract and Generalize

The fourth step in the cartographic process is the abstraction and generalization of data. Once you have determined the purpose, scale, format, and type of map, you then need to determine which data sets are required and how to appropriately abstract and generalize them so that you have a unified look on your map.

Additionally you should only show information on the map that is potentially meaningful to the context. That means you should ignore placing data on the map just because it looks pretty or because you have the data. You should critically analyze every piece of data you place in the map to determine whether it is useful to the map reader and the purpose of the map.

As you were making an abstraction of reality at a reduced scale of the size of the earth you will need to appropriately reduce the amount of detail in the data so that the map will be a simple visual image. Should you use data that is too detailed for the scale of which you are producing the map, the map will appear very busy, cluttered, and will be difficult to use.

Broadly speaking, there are four methods to abstract and generalize data for display on a map.

Selection

The first method is the selection of data. Selection is when you choose a subset of data that you wish to display on the map. For example, if you are showing the roads across the state of Texas you may only want to select the major roads and highways as showing every street in Texas would make the map look like a mass you cannot show that much detail at that scale.

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FID	Shape	STATEFP00	COUNTYFP00	CNTYIDFP00	NAME00	NAMELSAD00	LSAD00	CLASSFP00	MTFCC00	UR00
0	Polygon	48	037	48037	Bowie	Bowie County	06	H1	G4020	M
1	Polygon	48	215	48215	Hidalgo	Hidalgo County	06	H1	G4020	M
2	Polygon	48	295	48295	Lipscomb	Lipscomb County	06	H1	G4020	R
3	Polygon	48	357	48357	Ochiltree	Ochiltree County	06	H1	G4020	M
4	Polygon	48	229	48229	Hudspeth	Hudspeth County	06	H1	G4020	R
5	Polygon	48	121	48121	Denton	Denton County	06	H1	G4020	M
6	Polygon	48	113	48113	Dallas	Dallas County	06	H1	G4020	M
7	Polygon	48	203	48203	Harrison	Harrison County	06	H1	G4020	M
8	Polygon	48	213	48213	Henderson	Henderson County	06	H1	G4020	M
9	Polygon	48	489	48489	Willacy	Willacy County	06	H1	G4020	M
10	Polygon	48	057	48057	Calhoun	Calhoun County	06	H1	G4020	M
11	Polygon	48	495	48495	Winkler	Winkler County	06	H1	G4020	M
12	Polygon	48	129	48129	Donley	Donley County	06	H1	G4020	R
13	Polygon	48	241	48241	Jasper	Jasper County	06	H1	G4020	M
14	Polygon	48	247	48247	Jim Hogg	Jim Hogg County	06	H1	G4020	M
15	Polygon	48	459	48459	Upshur	Upshur County	06	H1	G4020	M
16	Polygon	48	483	48483	Wheeler	Wheeler County	06	H1	G4020	R
17	Polygon	48	463	48463	Uvalde	Uvalde County	06	H1	G4020	M
18	Polygon	48	275	48275	Knox	Knox County	06	H1	G4020	R
19	Polygon	48	269	48269	King	King County	06	H1	G4020	R

Figure 1 Example of Selection of Data

Classification

The second method is classification. Classification is when you combine observations into a larger group or class to simplify the data so that it can be displayed easier on the map.

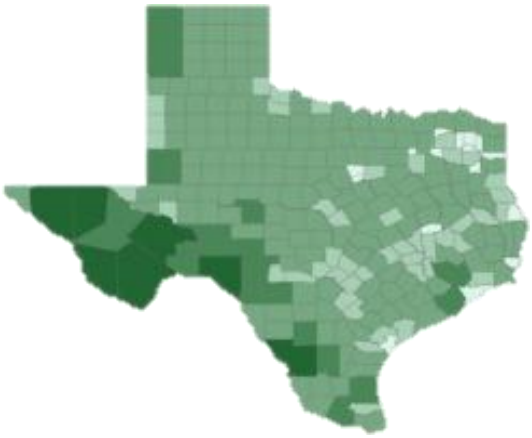

Figure 2 Classification

Simplification

The third method is simplification. If the data you wish to use for your map contains too much geometric detail you should simplify the geometry so that it looks smoother and appropriate for the scale which you are mapping. This can be done manually or through the use of algorithms.

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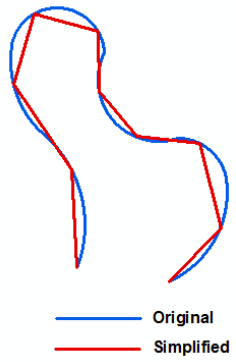

Figure 3 Simplification

Symbolization

The fourth method when abstracting and generalizing is the use of symbolization on the map. Symbolization is when we use representative shapes or pictures to represent items or spatial phenomena.

Figure 4 Symbolization

When choosing symbols for your map, there are a few things that you should keep in mind. The first is to use universally accepted symbols when possible. There is no need to reinvent the wheel and it may only lead to confusing your user. For instance if you want to show the location of an airport on a map, a universal symbol is an airplane. If instead of an airplane you chose to represent an airport terminal this may not be instantly recognizable to the user and will require them to visit the legend unnecessarily.

Second you should make sure that you use discrete and continuous symbols appropriately. This is actually fairly hard to do as continuous symbols are typically represented by rasters or surfaces. To be thorough it is important that discrete objects be displayed as discrete. Third, use universally accepted colors when possible. For example, hospital symbols are typically blue, and parks are typically green. As people are used to seeing these categories of items in these particular colors, if you adopt those color conventions, it will make your map easier to use as things will be more readily identifiable by your map reader.

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Step 5: Design Layout

The fifth step in the cartographic process is designing the maps layout. In this section we will only speak about design layout in general terms, but will soon discuss the map elements and map design principles in more detail.

When designing your map layout the first bit of advice is that you should always experiment with your map design! Rarely should you accept your first design. It is recommended that once you have created one map design you drastically rearrange elements to see if there any other layouts that may work better. Do not be afraid to start over from scratch if a map design is not working for you. Remember that cartography is a creative process that often requires multiple iterations of design.

For each map design you create you should critically evaluate the map for the following. First, you should make sure that in its current design, the map is still suited to the needs of its users and is not overly complicated, or too simplistic in nature. You should also make sure that you have included all relevant information that the map user will need to reference when viewing your map.

Second, the map should be easy to use. If you have included unnecessary detail, placed elements in awkward locations, used nonstandard symbols or colors, among other issues, the map will be difficult to use in your user will get quickly frustrated.

Last, you should always make sure that your map is an accurate representation of reality. You should double check to make sure that you have not included any false information or displayed the data in such a way that the user could easily arrive at an incorrect conclusion.

As you continue to evaluate your map design you should also consider these qualities. The language of the map should relate to elements or qualities represented. This means that the language of the map should not be stating one thing, when the map clearly points toward a contrary position. Both the visual portion and language portion of the map should have a cohesive and consistent message.

You should also consider whether the map is clear, legible, and attractive. This is often harder to determine therefore it is recommended that you show your map design to colleagues, friends, or family to get their opinion and see what they think about the map. Last, you should see if your map will permit interaction with the user and engage the user in a meaningful manner.

You should try to make sure that your map is as interesting as possible and has an important message to convey. If the map is boring, not visually attractive, or does not show any useful information, your map will not be useful to the map user.

Element Considerations

As you create your map design you should aim to design a map that is a functional visual communication device that is visually pleasing and is truthful and accurate. This is quite a tall order, however as you work iteratively through the cartographic process, you will achieve this goal.

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Harmony, Composition, and Clarity

Broadly speaking a cartographically well-designed map will have harmony, composition, and clarity. A map is harmonious with the map elements looking like they belong together which means all map elements have the same feel to them and the same style. No one element looks to be out of place or "pasted on". A well-designed map also has good composition. This speaks to the structural balance of the map. Does the map "feel" off balanced or do the map elements look to be placed very poorly.

Ideally the positioning of the map elements will be in accordance with their importance on the map and will be easy to reference in support of the main map body. Lastly, a well-designed map has clarity. This means that the map reader can instantly recognize elements on the map and can easily recognize and use all the elements you placed around the map for reference.

Map Aesthetics

Wright, in 1942 stated this about map aesthetics. "The quality of a map is also in part an aesthetic matter. Maps should have harmony within themselves. An ugly map, with crude colors, careless line work, and disagreeable, poorly arranged lettering may be intrinsically as accurate as a beautiful map, but it is less likely to inspire confidence." What Wright is alluding to is that in order for map to be effective in the eyes of a map user, the map must not only be accurate, but it must also have harmony, good composition, and clarity.

Map Design and Map Elements

A map is composed of multiple parts known as map elements. Map elements that may be included on the map are a neat line, map body, graticule, insets, title, legend, label, ancillary text, ancillary object, scale bar, directional indicator, and metadata. It is important to note that not all map elements are required for every map. In fact the only map element required to create a map is the map body which is what shows the data.

In the image the map elements are listed from top to bottom. The elements towards the top of the list are larger in size and the elements at the bottom of the list are smaller in size. On a map elements are sized relative to their importance to the map reader. For the rest of the section, we will discuss each map element in detail including its purpose, and design considerations.

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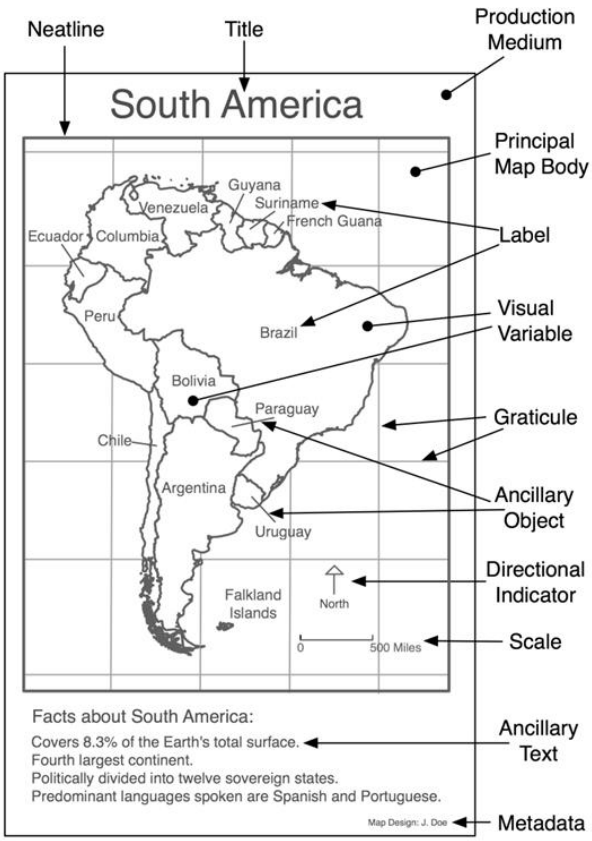

Figure 5 Map Elements

Title

The first map element to discuss is the title. The purpose of the title is to focus attention on the purpose the map; therefore, it is dominant in size and is typically placed at the top of the map and centered. A good map title is brief and will typically include where, what, and when as related to the map's topic. Every map should have a map title, however a common reason not to put a title on the map is if the map is a figure in a larger body of text and in it the map will have a caption. In that case place a map title as the caption text. You should avoid ornate or complex fonts for the map title so that it is easy for the map user to read quickly and with these. You should also use a bounding box around the title if the legibility of the title is decreased due to elements of the map. The following are examples of map titles.

Title Example

Figure 6 is an example of a map with the title "average annual income 2002-2012". This is a good map title as it uses a simple font that discusses the why and the when of the subject matter. The second example is "corn production contiguous United States". This too, is a good map title as it states in a clear font the: what and the where. Perhaps a statement about what time period the map covers would be useful.

The third title example is "traffic patterns in Texas". This map title leaves a little to be desired as it does not tell us important information about the time coverage of a map. As

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traffic patterns often change throughout time and based off of seasons, holidays, or workdays, the map title has a little too much ambiguity. The last title example is "pinball arcade museums". This is a reasonable map title, but perhaps the specification of where the map covers and what time period the map covers would be useful.

Average Annual Income
2002 - 2012

Cotton Production
Contiguous United States

Traffic Patterns in Texas

Pinball Arcade Museums

Figure 6 Examples of Titles

Map Body

The map body map element is the main focus of the map and should be visually dominant in every case. The map body contains the features important to the message of the map. The map body should be made as large as possible on the medium but should also leave room for other map elements and should not crowd the edges so that the map has a little "breathing room". The map body is the only map element that is absolutely required when composing a map. However, the map is often much more useful when other map elements are included. Review Figure 7.

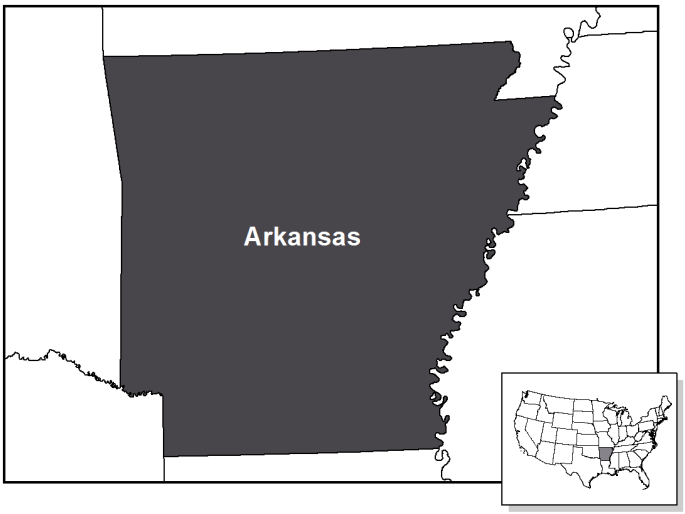

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Figure 7 Map Body Map Element: The lower right hand image is the map of the United States with the state of Arkansas highlighted. The center of the image is a close up image of the map showing only the state of Arkansas and the outlines of the surrounding states.

Map Body Varieties

There are two map body varieties: cropped and floating. Both map body varieties are widely used so it really comes down to preference when designing your map.

Cropped

A cropped map body represents a region of interest within a geographic context and the surrounding area is cut off often by a neat line. Figure 8 illustrates a cropped map showing Arkansas and portions of surrounding states for context.

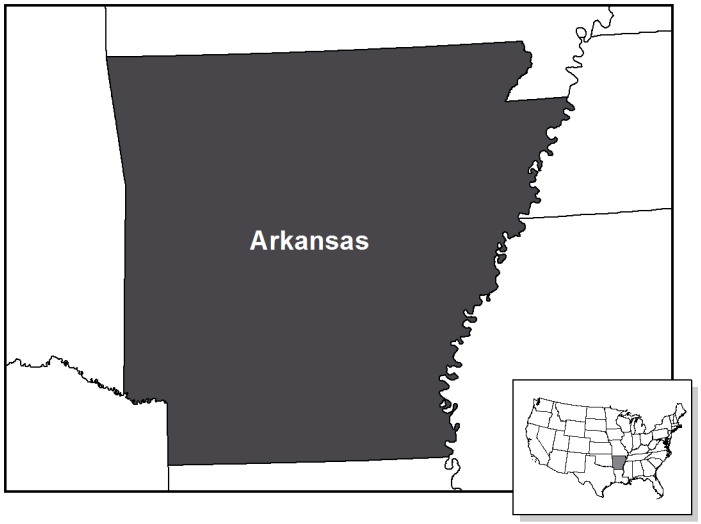

Figure 8 Cropped Map: Map Body Map Element: The lower right hand image is the map of the United States with the state of Arkansas highlighted. The center of the image is a close up image of the map showing only the state of Arkansas and the outlines of the surrounding states.

Floating Map

A floating map body is a region that is disconnected from neighboring regions. This might confuse map readers. However, it is good for opening space up for placement of other map elements. Figure 9 is a floating map that shows the contiguous United States, but does not show oceans, the Gulf of Mexico, or Canada and Mexico which might provide important context.

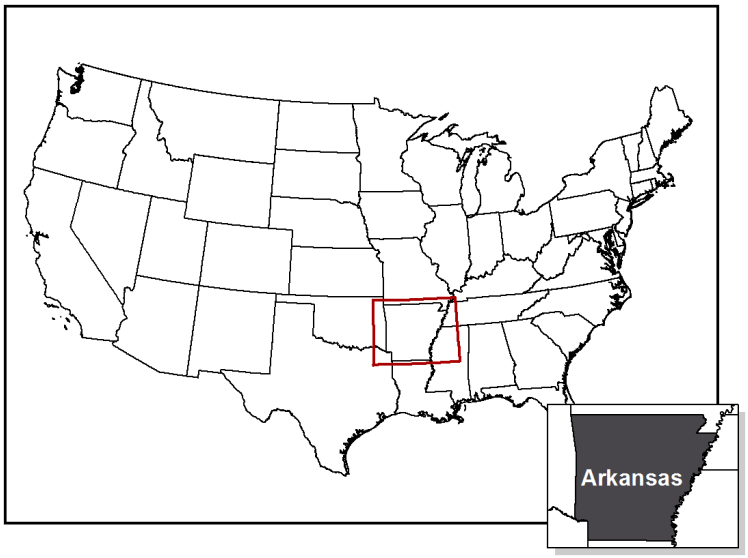

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Figure 9 Floating Map: The center map is of the United States including a red box outline of the state of Arkansas. The lower right hand image is the map of the Arkansas.

Inset Map

An inset map element is a small ancillary map that is typically larger in scale than the map body. The purpose of the inset map is to show more detail in the map body. For instance, it is common to see inset maps of the New England area when looking at a map of the states because there is so much detail that cannot be shown at a map scale that shows the entire United States.

To learn where the inset map is covering, an outline of the extents of the inset map may be shown on the main map body. Another use for an inset map to show other areas related to the primary map body, but at a different scale or location. A common example of this is when showing all 50 states (Figure 10), where Alaska and Hawaii are placed as inset maps. In this case, typically, Alaska is shown at a reduced scale and Hawaii is shown at an enlarged scale.

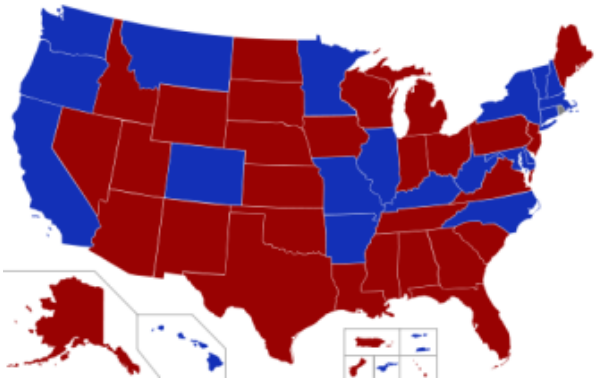

Figure 10 Inset Map

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Location Map

A location map is a small ancillary map that is at a smaller scale than the map body. The purpose of the location map is to identify the location of the main map body in relation to its larger geographic context. You should include location map on your map layout with the area is unfamiliar or non-intuitive to a map reader. For example, review Figure 11.

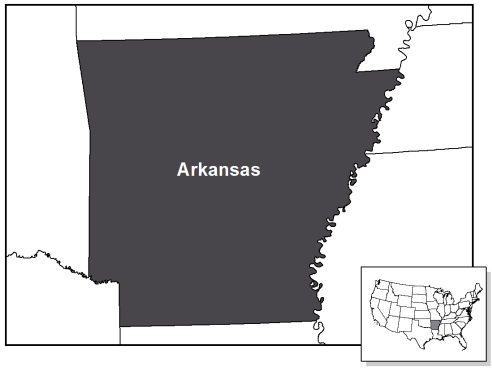

Figure 11 Location Map

Map Scale

The next map element is map scale. The purpose of the map scale is to measure linear relationships and distances on the map. Map scale should use a unit of measure that is appropriate for the audience and its purpose. Additionally, the map scale should be subtle and small. The scale should be noticeable but not stand out too much as map readers are expected to search for the map scale when required.

A map scale is typically included on a reference map as again if you remember, a general reference map does not have any one particular purpose. That means you should prepare for the possibility that the user wishes to measure distances on the map. Some thematic maps do not expect that the map reader will be able to measure meaningful distances on the map; therefore, it is appropriate for the map scale to not be included on some thematic maps.

When choosing and designing a map scale there are a few things you must keep in mind. The first is to use round, meaningful numbers on your map scale. Decimal numbers should be avoided on a map scale unless the decimal number is a meaningful and significant interval that you expect map readers to measure. The map scale should be long enough to be useful, but not too long. There are three types of scales that you can use for a map: graphic, verbal, and representative fraction.

Graphic

The graphic scale uses a graphic element, typically a bar or line, to represent a certain distance on the map. The graphic scale bar is often divided at meaningful intervals to assist the map reader in measuring. The graphic scale should show meaningful round numbers and the unit of measure. A major advantage in using a graphic scale is that if the map is ever enlarged or decreased in size the graphic scale will scale accordingly and will always be correct.

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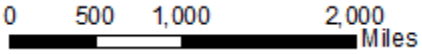

Figure 12 Graphic Scale

Verbal

The second type of scale is the verbal scale. The verbal scale is a sentence that describes the relationship of the distance on the ground to the distance on the map. Again it is important that you relate the ratio which the earth has been reduced in meaningful and appropriate numbers and units. For instance, in the verbal scale example provided, it reads "1 inch on the map equals 20 feet on the ground". Both units of measure are nice round numbers and are included in an appropriate measurement unit. One inch on the map translates to 20 feet of the earth. It would not be useful if you asked the map reader to measure on the map in feet when the map itself is less than 1 foot wide, and it might also be inappropriate to state the distance on the ground as millimeters, for instance, when a small distance of the map represents miles.

Verbal Scale

One inch on the map
equals twenty feet on the ground

Representative Fraction

The third type of scale is the representative fraction scale. In a representative fraction scale two numbers are written separated by a colon. The number of the left of the colon represents the distance measurement map and a number to the right of the colon represents distance measured on the ground. You can have a representative fraction scale without units as they are shown here.

That means that whatever units were used to measure on the map should be the units used to measure on the ground. In our example a representative fraction of 1 to 20 means that if I measure on the map 1 inch, it represents 20 inches on the ground. You can also have representative fractions that use units.

An example of this would be 1 inch to 20 feet. One important issue to note with both the verbal and representative fraction scale is that they do not scale accordingly if the map is enlarged or reduced.

Representative Scale

1:20

Scale Bar

When placing the scale bar on the map layout you should make sure that the scale bar is large enough to be found but small enough to be subtle. Finding the best balance requires experimentation on your map and there is no hard rule. Looking at our example you can see that the top and bottom scale bars are not appropriately sized.

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The top scale bar is quite small and is not really useful to the map user when measuring longer distances. The scale on the bottom is too large and it becomes visually dominant on the map. Therefore, the map scale in the middle is considered to be at a reasonable size for this particular map.

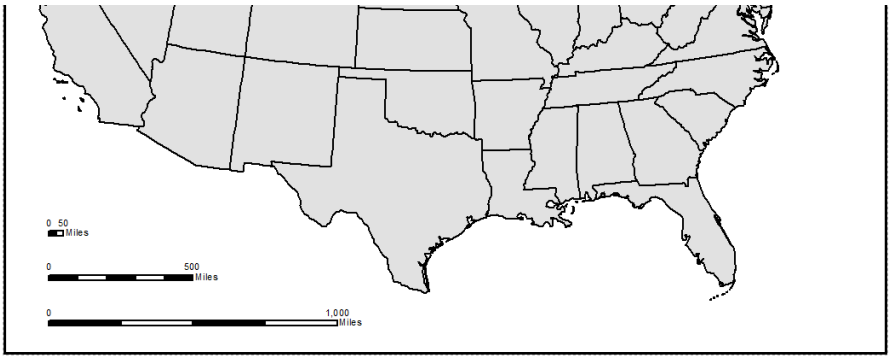

Figure 13 Scale Bar

Quality Criteria

When creating your map scale you should always make sure that they meet these three criteria. First, the scale units should be meaningful. If you are making a roadmap of Arkansas it would be appropriate to place a scale with units in miles or kilometers. A scale bar in feet would not be appropriate for that scale as people tend not to measure car trips in terms of feet. Additionally, decimal degrees would be inappropriate as it is not a useful linear distance measurement.

Second a scale unit should be appropriate to scale. That means that if you were showing a map of a small neighborhood maybe your map unit should be in feet or meters and not miles. Third, the scale interval should be rounded easy-to-use meaningful numbers. A map scale from the numbers 0 to 23.78 is not easy-to-use or meaningful to many map users. Therefore, if at all possible, you should use nice round numbers.

The third criterion related to quality is that the number divisions should divide equally into the scale range. As an example the middle scale bar is from the numbers 0 to 500 miles. There are five divisions in the scale bar and each division represents a distance of 100 miles which is a nice round, meaningful number. If you look at the top scale bar which goes from the number 0 to 2,750,000 feet, there are five divisions and each division represents 550,000 feet which may not be a very useful or meaningful number.

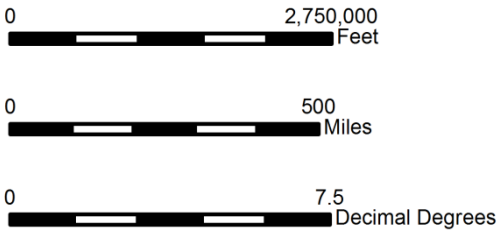

Figure 14 Quality Criteria

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Legend

The purpose of the legend is to identify unknown or unique map features succinctly. This means that a map legend does not need to include a representation of all map features that are self-evident such as water features, or roads. However, general reference maps traditionally define all symbols.

When designing a legend you should not include the word "legend" as a map reader knows that it is a legend. Instead you could put some other meaningful text at the top the legend or no text at all if it is not needed. An exception to this is if the audience is not skilled at map reading such as young children. Symbols that represent map features on the legend should be identical to the symbols on the map. If the symbol size is on the map, the legend entry should be the size of the average symbol on the map. If you choose, polygon and line symbols can be represented by irregular shapes instead of just using squares or straight lines.

General Reference Map Legend

Take a look at the general reference map legend example. This map legend has two columns of information that are roughly equal in size. Each map feature is identified with a symbol that is identical to the symbol found on the map followed by the name of the map feature to the right of the symbol. On this general reference map legend common features such as lakes, parks, rivers, railroads, and roads are included, where they may not be included on thematic maps. This thematic map legend is for a graduated symbol map.

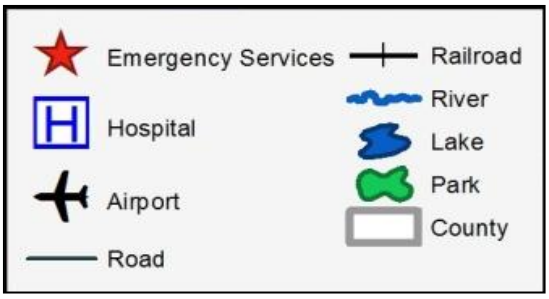

Figure 15 General Reference Map Legend

Graduated Symbol Map

In a graduated symbol map the symbols vary in size as related to the values they represent. Therefore it is important to show a representative size for each value, or range of values, as we wish the map reader to be able to determine the value at those locations based on the size of the circles. The figures below are examples of graduated symbol legends. In Figure 16, the Vertical Layout, we see the different size circles which are the same size of the circles shown on the map, followed by the value that each circle represents to the right. In Figure 17, the Nested Layout, to save room, the circles are nested inside of each other, and the labels are placed inside the appropriate circle.

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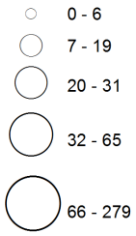

Figure 16 Vertical Layout

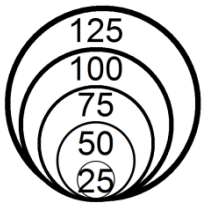

Figure 17 Nested Layout

Legend Design

When designing a legend you should take great care to make a legend look well-structured and consistent. There are a few issues you should pay attention to while designing your legend. First, the symbol should be at the left with the description to the right. The symbol should be evenly distributed and spaced from each other and the description. The symbol should be aligned with the descriptions to the right. The symbol should also be horizontally centered.

Last, the descriptions should be left justified in line with each other. Humans are very good at seeing slight irregularities and if a map reader notices any regularity and placement or alignment in your map legend it may diminish the map reader's trust in your map.

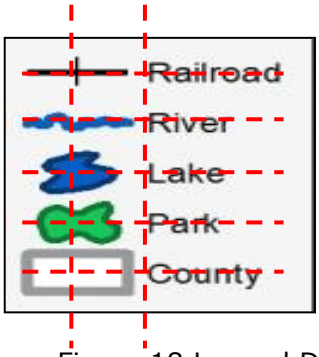

Figure 18 Legend Design

Columns

When designing your legend you can choose to split the legend of multiple columns so that the map legend is to be placed properly on the map or the legend entries can be split into meaningful separate columns. Any decimal numbers on your legend that are smaller than one should have a leading 0. Ranges of numbers are normally separated by a hyphen or the word "to", however, the word "to" can help reduce confusion when there are negative numbers in the legend.

