Digital Cartography

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I

Introduction

Welcome to digital cartography! This book was adapted from Penn State University's GEOG 486 – Cartography and Visualization Open Educational Resource. In this book, we will cover foundational cartographic principles that is needed to make effective maps. We will go over such concepts as data, lettering, along with multivariate and uncertainty visualization. By the end of this book, you will be able to:

1. Describe how cartographic concepts such generalization, scale and projection will affect mapping products.
2. Identify the medium, purpose, and spatial data requirements to create a map that is appropriate to a specific audience.
3. Evaluate maps produced by peers and various organizations.
4. Construct maps that effectively use color, font, and other design elements using ArcGIS Pro.

Overview of Chapters

This book contains five chapters. In the first chapter, we start off talking about the basics of map design and how to customize your map for a specific audience, medium, and purpose. In the second chapter, we transition to focusing on lettering and layouts in which we focus on how we label various items on maps including the text we use to label these items and how to place various elements in a map layout. Chapter three covers more conceptual ideas in cartography such as geographic phenomena and visual encoding. We will connect the relationship between understanding these concepts and how you would apply them in the symbolization of your map. In chapter 4, we transition from focusing symbolization to color and we learn about the types of color schemes, specifying colors, visual perception constraints, and making choropleth maps. We wrap up the book in chapter five in talking about multivariate and uncertainty visualization. We cover such concepts as multivariate choropleths, dot and proportional symbol maps along with more creative forms of multivariate mapping such as cartograms and multivariate glyphs.

Software Requirements

For this class, it is required that you have access to ArcGIS Pro. If you are a part of an academic institution, it is recommended to reach out to the ArcGIS Pro administrator at your university to receive a license. If you are at Washington University in St. Louis, you can download ArcGIS Pro to your personal computer for no cost or you can remotely access ArcGIS Pro through the research studio at Olin Library.

Lab Assignments

The purpose of the lab assignments is to apply the concepts you learned in each chapter, implement recommended data management principles, and to learn a little more about a city that you are interested in! In these set of labs, you will choose a city and create maps based on the lab objectives on your chosen city. In essence, you will be creating a story about your city which is similar to the U.S. Census Bureau State Profiles. At the end of the lab assignments, you will need to turn in a City Story either in a PDF or StoryMap format and incorporate the feedback given in the assignments. If you are using this book on your own, you should try to still create a City Story! The more you are able to design maps, the better cartographer you will be!

Accessibility

Currently, Digital Cartography is not as accessible as I wanted to be. For example, most of the images in the chapters do not have alt-text or image descriptions, and only the lab exercises contain alt-text. We are actively working on making the book fully accessible to those who have low-vision and we are also working on ways to ensure accessibility in other ways as well. To keep abreast of the progress we are making towards making this text accessible, please refer to the Book Updates section.

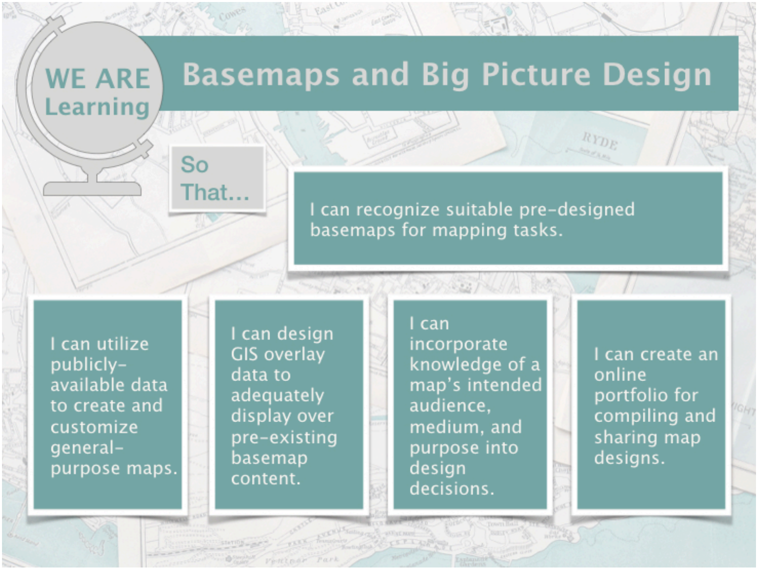
I hope that you enjoy this text and it helps you become a better cartographer!

I

Basemaps and Big Picture Design

Overview

Welcome to the first lesson! In this lesson, we will talk about the basics of map design, including how to customize your map to fit a specific audience, medium, and purpose. We will also introduce some topics that we will cover more in-depth later in the course, including visual variables, scale, and online map distribution. For the first six weeks of labs, you will be working with data pertaining to a city of your choosing. With this week's lab exercise, you will be doing two things; creating a geodatabase that contains administrative boundaries, hydrological and transportation features of the city of your choice and then creating two general-purpose maps. For the first two labs, you will be working with this geodatabase and you will add more data to your geodatabase from labs three to six. By the end of this lesson, you should be able to recognize pre-designed basemaps for mapping tasks.



By the end of this lesson, you should be able to: recognize pre-designed basemaps for mapping tasks, utilize publicly-available data to create and customize general-purpose maps, design GIS overlay data to adequately display over pre-existing basemap content, incorporate knowledge of a map's intended audience, medium, and purpose into design decisions, and create an online portfolio for compiling and sharing map designs.

Image description:

Top Row:

- Left Box (Circular design with a stand, resembling a globe which is grey): o "WE ARE Learning" in green text •

- Center Box (Long horizontal green band): o "Basemaps and Big Picture Design" in grey text Middle Row:
- Left Box (Small grey square with white background and white outline): o "So That…"
- Right Box (Large horizontal green rectangle with white outline): o "I can recognize suitable pre-designed basemaps for mapping tasks."
- Bottom Row (Four vertical green rectangles with white outline): •
    - First Box (Left): o "I can utilize publicly available data to create and customize general-purpose maps."
    - Second Box (Center-left): o "I can design GIS overlay data to adequately display over pre-existing basemap content."
    - Third Box (Center-right): o "I can incorporate knowledge of a map's intended audience, medium, and purpose into design decisions." • Fourth Box (Right): o "I can create an

online portfolio for
compiling and sharing map
designs."

Design Matters

> “Not only is it easy to lie with maps, it’s essential.” – Mark Monmonier, *How to Lie with Maps*, pg. 1

When making a map, it is impossible to map everything. In fact, to be a useful model of our world and of any phenomena in it, maps must always obscure, simplify, and/or embellish reality. These actions—which make maps useful—also make their construction subjective. Cartographic design, even when informed by well-established conventions, is an art as much as a science. Every design choice a cartographer makes ultimately influences the map readers’ comprehension, appreciation—and even trust—of the map that he or she creates.

Though maps may include or be supplemented by text or other media (even by sound, smell, or touch), map creation at its core is about visual design. As such, cartographers often talk of **graphicacy** and its importance in facilitating visual communication with maps (e.g., Field 2018, pg. 194). Graphicacy was first defined by Balchin and Coleman (1966) as “the intellectual skill necessary for the communication of relationships which cannot be successfully communicated by words or mathematical notation alone.” Graphicacy—like literacy—has its own grammar and syntax, and learning the rules of graphic language is essential for designing effective maps (Field 2018, pg. 194).

Student Reflection

Which map of the two below best communicates the trend of the data? Why?

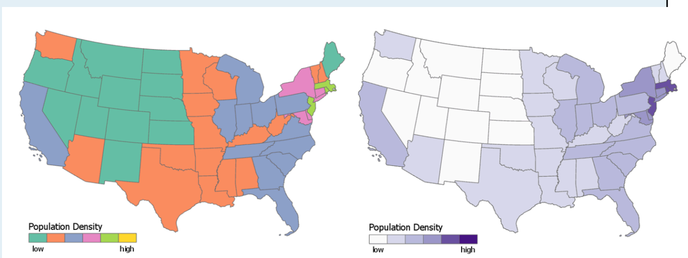


Figure 1.1.1 Two Choropleth Maps, with multi-hued categorical (left), and single-hue sequential (right) color schemes. Credit: Cary Anderson, Penn State University, Data Source: US Census, American Community Survey.

Image description: The image consists of two maps of the United States side by side. Both maps depict the population density across various states using different color schemes to represent varying density levels.

Left Map:

- The map is color-coded with shades of green, pink, purple, yellow, blue, and orange to represent population density.

- California, Texas, Illinois, and most southeastern states are colored orange, indicating low density.
- The states in the northeastern region, such as New York and New Jersey, are in green, indicating high density.
- A legend at the bottom left indicates the population density scale from low (orange) to high (yellow).

Right Map:

- The map uses gradients of purple and white to show population density.
- Northeast states, like New York and New Jersey, are in dark purple, signifying high population density.
- Most states in the west and central regions are light purple or white, indicating lower population densities.
- A legend at the bottom right uses colors ranging from white (low) to dark purple (high) to denote population density.

Observations

- Lower population density is more along the center part of the US and population density increases as one goes east. Also, population density is higher in the coastal areas.]

In the map on the left (Figure 1.1.1), the rainbow color scheme makes it easy to view the states as grouped into categories by hue, but the lack of an obvious order between the selected colors makes the overall trend unclear. A sequential color scheme (right), however, makes it easy to view the trend of the data, as low-to-high values as are encoded intuitively from light to dark.

The design decisions that go into making a map often go far beyond choosing a color scheme for a simple state-by-state choropleth map. The map below is a Russian Civil War map – flames and smoke are used as symbols of the Bolshevik uprising. This map not only communicates information; it conveys emotion.

Figure 1.1.2 Pobeda Oktiabria I ego mirovoe znachenie. Map by A. N. de-Lazari, A. N. Lesevitskii, and S. Starov. Credit: Geography and Map Division, Library of Congress.

Image description: The image is an old, detailed, and colorful map illustrating the impact and the extent of the Russian Civil War's engagements and Soviet power, with a focus on the victory of October and its global significance. The map covers the majority of Europe and parts of Asia. The background is predominantly divided into various colors indicating different regions and movements during the civil war period. The key at the bottom left corner explains the colors and symbols used.

The map is titled in Russian at the top center, with some additional text and details scattered around the map. Several arrows of varying colors and widths spread across the map, indicating movements, battles, and occupation areas. Differentiated regions are marked with varying shades, such as orange, green, blue, and red. The map also features several Soviet and national flags in various positions, providing context to the geopolitical landscape of that era.

As demonstrated by the examples above, the way in which you design a map can deeply influence how your readers interpret it. A well-designed map can intrigue and even surprise its readers, leaving a meaningful and memorable impression. Shown below is a map of projected future storm surge in New York City, designed by Penn State alum and cartographer Carolyn Fish. The map doesn't ask the reader to imagine what NYC might look like under future climate scenarios – it shows them.

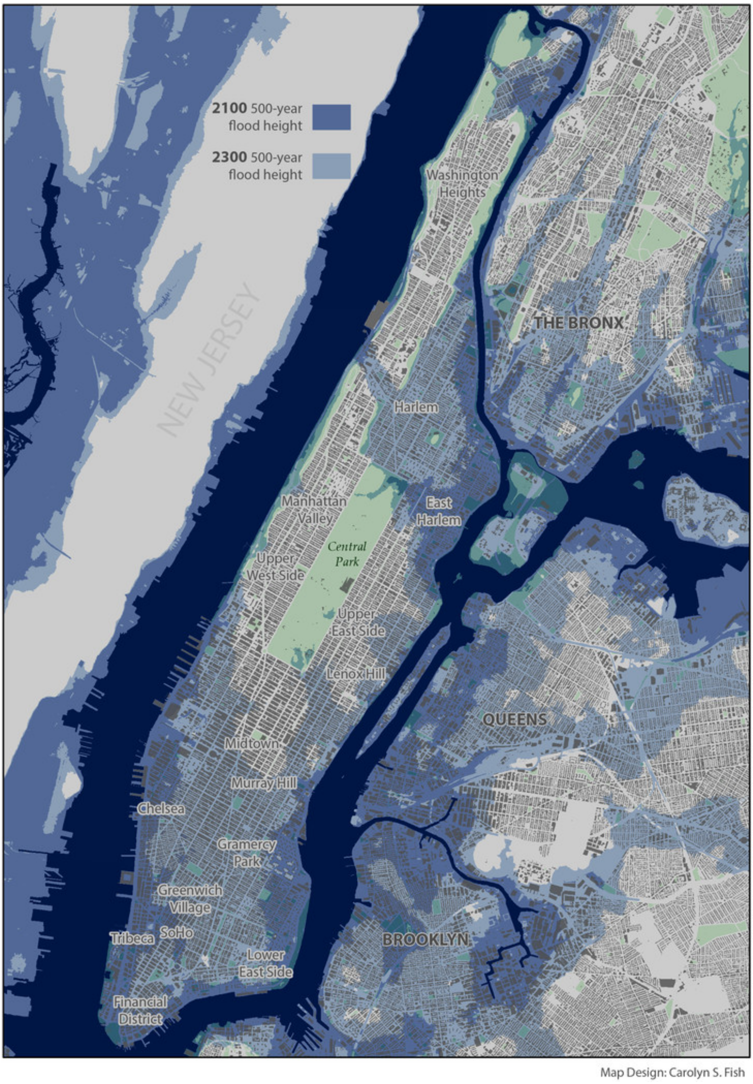


Figure 1.1.3 A map of predicted storm surge in NYC. Credit: Carolyn Fish. Permission granted by Dr. Carolyn Fish.

Image description: A detailed map showcasing future flood projections for parts of New York City and surrounding areas, including Manhattan, The Bronx, Queens, Brooklyn, and neighboring regions. In 2100, the 500-year flood height which will be reached by the year 2100 is indicated by dark blue-purple and in 2300, the 500-year flood height which will be reached by the year 2300 is indicated by a light blue-purple. The 2100 500-year flood height areas are in parts of New Jersey, and the periphery of queens, Brooklyn, the Bronx in addition to East Harlem, Lower East Side, the Financial District, Tribeca, and Chelsea. The 2300 500-year flood height areas are mostly in Brooklyn, Harlem, Midtown, Murray Hill, Gramercy Park, Greenwich Village, and SoHo.

Following cartographic conventions—such as applying sequential color schemes for sequential data—typically results in more effective maps. However, some maps diverge from these guidelines. Learning cartographic best practices will help you to both apply them—and thoughtfully disobey them—when prudent.

Student Reflection

View the maps in Figures 1.1.4 through 1.1.7 below: Do you think they are effective? Is there anything you think should have been done differently?

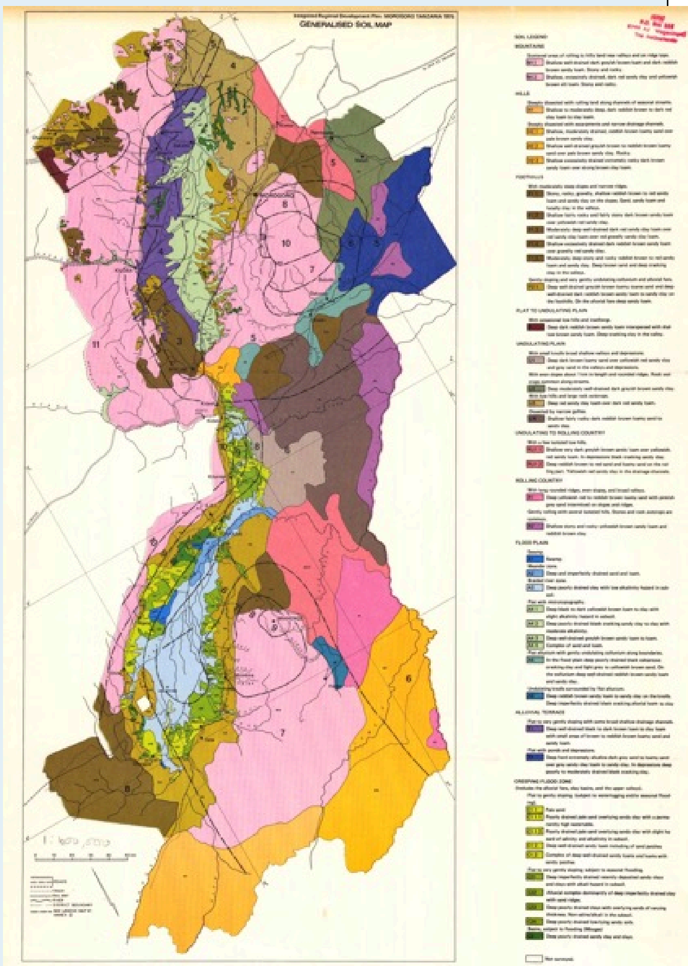


Figure 1.1.4 A Soil Map from Morogora, Tanzania, 1975. Credit: European Commission: Joint Research Centre – European Soil Data Centre (c) European Union, 1995-2018. Reuse is authorised, provided the source is acknowledged. The Commission's reuse policy is implemented by the Decision of 12 December 2011 – reuse of Commission documents.

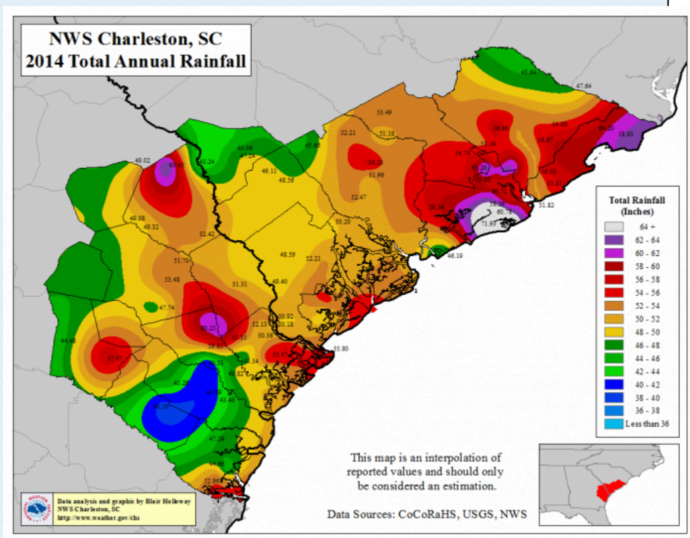


Figure 1.1.5 An annual precipitation map from the National Weather Service. Credit: NOAA.

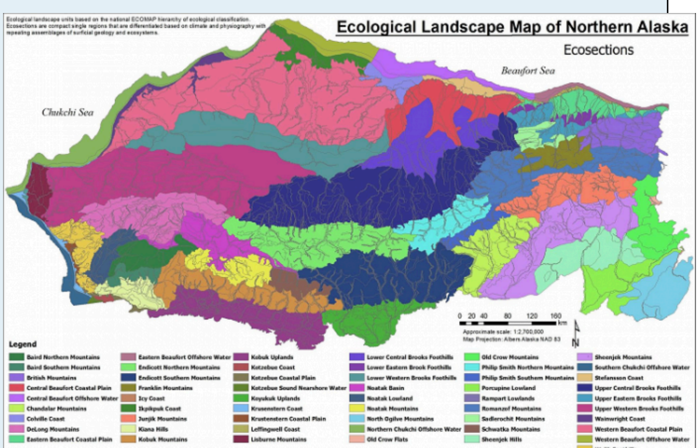


Figure 1.1.6 A Land Cover and Ecosystem Map of Northern Alaska. Credit: Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC)

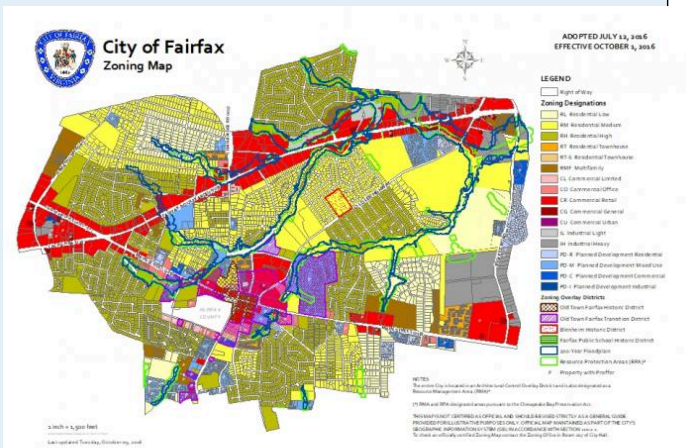


Figure 1.1.7 A zoning map from Fairfax, Virginia Credit: City of Fairfax, Virginia.

Image descriptions

Image 1.1.4: A soil map from Morogora Tanzania in which different colors indicate different soil types. The central region of the map includes various colored sections such as pink, purple, green, brown, yellow, orange, blue, and gray. These colors are used to differentiate areas that have distinct soil characteristics. The map is filled with intricate lines that likely denote boundaries and topographical elements, and small black numbers are scattered throughout the colored sections.On the right-hand side, there is a legend that lists the different soil types, each with its own description and corresponding color. This legend provides detailed explanations of the properties and distribution of the soils depicted on the map.

Image 1.1.5: A map titled “NWS Charleston, SC 2014 Total Annual Rainfall”. It shows the total annual rainfall distribution across South Carolina and its surrounding regions. The map uses various colors to represent different rainfall levels, ranging from less than 36 inches to more than 64 inches, as indicated by the legend on the right side of the map. The areas with the highest rainfall are in shades of purple and blue which are on parts of the south east coastal area, while areas with the lowest rainfall are in shades of yellow and green which are areas to the west, north and southwest. Several specific locations have rainfall data numbers printed directly on the map. In the bottom left corner, there is a small section with a label mentioning Blair Holloway, NWSCharleston, and a webpage link (http://www.weather.gov/chs). The bottom right corner features a small inset map showing the southeastern region of the United States with South Carolina highlighted in red.

Image 1.1.6: Ecological Landscape Map of Northern Alaska in which different colors indicate different ecological landscapes. On the right is the title in black bold text that says “Ecological Landscape Map of Northern Alaska” in which there is the subtitle of “Ecosections.” The most prominent ecosection is the Endicott Southern Mountain land scape which is found in the center and southern part of Northern Alaska. Other prominent ecosections are western Beaufort Coastal Plain and the Upper Western Brooks Foothills that are in the northwest part of Northern Alaska. The Western Beaufort Coastal Plain is farther north than the Western Brooks Foothills. The three least prominent ecosections are the Kiona hills, which is indicated by light green, Noutak Mountains, indicated by yellow, and Sadlerocht Mountains which indicated by a light bright green. The Kiona hills are in the far southwest, the Noutak mountains are in the southwest, and the Sadlerocht mountains are in northeast.

Image 1.1.7: The image is a zoning map of the City of Fairfax, displaying various zoning designations using vivid colors and patterns. Main and smaller roads are represented, along with water bodies like rivers indicated by blue lines. Each zoning district is represented by a different color. RH residential high, RM Residential Medium are the biggest zones which is signified by greenish yellow, and bright yellow colors respectively. The smallest zones are CO Commercial Office and PD-C Planned Development Commercial which is signified by salmon and blue colors respectively.

Types of Maps

Types of Maps

Maps are generally classified into one of three categories: (1) general purpose, (2) thematic, and (3) cartometric maps.

General Purpose Maps

General Purpose Maps are often also called basemaps or reference maps. They display natural and man-made features of general interest, and are intended for widespread public use (Dent, Torguson, and Hodler 2009).

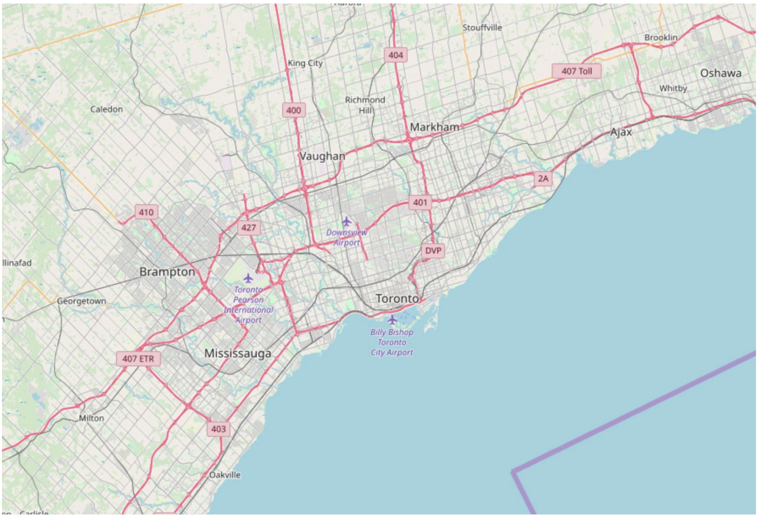


Figure 1.2.1 OpenStreetMap Basemap. Credit: OpenStreetMap © OpenStreetMap contributors. The data is available under the Open Database License (CC BY-SA).

Image description: OpenStreetMap basemap showing Toronto and the surrounding areas of Brampton, and Mississauga which is West of Toronto, Vaughaun and Markham which is north of Toronto, and Ajax and Oshawa which is west of Toronto. There are areas of green on the map which indicates park/greenspace while blue areas indicates lake/oceans. Red lines indicate main roads.

Thematic Maps

Thematic Maps are sometimes also called special purpose, single topic, or statistical maps. They highlight features, data, or concepts, and these data may be qualitative, quantitative, or both. Thematic maps can be further divided into two main categories: qualitative and quantitative. Qualitative thematic maps show the spatial extent of categorical, or nominal, data (e.g., soil type, land cover, political districts). Quantitative thematic maps, conversely, demonstrate the spatial patterns of numerical data (e.g., income, age, population).

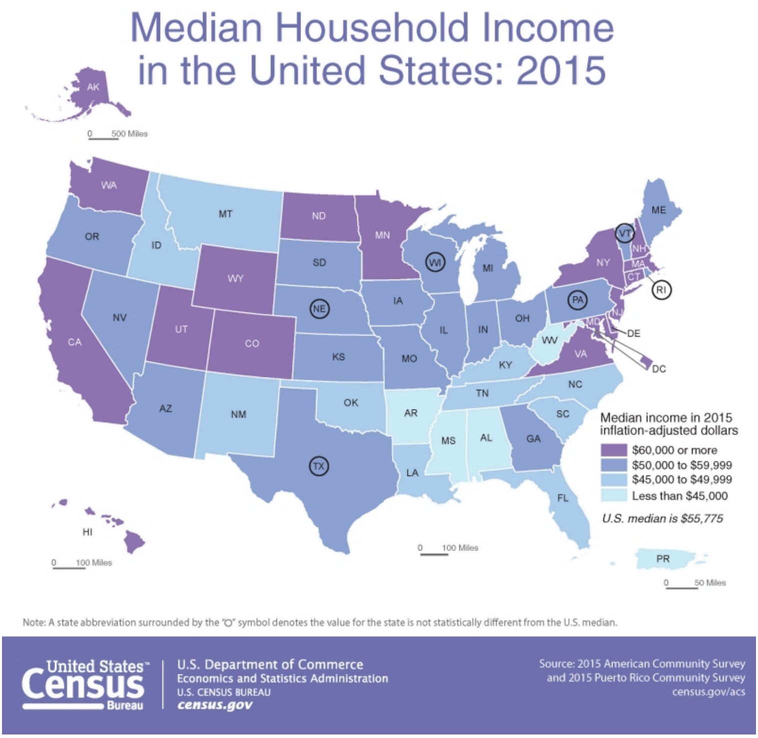


Figure 1.2.2 A Thematic Map from the US Census Bureau Credit: Census.gov

The image is a map of the United States depicting the median household income in 2015, presented in inflation-adjusted dollars. The states are color-coded based on income ranges. The map includes all 50 states, the District of Columbia (DC), and Puerto Rico (PR). A color legend is located in the bottom right corner of the map, which outlines four income categories: 60,000 or more(dark purple), 50,000 to 59,999(medium purple), 45,000 to 49,999(light blue), and less than 45,000 (lightest blue).

- States like Maryland, New Jersey, and Massachusetts are shaded in dark purple, indicating a median income of $60,000 or more.
- States such as Oregon, Indiana, and Illinois are in medium purple, indicating a median income between 50,000 and 59,999.
- States like North Carolina and Ohio are in light blue, indicating a median income between 45,000 and 49,999.
- States including Mississippi and Arkansas are in the lightest blue, indicating a median income of less than $45,000.

Alaska and Hawaii are represented in insets on the map. The U.S. median household income in 2015 is noted as $55,775. There is also a note indicating that states surrounded by an “O” symbol have values that are not statistically different from the U.S. median.

Cartometric Maps

Cartometric Maps are a more specialized type of map and are designed for making accurate measurements. Cartometrics, or cartometric analysis, refers to mathematical operations such as counting, measuring, and estimating—thus, cartometric maps are maps which are optimized for these purposes (Muehrcke, Muehrcke, and Kimerling 2001). Examples include aeronautical and nautical navigational charts—used for routing over land or sea—and USGS topographic maps, which are often used for tasks requiring accurate distance calculations, such as surveying, hiking, and resource management.

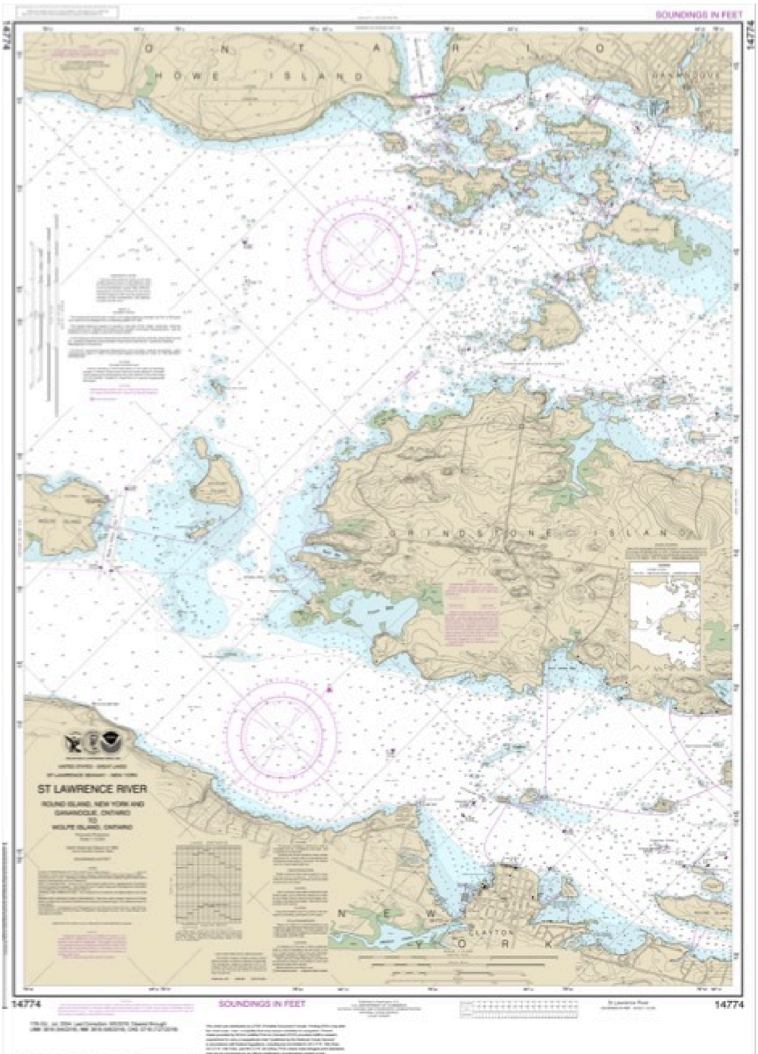


Figure 1.2.3 A Nautical Chart from NOAA Credit: NOAA

Image description: The image is a nautical chart of the St. Lawrence River, specifically the areas between Kingston, Ontario, and the Admiralty Islands. The chart is oriented in portrait mode and primarily beige with aqua blue patches representing water bodies. Brown contours and black lines indicate depth measurements. Two large circular compass roses, one located near the center and another towards the bottom left, provide directional information. A grid of longitude and latitude lines overlays the map. In the lower left corner, there is a section containing descriptive text and data. Several navigational aids, such as buoys and other markers, are shown as symbols scattered throughout the water areas. Annotations, including place names and navigational information, are printed in black.

In theory, these map categories are distinct, and it can be helpful to understand them as such. However, few maps fit cleanly into one of these categories—most maps in the real world are really hybrid general purpose/thematic maps.

Figure 1.2.4 A hybrid map of fire hazard severity zones from Orange County, CA Credit: Cal Fire from CA.gov

Image description: The image is a detailed map of Orange County with designated fire hazard severity zones as of November 7, 2007. The map encompasses coastal and inland regions, extending from the Pacific Ocean on the southwest side to the borders with Los Angeles, Riverside, and San Diego counties. Areas on the map are color-coded to represent different severities of fire hazards: red for 'Very High,' orange for 'High,' and yellow for 'Moderate.' The majority of the coastal region is marked in grey, indicating urban developments with limited fire risk. The inland areas, particularly towards the eastern part of the county, show larger red and orange zones indicating higher fire hazard areas. Major highways and roads are outlined in black, with specific routes highlighted in purple and pink. The map features several important features like the Pacific Ocean, county borders, and major road networks.

Advancements in technology and in the availability of data have resulted in the proliferation of many diverse types of maps. Some, as shown in Figure 1.2.5, are embedded into exploratory tools intended to inform researchers and policy-makers.

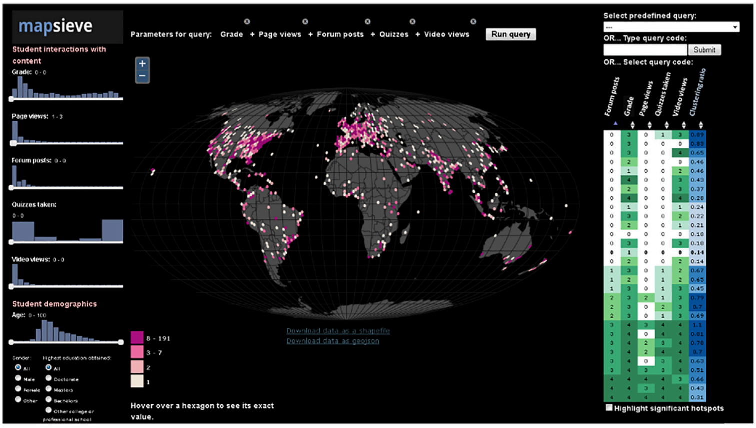


Figure 1.2.5 A Screenshot of the Geovisual Analytic tool MapSieve. Credit: Robinson, Anthony C., and Sterling D. Quinn. 2018. "A Brute Force Method for Spatially-Enhanced Multivariate Facet Analysis." Computers, Environment and Urban Systems 69 (June 2017). Elsevier: 28-38. Reproduced with permission from Dr. Anthony Robinson, Penn State University.

Image description: The image is a detailed data visualization dashboard titled "mapsieve." It features student interactions and demographics data overlaid on a map of the world. The central element is a dark spherical map with graticules displaying various points in pink and white, indicating student interaction hot spots. These points vary in color and size, with a legend at the bottom left corner explaining the interaction range: 1-2 (white), 3-7 (light pink), and 8-191 (dark pink).

On the left side of the dashboard, there are several histograms under the header "Student interactions with content." These histograms display data on different parameters including Grade, Page views, Forum posts, Quizzes taken, and Video views, all on a scale of 0 to a specific upper limit. Below these, there's another histogram graph titled "Student demographics" showing the age distribution from 0 to 100.

Various interactive control options are present at the top, labeled "Parameters for query," allowing selections such as Grade, Page views, Forum posts, Quizzes, and Video views. On the right, there's a pane for selecting predefined queries, typing or selecting query codes, and viewing a data table showing different interaction metrics (Forum posts, Grade, Page views, Quizzes taken, Video views, and Clustering ratio). The background of the dashboard is black, enhancing the contrast and clarity of the data visualizations.

Other maps are intended for a wider audience but share the goal of uncovering and visualizing interesting relationships in spatial data (Figure 1.2.6).

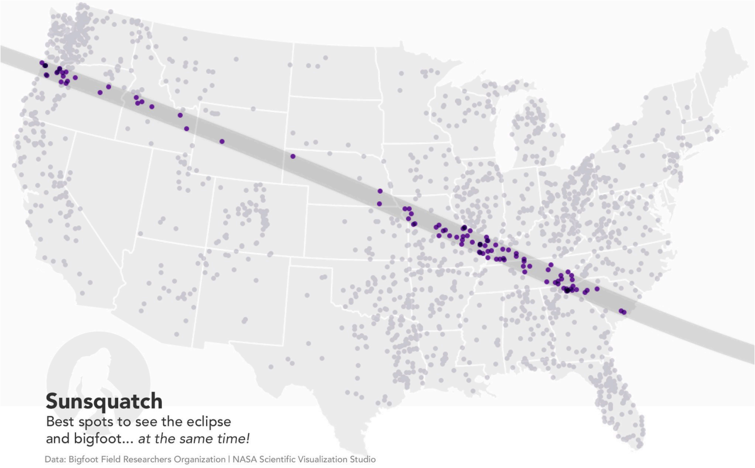


Figure 1.2.6 Places to see both bigfoot and the solar eclipse Credit: Sightings map by Joshua Stevens (JoshuaStevens.net)

Image description: A map of the US that shows places to see both bigfoot and the solar eclipse. Bigfoot sightings are indicated by grey dots outside the eclipse path and purple within the eclipse path. The eclipse path is a dark grey line and runs through Oregon, Idaho, Wyoming, Nebraska, Missouri, Tennessee, and South Carolina. On the bottom-left is an image of a bigfoot in which the bigfoot is white and there is a grey circle background. Black text is on the image which is "Sunsquatch best spots to see the eclipse and bigfoot…at the same time!". Below this text is smaller text that says "Data: Bigfoot Field Researchers Organizations | NASA Scientific Visualization Studio."

Maps also are not limited to depicting outdoor landscapes. Some maps, such as the one in Figure 1.2.7, are designed to help people navigate complicated indoor spaces, such as malls, airports, hotels, and hospitals.

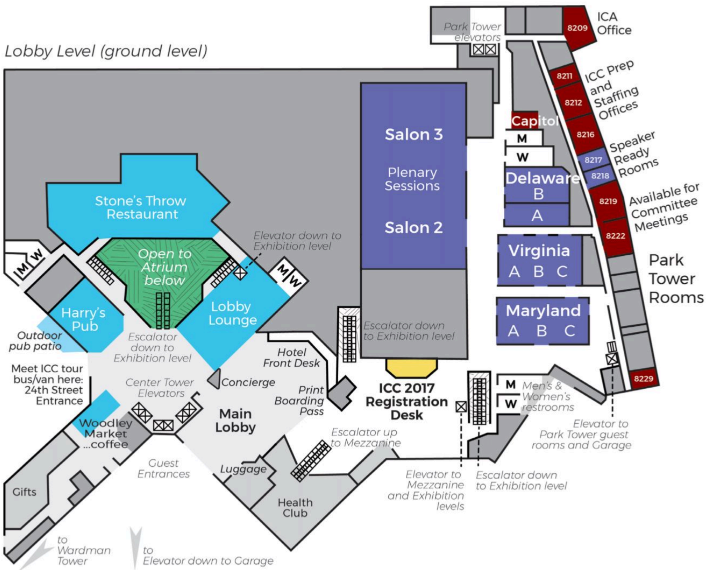


Figure 1.2.7 Indoor map of the Washington DC Marriott from the 2017 International Cartographic Conference Credit: Cary Anderson and Cindy Brewer. In-hotel walk throughs and detailed floor plans at www.marriott.com.

Image description: Indoor map of the Washington DC Marriott Lobby level from the 2017

International Cartographic Conference. The title of the map is “Lobby Level (ground level)” which is in grey and italic text. Restaurants are indicated in blue with white text such as “Stone’s Throw Restaurant, “Harry’s Pub,” “Lobby Lounge,” and “Woodley Market Coffee” which are on the west side of the Lobby level. Amentities and facilities such as “Gifts,” “Luggage,” and “Health Club” are indicated in light grey with black text and located in the southwest part of the lobby. The main lobby, hotel front desk, print boarding pass, concierge, escalator down to the exhibition level, and Center Tower elevators are on the west side of the floor. Session halls are indicated by purple with white bold text for the room names. “Salon 3” and “Salon 2” is in the center of the floor and will hold the plenary sessions which is indicated by “Plenary Sessions” in white text that is not bold. On the east side of the floor are the “Delaware B, A, Virginia A, B, C, and Maryland A, B, and C” rooms. On the far east are rooms that are indicated in maroon and in black text which are administrative rooms. These rooms are “ICA Office, ICC Prep” and “Staffing Offices.” There are also two rooms that are available for Committee meetings.

For a map to be useful, it is not always necessary that they realistically portray the geography they represent. This map of the public transit system in Boston, MA (Figure 1.2.8) drastically simplifies the geography of the area to create a map that is more useful for travelers than it would be if it were entirely spatially accurate.

Figure 1.2.8 A Public Transportation Map from Boston, M.A. Credit: Boston MBTA.

Image description: The image is a detailed schematic map of the rapid transit and key bus routes of the Boston metropolitan area. The map uses several colors to distinguish between different lines: Red, Blue, Orange, Green, Silver, and Purple, along with a dotted line representing key bus routes. The map is overlaid on a light background and includes waterways and other significant landmarks. Key transit stations are highlighted with specific symbols indicating types of services available, such as accessibility and transfer points to commuter rail or buses. Each transit line terminates at distinct locations, with terminal stations marked clearly.

The top left corner of the map contains the MBTA logo and the text "Rapid Transit and Key Bus Routes." Major lines include the Red Line ending at Alewife and Braintree, the Blue Line from Wonderland to Bowdoin, the Orange Line from Oak Grove to Forest Hills, and the Green Line with branches ending at Boston College, Cleveland Circle, Riverside, and Heath Street. The map also includes a legend explaining symbols and notes on how to use the system.

Maps that show general spatial relationships but not geography are often called diagrammatic maps, or **spatializations**. Spatializations are often significantly more abstract than public transit maps; the term refers to any visualization in which abstract information is converted into a visual-spatial framework (Slocum et al 2009).

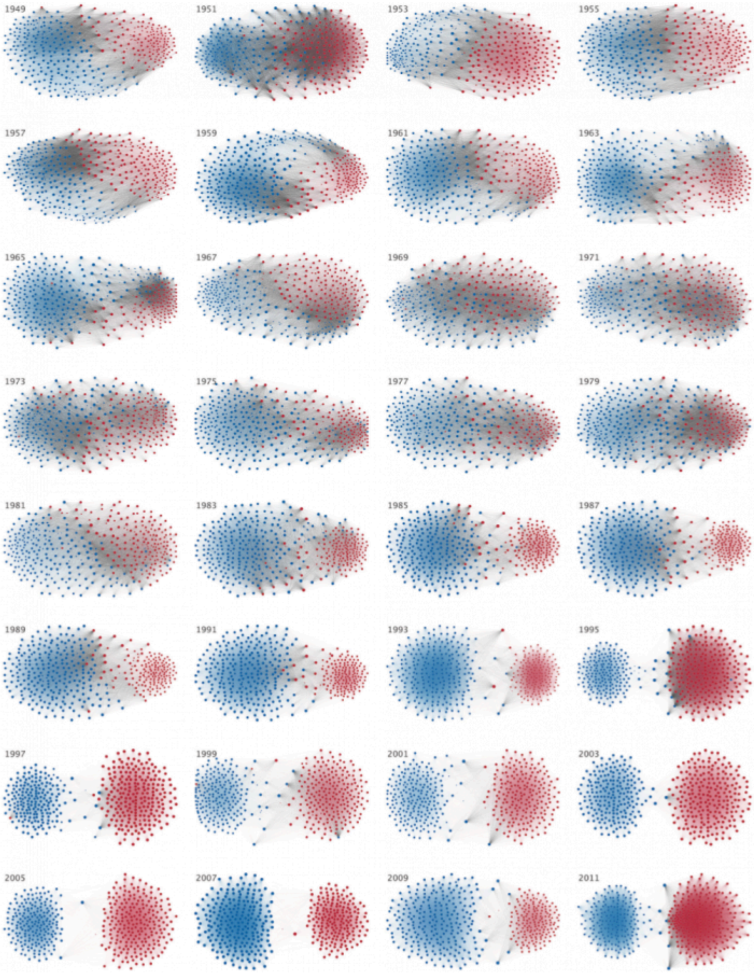


Figure 1.2.9 A spatialization by Andris et al., (2015) that demonstrates the increasing polarization between members of the US House of Representatives. Each dot represents a member of a congress (blue for democrat, red for republican); connections represent vote-based agreement above a threshold determined by the authors. For more details, see (Andris et al. 2015). Credit: Andris, Clio, David Lee, Marcus J. Hamilton, Mauro Martino, Christian E. Gunning, and John Armistead Selden. 2015. "The Rise of Partisanship and Super-Cooperators in the U.S. House of Representatives." PLoS ONE 10 (4). doi:10.1371/

Image description: The image consists of a 9×6 grid showing 54 individual network diagrams which represents the increasing polarization between members of the U.S. House of Representatives between 1949 and 2011 with nodes in blue and red.. Each diagram is a representation of a network made up of blue and red nodes connected by thin, curved lines, indicating edges. The network shapes change over time as the diagrams are labeled chronologically in sequence, starting from 1949 in the top-left corner and ending with 2011 in the bottom-right corner. The colors blue and red seem to indicate different categories or groups, with varying degrees of mixing and separation across different years. In many diagrams, there is a noticeable transition or shift in the spatial arrangement of the nodes.

Though there are many different types of maps, they share the goal of demonstrating complex spatial information in a clear and useful way. Rather than attempt to place maps into discrete categories, it is generally more productive to see them as individual entities designed to suit a particular audience, medium, and purpose. We will discuss this more in the next section.

Communicating with Maps

Communicating with Maps

Though you won't need to understand the biology of the human brain and visual system, making great maps requires understanding how people perceive visual information. When discussing how people interpret maps, we can frame this discussion in terms of perception, cognition, and behavior.

Perception in map design refers to the reader's immediate response to map symbology (e.g., instant recognition that symbols are different hues) (Slocum et al. 2009).

Cognition occurs when map readers incorporate that perception into conscious thought, and thus combine it with their own knowledge (Slocum et al. 2009). For example, readers might be able to interpret a weather radar map without its legend due to their previous experience with a similar map, or might incorporate knowledge of a map's topic into their interpretation of a visual data distribution (e.g., the higher concentration of people aged 65+ shown in some Florida cities makes sense given what I know about retirement communities).

Behavior refers to actions that go beyond just thinking about maps. Considering how design may influence behavior is essential in anticipating the real-world effects your maps may have. The way a map is designed can influence its readers' actions and decision-making, and these decisions may range from small (e.g., for how many seconds will the reader look at this map?) to great (e.g., will this flood-risk map convince the reader to purchase insurance?).

Figure 1.3.1 From perception to cognition and behavior Credit: Cary Anderson, Penn State Geography

Image description: A simple, symbolic representation of showing the process from perception to cognition. There are three main elements in a horizontal sequence:

1. On the left, there is a black icon of an eye, symbolizing vision.
2. In the center, there is a black icon of a human head in profile. Inside the head is a white brain with black lines representing neural connections, symbolizing cognition or thought processing.
3. On the right, there is a black icon of a walking human figure, symbolizing movement or action.

Connecting these three icons are two straight gray arrows pointing from the eye to the head and then from the head to the walking human figure, indicating the flow of the process from seeing to thinking and then to acting.

Another useful way to think about map communication is with the cartography-cubed model (MacEachren 1994). The model MacEachren (1994) proposed focuses on how different maps and visualizations are used. Within this framework, any map can be located within the cube by determining its location along three dimensions: (1) from public to private (with regards to the map audience), (2) from presenting knowns to revealing unknowns (e.g., is the map for displaying known information or for exploration?), and (3) from low to high interaction (e.g., a static map vs. an exploratory interactive mapping tool).

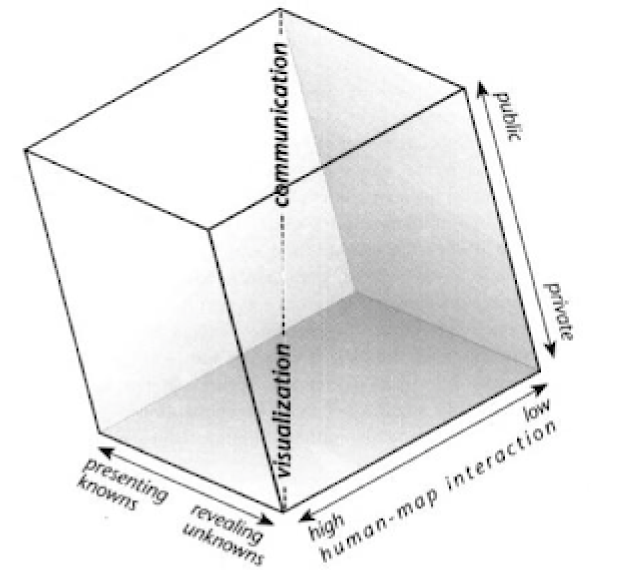


Figure 1.3.2 (Cartography)^3 Credit: MacEachren and Taylor, 1994

Image description:

The image is a black-and-white, three-dimensional cube diagram. The cube is oriented to show its top, front, and side faces. Each axis of the cube represents different variables.

- The vertical axis, labeled "communication," spans from the bottom to the top of the cube.
- The horizontal axis pointing towards the right is labeled "human-map

interaction," ranging from "low" at the near end to "high" at the far end.

- The horizontal axis pointing leftward and downward is labeled "visualization," going from "revealing unknowns" on the far right to "presenting knowns" on the near left.

The right side of the cube is labeled "public" on the top edge and "private" on the bottom edge, corresponding to the human-map interaction axis. The cube's left face is shaded, creating a sense of depth and dimension.

These dimensions are often correlated, hence the shown corner-to-corner continuum from visualization to communication. A printed map in a magazine article, for example, we could classify as a tool for communication, while an exploratory mapping tool designed for epidemiologists would be better described as (geo)visualization.

Student Reflection

Return to the previous section (Types of Maps). Where would you place each of the maps shown within the cartography cube?

Before you Map: Audience, Medium, and Purpose

Before you Map: Audience, Medium, and Purpose

There is no inherently good map—only a map that is well-designed and properly suited to its audience, medium, and purpose. Before creating a map, you should ask yourself (and if possible, your clients) several questions (Brewer 2015).

Audience—who is going to use this map?

- Will your map readers be novices or experts? Do they have advanced knowledge related to the data you intend to map? You would create, for example, a different map of crime hotspots for criminologists than for the public.
- Are your intended map readers knowledgeable about the area to be mapped? Those unfamiliar with a location might need more detail to understand its geographic context.
- How much time will a typical reader spend with your map? Some audiences will be happy to explore and analyze your map, while others may hope to understand the message of your map at a glance.

- Is your map accessible? Consider how colorblindness or low vision might affect your readers' interpretation of your map.

Figure 1.4.1 Two similar maps of city water utilities appropriate for different audiences. The map on the left includes additional symbols that are useful only to experts. The map on the right would be more suitable for a busy audience, or non-experts. Credit: BeavertonOregon.gov

Image description:Two side-by-side maps displaying a residential neighborhood. The maps are nearly identical, depicting streets, houses, and infrastructure lines in different colors.Each map shows a layout of streets, including "SW Cresmoor Dr," "SW Alpine Dr," "SW Blakeney St," and "SW Mesa Ct." Residential properties are marked with house numbers such as 7250, 7270, 7290, etc. Infrastructure lines in blue and red, along with various symbols, are overlaid across the maps.

Details:

- **Streets:** The main streets shown are “SW Cresmoor Dr,” “SW Alpine Dr,” “SW Blakeney St,” and “SW Mesa Ct.”
- **Residential Properties:** Houses are marked in light grey with numbers (e.g., 7250, 7270, 7290, etc.).
- **Infrastructure Lines:**
    - Blue lines represent one type of infrastructure on both maps, typically water or sewer lines.
    - The left map includes additional red lines, possibly indicating a different type of infrastructure like electrical or gas lines, which are absent in the right map.
    - Various symbols are used to mark utility points, such as small yellow squares with labels.
    - “8′ PVC” and “12′ PVC” are noted along a

segment on the bottom left of the left map.

Medium—how will this map be displayed?

- Maps are viewed in a vast number of formats—in desktop browsers, on mobile phone screens, in brightly-lit rooms on large-screen projectors, as well as printed in magazines, brochures, newspapers, posters, etc.
- In addition to the broad media category (e.g., mobile phone browser vs. poster), predict the specifics of your map's final viewing format as much as possible—details such as the map's size on a webpage or a reader's viewing distance from a poster can make a big difference in both a map's utility and aesthetics.
- If your map will be viewed in multiple media formats, you will likely have to create multiple versions of your map, each optimized for its respective display medium.

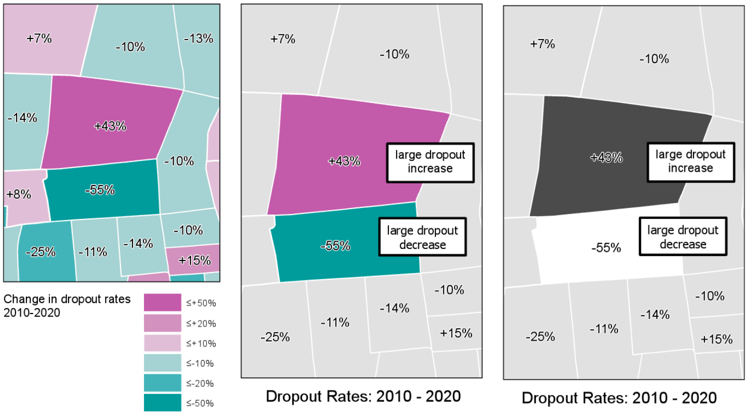


Figure 1.4.2 Three maps of the same data suited to different display mediums. (Left) This map is detailed and suitable for high-quality display media. (Middle) This map is simplified for lower-quality displays or when viewed from farther away. (Right) This map—rather than just being a black-and-white copy of another map—has been optimized for greyscale reproduction. Credit: Cary Anderson, Penn State University; boundary data source US Census, thematic data invented.

Image description:

Three maps representing changes in dropout rates from 2010 to 2020 in various regions. Each map shows regions colored differently to represent different ranges of dropout rate changes, with specific percentage values marked on them.

- **Left Map:** This colored map displays changes in dropout rates with a range of colors. Dark pink regions indicate increases greater than 50%, medium pink for increases up to 20%, light pink for increases up to 10%, light blue for decreases up to 10%, medium blue for decreases up to 20%, and dark blue for decreases greater than 50%. Specific values are marked on the regions, such as +7%, -10%, -13%, +43%, -55%, +8%, -25%, -11%, -14%, +15%.

- **Middle Map:** Similar to the left map, this map uses identical colors for the same ranges, and additionally labels regions experiencing notable changes. One region marked "+43%" is labeled "large dropout increase" in black-bordered white text, and another "-55%" is labeled "large dropout decrease".
- **Right Map:** Using grayscale, this map simplifies the display, with dark gray indicating a "large dropout increase" marking +43%, and white for a "large dropout decrease" marking -55%. This map features the same regions and percentages as the previous two but focuses on highlighting areas with significant changes.

Purpose—what is the intended function of your map?

- Maps are used for many purposes (e.g., for navigation, for understanding spatial trends in data, for site selection, for communicating the results of a research project, etc.) Different purposes necessitate different maps.
- When making design decisions, consider how they will influence the success of your users in completing their expected map-use tasks. Maps for driving navigation, for example, are generally more useful when detailed terrain data is excluded, creating a simpler interface. In a hiking map, however, such information is essential.
- Considering in what scenarios a map will be used is also important—users of maps for emergency response, for example, will likely be stressed and working under inflexible time constraints.

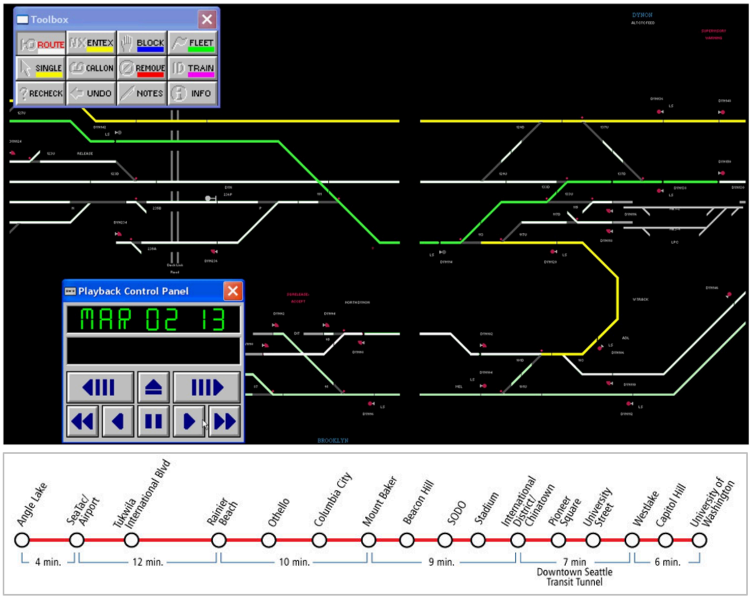


Figure 1.4.3 Two maps of trains designed for different purposes. The top map is specifically designed to be used in a train control center. The bottom map is designed for transit passengers – it is much simpler and only describes what passengers need to know. Note that while these maps do not depict the same location, they demonstrate how different symbol designs are more or less appropriate for different map use tasks. Credit: Australian Government Transport Safety Bureau; Seattle.gov.

Image description:

A graphical interface of a railway signaling system with a focus on train routes and signal control. The main portion is a network map with colored lines representing different train tracks, displayed predominantly in yellow, green, and white against a black background. Several intersecting lines and junctions are marked by text labels and small symbols. Adjacent to the network map is a “Toolbox” panel, showing various command buttons (e.g., ROUTE, BLOCK, TRAIN) with associated symbols, and a Playback Control Panel showing “MAR 02 13” with playback buttons. Below the network map, a simplified timeline depicts the train stations for a transit line, marking stops from Angel Lake to the University of Washington with time intervals between them and indicating the Downtown Seattle Transit Tunnel.

In this course and beyond, you will make many different kinds of maps. Some will be advertisements, some will be scientific documents – some may be just for fun. No matter the mapping project or process you use, pausing to reflect upon the *who*, *what*, and *why* of your map will always lead to better results.

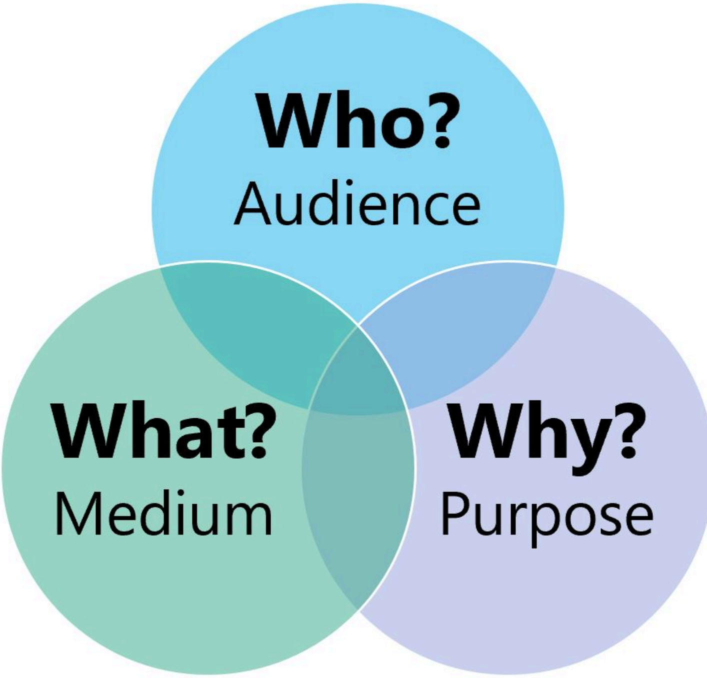


Figure 1.4.4 Considering the who, what, and why of a mapping project. Credit: Cary Anderson, Penn State University.

Image description: A Venn diagram with three overlapping circles, each a different shade of blue and green. The circles are labeled with texts, each representing a different element of consideration: “Who?”, “What?”, and “Why?”. The top circle is a light blue color and contains the word “Who?” in bold black text, with “Audience” in regular black text underneath. The left circle is teal-colored and contains the word “What?” in bold black text, with “Medium” in regular black text underneath. The right circle is a light blue-violet color and contains the word “Why?” in bold black text, with “Purpose” in regular black text underneath. The circles overlap in the center, creating a small central area showing the intersection of all three circles.

Student Reflection

Consider a mobile or desktop mapping application that you use frequently, such as Google Maps. What changes might you make to this mapping tool if a client asked you to alter it for a different, singular purpose—for example, as a wayfinding tool for young children, or for assisting police during emergency response?

Basemaps: Leveraging Location

Basemaps: Leveraging Location

Basemaps are essential – they provide the context for your map data. Selecting a basemap should never be just an afterthought, and though the final choice is always subjective, you can make a better decision by considering your map purpose, audience, and the nature of your overlay data.

Street Maps

Often the default basemap used in business web-mapping applications. Helpful when highly-detailed locational context is necessary (particularly for navigation). Though pre-designed street basemaps may not have the ideal aesthetic for overlaying complex data, they are particularly useful at large scales (at which they appear less visually cluttered) or when overlaying relatively simple social data (e.g., for a map showing all locations of a restaurant chain).

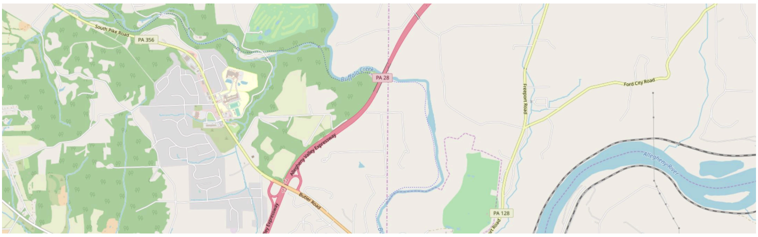


Figure 1.5.1 The OpenStreetMap basemap Credit: OpenStreetMap © OpenStreetMap contributors. The data is available under the Open Database License (CC BY-SA).

Image description: The image is a map that depicts a geographical area with a mix of residential, natural, and transportation features. The left and lower left sections of the map show a region dominated by large green areas, indicating forests or parks, interspersed with lighter, irregularly shaped patches representing cleared land or water bodies.

Near the center, there are clusters of grey and white lines, representing a dense network of smaller streets within a residential or urban area. This cluster is bordered by green areas.

Prominent roads are highlighted, such as PA 356 running horizontally near the top, and PA 28, a prominent red road running vertically, intersecting with PA 356. Butler Road and the Allegheny Valley Expressway (also marked PA 28) are in yellow and continue southward. The latter connects with a major interchange indicated by loops and curves.

To the far right of the map, there is another stretch of highlighted road, extending diagonally, labeled Ford City Road, and another smaller route labeled Freeport Road. The map also shows a large blue river, the Allegheny River, flowing horizontally from left to right near the bottom right. The river twists and turns, showing its natural, meandering course. The background color of the map is predominantly beige.

Satellite Imagery

Often useful for environmental or engineering applications. May be useful in rural areas that cannot be well-understood using street maps (as few streets exist). The colors and detail make overlay data much more challenging to design than over subtle basemaps – satellite basemaps work best when GIS data is structured and simple and understanding the physical structure of the landscape is essential to the mapping function (e.g., for a map of local water pipelines).

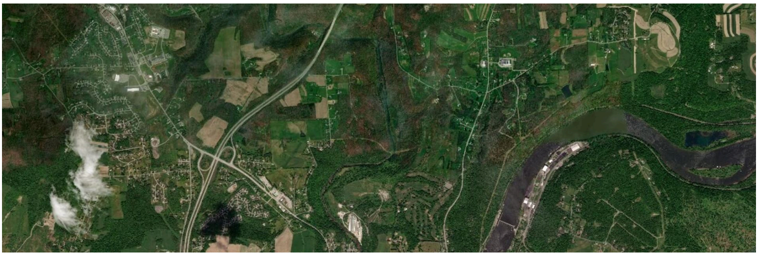


Figure 1.5.2 An imagery basemap Credit: Screen capture from ArcGIS Pro

Image description: The image is an aerial satellite view of a landscape characterized by a mix of residential areas, roads, farmland, a river, and forested regions. In the upper-left quadrant, there are clusters of houses arranged along winding roads, with some straight sections creating blocks. Moving towards the center, there is a prominent intersection of two major highways, forming a cloverleaf interchange. To the right of the interchange, the landscape primarily consists of agricultural fields with visible plots of land in various shades of green and brown. The bottom part of the image shows sections of dense forests and scattered patches of farmland. The right side of the image features a wide, winding river passing through the landscape, with some buildings situated along its banks. A mix of vegetation, developed areas, and water bodies dominates the overall scene.

Greyscale Basemaps

Usually reserved for thematic mapping, greyscale basemaps are helpful when the intended audience already knows the location context, or when significant detail is not important to fulfill the map's purpose. The simple backdrop adds visual emphasis to your overlay data – especially important for maps produced for entertainment or maps whose primary focus is statistical data (e.g., statistical mortality maps). Choose a light or dark background based on the content and mood of your map, and design overlay data accordingly.

Figure 1.5.3 Light gray (left) and dark gray (right) canvas basemaps Credit: Screen capture from ArcGIS Pro

Image description: The image is a side-by-side comparison of two maps, each occupying half of the frame horizontally. The left map features a light gray background with white lines denoting roads and faint, gray shapes indicating bodies of water. The right map has a dark gray background with lighter gray and white lines representing roads and black shapes indicating similar geographic features as the left map. Both maps include a variety of intersecting and curved lines representing a network of roads and infrastructure in the depicted areas, but with notable contrast differences between the two maps.

Terrain Basemaps

Terrain basemaps are particularly useful when the terrain of the landscape has an important relationship with the data being mapped (e.g., mapping wildfires; hiking maps). Shaded relief also adds visual interest and, when done well, creates a beautiful map. Just be sure to not let the basemap content overwhelm your own data.

Figure 1.5.4 A labeled terrain basemap Credit: Screen capture from ArcGIS Pro

Image description: A terrain basemap section showing a terrain characterized by multiple river systems and mountainous ridges. The rivers are marked with blue lines and labeled with names. Red lines demarcate certain borders or boundaries. The map features varying shades of gray to represent elevation changes and the contours of the mountain ranges. The rivers identified include “Rio Grande,” “Rio Conchos,” “Rio San Fernando,” “Rio Tamesi,” “Rio Soto la Marina,” “Rio de las Palmas,” “Rio Pánuco,” and “Rio Trinidad.” The rivers flow through a rugged landscape with marked elevation that is visualized through densely packed contour lines and color gradations.

A comparison of several example basemaps at the same location in Chicago are shown below in Figure 1.5.5. As shown, different basemaps can have vastly different overall looks, as well as differing levels of detail (LOD).

Figure 1.5.5 A comparative view of several basemaps available in ArcGIS Pro: Open Street Map (left), Light Grey Canvas (middle), and Imagery with labels (right) Credit: Screen capture from ArcGIS Pro

Image description: The image is divided into three vertical panels. The left panel is a detailed map showing streets, buildings, and landmarks with a variety of colors and labels. The center panel is a grey-scale map depicting streets and areas but with much less detail and no labels. The right panel is a satellite image showing a bird's-eye view of an urban area with buildings, streets, and a waterway.

When making a map, your basemap sets the tone – everything else builds from this important beginning.

Student Reflection

There are many more options for basemaps than the defaults available in ArcGIS Pro, though they are a great place to start. Have you used any mapping applications that you felt had an exceptionally-designed basemap?

Check out some more creative, exciting basemaps in the Mapbox Gallery!
There are many creative possibilities – visit Mapbox's selection of Designer Maps.

Base Data: Building a Map

Base Data: Building a Map

Though many pre-designed options exist, and can be selected as described above, the best reference map for a specific task is often the one you make yourself. When downloading base data for a map, you should consider the following data layers, of which you might need a few or many. This is not an exhaustive list of available base data content, but will help you start thinking about the kinds of data you may need.

Terrain Data

A good basemap will often include data that shows the shape of the physical landscape. All terrain layers are typically derived from a digital elevation model (DEM), which is a grid-based (raster) data layer that contains elevation layers.

Elevation can be mapped in several different ways; a common method is hypsometric tinting (hypso) or coloring based on elevation values, shown in Figure 1.6.1.

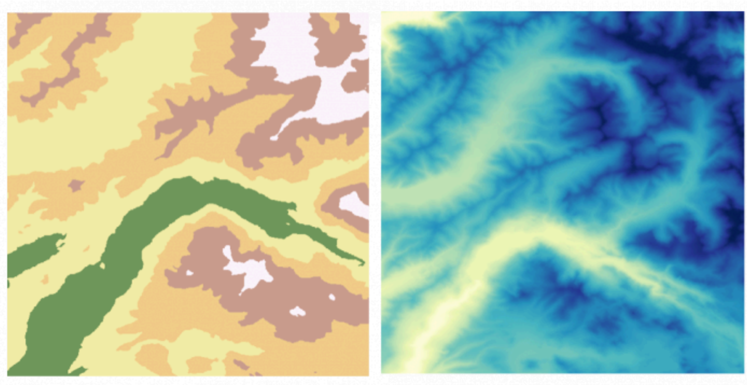


Figure 1.6.1 Hypsometric tints Credit: Cary Anderson, Penn State University, Data Source: The National Map.

Image description: The image consists of two adjacent square maps side by side in which one shows vectorized terrain and the other depicts terrain though color applied to a raster. Each map appears to illustrate geographical data using colors, potentially representing elevations or other topographical elements.

- **Left Map**: This map uses a variety of colors including beige, light yellow, pink, green, brown, and white. The colors form irregular, organic shapes that are contiguous and cover the entire area of the map. The green sections appear as elongated, meandering forms that suggest valleys or lower elevations. Surrounding these green sections are lighter colors, with beige and light yellow taking prominent roles, potentially indicating mid-level elevations. Pink and brown are scattered near the top and central regions, while white patches are dispersed, mainly towards the right side of the map.

- **Right Map**: This map is dominated by cooler colors, transitioning from light to dark shades of blue, green, and hints of yellow and white. The blue colors form complex, vein-like patterns, possibly indicating river systems or lower terrains. Lighter shades, with hints of yellow and white, create a network of lines mimicking geological folds or ridges, suggesting elevated areas.

Contour lines are often used to show more detail about the shape of the landscape, either alone or combined with hypsometric tinting, as shown below.

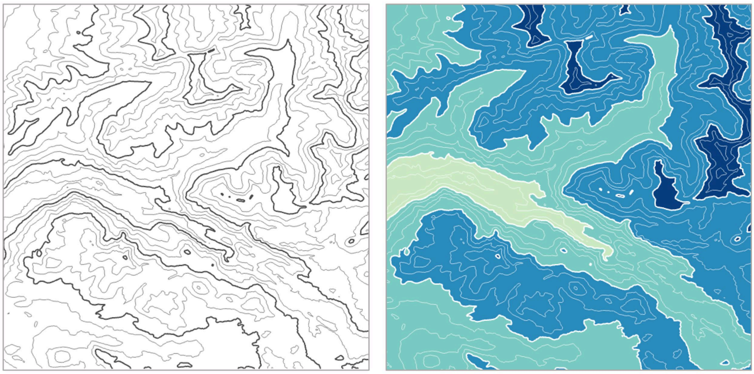


Figure 1.6.2 Contour lines (left), Contour lines with hypso (right) Credit: Cary Anderson, Penn State University, Data Source: The National Map

Image description: The image is divided into two vertical panels. The left panel features a topographic map with black contour lines on a white background, showing various elevations and the intricate patterns of the terrain. The contour lines are densely packed in certain areas, indicating steep gradients, while in other areas, the lines are more spaced out, suggesting flatter terrain.

The right panel displays a similar topographic map but in color. The contour lines are white against a gradient of colors ranging from dark blue to light green. The darker blue areas represent lower elevations, while the lighter green areas signify higher elevations. The color transitions provide a clear visual representation of the terrain's elevation changes.

Other layers such as hillshade and curvature are often added for additional visual detail.

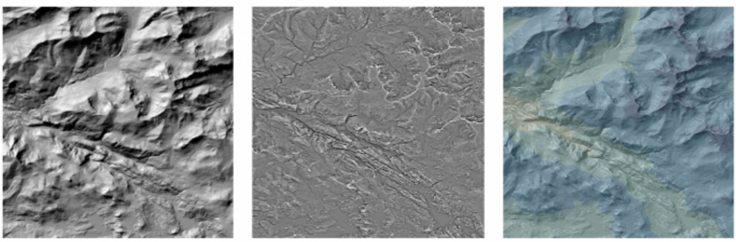


Figure 1.6.3 Hillshade (left), Curvature (middle), Hillshade with curvature and hypso (right) Credit: Cary Anderson, Penn State University, Data Source: The National Map

Image description: The image consists of three side-by-side panels, each showing a different representation of a topographical map.

- The left panel is a grayscale hillshade representation, displaying a high-contrast relief with sharp elevations and depictions of mountain ranges or rugged terrain.
- The center panel is a combination

of hillshade with curvature using shades of grey, exhibiting detailed textures of the landscape with less contrast but highlighting intricate drainages and terrain features.

- The right panel is a colored relief map, incorporating shades of blue, green, and yellow to represent varying elevations and terrain formations. The colors gradually transition, providing a more detailed visual differentiation of elevation changes.

