

# **GIS CAPACITY BUILDING EXPERT FOR UNION OF MUNICIPALITIES IN AKKAR AND NORTH LEBANON**

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## CHAPTER 1: CARTOGRAPHY AND MAP DESIGN

### 1.1 Design Principles for Cartography

Cartographers apply many design principles when compiling their maps and constructing page layouts. Five of the main design principles are legibility, visual contrast, figure-ground, hierarchical organization, and balance. Together these form a system for seeing and understanding the relative importance of the content in the map and on the page. Without these, map-based communication will fail. Together visual contrast and legibility provide the basis for seeing the contents on the map. Figure-ground, hierarchical organization, and balance lead the map reader through the contents to determine the importance of things and ultimately find patterns.

In this section, we introduce these five principles and explain their importance in cartography. It's worth noting that these principles are not applied in isolation but instead are complementary to each other. Collectively they help cartographers create maps that successfully communicate geographic information.

#### 1.1.1 *Visual Contrast*

Visual contrast which relates to how map features and page elements contrast with each other and their background. To understand this principle at work, consider your inability to see well in a dark environment. Your eyes are not receiving much reflected light so there is little visual contrast between features and you cannot easily distinguish objects from one another or from their surroundings. Add more light and you are now able to contrast features from the background. This concept of visual contrast also applies in cartography (figure 1). A well-designed map with a high degree of visual contrast can result in a crisp, clean, sharp-looking map. The higher the contrast between features, the more something will stand out, usually the feature that is darker or brighter. Conversely, a map that has low visual contrast can be used to promote a subtler impression. Features that have less contrast will appear to belong together.

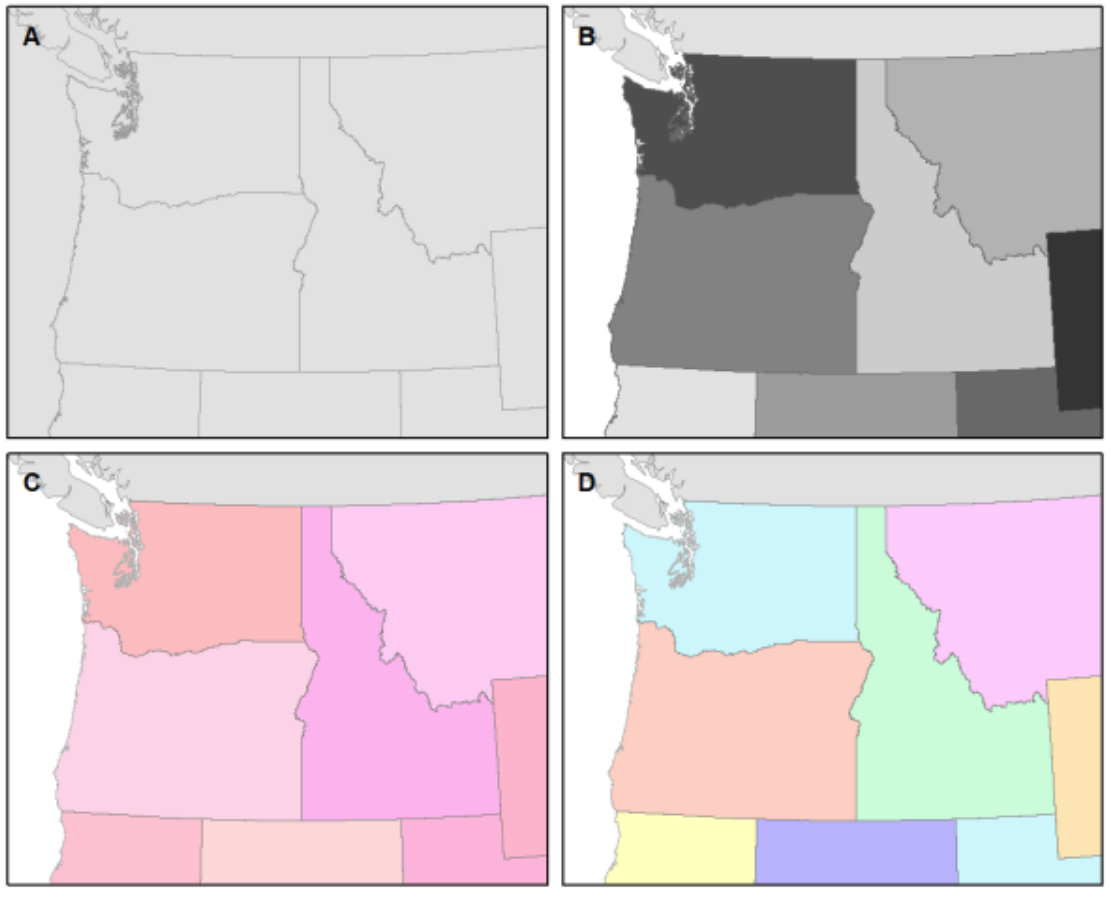


Figure 1.1: When there is no variation in visual contrast (A), the map reader has a hard time distinguishing features from the background. For quantitative distributions (B), there must be enough contrast between tones for the reader to distinguish unique classes. For qualitative distributions (C), using variations of a single color hue (e.g., red) does not provide as much contrast as using a variety of hues (e.g., red, green, blue, etc.)

### 1.1.2 Legibility

Legibility is “the ability to be seen and understood”. Many people work to make their map contents and page elements easily seen, but it is also important that they can be understood. Legibility depends on good decision-making for selecting symbols that are familiar and choosing appropriate sizes so that the results are effortlessly seen and easily understood (figure 1.1). Geometric symbols are easier to read at smaller sizes; more complex symbols require larger amounts of space to be legible.

Visual contrast and legibility are the basis for seeing. In addition to being able to distinguish features from one another and the background, the features need to be large enough to be seen and to be understood in order for your mind to decipher what your eyes are detecting. Visual contrast and legibility can also be used to promote the other design principles: figure-ground, hierarchical organization, and balance.

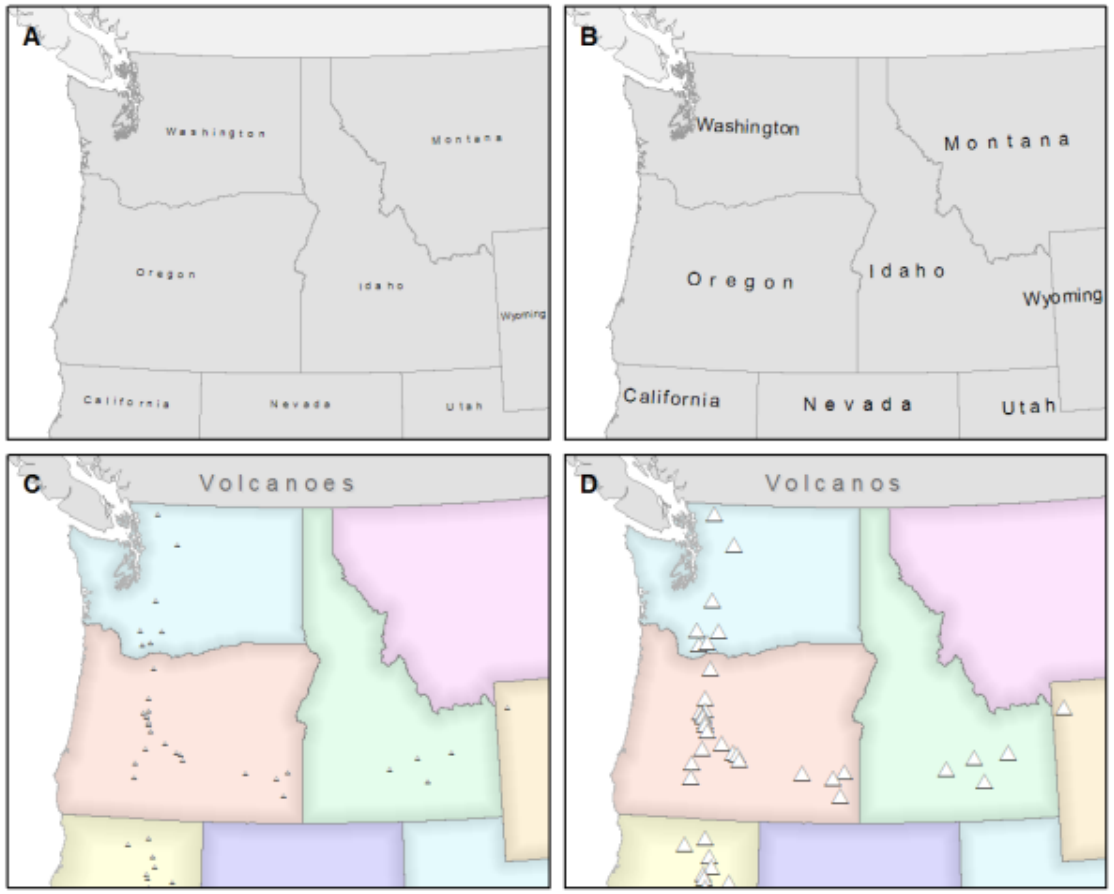


Figure 1.2: Text and symbols (A and C) that are too small cannot be seen. Once able to be seen (B and D), they must also be understood.

### 1.1.3 Figure-ground

Figure-ground organization is the spontaneous separation of the figure in the foreground from an “amorphous” background. Cartographers use this design principle to help their map readers find the area of the map or page to focus on. There are many to promote figure-ground organization, such as adding detail to the map or using a white wash, a drop shadow, or feathering.

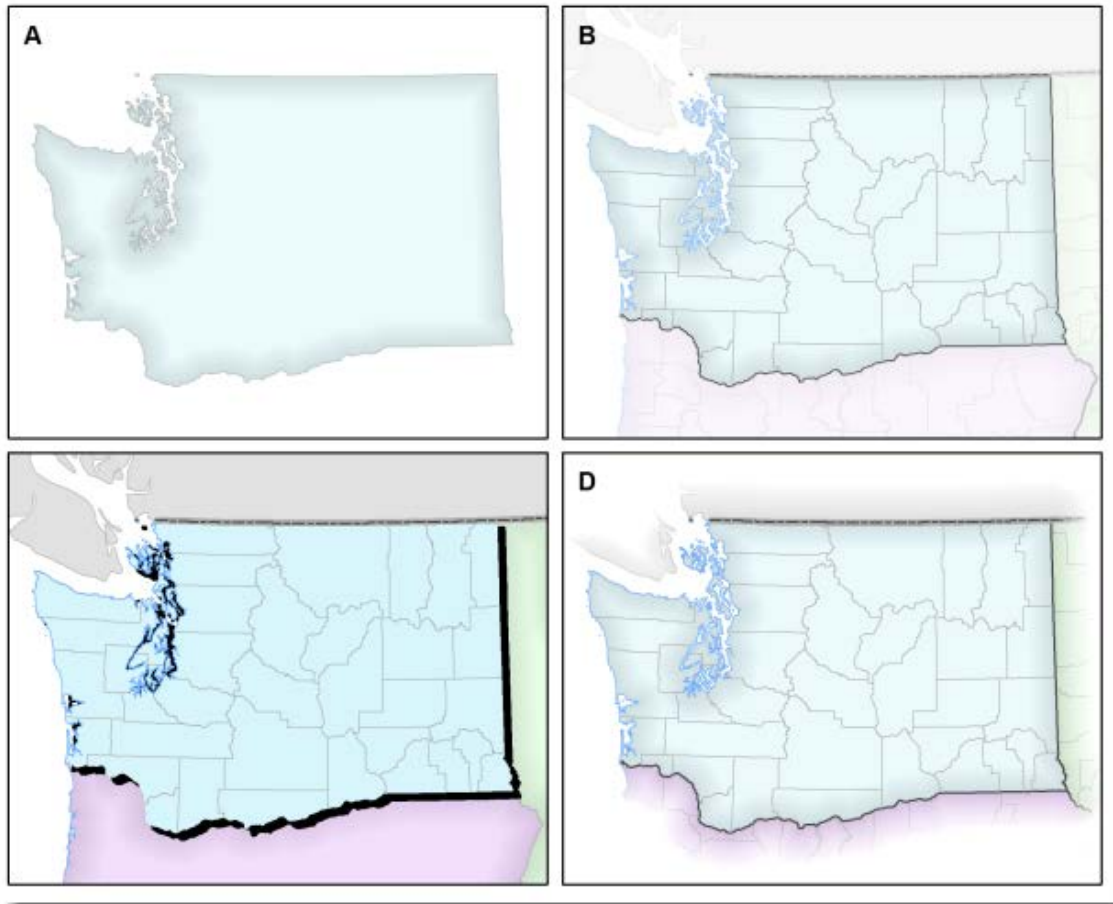


Figure 1.3: Using closed forms (A), a white wash (B), a drop shadow (C), or feathering (D) will promote figure-ground organization on your map.

#### 1.1.4 Hierarchical Organization

One of the major objectives in map making is to “separate meaningful characteristics and to portray likenesses, differences, and interrelationships” (Robinson, et al., 1995, p. 327). The internal graphic structuring of the map (and the page layout more generally) is fundamental to helping people read your map. You can think of a hierarchy as the visual separation of your map into layers of information. Some types of features will be seen as more important than other kinds of features, and some features will seem more important than other features of the same type. Some page elements (e.g., the map) will seem more important than others (e.g., the title or legend). This visual layering of information within the map and on the page helps readers focus on what is important and enables them to identify patterns. Hierarchical organization on reference maps (those that show the location of a variety of physical and cultural features, such as terrain, roads, boundaries, and settlements) works differently than on thematic maps (maps that concentrate on the distribution of a single attribute or the relationship among several attributes). For reference maps, many of the features should



be no more important than one another and so, visually, they should lie on essentially the same visual plane. In reference maps, hierarchy is usually subtler and the map reader brings elements to the forefront by focusing attention on them. For thematic maps, the theme is more important than the base that provides geographic context.

#### *1.1.5 Balance*

Balance involves the organization of the map and other elements on the page. A well-balanced map page results in an impression of equilibrium and harmony. We can also use balance in different ways to promote “edginess” or “tension” or create an impression that is more “organic”. Balance results from two primary factors, visual weight and visual direction. If you imagine that the center of your map page is balancing on a fulcrum, the factors that will “tip” the map in a particular direction include the relative location, shape, size, and subject matter of elements on the page.

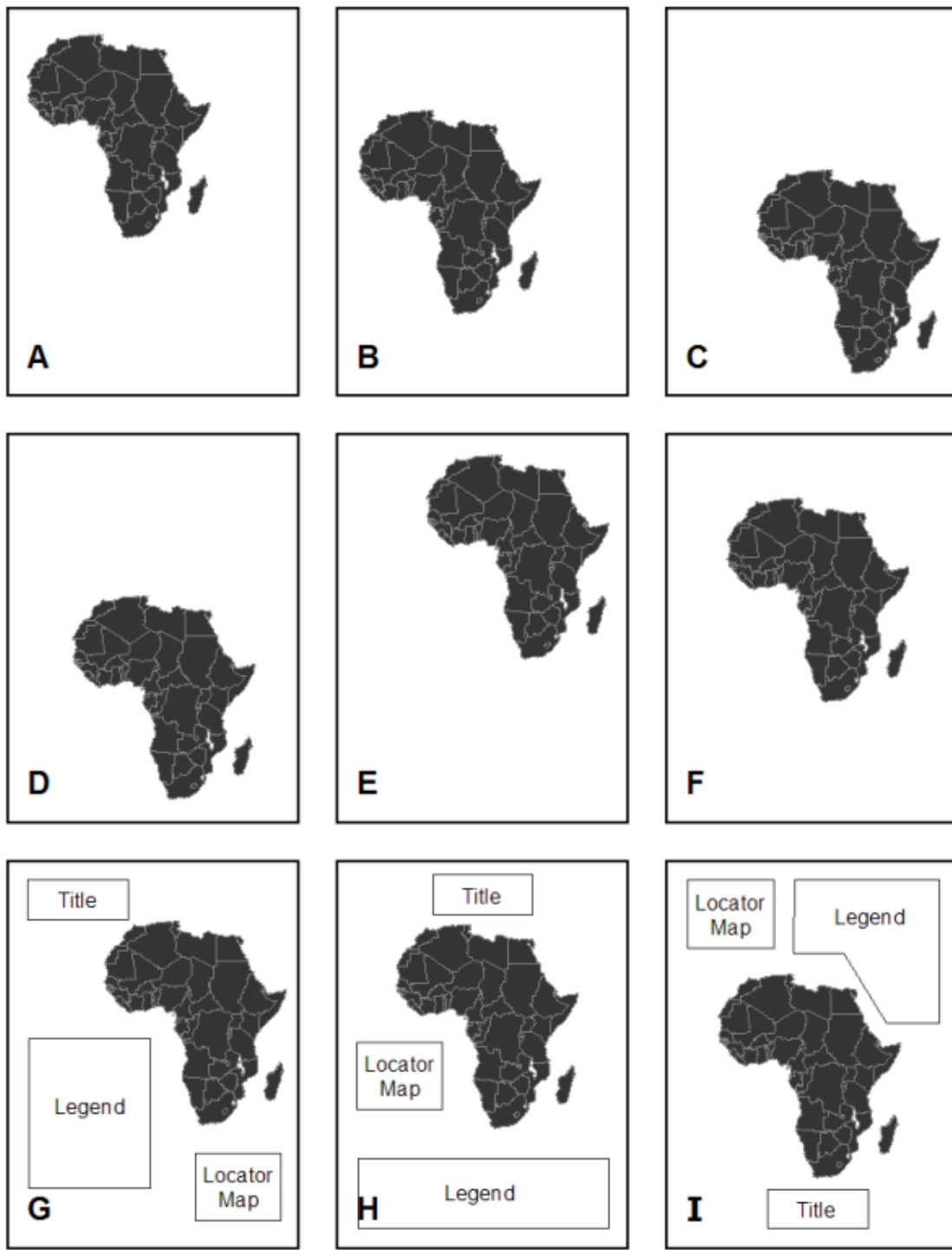


Figure 1.4: Which of the top six maps seems most balanced? It should appear that (F) has visual equilibrium, usually achieved by placing the central figure slightly above center on the page. However, the addition of page elements, such as the title and legend, will modify the visual impression, so all content on the page should be evaluated together to judge balance.

Together these five design principles have a significant impact on your map. How they are used will either draw the attention of your map readers or potentially repel them. Giving careful

thought to the design of your maps using these principles will help you to assure that your maps are ones' people will want to look at!

## 1.2 Labeling and text hierarchy in cartography

### 1.2.1 Background

The default thinking tends to be that labels and text on the map are for naming geographic features. While this is extremely important, they function in a number of other valuable ways, too. For example, **labels** also confirm the locations of features, reflect their character and shape, indicate relationships between them, and symbolize data associated with them. **Text**, in the form of short blocks or descriptions, is used for essential elements of map design like title, data sources, projection, and scale, as well as to provide an explanation about what a map is showing. Because of their prevalence (especially on reference maps) and tendency to compete for attention with other map symbols, labels and text make also make a strong aesthetic impression on the map reader and contribute to its overall 'look and feel'. Although every map is different, labels and text deepen our understanding of a place in ways that other graphical elements (like color) cannot.

The task of **1) selecting fonts** and font styles and **2) placing (or, positioning)** labels and text on the map is traditionally called "map lettering". Selection has to do with choosing fonts and font styles, whereas placement has to do with establishing relationships between labels and geographical features. They both have a great influence on how well a map functions as a whole. Given its complex and iterative nature (e.g., moving a label or changing a font often creates a domino effect of other necessary lettering changes), lettering has historically been one of the most time-consuming components of mapmaking, despite great advances in automating the process.

### 1.2.2 Important Questions to Ask Before Lettering a Map

#### 1) What is the intellectual hierarchy of the features I want to label?

Intellectual hierarchy has to do with ranking your map features in order of their importance. For example, on some maps capital cities might be considered more important than mid-sized cities, which in turn might be more important than small cities. States and countries

might be higher than all types of cities in the intellectual hierarchy. This kind of conceptual ranking can help you begin to create a visual hierarchy of map labels and text.

## 2) Why do I need a visual hierarchy of map labels and text?

A visual hierarchy is an essential aspect of map design that helps map readers organize graphical information so that it can be understood more quickly and easily. When applied to labels and text, a visual hierarchy allows people to more quickly and easily execute basic map reading tasks like categorizing, grouping, searching and scanning for information. The first map below shows a visual hierarchy of labels. Without visual hierarchy, as shown in the second example below, map reading becomes more taxing because everything is assigned an equal level of importance.



All else equal, bigger and bolder styles tend to promote labels and text in the visual hierarchy. Capitalization and bold colors like black, red, or purple can have a similar, promoting effect. Smaller point sizes and letterspacing (or, tracking) tend to demote labels, as do more muted text colors, like gray. Of course, the task becomes more complex as more labels are added and the number of necessary styles increases. Creating a good visual hierarchy will normally require some experimentation, revision, and refinement.

### 3) What are the basic map lettering conventions I should be aware of?

**There is no shortage** of map lettering conventions for placing and styling text on the map. While conventions are a great starting place, they should not be taken as rules that cannot be broken. A few of the more common conventions include:

- Prioritize the position of point feature labels: 1) above and to the right, then 2) below and to the right, then 3) above and to the left, then 4) below and to the left. Positioning directly above, below, or to the sides is not preferred.
- Visually center and increase the letter-spacing of labels within area features to reinforce their size/shape.
- Use uppercase to label area features.
- Categorize cultural and physical features using sans serif and serif fonts.
- Label water features blue and in an italic font.
- Distinguish ranked categories by at least two points when label sizes are small.
- Don't rotate labels upside-down.
- Labels should not be smaller than around 6-7pts for print maps / 9-10pts for maps displayed on screen.
- If necessary, use one serif and one sans serif font, but don't use more than one sans serif font on the map.

### 4) What is the overall map 'look and feel' that I want to convey?

Establishing a 'look and feel' has a lot to do with knowing the audience and purpose of the map. If the map has an overriding theme, this can also play a role. All fonts have "personalities" that can make a subjective impression on the map reader. Choose fonts that do not call undue attention to themselves (nothing too elaborate), yet whose personalities support the map's main purpose and theme. For example, choices can help make maps look and feel formal, informal, historical, modern, etc.

### 5) What is the end-use display environment for my map?

**The display environment is a huge** factor in determining whether your lettering choices will be legible to the map reader. This includes considering how the map will be reproduced

(e.g., laser printer, photocopier, scanner, fax machine, HDTV screen, projection screen, or mobile device?), as well as other factors such as viewing distance and lighting conditions. As a general rule, coarse resolutions, lossy or low-quality reproduction methods, low light and long distance reading all tend to require larger, more robust fonts with thicker strokes to remain legible.

#### 6) How much map lettering do I really need?

There is no easy answer to this question. Generally speaking, add enough to support the purpose of the map and provide some contextual information where this could be beneficial without cluttering the map or otherwise distracting from its use. General reference maps tend to include a wide range of densely spaced labels. Thematic maps, on the other hand, are often less densely labeled, using graphic symbols and colors and explanatory text to communicate their main message instead. It is also worth considering the “evenness” of text across the map. Distinct areas of high and low label density can make a map appear unbalanced. Overall, it’s easy to add labels and text to the map, more difficult to determine how much is appropriate.

#### 7) Do I need to know anything about typography?

**Yes.** Knowing a little bit about fonts, letterforms and their component parts can go a long way in helping to make the best choices for your map.

- i. **Point Size** is the height of a capital letter plus some space above and below. This is a holdover from the days of metal type setting, in which the characters in a font had to fit on a slug of the same body size to ensure uniform printing. *It’s important to note that different typefaces at the same point size can appear different in size, as shown below. Point size alone should never be used to determine legibility.*

-- 24 pt ITC Avant Garde -- 24 pt Adobe Jenson Pro --

- ii. **X-height** is the height of a lowercase letter minus its ascenders and descenders, shown with a blue dashed line in the example above. This property is nearly as important as point size when considering the legibility of text. All else equal, when point size gets small, fonts with larger x-heights tend to appear bigger than those with small x-heights. Fonts with largish x-heights also tend to have bigger interior spaces within letterforms that are less likely to collapse on screen at small sizes.

- iii. **Serifs** are the small marks that appear on the terminals of some letterforms, as shown below on the letter ‘T’. Fonts for screen-based maps should have robust serifs that won’t break down at small sizes. In fact, at small sizes on screen, the best choice is usually a sans serif font. However, when serifs are an option on screen, heavier block-like or square serifs are often the best choice, like those on the fonts Georgia, Droid Serif, or Bitstream Vera Serif.



- iv. **Depth of Family.** Font families that have a range of members are often good choices, given the variety of font styles regularly employed on maps. If a font comes in a regular, or Roman, weight, plus an italic and bold style, you’ll be able to cover the common uses for these without having to introduce another font family. Some font families, like Helvetica Neue, are very ‘deep’ and can include 10 or more members.
- v. **Cost.** Most of the time, good fonts cost money and require a license to use. *Good typography is worth paying for!* Don’t expect to find many freebie font families out there that look great across a range of sizes, work well in print and on screen, include a full set of glyphs, support multiple languages, contain a variety of members, and are otherwise suitable for mapping. That said, there are many decent free fonts out there through things like Google Fonts.
- vi. **Suggested fonts.** Below are a few of our go-to fonts. Some of these are better for web map user interfaces, some are better for map labeling, and some could be used for both. Note the condensed and narrow families, which can be useful for labeling. Also note the few families that have both a serif and sans serif counterpart, which can be handy for a fully unified look (e.g., map labels and body copy). Most have at least the four basic variants (regular, bold, italic, bold italic), some many more. Most are free on Google Fonts, but some are on Typekit or are paid.

#### **Sans serif**

- Open Sans and Open Sans Condensed (Google Fonts)
- Source Sans Pro (Google Fonts)
- PT Sans and PT Sans Narrow (Google Fonts)

- Myriad Pro and Myriad Web Pro (Paid, Typekit)
- Ubuntu and Ubuntu Condensed (Google Fonts)
- Arial and Arial Narrow (Paid but almost definitely on your computer already)
- Proxima Nova and Proxima Nova Condensed (Paid, Typekit)
- Oswald (Google Fonts)
- Merriweather Sans (Google Fonts)
- Fira Sans (Google Fonts)

### **Serif**

- Source Serif Pro (Google Fonts)
- PT Serif (Google Fonts)
- Merriweather (Google Fonts)
- Aver (Free)
- Lora (Google Fonts)
- Latienne Pro (Paid, Typekit)
- IM Fell Great Primer and others (Google Fonts)

### **Monospace**

- Fira Mono (Google Fonts)

### **Symbol**

- Font Awesome (Free)

## vii. **Typefaces and Fonts**

Maps may include text elements such as labels and ancillary text blocks. The choice of typeface (font family) and font (size, weight and style of a typeface) can impact the legibility of the map. A rule of thumb is to limit the number of fonts to two: a **serif** and a **sans serif** font.

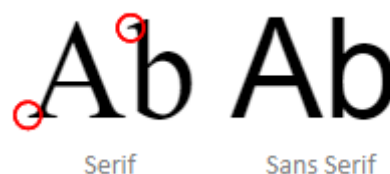


Figure 1.5: Serif fonts are characterized by brush strokes at the letter tips (circled in red in the figure). Sans Serif fonts are devoid of brush strokes.

Serif fonts are generally used to label natural features such as mountain ridges and water body names. Sans serif fonts are usually used to label anthropogenic features such as roads, cities and countries.



Varying the typeset size across the map should be avoided unless a visual hierarchy of labels is desired. You also may want to stick with a single font color across the map unless the differences in categories need to be emphasized. In the following example, a snapshot of a map before (left) and after (right) highlight how manipulating typeset colors and styles (i.e. italic, bold) can have a desirable effect **if done properly**.