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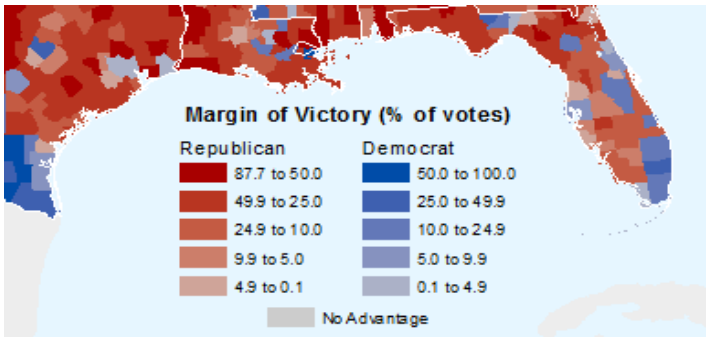


Figure 19 Columns

Headings

A legend may contain headings to meaningfully separate groups of legend entries. Symbols representing a single feature on the map should have a singular description and multiple features with the plural description.

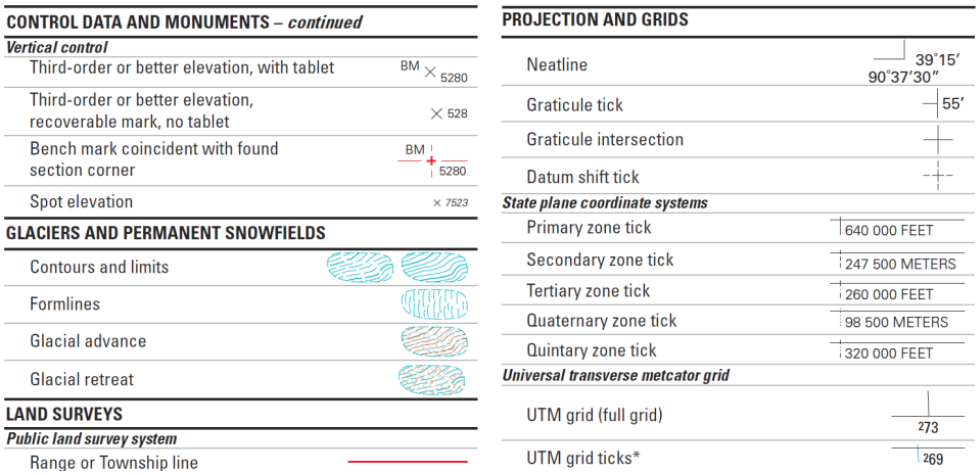
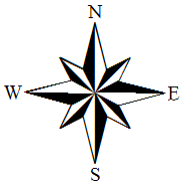


Figure 20 Headings

Directional Indicator



The directional indicator is typically a North arrow. The purpose of a directional indicator is to indicate a direction on a map. Map readers are used to most maps showing North as up. Unless you have a good reason to have north pointing anywhere but up you should not buck this trend. North arrows are necessary on a map when North is not at the top of the map and where map readers not familiar with the area on the map.

The directional arrow is often not necessary on a small scale map as many map readers are familiar with the orientation of larger landmasses or areas. The North arrow should not be made overly large and should not be placed in prominent locations. If a map reader needs to know the orientation of the map, they are expected the search to find the North arrow. A North arrow may come in many different designs and may show other directions other than North. When you choose a North arrow make sure it is not overly ornate and easy to use and understand.

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Indicator Examples

On this qualitative thematic map (Figure 21) showing the standard Time zones of the United States of America, notice that there is no North arrow. This is an appropriate choice as most map readers should be aware that North is at the top of this map. A North arrow could have been included on this map which would be fine; however, consideration should be taken to make sure that the North arrow is not visually dominant on this map.

Figure 21 Time Zones of the United States

On this map of California, since North is not up, a North arrow is appropriately included on this map.

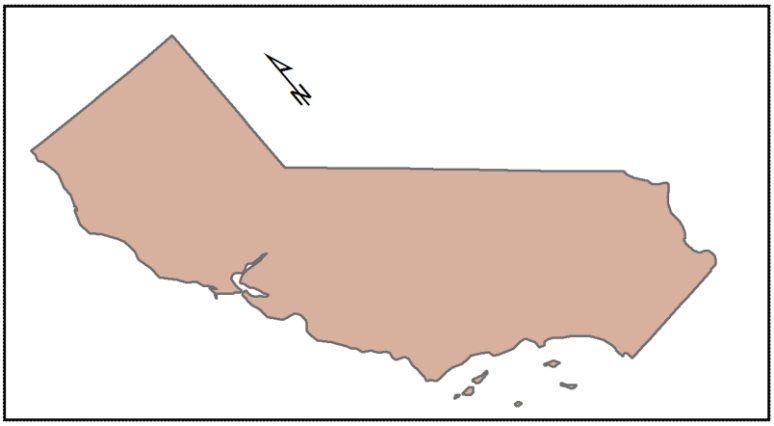

Figure 22 California

Label

The purpose of the label map element is the communicate attribute or ancillary information to the map user. A label helps orient the user to the map and the features shown on the map. Review Figure 23 for an example of a label map.

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Figure 23 Label

Metadata/Credits

The next map element is the metadata which may be referred to as the credits. The purpose of the metadata is to cite the source of data sets used to create the map. They can also contain the map author's information, such as their name, and contact information. Metadata should also include the date the map was created and other explanatory information about the creation of the map such as the map projection used.

Metadata is typically placed along the bottom edge of the map and deemphasized as it is typically not that important for the map reader to notice right away. The metadata should be among the smallest text on the map. If a map reader wishes is to learn more about the details of the map and its data they are expected to search the map for the metadata.

Graticule

A graticule is a visual representation of a coordinate system or location scheme used on the map. You should include graticule on a map if the map reader will be referencing coordinate locations throughout the map. The graticule should use meaningful divisions and meaningful units. Typically the graticule is omitted from a thematic map as thematic maps wish to convey the spatial distribution of a theme and is not to be used for determining precise locations. Graticules should be reasonably dominant on the map so that it is easy for the map reader to use even when the details of the map may become dense.

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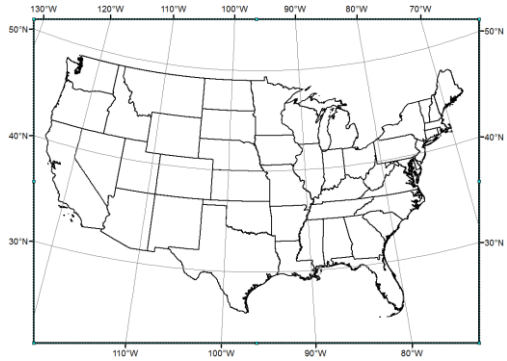

Figure 24 Graticule

Neat Line

The neat line map element serves as a frame around the entire map or individual map elements. The purpose of a neat line is to provide a nice, clean frame for the map. It helps the users find the center of the map which is where the most important map elements should be placed. A map layout may contain multiple neat lines surrounding other map elements should the map elements need a frame helping focus on a map element. The style of the neat line should be simple and subtle and should not be overly ornate. Looking at the example you see a single fixed neat line surrounding the entire map which allows the eye to focus on the center of the map to separate the map from the rest of the page. Figure 25 is an example of a very effective neat line serving as a frame.

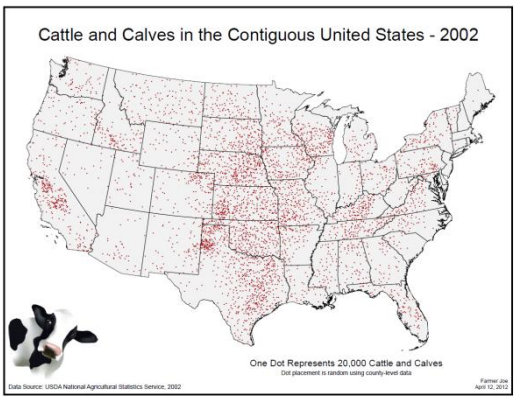

Figure 25 Neat Line

Ancillary Text and Objects

The final map elements to be covered are ancillary text and ancillary objects. The term ancillary refers to an item that supports another item. In our case the ancillary information is additional information if it provides a greater understanding of the topic of the map.

Examples of ancillary items are text, pictures, sounds, movies, and graphs to name a few. A common use of ancillary information is to indicate the data manipulation that is pertinent to the interpretation of the map. Examples also include additional explanatory information or discussion of special cases or missing data.

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Placement

When considering map elements and your map layout you should carefully consider map element placement. In general you should place map elements so that they are positioned and sized in accordance with their importance. You should also strive to reduce white space on the map. This means you should try to fill the available space with useful information and not have any large unused space on the map. If you find that you have a large amount of unused space of a map, perhaps you should bring the neat line in closer, reposition map elements, or consider a new layout altogether. You should also balance the map layout so that map elements are evenly distributed around the map if the map does not feel to be too "heavy" on one side of the map.

Planar and Hierarchical Organization on a Map

The purpose of the map composition is to develop an intellectual and visual structure that the map reader can use to understand the message the map author is trying to get across. A well composed map stresses the purpose of the map through the use of well selected and design map elements. A well-designed map and title directs readers' attention to the purpose and the primary focus of the map that the author wants the map reader to notice.

A properly composed map will also coordinate base and thematic elements so that the map reader has enough geographic contexts to interpret the focus features on the map. A well-designed map will maintain cartographic conventions that make the map easily accessible and familiar to as many map readers as possible so that they can have an easy time utilizing the map. A properly composed map attains all of this, for the map reader will have the highest possible chance to get the most out of the map and properly understand what the map is trying to convey. When properly designing a map there are two important concepts to consider: the planar organization on the map, and the hierarchical organization on the map.

Planar Organization

There are three aspects of planar organization as they relate to composing a map. These three aspects are balance, focus of attention, and internal organization. After discussing the two centers of an image, this part of the lesson will cover each of these three aspects in more detail.

On any image, and specifically a map, there are two centers of the image. The first center is the geometric center. The geometric center is the location that it is exactly half the height and half the width of the image. The optical center is a location that the human eye initially rests on when viewing an image. The optical center is slightly above the geometric center of the image. This is important to know for map composition as it is the first thing you want your map reader to view which is the most important feature on the map. Therefore, it is going to be important that you only place the most important features of your map in the optical center.

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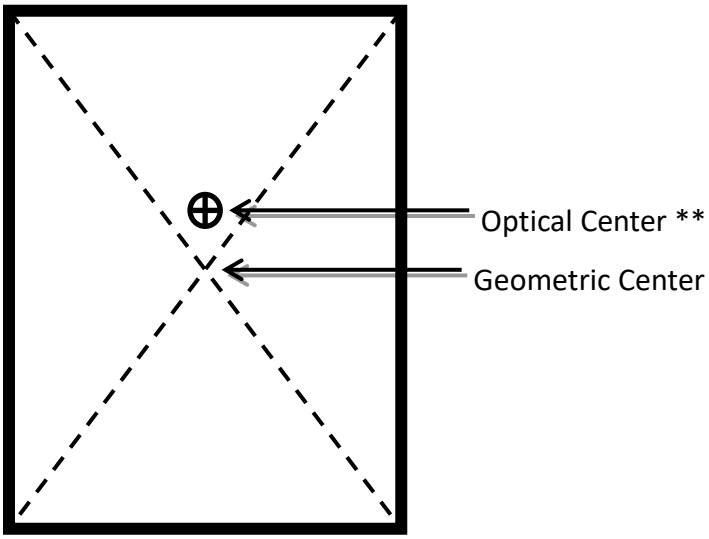

Figure 26 Map Centers

Balance

The first aspect of planar organization is balance. Defined, balance provides the visual impact of the arrangement of the map elements. There are two factors to consider related to the balance: weight and direction. Weight refers to the location, size, and shape of the map element of the map composition. Direction refers to the relative location, shape, and subject of the map elements on the map composition.

Weight

When considering weight as related to balance on a map, the visual weight of an object depends on its location on the map composition. Elements at the center of the map composition pull less weight than those off center and off-track. An object in the upper part has more weight than in the lower part of the map. Objects on the right are considered to be heavier than the objects on the left and weight increases in proportion to the distance from the center. Because of all this, it is important that we evenly distribute the weight around the map.

Imagine if the ink on a map weighed a significant amount and you try to place the piece of paper on the tip of a pen. Ideally if you place the geometric center of the map at the tip of the pen the map would balance. If the center of the map does not have as much weight as elements placed around the edges, or one edge of the map has significantly more elements on the other edges, the map would feel off balance to the map reader. Visual weight also depends on the size of the object. Large objects are heavier than small objects. If a large object is placed off center and off-track it will have significant weight and may run the risk of throwing the entire map off balance.

Visual weight also depends on color, interest, and isolation. Related to color red is heavier than blue, white is heavier than black, and bright is heavier than dark. Related to interest, objects of intrinsic interest to the map reader will be considered heavier as they will tend to linger at that portion of the map. With isolation if an item is significantly isolated from other objects, perhaps with a large amount of white space between them, then that object will be quite heavy.

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And finally, visual weight depends on shape. Regular shaped objects are heavier than irregular shaped objects. Compact shapes are heavier than those not so shaped. Therefore solid geometric objects such as circles, squares, and triangles are heavier than other geometric shapes such as stars, and +.

Direction

The second aspect of planar organization is direction. Visual direction depends on location. The weight of an element attracts neighboring objects imparting a direction to them. Visual direction also depends on shape. Shapes of objects create axes that impart directional forces into opposing directions. Visual direction depends on subject matter. Objects possessing intrinsic directional forces impart visual direction on other elements. Consider some examples of direction based on location, shape, and subject matter.

In these direction examples we see two circles, a large black circle and a small black circle. If we consider location and its effect on direction we can see that in Figure 25 where the large circle is in the upper right-hand corner the smaller circle is the lower left of the large circle, that figure seems to have a direction pointing in the top right-hand corner. This is because our eyes naturally started the visual center of the image and then it gets pulled to the small circle and finally to the large circle which imparts a direction to us.

For Figure 27, since a large circle is in the center of the image and the small circle is close but does not have as much weight, this image does not seem to have an overarching direction as our eyes do not wander too far from the center. It would consider shape of objects, in these cases, the circle does not have any intrinsic directional force; therefore, we are relying on location to determine direction. Had the circles been replaced with triangles, or lines, those shapes have axes that can impart a directional force.

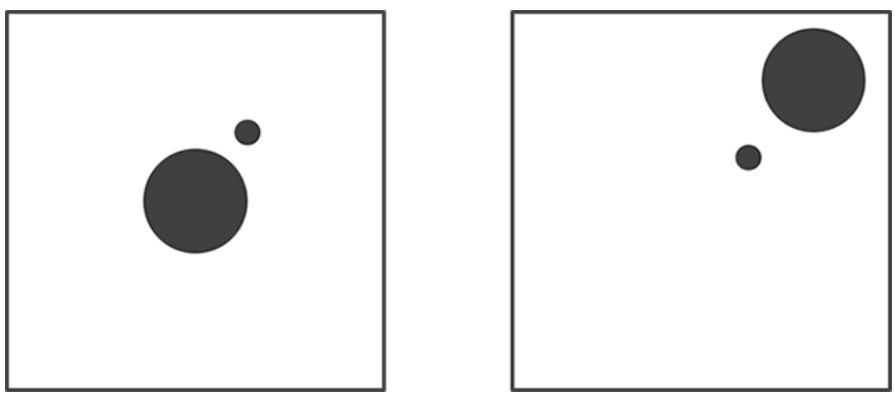

Figure 27 (Left) No Direction (Right) Upper Right Direction

White Balance

Also related to balance is the use of white space on the map. White space refers to a blank space on the map that does not have an element placed at the location. In general, white space should be minimized in a map; however, white space can be useful to visually

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separate or group elements. Excessive amounts of white space can also make the map visually unbalanced. Consider the white space around South America on these nine images in Figure 28. The center image has South America centered on the geometric and visual center. Because of this, even though there is as much white space on the images and the images around it, South America interrupts the whitespace and allows for the image to have doubts.

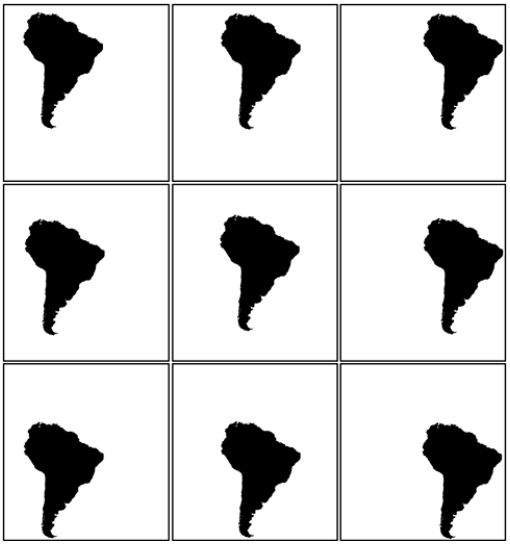

Figure 28 White Balance

If you look at the other eight images where South America is placed along the edges, significant amounts of white space are exposed and each individual image seems to be visually off-balanced which is not desirable. In order to counteract all the whitespace there are two options: reduce the size of the neat line to bring it in tighter around South America, or add map elements to fill in the whitespace.

Focus of Attention

The second aspect of planar organization is the focus of attention of the map reader. When a map reader first looks at a map they follow a path from the upper left corner to lower right corner passing through the optical center. Because of this, it is important to put the focus of the map at around the optical center and not skewed to one side of the optical center. If you look at Figure 29 and 31, Figure 29 has a location of the cities well to the left of the optical center.

As a user focuses on the optical center, the important map features are to the map reader's periphery and may be overlooked. In Figure 31 the locations of the cities are placed very close to the optical center and commanded the attention of the reader.

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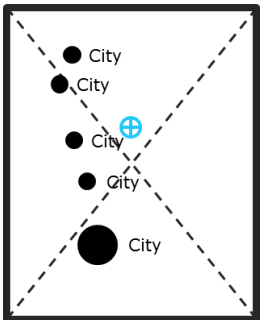

Figure 29 Focus to the Left

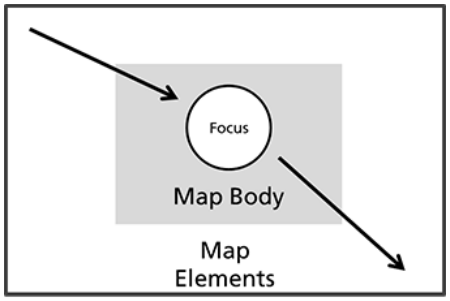

Figure 30 Focus of Attention Center

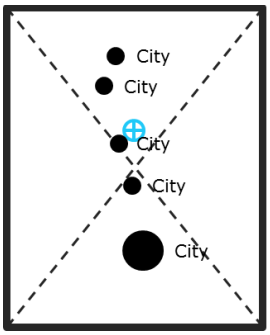

Figure 31 Focus to the Center

Internal Organization

The third and final aspect of planar organization is the internal organization of the map. You should strive to have order on all of your maps. An ordered map has an overall structure that defines place and function of every detail on the map. Without strong internal organization a map element may look out of place and awkward. We should strive for creating a structure of all elements, or a place for everything and everything in its place. We will now discuss how to create a strong, structured internal organization.

Contrast is the first method that we can use to assist in defining an internal organization on our map. Contrast leads to differentiation of objects in our map. Contrast can help distinguish between important and unimportant parts of a map as well. Contrast can be achieved through line, texture, value, detail, and color.

There are two types of line contrast: line character and line weight.

Line Character

Line character is the nature and pattern of the line. By varying the nature of the line, we can differentiate the lines from each other which will allow us to create contrast. Examples of ways which we can change the nature of the line is to dot the line, or dash-dot the line, or dash the line, or some other variation thereof.

Figure 32 The Nature of the Line

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Line Weight

We can also modify the line weight. Users can see half a point difference in line thickness pretty easily. Maps with multiple line thicknesses focus attention, are lively, and provide structure to the map. Users can see 0.5 point difference. The focal features of the map can have a thick line weight which will allow the user to differentiate from the background features.

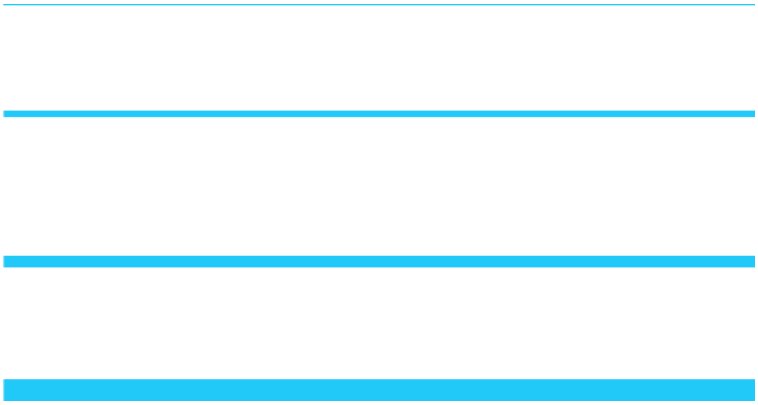

Figure 33 Line Weight

Map Examples

These images are two examples of maps: one with good structure, and one with poor structure

Figure 34 Poor Structure

Figure 35 Good Structure

Things that change between these two maps are the line thickness of the outline of the United States of America. Basically by increasing the line weight of the national outline, the map now has a strong visual contrast between the focus features in the background features and thus a good structure.

We can also modify texture to achieve contrast. Texture contrast is typically used more with grayscale mapping to show differences whereas on a color map texture is used less because color is typically a more attractive option. One thing to be careful about when considering use of texture to show contrast is that texture can be visually irritating to the eye and may confuse the readers.

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We can also use value to create contrast. Brighter areas on map tend to attract the eye more than dark areas; therefore, brighter areas are considered to be more interesting and are placed towards the top of the visual hierarchy.

Another method to show contrast is to vary the amount of detail on the map. Reader's eyes are naturally attracted areas of a map of the most amount of detail. Therefore, we want the reader to focus on an area of the map which can be done when you increase the amount of detail and remove detail in unimportant areas.

Here is an example of how the variation of detail on a map provides a visual hierarchy. In Figure 36 all counties surrounding San Antonio and Austin are labeled which does not allow the eye to focus in any one particular area. In Figure 37, only the counties that are between San Antonio and Austin and around Austin are labeled which allows our eyes to focus on the northeast corner of the map and the other counties that are not labeled to fall into the background and be considered less important for the purposes of this map.

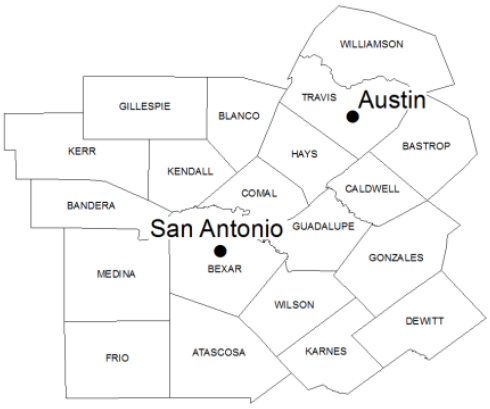

Figure 36 All Counties Labeled

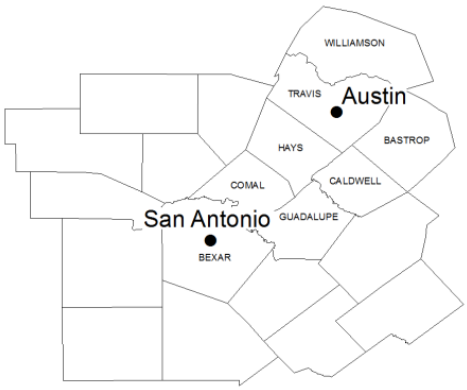

Figure 37 Specific Counties Labeled

Finally, we can vary the color of features to create contrast. By changing the color, or hue, of the feature, it allows us to differentiate between the features and kinds of features. If we have multiple features that are of the same kind, but have a different value, you can use a single hue, but change the value for that hue to represent different quantities.

Hierarchical Organization

Visual hierarchy is the intellectual plan for the map and the eventual graphic solution that satisfies the plan. In this section you will learn about strategies for planning and executing a visual hierarchy format.

Customary Positions in Hierarchy

When planning the hierarchy for your map design, there are some customary positions we may want to consider adopting. Assume that a map has five visual levels, visual level one being at the top of the visual hierarchy and immediately viewable and visual level five being deemphasized, something map user may have to search for briefly.

On visual level one, first and foremost, the map reader should immediately see the thematic symbols that create the map. Next, the map reader should easily see the title, legend, other symbols on a map, and labels on the map. On level two of a visual hierarchy, the user

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should become aware of the base map which may include land areas, and water features. In level three of the visual hierarchy, the map user should see the scale, graticule, inset map, and North arrow.

These items are important to the overall map layout; however, they are considered aids for the map that the map reader will rely on only when they need them so they do not need to be readily apparent. On visual level four we see the metadata which is typically deemphasized, the smallest text on a map, and which are is placed along the bottom edge. Finally, on level five is the neat line. With the neat line it is extremely important to help focus the reader to the center of the map. The neat line itself should not draw any attention.

Visual Level	Object
1	**Thematic Symbols**
1	**Title, legend, symbols, and labels**
2	Base map – land areas: political and physical
2	Base map – water features
3	Scale, graticule, inset map, north arrow
4	Metadata
5	Neatline

Symbols

It is important to note that symbols on the thematic map are almost always at the top rank in the visual hierarchy. Even the enumeration units in which the symbols' data are aggregated to should take a lower rank than the thematic symbols themselves.

Figures and Grounds

An important concept in visual hierarchy is the concept of figures and grounds. When we design a map we design elements on the map into two categories: category one is for the figures of the map and category two is for the grounds. Figures are items that have "thing" qualities and are important to the map.

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Figures should have solid lines and bright colors to attract attention. Grounds should be formless and lost in perception when the map reader is viewing the figures. Grounds are typically considered the background or supporting figures on the map. Ground should have gray or pastel colors and weaker lines. Grounds are considered to be unbroken behind the figure so there is no need to make the figure semitransparent so the map reader can see the grounds unless the ground is significantly obscured by the figures.

Figure and Ground example

In Figure 38 there is a strong figure, ground relationship. The United States has a strong outline that allows the eye to focus on the country. The graticule is considered to be the ground, has weaker lines, and is interrupted by the United States polygon, but the map reader can assume that the graticule continues uninterrupted by the figure.

Figure 38 Figure and Ground Relationship

How to Achieve Visual Hierarchy

To achieve a visual hierarchy you can employ perceptual grouping. In a perceptual group the viewer spontaneously combines elements that share similar properties. Elements can be grouped by shape or by size. In this example you will most likely consider the group of the three triangles together and the three circles together as two separate things.

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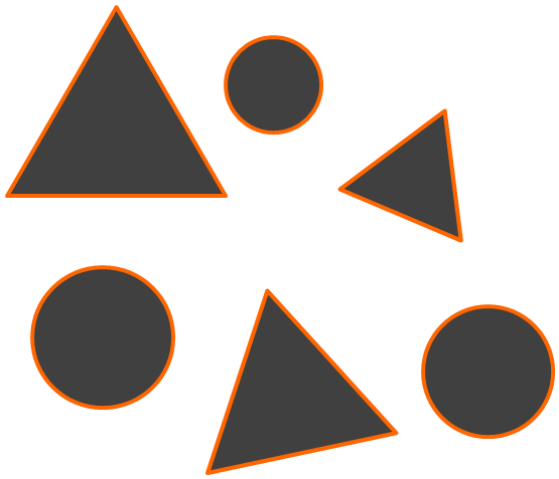

Figure 39 Grouping by Shape

The large circles will naturally be grouped together as will the medium and small circles since they all share the same size properties.

Figure 40 Grouping by Size

In addition to perceptual grouping by shape or size, users tend to group elements together based on proximity. For example, without explicitly stating so, they saw the proximity of the circles to each other, three groups of circles are perceived here.

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Figure 41 Grouping by Proximity

Figure Closure

Another concept related to visual hierarchy is figure closure. Figure closure is the tendency for the viewer to complete unfinished objects or objects that may be obscured by other elements. For example, in Figure 42 the left image includes a portion of the letter F, but we naturally will complete the outline of the letter F even though it is not drawn. In Figure 40, the image on the right is illustrates how the San Antonio label obscures multiple segments of outlines for multiple counties. We will assume that the county outlines exist beneath the label and will consider those items to be closed.

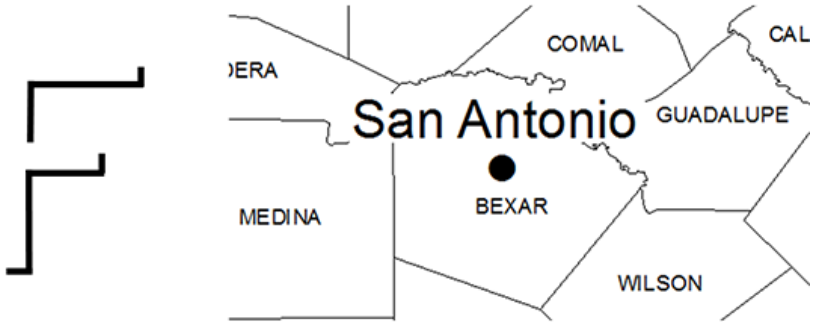

Figure 42 (Left) Portion of Letter F (Right) San Antonio Label

Strong Edges

Now consider the edge of objects and how they relate to visual hierarchy. Crisp edges help to define an object as a figure and visually set it apart from other objects. Reducing the edge definition of an object weakens it. Edges result from a contrast of brightness, texture, or line type.