Orthoimages, or images of the earth's surface that have been properly transformed for mapping purposes, can also be used alone or combined with terrain layers. We'll talk more about terrain visualization later in the course.

Figure 1.6.4 An aerial image from California (left), an aerial image with a transparent hillshade from a similar location (right) Credit: Cary Anderson, Penn State University, Data Source: The National Map

Image description: The image consists of two satellite views of different terrains, positioned side-by-side. The left side of the image depicts a forested landscape with varying shades of green indicating dense vegetation and several patchy lighter areas suggesting either less dense tree coverage or open land. A body of water is visible in the lower part of this section, displaying a dark blue hue.

On the right side of the image, the terrain is more rugged and mountainous, with steep rocky formations and ridges. The predominant colors are grays and browns, indicating rocky surfaces with minimal vegetation. There are also shadows present in the crevices which accentuate the rugged nature of the terrain. A couple of small, narrow water bodies are interspersed within the mountainous areas, appearing in a subdued blue color.

Cultural Data

Political boundaries are often important components of basemap design. Commonly-mapped boundaries include international borders, state or province boundaries, incorporated places, smaller census units such as tracts and blocks, and boundaries of Native American reservations, among others. Place names are used to add additional locational context.

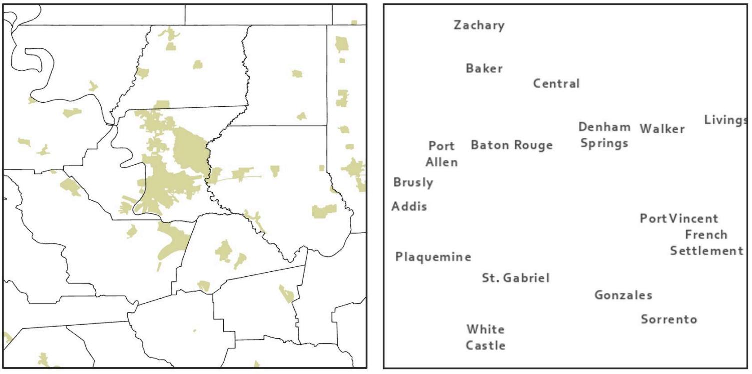


Figure 1.6.5 Counties and incorporated places (left) and place names (right) near Baton Rouge, LA Credit: Cary Anderson, Penn State University, Data Source: The National Map.

Image description: The image consists of two main parts. The left section is a map that outlines several regions with highlighted areas in light green, while the right section is a list of names corresponding to various locations on the map.

- **Left Section (Map):** This section depicts a geographical area divided into several regions. Some regions are shaded in light green, indicating particular areas of interest. The map has a simple outline with minimal details, primarily focused on highlighting the light green regions across the map.
- **Right Section (List of Names):** This section lists several location names, each spaced out and scattered across the white background. The names are written in black text of uniform size. The list is organized loosely to match the geographical positioning on the map.

Additional Data

Other layers that can be useful as base data include zoning and land use data. These data are often available in vector form from local GIS organizations. Land cover and impervious surface data, among other layers, are available in raster form from the National Land Cover Database (NLCD).

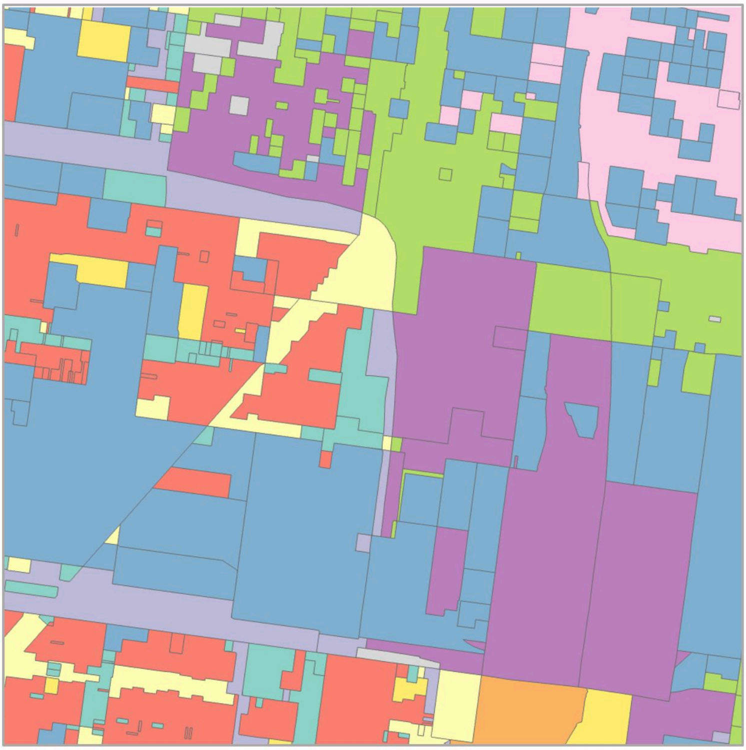


Figure 1.6.6 A map of zoning data from Chicago, IL Credit: Cary Anderson, Penn State University, Data Source: City of Chicago.

Image description: The image is a color-coded map consisting of various rectangular and irregular polygons with different colors. The map is divided into many sections, each represented by a distinct color including blue, red, green, yellow, purple, and pink. The map's color scheme appears to distinguish between different areas or types of regions, though there are no labels or legends to specify the exact meaning of the colors. The shapes are interconnected, touching each other along their borders, creating a patchwork effect. There are some larger contiguous areas of the same color, while other sections consist of smaller, more fragmented shapes. A diagonal path cuts through the middle of the image, bordered by different colored sections.

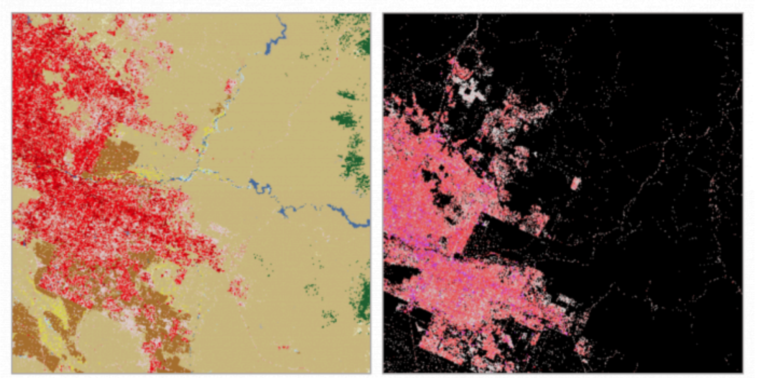


Figure 1.6.7 Maps of Land Cover (left), and Percent Impervious Surface (right), both from the National Land Cover Database(link is external). Credit: Cary Anderson, Penn State University, Data Source: The National Map.

Image description: The image is divided into two parts, presented side-by-side in a comparative format.

Left Side:

On the left side, the image showcases a color-coded map with various hues depicting different areas. The largest portion of the map on the left is a beige color, representing a central feature. Pockets of bright red and green dots are dispersed throughout, indicating different zones. Light blue lines run across the beige areas, representing rivers or streams. The red areas are densely concentrated in some regions indicating urban or highly populated zones. Smaller patches of green, brown, and light pink are distributed sporadically across the entire map.

Right Side:

The right side of the image portrays a contrasting view, possibly utilizing a different imaging technique or filter. The background is predominantly black with bright pink and white dots dispersed throughout. The pink areas appear dense and are scattered similarly to the bright red zones on the left map. Small, dispersed white dots are visible within the pink clusters, and the overlay creates a stark contrast against the dark background.

Hydrography can also play an important role in a basemap. Data used may include streams, rivers, lakes, swamps, marshes, and wetlands, among other water features.

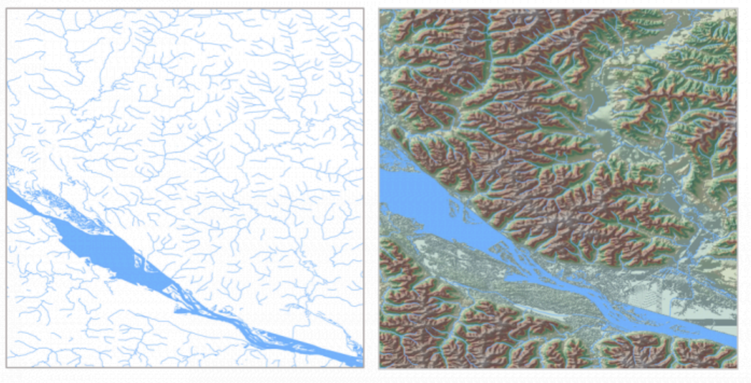


Figure 1.6.8 Flowlines and waterbodies from the National Hydrography Dataset (left), and this hydrography data combined with terrain (right) Credit: Cary Anderson, Penn State University, Data Source: The National Map.

Image description: The image consists of two side-by-side maps. The left map is a simplified, line-based representation of waterways, showing rivers and streams in varying thicknesses of blue lines against a white background. A thicker, prominent river runs diagonally from the top left to the bottom center. Several smaller tributaries branch off from the main river, creating an intricate network of waterways.

The right map is a detailed topographic representation of the same area. It shows elevation and land formations with a detailed texture and color. The same prominent river runs diagonally from the top left to the bottom center with blue color, surrounded by textured land masses in shades of green and brown indicating different elevations and terrain. The topographic map also includes smaller water bodies and streams, similar to the left map but with more detailed land relief representations.

Given the vast amount of data available, it is important to think carefully about the base data necessary for map's audience, medium, and purpose—and design accordingly.

Symbol Design: Visual Order and Categories

Symbol Design: Visual Order and Categories

When designing your maps, two ideas should be at the forefront of your symbol design process: (1) order, and (2) category. Map symbol design relies heavily on the proper use of visual variables—graphic marks that are used to symbolize data (White, 2017).

Cartographer Jacques Bertin (1967) was the first to present this system of encoding data via graphic elements. Suggestions of supplemental visual variables (e.g., transparency), as well as analyses of their utility in different cartographic contexts, have been brought forth by multiple well-known cartographers (e.g., MacEachren 1994).

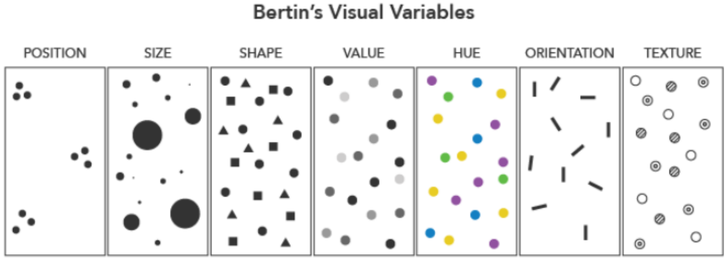


Figure 1.7.1 An illustration of Bertin's Visual Variables by Axis Maps Credit: Adapted from Visual Variables, Axis Maps. Available under the Open Database License CC BY-NC-SA 4.0

Image description: A chart illustrating Bertin's Visual Variables, displaying seven categories: Position, Size, Shape, Value, Hue, Orientation, and Texture. Each category is shown as a vertical column with a series of symbols exemplifying the visual variable.

- **Position:** Two groups of small black circles arranged diagonally within a white rectangular column.
- **Size:** Black circles of varying sizes scattered randomly within a white column.
- **Shape:** A mix of small black triangles, circles, and squares spread across a white column.
- **Value:** Black and gray circles with different shades of gray arranged within a white column, indicating varying values.
- **Hue:** Circles in different colors (purple, green, blue, yellow) scattered in a white column.
- **Orientation:** Black lines at various angles within a white column.
- **Texture:** Circles with different interior textures (solid black, white with dots, white with horizontal lines) arranged within a white column.

Some visual variables (e.g., size, color saturation, and color lightness) clearly indicate quantitative changes in magnitude. These are best for encoding data that has an order (e.g., a county-level map of population density; a road map with both highways and local roads). Other visual variables (e.g., color hue, pattern, and shape) signify qualitative—but not quantitative—differences. These are best applied when data categories have no inherent ordering (also often called nominal, or qualitative data), such as in a choropleth map showing political boundaries.

Figures 1.7.2, 1.7.3, and 1.7.4 demonstrate how visual variables can be used to symbolize common features in general purpose maps. These variables can be used either independently or in combination, to create the best visual representation of the underlying data.

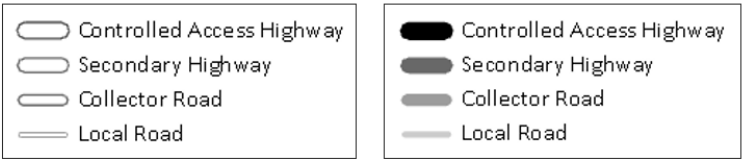


Figure 1.7.2 Visual order of road features using size (left), and size and value (right). Credit: Cary Anderson, Penn State University.

Image description: Two separate road classification legends placed side by side. Each legend consists of four distinct horizontal bars, each labeled with different types of roads and are of decreasing thickness as you go down the legend.

- **Left Legend:**
    - The top bar is black with two white horizontal stripes and is labeled “Controlled Access Highway.”
    - The second bar is completely white and is labeled “Secondary Highway.”
    - The third bar is light gray and is labeled “Collector Road.”
    - The bottom bar is a thin gray line labeled “Local Road.”
- **Right Legend:**
    - The top bar is completely black and labeled “Controlled Access Highway.”
    - The second bar is dark gray and labeled “Secondary Highway.”
    - The third bar is medium gray and labeled “Collector Road.”

- The bottom bar is light gray and labeled "Local Road."

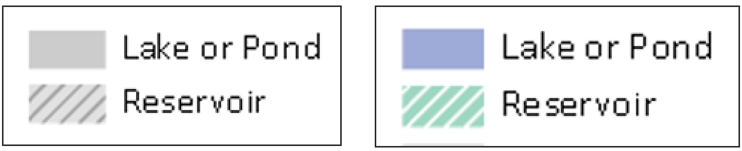


Figure 1.7.3 Categories of waterbody features using pattern (left), and pattern and hue (right) Credit: Cary Anderson, Penn State University.

Image description:Two small, side-by-side legend boxes, each containing a key for identifying "Lake or Pond" and "Reservoir."

- **Left Legend Box:**
  - A light gray solid square represents "Lake or Pond."
  - A light gray square with diagonal black stripes represents "Reservoir."

- **Right Legend Box:**
    - A blue solid square represents “Lake or Pond.”
    - A light green square with diagonal darker green stripes represents “Reservoir.”

Each legend box has a thin black border with a white background. The text is in black, and all elements are clearly distinguishable.

Figure 1.7.4 Combined visual order and category of roads using size and pattern. Credit: Cary Anderson, Penn State University.

Image description: A simple map legend contained within a rectangular white box outlined in black. The legend has two entries indicating different types of paths. The first entry consists of a solid grey line to the left, labeled “Local Road” on the right with black text. The second entry shows a dashed grey line, labeled “Trail” on the right side with black text.

Edward Tufte, a statistician and data visualization expert, said “the commonality between science and art is in trying to see profoundly—to develop strategies of seeing and showing” (Zachry and Thralls 2004, pg. 450). The goal of cartography, both an art and a science, is to optimally visualize—and help others see—the world, and various phenomena within it. To do so takes patience, practice, and skill—all of which you will continually develop throughout this course.

Student Reflection

Do a simple web search for maps of a topic that interests you. What visual variables are used in these maps? Are they effective?

Designing for Multiple Scales

Another important decision you will have to make when mapping is at what scale your map should be designed. When designing your symbols, you should always take scale into consideration. Generally, large-scale (zoomed-in) maps should include more features, such as local roads and points of interest, while small-scale maps should be simpler, to avoid visual clutter.

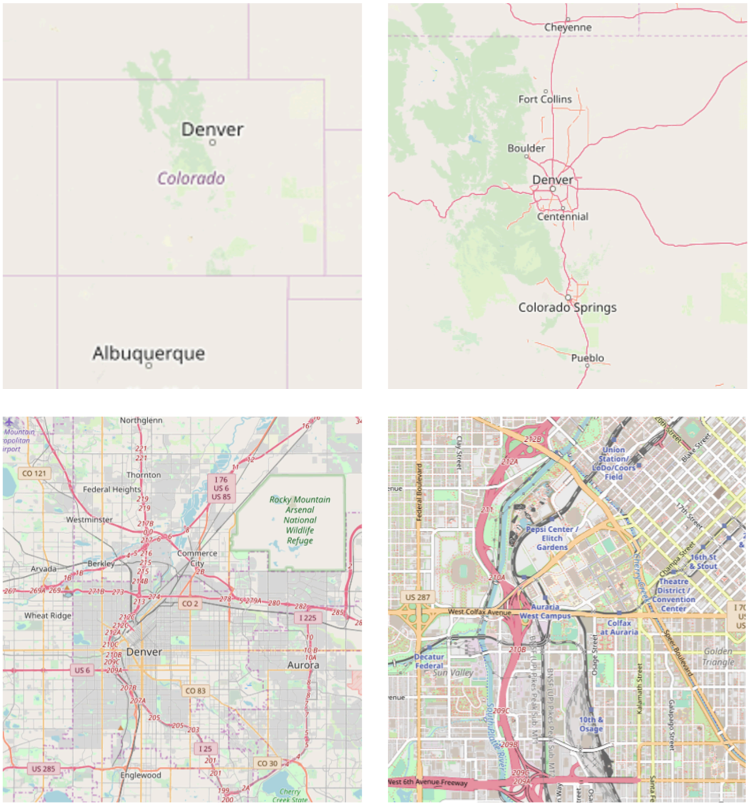


Figure 1.8.1 OpenStreepMap basemap showing Denver, CO through scale Credit: OpenStreetMap © OpenStreetMap contributors. The data is available under the Open Database License (CC BY-SA).

Image description: The image is a composite of four maps arranged in a 2×2 grid, showing various levels of detail for the area surrounding Denver, Colorado.

Top Left: A large-scale map showing the states of Colorado and part of New Mexico. Major cities like Denver and Albuquerque are labeled, with Denver centered in the map. The map highlights state boundaries with purple lines.

Top Right: A more detailed map of Colorado showing several cities connected by highways. Key cities labeled include Cheyenne, Fort Collins, Boulder, Denver, Centennial, Colorado Springs, and Pueblo. Major highways are depicted in red lines.

Bottom Left: A regional map focusing on the metropolitan area surrounding Denver. This map highlights highways, major roads, and neighboring cities such as Thornton, Westminster, Arvada, Wheat Ridge, Aurora, and Englewood. It includes the Rocky Mountain Arsenal National Wildlife Refuge.

Bottom Right: A highly detailed street map of downtown Denver. It shows specific landmarks including Union Station, Pepsi Center, Elitch Gardens, the Theatre District/Convention Center, and Auraria West Campus. Streets and highways are clearly marked, with a focus on the arrangement of the urban grid and prominent features.

Student Reflection

> What do you see at the four different scales shown in Figure 1.8.1? What features are prominent at the smallest scale (top left)? What features do not appear until the largest scale (bottom right)?

Web-based basemaps, such as the one shown in Figure 1.8.1, are often designed to adjust the level of detail automatically, as the user adjusts the map's scale. If you are mapping your own data over a web map, however, you will still need to make decisions about the level of detail you include at each scale, as well as the sizes and styles of your symbol designs.

Lab 1: Building Your City Story Dataset

Total Points

20 points

Instructions

The six labs throughout this course will be focused on creating maps of a city of your choice. Once you finish Lab 6, you will create a map book either using StoryMap or in PDF form which incorporates the feedback you receive regarding your maps and weaves all your maps into a story about the city. For this lab, you will create a geodatabase which will include boundary, transportation, and hydrology data pertaining to your chosen city and a README file which will contain metadata about your geodatabase contents. For some of the labs, you will have to add additional data to your geodatabase such as Census tables which has population information. You will primarily be working with Census data for these labs and by the end of these labs, you will be very comfortable with using the Census data portal along with the U.S. Census TIGER/Lines download page. We are also going to focus on data management with this lab. As a GIS practitioner, data management should be the foundation of your work. If you follow sound data management practices from the beginning, it will pay itself forward in the long run! Data management is here to help the current and future you in your GIS work.

Learning Objectives

1. Apply data retrieval skills in downloading geospatial data from a variety of national and local government data sources.
2. Generate a geodatabase which will contain administrative boundaries, hydrographic features, and transportation features.
3. Produce a README file which will give information about the geodatabase and the datasets within the geodatabase.

Data Management Tips

These tips are based off the Managing Your Data research guide.

1. Don't use special characters and use an underscore in place of a space in your file names and in any columns in your table.
2. Use lowercase letters to name your files.
3. Use versioning to keep track of your files. An example is using file_v1 as a name for your original file and if you make subsequent updates, you can give the new file the name of file_v2, file_v3 and so on.
4. You should not create long file names. A long

file name is one that exceeds 31 characters.

5. Implement a logical file hierarchy for your data. For example, if you wanted to create a data folder and geodatabase for data pertaining to Cleveland, it would be structured this way.
    - cleveland_data (data folder)
        - clevleand_data (geodatabase name)
            - boundaries (feature dataset)
                - cleveland_city (feature class name)
                - us_counties (feature class name)
                - oh_county (feature class name)
                - oh_state (feature class name)
                - oh_tract

s (feature class name)

- us_states (feature class name)
- transportation (feature dataset)
    - ohio_rail (feature class name)
    - ohio_streets (feature class name)
- hydrology (feature dataset)
    - oh_flowline (feature class name)
    - oh_waterbody (feature

class name)

6. Have a README file in an open file format (.rtf, .txt) which contains metadata about your data (data about data). Geospatial data uses the content standard for digital geospatial metadata (CSGDM) created by the Federal Geographic Data Committee (FGDC). For this lab, you create a modified version of the CSGDM and your README file will need to have this information:
– Description: A description of the dataset, intended use, and limitations
– Creator: Name of the organization or people who created the data.
– Keywords: words or phrases summarizing the dataset
– Place: Geographic locations characterized by the dataset
– Point of contact: Contact information for the creator of the dataset (name and e-mail are sufficient).

Deliverables

Geodatabase

Find the following relevant files related to your city of interest and create a data folder that has a geodatabase which includes boundary, hydrology, and road shapefiles:

1. Administrative Boundaries: You will need to

download state, city, county, Census tract, Census block, and Census block group boundaries. I would recommend you download them from the U.S. Census TIGER/Lines download page. Downloading the city boundary might be easier from the data portal of your selected city.

2. Transportation: You will need to download road and rail shapefiles. You can download this from the U.S. Census TIGER/Lines download page or from the data portal of your selected city.
3. Hydrology: The minimum requirement is that you have shapefiles that include lake, river, and pond features. Feel free to add any more hydrological features as you see fit. You can refer to the National Hydrology Dataset (NHD) since it is the most comprehensive dataset for hydrological features. You can use The National Map data downloader to download the NHD dataset for your area of interest. This dataset can be a little bit confusing to those who are unfamiliar with it, so read the National Hydrography Dataset Data Dictionary for more information about the feature classes in the dataset.

You will have to do some basic data manipulation to make sure that your shapefiles are within the city boundaries.

README file

You will need to create a README file in a .rtf or .txt file format (You can create this in Microsoft Office when you click **Save As…**) that has information about your datasets. List the name of the dataset, what is contained in the dataset, along with the dataset source. This can be either in or a separate part of the geodatabase. Use this naming convention for this file: CityName_readme.

ArcGIS Pro Project Package

Once you are done with Lab 1, click on Share and export your project as a project package. A project package will contain all the data related to the project such as the geodatabase, layers, and data folders. Make sure your package has the naming convention of LastName_Lab1.

Lab 1 Rubric

This lab is worth 20 points total. Use the following rubric to help you complete your assignment. Adhering to the rubric will assure that you receive full points for the assignment. Make sure to put all deliverables within a folder named LastName_Lab1. Failure to do so will result in a one point deduction. In your LastName_Lab1 folder, you should have the ArcGIS Pro project package and README file.

Geodatabase and project package: 10 points

Criteria	Point Value
ArcGIS Project package with a geodatabase containing the data for your chosen city using the required naming conventions for both the folder and the geodatabase.	3
Geodatabase that contains administrative boundaries, hydrology, and transportation feature datasets that contains the relevant shapefiles for each feature dataset.	5
File names have a naming convention based on recommended data management practices.	2

README file: 10 points

Criteria	**Point Value**
The README file should be in a .txt or .rtf format.	1
The README file should contain a description section.	3
The README file should contain a creator section.	1
The README file should contain a keywords section.	1
The README file should contain a place section.	1
The README file should contain a point of contact section.	3

Lab 1 Visual Guide

Lab 1 Visual Guide Index

1. Choosing a city for your City Story Dataset
2. Downloading Census Data
3. Creating a new project
4. Data preparation

1. Choosing a city for your City Profile Dataset

You will need to choose a city of interest for your City Profile dataset. For the purposes of Lab 1 and Lab 2, we will use Cleveland for our example city. The cities will vary throughout the lab exercises to give you exposure to different datasets. Do not choose cities that are used as examples in the Visual Guides.

2. Downloading Census Data

Now that we have chosen our city, it's time to download the pertinent Census Data. To build our City Profile dataset, we will need to download boundaries, transportation and hydrology shapefiles. Create a folder and name it "cityname_data." For example, the data folder that will contain the data pertaining to Cleveland will be called "cleveland_data." In that folder, create sub-folders called "boundaries," "transportation," and "hydrology."You will need to make sure to download the most recent datasets. For example, at this time, the most current dataset for the U.S. TIGER/Line shapefiles are the 2023 shapefiles.

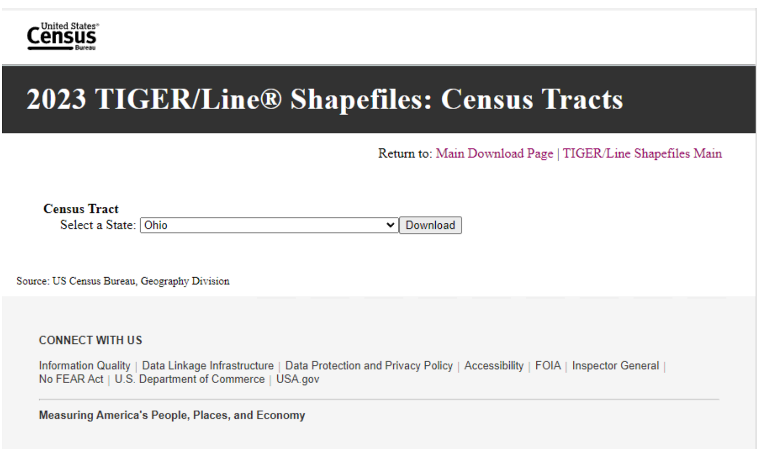
Boundary shapefiles

Make sure that you put your downloaded data into the "boundaries" sub-folder and that the folders are unzipped.

State, County, and Census Tract boundaries

We will need to download the city boundary for Cleveland along with the Ohio county, state, and Census tract boundaries. We will not use the Census tract boundaries for this lab, but for Lab 3. Go to the U.S. Census Bureau Tiger/Line Shapefiles website and download the relevant boundary files. On the Census Bureau Tiger/Line Shapefiles website, the state and county data comes as a national file. You will need to select by attribute (it is recommended to use the state FIPS code) and export the selection into shapefiles for your city of interest. For the Census tract boundaries, you will be able to select by state.

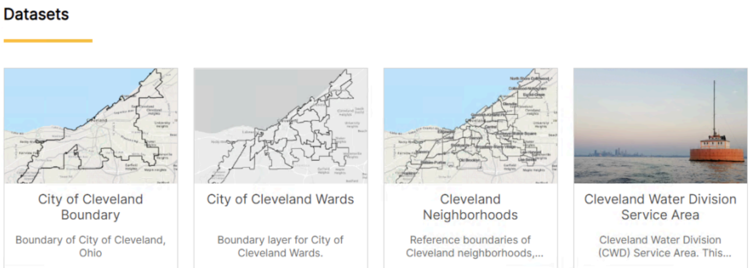
Visual Guide Figure 1.1. 2023 TIGER/Line Shapefiles: States (and equivalent) download page.



Visual Guide Figure 1.2. 2023 TIGER/Line Shapefiles: Census Tracts download page.

City boundary

Many cities have a GIS or Open Data portal. Do an internet search to find the data portal of your city. The City of Cleveland has an open data portal which has various types of data such as health data, public safety data, and transit data. This open data portal also contains data products such apps and maps, dashboards and analytics, and data stories. The city boundary shapefile is found under the Locations & Boundaries category of the open data portal.



Visual Guide 1.3 Figure. Datasets from the City of Cleveland data portal.

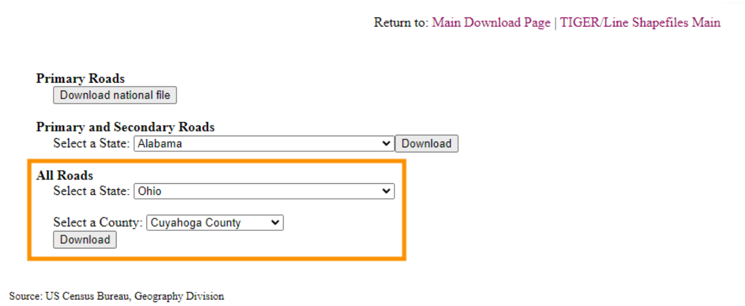
Put all your boundary files in the "boundaries" sub-folder and unzip the folder.

Transportation shapefiles

You will need to download roads and rail line shapefiles from the U.S. Census Bureau TIGER/Line Shapefiles website. Put the files in the "transportation" sub-folder and make sure to unzip the files.

Roads

On the U.S. Census Bureau TIGER/Line Shapefiles dropdown menu, click on **Roads**. Under **Select a State**, select the state your city is in. You need to download **All Roads**. You will need to select the state and the county that your city is in.



Visual Guide Figure 1.4.2023 TIGER/Lines Shapefiles roads download page.

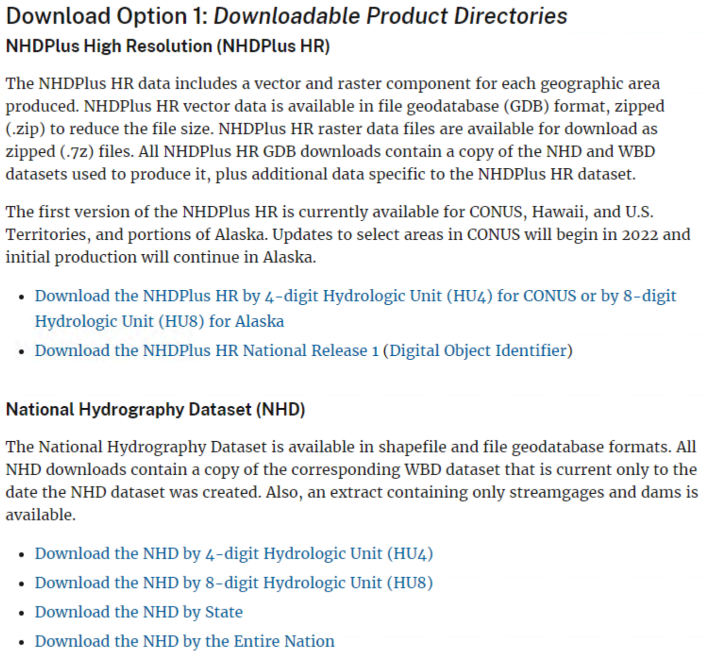
Rails

The Rails shapefile only comes as a national file.You will need to select by attribute (it is recommended to use the state FIPS code) and export the selection into shapefiles for your city of interest.

Visual Guide 1.5. 2023 TIGER/Line Shapefiles: Rails download page.

Hydrology shapefiles

We will be using the National Hydrography Dataset (NHD) for the hydrological features. It is important to note that as of October 1 2023, this dataset will no longer be maintained and the most current data will be available through the 3D Hydrography program. For the sake of simplicity, we will be using the NHD to map the hydrological features. You can download the data from the Access National Hydrography Products section of the US Geological Survey (USGS) website. There are various ways to access this data, but the easiest way is to scroll to the **Downloading Datasets** section and click on **Download the NHD by State** under **Download Option 1: Downloadable Product Directories**. You can access the geodatabase for the state that your city is in at the Staged Products Directory. Scroll down to your state of interest and click on the **_GDB.zip** file for your state.



Download Option 1: *Downloadable Product Directories*

NHDPlus High Resolution (NHDPlus HR)

The NHDPlus HR data includes a vector and raster component for each geographic area produced. NHDPlus HR vector data is available in file geodatabase (GDB) format, zipped (.zip) to reduce the file size. NHDPlus HR raster data files are available for download as zipped (.7z) files. All NHDPlus HR GDB downloads contain a copy of the NHD and WBD datasets used to produce it, plus additional data specific to the NHDPlus HR dataset.

The first version of the NHDPlus HR is currently available for CONUS, Hawaii, and U.S. Territories, and portions of Alaska. Updates to select areas in CONUS will begin in 2022 and initial production will continue in Alaska.

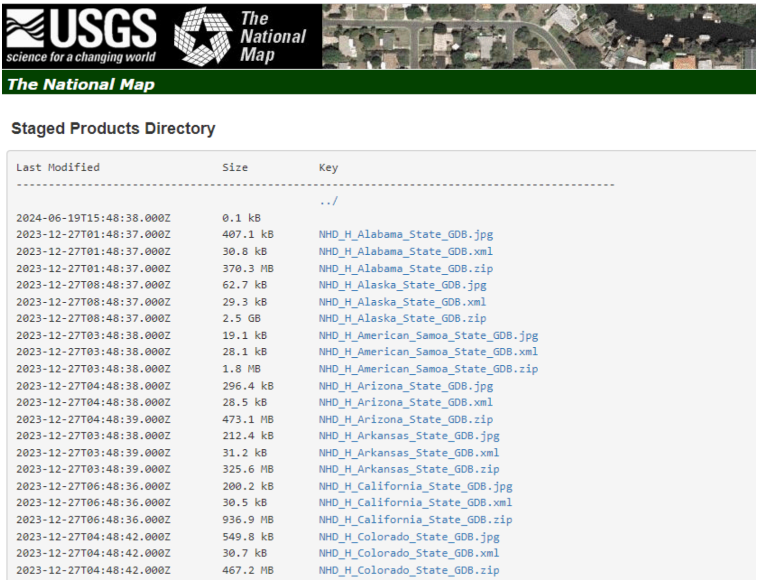
- Download the NHDPlus HR by 4-digit Hydrologic Unit (HU4) for CONUS or by 8-digit Hydrologic Unit (HU8) for Alaska
- Download the NHDPlus HR National Release 1 (Digital Object Identifier)

National Hydrography Dataset (NHD)

The National Hydrography Dataset is available in shapefile and file geodatabase formats. All NHD downloads contain a copy of the corresponding WBD dataset that is current only to the date the NHD dataset was created. Also, an extract containing only streamgages and dams is available.

- Download the NHD by 4-digit Hydrologic Unit (HU4)
- Download the NHD by 8-digit Hydrologic Unit (HU8)
- Download the NHD by State
- Download the NHD by the Entire Nation

Visual Guide Figure 1.6. USGS National Hydrology Dataset download page.


USGS science for a changing world
The National Map
The National Map

Staged Products Directory

Last Modified	Size	Key
		../
2024-06-19T15:48:38.000Z	0.1 kB	
2023-12-27T01:48:37.000Z	407.1 kB	NHD_H_Alabama_State_GDB.jpg
2023-12-27T01:48:37.000Z	30.8 kB	NHD_H_Alabama_State_GDB.xml
2023-12-27T01:48:37.000Z	370.3 MB	NHD_H_Alabama_State_GDB.zip
2023-12-27T08:48:37.000Z	62.7 kB	NHD_H_Alaska_State_GDB.jpg
2023-12-27T08:48:37.000Z	29.3 kB	NHD_H_Alaska_State_GDB.xml
2023-12-27T08:48:37.000Z	2.5 GB	NHD_H_Alaska_State_GDB.zip
2023-12-27T03:48:38.000Z	19.1 kB	NHD_H_American_Samoa_State_GDB.jpg
2023-12-27T03:48:38.000Z	28.1 kB	NHD_H_American_Samoa_State_GDB.xml
2023-12-27T03:48:38.000Z	1.8 MB	NHD_H_American_Samoa_State_GDB.zip
2023-12-27T04:48:38.000Z	296.4 kB	NHD_H_Arizona_State_GDB.jpg
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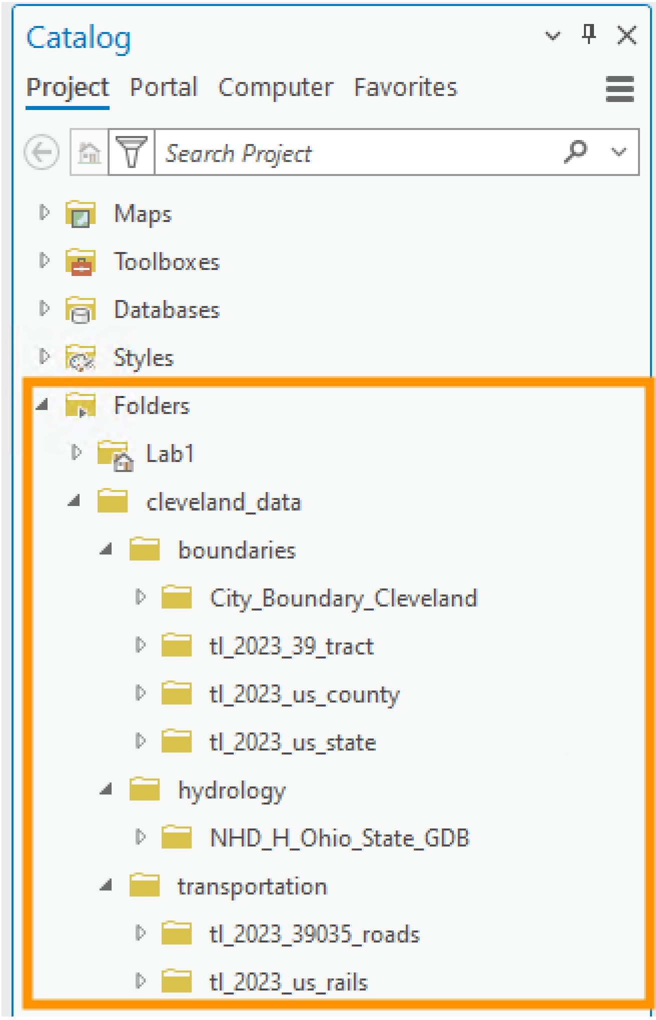
2023-12-27T04:48:39.000Z	473.1 MB	NHD_H_Arizona_State_GDB.zip
2023-12-27T03:48:38.000Z	212.4 kB	NHD_H_Arkansas_State_GDB.jpg
2023-12-27T03:48:39.000Z	31.2 kB	NHD_H_Arkansas_State_GDB.xml
2023-12-27T03:48:39.000Z	325.6 MB	NHD_H_Arkansas_State_GDB.zip
2023-12-27T06:48:36.000Z	200.2 kB	NHD_H_California_State_GDB.jpg
2023-12-27T06:48:36.000Z	30.5 kB	NHD_H_California_State_GDB.xml
2023-12-27T06:48:36.000Z	936.9 MB	NHD_H_California_State_GDB.zip
2023-12-27T04:48:42.000Z	549.8 kB	NHD_H_Colorado_State_GDB.jpg
2023-12-27T04:48:42.000Z	30.7 kB	NHD_H_Colorado_State_GDB.xml
2023-12-27T04:48:42.000Z	467.2 MB	NHD_H_Colorado_State_GDB.zip

Visual Guide Figure 1.7.USGS Staged Products Directory containing National Hydrology Dataset geodatabases by state.

After you download the geodatabase pertaining to your state of interest, move the data to your "hydrology" subfolder and unzip the file.

3. Creating a new project

Open up ArcGIS Pro and if necessary, enter your credentials to have access to the program. Under **New Project**, click on **Map** and name your project "Lab1." You can keep the location in the Projects folder or save it to a readily accessible folder of your choice. In the ArcGIS Pro Catalog, connect to the folder with your "cityname_data" file. You should be able to see all the downloaded folders if you unzipped the folders.

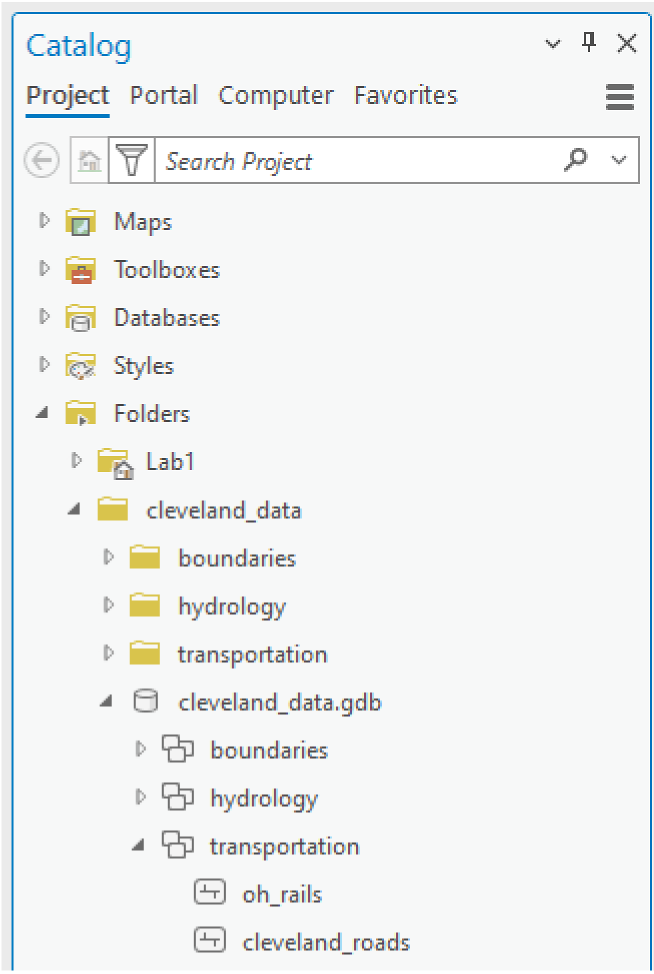


Visual Guide Figure 1.8. ArcGIS Pro Catalog panel showing project files, geodatabases, and toolboxes.

4. Data Preparation

Geodatabase creation

As mentioned previously, you will need to create a geodatabase and feature datasets that are similar to your folder and subfolder naming structure. In this example, I created a geodatabase for Cleveland along with feature datasets for boundaries, hydrology and transportation. Make sure that you assign an appropriate projection to your feature datasets. In this case, I applied the NAD 1983 (2011) State Plane Ohio North FIPS projection to the feature datasets. Import the shapefiles you downloaded in the appropriate feature dataset and give them a meaningful name. The hydrology dataset is already in a geodatabase. You will only need to add the **NHDWaterbody** and **NHDFlowLine** features (located in the **Hydrography** feature dataset) to your hydrology feature dataset. For some datasets (i.e. the rails shapefile), will need to perform either a **Select by Attribute** or **Select by Location** query to narrow down your datasets to your city and state of interest and then export your data into the appropriate feature dataset in your geodatabase. Once you are finished with the data preparation, your geodatabase should look similar to below.

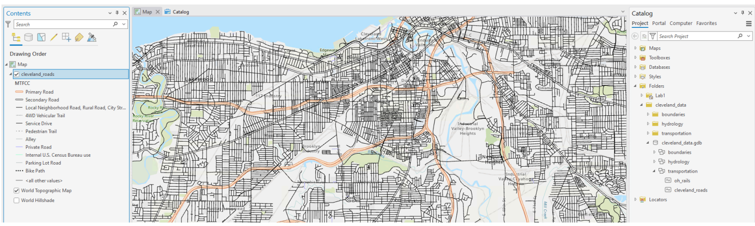


Visual Guide Figure 1.9. Cleveland data geodatabase with boundary, hydrology, and transportation feature datasets.

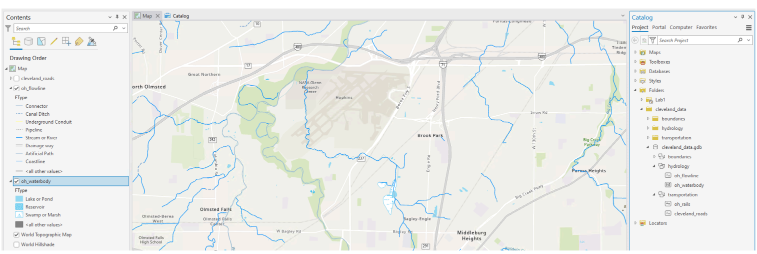
Categorizing data

You are going to need to add symbology to the roads, waterbody, and flowline feature classes by category so you can do Lab 2. For the roads feature class, you will need to add symbology by MTFCC code. Please refer to the

2022 MAF/TIGER Feature class codes document when adding symbology to the roads feature classes to rename the labels. For the NHD dataset, refer to the National Hydrography Dataset (NHD) Data Dictionary Feature Classes document when adding symbology to the flowline and waterbody feature classes. Add whatever symbology you think is appropriate for the time being.



Visual Guide Figure 1.10. ArcGIS Pro map and contents windows displaying the roads features class being symbolized by MTFCC code.



Visual Guide 1.11. ArcGIS Pro contents and map windows showing the flowline and waterbody feature classes symbolized by code.

Now that you have done all the data preparation, you are now ready to do Lab 2! It is worth repeating that you will have to change your symbology for both Lab 2 and 3 but working with map symbology in this lab gave you a little more familiarity with the Symbology feature in ArcGIS Pro along with giving you experience with using U.S. Geological Survey (USGS) and U.S. Census Bureau documentation to aid you with the symbolization of the feature classes. You will get more detailed guidance regarding symbology in the Lab 2 Visual Guide.

Lab 2: Creating a General Purpose Map with the City Story Dataset

Total Points

20 points

Instructions

In this lab you will be creating two general-purpose maps in an area in your city that is of interest to you.

Learning Objectives

1. Design two general-purpose maps using cartographic principles learned so far.
2. Write a report that summarizes why you chose the city that you did, the intended audience and purpose of the map, along with the visual order of importance of the map features.

Deliverables

General Purpose Maps

Create two general-purpose 8.5” x 11” maps of your city based on the cartographic principles you have learned so far.

Map One

- Scale: 1:24,000
- Must not include any color – design in greyscale only.
- Must include the following features:
    - At least three types of transportation features (e.g., interstate, local roads, rails, trails, etc.)
    - At least three types of waterbodies (e.g., lake or pond, reservoir, etc.)
    - At least one type of flowlines (e.g., streams, artificial paths, etc.)
    - At least one political boundary feature.
- For the purpose of this lab, features are considered different if defined differently in the data (e.g., local and collector roads have different TNMFRC codes; lakes and reservoirs have different FTypes).
- Produce the map at 8.5” x 11’’

Map Two

- Scale: 1:100,000
- Must include some or all color.
- Must include the following features:
    - At least four types of transportation features (e.g., interstate, local roads, rails, trails, etc.)
    - At least two types of waterbodies (e.g., lake or pond, reservoir, etc.)
    - At least two types of flowlines (e.g., streams, artificial paths, etc.)
    - At least one political boundary feature (e.g., parish, city limits)
- For the purpose of this lab, features are considered different if defined differently in the data (e.g., local and collector roads have different TNMFRC codes; lakes and reservoirs have different FTypes).
- Produce the map at 8.5” x 11”

Report

Include a 100-word report in which you discuss the area of interest that you mapped. Explain the your intended purpose and audience for the map (you can come up with a scenario). Also, be able to explain the intended visual order of importance to the map features that you included and symbolized on the map and how that order was achieved. Use this naming convention for your report: LastName_Lab2_Report.

Submitting Deliverables

- 100-word report in which you discuss why you chose the city that you did and some of the trends you might be interested in exploring in your chosen city given the datasets that you downloaded. Use this naming convention for your report: LastName_Lab2_Report.
- General purpose maps of your city. Use this naming convention for your maps: LastName_Lab2_Map1, LastName_Lab2_Map2.
- Include your maps, report, and data folder in a folder with the name LastName_Lab2.

Lab 2 Rubric

This lab is worth 20 points total. Use the following rubric to help you complete your assignment. Adhering to the rubric will assure that you receive full points for the assignment.

Report: 8 points

Criteria	Points Value
The report is at least 100 words long.	3
The report discusses why you chose the city that you did, some of the trends that you would like to explore and other relevant information about your maps.	4
The report has the required naming convention.	1

General Purpose Map: 10 points

Criteria	Points Value
An 8.5″ x 11″ general purpose greyscale map that is 1:24,000 scale, includes three types of transportation features, three types of water bodies, two types of flow lines, and one political boundary feature.	5
Am 8.5″ x 11″ general purpose map that has some or all color that is 1:100,000 scale, includes four types of transportation features, two types of waterbodies, two types of flowlines, and one political boundary.	5

Submission Folder: 2 points

Criteria	Points Value
A folder using the naming convention of LastName_Lab2 which contains all required deliverables	2

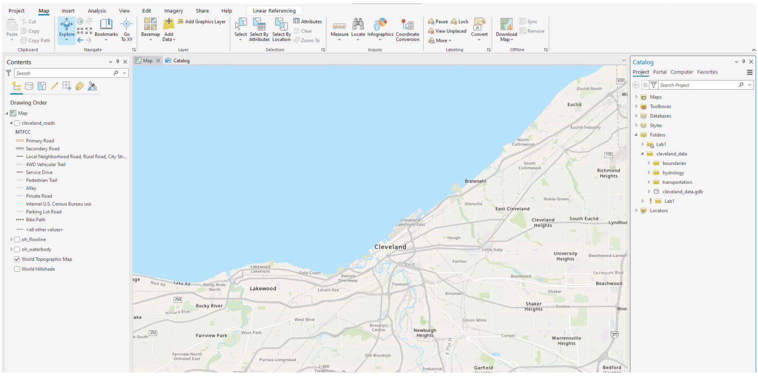
Lab 2 Visual Guide

Lab 2 Visual Guide Index

1. Explore the data via the Contents pane
2. Design symbols using the Symbology pane
3. Make your second (smaller-scale) map
4. Add each map to a layout
5. Finalize and save your layouts
6. Additional tips and tricks

1. Explore the data via the Contents pane

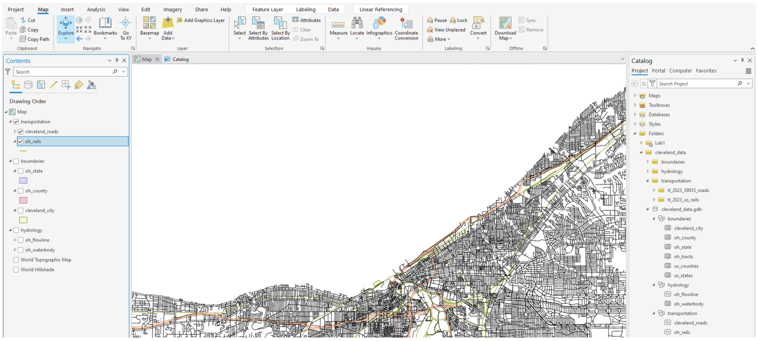
Open up the ArcGIS Pro Project that you created in Lab 1. Make sure that you incorporate any feedback that you received from Lab 1 regarding your geodatabase (using recommended naming conventions, etc.).



Visual Guide Figure 2.1.ArcGIS Pro Project displaying a basemap that is focused on the city of Cleveland.

You can toggle on and off layers using the associated checkboxes in the **Contents** pane. The **World Topographic Map** basemap should be the default basemap in your ArcGIS Pro project. The basemap also comes with a reference layer (that you can use to help locate an area of interest to map) that you can toggle on and off, but we won't be including any labels on our map in Lab 2. We will work with labeling in Lab 3. While you can use the World Topographic Map layer as a guide during the map design process, make sure that you **toggle off the World Topographic Map layer** before you submit your final maps for this lesson.

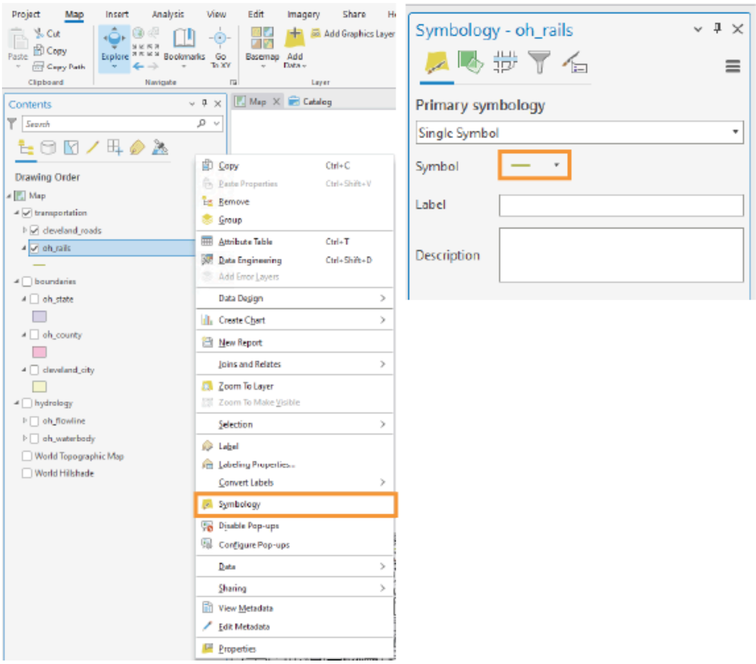
Add all your layers to your map. For better handling of your layers, you can group them in the same way they are grouped in your geodatabase. Highlight the layers that are in the same feature class and right-click and then click on **Group**. Make sure the name your groups the same name as your feature datasets. Eventually, you will need to look at multiple layers at once, so that you can see how all your symbols look together. It will likely be easiest at first, however, to turn off (un-check) most of the layers so you can focus on one layer at a time.



Visual Guide Figure 2.2. ArcGIS Pro Project Interface which shows the layers in the contents panel and transportation features in the map window.

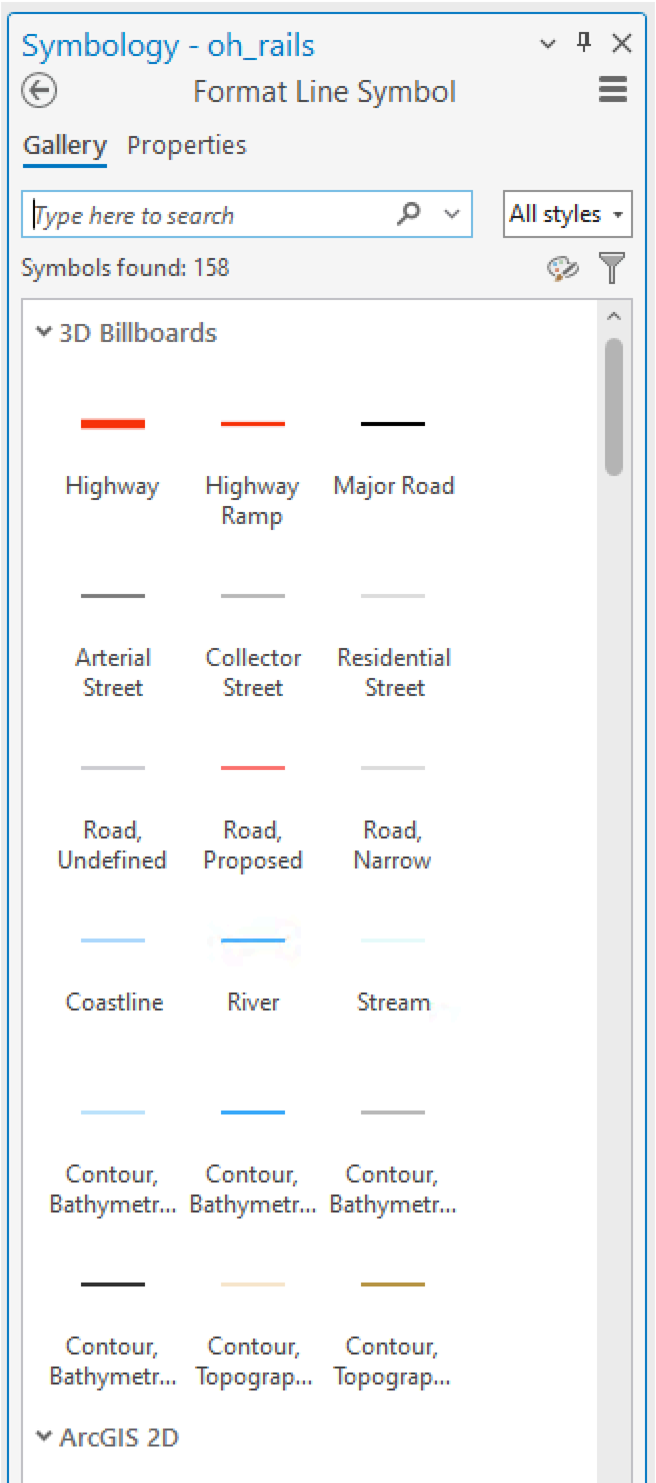
3. Design symbols using the Symbology Pane

As a suggestion, it may make sense if you started from the “bottom” layer and worked your way “up.” In other words, think about “visually” what is the lowest layer in the list of data. For example, let’s assume the area of interest you selected is near a large water body. What color would you assign to that water body? Figure 2.3 shows how to select a layer (here, railroads) and open the **Symbology** pane. Clicking on the symbol will let you edit its properties. The next layer to work with may be “land.” Again, what color do you imagine appropriate for land given you color choice for the water body. How does the land color you selected contrast/compliment with the water color you chose? Upon inspection, you will likely have to change the colors associated with one or more of the layers until you have achieved a visual agreement with all of the layers, their colors, line thickness, and line styles. Continue adding additional layers according to your visual hierarchy.



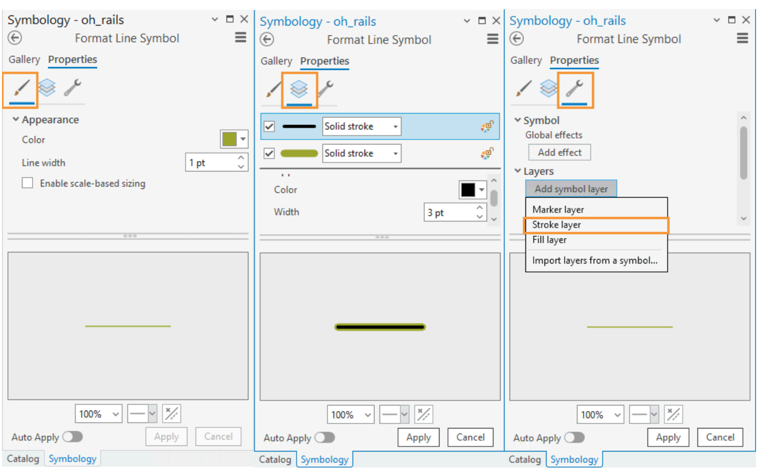
Visual Guide Figure 2.3. Symbolizing the oh_rails feature class.

Looking in the Gallery of the Symbology pane will give you some ideas, but you should alter these symbols – **do not accept the defaults**.


Symbology - oh_rails
Format Line Symbol
Gallery
Properties
Type here to search
All styles
Symbols found: 158
3D Billboards
Highway
Highway Ramp
Major Road
Arterial Street
Collector Street
Residential Street
Road, Undefined
Road, Proposed
Road, Narrow
Coastline
River
Stream
Contour, Bathymetr...
Contour, Bathymetr...
Contour, Bathymetr...
Contour, Bathymetr...
Contour, Topograp...
Contour, Topograp...
ArcGIS 2D

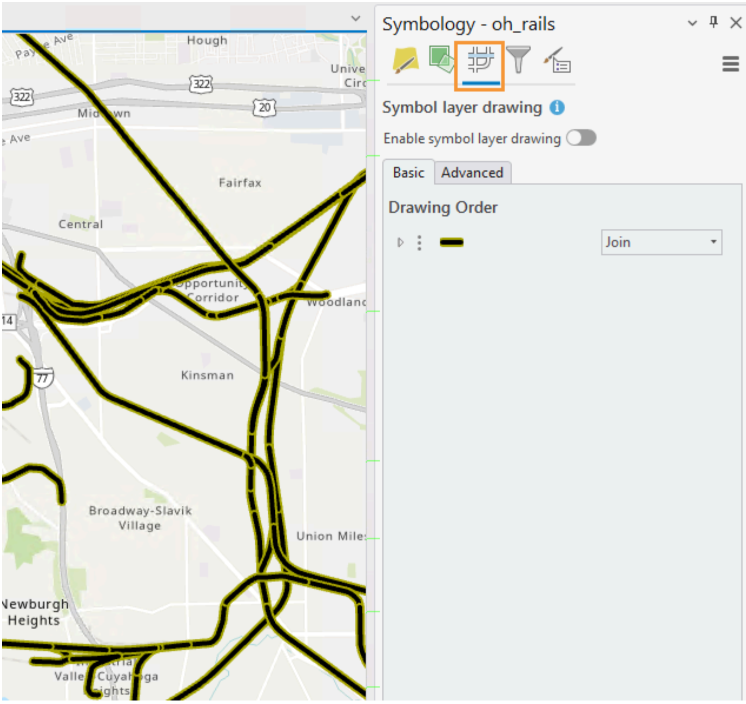
Visual Guide Figure 2.4 .Symbology options panel in ArcGIS Pro.

Design changes (e.g., color; thickness, style) are made in the **symbol properties** tab (Figure 2.5; left tab of the Symbology pane). Note that for Map 1 in this lesson you must work only in greyscale. Think about symbol ordering/ importance as you design – more important features should have greater visual emphasis. Most detailed work is done in the **symbol layers** tab (Figure 2.5; middle tab). Experiment with the many options available (e.g., offsets and dashes). You can also preview your symbol at the bottom of the pane. The Symbol Structure tab (Figure 2.5; right tab) allows you to make multilayer lines. You can also drag to re-order these lines.



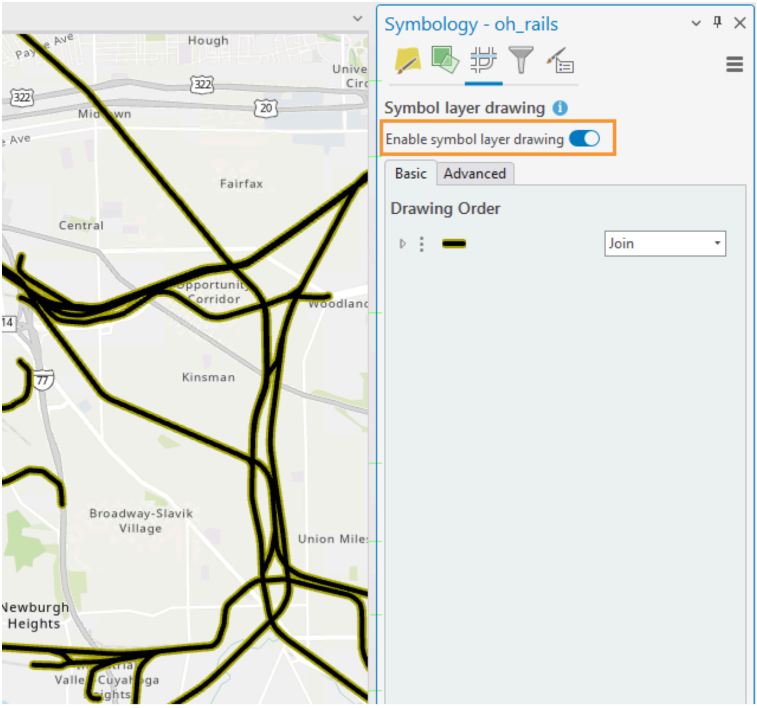
Lab 2 Visual Guide Figure 2.5. Symbology options panes to edit the appearance, stroke, and to add a stroke.

You may notice a strange "caterpillar" effect when you create multi-layer lines. This is due to the default layering of line segments in ArcGIS Pro, but it's easy to fix.



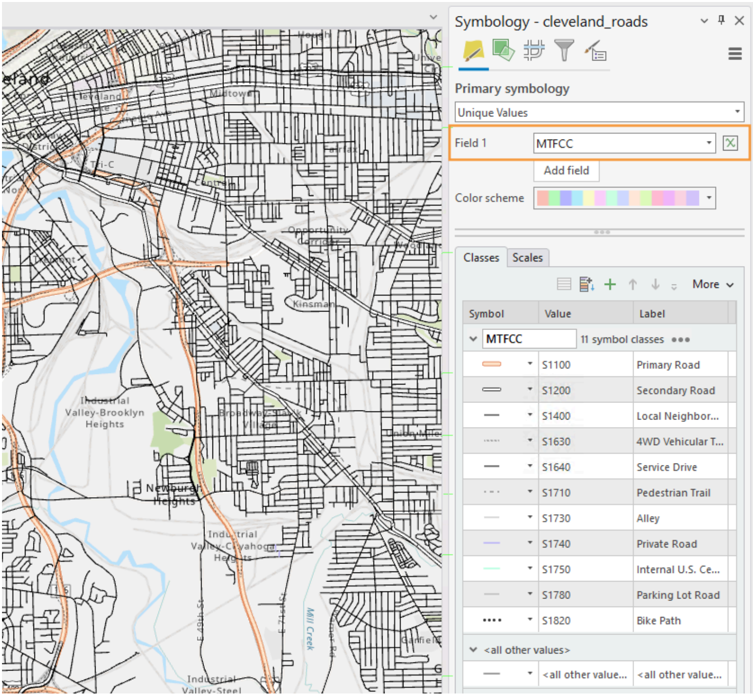
Visual Guide Figure 2.5. Cleaning up "caterpillar" line segments.

You can fix this layering issue by enabling *Symbol layer drawing* within that layer from the Symbology Pane.

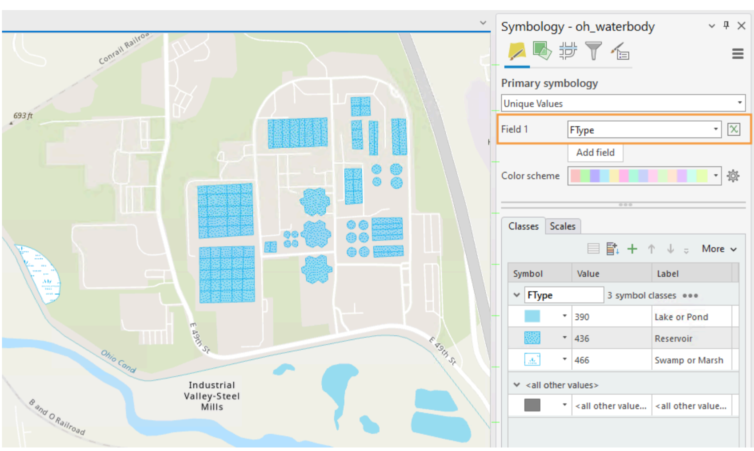


Visual Guide Figure 2.6. Turning on Symbol Layer Drawing.

In Lab 1, you classified the road and water features. See if you can make any improvements upon your existing symbology for these features using what you learned so far. One example of the way you can change the line symbology is making more important road types such as highways more visually prominent) while one way you can change the area symbology is to explore the fill and outline color/pattern options. Experiment with different patterns but be careful with their implementation as patterns can look harsh and visually disruptive: remember that your main map must be designed in greyscale. Exploring the Gallery tab may help you develop ideas.

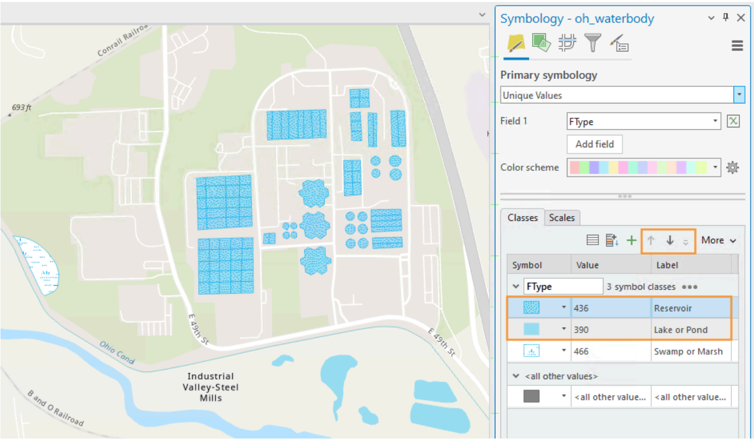


Visual Guide Figure 2.8. Symbolizing the roads layer by MTFCC code utilizing symbolization schemes from the Gallery tab.



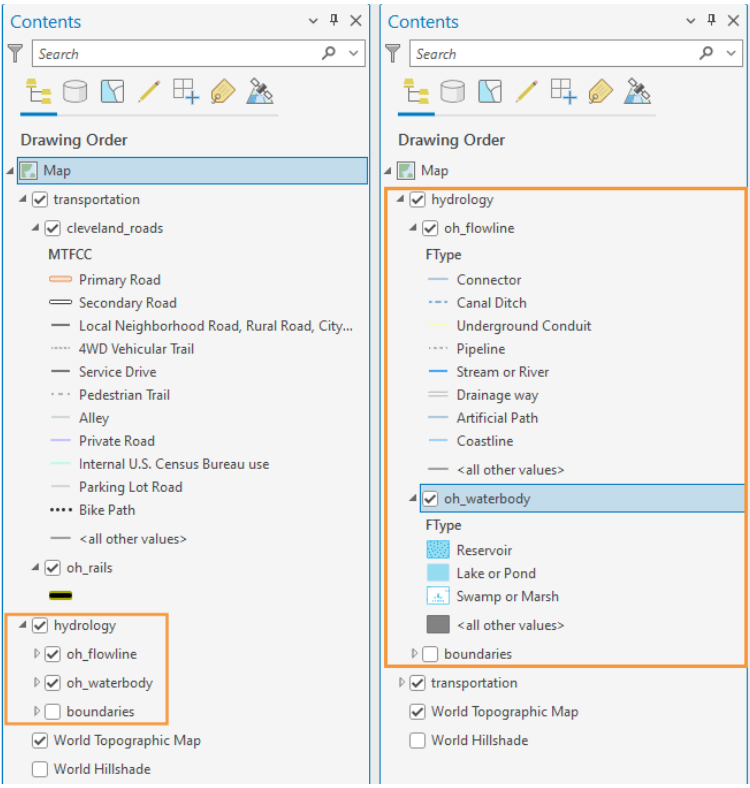
Lab 2 Visual Guide Figure 2.9. Symbolizing the oh_waterbody layer by FType.

You are free to alter the labels for each feature type, or change their order using the arrows in the Symbology pane. Note that it doesn't really matter what your labels are for this lab, as long as you understand them. **We will not be creating a legend in Lab 2**, so these labels will only be visible to you.



Visual Guide Figure 2.10. Moving the label order in ArcGIS Pro.

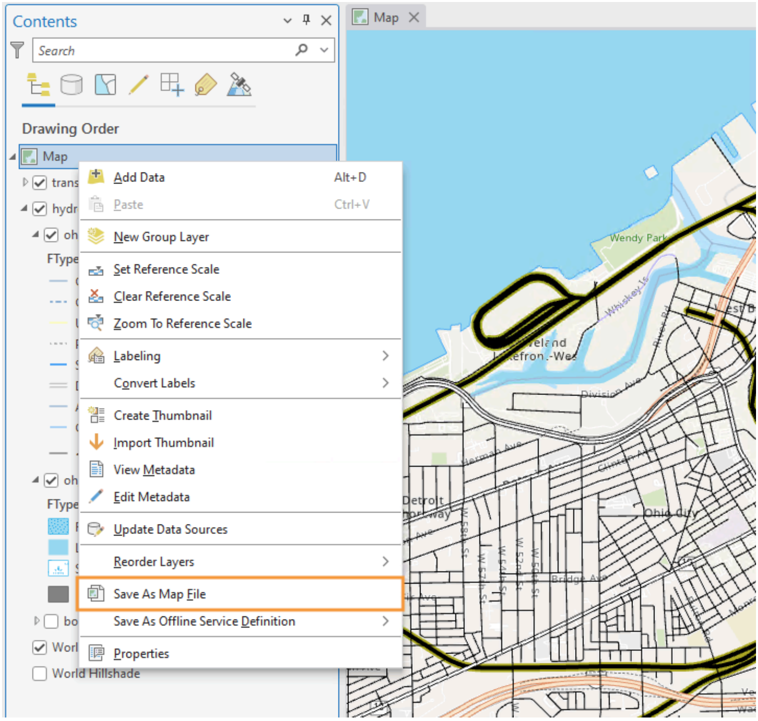
You can also drag to re-arrange entire layers within the Contents pane. Think carefully about the ordering of the features on your map. Should railroads be drawn above or below lakes and rivers? What about political boundaries? Why? You may want to reference popular general purpose maps such as Google maps to compare your choices, but there is not always a right answer. Think of your audience and map purpose!



Visual Guide Figure 2.11. Changing the order of features on the Contents pane.

4. Make your second (smaller-scale) map

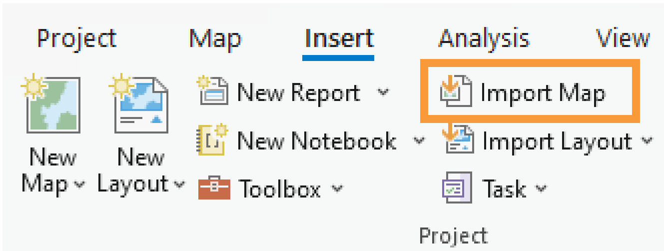
Once you're happy with your large-scale (1:24,000) map, save it as a map file by right-clicking on the map name in the Contents pane – you should save it in the same folder as this ArcGIS project folder to keep everything organized and connected.