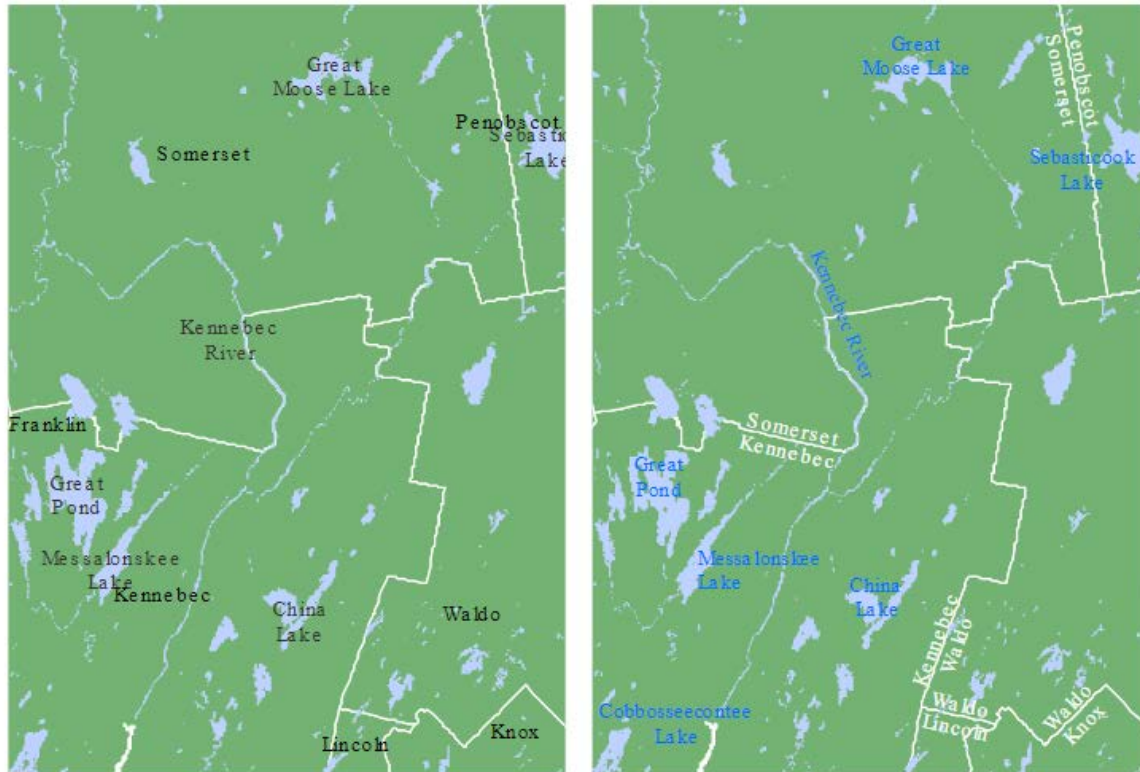


Figure 6: The lack of typeset differences makes the map on the left difficult to differentiate county names from lake/river names. The judicious use of font colors and style on the right facilitate the separation of features.

### 1.3 Elements of a Map

A map can be composed of many different map elements. They may include: Main map body, legend, title, scale indicator, orientation indicator, inset map and source and ancillary information. The following elements are often used to enhance map communication.

- i. **Borders or neat lines:** A fine line often encloses a map, unless the map content itself provides a strong contrast with the page. Other lines may be necessary in the figure to emphasize hierarchy and focus.
- ii. **Title:** Include either on the map or in a figure caption. A subtitle is sometimes useful. *\*\*The word “Map” in the map title is unnecessary (it is obvious that it is a map).*

- iii. **North arrow:** A north arrow is useful on maps that are oriented in some direction other than north or for very large scale maps.
- iv. **Graticule:** The graticule is a representation of meridians of longitude and parallels of latitude on a map. The graticule is useful for orientation and for visualizing the projection used on the map.
- v. **Scale:** A scale bar or verbal/numeric scale may be included on maps. Map scale varies throughout a map depending on the projection used, particularly on small scale maps. A variable scale bar may be used on maps that have large scale variations, but omitting a graphic scale bar altogether may also be appropriate.
- vi. **Inset maps:** Inset maps are useful for providing broader context to the information on the main map. They can be at a smaller or larger scale than the main map.
- vii. **Type:** Type refers to the labels put on a map. Typography is the process of selecting and stylizing labels. Changes in type family, type style, type size, lettering and word spacing, color, and orientation are used to create visual contrast between more important and less important typographical map content.
- viii. **Legend:** A legend explaining the map symbols should be included. The legend should be easy to understand, and self-explanatory. The following practices generally are applicable to legends for thematic data:
  - Legend symbols should match their corresponding map symbols exactly.
  - Items in the legend should be placed in a logical order based upon the data.
  - Ranges of numbers can be separated by a dash or by the word “to,” which is useful for avoiding consecutively placed dashes when negative numbers are present.
  - Numbers greater than 1,000 should include commas; numbers less than 1 should include a leading zero before the decimal point.

*\*\*The word “Legend” as a legend heading is unnecessary (the legend is obvious).*

*\*\*Using “Percent” in the map title and “Percentage” as a legend heading is not recommended. Instead, titles should use “Percentage” and legend headings should use “Percent.”*

- ix. **Other items:** Data sources, dates, information about data processing, and, if required, map status (draft, final, etc.), should be indicated either in the legend or elsewhere.

Not all elements need to be present in a map. In fact, in some cases they may not be appropriate at all. A scale bar, for instance, may not be appropriate if the coordinate system used does not preserve distance across the map's extent.

Knowing why and for whom a map is being made will dictate its layout. If it's to be included in a paper as a figure, then parsimony should be the guiding principle. If it's intended to be a standalone map, then additional map elements may be required.

Knowing the intended audience should also dictate what you will convey and how. If it's a general audience with little technical expertise then a simpler presentation may be in order. If the audience is well versed in the topic, then the map may be more complex.



Figure 1.7: Map elements. Note that not all elements are needed, nor are they appropriate in some cases. Can you identify at least one element that does not belong in the map (hint, note the orientation of the longitudinal lines; are they parallel to one another? What implication does this have on the North direction and the placement of the North arrow?)

## 1.4 How to Create a Good Map

Here's an example of a map layout that showcases several bad practices.

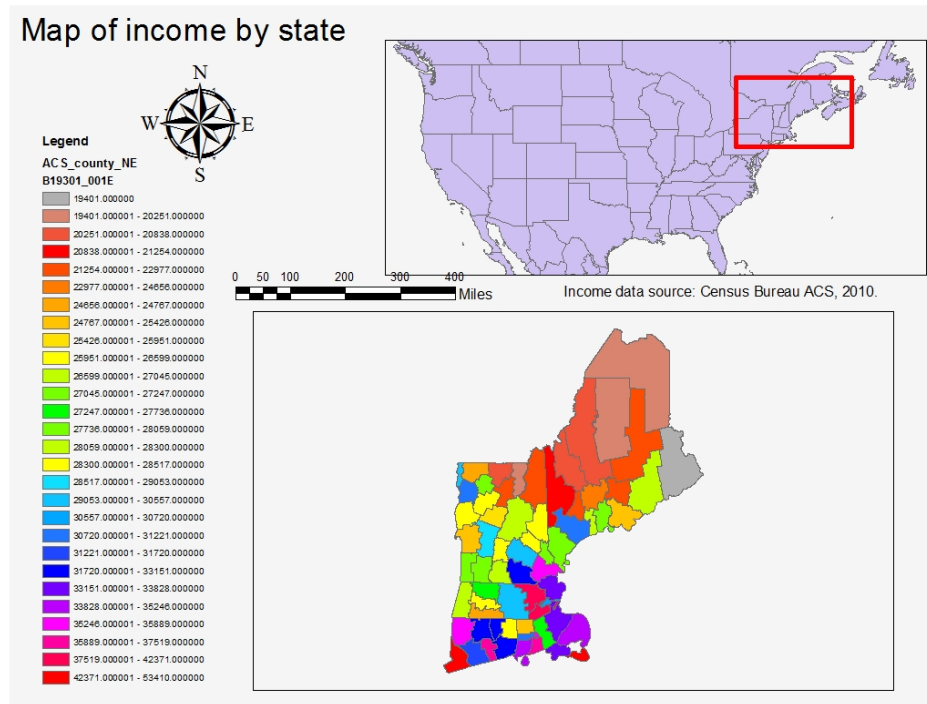


Figure 1.8: Example of a *bad* map.

A good map establishes a **visual hierarchy** that ensures that the most important elements are at the top of this hierarchy and the least important are at the bottom. Typically, the top elements should consist of the main map body, the title (if this is a standalone map) and a legend (when appropriate).

When showcasing Choropleth maps, it's best to limit the **color swatches** to less than a dozen—it becomes difficult for the viewer to tie too many different colors in a map to a color swatch element in the legend. Also, classification breaks should not be chosen at random but should be chosen carefully; for example adopting a quantile classifications scheme to maximize the inclusion of the different color swatches in the map; or a classification system designed based on logical breaks (or easy to interpret breaks) when dictated by theory or cultural predisposition.

**Scale bars** and **north arrows** should be used judiciously and need *not* be present in *every* map. These elements are used to measure orientation and distances. Such elements are critical in reference maps such as USGS Topo maps and navigation maps but serve little

purpose in a thematic map where the goal is to highlight *differences* between aerial units. If, however, these elements are to be placed in a thematic map, reduce their visual prominence (see Figure 1.7 for examples of scale bars). The same principle applies to the selection of an orientation indicator (north arrow) element. Use a small north arrow design if it is to be placed low in the hierarchy, larger if it is to be used as a reference (such as a nautical chart).

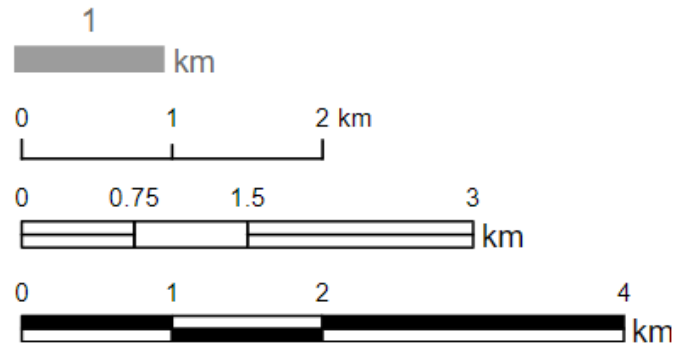


Figure 1.9: Scale bar designs from simplest (top) to more complex (bottom). Use the simpler design if it's to be placed low in the visual hierarchy.

**Title** and other **text elements** should be concise and to the point. If the map is to be embedded in a write-up such as a journal article, book or web page, title and text(s) elements should be omitted in favor of figure captions and written description in the accompanying text.

Following the aforementioned guidelines can go a long way in producing a *good* map. Here, a divergent color scheme is chosen whereby the two hues converge to the median income value. A coordinate system that minimizes distance error measurements and that preserves “north” orientation across the main map’s extent is chosen since a scale bar and north arrow are present in the map. The inset map (lower left map body) is placed lower in the visual hierarchy and could be omitted if the intended audience was familiar with the New England area. A unique (and unconventional) legend orders the color swatches in the order in which they appear in the map (i.e. following a strong north-south income gradient).

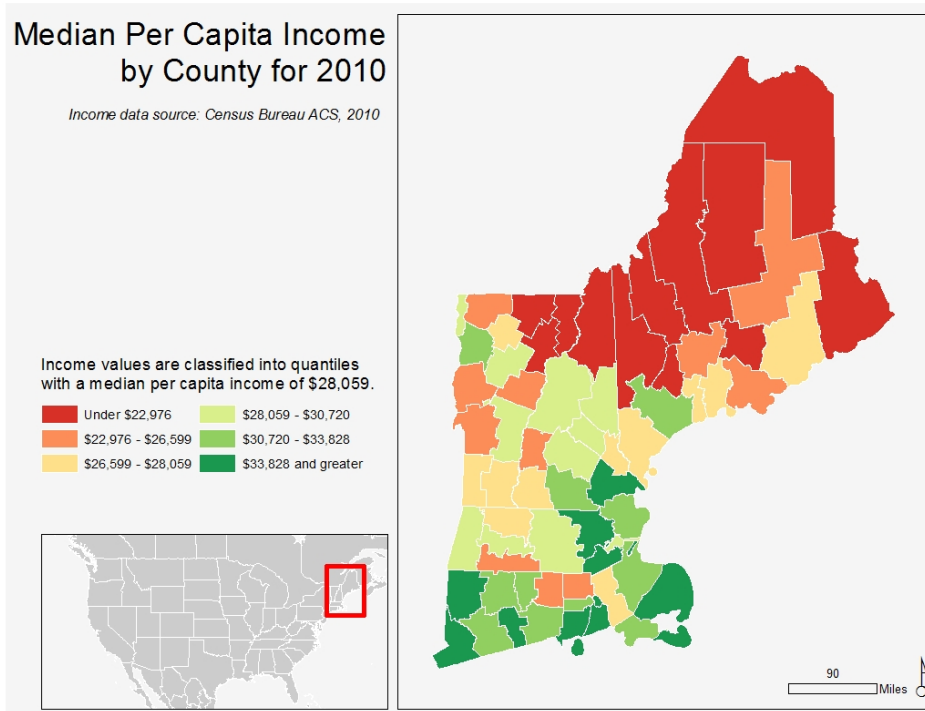


Figure 1.10: Example of an *improved* map.

## CHAPTER 2: SYMBOLIZING FEATURES

### 2.1 Color

Each color is a combination of three perceptual dimensions: **hue**, **lightness** and **saturation**.

#### 2.1.1 Hue

**Hue** is the perceptual dimension associated with color names. Typically, we use different hues to represent different *categories* of data.



Note that magentas and purples are not part of the natural visible light spectrum; instead they are a mix of reds and blues (or violets) from the spectrum's tail ends.

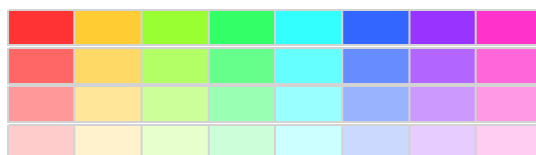
#### 2.1.2 Lightness

**Lightness** (sometimes referred to as *value*) describes how much light reflects (or is emitted) off of a surface. Lightness is an important dimension for representing ordinal/interval/ratio data.



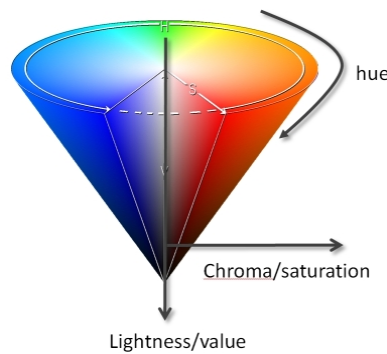
#### 2.1.3 Saturation

**Saturation** (sometimes referred to as *chroma*) is a measure of a color's vividness. You can use saturated colors to help distinguish map symbols. But be careful when manipulating saturation, its property should be modified sparingly in most maps.



## 2.2 Color Scheme

The three perceptual dimensions of color can be used to construct a 3D color space. This 3D space need not be a cube (as one would expect given that we are combining three dimensions) but a cone where lightness, saturation and hue are the cone's height, radius and circumference respectively.



The cone shape reflects the fact that as one decreases saturation, the distinction between different hues disappears leading to a grayscale color (the central axis of the cone). So if one sets the saturation value of a color to 0, the hue ends up being some shade of grey.

The color space implemented in most software is symmetrical about the value/lightness axis. However, this is not how we “perceive” color space: our perceptual view of the color space is *not* perfectly symmetrical.

Let's examine a slice of the symmetrical color space along the blue/yellow hue axis at a lightness value of about 90%.



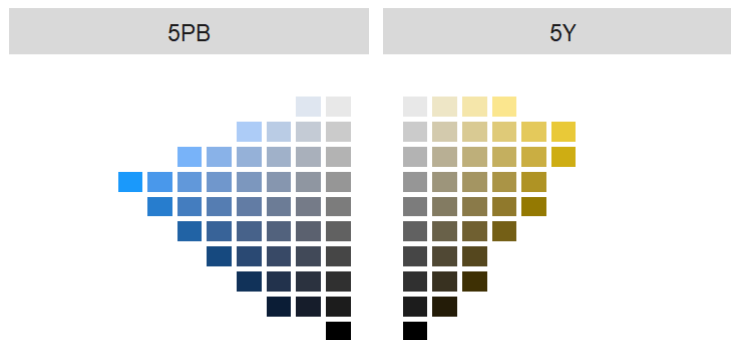
Now, how many distinct yellows can you make out? How many distinct blues can you make out? Do the numbers match? Unless you have incredible color perception, you will probably observe that the number of distinct colors do not match when in fact they do! There are exactly 30 distinct blues and 30 distinct yellows. Let's add a border to each color to convince ourselves that the software did indeed generate the same number of distinct colors.



It should be clear by now that a symmetrical color space does not reflect the way we “perceive” colors. There are more rigorously designed color spaces such as **CIELAB** and **Munsell** that



depict the color space as a non-symmetrical object as perceived by humans. For example, in a Munsell color space, a vertical slice of the cone along the blue/yellow axis looks like this.



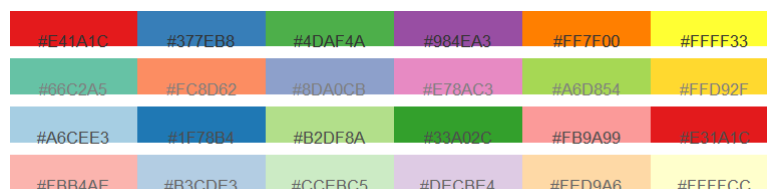
Note that based on the Munsell color space, we can make out fewer yellows than blues across all lightness values. In fact, for these two hues, we can make out only 29 different shades of yellow (we do not include the gray levels where saturation = 0) vs. 36 shades of blue.

So how do we leverage our understanding of color spaces when choosing colors for our map features? The next section highlights three different color schemes: **qualitative**, **sequential** and **divergent**.

## 2.3 Classification

### 2.3.1 Qualitative Color Scheme

Qualitative schemes are used to symbolize data having no inherent order (i.e. categorical data). Different hues with equal lightness and saturation values are normally used to distinguish different categorical values.



Election results is an example of a dataset that can be displayed using a qualitative color scheme. But be careful in your choice of hues if a cultural bias exists (i.e. it may not make sense to assign “blue” to republican or “red” to democratic regions).

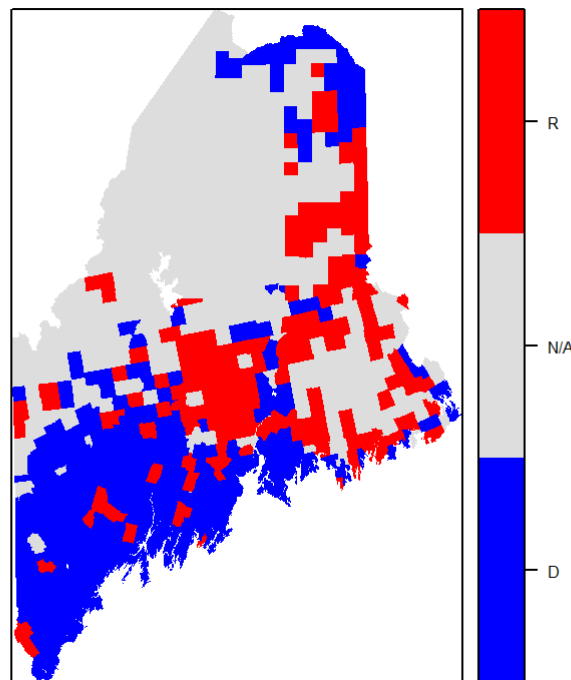
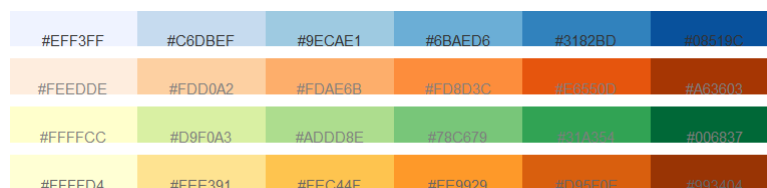


Figure 2.1: Map of 2012 election results shown in a qualitative color scheme. Note the use of three hues (red, blue and gray) of equal lightness and saturation.

### 2.3.2 Sequential Color Scheme

Sequential color schemes are used to highlight ordered data such as income, temperature, elevation or infection rates. A well designed sequential color scheme ranges from a light color (representing low attribute values) to a dark color (representing high attribute values). Such color schemes are typically composed of a single hue, but may include two hues as shown in the last two color schemes of the following figure.



Distribution of income is a good example of a sequential map. Income values are interval/ratio data which have an implied order.

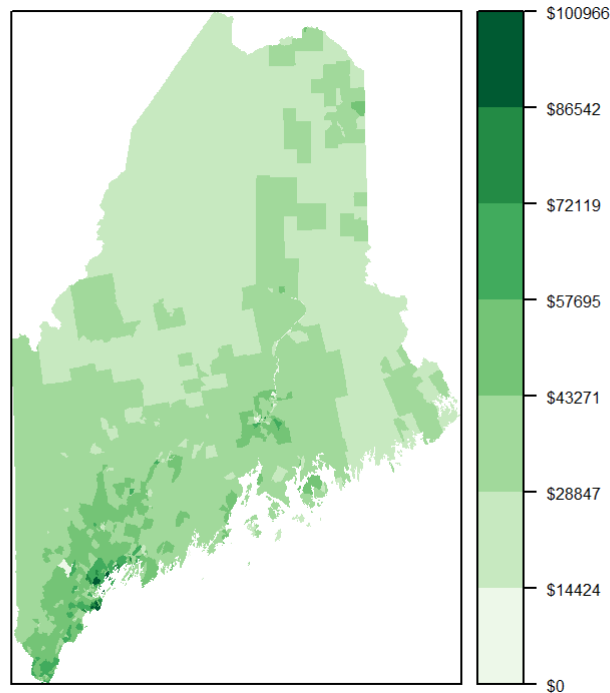
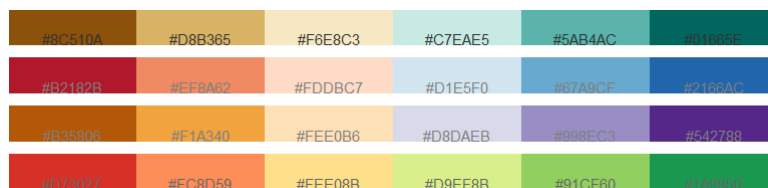


Figure 2.2: Map of household income shown in a sequential color scheme. Note the use of a single hue (green) and 7 different lightness levels.

### 2.3.3 Divergent Color Scheme

Divergent color schemes apply to ordered data as well. However, there is an implied central value about which all values are compared. Typically, a divergent color scheme is composed of two hues—one for each side of the central value. Each hue’s lightness/saturation value is then adjusted symmetrically about the central value. Examples of such a color scheme follows:



Continuing with the last example, we now focus on the divergence of income values about the median value of \$36,641. We use a brown hue for income values below the median and a green/blue hue for values above the median.

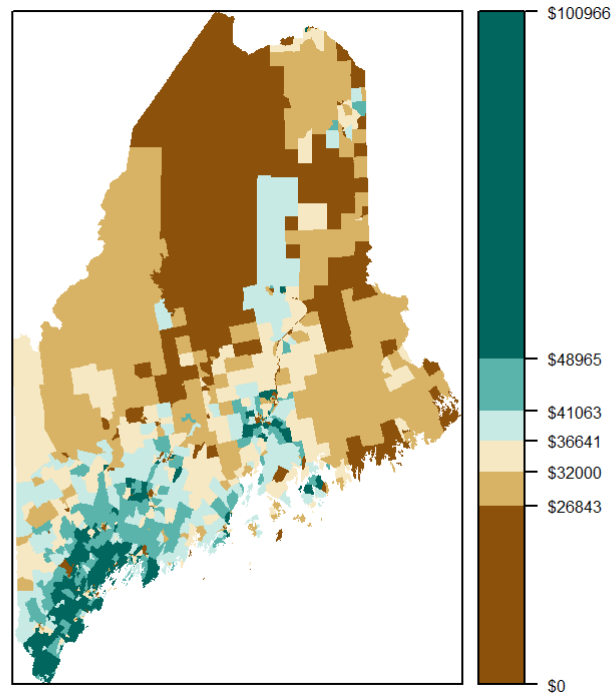
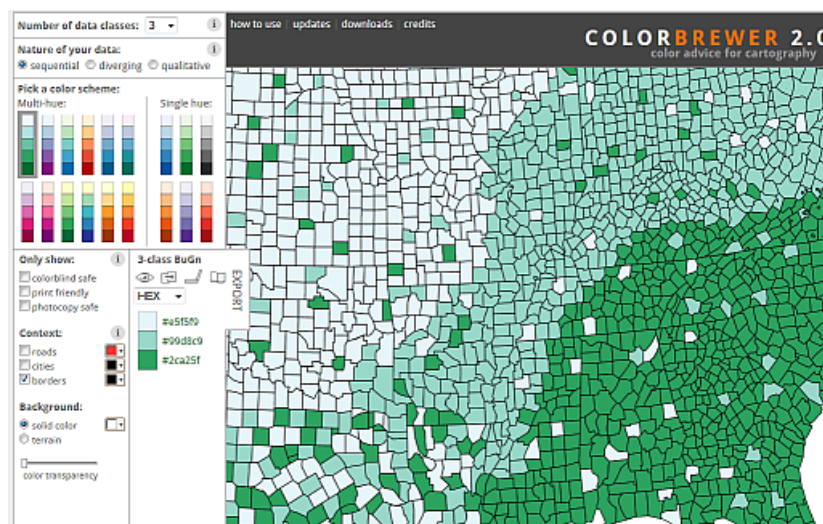


Figure 2.3: This map of household income uses a divergent color scheme where two different hues (brown and blue-green) are used for two sets of values separated by the median income of 36,641 dollars. Each hue is then split into three separate colors using decreasing lightness values away from the median.

## 2.4 So how do I find a proper color scheme for my data?

Fortunately, there is a wonderful online resource that will guide you through the process of picking a proper set of color swatches given the nature of your data (i.e. sequential, diverging, and qualitative) and the number of intervals (aka classes). The website is <http://colorbrewer2.org/> and was developed by Cynthia Brewer *et. al* at the Pennsylvania State University.



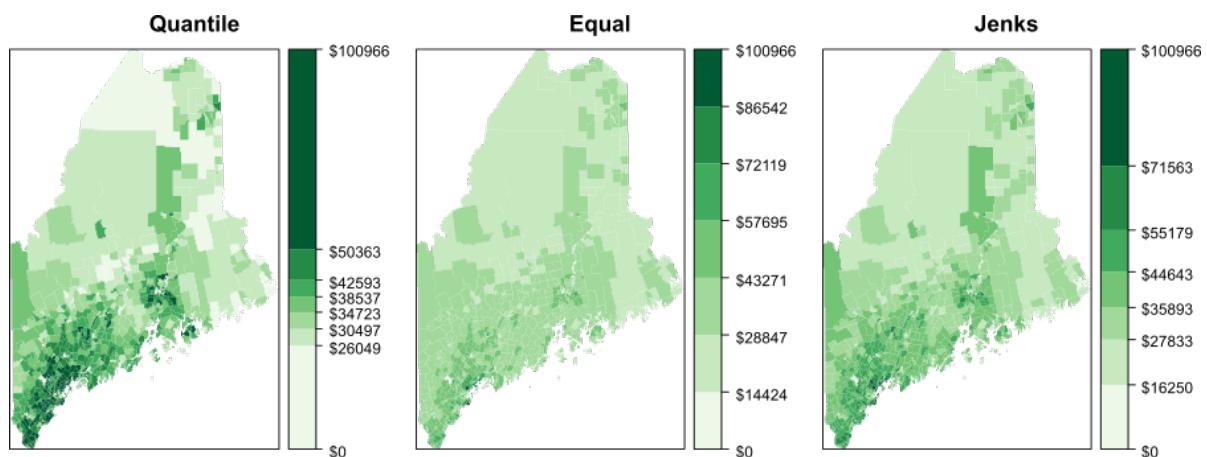
You'll note that the ColorBrewer website limits the total number of color swatches to 12 or less. There is a good reason for this in that our eyes can only associate so many different colors with value ranges/bins. Try matching 9 different shades of green in a map to the legend box swatches!

Additional features available on that website include choosing colorblind safe colors and color schemes that translate well into grayscale colors (useful if your work is to be published in journals that do not offer color prints).

## 2.5 Classification Intervals

You may have noticed the use of different classification breaks in the last two maps. For the sequential color scheme map, an *equal interval* classification scheme was used where the full range of values in the map are split equally into 7 intervals so that each color swatch covers an equal range of values. The divergent color scheme map adopts a *quantile interval* classification where each color swatch is represented an equal number of times across each polygon.

Using different classification intervals will result in different looking maps. In the following figure, three maps of household income (aggregated at the census tract level) are presented using different classification intervals: **quantile**, **equal** and **Jenks**. Note the different range of values covered by each color swatch.



The **quantile interval** scheme ensures that each color swatch is represented an equal number of times. If we have 20 polygons and 5 classes, the interval breaks will be such that each color is assigned to 4 different polygons.

The **equal interval** scheme breaks up the range of values into equal interval widths. If the polygon values range from 10,000 to 25,000 and we have 5 classes, the intervals will be [10,000 ; 13,000], [13,000 ; 16,000], ..., [22,000 ; 25,000].

The **Jenks interval** scheme (aka natural breaks) uses an algorithm that identifies clusters in the dataset. The number of clusters is defined by the desired number of intervals.

It may help to view the breaks when superimposed on top of a distribution of the attribute data. In the following graphics the three classification intervals are superimposed on a histogram of the per-household income data. The histogram shows the distribution of values as “bins” where each bin represents a range of income values. The y-axis shows the frequency (or number of occurrences) for values in each bin.