In Figure 43, the counties are well-defined as they have strong solid edges. The circles are also well-defined as they have crisp edges. Where the two circles overlap in the center, the

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larger circle has been given a white edge so that it is visually distinct from the circle and county outlines that lie underneath.

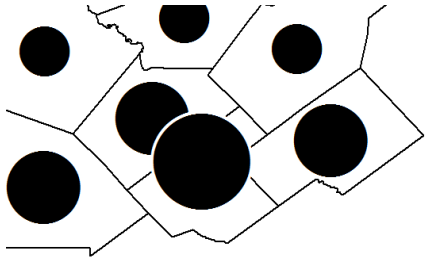

Figure 43 Strong Edges

Interposition

The next topic in visual hierarchy is interposition. Interposition is the interrupting of the edge of one object with another object that causes the object to appear on top and closer to the viewer. If you do overlap two objects, be careful to not overlap the two objects too much especially with quantitative data. The rule of thumb is that there should be no more than 1/3 overlap between the objects.

To illustrate this point consider these two interposition examples. In Figure 44, the northernmost square is overlapping the southernmost square. As the northernmost square is complete and the southernmost square is being interrupted, we visually perceive the northernmost square as closer to us in the southernmost square as further away. In Figure 45, the black bar is obscuring the white box. Because of this, the black bars perceived to be closer to us.

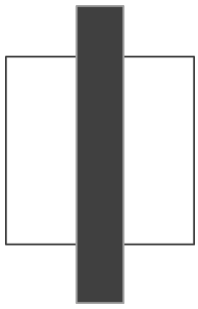

Figure 44 Interposition Example 1: Overlapping Squares Figure 45 Interposition Example 2: Black Bar obscuring white box

Water

Water plays an important part in establishing a visual hierarchy. Water provides significant geographic clues as to where landmasses begin and end and also often serve to be the base for all other objects in the map. On thematic maps it is commonplace to leave the water off of the map. We shall include water on a map if it is important to the thematic variable. This also goes for other general reference features such as roads, locations of towns, or locations of parks for example.

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Here we see a thematic map. Figure 46 is the Standard Time Zones map which includes water. The waters considered a ground on this map and serves to punctuate the location of landmasses. Figure 47 shows election results by state but without water. Water is not included on this map because it is not an important indicator for election results.

Figure 46 Standard Time Zone Map

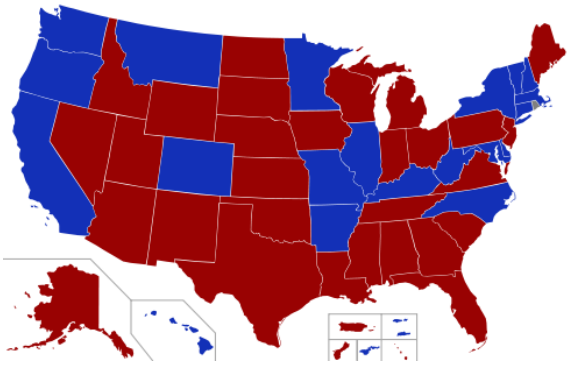

Figure 47 Election Results by State

Example Map Critique

This is a map that may be considered typical for someone who is new at making maps. Some of the undesirable characteristics of the map result from the map author choosing not to alter the default behavior of the mapping software. Other issues with the map are probably due to the map author not knowing any better. In either case look at the map and determine how the map design could be improved. As the title is often the first thing a map user reads, and provides a concise description of the map, you can examine that first.

Map Title

The map is simply current entitled population density. While at its core the map is about population density, the title is still fairly vague. It does not answer the question of when the population was that dense, and why we are only seeing the lower 48 states of United States. Why were Alaska and Hawaii left off the map? Additionally the title is slightly off center. It would be much better if the title was centered on the top of the page.

North Arrow

Now take a look at the North arrow. The North Arrow is way too large for this map. Remember that items should be sized relative to their importance. The North arrow is not so important for this map that it needs to stand out that much. Additionally, assuming that the audience for this map would be Americans, the North arrow might not even be necessary since Americans are used to seeing United States, and having north be up on a map, making the north arrow redundant. If the North arrow is to be left on this map, it should be made considerably smaller, and placed out-of-the-way.

Metadata

If you look right below the North arrow you have the metadata showing the map author and the data source. There are two problems here. One, the text is too large. Map readers will look for the metadata if they want to see it, but it should not jump out this much. The font size should be reduced for the metadata. For the data source, 'ESRI' is not very descriptive. It doesn't tell us what year the data set was created, and a majority of map users would not be able to track down the original data source simply by 'ESRI'.

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Scale Bars

The next elements to consider are the scale bars. The scale bars have multiple problems. First, one of the scale bars represents the distance in decimal degrees. Decimal degrees are not a useful unit to measure distances on a map. Second the divisions and end points of the scale bars are not in meaningful, easy-to-use numbers. Instead of 0 to 32, why not 0 to 30? Instead of 0 to 2,840, why not 0 to 3,000? Using round numbers on your scale bars, make it easy for the map reader to scale distances. Third the scale bars are too wide. The scale bars could easily be one third their width and be just as useful, and not so visually dominate the map. Remember the scale bars in this map are not that important and should be deemphasized so as to not attract the eye from the map body. The last problem is that the scale bars are too tall. Again, having scale bars that large detract from the map too much. The scale bars are emphasized too much.

Legend

As a matter of style, you should not title the legend with the word legend. Map readers know that this is the legend, and you could use that space better by replacing it with a descriptive title for the legend. One exception would be for, say, elementary school children who are not familiar with the components of a map yet and therefore need this instruction about what a legend is and looks like. Next the description of the population density data is not well formed and provides the column name from the attribute table which is not useful to the map reader. Instead of the word counties, and POP07_SQMI, a more appropriate legend title would be 'Persons per square mile'. Looking at the numbers to the right of each patch in the legend, it is not consistent with the number of decimal places.

For instance, the bottom entry has no decimal places and is simply the entry 0 – 10. The next three entries above it have two decimal places for the lower number and no decimal places for the higher number, while the top entry has two decimal places for the lower number, and one decimal place for the higher number. Since we are talking about persons, we should round to the nearest whole person. The bottom two entries referring to Canada and Mexico background, and the ocean background, are not required for this legend, as the water and surrounding countries features aren't unfamiliar for the map reader, and therefore, do not need to be placed on the legend. Additionally, the symbol for the ocean background on the legend blends in with the actual ocean background behind it, therefore, making it look like there is no legend entry for the ocean background.

Overall Map

Now you can look at the map itself. The United States is slightly off center and could be made quite a bit larger to fill the page. There is quite a bit of white space above and below the main feature of the map, which is considered wasteful. Additionally only the Southern tail of Alaska is shown on the map which looks sloppy and makes the map reader wonder why only a portion of Alaska was shown. By enlarging the contiguous United States the tail of Alaska would not be shown.

If we consider the features included on the map, we have county outlines, roads, and rivers. The question becomes: "Are roads and rivers really necessary to show a map of population density?" Perhaps the roads, and/or rivers should be left off the map so that it is less cluttered and simpler to read. Additionally, the color of the roads is very close to the color of the most densely populated area, which makes it hard to see exactly what is going on in the counties underneath the roads, and smaller counties may be completely covered by road lines, therefore making it look like a county is densely populated when it is not. Moving to

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the map projection, it's clear that this map is not any particular projection based on the flatness of the northern boundary line of the United States.

As the data that we are showing is based off of population per square mile, an equal area projection should be applied to this map as relative size is important when determining how dense counties are. Another thing to note about the map is that although Canada and Mexico are included, South America is not. If you're going to include surrounding countries, you need to include all of the surrounding countries that my show up on the map. Lastly, there is no neat line surrounding the map. In order to provide a nice frame for the map, and to have it stand out against its surroundings, a neat line should be included.

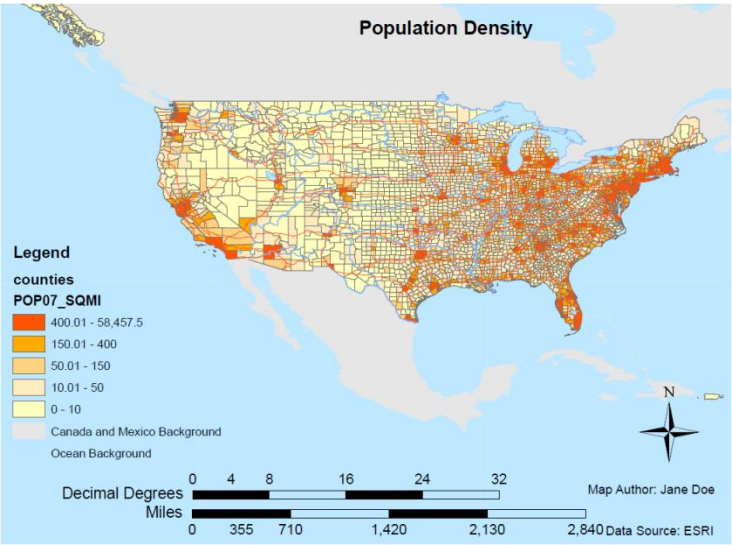

Figure 48 Overall Map

Issues Highlighted

Figure 49 is the same map with all the issues highlighted. As you can see what may initially look like an 'OK' map really has many problems.

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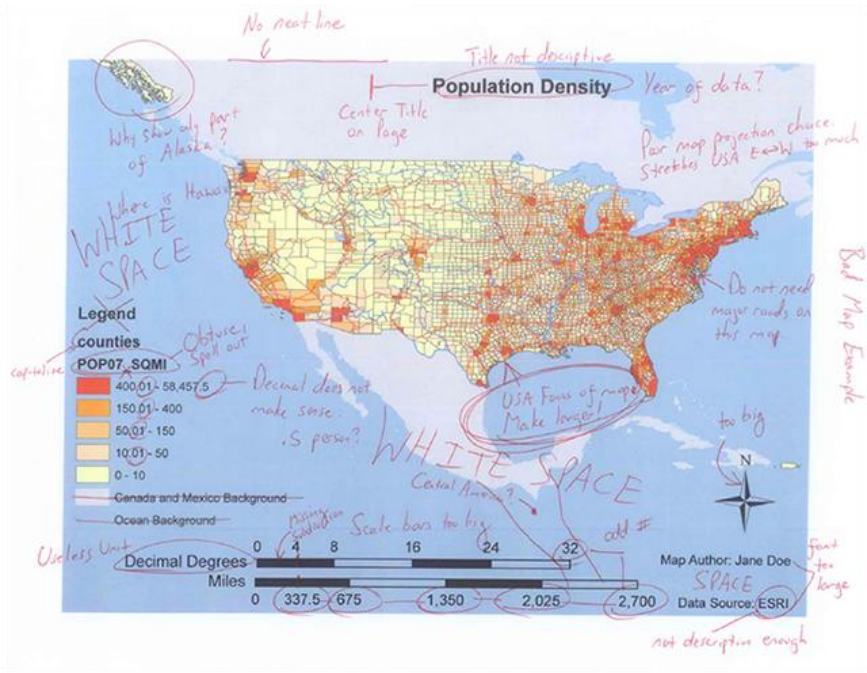

Figure 49 Map Issues Highlighted

Redesigned Map

Figure 50 is a redesign of the map.

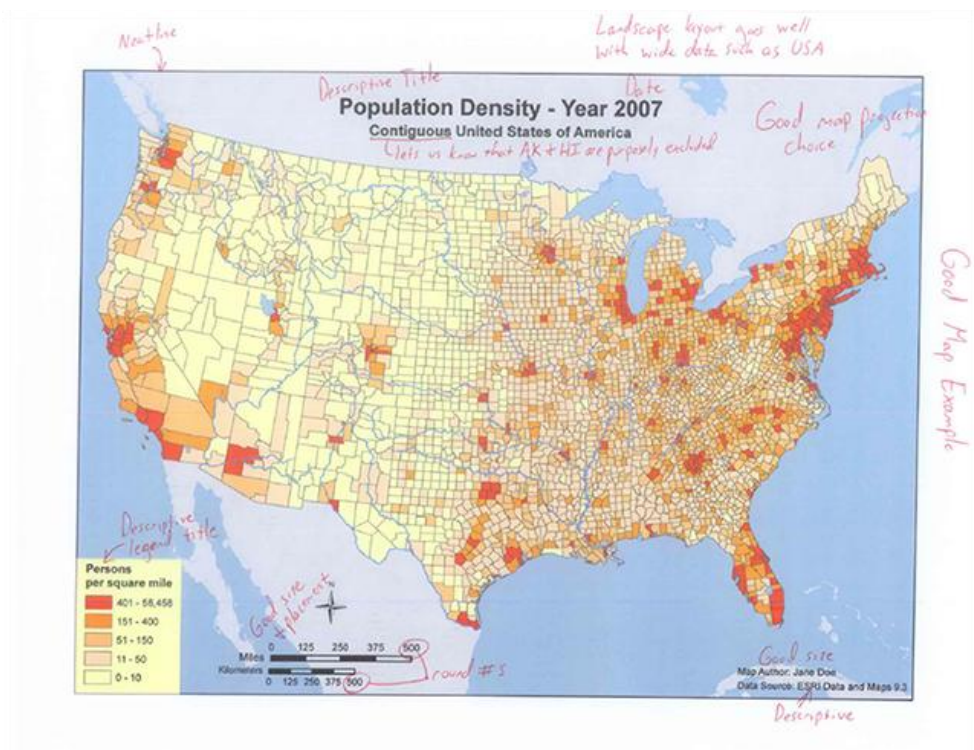

Figure 50 Redesigned Map

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This redesign took about five minutes of time, made the map significantly more attractive, and useful. Consider the following updates that were made.

- Note that the title is much more descriptive. It states that it is the population density for the year 2007, and specifically notes that it is for the contiguous United States of America which lets the map reader know that Alaska and Hawaii are purposely excluded from the map.
- The projection is changed to an equal area projection that allows for the map reader to make proper areal comparisons between counties.
- The roads have also been taken off the map which allows for the counties to be the main focus of the map and not be obscured.
- The scale bars have been greatly reduced in size and are using round numbers in meaningful units.
- The North arrow has been greatly reduced in size and placed in a better location.
- The metadata is more descriptive and is a good size.
- The legend has been reduced in size has been given a descriptive title, and the numbers are now consistent with respect to the number of decimal places and included around the map is a nice frame.

Even with this redesign one could argue there are still a few issues. For instance, the metadata is placed on top of some background data which makes it a little difficult to read. Additionally, the scale bars are half on and half off of Mexico and rivers are still included on the map, which might be a feature that is not required. However with just a little extra work and careful consideration the map has gone from a very poorly designed map that was hard to read, not pleasing to the eye, to a well-designed map that is much easier to read and is pleasing to the eye. Remember, map design is an iterative process, so do not be afraid to radically redesign your map a few times to see how you might improve it. Also show your map to a friend, family member, or colleague and get feedback. Even though they may not be trained in cartography people can often easily identify an ugly map, and might provide an important perspective on your map design.

Ethics in Cartography

Ethics in cartography are important to review. This section focuses briefly on ethics and cartography. There are 10 items in the cartographer's code of ethics. *Note:* The recommended text to cover the topic of "Ethics in Cartography" is as follows:

Dent, Torguson, and Hodler. "Cartography: Thematic Map Design" 6th Ed. McGraw-Hill, New York. 2009. Pages 19-20.

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SUMMARY

This lesson focused on map elements, design principles and the cartographic process. In this lesson you learned about why one would want to create a map and for what purpose. Planar and hierarchical organization were outlined which are important concepts that help to guide how one would determine the organization of a map. The lesson concluded with an example map critique which highlights issues and identifies solutions to make the map more attractive and useful.

ASSIGNMENTS

1. Quiz: Map Elements and Design Principles
2. Lab: Map Elements and Design

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Lesson 4: Types of Maps

INTRODUCTION

This lesson covers various types of maps and their features. Many types of maps exist so that cartographers can visualize spatial phenomenon in the most advantageous way. It is important that you be aware of all the different map types available to you so that you can visualize your data in the format that will be most appropriate for the content of your map and your map user. This lesson covers three map types: choropleth maps, proportional symbol maps, and dot density maps.

LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Identify map elements and design principles.

2. Employ appropriate map elements and design principles for different types of maps and audiences.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz: Types of Maps • Lab: IDP and Refugee Proportional Symbol Map

INSTRUCTION

Types of Maps

There are three specific types of maps that will be introduced in this lesson: choropleth maps, proportional maps, and dot density maps.

Choropleth Maps

A choropleth map is a map where colored or shaded areas represent the magnitude of an attribute. For example this map shows the population density in the year 2007 for the United States of America. For each state the number of persons per square mile has been calculated. The states with a lower population density are shaded with a lighter gray color. The states of a higher population density are shaded with a dark gray color. The states with population densities between the two extremes are shaded on a continuum from the lightest

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gray to the darkest gray. Based on the five different shades of gray, the map visually represents in an intuitive manner where the most densely populated states are in the United States.

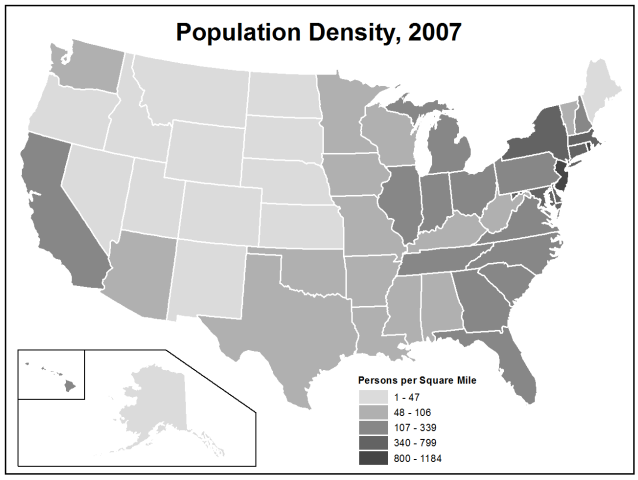

Figure 1 Choropleth Map

Why Create a Choropleth Map?

There are many reasons why you would want to create a choropleth map. Choropleth maps is relatively easy to create and easy to interpret by map readers. A choropleth map excels at displaying variables overall geographic pattern. As each color or shade is assigned a value or range of values the map reader can ascertain the values displayed on the map easily. Choropleth maps are also excellent for comparing multiple choropleth maps with one another to see how the spatial distribution of a variable changes. We refer to multiple small maps on the same page as small multiples. A small multiple is when you have multiple small choropleth maps made with similar structure and context.

It is important that the only data represented on the choropleth map is data that can be linked to an enumeration area. An enumeration area is an area where data is collected and combined. Common enumeration areas in the United States are states, counties, and regions. It is important that the data be normalized against enumeration areas or a total population true blue area or size bias. What is meant by area or size bias is that larger areas might tend to have more population simply because there is more area for people to live. Smaller areas will naturally have less population because there is less area to live in.

By normalizing data against the enumeration area and taking size out of the equation you can do apples to apples comparisons between areas that have different sizes. Examples of normalized data are population per square mile which gives us population density, and percent unemployed which is the number of unemployed people divided by the total number of people eligible for work. In a choropleth map the boundaries of areas do not have a related value. In other words, the outline of an area is in no way related to the value of the area. Only the different color or shaded the area is related to the value.

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Inappropriate Data

There are several types of inappropriate data for choropleth mapping. Continuous data is not appropriate for inclusion on the choropleth map as continuous data is not controlled by an enumeration unit. For example, air temperature is not confined on County outlines nor is it logical to assume so.

Another type of inappropriate data is any map ratio not involving an area. That means if a value can be assigned to a very specific point and it is not logical to aggregate that data value to a larger area, it should not be used for choropleth map. Total values should not be used on a choropleth map. Variables where the values vary too much should also not be used for choropleth maps. If you still wish to use variables with a large value range you may want to consider choosing a smaller enumeration unit so that there is smaller variation in each enumeration unit.

Data Classification

In order to display vast majority of data on a choropleth map, you must employ some data classification schemes. We classify to simplify generalized the data for display on the map. In general four to seven classes are preferred. If you need to exceed seven classes you need to keep in mind that humans cannot effectively use more than eleven classes at once.

Now consider the five types of classification methods to determine when to use each one on a choropleth map. The equal area data classification method is useful for layouts including multiple maps. The equal frequency data classification method is useful if you are performing statistical test between classes. The arithmetic and geometric data classification methods are useful for the data shows a normal distribution. The nested means data classification method is useful for non-normal distributions. And finally, the natural breaks data classification method maximizes homogeneity within classes and is typically going to be your best general choice for displaying data on a choropleth map.

Projection

In most cases for choropleth maps the equivalent, or equal area, projection are the most appropriate. The reason why the equal area map projections are the most appropriate is that since we typically normalize data based on area, relative size is important to maintain when comparing the values of the underlying enumeration.

Symbolization

Consider the symbolization choices for choropleth maps. If you are producing your choropleth map using black and white colors only, then the black color should represent larger values in the light grey color should represent smaller values. The color white should be generally reserved for the background of the map or outlines. Additionally, you should use caution with pure black and white fills as they may obscure boundary lines. You may use pattern, dot, line, or Hatcher patterns, instead of shades of gray, but this is considered to be the "old style" of choropleth mapping.

Black and White

Here is the population density choropleth map of the United States for the year 2007. In this black and white map the color white is used for the background and state outlines. The light gray color represents lower values and the dark gray color represents higher values.

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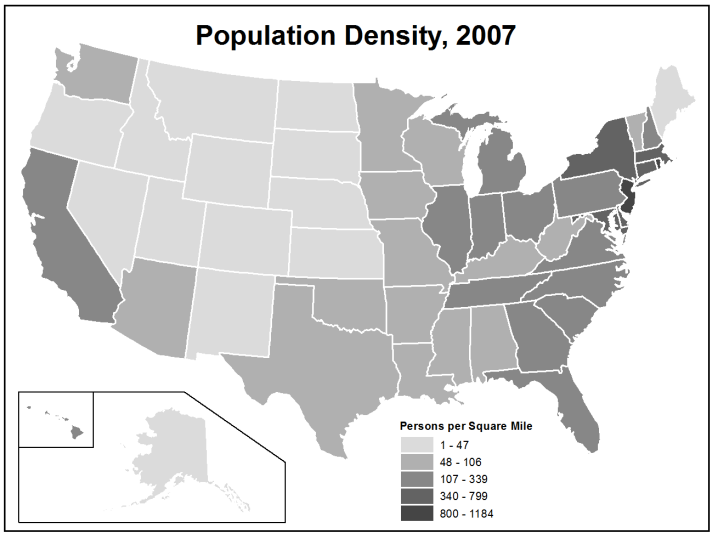

Figure 2 Black and White Choropleth Map

Color

If you are producing your choropleth mapping color you should consider these points. Darker or more saturated colors represent larger values. Lighter or less saturated colors represent smaller values. Make sure you can easily differentiate between colors of different classes, that is, make sure that no two adjacent colors are too similar.

You should avoid qualitative color schemes on a quantitative choropleth map. That means, if you only have one variable on your map, such as population, you should choose a single color, or hue to represent that you are only showing different values of a single kind of thing. To represent the different quantities of that single thing, vary the saturation or value of the chosen color. On a color map, white suggests 'light gray' can effectively represent "no data". Black or white is an effective boundary color on a color choropleth map.

On this color choropleth map that deals with a single variable of population, a single hue of green was chosen. The green hue is varied in saturation so that the lighter color green represents lower population density in the darker color green represents a higher population density. The color black was chosen as the state outlines as it provides great contrast against the green hue.

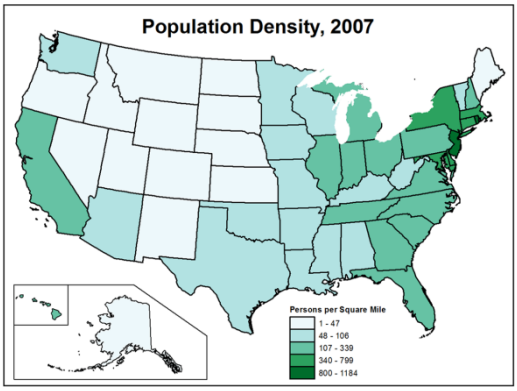

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Figure 3 Color Choropleth Map

Color Schemes

In general there are three color schemes that should be used on a color choropleth map based on the type of data being displayed. If your data is considered unipolar data, which means that there is no natural dividing point, you should use a sequential color scheme. An example of unipolar data is population density.

If you have bipolar data, which means that has a natural dividing point such as 0, or mean, then you should use diverging color scheme. Examples of bipolar data are population gains and losses. If you have balanced data, this means you have two complementary phenomena. In this case a diverging color scheme is appropriate. An example of this would be the ratio of males to females.

Reference Features

Thematic maps should be simple by design by focusing on the featured variable. When creating them you should avoid placing reference features on the map and less they are important in explaining the pattern of the variable being mapped.

Legend Design

To wrap up our discussion of choropleth maps this section will focus on legend design.

Legend Boxes

Choropleth maps typically use legend boxes. The legend boxes are typically square or rectangular and are large enough to provide a visual anchor but not too large to distract the eye from the main map body. The symbols in the legend should be identical to the symbols on the map in both color and line weight.

If the enumeration units on the map are reasonably small then the size of the symbol on the legend should be about the average size of the enumeration unit on the map. If the enumeration units on the map are very large then you may consider making the boxes ½ to 1/3 the average size of the enumeration unit on the map.

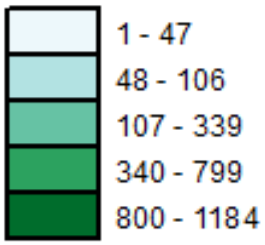

Figure 4 Legend Box

Legend Layout

The legend should be laid out into orientations: horizontally or vertically. With the horizontal orientation the lowest value should be on the left and the highest value should be on the right. The value numbers should be located below the boxes. In a vertical layout you can either have the lowest or highest value on the top and the lowest or highest value on the

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bottom as neither layout is considered standard. The numbers representing the value should be to the right of the boxes.

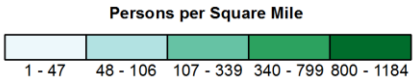

Figure 5 Horizontal Legend Box

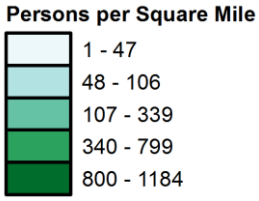

Figure 6 Vertical Legend Box

Continuous Classes

In the case where the values on your map represent continuous data, which means that the maximum value in one class is slightly less than the minimum value of the next class, you should follow these guidelines. Your legend should emphasize degradation of values and show that the values on the map exhaust the data. Additionally the legend should reinforce the fact that there is no data that falls between the cracks. By having a continuous legend it allows the same legend to be applied to multiple maps. In our example, to reinforce the fact that the data is exhaustive and there are no cracks, the boxes of but each other and look like a single continuum.

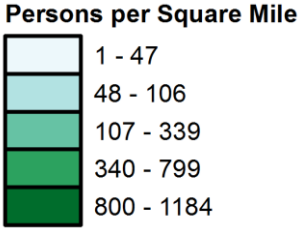

Figure 7 Continuous Classes

Non-Continuous Classes

If you have non-continuous classes on your map then your legend should show the actual extreme values in each class. You would want to do this to narrow the reader's estimate of the actual values in each class. A non-continuous legend is best with a single map displaying non-continuous data. For example, our legend shows each box separated from the other boxes to reinforce the fact the classes are not exhaustive and on a single continuum.

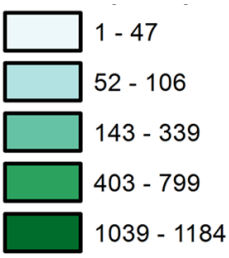

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Figure 8 Non-Continuous Classes

Formatting Conventions

Use either "to" or "-" between class ranges. If there are more than four numbers a value, use a comma after every third number left of the decimal value. If you choose to have a legend title, the legend title should match the topic of the map and should not use abbreviations including symbols.

You should place any ancillary text below the legend of the information will not fit into a concise legend title. If you are creating an animated map which shows the change of the variable throughout time, you should use a single continuous legend that encompasses the global maximum and global minimum over the entire series of the maps included in the animation.

Proportional Symbol Maps

On a proportional symbol map, a symbol's size is buried in proportion to the quantity it represents. The most common symbol used in a proportional symbol map is a circle. On this example proportional symbol map it shows the total population per state in the year 2007 for the United States of America. The circles vary in size as the total population it represents increases. On this map, map readers can quickly and easily determine which states have the largest population in relation to other states.