Visual Guide Figure 2.12. Saving your map as a map file.

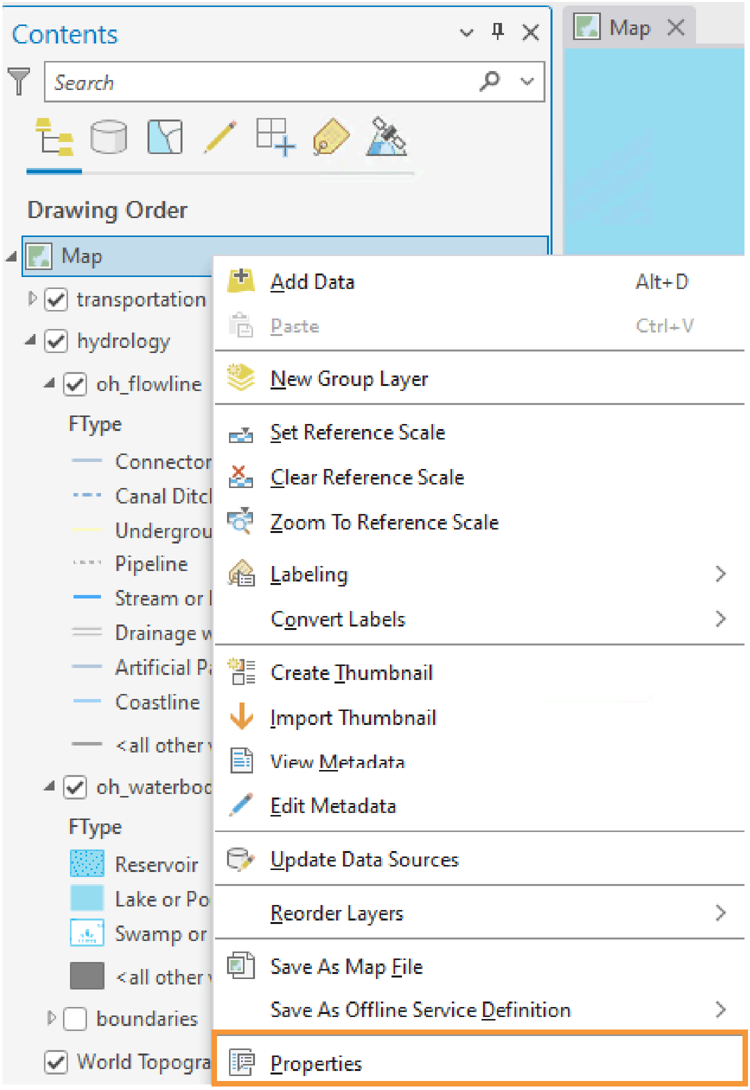
You can then *import* that saved map into this map project. Note that a map project can contain several different maps and map layouts. Once you re-import your map, this will create a duplicate map within the project file. You can then use this as a starting map for making your smaller scale map. Your main tasks then will be to add color and adjust your symbols for this smaller scale.

Creating a duplicate map this way is not required. Another option is to start your second map from scratch. I recommend creating and editing a copy of your first map instead, as this map will likely have a similar design to your first map, and creating a copy will prevent you from having to re-do a significant amount of design work (unless your second map has a different scope and purpose than the first map).



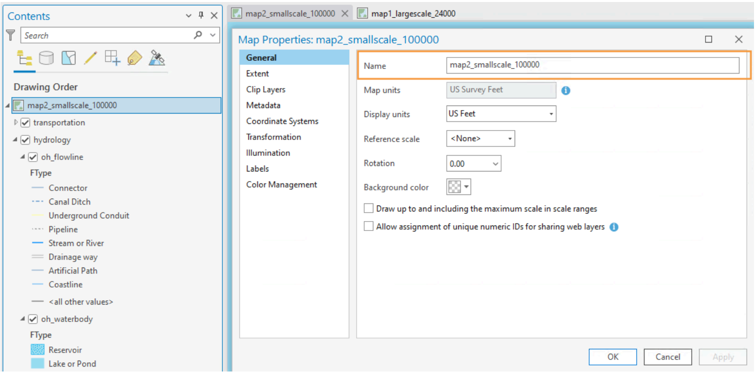
Visual Guide 2.13. Importing a map file.

Staying organized will help you tremendously in the long run. A big part of this is saving your map files with useful file names. Use the Properties dialog box to change your map names to something memorable and descriptive – you don't want to mix them up.



Visual Guide Figure 2.14. Opening the properties dialog box.

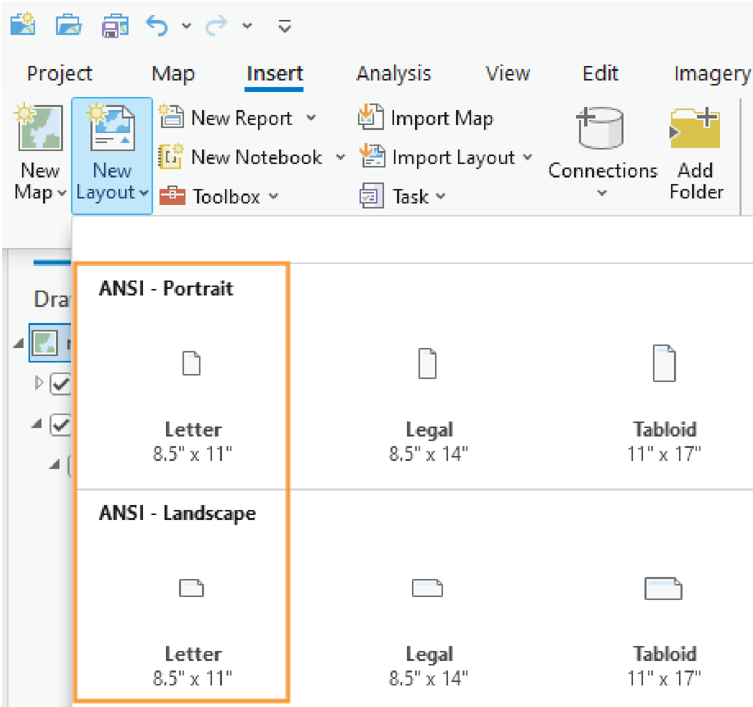
Some ideas for descriptive map names are shown below:



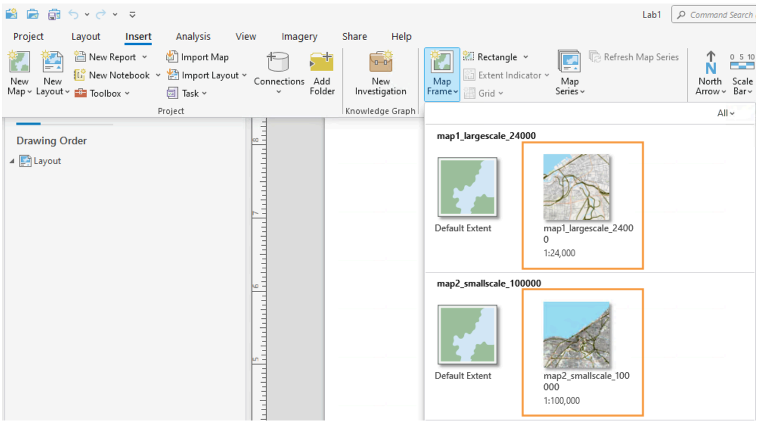
Visual Guide Figure 2.15. The properties dialog box – creating descriptive map names.

5. Add each map to a layout

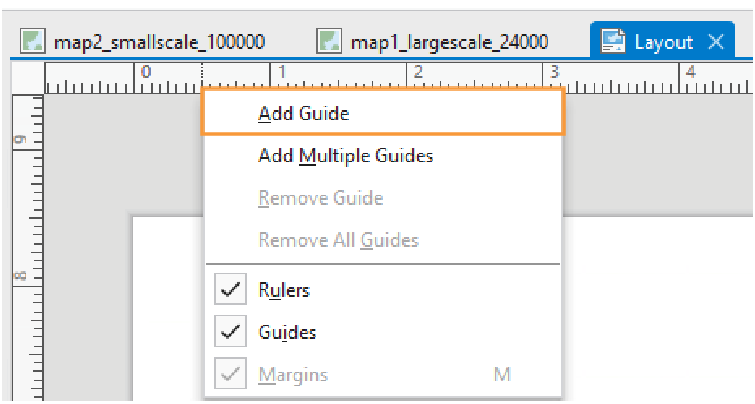
Use the Insert tab to create an 8.5″ by 11″ layout. Either Portrait or Landscape layouts are fine—but either way, use guides to create a ½ inch margin all around. Once you've created a layout, you can import your map as shown below. Use the labeled map rather than the "default" map to insert your map at the appropriate scale.



Visual Guide 2.16. Choosing a layout size.



Visual Guide Figure 2.17 Choosing a map frame to put in the map layout.



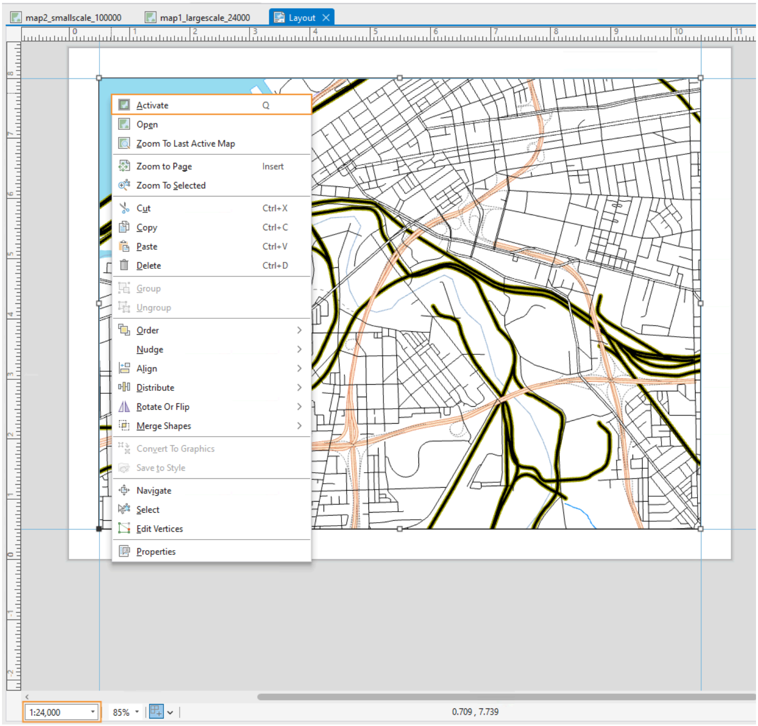
Visual Guide Figure 2.18. Adding guides to the map layout.

6. Finalize and save your layouts

Once you've added your map to a layout, you'll want to make some final adjustments.

- You'll need to activate your map as shown below to pan around the area.

- Make sure you've chosen an area of interest that suits the map requirements. It's ok to adjust your map's location at the end – when you designed your map symbols, they were automatically applied to the entire dataset.
- Whether or not your map is activated, you can adjust its scale at the bottom of the page.
- Make sure that you **toggle off any basemaps** before you submit your final maps. Except for your name, there shouldn't be any labels or text on the map.
- Note that the map in Visual Guide Figure 2.19 is **not well-designed at all** – it's intended only as an example of how to insert and activate a map in a layout.



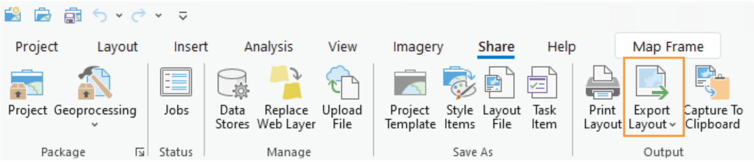
Visual Guide Figure 2.19. Activating the map and changing the scale.

The final step is to export your maps as PDFs. Remember you will have **two** layouts, one for each map. Use the **Share** tab to export your layouts.

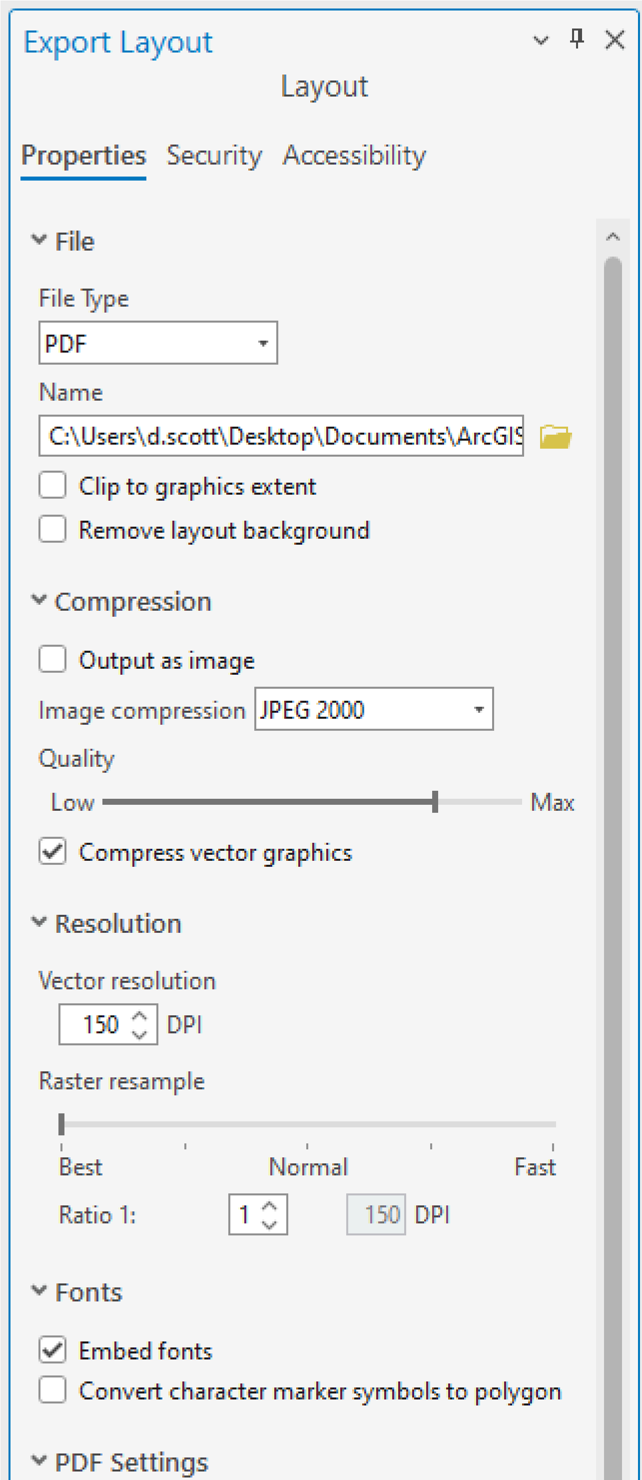
Considerations when exporting. For most maps, a 300dpi is fine. However, if you use

- **gradient area fills**
- **complex area patterns**
- **coastline effects**

then, change the resolution to **150dpi**. Otherwise, the file sizes will become extremely large and Canvas can't display these large file sizes. Once your PDF is exported, check the file size. You should keep your exported PDF's file size to less than 10MB. When I go to look at your maps, Canvas has a difficult time displaying files larger than 10MB.



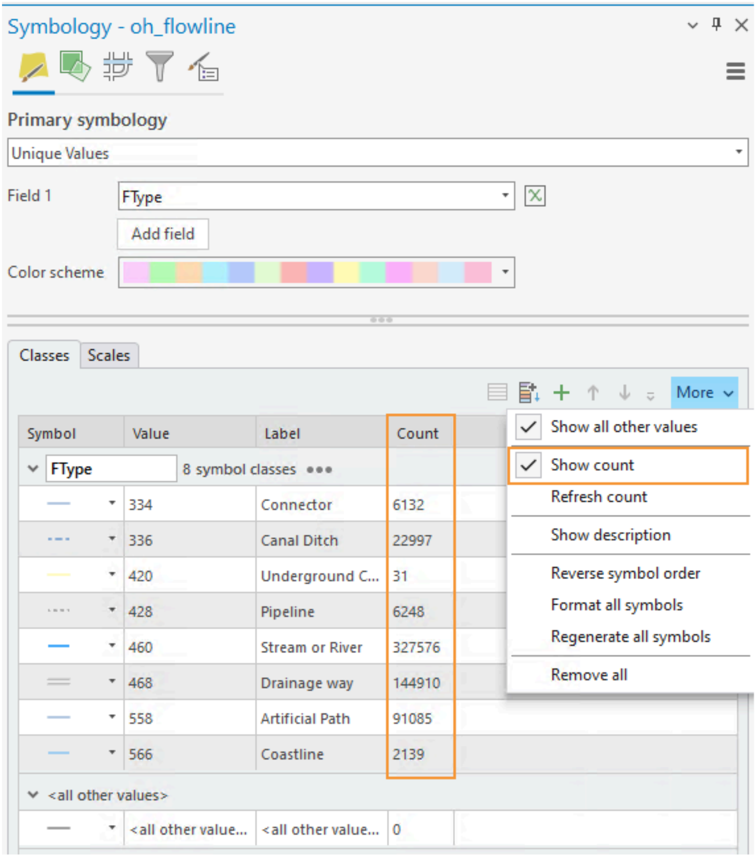
Visual Guide Figure 2.20. Export Layout button.


Export Layout
Layout
Properties
Security
Accessibility
File
File Type
PDF
Name
C:\Users\d.scott\Desktop\Documents\ArcGIS
Clip to graphics extent
Remove layout background
Compression
Output as image
Image compression
JPEG 2000
Quality
Low
Max
Compress vector graphics
Resolution
Vector resolution
150
DPI
Raster resample
Best
Normal
Fast
Ratio 1:
1
150
DPI
Fonts
Embed fonts
Convert character marker symbols to polygon
PDF Settings

Visual Guide Figure 2.21. Exporting a map layout.

7. Additional tips and tricks

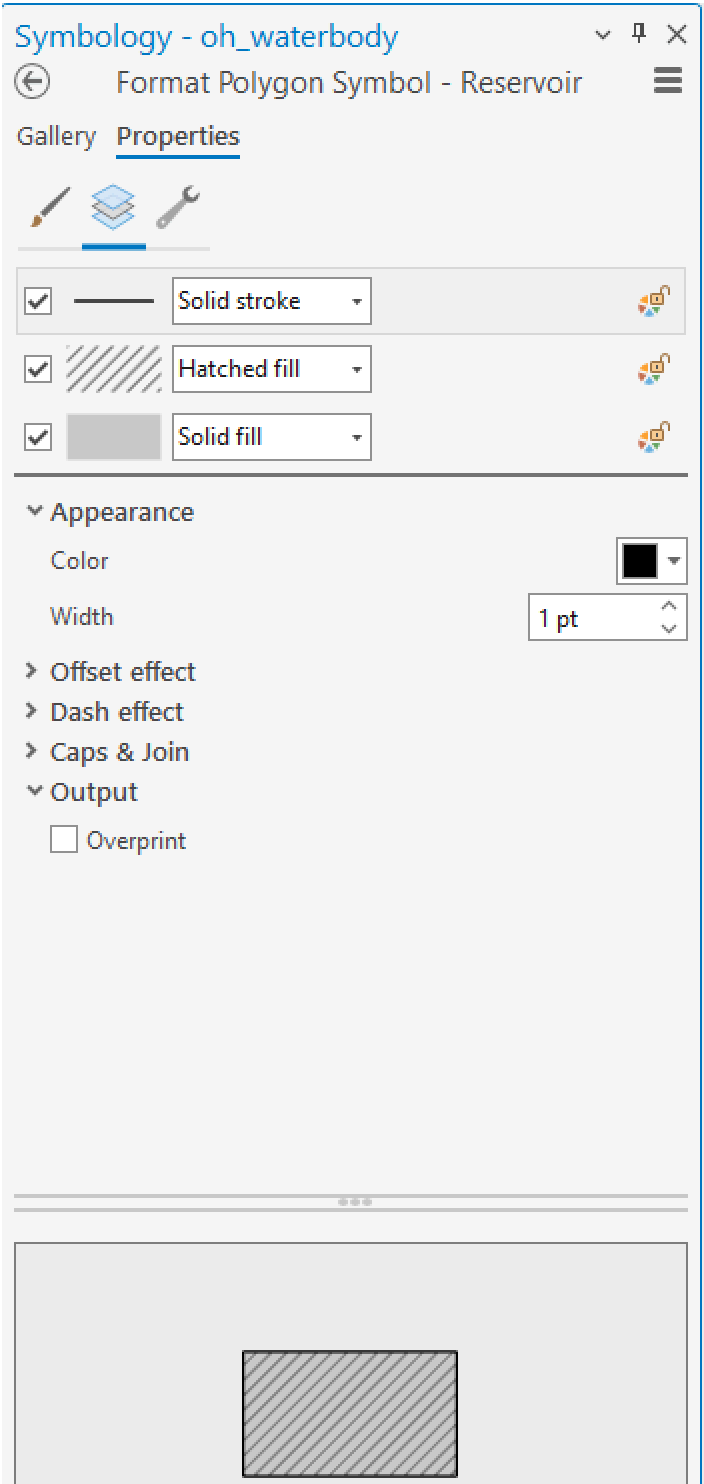
Use "Show count" to view how many of each feature type are included in the map data.



Visual Guide Figure 2.22. Toggling on the "Show count" option in the Symbology pane.

Remember to experiment with multiple layers, verify your map design meets all requirements, and design your

1:24,000 map in only greyscale and your 1:100,000 using color. Designing a map in greyscale may require you to be a bit creative with multilayer symbols and patterns – but that's a good thing! As shown in the example below, you can use different shades of grey and patterns or other fill ideas to create interesting map symbols.


Symbology - oh_waterbody
Format Polygon Symbol - Reservoir
Gallery
Properties
Solid stroke
Hatched fill
Solid fill
Appearance
Color
Width
1 pt
Offset effect
Dash effect
Caps & Join
Output
Overprint

Visual Guide Figure 2.23. Creating multilayer area/polygon symbols.

Data Source: The National Map.

Summary

In this lesson, we learned about designing with the purpose of the map in mind. You learned about the various considerations you need to think about when creating a map for a given audience. Examples of such considerations are the age and knowledge level of our audience along with audience members who might have low-vision. Finally, you learned on how you should plan a layout and how visual hierarchy of our features, balancing empty spaces and projections can affect maps.

II

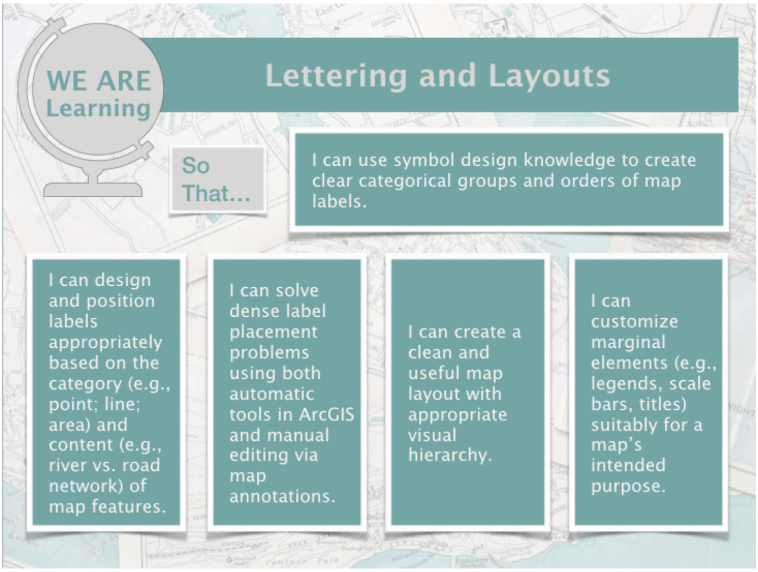
Lettering and Layouts

Overview

Welcome to Lesson 2! In the previous lesson, we learned the basics of map and map
symbol design, and created some general-purpose maps in ArcGIS Pro. This week,
we're going to focus on what we left out of those maps – most notably, place labels and
marginal map elements (e.g., scale bars, north arrows, etc.). We'll discuss typography
and the art of text-based elements: you'll learn how to classify and select appropriate
fonts, and how to apply this knowledge when creating place labels for maps. Then, we'll
focus on another important topic in cartography: the design of a map layout. You'll build
and customize a map legend, and practice designing with appropriate visual hierarchy
and balanced negative space.

In this week's lab, we'll be working from the maps we designed in the last lesson. That way,
you'll be able to focus on applying the new topics we have learned, rather than starting
from the beginning. By the end of this lesson, you will have learned how to create a
complete, well-designed general-purpose map from open-source data. In addition to
that being an achievement in itself, these general skills will prepare you for creating
more specific, topic-driven thematic maps in labs to come. By the end of this lesson,

you can use symbol design knowledge to create clear categorical groups and orders of
map labels.



By the end of this lesson, you should be able to: use symbol design knowledge to create clear categorical groups and orders of map labels; design and position labels appropriately based on the category (e.g., point; line; area) and content (e.g., river vs. road network) of map features; solve dense label placement problems using automatic tools in ArcGIS Pro; create a clean and useful map layout with appropriate visual hierarchy; customize marginal elements (e.g., legends, scale bars, titles) suitably for a map's intended purpose.

Text on Maps

Text on Maps

When you think of maps, you likely don't think much about text. In Lesson One, we defined *graphicacy*—the skill needed to interpret that which cannot be communicated by text or numbers alone—as distinct from *literacy* (Balchin and Coleman 1966). Despite this, map graphics are often augmented with text, either on the map itself (as in map labels), or in the margins (titles, legends, etc.) Thus, text plays an important role in map design.

View the map in Figure 2.1.1 below—can you immediately tell what is missing? Can you still recognize the location?

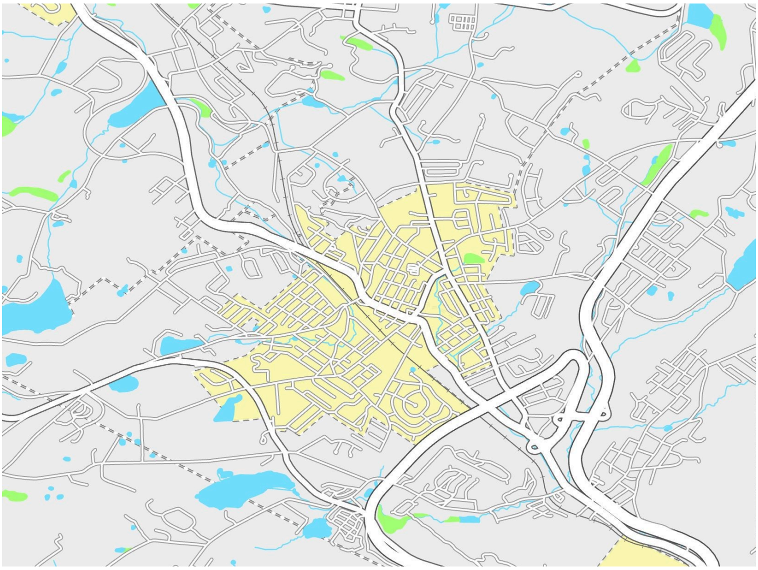


Figure 2.1.1 A general purpose map without labels. Credit: Cary Anderson, Penn State University; Data Source: The National Map.

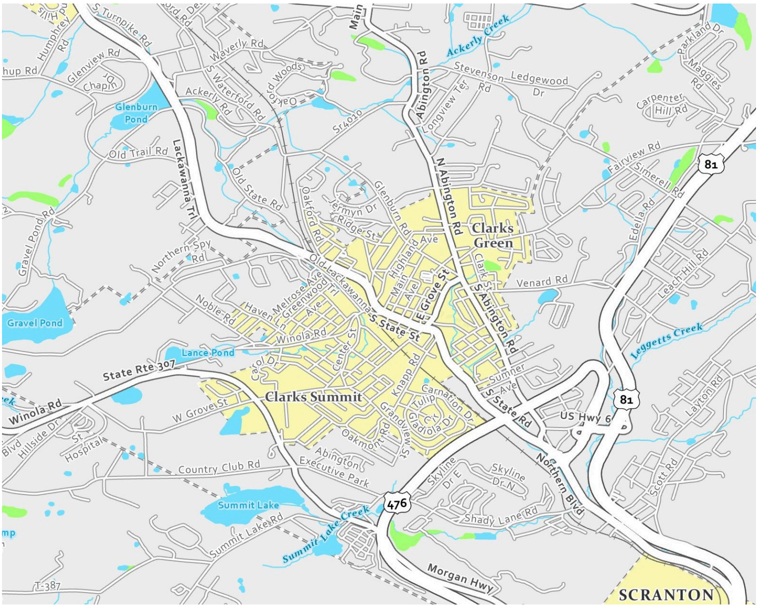


Figure 2.1.2 The map from Figure 2.1.1, now with labels applied. Credit: Cary Anderson, Penn State University; Data Source: The National Map.

As shown above, good label design often employs different colors, font styles, sizing, and more. Map labels play an important role in mapping—not only by labeling symbols, but also by serving as symbols themselves. In this lesson, we'll learn about the many design effects that can be used to make appropriate text symbols and aesthetically pleasing designs.

Text on maps, as seen in Figure 2.1.1 above, often refers to place names. The study of geographic names is its own subject of study. A commission within the International Cartographic Association (ICA) is dedicated to toponomy, or the study of the use, history, and meaning of place names. If this interests you, you can learn more about toponomy and the ICA on the ICA website.

Particularly in thematic mapping, text is employed not just to identify places, but to explain data. In Figure 2.1.3 below, text is used in the making of map legends, scale bars, and so on. Despite this map's careful color and layout design, without text—it would be unusable.

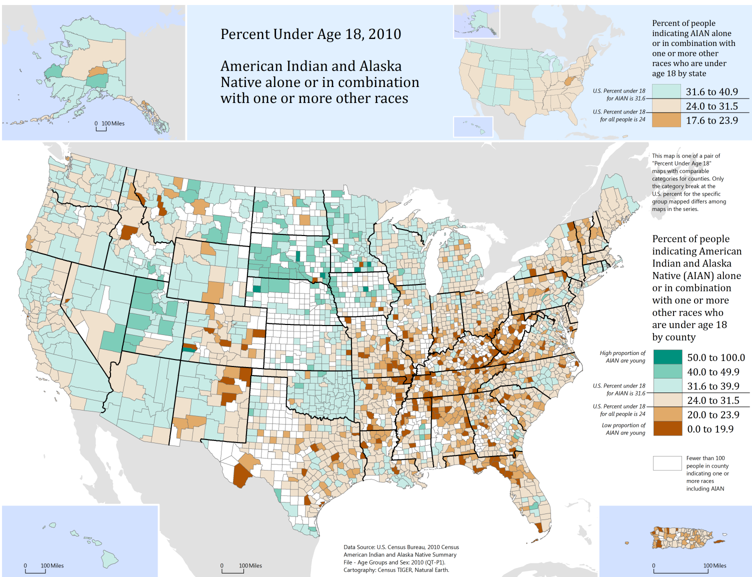


Figure 2.1.3 A map layout with significant accompanying text. Credit: US Census Bureau. Made with Natural Earth. Map updated by P. Limpisathian, Penn State Geography.

Student Reflection

Place naming is often a contentious and complicated task. Can you think of a place that is referred to differently by those who live there than by those who do not? How do these different names influence the identity of this place?

Typographic Design

> "The choices of fonts for uses can be seen as related to the personality of the fonts. The Script/Funny fonts scored high on Youthful, Casual, Attractive, and Elegant traits which are all related to Children's Documents and artistic elements. The Serif and Sans Serif fonts were seen as more stable, practical, mature, and formal; the uses they are appropriate for fit these characteristics." (Shaikh, Chaparro, and Fox 2006)
>
> "Make it easy to read." – Roger Black

There are many elements to consider when designing text for maps. As a cartographer, you want your text to be clearly legible against the map background, be appropriate for the features you are labeling, and match the overall aesthetics of your map.

As you start designing labels, it is best to learn a bit about typographic design.

A **typeface** is a design applied to text that gives letters a certain style. An example of a typeface is Arial. Many typefaces contain multiple fonts, so typefaces are sometimes called font families. For example, the Arial font family contains several fonts, including Arial Black and Arial Narrow (Silverant 2016). Though it is technically incorrect to do so, the words typeface and font are often used interchangeably. It is less important to understand this nuance than to understand how to apply fonts in practice.

Classifying Fonts

Fonts can be classified in several ways. For example, as text fonts vs. display fonts (Figure 2.2.1).

Text fonts are designed to be simple and legible: examples include Arial, Calibri, Cambria, and Tahoma. Display fonts are decorative fonts like Stencil, Curlz MT, Bauhaus 93, and Castellar. These fonts are often used in branding and for advertisements. Use these fonts with caution, and sparingly on maps. They are perhaps appropriate for a map title, but for little else (Brewer 2015).

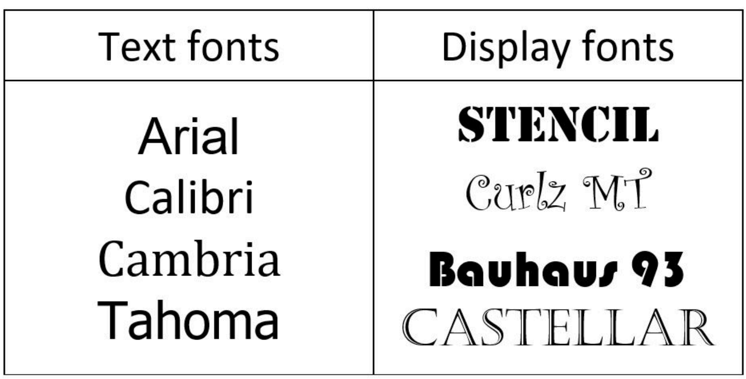


Figure 2.2.1 Examples of text and display fonts. Credit: Cary Anderson, Penn State University.

Possibly the most common way to classify fonts is as **serif** or **sans-serif** (Figure 2.2.2). **Serifs** are small strokes added to the end of some letters in a font, such as in the widely-recognized font Times New Roman. Sans-serif fonts do not contain these small strokes. Sans-serif fonts as sometimes viewed as informal, modern, and best suited to digital formats; serifs are often described as best for formal print production. These general guidelines, however, are less important than the specific context in which you use a font. In map design, pairing a serif and a sans-serif together in a map often works best.

Serif fonts	Sans-serif fonts
Cambria Constantia Times New Roman	Arial Calibri Seguoe UI

Figure 2.2.2 Examples of common serif and sans-serif fonts. Credit: Cary Anderson, Penn State University.

Though the presence or absence of serifs may be one of the most obvious characteristics of a font, there are many design factors that influence a font's style. Figure 2.2.3 below illustrates many of the different components of type design. Changes to these elements create the difference between different font styles.

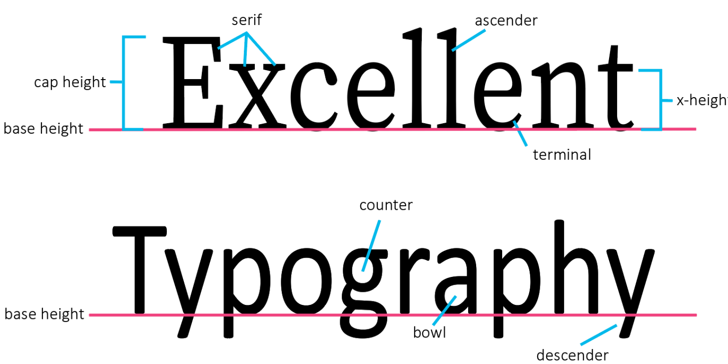


Figure 2.2.3 Elements of text. Credit: Cary Anderson, Penn State University.

Student Reflection

Browse the web—or your closet—looking for logos and similar advertisements that employ text as part of their branding design. How does the style of a font change your perception of that brand or item? Do you notice any that work particularly well? Why is this?

There are a wide number of web resources available for learning more about typography—some are linked in the recommended reading section of this lesson topic. Much of this advice, developed for graphic designers, journalists, and others, will also apply to text design for maps. In *Designing Better Maps*, Cynthia Brewer (2015) outlines several features of fonts that make them particularly useful for cartographers. You should keep these in mind when selecting fonts for your maps.

1. A large font family (i.e., the availability of many fonts within a single typeface):

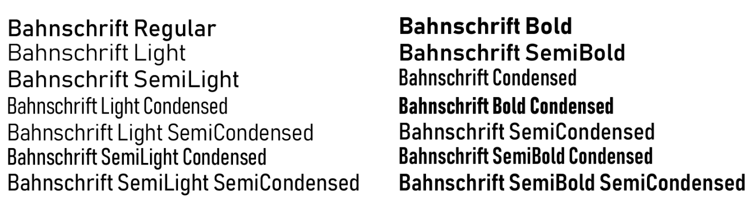


Figure 2.2.4 Many fonts are available within the Bahnschrift typeface. Credit: Cary Anderson, Penn State University.

As shown in Figure 2.2.4, some typefaces contain many font variations. This can be very useful for map labeling, as it permits the cartographer to create distinct labels for different types of features while maintaining a consistent look and feel throughout the map.

2. Italic as a separately installed font:

Figure 2.2.5 Integrated vs. applied bold and italics Credit: Cary Anderson, Penn State University.

You are likely quite familiar with the use of bolding and/or italics to create distinct font styles. A distinction of note, however, is shown in Figure 2.2.5—the difference between an italic and bold *font*, and bold and italics as applied afterword by a word processing program such as Microsoft Word. Though applied italics and bolding (Figure 2.2.5; right) will work in a pinch, bold and italic fonts designed as a separate font style (Figure 2.2.5; left) take specific characteristics of the typeface into careful account when applying these styles, typically resulting in improved aesthetics and legibility.

3. Text that is readable at small point sizes and at angles:

Unlike when writing a paper, where most of your text is horizontal and of similar size, the variability of text sizes and angles on a map presents and additional challenge to cartographers. As you will likely use a font in many different instances on your map, a good font choice is one that remains legible when angled and printed small or viewed from a large distance.

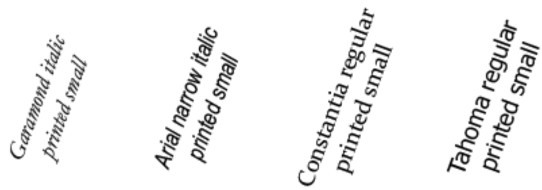


Figure 2.2.6 Comparing small, angled fonts. Credit: Cary Anderson, Penn State University.

4. A large x-height:

X-height has a simple definition – the height of a lowercase x.

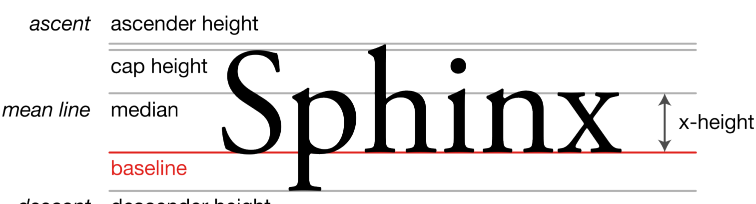


Figure 2.2.7 A demonstration of x-height for the Adobe Garamond typeface Credit: Max Naylor, public domain.

A small x-height results in greater distinction between different letters, which is helpful when reading a block of text. When creating labels for maps, however, a large x-height is typically preferred, it results in fonts that are easier to read when printed small on a page.

5. Distinction between a capital i, lowercase L, and number 1:

This one is self-explanatory, though it may not always be possible (e.g., when using most sans serif fonts). Legibility is improved when the reader can tell immediately whether a letter is an uppercase i, lowercase L, or a number 1. The same goes for distinguishing between a zero and an uppercase O. Though typically a zero is shown as a thinner ellipsoid, in some fonts this difference is more distinct than in others.

In addition to selecting proper fonts, there are many design details that can be applied to improve your map labels. These include text color, halos, and shadows, as well as changes to character spacing and sizing.

A halo is often helpful, particularly against busy backgrounds, for helping text display over the background of a map. Halos are distinct from outlines, as they are placed behind text—and they are typically a better choice for legibility, as they do not interfere at all with the text itself (Figure 2.2.8).

Figure 2.2.8 A white halo (left) vs. a white outline (right) of equivalent weight; font: Corbel Bold. Credit: Figure by Cary Anderson, Penn State Geography, Data Source: The Kansas Data Access & Support Center.

Halos are not always as pronounced as the one shown in Figure 2.2.8. Choosing a halo that blends in with the background color of the map creates a subtle look that doesn't call attention to the halo, but still sets the text legibly apart from any lines that may cross beneath it. See Figure 2.2.9 below – a subdued yellow-green halo blends into most of the background but prevents contour lines from obscuring the legibility of the interval numbers.

Figure 2.2.9 Simple contour labels (left); improved legibility with a subtle halo (right) Credit: Maps by Cary Anderson, Penn State Department of Geography, Data Source: The National Map.

Many text effects are available in ArcGIS, and in graphic design software such as Adobe Illustrator. Experiment with text effects when designing your maps, and don't be afraid to move beyond default settings to create more engaging, legible, and attractive maps.

Creating Symbols with Labels

We learned about visual variables in Lesson One and applied those ideas to create general purpose maps. For example, you might have used different line weights to create hierarchies of road features, or different hues and/or patterns to differentiate between types of waterbodies. In this lesson, we apply these same ideas to text.

Student Reflection

Look at the labels on the map in Figure 2.3.1. Which show categorical differences from others? Which show order differences? Which show both?

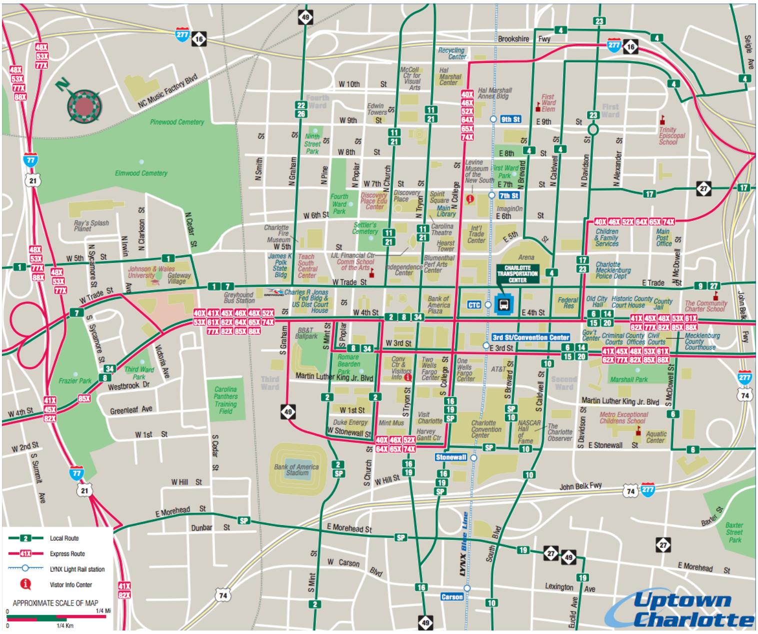


Figure 2.3.1 A map with label symbols. Credit: [Charlotte Area Transit System](), Charlotte, NC. (click the source for a bigger image!)

When designing labels to show order (e.g., population size, (road) speed limit), choose text characteristics that demonstrate differing levels of importance, such as those shown in Figure 2.3.2.

Point Size	Weight	Lightness	Character Spacing
London Manchester Nottingham	**Paris** Bordeaux	**I-678** **JFK Expressway** **148th St**	TROUT LAKE R O U N D L A K E

Figure 2.3.2 Examples of font characteristics to show order. Credit: Cary Anderson, Penn State University.

When designing labels to demonstrate category, choose text characteristics that demonstrate difference, but not importance or order (Figure 2.3.3).

Typeface	Posture	Color Hue	Arrangement
Paris Berlin	*Nottingham* Bordeaux	JFK Airport Central Park Times Square	Saratoga Lake Round Lake

Figure 2.3.3 Examples of font characteristics to show category. Credit: Cary Anderson, Penn State University.

As with symbol design, it may often be prudent to use both types of characteristics together—creating labels that show both order and category. When designing labels, be cautious to attend to the aesthetics of your map, and avoid over cluttered or overcomplicated design. It often looks messy to use more than two fonts on a map, so try to stick to two: as noted previously, pairing a serif and a sans-serif font that look good together often does the trick.

Label Placement

Ideal label placements are always context dependent—many factors, such as the density of map features or character length of place names, will determine the best way to place your labels. Even so, it is helpful to understand best-practice guidelines for placing labels on maps. In this section, we will learn how best to place map labels for point, line, and area (polygon) features. As a cartographer, you will apply these guidelines using both automatic labeling procedures in GIS software and though the manual editing of graphic text.

Point labels

When placing point labels, two factors are of primary importance: (1) legibility, and (2) association. You don't want your reader to struggle to read your map labels, and it should always be clear to which point each label refers.

The first guideline to remember is that adding point labels is not like making a bulleted list—your labels should be shifted up or down from their associated point feature. An example ordered ranking of label placements for point feature labels is shown in Figure 2.4.1.

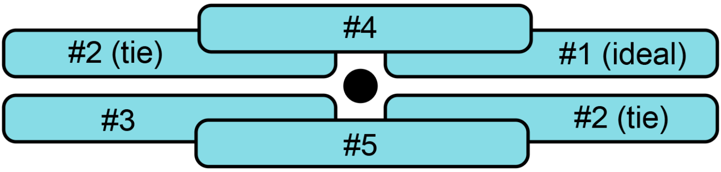


Figure 2.4.1 Ranked locations for placing point symbols. Credit: Cary Anderson, Penn State University. Rankings adapted from (Brewer, 2015; Field, 2018).

Though the placement ranking guidelines in Figure 2.4.1 provide a good starting point, it is notable that cartographers do not always agree on this specific order. If you are a very astute reader, you may notice that these recommendations vary slightly from the point label placement guidelines given by Field (2018) in this week's required reading. Cartography is not only a science but an art, and sometimes there is more than one right answer. Additionally, while such guidelines are helpful, label placement is a continuous balancing act. Figure 2.4.2 (left) shows two labeled points, both placed at the ideal label position shown in Figure 2.4.1. This arrangement of point labels, however, makes it seem ambiguous to which point "East Gate Shopping Center" refers. In Figure 2.4.2 (right), this label is moved to the second position. The ambiguity disappears.

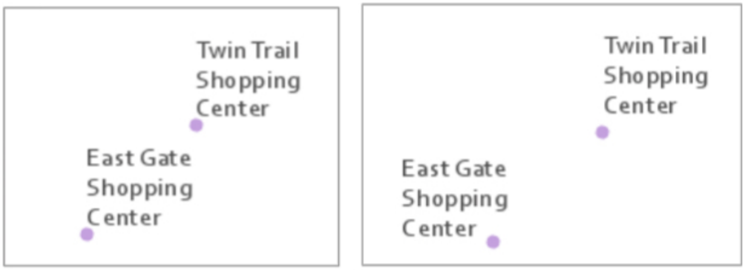


Figure 2.4.2 (left) ambiguous label placement, (right) improved label placement. Credit: Cary Anderson, Penn State University; Data Source: The Kansas Data Access & Support Center.

In addition to the orientation of point labels, you will also need to decide how closely to place them to your point features. In the left image, labels are placed very close to points, while on the right, labels are placed at a greater distance from their associated point symbols. Though map elements that appear too tightly packed are generally undesirable, how closely your labels and points are placed will depend on the size, shape, and density of your labels, points, and map. Most important is maintaining consistency throughout your map design.

Another important consideration is when and where you will apply line breaks to the text on your map. When it fits on the map, showing the entire label on one line (Figure 2.4.3; left) is appropriate. However, due to the density of map features and length of feature names, this is often not possible.

Figure 2.4.3 Making thoughtful line breaks for point labels. Showing the entire label on one line (left); confusing breaks (middle); thoughtful breaks (right). Credit: Cary Anderson, Penn State University; Data Source: The Kansas Data Access & Support Center.

When line breaks are used, place them at natural breaks in the feature name. For example, Mission Hills Country Club looks strange as Mission/Hills Country/Club (Figure 2.4.3; middle) but natural as Mission Hills/Country Club (Figure 2.4.3; right). You should also use spacing between lines that is smaller than the spacing between other labels on the map, clearly demonstrating that these lines of text belong together.

Point labeling is further complicated when labeling multiple types of point features. Your goal should be again to avoid ambiguity—labels should help demonstrate feature categories. As shown in Figure 2.4.4, it is best to label land features on land, and coastal features in water.

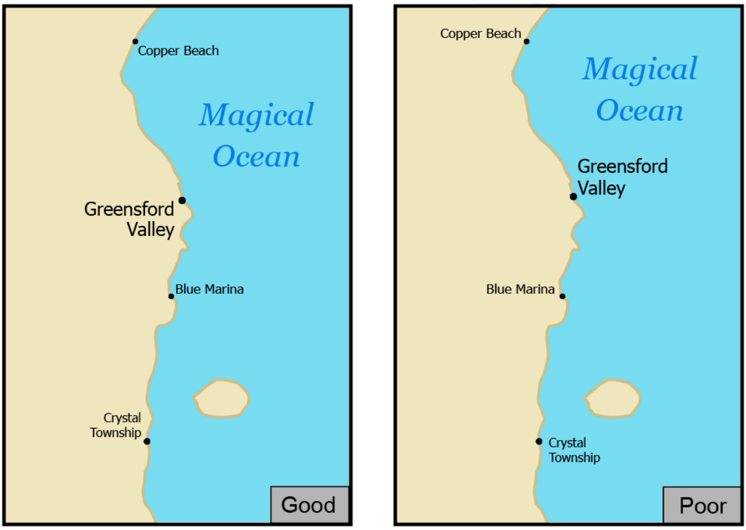


Figure 2.4.4 Land labels should stay on land; coastal feature labels should be placed in water. Credit: Cary Anderson, Penn State University.

Label design is about the details, and often very small changes to label placements can really improve the readability of your map. Figure 2.4.5 below shows how a couple of small edits were used to improve a set map labels. From left to right, line spacing within the "Shawnee Nieman Center" label was decreased to -2 pts., and then the "Nieman Plaza label" was shifted to the left.

Figure 2.4.5 (left) ok label placement, (middle) better, (right) good. Credit: Cary Anderson, Penn State University; Data Source: The Kansas Data Access & Support Center.

Note that though counterintuitive, the use of -2 line spacing, or leading, does not create overlapping lines. Negative leading is generally recommended for multi-line labels—too much space between lines makes them look disjointed, which may cause map readers to incorrectly perceive them as separate labels (referring to separate features).

Line Labels

When labeling line features, similar guidelines as for point labeling exist—**design for association, but not at the expense of legibility**. Labels should generally follow line features—but not cross over perpendicular lines—as this makes the text harder to read. In some instances, this advice will not be practical, but it is best to first learn the rules so you can more thoughtfully break them.

Figure 2.4.6 shows two maps with labeled streets; the right-sided image is a definite improvement. Unlike in the left map, labels in the right map are aligned with streets and do not cross other lines. Labels in the right map are also better aligned for the eye to understand the naming conventions of the neighborhood: see W 100th Ter, W 101st St, and W 101st Ter, from North to South (maps are North-up). It is much easier to understand this progression in the right map. This sort of line placement is also useful when labeling contour lines, which have an even more important orderly progression.

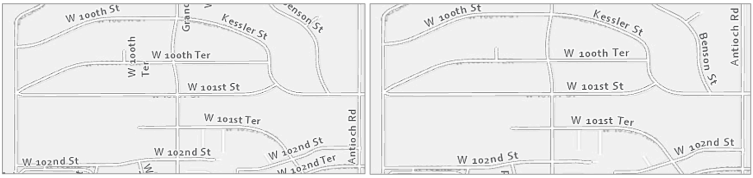


Figure 2.4.6 Improved street label placements (left to right). Credit: Cary Anderson, Penn State University; Data Source: The Kansas Data Access & Support Center, ArcGIS Pro 2.0 Light Grey Canvas Basemap.

In lieu of map labels, shields are often used to label highways and other important roads. Though interstate shields in the US are consistent, many states have unique highway shield designs. Using these custom shields in your maps is not always practical, but it can give them local character, and create a better match between the map and the real world.

Figure 2.4.7 Distinct US State Highway Marker Shields. From left to right: Utah, Louisiana, Washington, and Minnesota. Credit: Public domain, wikimedia commons. Figure updated by Cary Anderson, Penn State University.

Similar but additional guidelines exist for labeling non-road line features, such as flowlines. Streams, rivers, and other waterlines should be labeled with text that shows their categorical difference from road features. This is often done with italics (text posture), and/or by using a hue that matches the feature symbol. Figure 2.4.7 shows several examples of labels applied to the stream “Little

Cedar Creek". The label in the map at the left is legible but does not follow the flow of the creek—it looks rigid, as if it is a road label. In the middle map, the label does follow the creek, but this time too much so—it is difficult to read. The label placement in the far-right map is best—a gentle curve makes it clear that this label refers to a water feature, but not at the expense of legibility.

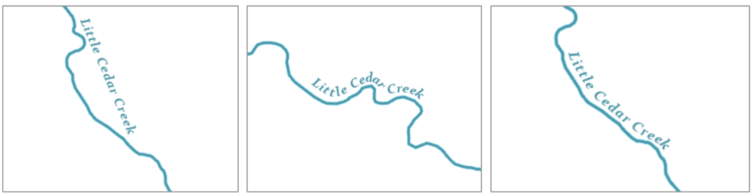


Figure 2.4.8 Poor river label placement (left and middle); Better label placement (right). Credit: Cary Anderson, Penn State University; Data Source: The Kansas Data Access & Support Center.

Figure 2.4.9 contains additional examples of line label improvements. Three general guidelines are demonstrated by this figure: (1) follow the feature, but not at the expense of legibility, (2) place labels above lines rather than below, (3) don't write upside down.

If a line feature is quite long, the label will need to be repeated periodically. The interval at which your line labels repeat is up to you as the map designer and will depend on the map's feature density, audience, presentation medium, and purpose.

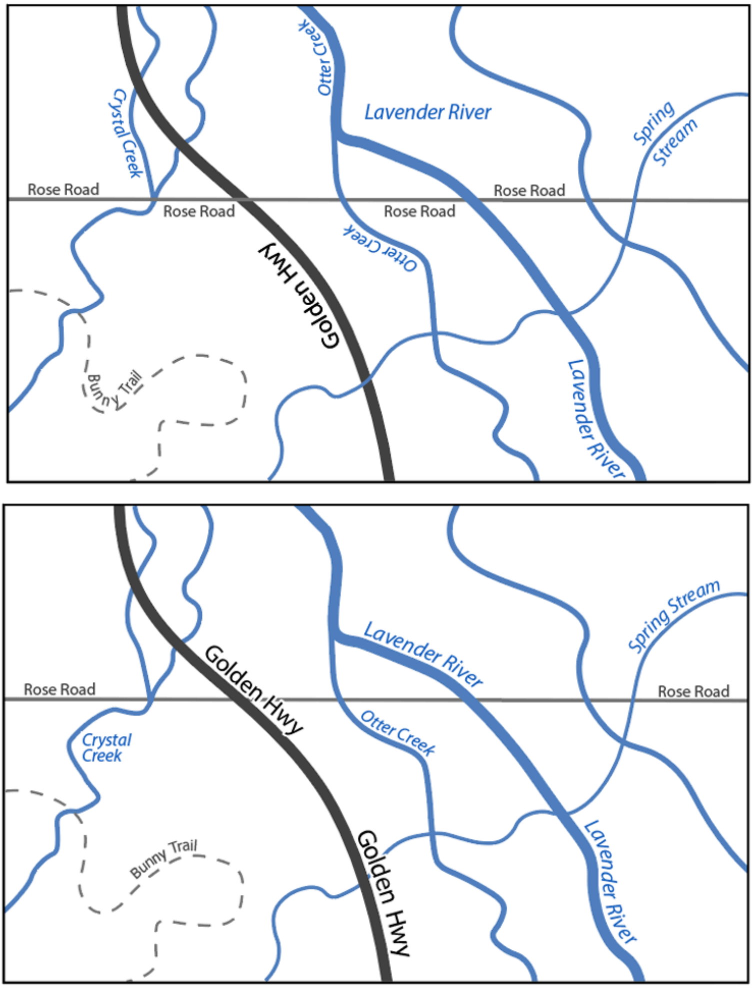


Figure 2.4.9 Line label placement – Poor (top), Improved (bottom). Credit: Cary Anderson, Penn State University.

Area labels

Just as rivers are labeled with curves to follow the flow of water, area features should be labeled in a way that highlights their most characteristic feature: extent. Labels for natural features such as water bodies and mountain ranges should demonstrate their physical extent across the landscape. Use UPPERCASE letters and stretch the label across the area of the feature.

Figure 2.4.10 Improved area label placement (left to right). Credit: Cary Anderson, Penn State University; Data Source: The Kansas Data Access & Support Center.

When covering areal extent with labels, focus on finding a balance between character spacing and size. Increasing spacing is generally best—recall that increased font size suggests increased importance. To cover the extent of a feature, however, you may want to increase font sizing somewhat—too distant spacing with a small font size is likely to be challenging to read.

A common mistake to avoid is aligning area labels horizontally across the map frame. Though horizontal alignment is helpful when reading large blocks of text, this design is off-putting when viewed on a map (Figure 2.4.11; top). Stagger area labels for increased legibility (Figure 2.4.11; bottom).


DOOLY
PULASKI
DODGE
WHEELER
TOOMBS
CRISP
WILCOX
TELFAIR
TURNER
BEN HILL
JEFF DAVIS
APPLING
IRWIN
COFFEE
BACON
WORTH
TIFT
BERRIEN
ATKINSON
WARE
COLQUITT
COOK
BROOKS
LOWNDEN
LANIER
CLINCH


PULASKI
DOOLY
DO DGE
WHEELER
TOOMBS
WILCOX
CRISP
TELFAIR
JEFF DAVIS
BEN HILL
APPLING
TURNER
IRWIN
BACON
WORTH
COFFEE
TIFT
BERRIEN
ATKINSON
COLQUITT
WARE
COOK
LANIER
CLINCH
BROOKS
LOWNDEN

Figure 2.4.11 Horizontally aligned (top) vs. staggered area labels (bottom). Credit: Cary Anderson, Penn State University.

Like regular line feature (e.g., roads, rivers) labeling, avoid labeling across boundary lines when prudent. When labels must cross over map lines, ensure that this does not compromise their legibility, nor overly obscure the feature underneath.

Figure 2.4.12 State boundaries as shown in OpenStreetMap's transit map. Credit: OpenStreetMap © OpenStreetMap contributors. The data is available under the Open Database License [CC BY-SA](#).

In some instances, particularly for political boundaries, it makes more sense to label the boundary of a feature, rather than its extent. You have likely seen this implemented in maps for navigation, or other interactive basemaps (Figure 2.4.12).

When labeling maps, you will often encounter locations with a lot of features in need of labels; this can pose a significant challenge. Leader lines can be used to connect features with labels that do not fit on or directly adjacent to their respective feature on the map. However, you should not overuse text halos, as these can obscure the map features underneath (Figure 2.4.13; top left). Nor should you overuse leader lines (as shown in Figure 2.4.13; top right)—this leads to a visually confusing map. Instead, find a balance between these techniques; experiment with label hue contrast and use leader lines sparingly. With practice, you will be able to create a well-balanced set of labels, such as shown in Figure 2.4.13 (bottom).

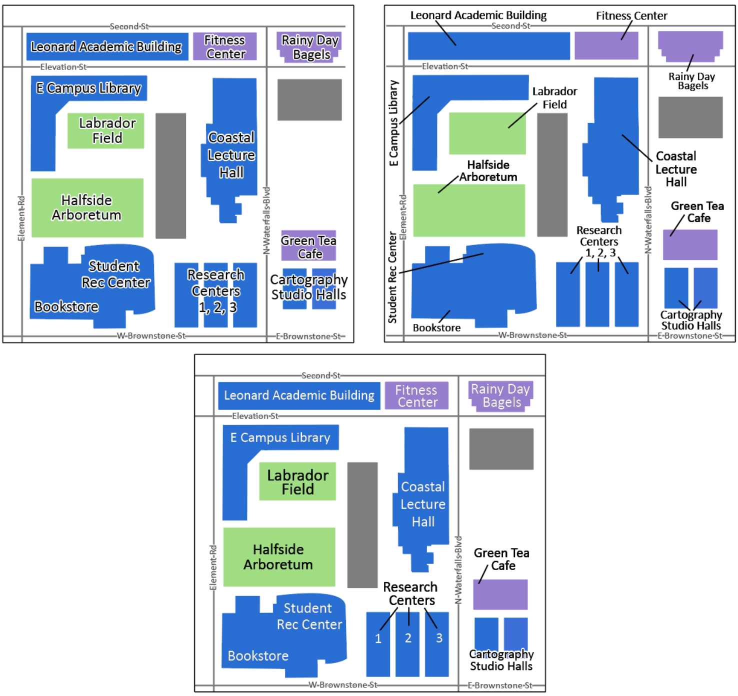


Figure 2.4.13 Techniques for labeling feature-dense locations. Credit: Cary Anderson, Penn State University.

Further improved cartographic design is shown in Figure 2.4.14. This map shows how text color contrast, sizing, and occasional use of leader lines can create a balanced, legible, and aesthetically pleasing map design—even in a complicated map with many labels.

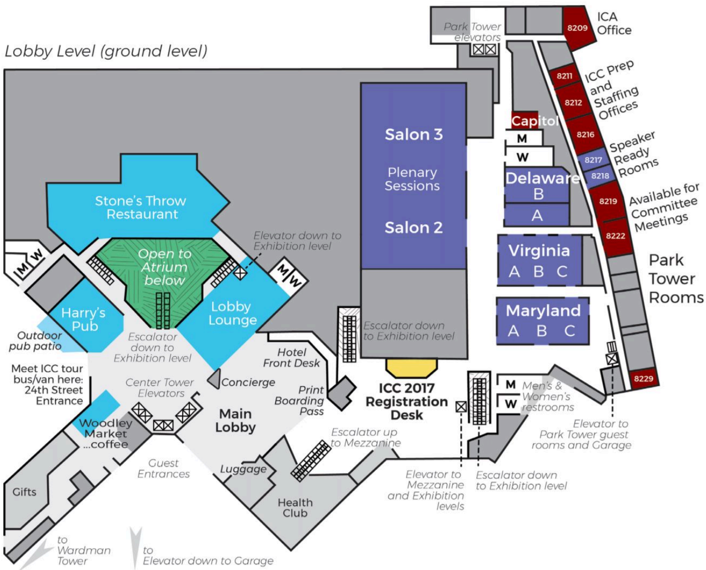


Figure 2.4.14 (also 1.2.7) Indoor map of the Washington DC Marriott from the 2017 International Cartographic Conference. Credit: Cary Anderson and Cindy Brewer. In-hotel walk throughs and detailed floor plans at www.marriott.com.

In summary: when creating a map feature label, balance different techniques, and continually ask yourself two over-arching questions: (1) Is the label clearly associated—both in style and positioning—with the feature being labeled? (2) Can I read it?

Layout Essentials

> "Design is as much an act of spacing as it is an act of marking." – Ellen Lupton, Thinking with Type

When designing a map layout, it is important to design using **visual hierarchy—**arrangement of graphic elements in a way that signifies their order.

The following map elements are listed by (Slocum et al., 2009) in their general order of importance:

1. Frameline and neat line
2. Mapped Area
3. Inset (e.g., locator map)
4. Title and Subtitle
5. Legend
6. Metadata (Author, Date when map was made, Data Source, Data Source Year)
7. Scale
8. Orientation (e.g., a north arrow)

Frameline

Most of these elements are intuitively named, but the difference between a map's **frameline** and **neat line** can be confusing. A frame line encloses all elements on the map layout, while a neat line crops the map area. A graphic explanation is shown in Figure 2.5.1. A frame line might also act as a neat line if all elements (e.g., legend, title) are shown within the map area (Slocum et al., 2009).

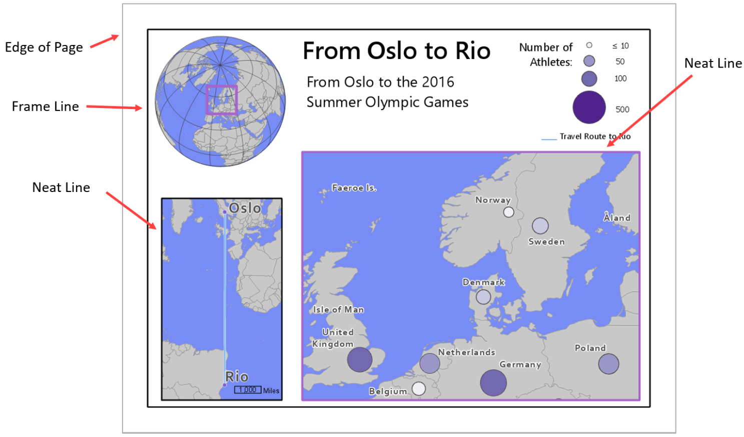


Figure 2.5.1 Neat lines vs. Frame lines. Credit: Cary Anderson, Penn State University. Data Source: Natural Earth and Wikipedia.

Organizing Space

It is typically efficient to place the most important features first, as they will take up the most space on the page. Be cautious, however, not to just start adding items wherever there are holes in the layout—good design is about *balancing* white space, which does not mean just filling it in. Often, the best way to find a good layout arrangement is to try many different arrangements and note what works. There will never be just one correct way to arrange all map elements.

When placing elements on the page, be cautious to leave enough space between them. For example, Figure 2.5.2 below shows how adding just a bit of negative space can result in a cleaner, clearer map design.

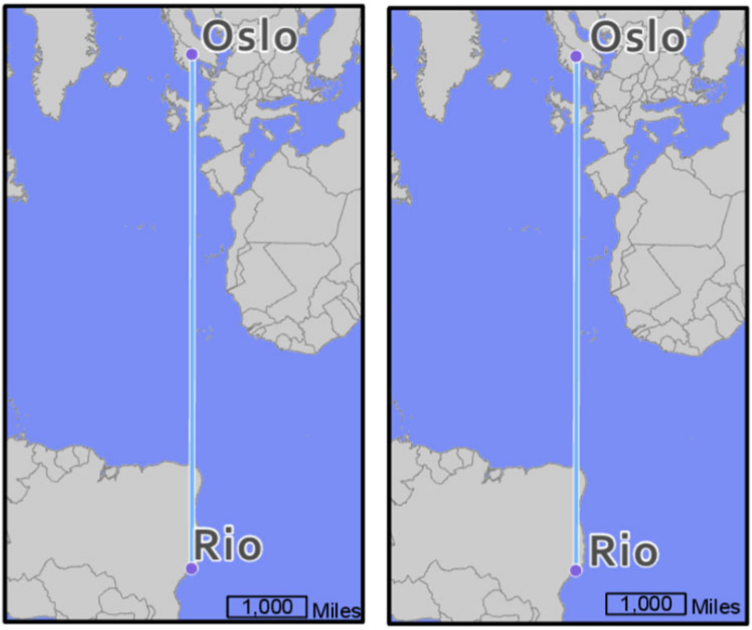


Figure 2.5.2 A map layout with pinched elements near the bottom (left); corrected (right) Credit: Map by Cary Anderson, Penn State Geography, Data Source: Natural Earth and Wikipedia.

Another important component of layout design is the intentional reduction of ambiguity. For example, if your layout includes multiple maps (e.g., a primary and a locator map), and multiple scale bars, it should be clear which scale bar is associated with which map.

Using boxes (e.g., boxed legends) will often seem like an easy solution, but you should use these sparingly, as they tend to create crowding and making aligning map elements more challenging. As you finish designing your layout, ensure that all elements are visually aligned. See the recommended reading below, as well as the required reading for this week, for additional detail and images of proper layout alignment and design.

Building a Legend

The part of your map layout that will likely require the most thought—except of course, for your map itself—is your map's **legend**. A map legend is a key composed of graphics and text that explains the meaning of any non-obvious map symbols. This *non-obvious* component is important to remember. Consider the general purpose map in Figure 2.6.1 below:

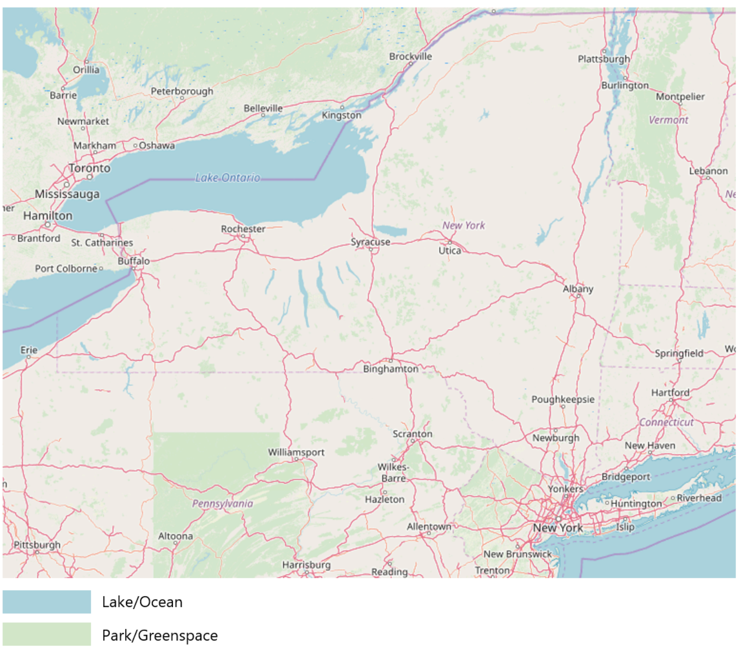


Figure 2.6.1 A map with an unnecessary legend Credit: Map by OpenStreetMap © OpenStreetMap contributors. The data is available under the Open Database License ([CC BY-SA](#)). Figure modified by Cary Anderson, Penn State Geography.

The legend isn't incorrect, but it doesn't help explain the map's already clear design. Did you need a legend to understand that the blue features were water? Every element in your layout takes up precious space—there is no need to waste it explaining symbols that your readers will understand without it.

The same principle applies when adding text to your legend, such as a legend title. Legend titles should be used to add context and explain your map. Don't title your legend "legend"—your reader will know it is a legend. If there's no better title then "legend", it doesn't need a title at all.

If your map does require a legend, use the same care to design it as you do with map symbols and labels. Be cautious of the way you create column breaks or other visual groups in your legend design. People tend to perceive groups of things as related – use this to your advantage in your legend design.

Figures 2.6.2 below shows a choropleth map with an accompanying legend. Though the legend accurately prints the map colors and their matching data values, the splitting of legend items across three columns breaks up the list in a way that may be confusing to the reader.

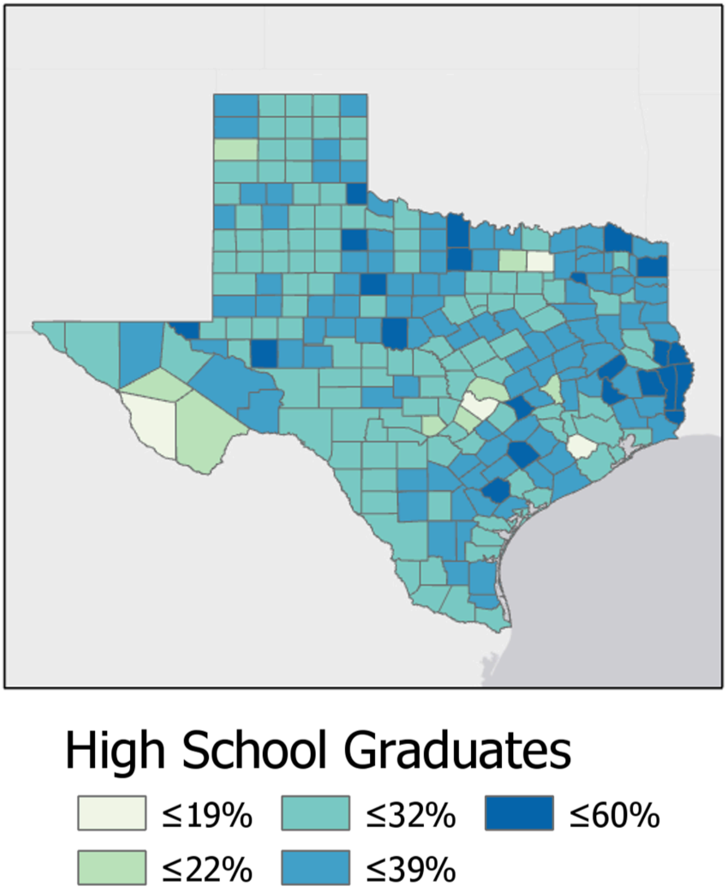


Figure 2.6.2 Poor legend design—visual discontinuity in legend items Credit: Map by Cary Anderson, Penn State University; Data Source: US Census

Below in Figure 2.6.3, the legend design has been much improved. A single column creates an easy visual representation of the color scheme for the reader.