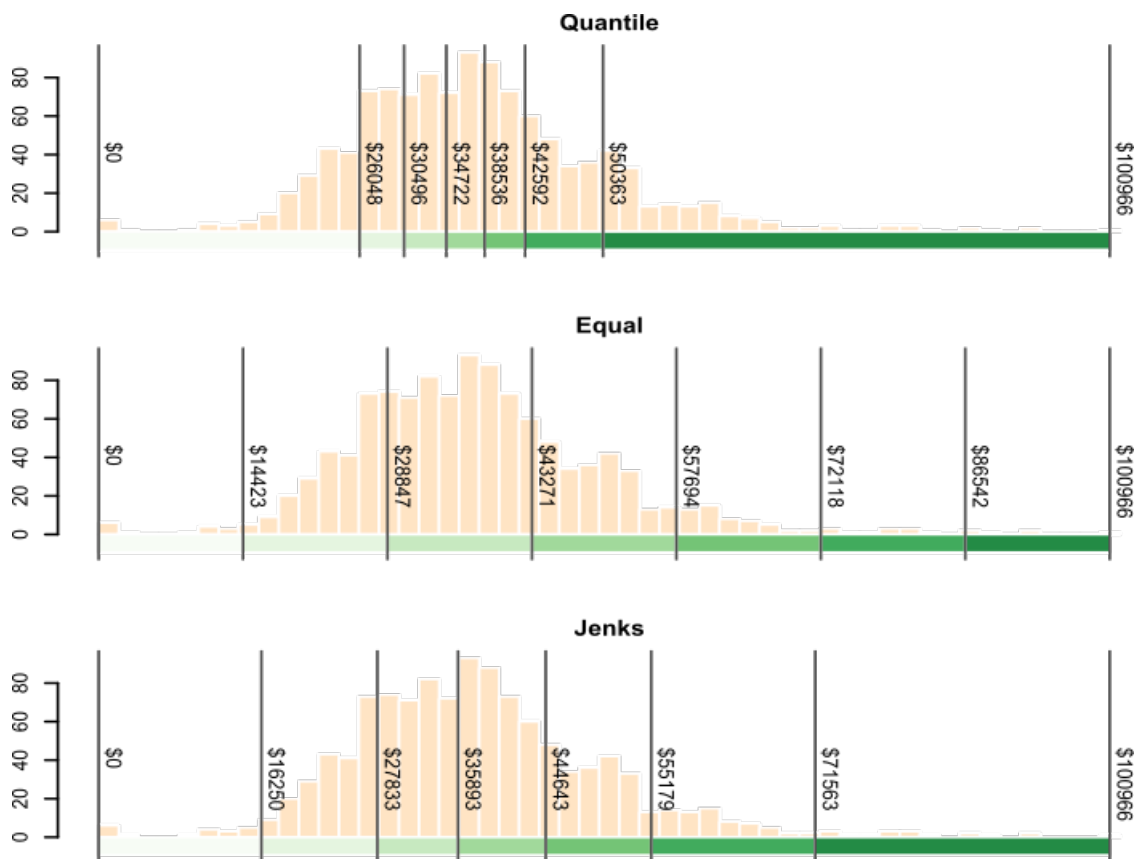


Figure 2.4: Three different classification intervals used in the three maps. Note how each interval scheme encompasses different ranges of values (hence the reason all three maps look so different).

## 2.6 Types of information and their visualization

We already know that the thematic component of geographical information can be numeric or alphanumeric and that numeric variables can be nominal, ordinal, intervals, or ratios. Selecting

a correct symbology according to the type of information that we are working with is key to producing an effective map. In particular, we must use a visual variable that has the correct properties (levels of organization) for the variable that we want to visualize.

For instance, the associative property and the selective property are of interest just for qualitative information, while size is the only visual variable that we can use that has the quantitative property and therefore, the only one that should be used to represent ratios.

The following are some of the more important ideas about this, referred to the aforementioned types of information.

- **Nominal.** Nominal information is correctly represented using the visual variable shape. This information shows *what* is found in the different locations of a map, and not *how much* is found, and it is more related to base cartography than to thematic cartography. Using different symbols for point elements and line elements is a common and very effective solution. For the case of areal symbols, hue and texture are the most common solutions.

Alphanumeric information has similar properties, and the same ideas apply to it.

- **Ordinal.** Since values of the variable define an order, a visual variable with the ordered property is needed to correctly visualize this type of information
- **Interval and ratio.** Visual variables with the ordered property can be used in this case. However, size is a better choice, as it is the only one which has the quantitative property.

Values are normally grouped into classes so the same value of the visual variable (same size of the symbols or same color value, for instance) is used for different values of the variable that we are visualizing. There are different strategies for this, which try to maximize the information that the map transmits. The most common ones are **equal intervals**, **intervals using percentiles** or **natural intervals** (intervals that try to minimize the variance within each class).

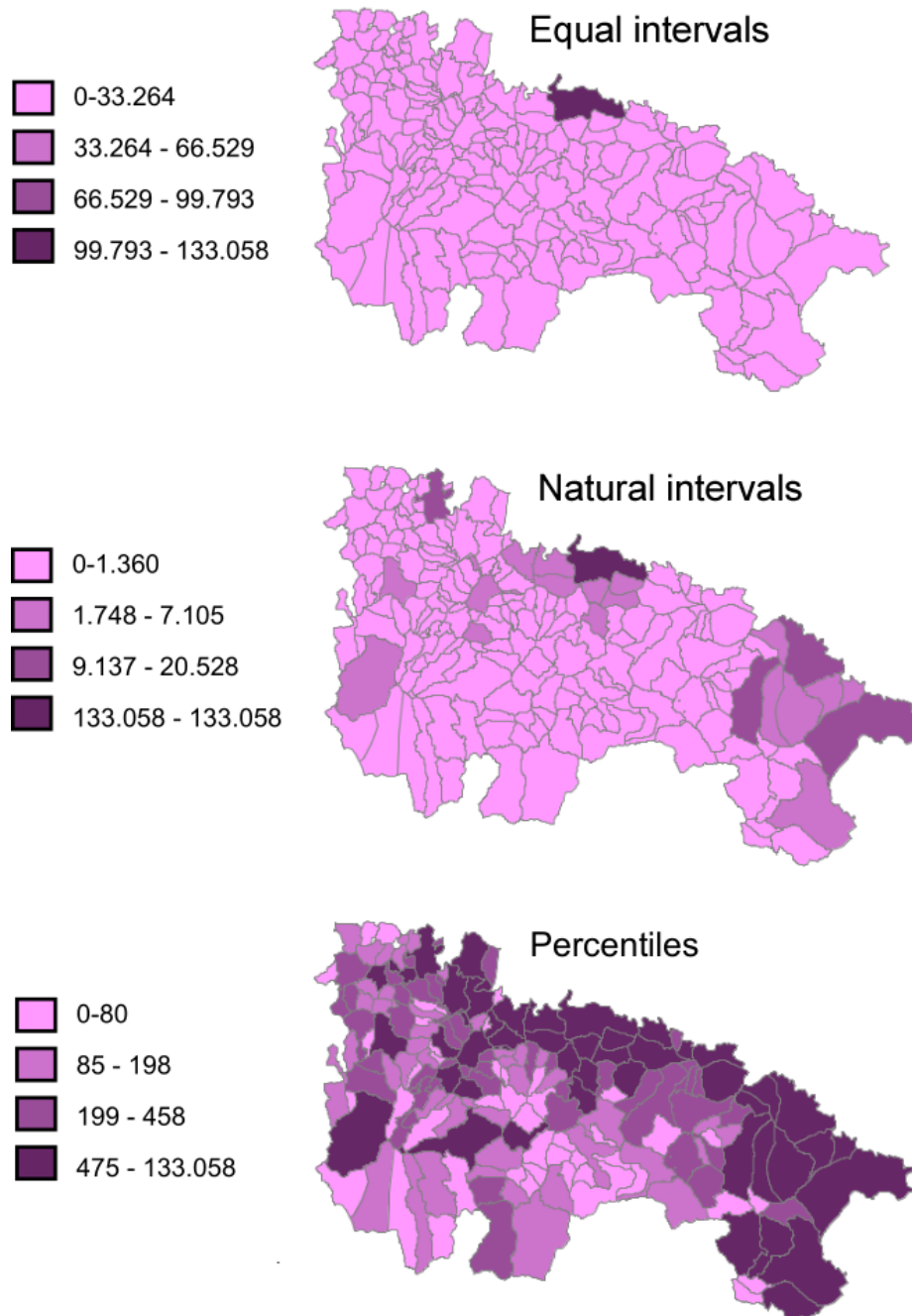


Figure 2.5: Comparison between different methods of defining intervals.

It is important to remark that, although levels of organization indicate increasing potential (that is, with a variable such as size or value we can convey all the information that can be conveyed with hue, since they have properties with a higher level), **it is not always better to use visual variables with a higher level of organization**, and it is not true that they will always be better than those with a lower one. For instance, using the visual variable value for a map with qualitative information (like using a ramp of different tones of blue for a map with soil type



information) might not be a good idea, because it has the ordered property, and that might cause the map user to think that there is some hierarchy (that some soil types are ``better" than others), which is false.

## 2.7 Types of thematic maps

There are many different ways of visualizing a given variable in a map. Several of them can be combined in a single map, especially if it includes more than one variable. In this case, the combination should strive to obtain the maximum possible clarity for all of them so the rendering of a variable does not overshadow the remaining ones.

In this section, we will describe the following types of thematic maps: proportional symbol maps, point density maps, isoline maps and choropleth maps.

### 2.7.1 *Proportional symbol maps*

A proportional symbol map represents **quantitative variables** using symbols whose sizes **are proportional to the value** of the variable. That is, the map uses the visual variable size (the only one with the quantitative property) to transmit the value of the variable being represented. If the symbol used is linear (such as a bar), its length is used to scale the values to render. If it is areal, area is used. That means that, in case of using circles, a value three times larger than a reference one will not be rendered with a circle with a radius three times longer, but with a circle with an area three times the area of the reference circle.

Symbol scaling can be done in a continuous way, but it is usually more convenient to use a discrete approach, grouping values in classes and assigning a single size for all values in each class, usually the size that corresponds to the center value of the class.

To avoid problems when perceiving the size of each symbol, it is important to show in the legend the relation between the different sizes and their corresponding values, as can be seen in figure 2.6.

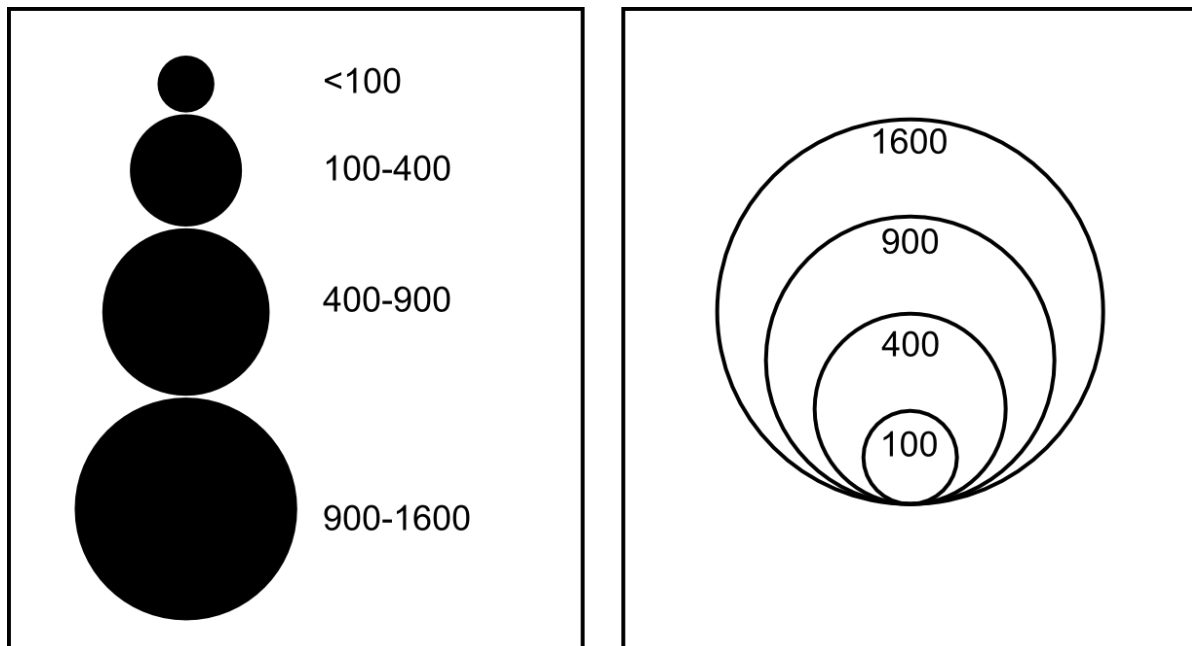


Figure 2.6: Two types of legend for proportional symbols maps.

### 2.7.2 Point density maps

Point density maps are particularly suitable for countable variables such as population or crop yield. These quantities are represented using **repeated points** whose number is proportional to the quantity itself. Each point represents a unitary value and all the points within an area add up to the total value of the variable in it. All points have the same size and shape, unlike what we saw in the case of proportional symbols.

When creating a point density map, three parameters have to be defined: the **value of each point** (that is, how many units of the variable the point represents), its **size** and its **position**.

The value of each point should be defined **based on the range of values** covered by the variable, so points in the resulting map are not too scarce or too numerous. This value will be included in the legend, usually in text form, writing, for instance, that "a point represents 1000 inhabitants".

Size must guarantee that points are visible and at the same time they do not take too much space in the map. The **optimal size is linked to the selected value of each point** and both parameters should be considered together, so as to find the best combination of them.

The position of the points is of great importance, as it should not convey wrong information or cause the user to misinterpret its meaning. If we do not have any additional information, points

should be regularly distributed, covering the whole area that correspond to the variable value. If, on the other hand, we have more information about the distribution of the variable, we should use it to give the points a more realistic position. For instance, if we are creating a density map with population values for regions, there should be more points in the surroundings of the cities within the region, since there are more inhabitants in those areas.

Another thing to consider is the meaning of the variable and whether or not the phenomenon that it represent can appear at a given point. For instance, if the variable that we are representing is the number of water birds know to nest in each region, it will be wrong to place the density points in forest areas or city ones, since it might be inferred that birds are found there, which is likely not true.



Figure 2.7: Point density map.

### 2.7.3 *Isoline maps*

Isoline maps are commonly used to represent **continuous variables**. Containing only lines, they mix well with other types of maps without being obtrusive.

An isoline map is formed by a set of lines, each of them connecting points that have the same value of the variable being represented. These lines cannot cross with each other, since a point cannot have two values at the same time. The most common use of isolines are contour lines in topographic maps which represent points with the same elevation.

Isolines are defined by their **equidistance** which indicate the difference between the values represented by any two contiguous isolines. A lower equidistance means more isolines and a denser map.

Size is the only visual variable used with isolines. It is used to highlight those that represent a value that is a multiple of a given number, to make the map easier to read. These lines are known as **index lines**.

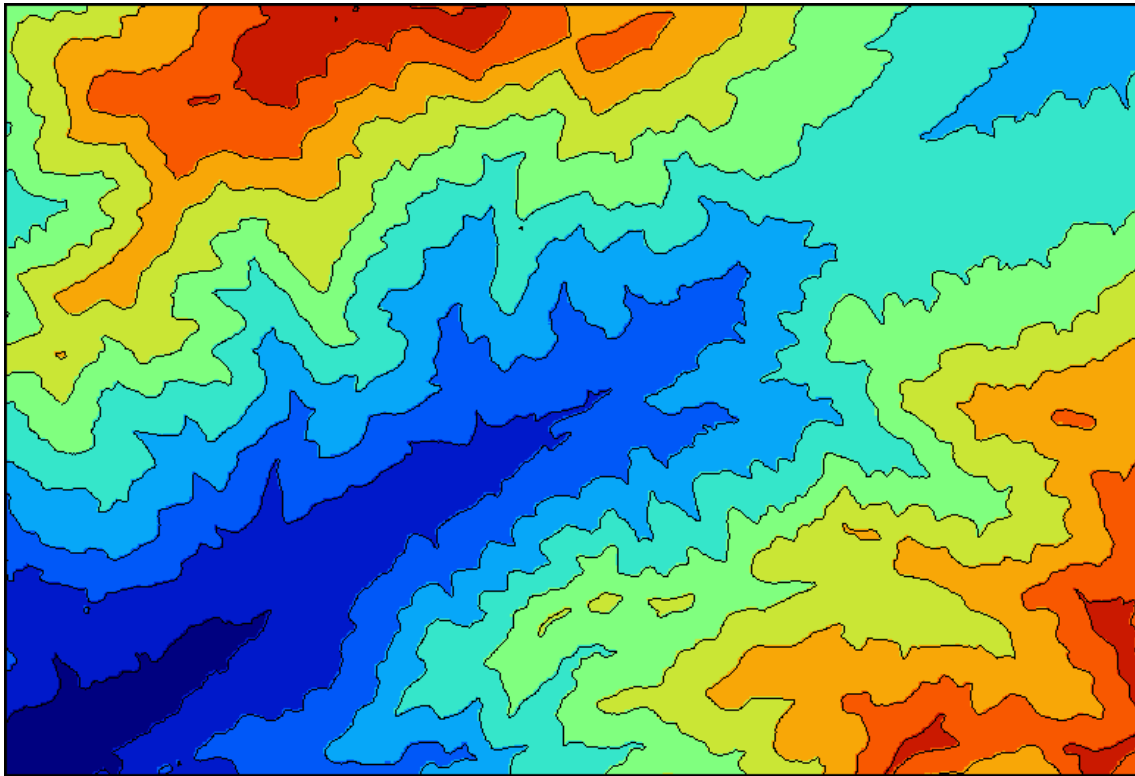


Figure 2.8: Map with isolines and hypsometric tints.

Lines are labeled with their value over the line itself, usually only on the index lines (the value of other lines between the index ones can be easily figured out knowing the equidistance).

A particular case of isolines are the so called **hypsometric tints**. Apart from drawing the lines themselves, the areas between them are colored, each with a different color (usually using a graduated scheme).

#### 2.7.4 Choropleth maps

Choropleth maps are a very common type of map in GIS. In a choropleth map, there is a set of areas, each of them representing a single value of a variable. This value applies to the whole area, and is normally represented using hue applied to the areal symbol.

Choropleth maps have some important limitations. One of them is the **sharp change in the boundaries between areas**, which might be interpreted as an abrupt change in the variable value in that boundary. This could hide the continuity of the variable distribution, in case it exists. Another problem is the **homogeneity within each area**, which might lead to thinking that the variable has a uniform distribution, even if that is false.

In many cases, and in order to correctly transmit the information contained in the variable, its values have to be **normalized using the area of each region**.

## 2.8 Lab: Designing Maps with ArcGIS

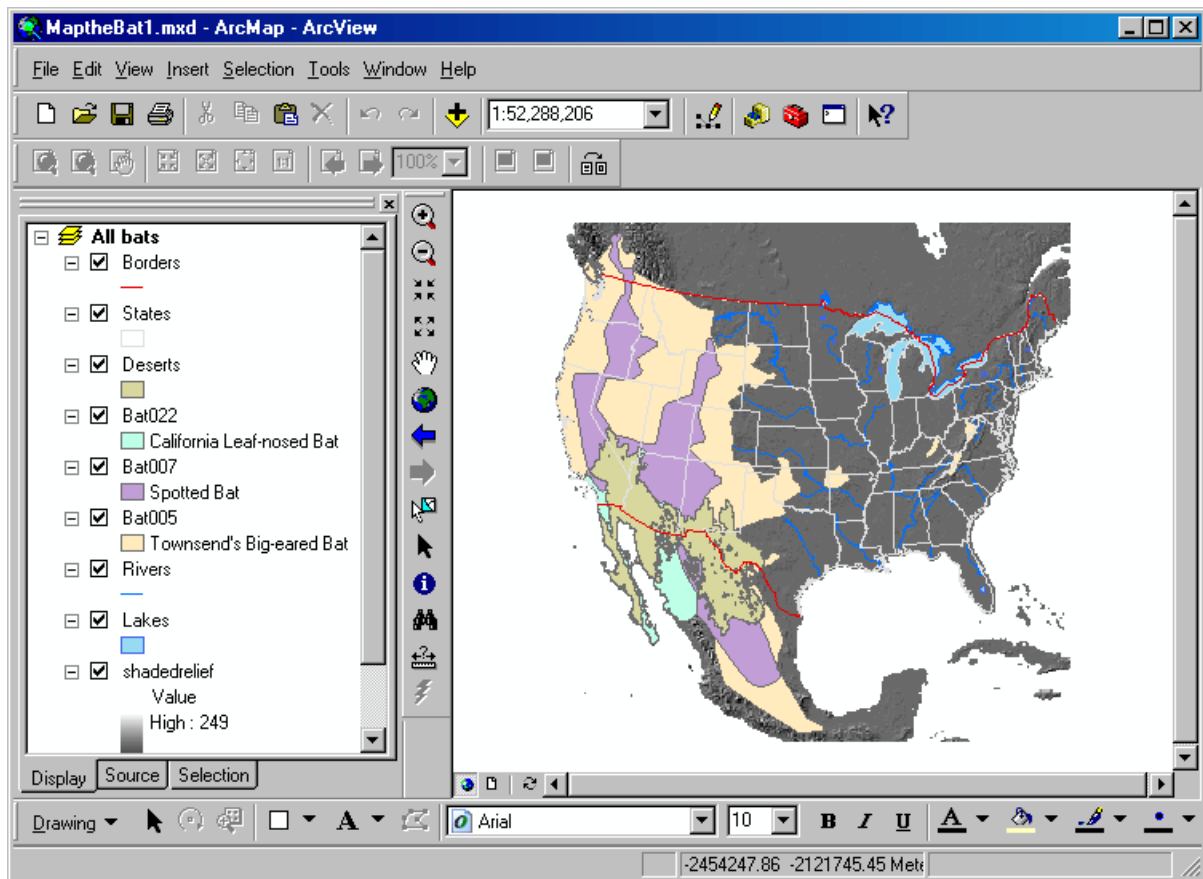
### Part I. Create a presentation map

GIS Day is approaching and you're going to give a presentation called "Map the Bat" at a local high school. You plan to create a presentation map that shows the ranges of three bat species and their relationship to each other and to the desert ecoregion that is their common habitat.

In this exercise, you will create a basic map layout by applying a map template and designing the main data frame. You will continue by creating other map elements and fine-tuning the layout. You will finish the map by creating an inset map, modifying the template and the legend, and adding scale information and other elements to the layout.

#### Step 1 Start ArcMap and open a map document

Start ArcMap and open MaptheBat1.mxd from your Lab1\Bats folder.



Step 1: Start ArcMap and open a map document.

The map shows the ranges of three bat species (California Leaf-nosed bat, Spotted bat, Townsend's Big-eared bat) as they extend across the U.S. into Canada and south into Mexico.

Besides the bat ranges, the map contains some base layers as well as a raster layer called shaded relief that shows elevation. The Deserts layer shows the southwestern desert habitat that is common to all three species.

For convenience, the layers are already in the correct order and most of the symbols are defined.

Step 2 Apply a template to the layout

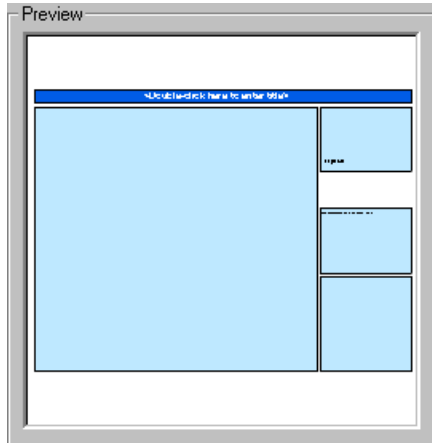
To speed up the design process, you will apply a predefined map template that contains most of the elements you will need for your presentation map.

First, click the Layout View button below the map display.

To apply a more suitable template to your layout, on the Layout toolbar, click the Change Layout button.

In the General tab, you see a list of available templates and on the right, their preview image. ArcMap provides a variety of templates suitable for different layouts.

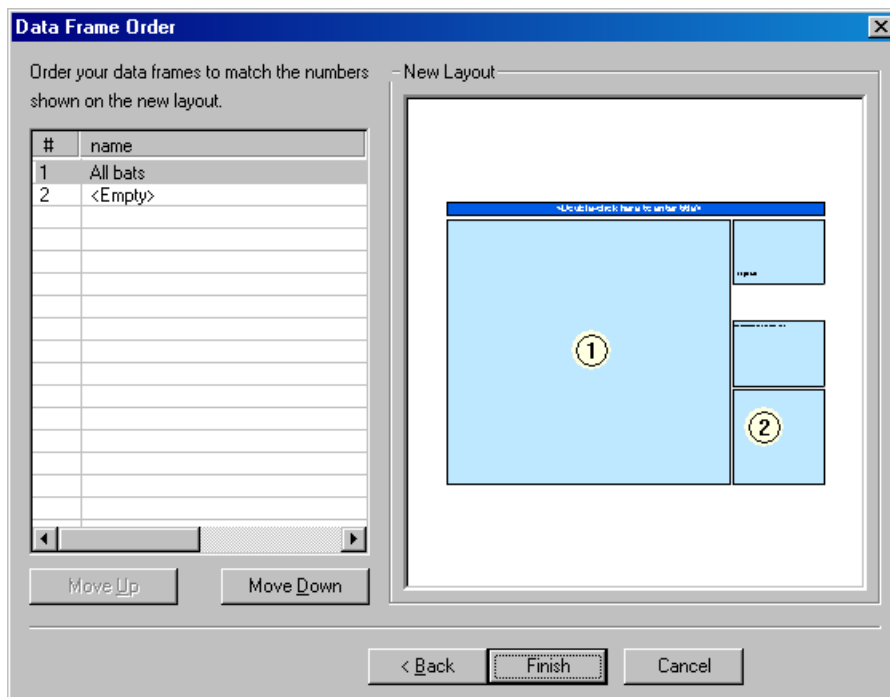
Click LandscapeModernInset.mxt.



Step 2a: Apply a template to the layout.

This template contains a number of predesigned elements and will work well for your map.


Click Next.

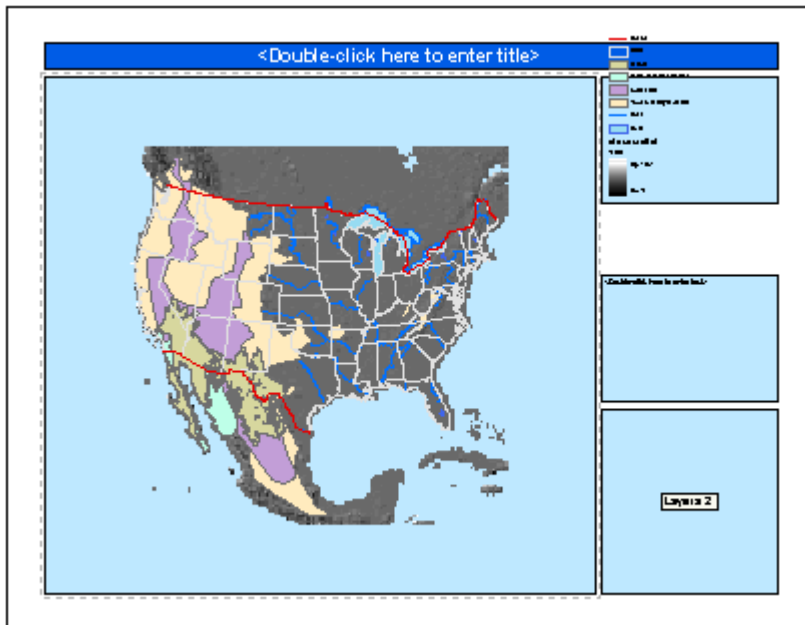


Step 2b: Apply a template to the layout.

The template includes boxes for two data frames. The All bats data frame is selected for the main data frame (data frame 1), while the second data frame is intended for an inset map.

The inset map box is currently empty because you haven't created the inset map data frame yet. The template includes a map title and some other elements that you will create in the next exercise.

Click Finish. If you don't see the layers in the main data frame, click Refresh .



Step 2c: Apply a template to the layout.

Notice that a second data frame was added to the bottom of the Table of Contents (you might need to scroll down to see it). Later, this data frame will contain the layers for the inset map.