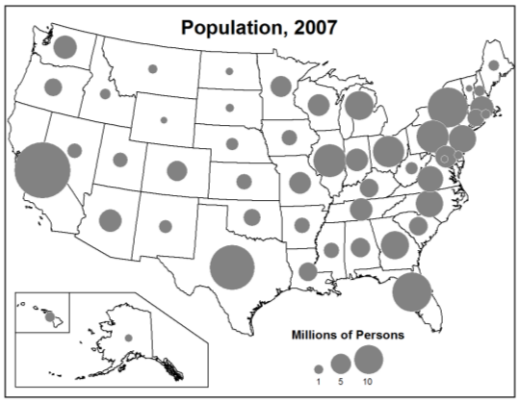

Figure 9 Proportional Symbol Map

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Why Create Proportional Symbol Maps?

So why should you create a proportional symbol map? A proportional symbol map is easy for map reader to understand. Multiple variables can be displayed simultaneously on a proportional symbol map. For example, the symbols size, symbols color, and symbols a shape can all represent different variables.

Additionally, you can overlay a proportional symbol onto another type of thematic map such as a choropleth map. Finally, a main reason to create a proportional symbol map is when you want to display a quantitative distribution of a variable throughout space.

Why not Create Proportional Maps?

Here is why you should not create a proportional symbol map. In general, map readers tend to underestimate the relative size of the symbols on the map this leads to over or under estimation of values. Also, symbols can easily overlap too much a dense locations in the user will not be able to see enough of the symbols to determine the values in the map will look cluttered.

Appropriate Data

Appropriate data for a proportional symbol map is either total values, percentage values, or rate values. Additionally the data should occur at a point or the data should be aggregated to an enumeration unit such as accounting. If the data is aggregated to a point within an area the dot is typically placed in the center of the area.

Inappropriate Data

An inappropriate data for a proportional symbol map is interval data. As the size of a symbol can be reduced to 0, which is a natural 0 state for the symbol, the data to should have a natural 0 point. This would exclude data that does not have a natural 0 point such as temperature. Another type of inappropriate data for proportional symbol map is data with small ranges in the values. Data with small ranges of values will make for an interesting map as the size of the symbols will not very too greatly. There is also density data. Density data is not appropriate for proportional symbol map and you should consider making a choropleth map instead.

Projections

The equivalent, or equal area projections are the most appropriate map projections for proportional symbol map. Since relative size is important to maintain and comparing values within enumeration units you should choose a map projection that maintains the relative sizes of the areas.

Proportional Symbols

Now consider the proportional symbols themselves. Various shapes can be used for proportional symbol although the circle is the most common. There are two categories of point symbols that we can use: geometric symbols, and pictographic symbols.

A geometric symbol can be either two-dimensional or three-dimensional and it should not look like the image or area that is being mapped.

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Two-Dimensional symbols

Examples of 2-D geometric symbols are a circle, triangle, and a star. A pictographic symbol looks like the thing being mapped. First focus on the two-dimensional geometric symbol as this will probably be the most common symbol you will use of a proportional symbol map. For the 2-D geometric symbol, the area of the symbol is scale to represent the magnitude difference of the value of represents. The circle is the most widely used symbol of proportional symbol map.

Advantages for using a circle are that its geometric form is compact and the circles are visually stable since the eye does not wander across the circle too much. If circle symbols overlap they can still be effective in indicating magnitude. And finally, circles can easily, lend to a second variable by changing its color or texture. Squares are also popular choices as their main advantage is that the proportional areas are nearly perfectly perceived whereas they will be over or underestimated for circles and most other two-dimensional geometric symbols.

A disadvantage of using squares is that it adds "squareness" to the map which may not be desirable. It can also be confused for other common symbols like houses.

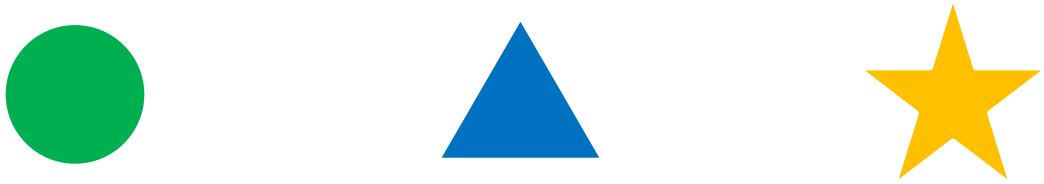

Figure 10 (left to right) 2-D Circle, Triangle, and Star

Three Dimensional symbols

Three-dimensional geometric symbols can also be used as proportional symbols. Examples of three-dimensional geometric symbols are a sphere, prism, or pyramid. Advantages of three-dimensional geometric symbols are that they are visually attractive and they allow for less crowding of the map because they add the third dimension which allows it to be slightly more compact.

Disadvantages of three-dimensional geometric symbols are that readers cannot accurately judge scaling differences because the readers now have to judge changes in volume. Range grading the symbols is recommended for three-dimensional symbols to combat scaling issues. Complicated three-dimensional geometric symbols can also be hard to understand on a map.

Figure 11 3-D Square and Cylinder

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Pictographic

Pictorial symbols are sometimes good choices for proportional symbols. Advantages of pictorial symbols are they are visually attractive and attention grabbing. Disadvantages for pictorial symbols are the more regular the shape of the control symbol, the harder will be to perceive the magnitude differences. Additionally mapping a second variable is difficult except for simple hue changes.

Three examples of pictographic symbols are the front of a bus, and outline of an airplane, and a taco.

Figure 12 Pictograms of a Bus, Airplane, and Taco

Proportional Symbol Color

Now consider proportional symbol color. Different colors apparently do not affect the estimation of symbol size differences. Symbols that are too darkly tinted command a lot of attention so you should avoid extremely dark symbols unless you wish them to command a significant amount of attention on the map.

Symbols with little contrast from its surroundings may be lost and are not popular choices. You should consider using appropriate strategies for contrast. Symbols that are black or gray colors are the most popular with map readers for a proportional symbol map. And finally, changing the color of the symbol can be used for a second variable.

Overlap

Sometimes on proportional symbol map symbols will overlap. Overlapping symbols express a sense of visual cohesiveness and may make the map more memorable to the user as it will make a strong visual imprint in their mind. The downside to symbol overlap is that it may make it harder for the map reader to estimate the individual symbol sizes as they will be partially obscured.

To combat this try not to overlap symbols more than 25% to 33%. Additionally, when symbols overlap, smaller symbols must cover the larger symbols as shown in Figure 13. If you cannot avoid significant symbol overlap another option is to make the circles transparent, or semitransparent to help users perceive of overlapping symbols.

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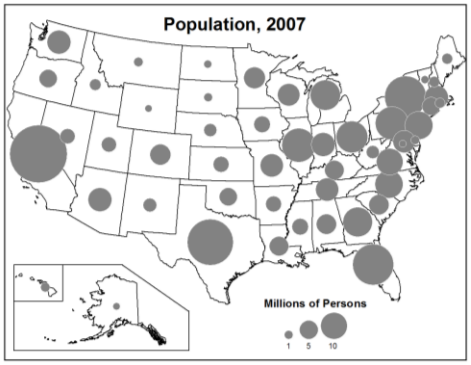
Figure 13 Overlap

Appropriate Overlap

The maps on Figure 14 are examples of maps using appropriate symbol overlap. In both maps the symbols overlap state outlines and other proportional symbols but not so significantly that you cannot estimate the size of the circles that are being obscured. Additionally, with this amount of symbol overlap, the map has a cohesive feel to it in the large amount of overlap in the northeast part of the United States makes the data memorable.



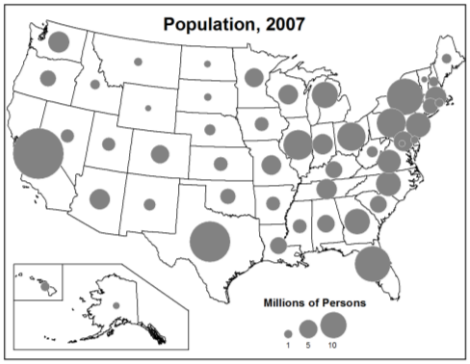


Figure 14 Appropriate Overlapping on a Map

Inappropriate Overlap

Figures 15 and 16 are examples of inappropriate amounts of symbol overlap. In Figure 15 there is too little overlap which makes it seem empty and uninteresting. On the map on the right there is too much overlap of the circles which causes circles to be obscured. Also, the proportional symbol for California exceeds the neat line of the map which looks very messy.

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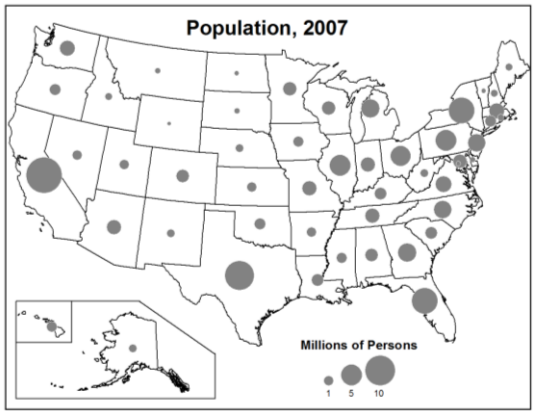

Figure 15 Too Little Overlap, Empty, Uninteresting

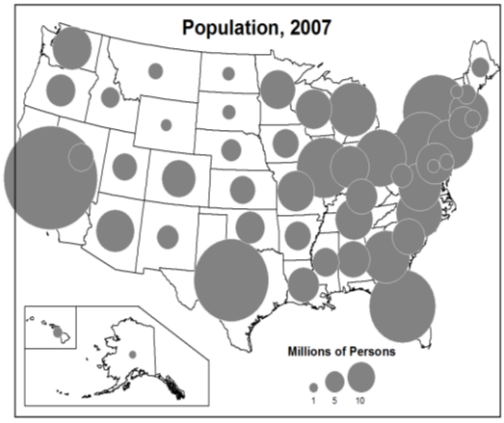

Figure 16 Too Much Overlap

Scaling Methods

There are three primary methods of scaling proportional symbols: absolute, apparent magnitude, which is also known as perceptual, and range grading.

Absolute Scaling

In absolute scaling symbols scale proportionally to their data values and to each other. Absolute scaling is great if you want each symbol to be unique in size and to give a true visualization of the relative values. Negative aspect of absolute scaling is that it can be difficult for the map user to interpret because the map user can only differentiate a given number of symbol sizes effectively.

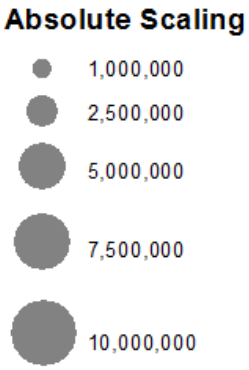

Figure 17 Absolute Scaling

Apparent Magnitude Scaling

In apparent magnitude scaling it applies factors to compensate for the users underestimation of area and volume of the symbols. Typically this factor is used to increase the size of the circles faster than in absolute scaling. Apparent magnitude scaling is also known as Flannery, perceptual, or psychological scaling. Looking at the two example legends in Figure 18, there are five proportional circles in each legend, with the same value;

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however, the circle sizes and the apparent magnitude scaling legend are a bit larger to compensate for the map user's tendency to underestimate relative areas of the circles.

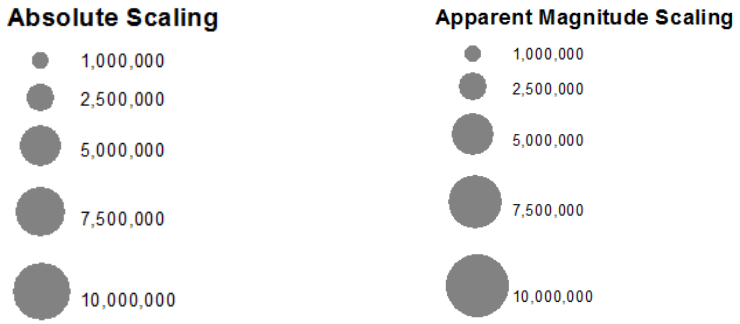

Figure 18 Comparing Absolute and Apparent Magnitude Scaling

Range Grading Scaling

Another type of scaling is range grading scaling. In range grading scaling each symbol size represents a range of data values and not a single data value. Range grading is similar to choropleth mapping as you employ data classification methods to determine class breaks. The main advantage to range grading scaling is that readers can easily discriminate symbol sizes and match them to the legend symbols.

For instance, if there are five circles on the legend of different sizes and there will only be circles of five different sizes on the map it should be easy for the map reader to match the symbols from the map to the legend thereby getting the range of values for that location. Range grading is recommended for three-dimensional geometric or pectoral symbols as users tend to have difficulty in estimating sizes properly for the symbols.

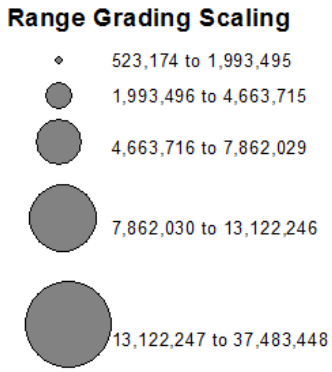

Figure 19 Range Grading Scaling

Redundant Coding

One option available to you when creating a proportional symbol map is the idea of redundant coding. Redundant coding is the use of more than one visual variable to differentiate the symbols from each other. For example, as the value of the attribute increases, we can increase the size of the symbol and darken the color of the symbol. By using more than one visual variable to differentiate the symbols, this reinforces the idea of increasing or decreasing magnitude.

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The most common way in which redundant coding is used on a proportional symbol map is through varying the lightness and hue in concert with the size of the symbol. In this case, lighter colors should represent lower values and darker colors should represent higher values. If the circles represent one kind of thing, and it is recommended that you choose a single color and simply vary the lightness and darkness.

Figure 20 is an example map that employs redundant coding. The smaller circles are colored with lighter colors and represent smaller values. The higher values used darker colors to represent higher values. Using redundant coding can add a nice visual impact to the map.

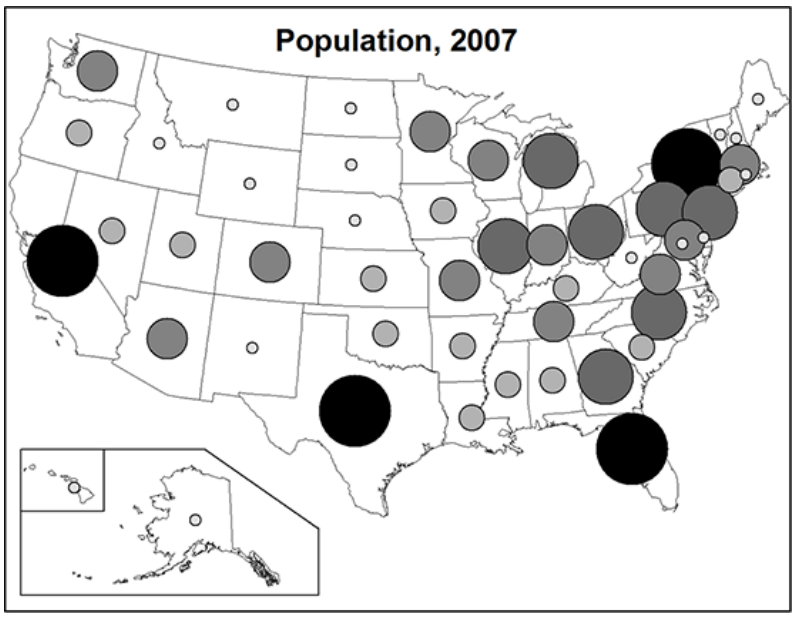

Figure 20 Redundant Coding

Reference Features

Now you can consider the use of reference features on a proportional symbol map. Again, thematic maps should be simple by design so that the map user can focus on the proportional symbols and the data they represent. You should avoid placing reference features unless they are important in explaining the pattern of the variable being mapped.

Legend Design

On a proportional symbol map the legend serves as a visual anchor for interpreting symbol sizes. There are four common legend layouts which are: vertical, horizontal, nested symbols, and nested semi-symbols. In these different legend layouts numbers or data values are placed to the right of the symbols with the vertical or nested legend layout and below the symbols if it is a horizontal layout.

Vertical Layout

For the vertical legend layout the values are displayed to the right of the symbol. Also, small values are at the top and large values are at the bottom

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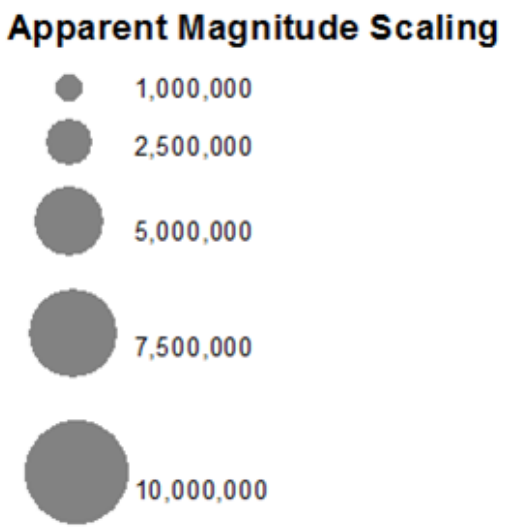


Figure 21 Vertical Layout

Horizontal Layout

For the horizontal legend layout values are below the symbols and small values are on the left and large values are on the right.

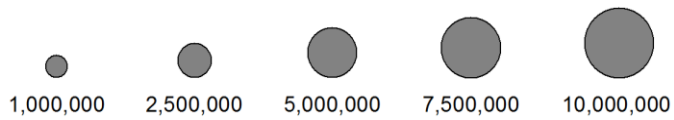
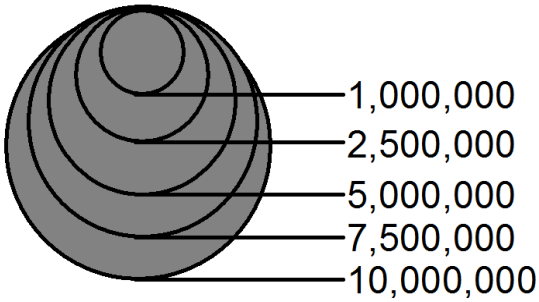


Figure 22 Horizontal Layout

Nested Symbols Layout

In the nested symbols legend layout the symbols are placed on top of each other with the smallest symbol on top of the largest symbol on bottom. The symbols are also a line along their tops, or bottoms.

The main reason to use a nested symbols legend layout is that it requires less space on the map layout and the vertical or horizontal legend layout. To save even more space you can place the values inside the symbols if there is space available, otherwise the value should be to the right of the nested symbols with a leader line connecting the values to the symbols.



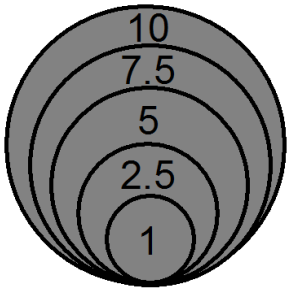


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Figure 23 Nested Symbols Layout

Nested Semi-Symbol Layout

The nested semi-symbols legend layout requires the least amount of space on a map. This is essentially the nested symbols legend but with half of the symbol missing and replaced with the values. You may also have leader lines from the top of the symbols to values as well.

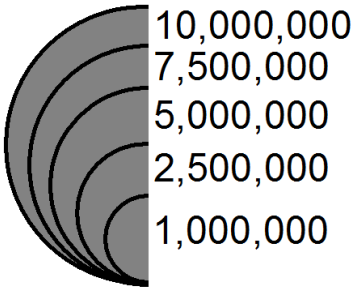

Figure 24 Nested Semi-Symbol Layout

Proportional Symbol Map: Legend Design

With respect to legend designed for proportional symbol maps there are a few special cases to consider. If a single, or if your values are significantly larger or smaller than all the other values, we may consider these outliers. In the case of outliers we can label the symbol on the map with its name and value to bring attention to it. We can also label the symbol on the legend with each unique name and value or change the color of the outlier to bring attention to it to show that it is different in some way than the other symbols. If there is not much congestion on the map it is okay to label the proportional symbols on the map itself with their values.

Dot Density Maps

A dot density map is a map showing total values represented by randomly placed dots within an enumeration area to represent density and spatial distribution. This example map shows population density for the year 2007 for the United States of America.

On this map, 1 dot represents 200,000 people. Each dot is randomly placed within its enumeration unit, which in this case, is the county. Where the dots are denser on the map the user will interpret this area as having more value. Where there are less dots on the map, the user will interpret this is having less value.

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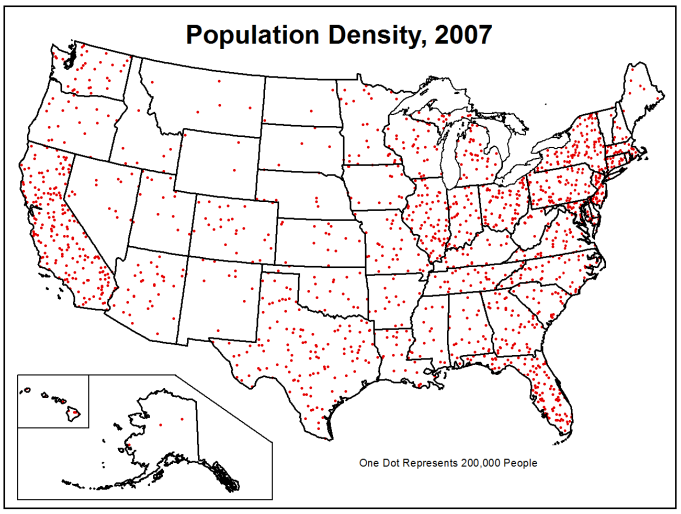

Figure 25 Dot Density Map

Why Create a Dot Density Map?

A dot density map is easy to create and easy to interpret. It excels at displaying a variable's overall geographic pattern and density. Counting the number of dots in an area will allow the map user to ascertain total values with some rounding error. Dot density maps can reflect distributions more accurately than other thematic map types.

Why Not Create a Dot Density Map?

So why should you not create a dot density map? First, map readers do not perceive dot densities linearly; they may overestimate or underestimate the densities of the dots as density increases in an area. Second the dots may not be automatically placed close to the phenomenon they represent since the dots are randomly placed.

Third the large ranges of data values make it hard to choose a single dot value. Fourth it may be hard for the map users to recover original totals when dots are place close together making it hard to pick out individual dots. Fifth and finally dots may appear where they cannot possibly exist. For example a dot representing cattle may show up in a lake when that does not make sense for the dot to be there.

Appropriate Data

Total values are the types of data that are appropriate for a dot density map. The data should be represented and aggregated to an enumeration area. You should strive for the smallest enumeration units possible to maximize the likelihood that the dot will be placed close to the location of the phenomenon. Generally the enumeration units themselves should not be shown on the map.

If you wish to show the enumeration units on the map, either deemphasize enumeration units or keep the enumeration units off the map and shows the next level up of an enumeration unit. For example, if our data's enumeration unit is counties, then we could not show counties of a map, but instead, show state boundaries. Data sets that do not have large or small ranges are also appropriate for dot density map. If the data set has a small

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range of values it will lead to a uniformed look on the map. If the data set has a large range of values it will be hard to choose a good size.

Inappropriate Data

Inappropriate data for a dot density map is continuous data that is not controlled by an enumeration unit. Data sets with small or large ranges are not appropriate. Derived data such as persons per square mile is not appropriate for dot density map.

Map Projections

The best map projection for dot density map is the equivalent, or equal area map projection. As relative size is important to maintain when comparing values within enumeration units, you should choose a map projection that maintains relative size.

About the Dots

It is important that on all dot density maps each dot represents more than one item. If the dot represents exactly one item then the dot should be placed exactly where the item it represents is located. If this is the case then what you are creating is a general reference map, not a dot density map.

Dots should be large enough to stand out but small enough to not be totally dominant on their own. Generalization of the dot values occurs at one half of the dot value. That means a dot that has the value 100,000 can be considered to represent all values between 50,000 and 149,999. Each dot is a spatial proxy which means that the dots are placed around the center of gravity of the geographic phenomenon.

Random Placement

Each dot is randomly placed inside the enumeration unit. The dots are randomly placed to avoid giving the impression that the dots are precisely placed and to avoid regular placement of the dots having large values. You can use ancillary data to restrict the placement of dots. For example, you could tell the software to not place the dots within lakes if it does not make sense for the dots to appear within the lake.

General Dot Guidelines

Here are some general dot size guidelines. Enumeration units with the smallest value should have about two to three dots inside of it. Dots should just begin to coalesce in the most dense enumeration area. Dot values should be easy to understand and to count with. For example 500 and 1000 are good dot values.

Good Dot Size and Value

In Figure 26, the dots are of a good size and of good value. In the densest area of the maps the dots just begin to coalesce; you can still generally pick out each individual dot.

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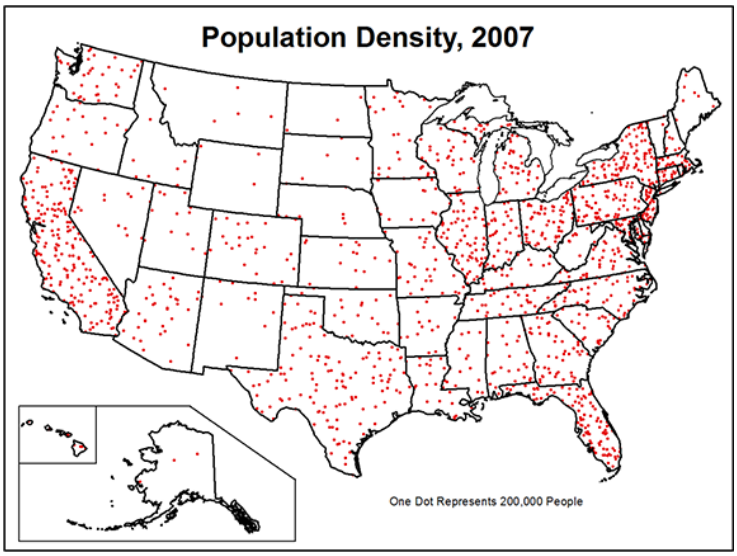

Figure 26 Good Dot Size and Value

Good Dot Size, Poor Value

In Figure 27 the dots are of a good size; however, the dot value was chosen poorly and is too large. Because the dot value is so large most of the map looks sparse and the densest areas do not give a good feeling of high density.

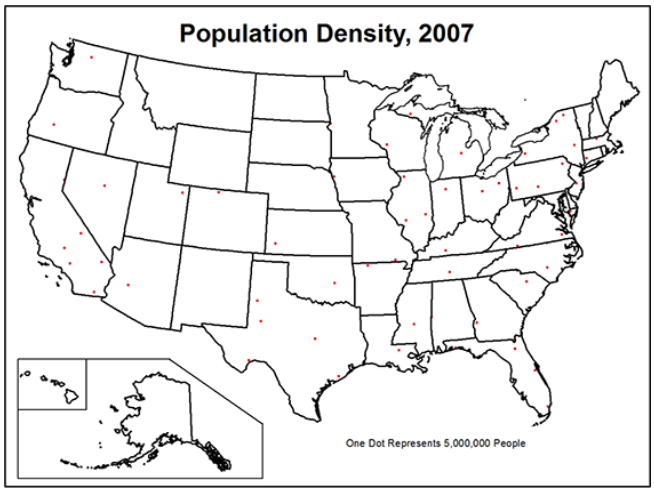

Figure 27 Good Dot Size, Poor Value

Poor Dot Size, Good Value

In Figure 28 the dots are of a poor size but the dot value is good. As the dot size is so small it still leaves the map looking sparse. The dot size should be increased so that the dots are easier to see and the map looks more filled in.

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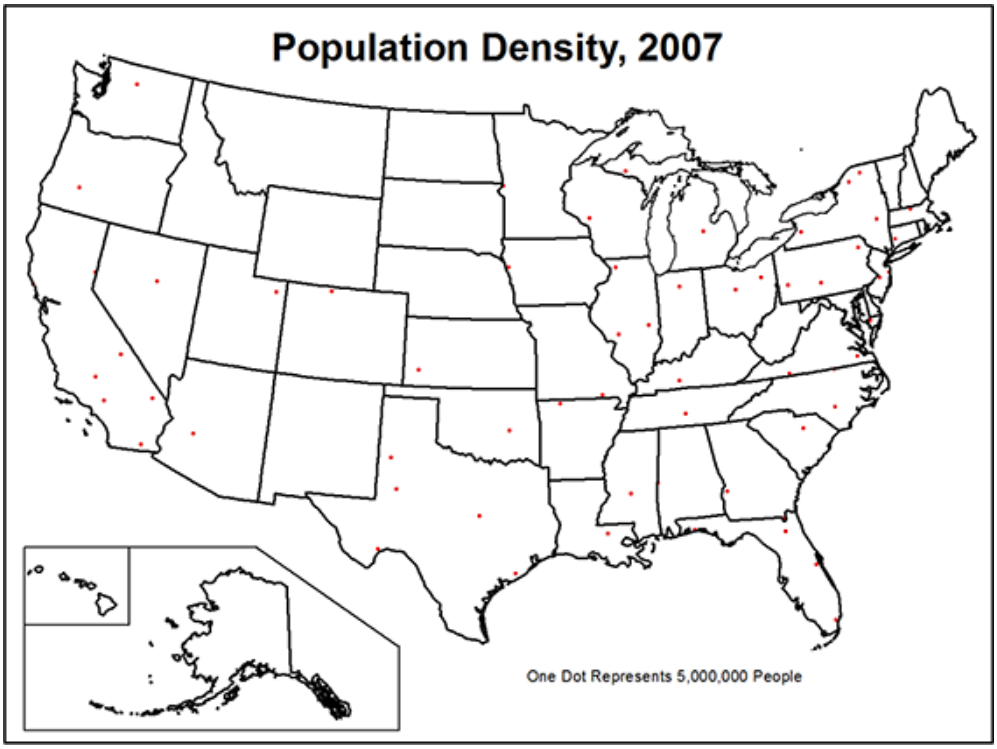

Figure 28 Poor Dot Size, Good Value

Other Symbols

It is possible to use other symbols than dots. You can use geometric shapes which are familiar to map readers and are simple and easily recognizable at multiple sizes. Another option is to use pictorial shapes which may add to the theme and memorability of the map. The negative aspect of pectoral shapes is that if the pectoral shapes are too complex they may not scale well to multiple sizes.