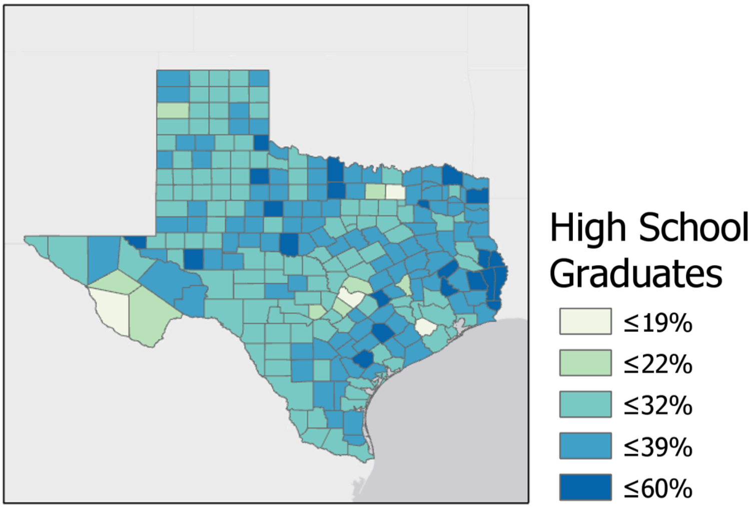


Figure 2.6.3 Improved legend design—a full column of color better demonstrates the trend of the data. Credit: Map by Cary Anderson, Penn State University; Data Source: US Census

For some legends, you will want not to eliminate column groupings, but to re-position or even create them. In Figure 2.6.4 below, inappropriate column groupings lead to ambiguity regarding the classification of some symbols. Are trails part of transportation, or are they their own category? What about streams? This legend leaves too much up to the reader to interpret.

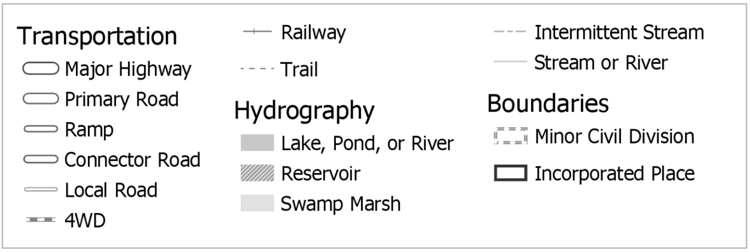


Figure 2.6.4 Poor legend design—column breaks are inappropriately located. Credit: Cary Anderson, Penn State University, Data Source: The National Map.

Figure 2.6.5 shows an improved version of this legend. Note that the different shape of the legend container means that it will need to be placed differently on the page—this highlights the importance of experimenting with layout arrangements throughout the design process.

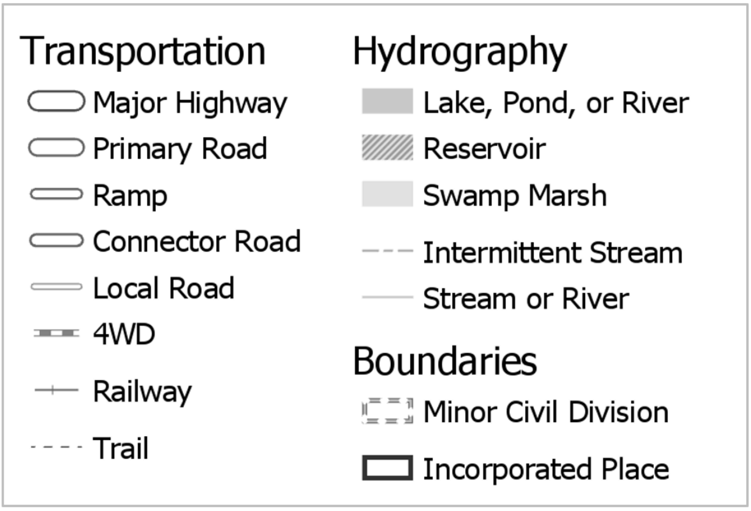


Figure 2.6.5 Improved legend design—symbol groupings easily interpreted. Credit: Cary Anderson, Penn State University, Data Source: The National Map.

Note that the examples in 2.6.4 and 2.6.5 contradict the *previous statement that obvious symbols like "lake" can be left off the legend. We will slightly relax this "only non-obvious features" guideline in order to practice creating well-designed legends, and due to the presumption that some of our symbol designs may stray far enough from cartographic convention to be nonintuitive to map readers.*

Marginalia Design

In addition to a legend, your maps will often contain other supporting graphic elements such as a scale bar and north arrow. Similar principles apply—you should make your design as simple as possible while still supporting the reader's understanding of the map. Commercial GIS software such as ArcGIS permits you to easily add accurate scale bars to your map. These will automatically match your map's scale, and dynamically update if you re-scale your map within your layout. When it comes to visual design, however—be wary of GIS defaults. You will typically have to make manual simplifications to these elements, scale bars in particular.

Figure 2.7.1 shows examples of default scale bar designs inserted into a map layout in ArcGIS, alongside illustrations of their appearance after manual adjustment.

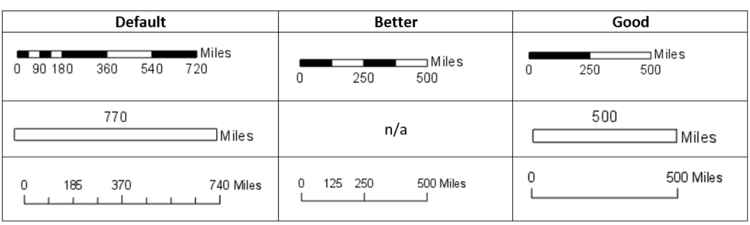


Figure 2.7.1 Adjusting default scale bars in ArcGIS Credit: Cary Anderson, Penn State University.

Like making a legend, the first question you should ask yourself before designing a north arrow for your map is: do you need it? Depending on the map projection you use, the direction which points north may not be consistent across your map—in this case, a background grid may be more appropriate. Most maps do use a north arrow, however, and if you do use one, similar conventions to scale bar design exist. Aim to make your design as simple as possible without sacrificing comprehensibility.

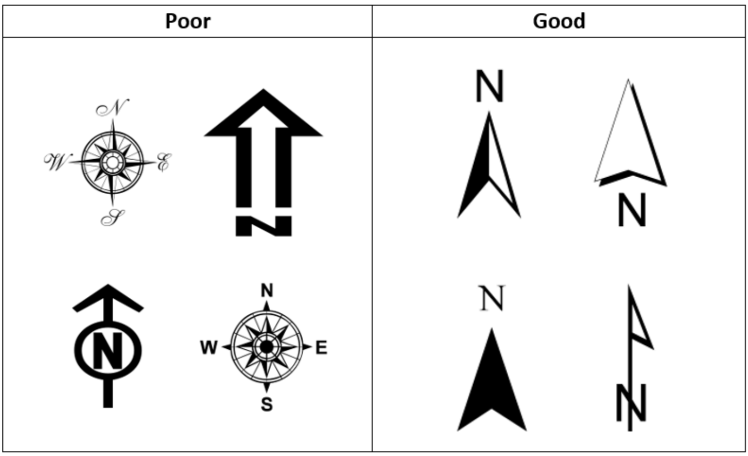


Figure 2.7.2 Choosing a north arrow in ArcGIS—generally: simple is better Credit: Cary Anderson, Penn State University.

Student Reflection

View the two scale bars in Figure 2.7.3. In general, as described in Figure 2.7.1, the top scale bar is considered better design. Can you think of a map for which the scale bar at the bottom would be more suitable? Why would it be?

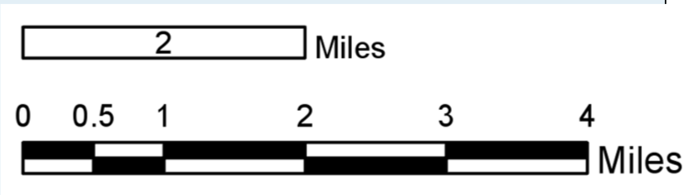


Figure 2.7.3 Two different scale bars created in ArcGIS Pro. Credit: Cary Anderson, Penn State University.

Lab 3: Lettering and Layouts

Total Points

20 points

Instructions

This week, we'll revise and combine our two maps from Lab 2 into one neat, well-designed layout with labels, a legend, and marginal map elements (e.g., scale bars, north arrow). You'll get to build off your hard work from last week and apply new knowledge from this week: typographic design, label symbology, and layout design.

Learning Objectives

- Create appropriate labels for map features using Maplex automated labeling tools in ArcGIS Pro.
- Apply labels to your maps from Lab 2, designing to show both category and hierarchy.
- Apply what you learned about multi-scale map design in Lab 2 by creating both a main map frame and an accompanying locator map.
- Use visual hierarchy when designing symbols, labels, a legend, and a layout.

Overall Lab Requirements

- Modify your maps from Lab 2 to create new maps – you will need to make significant changes for them to work at the new scales; you may start over from the beginning if you wish.
- The best approach is likely to design your main map first, then create a copy of this map which you will modify/generalize/redesign as appropriate for the smaller (1:1,000,000) inset map scale.
- Use these approximate scales: 1:40,000 for the main map, 1:1,000,000 for the locator map.
- Design over ArcGIS Pro's **World Topographic Map layer or similar basemap** – the same basemap we used in Lab 2 but please turn off the Esri basemap before submitting your lesson. For this lab, we will use the **Light Gray Canvas** basemap. You can add a new basemap by going to **Map** > **Basemap** and choose a basemap of your choice.
- Use color hue as you wish – be cautious to overuse it. There is no restriction on color use for this lab.

Labeling Requirements

- Coordinate label appearance with feature symbol design.
- Create label types with style settings; use SQL queries which will create specific feature label

classes.

- Remove all nonsensical labels, using SQL queries and other methods of feature removal.
- Use expressions to augment at least one category of labels with additional text and/or combine data attributes. Use label placement conventions for line and area features.

Layout Requirements

- Create two frames at different scales (main map and locator map). The main map should be larger in size than the inset map.
- Create appropriate marginal elements:
    - A north arrow for the locator map (confirm north is up in both map frames).
    - Two scale bars; use clean design and label with sensible numbers.
    - A legend; design its style, placement, and descriptive text.
    - A hierarchy of marginal text (e.g., title, subtitle, data source, your name, legend text, legend title) – not necessarily in this order.
- Create a balanced page layout (either portrait or landscape). Attend to negative space.

Deliverable

One map layout with a main map and a locator map

1. Map One: Primary Map (1:40,000)

- Examine your map and develop at least four or more label categories based on the map feature classes (e.g., Highways, Lakes, Streams, Boundaries, etc.). You can use other names for your label categories.
- Within each label category, create one more label classes. The label classes should demonstrate a hierarchy (e.g., interstate, collector road, local road, etc.).
- Create at least eight different label classes in total. You will likely have more label classes in some label categories than others.
- For this lab, a map feature class is considered different if defined differently in the data (e.g., local and collector roads have different MTFCC codes; lakes and reservoirs have different FTypes). Note that while some map feature classes have a different FType, for instance, this difference doesn't necessarily mean that those features need to have unique label designs (e.g., what is the practical difference between a lake and reservoir on your map?). You do not need to create a unique label class for every map feature class, just the eight in total as described above. Some of the geographic areas in LA, for example, don't have a tunnel.

2. Map Two: Locator Map (1:1,000,000)

- The locator map should be placed on the same layout as the main map.
- Label prominent map features as needed at this scale.
- Remember that this inset map is needed to provide locational context for people unfamiliar with the location you are mapping– design features and labels accordingly. Also, be judicious in how much information you show on your locator map.

Submitting Deliverables

Submit one PDF – all elements must be included on one 8.5 x 11 page. Use the naming convention outlined as follows: LastName_Lab3. You do not need to include a written statement or explanation with this lab assignment. Your layout will undergo peer review the following week as part of the discussion board assignment.

Lab 3 Rubric

Map 1 Primary Map: 14 points total

Criteria	Points
Scale should be 1:40,000.	2
Develop at least four or more label categories based on the map feature classes (e.g., highways, lakes, streams, boundaries, etc.). You can use other names for your label categories.	4
Within each label category, create one or more label classes. The label classes should demonstrate a hierarchy to a label category (e.g., interstate, collector road, local road, etc).	3
Create at least eight different label classes in total. You will likely have more label classes in some label categories than others.	4
The map is 8.5 x 11.	1
Total Points	**14**

Map 2 Locator Map: 6 points total

Criteria	Points
Scale should be 1:1,000,000	2
Should be placed on the same layout as the main map.	2
Label prominent features as needed at this scale.	2
Total	**6**

Lab 3 Visual Guide

Chapter 3 Lab Visual Guide Index

Part I: Labeling

1. Starting file
2. Finding names in your data
3. Adding labels to your map
4. Editing label classes
5. Designing label symbols
6. Positioning label symbols
7. Creating label expressions

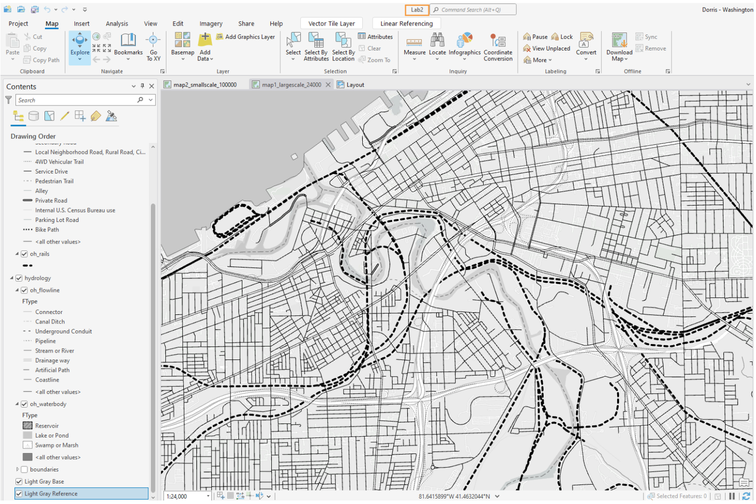
Part II: Layouts

1. Putting it all together
2. Build your layout
3. Add marginal elements
4. Create a legend
5. Final tips and tricks

Part I: Labeling

1. Starting file

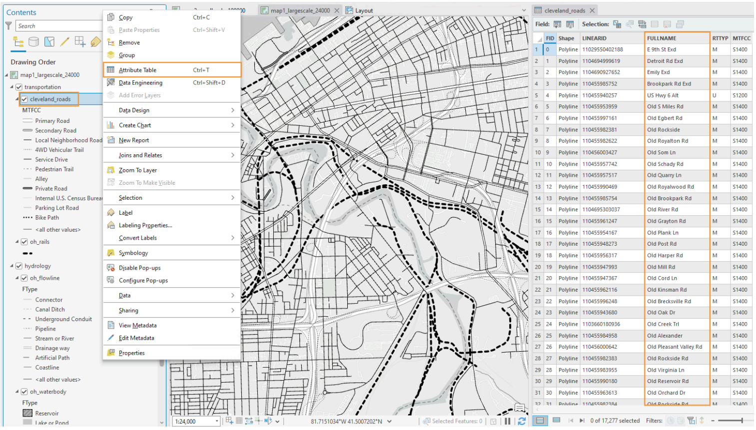
Start this lab by opening your project file from Lab 2. Use “Save As” to create a new project for Lab 2. After this, you’ll be ready to add labels!



Visual Guide Figure 3.1. Opening and saving your Lab 2 as a second file.

2. Finding names in your data

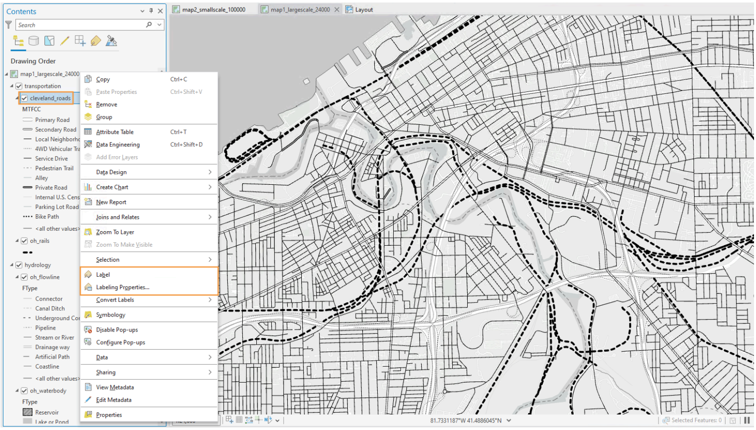
We do not have to write our own labels for map features – they’re already in our data – we just need to make them visible. Map features often contain multiple **fields** (data columns) with possible names, so we need to identify the best ones to use. To do this, open the attribute table for the layer you want to label. We can see the Full_Street_Name field seems like a good option to start with for this layer.



Visual Guide Figure 3.2. Searching the Roads attribute table for an appropriate field to use for naming.

3. Adding labels to your map

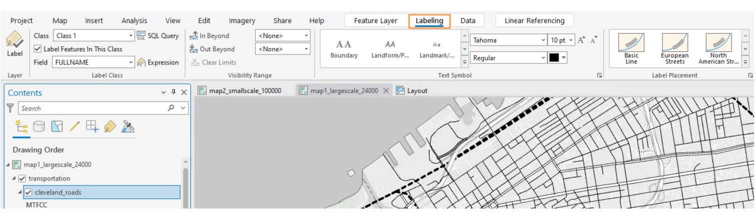
To turn on labels for a layer, right-click the layer and toggle labeling on. To edit the labels, open *Labeling Properties* as shown below. This will open the Label Class pane. In this pane, the **expression** box shows how your labels are being drawn from a field in the attribute table. In some cases, ArcGIS will correctly identify the best field to use for labels. In other cases, it will not, and you will have to alter the expression manually. We will use Full_Street_Name, the field we identified earlier.



Visual Guide Figure 3.3. Opening and editing labeling properties.

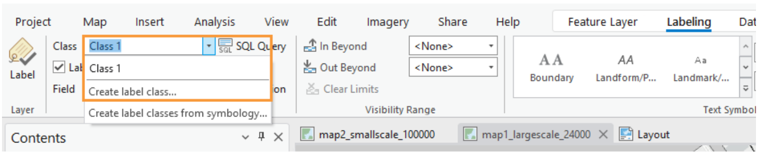
4. Editing label classes

Begin editing the style of your labels with the Labeling menu in the ribbon shown below. The default label symbols available are good starting points – they will help give you an idea of how to best design your own labels.



Visual Guide Figure 3.4. The labeling menu in the ribbon.

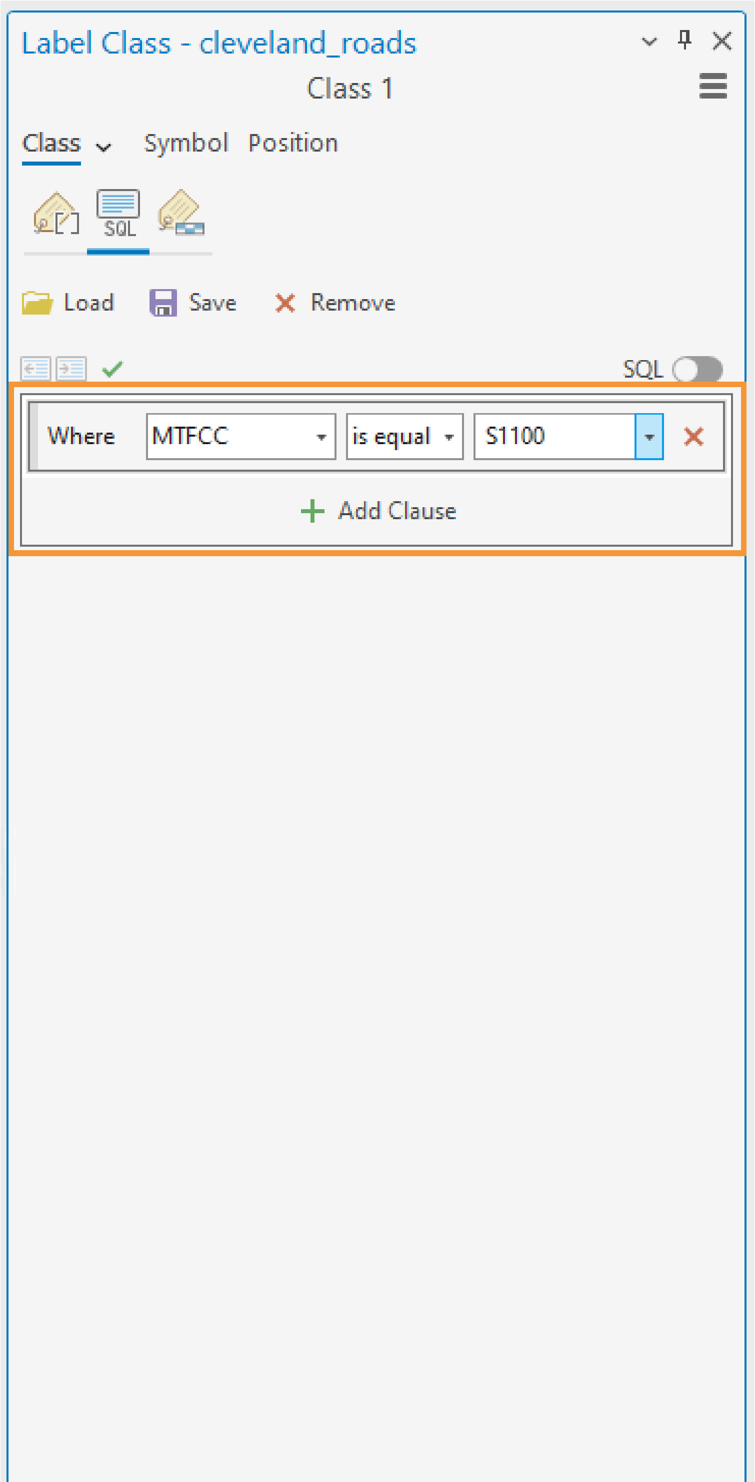
You should also create **label classes** using this top menu bar. Similar to when we classified roads by their MTFCC code in Lab 2, we create label classes so that we can create different *types* of labels within a feature category, and use these classes to design our labels with visual order and/or category.



Visual Guide Figure 3.5. Creating a new label class in the Labeling menu in the ribbon.

When you create a label class, all you are creating is a class with a name – ArcGIS will not automatically recognize, for example, that a label class named “Interstates” should only be applied to roads which are interstates. We will tell ArcGIS this using SQL (structured query language).

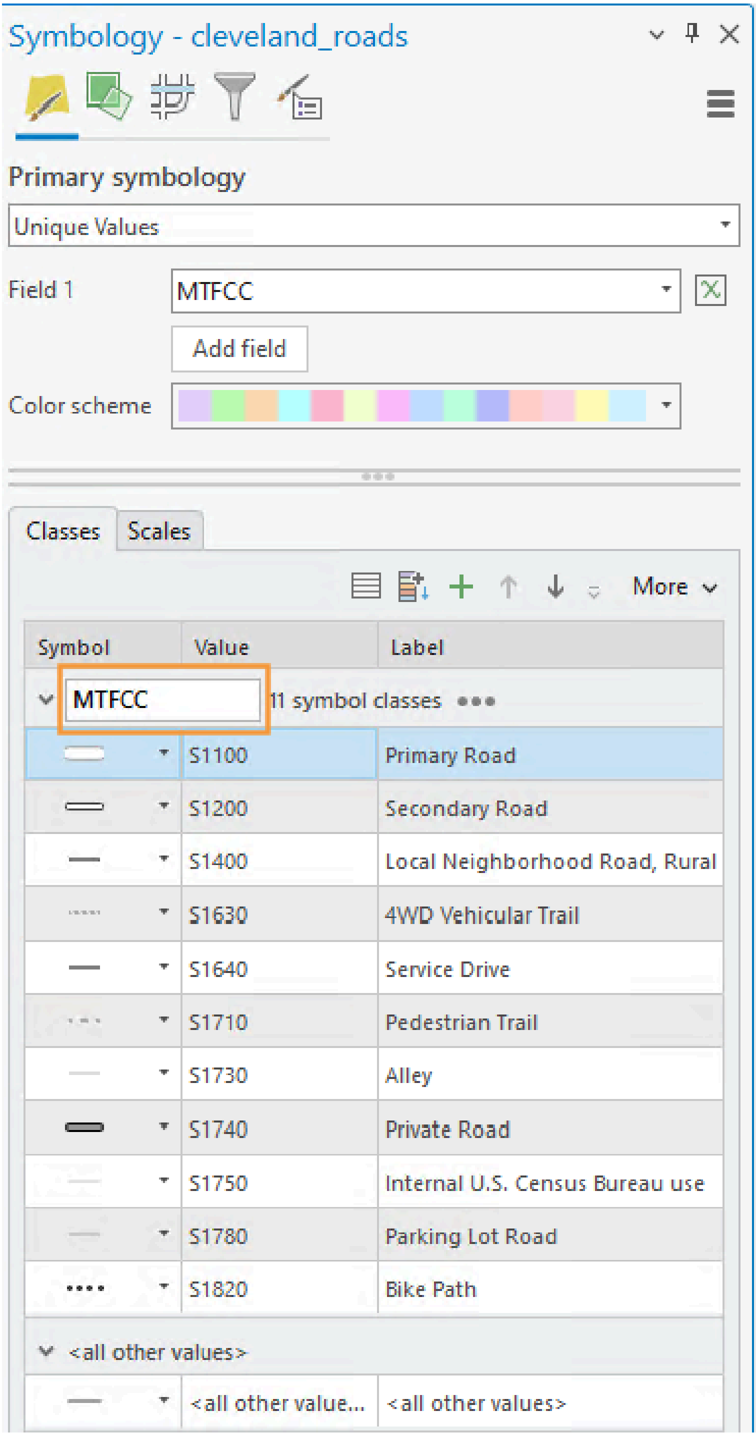
In our data, all interstates have a MTFCC code of S1100 (this code signifies the interstate road-type; see the [2022 MAF/TIGER Feature Class Codes] document). We can *define* this label class using the SQL view in the label class pane. See below:


Label Class - cleveland_roads
Class 1
Class
Symbol
Position
SQL
Load
Save
Remove
SQL
Where
MTFCC
is equal
S1100
Add Clause

Visual Guide Figure 3.6. Adding an SQL clause to define a label class.

Note: The Label Class Pane can also be used to create label classes, instead of the top menu bar. You may find it more helpful to use the Label Class Pane for most labeling tasks.

If you forget which MTFCC code refers to which road type, you should refer to the image below. You can also open this view in your project – your road features should still be classified by MTFCC code, so viewing it in the symbology pane should create a view similar to the one below.

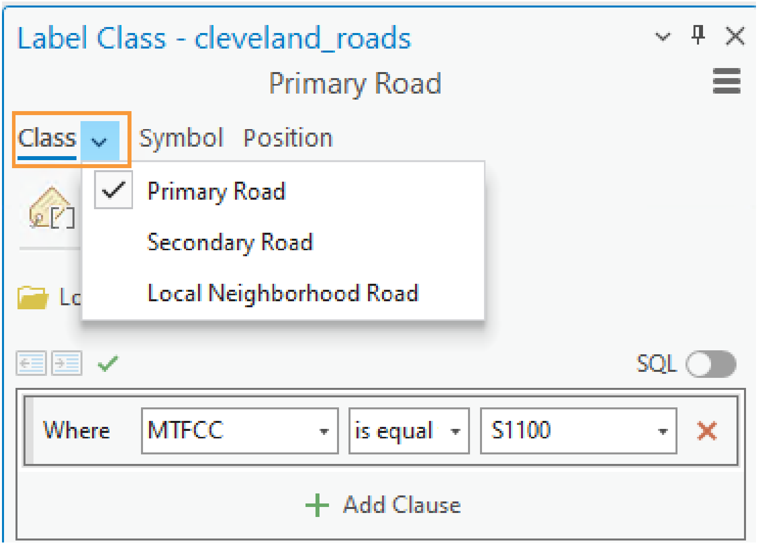

Symbology - cleveland_roads
Primary symbology
Unique Values
Field 1
MTFCC
Add field
Color scheme
Classes
Scales
More
Symbol
Value
Label
MTFCC
11 symbol classes
S1100
Primary Road
S1200
Secondary Road
S1400
Local Neighborhood Road, Rural
S1630
4WD Vehicular Trail
S1640
Service Drive
S1710
Pedestrian Trail
S1730
Alley
S1740
Private Road
S1750
Internal U.S. Census Bureau use
S1780
Parking Lot Road
S1820
Bike Path
<all other values>
<all other value...
<all other values>

Visual Guide Figure 3.7. Referencing the MTFCC code definitions in the Symbology pane.

You should create a different label class for each road type for which you wish to have a different *type* of label. This includes small differences, such as font size. You do not necessarily have to create a different label class for every road type, but you will likely have several (e.g., local road, collector road, highway, etc.). You should reference the lab requirements page to ensure that you have created enough different label classes throughout your map.

Once you create your label classes, you can switch back and forth between them while editing using the **Class** dropdown menu. Note that if you create multiple label classes, you will need to define *all* of them, including the default label class. If you do not, you will have duplicate labels. For example, you may have Interstates labeled in one class, and all roads labeled in the default class – causing interstates to be labeled in both classes.

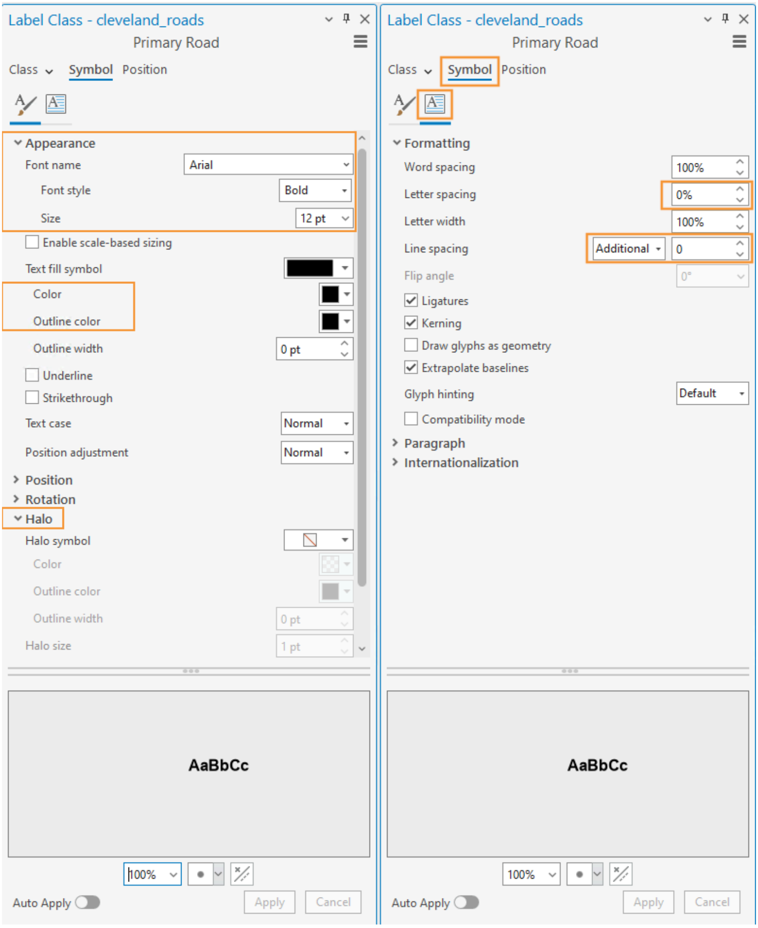
Another option is to delete the default label class – but be careful when doing so that you are maintaining all the labels you need.



Visual Guide Figure 3.8. Switching back and forth between label classes.

5. Designing label symbols

Once you've created a label class, you can use the **Symbol** tab in the **Label Class** pane to edit its style. Shown here is the label symbol editing menu (left), and the formatting menu (right). These are used to change many aspects of a label's symbology – including fonts, sizes, spacing, color, etc. Highlighted in green are options I've found especially helpful – but don't limit yourself to these. You should experiment with all options for symbol design—font, weight, spacing, etc. Recall from the lesson content that line spacing (leading) *can* be a negative value.



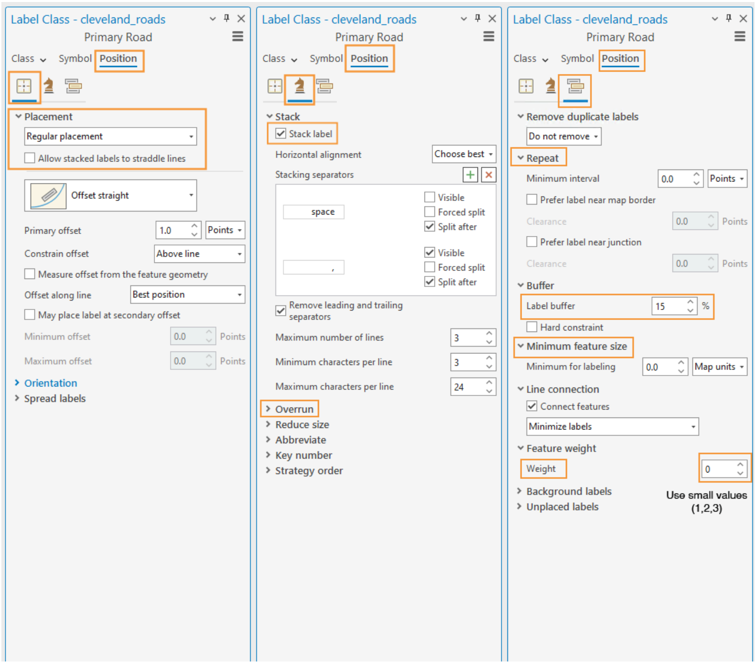
Visual Guide Figure 3.9. Editing the label symbology.

Symbology editing tip: As you work with the labels, you may find that there is a lot of "clutter." The number of labels can be overwhelming. When you initially try to label the roads layer, it will likely slow your computer way down to the point of stopping (or at least appearing that it stops). To reduce the clutter, consider using the select tools in ArcGIS Pro to select roads by attribute or by location and then export the selected data to its own layer. Then, work with just that layer when labeling. This is a quick way to remove some of the road clutter from the map. Simply "un" -symbolizing the layers does not prevent the roads from being labeled. Using this method to select roads that, for example, intersect with another feature or have one or two MTFCCs, can save you computing power (and frustration).

6. Positioning label symbols

In addition to changing the style of your labels, it is important to also assign how they should be *positioned*. Recall the lesson content on text placement – our goal for this lab is to place labels only with automatic rules. We will not be placing or adjusting labels by hand.

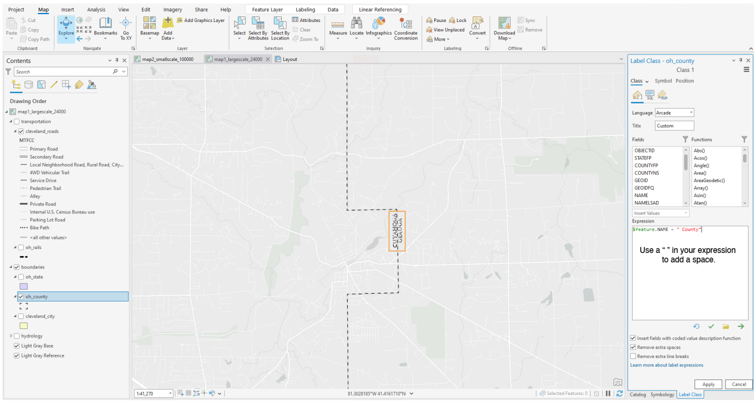
There are many positioning parameters you can adjust in the label position tab—try them out and watch how your labels change. There are a lot of useful options (e.g., Feature Weight) whose function may not be immediately clear to you – I recommend using the link at the end of this sentence to learn more about labeling with the ArcGIS Pro Maplex Label Engine.



Visual Guide Figure 3.10. Label positioning options.

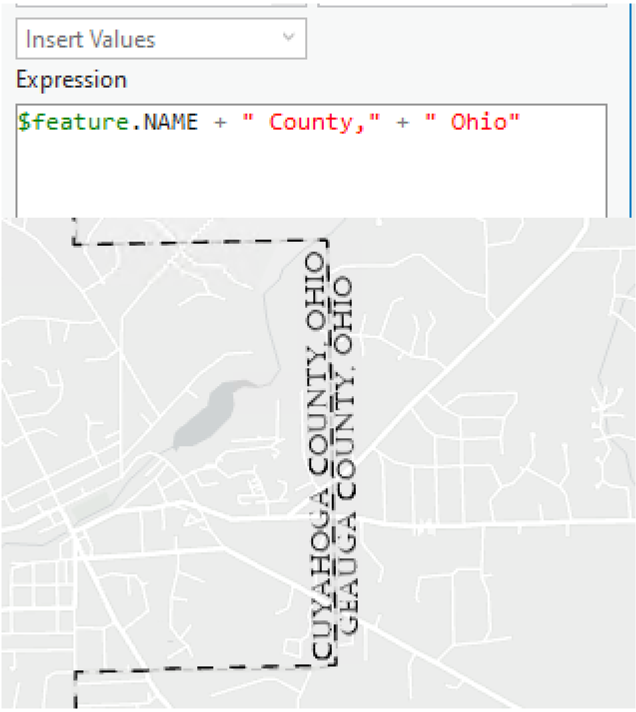
7. Creating label expressions

In addition to simply drawing a label from a feature's attribute table, you can edit label expressions using SQL to append words or other text for more descriptive labels. Don't worry if you haven't done any programming – you only need to make minor edits to create label expressions.



Visual Guide Figure 3.11. Creating a label expression by appending the word “County” to labels using SQL.

You can also use SQL to append additional text to a label from the attribute table. An example is shown below – though, in this example, you are creating quite a wordy label, which is generally not recommended.



Visual Guide Figure 3.12. Using SQL to create another label expression.

Part II: Layouts

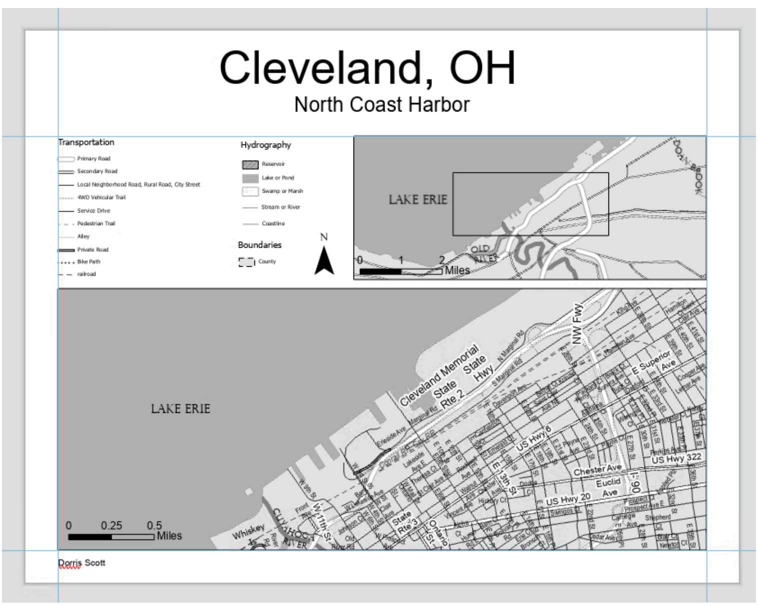
1. Putting it all together

Remember that you will be adding labels both to your large-scale (primary) map, and your small-scale (locator) map. Once you've finished adding labels to your primary map, you can add similar labels to your locator map. You can also save and then import a copy of your large scale map into your project, and then adjust it for the new smaller scale. This is the same process we used to create our second map in Lab 1.

To duplicate/re-import (a refresher):

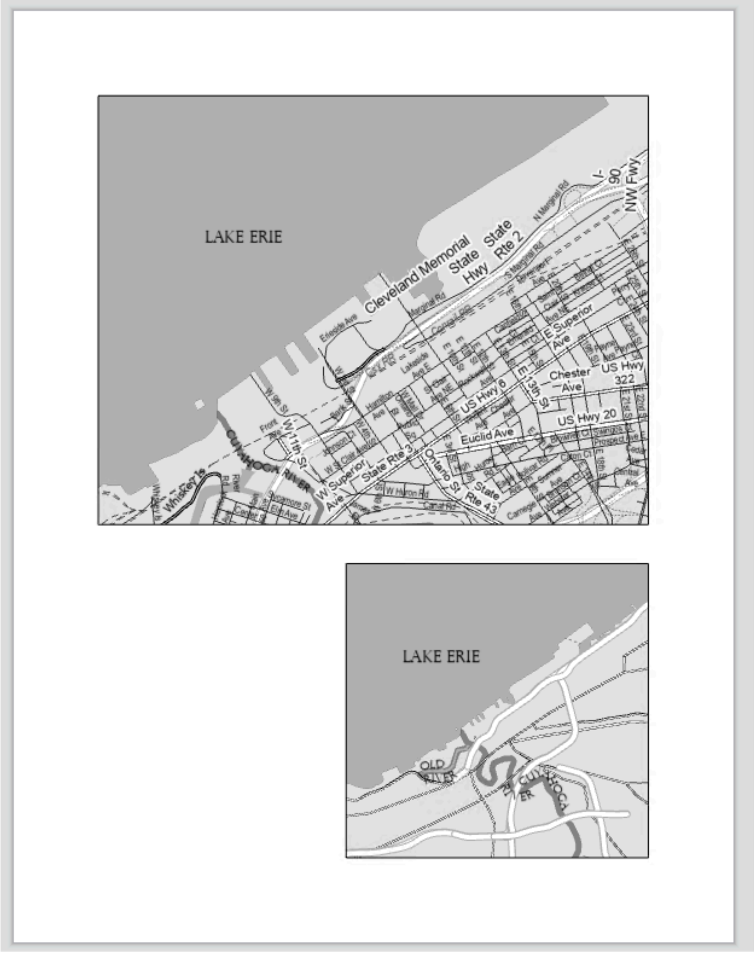
1. Save the most current version of your map as a map file (right-click on the Map in the Table of Contents (TOC)).
2. Import that saved the map as a copy back into your project (Insert Tab –> Import Map).
3. Change the scale of your new map, and design for this new smaller scale as a locator map.

Your final task is to create a Portrait or Landscape layout with your two maps, a legend, and text elements. An example layout design is shown below.



Visual Guide Figure 3.13. An example landscape layout.

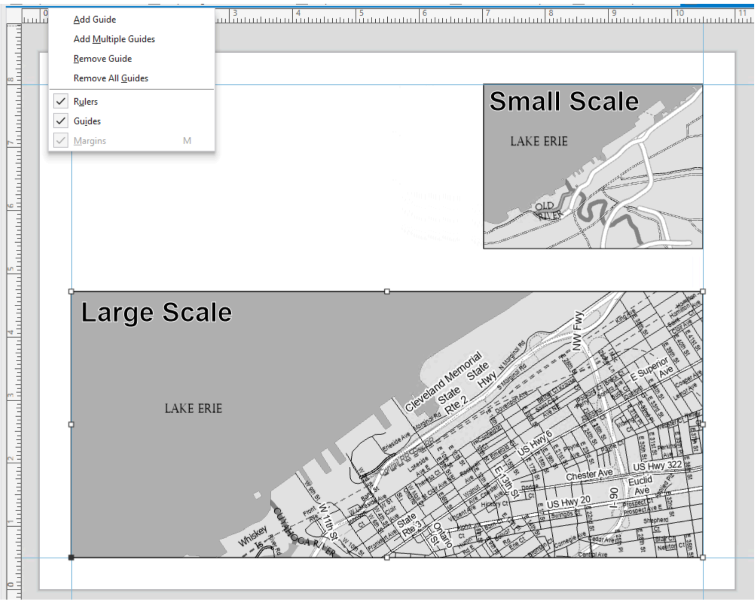
An example of a portrait layer is shown below: not that your map will also include a title, legend, etc. Additionally, these map examples are **not** shown in their final form – you are encouraged to use them for layout ideas, but you should not copy their designs. You should make sure your map meet the lab requirements. Refer to the lab rubric to confirm that you have the required elements in your map.



Visual Guide Figure 3.14. Designing a Portrait layout.

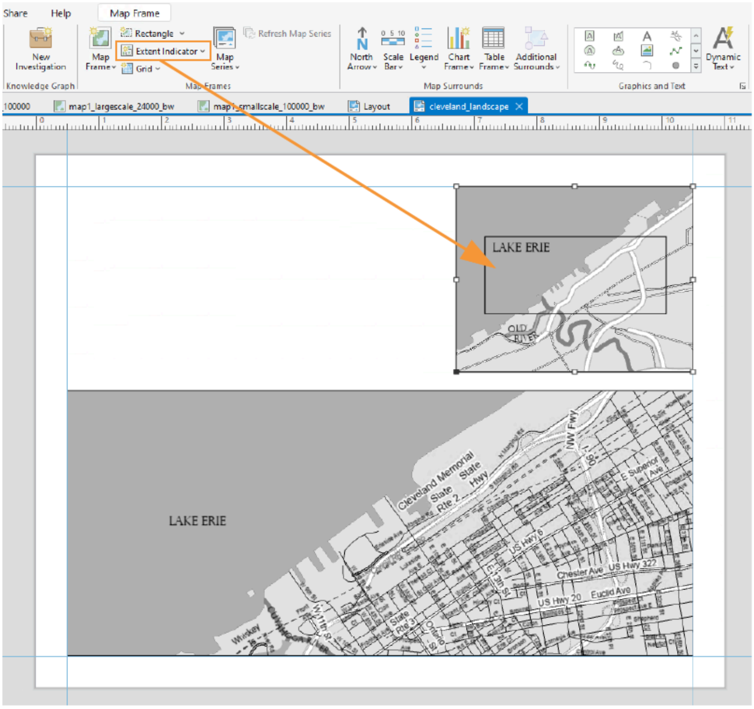
2. Build your layout

Before importing your maps, add guides for ½ inch margins – you should not include **anything** on the page outside of these margins. Note again that the examples below contain unfinished design—they should not be interpreted as examples of finished feature or label symbology.



Visual Guide Figure 3.15. Adding guides to a layout to ensure a 1/2" margin.

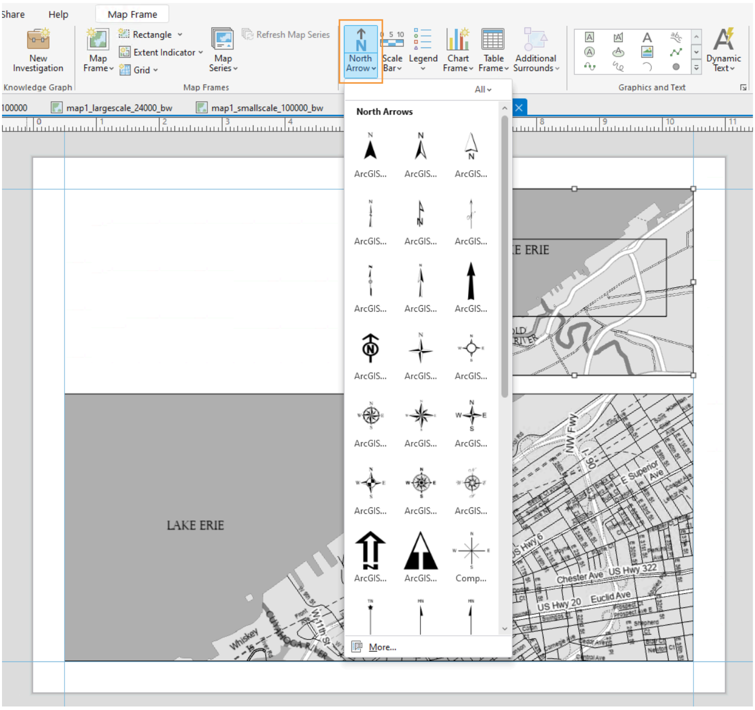
For the locator map to be useful, you will need to insert an **extent indicator.** You should do so with the small scale map selected. This will draw a rectangle showing the extent of your large-scale map within the (larger) region covered by your small-scale, inset/locator map.



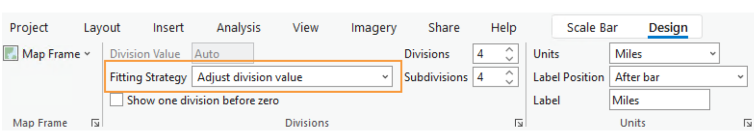
Visual Guide Figure 3.16. Adding an extent indicator.

3. Add marginal elements

Marginal elements such as north arrows and scale bars should be added at this point. Keep your North arrow and scale bars simple and easy to read. Use "adjust width" to create clean scale bar values. You can also edit the color, font, label locations, etc., of all marginal elements. Reference lesson content for design ideas.



Visual Guide Figure 3.17. Adding a north arrow.

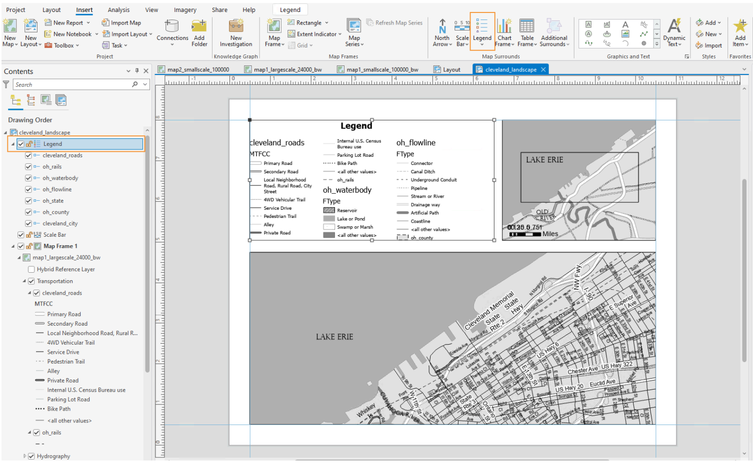


Visual Guide Figure 3.18. Adjusting the design of a scale bar.

4. Create a legend

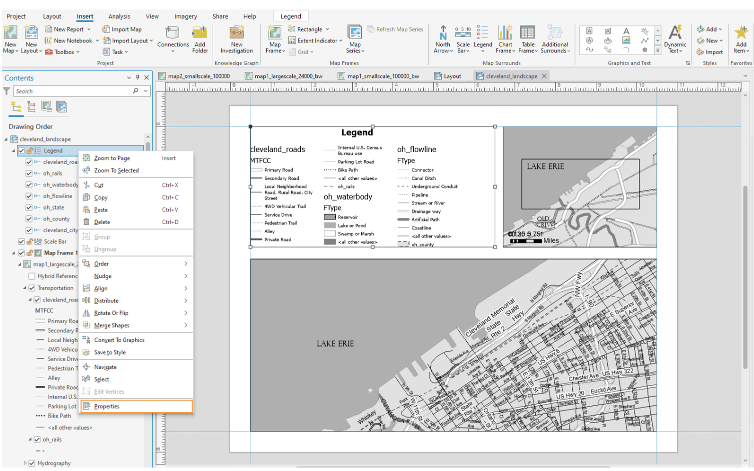
Another important component of your map layout for this lab will be its legend. Insert a legend with your large-scale map selected so it reflects your large-scale symbol design.

Your locator map should use similar symbols, and therefore should not need a legend.

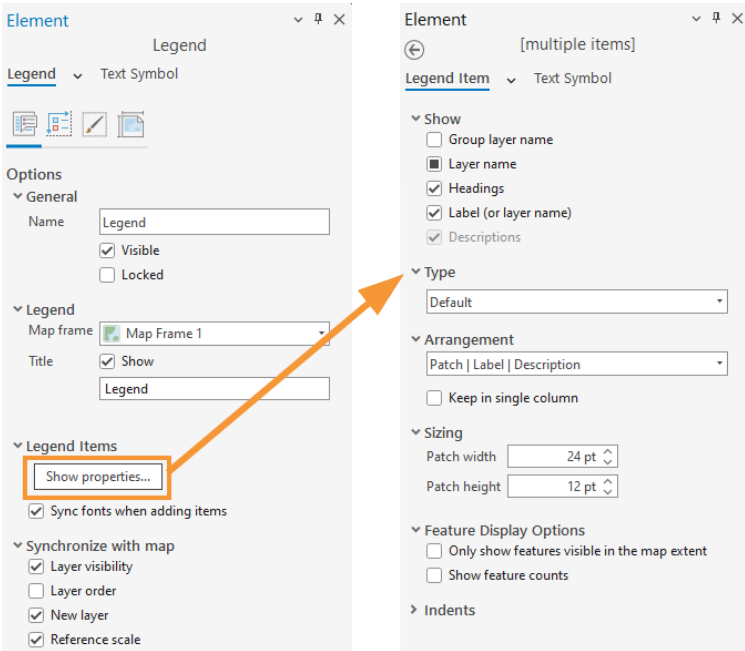


Visual Guide Figure 3.19. Adding a legend.

Right-click your new legend element in the contents pane, and choose "Properties" to edit.

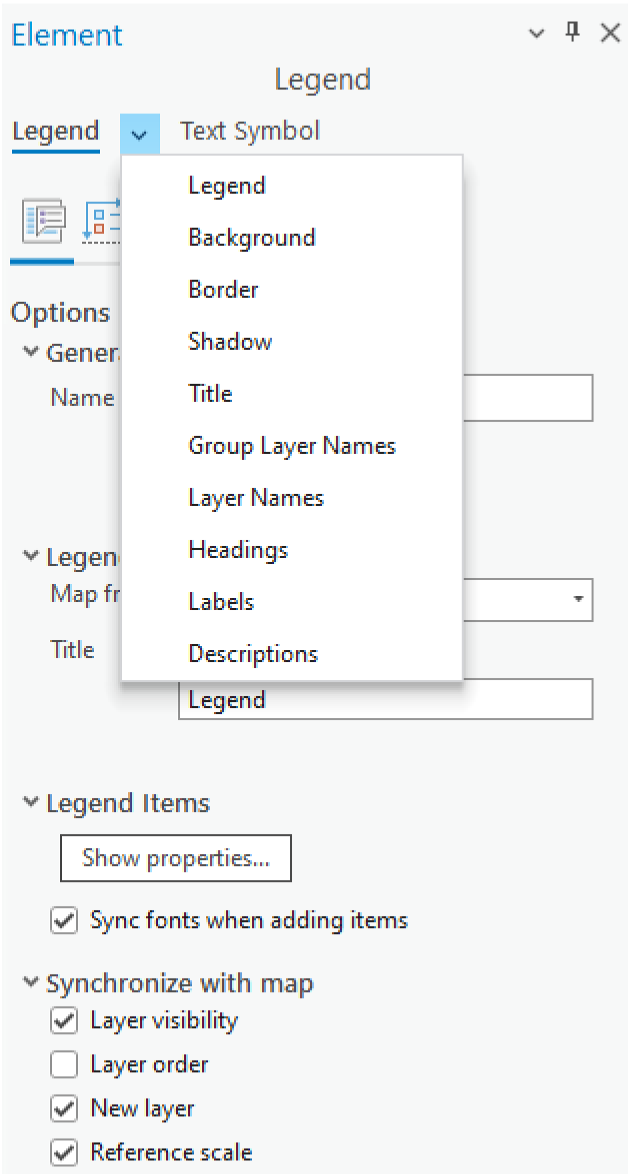


Visual Guide Figure 3.20. Opening legend properties.



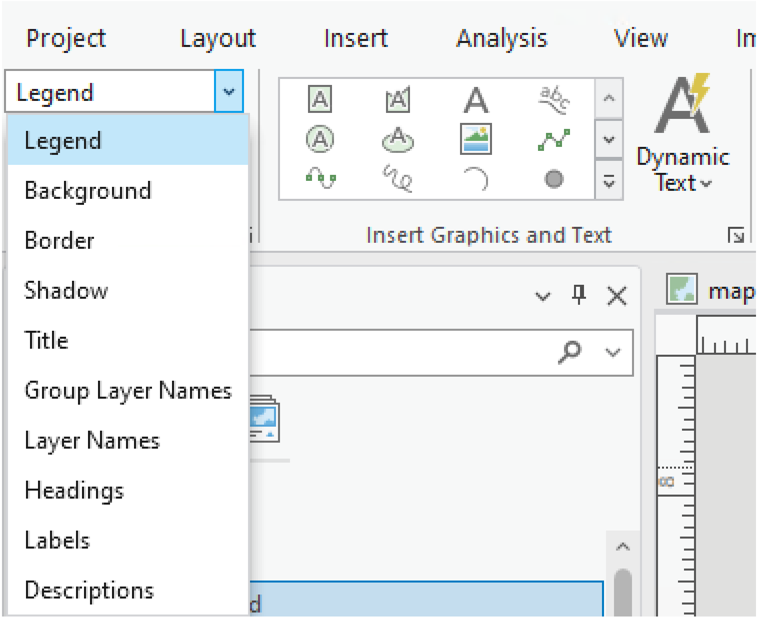
Visual Guide Figure 3.21. Editing legend properties.

You do not have to include every item in your legend, and you may want to change the names of some items significantly. Your goal is to create a comprehensible map. To change the design of different legend elements, select them from the drop-down menu in the *Format Legend* pane.



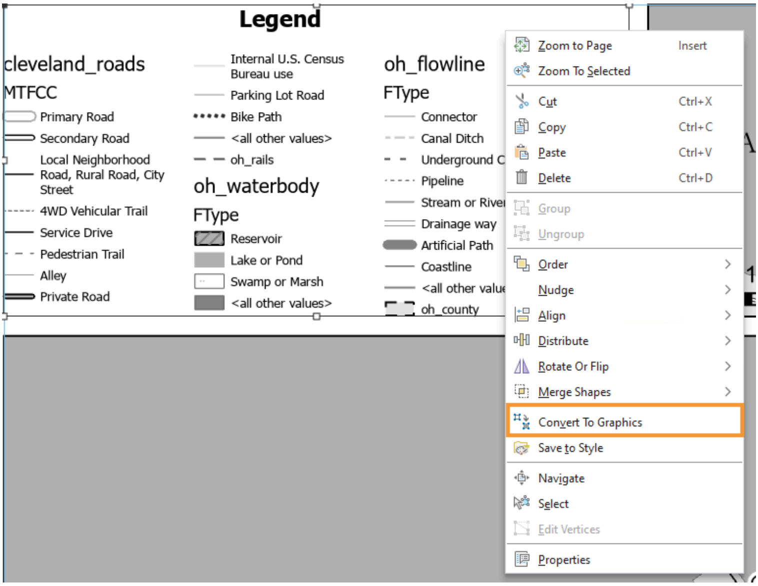
Lab 3 Visual Guide Figure 3.22. Selecting a legend element to edit.

You can also make changes from the ribbon.

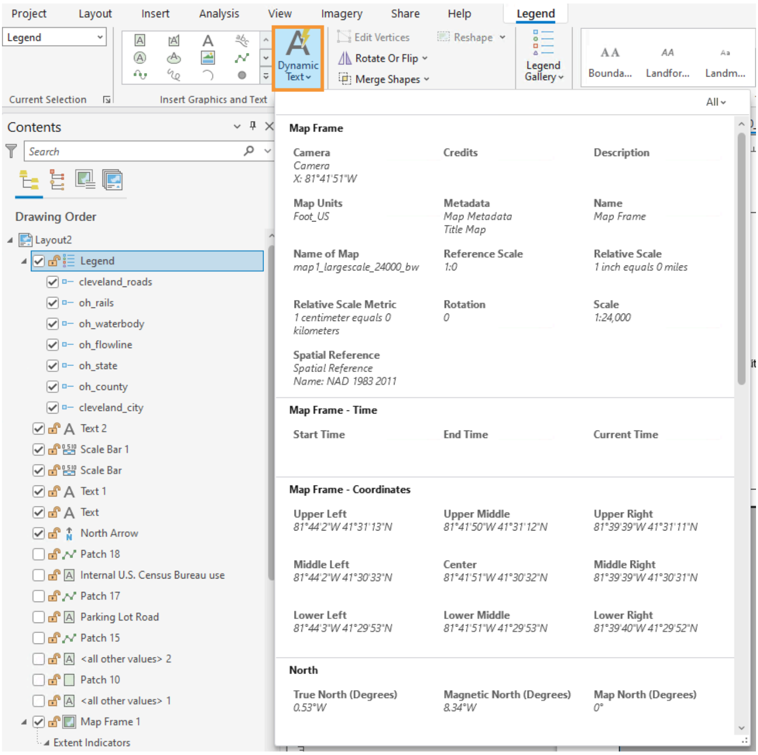


Visual Guide Figure 3.23. The Format-Legend menu bar in the ribbon.

Once you have made sufficient edits, you may want to disconnect your legend from the data by *converting to graphics*. This will give you more freedom over the design, but as your legend will no longer update dynamically if you update any map symbols, you should save this step until the end. You will have to "ungroup" the elements to edit them. Once you convert to graphics, you will need to right-click and "ungroup" multiple times to edit the elements for detailed design work. (Note that this is not a well-edited legend, just an example of one in process).

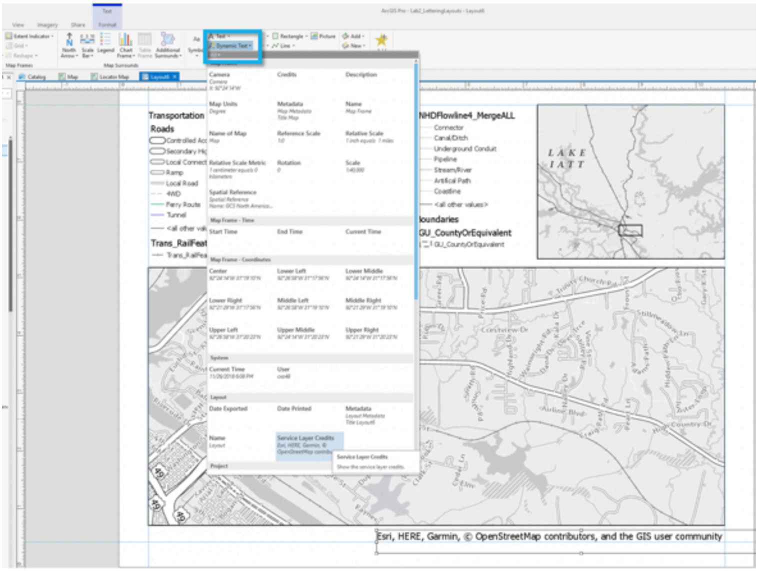


Visual Guide Figure 3.24. Converting a legend to graphics for fine-grained edits.



Visual Guide Figure 3.25. Adding service layer credits as dynamic text.

Once your legend is complete, there are only a few final touches to be made. Use the “Dynamic Text” dropdown to move the service layer (basemap) credits out of the map frame and place them elsewhere in your layout, for a cleaner look.



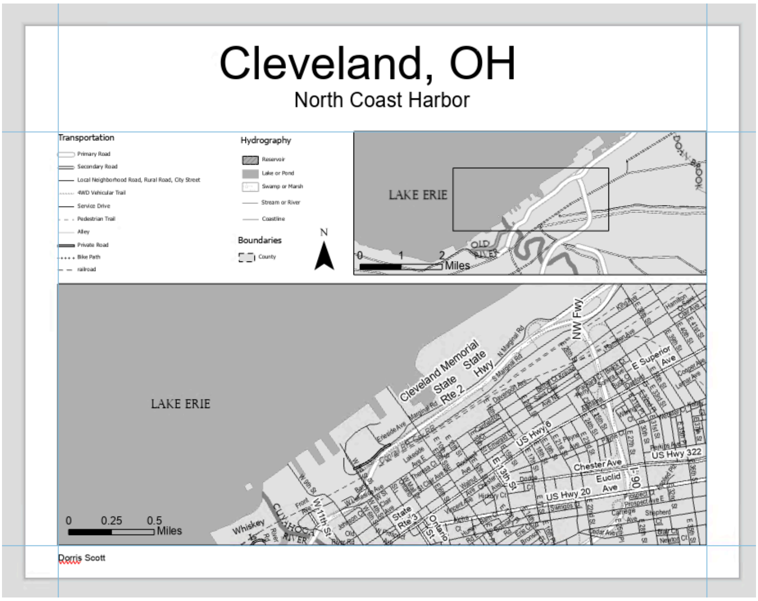
Visual Guide Figure 3.26. Adding service layer credits as dynamic text.

Don’t be afraid to re-arrange your layout elements as you go! It may take quite a few tries before you find an optimal design.

Remember to create visual hierarchy for marginalia elements:

1. Title
2. Subtitle
3. Legend Titles
4. Legend Text
5. Data Source
6. Name

Below is an example of a landscape layout made from similar data – you will need to adjust your map to work with the assigned data and location. Note also that the map below may not include all required elements for this lab, but is **an example of how your layout might look if you are on the right track**.



Visual Guide Figure 3.27. Example map layout.

5. Final tips and tricks

- You may use color, but do not over-rely on it. It is often advised to use all greyscale at first, and then add color later on for emphasis. Too much color on a map that is not well balanced will result in a poorly designed map.
- Don’t be afraid to change course while you work—try out different labeling and layout options before committing to a final design.

- The Lab 3 Visual Guide contains many design ideas and suggestions. Do not rely on the Guide to tell you how to design your map. Instead, use the instructions to learn how tools in ArcGIS Pro are used and then let your creativity guide your design.
- See the Lab 2 and Lab 2 Visual Guide instructions if you need a refresher on how to design symbols or how to export your map. Remember, if your map uses a gradient fill, complex area fill patterns, or coastline effects, export the map setting the resolution to be no more than 150dpi.
- Check that your map meets all listed requirements by referring to the lab instruction document and rubric before you submit.

Data Source: The National Map.

Summary

By the end of this week you should feel pretty confident on the foundations of typography and labeling different features. We covered:

- The anatomy of a font.
- Different types of fonts.
- Different types of labels.
- How to demonstrate differing levels of importance with text.
- How to demonstrate category with text.
- Recommended practices in using shadows, halos, and callouts.
- Label placement when it comes to points, lines, and polygons.

Remember not to take what you do in ArcGIS Pro at face value. Experiment with these various techniques to add extra finesse to your map! However, make sure not to sacrifice finesse with legibility.

Take a look at this topographic map of University City. How is typography used to delineate certain elements of the map?

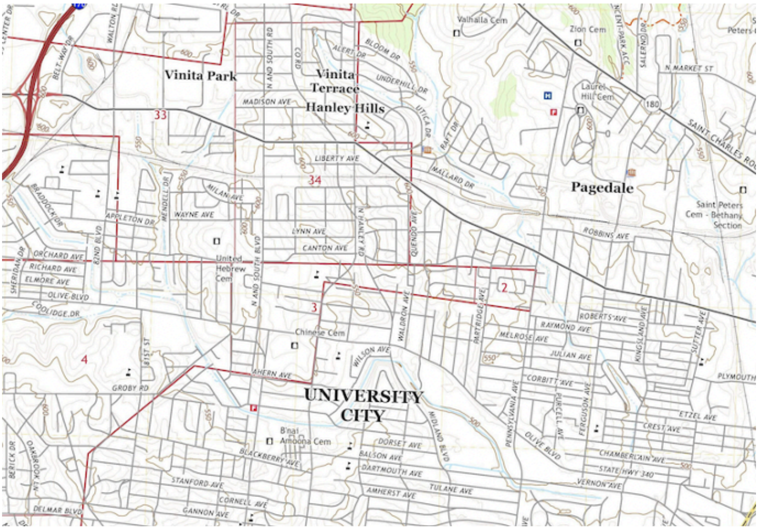


Figure 3.9.1. Topographic map of University City.

Image source: [USGS Topoview]

III

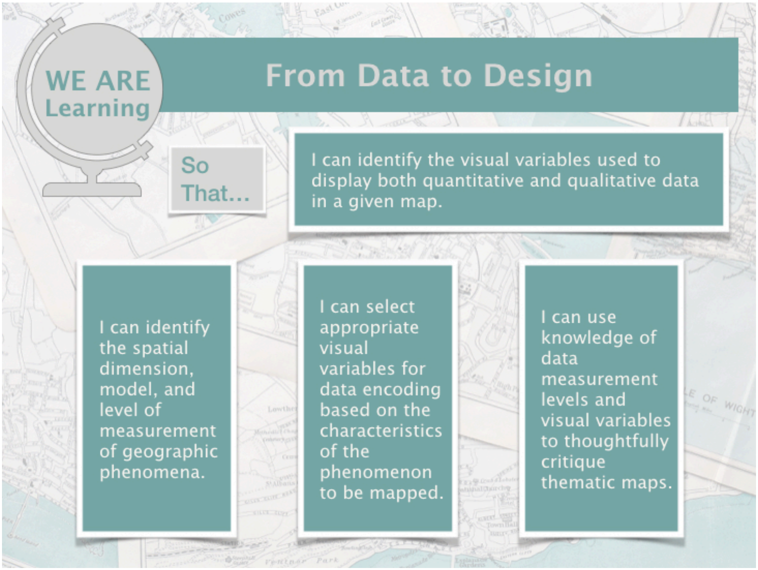
From Data to Design

Overview

Welcome to Chapter 3! In previous chapters, we discussed broad concepts related to map and map symbol design, including designing for a map's audience, medium, and purpose. We learned about visual variables and how to designate order and category with map symbols. In the context of text on maps, we discussed these ideas in greater detail; we created symbols with labels and learned how to place them appropriately on maps. We then put everything together in a map layout.

So far, we have only designed general purpose maps. Though these maps still contain data (e.g., road networks, lakes, boundaries), we have not yet added more abstract data to maps. In this lesson, we discuss thematic maps and the ways in which we can use maps to effectively visualize spatial data. When deciding how to map, we'll consider the spatial dimensions and models of geographic phenomena, levels of data measurement, and appropriate methods of visual encoding. We'll compare and contrast the four most common types of thematic maps (choropleth, isopleth, proportional symbol, dot) and map two of these in Lab 3, using a popular data source for thematic mapping – the US Census Bureau. You will need to download spreadsheet (.csv) data pertaining to your chosen city for the state, county, and census tracts that it is located in.

Learning Outcomes



By the end of this lesson, you should be able to: 1) identify the visual variables used to display both quantitative and qualitative data in a given map, 2) identify the spatial dimension, model, and level of measurement of geographic phenomena. select appropriate visual variables for data encoding based on the characteristics of the phenomenon to be mapped, 3) use knowledge of data measurement levels and visual variables to thoughtfully critique thematic maps.

Thematic Maps: Visualizing Data

We first introduced thematic maps in Lesson One, and described them as maps intended to highlight features, data, or concepts (either quantitative or qualitative). In Labs One and Two, we used visual variables to show order and category of typical map features on maps.

The maps we've created so far have been general purpose maps—designed to display features of general interest. In designing our maps, we created abstract representations of the real world, with roads, rivers, lakes, county lines, etc., with hues and shapes different from what would be captured by a photograph. Despite this, our designs have still reasonably matched their physical reality. In this lesson, we turn to more abstract depictions of the world, designed using thematic data. View for example, the map in Figure 3.1.1.

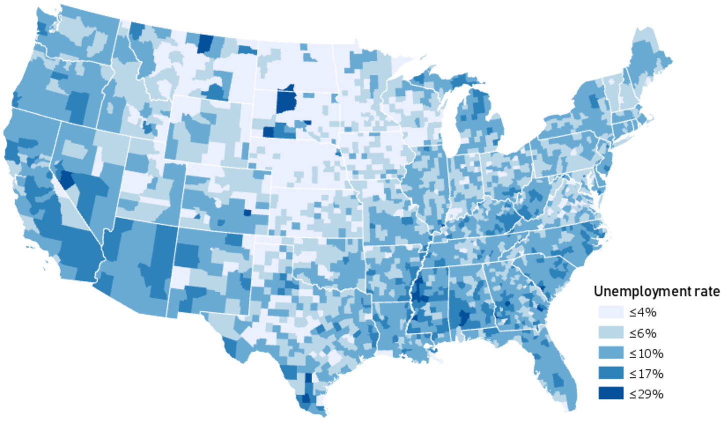


Figure 3.1.1: A county-level map of unemployment. Credit: Cary Anderson, Penn State University. Data Sources: Esri, US Census Bureau.

This map uses color value—not to show category or hierarchy of map features—but to *visually encode* county-level unemployment data. Figure 3.1.1 also simplifies the map of the US (not showing even major highways or mountain ranges, but only state and county boundaries) to emphasize the map's theme.

Due to thoughtful use of color and a simple layout design, this map successfully communicates geographic trends of unemployment in the United States. But was this the best choice to show this concept? Might there be a better way?

View the map in Figure 3.1.2 below.

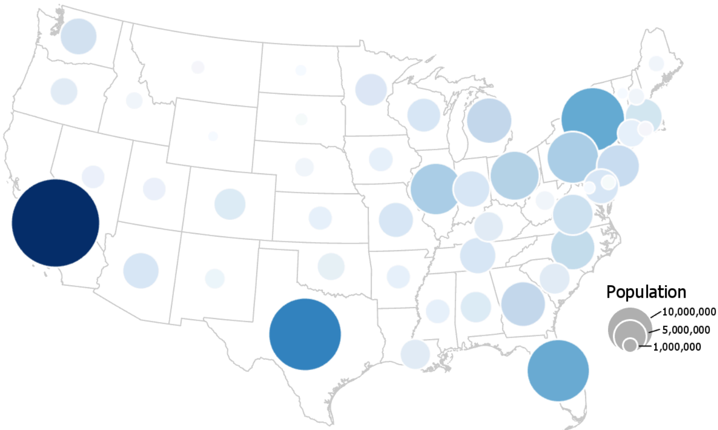


Figure 3.1.2 A proportional symbol map of population. Credit: Cary Anderson, Penn State University, Data Source: Esri, The National Map

This map uses a similar color scheme and layout, but encodes its data primarily using proportionally-sized symbols. Color value is used for additional effect, a technique called *dual encoding*.