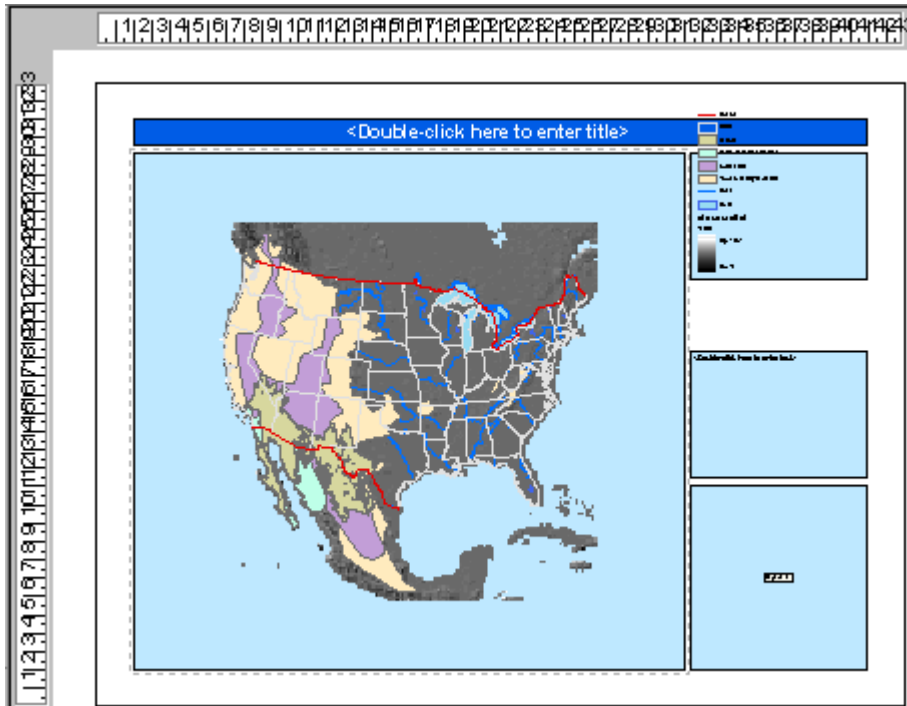
Step 3 Enlarge the page size

Remember, the map is intended for a presentation. It will be seen by a lot of people from a distance, so it should be fairly large in size.

From the File menu, choose Page and Print Setup. In the Map Page Size area, in the Standard Sizes dropdown list, choose ANSI E (44 x 34 inches).

Click OK.





Step 3: Enlarge the page size.

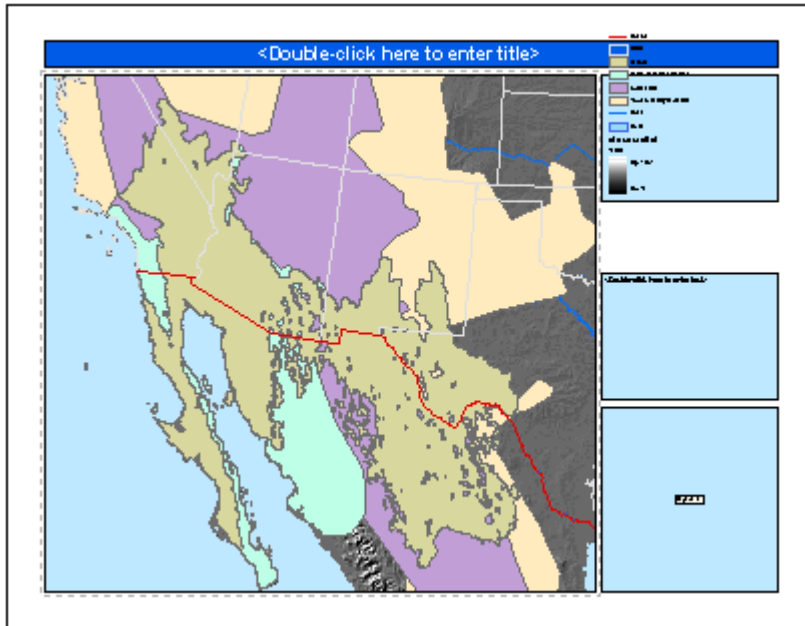
The layout rulers show the new page dimensions.

You have made considerable changes to the map, so save your work.

Step 4 Set the map scale

The presentation will concentrate on the area of the bat ranges that overlap the southwestern desert, which is the extent of the Deserts layer. You will change the extent shown in the data frame as well as the map scale so that this area is the focus of the data frame.

In the Table of Contents, right-click Deserts and choose Zoom To Layer.



Step 4a: Set the map scale.

Notice that the map scale is a large number that is hard to read and understand. To make it more user-friendly, you will round it.

Change the scale to 1:3,000,000.



Step 4b: Set the map scale

If necessary, pan the map so that the Deserts layer is centered in the data frame.

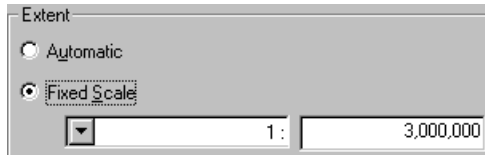
Step 5 Lock the scale

To safeguard against inadvertently changing the map scale as you work on the layout by using the wrong zoom tool, you will fix the current scale so that it can't be changed.

Click the Select Elements button, then right-click in the data frame and choose Properties. In the Data Frame Properties dialog, click the Data Frame tab.

The extent is currently set to Automatic.

Click Fixed Scale.



Step 5a: Lock the scale.

Click OK.

On the Tools toolbar, notice that the Zoom In, Zoom Out, and Full Extent buttons are now disabled.

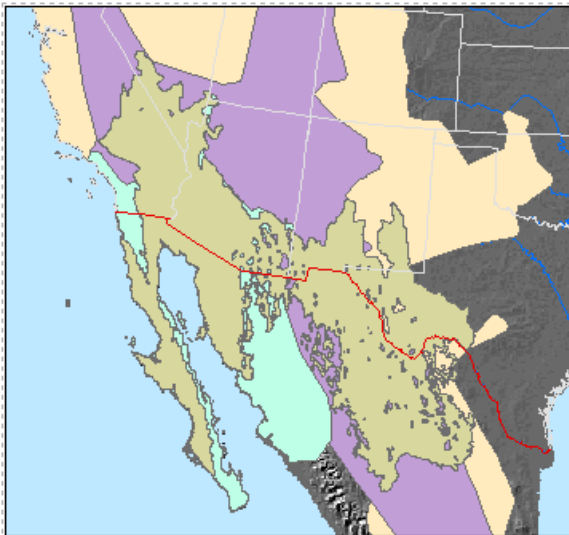
Step 5b: Lock the scale.

Click away from the data frame to unselect it and save your work.

Step 6 Choose the data frame layers

The main data frame is currently confusing and difficult to read—it contains too much information. You will fix this problem by turning off unneeded layers and making others partially transparent.

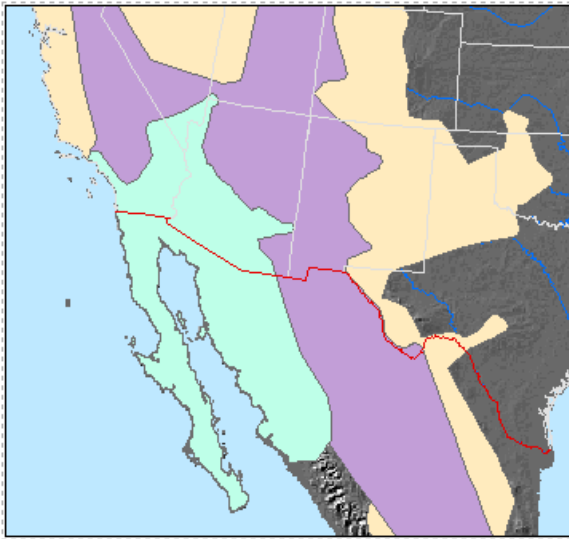
To see the data frame as clearly as possible, zoom in on it to maximize its size in the map display area.



Step 6a: Choose the data frame layers.

The map shows how the bat species extend across the southwestern desert, but the Deserts layer obscures the bat ranges. For your map, showing the bat ranges is of primary importance, so you will turn off the Deserts layer and display it in the inset map.

In the Table of Contents, turn off the Deserts layer.



Step 6b: Choose the data frame layers.

Now the bat ranges are unobstructed.

Save your work.

Step 7 Adjust layer transparency

Because the bat ranges are symbolized with a solid fill, each layer obscures the one below it. If you make them partially transparent, you will be able to see the underlying layers.

Right-click in the gray area next to the Help menu and click Effects.

You see the Effects toolbar.

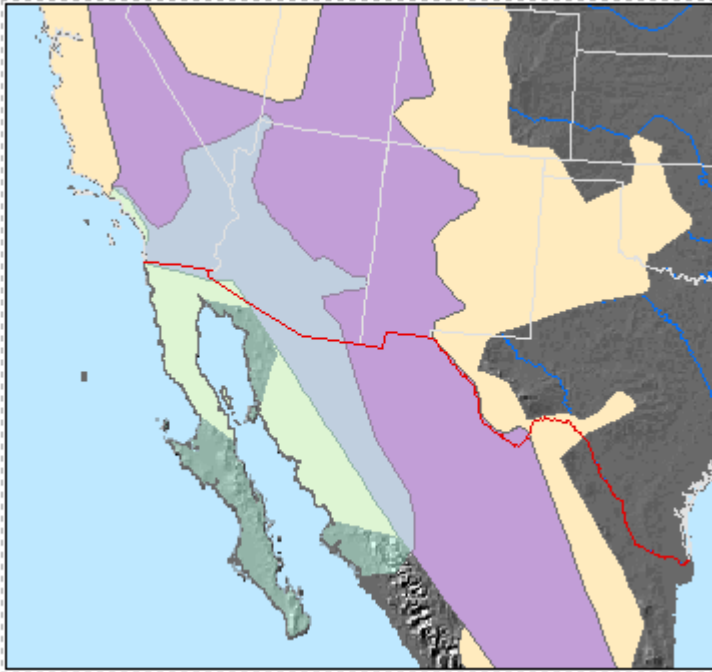
Step 7a: Adjust layer transparency.

Dock the Effects toolbar on your ArcMap window if desired.

In the Layer dropdown list, choose the Bat022 layer. Click the Adjust Transparency button.

Step 7b: Adjust layer transparency.

Drag the Transparency slider up to 50%.



Step 7c: Adjust layer transparency.

Now the layer is transparent and you can see the underlying layers through it.

Make the Bat007 and Bat005 layers 50% transparent as well.



Step 7d: Adjust layer transparency.

The base layers that were obscured by the bat ranges are now visible.

Adjusting layer transparency is a good way to optimize the information shown in a map. In addition to seeing each bat range, you can now also see:

- The relationship of bat ranges to each other

- The state or country that a bat range traverses
- The physical features underlying the bat ranges
- The part of the southwestern desert that is habitat for all three bat species

Close the Effects toolbar and zoom out to the full extent of the page . Save your work.

#### Step 8 Convert labels to annotation

Showing the state outlines in the map is useful for orientation, but the map could be improved by adding the state names. You will add state name labels.

Double-click the States layer to open its Layer Properties dialog. Click the Labels tab.

Check the option to "Label features in this layer." For Label Field, choose STATE\_NAME.

Modify the default label symbol using the information below:

- Font: Arial
- Font size: 38 (type 38 into the size box)
- Font color: White

Step 8a: Convert labels to annotation.

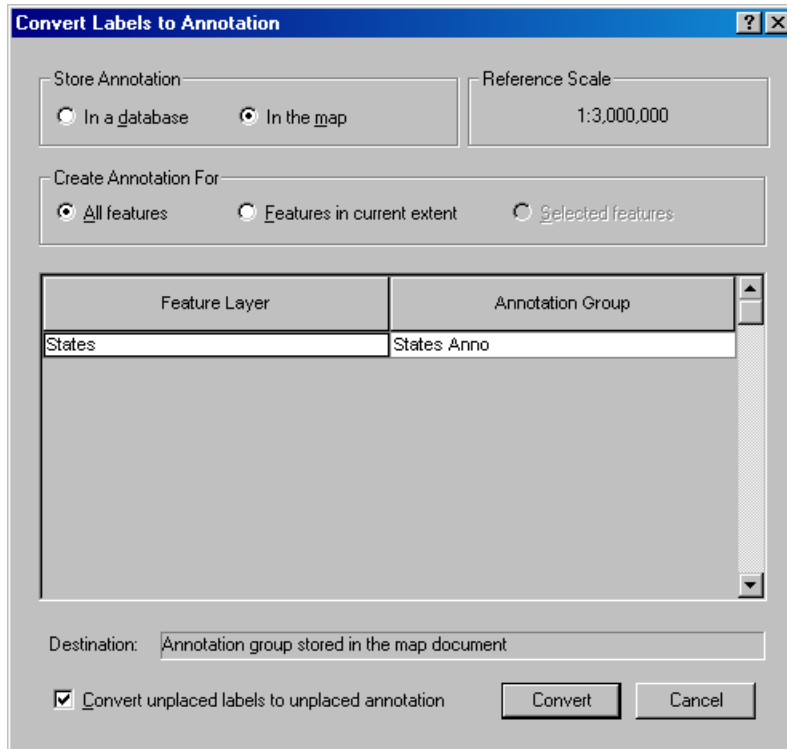
Click OK.

Some of the labels intersect bat range outlines as shown in the graphic below.



You will move the problem labels. In order to move individual labels, however, you need to convert the layer's dynamic labels to annotation.

Right-click States and choose Convert Labels to Annotation. In the dialog, check the option to store the annotation in the map.



Step 8b: Convert labels to annotation.

Click Convert.

There is no apparent change to the map, but the state names are now annotation that you can edit.

The data frame is selected in the layout, but in order to edit annotation, you must give the data frame "focus."

On the Layout toolbar, click the Focus Data Frame button.



Step 8c: Convert labels to annotation.

The diagonal hatched symbol around the data frame indicates that it is focused.

With the Select Elements tool, click each piece of annotation to select it, then drag it to the new position shown in the graphic below.



Click outside the data frame to remove the focus and unselect the annotation. Click the Refresh button at the bottom of the map display area.

Save your work.

Step 9 Add new text

In this step, you will add the country name for Mexico.

Zoom in to the part of Mexico that is visible in the data frame (below the red border line).

On the Draw toolbar, type 60 into the font size box and press Enter. Click the Bold (B) button.

Click the New Text button, click in the center of the data frame, then type MEXICO. Press Enter.

Double-click Mexico and change the character spacing to 100 in the Properties dialog. Click OK.

If the country name intersects one or more of the bat range outlines, reposition it so that it's entirely within a bat range.





Step 9: Add new text.

Zoom out to the whole page. Unselect the annotation and save your work.

Next, you will add a reference system to the data frame.

Step 10 Add a graticule

To make it easier to understand the extent covered by the bat ranges, you will add a graticule to the map.

Because you will use a wizard to create the graticule, you need to make sure that wizards are enabled.

From the Tools menu, choose Options. In the General tab, make sure the option to "Show Wizards when available" is checked.

Step 10a: Add a graticule.

Click OK.

Right-click the data frame and choose Properties. Click the Grids tab.

Click New Grid.

In the Grids and Graticules Wizard, click the available options and preview the types of grids you can create.

Click the option to create a graticule.



Step 10b: Add a graticule.

Click Next.

In the Appearance area, choose Graticule and labels.

Graticule lines labeled with latitude and longitude will be shown in the map.

Click the button under Style and in the Symbol Selector, change the color to Gray 50%.

Click OK.

You want the map to display a  $10^{\circ} \times 10^{\circ}$  graticule.

In the Intervals area, in the box under Deg (degrees) type 10 for the parallels. Press Tab.

Click in the Deg box next to meridians and type 10, then press Tab.

Notice that the preview has updated.



Step 10c: Add a graticule.

Click Next.

In the Labeling area, click the Text style button. Change the font size to 12, then click OK.



Step 10d: Add a graticule.

Click Next. The graticule is set up the way you want it, so click Finish.

The graticule option is now checked in the Data Frame Properties dialog.

Click OK.

The graticule is added to the data frame.

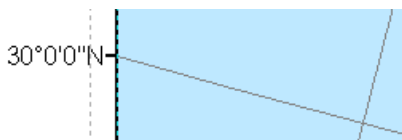


Step 10e: Add a graticule.

Unselect the data frame and zoom in if necessary to see the graticule better.

The graticule also is useful for showing which direction is north. The projection used for this map causes north to vary from one area to another, so it would not be appropriate to add a north arrow to this map.

Zoom in to the middle of the data frame's left border and examine the graticule's label.

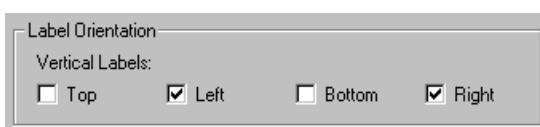


Step 10f: Add a graticule.

To reduce the amount of space occupied by the labels, you will change the orientation of the labels on the left and right side of the data frame so they're drawn vertically (parallel to the border).

Reopen the Data Frame Properties dialog. In the Grids tab, click Properties.

In the Reference System Properties dialog, click the Labels tab. In the Label Orientation area, check the Left and Right boxes.

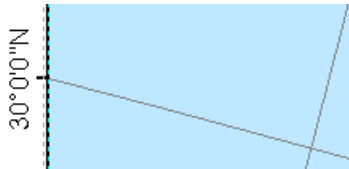


Step 10g: Add a graticule.

Click OK.

Click OK again to close the Data Frame Properties dialog.

The label is now oriented vertically.



Step 10h: Add a graticule.

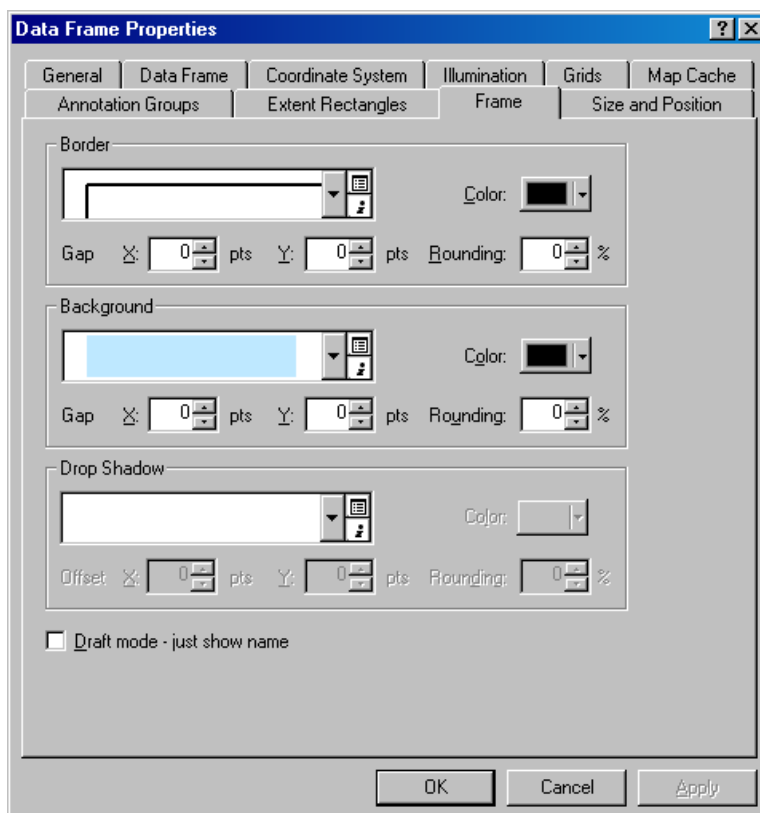
Save your work.

Step 11 Change the background color

The last thing you will do is change the data frame's background color.

Zoom to the whole page.

Once more, open the Data Frame Properties dialog. This time, click the Frame tab.



Step 11a: Change the background color.

Click the dropdown arrow next to Background and choose any color (e.g., Black).

Click Apply.

Now the colors in the Background box and the Color box are the same.

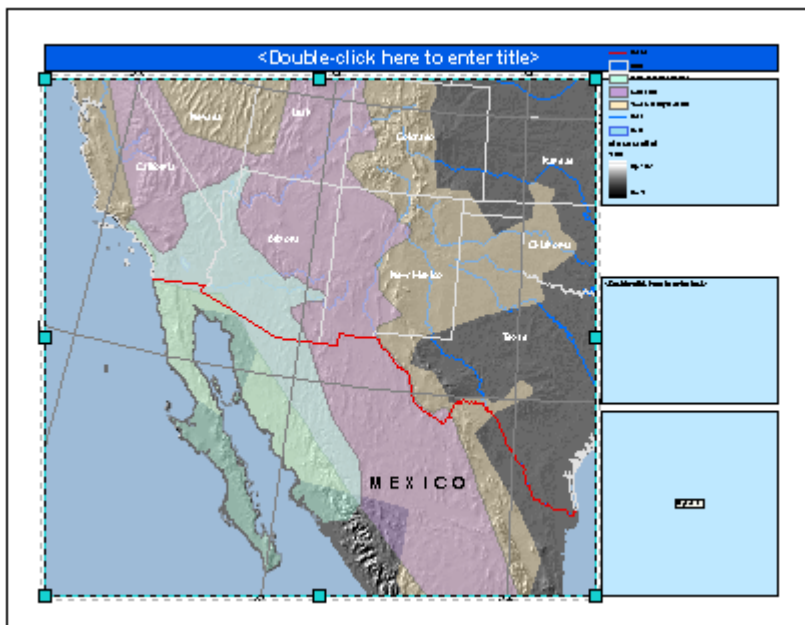


Step 11b: Change the background color.

Click the Color box and choose Blue Gray Dust.



Click OK.



Step 11c: Change the background color.

Step 12 Save your work

You have now made all the changes to the main data frame.

Save your work.

### Step 13 Add the layers for the inset map

When you applied the map template, a second data frame (Layers 2) was added to the Table of Contents. It is currently empty. In this step, you will decide which layers to use and add them to the inset map data frame.

The inset map needs to show the relationship between the bat ranges, the U.S. states, the countries in North America, and the southwestern desert ecoregion.

First, in the Table of Contents, rename the Layers 2 data frame to Inset map.

For the inset map, consider the following:

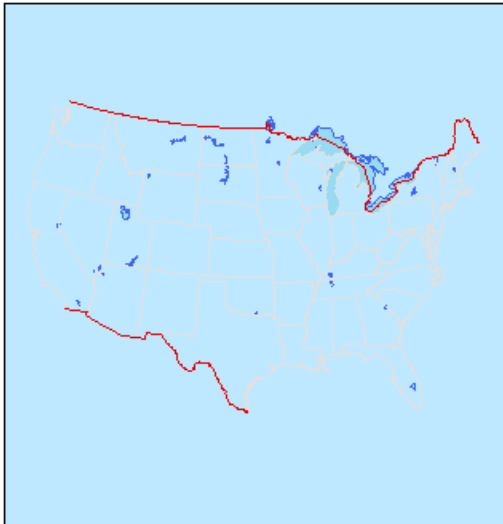
- Base map information can be shown by adjusting the symbology of the States and Lakes layers, so you will use them.
- The shadedrelief and Rivers layers show more detail than is necessary, so you won't use them.
- To show the broader area in which the study area is located, you will add a new layer that shows Canada and Mexico, and also use the Borders layer.
- Instead of displaying a separate range for each bat species (it's more detail than you need in an inset map), you will add a new layer that shows all bat ranges together.
- The desert ecoregion inhabited by the bat species is shown in the Deserts layer, so you will use this layer.

Based on the above, copy the layers that you will use from the All bats data frame and paste them into the Inset map data frame.



### Step 13a: Add the layers for the inset map

On the layout, zoom in to the Inset map data frame.



Step 13b: Add the layers for the inset map.

In the next step, you will add the remaining layers and symbolize them.

You won't be working with the All bats data frame, so collapse it.

Step 14 Add and symbolize layers in the inset map

Now you will add the missing layers to the inset map and symbolize them.

With the Select Elements tool , click the Inset map data frame to select it.

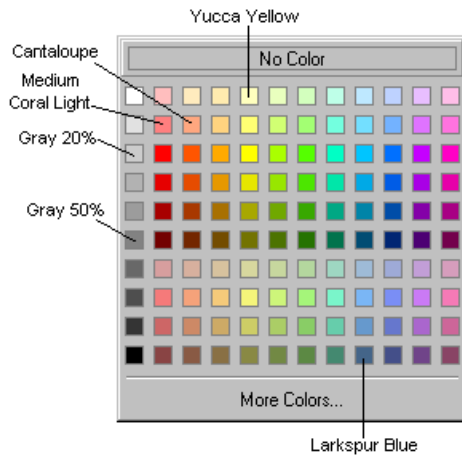
Click the Add Data button and navigate to Lab14\Bats\BatRanges.mdb. Add the AllRanges and Countries layers.

Turn on the Deserts layer.

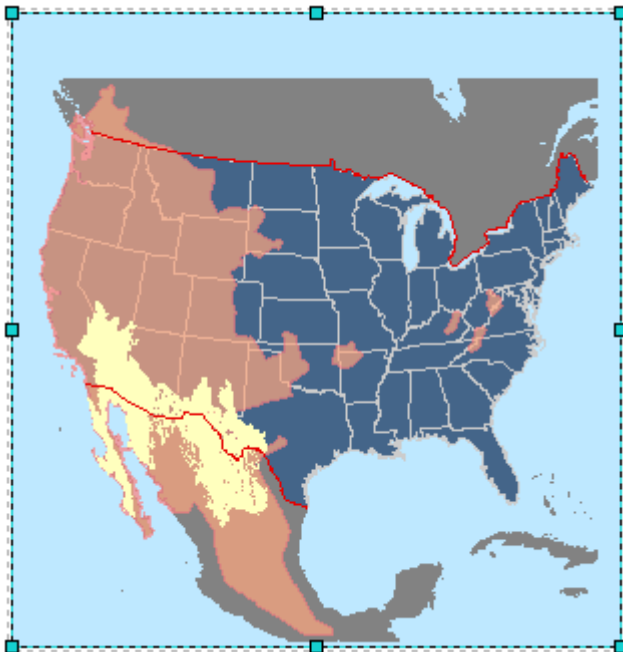
Using the table and graphic below, apply the symbology listed for each layer. Remember to display the Effects toolbar to adjust the transparency of the AllRanges layer.

Layer	Fill Color	Outline Color	Outline Width	Transparency
Borders			2	
Deserts	Yucca Yellow		0	
States	Larkspur Blue	Gray 20%	1	
AllRanges	Cantaloupe	Medium Coral Light		30%
Countries		Gray 50%	0	





In the Table of Contents, move the Deserts layer above the AllRanges layer so that it's not obscured.



Step 14: Add and symbolize layers in the inset map.

You've done a lot of work, so save the map document.

Step 15 Adjust the inset map scale and extent

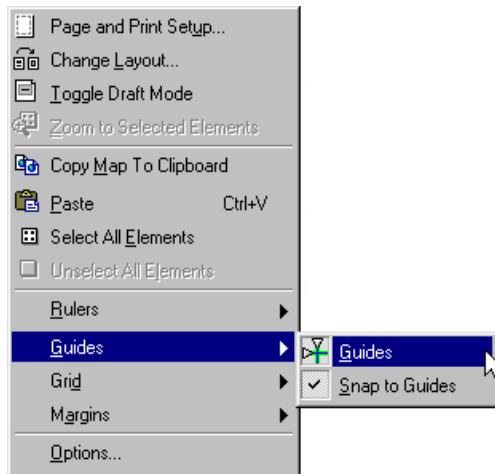
Now you need to set an appropriate scale and extent for the inset map.

Make sure the Inset map data frame is still selected. Change the scale to 1:18,500,000

To lock the scale so that it remains constant, open the Data Frame Properties dialog. In the Data Frame tab, click Fixed scale, then click OK.

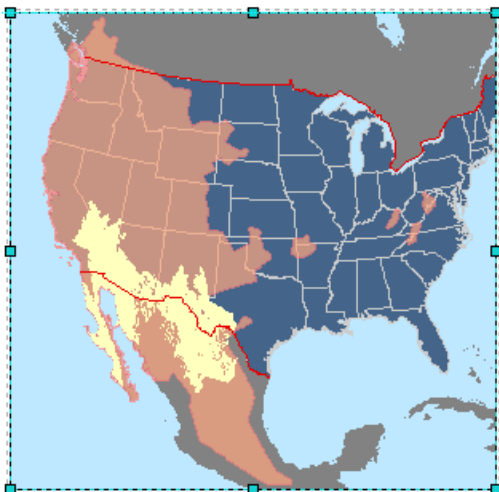
Notice that that the information inside the data frame conforms to a square shape, and that the data frame itself is almost square. You will resize the data frame so that it's 9.5 x 9.5 inches. You'll use a guide and snapping to make this task easier.

Add a horizontal guide at 11.5 inches (left ruler).



With the Select Elements tool, drag the data frame's top-middle selection handle down until it snaps to the guide.