Reference Features

With respect to reference features on a dot density map, like other thematic maps, it too should be kept simple by design. You should avoid placing reference features unless they are important in explaining the pattern of the variable being mapped.

Dot Density Map: Legend Designs

Designing legends for dot density map is fairly straightforward. On the legend you should have a representative symbol and a statement about the value of that symbol. Rarely are legend headings required for a dot density map legend. You can include additional information in the legend if necessary, such as the total of all values of a map, or representation of what a low, medium, and high density looks like on the map.

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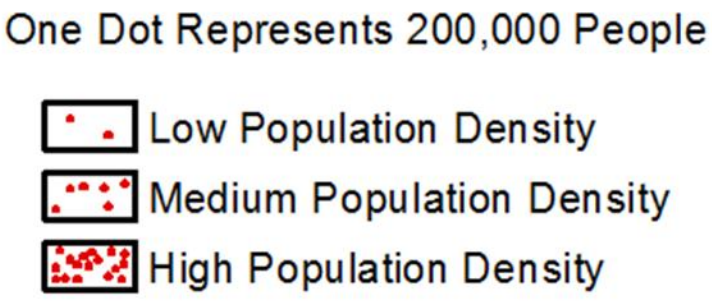

Figure 29 Legend Design

SUMMARY

This lesson covered various types of maps and their features. Choropleth, Dot Density, and Proportional Symbol Maps were exhibited and explained. You learned about appropriate and inappropriate data as well as data classifications and symbolization for each map type. Map legends and the elements that should be considered when using this feature were also covered.

ASSIGNMENTS

1. Quiz: Types of Maps
2. Lab: IDP and Refugee Proportional Symbol Map

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Lesson 5: Data for a Map

INTRODUCTION

This lesson teaches you about the elements related to data for a map. You will learn about the common data types and formats used in map creation. The lesson will help you gain an understanding of normalized data and descriptive statistics. You will also learn about data classification and the various classification requirements and methods used when making a map.

LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Identify data elements of a map.
2. Compare data classification methods.
3. Create maps using different data classifications.
4. Manage different types of data (vector, raster, and imagery), databases, and metadata to create different types of maps and map scales.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • *Example Classification in ArcGIS 10.1* (1:15) • *Example Binary Classification in ArcGIS 10.1* (1:34)
Assignments	Complete the following: • Quiz: Data for a Map • Lab: IDP and Refugee Proportional Symbol Map – Designing the Final Map

INSTRUCTION

Data for a Mapping Project

So why is data important? For any GIS and mapping project you will spend roughly 50% of your time acquiring, converting, projecting, modifying, and managing your data to get prepared for use. The other 50% of your time will be used for actually doing the project. Therefore, you should plan accordingly to spend a significant amount of time simply finding and preparing data for usage.

Data is not always easy to find or in the format in which you need it. In almost all cases you will need to perform some data transformation, selection, generalization, or other data

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preparation operations before you can use the data for your GIS project or map. Quite often knowing someone will help you get the data quicker. While there are many GIS data clearinghouses and websites on the Internet, they are quite dispersed and sometimes difficult to find and navigate. Additionally some of the data you desire may not be available online so you should use your social network to find data when appropriate.

Digital Data

There is digital data available almost everywhere. Even though the data is available in many places sometimes it is still difficult to find. In either case digital data is the least expensive source of spatial data because the reproduction costs are close to zero. Digital data are often developed by governments because the data helps provide basic public services and adds value to the comments.

There are many available data formats that a GIS can ingest, however, typically when acquiring data from sources, the data is typically going to be in one of these for formats: raster, vector, ASCII, or an interchange format. The raster and vector data types are ready for use in a GIS that any conversion in most cases. The ASCII and interchange formats typically require some data transformation and conversion in order for it to be ready for use in a GIS.

Digital Raster Graphic (DRG)

A digital raster graphic, more commonly referred to as a DRG, is a geo-referenced raster from scanned USGS maps. The DRGs come in three scales of 1 to 24,000, 1 to 100,000, and 1 to 250,000. The USGS maps that are scanned into DRGs are typically older data but reasonably reliable. Therefore a good use for a DRG is for a quick check for consistency and new data collection. For instance if you receive a road data set and you want to quickly make sure that it is geo-referenced to the correct place you can overlay on top of the DRG to see if they line up. Figure 1 is a portion of a USGS map. This is considered a general reference map and displays things such as buildings, contour lines, rivers, political boundaries, roads, railroads, among other features.

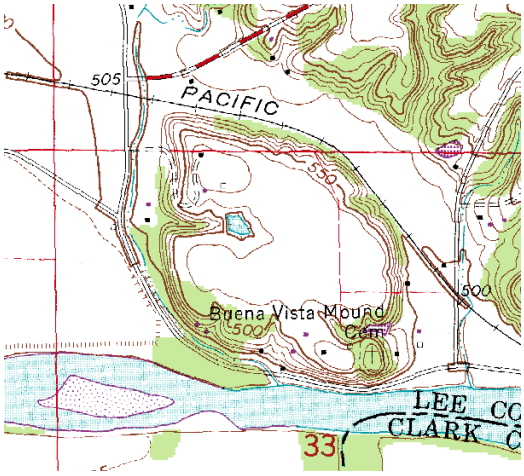

Figure 1 General Reference Map

Populated Area

Figure 2 is a portion a DRG of a populated area. The squares represent buildings. Notice that some of the squares are black and some of the squares are purple. The black squares

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and symbols are from the original publishing of the map. The purple squares in figures are from a subsequent update of the map.

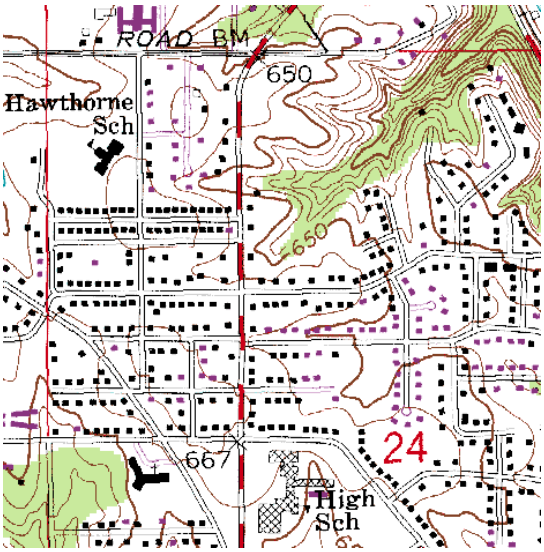

Figure 2 Populated Area

Digital Line Graph (DLG)

A digital line graph, commonly referred to as a DLG, is the vector representation of most features on the USGS national series of maps which we just saw as DRGs. DLG's come in three scales: 1 to 24,000, 1 to 100,000, 1 to 2 million. The DLG's are separated out by theme.

So for example you will have a DLG shapefile for boundaries, a DLG shapefile for roads, hypsography, and hydrography. Like the DRGs, DLG shapefiles are useful for quick check for consistency and data collection. Additionally DLG's cover the entire United States so they can provide a reasonably good national data set. Figures 3 and 4 are examples of a road and hydrography data set from a DLG.

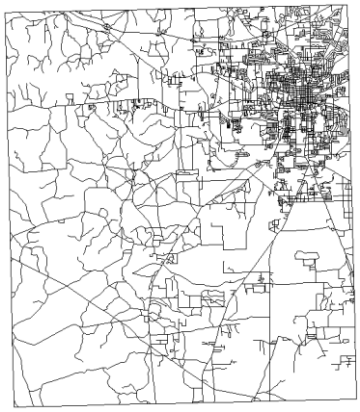

Figure 3 Roads

Figure 4 Hydrography

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Edge Mapping

One of the nice things about the DLG data set is that they perform edge matching. As the DLG's were digitized from DRGs, there are cases where features exist across to different maps. When the DLG's were created the features were matched up across the two different maps.

Figure 5 Edge Mapping

Vertical Line Edge Mapping

In this image the vertical line in the center of the image represents the separation of the two maps. The polygons represent lakes. If you take a look at the lakes that cross the vertical line you can see that the features connect to each other and allow for continuity across multiple DLG data sets.

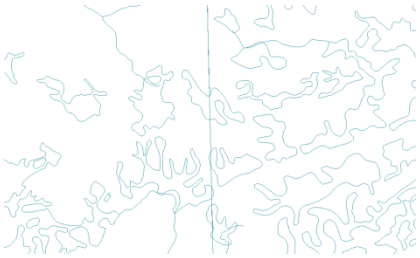

Figure 6 Vertical Lin Edge Mapping

Digital Elevation Model (DEM)

A digital elevation model, or more commonly referred to as a DEM, is a continuous data set that provides elevation data and a raster format. As raster can sometimes be very large in file size, DEM's may be initially provided in an ASCII format so that it can be easily compressed down to a smaller size.

DEMs are provided at various scales depending on who collected the elevation data and for what purpose. DEM's are extremely useful for analysis and visualization of elevation information. A challenge with DEM data is that there are so many different formats for it, that you may need to do significant amounts of converting before you can place it into your GIS.

Multiple Stream Networks

Figure 7 is an example of a DEM that is showing multiple stream networks in a fairly mountainous terrain. As the raster only contains elevation information, DEMs do not have any color information stored inside of them. Therefore, it is up to you to assign a color

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ramp, or color map to the DEM to represent the different elevations. In a black and white image of a DEM higher elevations are typically represented in lighter colors, and lower elevations are presented with darker colors. For this DEM the highest value is pure white and the lowest value is a dark black. Knowing this we can easily identify where the streams are and the mountain ridges are.

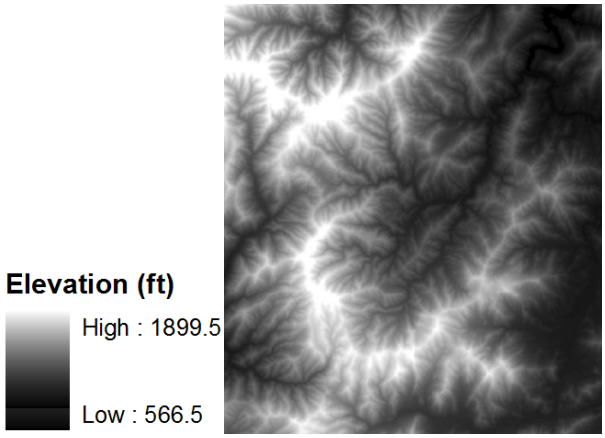

Figure 7 Digital Elevation Model

Various Coverage Area

DEMs come in many different resolutions and cover different amounts of space. In Figure 8 (top image) the DEM covers the entire United States at a very low raster resolution. The DEM in the bottom image covers a smaller area of the United States, as a high-resolution and thus has more detail.

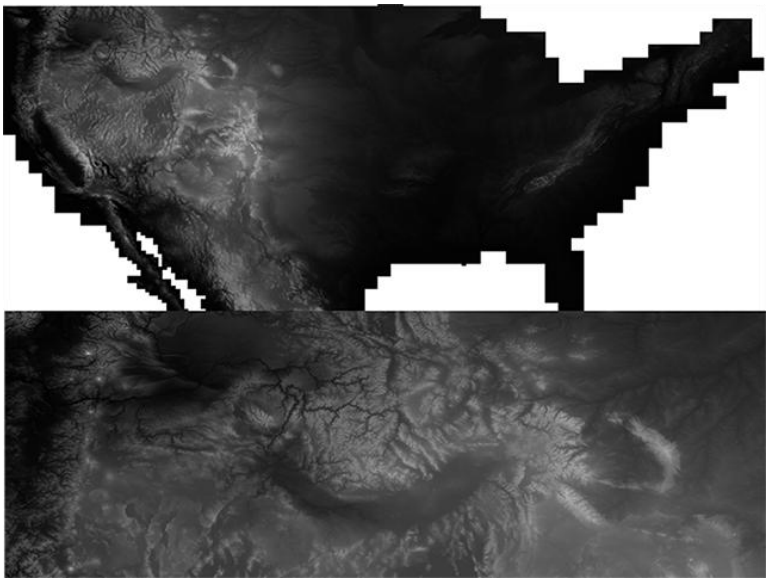

Figure 8 (Top image) Low Resolution DEM (Bottom image) High-Resolution DEM

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Color

It is common for DEM's to be assigned different shades of color to represent different types of terrain at different elevations. Additionally it is common to do shadow modeling based off the DEM's so that the terrain has a three dimensional look.

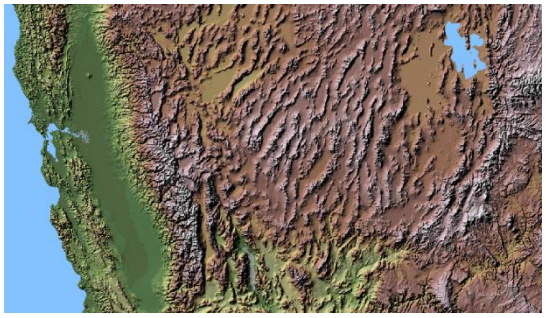

Figure 9 Color DEM

Digital Orthophoto Quadrangle (DOQ)

A Digital Orthophoto quadrangle, commonly referred to as a DOQ, is a digital or film photo saved in a raster format that is been corrected for distortion. DOQs are available for most of the United States at many different epochs in time. DOQs are useful for serving as a background image to your map, identifying control points for geo-rectification or projects, or for using as a base for digitizing new data.

True Color DOQ

Figure 10 is an example of a DOQ that shows a portion of the earth in its true color representation.

Figure 10 True Color DOQ

Infrared DOQ

Figure 11 is an example of a DOQ that shows a portion of the earth using the infrared portion of the electromagnetic spectrum.

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Figure 11 Infrared DOQ

Color DOQ Zoom

If we zoom into the true color DOQ, we can see that it starts to become slightly pixelated as we are reaching the limits of its resolution. However we can still see quite a bit of detail on this DOQ such as paint on the street, houses, cars, and other interesting features.

Figure 12 Color DOQ Zoom

National Aerial Imagery Program (NAIP)

The National Aerial Imagery Program (NAIP) is a program sponsored by the USDA Farm service agency. Their object is to acquire raster photos during growing season the continental United States of America at the one to two meter resolution. NAIP imagery is useful for digitizing and identifying information about vegetation type or condition.

NAIP Image

NAIP images are collected using infrared which makes it very easy to identify and differentiate different types of vegetation, and their health.

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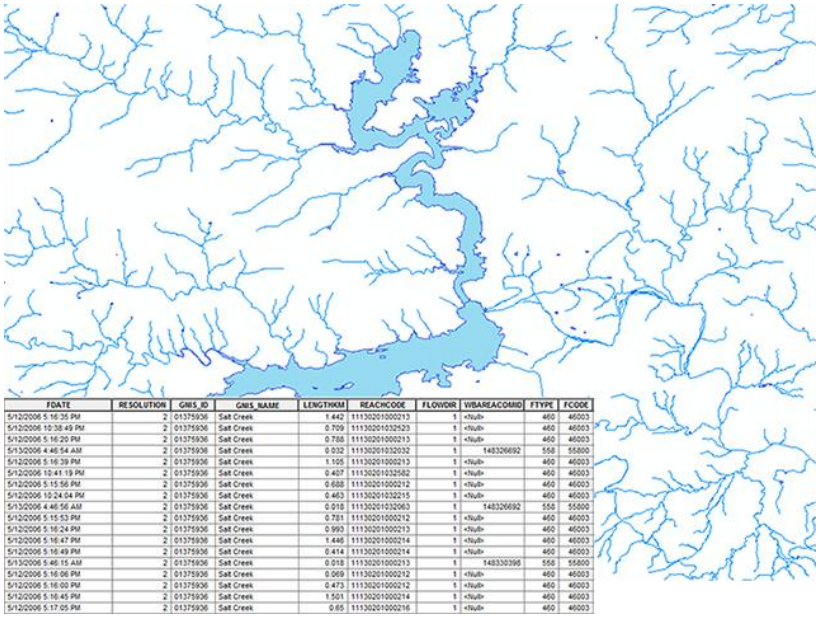
Figure 13 NAIP Image

Hydrologic Data

For hydrologic data a good source is the National Hydrologic Data Set (NHD). The NHD contains a database of surface waters derived from USGS DLG and EPA reach data. The data is provided at a 1 to 100,000 scale and represents networked topology. The EPA also provides information on watersheds and other data sets. The NHD is provided in a vector format but it might be provided in an exchange format that needs to be converted before use.

Figure 14 is an example of a portion of the NHD. The NHD has both line and polygon information and detailed attributes.



FDATE	RESOLUTION	GNIS_ID	GNIS_NAME	LENGTHKM	REACHCODE	FLOWDIR	WBAREACOMID	FTYPE	FCODE
5/12/2006 5:16:35 PM	2	01375936	Salt Creek	1.442	11130201000213	1	<Null>	460	46003
5/12/2006 10:38:49 PM	2	01375936	Salt Creek	0.709	11130201032523	1	<Null>	460	46003
5/12/2006 5:16:20 PM	2	01375936	Salt Creek	0.788	11130201000213	1	<Null>	460	46003
5/13/2006 4:46:54 AM	2	01375936	Salt Creek	0.032	11130201032032	1	148326692	558	55800
5/12/2006 5:16:39 PM	2	01375936	Salt Creek	1.105	11130201000213	1	<Null>	460	46003
5/12/2006 10:41:19 PM	2	01375936	Salt Creek	0.407	11130201032582	1	<Null>	460	46003
5/12/2006 5:15:56 PM	2	01375936	Salt Creek	0.688	11130201000212	1	<Null>	460	46003
5/12/2006 10:24:04 PM	2	01375936	Salt Creek	0.463	11130201032215	1	<Null>	460	46003
5/13/2006 4:46:56 AM	2	01375936	Salt Creek	0.018	11130201032063	1	148326692	558	55800
5/12/2006 5:15:53 PM	2	01375936	Salt Creek	0.781	11130201000212	1	<Null>	460	46003
5/12/2006 5:16:24 PM	2	01375936	Salt Creek	0.990	11130201000213	1	<Null>	460	46003
5/12/2006 5:16:47 PM	2	01375936	Salt Creek	1.446	11130201000214	1	<Null>	460	46003
5/12/2006 5:16:49 PM	2	01375936	Salt Creek	0.414	11130201000214	1	<Null>	460	46003
5/13/2006 5:46:15 AM	2	01375936	Salt Creek	0.018	11130201000213	1	148330396	558	55800
5/12/2006 5:16:06 PM	2	01375936	Salt Creek	0.069	11130201000212	1	<Null>	460	46003
5/12/2006 5:16:00 PM	2	01375936	Salt Creek	0.473	11130201000212	1	<Null>	460	46003
5/12/2006 5:16:45 PM	2	01375936	Salt Creek	1.501	11130201000214	1	<Null>	460	46003
5/12/2006 5:17:05 PM	2	01375936	Salt Creek	0.65	11130201000216	1	<Null>	460	46003

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Figure 14 Hydrologic Data

Digital Soils Data

The natural resource conservation service of the USDA has developed vector data sets of soils data. The digital soils data are provided in three different data sets. NATSGO provides soils data at a small scale. STATSGO provides soils data at a medium scale, and SSURGO provides soils data at a large scale. All of these data sets were developed from soil surveys. The data sets link to very detailed databases that may require some training or reading the instructions to use.

Soils Data Example

Figure 15 is a snapshot of a data set from the soils data. Each polygon of a different color represents a different type of soil. Each polygon relates to a detailed database that outlines things such as the type of soils and permeability.

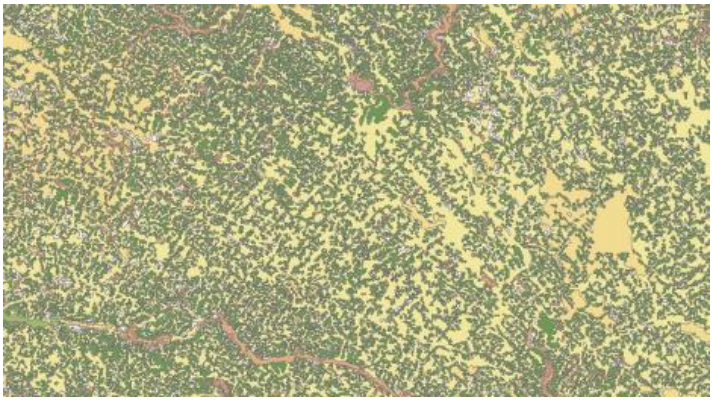

Figure 15 Soils Data Example

Digital Floodplain Data

If you are looking for digital floodplain data, FEMA developed floodplain maps and a vector data set that is useful for floodplain determination and for setting insurance rates. Figure 16 is an example from the FEMA floodplain data. The polygons represent different types of floodplains.

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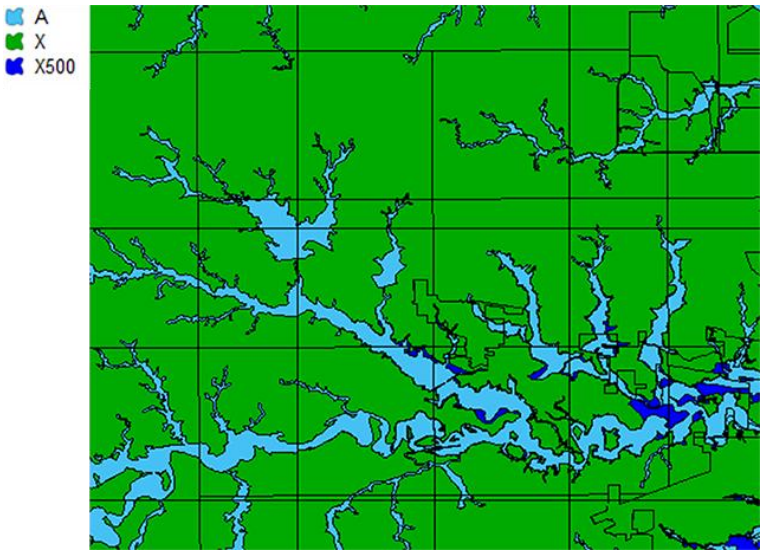

Figure 16 Floodplain Data Example

Census Data

The U.S. Census Bureau develops vector Tiger files that contain information collected during the national census. The Tiger files are organized by state, county, tract, block, and group. The Tiger files are in a GIS format that can easily link to census statistical data. This data is useful for a wide number of applications and the census data uses the topology.

Figure 17 is an image of information created by the US Census Bureau that shows the 2010 census profile for Colorado. The census data provides information such as total population, population by race, population by sex and age, what types of houses the population lives in, and many, many other useful facets of the population of the United States.

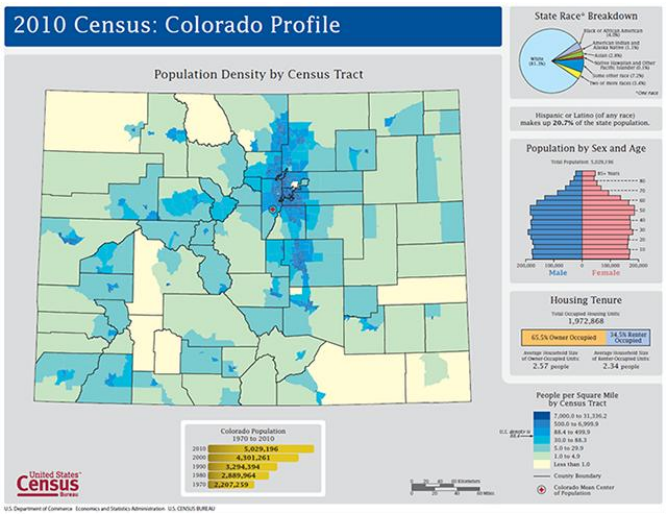

Figure 17 Census Data

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National Land Cover

The national land cover data set is provided in a raster format at a 30 meter resolution that covers the United States. The national land cover data set contains many classes such as where urban areas are, and agricultural areas. The national land cover data set is based on photo interpretation and classification and can be useful for analysis of land-use.

Figure 18 is an example of a portion of a land cover data set. Each raster cell contains a value that represents a different type of land cover.

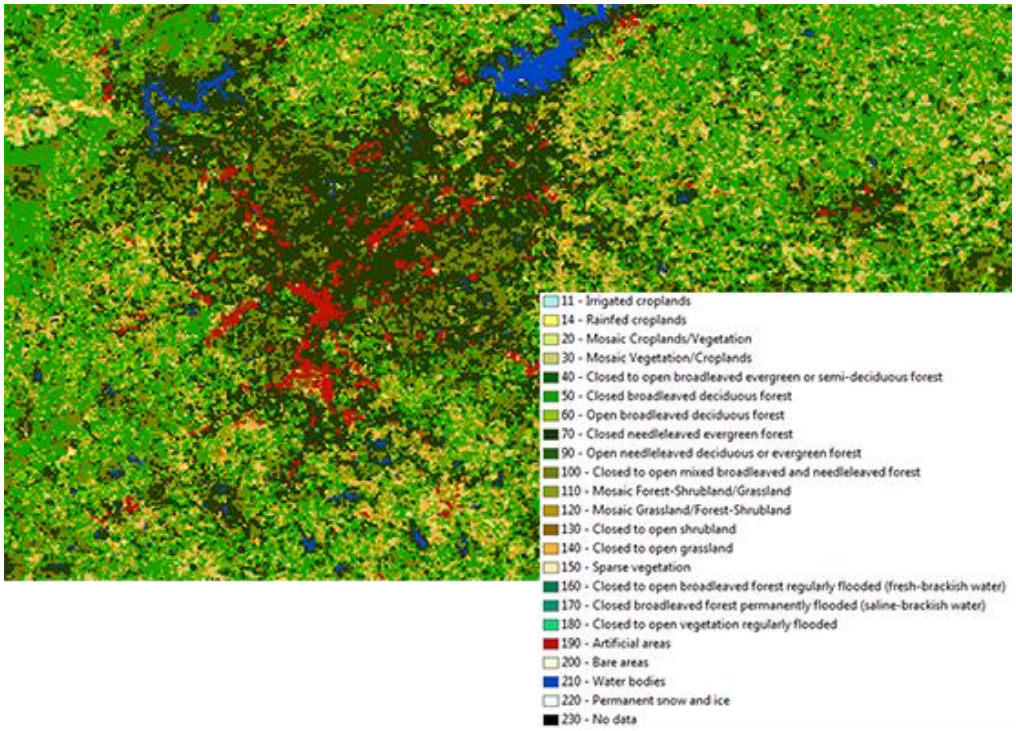

Figure 18 Land Cover Data Set

Natural Earth Data

Another useful data set is known as the Natural Earth data. Natural Earth data is a data set that is in the public domain and contains both raster and vector data sets. The Natural Earth data set contains cultural and physical data with worldwide coverage at 1 to 10 million, 1 to 50 million and 1 to 100 million scales. The Natural Earth data provides a very nice generalized data set for small scale mapping.

Vector Data

This image is an example of the vector data offered in the Natural Earth data set. It provides information such as physical and political boundaries, water, and man-made features.

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Figure 19 Vector Data

Raster Data

Figure 20 is an example of the raster data offered in the Natural Earth data set. This raster data provides attractive elevation rasters with modeled shadows so that it achieves a good three-dimensional look.

Figure 20 Raster Data

Websites for Data

This is by no means an exhaustive list of websites that are useful for downloading freely available GIS data sets, but are good sources to collect the data that was discussed in the previous section. In addition to these websites each state usually has its own GIS clearinghouse so you should check for one in your state of interest.