These maps (3.1.1; 3.1.2) are both correct—they fit into cartographic conventions. But there are other maps that this cartographer could have made with each dataset that would have been equally correct. There are also maps they could have made that would have been—arguably—quite wrong. How to decide?

Student Reflection

Do you think the data mapped in Figure 3.1.1 would be appropriate for making a proportional symbol map (e.g., Figure 3.1.2)? Why or why not?

Before beginning the *how* of making a map, we need to take a step back and consider the *what*—the **geographic phenomena** we want our map to be about.

Geographic phenomena are elements that exist over geographic space. When we say **geographic** we typically mean anything between the size of a human and the size of the world. So, while still spatial, the connections between the neurons in your brain or the arrangement of atoms in a ceramic material do not constitute geographic phenomena. In this lesson, you will learn tools for conceptualizing, visualizing, and communicating the many phenomena that do.

Geographic Phenomena: Spatial Dimensions

Geographic phenomena are often classified according to the spatial dimension best used to describe their nature. These include points, lines, areas, and volumes (3D). As you likely remember, we used the spatial dimension of map elements (e.g., line vs. point) in the last lab to decide how to symbolize and apply feature labels to our maps.

Points exist in a singular location and thus have theoretically zero dimensions. Points are usually specified using a coordinate pair (x, y) of latitude and longitude, though they occasionally include a z (height).

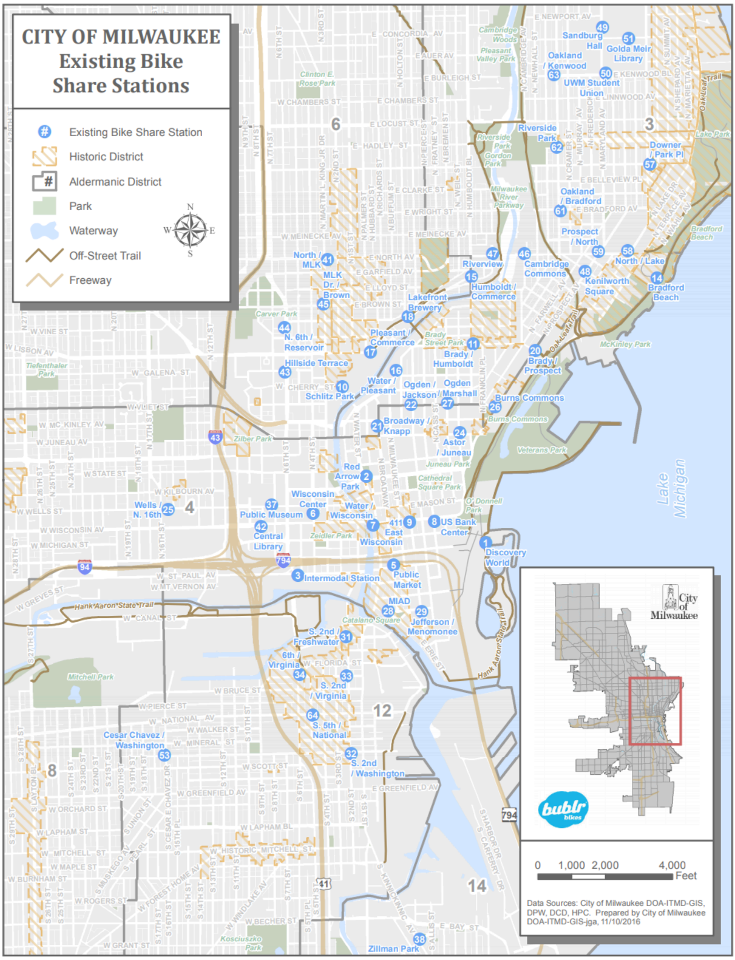


Figure 3.2.1 This map uses point symbols to show bike share stations in the city of Milwaukee. Credit: city.milwaukee.gov/

Lines are one-dimensional spatial features, typically defined by a series of (x, y) coordinates. A z (height) dimension can also be assigned to lines, but this is uncommon. Lines are used to map phenomena that are best conceived of as linear features, including both some features that have greater dimensionality in reality (e.g., rivers) and those that do not visibly exist in the real world at all (e.g., property lines).

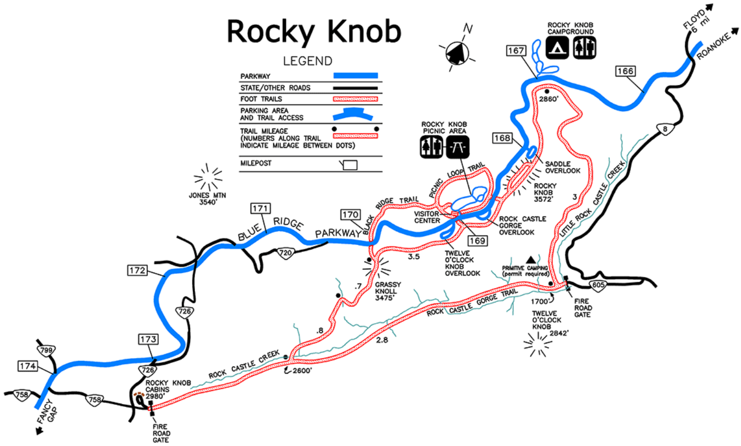


Figure 3.2.2 A map that uses linear features to encode roads and hiking trails. Credit: nps.gov/

Area features are two dimensional and are represented by a series of (x, y) points that enclose a space. Areal phenomena include natural features like lakes and parks, as well as human-defined locations—from continents to census blocks.

Figure 3.2.3 A map that uses area features to show buildings, parking lots, so on. Credit: health.act.gov.au/

2-½ and 3-D features are sometimes grouped together, but the distinction between them is important. 2-½D features define a continuous *surface*—they have an x, y, and a z at every location. A good example is elevation, which varies continuously across the landscape. Therefore, a topographic map is a common depiction of 2-½D phenomena.

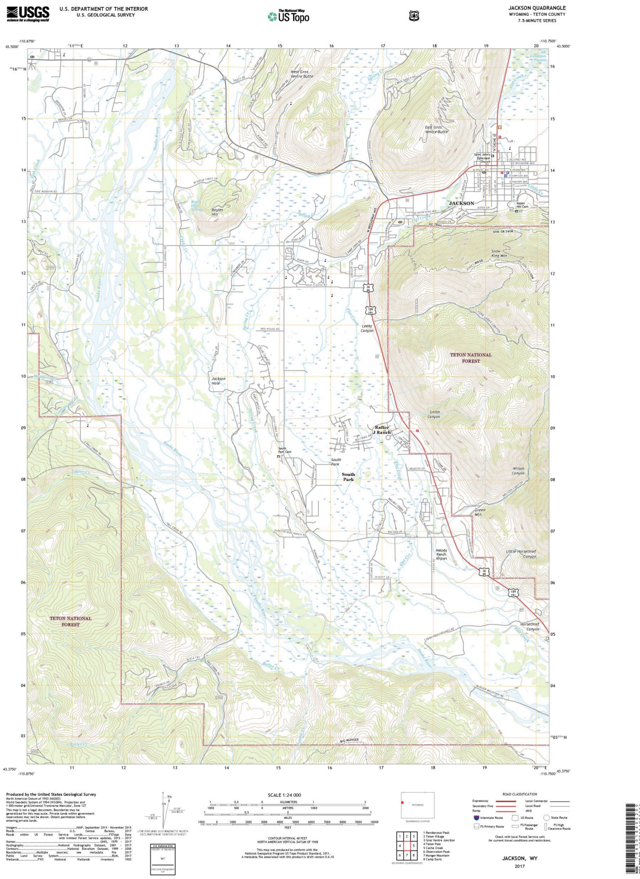


Figure 3.2.4 A Topographic Map, which depicts a 2½ D surface. Credit: USGS

True 3D maps have an x, y, and z, plus an additional data value, at every location. Imagine, as an example, a map of elevation like the one above; but at every point along the terrain surface, there are additional measurements being taken at various depths. Thus, rather than depicting a continuous surface, true 3D maps depict a continuous volume.

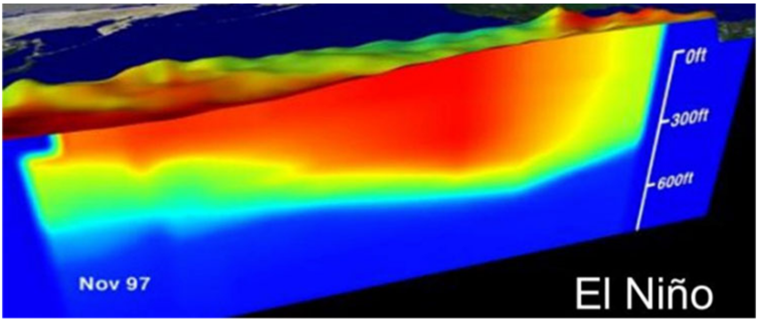


Figure 3.2.5 A 3D map showing sea depth and temperature. Credit: NOAA

Keep in mind that the scale of your map has significant influence on what spatial dimension will best represent the phenomenon you intend to map. Cities, for example, are usually drawn as areas on large-scale maps, but appear as points on smaller-scale maps. Rivers are usually drawn as lines on small-scale maps but are better represented as areas on large-scale maps. We will discuss this more during discussions of cartographic generalization later in the course.

Geographic Phenomena: Models

When conceptualizing the geographic phenomena we want to map, it is important to consider the best way that these phenomena can be modeled. In general, we can categorize the best model for a given phenomenon as existing somewhere along two continuums: (1) from discrete to continuous, and (2) from smooth to abrupt.

You likely learned the difference between discrete (e.g., as shown by a histogram) and continuous (e.g., as shown by the bell curve) variables in an introductory statistics course. The distinction in cartography is similar.

Discrete phenomena have well-defined boundaries: they occur at specific locations, with space in between. Examples include people, cars, houses, hospitals, and roads.

Continuous phenomena, conversely, have ill-defined or irrelevant boundaries. Examples include temperature, air quality, and elevation.

Phenomena can also—independent of their classification as discrete or continuous—be considered either smooth or abrupt.

Smooth phenomena are those that change gradually over geographic space. Examples include precipitation levels and solid aridity: they vary by location but do not typically change abruptly at geographic bounds.

Abrupt phenomena *do* change suddenly at a geographic boundaries, whether physical or cultural. Often, phenomena are not clearly smooth or abrupt, but fall somewhere in between. The amount of pesticides in soil, for example, might vary somewhat continuously over space, but change rather abruptly at political boundaries (e.g., due to changing government regulations).

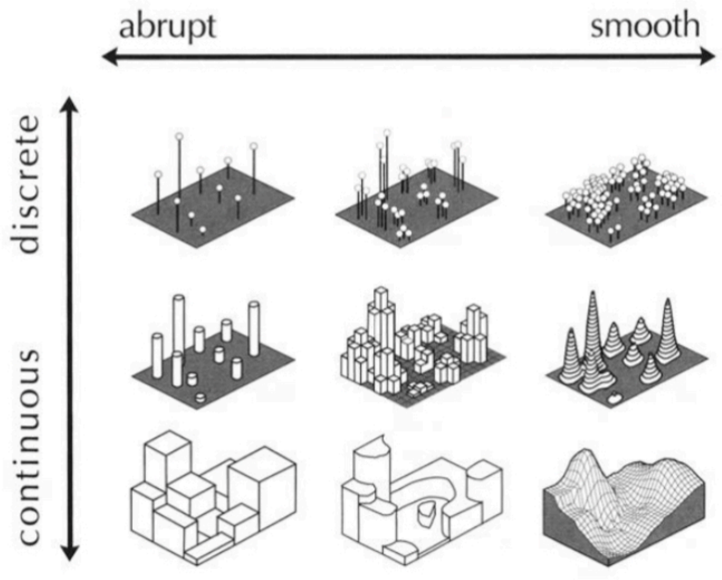


Figure 3.3.1 Discrete vs. Continuous; Abrupt vs. Smooth. Credit: (MacEachren 1992)

Figure 3.3.1 illustrates various surfaces used to represent geographic phenomena throughout the discrete to continuous and abrupt to smooth continuums. Keep this idea of a continuum in mind—geographic phenomena often cannot be classified into neat categories, and it is typically more fruitful to think of them as "more continuous" or "more discrete" than to try and fit them into a box.

Student Reflection

Identify the proper (approximate) location in Figure 3.3.1 or the following phenomena: Health insurance (% of people covered); water quality; political affiliation; surface porosity. Why did you place them where you did?

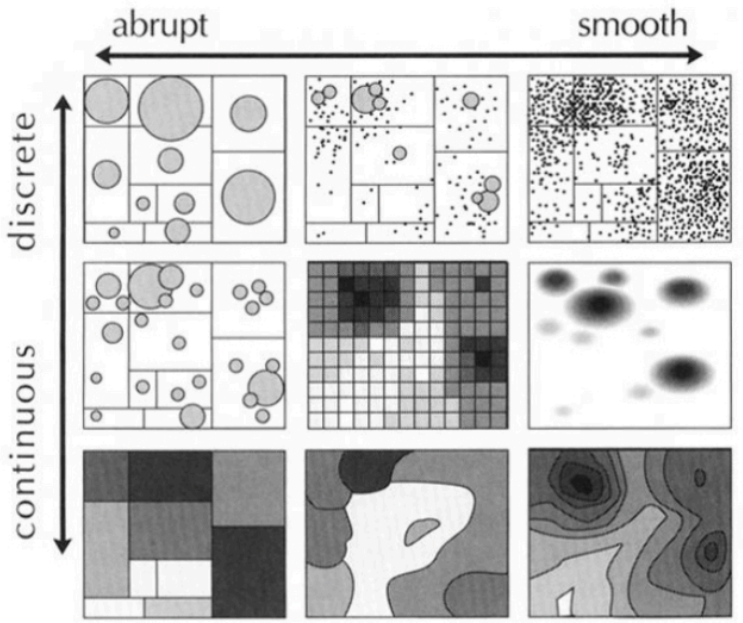


Figure 3.3.2 Map representations that match the phenomena in Figure 3.3.1 above Credit: (MacEachren 1992)

Figure 3.3.2 above shows different map representations that are suited to mapping the geographic phenomena located at these relative positions along the continuous-discrete and abrupt-smooth continua. We will discuss the appropriateness of various thematic mapping methods further later in this lesson.

Practical Mapping: What about the data?

Considering the characteristics of the geographic phenomena you wish to map will inevitably improve the quality of your maps. However, before you design your map, you must understand the distinction between the characteristics of the *phenomena* and those of your *data*.

Consider again the map from Figure 3.1.1.

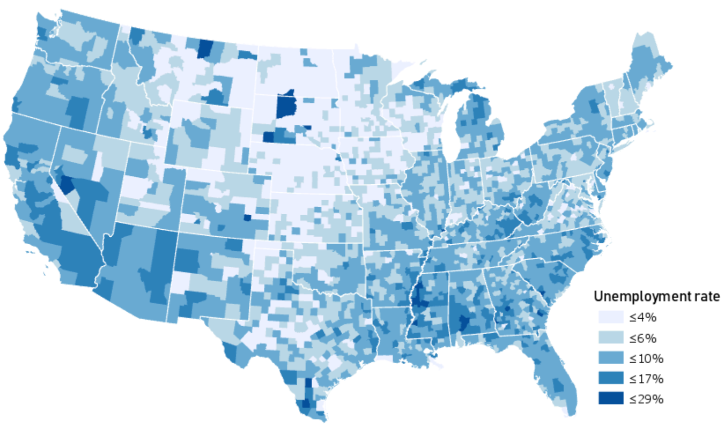


Figure 3.1.1: A county-level map of unemployment. Credit: Cary Anderson, Penn State University. Data Sources: Esri, US Census Bureau.

This map illustrates unemployment rates in the US at the county level. Though it is a well-designed and attractive map, consider the characteristics of unemployment as a geographic phenomenon. The abrupt change in unemployment rates at county boundaries in this map obscures the underlying heterogeneity in unemployment within county bounds. The phenomenon of unemployment varies *by person*, while the mapped unemployment data varies *by county*. This doesn't mean the map is wrong, but it is a reality important to be cognizant of, both while creating your own maps and while critiquing those designed by others.

Relatedly, when creating maps, you will often rely on data that has already been collected by others. Often, this data is collected (as in the example in Figure 3.1.1 above) by enumeration units, such as counties, census tracts, or states. Unemployment does vary by person, but it is unlikely that this fine-grained data will be available to you. If you have somewhat coarse (e.g., state level) data, you cannot create a map that shows variation by person, by county, etc., even if this would be a more accurate depiction of the phenomena. The only way to create a more detailed map is to collect more granular data. Your map design can always be altered to present a simplified depiction of your data—but not the other way around.

Geographic Data: Levels of measurement

Data is typically classified as either **qualitative** (e.g., land use; political boundaries) or **quantitative** (e.g., per capita income; temperature)—you likely recall learning about this distinction in earlier courses. The classification of your data as qualitative or quantitative will have significant influence on which visual variables you use to map your data. Color hue, for example, is excellent for qualitative data, while color value demonstrates order and thus is a better choice for designing quantitative maps.

Nominal is a common term used to described qualitative, or categorical data. Land use and land cover maps are popular examples of nominal data. They might show, for example, residential blocks as distinct from parks and green space, but this does not suggest that one is lesser or greater than the other.

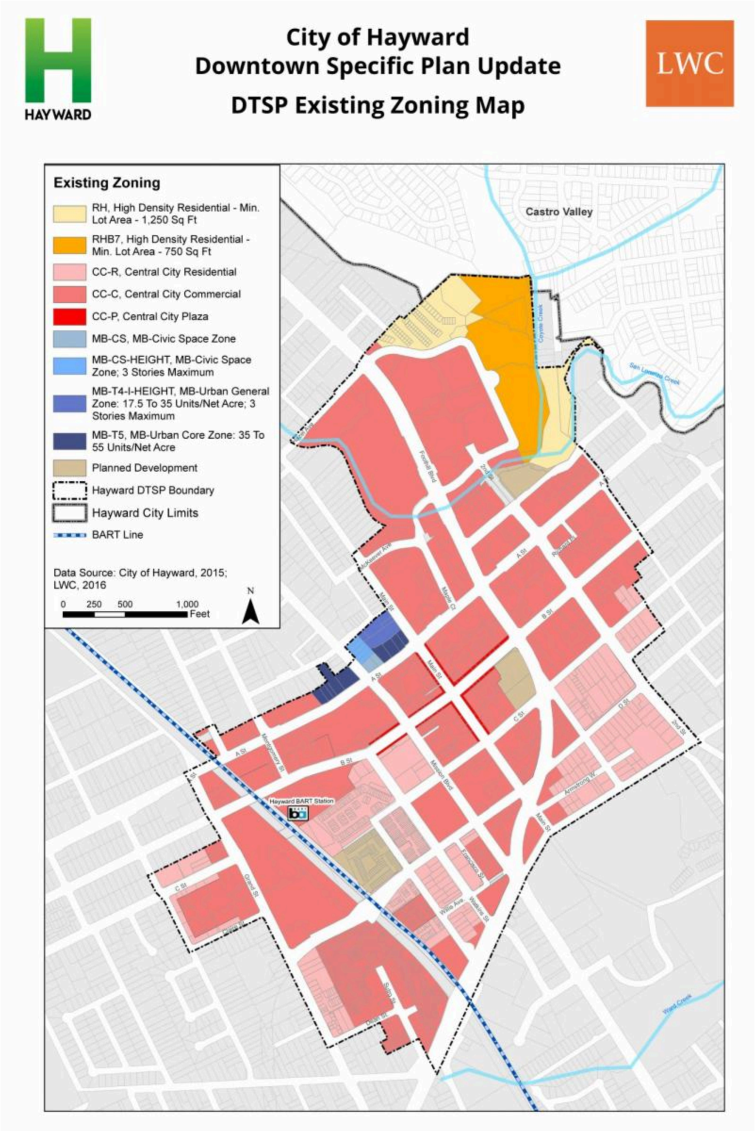


Figure 3.4.1 A zoning map using the visual variable color hue. Credit: hayward-ca.gov

Quantitative data can be further classified as ordinal, interval, or ratio data.

Ordinal data has an order, but cannot be presumed to show differences in magnitude. Sports team rankings, for example, describe which teams are better, but not by how much.

Interval data describes orders of magnitude but has an arbitrary zero point. The classic example is temperature: 30 degrees is warmer than 10 degrees, but it’s not necessarily three times as warm. Another good example is shoe size—you can say that a size 12 is larger than a size 6, and that (unlike if it were ordinal data) there is more difference between a 6 and a 12 than between a 12 and a 13, but the 12 is not twice as large as 6.

Ratio data, conversely, has a non-arbitrary zero point. Examples of ratio data include counts of forest fire incidence, and yearly household income (e.g., $50,000 is twice as much as $25,000). Interval and ratio data are often grouped together and classified as numerical data.

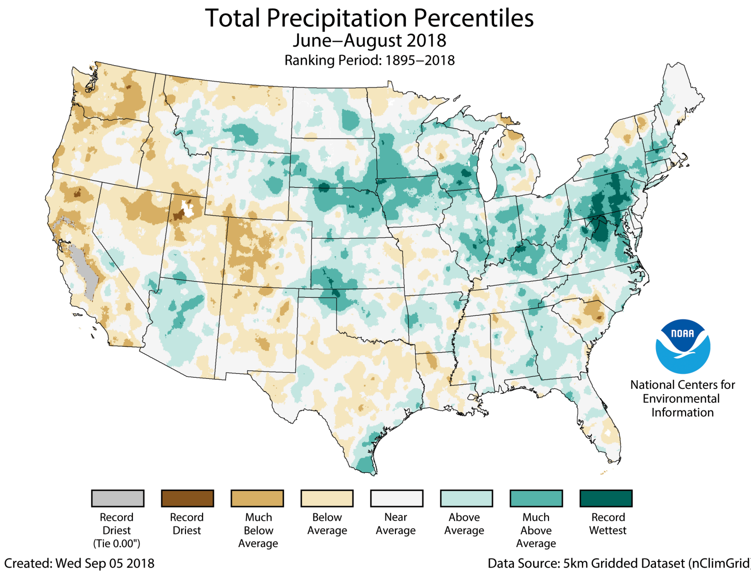


Figure 3.4.2 A map about precipitation across the US. Credit: [NOAA]

Student Reflection

- View the map in Figure 3.4.2 above—is the data shown qualitative, ordinal, interval, or ratio? How does this compare to the likely level of measurement of this data when it was first collected?
- Consider time—would you usually consider this to be nominal, ordinal, interval, or ratio data? Why?

Choosing Symbols for Maps

Understanding your data's spatial dimensions, geographic model, and levels of measurement will help you select which visual variables to use in your map. Recall the table of visual variables we first encountered in Lesson One (Figure 3.5.1). This is a good time to check your own knowledge and consider which of the follow seven variables are best for visualizing data **category**, and which are best for visualizing **order**.

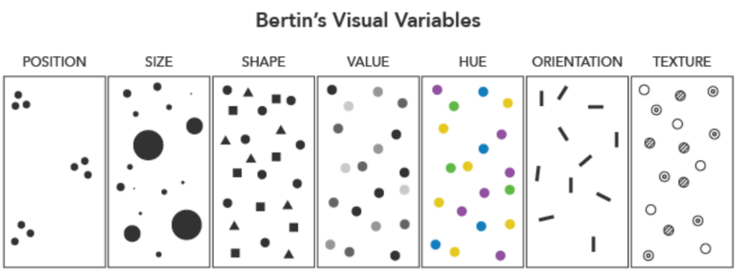


Figure 3.5.1 Bertin's visual variables. Credit: Adapted from Visual Variables, [Axis Maps](). Available under the Open Database License [CC BY-NC-SA 4.0.]()

Some visual variables are also better than others for encoding data with different levels of measurement. Bertin (1967) only considered size (other than position on the map) to be a truly quantitative variable, its visual representation able to be matched precisely to a numerical value. This makes it a good choice for mapping ratio-level data, as making mathematical calculations with such data can be useful. Visual variables that can typically encode only category, not order (e.g., color hue; shape) are best for qualitative data.

Note that the visual variables presented in Figure 3.5.1 are those originally proposed by Bertin, and though they are arguably the most common still in use, this is not a comprehensive list. The graphic also does not demonstrate the many ways in which these variables might be altered and/or combined to create new designs. At the end of this lesson, we will assess a variety of maps, many of which use multiple visual variables. We will also discuss multivariate mapping further in Lesson 7 (Multivariate and Uncertainty Visualization).

The figures above focus on geometric visual variables (e.g., color; pattern; size), though another common mapping technique is to use pictographic or iconic symbols (Figure 3.5.2).

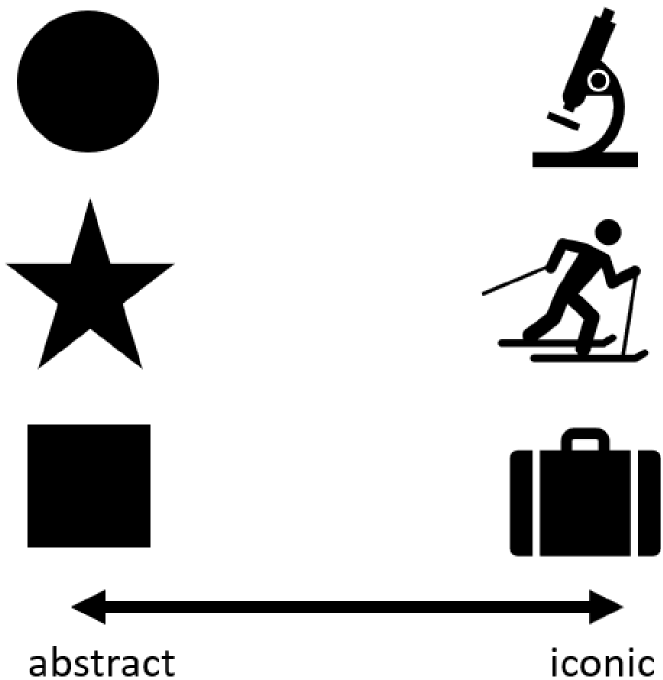


Figure 3.5.2 Symbol iconicity. Credit: Cary Anderson, Penn State University, after (MacEachren et al. 2012).

Iconic symbols are those that provide a closer visual match to their referent, or the real-world element meant to be depicted by the map symbol (Maceachren et al. 2012). The map in Figure 3.5.3 below uses flower symbols that are drawn similarly to how they appear in reality to create an engaging and useful map. It is important to balance usability and realism when using iconic symbols on maps – ensure that they do not become overcrowd, or distract from the map's purpose.

Another important consideration that should be weighed when considering the use of iconic symbols is the cultural context of those symbols. Iconic symbols can have meaning only to a specific group of individuals. For example, imagine that you are driving down the interstate and see a road sign that shows a knife and fork. Some people would understand these icons to imply food. However, the knife and fork icon is not necessarily understood to imply food by individuals who, for example, only use their hands while eating and may have never seen a knife and fork. Iconic symbols, therefore, are very culturally contextualized and that context should be weighed before icon symbols are chosen to be used on a map. Here is an article(link is external) that further explores the idea of symbols and icons and their meaning in cartography.

Figure 3.5.3 A map of the National Cherry Blossom Festival. Credit: [National Parks Service]

Like other continuums we have discussed (e.g., discrete to continuous; abrupt to smooth), map symbols cannot always be classified as simply abstract or iconic, and instead, exist somewhere in the middle. National Geographic's Atlas of Happiness for example, uses smiling face graphics to encode data about happiness. Thus, it is less abstract than if this data had been encoded only with color value or size, but less iconic than if more realistic graphic images of people were used.

Visual variables are used in many mapping techniques: in addition to selecting which visual variables you use for your maps, you will also need to choose what type of thematic map you will create. The four most popular thematic map types are **choropleth**, **isopleth**, **proportional symbol**, and **dot** maps.

Below we give a general overview of the four most popular types of thematic maps.

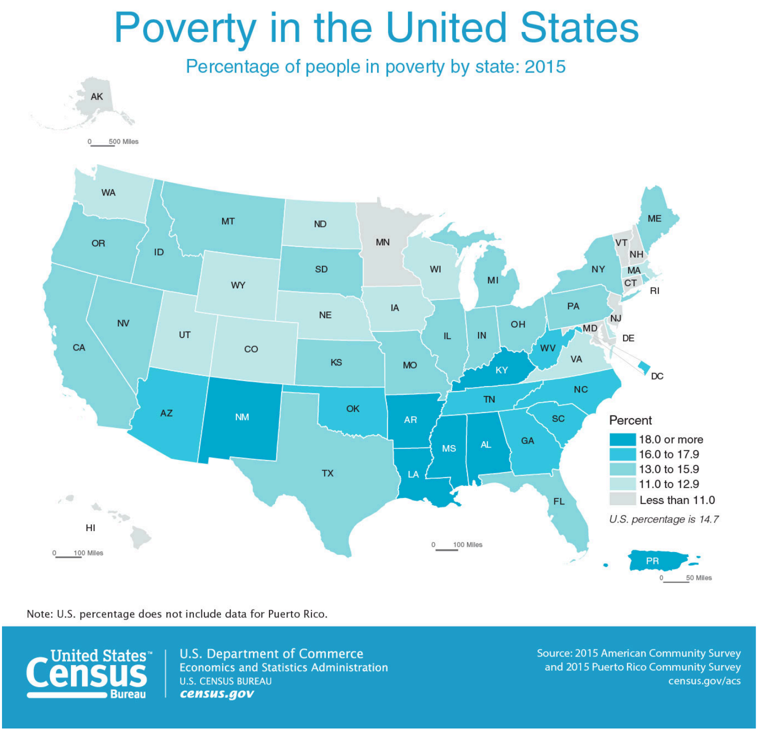


Figure 3.5.4 A choropleth Map. Credit: Census.gov

Choropleth Maps are maps in which color or shading is applied to distinct enumeration units, usually statistical or administrative areas. Color hue, saturation, and value are the most frequently used visual variables in choropleth mapping, though pattern is sometimes used as well. Choropleth mapping should **not** be used to encode exact counts (e.g., number of people living in each state), as the visual encoding of color by enumeration units makes this confusing. For example, consider that more people live in California than in any other state. You could create a state-by-state choropleth map showing counts of, say, universities or gas stations, and California would likely lead in both. But a map showing this would not be interesting—California has more people and things because it is a bigger enumeration unit. The map would tell us nothing interesting about California's system of education, or its residents' consumption of gas.

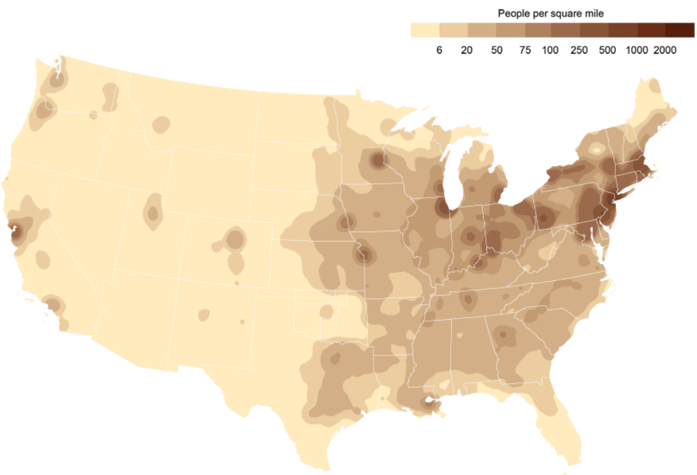


Figure 3.5.5 An isopleth map of US population density in 1890. Credit: [Census.gov]()

Isopleth Maps are like choropleth maps in that they typically use color value to encode data values, but unlike choropleth maps, they do not visualize the enumeration units from which they are built. Isopleth maps are preferred for mapping phenomena that vary continuously over space, as they better represent the distributions of these phenomena than choropleth maps. The primary disadvantage of isopleth maps is that they require quite a bit of data to design them accurately. They should also not be used to map data that change abruptly at administrative boundaries (e.g., percent sales tax). Choropleth mapping is a simpler and more appropriate method for mapping such data.

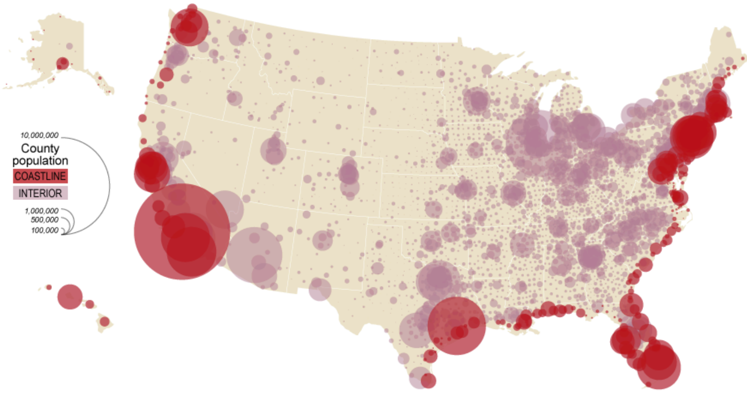


Figure 3.5.6 A proportional symbol map of county populations. Credit: [Census.gov]

Proportional Symbol Maps are best for mapping abrupt, discrete data; they visualize data using the size of a symbol (most often a circle) placed inside an enumeration unit. As the symbols are scaled only based on the data value—irrespective of the size of the enumeration unit—this permits the reader to not only view the variation between symbols, but also perform a visual comparison of the size of the symbol and the size of the enumeration unit over which it is placed. Note that the map in 3.5.6, unlike the previous two maps (3.5.4 and 3.5.5) displays count data (population) rather than a rate (percent in poverty; people per sq. mile). This is an appropriate choice for a proportional symbol map.

Size, the visual variable used in proportional symbol mapping, should not be used to map standardized data such as rates (e.g., people per sq. mile). When mapping count data such as population counts, you *should* use a proportional symbol map, or you should **standardize** your data before using it to make a choropleth or isoline map. We will talk more about standardization in Lesson Four.

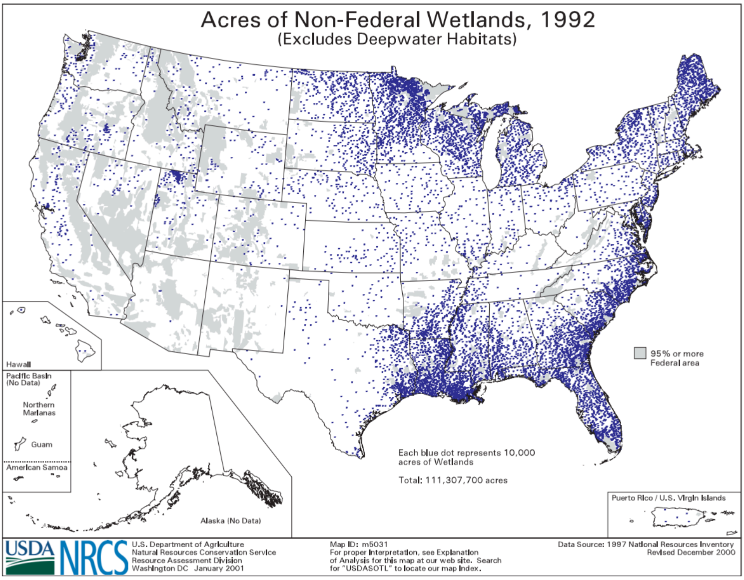


Figure 3.5.7 A dot map showing acres of wetlands in the US in 1992. Credit: nrcs.usda.gov

Dot Maps are like proportional symbol maps in that they are excellent for visualizing discrete data. Rather than displaying a different-sized symbol per enumeration unit, however, dot maps are constructed by filling enumeration units with a count of symbols (usually dots) based on the count of the variable of interest within the unit. Thus, this technique is preferred over proportional symbol mapping for mapping data which vary more continuously over geographic space.

It's important to think critically when creating and reading dot maps. Often, dot maps are made by scattering the appropriate number of dots randomly throughout each enumeration unit. To a novice viewer, they give the illusion of high precision – you might assume that if every dot represents one person, that the dots are placed on the map exactly where those people live! However, this is very rarely the case. We will explore the differences between dot and proportional symbol maps more in the lab at the end of this lesson. As you will see, which method is most appropriate depends not only on what phenomenon you are mapping, but also on the scale at which you map it.

Visual Encoding: Examples for Reflection

Student Reflection

Analyze the maps shown below. For each map, identify the level of measurement of the data mapped. What visual variables are used to encode this data? Is the map effective—does it tell you what you need to know?

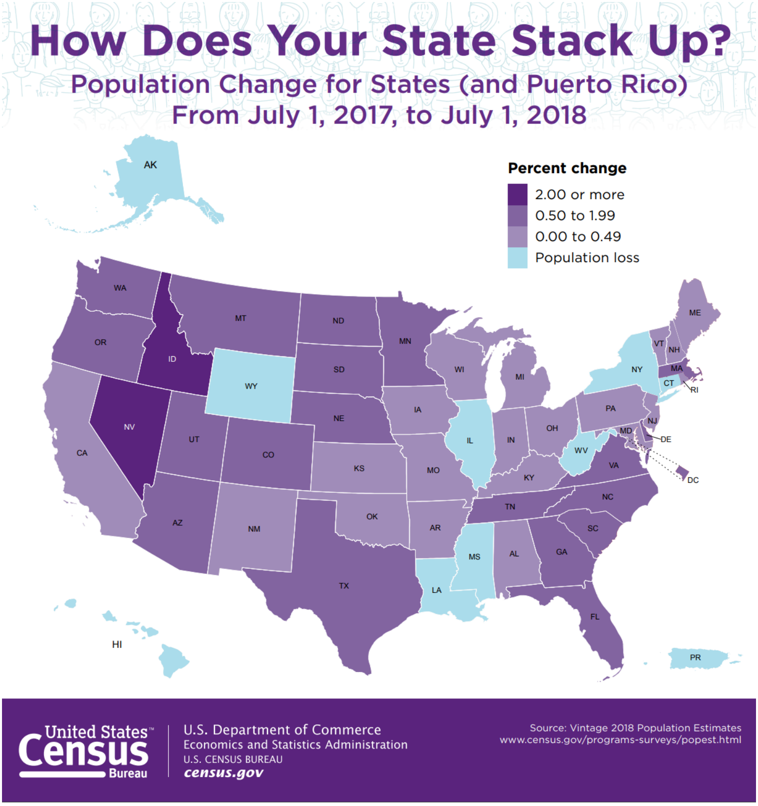


Figure 3.6.1 Example Map #1 Credit: Census.gov

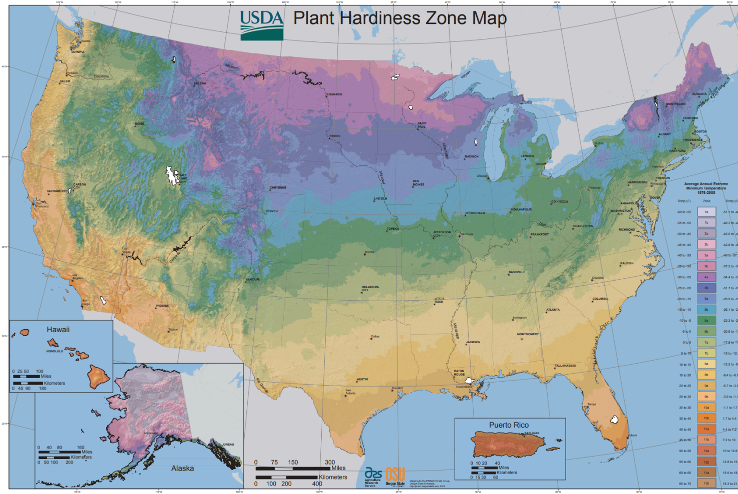


Figure 3.6.2 Example Map #2 Credit: usda.gov (click link for a larger image!)

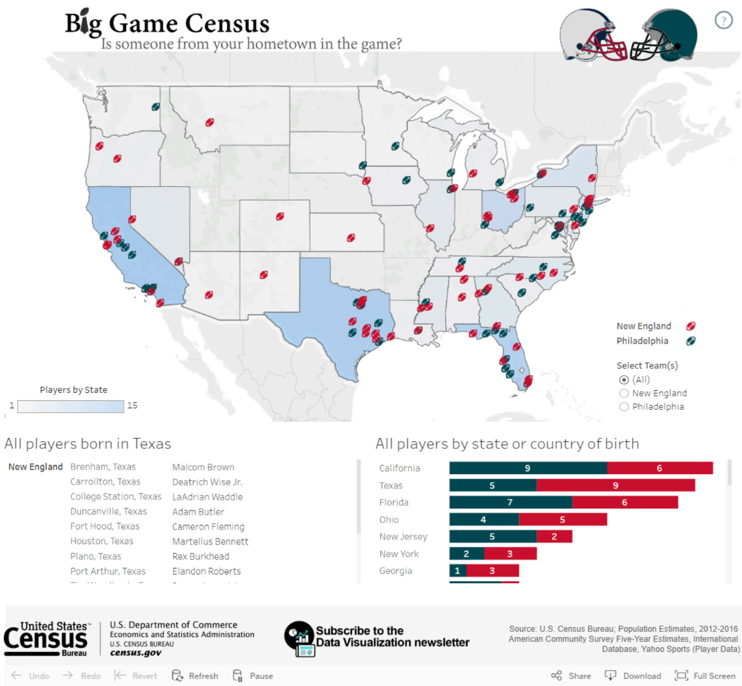


Figure 3.6.3 Example Map #3 Credit: Census.gov (click link for an interactive graphic!)

Lab 4: From Data to Design

Instructions

For this week only, we'll be moving away from working with data pertaining to your chosen city to the state level. You will making two map layouts with an acceptable Census variable of your choosing, so as to compare two different thematic mapping techniques. The Census variable you choose should make sense; for example, choosing a Census variable of land area would not be acceptable. Examples of acceptable Census variables are variables related to population, education, housing, and families. You should already have the boundary data from Lab 1 so you will just need to choose a Census data table of a variable of interest and join that data to your shapefiles using the GEOID as the key. This lab is our first thematic mapping lab, but when mapping, you should integrate your design knowledge from previous lessons, such as techniques for creating balanced map layouts and neat map marginalia.

Learning Objectives

- Explore the influence of symbolization method (dot density vs. proportional symbol) and scale (state vs. county vs. Census tract) on map output and design using ArcGIS.
- Download, join, and symbolize data from the

US Census Bureau.

- Create two map layouts to demonstrate the assigned thematic mapping techniques.

Overall Lab Requirements

For Lab 4, you will create and submit two map layouts. One will be composed of three proportional symbol maps; the other will be composed of three dot maps. Your final task will be to write a reflection that compares these two techniques in the context of this lab.

- Symbolize data from the American Community Survey (ACS) – chose a variable appropriate for mapping with these two symbolization methods.
- Include a written reflection (250+ words); use the following questions to guide your writing:
- For each scale (state; county; tract), which symbolization method is most appropriate?
- At the state scale, which map is most misleading? Why?
- Submit this reflection as a text comment or in a separate .pdf document.

Deliverables

Proportional Symbol Map

- Symbolize data from the American Community Survey (ACS) – chose a variable appropriate for mapping with these two symbolization methods.

- Include a written reflection (250+ words); use the following questions to guide your writing:
    - For each scale (state; county; tract), which symbolization method is most appropriate?
    - At the state scale, which map is most misleading? Why?
    - Submit this reflection as a text comment or separate .pdf document.

Dot Density Map

- Create three maps at the same scale using Census data to show a variable of interest to you at three scales (Census tract, Census block group,).
- Use the dot density thematic mapping technique to symbolize your data.
- Combine your three maps into one map layout with scale bars, legends, and supplemental map text (e.g., map titles, legend titles) as appropriate.

Bonus!

- Create three maps at the same scale of your city of the same variable at the Census tract, block, and block group level using the proportional symbol and dot density techniques (you should have six maps total).
- Write a written reflection (at least 100 words) on which symbolization technique is most

appropriate and compare it to what you did with the dot density maps and proportional symbol maps you created for the state your city is in.

- Make sure to only use the city boundaries as your extent.
- You will get three extra points to use on this assignment or another assignment.

Submitting Deliverables

Submit all the materials in a zipped file with the naming convention of LastName_Lab3

- Submit 2 PDFs of the maps in a 8.5 x 11 inch layout using the naming conventions below:
    - Map Layout 1 – Proportional Symbols: LastName_Lab4_Map1.pdf
    - Map Layout 2 – Dot Density: LastName_Lab4_Map2.pdf
- PDF of your reflection statement OR you can add the text as a comment within your assignment.

Lab 4 Grading Rubric

Map 1 – Proportional Symbol Map: 6 points

Criteria	Points Value
Three maps using Census data to show a variable of interest of you at different scales (state; county; census tract).	3
Use the proportional thematic mapping technique to symbolize your data with all three maps.	2.5
Combine your three maps into one map layout with scale bars, legends, and supplemental map text (e.g., map titles, legend titles) as appropriate.	1.5
The map is 8.5”x11.”	.5
Total points	**7.5**

Map Two – Dot Density Map: 6 points

Criteria	Points Value
Three maps using Census data to show a variable of interest of you at different scales (state; county; census tract).	3
Use the dot density thematic mapping technique to symbolize your data.	2.5
Combine your three maps into one map layout with scale bars, legends, and supplemental map text (e.g., map titles, legend titles) as appropriate.	1.5
The map is 8.5”x11”	.5
Total points	**7.5**

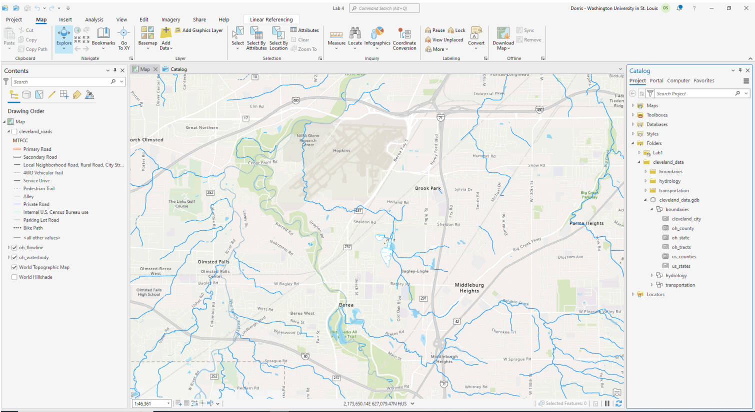
Lab 4 Visual Guide

Lesson 4 Lab Visual Guide Index

1. Saving a Lab 4 Project
2. Download Census Data to Map
3. Format Census Data for Import
4. Add ACS data to your project
5. Joining Census data to boundary files
6. Symbolizing Data
7. Creating a Layout
8. Save-As: Building Dot Density Maps
9. Additional Tips

1. Saving a Lab 4 Project

Open up a previous project from a lab. I would recommend Lab 1 given that lab was dedicated to downloading and preparing your data for subsequent labs. Click on **Project** > **Save Project As** and name it **Lab 4**. Your map will focus on the state of your chosen city for your City Story. For each mapping technique (proportional symbol; dot map), you will create three maps: state-level, county-level, and census-tract level.



Visual Guide Figure 4.1. Creating Lab 4 project from Lab 1 in ArcGIS Pro.

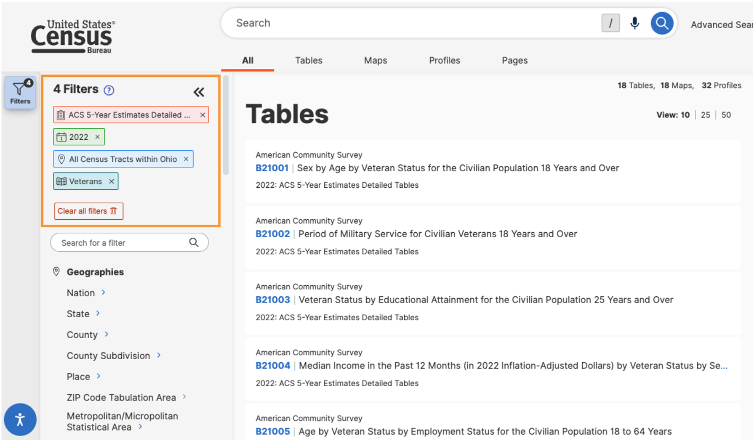
2. Download Census Data to Map

The ACS census data that you download will include demographic data of your choosing for the state, county, and tract level geographies. This demographic data will be in spreadsheet format that you will then join to the TIGER boundary files. If you use the [Advanced Search] option in the census data tool, you may find it easier to search for Census data according to specific topics, geography, years, surveys, or codes. For example, assume I am interested in choosing ACS 2022 five year surveys for all census tracts in Ohio for the purpose of examining the number of veterans. Here is what I would search on using the Advanced Search option. The words listed below correspond to the search criteria in the Advanced Search interface. Note that you can narrow your search for data by clicking on any of the search criteria in any order. Here is the order I used.

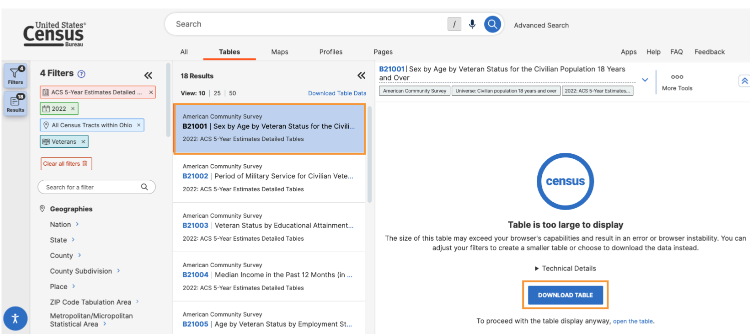
  - Surveys: Choose the **American**

Community Survey > **5-Year Estimates** > **Detailed Tables**

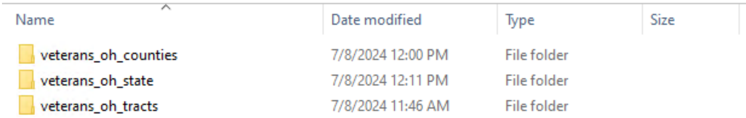
- Years: Choose **2022**
- Geography: Choose **Census Tract** > **Ohio** > **All Census Tracts within Ohio**
- Topics: Download topic of interest for a variable of interest (e.g., **Populations and People** > **Veterans**)
- A listing of detailed tables will be returned from which you can choose one table.
- The census tract results will likely too large to display (no worries). On the screen that appears, download the data as a zipped CSV file format.
- To follow recommended data management guidelines, a folder called veterans_data was created to store the data on the state, county, and census tract level. They were renamed veterans_oh_state, veterans_oh_counties, and veterans_oh_tracts respectively.



Lab 4 Visual Guide Figure 4.2. U.S. Census Bureau search results based on selected filters.



Lab 4 Visual Guide Figure 4.3. Search results along with the table preview window.



Lab 4 Visual Guide Figure 4.4.Sub-folders in the veterans_data folder.

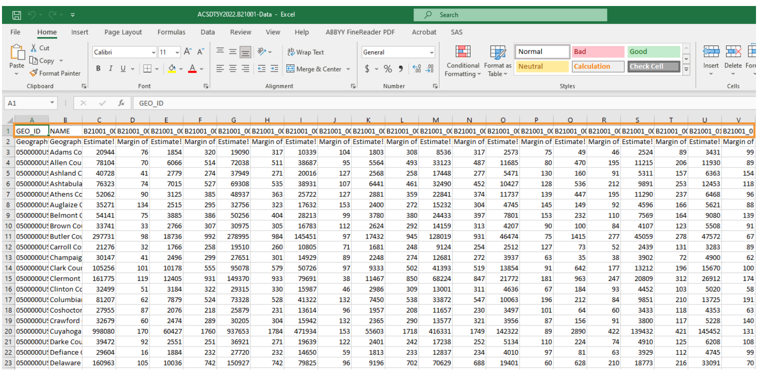
4. Format Census Data for Import

For each geographic scale (state; county; tract), open the appropriate CSV file from your downloaded data folder and follow these steps:

1. Delete the top row (you only want one header row; this will become your top row/field names in ArcGIS).
2. As you scan through our file, you will see that there are likely a lot of data columns and they use a naming convention. . Choose one column (variable) that interests you. Most of the columns (variables) you will not use for this lesson. Therefore, it is also helpful to delete the columns you don't need for your map, as this will make the table easier (and faster) to import and deal with in ArcGIS. can refer to the metadata table to see a full listing of the columns and their corresponding labels. (Tip: Change the first column labeled "Geography" to "GEOID")
3. To make the column names easier to read, do a "Find and Replace" (Control + F) to replace the !! with spaces. Just leave the **Replace with** section blank and make sure to click **Replace**

All.

4. Go to **File** > **Save As** and save each CSV file with a name that follows recommended data management guidelines (hint: look at the naming structure of your folder). By doing this, you create a new CSV file that includes your modifications and keeps the original data table in tact.



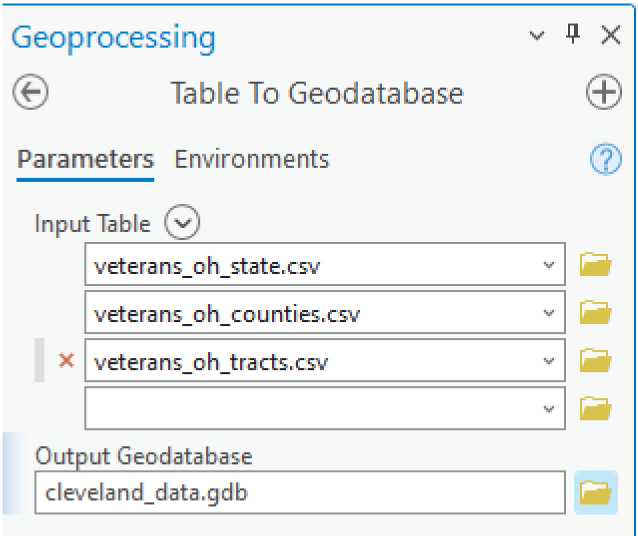
Lab 4 Visual Guide Figure 4.5. Formatting the census data table. You should delete the top row.

1	Column Name	Label
2	GEO_ID	Geography
3	NAME	Geographic Area Name
4	B21001_001E	Estimate!!Total:
5	B21001_001M	Margin of Error!!Total:
6	B21001_002E	Estimate!!Total:!!Veteran
7	B21001_002M	Margin of Error!!Total:!!Veteran
8	B21001_003E	Estimate!!Total:!!Nonveteran
9	B21001_003M	Margin of Error!!Total:!!Nonveteran
10	B21001_004E	Estimate!!Total:!!Male:
11	B21001_004M	Margin of Error!!Total:!!Male:
12	B21001_005E	Estimate!!Total:!!Male:!!Veteran
13	B21001_005M	Margin of Error!!Total:!!Male:!!Veteran
14	B21001_006E	Estimate!!Total:!!Male:!!Nonveteran
15	B21001_006M	Margin of Error!!Total:!!Male:!!Nonveteran
16	B21001_007E	Estimate!!Total:!!Male:!!18 to 34 years:
17	B21001_007M	Margin of Error!!Total:!!Male:!!18 to 34 years:
18	B21001_008E	Estimate!!Total:!!Male:!!18 to 34 years:!!Veteran
19	B21001_008M	Margin of Error!!Total:!!Male:!!18 to 34 years:!!Veteran
20	B21001_009E	Estimate!!Total:!!Male:!!18 to 34 years:!!Nonveteran
21	B21001_009M	Margin of Error!!Total:!!Male:!!18 to 34 years:!!Nonveteran
22	B21001_010E	Estimate!!Total:!!Male:!!35 to 54 years:
23	B21001_010M	Margin of Error!!Total:!!Male:!!35 to 54 years:
24	B21001_011E	Estimate!!Total:!!Male:!!35 to 54 years:!!Veteran

Lab 4 Visual Guide Figure 4.6. Census metadata table.

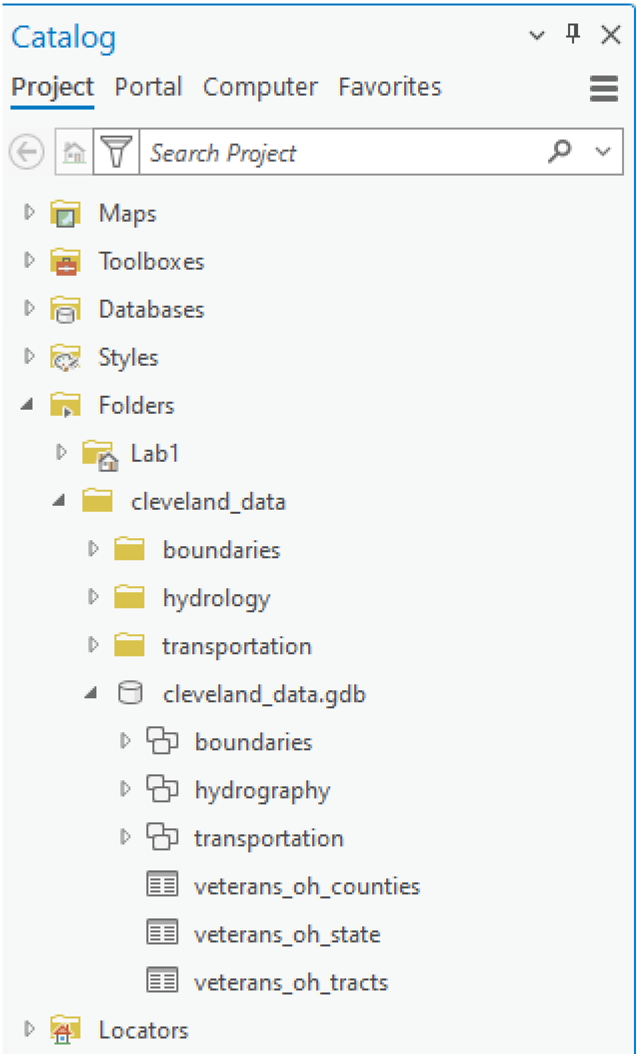
5. Add ACS data to your project

Use the import table(s) function to import your CSV files. Hit F5 (refresh) is your data appears to be missing! It likely just needs to be refreshed.



Lab 4 Visual Guide Figure 4.7. Importing your .csv files as tables in ArcGIS Pro.

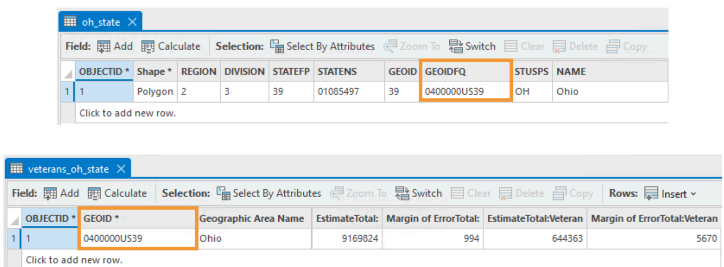
Refresh your database in the catalog pane to see the tables you have imported.



Visual Guide Figure 4.8. The Catalog Pane.

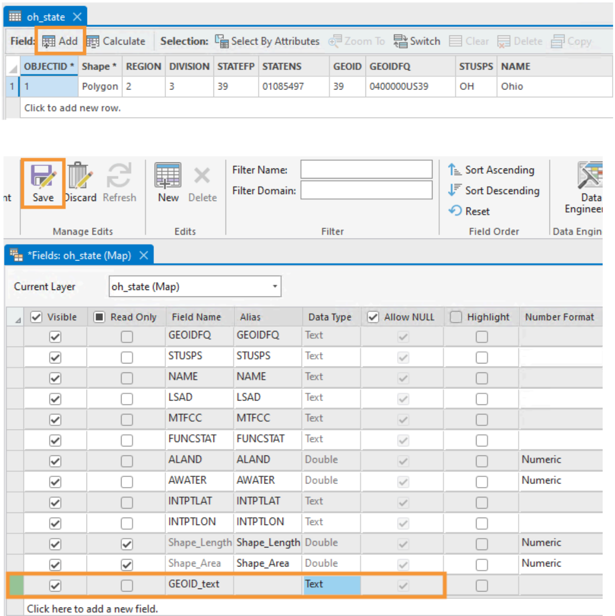
6. Joining Census data to boundary files

For each map, we want to join our imported ACS table to the spatial boundary file. To do this, we want to find the field that matches the ACS table and the spatial attribute table – we will join them using this field. Figure 4.9 below shows that the GEOID field in the veterans_oh_states census table matches the GEOIDFQ field in the oh_state boundary file. We will **join** them using this field. You also need to make sure that the fields have the same data types. For example, if the GEOID field is a numerical field (double, long, short) and GEOIDFQ is a text field, then you will not be able to join the fields.

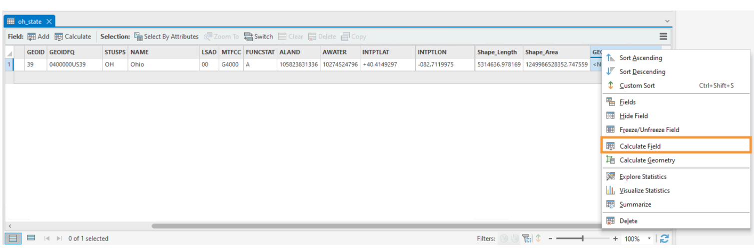


Visual Guide Figure 4.9. Comparing the type of values in the two attribute tables we want to join.

In the case that the data types are not the same, in the boundary file, you will need to create a new field and make sure the field type corresponds to the data table field type. For example, the veterans_oh_state GEOID table is a text field, but the oh_state GEOIDFQ field is a double field (you will see that the data types match but consider this as the scenario!). You will need to make sure that the GEOIDFQ information is text data. First, add a new field and make sure that the field's data type is a text field (Note: The GEOIDFQ field is in the correct data type (text) and this process is being done for demonstration purposes only). Make sure to save after adding the field.

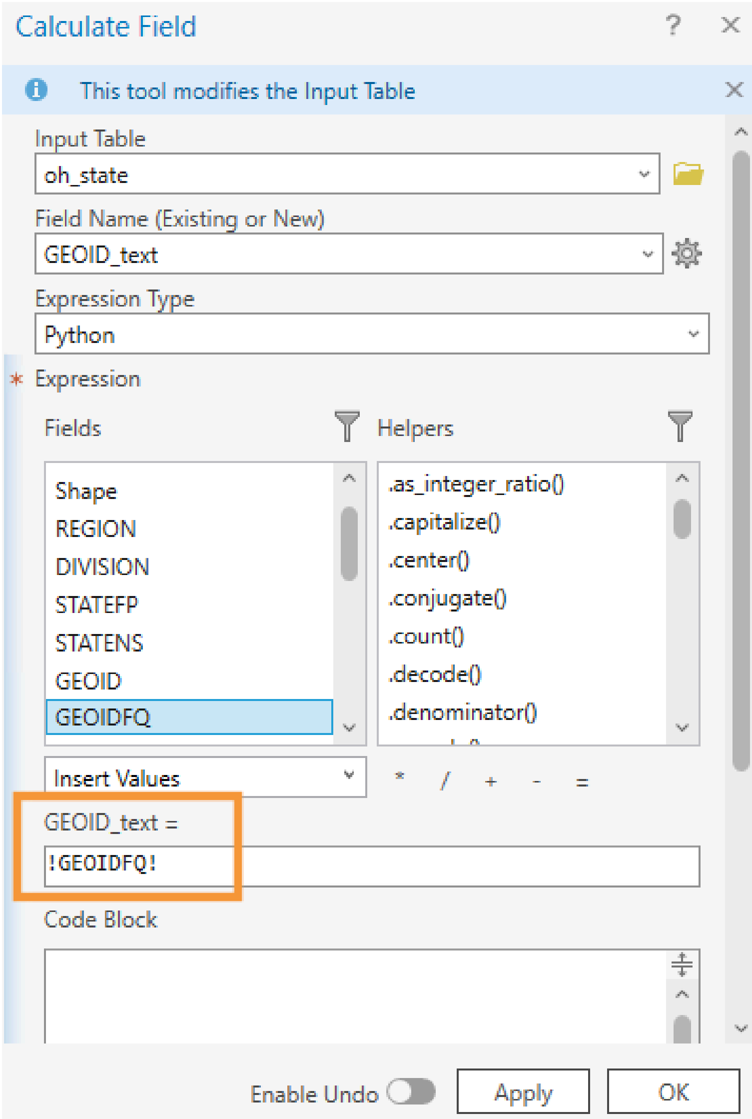


Lab 4 Visual Guide figure 4.10. Adding a new (text) field.



Visual Guide Figure 4.11. Calculating our newly-created field.

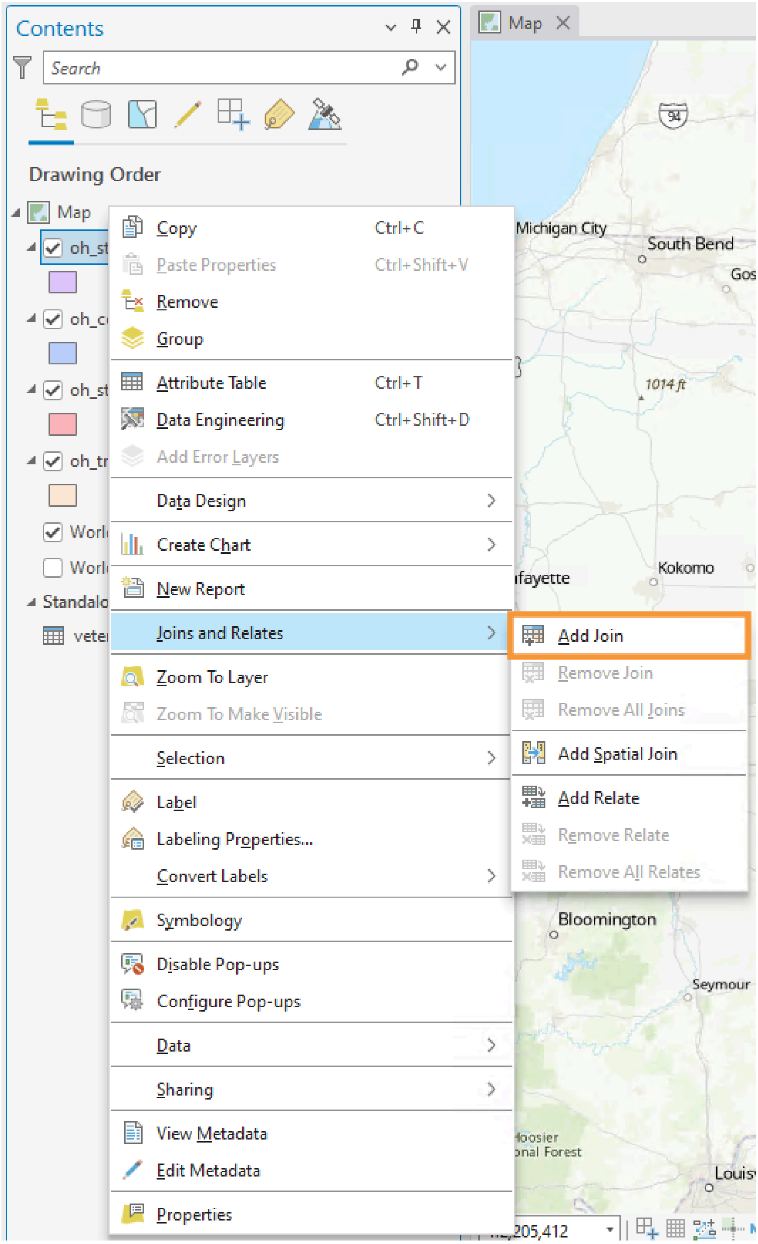
We will calculate this field by requesting that the new values be equivalent to those in the original field (GEOIDFQ) that we want to use. In essence, we are creating a duplicate field with the same values and the data will be saved in the chosen data type format.



Visual Guide Figure 4.12. Calculating the field via an expression in ArcGIS Pro.

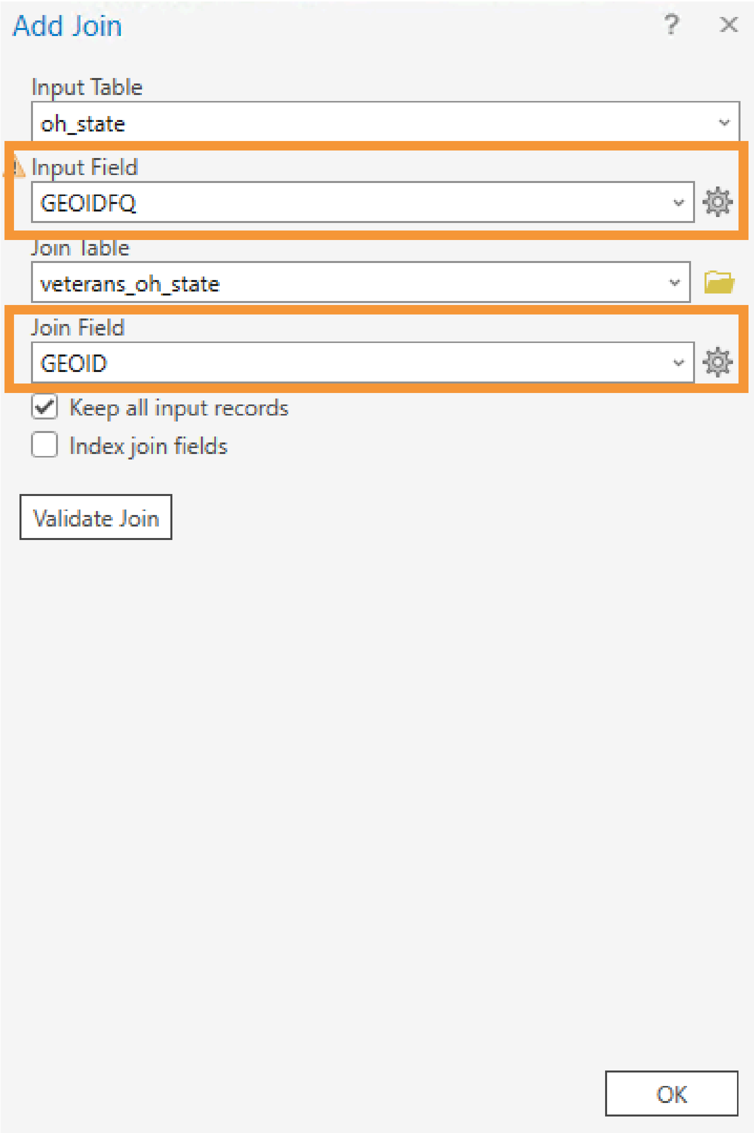
Once you made sure that the data types of GEOID and

GEOIDFQ are the same, you are now ready to join the data.



Lab 4 Visual Guide figure 4.13. Adding a join.

Add the join, using your newly calculated field and the matching field in your ACS data.

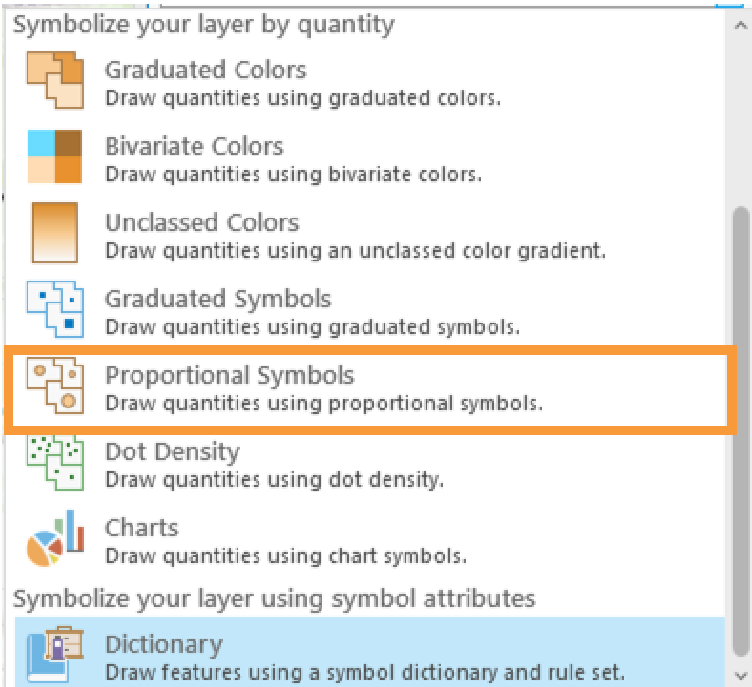


Lab 4 Visual Guide Figure 4.14. Adding a join.