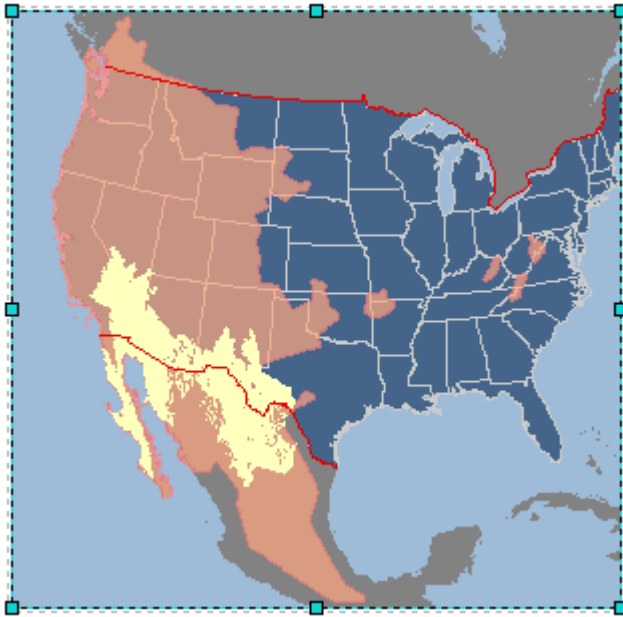
Pan the map, if necessary, so that Canada fills the top of the frame.



Step 15a: Adjust the inset map scale and extent.

You no longer need the guide, so drag the marker off the ruler to remove the guide.

Change the data frame's background color to Blue Gray Dust to match the All bats data frame.



Step 15b: Adjust the inset map scale and extent.

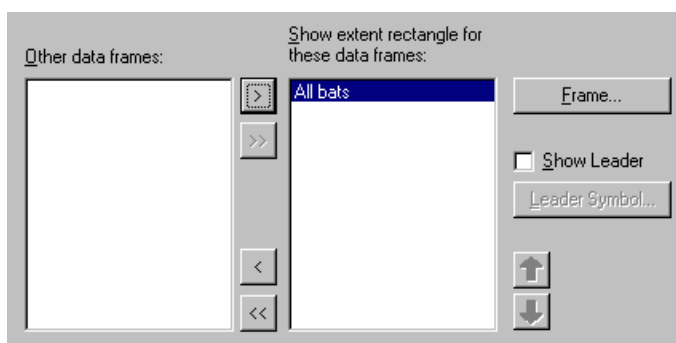
Save your work.

Step 16 Add an extent rectangle and labels

In this step, you will continue to work with the inset map. You'll add an extent rectangle to show the study area as well as state and country labels.

Open the Data Frame Properties dialog and click the Extent Rectangles tab.

Click All bats (this is the data frame for which you will create the extent rectangle), then click the right arrow button to move it to the box on the right.



Step 16a: Add an extent rectangle and labels.

Click Frame.

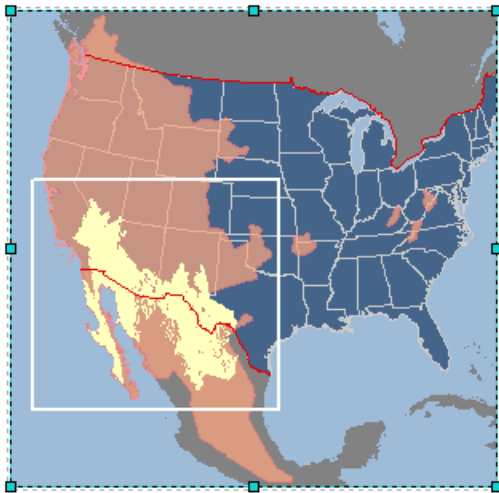
In the Frame Properties dialog, click the Border color box and click White.



Step 16b: Add an extent rectangle and labels.

Click OK, then OK again to update the layout.

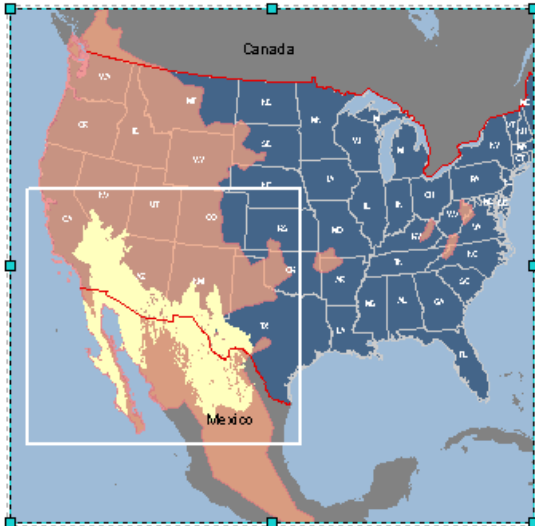
If necessary, pan the map to the right so that the extent rectangle is not cut off.



Step 16c: Add an extent rectangle and labels.

To make the inset map more informative, add labels for the state and country names using the settings below:

Layer	Label Field	Label Symbol
States	STATE_ABBR	Arial, 10, Bold, White
Countries	INSET_NAME	Arial, 20, Black



Step 16d: Add an extent rectangle and labels.

Save your work.

Step 17 Create a legend for the inset map

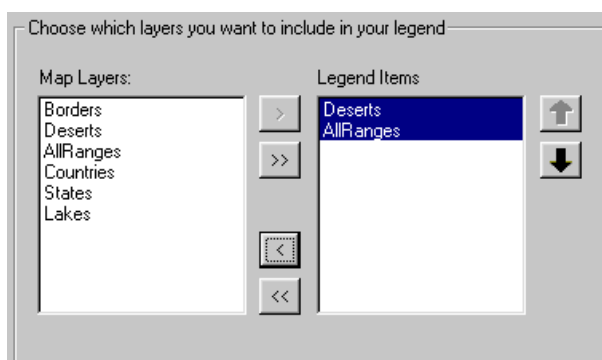
To help map readers understand the symbols in the inset map, you need to create a legend for the inset map.

The inset map data frame should still be selected.

From the Insert menu, choose Legend.

For this legend, you will use only the Deserts and AllRanges layers.

In the Legend Items box, hold down your Ctrl key and click all the other layers. Click the left arrow button to remove them.



Step 17a: Create a legend for the inset map.

Click Next.

You don't want the inset map legend to have a title.

In the Legend Title box, delete the word "Legend."

Click Next.

Move the Legend Wizard so you can see both it and the inset map data frame.

Click Preview.

Examine the legend that is shown near the middle of the data frame.

Click Finish.

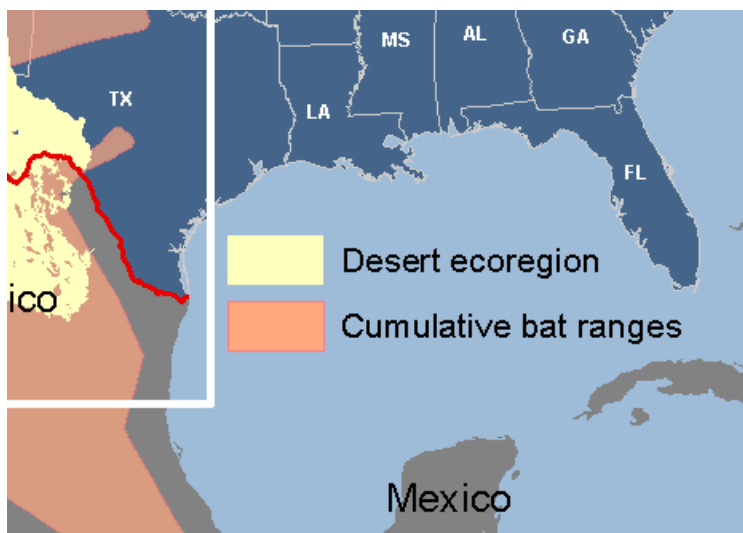
The legend is added to the inset map.

You will change the legend labels so they are easier to understand.

In the Table of Contents, click in the white space to the right of the Deserts symbol. Click inside the blue patch that displays and type Desert ecoregion. Press Enter.

Add a label for the AllRanges layer that says Cumulative bat ranges.

On the layout, move the inset map legend to the right of the extent rectangle, so that it's entirely within the Gulf of Mexico area. Zoom in to position and resize the legend if necessary (it shouldn't overlap any feature).



Step 17b: Create a legend for the inset map.

The design work on the inset map is now finished.

Zoom out to the extent of the whole layout page . Save your work.

### Step 18 Modify the template

Besides the two data frames that you have already worked on, the layout contains two boxes above the inset map. For this layout, you need only one of the boxes.

Zoom in closely to the two boxes.

#### Step 18a: Modify the template.

Click the box immediately above the inset map to select it. Hold down your Ctrl key and select the text element that is inside the box.

Press Delete to remove them from the layout.

Next, you will add a guide to which you will snap the remaining box when you resize it. You want the distance between the resized box and the inset map to be the same as the distance between the two data frames.

The distance is about 0.40 inches, so add a horizontal guide at 11.80 on the left ruler.

Tip: To make sure you're adding a guide at 11.80, look at the tooltip that displays below the top ruler when you click to add the guide. You may need to pan up on the page to see the guide.

Zoom to the extent of the whole page.

Select the box and drag its bottom edge down until it snaps to the guide. Its top edge should remain aligned with the top edge of the All bats data frame.

#### Step 18: Modify the template.

Now you will change some of the box properties so that the elements you place inside it will be as legible as possible.

Right-click the box to open the Properties dialog.

Click the Frame tab and make these changes:

Border	2.5 Point, Black
Background	Hollow

#### Step 18c: Modify the template.

Save your work.

### Step 19 Modify the All bats legend

By default, the All bats data frame legend shows the symbols for all the layers. These are more than you need to show, so you will modify the legend to show only the symbols for the bat species.

First, zoom in to the box.

With the Select Elements tool, select the legend and move it to the bottom of the box.

Step 19a: Modify the All bats legend.

Now you will remove the layers you don't need.

Right-click the legend and choose Properties.

In the Legend Items box, hold down your Ctrl key and click all the layers, except for the three bat range layers (Bat022, Bat007, Bat005).

Click the left arrow button to remove them.

Click OK.

Step 19b: Modify the All bats legend.

Save your work.

Step 20 Add a logo, subtitle, and informative text

To the box that contains the legend you will add a logo, a subtitle for the map, and informative text about the bats that are the subject of this presentation.

First, you will add the logo.

From the Insert menu, choose Picture.

Navigate to the Lab14\Bats folder and add bat\_logo.gif.

Step 20a: Add a logo, subtitle, and informative text.

Move the logo near the upper left corner of the box.

Now you will add the subtitle.

On the Draw toolbar, click the New Text tool . Click to the right of the logo and add the text Map the Bat. Press Enter.

Move the text, if necessary, to align it with the logo's bottom edge.



Step 20b: Add a logo, subtitle, and informative text.

To show how unique the three bat species are, you will add informative text about them in the empty space below the logo and subtitle.

Copy all the text from the box below.

“California leaf-nosed bat (*Macrotus californicus*)

This bat lives in some of the most extreme North American deserts and is the only bat in the United States to have a leaf-shaped nose. It flies helicopter-like at low speeds using minimal energy. It is a "gleaning" insectivore, capturing its prey straight from the ground or foliage, rather than in flight. Because of its short, broad wings, it cannot fly long distances so it does not migrate.

Spotted bat (*Euderma maculatum*)

Although it is not rare, the spotted bat is one of America's least known animals. It has black fur accentuated by large white spots on its back, white fur on its underside, pink wings and ears almost as large as its body. The echolocation frequencies it uses to locate its prey are low enough to be audible to humans. It might feed almost exclusively on moths.

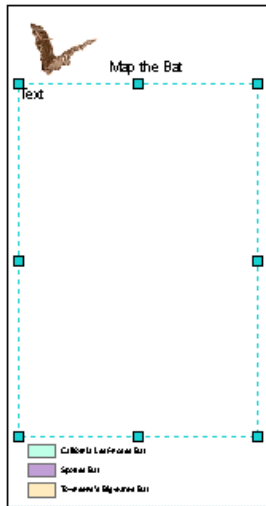
Townsend's big-eared bat (*Corynorhinus townsendii*)

Their most typical habitat is arid western desert scrub and pine forest regions. These bats are extremely sensitive to disturbance at their roosting and hibernation sites in caves and abandoned mines. They have suffered severe population declines throughout the U.S. and two isolated subspecies are in danger of extinction. In addition to other functions, it is thought that their large ears might assist in lift during flight (Bat Conservation International, Inc. 2002).”

There's quite a lot of text that you want to fit into a rectangular space.

Click the dropdown arrow next to the New Text tool and click the New Rectangle Text tool .

Draw a rectangle about 0.5 inches inside the box borders, below the logo and subtitle, and above the legend.



Step 20c: Add a logo, subtitle, and informative text.

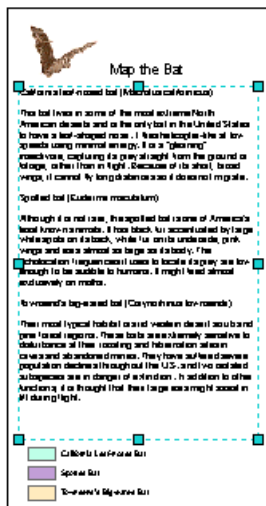
Double-click the text rectangle to open the Properties dialog.

In the Text tab, press Ctrl+v to paste the bat text. Align the text to the left.

Step 20d: Add a logo, subtitle, and informative text.

Click OK.

If you don't see all the text on the layout, on the Draw toolbar, change the font size to 24. At that size, you should be able to see all of it.



Step 20e: Add a logo, subtitle, and informative text.

You have now created all the elements for the box. Resize, align, and move them until you're satisfied with their arrangement. Group elements as needed.

When you're finished, unselect all elements.

The View Result graphic below shows one possible way of arranging the elements.

Step 20f: Add a logo, subtitle, and informative text.

Zoom to the whole page and save your work.

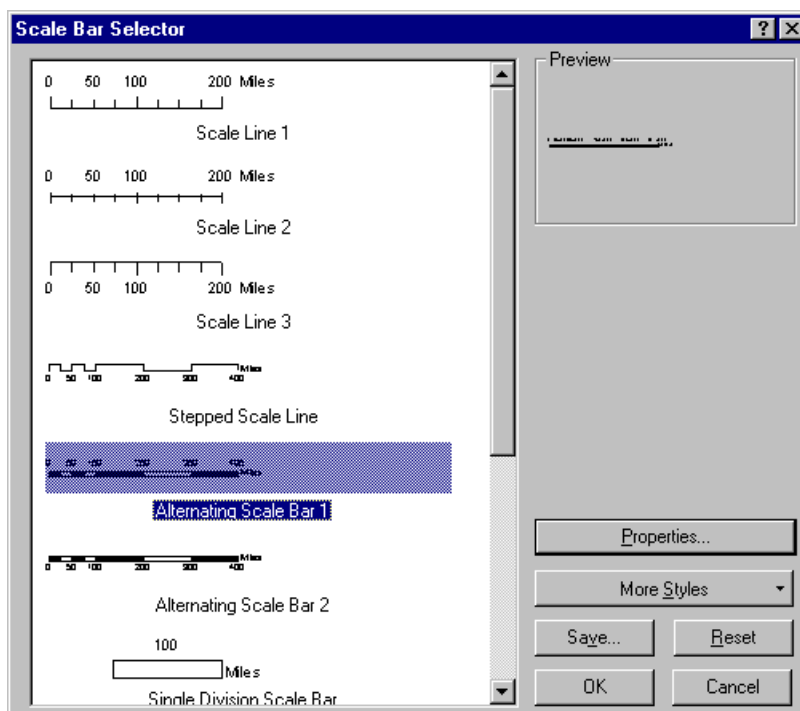
Step 21 Add a scale bar

Remove the guide from the ruler on the left; you don't need it any more.

Select the All bats data frame, then zoom to the area shown below.



From the Insert menu, choose Scale bar, then click Alternating Scale Bar 1.



Step 21a: Add a scale bar.

Click Properties.

In the Scale and Units tab, in the Scale area, under "When resizing" click the down arrow and choose Adjust number of divisions.

Notice that the Division Value field becomes active.

For Division Value, enter 100. For Division Units, choose Miles.

Step 21b: Add a scale bar.

These settings mean that the scale bar is divided into sections that represent 100 miles. Also, when you resize the scale bar it will change in 100-mile increments, its division.

Click the Format tab and change the text size to 14. Change the bar size to 8 (you may need to type this value).

Step 21c: Add a scale bar.

Click OK, then OK again.

Step 21d: Add a scale bar.

You need to adjust the scale bar's size and position.

Zoom in if necessary to see the scale divisions. Resize the scale bar so that it shows 400 miles.

Reposition the scale bar so that it is centered between the left edge of the data frame and the Baja California peninsula to the right.

Step 21e: Add a scale bar.

Save your work.

Step 22 Add map source text

In this step, you will add text with information about the map's data sources, then you will align it with the scale bar.

Copy the text from the box beneath.

Map source

Albers Conical Equal Area projection North American Datum 1983

The bat range layers were downloaded from the National Atlas Web site. They were compiled by Bat Conservation International, Inc., using data from various sources that was originally

published in 1981. The desert ecoregion is derived from the World Wildlife Fund Terrestrial Ecoregions.

This map was made for the Map the Bat presentation, using ESRI ArcGIS 9 software. May 10, 2005

Click the New Rectangle Text tool and draw a text box 9 inches wide by 2.5 inches high, about 1 inch below the scale bar.

Right-click the text box and choose Properties. In the Text tab, paste the map source text.

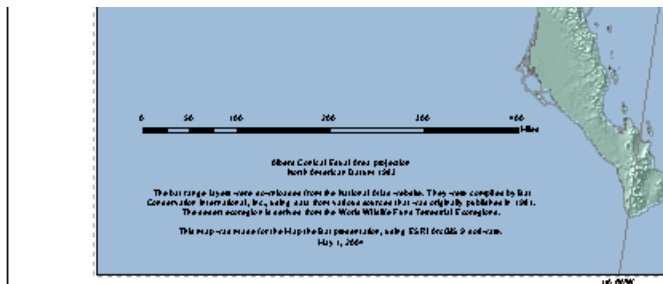
Align the text in the center. Click Change Symbol and change the font size to 14.

Click OK to close the open dialogs.

If necessary, enlarge the box so that all the text is visible.

Hold down your Ctrl key and select the scale bar and map source text. From the Drawing menu, choose Align, then click Align Center. Group the elements.

Move the group so it's about 1 inch inside the data frame borders.



Step 22: Add map source text.

When you're done, zoom to the whole page and save your work.

Step 23 Create the map title

The last layout element you will work on is the map title.

Double-click the map title element and enter Bats of the Southwestern Desert - GIS Day. Click OK.

Zoom to the upper-right quarter of the layout.

Select the title and the text box with the bat information below it.

Align them on their right side.

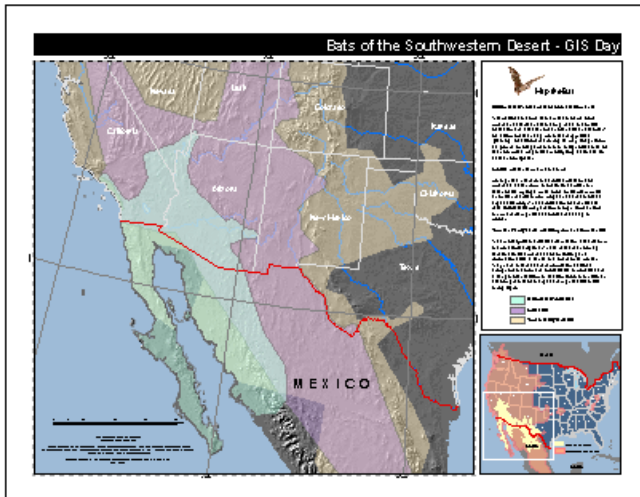
Click in an empty white area to unselect both elements.

Now select the map title and the blue rectangle behind it.

From the Drawing menu, choose Align, then click Align Vertical Center.

Now select just the blue rectangle. On the Draw toolbar, change the fill color to Black.

Unselect the rectangle and zoom to the whole page.



Step 23: Create the map title.

Your design work is done!

Step 24 Save your work and close ArcMap

You've finished your layout, so save your work.

As in the previous exercise, export your map to both a PDF and a PNG file. Set a link to the PNG file and inform Jing Li about the availability of your lab submission.

Close ArcMap.

In this exercise, you continued to work in the layout environment, concentrating on creating, fine-tuning, and then balancing the elements for a presentation map.

Some layout elements, such as the scale bar and legend, are dynamic and automatically update when you change the data frame they're associated with. Others, such as the informative text, help the audience to fully understand the map. The layout you created also contains a purely decorative element, the bat logo.

Review

An effective map communicates a clear message to its intended audience. In a well designed map, all the elements work together as a visually balanced composition that emphasizes and supports the map's main purpose. In ArcGIS, you design a map by creating a layout in ArcMap.

- Visually, the map body should be the most prominent element on the map.
- The main elements of a map are the map body, legend, title, scale, north arrow, and the inset map. Maps can also contain other elements such as graticules, text boxes, charts, graphics, and images.
- You can modify the properties of all the elements in a layout to suit your needs. ArcMap gives you tools to organize and arrange the elements so that a map is easy to read.
- To increase the information conveyed by a map and to make a map more readable, you can adjust layer transparency, convert labels to annotation, and add a reference system.
- To improve a map's visual balance, you can add graphic elements such as borders and text boxes.

#### Review questions

1. What are some questions you should ask before creating a map?
2. When is a map template especially useful?
3. What are some of the tools used to organize and arrange elements in a layout?

## CHAPTER 3: GEOREFERNCING

### 3.1 Spatial Adjustment

Spatial adjustment lets you transform, rubbersheet, and edgematch vector features in your map. It works within the ArcMap editing environment to provide a highly productive adjustment environment. Spatial adjustment supports a variety of adjustment methods and will adjust all editable data sources. Spatial adjustment commands and tools are located on an additional editing toolbar called the Spatial Adjustment toolbar. These tools and commands allow you to define a spatial adjustment. Since spatial adjustment operates within an edit session, you can use existing editing functionality, such as snapping, to enhance your adjustments.

Along with the ability to spatially adjust your data, the Spatial Adjustment toolbar also provides a way for you to transfer the attributes from one feature to another. This tool is called the Attribute Transfer tool and relies on matching common fields between two layers.

Together, the adjustment and attribute transfer functions available on the Spatial Adjustment toolbar allow you to improve the quality of your data.

### 3.2 Spatial adjustment methods

The following sections briefly describe the spatial adjustment methods and related concepts.

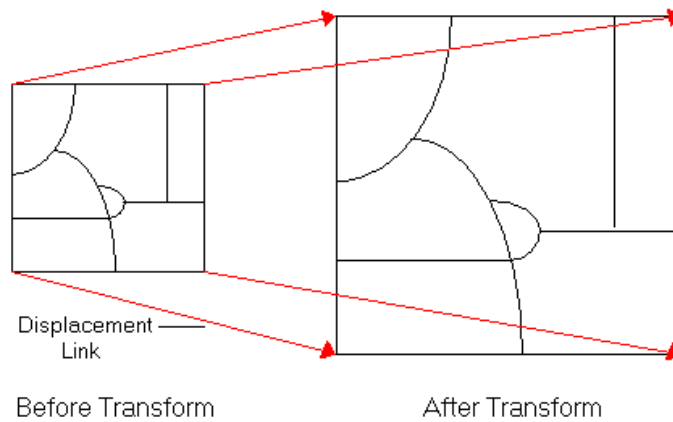
#### 3.2.1 *Transformations*

Transformations move or shift data within a coordinate system. They are often used to convert data from unknown digitizer or scanner units to real-world coordinates. Transformations can also be used to convert units within a coordinate system, such as converting feet to meters. To convert data between coordinate systems, such as geographic to UTM, you should project the data instead.

The transformation functions are based on the comparison of the coordinates of source and destination points, also called control points, in special graphical elements called displacement

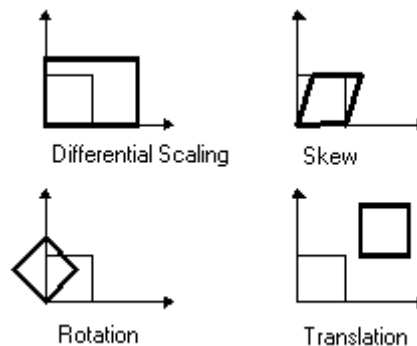


links. You can create these links interactively, pointing at known source and destination locations, or by loading a link text file or control points file.



By default, ArcMap supports three types of transformations: affine, similarity, and projective.

An affine transformation can differentially scale the data, skew it, rotate it, and translate it. The graphic below illustrates the four possible changes.



The affine transformation function is:

$$x' = Ax + By + C$$

$$y' = Dx + Ey + F$$

where  $x$  and  $y$  are coordinates of the input layer and  $x'$  and  $y'$  are the transformed coordinates.  $A$ ,  $B$ ,  $C$ ,  $D$ ,  $E$  and  $F$  are determined by comparing the location of source and destination control points. They scale, skew, rotate, and translate the layer coordinates.

The affine transformation requires a minimum of three displacement links.

The similarity transformation scales, rotates, and translates the data. It will not independently scale the axes, nor will it introduce any skew. It maintains the aspect ratio of the features transformed, which is important if you want to maintain the relative shape of features.

The similarity transform function is:

$$x' = Ax + By + C \quad y' = -Bx + Ay + F$$

where:

$A = s \cdot \cos(t)$ ,  $B = s \cdot \sin(t)$ ,  $C$  = translation in x direction,  $F$  = translation in y direction

and:

$s$  = scale change (same in x and y directions),

$t$  = rotation angle, measured counterclockwise from the x-axis

A similarity transformation requires a minimum of two displacement links. However, three or more links are needed to produce a root mean square (RMS) error.

The projective transformation is based on a more complex formula that requires a minimum of four displacement links.

$$x' = (Ax + By + C) / (Gx + Hy + 1)$$

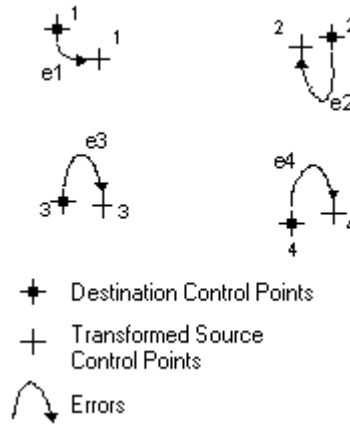
$$y' = (Dx + Ey + F) / (Gx + Hy + 1)$$

This method is used to transform data captured directly from aerial photography. For more information, refer to one of the photogrammetric texts listed in the references at the end of this document.

### 3.2.2 *Understanding residual and root mean square (RMS)*

The transformation parameters are a best fit between the source and destination control points. If you use the transformation parameters to transform the actual source control points, the transformed output locations won't match the true output control point locations. This is called the residual error; it is a measure of the fit between the true locations and the transformed locations of the output control points. This error is generated for each displacement link.

A root mean square error is calculated for each transformation performed and indicates how good the derived transformation is. The following example illustrates the relative location of four destination control points and the transformed source control points:



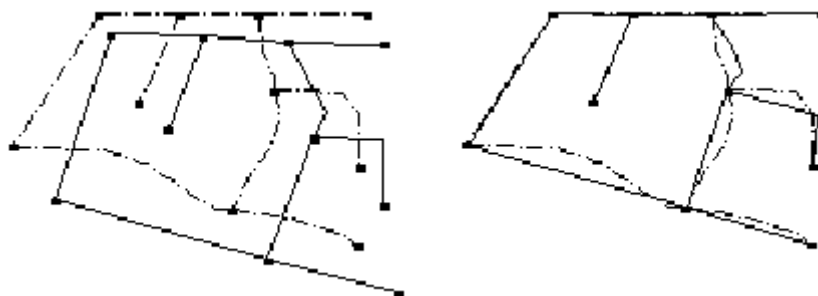
The RMS error measures the errors between the destination control points and the transformed locations of the source control points.

$$\text{RMS error} = \sqrt{\frac{e_1^2 + e_2^2 + e_3^2 + \dots + e_n^2}{n}}$$

The transformation is derived using least squares, so more links can be given than are necessary. Specifying a minimum of three links is required to produce a transformation that results in an RMS error.

### 3.2.3 Rubbersheeting

Geometric distortions commonly occur in source maps. They may be introduced by imperfect registration in map compilation, lack of geodetic control in source data, or a variety of other causes. Rubbersheeting corrects flaws through the geometric adjustment of coordinates.



The source layer (drawn with solid lines) is adjusted to the more accurate target layer. During rubbersheeting, the surface is literally stretched, moving features using a piecewise transformation that preserves straight lines. Similar to transformations, displacement links are used in rubbersheeting to determine where features are moved. The closer features are to displacement links, the further they will move. Locations that are known to be accurate, such as those that already match the target layer, can be held in place with another type of link called an identity link. Identity links "nail" down the surface at the specified point. Additionally, you can specify an area in which rubbersheeting occurs to further localize the adjustment.