- US Geo Data
- National Atlas
- USGS National Map
- National Hydro Data
- National Cooperative Soil Survey Soil Characterization Data
- Natural Earth
- National Historical Geographic Information System

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- Census TIGER files from Census Bureau
- Census Bureau State Data Centers Program

Normalization of Data

To begin learning about appropriate data use for thematic maps we start with the normalization of data concept. Raw and total values are often useful to maps; however, areas that are larger in size may have more of some value than areas that are smaller in size simply because there is more area. If you want to compare the density of an object between two areas that are different sizes a fair comparison is not possible. Therefore, we normalize data to allow for meaningful comparisons of values by taking size out of the equation. Raw data that is not normalized does not accurately display densities or proportions.

Raw vs. Normalized Data

If we compare raw data versus normalized data by looking at the total population of United States we get two completely different looking maps. Figure 21 displays total population by state as a choropleth map. The lighter colors are where there is less population and the darker colors are where there is more population. Note that California and Texas are the highest states and are also among the larger states which means that there is more room for people to live so they naturally have higher populations.

However if we normalize the data by area we can get a view of how dense each state is with respect to population. Figure 22 shows the population per square mile which shows a significantly different view than the total population map. Here, the smaller states in the Northeast have less total population but have more people per square mile because the states are significantly smaller than the states out West.

Figure 21 Choropleth Map of Total Population by State

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Figure 22 Choropleth Map of Population per Square Mile

Density

When discussing density, the idea is that larger enumeration or statistical units often have more of an attribute simply because it covers a larger area. Showing raw numbers per enumeration unit ignores the effect that the size the numeration unit might have on its total values. By accounting for the size of the enumeration unit it allows for a fair comparison between different locations as size is no longer a factor.

Enumeration Units

Again we have the two maps of population. In the total population map, large enumeration units lead to larger total population. Small enumeration units with more population per area mean that they are denser.

Figure 23 Total Population

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Figure 24 Population per Square Mile

How Much Exists?

Density reveals how much of an item exists within a given enumeration unit. In other words, you normalized the raw data value by the size of the numeration unit. For example, we would normalize population which is the raw data value by a square mile. This is an areal unit inside the statistical or enumeration unit. Having the size of the numeration units accounted for by normalization reveals a more meaningful pattern in the data.

Proportions

Proportions represent a relationship of a part of the whole. Proportions can be presented as percentages, for example, a population is 59% female. Proportions can also be presented as rates or N per X. For example: 37 infections per 10,000 people. Similarly to density, proportions allow meaningful comparisons between enumeration units.

Raw Data

If you look at the raw data of total population under the age of five in the United States shown in Figure 25 we see that again Texas and California dominate the nation. However if we change the data and enter a proportion so that we show the percent population under five years old per state, we see that Louisiana and Utah top the nation (Figure 26).

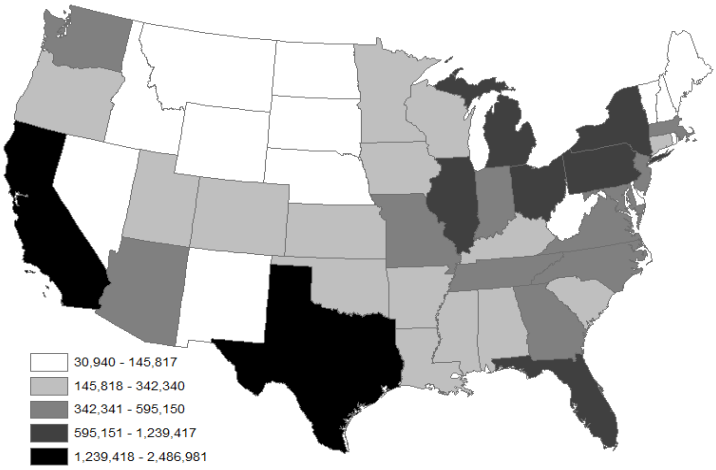

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Figure 25 Total Population under 5 years old

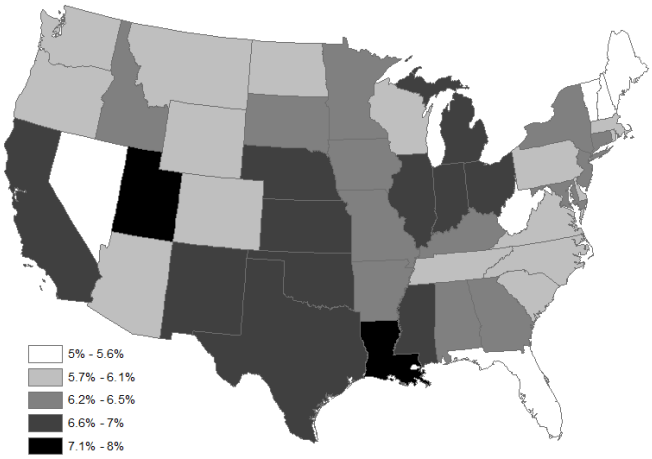

Figure 26 Percentage of Population under 5 years old

Descriptive Statistics

So what are descriptive statistics and why should you know about them for mapping? Descriptive statistics are quantitative descriptions of data that provides some basic descriptions of the data set. Cartographers use descriptive statistics to explore the character of the data. Descriptive statistics can describe things such as the central tendency of the data, the dispersion of the data, and the shape of the data.

Central Tendency

Central tendency of data describes the distribution of the data. There are six measures that we commonly used to describe the central tendency of a data set: maximum, minimum, range, mean, median, and mode.

Maximum and Minumum

The maximum measure of central tendency simply reports the maximum value in a data set. The minimum measure of central tendency returns the minimum value in a data set. The range measure returns the maximum value minus the minimum value of a data set.

Mean

The mean measure of central tendency is the average value of the data set. The average value is defined by summing all values of the data set and dividing it by the number of values in the data set.

Mean Equation

$$\bar{X} = \frac{\Sigma x}{N}$$

Median

The median measure of central tendency reports the middle point of the data. For instance, if we had three observations in our data set we would sort the observations in ascending order and then look at the value at the midway point which would be the second

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observation of this case. If there is an even number of observations in a data set then the media will be the average of the two most central observations.

Mode

The mode measure of central tendency reports the most common value found in the data set. If multiple values are tied as the most common value, the data set has multiple mode values.

Dispersion

Dispersion measures the variability of the data set. There are two measures of dispersion: variants and standard deviation.

Variance

The variance measure of dispersion takes the sum of the squares of the deviations divided by the number of observations. The units of variance are identical to the original units of measure. So for instance, if the original units of the observations were in feet then they variance will report how much the observations vary on average in feet.

Variance Equation

$$\sigma^2 = \frac{\Sigma(x - \bar{X})^2}{N}$$

Standard Deviation

The standard deviation is similar to the variance except that it takes the square root of the sum of the squares of the variance divided by the number of observations. The standard deviation measures dispersion in a standard way so that two different data sets can be compared. Standard deviation does not report the dispersion in the original units of the observations.

Standard Deviation Equation

$$\sigma = \sqrt{\frac{\Sigma(x - \bar{X})^2}{N}}$$

Normal Distribution

In the image here you are looking at a normal distribution of data which means that most of the examples of the data set are close to the average value while relatively few examples tend to one extreme or the other. The X axis is the value in question and the y-axis is the

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number of observations for each value on the x-axis. The standard deviation of tells us how tightly all the various observations are clustered around the mean of the data set.

When the examples are pretty tightly bunched together the bell shaped curve is steep and the standard deviation is small. When the examples are spread apart the Bell curve is relatively flat which tells you that you have a reasonably large standard deviation. One standard deviation away from the mean in either direction on the horizontal axis accounts for about 68% of the observations in the data set. Two standard deviations away from the mean which are the four areas closest to the center account for about 95% of the observations the data set. Three standard deviations account for about 99% of all the observations of the curve.

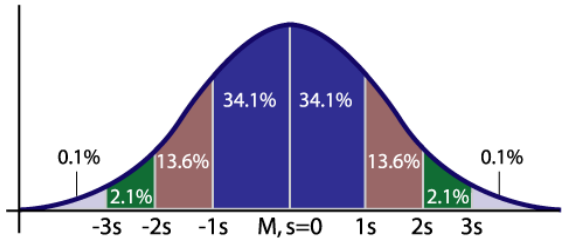

Figure 27 Normal Distribution

Skewness

The skewness measure tells us whether the peak of a distribution is to one side of the mean or the other. If a data set has a negative skew then the peak of the distribution is above the average. If a data set has a positive skew the peak of the data set is below the average.

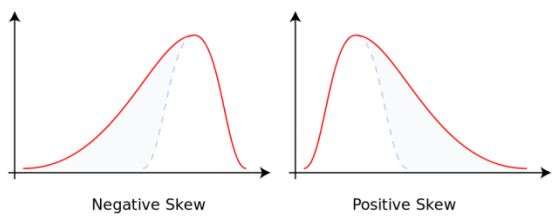

Figure 28 Skewness

Kurtosis

The final measure of central tendency is Kurtosis. Kurtosis describes the flatness or peakedness of a distribution. For normal distribution, the Kurtosis is equal to the value of 3.0. A normally distributed data set having the Kurtosis value of 3.0 is a mesokurtic distribution. A value above 3.0 is a leptokurtic distribution. A value less than 3.0 is a platykurtic distribution.

Figure 29 is a visualization of the three types of kurtosis. The green line is the normal distribution with a value of 3.0 and is mesokurtic. The red line with a strong peak is the leptokurtic distribution an d has a value greater than 3.0. The blue line which has a flat top is the platykurtic distribution which has a value less than 3.0.

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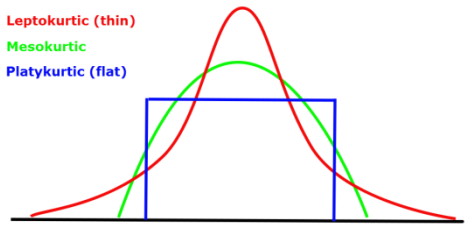

Figure 29 Kurtosis

Data Classification

Data classification categorizes objects based on a set of conditions into separate bins or classes. Classification may add to or modify attribute data for each geographic object. For example a classification could add a new code such as large or small. Classification could also recode an attribute such as changing urban to dense. One attribute can yield many different maps depending on which classification method is chosen. Different classification methods will have a direct effect on how the map and data are perceived by the map user, therefore much care must be taken when choosing a data classification method.

Why Classify Data?

The primary reason to classify data is to simplify the data for visual display. For instance, Figure 30 assigns each value a unique color which in this case means that each county has its own unique color. It is very difficult to look for patterns in this case when each county has its own unique color. The map in Figure 31 uses the same data but uses a data classification method to categorize the counties to make it easier to visualize the data. With the classified data the lighter values represent less of an item and the darker values represent more of an item, spatial patterns of distribution begin to emerge.

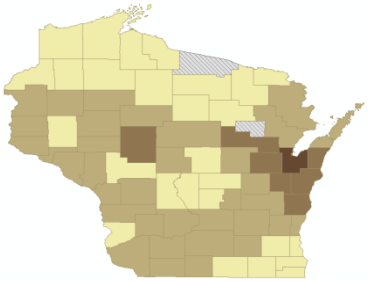

Figure 30 Data Classification

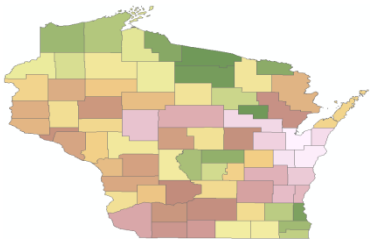

Figure 31 Unique Color

Example of a Classification

Figure 32 is an example of a classification showing countries with high, medium, and low values of population.

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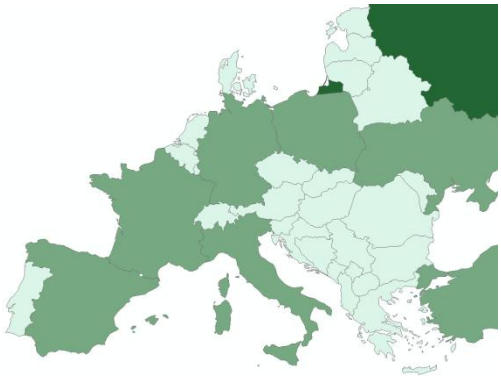
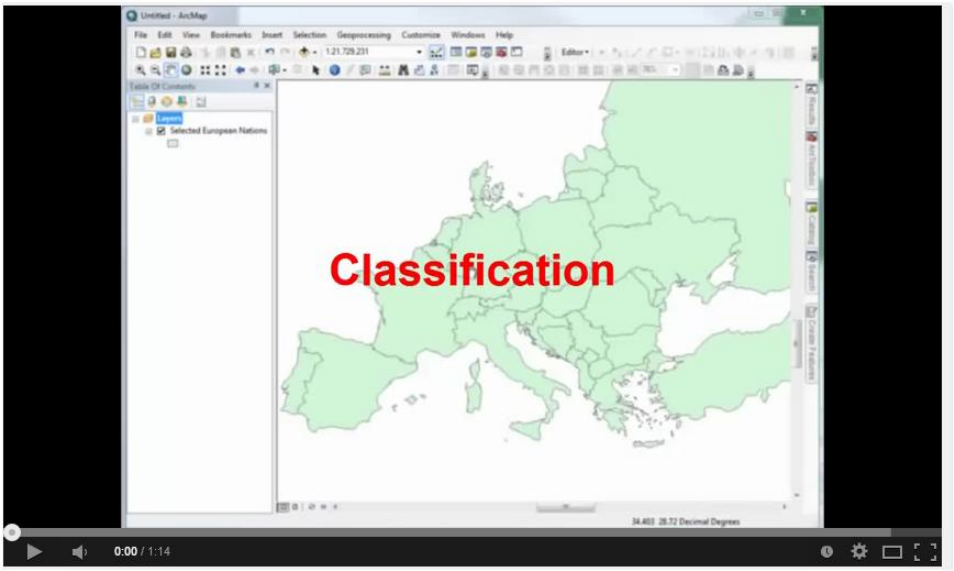


Figure 32 High, Medium, and Low Population Values

Video Example

The video, *Example Classification in ArcGIS 10.1* (1:15), demonstrates how to create a classification and ArcGIS based on total population for European countries.



Classification Goals

There are three goals for data classification with regards to cartography. The first goal is to simplify the visualization so that spatial patterns of distribution can become more easily viewable by the map reader. The second goal is to group similar observations together. The third goal is to show the difference between the groups.

Classification Requirements

The main consideration when classifying data is that you should maintain the character of the original data even after classification. The class of data should still represent the trend of the data. Also, do not choose colors or classes that intentionally mislead the map reader. Your goal in classifying data is to simplify the data for visualization, not to modify the character of the data.

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Full Range of Data

The next classification requirement is that you should always encompass the full range of data. Do not exclude data because it is convenient or inconvenient. You will want to exclude "no data" values from the classification. The "no data" data values should still be visualized but not as part of the classification continua. Instead the "no data" values should be visualized differently than the other classes. When looking for "no data" values in a data set you should read the metadata for the data set to see how they represent the no data values. Common no data values are: no data, -99, -9999, null, ND, NA.

No Overlapping or Vacancies

When classifying the data you should never have overlapping or vacant classes. For example, if we look at this legend for the choropleth map, two classes claim to contain the value of 30. This should never happen as a single value can only exist in a single class. To fix this, you should change the range of one of the two classes.

The class that holds 17 to 30 could be changed to hold the values 17 to 29. You should never have vacant classes, which means a class that has no observations inside of it. The only exception is if you're making a series of maps covering a wide time range and you want to use a single legend for all of the maps.

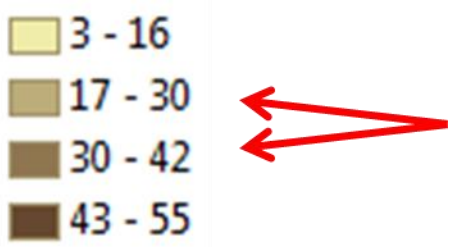

Figure 33 Overlapping Classes

Balance

The next classification requirement is that you should strike a balance of the number of classes for your map and data. As a number of classes increase visual interpretation becomes more difficult for the map reader. Therefore you should choose a number of classes that is equal to interpret but still shows adequate complexity in the data.

Choosing Number of Classes

When considering the following when determining the number of classes to choose. If you choose too many classes it requires the map reader to remember too much when viewing your map and that may require them to make frequent trips to the legend. It may also make the differentiation of class colors difficult for the map reader.

If you choose to view classes it oversimplifies the data possibly hiding important patterns. Additionally each class may group dissimilar items together which is in direct opposition of one of the main goals of classification. Typically in cartography three to seven classes are preferred and five is probably the most common and optimal for most thematic maps. Feel free to use more or less classes as you see fit. Keep in mind the issues with choosing many, or few classes.

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Two Classes Example

On this map in Figure 34 there are only two classes which make for a fairly boring map and it is probably hiding more complex patterns. Notice the two counties that are not shaded the color but instead have the hachures. These two counties are symbolized differently from all the other counties because those two counties did not have any data reported.

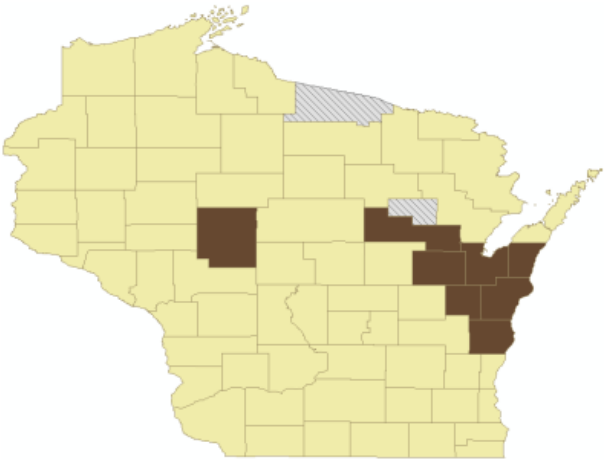

Figure 34 Two Classes

Too Many Classes Example

On the map in Figure 35 there are way too many classes which make it difficult to tell some shades apart and will require multiple trips to the legend to remember which shade of color corresponds to which value range.

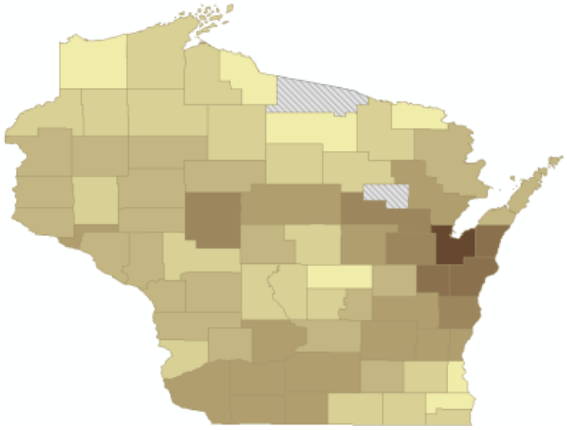

Figure 35 Too Many Classes

Four Classes Example

The map in Figure 36 has a good number of classes. This map has four classes and still shows useful patterns and complexity.

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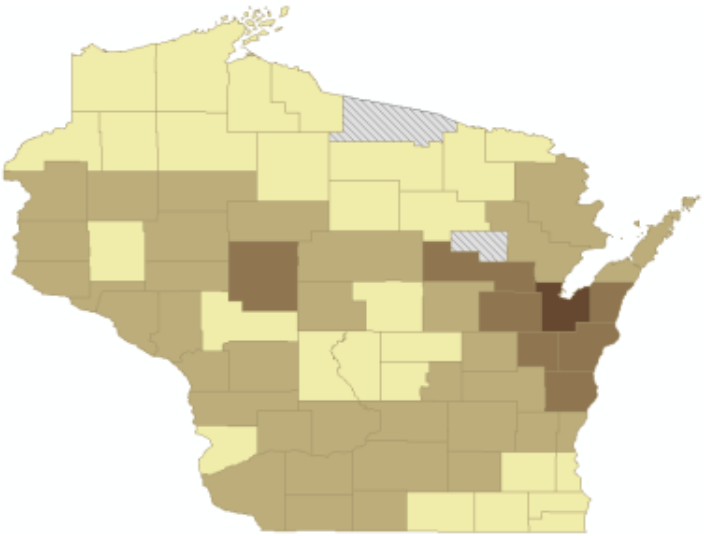

Figure 36 Four Classes

Divide Data

The next classification requirement is that you should always divide data into reasonably equal groups. Classes do not always need to be equal in size; however, classes should not have very large discrepancies and observations and has a goal of classification as a group like observations. In Figure 37 classes one, three, and four have two, six, and one observations respectively. The second class has 96 observations, and encompasses a disproportionately large portion of the data observations thus making for a very boring, and unbalanced map.

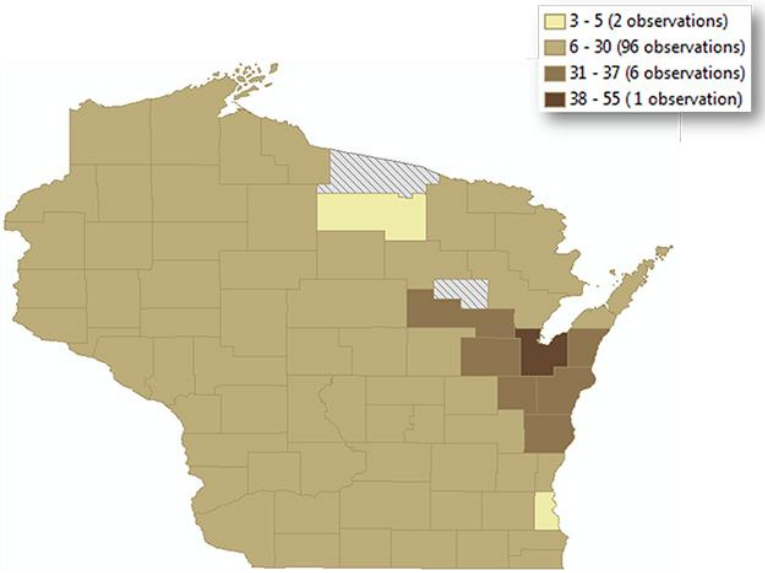

Figure 37 Varying Observations

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Logical Mathematical Relationships

When classifying data you should have logical mathematical relationships if possible. This means that if the data lends itself to common mathematical relationship you should use it. If the data set has a normal distribution perhaps you should choose the standard deviation data classification method.

Example: Academic Grades

100-90 = "A"
89-80 = "B"

Choose Colors Wisely

You should choose colors wisely when applying them to classes. There are two categories of color choices that are appropriate for classifying quantitative data: sequential, and divergent.

Figure 38 (Left) Sequential and (Right) Divergent Color Classifications

Sequential Color

Use a sequential color ramp to represent categories with data that increase incrementally from a low to high value. To accomplish this you may choose a single queue, or color, with incremental changes in its value or saturation, but not both. Colors that are more saturated represent higher data values and colors that are less saturated represent lower data values.

Divergent Color

Use a divergent color ramp to represent categories with data that increase in opposite directions from some neutral point. Complementary hues should be used in saturations should increase towards each extreme. Colors that are more saturated represent more extreme data values and colors are less saturated represent less extreme data values that are closer to the neutral point. If a central value does exist it should be neutral gray or equal low saturation amounts.

Classification Methods

In the following section you will be introduced to various types of classification methods including binary, dissolve and automatic.

Binary Classification

Binary classification is when objects are placed into two classes. The two classes can be the value of 0 and 1, true and false, or any other dichotomy that you would use. Typically a binary classification is used to store the results of complex operations when the operation returns either a yes or no answer. In Figure 39 the states were classified into two binary classes: one class for the northern states and one class for the southern states.

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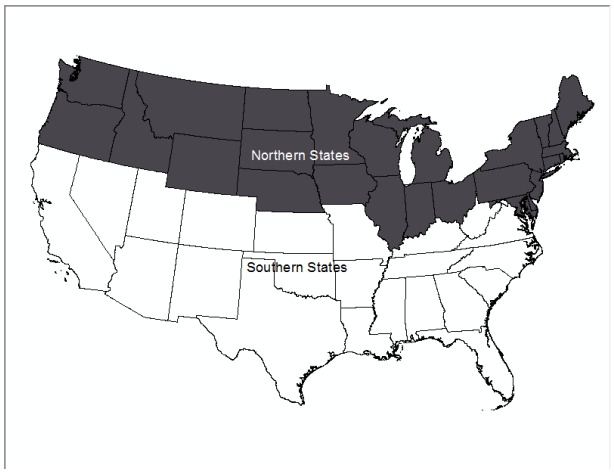
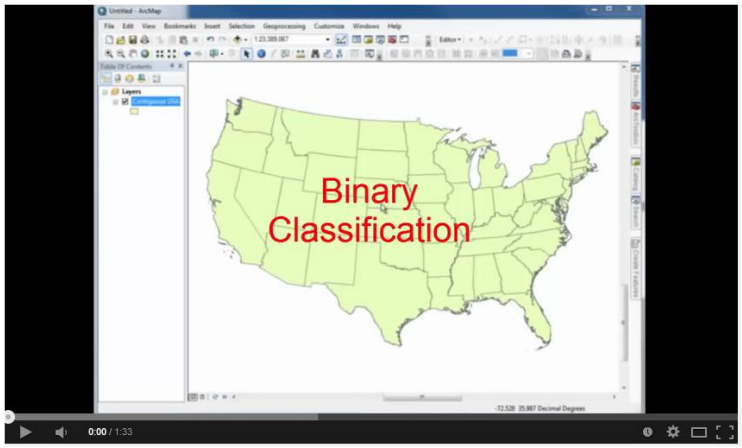


Figure 39 Two Binary Classes

The video, *Example Binary Classification in ArcGIS 10.1* (1:34) demonstrates how to perform the binary classification to achieve the classification of northern and southern states using ArcGIS 10.1.



Dissolve Classification Method

The next classification method we can use is the dissolve method. The dissolve method combines similar features within a data layer based on a shared attribute. Considering the northern and southern states example again we can dissolve all the states based on whether they are a northern state or a southern state. The dissolve operation creates new geometry which in this case is polygons. One polygon combines the extents of all of the northern states. The second polygon combines all the extents of the southern states. Take note that the new geometry does not transfer any of the attributes of the dissolved.

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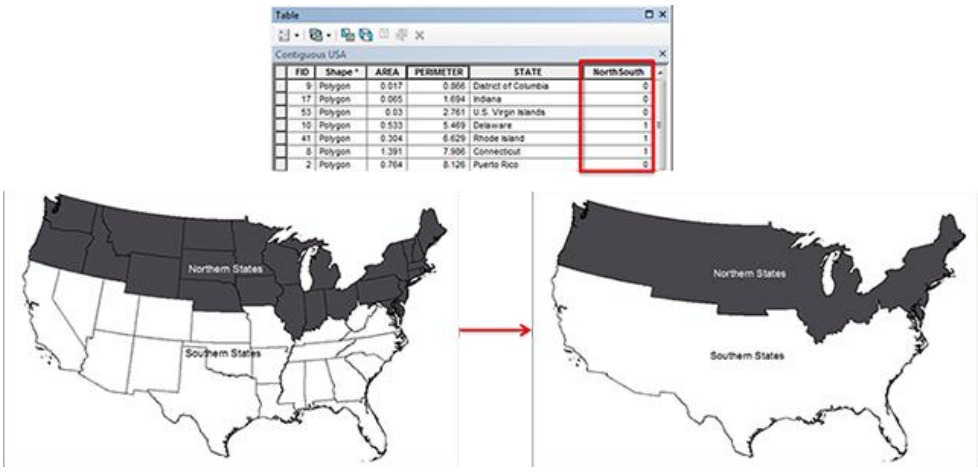

Figure 40 Dissolve

Automatic Classification Methods

This next section will explain several types of automatic classification methods. An automatic classification method is where you set up rules for the computer to follow and in the computer executes the data classification.

Jenk's Natural Breaks Classification Method

The Jenks natural breaks classification method aims to maximize homogenate classes. It uses breaks in a histogram as class breaks and assumes that group data are alike. Advantages of the Jenks natural breaks automatic classification method is that it considers the distribution of data to minimize in class variance and maximize between class periods. This method produces a classification with high accuracy of maximizing homogenate eating classes. A disadvantage of the Jenks natural breaks is that it is complicated to understand how it works.

Advantages	Disadvantages
Considers distribution of data and produces classification with high accuracy.	Complicated
Minimizes in-class variance and maximizes between-class variance.	Difficult to understand procedure for grouping.

Figure 41 includes an example of a Wisconsin map classified using the natural breaks method. On the right is the histogram of the values where the X axis is the observation value and the y-axis is the number of observations for each value. The vertical blue lines show the extent of each class and are considered to be the class breaks.

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Looking at the histogram and the blue lines you can see that natural breaks tend to place the class breaks whether our natural valleys or vacancies in the data set. The map in Figure 48 displays the result of the classification visually and shows the five classes varying from a light brown to a dark brown in a sequential color. This map is interesting to look at and displays interesting patterns in the data.