7. Symbolizing Data

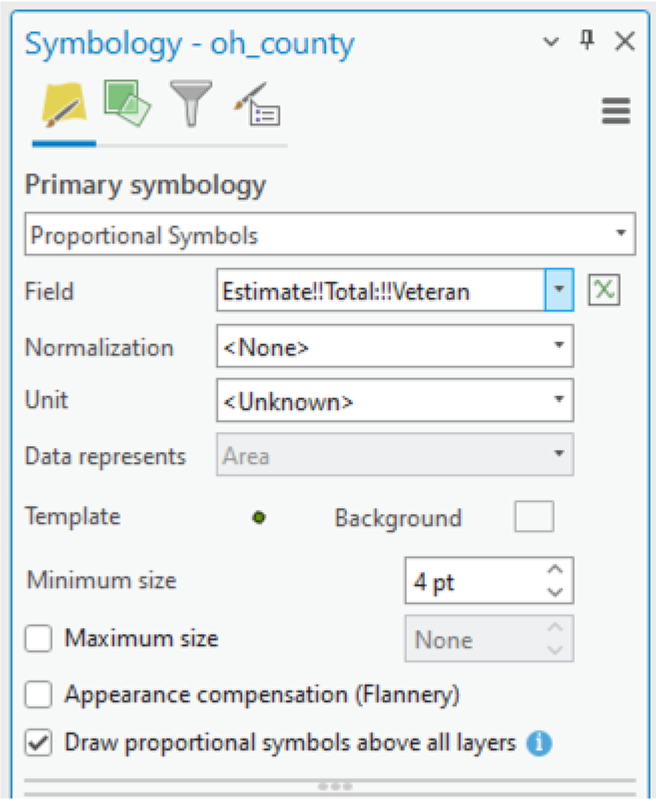
Reminder: Please make sure that your data is projected before proceeding with this step!

Before symbolizing your maps, repeat the previous steps (create and calculate new field; join ACS data) for your county-level and census-tract level maps. You will then have three maps ready to symbolize.



Lab 4 Visual Guide 4.15. ArcGIS Pro symbolization choices.

Use the **Proportional Symbols** method to symbolize your data.



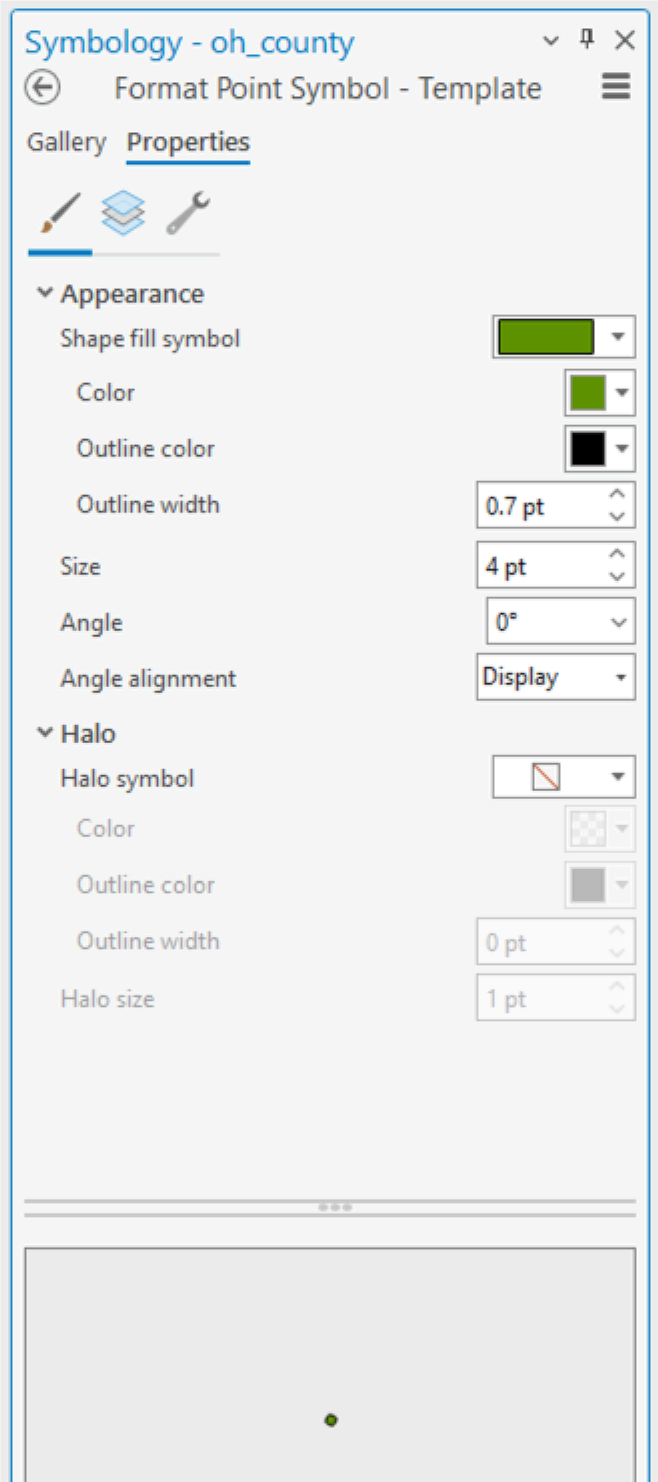
Lab 4 Visual Guide Figure 4.16. Proportional symbols in the Symbology pane.

Proportional Versus Graduated Symbols

Think carefully about the parameters you choose here! If you set the parameter to <None>, the software will give you *truly* proportional symbols – allowing the symbol sizes to vary according to the range of data values. In some cases, your range of data may be very large. As a result, unless you constrict the Maximum Size to some value, your proportional symbols *may* become too large, cover up much of the map space, and create a visually undesirable design. Setting the Maximum size to some value constricts the range of symbol sizes and therefore does not portray a true proportional symbol approach. However, your design may benefit from setting the Maximum size to some finite value. Note that for true proportional symbols, your maximum symbol size should be <None> – otherwise, you are creating **graduated**, not **proportional** symbols. Remember that **graduated** symbols create individual classes of symbols where each class represents a range of data values and that range is symbolized by a single symbol. **Proportional** symbols, on the other hand, are displayed on a map where each symbol is shown in proportion to a data value. With proportional symbols, if you have 50 unique data values, then you will have 50 unqiuely sized symbols. You will need to experiment a bit here to determine which approach creates a more appropriate design for your data.

Background Option

On the Proportional Symbol window shown in Figure 4.17, the **Background** option is present. This option allows you to alter the outline style and fill color of the enumeration unit. This option comes in handy so that you don’t need to add an unnecessary data layer of your enumeration units to your map environment. By setting the outline style and fill color using the Background option, your enumeration units will have a cohesive and appropriate design to them.

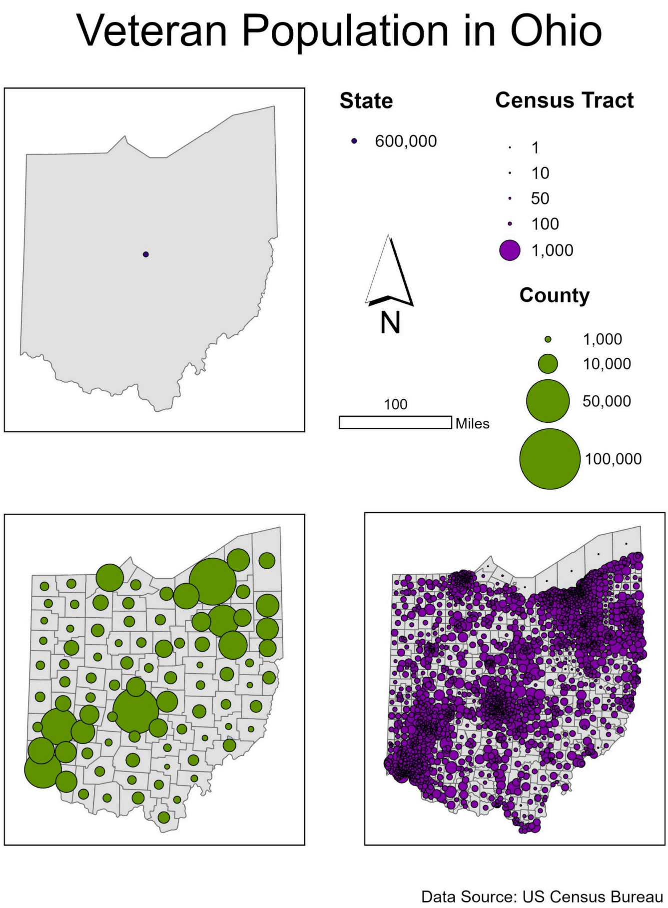

Symbology - oh_county
Format Point Symbol - Template
Gallery
Properties
Appearance
Shape fill symbol
Color
Outline color
Outline width
0.7 pt
Size
4 pt
Angle
0°
Angle alignment
Display
Halo
Halo symbol
Color
Outline color
Outline width
0 pt
Halo size
1 pt

Lab 4 Visual Guide Figure 4.17. Changing the style of your proportional symbol template.

8. Creating a Layout

Create a new standard-size (8.5″ x 11″) layout as you did in Lab #1. Insert a map frame and copy and paste it in the layout: this will create three maps at the same scale.

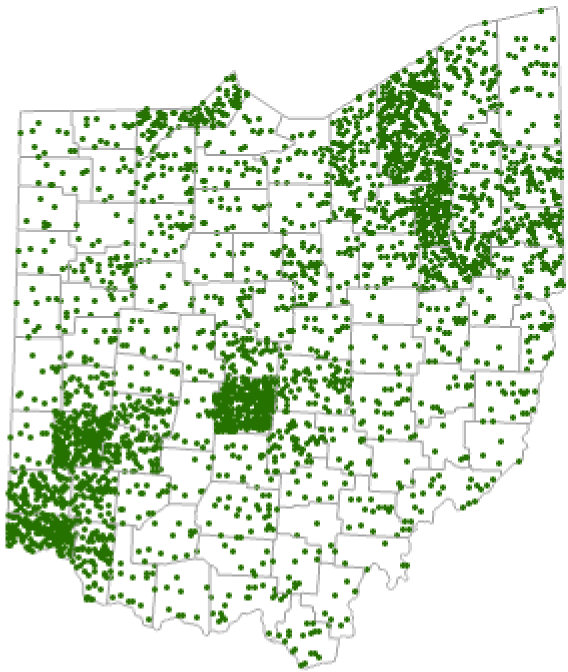
This (Figure 3.20) is just a quick layout example and should not be considered finished! You should follow the guidelines we have learned for creating a visual hierarchy and an excellent layout, etc.



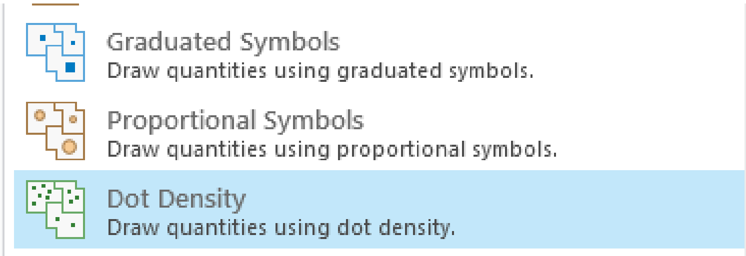
Lab 4 Visual Guide Figure 4.19. Example map layout with three maps, one for each scale. This is NOT a finalized design!

9. Save-As Building Dot Density Maps

Use the "Save-As" function and save a copy of your map project with a new name (like YourName_DotDensityMaps). This way, you won't have to add any new data. Creating your second layout will be much easier this way – instead of doing data joining, downloading, etc., you can just focus on the design!

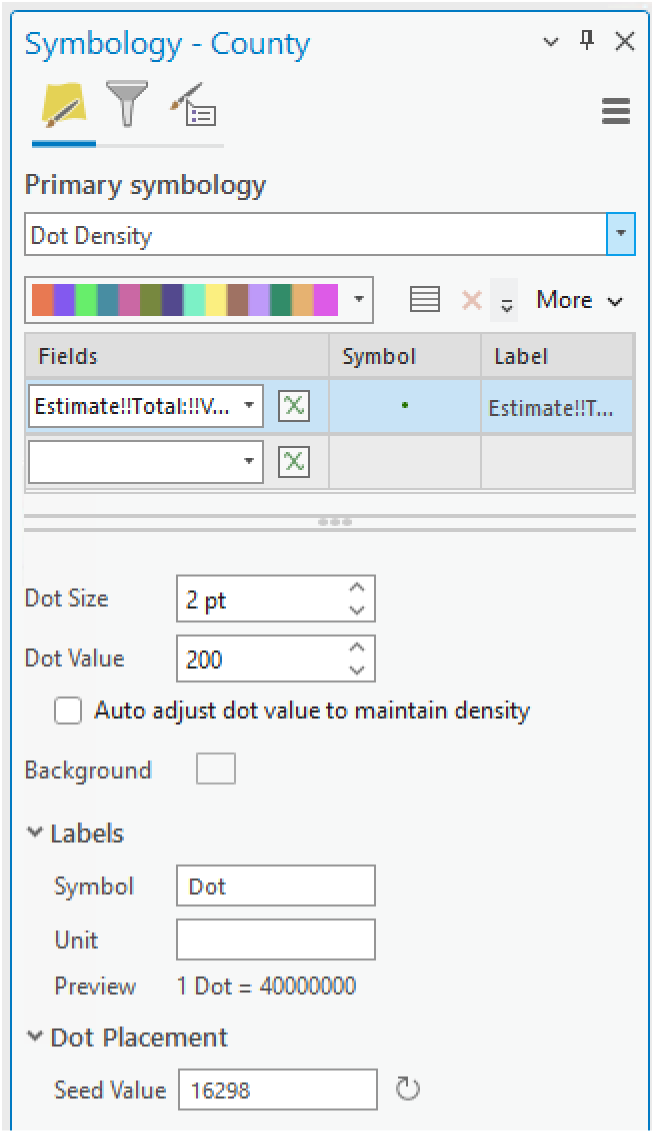


Visual Guide Figure 4.19. Example view of dots on a map.



Visual Guide Figure 4.19. Choosing the dot density symbolization method.

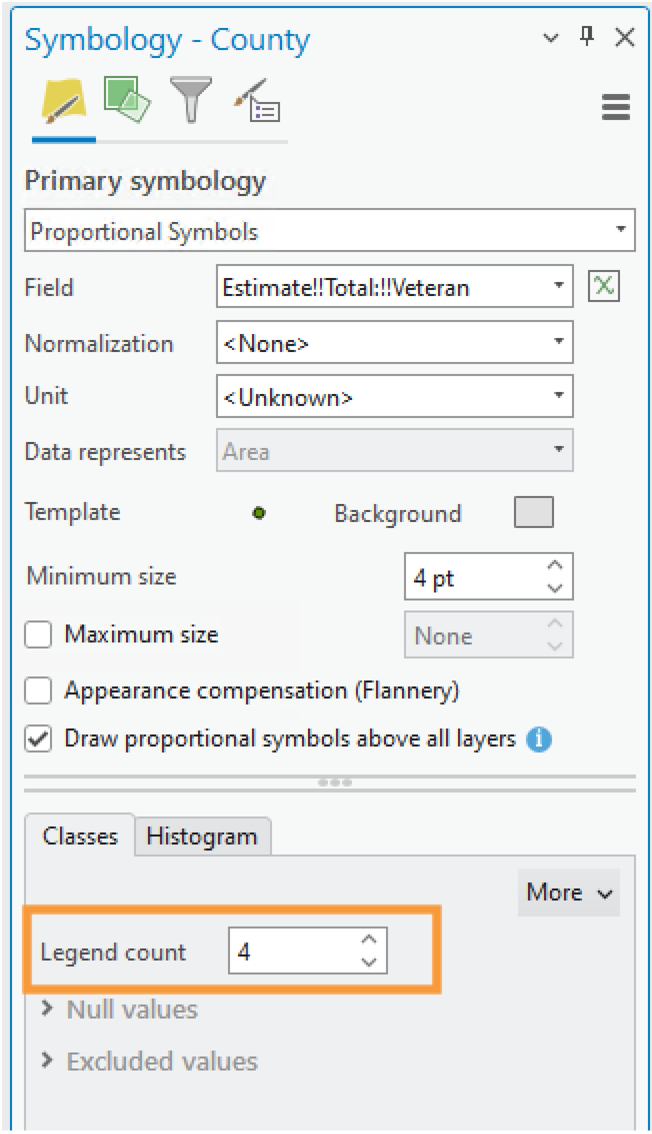
Have fun adjusting your symbolization as appropriate! Try out different colors and symbols. Experiment with the parameters to see what works! The best design will depend on many factors, including the scale of your map, your chosen state, and the data you are mapping.



Lab 4 Visual Guide Figure 4.20. Adjusting parameters using the dot density symbolization method.

10. Additional Tips

You are free to edit your data in this lab as needed to clean it up. You may want to make any unneeded boundaries invisible instead, as this will make it easier to bring them back if necessary. You can also change the number of legend items using the symbology pane.



Lab 4 Visual Guide Figure 4.21. Adjusting your map legend via the symbology pane.

Reference current and previous lesson content for design ideas. Test several layout configurations and lots of symbol designs (sizes; colors; outlines; transparency) – you'll learn a lot as you go!

Summary

This week we covered these topics:

- Symbolizing points, lines, polygons, 2.5D and 3D features
- The major types of thematic maps
- Geographic phenomena models
- Geographic representation by data type
- Types of maps
- Legends for different types of maps
- Map wording

One interesting map that makes use of the dot density map is Mapping Segregation by New York Times, which is a dot density map by ethnicity across the U.S. Take a look at the dot density map of various metropolitan areas. What patterns do you see? Do you think the dot density map best shows ethnicity across the U.S?

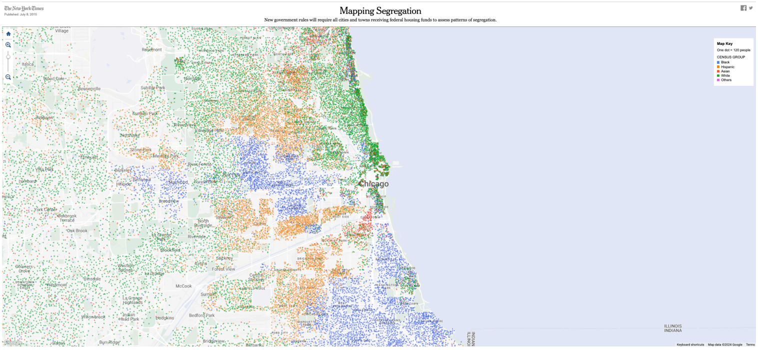


Figure 1.10.1 Map of Chicago classified by various dots which represents racial makeup in the Mapping Segregation project.

Image source: [New York Times]

IV

Color and Choropleth Maps

Overview

Overview

Welcome to Lesson 4! Last lesson, we learned about thematic maps, including how to choose a thematic mapping method and adjust our designs based on the characteristics of a geographic phenomenon. This week, we focus on a specific type of thematic map: choropleth maps. Choropleth maps are the most popular thematic map type, and designing them properly relies on adequate understanding of other important topics in cartography, such as data standardization and classification methods. Choropleth maps also typically employ color in their design: in Lesson 4, we discuss color in-depth. You will learn about the different ways in which we can model color space, and how visual perception constraints – both in the general population, and in those with color-vision impairments – influence map perception.

In Lab 4, we'll explore how choosing a different color scheme and/or classification method can alter how readers interpret your maps. We'll also learn how to make maps that work well in pairs—a common task that is often significantly more challenging than making one map that stands alone.

Learning Outcomes

By the end of this lesson, you should be able to: Demonstrate how to identify and specify colors using the three perceptual dimensions of hue, saturation, and lightness, integrate knowledge of color perception and human visual limitations (including color-vision impairment into map color decision-making, standardize and classify data appropriately for use on choropleth maps, and select an appropriate color scheme for a map based on probable perceived connotations of those colors as they relate to the map's data.

Color Overview

Color Overview

Color is frequently used to symbolize information on maps. In recent years, cartographers have begun to employ color more and more: in a study of map-color use in scientific journals, White et al., (2017) found that the use of color in published map figures increased from 18.4% in 2004 to 69.9% in 2013. This trend can primarily be attributed to the loosening of practical map production constraints. The cost of color printing, for example, is no longer prohibitory. This is in large part due to the increasing popularity of web-based dissemination of maps and other visual graphics, which makes such costs irrelevant. Tools such as ColorBrewer and Colorgorical have also made color selection easier; the first of these is even now integrated into the color selection tools in ArcGIS Pro.

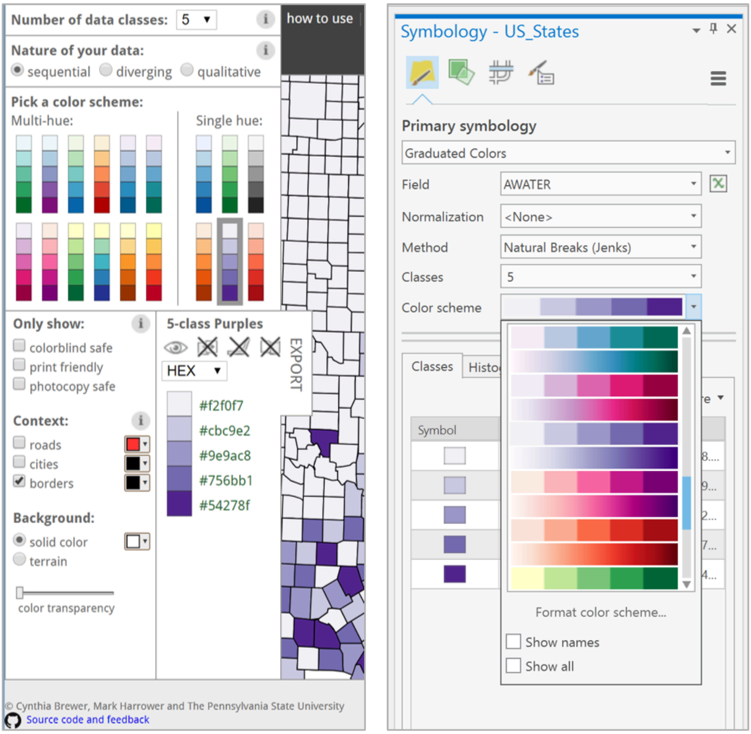


Figure 4.1.1 ColorBrewer (left), and Color Schemes in ArcGIS Pro (right) Credit: Cynthia Brewer, Mark Harrower and The Pennsylvania State University: ColorBrewer2.org; Screen capture from ArcGIS Pro.

In this lesson, we will explore the basics of specifying, mixing, and selecting colors for maps. You should aim to understand and properly apply the color schemes available in GIS software, as well as to alter them as appropriate based on your maps' audience, medium, and purpose. Eventually, you might even design your own color schemes from scratch.

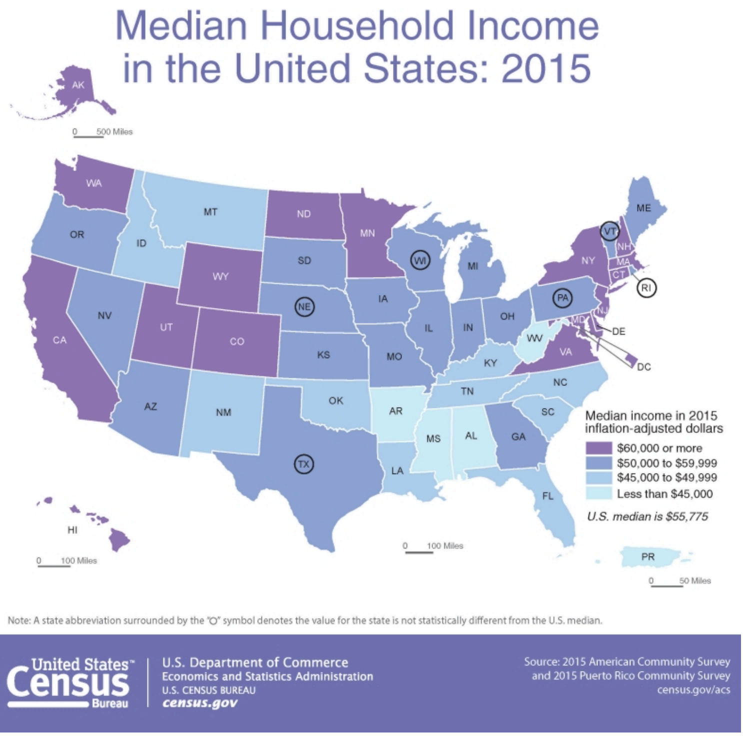


Figure 4.1.2 A choropleth thematic map from the Census Credit: *[United States Census Bureau]*

You might remember the map in Figure 4.1.2 from Lesson 1. This map is a thematic map, and more specifically, a **choropleth** map. Discussions of color in mapping often focus on choropleth maps. This is for good reason—choropleth mapping is the most common thematic mapping technique, and its employment typically requires thoughtful analytical use of color. We will discuss the details of choropleth mapping later in this lesson, but note that color is frequently used on other types of maps as well. General purpose maps often employ color to delineate between kinds of features, and maps that focus on other visual variables (e.g., proportional symbol maps) often also use color to encode an additional variable, or to add visual interest.

Specifying Colors

Specifying Colors

When you hear the word "color," words such as blue, red, and green likely spring to mind. Though these are colors in the colloquial sense, these are better described as **color hues**. When using color as a visual variable, each color is specified not just by color hue but by three dimensions: hue, lightness, and saturation (Figure 4.2.1).

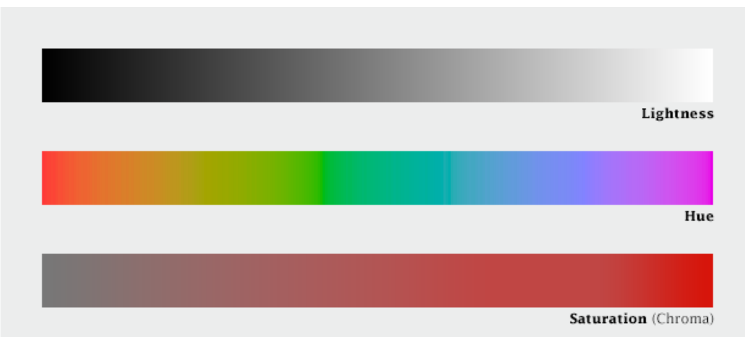


Figure 4.2.1 Lightness, Hue, and Saturation. Credit: NASA Earth Observatory

Color is produced when light is either reflected off of (e.g., a car; a printed map) or emitted by (e.g., a computer screen) an object. Hue refers to the wavelength of that light, from longest (oranges and reds), to shortest (blues and violets). Figure 4.2.2 shows nine swatches of color with different hues, in the order of the rainbow spectrum.

Figure 4.2.2 A set of color hues in spectral order. Credit: Cary Anderson, Penn State University.

In mapping contexts, hue is typically used to differentiate *between* features. In general purpose maps, for example, hue is used to create categories, and to help the reader identify different features as belonging to a particular group. In Figure 4.2.3, for example, color is used well, and improves the legibility and aesthetics of the map. Though multiple types of roads are shown, all roads are shown in red. Similarly, all hydrologic features and labels are shown in blue – a familiar color easily recognizable by map-readers as associated with water.

Figure 4.2.3 A general purpose map that uses color hue. Credit: [National Institute of Standards and Technology](#)

Lightness is another dimension of color; it describes how perceptually close a color appears to a pure white object. Lightness is also commonly called **value**, though cartographers sometimes avoid that term, as value is also used to describe data values—using the same word for both items can cause confusion. Lightness works well for visually encoding the order and/or magnitude of thematic data values—typically, lighter colors signify lower data values (i.e., less signifies less), and darker, more visually-prominent features signify higher data values.

The third dimension of color is **saturation**. Saturation is also sometimes called **chroma**. In map design, saturation is generally less important than hue and value, but it still can play an important role. Highly saturated colors are particularly useful for calling attention to small but important map elements that would otherwise be lost (Figure 4.2.4). Caution should be used when using saturation in this way, however—the use of too highly saturated colors, particularly over large areas, may be distracting or accidentally overemphasize those features.

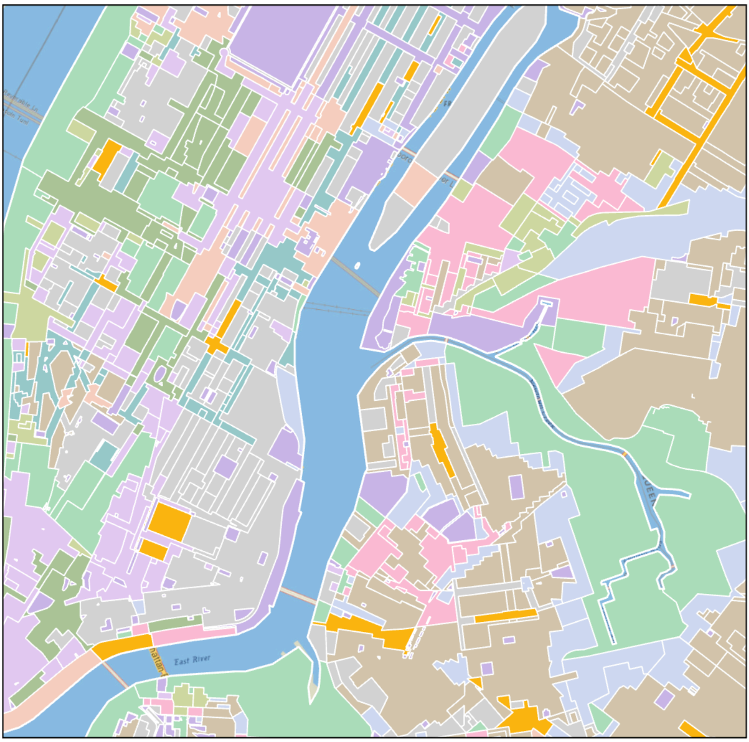


Figure 4.2.4 Using saturation to call out important elements on the map. Bright orange is used to highlight areas with zone classifications important given the map's purpose. Credit: Cary Anderson, Penn State University; data source: [NYC GIS](NYC GIS).

These three dimensions (hue; lightness; saturation) were originally identified by Dr. Albert H. Munsell in the early 20th century. Munsell's first color model, a color sphere, was an attempt to fit these three dimensions of color into a regular shape. Though this model was still a breakthrough, Munsell realized that it was quite insufficient, as human color perception is not linear and cannot be accurately modeled by a regular shape. The final shape he landed on looks more like a lopsided ellipsoid.

> *99% Invisible* has written an excellent short piece on the origins and specifics of the Munsell's color system, with helpful explanatory graphics. Read it here: The Color Sphere: A Professor's Pivotal "Color Space" Numbering System.

Figure 4.2.5 below takes a top-down approach to visualizing this color space: each of the four graphics demonstrate what is, in essence, a slice of the Munsell model, with increasing lightness from left to right. As shown, the colors which the human eye can perceive do not change linearly through color space—this makes color specification and design a challenging task.

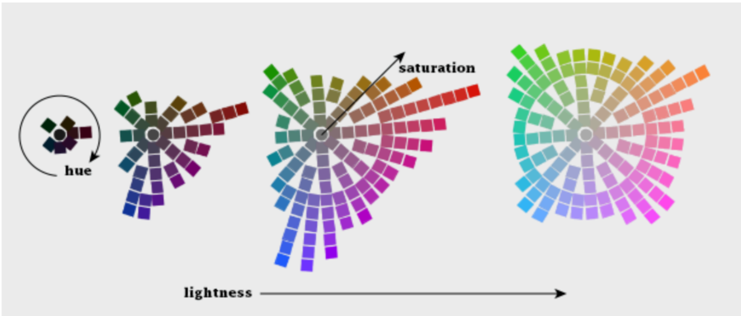


Figure 4.2.5 Colors perceived by humans at different "slices of lightness", as shown by the NASA Ames Color Tool. Credit: NASA Earth Observatory.

Student Reflection

Imagine you want to create a categorical map with a large variety of colors. What does Munsell's model suggest about what kind of colors would be best used for this purpose?

Though Munsell's model is helpful for understanding color perception, and perhaps for sharing color specifications with others, a working knowledge of other models is required for building color schemes in GIS and graphic design software. When specifying colors, it is important to consider the display medium that you are using to create them. When mixing paint, cyan, magenta, and yellow (CMY) are used. As mixing paint (or laser printing inks) results in less light being reflected from the color surface, this is called **subtractive mixing**. The opposite occurs on digital display screens, which create colors by mixing red, blue, and green (RGB) light. Mixing these primaries is called **additive mixing**.

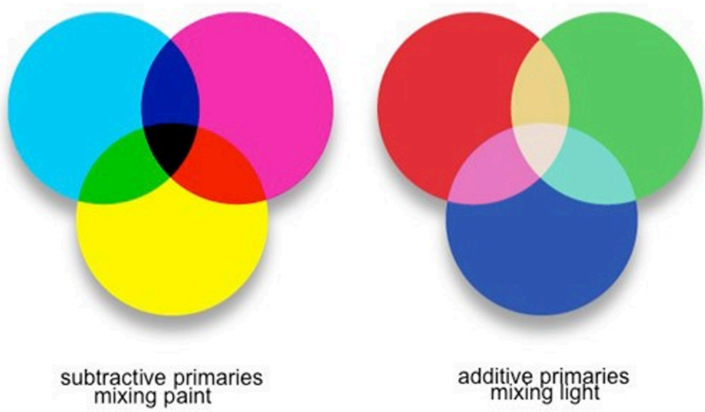


Figure 4.2.6 Subtractive vs. additive primaries (color models) Credit: [National Gallery of Art](#).

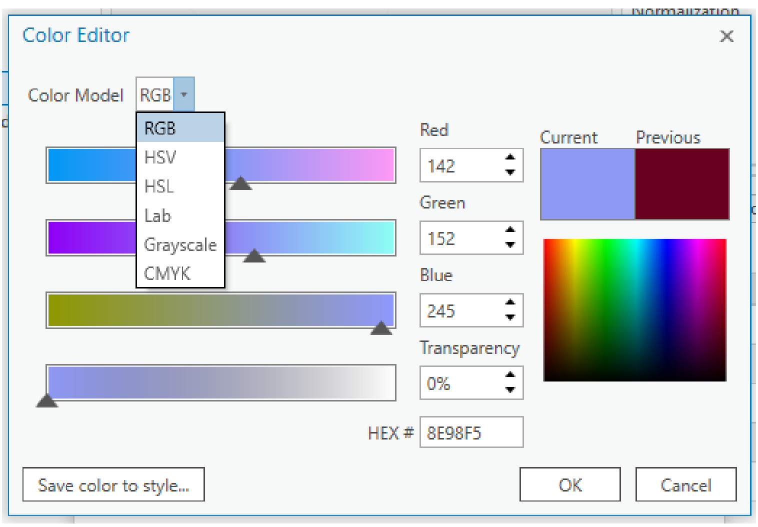


Figure 4.2.7 Specifying a color in ArcGIS Pro. Credit: Screenshot from ArcGIS Pro.

ArcGIS offers a wide selection of color model choices for specifying colors, including RGB, HSV, and CMYK. RGB and CMYK color models refer to the aforementioned models for mixing additive and subtractive primaries, respectively. RGB is useful for digital media, and CMYK is the color language typically used by graphic artists. Another popular model is HSV (hue, saturation, and value). HSV is reminiscent of the Munsell model (see Figure 4.2.8), but with much greater symmetry—recall the oddly-shaped structure of Munsell's model.

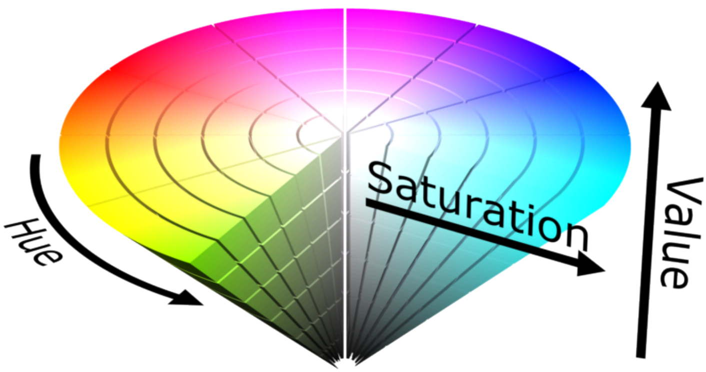


Figure 4.2.8 A visual model of the HSV color system. Credit: Datumizer via Wikimedia Commons (CC BY-SA 3.0).

The symmetry of HSV makes it fit much better into the language of computers, but as human color perception is not linear (recall Figure 4.2.5), using HSV can cause problems unless you remain cognizant of this shortcoming.

Additional color models, including HSL and CIELAB, offer other ways of specifying colors. We will not go further into the details of color specification here, but you are encouraged to explore the recommended readings for more information.

Types of Color Schemes

Types of color schemes

When applying color schemes to maps, there are many factors to consider. First and foremost, keep this rule in mind: the perceptual structure of the color scheme should match the perceptual structure of the data. For example, if your data go from high to low (sequential data), you should use a color scheme that demonstrates this order, as shown in the map in Figure 4.3.1.

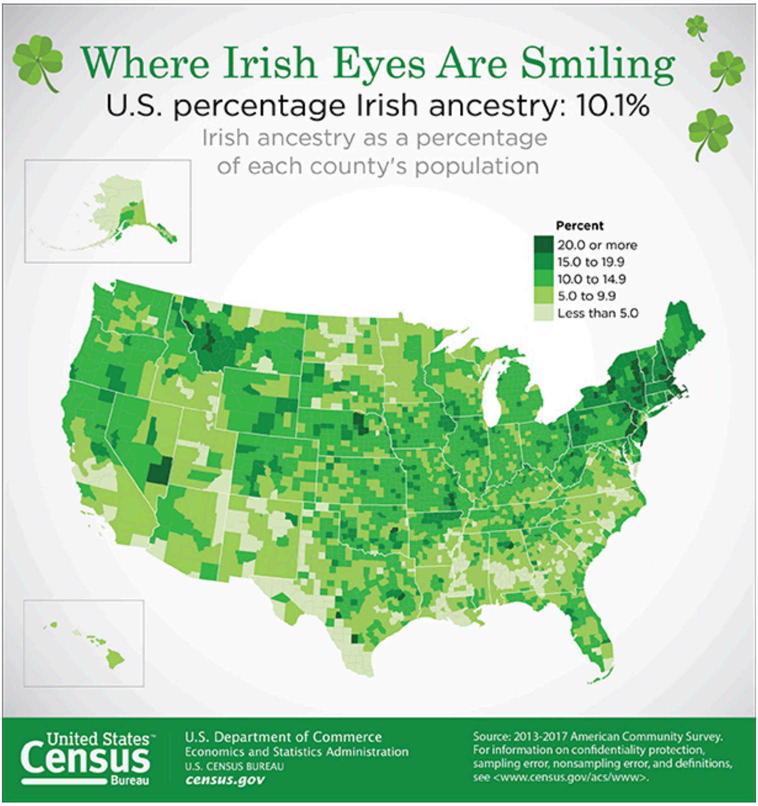


Figure 4.3.1 Color lightness demonstrating data order. Credit: US Census Bureau, [Census.gov](https://census.gov)

There are three main types of color schemes: **sequential**, **diverging**, and **qualitative**. A popular tool for choosing color schemes on maps is ColorBrewer, designed by Dr. Cynthia A. Brewer at Penn State. ColorBrewer's interface is shown in Figure 4.3.2. You may find it helpful to explore the many color schemes available on the site as you read more about types of color schemes in this lesson and consider how you might apply them to your maps.

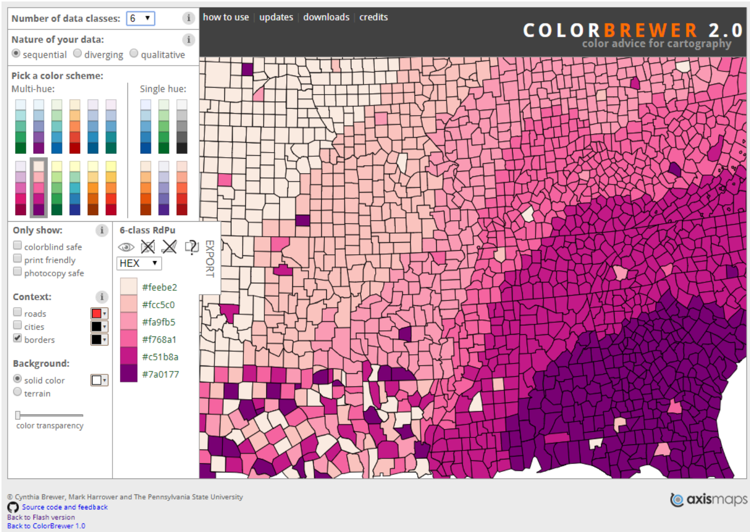


Figure 4.3.2 A Screenshot from Colorbrewer.org. Credit: Cynthia Brewer, Mark Harrower, and The Pennsylvania State University, ColorBrewer2.org.

Sequential color schemes are the most popular color schemes used in thematic mapping, as they are excellent for demonstrating the order of data values. Several examples of sequential color schemes are shown in Figure 4.3.3.

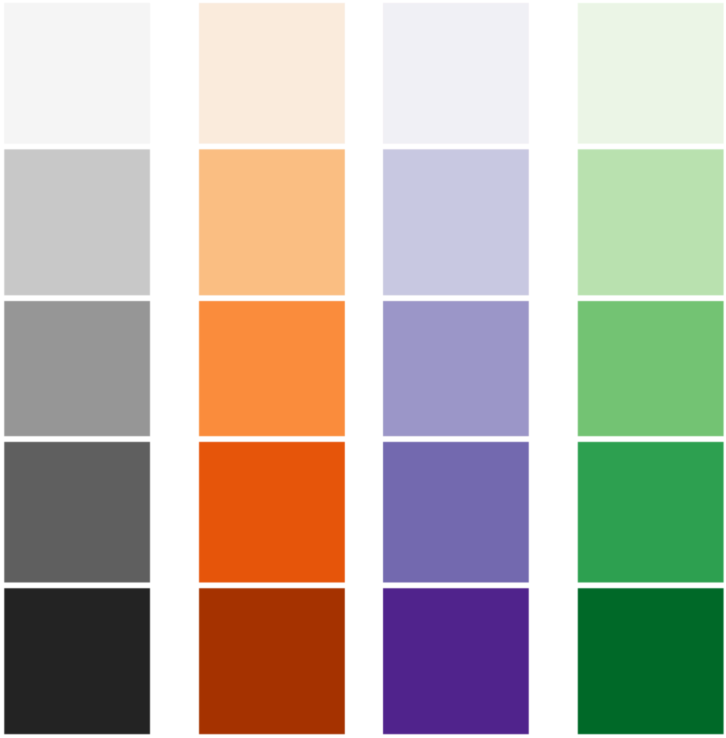


Figure 4.3.3 Sequential color schemes using color lightness. Credit: Cary Anderson, Penn State University; color specifications via ColorBrewer2.org.

Though color lightness is effective on its own, sequential color schemes are also often designed with multiple harmonious hues, such as in the color schemes shown in Figure 4.3.4. The multi-hued nature of these color schemes can make it easier for viewers to discriminate between all data classes on the map. They also often create more aesthetically-pleasing visualizations. As long as it doesn't take away from readers' comprehension of your data, why not make a better-looking map?

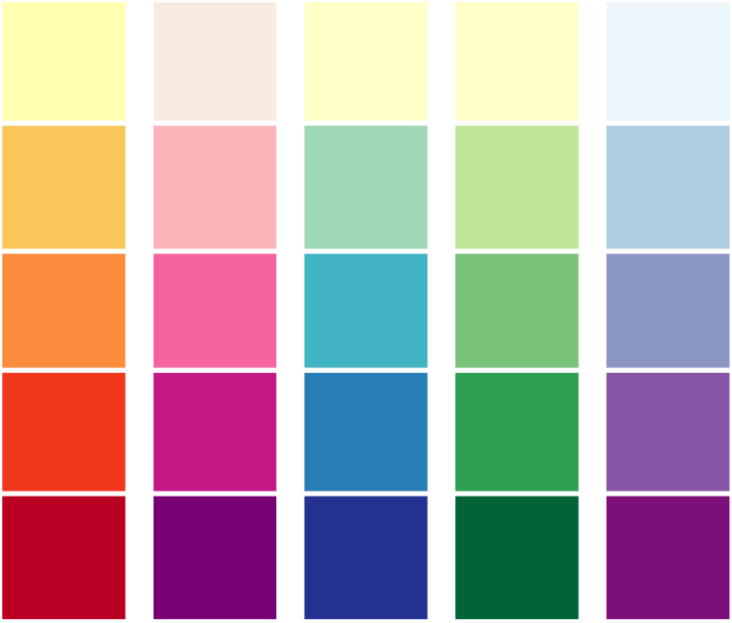


Figure 4.3.4 Sequential color schemes using color lightness and color hue. Credit: Cary Anderson, Penn State University; color specifications via ColorBrewer2.org.

As shown in Figure 4.3.5, when hue is paired with lightness it can create a dramatic effect in a sequential map. When making such maps, ensure that they accurately reflect the progression of your data—it is challenging to create an effective sequential color scheme that relies heavily on hue.

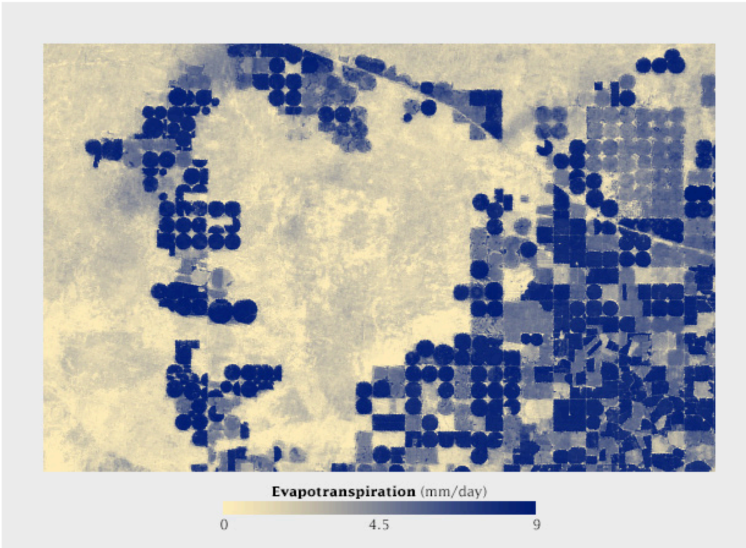


Figure 4.3.5 A map that uses a sequential color scheme with changing lightness, hue, and saturation. Credit: [NASA Earth Observatory]

Diverging color schemes are similar to sequential color schemes, as they also demonstrate order. Instead of showing a single progression, however, they visualize the distance of all values from a critical point. These color schemes work well for depicting data that have a critical middle value or class (such as maps showing percent change).

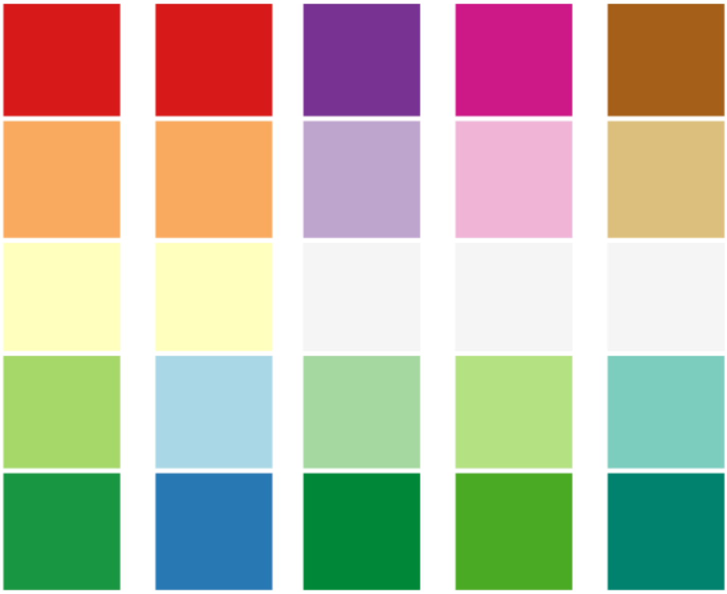


Figure 4.3.6 Diverging Color Schemes Credit: Cary Anderson, Penn State University; color specifications via ColorBrewer2.org.

If your data has a natural midpoint—such as the absence of change— a diverging color scheme works well, as it permits the reader to easily identify values on the map as either above or below that value. An example of this is shown in Figure 4.3.7 below.

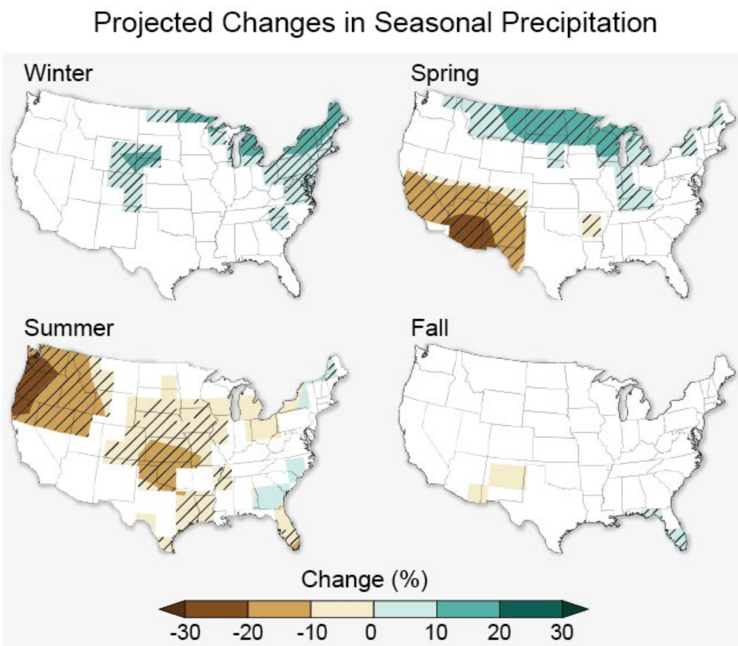


Figure 4.3.7 A map with a diverging color scheme, showing a critical midpoint of 0% change. Credit: [GlobalChange]

Other values can also serve as helpful midpoints in mapped data. For example, a map might use a diverging color scheme to demonstrate values that fall above or below the data's mean, or perhaps some external goal-worthy value (e.g., a choropleth map of median income where a diverging color scheme is centered around a calculated value of a living wage).

An important consideration when applying a diverging color scheme is whether your data has a critical **break** or a critical **class** (Figure 4.3.8). Using a diverging scheme with a critical class will highlight a critical group of areas on your map, as well as those above and below. A critical break will show all areas as either above or below a critical value –there is no “neutral” color class in this scheme. Diverging schemes also do not always have to be symmetrical. Your critical break/class will often be near the center of your data range, but it in no way needs to be.

Keep the divergent schemes shown in Figure 4.3.8 below in mind as we discuss data classification for choropleth mapping later in the lesson.

Figure 4.3.8 Diverging schemes with a critical class (left), and critical break (right). Credit: Cary Anderson, Penn State University; color specifications via colorbrew2.

Student Reflection

View the map in Figure 4.3.9 below. Why is a diverging color scheme used here? What does the map tell you? What doesn't it tell you? Would you design it differently?

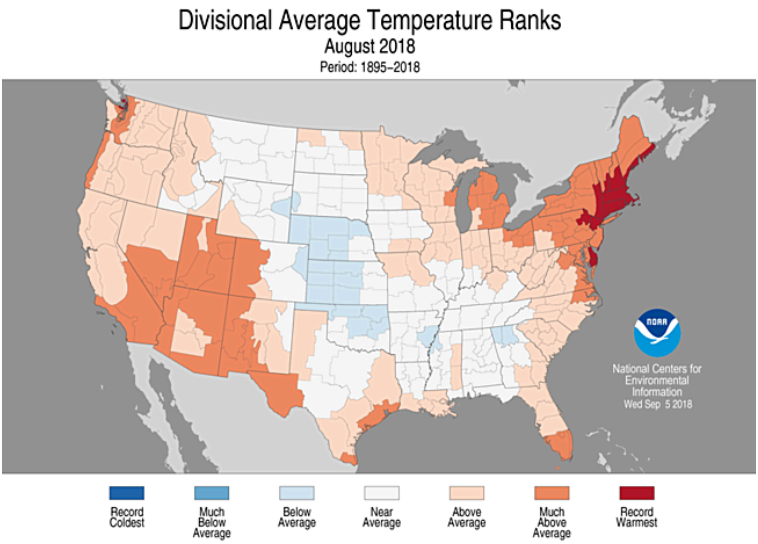


Figure 4.3.9 A diverging color scheme used on a map about temperature. Credit: [NOAA]

The third type of color scheme is the **qualitative** color scheme. These schemes are used to demonstrate differences—but not order—between map features. Several examples are shown in Figure 4.3.10 below.

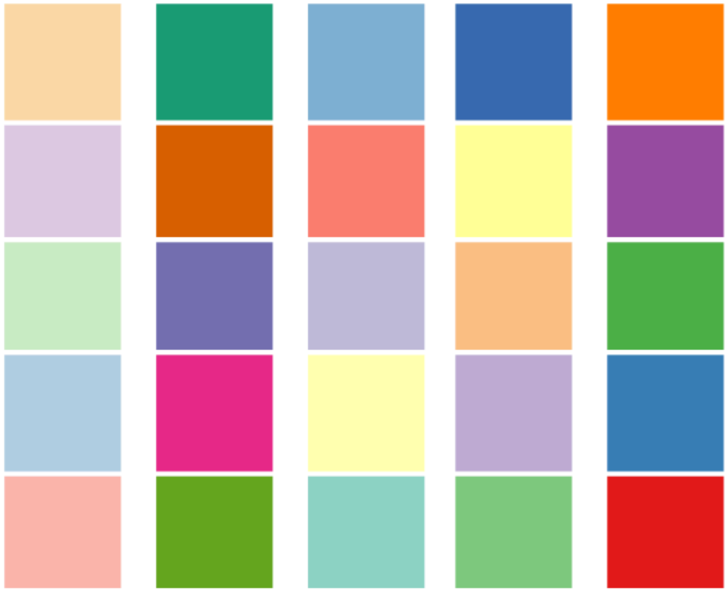


Figure 4.3.10 Qualitative Color Schemes. Credit: Cary Anderson, Penn State University; color specifications via ColorBrewer2.org.

Qualitative color schemes are often used when creating maps of political boundaries, or to create categorical choropleth maps, such as the one in Figure 4.3.11. As the term *choropleth* is composed of the Greek words for "area/ region" and "multitude," it is technically incorrect to refer to a map of nominal values as a choropleth map, despite the characteristic enumeration-unit shading such maps employ. These maps should instead be called **chorochromatic** maps.

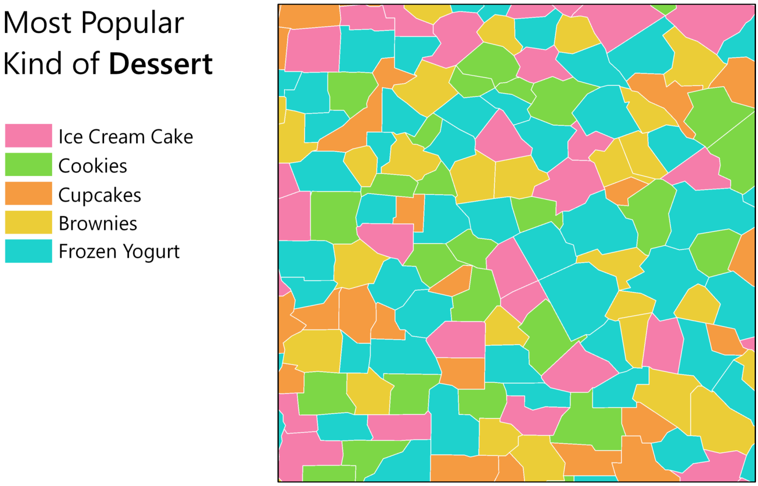


Figure 4.3.11 A Chorochromatic Map. Credit: Map by Cary Anderson, The Pennsylvania State University, Data Source: Boundaries, [US Census](). Thematic data are invented.

Perhaps the most common use of qualitative color schemes in mapping is in land use/land cover maps. These maps seek to demonstrate category (e.g., residential vs. commercial) but not to demonstrate order. An example of a land cover map is shown in Figure 4.3.12.

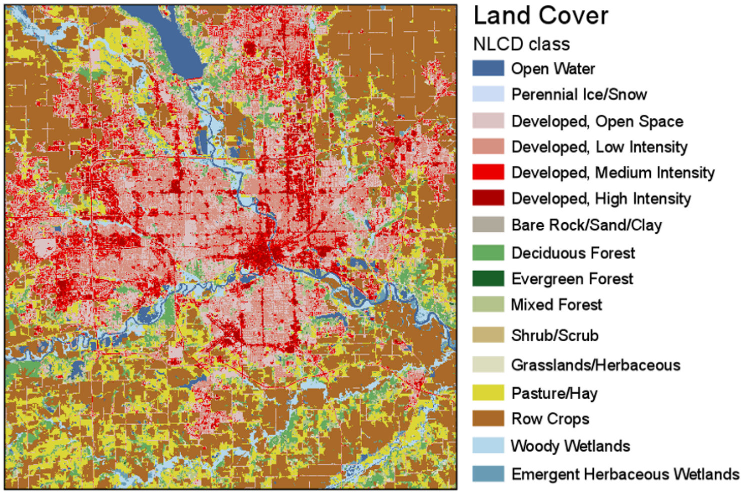


Figure 4.3.12 A map of land cover in Des Moines, Iowa, using a qualitative color scheme with additional variation added in lightness and saturation. Credit: Cary Anderson, Penn State University; Data source: USGS, The National Map.

The (color vision unimpaired) human eye can discriminate between about twelve different hues; dependent on the reader and the design of the map, often even less. Many maps, and land use/land cover maps in particular, contain more than this number of categories. A frequent strategy is to group categories into hue classes (e.g., green for vegetation) and then to use lightness and saturation to create intra-class differences. In Figure 4.3.12, for example, green hue is used for forest, and lightness variations are used to differentiate between forest types.

Student Reflection

View the categories of land cover in Figure 4.3.12.

Does the perceptual structure of the data match the perceptual structure of the colors assigned? Does it do so in more ways than one?

Visual Perception Constraints

Visual perception constraints

So far this lesson, we have talked about multiple ways to specify colors, and how we might apply them to maps. As we discuss color, however, we also need to discuss color vision deficiency—the inability to discriminate between certain (or occasionally, all) colors. Though color blindness varies by gender and ethnicity, you can generally expect that about five percent of your map readers will have some form of color deficiency. You may have some form of color vision deficiency yourself.

The good news is that several web tools exist to help you design more accessible maps. Viz Palette, developed by Elijah Meeks and Susie Lu, is one useful example. It permits you to import your own color schemes from popular color-picking tools such as ColorBrewer and view their appearance through the eyes of those with different types of color vision deficiencies.

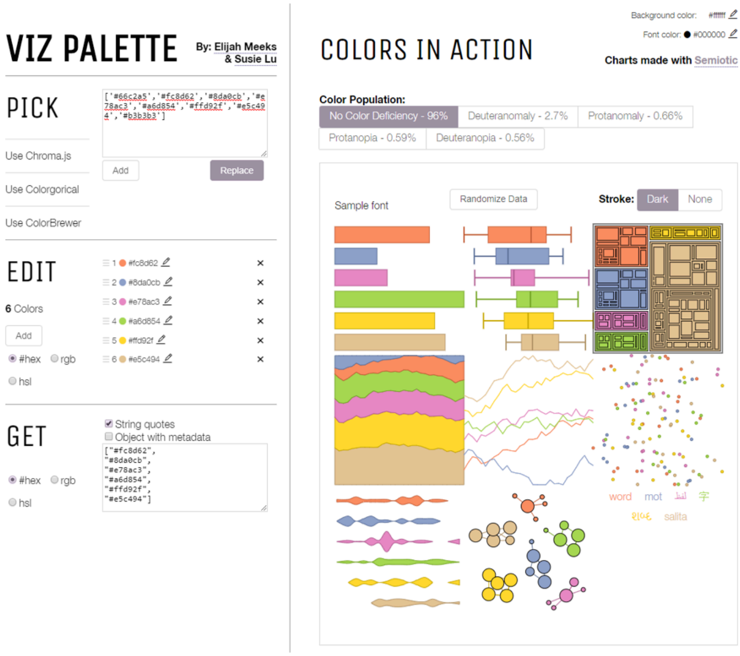


Figure 4.4.1 Viz Palette, using colors from ColorBrewer's qualitative color palette "Set2." Credit: Elijah Meeks and Susie Lu, [Viz-Palette](#) (click the link to try it out!)

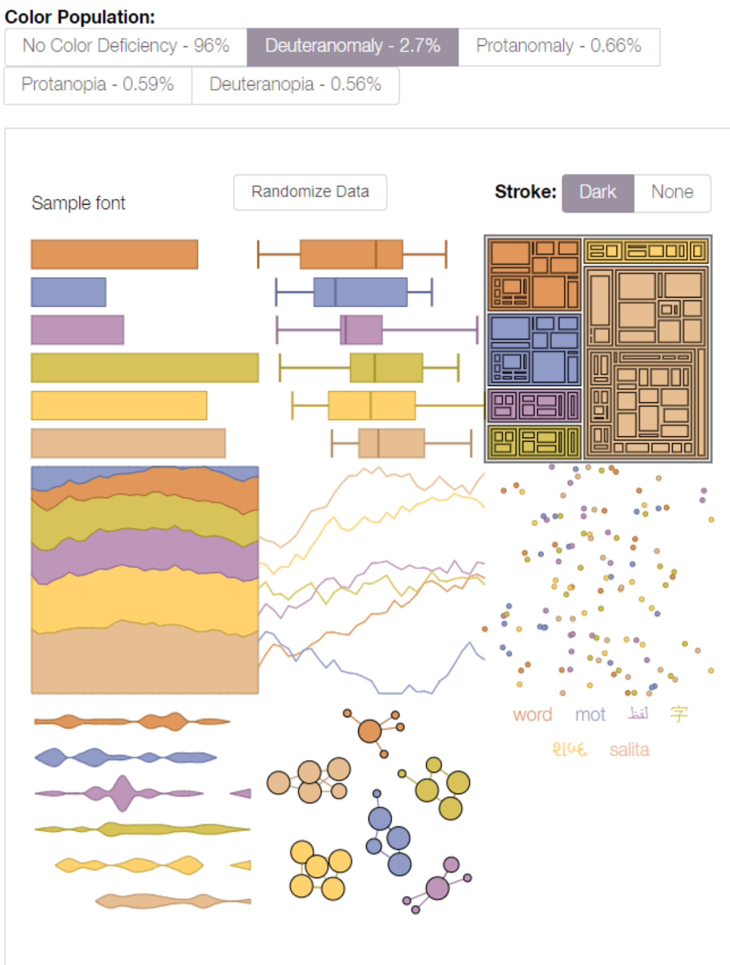


Figure 4.4.2 Viz Palette: The same ColorBrewer scheme as used in Figure 4.4.1 above, as seen through the eyes of someone with deuteranomaly—the most common form of colorblindness. Credit: Elijah Meeks and Susie Lu, Viz-Palette.

Tools such as Viz Palette are useful for understanding how different people might view your data visualizations and maps. You can then decide for yourself whether your chosen palette is acceptable. ColorBrewer also lets you select from among only color schemes that have been empirically-verified as colorblind friendly – its interface includes an option to show only “colorblind safe” color schemes. Unsurprisingly, the scheme in Figure 4.4.1(2) does not appear.

How much you factor color accessibility into your map design will depend greatly on its audience, medium, and purpose. Color discriminability is affected by many factors outside of genetics, including reader age, lighting conditions, and map resolution. It is also more crucial in some mapping contexts than in others. A map for entertainment, for example, may sacrifice accessibility for increased aesthetics and visual interest among the not color-vision impaired. When a map’s purpose is emergency management or vehicle routing, however, the cartographer may place a greater value on ensuring readability for all map users.

Even among those without color vision impairments, human color perception does not come without flaws. View the squares labeled A and B in Figure 4.4.3—do they look the same to you?

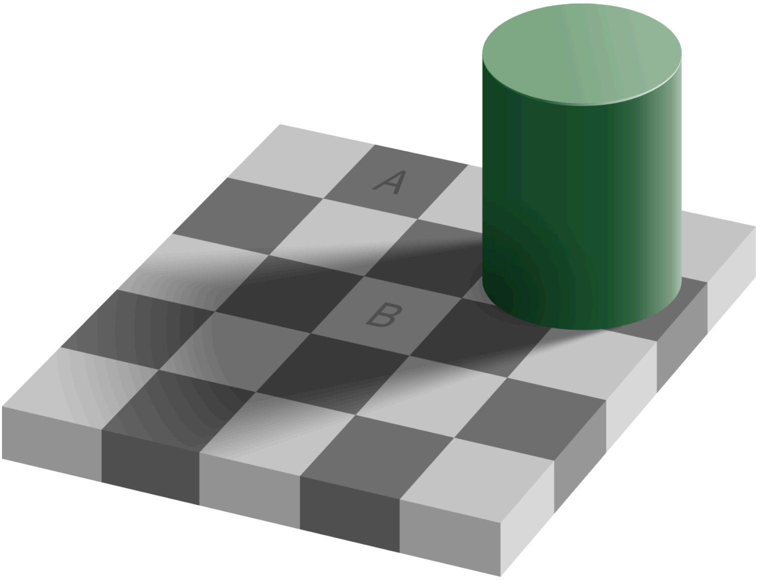


Figure 4.4.3 The Checker Shadow Illusion Credit: Edward H. Adelson, available under the Open Database License ([CC BY-SA 4.0](#))

Your eyes are deceiving you—these two squares are exactly the same shade of grey. (If you don't believe it, check out the interactive version of this graphic at illusionsindex.org). This is the result of a principle of color interpretation called **simultaneous contrast**, or **induction**—colors appear differently, dependent on the backdrop against which they appear.

Student Reflection

View the maps in Figure 4.4.4: which colors in the second map (1, 2, 3, 4) do you think match the colors in areas A and B?

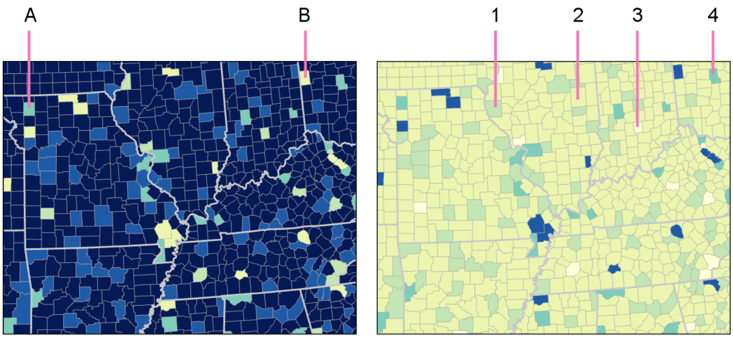


Figure 4.4.4 A set of choropleth maps demonstrating the principle of induction. Credit: Cary Anderson, Penn State University; data boundary source: US Census Bureau, thematic data invented.

Student Reflection answer: The color in A matches the color in 4; the color in area B matches area 2. Is this what you were expecting?

To date, little empirical research in cartography has evaluated the influence of induction on map interpretation, and, thus, few suggestions exist for minimizing its effects in practice. You should, however, anticipate the effects that varied backgrounds will have on the interpretation of your map symbol colors, particularly for maps in which such comparisons are common and/or critical.

So far in this lesson, many of our examples have been choropleth maps—the most common thematic mapping technique, and one which typically makes extensive use of color as a visual variable. In the next section, we will focus on other aspects of choropleth mapping, including data standardization and classification, as a deeper understanding of how these maps are built using data is required for selecting an effective color scheme.

Data Standardization

Data Standardization

As discussed in Lesson 3, the **choropleth** mapping technique should be used on standardized data such as rates and percentages—rather than on totals or counts—which are better represented by point symbol maps.

Your data will sometimes be delivered in the proper standardized format. For example, you might have for each enumeration unit in your data a rate, density, or index value. All of these are appropriate for choropleth mapping. Oftentimes, however, you will need to calculate these values yourself. Data from the US Census, for example, is often delivered as count data by enumeration unit but includes a population field which can be used for standardization.

	A	B	C	D	E	F	G
1	GEO.id	GEO.id2	GEO.display-label	HD01_VD0	HD01_VD02	HD01_VD03	HD01_VD04
2	Id	Id2	Geography	Estimate; Total:	Estimate; Under 18 years:	Estimate; Under 18 years: - With one type of health insurance coverage:	Estimate; Under 18 years: - With one type of health insurance coverage: - With employer-based health insurance only
3	0500000US	37001	Alamance County, North Carolina	155264	35666	32537	13567
4	0500000US	37003	Alexander County, North Carolina	35980	7972	7220	2732
5	0500000US	37005	Alleghany County, North Carolina	10738	1987	1680	457
6	0500000US	37007	Anson County, North Carolina	24129	5262	4904	1730
7	0500000US	37009	Ashe County, North Carolina	26750	4985	4257	1631
8	0500000US	37011	Avery County, North Carolina	15633	2695	2361	1066
9	0500000US	37013	Beaufort County, North Carolina	47150	10080	8249	2398
10	0500000US	37015	Bertie County, North Carolina	19081	3668	3373	850
11	0500000US	37017	Bladen County, North Carolina	34088	7487	6706	1514
12	0500000US	37019	Brunswick County, North Carolina	118194	20465	18079	6526
13	0500000US	37021	Buncombe County, North Carolina	246270	48348	44702	19904
14	0500000US	37023	Burke County, North Carolina	86692	17692	15829	6093
15	0500000US	37025	Cabarrus County, North Carolina	190935	50471	45791	27262
16	0500000US	37027	Caldwell County, North Carolina	80778	17172	15739	5903

Figure 4.5.1 Census data from the American Community Survey. Credit: Health Insurance data from North Carolina, US Census Bureau. Screenshot by Cary Anderson, Penn State University.

Using the example data in Figure 4.5.1 above, imagine we wanted to map the number of people in each county who are under 18 years old AND have one type of health insurance coverage (Column F). And imagine we created a county-level choropleth map using those Column F values. What would this map tell us? It might tell us a little something about geographic health insurance trends in North Carolina, but mostly it would just show us in which counties more people live.

Remember the importance of map purpose: rather than just making a population map, we want to understand the geography of health insurance coverage for young people. For this, we need to map standardized values. To do so, we can divide the number of under 18-year-olds with one type of health insurance (Column F) by the appropriate *universe*: the count of items (here, people) that could possibly fall into this category. Since our data value of interest only applies to a specific age group, our universe, in this case, is not all people (Column D), but all people under 18 (Column E).

Some texts and software programs, including ArcGIS, call this process *normalization* rather than **standardization**. As suggested by (Slocum et al. 2009) we use the term standardization, as normalization has a more specific meaning in statistics with which we do not want this process to be confused.

Making Chloropleth Maps

Making Chloropleth Maps

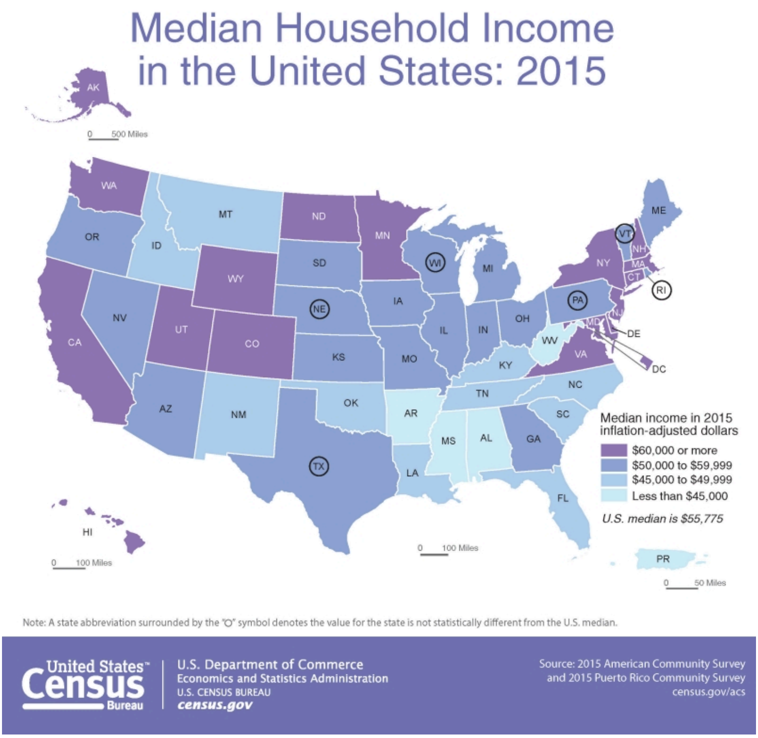


Figure 4.6.1 A choropleth map from the Census (posted earlier as Figure 4.1.2) Credit: US Census Bureau

Let's return again to a map that should be becoming familiar, posted now as Figure 4.6.1. Median income is visually encoded in each state as belonging to one of four classes: (1) less than $45,000; (2) $45,000 to $49,999; (3) $50,000 to $59,999, and (4) $60,0000 and more. How were these classes chosen?

Student Reflection

One side-step before we discuss data classification: think back to our discussion of types of color schemes—can you think of another type of color scheme that would be effective in Figure 4.6.1? Do you think it would be better?

When the map in Figure 4.6.1 was being designed, the aforementioned classes had to be decided upon – and there are many different ways in which class breaks in median income could have been drawn. So, how do you choose? Rather than simply choosing the default classification scheme that your GIS software suggests, you should think critically about how your data classes are defined. The first decision you should make, however, is not how, but *whether* to class your data.