Rubbersheeting is commonly used after a transformation to further refine the accuracy of the features to an existing layer or raster dataset.

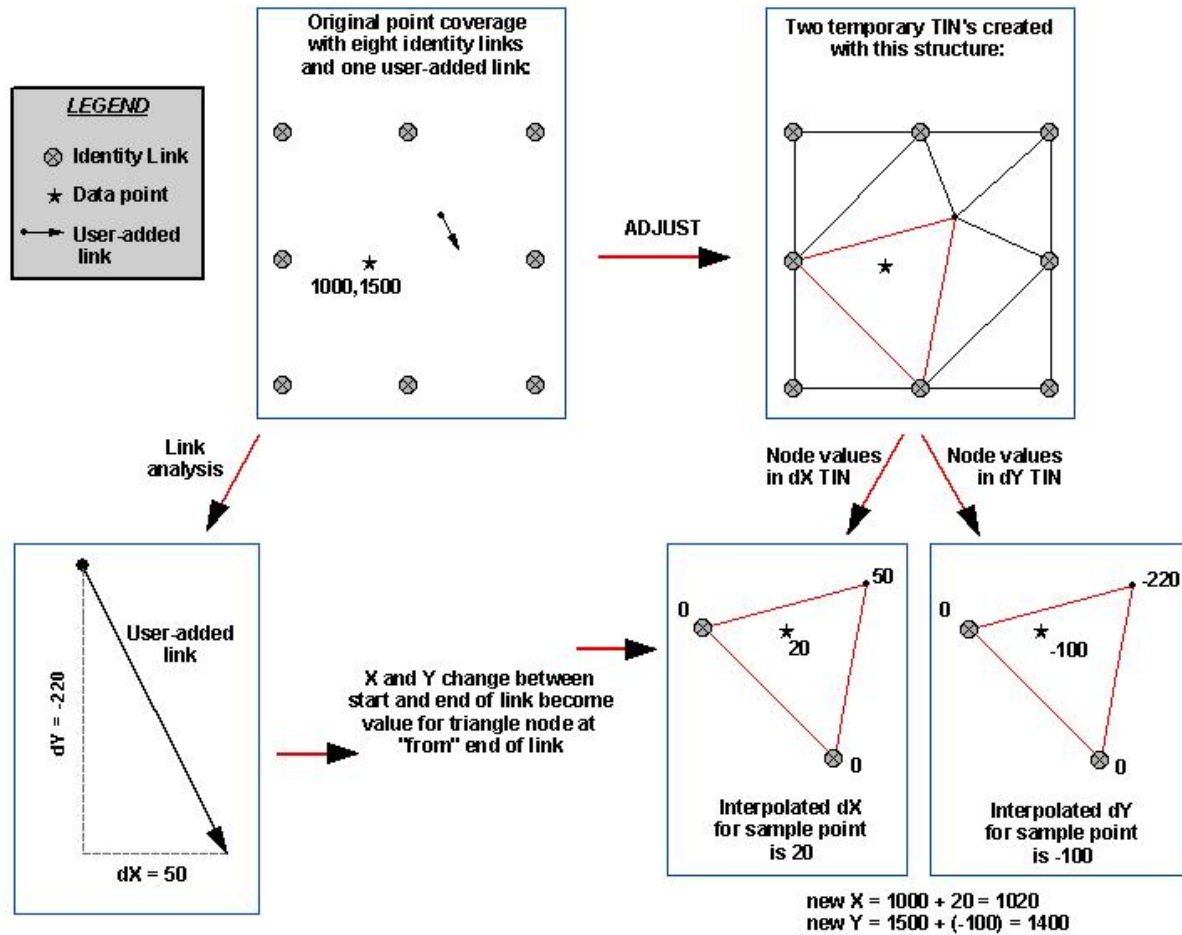
Conflation applications use rubbersheeting to align layers in preparation for transferring attributes.

#### 3.2.4 *Understanding how rubbersheeting works*

Rubbersheeting uses two temporary triangulated irregular networks (TINs) to interpolate changes in x (dX) and changes in y (dY) for feature coordinates along user-specified links. Each TIN has the same triangulation structure. The from-end of the displacement links and all identity links are used as the TIN triangle corners (nodes). A node is defined by its x,y location and a z value.

The z value of each node is used to interpolate the amount of x,y adjustment applied to each feature coordinate. The z value is the amount of change between the from-end and to-end of a link. For example, if the change in x for a link is 10 map units, the z value of the TIN node at the from-end of that link will be 10. Since identity links represent no change, the z value is zero. Once each node of a TIN triangle has a z value, the corresponding z value of any point falling on that triangle can be interpolated.

The interpolated z value from the x-shift TIN is added to the x ordinal of the feature's coordinate. The z value interpolated from the y-shift TIN is added to the y ordinal of the coordinate. For example, if an input feature coordinate is 1000,1500, the interpolated dX for this point is 20, and the interpolated dY is -100, the output coordinates after ADJUST will be 1020,1400 ( $1000 + 20 = 1020$  and  $1500 + (-100) = 1400$ ).



The rubbersheeting adjustment has two options: linear and natural neighbor. These options refer to the interpolation method used to create the temporary TINs. You can read about these well-known mathematical models online or in the reference texts.

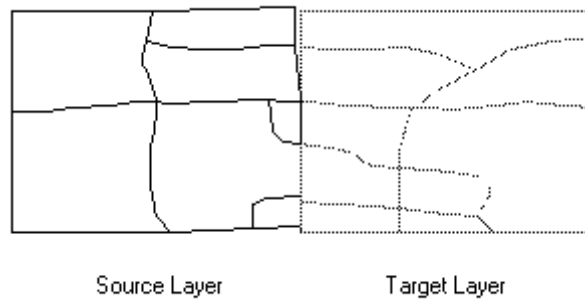
The linear method creates a quick TIN surface does not really take into account the neighborhood. It's quick and accurate if you have lots of displacement links over the area you are adjusting (that is, if the triangles are uniform).

Natural neighbor (similar to IDW) is slower but is more accurate when you don't have many displacement links and they are scattered across your dataset. Using linear in this case will be less accurate.

### 3.2.5 Edgematching

The edgematching process aligns features along the edge of one layer to features of an adjoining layer. It is mainly used when you want to merge separate adjacent layers such as soils or contours sheets etc and you need to ensure the features from those layers will meet at the

join. The layer with the less accurate features is typically adjusted, while the adjoining layer is used as the control.



### 3.2.6 Attribute transfer

Attribute transfer is typically used to copy attributes from a less accurate layer to a more accurate one. For example, it can be used to transfer the names of hydrological features from a previously digitized and highly generalized 1:500,000 scale map to a more detailed 1:24,000 scale map. In ArcMap, you can specify what attributes to transfer between layers, then interactively choose the source and target features.

## 3.3 Georeferencing


Raster data is commonly obtained by scanning maps or collecting aerial photographs and satellite images. Scanned map datasets don't normally contain spatial reference information (either embedded in the file or as a separate file). With aerial photography and satellite imagery, sometimes the location information delivered with them is inadequate, and the data does not align properly with other data you have. Thus, to use some raster datasets in conjunction with your other spatial data, you may need to align or georeference them to a map coordinate system. A map coordinate system is defined using a map projection (a method by which the curved surface of the earth is portrayed on a flat surface).

When you georeference your raster data, you define its location using map coordinates and assign the coordinate system of the data frame. Georeferencing raster data allows it to be viewed, queried, and analyzed with other geographic data. The **Georeferencing** toolbar allows you to georeference raster datasets, raster layers (which may have raster functions), image services, and raster products.

In general, the steps for georeferencing a raster dataset are the following:

- 1) In ArcMap, add the raster that you want to align with your projected data.

*\*\*The **Georeferencing** toolbar layer list will display raster layers, image service layers, and CAD layers as valid data types. The layers must either be in the same coordinate system as the data frame or have no spatial reference defined.*

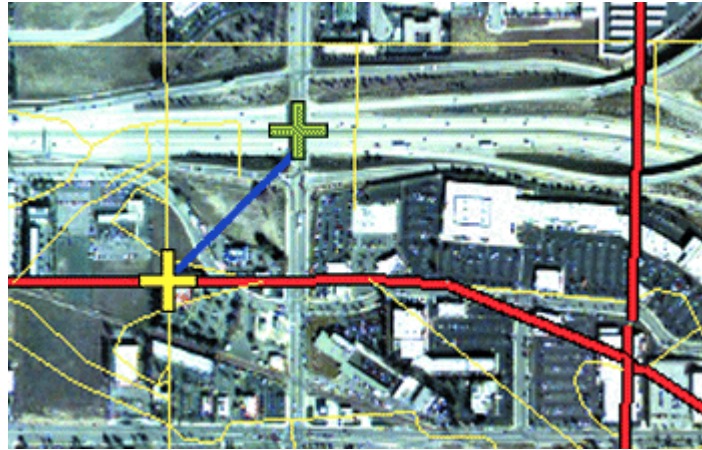
- 2) Add links that connect known raster dataset positions to known positions in map coordinates. The **Auto Registration** tool  can help you automatically create links.
- 3) Save the georeferencing information when you're satisfied with the alignment (also referred to as registration).
- 4) Permanently transform the raster dataset (this is optional).

### 3.3.1 *Aligning the raster with control points*

Generally, you will georeference your raster data using existing spatial data (target data)—such as georeferenced rasters or a vector feature class—that resides in the desired map coordinate system. The process involves identifying a series of ground control points—known x,y coordinates—that link locations on the raster dataset with locations in the spatially referenced data (target data). Control points are locations that can be accurately identified on the raster dataset and in real-world coordinates. Many different types of features can be used as identifiable locations, such as road or stream intersections, the mouth of a stream, rock outcrops, the end of a jetty of land, the corner of an established field, street corners, or the intersection of two hedgerows.

The control points are used to build a polynomial transformation that will shift the raster dataset from its existing location to the spatially correct location. The connection between one control point on the raster dataset (the from point) and the corresponding control point on the aligned target data (the to point) is a link.

The example below shows a from control point (yellow cross) placed on the vector target data at a street crossing and the associated control point (green cross) placed on the raster dataset. The associated link is represented by the blue line joining the control points.



The number of links you need to create depends on the complexity of the transformation you plan to use to transform the raster dataset to map coordinates. However, adding more links will not necessarily yield a better registration. If possible, you should spread the links over the entire raster dataset rather than concentrating them in one area. Typically, having at least one link near each corner of the raster dataset and a few throughout the interior produces the best results.

Generally, the greater the overlap between the raster dataset and target data, the better the alignment results, because you'll have more widely spaced points with which to georeference the raster dataset. For example, if your target data only occupies one-quarter of the area of your raster dataset, the points you could use to align the raster dataset would be confined to that area of overlap. Thus, the areas outside the overlap area are not likely to be properly aligned.

Keep in mind that your georeferenced data is only as accurate as the data to which it is aligned. To minimize errors, you should georeference to data that is at the highest resolution and largest scale for your needs.

### 3.3.2 *Transforming the raster*

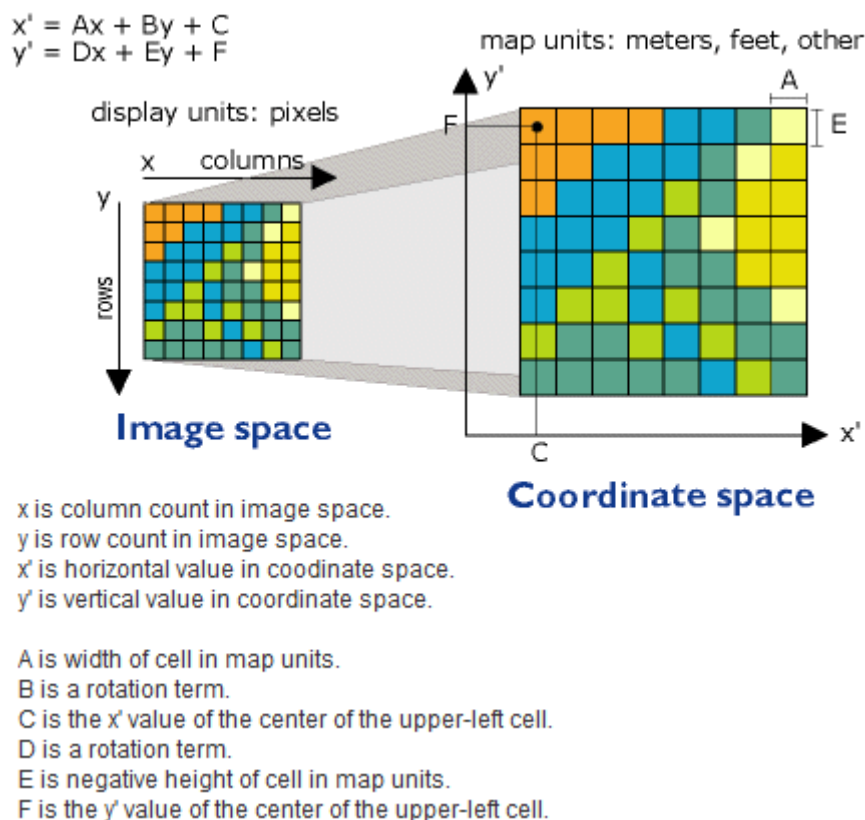
When you've created enough links, you can transform—or warp—the raster dataset to permanently match the map coordinates of the target data. You have the choice of using a polynomial, a spline, an adjust, or a projective transformation to determine the correct map coordinate location for each cell in the raster.

The polynomial transformation uses a polynomial built on control points and a least-squares fitting (LSF) algorithm. It is optimized for global accuracy but does not guarantee local accuracy. The polynomial transformation yields two formulas: one for computing the output



x-coordinate for an input (x,y) location and one for computing the y-coordinate for an input (x,y) location. The goal of the least-squares fitting algorithm is to derive a general formula that can be applied to all points, usually at the expense of slight movement of the to positions of the control points. The number of the noncorrelated control points required for this method must be 1 for a zero-order shift, 3 for a first order affine, 6 for a second order, and 10 for a third order. The lower order polynomials tend to give a random type error, while the higher order polynomials tend to give an extrapolation error.

The first-order polynomial transformation is commonly used to georeference an image. Below is the equation to transform a raster dataset using the affine (first order) polynomial transformation. You can see how six parameters define how a raster's rows and columns transform into map coordinates.



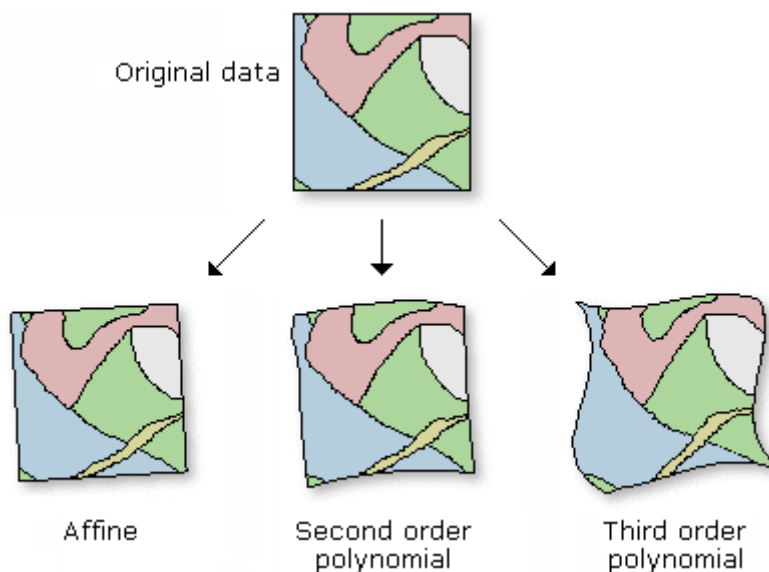
A zero-order polynomial is used to shift your data. This is commonly used when your data is already georeferenced, but a small shift will better line up your data. Only one link is required to perform a zero-order polynomial shift. It may be a good idea to create a few links, then choose the one that looks the most accurate.

Use a first-order or affine transformation to shift, scale, and rotate a raster dataset. This generally results in straight lines on the raster dataset mapped as straight lines in the warped

raster dataset. Thus, squares and rectangles on the raster dataset are commonly changed into parallelograms of arbitrary scaling and angle orientation.

With a minimum of three links, the mathematical equation used with a first-order transformation can exactly map each raster point to the target location. Any more than three links introduces errors, or residuals, that are distributed throughout all the links. However, you should add more than three links, because if one link is positionally wrong, it has a much greater impact on the transformation. Thus, even though the mathematical transformation error may increase as you create more links, the overall accuracy of the transformation will increase as well.

The higher the transformation order, the more complex the distortion that can be corrected. However, transformations higher than third order are rarely needed. Higher-order transformations require more links and, thus, will involve progressively more processing time. In general, if your raster dataset needs to be stretched, scaled, and rotated, use a first-order transformation. If, however, the raster dataset must be bent or curved, use a second- or third-order transformation.



The spline transformation is a true rubber sheeting method and optimizes for local accuracy but not global accuracy. It is based on a spline function—a piecewise polynomial that maintains continuity and smoothness between adjacent polynomials. Spline transforms the source control points exactly to target control points; the pixels that are a distance from the control points are not guaranteed to be accurate. This transformation is useful when the control points are important, and it is required that they be registered precisely. Adding more control points can

increase overall accuracy of the spline transformation. Spline requires a minimum of 10 control points.

The adjust transformation optimizes for both global LSF and local accuracy. It is built on an algorithm that combines a polynomial transformation and triangulated irregular network (TIN) interpolation techniques. The adjust transformation performs a polynomial transformation using two sets of control points and adjusts the control points locally to better match the target control points using a TIN interpolation technique. Adjust requires a minimum of three control points.

The projective transformation can warp lines so that they remain straight. In doing so, lines which were once parallel may no longer remain parallel. The projective transformation is especially useful for oblique imagery, scanned maps, and for some imagery products such as Landsat and Digital Globe. A minimum of four links are required to perform a projective transformation. When only four links are used, the RMS error will be zero. When more points are used, the RMS error will be slightly above zero.

### 3.3.3 *Interpreting the root mean square error*

When the general formula is derived and applied to the control point, a measure of the error—the residual error—is returned. The error is the difference between where the from point ended up as opposed to the actual location that was specified—the to point position. The total error is computed by taking the root mean square (RMS) sum of all the residuals to compute the RMS error. This value describes how consistent the transformation is between the different control points (links). When the error is particularly large, you can remove and add control points to adjust the error.

Although the RMS error is a good assessment of the transformation's accuracy, don't confuse a low RMS error with an accurate registration. For example, the transformation may still contain significant errors due to a poorly entered control point. The more control points of equal quality used, the more accurately the polynomial can convert the input data to output coordinates. Typically, the adjust and spline transformations give an RMS of nearly zero or zero; however, this does not mean that the image will be perfectly georeferenced.

The forward residual shows you the error in the same units as the data frame spatial reference. The inverse residual shows you the error in the pixels units. The forward-inverse residual is a

measure of how close your accuracy is, measured in pixels. All residuals closer to zero are considered more accurate.

### 3.3.4 *Resampling the raster dataset*

When you rectify or transform, project, or resample a raster dataset, convert it from one projection to another, or change the cell size, you are performing a geometric transformation. Geometric transformation is the process of changing the geometry of a raster dataset from one coordinate space to another. Types of geometric transformations include rubber sheeting (usually used for georeferencing), projection (using the projection information to transform the data from one projection to another), translation (shifting all the coordinates equally), rotation (rotating all the coordinates by some angle), and changing the cell size of the dataset.

After the geometric transformation is applied to the input raster, the cell centers of the input raster rarely line up with the cell centers on the output raster; however, values need to be assigned to the centers.

Although you might think each cell in a raster dataset is transformed to its new map coordinate location, the process actually works in reverse. During georeferencing, a matrix of empty cells is computed using the map coordinates. Each empty cell is given a value based on the resampling process.

The three most common resampling techniques are nearest neighbor assignment, bilinear interpolation, and cubic convolution. These techniques assign a value to each empty cell by examining the cells in the ungeoreferenced raster dataset.

Nearest neighbor assignment is the fastest resampling technique and is appropriate for categorical or thematic data, since it does not alter the value of the input cells. Once the location of the cell's center on the output raster dataset is located on the input raster, nearest neighbor assignment determines the location of the closest cell center on the input raster and assigns the value of that cell to the cell on the output raster.

The nearest neighbor assignment does not change any of the values of cells from the input raster dataset. The value 2 in the input raster will always be the value 2 in the output raster; it will never be 2.2 or 3. Since the output cell values remain the same, nearest neighbor

assignment should be used for nominal or ordinal data where each value represents a class, member, or classification—this may be categorical data such as a land-use, soil, or forest type.

Bilinear interpolation uses the value of the four nearest input cell centers to determine the value of the output raster. The new value for the output cell is a weighted average of these four values, adjusted to account for their distance from the center of the output cell in the input raster. This interpolation method results in a smoother-looking surface than can be obtained using nearest neighbor.

Since the values for the output cells are calculated according to the relative position and the value of the input cells, bilinear interpolation is preferred for data where the location from a known point or phenomenon determines the value assigned to the cell—that is, continuous surfaces. Elevation, slope, intensity of noise from an airport, and salinity of the groundwater near an estuary are all phenomena represented as continuous surfaces and are most appropriately resampled using bilinear interpolation.

Cubic convolution is similar to bilinear interpolation, except the weighted average is calculated from the 16 nearest input cell centers and their values. Cubic convolution tends to sharpen the data more than bilinear interpolation, since more cells are involved in the calculation of the output value. Therefore, this resampling method is often used when resampling imagery, such as aerial photography and satellite imagery.

Bilinear interpolation or cubic convolution should not be used on categorical data, since the categories will not be maintained in the output raster dataset. However, all three techniques can be applied to continuous data, with nearest neighbor producing a blocky output, bilinear interpolation producing smoother results, and cubic convolution producing the sharpest results. When undertaking a large resampling project, it is recommended that you create a prototype, utilizing more than one of the resampling techniques to make an accurate assessment of the most appropriate method to use for your data.

### 3.3.5 *Should you rectify your raster?*

You can permanently transform your raster dataset after georeferencing it by using the **Rectify** command on the **Georeferencing** toolbar or by using the Warp tool. You can also store the transformation information in the auxiliary files using the **Update Georeferencing** command on the **Georeferencing** toolbar.

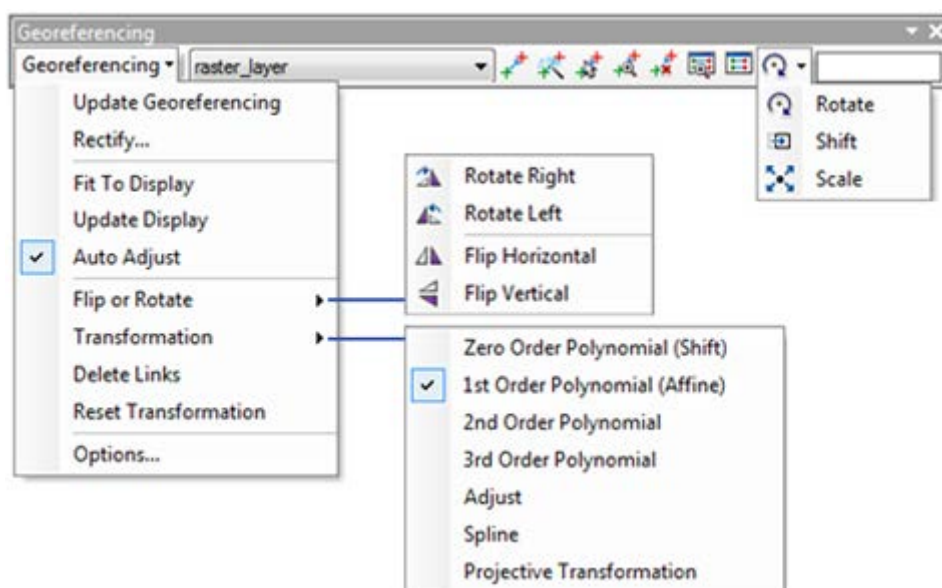
Rectifying or warping will create a new raster dataset that is georeferenced using the map coordinates and the spatial reference. You can save this as a BIL, BIP, BMP, BSQ, DAT, GIF, GRID, IMG, JPEG, JPEG 2000, PNG, or TIFF. ArcGIS doesn't require you to permanently transform your raster dataset to display it with other spatial data; however, you should do so if you plan to perform analysis with it or want to use it with another software package that doesn't recognize the external georeferencing information created in the world file.

Updating the georeferencing will store the transformation information in external files—it will not create a new raster dataset, which happens when you permanently transform your raster dataset. For a raster dataset that is file based, such as a TIFF, the transformation will generally be stored in an external XML file—with an .AUX.XML extension. If the raster dataset is a raw image, such as BMP, and the transformation is affine, it will be written to a world file. For a raster dataset in a geodatabase, **Update Georeferencing** will store the geodata transformation to an internal auxiliary file of the raster dataset. Updating a raster layer, an image service, or a mosaic layer will only update the layer within your map document; it will not save the georeferencing information back to the source.

The table below shows how each type of target will be saved.

### 3.4 Georeferencing toolbar

The **Georeferencing** toolbar is used to georeference raster and CAD data.



The toolbar has a collection of drop-down items and interactive tools. There are also other components that you can use to make georeferencing your data easier.

### 3.4.1 Georeferencing toolbar drop-down items

The toolbar has a drop-down list of tools for controlling the georeferencing process.




Georeferencing toolbar drop-down menu

Item	Function
Update Georeferencing	Saves the transformation with the raster.
Rectify	Creates a new transformed raster dataset.
Fit To Display	Shifts the raster to the current display extent area.
Update Display	Updates the display with the current transformation. This is useful when <b>Auto Adjust</b> is disabled.
Auto Adjust	Updates the display with each link that is created.
Flip or Rotate	Corrects for common scanning distortions.
Transformation	Sets the <a href="#">transformation</a> .
Delete Control Points	Deletes all the control points.
Reset Transformation	Resets the raster back to its original location. The control points are not deleted.
Options	Opens the <b>Georeferencing Options</b> window.

### 3.4.2 Georeferencing toolbar drop-down Options window

The **Georeferencing Options** window allows you to specify default behaviors while you are georeferencing.

Georeferencing Options dialog box controls












Button or checkbox	Button name	Function
	From point symbol	Opens the <b>Symbol Selector</b> window to allow you to choose any point symbol as your from-point.
	To point symbol	Opens the <b>Symbol Selector</b> window to allow you to choose any point symbol as your to-point.
	Residual	Opens the <b>Symbol Selector</b> window to allow you to choose any line symbol as your residual line.
Residual		Check this box to show the residuals and RMS error in the link table. The residual shows you the error in the same units as the data frame spatial reference.
Inverse Residual		Check this box to show the inverse residuals and inverse RMS error in the link table. The inverse residual shows you the error in the pixels.
Forward-Inverse Residual		Check this box to show the forward-inverse residuals and RMS error in the link table. This is a measure of how close your accuracy is, measured in pixels. First the transformation is used to find a point in the forward direction. Then that point is used with the inverse transformation and mapped back to image space. This second point is then compared to your from-point that the link tool created.
Auto complete		Check this box to automatically show the user where the system thinks the corresponding to-point should be. Autocomplete only works when you georeference your layer to another raster, after the first two points have been created. When Autocomplete finds a more suitable link pair, it may adjust the from-point that you specified. If no corresponding point can be found, you may need to manually specify the to-point.
Maximum number of sampling blocks		Choose how many sampling blocks to use while autoregistering your raster dataset. Use the drop-down box to choose the number of resampling blocks. The default is to use as many sampling blocks as necessary.

### 3.4.3 Georeferencing toolbar interactive tools


The toolbar has a collection of interactive tools for graphically controlling the georeferencing process.

Georeferencing toolbar interactive tools




Tool	Name	Function
	Add Control Points	Allows you to select control points from a layer and add them to the map.
	Auto Registration	Automatically creates links for your source raster against a target raster. The source raster must be in a relatively close geographic location in order for the autoregistration to work. See <a href="#">Georeferencing a raster automatically</a> for steps to perform autoregistration.
	Select Link	Selects and highlights a link within the display.
	Zoom To Selected Link	Centers and zooms in to a selected link. If you want to zoom in further, you can click this tool multiple times.
	Delete Link	Deletes the selected link.
	Viewer	Opens a viewer window that only displays the raster that you will be georeferencing. This window will allow you to georeference a raster using two windows.
	View Link Table	Shows links and errors in tabular form.
	Rotate	Rotates the source layer. You can manually rotate the source layer, or you can type a degrees value in the measurement text box.
	Shift	Shifts the source layer. You can manually shift the source layer, or you can type an x,y value in the measurement text box.
	Scale	Rescales the source layer. You can manually rescale the source layer, or you can type a rescale factor in the measurement text box.
	Measurement	Type in the rotation angle, x,y shift, or rescale factor.