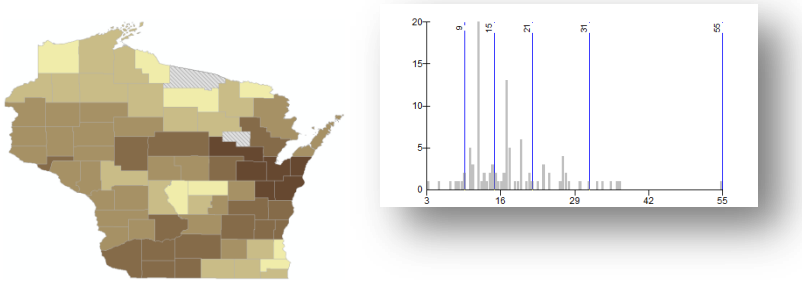

Figure 41 Natural Breaks

Nested Means

The nested means automatic classification method creates classes about the arithmetic means of the data set. Additional means can be calculated about the first mean to create additional classes. The advantage of the nested means automatic classification method is that it is easily computed and mathematically intuitive. The disadvantages are that this classification method is limited to 2, 4, 8, or additional powers of two numbers of classes. Additionally, the nested means does not consider the distribution of data, only where the averages of the data fall.

Nested Means Explanation

The way the nested means works is at first two classes are created 1 above the mean and 1 below the mean. The third and fourth classes are created above and below the means from the first two classes. In this case it creates a reasonably interesting map and each class has about the same number of observations.

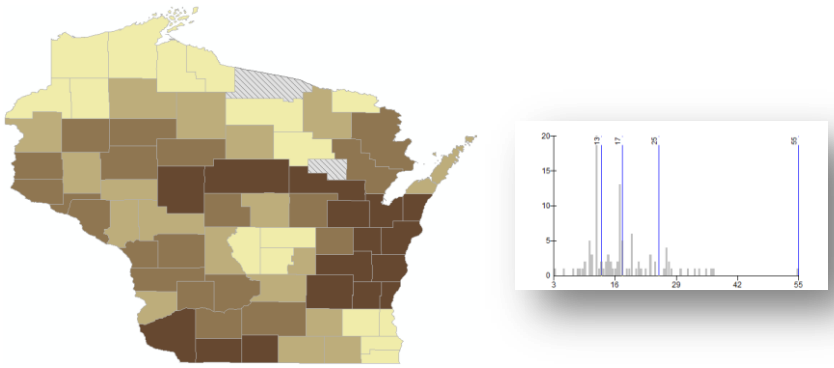

Figure 42 Nested Means

Review the following advantages and disadvantages associated with the use of nested means.

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Mean and Standard Deviation

The mean and standard deviation automatic classification method creates classes about the arithmetic mean and standard deviations above and below the mean. For this method since we are looking at divergent behavior you should use a diverging color red.

Advantages of this classification method are that it is good for displaying data with a normal distribution and it considers the distribution of data. It produces constant class intervals, one for each standard deviation above and below the mean. Disadvantages of this method are that most data is not normally distributed and is not a good fit for this method. This method requires that the map user understands statistics to appropriately interpret the map.

In Figure 43 a diverging color map is used with the colors tending towards brown being observations below the mean and observations towards blue being above the mean. The data for the state has a positive skew, it is not normally distributed, and therefore this method is not ideal for this data set but does still tend to display interesting geographic patterns.

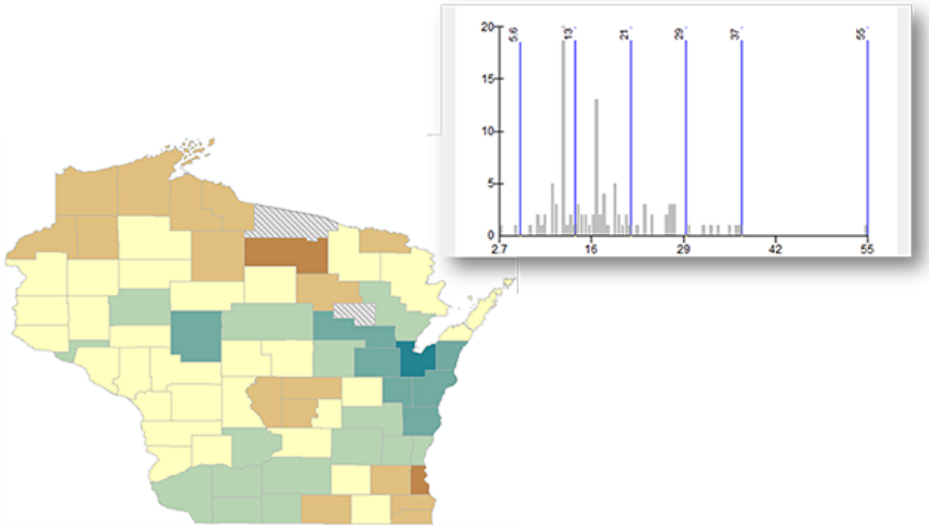

Figure 43 Mean and Standard Deviation

Equal Interval

The equal interval automatic classification method creates classes with equal ranges. The class range is calculated by taking the maximum value of the data set, subtracting the minimum value from it, and then dividing that by the number of observations the data set. The advantages of the equal interval classification method are that it is easy to understand, simple to compute, and leaves no gaps in the legend. Disadvantages are that it does not consider the distribution of data at all and it may produce classes with zero observations which is highly undesirable.

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$$Class\ Range = \frac{Max\ Value\ - Min\ Value}{number\ observations}$$

Equal Interval Example

If we look at the histogram of the data we can see that the class breaks are evenly distributed which is the goal of the equal interval classification method. Looking at the map you see some of the interesting patterns are now hidden since the class ranges are including data that is different from each other. The map is a little boring for this data set.

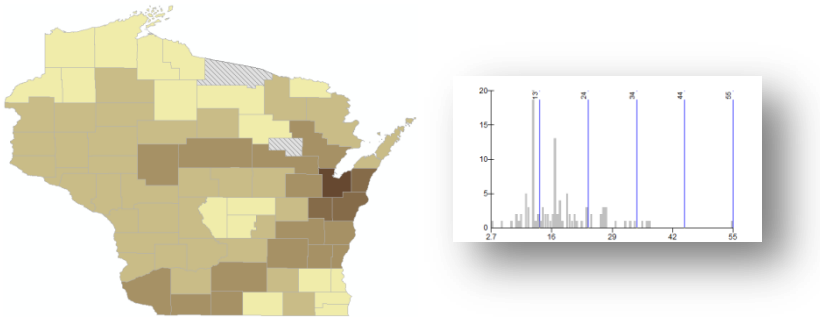

Figure 44 Equal Interval

Equal Frequency

The equal frequency automatic classification method is also known as the Quantile classification method. The goal of the equal frequency method is to distribute observations equally among classes which mean each class will have the same number of observations. If the number of observations does not divide equally into the number of classes then you should place the extra observations across the lower classes which will overload the lower classes.

Advantages of this classification method are that it is easily calculated, applicable to ordinal data, and will not create a class with zero observations. Disadvantages of the equal frequency automatic classification methods are that it does not consider the distribution of data, it can create gaps in the legend, and observation values inside of a class may not be similar.

Equal Frequency Example

As the equal frequency automatic classification method aims to have the same number of observations in each class there should be about the same amount of each color on the map which leads towards a balanced looking map. A major negative is at a class may contain data values that are dissimilar which goes against the purpose of classifying data.

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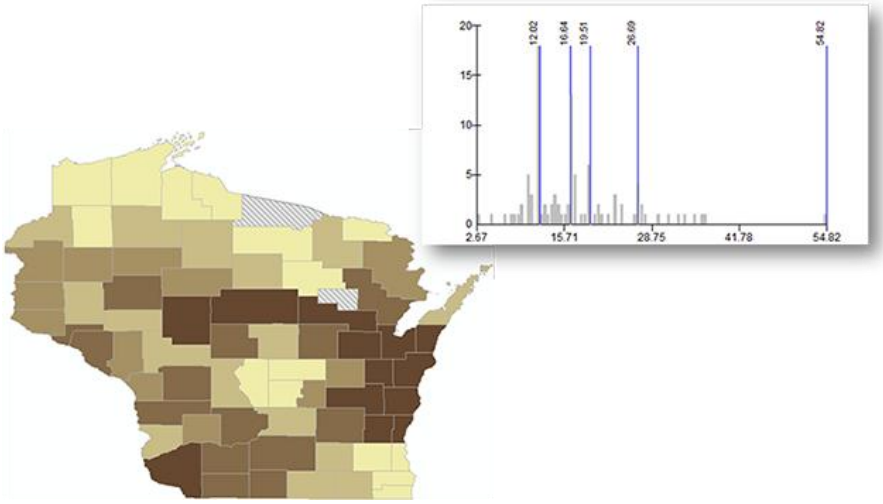

Figure 45 Equal Frequency

Arithmetic and Geometric Intervals

The arithmetic and geometric intervals automatic classification methods create class boundaries that change systematically with a mathematical progression. This classification method is useful when a range of observations are significant and the observations follow some sort of mathematical progression that can be followed with the classes. Advantages are that it is good for data with large ranges and the breakpoints are determined by the rate of change in the data set. Disadvantages are that it is not appropriate for data with a small range or with linear trends.

Arithmetic and Geometric Example

If you look at the histogram you can see that the class ranges slowly increase along the x-axis as this trying to fit the data in the classes that increase at increasing rates. On the map this creates a reasonably interesting map but in this case does seem to over fit the data and make additional patterns exist were they probably should not.

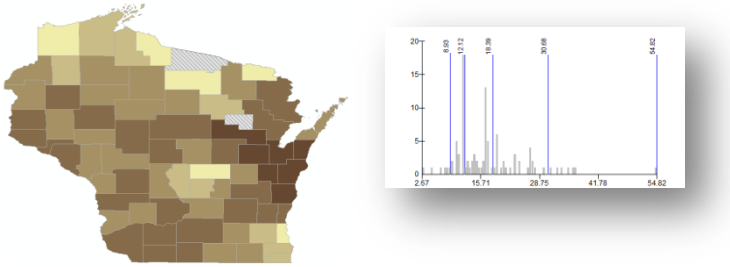

Figure 46 Arithmetic and Geometric Example

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Manual Classification

Finally, the user can define a classification method which is known as manual classification. In this case you can choose your own class boundaries to create your own classification scheme.

SUMMARY

In this lesson you learned about the elements related to data for a map. You learned the common data types and formats used in map creation. The lesson helped you gain an understanding of normalized data and descriptive statistics. You also learned about data classifications and the various classification requirements and methods used when making maps.

ASSIGNMENTS

1. Quiz: Data for a Map
2. Lab: IDP and Refugee Proportional Symbol Map – Designing the Final Map

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Lesson 6: Map Symbols, Visual Variables, and Color

INTRODUCTION

In this lesson the materials provide context on map symbols and visual variables. You will learn about map symbols, visual variables, and color as they relate to cartography. The lesson also provides information on two color theories, components of color and color models. You will learn how to consider your audience and about subjective reactions to color to help in the map creation process.

LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Identify characteristics of the following map elements: map symbols, visual variables, and color.
2. Apply appropriate symbology to create maps that accurately and effectively communicate the desired information for different map types and output formats.
3. Apply appropriate colors and patterns to create effective communication of data for different map types and output formats.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz: Map Symbols and Visual Variables • Lab: Countries with Refugees and Internally Displaced Persons Over 1 Million Map Design

INSTRUCTION

Map Symbols

Map symbols are graphic marks used to encode thematic information on the map. Map symbols provide a graphic, simplified representation of the environment and come in many different forms.

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Figure 1 Example of Map Symbols

Geometric symbols

Geometric symbols are commonly used map symbols. Geometric symbols do not visually resemble the phenomenon being mapped as they are considered abstract representations. Geometric symbols are typically point symbols and require a legend to understand since they do not resemble the phenomena. Geometric symbols are circles, triangles, squares, crosses, and symbols with crosshairs, dots, or other symbols embedded within.

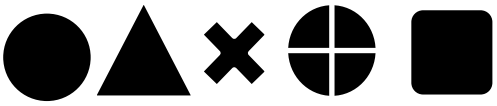

Figure 2 Examples of Geometric Symbols

Pictographic Symbols

Pictographic symbols visually resemble the phenomenon being mapped. The pictographic symbols typically represent point data sets. A major benefit of pictographic symbols is that they may be understandable without a legend and since many pictographic symbols are so widely used they may be immediately interpretable by the map reader. The use of pictographic symbols will add to the theme or memorability of your map.

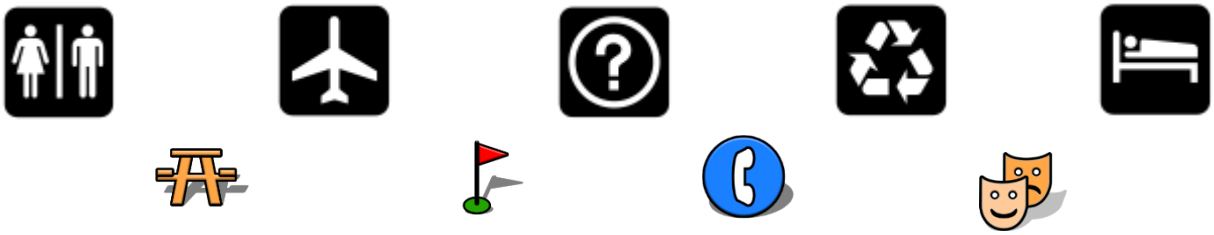

Figure 3 Examples of Pictograms

Spatial Arrangement

Arrangement of spatial phenomena influences how they are symbolized on a map. There are four spatial arrangements: continuity, dimensionality, scale, and level of measurement.

Continuity

Continuity refers to whether an item is discrete in nature having well-defined boundaries and locations or continuous in nature where the measurements exist along a surface or

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continual. Discrete phenomenon is symbolized with points, lines, and polygons. Continuous spatial phenomenon is symbolized with surfaces, shading, and hatching to name a few.

Figure 4 Example of Discrete Phenomenon

Figure 5 Example of Continuous Phenomenon

Dimensionality

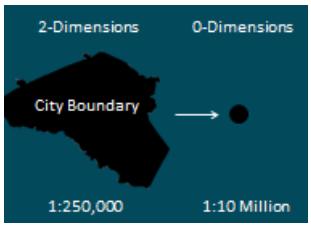
Dimensionality refers the different dimensions that are symbolized in different ways with respect to spatial data. Review the chart for details.

Dimensionality Type	Function
Dimension Points	A point is considered to have zero dimensions.
Dimensional Lines	A line is considered to have one dimension.
Dimensions Area/Polygon	An area or polygon is considered to have two dimensions.
Dimensions Surface	A surface is considered to have 2.5 dimensions.
Dimensions Volume	A volume has three dimensions.
Dimension Space and Time	A data set representing both space and time is considered to have four dimensions.

Scale

Scale is defined as the ratio at which the earth has been reduced in order to be placed on the map. Scale can determine the dimensionality of the spatial phenomenon. For instance in Figure 6, at a scale of 1 to 250,000, the boundary of the city can be shown with two dimensions because of that scale there is sufficient detail to warrant the use of a more complex symbol. If we zoom out to a scale of 1 to 10,000,000 we can switch the dimensionality of the city boundary to 0 dimensions and therefore can be represented using a point.

As another example in Figure 7, at a scale of 1 to 10,000,000, a river will be represented as a one-dimensional object and would be best visualized using a line symbol. However if we zoom in significantly to a scale of 1 to 500 we can see the banks of the river along with the body of the river. Therefore we can represent the river using two-dimensional symbols such as a polygon.



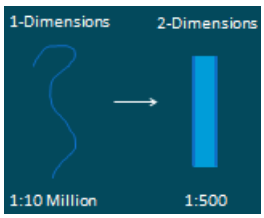


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Figure 6 Scale of 1 to 250,000 Figure 7 Scale of 1 to 10,000,000

Level of Measurement

The level of measurement refers to which category the data values fall within: nominal, ordinal, interval, or ratio. If the data is of nominal type, which means that its goal is to uniquely identify items and show them as different from other items, then we should use a different hue for each type of item in the data set. On the legend, there should be spaces between the representative patches to show that there is no continuity between the different types of items in that they are unique.

If the data is an ordinal, interval, or ratio type you should use a single hue to represent the items as they are of a single type, but you should vary the saturation or value to represent their change in order or magnitude. In the legend there should be no spaces between the representative patches to represent that the data exists along a continuum. The exception is if the data has naturally occurring gaps, then you would want to include gaps between the patches in the legend.

Figure 8 Levels of Measurement

There are three types of data and ways to symbolize that data: there is unipolar data, bipolar data, and balanced data.

Unipolar Data

Unipolar data is data has no natural dividing point. If we wanted to represent the number of bales of hay per acre there are no meaningful divisions and a continuum of the number of bales of hay. Simply start with zero bales of hay and increase. For this you will choose a single hue and vary the saturation or value depending on the change of magnitude or order of the data.

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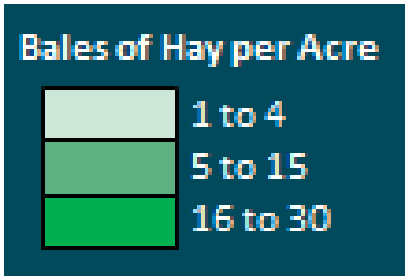

Figure 9 Unipolar Data

Bipolar Data

Bipolar data has a natural and meaningful dividing point. For example if we look at population change between the years 2000 and 2012 we can probably classify each state where it is gained population, had no change in population, or lost population. For bipolar data we should use a divergent color ramp. For the natural or dividing point, it is recommended to choose a gray color, or a color with equal parts saturation of the other two hues on the color.

Figure 10 Bipolar Data

Balanced Data

Balanced data has complimentary phenomena. We can show the ratio of Democrats to Republicans in a voting district. For balance data we should use a divergent color ramp.

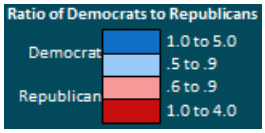

Figure 11 Balanced Data

Visual Variables

Visual variables are distinctions that we can use to create and differentiate symbols on a map. There are 10 visual distinctions available for symbolization: location, size, shape, orientation, focus, arrangement, texture, saturation, hue, and value. This section will cover each one of these nine distinctions. Nine of the ten visual variables will be discussed in the context of whether it is most useful for qualitative or quantitative mapping.

Visual Variable - Location

The location visual variable is the position of the object and the environment. Location can be determined in absolute, relative, or cognitive terms. In any case location determines where in our environment the object exists. No matter whether the data is qualitative or quantitative in nature in order for to be map it must have a location.

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Qualitative Visual Variables

Qualitative visual variables are used for nominal data. The goal of qualitative visual variables is to show how entities differ from each other. Qualitative visual variables show grouping of similar entities.

Hue

Hue, more commonly known as color, represents a wavelength on the visible portion of electromagnetic spectrum. Hue is great for identifying items as unique, or of a type of item. Hue creates a perception of groups, or likeness. The example images in Figure 11 show how hue can be applied to data with 0 to 3 dimensions.

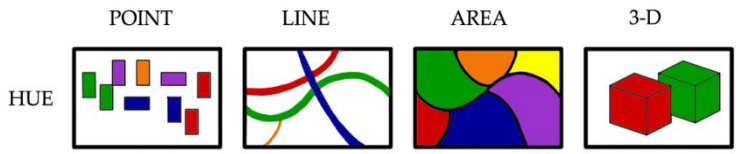

Figure 12 Hue

Visual Variable - Orientation

The orientation visual variable changes the orientation of the object and creates a perception of group or likeness.

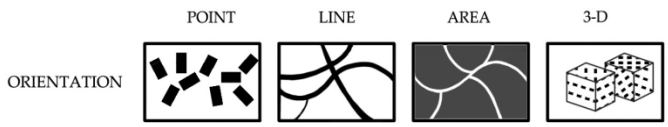

Figure 13 Examples of Orientation

Visual Variable - Shape

The shape visual variable identifies an item as unique or of a type. The shape visual variable refers to a point symbol although it can be arranged to resemble a line and placed inside an area or three-dimensional shape. The shape does not have to be a geometric form; it can also be a pictorial form.

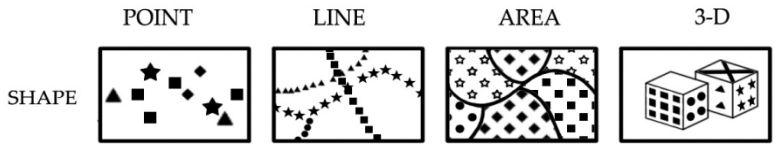

Figure 14 Examples of Shape

Visual Variable – Arrangement

The arrangement visual variable refers to the placement of elements composing a pattern or a texture. Arranging patterns or textures differently can create a perception of a single unique item or a group of items.

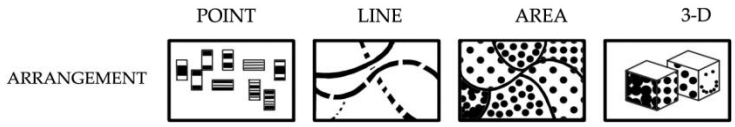

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Figure 15 Examples of Arrangement

Visual Variable – Texture

Texture refers to the symbols covering an area. Textures identify items as unique or of a type.

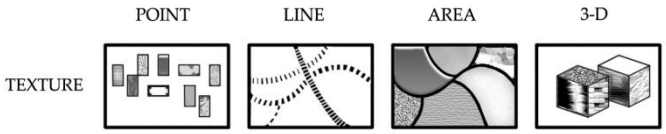

Figure 16 Examples of Texture

Visual Variable - Focus

Focus represents uncertainty by making the symbols look fuzzy or out of focus. The more uncertain a value is the fuzzier or out of focus it should look.

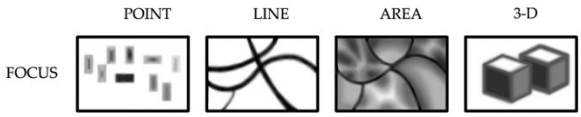

Figure 17 Examples of Focus

Quantitative Visual Variables

Now consider quantitative visual variables. Quantitative visual variables are used to display ordinal, interval, or ratio data. The goal of the quantitative visual variable is to show relative magnitude or order between entities.

Visual Variable – Size

The size visual variable changes the size of the symbol to imply relative levels of importance. Line thickness implies relative flow levels in the case of road traffic, or water flow through a river.

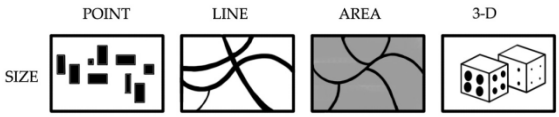

Figure 18 Examples of Size

Visual Variable – Value, Saturation

The visual variables value and saturation represent different magnitudes or order in a data value. It is important that you only very the saturation or value but not both for a given hue. This represents a single variable, which is represented by a single hue, with different quantitative values, which are represented by a difference in saturation or value.

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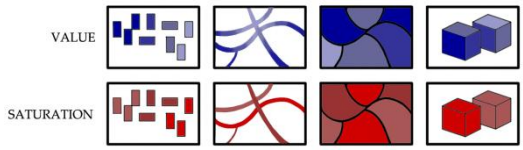

Figure 19 Examples of Value and Saturation

Visual Variable – Focus

Again, the focus visual variable represents uncertainty in quantitative values.

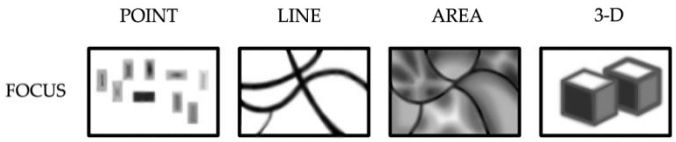

Figure 20 Examples of Focus

Nine Visual Variables

Figure 21 shows the nine visual variables in a single graphic for you to compare and contrast.

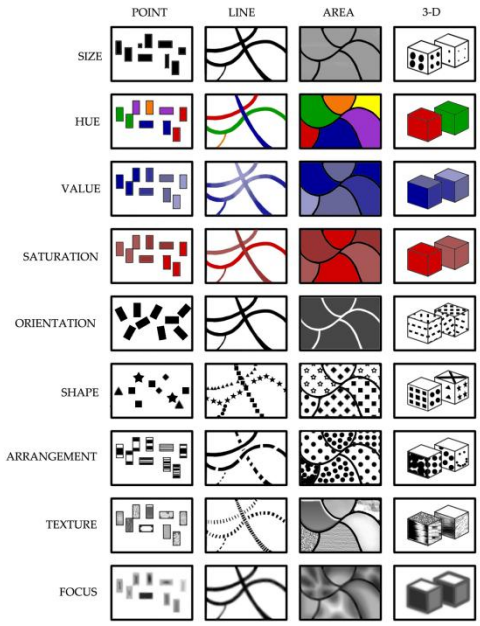

Figure 21 Nine Visual Variables

Matrix

This is a matrix that matches visual variables with attribute types that you can use for reference. The white value represents a poor matching of visual variable and attribute type and therefore, the use of visual variable for that attribute should be avoided. The light grey value represents a marginal matching of the visual variable at the attribute type it should be

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used with careful consideration. The dark gray value represents a good matching of the visual variable with the attribute type that should be the most common paring.

	Interval	Ordinal	Nominal
Location	Good	Good	Good
Size	Good	Good	Good
Focus	Poor	Good	Poor
Value	Marginal	Good	Poor
Saturation	Marginal	Good	Poor
Hue	Marginal	Marginal	Good
Texture	Marginal	Marginal	Good
Orientation	Marginal	Marginal	Good
Arrangement	Poor	Poor	Marginal
Shape	Poor	Poor	Good

Color and Cartography

Color is an extremely valuable tool to cartographers. Color grabs the attention of your map reader and engages them with your map. Color also provides more design options than black and white printing and allows you to be more expressive and creative with your map creations. To maximize the effectiveness of our maps we must employ color in a proper fashion and beware of the following pitfalls: color complicates the map and makes reproduction more difficult.

Printing in color is quite a bit more expensive the printing and black and white. Additionally if colors are used incorrectly it may only confuse your users or have users perceive the map as being unattractive. People may perceive colors differently depending on their own biases or their culture. So while colors can really increase the effectiveness of our map they must use be with care and careful consideration.

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What is Color?

The discussion of color begins with watching the short video, *Tour of the EMS 05 - Visible Light Waves* (4:50), which gives us a tour of the visual portion of the electromagnetic spectrum.

Electromagnetic Spectrum

To review, the visible portion of the electromagnetic spectrum is where we perceive colors as they differ in wavelength. The visible spectrum has longer wavelengths than ultraviolet, x-rays, and gamma rays, and has shorter wavelengths than infrared, microwave, radio waves, and long radio waves. Within this visible spectrum, we can compose any color we want to be used on a map.

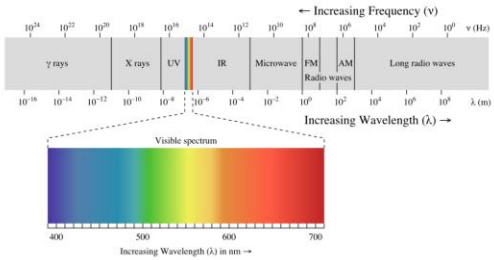

Figure 22 Electromagnetic Spectrum

Two Color Modes

There are two modes of color: the illuminant, and reflective. Illuminant color requires a light source and an eye brain system. Examples of illuminant color are a computer monitor that illuminates light and color, and the human eye that senses those colors. The reflective motive color requires a light source, an object, and an eye brain system. An example of the reflective system is a sun that provides the light, a tree which is the object, and the eye that will sense the sun's light source that reflects off of the tree.

Additive Color

Additive color is light made up of red, green, and blue which is commonly shortened to RGB. The idea is that we combine the red green and blue values to make all of the other colors. In the additive color theory red, green, and blue are considered the primary colors as they

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cannot be made by combining any other colors. RGB is used by monitors, TVs, movie films, your telephone screen, and other similar devices.

Figure 23 is a Venn diagram showing how red, green, and blue work together to create other colors. If the maximum values of red, green, and blue are used white is produced. If no red, green or blue light is produced then the color black occurs. If you only combine red and green, then the color yellow is created. If you combine red and blue, the color magenta is created. And if you only combine green and blue, the color cyan is created.

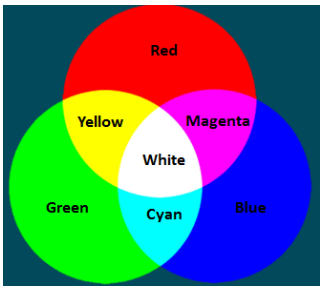

Figure 23 Venn Diagram of Additive Colors

Subtractive Color

Subtractive color is where light reflectance is reduced by ink. Magenta, cyan, and yellow which is often shortened to CMY, are the primary colors in the subtractive color theory. You combine CMY values to create other colors by reducing which light waves are reflected. Magenta, cyan, and yellow are used in print.

Figure 24 is a Venn diagram showing how cyan, magenta, and yellow, the primary colors of subtractive color theory, work together to create other colors. If the maximum values of yellow, cyan, and magenta are used, then no light is reflected off the, and black is the resulting color. If you do not use any yellow, cyan, or magenta, then the resulting color is whatever color the medium is.