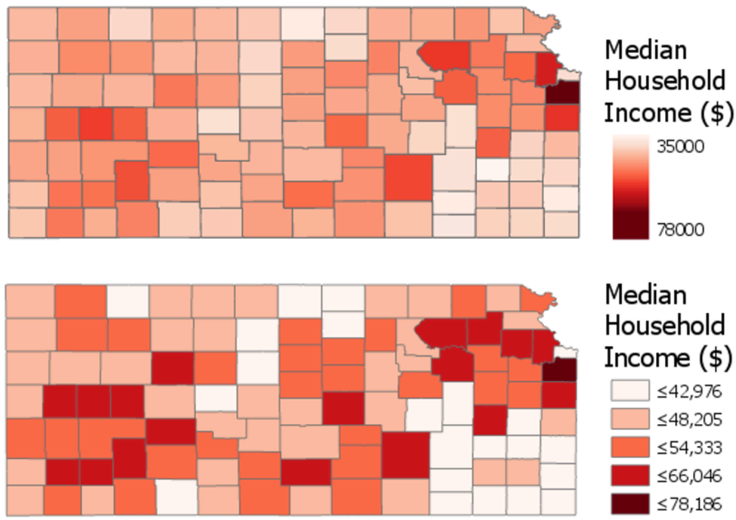
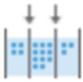


Figure 4.6.2 An unclassed (top) and classed (bottom) choropleth map. Credit: Maps by Cary Anderson, Penn State University; Data Source: United States Census Bureau, American Community Survey.

Figure 4.6.2 shows an example of two maps—one unclassed (sometimes called a “class-less” map), and one classed. Unclassed maps encode color (usually with lightness) based on the specific value within each enumeration unit, rather than based on a pre-defined class within which the data value falls. These maps are useful as—if designed properly—they may more accurately reflect nuances in the distribution of the data. However, they should not be considered an easy solution to the problem of data classification. They have their own disadvantages, for example, they make it challenging for the reader to match the value encoded in an enumeration unit to its location on the legend.

Before modern GIS software, unclassed maps were quite difficult to create, but new technology has made their design quite simple. Unclassed maps show a more "direct" visualization of the data, while classifying maps gives you more control over the final map. It will be up to you as the map designer to decide whether to class your map; however, many map readers—and cartographers—still prefer classed maps.

As you will likely be classifying your maps, it is important to understand how this process can influence your final map design. Most of the commonly-used classification methods are available in ArcGIS, and the software interface gives a good simple explanation of each of these methods (Figure 4.6.3). We will not discuss the mathematical details of each of these classification methods here—it is recommended that you explore the recommended readings or do your own research on the web to learn more.

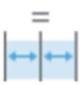


Natural Breaks (Jenks)

Numerical values of ranked data are examined to account for non-uniform distributions, giving an unequal class width with varying frequency of observations per class.

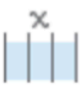
Quantile

Distributes the observations equally across the class interval, giving unequal class widths but the same frequency of observations per class.



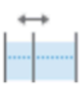
Equal Interval

The data range of each class is held constant, giving an equal class width with varying frequency of observations per class.



Defined Interval

Specify an interval size to define equal class widths with varying frequency of observations per class.



Manual Interval

Create class breaks manually or modify one of the preset classification methods appropriate for your data.

Geometric Interval

Mathematically defined class widths based on a geometric series, giving an approximately equal class width and consistent frequency of observations per class.

Standard Deviation

For normally distributed data, class widths are defined using standard deviations from the mean of the data array, giving an equal class width and varying frequency of observations per class.

Figure 4.6.3 Classification options available in ArcGIS Pro. Credit: Screenshot from ArcGIS Pro. Text Alternative to Image: ***Natural Breaks (Jenks)****: Numerical values of ranked data are examined to account for non-uniform distributions, giving an unequal class width with varying frequency of observations per class.* ***Quantile****: Distributes the observations equally across the class interval, giving unequal class width but the same frequency of observations per class.* ***Equal Interval****: The data range of each class is held constant, giving an equal class width with varying frequency of observations per class.* ***Defined Interval****: Specify an interval size to define equal class widths with varying frequency of observations per class.* ***Manual Interval****: Create class breaks manually or modify one of the present classification methods appropriate for your data.* ***Geometric Interval****: Mathematically defined class widths based on a geometric series, giving an approximately equal class width and consistent frequency of observations per class.* ***Standard Deviation****: For normally distributed data, class widths are defined using standard deviations from the mean of the data array, giving an equal class width and varying frequency of observations per class.*

Though Figure 4.6.3 gives helpful descriptions of each classification method, it offers little advice as to when to use them. A good way to approach this question is to view your data along the number line. You can use histograms (for large data sets) or dot plots (for small data sets) to visualize how your data is distributed, and to select class breaks accordingly. The following suggestions are given by Penn State cartographer Dr. Cynthia Brewer.

1. For data with near-normal distributions, consider classifying your data based on the mean and standard deviation.
2. For skewed distributions, consider systematically increasing classes, such as arithmetic and geometric classing methods.

3. If your data are evenly distributed, equal interval and quantile classing methods work well. These methods are also best for ranked data.
4. Natural breaks, created using Jenks classing method or in selecting breaks by eye, work best for data which shows obvious groupings through the range. The natural breaks method highlights the natural sets of values in the data.

We will look at data using dot plots during this lab associated with this lesson. When you make maps, unless you are working with a very large data set, this will often be the most effective way to visually investigate your dataset in order to choose a classification method or visually/manually place your own breaks. ArcGIS, however, creates histograms of your data that you can also use to understand how the breaks you have chosen relate to the spread of your data.

Student Reflections

Compare the breaks, histograms, and maps in Figure 4.6.4 below. Which classification method would you have chosen? Why?

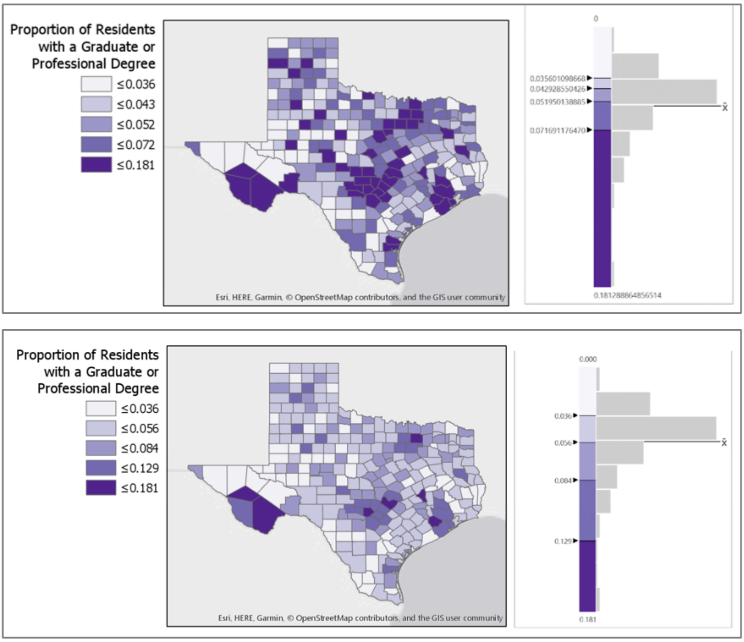


Figure 4.6.4 Two maps created using the quantiles classification method (top), and natural breaks (Jenks) method (bottom). Credit: Maps by Cary Anderson, Penn State University, Data Source: US Census.

Note that the spread of your data is only one of multiple elements you should consider when choosing how to classify your data. As with other map design choices, your map's intended audience, medium, and purpose are also of vital importance here.

In addition to choosing a classification method for your maps, you also must decide how many classes to create. It may be tempting to create a large number of classes, as more classes means less simplification of your data, and thus more information conveyed to the map viewer. Unfortunately, the human eye can only differentiate between so many colors. The limit is about a dozen colors for a qualitative map, ten for a diverging scheme, and only eight for a sequential scheme. If anything, these are optimistic estimates—your map reader is likely to be able to differentiate between even less.

Student Reflection

View the maps in Figure 4.6.5 below. Looking at the map on the left, can you identify within which class county x belongs? How confident are you that this is the correct answer? What about in the map on the right?

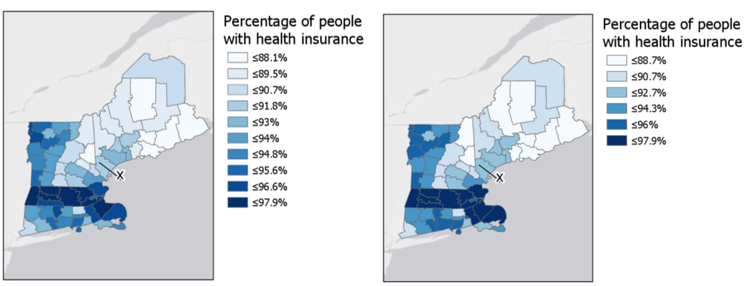


Figure 4.6.5 A map with many classes (left) makes it more difficult to interpret than a simpler map (right). Credit: Maps by Cary Anderson, Penn State University, Data Source: US Census.

Finally, when classifying your map data, you will have to contend with outliers in your dataset. Consider a county-level map, where one county has double the rate (for example, of people with graduate-level degrees) of any other county in your data. Some classification methods, such as natural breaks or equal intervals, will most likely group this outlier into a class of its own. Other methods, such as quartiles, will simply place it into a group with all the next-highest counties.

There is no rule for which method is best, except that context matters. Is the rate high because that county contains the most prestigious university in the state? In that case, you probably want it to be highlighted on your map. If instead, it is the highest because only five people live there—and two are college professors—you probably don't. In general, the more data you have, the less likely an outlier is to be noise: this is called *the law of large numbers*. Whenever possible, however, you should investigate the possible causes of an outlier—there is no substitute for contextual clues.

There are additional ways to classify your data, including by combining methods—for example, using equal intervals for most of the range, and then switching to natural breaks. Methods also exist that consider not just the distribution of data along the number line, but its distribution through geographic space as well. These are beyond the scope and intent of this lesson, but be aware that you may encounter them in the future.

Making Sense of Maps

Making Sense of Maps

By now, you should feel pretty good about creating a single, choropleth map. Such maps are often requested, designed, and distributed. Yet the power of maps often comes from our ability to compare them. Static maps—all of the maps we've discussed thus far—typically only represent one snapshot in time. What if we are interested in how a phenomenon has changed over time, or how it varies between two disparate locations?

View the two maps below in Figure 4.7.1. They are both maps of population density in the United States and are shown at the same scale. At first glance (to non-US residents, perhaps), it might appear that Vermont has a higher level of population density. But take a closer look at the legends –

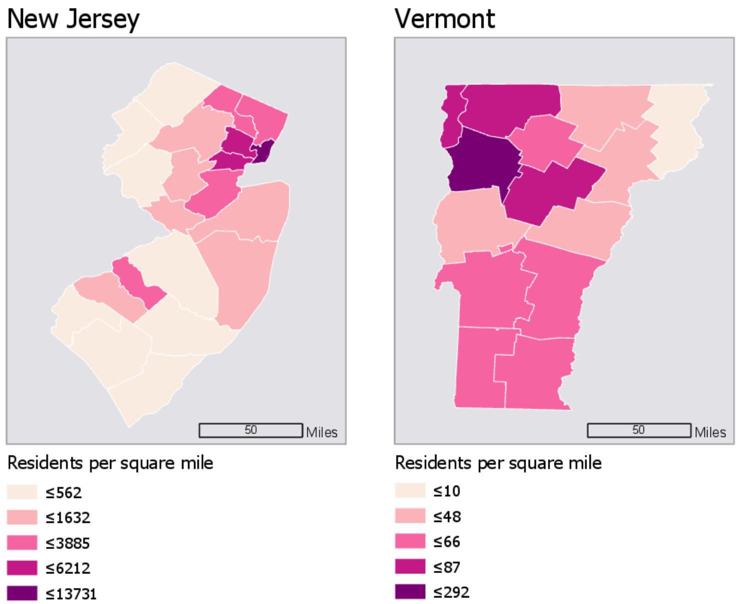


Figure 4.7.1 A map of population density (2010) in NJ and VT, each designed with the default ArcGIS classification scheme. Credit: Cary Anderson, Penn State University, Data Source: US Census Bureau.

The legends in the maps in Figure 4.7.1 don't match—the darkest color, for example, represents a vastly higher level of population in the first map than in the second. How much does population density differ between New Jersey and Vermont?—due to the unmatched legends, it's really almost impossible to tell.

Using the same data classification scheme for a set of maps is the easiest way to make them directly comparable. For example, the maps in Figure 4.7.2 use the same data, but this time, both legends are equivalent.

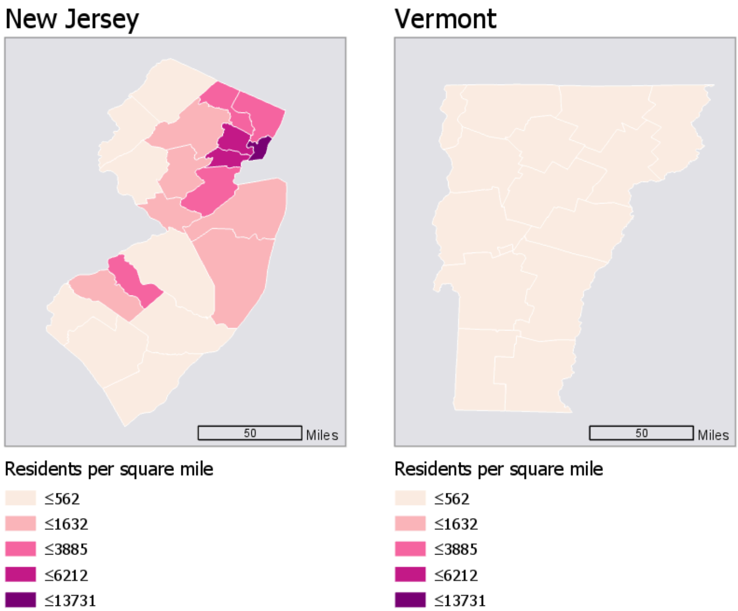


Figure 4.7.2 A map of population density (2010) in NJ and VT, with matching classification schemes. Credit: Cary Anderson, Penn State University, Data Source: US Census Bureau.

This gives us an entirely different view of the data—New Jersey is now visible as obviously more densely populated. Note, however, that this map just took the default classification scheme from New Jersey, and applied it to Vermont, which is still not a good solution. Though it is now easy to compare these states, we are unable to discern which areas of Vermont are more populated than others: they are all simply classified as "less than 562 residents per square mile." Making maps that work well both independently and when compared is a challenging task, and one which we will contend with in Lab 4.

Another important aspect of choropleth—and any—map design is making sure that marginal elements such as legends and labels are well-crafted to support reader comprehension of your map. For example, see Figure 4.7.3. It may seem at first that this legend is too text-heavy: you don't generally create visual graphics with the intention of asking people to read. However, without this level of detail, the content of the map would be confusing, and many readers would likely misinterpret it.

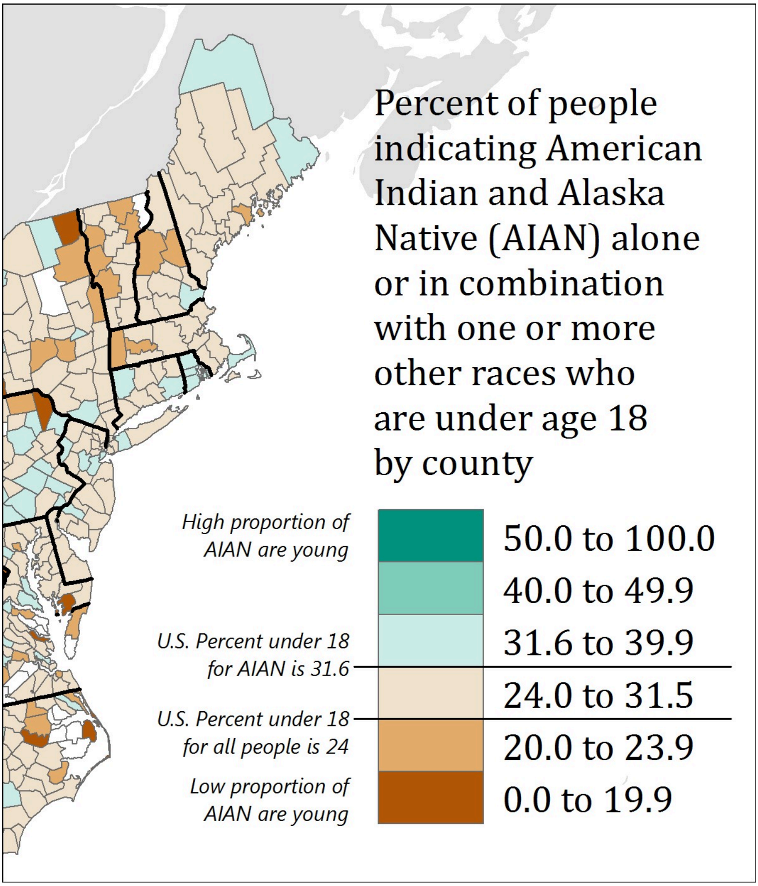


Figure 4.7.3 A map legend with thorough annotations. Credit: Cynthia A. Brewer. US Census Bureau. Made with Natural Earth. Map updated by P. Limpisathian, Penn State Geography.

This map also purposefully places breaks in the data—for example, one break is placed at 24 percent, which is the percentage of all people in the US who are under 18 years old. The break is annotated to inform the reader of this fact—without this annotation, the use of this specific break would not be useful. Additional legend annotations (e.g., “High proportion of AIAN are young”) serve to clarify the map.

Figure 4.7.4 below similarly uses a text explanation to clarify the data mapped. Due to the classification scheme used, the location indicated by the leader line and Prisons* note does not immediately stand out as an outlier. However, given the topic of the map, this explanation is important. We discussed dealing with outliers earlier in the lesson—one option for dealing with a relevant outlier is simply to point it out to your readers via explanatory text. Mapping is all about graphic presentation, but sometimes the best solution is a simple, concise, text explanation.

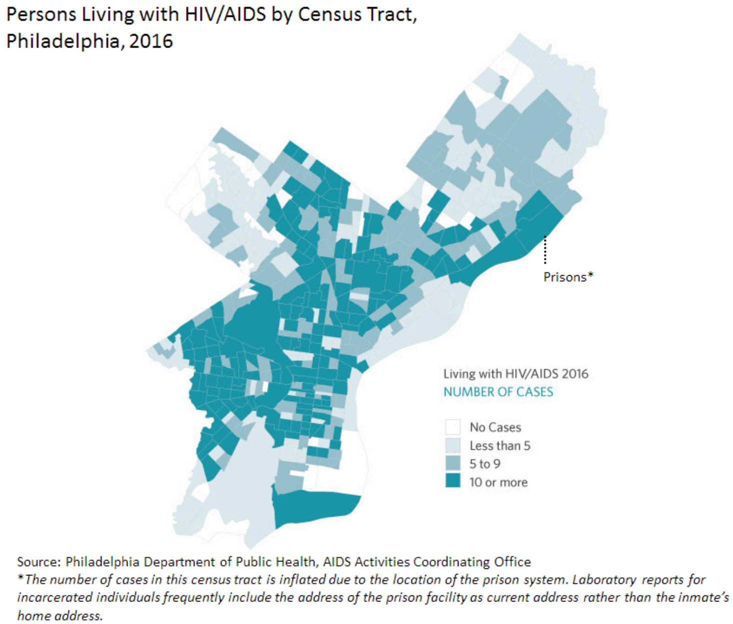


Figure 4.7.4 A map showing HIV/AIDS causes with a note attached that explains an outlier. Credit: City of Philadelphia [Department of Public Health](#)

Color and Data

Color and Data

When using color as a symbol on your maps, your first priority should be to apply it analytically. As stated before: the perceptual structure of your color scheme should match the perceptual structure of your data. You should apply color based on the guidelines previously discussed in this lesson before worrying about choosing aesthetically-pleasing colors, or your audiences' likely favorite colors, or colors that correspond to the context of the data (e.g., using a green color scheme to create a map about sustainability).

However—when appropriate—adding context to colors in your maps can benefit your readers. See the map in Figure 4.8.1 below. Rather than choosing a traditional sequential color scheme, this cartographer chose to match the colors of the leaves to the colors on the map.

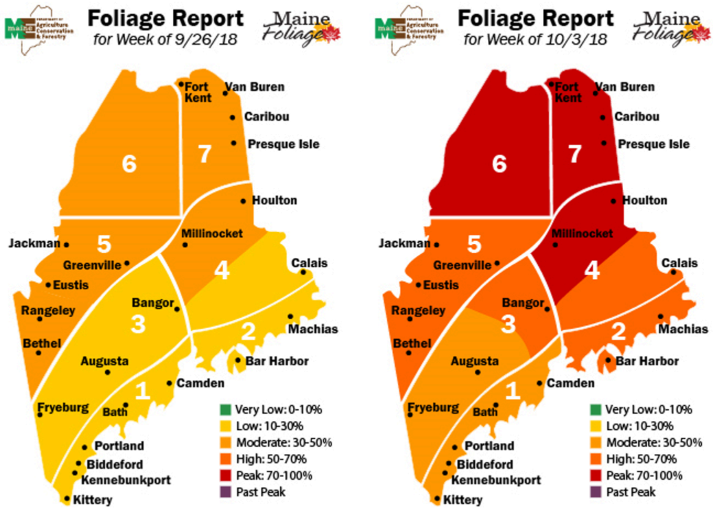


Figure 4.8.1 Maps indicating foliage colors during two weeks in Maine. Credit: [Maine Department of Agriculture Conservation & Forestry](#).

This approach may not always work to best represent the mathematical order of your data classes. But your maps aren't just about dots along a number line—they represent real-world phenomena. Using color assignments that make sense (e.g., red for negative values), or are customary (e.g., yellow for residential in zoning maps) can improve the clarity and comprehensibility of your maps.

Lab 5: Color and Choropleth Mapping in Series

Total Points

20 points

Instructions

In Lab 5, we will explore different ways of choosing data classification and color schemes for choropleth maps. As a cartographer, you will often have to choose between several of these options – many of which may seem at first glance to be equally appropriate. In Lab 4, we used data from the American Community Survey, provided by the US Census – a commonly-used source of data for statistical maps. In this lab, we use the same data source but focus on a specific variable frequently in focus during public policy debates: health insurance. You will need to go to the Census data portal and use the Advanced Search option to download health insurance data for the state that your chosen city is in on the county level. You should focus on the S7201 Selected Characteristics of Health Insurance 5-Year Estimates Subject Tables. Make sure to pick two related variables to map. Make sure to follow the Lab 5 Visual Guide to do the necessary calculations.

The first part of Lab 5 will focus on data classification. There are many ways to classify statistical data on maps, and it is important that you understand them, and be able to defend your choice of classification scheme to others. As we will be not only be classifying data but also adding that data to maps, this lab will also focus on the use of color on maps. Finally, as suggested in the lesson content, we will explore ways of making comparable maps – in this lab, we will be making three pairs of maps.

Learning Objectives

- Create three pairs of choropleth maps describing health insurance in your chosen city on the Census-tract level.
- Utilize shared or similar legends to help readers understand the relationships between pairs of maps.
- Use information about data distributions in your chosen city to plan shared data classification breaks
- Understand the impact of different color schemes and classification methods; be able to reflect upon and write about these decisions.

Overall Lab Requirements

For Lab 5, you will create three pairs of maps, each pair as its own full-page map layout. In total, you will have three separate pages. Two maps will appear on each page. You will also write a short reflection statement about each pair of maps.

- For each pair, use the same map positioning and scale within each frame; one scale bar for both maps.
- Prepare balanced page layouts with all elements suitably sized and balanced negative space – no pinched elements or visual collisions.
- Attend to text hierarchy: overall title, subtitles, legend title(s), legend class labels, scale, data source, and name. Use thoughtful and efficient wording when labeling map elements.

Deliverables

Map Pair One: Use a Sequential Color Scheme

- Choose two related variables to map from the S7201 **Selected Characteristics of Health Insurance 5-Year Estimates Subject Tables**. Do not just choose two age groups (e.g., 18-under; 19-25 years).
- Select class breaks manually: Create dot plots in Microsoft Excel and draw appropriate breaks using your eye to judge the data; enter these as manual breaks in ArcGIS Pro (instructions on how to do this is in the Lab 5 Visual guide).
- Use a sequential color scheme and one legend for both maps.
- Include a short write-up (100+ words) which includes a screenshot of your dot plot with lines drawn to demonstrate the breaks you chose, as

well as a short description of how you selected these breaks. Also, include a screenshot of the symbology pane for both maps.

Map Pair Two: Use a Diverging Color Scheme

- Re-create your maps from map pair one using a diverging color scheme.
- Choose a critical break or class using external information – something that cannot be calculated from the provided data alone (example: U.S. average); adjust other class breaks accordingly.
- Use one well-designed legend for both maps.
- Include a short write-up (100+ words) describing the critical break or class you chose and why. You may also discuss why you selected this particular color scheme.

Map Pair Three: Unclassed vs Classed Maps (Choose your own appropriate color scheme)

- Choose one of the maps from map pairs one and two and create two more maps of this data – unlike in the previous layouts you made, these two maps will show the same data/topic.
- One of the maps should be an unclassed map; one should be classed.
- For the classed map, choose a classification method available in ArcGIS Pro – do not manually adjust the class breaks created, but

ensure this method is appropriate for the data you are mapping.

- Include a well-designed legend for each map.
- Include a short write-up (100 words) that describes why you chose the classification method you did, and how you think its effectiveness compares to that of the unclassed map.

Submission Instructions

- You will have three map layout PDFs to submit. Each will contain one map pair using the naming conventions outlined below.
    - Map Layout/Pair 1: LastName_Lab5_MapPair1.pdf
    - Map Layout/Pair 2: LastName_Lab5_MapPair2.pdf
    - Map Layout/Pair 3: LastName_Lab5_MapPair3.pdf
- Include your write-ups (all three in one document as a separate PDF.
    - Lab Write-up: LastName_Lab5_WriteUp.pdf
        - Remember that your write-up should include three 100+ word write-ups for each section (300+ words in

total) – these write-ups should defend your data classification and color scheme choices. The write-up for your first pair of maps should also include an image of your dot plot with annotated breaks, and screenshots of the Symbology Pane in ArcGIS Pro for both maps.

Lab 5 Rubric

Use the following rubric to help you complete your assignment. Adhering to the rubric and the naming convention will assure that you receive full points for the assignment.

Map Pair One – Use a Sequential Color Scheme: 7 points

Criteria	**Points Value**
Use the same map positioning and scale within each frame along with one scale bar for both maps.	1
Prepare balanced page layouts with all elements suitably sized and balanced negative space – no pinched elements or visual collisions (i.e., scale bar obstructing other map elements).	1
Attend to text hierarchy: overall title, subtitles, legend title(s), thoughtful labeling, data source, and name.	1
Using two related variables to map from the ACS data and select class breaks manually: Create dot plots in Microsoft Excel and draw appropriate breaks using your eye to judge the data; enter these as manual breaks in ArcGIS Pro.	2
Short write up (100+ words) that includes a screenshot of your dot plot with lines drawn to demonstrate the breaks you chose as well as a short description on how you selected these breaks. Also, include a screenshot of the symbology pane for both maps.	2

Map Pair Two – Use a Diverging Color Scheme: 7 points

Criteria	Points Value
Use the same map positioning and scale within each frame, one scale bar, and well-designed legend for both maps.	1
Prepare balanced page layouts with all elements suitably sized and balanced negative space – no pinched elements or visual collisions (i.e., scale bar obstructing other map elements).	1
Attend to text hierarchy: overall title, subtitles, legend title(s), thoughtful labeling, data source, and name.	1
Re-create your maps from map pair #1 using a diverging color scheme and choose a critical break or class using external information – you can either use a value that is directly derived from your chosen data set (i.e., mean of your data) or any logical dividing point that is calculated from an external source (i.e., the U.S. national average); adjust other breaks accordingly.	2
Short write up (100+ words) describing the critical break or class you chose and why. You may also discuss why you selected this particular color scheme.	2

Map Pair Three – Unclassed vs. Classed Maps: 6 points

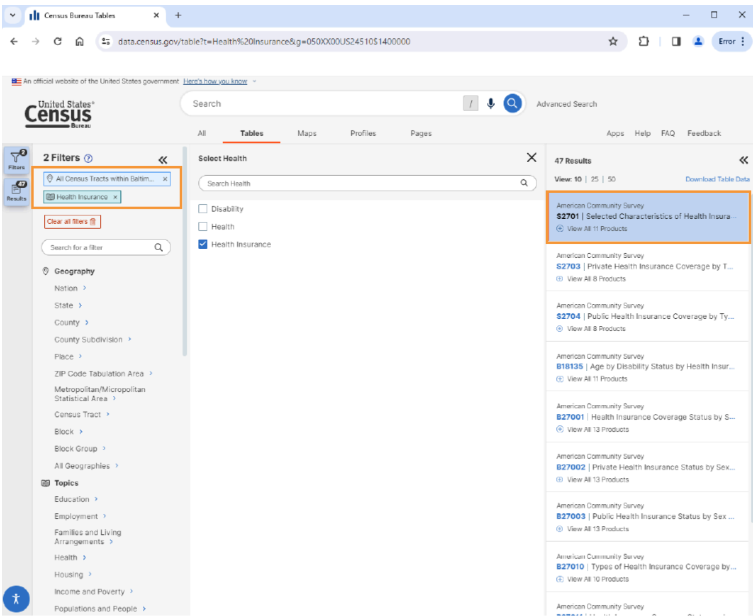
Criteria	Points Value
Use the same map positioning and scale within each frame, one scale bar, and well-designed legend for both maps.	1
Prepare balanced page layouts with all elements suitably sized and balanced negative space – no pinched elements or visual collisions (i.e., scale bar obstructing other map elements).	1
Attend to text hierarchy: overall title, subtitles, legend title(s), thoughtful labeling, data source, and name.	1
Choose one of the maps from map pairs #1 and #2 and create an unclassed and classed map of this data on the same topic. For the classed map, choose an appropriate classification method available in ArcGIS pro – do not manually adjust the class breaks.	1
Short write up (100+ words) describing why you chose the classification method that you did, and how you think its effectiveness compares to that of the unclassed map.	2

Lab 5 Visual Guide

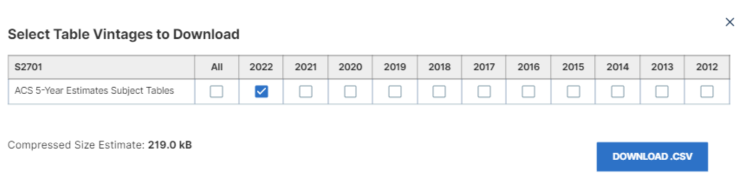
Lab 5 Visual Guide Index

1. Downloading Census Data

You will need to go to data.census.gov and click on the Advanced Search option. This will allow you to do a filtered search. Under **Geography**, click on County and choose the census tracts of your chosen city. The following example will use census tracts in Baltimore City. Under Topics, choose **Health** > **Health Insurance**. Once you are finished, click on **Tables**. You should see **S2701 – Selected Characteristics of Health Insurance Coverage in the United States along with a preview of the table**. Download the table and make sure it is the ACS 5-Year Estimates Subject table for 2022.



Lab 5 Visual Guide Figure 5.1. Census data portal showing results based selected filters.



Lab 5 Visual Guide Figure 5.2. Selecting ACS 5-Year Estimates Subject Tables.

2. Explore the Health Insurance Data in Excel

Your data should be in a zipped folder with the actual data, metadata, and table notes. You will have to create a new file in the Excel workbook (.xlsx) file format that includes columns to your two variables of interest, the GEO_ID column, and the NAME column. Open the metadata file to find the columns with columns pertaining to uninsured populations. For example, if I were to compare the uninsured rate with the population with a disability and no disability, these columns would need to be in my new Excel workbook file:

- GEO_ID: Geography
- NAME: Geographic Area Name
- S2701_C01_035E: Estimate!!Total !!Civilian noninstitutionalized population!!DISABILITY STATUS!!With a disability
- S2701_C01_036E: Estimate!!Total!!Civilian noninstitutionalized population!!DISABILITY STATUS!!
- S2701_C04_035E: Estimate!!Uninsured!!Civilian noninstitutionalized population!!DISABILITY STATUS!!With a disability
- S2701_C04_036E: Estimate!!Uninsured!!Civilian noninstutionalized population!!DISABILITY STATUS!!With a disability

You can just delete what you don’t need, go to File > Save As > and use the naming convention

CityName_Uninsured. Make sure that you save your csv file in a folder that is easily accessible. Change the file type under **Save as type** to **Excel Workbook**. Your updated data file should look like below:

GEO_ID	NAME	S2701_C01_035E	S2701_C01_036E	S2701_C04_035E	S2701_C04_036E
Geography	Geographic Area Name	Estimate!!Total!	Estimate!!Total!!(	Estimate!!Uninsu	Estimate!!Uninsur
1400000US24510010100	Census Tract 101; Baltimore city; Maryland	208	2398	31	71
1400000US24510010200	Census Tract 102; Baltimore city; Maryland	134	2719	7	41
1400000US24510010300	Census Tract 103; Baltimore city; Maryland	91	1967	0	0
1400000US24510010400	Census Tract 104; Baltimore city; Maryland	215	2717	0	90
1400000US24510010500	Census Tract 105; Baltimore city; Maryland	208	1688	0	137
1400000US24510020100	Census Tract 201; Baltimore city; Maryland	113	1568	0	26
1400000US24510020200	Census Tract 202; Baltimore city; Maryland	140	1340	0	59
1400000US24510020300	Census Tract 203; Baltimore city; Maryland	221	3603	0	43
1400000US24510030100	Census Tract 301; Baltimore city; Maryland	265	1444	0	58
1400000US24510030200	Census Tract 302; Baltimore city; Maryland	374	2332	0	36
1400000US24510040100	Census Tract 401; Baltimore city; Maryland	725	5075	146	153
1400000US24510040200	Census Tract 402; Baltimore city; Maryland	51	1230	0	25
1400000US24510060100	Census Tract 601; Baltimore city; Maryland	232	2703	86	261
1400000US24510060200	Census Tract 602; Baltimore city; Maryland	376	2189	54	105
1400000US24510060300	Census Tract 603; Baltimore city; Maryland	68	1412	0	45
1400000US24510060400	Census Tract 604; Baltimore city; Maryland	294	1600	11	37
1400000US24510070100	Census Tract 701; Baltimore city; Maryland	519	2036	25	226
1400000US24510070200	Census Tract 702; Baltimore city; Maryland	691	2538	0	141
1400000US24510070300	Census Tract 703; Baltimore city; Maryland	201	919	0	112
1400000US24510070400	Census Tract 704; Baltimore city; Maryland	183	1406	0	30

Lab 5 Visual Guide Figure 5.3. Census data table in Excel.

3. Standardize Chosen Data for Visualization

We will calculate standardized values from your newly created Excel workbook. We will use these standardized values to determine class breaks for our first set of maps.

Let's first do some formatting of the columns. Replace the column codes with the actual name of the column category. Feel free to clean the column names to make them more legible such as removing the "!!" and replacing them with a ";" Columns with the same variable were also moved next to each other. See the below image for a reference.

GEO_ID	NAME	Estimate; Total; Civilian noninstitutionalized population; DISABILITY STATUS - With a disability	Estimate; Uninsured; Civilian noninstitutionalized population; DISABILITY STATUS - With a disability	Estimate; Total; Civilian noninstitutionalized population; DISABILITY STATUS - No disability	Estimate; Uninsured; Civilian noninstitutionalized population; DISABILITY STATUS - No disability
1400000US24510010100	Census Tract 101; Baltimore city; Maryland	208	31	2398	71
1400000US24510010200	Census Tract 102; Baltimore city; Maryland	134	7	2719	41
1400000US24510010300	Census Tract 103; Baltimore city; Maryland	91	0	1967	0
1400000US24510010400	Census Tract 104; Baltimore city; Maryland	215	0	2717	90

Lab 5 Visual Guide Figure 5.4. Formatting column names in Excel.

Once you have your variables of interest (i.e. with a disability, with no disability) and their total counts, use Excel to calculate a standardized column of data for each of your variables. You want to divide each variable of interest by the total count in that category. Check the data to see if there are any errors such as **#DIV/0!** And change the value to zero.

GEO_ID	NAME	Estimate; Total; Civilian noninstitutionalized population; DISABILITY STATUS - With a disability	Estimate; Uninsured; Civilian noninstitutionalized population; DISABILITY STATUS - With a disability	**% of people with a disability uninsured**	Estimate; Total; Civilian noninstitutionalized population; DISABILITY STATUS - No disability	Estimate; Uninsured; Civilian noninstitutionalized population; DISABILITY STATUS - No disability
1400000US24510010100	Census Tract 101; Baltimore city; Maryland	208	31	=D2/C2	2398	71
1400000US24510010200	Census Tract 102; Baltimore city; Maryland	134	7		2719	41
1400000US24510010300	Census Tract 103; Baltimore city; Maryland	91	0		1967	0
1400000US24510010400	Census Tract 104; Baltimore city; Maryland	215	0		2717	90

Lab 5 Visual Guide Figure 5.5. Using Excel formulas to make calculations.

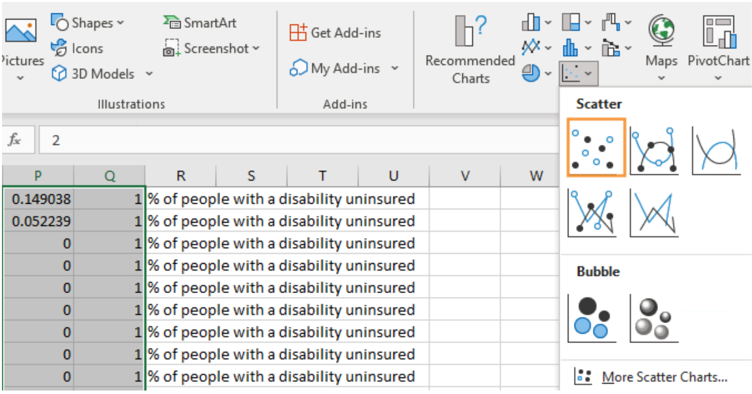
4. Create Dot Plots Using your Standardized Data

Go to an empty set of columns to do these steps. Copy the standardized values for both variables on the spreadsheet in the same column in which you put a space between the two variables.

0	1	% of people with a disability uninsured
0.046324	1	% of people with a disability uninsured
0.013915	1	% of people with a disability uninsured
0.023915	1	% of people with a disability uninsured
0.105042	1	% of people with a disability uninsured
0	1	% of people with a disability uninsured
0	1	% of people with a disability uninsured
0.198473	1	% of people with a disability uninsured
0.0275	1	% of people with a disability uninsured
0.043675	1	% of people with a disability uninsured
0	1	% of people with a disability uninsured
0.029608	2	% of people with no disability uninsured
0.015079	2	% of people with no disability uninsured
0	2	% of people with no disability uninsured
0.033125	2	% of people with no disability uninsured
0.081161	2	% of people with no disability uninsured
0.016582	2	% of people with no disability uninsured
0.04403	2	% of people with no disability uninsured
0.011934	2	% of people with no disability uninsured
0.040166	2	% of people with no disability uninsured

Lab 5 Visual Guide Figure 5.6. Adding values in a second column – these are just so we can create a neat dot plot.

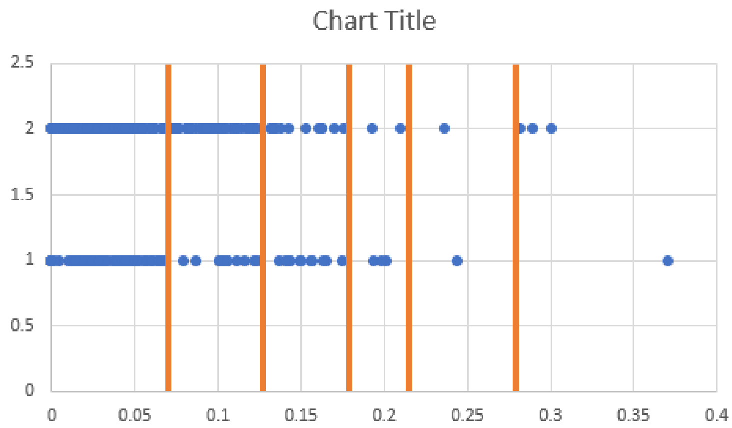
Insert a column of 1s and 2s as shown – we will use this to create a dot plot. Highlight columns with the percentages and the 1s and 2s. Go to **Insert** > **Charts** > **Scatter** and choose the **Scatter** option. This will create a dot plot showing the distribution of your two standardized variables along the number line.



Lab 5 Visual Guide Figure 5.7. Using our two columns (standardized data; 1s and 2s) to insert a scatter plot in Excel.

5. Use this Plot to Visually Select Breaks

Draw lines with the "insert shape" tool to illustrate where you will be placing breaks in your data. Annotate your lines if you choose the breaks for a reason other than just eyeing the dot distribution. For example, if you place a break at the national average for a variable, annotate this break with a text box explanation such as "US national average." "Ex: national average."



Lab 5 Visual Guide Figure 5.8. Dot plot of two standardized variables in Excel.

Note that this example is how to draw lines above your dot plot, but these are not good breaks. Make sure to save your file.

6. Joining Data in ArcGIS Pro

Open ArcGIS Pro and create a new project. Make sure to connect the folder that contains your workbook. Import the Census tract shapefile, city boundary (which should be in the geodatabase you completed for Lab 1), and Census data table of your chosen city to the project geodatabase for Lab 4. The easiest way to import the data table is to click on the arrow next to the workbook in your catalog panel to expand the workbook to see the spreadsheets and add the spreadsheet to the Contents panel and then right-click on your project geodatabase > **Import** > **Table(s)**. Before joining the data, lets only use the Census tracts that are within your city. You can do this by doing Select By Attributes and using the COUNTYFP of your city or a

Select by Location in which you select Census Tracts that are within a city boundary. Right-click on the Census tract shapefile >Export Features and name it CityName_Tracts. Make sure to save this layer in your geodatabase. When joining the data, use the data table in the contents pane. You will need to use the **GEO_ID** field in your spreadsheet file and the **GEOIDFQ** field in your shapefile.

GEOIDFQ	NAME	NAMELSAD	MTFCC	FUNCSTAT	ALAND	AWATER	INTPTLAT	INTPTLON	GEO_ID	NAME
1400000US24510280600	2806	Census Tract 2806	G5020	S	576317	0	+39.2916116	-076.6329627	1400000US24510280600	Census Tract 2806; Balt...
1400000US24510280500	2805	Census Tract 2805	G5020	S	923979	0	+39.2951239	-076.6029382	1400000US24510280500	Census Tract 2805; Balt...
1400000US24510280404	2804.04	Census Tract 2804.04	G5020	S	848958	0	+39.2878046	-076.6917566	1400000US24510280404	Census Tract 2804.04;...
1400000US24510280403	2804.03	Census Tract 2804.03	G5020	S	1831350	0	+39.2859905	-076.7033384	1400000US24510280403	Census Tract 2804.03;...
1400000US24510280402	2804.02	Census Tract 2804.02	G5020	S	561712	0	+39.2992263	-076.6903724	1400000US24510280402	Census Tract 2804.02;...
1400000US24510280401	2804.01	Census Tract 2804.01	G5020	S	1645634	0	+39.2970477	-076.7022192	1400000US24510280401	Census Tract 2804.01;...
1400000US24510280302	2803.02	Census Tract 2803.02	G5020	S	1006761	0	+39.3179241	-076.6935132	1400000US24510280302	Census Tract 2803.02;...
1400000US24510280301	2803.01	Census Tract 2803.01	G5020	S	3160921	20250	+39.3106632	-076.7022121	1400000US24510280301	Census Tract 2803.01;...
1400000US24510280200	2802	Census Tract 2802	G5020	S	2413240	0	+39.3274111	-076.7016139	1400000US24510280200	Census Tract 2802; Balt...
1400000US24510280102	2801.02	Census Tract 2801.02	G5020	S	3498689	0	+39.3411885	-076.7000831	1400000US24510280102	Census Tract 2801.02;...
1400000US24510280101	2801.01	Census Tract 2801.01	G5020	S	1408316	0	+39.3516279	-076.6998407	1400000US24510280101	Census Tract 2801.01;...
1400000US24510272007	2720.07	Census Tract 2720.07	G5020	S	802298	0	+39.3636968	-076.7064881	1400000US24510272007	Census Tract 2720.07;...
1400000US24510272006	2720.06	Census Tract 2720.06	G5020	S	736776	0	+39.3566463	-076.6965328	1400000US24510272006	Census Tract 2720.06;...

Lab 5 Visual Guide Figure 5.9. Attribute table for the Baltimore census tracts shapefile. The GEOIDFQ field in the shapefile is highlighted.

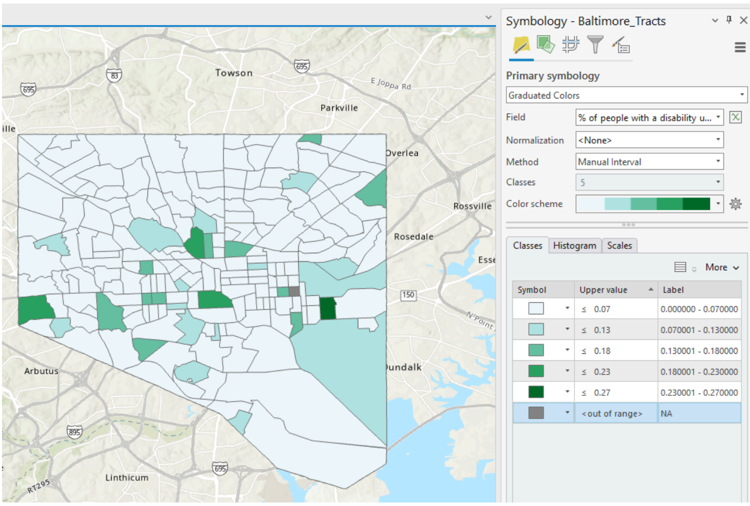
GEO_ID	NAME	Estimate; Total; Civilian noninstitutionalized population; DISAB	Estimate; Uninsured; Civilian noninstitutionalized population; D	% of people with a disability uninsured
1400000US24510010100	Census Tract 101; Balti...	208	31	0.149038
1400000US24510010200	Census Tract 102; Balti...	134	7	0.052239
1400000US24510010300	Census Tract 103; Balti...	91	0	0
1400000US24510010400	Census Tract 104; Balti...	215	0	0
1400000US24510010500	Census Tract 105; Balti...	208	0	0
1400000US24510020100	Census Tract 201; Balti...	113	0	0
1400000US24510020200	Census Tract 202; Balti...	140	0	0
1400000US24510020300	Census Tract 203; Balti...	221	0	0
1400000US24510030100	Census Tract 301; Balti...	265	0	0
1400000US24510030200	Census Tract 302; Balti...	374	0	0
1400000US24510040100	Census Tract 401; Balti...	725	146	0.201379
1400000US24510040200	Census Tract 402; Balti...	51	0	0
1400000US24510060100	Census Tract 601; Balti...	232	86	0.37069

Lab 5 Visual Guide Figure 5.10: Baltimore_uninsured spreadsheet.

7. Create Maps (1 & 2) Using these Breaks

When adding a symbology to your map, manually edit the class breaks that you made on your dot plot (use your eye to estimate the values). Use the field indicating the percentage of uninsured that you calculated for the **Field**. Under More, click on Show values out of range and give it the label of

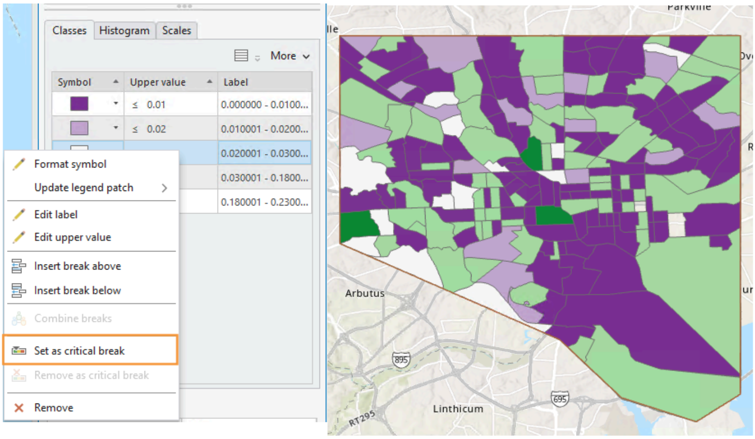
NA. You will submit a Screenshot of the Symbology Pane for both maps in layout one, in addition to an image of your plot with annotated breaks.



Visual Guide Figure 5.11. A sequential color map (left); manually editing data classes (right).

8. Create Maps (3 & 4) Using Diverging Colors

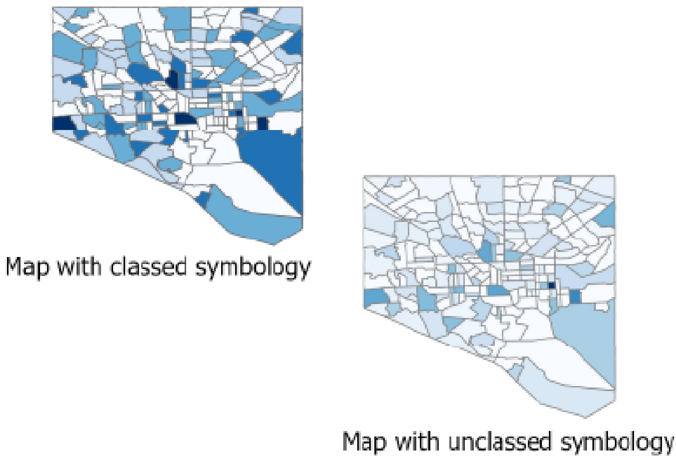
For these maps, you will be setting a critical class break (e.g., based on the mean of the data) and a diverging color scheme. To create your second pair of maps, choose a diverging color scheme. Then, set a deliberate and useful critical **class** or **break**. Once the break is set, you should manipulate the other class breaks manually. As a suggestion, for the other class breaks you could start with the manual breaks you chose for your first two maps, but you may need to adjust them to work with this new color scheme.



Lab 6 Visual Guide Figure 5.12. Adjusting class breaks and setting a critical break in ArcGIS Pro.

9. Create Maps (5 & 6) Unclassed vs. Classed

For the third set of maps, abandon your previously selected class breaks. In this set of maps, you will compare the visual difference between a classed map and unclassed map. Use the same sequential color scheme for both maps so they can be adequately compared. You should also use consistent line design, etc., so as to not distract from the primary difference of interest – the classification method used. Unlike with the two sets of maps, you will not be mapping two different variables for comparison here. You will choose just one of the variables from your previous maps and visualized this variable on both of maps 5 & 6.



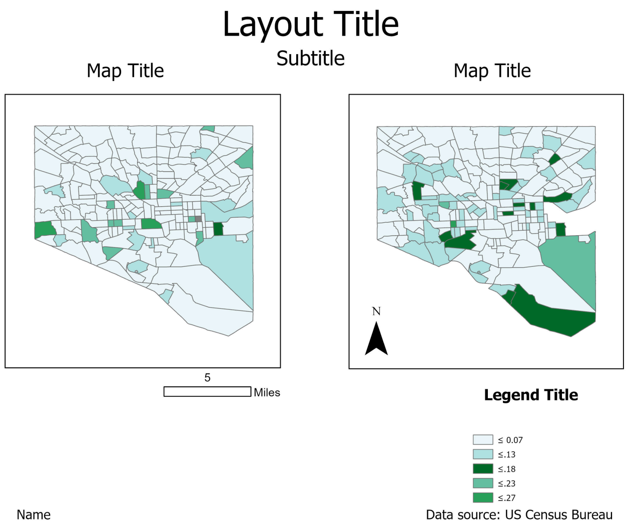
Lab 6 Visual Guide Figure 5.13. An example of a classed and unclassed map, shown here without their respective legends.

For your classed map, choose any of the methods available in ArcGIS Pro – but have a reason why! You will discuss your reasoning for choosing one of the methods in your write-up for this map pair.

10. Final Deliverables

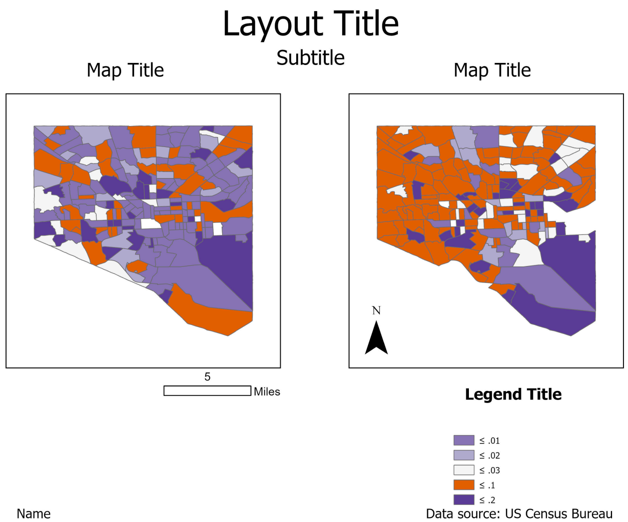
For this lab you will submit three layout, each containing a pair of maps. You will also submit a write-up document, with a 100+ word explanation of your design (data classification and color) choices for each map pair. Make sure to also design a neat and useful layout. Do not copy these layout designs. These are for demonstration purposes only. Use your knowledge of good cartographic design principles when creating these maps (i.e. you would have to give your legend an actual title). Note that elements which refer to both maps (legend; north arrow; scale bar) need to only be included once.

Example Map Pair #1



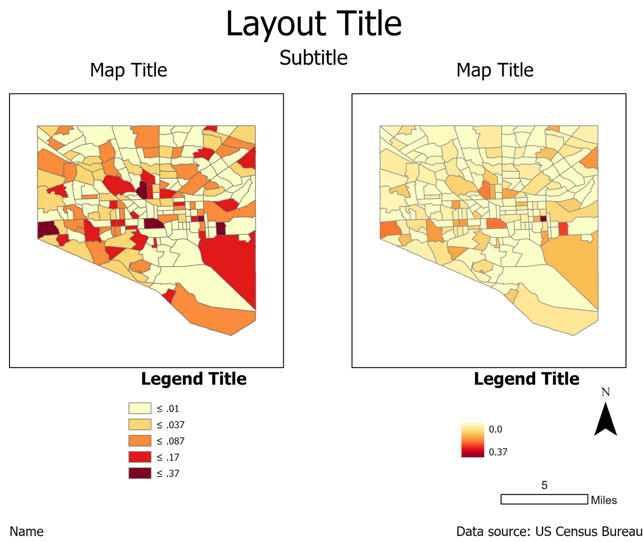
Lab 6 Visual Guide Figure 5.14: Example Map Layout #1 using a sequential color scheme and manual class breaks.

Example Map Pair #2



Visual Guide Figure 5.15. Example Map Layout #2 in which a critical break was applied to the symbology.

Example Map Pair #3

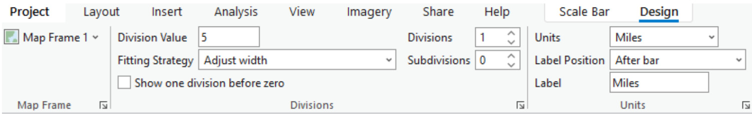


Lab 5 Visual Guide Figure 5.16. Example Map Layout #3 showing the classed and unclassed color symbolization schemes.

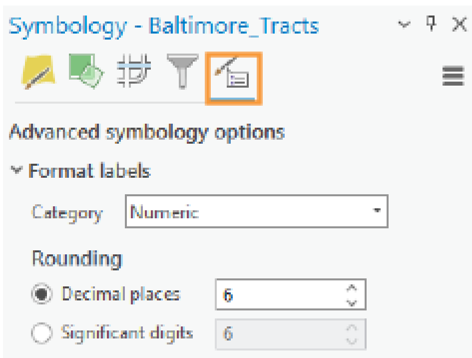
11. Additional Tips

Think about color and what you are mapping. Are you mapping insured or uninsured? Choose colors wisely – what do they represent?

Remember that you can employ text to explain your map! Use text sparingly but effectively – don't be afraid to use convert to graphics and/or manually edit text and layout elements. When choosing a color scheme as well as when doing your write-up, keep in mind: the perceptual progression of your data should match the perceptual progression of your color scheme.



Lab 5 Visual Guide Figure 5.17. Cleaning up your scale bar design – the "adjust width" option for resize behavior can be very helpful!



Lab 5 Visual Guide Figure 5.18. Simplifying legend labels in the Symbology Pane – think about your data values were calculated when selecting a label format.

Summary

By the end of this week, you should feel confident in taking in considerations regarding color and classification schemes when it comes to creating choropleth maps. This week we covered:

- The perceptual dimensions of color which are hue, lightness, or value and saturation or chroma
- Munsell's color system
- Types of color schemes which are sequential, diverging, and qualitative
- Tips on choosing hues for your color scheme
- Accessibility
- Useful resources to help you choose color and classification schemes

The Washington Post created a web map where you can look to see the change of rent per county. Does this map effectively communicate the change in rent in terms of the color scale and classification breaks? What can be improved?

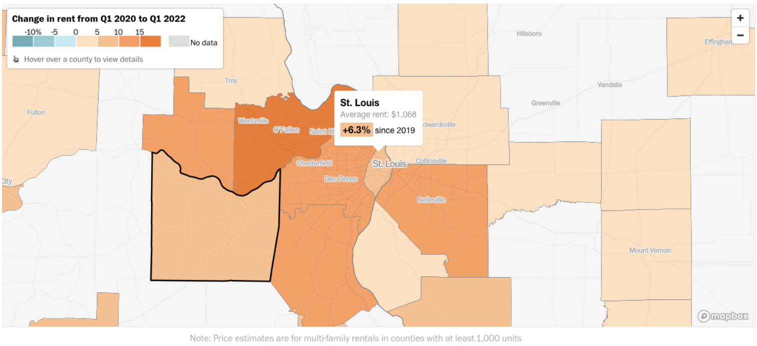


Figure 4.10.1. Washington Post map showing the increase and decrease in rent prices.

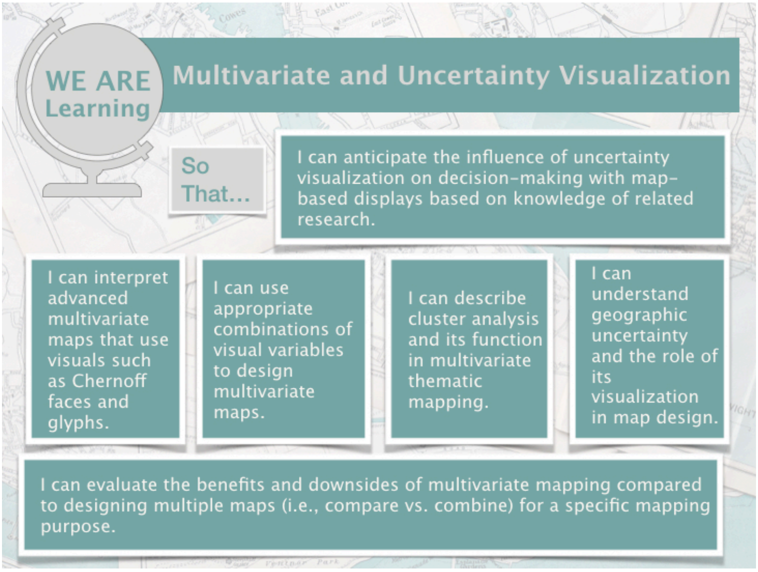
Image source: [Washington Post]

V

Multivariate and Uncertainty Visualization

Overview

So far, we have talked about mapping only one variable on the map. These type of maps are known as univariate maps. For example, we have seen maps of unemployment rates, zoning maps, and populations maps. But what if you want to map more than one variable and have these variables share the same color scheme? In lesson 5, we will talk about maps in which you map two or variables, which are called multivariate maps. We will also talk about geographic uncertainty. When you make and display a map, many viewers might take that as the ground truth. However, the data we use for a map is not a perfect representation of a population due to various reasons which can range from data collection issues to using faulty data sources. Through mapping geographic uncertainty in which we indicate the level of uncertainty for the areas we map, we are transparent about what we depict which can create trust to the target audiences of the map.



By the end of this lesson, you should be able to: anticipate the influence of uncertainty visualization on decision-making with map-based displays based on knowledge of related research, can interpret advanced multivariate maps that use visuals such as Chernoff faces and glyphs, use appropriate combinations of visual variables to design multivariate maps, describe cluster analysis and its function in multivariate thematic mapping, understand geographic uncertainty and the role of its visualization in map design, and evaluate the benefits and downsides of multivariate mapping compared to designing multiple maps (i.e., compare vs. combine) for a specific mapping purpose.

Multivariate Maps

Multivariate Maps

So far in this course, we have discussed many different ways of symbolizing data using visual variables. Our focus has been primarily on univariate maps—maps that show only one thematic data attribute.

This is a good start, but cartographers often wish to map more than one variable in a thematic map. This is called **multivariate** mapping. When creating multivariate maps, you should think about the best way to map each individual variable, as well as how you can best combine them to suit your maps audience, medium, and purpose.

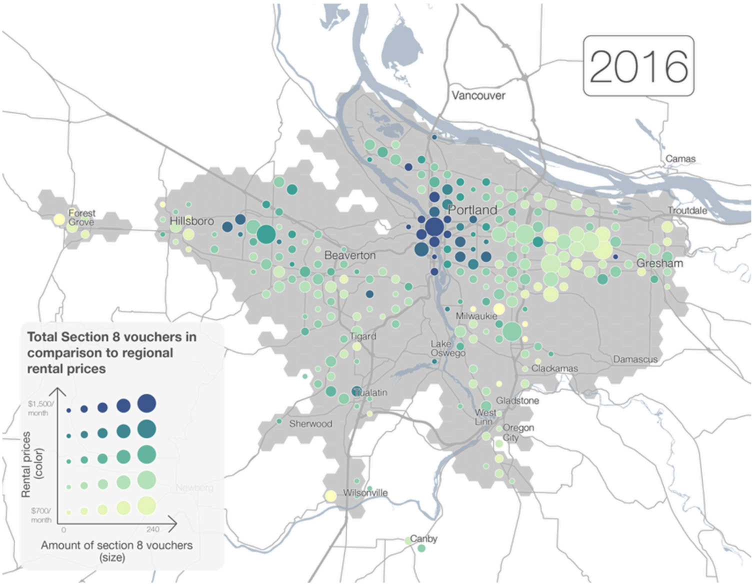


Figure 5.1.1. A map of section 8 housing and rent prices in Portland, Oregon. Credit: [Oregon Metro Council]

The map in Figure 5.1.1 is a multivariate map. The map visualizes two variables at each location—rent prices, and the number of Section 8 vouchers. These variables are each mapped appropriately individually: first, rental prices are visually encoded with a sequential color scheme, a good symbolization choice for normalized data such as rates. The number of Section 8 vouchers at each location is mapped with size, an appropriate visual variable for mapping count data. Together, these symbols work together to visualize this housing data from Portland.

Note that the legend in Figure 5.1.1 is more complicated than many of the legends that we've seen so far. The format shown—one variable along the x-axis, and one along the y-axis, is common in **bivariate** maps, or maps that display two data variables. It not only explains how to data is encoded, but helps the map reader to understand how the data are related to each other. The more complicated a map becomes, the more challenging it will be to design a useful legend. Legend design is an important task however, as your legend is key for proper reader interpretation of your map. The map in Figure 5.1.2 below uses short text blurbs to assist the reader in this interpretation.

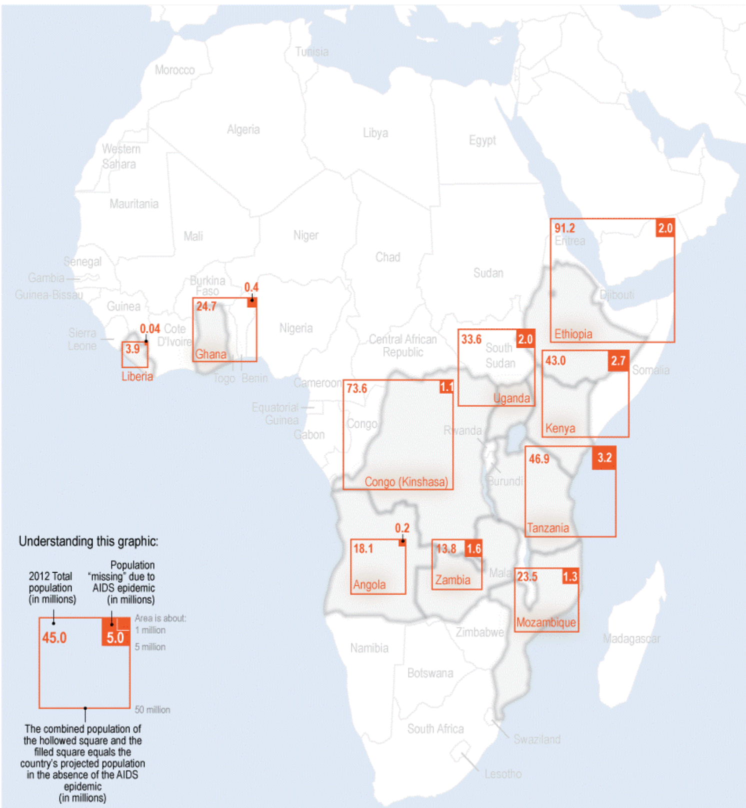


Figure 5.1.2. A multivariate map about the AIDS epidemic in Africa. Credit: [US Census Bureau]

As we continue through this lesson, keep an eye on the legends used in various maps. Some maps, such as bivariate choropleth maps, have somewhat standard legend designs. Others, such as the one used in Figure 5.1.2, are somewhat less so; they are designed and customized by the cartographer to suit the map's data and purpose. Legend design is an important component of cartographic design in general, but is particularly important for multivariate maps.

Student Reflection

Consider the legends you have made for your maps in the labs thus far. For which map did you find designing the most challenging? Why?

Multivariate Choropleths

Multivariate Choropleths

As choropleth maps are the most popular type of *univariate* thematic map, it is not surprising that they are also commonly used in multivariate mapping. Most common are bivariate choropleths—choropleth maps that visualize two variables. Note that while cartographers have historically described maps of two data variables as bivariate, these maps can also be described as multivariate (more than one variable). In the context of this lesson and course, we will generally use the more comprehensive description *multivariate maps.*

The map in Figure 5.2.1 is an example of a bivariate choropleth distributed by the U.S. Census Bureau. It uses a hue progression (yellow to blue) to visually encode population density, and color lightness to visually encode population change. The way these symbols are combined is explained by the 3×3 box legend in the lower right.

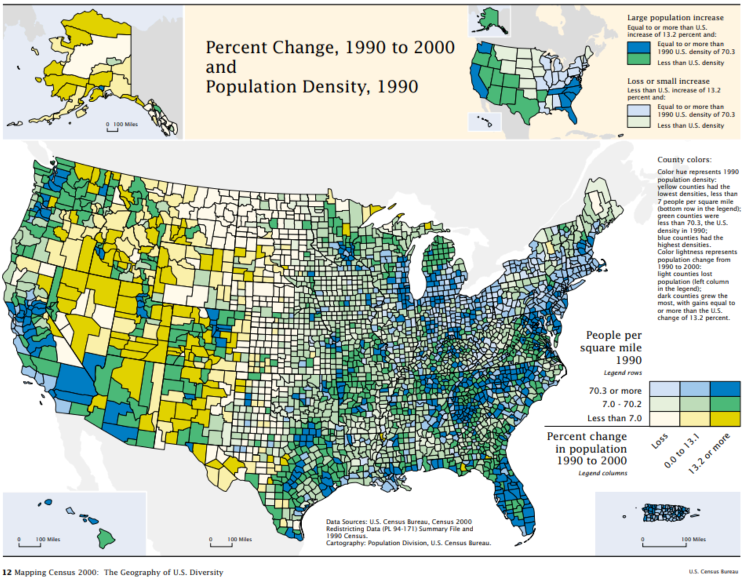


Figure 5.2.1. A bivariate choropleth map visualizing change in population density over time. Credit: US Census

You might notice that this map uses **color hue** to encode population density, which is a sequential quantitative variable—a design choice we have discouraged in previous lessons. In general, color **lightness** is a much better choice for encoding quantitative data. In this map, however, color lightness is already being used to map the other variable—population change. Creating multivariate maps sometimes requires bending the rules of cartographic conventions a bit so as to best represent all of your data.

Multivariate Dot and Proportional Symbol Maps

Multivariate Dot and Proportional Symbol Maps

Another commonly-used thematic map type for multivariate mapping is the proportional symbol map. Making these types of maps is often easier than making bivariate choropleth maps. As the main visual variable used in proportional symbol mapping is *size*, another variable can be added quite easily—color. The challenge lies in their interpretation: as the visual variables of size and color are quite different, this can make it challenging for the multiple variables on the map to be directly compared by readers.

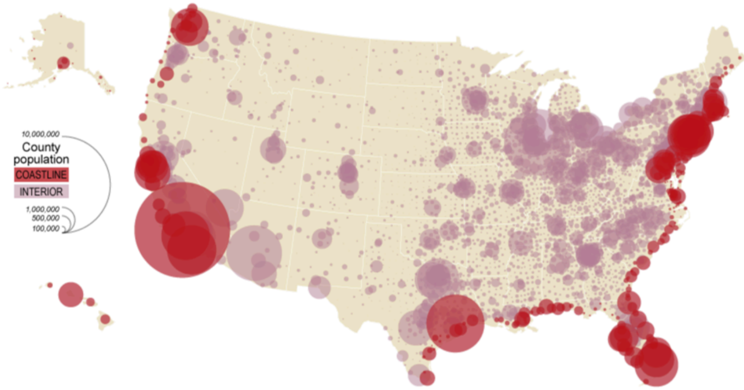


Figure 5.3.1. A bivariate proportional symbol map using size and color hue. Credit: [US Census Bureau]()

Figure 5.3.1 above is a bivariate proportional symbol map that visualizes two variables: population by county (a quantitative variable, with the visual variable **size**) and coastline vs. interior (a qualitative variable, with the visual variable **color hue**).

Student Reflection

Imagine you were tasked to create the map above, but instead of symbolizing points as coastline vs. interior, you were asked to symbolize all points by income per capita (in addition to population). What would you change about this map design to fit that new data?

Another method of multivariate map design is to stack multiple layers so they can be viewed simultaneously. Often, this is done by displaying proportional or graduated symbols on top of a choropleth or isoline map. An example is shown in Figure 5.3.2.

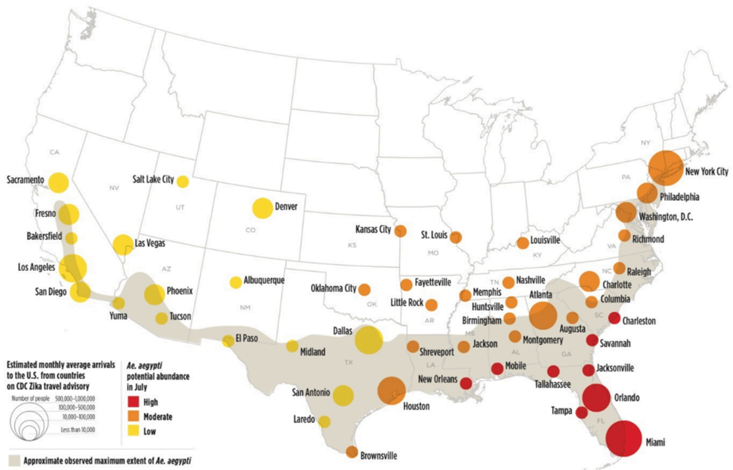


Figure 5.3.2. Using layering to create a multivariate thematic map. Credit: National Science Foundation

In the map above, visual emphasis is placed on the proportional symbols: they use size to symbolize a primary variable of interest—the estimated count of people in each city who arrived there after visiting a country on the CDC's Zika travel advisory list. Another variable, *Ae. aegypti* (a mosquito capable of transporting the Zika virus) abundance, is visualized with color lightness/hue. A third variable—the approximate observed maximum extent of this mosquito, is visualized in the background for additional context. Note the careful legend design.

Making a map such as this one is a challenge, but is an example of how related variables can be mapped together to create an engaging and useful map.

Cartograms

Cartograms

Thus far, we have discussed several methods for visually encoding maps with multiple variables via the addition of map symbols. There is another popular option: encoding data by altering the map's shape or size itself. Area **cartograms** are maps in which the areal relationships of enumeration units are distorted based on a data attribute (e.g., the size of states on a map might be drawn proportional to their populations) (Slocum et al. 2009).

Figure 7.4.1 shows a choropleth map of *Social Capital Index ratings* (Lee 2018) at the top, and two cartograms beneath it. Each of these maps encode every state's *Social Capital Index* ranking using a multi-hue sequential color scheme. The bottom two cartograms also distort the area of each state by sizing them based on their population—but they use different techniques for doing so.