#### 3.4.4 Link Table

The **Link Table** can be accessed by clicking the **View Link Table**  button. It provides information regarding the links that have been created and the residual error associated with the links.

There are several tool that you can use to evaluate your links:

- Each link can be turned on or off to evaluate what the result would be.
- The **Zoom To Selected Link** tool  can zoom in on the highlighted link.

- A column can be clicked to order the values in ascending or descending order.
- Link Table buttons and their functions

Option/ Button	Button name	Function
	Open	Opens a georeferencing link file.
	Save	Saves a georeferencing link file.
	Zoom To Selected Link	Centers and zooms in to a selected link. If you want to zoom in farther, you can click this tool multiple times.
	Delete Link	Deletes the selected link.
	Insert Link	Opens a viewer window that only displays the raster that you will be georeferencing. This window will allow you to georeference a raster using two windows.
Auto Adjust		Check this box to adjust the raster to immediately show the transformation, after each link is chosen.
Degrees Minutes Seconds		Check this box to show the coordinates in degrees/minutes/seconds. This is only valid when the data frame is using a geographic coordinate system.
Transformation		This drop-down menu allows you to choose a valid transformation. To see more transformations, you may need to choose more links.

### 3.5 Lab: Georeferencing Images in ArcMap

NOTE: You will need at least two layers:

- 1) your layer that needs to be georeferenced, and
- 2) a layer that is already georeferenced, which you will use as a basemap. For a

Open ArcMap & Turn on the Georeferencing Toolbar and the Editor Toolbar

1. Open ArcMap
2. Click the View menu, Toolbars, and Georeferencing Toolbar
3. You will see this toolbar appear. You may 'dock' it within ArcMap so that it will always be in the same place.

Add and convert the scanned image that will be georeferenced

4. Click Add data button and browse to the scanned images
5. In the Georeferencing Toolbar, make sure the layer dropdown choice is pointing to the layer you want to georeference.
6. If you're not already looking at the scanned image, right click its name in the table of contents and click Zoom to Layer.
7. Identify what area the map represents, for example if it's a map of Ashland County you'll see that in the title or may have to find some identifying features.
8. Now zoom to the general vicinity of the basemap, where the image you want to georeference belongs.
9. Now that you're zoomed into the general area, Click Georeferencing, and Fit to Display to bring the scanned image to the same general area as the basemap.
10. Save your map so you don't lose work if anything crashes. Georeferencing the image
11. On the Georeferencing Toolbar, click the Control Points tool (note red arrow below) to begin adding "control points"
12. Then, to add a link,
  - i. find and click on a known location on your image,
  - ii. then find and click on the same location in the basemap.
13. Perform Step 12 three more times so that you have four "control points".

Tips:

You could look for road intersections, land features, building corners, or other objects that you can identify and match in both your image and the basemap.

### 3.6 Lab: Digitalization and image correction

#### PURPOSE

The exercise is divided in two parts and you will work with data from two different study areas in southern Sweden. The purpose of Part 1 is to georeference an aerial photograph, covering southwest corner of a south Swedish city, using georeferenced data from the Swedish economic map. The purpose of Part 2 is to interpret and digitize landscape features (line and polygon) and add attributes to them, in an area on the east coast of southern Sweden.

You will have the possibility to use satellite image, black and white orthophoto and infrared aerial photograph. The end product will be a land-use map over a 2 x 2 km large area.

#### DATA

##### Part 1:

- aerial\_photo (raster data)
- major\_roads (vector data)
- official\_buildings (vector data)

##### Part2:

- Satellite.tif (raster data)
- Infrared.tif (raster data)
- Orthophoto (raster data)

#### BACKGROUND

##### Part1

Raster data is obtained when scanning maps and aerial photographs, or directly in digital format, e.g. satellite images. Scanned maps and aerial photographs don't usually contain information about projection and coordinate system (they are not georeferenced), and consequently you need to georeference it to a map coordinate system in order to use these types of raster data together with your other spatial data.

##### Part2

When interpreting landscape features it is important to use a data source that is appropriate for the purpose of the study. Satellite image usually covers larger areas than aerial photographs;

however, do they provide the necessary information? This is something you will find out during this part of the exercise. When digitizing an area with many geometrical objects it is important to plan the work carefully and be consequent (e.g. working systematically over that area to digitize). In this part of the exercise you will have the opportunity to train you skills in this.

#### ANSWERS TO BE SENT

All trainees have to send in answers for questions 2.1 – 2.8 and the final maps in a word document.

#### METHOD

##### Part 1 Georeferencing a map in ArcMap

Generally, you'll align your raster to existing spatial data that resides in the desired map coordinate system. This assumes that there are features in your spatial data (target data) that are also visible in the raster—for example, streets, building footprints, and streams. The basic procedure for georeferencing is to move the raster into the same space as the target data by identifying a series of ground control points (GCP's) - of known x, y coordinates - that link locations on the raster with locations in the target data in map coordinates. A combination of one control point on the raster and the corresponding control point on the target data is called a link.

To start the georeferencing work, activate the georeferencing toolbar (View, Toolbar, Georeferencing).

1. Add the target layers with known coordinates (major\_roads and official\_buildings) and the raster image (aerial\_photo) to the map document.
2. In the table of contents, right-click one of the target layers and click Zoom to Layer.
3. From the Georeferencing toolbar, click the raster you want to georeference.
4. Click Georeferencing and click Fit to Display. This will display the raster in the same area as the target layers. You can also use the Shift and Rotate tools to move the raster as needed.
5. Click the button to add control points and link them.
6. To add GCP links between raster and target files, click the mouse pointer on a location in the raster image, then over the same location in the target files. You may find it useful to use a Magnification window to add your links in. If you for example use a road junction as GCP, click in the middle of the road in the raster image to achieve the best fit between raster and target layer.

7. Add enough links for the transformation order. You need a minimum of three links for a first-order transformation; but we suggest using about 15 at least. Click View Link Table to evaluate the transformation.
8. Press the Esc key to remove a link while you're in the process of creating it.
9. You can examine the residual error for each link and the RMS error. If you're satisfied with the transformation errors, you can stop entering links. (The lower value the better!)
10. You can delete an unwanted link from the Link Table dialog box. Note that deleting a "bad" link will change the value of all the others.
11. Click Georeferencing and click Update Georeferencing to save the transformation information with the raster. This creates a new file with the same name as the raster but with an .aux file extension.
12. Permanently transform your raster after georeferencing by using the Rectify command. Click Georeferencing and click Rectify. This creates a new raster dataset in GRID, TIFF, or ERDAS IMAGINE format.

Part 1 Send in: Inserted in a word file: A map showing the rectified aerial photograph with the overlays from the Swedish Economic map and Answers to the following questions.

Question 2.1: How many GCP points did you add?

Question 2.2: What kind of GCP points did you use (road junction, house corners)?

Question 2.3: What transformation did you use?

Question 2.4: What RSME did you get? Do you think it reasonable?

Part 2 Digitizing landscape features and adding attributes

You will use the three data sources (satellite, orthophoto and infrared aerial photograph) and classify the landscape into land-use types in a 2x2 km large area. During the digitizing you will add the land-use classification in the attribute tables. Below you see examples of the different land-use types that you are able to identify in the infrared aerial photograph.

1. Add the data to a new map document. Compare the three data sources and answer the questions below.

Question 2.5: How many rows and columns do the satellite image, the infrared aerial photograph and the orthophoto contain respectively?

Question 2.6: What is the pixel size of the satellite image, the infrared aerial photograph and the orthophoto contain respectively?

Question 2.7: How large area does the data cover?

Question 2.8: What land-use do the darker areas in the satellite image represent? (There may be several possibilities. Mention two that you think are most important.)

2. Create two new shape files for linear and polygon features, respectively, and add them to the map document.
3. Select a 2x2 km large area to interpret in terms of roads, rivers, lakes and different land-use types. You should use the infrared aerial photograph as background for the digitizing.
4. When you move the digitizing cursor over the tablet you should see the coordinates at the bottom of ArcMap. Make sure that the coordinate system is OK.

### Editing

Before you start editing, read through the text once down to point 10. If you want to correct any of the lines or polygons, read through “Moving points and vertices” below. Note that for vertices shared by features, you should use topology editing also described below.

1. The Editor toolbar contains the basic commands you will need to edit geographic features. You must add the Editor toolbar to ArcMap before you can begin editing. (Click the Editor Toolbar button on the ArcMap Standard toolbar to display the Editor toolbar. Click the toolbar's title bar and drag it to the top of the ArcMap application window.)
2. Start an edit session by choosing Start editing from the Editor toolbar.
3. Define which layer you will edit as Target. Be very careful to select the correct layer!
4. Define what you want to do by choosing a task from the Task dropdown list.
5. Start to create your sketch by activating the Sketch tool . It has an accompanying context menu that opens if you right-click in the map. This helps you place vertices and segments more accurately.
6. Keep open the attribute table to the shapefile that will be edited, in order to keep track on the digitizing process.

7. When creating polygon features it is important that you plan your digitizing in advance. Start in one corner of the area you are supposed to digitize and work towards the opposite corner.

8. Click with the mouse once to place the first vertex (start node). Then move the cursor along the feature you want to create and place vertices (coordinates) by clicking until you reach the end of the feature, where you double-click, or press F2, to place the end vertex (end node).

The feature you just digitized is selected. Note that one record (row) is added to the attribute table for every new feature created. If you are not happy with your digitization, you can simply press the Delete button on your keyboard and start again. (The feature to be deleted must be selected.)

9. Note! When creating polygons that share borders with an existent polygon, use the Task: Auto-Complete Polygon (see figure below).

In the figure, the dotted line is the new polygon to create, which share boundary with the polygon with a solid line. The boxes show where you place your start and stop nodes when using Auto-Complete Polygon.

10. Choose Save Editing from the Editor drop-down menu regularly. When you are satisfied with your digitizing, click Stop Editing and save your edits.

#### Moving points and vertices

1. Change the Task to Modify feature.

2. Use the Edit tool and click on the feature whose vertices you want to move. Move the vertex by dragging it to a new position. Finish by pressing F2 or by right-clicking and selecting Finish Sketch.

3. Note! Moving vertices shared by features, e.g. lines between polygons, see topology editing below.

#### Using topology editing

1. Open the Topology toolbar.

2. Click the Topology Edit tool and click the features you want to edit using the map topology.

3. In Task Toolbar, select Modify Edge. Double click on the vertex (not line) you want to



move and move it to the new location. Press F2. Don't forget to save your changes and press Stop Editing when finished.

#### Visualization of results

1. Now it is time to make a map to visualize the results. Double-click on land use polygon in the Table of Contents. The Layer properties screen opens. Select the tab Symbology, click Categories, and select land-use under Value Field. Click Add All Values, and then OK.

All land use types should now have a unique colour. It is possible to modify the individual colours, but not really necessary right now. Check that all polygons belonging to the same class have the same colour, otherwise update land-use in the table. Save your map.

2. When you made a nice land use map over the area you have digitised, add a legend where the different land-use types are visible, add a scale-bar and add a north arrow.


Insert the map in a word document together with your answers to questions 2.5-2.8 and send it to teacher.

## CHAPTER 4: TOPOLOGY

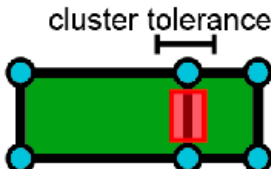
You can create simple, temporary topological relationships between features in ArcGIS for Desktop Basic. Creating or editing geodatabase topology requires an ArcGIS for Desktop Standard or ArcGIS for Desktop Advanced license.


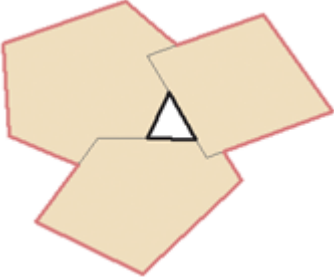
There are many topology rules you can implement in your geodatabase, depending on the spatial relationships that are most important for your organization to maintain. You should carefully plan the spatial relationships you will enforce on your features. Some topology rules govern the relationships of features within a given feature class, while others govern the relationships between features in two different feature classes or subtypes. Topology rules can be defined between subtypes of features in one or another feature class. This could be used, for example, to require street features to be connected to other street features at both ends, except in the case of streets belonging to the cul-de-sac or dead-end subtypes.

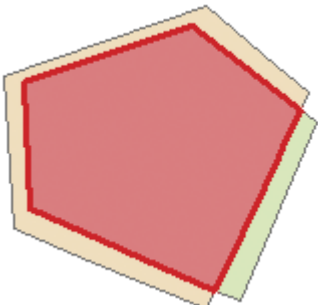
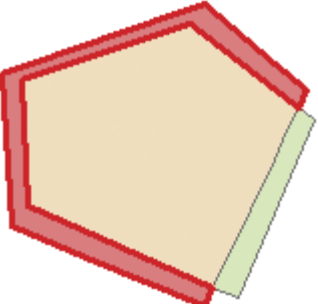
Many topology rules can be imposed on features in a geodatabase. A well-designed geodatabase will have only those topology rules that define key spatial relationships needed by an organization.

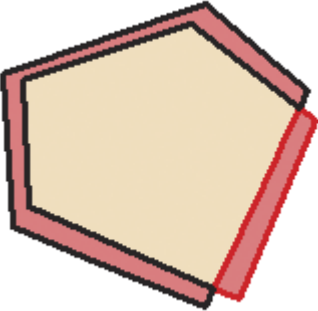
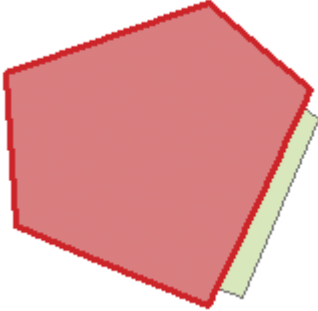
Most topology violations have fixes that you can use to correct errors. Some topology rules, however, have no predefined fixes. Once you have discovered the topology errors, you can select the error on the map with the Fix Topology Error tool , or select the error from within the Error Inspector.

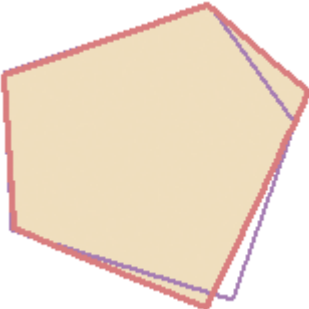
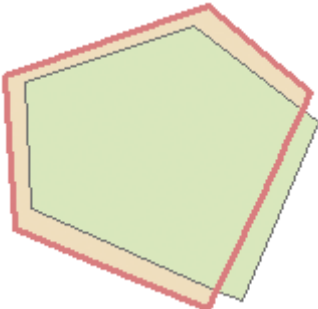
### 4.1 Polygon rules

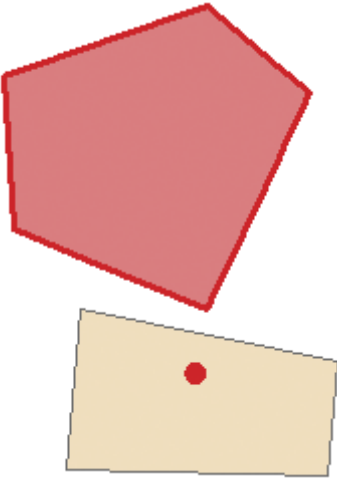
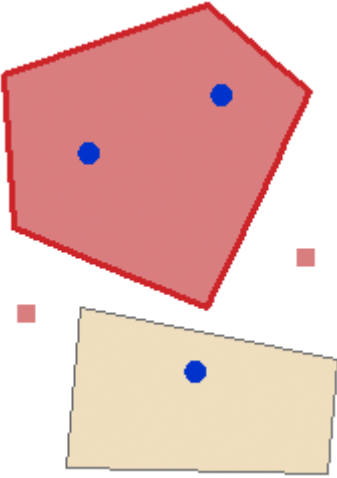
Topology rule	Rule description	Potential fixes	Examples
<b>Must Be Larger Than Cluster Tolerance</b>	Requires that a feature does not collapse during a validate process. This rule is mandatory for a topology and applies to all line and polygon feature classes. In instances where this rule is	<b>Delete:</b> The Delete fix removes polygon features that would collapse during the validate process based on the topology's cluster tolerance. This fix can be applied to one or more Must Be Larger Than Cluster Tolerance errors.	 <p>Any polygon feature, such as the one in red, that would collapse</p>

Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Not Overlap</b></p>	<p>violated, the original geometry is left unchanged.</p> <p>Requires that the interior of polygons not overlap. The polygons can share edges or vertices. This rule is used when an area cannot belong to two or more polygons. It is useful for modeling administrative boundaries, such as ZIP Codes or voting districts, and mutually exclusive area classifications, such as land cover or landform type.</p>	<p><b>Subtract:</b> The Subtract fix removes the overlapping portion of geometry from each feature that is causing the error and leaves a gap or void in its place. This fix can be applied to one or more selected Must Not Overlap errors.</p> <p><b>Merge:</b> The Merge fix adds the portion of overlap from one feature and subtracts it from the others that are violating the rule. You need to pick the feature that receives the portion of overlap using the Merge dialog box. This fix can be applied to one Must Not Overlap error only.</p> <p><b>Create Feature:</b> The Create Feature fix creates a new polygon feature out of the error shape and removes the portion of overlap from each of the features, causing the error to create a planar representation of the feature geometry. This fix can be applied to one or more selected Must Not Overlap errors.</p>	<p>when validating the topology is an error.</p> 
<p><b>Must Not Have Gaps</b></p>	<p>This rule requires that there are no voids within a single polygon or between adjacent polygons. All polygons must form a continuous surface. An error will always exist on the perimeter of the surface. You can either ignore this error or mark it as an exception. Use this rule on data that must completely cover an area. For example, soil polygons cannot include</p>	<p><b>Create Feature:</b> The Create Feature fix creates new polygon features using a closed ring of the line error shapes that form a gap. This fix can be applied to one or more selected Must Not Have Gaps errors. If you select two errors and use the Create Feature fix, the result will be one polygon feature per ring. If you want one multipart feature as a result, you will</p>	 <p>You can use Create Feature to create a new polygon in the void in the center. You can also use Create Feature or mark the error</p>

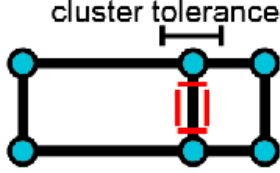
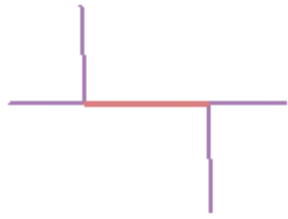
Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Not Overlap With</b></p>	<p>gaps or form voids—they must cover an entire area.</p> <p>Requires that the interior of polygons in one feature class (or subtype) must not overlap with the interior of polygons in another feature class (or subtype). Polygons of the two feature classes can share edges or vertices or be completely disjointed. This rule is used when an area cannot belong to two separate feature classes. It is useful for combining two mutually exclusive systems of area classification, such as zoning and water body type, where areas defined within the zoning class cannot also be defined in the water body class and vice versa.</p>	<p>need to select each new feature and click Merge from the Editor menu. Note that the ring that forms the outer bounds of your feature class will be in error. Using the Create Feature fix for this specific error can create overlapping polygons. Remember that you can mark this error as an exception.</p> <p><b>Subtract:</b> The Subtract fix removes the overlapping portion of each feature that is causing the error and leaves a gap or void in its place. This fix can be applied to one or more selected Must Not Overlap With errors.</p> <p><b>Merge:</b> The Merge fix adds the portion of overlap from one feature and subtracts it from the others that are violating the rule. You need to pick the feature that receives the portion of overlap using the Merge dialog box. This fix can be applied to one Must Not Overlap With error only.</p>	<p>on the outside boundary as an exception.</p> 
<p><b>Must Be Covered By Feature Class Of</b></p>	<p>Requires that a polygon in one feature class (or subtype) must share all of its area with polygons in another feature class (or subtype). An area in the first feature class that is not covered by polygons from the other feature class is an error. This rule is used when an area of one type, such as a state, should be completely covered by areas of another type, such as counties.</p>	<p><b>Subtract:</b> The Subtract fix removes the overlapping portion of each feature that is causing the error so the boundary of each feature from both feature classes is the same. This fix can be applied to one or more selected Must Be Covered By Feature Class Of errors.</p> <p><b>Create Feature:</b> The Create Feature fix creates a new polygon feature out of the portion of overlap from the existing polygon so the boundary of each feature</p>	

Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Cover Each Other</b></p>	<p>Requires that the polygons of one feature class (or subtype) must share all of their area with the polygons of another feature class (or subtype). Polygons may share edges or vertices. Any area defined in either feature class that is not shared with the other is an error. This rule is used when two systems of classification are used for the same geographic area, and any given point defined in one system must also be defined in the other. One such case occurs with nested hierarchical datasets, such as census blocks and block groups or small watersheds and large drainage basins. The rule can also be applied to nonhierarchically related polygon feature classes, such as soil type and slope class.</p>	<p>from both feature classes is the same. This fix can be applied to one or more selected Must Be Covered By Feature Class Of errors.</p> <p><b>Subtract:</b> The Subtract fix removes the overlapping portion of each feature that is causing the error so the boundary of each feature from both feature classes is the same. This fix can be applied to one or more selected Must Cover Each Other errors.</p> <p><b>Create Feature:</b> The Create Feature fix creates a new polygon feature out of the portion of overlap from the existing polygon so the boundary of each feature from both feature classes is the same. This fix can be applied to one or more selected Must Cover Each Other errors.</p>	
<p><b>Must Be Covered By</b></p>	<p>Requires that polygons of one feature class (or subtype) must be contained within polygons of another feature class (or subtype). Polygons may share edges or vertices. Any area defined in the contained feature class must be covered by an area in the covering feature class. This rule is used when area features of a given type must be located within features of another type. This rule is useful when modeling areas that are subsets of a larger surrounding area, such as</p>	<p><b>Create Feature:</b> The Create Feature fix creates a new polygon feature out of the portion of overlap from the existing polygon so the boundary of each feature from both feature classes is the same. This fix can be applied to one or more selected Must Be Covered By errors.</p>	

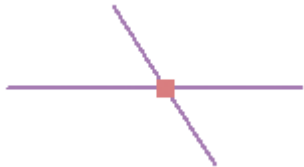
Topology rule	Rule description	Potential fixes	Examples
<p><b>Boundary Must Be Covered By</b></p>	<p>management units within forests or blocks within block groups.</p> <p>Requires that boundaries of polygon features must be covered by lines in another feature class. This rule is used when area features need to have line features that mark the boundaries of the areas. This is usually when the areas have one set of attributes and their boundaries have other attributes. For example, parcels might be stored in the geodatabase along with their boundaries. Each parcel might be defined by one or more line features that store information about their length or the date surveyed, and every parcel should exactly match its boundaries.</p>	<p><b>Create Feature:</b> The Create Feature fix creates a new line feature from the boundary segments of the polygon feature generating the error. This fix can be applied to one or more selected Boundary Must Be Covered By errors.</p>	
<p><b>Area Boundary Must Be Covered By Boundary Of</b></p>	<p>Requires that boundaries of polygon features in one feature class (or subtype) be covered by boundaries of polygon features in another feature class (or subtype). This is useful when polygon features in one feature class, such as subdivisions, are composed of multiple polygons in another class, such as parcels, and the shared boundaries must be aligned.</p>	<p>None</p>	

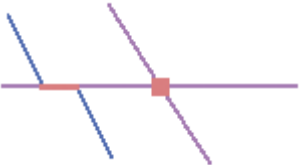
Topology rule	Rule description	Potential fixes	Examples
<p><b>Contains Point</b></p>	<p>Requires that a polygon in one feature class contain at least one point from another feature class. Points must be within the polygon, not on the boundary. This is useful when every polygon should have at least one associated point, such as when parcels must have an address point.</p>	<p><b>Create Feature:</b> The Create Feature fix creates a new point feature at the centroid of the polygon feature that is causing the error. The point feature that is created is guaranteed to be within the polygon feature. This fix can be applied to one or more selected Contains Point errors.</p>	 <p>The top polygon is an error because it does not contain a point.</p>
<p><b>Contains One Point</b></p>	<p>Requires that each polygon contains one point feature and that each point feature falls within a single polygon. This is used when there must be a one-to-one correspondence between features of a polygon feature class and features of a point feature class, such as administrative boundaries and their capital cities. Each point must be properly inside exactly one polygon and each polygon must properly contain exactly one point. Points must be within the polygon, not on the boundary.</p>	<p>None</p>	 <p>The top polygon is an error because it contains more than one point. Points are errors when they are outside a polygon.</p>


## 4.2 Line rules

Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Be Larger Than Cluster Tolerance</b></p>	<p>Requires that a feature does not collapse during a validate process. This rule is mandatory for a topology and applies to all line and polygon feature classes. In instances where this rule is violated, the original geometry is left unchanged.</p>	<p><b>Delete:</b> The Delete fix removes line features that would collapse during the validate process based on the topology's cluster tolerance. This fix can be applied to one or more Must Be Larger Than Cluster Tolerance errors.</p>	 <p>Any line feature, such as these lines in red, that would collapse when validating the topology is an error.</p>
<p><b>Must Not Overlap</b></p>	<p>Requires that lines not overlap with lines in the same feature class (or subtype). This rule is used where line segments should not be duplicated, for example, in a stream feature class. Lines can cross or intersect but cannot share segments.</p>	<p><b>Subtract:</b> The Subtract fix removes the overlapping line segments from the feature causing the error. You must select the feature from which the error will be removed. If you have duplicate line features, select the line feature you want to delete from the Subtract dialog box. Note that the Subtract fix will create multipart features, so if the overlapping segments are not at the end or start of a line feature, you might want to use the Explode command on the Advanced Editing toolbar to create single-part features. This fix can be applied to one</p>	

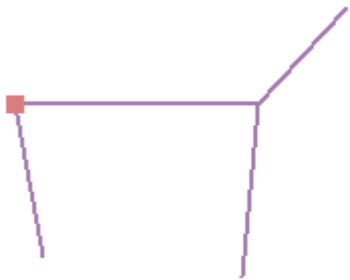


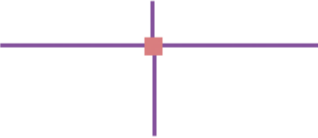
Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Not Intersect</b></p>	<p>Requires that line features from the same feature class (or subtype) not cross or overlap each other. Lines can share endpoints. This rule is used for contour lines that should never cross each other or in cases where the intersection of lines should only occur at endpoints, such as street segments and intersections.</p>	<p>selected Must Not Overlap error only.</p> <p><b>Subtract:</b> The Subtract fix removes the overlapping line segments from the feature causing the error. You must select the feature from which the error will be removed. If you have duplicate line features, select the line feature you want to delete from the Subtract dialog box. Note that the Subtract fix will create multipart features, so if the overlapping segments are not at the end or start of a line feature, you might want to use the Explode command on the Advanced Editing toolbar to create single-part features. This fix can be applied to one Must Not Intersect error only.</p> <p><b>Split:</b> The Split fix splits the line features that cross one another at their point of intersection. If two lines cross at a single point, applying the Split fix at that location will result in four features. Attributes from the original</p>	

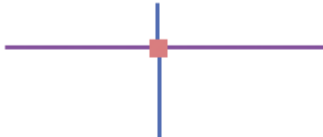
Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Not Intersect With</b></p>	<p>Requires that line features from one feature class (or subtype) not cross or overlap lines from another feature class (or subtype). Lines can share endpoints. This rule is used when there are lines from two layers that should never cross each other or in cases where the intersection of lines should only occur at endpoints, such as streets and railroads.</p>	<p>features will be maintained in the split features. If a split policy is present, the attributes will be updated accordingly. This fix can be applied to one or more Must Not Intersect errors.</p> <p><b>Subtract:</b> The Subtract fix removes the overlapping line segments from the feature causing the error. You must select the feature from which the error will be removed. If you have duplicate line features, select the line feature you want to delete from the Subtract dialog box. Note that the Subtract fix will create multipart features, so if the overlapping segments are not at the end or start of a line feature, you might want to use the Explode command on the Advanced Editing toolbar to create single-part features. This fix can be applied to one Must Not Intersect With error only.</p> <p><b>Split:</b> The Split fix splits the line features that cross one</p>	


Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Not Have Dangles</b></p>	<p>Requires that a line feature must touch lines from the same feature class (or subtype) at both endpoints. An endpoint that is not connected to another line is called a dangle. This rule is used when line features must form closed loops, such as when they are defining the boundaries of polygon features. It may also be used in cases where lines typically connect to other lines, as with streets. In this case, exceptions can be used where the rule is</p>	<p>another at their point of intersection. If two lines cross at a single point, applying the Split fix at that location will result in four features. Attributes from the original features will be maintained in the split features. If a split policy is present, the attributes will be updated accordingly. This fix can be applied to one or more Must Not Intersect With errors.</p> <p><b>Extend:</b> The Extend fix will extend the dangling end of line features if they snap to other line features within a given distance. If no feature is found within the distance specified, the feature will not extend to the distance specified. Also, if several errors were selected, the fix will simply skip the features that it cannot extend and attempt to extend the next feature in the list. The errors of features that could not be extended remain on the Error Inspector dialog box. If the</p>	

Topology rule	Rule description	Potential fixes	Examples
	<p>occasionally violated, as with cul-de-sac or dead-end street segments.</p>	<p>distance value is 0, lines will extend until they find a feature to snap to. This fix can be applied to one or more Must Not Have Dangles errors.</p> <p><b>Trim:</b> The Trim fix will trim dangling line features if a point of intersection is found within a given distance. If no feature is found within the distance specified, the feature will not be trimmed, nor will it be deleted if the distance is greater than the length of the feature in error. If the distance value is 0, lines will be trimmed back until they find a point of intersection. If no intersection is located, the feature will not be trimmed and the fix will attempt to trim the next feature in error. This fix can be applied to one or more Must Not Have dangles errors.</p> <p><b>Snap:</b> The Snap fix will snap dangling line features to the nearest line feature within a given distance. If no line feature is found within the</p>	

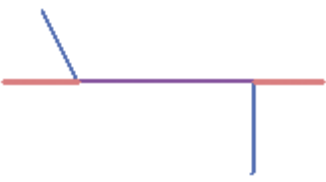
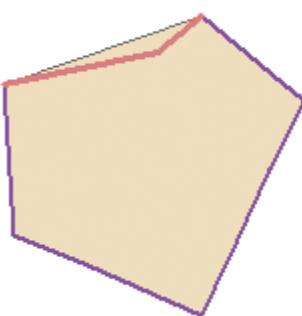
Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Not Have Pseudo Nodes</b></p>	<p>Requires that a line connect to at least two other lines at each endpoint. Lines that connect to one other line (or to themselves) are said to have pseudo nodes. This rule is used where line features must form closed loops, such as when they define the boundaries of polygons or when line features logically must connect to two other line features at each end, as with segments in a stream network, with exceptions being marked for the originating ends of first-order streams.</p>	<p>distance specified, the line will not be snapped. The Snap fix will snap to the nearest feature found within the distance. It searches for endpoints to snap to first, then vertices, and finally to the edge of line features within the feature class. The Snap fix can be applied to one or more Must Not Have Dangles errors.</p> <p><b>Merge To Largest:</b> The Merge To Largest fix will merge the geometry of the shorter line into the geometry of the longest line. The attributes of the longest line feature will be retained. This fix can be applied to one or more Must Not Have Pseudo Nodes errors.</p> <p><b>Merge:</b> The Merge fix adds the geometry of one line feature into the other line feature causing the error. You must pick the line feature into which to merge. This fix can be applied to one selected</p>	

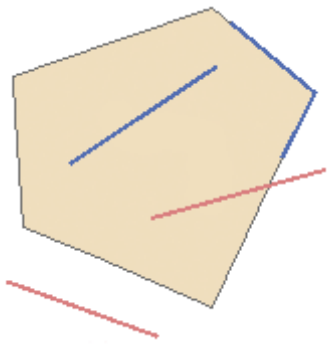
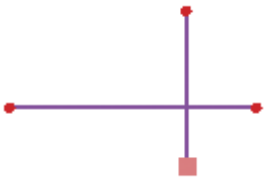
Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Not Intersect Or Touch Interior</b></p>	<p>Requires that a line in one feature class (or subtype) must only touch other lines of the same feature class (or subtype) at endpoints. Any line segment in which features overlap or any intersection not at an endpoint is an error. This rule is useful where lines must only be connected at endpoints, such as in the case of lot lines, which must split (only connect to the endpoints of) back lot lines and cannot overlap each other.</p>	<p>Must Not Have Pseudo Nodes error.</p> <p><b>Subtract:</b> The Subtract fix removes the overlapping line segments from the feature causing the error. You must select the feature from which the error will be removed. If you have duplicate line features, choose the line feature you want to delete from the Subtract dialog box. The Subtract fix creates multipart features, so if the overlapping segments are not at the end or start of a line feature, you might want to use the Explode command on the Advanced Editing toolbar to create single-part features. This fix can be applied to one selected Must Not Intersect Or Touch Interior error only.</p> <p><b>Split:</b> The Split fix splits the line features that cross one another at their point of intersection. If two lines cross at a single point, applying the Split fix at that location will result in four features.</p>	


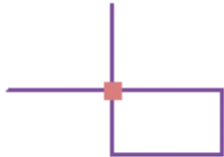

Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Not Intersect Or Touch Interior With</b></p>	<p>Requires that a line in one feature class (or subtype) must only touch other lines of another feature class (or subtype) at endpoints. Any line segment in which features overlap or any intersection not at an endpoint is an error. This rule is useful where lines from two layers must only be connected at endpoints.</p>	<p>Attributes from the original features will be maintained in the split features. If a split policy is present, the attributes will be updated accordingly. This fix can be applied to one or more Must Not Intersect Or Touch Interior errors.</p> <p><b>Subtract:</b> The Subtract fix removes the overlapping line segments from the feature causing the error. You must select the feature from which the error will be removed. If you have duplicate line features, choose the line feature you want to delete from the Subtract dialog box. The Subtract fix creates multipart features, so if the overlapping segments are not at the end or start of a line feature, you might want to use the Explode command on the Advanced Editing toolbar to create single-part features. This fix can be applied to one selected Must Not Intersect</p>	

Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Not Overlap With</b></p>	<p>Requires that a line from one feature class (or subtype) not overlap with line features in another feature class (or subtype). This rule is used when line features cannot share the same space. For example, roads must not overlap with railroads or depression subtypes of contour lines cannot overlap with other contour lines.</p>	<p>Or Touch Interior With error only.</p> <p><b>Split:</b> The Split fix splits the line features that cross one another at their point of intersection. If two lines cross at a single point, applying the Split fix at that location will result in four features. Attributes from the original features will be maintained in the split features. If a split policy is present, the attributes will be updated accordingly. This fix can be applied to one or more Must Not Intersect Or Touch Interior With errors.</p> <p><b>Subtract:</b> The Subtract fix removes the overlapping line segments from the feature causing the error. You must select the feature from which the error will be removed. If you have duplicate line features, choose the line feature you want to delete from the Subtract dialog box. The Subtract fix creates multipart features, so if the</p>	 <p>Where the purple lines overlap is an error.</p>


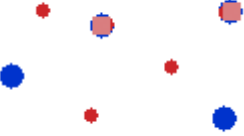


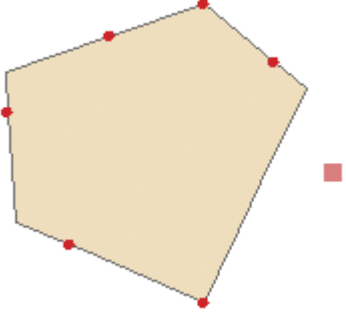
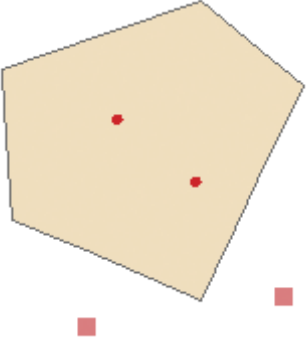
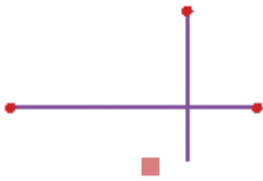
Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Be Covered By Feature Class Of</b></p>	<p>Requires that lines from one feature class (or subtype) must be covered by the lines in another feature class (or subtype). This is useful for modeling logically different but spatially coincident lines, such as routes and streets. A bus route feature class must not depart from the streets defined in the street feature class.</p>	<p>overlapping segments are not at the end or start of a line feature, you might want to use the Explode command on the Advanced Editing toolbar to create single-part features. This fix can be applied to one selected Must Not Overlap With error only.</p> <p>None</p>	 <p>Where the purple lines do not overlap is an error.</p>
<p><b>Must Be Covered By Boundary Of</b></p>	<p>Requires that lines be covered by the boundaries of area features. This is useful for modeling lines, such as lot lines, that must coincide with the edge of polygon features, such as lots.</p>	<p><b>Subtract:</b> The Subtract fix removes line segments that are not coincident with the boundary of polygon features. If the line feature does not share any segments in common with the boundary of a polygon feature, the</p>	


Topology rule	Rule description	Potential fixes	Examples
<b>Must Be Inside</b>	<p>Requires that a line is contained within the boundary of an area feature. This is useful for cases where lines may partially or totally coincide with area boundaries but cannot extend beyond polygons, such as state highways that must be inside state borders and rivers that must be within watersheds.</p>	<p>feature will be deleted. This fix can be applied to one or more Must Be Covered By Boundary Of errors.</p> <p><b>Delete:</b> The Delete fix removes line features that are not within polygon features. Note that you can use the Edit tool and move the line inside the polygon feature if you do not want to delete it. This fix can be applied to one or more Must Be Inside errors.</p>	
<b>Endpoint Must Be Covered By</b>	<p>Requires that the endpoints of line features must be covered by point features in another feature class. This is useful for modeling cases where a fitting must connect two pipes or a street intersection must be found at the junction of two streets.</p>	<p><b>Create Feature:</b> The Create Feature fix adds a new point feature at the endpoint of the line feature that is in error. The Create Feature fix can be applied to one or more Endpoint Must Be Covered By errors.</p>	 <p>The square at the bottom indicates an error, because there is no point covering the endpoint of the line.</p>

Topology rule	Rule description	Potential fixes	Examples
<b>Must Not Self-Overlap</b>	<p>Requires that line features not overlap themselves. They can cross or touch themselves but must not have coincident segments. This rule is useful for features, such as streets, where segments might touch in a loop but where the same street should not follow the same course twice.</p>	<p><b>Simplify:</b> The Simplify fix removes self-overlapping line segments from the feature in error. Applying the Simplify fix can result in multipart features, which you can detect using the Must Be Single Part rule. The Simplify fix can be applied to one or more Must Not Self-Overlap errors.</p>	 <p>The individual line feature overlaps itself, with the error indicated by the coral line.</p>
<b>Must Not Self-Intersect</b>	<p>Requires that line features not cross or overlap themselves. This rule is useful for lines, such as contour lines, that cannot cross themselves.</p>	<p><b>Simplify:</b> The Simplify fix removes self-overlapping line segments from the feature in error. Note that applying the Simplify fix can result in multipart features. You can detect multipart features using the Must Be Single Part rule. This fix can be applied to one or more Must Not Self-Intersect errors.</p>	
<b>Must Be Single Part</b>	<p>Requires that lines have only one part. This rule is useful where line features, such as highways, may not have multiple parts.</p>	<p><b>Explode:</b> The Explode fix creates single-part line features from each part of the multipart line feature that is in error. This fix can be applied to one or more Must Be Single Part errors.</p>	 <p>Multipart lines are created from a single sketch.</p>

### 4.3 Point rules

Topology rule	Rule description	Potential fixes	Examples
<b>Must Coincide With</b>	<p>Requires that points in one feature class (or subtype) be coincident with points in another feature class (or subtype). This is useful for cases where points must be covered by other points, such as transformers must coincide with power poles in electric distribution networks and observation points must coincide with stations.</p>	<p><b>Snap:</b> The Snap fix will move a point feature in the first feature class or subtype to the nearest point in the second feature class or subtype that is located within a given distance. If no point feature is found within the tolerance specified, the point will not be snapped. The Snap fix can be applied to one or more Must Coincide With errors.</p>	 <p>Where a red point is not coincident with a blue point is an error.</p>
<b>Must Be Disjoint</b>	<p>Requires that points be separated spatially from other points in the same feature class (or subtype). Any points that overlap are errors. This is useful for ensuring that points are not coincident or duplicated within the same feature class, such as in layers of cities, parcel lot ID points, wells, or streetlamp poles.</p>	<p>None</p>	 <p>Where a red point and a blue point overlap is an error.</p>

Topology rule	Rule description	Potential fixes	Examples
<p><b>Must Be Covered By Boundary Of</b></p>	<p>Requires that points fall on the boundaries of area features. This is useful when the point features help support the boundary system, such as boundary markers, which must be found on the edges of certain areas.</p>	<p>None</p>	 <p>The square on the right indicates an error because it is a point that is not on the boundary of the polygon.</p>
<p><b>Must Be Properly Inside</b></p>	<p>Requires that points fall within area features. This is useful when the point features are related to polygons, such as wells and well pads or address points and parcels.</p>	<p><b>Delete:</b> The Delete fix removes point features that are not properly within polygon features. Note that you can use the Edit tool and move the point inside the polygon feature if you do not want to delete it. This fix can be applied to one or more Must Be Properly Inside errors.</p>	 <p>The squares are errors where there are points that are not inside the polygon.</p>
<p><b>Must Be Covered By Endpoint Of</b></p>	<p>Requires that points in one feature class must be covered by the endpoints of lines in another feature class. This rule is similar to the line rule Endpoint Must Be Covered</p>	<p><b>Delete:</b> The Delete fix removes point features that are not coincident with the endpoint of line features. Note that you can snap the point to the line by setting</p>	

Topology rule	Rule description	Potential fixes	Examples
<p><b>Point Must Be Covered By Line</b></p>	<p>By except that, in cases where the rule is violated, it is the point feature that is marked as an error rather than the line. Boundary corner markers might be constrained to be covered by the endpoints of boundary lines.</p> <p>Requires that points in one feature class be covered by lines in another feature class.</p> <p>It does not constrain the covering portion of the line to be an endpoint. This rule is useful for points that fall along a set of lines, such as highway signs along highways.</p>	<p>edge snapping to the line layer, then moving the point with the Edit tool. This fix can be applied to one or more</p> <p>Must Be Covered By Endpoint Of errors.</p> <p>None</p>	<p>The square indicates an error where the point is not on an endpoint of a line.</p>  <p>The squares are points that are not covered by the line.</p>

## CHAPTER 5: DIGITIZING IN ARCMAP

### 5.1 Manual Digitizing

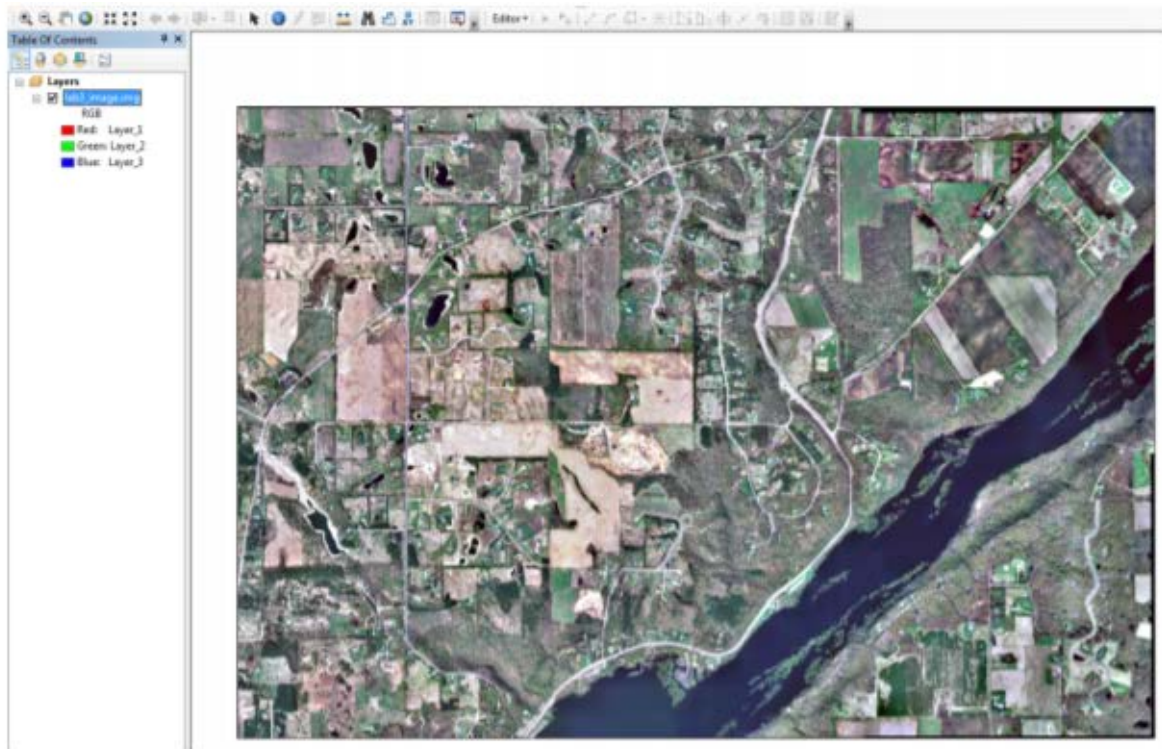
Digitizing is the process of interpreting and converting paper map or image data to vector digital data. In manual digitizing you trace the lines or points from the source media. You control a cursor, usually with a mouse or digitizing puck, and sample vertices to define the point, line, or polygonal features you wish to capture. The source media may be hardcopy, e.g., maps taped to a digitizing table, or softcopy, e.g., a digital image or scanned map. ESRI software allows us to digitize using either hardcopy or softcopy sources.

### 5.2 On Screen Digitizing in ArcMap

Digitizing directly on screen is sometimes called “heads-up” or softcopy digitizing. Flatbed scanners and digital cameras are common, so softcopy digitizing is a standard procedure. Scanned photos have some geometric distortion that depends primarily on how the photo was taken (flying height, terrain, camera tilt, and other factors). GIS data are commonly entered from scanned photos because we can easily adjust the display scale, zooming in or out as needed. This often reduces both interpretation and digitizing.

### 5.3 Digitizing

- Start ArcMap, and create a new, blank document.
- Select the add **Add Data** button;
- navigate to data folder and add the image to display something similar to the figure right.

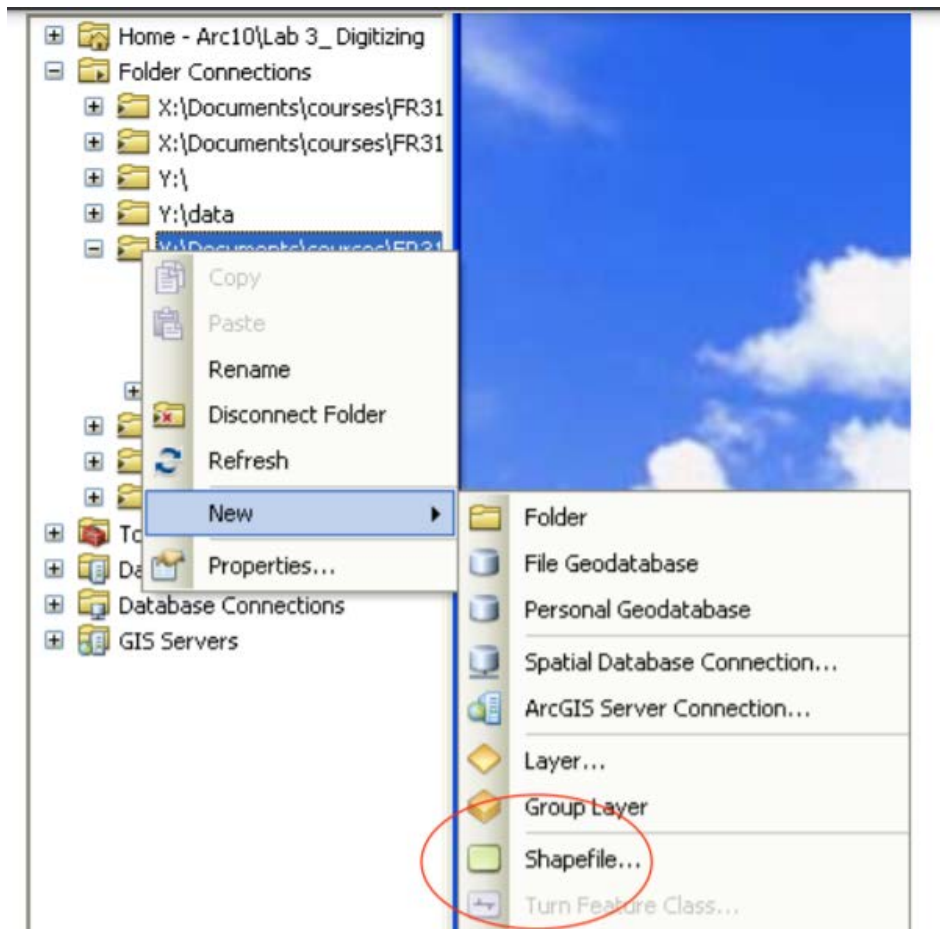


The image is a scanned True Color photograph of the type often used for land cover and vegetation mapping.

- **Create a New Shapefile or GeoDatabase/Feature Using ArcCatalog**
- Open ArcCatalog by clicking on the icon in the main ArcMap toolbar
- Navigate to the subdirectory containing the data
- Right click on the subdirectory and then in the dropdown window, select **New**, then

**Shapefile.** This should open a “Create New Shapefile” window.





- You have entry boxes for a **Name**, and a **Feature Type**. The default feature type will initially come up as point, but you could also select line or polygon as the default types, using the selection triangle to the right of the Feature Type block.
- Enter something descriptive for a **Name**, e.g., Ponds. If you leave the default “New\_Shapefile” name you may have difficulty keeping track of your files.
- Specify a **Feature Type** of point Left click on **Edit** to set the coordinate system.
- Specify Select > Projected.

#### 5.4.1 Digitizing Features

- Close the ArcCatalog window (click the X in the upper right corner), and add the *IMAGE* to your data frame. Your goal is to digitize points (ponds), lines (major roads), and polygons (selected fields) from this image.

#### 5.4.2 Points

- Add the *Ponds, Fields & Roads* layers to your ArcMap.
- Make sure the new, empty point, line, and polygon layers appear in your table of contents.
- Left click on **Editor, Start Editing**
- A window pops up that shows the available layers in a top panel, and the source directories/GeoDatabases and types in a bottom panel.
- You select a target layer by left-clicking on it; it should then be hi-lighted in blue.
- You should click on the “About Editing and Workspaces” button in the lower left, and read the description. (*Note, this Window may not appear if all the layers are in the same directory*)
- Select “*ponds*” (shapefile version) or “*pondsGDB*” (GeoDatabase version) as your target layer to digitize, and then click O.K.
- Select Editing Windows and choose Create Features or click on the tool
- A new “Create Features” window will display (see at right), either free-floating, or docked on the right edge of your workspace.
- Left-click on the ponds layer as the target for edits, a blue box will appear around the name.

*\*\*Note that the “Construction Tools” in the bottom panel of the window change as you select different types of features. Make sure you have ponds selected, and it is a point feature, with Construction Tools as shown at right.*

- Find the Editor Toolbar, usually a horizontal series of icons near the upper-left side of the ArcGIS window.
- To digitize points, place the cursor over a pond, and single left-click. Each click creates a feature.
- Place the point in the middle of the pond by positioning the cursor and left-clicking.
- If the default point symbols are difficult to see, you can change the symbol color, size, or type by double clicking on the legend entry for the layer in the table of contents, as you would for any theme.

*\*\*Note that when you select other functions during digitizing, e.g., changing the color or size of a symbol, you will often have to re-activate the point data layer (here pointGDB),*

and click on the kind of feature in the *Constructions Tools* you'd like to add, and then continue digitizing.

- You should click on **Editor** > **Save Edits** every few features, and when you are done digitizing ponds.
- You typically select features to either delete, or modify them. Hold the cursor over a feature while the caret is active, and left click on the feature. Note that it changes color, typically cyan, the default “selected feature” color.
- A left click and hold allows you to drag a feature, try it with a few points.
- A left click to select a feature, then a right click over the selected feature will display various options, most important among them an option to Delete the feature.
- To de-select feature(s), left click on ArcMap main **Selection** menu and left click on
- **Clear Selected Features**. The color should now match the rest of the features.

Finish digitizing all your ponds, save your edits, and stop editing (click on the dropdown control in the Editor Toolbar).

#### 5.4.3 Digitizing Lines, and Snapping

- First we must set the snapping environment. As with many actions in ArcGIS, this is a bit complicated. You can use the new snapping tool, or the classic snapping tool.

To use the new snapping tool, first:

- Left click on **Customize** along the top of the main ArcGIS window, then click on **Toolbars**. This will display a dropdown list of choices.
- Find **Snapping**, and left click on it. This should show a checkmark to the left of the name. This display the snapping toolbar, also a floating toolbar, so it may appear anywhere and you may click and drag to reposition it
- Now click on the snapping dropdown pointer, and then select **Options**: This will display a window that allows you to set options, most importantly the snapping tolerance. Unfortunately, we can only set it in pixels, the default units it chooses because we have an image loaded.

We can calculate the tolerance distance we want, but we have to convert the distance we want (e.g., 4 meters) to the proper number of pixels. If you don't know the units for the image, we

can look them up (remember, right click on the image in the TOC, then Properties, then **Source**).

Many folks choose “Classic Snapping,” for among other reasons, because it allows us to specify the units in real-measurements, e.g., meters, and provides a more obvious display of the features participating in the snapping.

- To activate Classic Snapping, left click on Editor, then select Options from the bottom of the dropdown menu, then place a check in the box next to “Use classic snapping” (see the figure, at right).
- To set the snap tolerance and units, left click on **Editor, Snapping, Options**
- The Snapping Options t allows you to set the snapping tolerance in map units or pixels.
- To change snapping approaches select Editor, Options and select “Classic Snapping.”

We recommend you use one, or the other, so if you choose to use classic snapping, remember to turn off the Snapping Toolbar (via **Customize, Toolbars**, and then click again on **Snapping** to toggle off the check mark).

- Set snapping for something like 4 to 6 meters.
- One final step to set up snapping. If you are using Classic Snapping then your need say what layers will be snapped.
- Left click again on **Editor, Snapping**, as in the figure at above left, but this time select **Snapping Window**. This will display the layers, and what features will participate in the Snapping Environment.
- Left click to check the Vertex, Edge, and End boxes for the roads layer, so that these elements of a feature will snap.

#### 5.4.3.1 Digitizing Lines

You’ll digitize the set of roads shown in the map at the end of these instructions.

- Move the cursor to the start of the road you wish to digitize, and left click. Move along the center of the road, left-clicking when you need a vertex. Note that this shows both the vertices (knots on the path) and the “thread” connecting these knots. This is your digitized line.

- Double click to end a line. If the entire road segment you wish to digitize is not in the view, navigate around the image using the pan and zoom tool. Note that you first pan or zoom, and then you must click again on the target feature (roads, here) in the Create Features window to return to the digitizing cursor. If you are digitizing and the road continues beyond the edge of the view, the feature is still active, and you can add to it, after you click on the layer again in the Create Features window.

You may need to refresh after a pan and zoom, using the refresh button next to the data and layout view buttons.

#### 5.4.4 Fixing Mistakes

What if you make a mistake while digitizing?

- Placing the sketch cursor over the last point digitized, and right clicking reveals a dropdown menu, as shown at right. You may then select Delete Vertex, but only to remove the last vertex digitized.
- If there is a sequence of bad vertices, you can move backward, positioning the cursor and right clicking over each one in turn.
- If you wish to remove an entire line, you may:
  - i. terminate the line (double click with the sketch tool to end digitizing), then single left click on the line with the caret tool, then
  - ii. right click and select **Delete** from the dropdown menu (not shown).
- You may select several lines by holding down the shift key, and left clicking on each of them to select, then single right-click and Delete.
- If you want to reshape a line, either to move or add vertices, you can double left click on the line, which will display a segment editor toolbar:
- Double left-clicking on a line segment reveals the vertices. If you select the leftmost caret, and hold it over a vertex, you can left-click and drag to move the vertex. The caret-plus and caret-minus icons allow you to add or delete a vertex in a selected segment.
- Digitize and fix mistakes until all indicated roads are digitized. Remember to set and use your snapping tolerance so you don't have under and overshoots.

- Save frequently using **Editor > Save Edits**, and stop editing when you've digitized the roads shown in the example map below.
- Change your Create Features layer to the empty polygon data set you created, and set the Construction Tool to Polygon.
- Digitize the fields shown in the example map.
- Move the cursor to a border of the field you wish to digitize and left-click the mouse. This starts a new polygon. Each time you left-click, you will be placing a vertex for a polygon, until you double click, which closes the polygon.
- Move the cursor to the next field, and repeat the digitizing process.
- Continue digitizing features, at least as many as are shown in the sample map at right.
- Save frequently using the **Save Edits** option of the Editor Toolbar and **Stop Edits** option when you are done.