For instance, if you are using a green sheet of paper and you do not add any cyan, yellow, or magenta ink the result will be green, which is the color of the paper. If you combine cyan and yellow only, you get the color green. If you combine the color cyan, and magenta only, you get the color blue. If you combine the color magenta, and yellow, you get the color red. Notice that the combination of the three primary colors in the subtractive color theory which are the three primary colors in the additive color theory and vice versa.

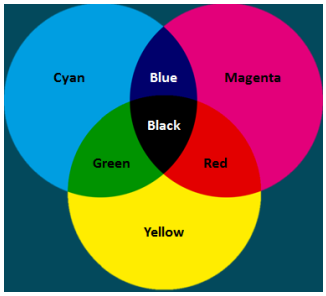

Figure 24 Venn Diagram of Subtractive Colors

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Components of Color

This section will cover the various components of color: hue, saturation, and value.

Hue

Hue is the name that we give to colors. Some common color names are red, orange, green, blue, and violet, among others. In the electromagnetic spectrum each hue has its own wavelength. The wavelengths generally run from the color red which is the longest wavelength to violet which has the shortest wavelength.

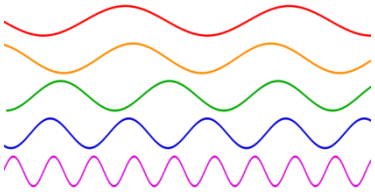

Figure 25 Hue

Saturation

The second component of color is saturation. Saturation is also known as chroma, intensity, or purity. Chroma represents how intense the color is for a particular hue. Saturation is specified in percentages where 0% represents a neutral gray, and 100% represents maximum color. Sometimes it is useful to think about saturation as determining how much great use in a color.

Figure 26 Saturation

Value

The value component of color represents the quality of lightness or darkness in a hue. Value is often considered to represent the shades of a hue. Value is specified in percentages were 0% represents a light neutral gray, and 100% represents the color black.

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Figure 27 Color Value

Munsell Color System

To help you understand how hue, value, and saturation, commonly referred to as chroma, work together learn about the Munsell color system. The column in the center represents the value and it ranges from a pure light color only down to a dark color to black. As you move away from the value outwards you increase the chroma which increases the intensity of a color away from the neutral gray. As you rotate around the value you change the hue.

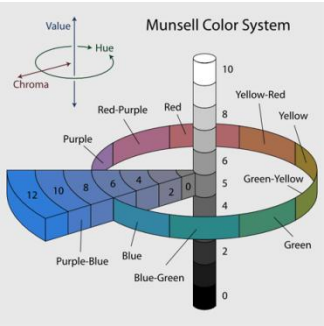

Figure 28 Munsell Color System

Figure 29 is another visualization of the three components of color in the format of the color wheel.

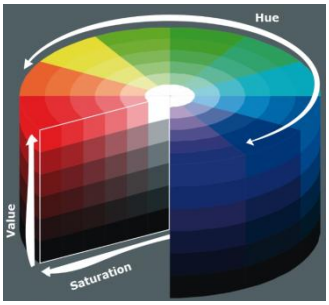

Figure 29 Color Wheel Components

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Color Models

A color model is an abstract mathematical model describing the ways colors can be represented by numbers. There are six common color models used today: HSV, HSB, HSL, RGB, CMYK, CIE Lab, and Grayscale. Many GIS and mapping software packages support the majority of these color models.

HSV

The HSV color model refers to the components of color which are hue, saturation, and value. In the HSV color model hue is measured between the numbers 0 and 360. Saturation is measured from 0% to 100%. Value is measured from 0% to 100%.

Perhaps HSV is best visualized as a color wheel. As you move around the color wheel you change the hue between the values of 0 and 360. As you move outwards from the center of the color wheel you increase the saturation between 0% and 100%. And as you move for the bottom of the color wheel to the top of the color wheel you increase the value between 0% and 100%. A few other common visual representations of the HSV color model are included in Figure 30 for you to review.

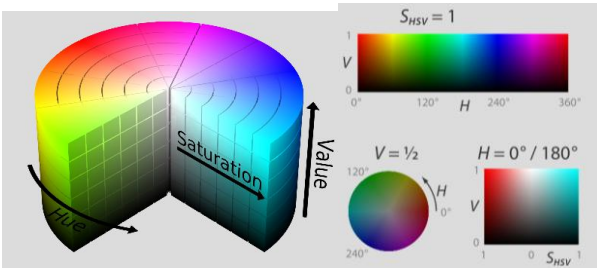

Figure 30 HSV Color Model

HSB/HSL

The HSB and HSL color models are similar to the HSV color model. The difference is that the B in HSB refers to brightness and references black to indicate how much light is received. The L in HSL refers to lightness and references white to indicate how much light is reflected.

Figure 31 is a visual representation of the HSL color model. The main difference between the HSL color wheel and the HSV color wheel is that instead of value increasing from the bottom of the color will to the top the lightness increases from the bottom of the color wheel to the top. The HSB color model visualization is the same as the HSL color model visualization except that lightness is replaced with brightness.

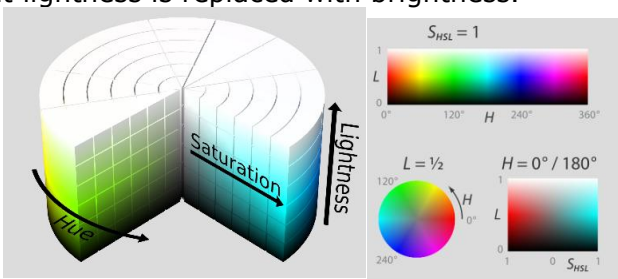

Figure 31 HSB Color Model

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RGB

The RGB color model refers to the primary colors in the additive color theory which are red, green, and blue. The RGB color model uses 256 distinct numbers ranging between the values of 0 and 255 to determine how much red, green, and blue will be used to define the color. When there is a value of 0 it means that none of that color is included. When there is a value of 255 it means that the maximum amount of that color is included. The RGB color model can produce over 16 million colors. The RGB color model should be used when the output of a map is on a computer screen, TV, or film, as these devices natively use the red, green, and blue color model to display colors.

RGB Cube

Figure 32 is a visualization of the RGB color model as a cube. Each axis represents one of the three primary colors in the additive color theory and RGB color model. As you increase the values along these three axes either independently or together you can create any of the other 16 million possible colors available in this color model.

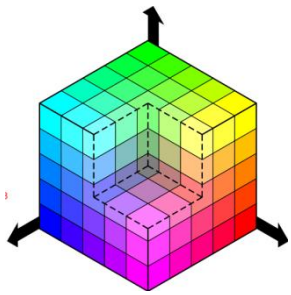

Figure 32 RGB Cube

Remember that in the RGB color model colors are represented by three numbers ranging between 0 and 255. In Figure 33 the first number represents red, the second number represents green, and the third number represents blue. The RGB value of 0, 0, 0 represents the color black. The RGB value of 255, 255, 255 represents the color white. Notice that when you combine the maximum amount of only two of the three colors you produced the primary colors of this additive color theory.

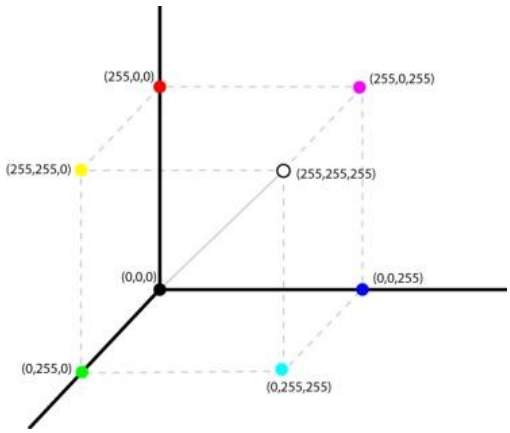

Figure 33 Color Range

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CMYK

The CMYK color model refers to the subtractive color theory CMY. The CMYK color model specifies each cyan, magenta, and yellow color in percentages from 0% to 100%. The K in CMYK refers to the color black and is specified because impurities in ink may not create a pure black; therefore, many printing devices include a separate ink canister for the color black. You should use the CMYK color model when you are printing a map on a tangible medium.

Figure 34 is a visualization of the CMYK color model represented as a color cube. Each axis represents one of the three primary colors in the subtractive color theory. A value of all 0% represents the color white, or the color of the tangible production medium. Values of all 100 represent the color black. As you increase the values along the 3 axes either independently or together you can create any of the other possible colors available in this color model.

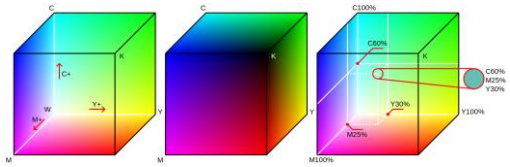

Figure 34 CMYK Color Model

CIE L*A*B

The CIE lab color model describes colors as perceived by the human eye. This color model represents color using three values. The first value is for L which represents lightness of the color between black which is represented by the value of 0 and white which is represented by the value of 100. The second value is a which represents the relative position between magenta which has a value of positive 100 and green which is a value of negative 100. The third value in this color model is B which represents the relative position of the color between the yellow which is represented by the value of positive 100 and blue which is represented by the value of negative 100.

Figure 35 consists of three example visualizations showing how the values for L, A, and B work together to create color. On the left, the L value is at 75 which mean that it is closer to the color white. As a values for A and B change, unique colors are created. On the middle image the L value is 50 which mean that it is halfway between white and black. Again, as the values for A and B change, unique colors are created. And finally, on the right image the value for L is 25 which means that it is closer to black. As the A and B values change or unique colors are created.

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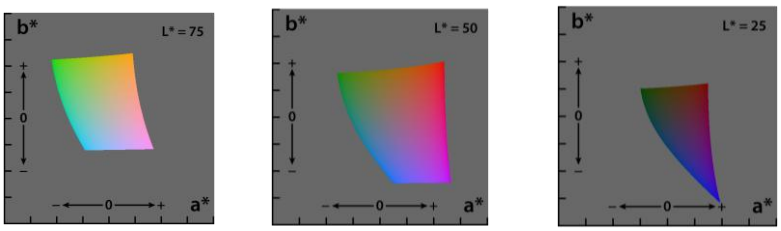

Figure 35 CIE L*A*B

Grayscale

The grayscale color model presents different shades of black. If the map is going to be presented in an achromatic fashion then you should using the grayscale color model as it will not introduce any color into the print, only intensities of light between black and white. If you choose to use the grayscale color model it is recommended that you limit the number of grayscale levels to six or seven at a maximum. The reason to limit the number of grayscale levels is at humans have a hard time differentiating levels of gray if there are more than six or seven on the map.

Figure 36 is a visualization of the grayscale color model. The amount of black or white available to grayscale model can be specified multiple ways. There are two common ways of specifying the shade of gray: between the value of 0 which represents black and the value of 100 which represents white, where the value of 0% which represents white and the value of 100% which represents black.

Figure 36 Grayscale

Color Translation

Ideally you will choose which color model to work with when you begin your map design process. However, should you need to convert between different color models, you need to be aware that not all colors translate well between the color models. For instance, if you choose to create a map that will ultimately be printed on a piece of paper it is recommended that you initially choose the CMYK color model to create a map. Had you initially chosen the RGB color model in the later converted the colors to the CMYK color model, you may find that the colors did not translate as well as you had hoped and the printed product is different than the designed product.

Color Preferences

There are various methods to determine color preferences depending on your audience and type of map you are working to create. This section will provide some information you should consider before determining your color strategy.

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Warm and Cool Colors

Colors can probably be classified into warm colors and cool colors. Warm colors tend to have longer wavelengths and cool colors tend to have shorter wavelengths.

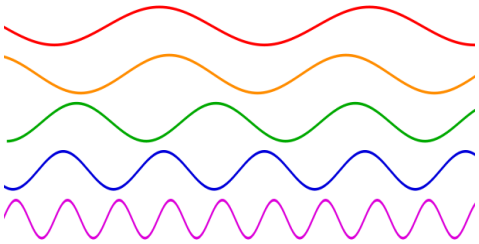

Figure 37 Warm and Cool Colors

Advancing and Retreating Colors

Colors can also be classified as advancing colors or retreating colors. Advancing colors appear to be closer to you. Advancing colors have longer wavelengths high values and high saturations. Retreating colors appear further away from you and they have a longer wavelength low values and low saturations.

Young Children

When you are making a map for young children you should keep these color preferences in mind. Young children tend to prefer warm colors. Red is the most popular color followed by blue and green. Young children tend to prefer high saturation colors until about the 6th grade when saturation can be toned down.

Young children are only aware of a small range in a hue; therefore, you should not use two hues that are similar in color if you wish the hues to be perceived as distinct. Young children dislike attractive colors. They also tend to reject achromatic color schemes, where achromatic refers to a grayscale color scheme. Young children also prefer expected colors which means that they expect water to be blue, parks to be green, and roads to be black, for instance.

Adults

Adults favor colors with shorter wavelengths. Greenish yellow is the adult's least favorite hue. Women prefer the color red over blue, and the color yellow over orange. Men prefer blue over red, and orange over yellow. Adults prefer saturated colors. Adults most to least favorite colors in order are blue, red, green, violet, orange, and the least favorite yellow.

Color Conventions

While it is nice to design your map in line with the color preferences of your audience, general color conventions should overrule the broader color preferences. This means that, you should not buck common trends such as making water any other color the blue, or a cool color to represent danger when warm colors and especially red conventionally represent danger.

Colors in Combination

You must careful when you use colors in combination. Colors have an interesting way of affecting each other when they are placed in proximity and can create a disjointed, confusing, and ugly map. Background colors should be light or dark and not intermediate

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colors. Consistently pleasing object colors are hues and the green to blue range and others use with very little gray, which means they will have higher saturation values.

Consistently unpleasant colors are hues in the yellow to yellow-green range and other hues with a large amount of gray, which means low saturation. The color of the focus objects must stand out from the color of the background. This is referred to as having a good figure to ground relationship. Vivid colors combined with great colors are judged to be a pleasant combination.

Connotative Meanings of Color

There are many connotative meanings of color and they can vary greatly across different cultures. In the United State, these are commonly agreed-upon connotative meanings of color.

Color	Connotations
Yellow	Cheerful, dishonest, youth, light, coward, joyous, spring, warning
Red	Blood, fire, danger, power, loyalty, bravery, anger, strong, action
Blue	Silence, depression, truth, purity, formality, cold, depth
Orange	Fire, attention, action, fall, harvest, abundance
Green	Money, spring, nature, envy, jealousy, peace, youth
Purple	Dignity, royalty, despair, richness, elegant, painful
White	Clean, strong, mourning, heaviness
Black	Mourning, heavy, strength, mystery, death, deep, dark
Grays	Controlled, quiet, reserved, neutral

Color in Cartographic Design

In cartography there are some commonly considered color conventions that you should generally follow. The first is that water is commonly blue. Unless the map is highly stylized, water should almost always be blue on a map. Forests, parks, or representations of any other green space are commonly green on a map. Red should represent hot temperatures, and blue should represent cold temperatures. Yellows and tans should represent arid regions. Browns and greens and other related earth tones typically represent land surfaces.

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Functions of Color in Design

We use color in map design to provide structure, readability, and psychological reactions to maps. If color is used well, it can greatly increase the attractiveness and usefulness of our map. Conversely, if colors used poorly, are maps will seem unattractive and untrustworthy to our users.

Figure to Ground Relationship

The use of color cartographic design can allow us to produce strong figure to ground relationships. Color provides contrast between the background, which we consider a ground, and the focus of the map, which we consider the figures. Our wish is to have the figures be immediately visible and interesting to the user while the ground is useful for surrounding and contextual information. Similar hues, brightness, and saturation values are perceived to be grouped items. Warm colors represent figures better than cool colors.

Stronger colors should be selected for smaller areas to compensate for the smaller areas of the cover. If a large area of the map is covered by a high value, high saturation warm color, it may detract from the smaller areas and overpower the map. We can also use whitespace, or lack of color, to help establish a figure ground relationship an organization by allowing the user to focus on individual components of a map that are separated by the whitespace.

Poor Figure to Ground Examples

Figure 38 has two examples there are poor figure to ground relationships. While there is a significant contrast between the figure and the ground they both compete for the height equally and it is difficult to determine where the land features are and where the water features are. For your reference, both these maps are of the Gulf of Mexico.

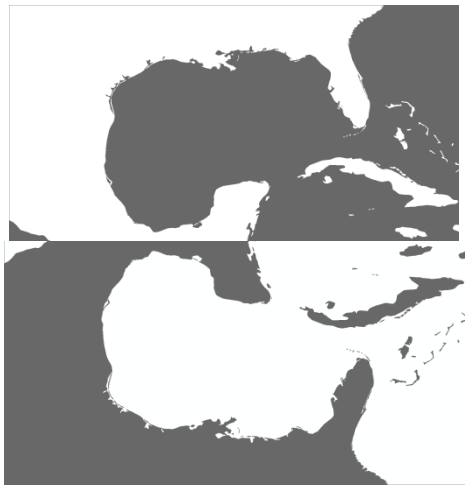

Figure 38 Poor Figure to Ground Relationships

Figure to Ground Examples

The example in Figure 39 represents good figure ground relationship. South America is represented with a high saturation high value color in the ground is a cool devalued blue. The example in Figure 40 is an example of poor figure to ground relationship since both South America and the water have similar values even though the user is different. Colors of a similar value tend to be grouped together and it makes it hard for the eye to differentiate between the two.

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Figure 39 Good Figure Ground Relationship

Figure 40 Bad Figure Ground Relationship

Good Black and White and Color Examples

These last two examples show good figure to ground relationships using either black and white printing or color printing. In Figure 41 the color white is chosen for South America because it is visually more demanding than the color black. Therefore the water, which is black in this case, is considered to be a good ground. In Figure 42, just as we saw in the previous slide the color chosen for South America is a strong hue with a high saturation and value which is significantly different than the white blue.

Figure 41 Good Figure to Ground Relationship-Black and White

Figure 42 Good Figure to Ground Relationship - Color

SUMMARY

In this lesson the materials provided a context on map symbols and visual variables. You learned about map symbols, visual variables, and color as they relate to cartography. The lesson also provided information on two color theories, components of color and color models. You learned why you need to consider your audience and subjective reactions to color as it will help in the map creation process.

ASSIGNMENTS

1. Quiz: Map Symbols and Visual Variables
2. Lab: Countries with Refugees and Internally Displaced Persons Over 1 Million Map Design

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Lesson 7: Typography

INTRODUCTION

This lesson introduces and teaches you about typography. You will learn about the elements that make up typography and the effect it has on understand a map. The information includes defining type, characteristics of type, and the various uses of type on maps.

LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Identify basic elements of typography.
2. Create maps using topography basics to consider the design and placement of type, characteristics of type and the use of type on a map.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Lab: Design and Label a Downtown Street Map • Quiz: Typography

INSTRUCTION

Introduction to Typography

Typography is the process of designing and placing type on a map. Type is placed on maps to inform the users of things like the purpose of the map, the source of information, and attribute values of the features displayed on the map. When type is well placed the type will greatly improve the usefulness of a map.

Placing type on a map can be a time-consuming and frustrating process. Unfortunately labeling routines rarely do an adequate job of placing type on a map automatically. Therefore it is typically up to you, the cartographer, to manually adjust or place type on a map. Unfortunately placing type of a map is often treated as an afterthought when it is actually one of the most important and useful map elements for the map user. This lesson will teach you about typography and start you down the path of properly using text on a map.

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Map with Type

Consider this map in Figure 1 of the states in the contiguous United States of America. This map does a reasonably good job of clearly identify the names of each state and three large water bodies.

Figure 1 Map with Type

Map with No Labels

Now consider the same map without any of the labels as shown in Figure 2. While this map is cartographically well-designed, it is much less useful to the map user because none of the states are bodies of water are identified.

Figure 2 Map with No Labels

Value of Labels

The 48 state labels and the three water body labels, when placed properly on a map, can add much value and usefulness. Review figures 3 and 4.

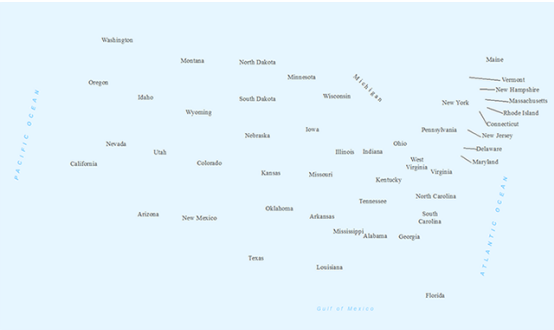

Figure 3 Example of Non-Complete Labeling

Figure 4 Example of Complete Labeling

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Defining Type

Type is generally organized by typeface, style, size, and family. You will now explore each one of these for type definitions more detail.

Typeface/Font

A typeface or font is a set of all alpha, numeric, and special characters and the type family, style, and size. For an example of a character map which shows all of the characters in the Times New Roman font review [How to Use Special Characters in Windows with Character Map](#).

Type Style

The type style is a design variation of a typeface. Common type styles are Roman style which is considered the normal style, italic style, where the characters are slanted to the right for emphasis, the bold style, where the characters are thickened, and the bold italic style which is a combination of bold and italic type styles.

Examples of Type Style

- Roman (normal style)
- *Italic*
- **Bold**
- ***Bold Italic***

Type Size

Type size is the scaling of a font to make it larger and smaller. Type sizes are measured in one of two ways: points or picas. One point is equal to 1/72 of an inch. One pica is equal to 12 points. The illustration on the right shows a font in 72 point font size.

Figure 5 Type Size

Oldstyle

The old-style type family is widely used between the 15th and 17th centuries. It is a minimal variation of stroke thickness among each character. It has small serifs. A serif is a small decoration typically placed at the extremities of a character. Old-style also has a small x-height which means that the standard height of lowercase characters is generally short. Please review the examples of uppercase and lowercase letters, including the numbers, and common symbols in the old-style font family.

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- The **transitional** font family was used during the 18th century heavily and has a greater contrast between stroke thicknesses. It has wider serifs with flatter bases and a larger x-height. Numerals are consistent and size in a transitional font family.
- The **slab serif** font family began to be used in the 19th century. It has minimal variations in stroke thickness, heavy serifs with squared-off ends, and large x-heights.
- The **sans serif** font family began to be heavily used in the 19th and 20th century. There is no variation in stroke thickness, no serifs, and a large-ish x-height.
- The **decorative** font family began to be used in 19th and 20th century and is easily recognizable as heavily ornamented characters.
- The **script** font family began use in the 19th and 20th century and resembles handwriting.

Type Characteristics

Review the following examples to become familiar with typical type characteristics of case, serif and sans serif, x-height, kerning, spacing, and leading.

Case

Case refers to whether also characters are displayed in uppercase or lowercase form. Lowercase letters have been proven to be easier to read and distinguished from each other because they have more detail in the lower half of the letter.

Example

UPPERCASE

lowercase

Sans Serif

A serif is a short extension at the ends of letter strokes. Serifs make type easier to read by guiding the eye from letter to letter and word to word. Sans serif is simply a font without serifs.

Figure 6 Serif

X-height

X-height refers the distance between the mean line and the baseline and is typically the height of the "x" character in the font.

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Figure 7 X-Height

Kerning

Kerning is a variation of space between adjacent letters to achieve a visually pleasing spacing. If we look at the word war in Figure 8, the top word war has no kerning in the letter seemed to be far away from each other and disjointed. With automatic kerning, which is often done in word processors, the letters are brought closer together spacing to be more cohesive. It is also possible to do manual kerning in which you can bring letters closer together or further apart depending on your need.

Figure 8 Kerning

Spacing

Letter spacing is space added between characters in a word. Word spacing is when spaces are added between words.

Figure 9 Spacing

Leading

Leading refers to the space vertically between baselines of text. Leads between texts are measured in points.

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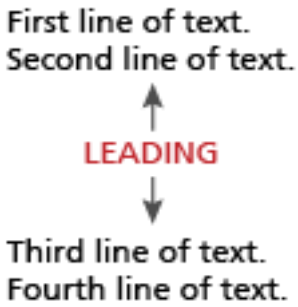

Figure 10 Leading

Use of Type Maps

A majority of type on a map will be set in title case. Title cases are where the first letter of every word is uppercase. Feature labels will almost always be in title case. Sentence case is only used on a map when sentences are included on a map. Sentence cases are where the first letter of a sentence is uppercase. Words in all uppercase are appropriate for labeling large aerial features such as oceans or countries. As features becomes smaller in space, or importance, title case should be used.

Figure 11 Example of a Type Map

Serif vs. Sans Serif

One common question is whether serif or sans serif fonts should be used on a map. Neither has been shown to be preferred on a map so you should just pick one and be consistent across the entire map design. You may mix serif and sans serif fonts between map labels and other map elements like the title or metadata, however be consistent. For example, all labels should be serif, and all of the map elements sans serif.

Word and Letter Spacing

In most cases the default worded letter spacing is preferred. Should you need to save space you can reduce the word and letter spacing so that the label will be easier to place. Expanded word and letter spacing provides a less compact type and will be easier to read. Typically expanded worded letter spacing is used with all uppercase text when labeling large

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areas. All uppercase words require word spacing to allow the letters to "breathe". If you decide to modify the word and letter spacing you should be consistent within blocks of type and among types that represent similar phenomena.

Type to Avoid

In general you should avoid decorative or hard to read type families such as fonts from the decorative or script font families. Too much bold on a map will greatly deemphasize the regular type on the map. Instead of bolding text first try different sizes to see if that fits the need.

Italic Type

Italic type should be used for the following: water features, which should also be labeled in blue, to identify publications in a data source, which is a fairly standard reference practice, and to identify species of an organism. You may use italics for other reasons like emphasis but these are common italic practices.

Type Size

When considering type size on a map you should choose a reasonable upper and lower limit. Generally six point is the smallest type size you should use on a map that is still easily readable by your audience and you should use type size this small sparingly. The production medium, lighting conditions your map will be used in, and audience type and age may dictate upper and lower limits. Type size corresponds with relative size of features with larger or more important features gaining a larger type size, and less important smaller features gaining a smaller type size.

Orientation

If at all possible type should reflect the orientation of the features it is labeling including diagonal or curved features. Type should never be upside down on a map. Label between -90° and a positive 90° and be consistent across the entire map if possible. Looking at the example here, the white text is at an acceptable orientation, but the red text is considered to be upside down and should be avoided.

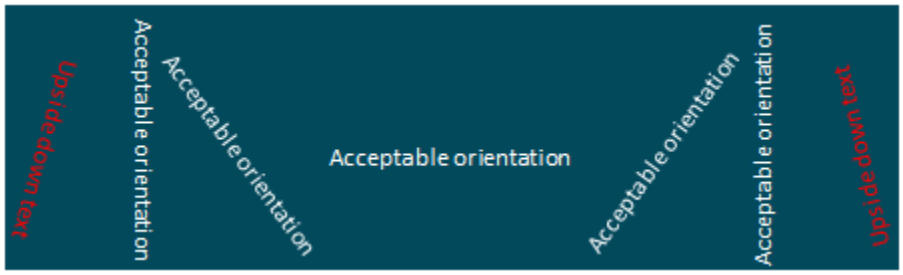

Figure 12 Orientation

Overprinting

It is possible that in some cases your label will be over printed on top of the map feature. When this happens it may obscure the map feature and make the map and label difficult to read. You can fix overprinting in a few ways such as employing masks, halos, callouts or leader lines, or better placement.

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Mask

A mask should be the same color as a feature that is being over printed. In Figure 15, the mask is the same base color as the state so that when Mississippi is over printed there appears to be a blank area behind it.

Figure 13 Mask

Halo

A halo is similar to a mask except that the color is different from the color of the background. Halos can make the labels stand out very well if the surrounding areas are very complicated, but be careful not to make a halo too large because it may draw undue attention to the label.

Figure 14 Halo

Callout/Leader Line

If the label is significantly larger than the area it is supposed to be you can use a callout or leader line (Figure 15) so that you can place a label away from the feature. This will direct the user's attention to the fact that the label belongs to a feature further away. The last option is to consider placing the label better on the map. In some cases it is acceptable to reduce the font size but this does run the risk of making that feature not be perceived to be of the same type as other features in its class. In Figure 16 there is better placement in the map on the right due to the reduced font size used.

Figure 15 Callout/Leader Line

Figure 16 Better Placement

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Spell Check

And last but certainly not least, you should always perform a spell check on all the text on your maps. Misspellings can undermine the authority or trust on your map. If map readers see spelling mistakes they may wonder what else you've overlooked and got wrong. You should not assume that the mapping software you are using has spellchecking capabilities as even some of the most popular mapping programs do not have spell check. The last bit of advice with regards to type is that you should carefully consider the placement of type and do not passively accept software defaults with regards to placement and type characteristics as they may not be optimal for the map.

SUMMARY

This lesson introduced and taught you about typography. You learned about the elements that make up typography and the effect it has for a reader to understand a map. The information included defining type, characteristics of type, and the various uses of type on maps.

ASSIGNMENTS

1. Lab: Design and Label a Downtown Street Map
2. Quiz: Typography

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