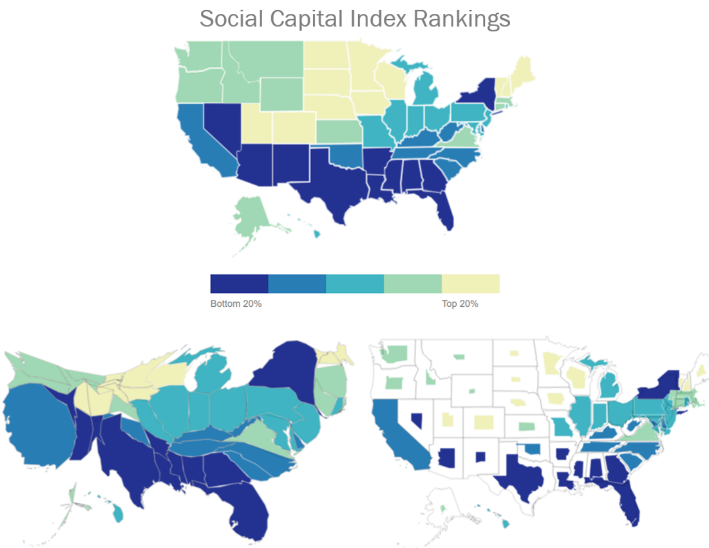


Figure 5.4.1. A choropleth map, and two related cartograms. Credit: [Mike Lee US Senator for Utah]()

In Figure 7.4.1, the map on the bottom left is a density-equalizing, or **contiguous cartogram**. Though areas are distorted, connections between the areal units (here, states) are maintained. The map on the right, conversely, is a **noncontiguous cartogram**. States are still sized according to their population, but this method used does not require the maintenance of connections at areal boundaries. The relaxation of this requirement allows areas to be re-sized without their shapes being particularly distorted. The inclusion of state political boundaries on this map also allows the reader to make an interesting comparison: which states are disproportionally populated, and which as disproportionally less so?

Student Reflection

Think back to earlier lessons—how might you apply color differently to improve the maps in Figure 5.4.1?

An alternative technique to constructing cartograms, called "**Value-by-Alpha**" mapping, was recently defined by Roth, Woodruff, and Johnson (2010). Rather than re-sizing areas based on their population, value-by-alpha maps use *transparency* to fade less-populated areas into the background, giving areas of higher population greater visual prominence. Thus, they serve a similar purpose to cartograms, but do not distort the map's geography. This is not to say that they should always be used instead of cartograms—but they are perhaps an appropriate alternative when the shock value of a cartogram is undesirable, and maintenance of both area borders and shapes is desired (Roth, Woodruff, and Johnson 2010), which is not possible with traditional cartogram maps.

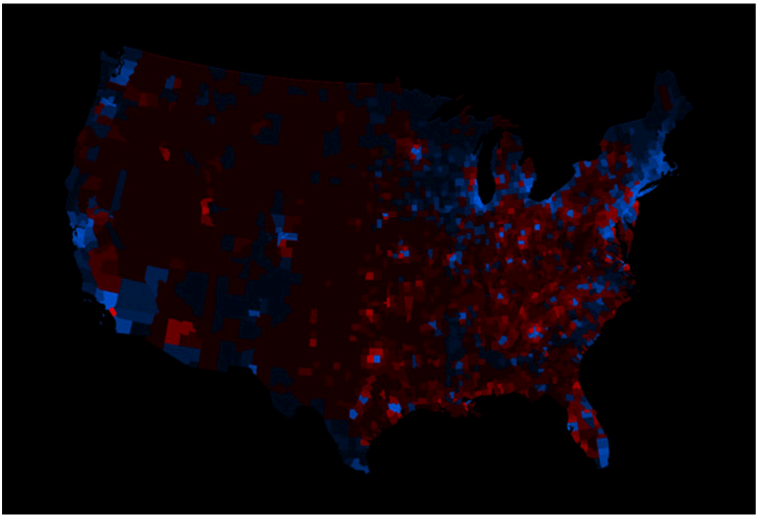


Figure 5.4.2 A Value-by-Alpha Map of results of the United States 2008 Presidential Election. Credit: Axis Maps / CC BY-NC-SA 4.0

Multivariate Glyphs

Multivariate Glyphs

The examples we have explored so far have only visualized two or three variables at once. Occasionally, you may want to visualize more. One possible solution is to design data graphics that can then be incorporated into your map. A classic example of this is the use of pie charts as proportional symbols: an example is shown in Figure 5.5.1 below.

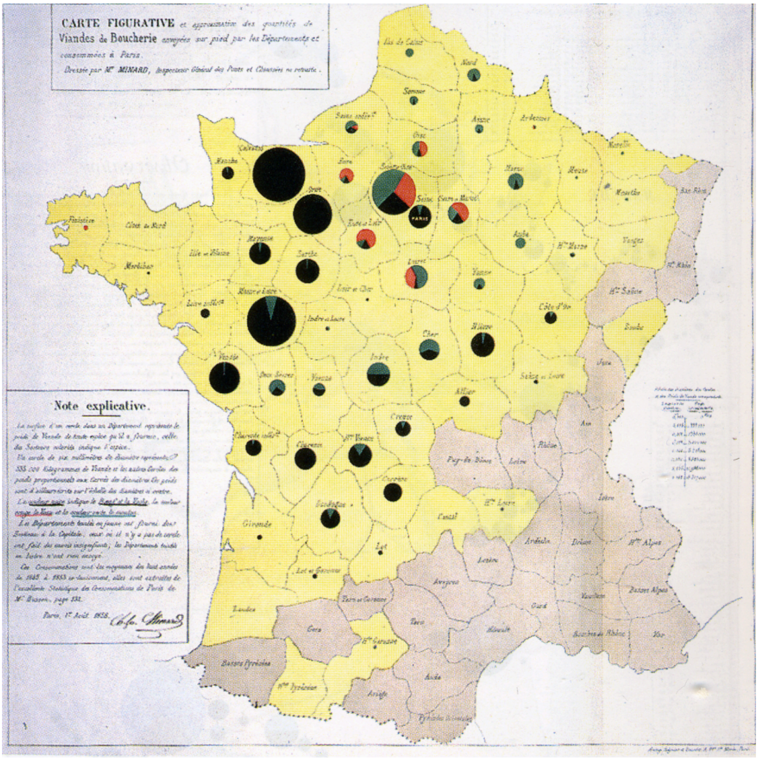


Figure 5.5.1. A map using pie charts by Charles Minard.Credit: Charles Joseph Minard – Scanned from the book by Gilles Palsky, "Des chiffres et des cartes: la cartographie quantitative au XIXè siècle". Paris: Comité des travaux historiques et scientifiques, 1996. ISBN 2-7355-0336-4. Public Domain.

A more recent (and more complicated) example is shown in Figure 5.5.2.

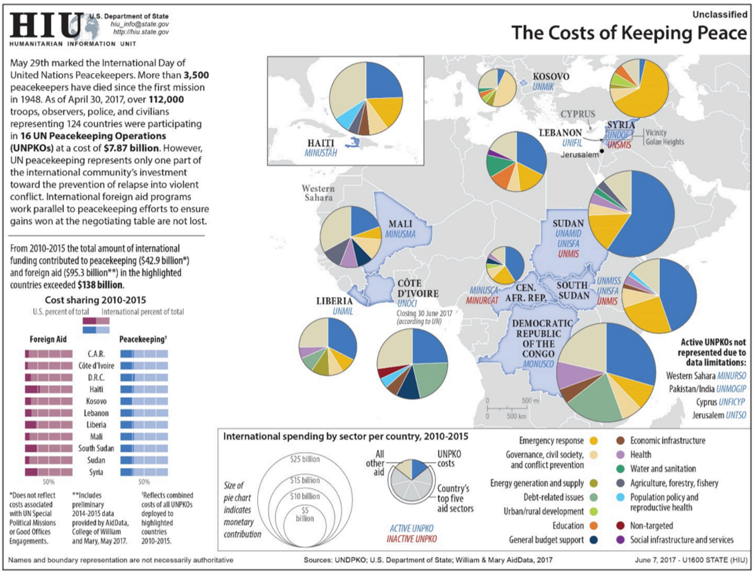


Figure 5.5.2 A Multivariate Map using Pie Charts. Credit Humanitarian information Unit – US Department of State

Though the use of overlay glyphs does permit the addition of many variables onto the map, this does not mean it is always the best solution. As shown in the above examples, including a large amount of data in a map can make it challenging to interpret. Additionally, multivariate glyphs in general—and pie charts in particular—have well-documented disadvantages in terms of reader comprehension (Tufte 2001). Adding graphics that are already challenging for people to understand to maps tends to exacerbate such issues. This is not to say that they should never be used, however—just with caution. And fortunately, there are ways in which such maps can be made easier to interpret.

One way that multivariate maps can be made more comprehensible is through the addition of user interaction. Figure 5.5.3, for example, is challenging to interpret as a static image, particularly as the glyphs used are quite small. However, this is an interactive map. Clicking on a state creates a more informative pop-up, shown in Figure 5.5.4.

Blooming States, US Census Bureau

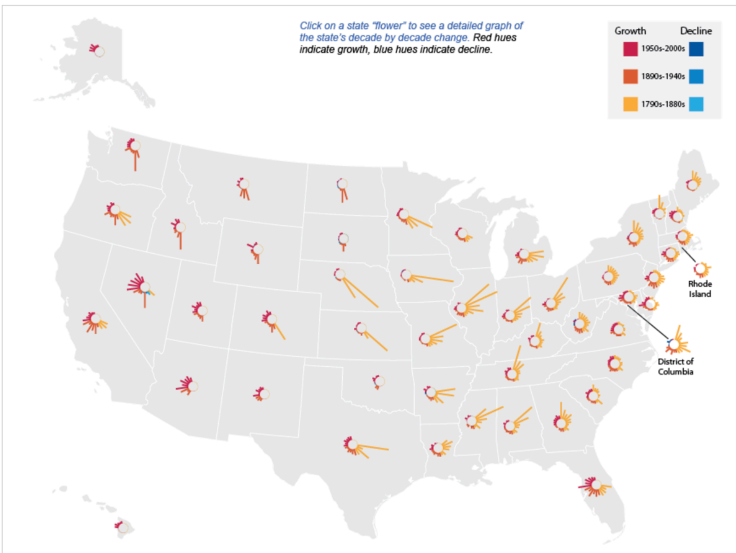


Figure 5.5.3. An example of a map created with multivariate glyphs. Credit: [Blooming States, US Census Bureau]

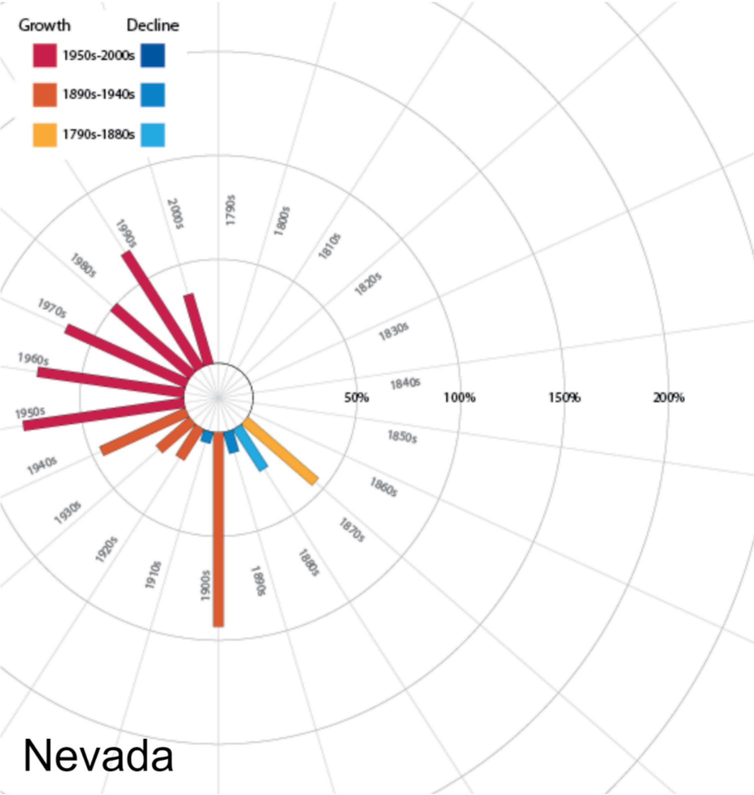


Figure 5.5.4. The pop-up created on-click in Figure 5.5.3. Credit: US Census Bureau.

Student Reflection

Explore the use of multivariate glyphs to explore data about well-being. Can you think of ways in which this data might be symbolized instead as a static map or maps?

Despite the difficulty of creating maps with multivariate glyphs, cartographers have long attempted to tackle this challenge. One particularly interesting example of this is **Chernoff faces.** Chernoff faces are glyphs created by mapping variables onto facial attributes. When mapping the variable *average household income*, for example, a bigger smile might indicate a higher income level.

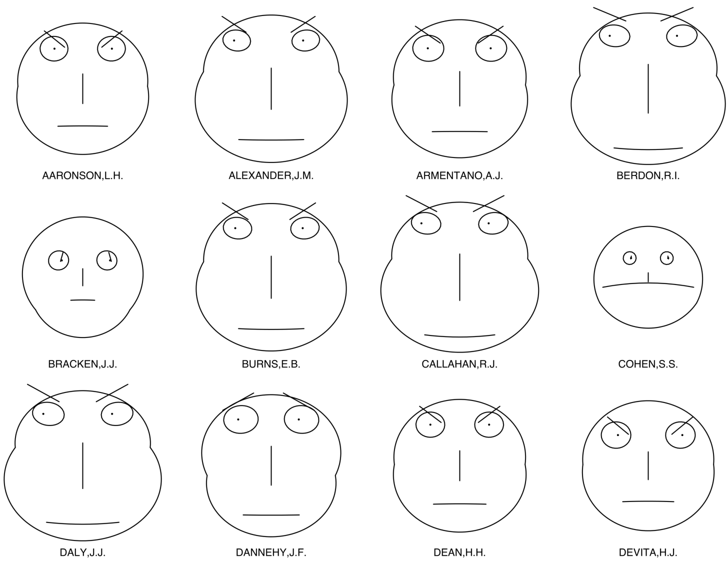


Figure 5.5.5. An example of Chernoff faces. Credit: Avenue, Wikimedia Commons, public domain

The Chernoff face technique was first proposed by Herman Chernoff in 1973. Chernoff's intention was to capitalize on the ability of humans to intuitively interpret differences in facial characteristics—both by subconsciously noting important differences in expressions that are almost unmeasurable—and by being able to ignore large differences when these differences are not relevant in context (Chernoff 1973). Chernoff also noted that his method was desirable as it permitted the designer to map many variables (as many as 18!) onto just one graphic.

Chernoff's original application of his technique used fossil and geological data, but Chernoff mapping is more commonly used to depict social data such as well-being, or other topics related to the emotions that might be intuitively encoded using facial attribute variables. The history of Chernoff mapping is rife with controversy—some Chernoff maps such as this one: Life in Los Angeles by Eugene Turner, 1977(link is external), have been heavily criticized for their use of stereotypical facial attributes and a cartoonish over-simplification of complex issues.

In response to these critiques, some cartographers have developed techniques for utilizing the advantages of Chernoff faces without some of the downsides. Heather Rosenfeld and her colleagues, for example, proposed using Zombieface glyphs rather than human faces—maintaining the emotive content and still capitalizing on people's ability to intuitively interpret facial features, but removing the human context and thus lowering the likelihood of reinforcing harmful stereotypes (Figure 5.5.6).

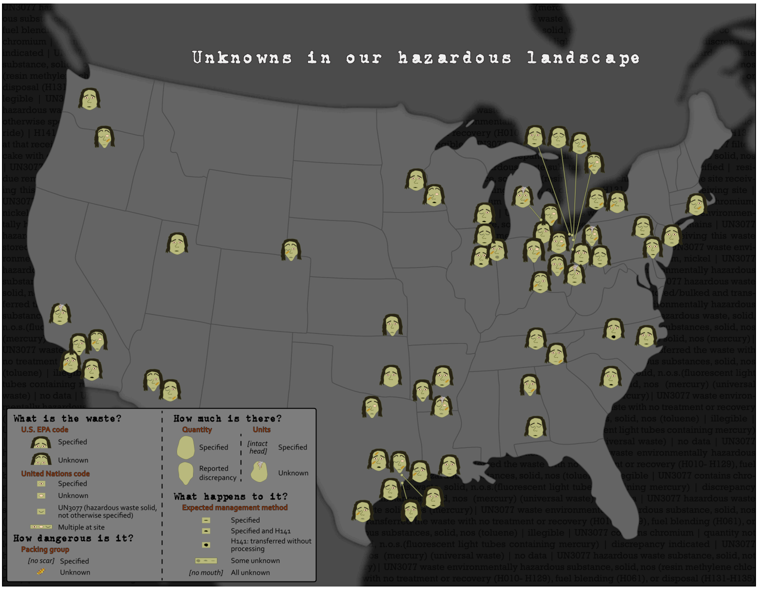


Figure 5.5.6. Unknowns in our hazardous landscape, a map by Heather Rosenfield and colleagues which uses the Chernoff Zombies mapping technique.b View her conference talk to learn more about Chernoff maps and the Chernoff Zombie mapping technique here! [Chernoff Zombies, Nacis 2017]

Take a closer look at the legend of this map—which demonstrates how the hazardous waste data was mapped to Zombie facial attributes—in the image below. As you can see, the map focuses on visualizing the presence of unknowns and uncertainty in the mapped dataset. We'll discuss further techniques for visualizing uncertainty later in this lesson.

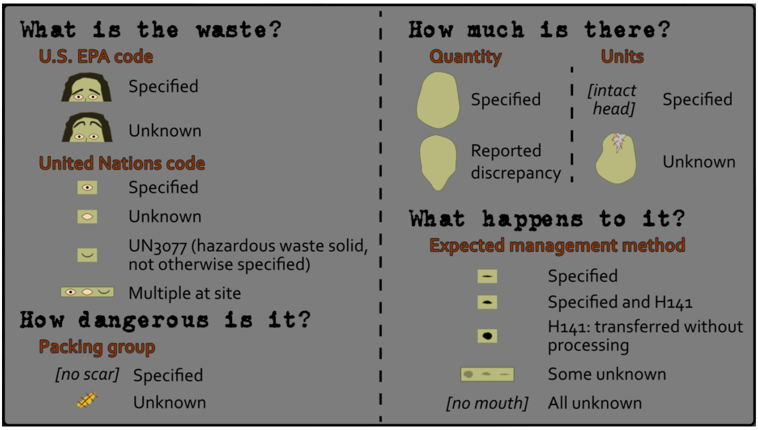


Figure 5.5.7. The legend from this Chernoff Zombies maps, Unknowns in our hazardous landscape.Credit: Heather Rosenfeld; co-authors: Sarah Moore, Eric Nost, Robert Roth, Kristen Vincent. You can learn more about this project as a whole at their website: HazMatMapping.

Chernoff Zombies are among several creative solutions recently proposed: a fun example is shown in the following quasi-Chernoff map: [Mapping Happiness(link is external)](Mapping Happiness). It maps happiness, or well-being, across the United States using emoticons. Though these abstract icons cannot easily encode as many data attributes as Chernoff faces, they share the benefit of visualizing data at-a-glance using facial expressions.

Comparing vs. Combining

Comparing vs. Combining

As demonstrated by previous examples, multivariate maps are often challenging—both for cartographers to create and for readers to interpret. The term *multivariate map* is typically defined as a map that displays two or more variables at once (Field 2018). There is another popular option, however—comparing multiple maps. One common and often useful technique is to design a layout with many maps and show them in a progression—this is called **small multiple** mapping.

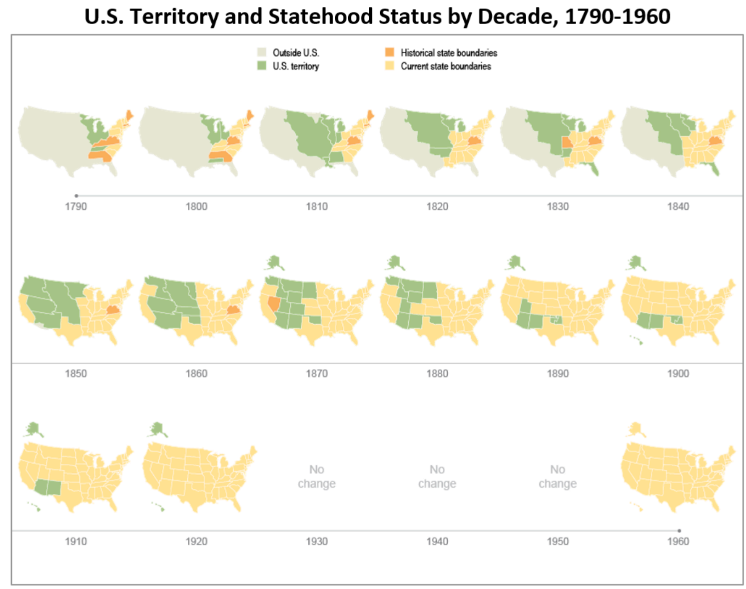


Figure 5.6.1. An example of the small multiples mapping technique. Credit: US Census Bureau

Small multiple maps are particularly useful for depicting data over time, as they can be arranged in a linear sequence, the way that time is typically depicted. With the increasing popularity of web-maps, small multiple mapping is often replaced with an animated map—in such maps, each map shown is shown as an individual time-stamped frame. Despite the advantages of animated maps (e.g., creating visual interest, efficient use of layout space), there are still benefits to traditional small multiple mapping. One primary advantage? The ability to simultaneously compare the various maps.

While multivariate maps are often engaging and visually interesting, it is important to keep in mind the alternatives available. We can imagine combing the set of maps in Figure 7.6.1 with some sort of transparent layering, or perhaps with an animated map that alternates between the two views. In this case, however, such designs would likely add little to the presentation value of these maps and be quite challenging to create. Here, simple works well.

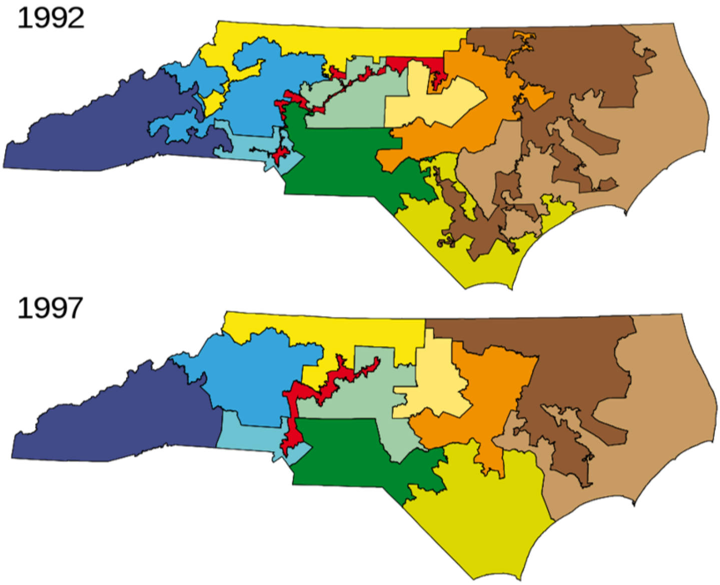


Figure 5.6.2. A successful side-by-side map comparison of voting districts in North Carolina. Credit: Furfur, CC BY-SA 4.0, from Wikimedia Commons

Cluster Analysis

Cluster Analysis

So far, we have discussed two ways of mapping multiple variables—combining visual variables to encode multiple variables into one map, and visually comparing sets of maps of different data. There is a third, considerably different method that is often used for mapping multivariate data sets: cluster analysis. Cluster analysis refers to mathematical methods used to combine multiple quantitative variables into one map (Slocum et al. 2009).

There are multiple methods for clustering, the most popular of which is the K-Means algorithm, the goal of which is to identify groups of like observations based on several attributes—groups are assigned in a way that minimizes intra-group differences, while maximizing inter-group differences. Consider, for example, that you are interested in visualizing education, income, and access to green space in the US by county. You could map these three variables individually, or you could use cluster analysis to identify groups of counties that are similar along all three dimensions. Once such groups are determined, you could map them with a qualitative color scheme onto a chorochromatic map.

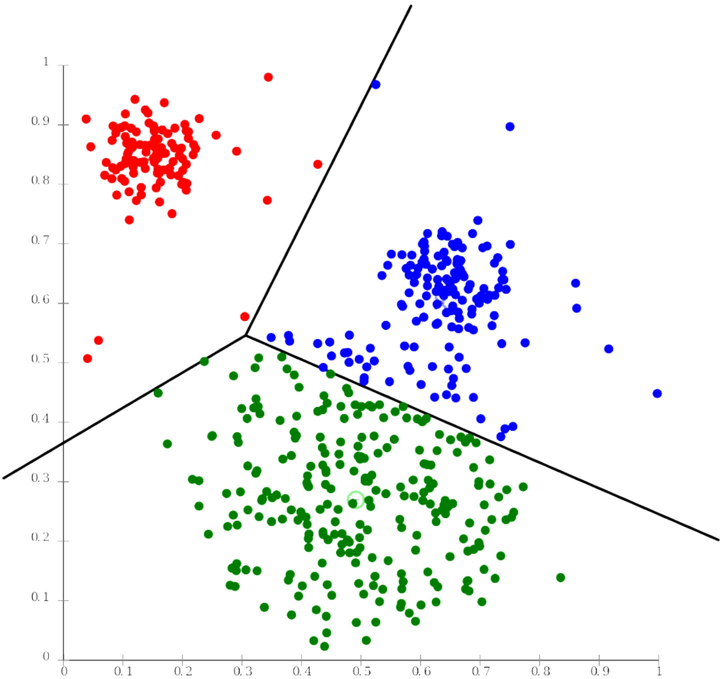


Figure 5.7.1. An example output of cluster analysis with k-means. Credit: Chire, [Wikimedia Commons](), (CC BY-SA)

Cluster analysis is a complicated topic, and we will not go into its details in this course. What is important to understand is that it provides a mathematical alternative to the other more design-based multivariate mapping techniques we have explored so far. You are encouraged to explore the recommended readings if you are interested in learning more about cluster analysis and about implementing it in GIS.

The Visualization of Uncertainty

The Visualization of Uncertainty

Of the many variables you may wish to include in your maps, there is one that has received particular focus from cartographers due to its unique characteristics—**uncertainty**. Uncertainty is a complex concept which has been defined differently by various authors. For example, Longley et al. (2005) define uncertainty as "the difference between a real geographic phenomenon and the user's understanding of the geographic phenomenon." We use this definition as it encompasses the many variations of uncertainty that in emerge during multiple stages of map-making—during data collection, data classification, visualization, map-reader interpretation, and more (Kinkeldey and Senaratne, 2018).

It can be assumed that all geographic data contain some level of uncertainty. A map of average income by county, for example, might classify a county as having an average household income between $50,000 and $60,000. Despite this, it is possible that the actual value falls outside of this range—due to survey response errors, non-response to survey (e.g., Census) requests by some residents, or changes in the data over time (e.g., some survey respondents have moved in or out of the county since the data was collected). A map of precipitation levels, similarly, will also contain uncertainty, likely due to the imprecision or inaccuracy of measurement instruments, but possibly due to human error or related factors as well.

Traditionally, researchers have grouped geodata uncertainty into three categories – the what (attribute/ thematic uncertainty), the where (positional or locational uncertainty), and the when (temporal uncertainty) (MacEachren et al. 2005). The success of visual variables for depicting uncertainty depends on the type of uncertainty to be mapping. Containing a point within a colored glyph or circle, such as Google's "blue dot," might be most effective for depicting positional uncertainty (Google Maps; McKenzie et al. 2016). Use of another variable such as transparency might be more effective for depicting attribute uncertainty, such as uncertainty of unemployment rates in a county-level map.

Like other multivariate data, uncertainty can be *combined* with the other visualized data in a map, or *compared* by visualizing it in a separate map view. Figure 7.8.1 shows two maps that use different techniques to visualize the uncertainty in the data. Figure 7.8.1 (top) uses a combining technique, in which a visual overlay is used to show attributional uncertainty. Figure 7.8.1 (bottom) uses a reliability diagram—an inset map that the reader can reference to understand which locations on the map contain the most certain data values. In general, the combining method is a more popular technique, though a compare technique might be useful if the primary map is sufficiently complex, and thus adding overlay would make the map difficult to comprehend.

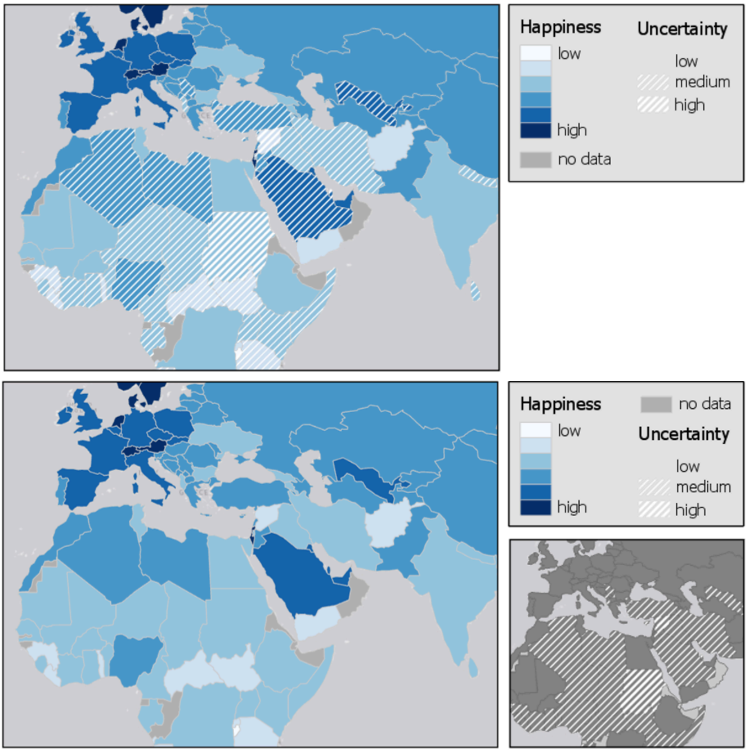


Figure 5.8.1. Combining (top) vs. comparing (bottom) uncertainty visualization techniques. Credit: Cary Anderson, Penn State University. Data Source: The World Happiness Report (Helliwell et al. 2018), Natural Earth.

Among *combined* uncertainty visualization techniques, methods for visualizing uncertainty are typically classified as either **intrinsic** or **extrinsic**. Intrinsic uncertainty visualization techniques cannot be visually separated from the visualization of one or more other variables, while extrinsic visualization techniques are easier to interpret separately. An example of the difference between these two techniques is shown in Figure 5.8.2.

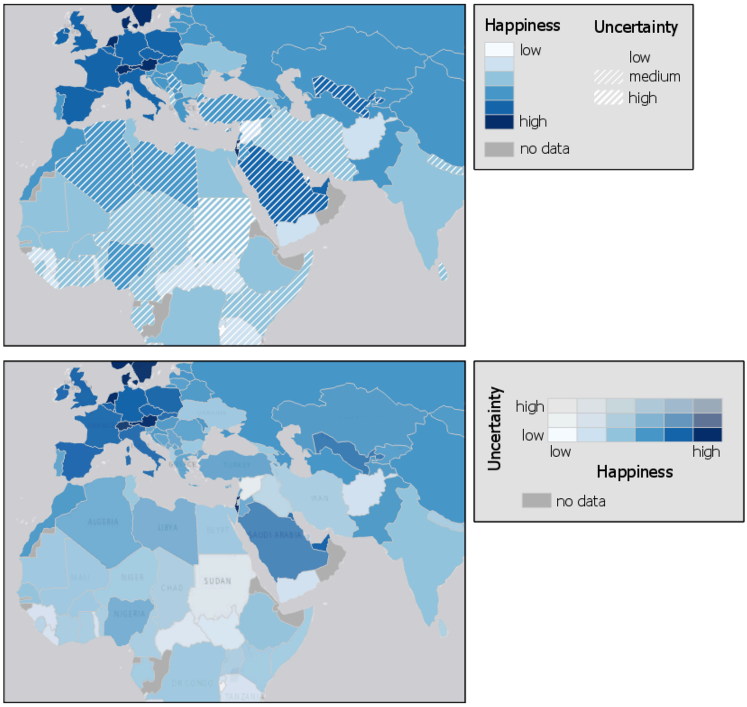


Figure 5.8.2 Extrinsic (top) vs. intrinsic (bottom) uncertainty visualization techniques. Credit: Cary Anderson, Penn State University. Data Source: The World Happiness Report (Helliwell et al. 2018), Natural Earth.

In Figure 5.8.2, both extrinsic (top) and intrinsic (bottom) uncertainly visualization techniques are shown. The extrinsic visualization uses a hatched fill overlay to denote uncertain values—thus, the visualization of uncertainty is visually separable from the visualization of the data underneath. Figure 5.8.2 (bottom) by contrast, uses an intrinsic visual variable—transparency—to visualize data uncertainty. The two variables are combined together to create the legend as well.

Any visual variable can be adapted to demonstrate uncertainty. However, some have been developed specifically for this purpose. MacEachren (1995) proposed the idea of **clarity** as a visual variable for static maps, an overarching concept that can be further divided into three visual variables: **transparency**, **crispness**, and **resolution** (MacEachren 1995). Transparency is a somewhat familiar visual variable, as it has been adapted for other purposes than displaying uncertainty, such as in the value-by-alpha maps described earlier in this lesson.

Crispness is a particularly intuitive way of visualizing uncertainty. Features are depicted on a continuum from crisp to blurry, with less certain values appearing appropriately out-of-focus (Figure 5.8.3).

Figure 7.8.3 Crisp vs. blurry areal unit boundaries – higher crispness indicates greater certainty. Credit: Cary Anderson, Penn State University.

Resolution creates a similar effect—features with less certain boundaries or attributes are depicted in courser resolution, suggesting a lack of certainty in the map.

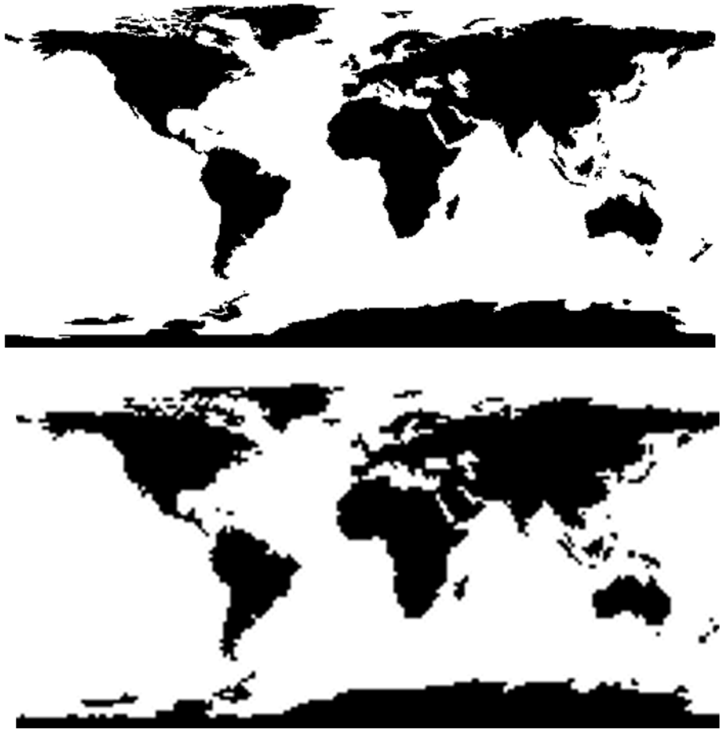


Figure 5.8.4 High vs. low resolution – higher resolution indicates greater certainty. Credit: Cary Anderson, Penn State University, Data Source: NASA.

These visual variables are popular for depicting uncertainty as they intuitively suggest uncertainty (or certainty) by design. Just as higher data values are visually encoded with larger symbols, less certain boundaries, for example, may be visually encoded with fuzzy boundaries.

Though uncertainty is often discussed in terms of uncertainty within data due to imprecise instruments, imperfect collection methods, etc., an important additional context where uncertainty plays a role is in the mapping of future scenarios. Climate models, for example, use past and present data to predict future conditions, but these predictions are inherently uncertain. Figure 7.8.5 below contains maps of temperature and precipitation change predictions. The first map (top left) maps the average result of 37 predictive models intended to estimate temperature change by 2050 (Kennedy 2014). The middle map shows the warmest 20% of models—the 20% coldest models are summarized at the right. The bottom three maps show a similar comparison of maps created from precipitation models.

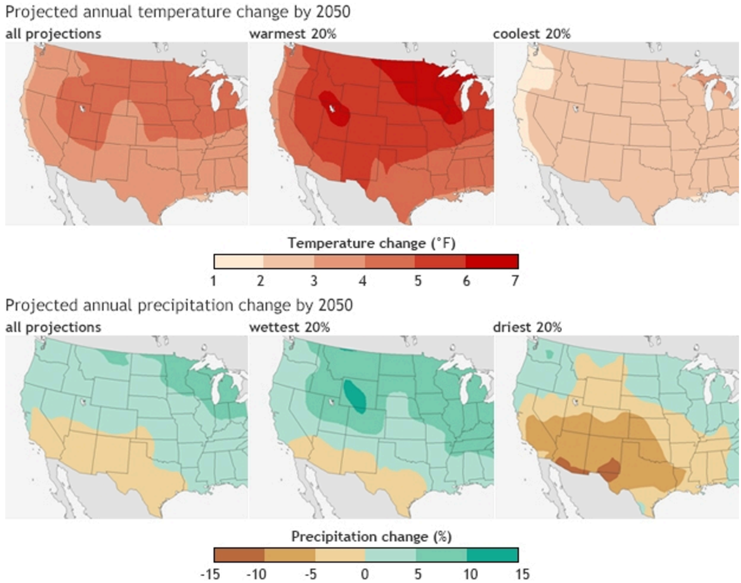


Figure 5.8.5 Prediction maps of Temperature and Precipitation change in the American West. Credit: [NOAA Climate.gov.]()

Unlike previous examples, these maps do not use intuitive visual depictions of uncertainty. However, the map-maker's inclusion of all three maps for each data variable shows the range of possibilities that might lie ahead: the future is always an uncertain entity. It is implied that these maps depict not all possible scenarios but a range of likely ones; they intend not to precisely predict the future but to help users understand what might future conditions they might expect to come about.

Uncertainty and Decision-Making

Uncertainty and Decision-Making

In the last section, we discussed how to conceptualize uncertainty, and ways in which it can be visualized. One important question remains: why should we do so? Creating well-designed maps can be challenging, and adding a depiction of uncertainty makes this process even more so.

Uncertainty is typically depicted in maps for two primary reasons: (1) its inclusion may be regarded as an ethical necessity—many maps are created with significantly uncertain data, and a cartographer might feel that withholding this information from the map reader would be misleading. (2) Consideration of uncertainty plays an important role in decision-making, and thus its visualization might be necessary in some contexts—for example, maps of predictive hurricane paths tend to include a “cone of uncertainty” (Figure 7.9.1)—and such maps often play an important role in decisions made by residents of storm-affected areas.

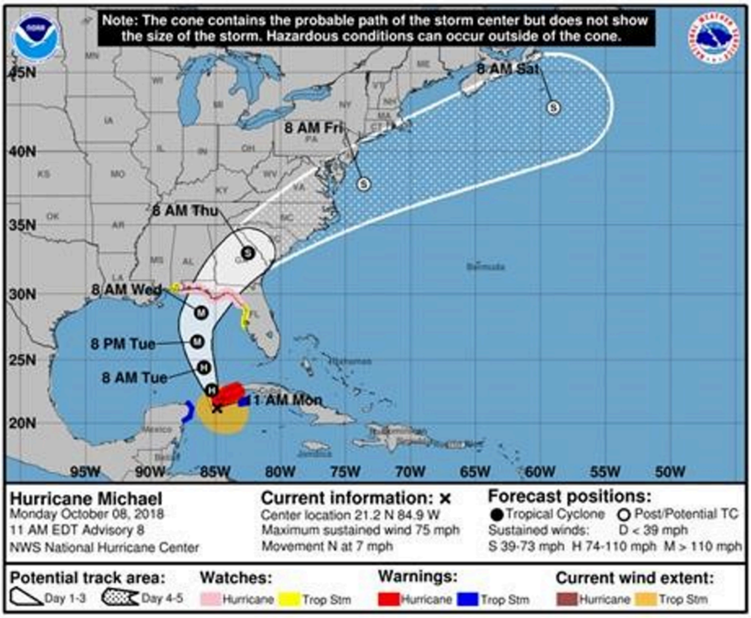


Figure 7.9.1 A Map of Hurricane Michael which includes the cone of uncertainty, showing a probable path of the storm based on NOAA's model predictions. Credit: [Official Site of the Town of Fort Mill, SC.]

So how does the visualization of uncertainty effect decision-making with maps? Kinkeldey et al. (2015) conducted a review of studies that attempted to answer this question. Most of the studies they analyzed suggested that the visualization of uncertainty *does* have an effect on task performance with maps and similar spatial displays (Kinkeldey et al. 2015). Simpson et al. (2006), for example, studied the use of uncertainty visualization in surgical tasks with graphic displays, and noted that the inclusion of uncertainty visualization improved performance accuracy. The positive influence of uncertainty visualization on task-completion accuracy with maps is a somewhat common finding. Though findings are less consistent with regards to task completion times (i.e., speed), uncertainty visualization seems at least not to significantly increase task-completion times (Kinkeldey et al. 2015).

Despite this, there is still not a consensus concerning whether uncertainty visualization is always helpful for decision-makers—some studies note that participants perceive uncertain data as risky, which can induce irrational decision-making via loss-aversion (Hope and Hunter 2007). Whether uncertainty visualization is useful—and whether it is useful enough to warrant the design efforts it requires—is context dependent and still thoroughly up for debate.

Lab 6: Multivariate Visualization

Total Points

20 points

Instructions

In this lab, we will map uncertainty and multivariate mapping with census data with census variables related to employment related to your city. For this lab, you will imagine yourself as working as a GIS analyst for the economic development agency in your chosen city. You will show the unemployment rate on the city level by census tract. In addition, you will consult on site selection based on the needs of three types of businesses by mapping the percentage of the population in these trades. To show employment trends on the city level, you will need to do this by census tract. You will be using the Census S2301 – Employment Status table for the employment rate data and Census S2405 – Industry by Occupation for the Civilian Employed Population 16 Years and Over for the industry data.

You will need to create a report analyzing the trends you see in your maps. Your report should be no longer than 7 pages (this page count is inclusive of all text and maps). In addition, you will do a small multiples map showing a different employment related variables by census tract.

For the sake of simplicity, we are using census tracts, but in a real-world setting, it is recommended to use community boundaries that are relevant to the needs of your organization which might be neighborhoods or wards.

Learning Objectives

- Create both a primary map and three smaller maps.
- Compile these maps into a neat and useful document with supporting text and good design.

Overall Lab Requirements

For Lab 5, your only deliverable will be a single compiled PDF with text and images of your maps.

Deliverables

Primary Map

- Create a map showing the **unemployment rate** (column S2301_C04_001E in the S2301 data table) of the state that your chosen city resides in by county along with the **associated uncertainty** by **Census tract**. You will use the percent margin of error to map the uncertainty (column S2301_C04_001M in the S2301 data table).
- Any null values should be mapped but not prominent in the map's visual hierarchy.
- Thoughtfully select an appropriate symbolization method, projection, and visual

variables for your map.

Small Multiples

- The economic development agency is working with three types of businesses with the desire to increase the number of jobs in the city:
    - A major logistics company that is interested in opening a distribution center (transportation, and warehousing, and utilities).
    - A mid-size retailer who is interested in opening a new store site (retail trade).
    - A consumer goods start-up who wants to open a manufacturing plant (manufacturing).
- Create three small multiple maps within one map frame showing the percentage of the population in the selected industries: 1) transportation, and warehousing, and utilities 2) retail trade 3) manufacturing. Look for areas that have a low percentage of the population working in these trades and identify areas that would be suitable to place the above facilities.
- One small multiple map per variable (so it should be three maps total) so the economic development agency can have a better look of the employment trends per variable.

Submission Instructions

- Export your maps as jpegs and include them as figures in a report with accompanying text. As when creating a map layout, attend to aesthetics, visual hierarchy, and negative space.

Lab 6 Rubric

Use the following rubric to help you complete your assignment. Adhering to the rubric will assure you will receive full points for the assignment. You must make sure all maps follow recommended cartographic principles regarding symbolization method, projection, and visual variables.

Map 1: Primary Map, 3 points

Criteria	Points Given
Mapping the unemployment rate along with an uncertainty map. Any null values should be mapped and not prominent (-1 point if you fail to do this).	3

Map 2: Small multiples map, 8 points

Criteria	Points Given
A small multiples map that shows the percentage of individuals employed in transportation, warehousing, and utilities.	2
A small multiples map that shows the percentage of individuals employed in manufacturing.	2
A small multiples map in which maps of the three variables related to 1. Transportation, warehousing, and utilities 2. Retail and 3. Manufacturing are in one map frame and are side by side for easy comparison.	2

Map 3: Compiled document, 9 points

Criteria	Points Given
Use concise explanatory text for legends, titles, and any additional map text.	3

500+ word report answering the following questions

1. What is average unemployment rate in your city and where is the highest and lowest unemployment rates within your city?
2. What is the average rate employment in the trades of interest of the economic development agency?
3. Which trade has the highest and lowest employment rates?
4. Given the economic development agency is working with three 6
stakeholders recommend the best areas in the city to pursue these initiatives and provide a rationale behind your recommendation:
    1. A major logistics company wanting to open a distribution center
    2. A mid-size retailer who is interested in opening a

new store site

3. A consumer goods start-up who wants to open a manufacturing plant.

What role should the knowledge of data uncertainty play in your recommendations?

Lab 6 Visual Guide

Lab 6 Visual Guide Index

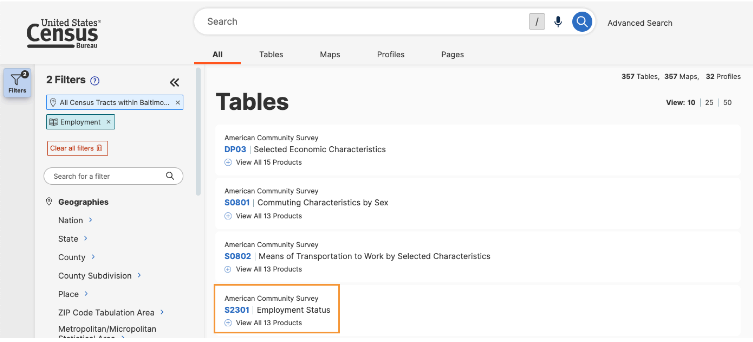
1. Downloading the Census Data
2. Explore the Health Insurance Data in Excel
3. Standardize Chosen Data for Visualization
4. Create Dot Plots Using your Standardized Data
5. Use this Plot to Visually Select Breaks
6. Joining Data in ArcGIS Pro
7. Create Maps (1 & 2) Using these Breaks
8. Creat Maps (3 & 4) Using Diverging Colors
9. Create Maps (5 & 6) Unclassed vs. Classed
10. Final Deliverables

Lab 6 Visual Guide

1. Downloading the Census Data

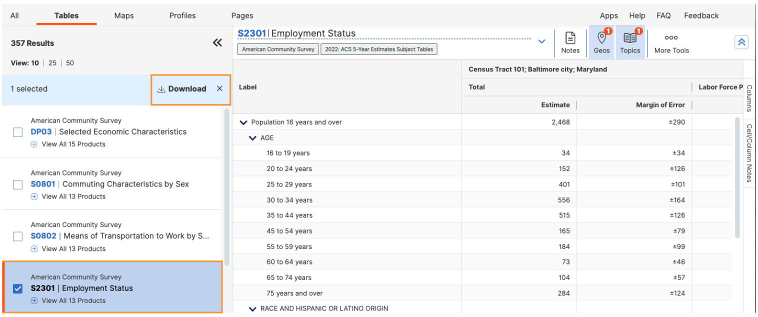
You should have already have downloaded the census tract data in Lab 1. If not, go to the Census TIGER/Line Shapefiles webpage and download the files for your chosen city. For this visual guide, we will use Baltimore census tracts.

F5tor the unemployment data, go to the Census data portal and click on Advanced Search. Under Geography, click on **Census Tract** and choose the Census tracts for your city of interest. Make sure to click **All Census Tracts** within your city of interest. Under **Topics**, click on **Employment** > **Employment** and then click **Search** on the bottom right-hand corner. You will see various tables in your search results. You will need to download the **S2301 Employment Status** table.



Lab 6 Visual Guide Figure 6.1. Search results from the Census data portal advanced search.

Click on the table and you should see a preview of the S2301 table. Make sure that you check the box before the name of the data table so you can download it. Before downloading, confirm that you are downloading the **2022: ACS 5-Year Estimates Data Profiles**. If not, you can click the "+" next to View All __ Products to show the available datasets for the given table. Once you confirm you are downloading the correct table, then click **Download**.



Lab 6 Visual Guide Figure 6.2. Table preview of Table S2301: Employment Status in the Census data portal.

You will see the **Select Table Vintages to Download** prompt. Make sure to click 2022 under **ACS 5-Year Estimates Data Profiles**. Click **Download.ZIP** to download the data table.

2. Exploring the Employment Data

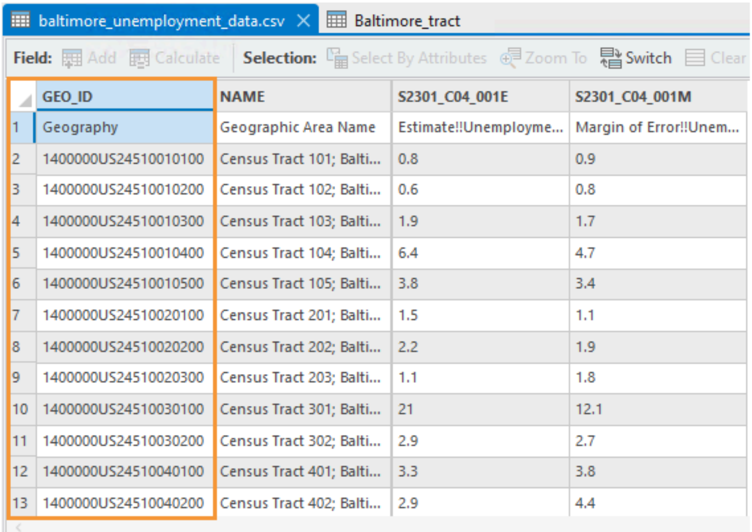
Next, we will look at the employment data in Excel. We will single out what we need and then create a new data table. This will be the table we use when we join the data. We will need the GEO_ID and NAME fields to do this. The other columns we are interested in are **S2301_C04_001E: Estimate – Unemployment Rate – Population 16 years and over** and **C2301_C04_001M: Margin of Error – Unemployment rate – Population 16 years and over**. Create a new blank workbook and copy and paste those four fields in your new workbook. Save the workbook as a **CSV (Comma delimited)** file and name it city_unemployment_data. In case of this example, the csv file will be named baltimore_unemployment_data.

GEO_ID	NAME	S2701_C01_035E	S2701_C01_036E	S2701_C04_035E	S2701_C04_036E
Geography	Geographic Area Name	Estimate!!Total!	Estimate!!Total!!(	Estimate!!Uninsu	Estimate!!Uninsur
1400000US24510010100	Census Tract 101; Baltimore city; Maryland	208	2398	31	71
1400000US24510010200	Census Tract 102; Baltimore city; Maryland	134	2719	7	41
1400000US24510010300	Census Tract 103; Baltimore city; Maryland	91	1967	0	0
1400000US24510010400	Census Tract 104; Baltimore city; Maryland	215	2717	0	90
1400000US24510010500	Census Tract 105; Baltimore city; Maryland	208	1688	0	137
1400000US24510020100	Census Tract 201; Baltimore city; Maryland	113	1568	0	26
1400000US24510020200	Census Tract 202; Baltimore city; Maryland	140	1340	0	59
1400000US24510020300	Census Tract 203; Baltimore city; Maryland	221	3603	0	43
1400000US24510030100	Census Tract 301; Baltimore city; Maryland	265	1444	0	58
1400000US24510030200	Census Tract 302; Baltimore city; Maryland	374	2332	0	36
1400000US24510040100	Census Tract 401; Baltimore city; Maryland	725	5075	146	153
1400000US24510040200	Census Tract 402; Baltimore city; Maryland	51	1230	0	25
1400000US24510060100	Census Tract 601; Baltimore city; Maryland	232	2703	86	261
1400000US24510060200	Census Tract 602; Baltimore city; Maryland	376	2189	54	105
1400000US24510060300	Census Tract 603; Baltimore city; Maryland	68	1412	0	45
1400000US24510060400	Census Tract 604; Baltimore city; Maryland	294	1600	11	37
1400000US24510070100	Census Tract 701; Baltimore city; Maryland	519	2036	25	226
1400000US24510070200	Census Tract 702; Baltimore city; Maryland	691	2538	0	141
1400000US24510070300	Census Tract 703; Baltimore city; Maryland	201	919	0	112
1400000US24510070400	Census Tract 704; Baltimore city; Maryland	183	1406	0	30

Lab 6 Visual Guide Figure 6.3. Baltimore_unemployment_data csv file. This file is a cleaned version of the downloaded census data.

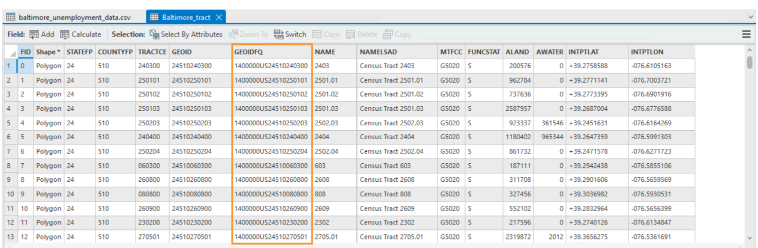
3. Joining data in ArcGIS Pro

Open up ArcGIS Pro and add the census tracts and the CSV file to your project. You will now need to join the CSV file to the census tract shapefile using the **GEO_ID** in the CSV file and **GEOIDFQ** in the census tract shapefile.



	GEO_ID	NAME	S2301_C04_001E	S2301_C04_001M
1	Geography	Geographic Area Name	Estimate!!Unemployme...	Margin of Error!!Unem...
2	1400000US24510010100	Census Tract 101; Balti...	0.8	0.9
3	1400000US24510010200	Census Tract 102; Balti...	0.6	0.8
4	1400000US24510010300	Census Tract 103; Balti...	1.9	1.7
5	1400000US24510010400	Census Tract 104; Balti...	6.4	4.7
6	1400000US24510010500	Census Tract 105; Balti...	3.8	3.4
7	1400000US24510020100	Census Tract 201; Balti...	1.5	1.1
8	1400000US24510020200	Census Tract 202; Balti...	2.2	1.9
9	1400000US24510020300	Census Tract 203; Balti...	1.1	1.8
10	1400000US24510030100	Census Tract 301; Balti...	21	12.1
11	1400000US24510030200	Census Tract 302; Balti...	2.9	2.7
12	1400000US24510040100	Census Tract 401; Balti...	3.3	3.8
13	1400000US24510040200	Census Tract 402; Balti...	2.9	4.4

Lab 6 Visual Guide Figure 6.4. Baltimore employment data csv file.



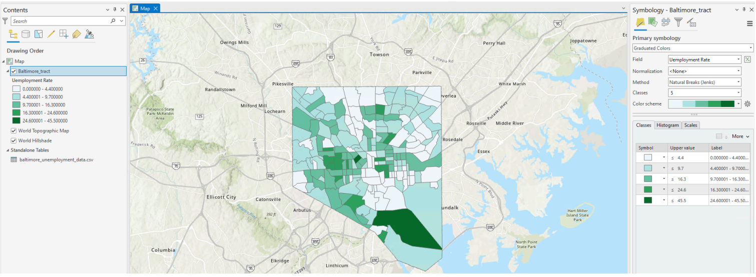
	FID	Shape *	STATEFP	COUNTYFP	TRACTCE	GEOID	GEOIDFQ	NAME	NAMELSAD	MTFCC	FUNCSTAT	ALAND	AWATER	INTPTLAT	INTPTLON
1	0	Polygon	24	510	240300	24510240300	1400000US24510240300	2403	Census Tract 2403	G5020	S	200576	0	+39.2758588	-076.6105163
2	1	Polygon	24	510	250101	24510250101	1400000US24510250101	2501.01	Census Tract 2501.01	G5020	S	962784	0	+39.2771141	-076.7003721
3	2	Polygon	24	510	250102	24510250102	1400000US24510250102	2501.02	Census Tract 2501.02	G5020	S	737636	0	+39.2773395	-076.6901916
4	3	Polygon	24	510	250103	24510250103	1400000US24510250103	2501.03	Census Tract 2501.03	G5020	S	2587957	0	+39.2687004	-076.6776588
5	4	Polygon	24	510	250203	24510250203	1400000US24510250203	2502.03	Census Tract 2502.03	G5020	S	923337	361546	+39.2451631	-076.6164269
6	5	Polygon	24	510	240400	24510240400	1400000US24510240400	2404	Census Tract 2404	G5020	S	1180402	965344	+39.2647359	-076.5991303
7	6	Polygon	24	510	250204	24510250204	1400000US24510250204	2502.04	Census Tract 2502.04	G5020	S	861732	0	+39.2471578	-076.6271723
8	7	Polygon	24	510	060300	24510060300	1400000US24510060300	603	Census Tract 603	G5020	S	187111	0	+39.2942438	-076.5855106
9	8	Polygon	24	510	260800	24510260800	1400000US24510260800	2608	Census Tract 2608	G5020	S	311708	0	+39.2901606	-076.5659569
10	9	Polygon	24	510	080800	24510080800	1400000US24510080800	808	Census Tract 808	G5020	S	327456	0	+39.3036982	-076.5930531
11	10	Polygon	24	510	260900	24510260900	1400000US24510260900	2609	Census Tract 2609	G5020	S	552102	0	+39.2832964	-076.5656399
12	11	Polygon	24	510	230200	24510230200	1400000US24510230200	2302	Census Tract 2302	G5020	S	217596	0	+39.2740126	-076.6134847
13	12	Polygon	24	510	270501	24510270501	1400000US24510270501	2705.01	Census Tract 2705.01	G5020	S	2319872	2012	+39.3656275	-076.5361691

Lab 6 Visual Guide Figure 5.5. Baltimore census tract shapefile attribute table.

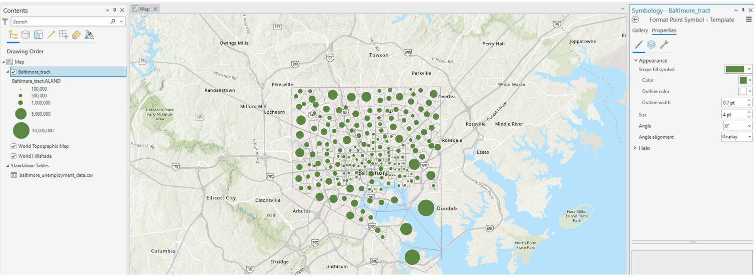
Make sure to follow the same steps for the industry related data with the S2405 table. For this data, call your new csv file city_industry_data. Join this CSV file to your shapefile.

4. Create your Primary Map

With your primary map, you will show the unemployment rate across your city by census tract. Having such information will help with selecting areas in terms of targeting vocational education and job training to certain parts of the city. When mapping this variable, you may choose among several thematic mapping options (choropleth; graduated symbol; proportional symbol, etc). Shown below are some examples of symbolization you might use for your primary map.

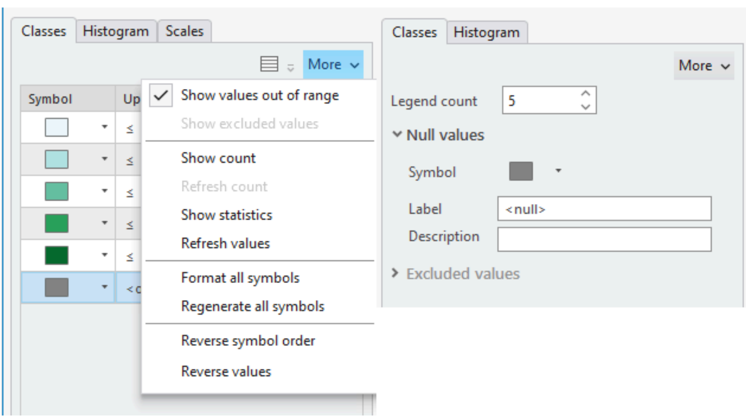


Lab 6 Visual Guide Figure 6.6. Example visualization method – Graduated colors.



Lab 6 Visual Guide Figure 6.7. Example visualization method – proportional symbols.

You might come upon a situation in which some census tracts do not have an unemployment rate. Due to this, an element of your map design will be deciding how to visualize null values. You want it to be clear to the map reader which census tracts do not have an unemployment rate, but you do not want these to be too prominent in your map's visual hierarchy – they should not distract from your map's main purpose. As shown below, symbolizing null or "out of range" values is a slightly different process depending on which symbolization method you choose.



Lab 6 Visual Guide Figure 6.8. Visualizing null figures in ArcGIS Pro. Choropleth maps (left) and graduated symbols (right).

5. Add Visual Depiction of Uncertainty

Your primary map should visualize not only the unemployment rate you have selected, but also its associated uncertainty. For this lab, you will use the margin of error field as a proxy for uncertainty. Assume that a higher margin of error = higher uncertainty. Though the statistics involved are slightly more complicated than this, this focus is on visualization and thus this generous assumption is suitable for our purposes. Additionally, as we are interested in where the data is more or less certain, rather than in the actual standard error values, you should classify uncertainty data into general groupings (e.g., “low,” “medium,” “high”).

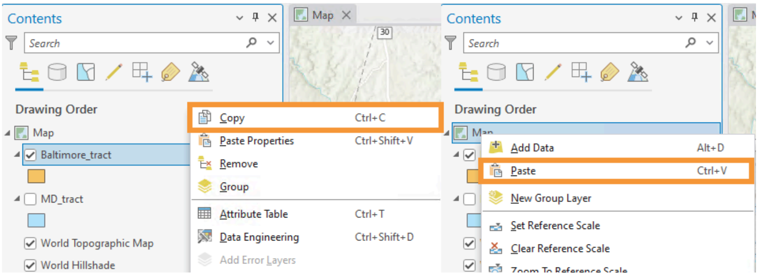
NAME	Uemployment Rate	Margin of Error
Census Tract 2403; Baltimore city; Maryland	2.2	2.6
Census Tract 2501.01; Baltimore city; Maryland	1.1	1.2
Census Tract 2501.02; Baltimore city; Maryland	9.7	8.5
Census Tract 2501.03; Baltimore city; Maryland	7.5	4.3
Census Tract 2502.03; Baltimore city; Maryland	8.2	5.9
Census Tract 2404; Baltimore city; Maryland	0.8	1
Census Tract 2502.04; Baltimore city; Maryland	10.3	7.5
Census Tract 603; Baltimore city; Maryland	4	2.6
Census Tract 2608; Baltimore city; Maryland	2.9	3.2
Census Tract 808; Baltimore city; Maryland	6.7	6.8
Census Tract 2609; Baltimore city; Maryland	3.9	4.9
Census Tract 2302; Baltimore city; Maryland	0.8	1.1
Census Tract 2705.01; Baltimore city; Maryland	0	1.8

Lab 6 Visual Guide Figure 6.9. Unemployment rate uncertainty which will be represented by the margin of error.

You may choose to visualize uncertainty either extrinsically or intrinsically. When selecting a method, consider how you will represent this uncertainty in your map’s legend as well as how your design might be interpreted by your map’s intended audience. This guide presents two popular methods for visualizing uncertainty, though there may be others.

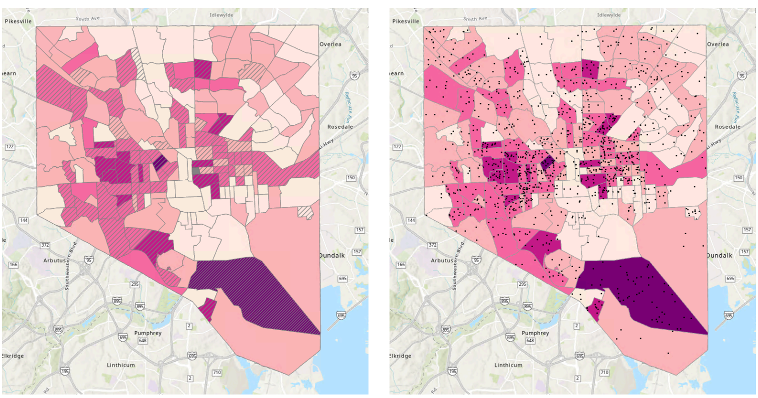
Option #1: Extrinsic uncertainty visualization

The easiest way to create an extrinsic uncertainty visualization is to copy-and-paste your census tract boundary data and symbolize uncertainty with the duplicate layer.

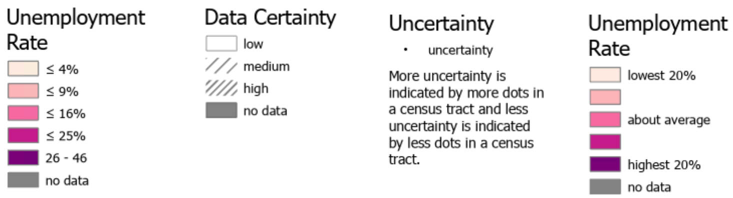


Lab 6 Visual Guide Figure 6.10. Copying and pasting a layer int he ArcGIS Pro contents pane.

Two examples of extrinsic uncertainty are shown in figure 6.9. Recall from the lesson content the visual variables most effective for visualizing uncertainty. Your goal should be to create an intuitive design.



Lab 6 Visual Guide Figure 6.11. Examples of extrinsic uncertainty visualization. Overlay data is used to obscure less-certain values.



Lab 6 Visual Guide Figure 6.12. Example multivariate map legend designs.

Option #2: Intrinsic uncertainty visualization.

The other primary option for visualizing uncertainty in your map is intrinsically, via the "vary symbology by attribute" option in ArcGIS Pro. Think carefully about how you apply elements like transparency – the progression of your data should match the visual progression of your design. To accurately depict your data and its uncertainty, you may have to manually edit or reverse a color scheme or transparency range. You can open up the color scheme editor by clicking on the color bar next to the **Color Scheme** option and then clicking on **Format color scheme**.

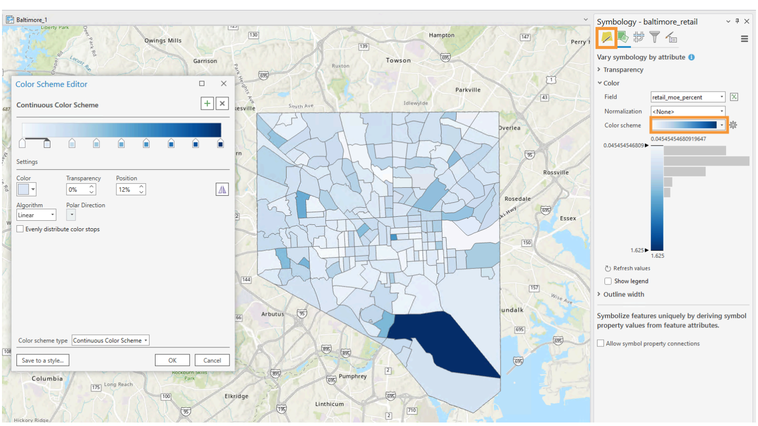


Figure 6.13.Varying symbology by attribute in ArcGIS Pro.

6. Create Small Multiple Maps and Report

Once you finished your primary map, you will create three smaller maps showing the percentage of population on variables of interest for the economic development agency which are:

- Transportation and warehousing, and utilities
- Retail trade
- Manufacturing

All three of these maps should be in one map frame. You should also make sure that there is one map per variable. There will be a total of four maps for this section. Revisit the **Comparing vs. Combining** section for an example of a small multiples map within one map frame. You do not need to visualize uncertainty in these smaller maps. For this lab's final deliverable, you will need to submit a report in which you analyze the trends you see in your maps. Feel free to add additional information outside of the Census data you are working with. Be creative as you want with this report! The more information you include, the more the economic development organization will be better informed in their decision-making Your report should be able to answer these questions:

1. What is average unemployment rate in your city and where is the highest and lowest unemployment rates within your city? Along with indicating where the highest and lowest unemployment rates are (i.e. in the north part of the city) you should include names of some neighborhoods in this report (tip: adjust the

transparency to see the neighborhoods)

2. What is the average rate employment in the trades of interest of the economic development agency?
3. Which trade has the highest and lowest employment rates?
4. Given the economic development agency is working with three stakeholders recommend the best areas in the city to pursue these initiatives and provide a rationale behind your recommendation:
    1. A major logistics company wanting to open a distribution center.
    2. A mid-size retailer who is interested in opening a new store site.
    3. A consumer goods start-up who wants to open a manufacturing plant.
5. What role should the knowledge of data uncertainty play in your recommendations?

7. Additional Tips

Remember design ideas from previous labs – you may want to add elements such as a grid, explanatory text, and data credits to your layouts. It's up to you how you balance your final document with such elements – for example, instead of listing a data source on your map images, you can simply include this source in the text you write. Focus on creating a useful and cohesive document, as well as smartly-designed legends.

Summary

This chapter we covered:

- Various types of multivariate maps such as multivariate choropleth, multivariate dot/ proportional symbol maps, cartograms, and multivariate glyphs.
- Multivariate color schemes.
- Visualizing uncertainty.

Creating multivariate maps might be more complex, but it is a powerful tool in giving a more nuanced analysis of a particular trend. If you are looking form ore opportunity to learn how to create multivariate maps beyond the assigned lab, please check out the ESRI Multivariate Maps tutorial.

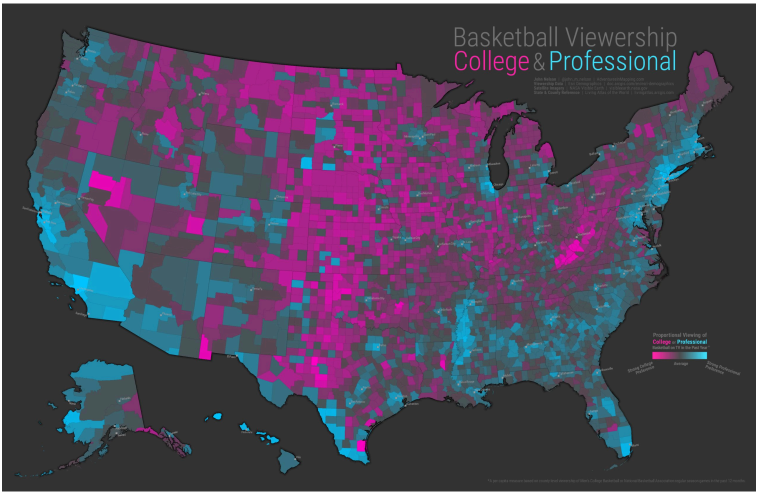


Figure 5.11.1. Multivariate map of Basketball Viewership for College & Basketball.

Image source: [ESRI]

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Conclusion

Congratulations on finishing the book! You should feel more confident in your map design skills along with giving feedback on other's maps on the use of various cartographic elements such as the use of text, color, and symbolization. Hopefully you have learned a little bit more about a city that you have been interested in as well! Even if we feel like we might know something about a city due to us being from that city or living in that city for a long time, maps might uncover relationships that you might have never thought about!

Where to go next?

If you are eager to learn more about cartography, then I recommend that you check out Penn State's GEOG 486 course which this book was adapted from. The GEOG 486 course covers things that were not covered in this book such as flow mapping and projections, terrain visualization, and multiscale mapping. Other books that I recommend is Designing Better Maps: A Guide for GIS Users by Cynthia Brewer which goes more in-depth on the topics we learned in Digital Cartography. If you are interested in making maps for community purposes, then I would recommend Making Maps: A Visual Guide to

Map Design for GIS. This book combines storytelling and teaching cartographic principles all in one text!

If you enrolled in the Digital Cartography course, then we will be transitioning to learning how to maps using the ArcGIS Maps for Adobe Creative Cloud extension in Adobe Illustrator and will be using the Mapping by Design, A Guide to ArcGIS Maps for Adobe Creative Cloud by Sarah Bell. If you are not enrolled in the course, I highly recommend this book if you are interested in learning how to create maps using Adobe Illustrator.

Remember that your education in digital cartography should not stop at the end of this book. You must engage in lifelong learning if you want to improve your map making skills and find ways in which you can use your cartography skills! Things that you can do beyond reading is attending local conferences or GIS user groups focused on cartography. Also consider having a passion project (i.e. The Middle Earth Map) or be a volunteer and make some maps for a community organization to really apply and expand upon the skills that you learned in this book! Happy mapping!

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Book Updates

Overall Updates

Accessibility Updates

- 8/27/2024: Finished adding alt-text and image descriptions to II. Basemaps and Big Picture Design: Types of Maps, Communicating with Maps, Before you Map: Audience, Medium and Purpose, Basemaps: Leveraging Location, Base Data: Building a Map, Symbol Design: Visual Order and Categories, and Designing for Multiple Scales
- 08/27/2024: Finished adding alt-text and image descriptions to I. Introduction and II. Basemaps and Big Picture Design: Overview and Design Matters.

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This is where you can add appendices or other back matter.