Mapping, Society, and Technology

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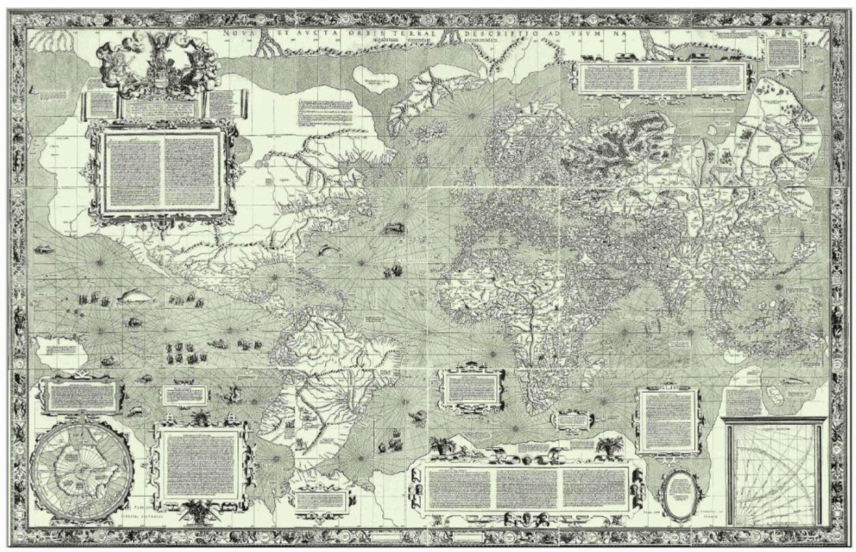


Mercator projection. One of the first maps of the world developed was by Mercator (Carta do Mundo de Mercator, 1569).

1. Maps, Society, and Technology

Steven Manson and Laura Matson

People have long used maps, from scratching their worldviews on clay tablets thousands of years ago to people today creating sophisticated web-based maps to change their societies. Alongside nanotechnology and biotechnology, the White House touts mapping as one of the three most important industries of the 21st century, and one that accounts annually for a trillion dollars of economic activity. Mapping is an essential form of inquiry across the arts, humanities, and sciences that uses geospatial technologies to gather data on people and places. Mapping technologies—ranging from the earliest forms of drawing on clay tablets to modern satellite imaging and sharing information on web-based social networks—spring from and play out in a social context, exemplifying the interplay of society and technology.

This book is about how to read, use, and create maps. Our exploration of maps will be informed by a contextual understanding of how maps reflect the relationship between society and technology, and how mapping is an essential form of scientific and artistic inquiry. We will also explore how mapping is used to address a variety of societal issues, such as land-use planning and political gerrymandering to selling yogurt. You will gain insight into the technical underpinnings of mapping as a scientific approach, complement on-going interest, and activities, or provide an applied focus for research or policy.

This chapter will introduce you to:

- Basic social and technical elements of maps
- A very short history of mapping
- Mapping and liberal education

By the end of this chapter, you should be able to identify the basic characteristics of mapping, its history, and important ways that mapping, society, and technology interact.

1.1 Maps, Society, & Technology

The standard or dictionary definition of a map usually revolves around the idea that a map is a representation, usually on a flat surface, of an area. The Wiktionary, for example, defines a map as “a visual representation of an area, whether real or imaginary.”

This definition is not very useful on its own, so in order to figure out what maps are about, we usually instead look at what maps do.

In particular, maps:

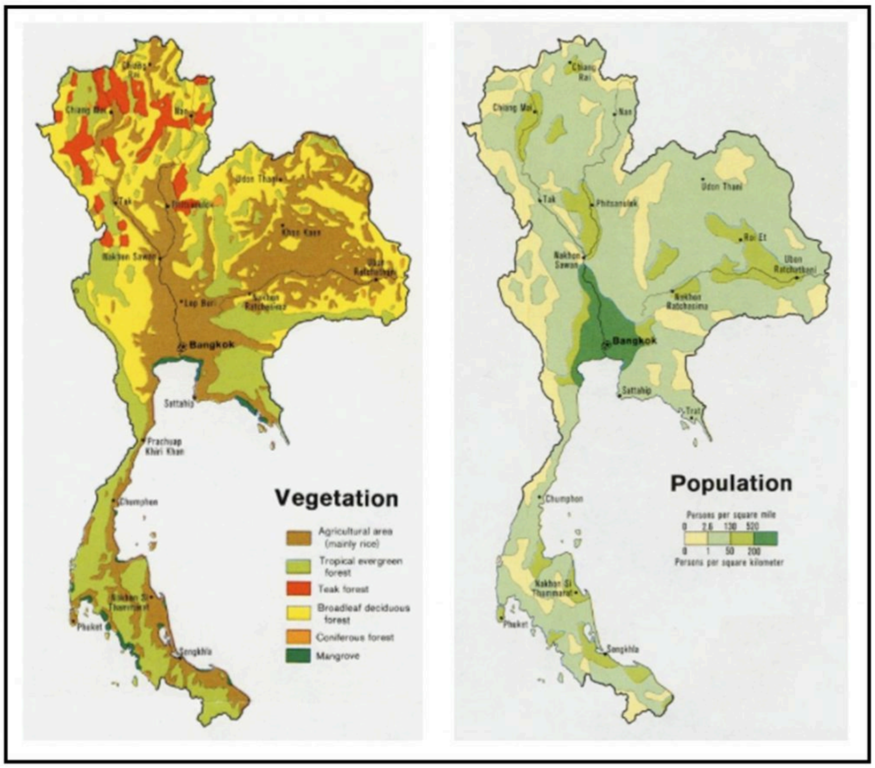
- Show an area larger than we can see. Most often this view is from above but not always.
- Present information concisely, especially the features of most interest to the user.
- Demonstrate spatial relationships.
- Show things we cannot see directly, such as minerals below ground or records of daily temperatures.

It is also helpful to look at kinds of maps in addition to what they do. We can distinguish between two major kinds of maps: reference maps and thematic maps.

Reference maps store data and show a variety of features for a variety of uses. These maps function like general storehouses of information. The figure below is a reference map of China because it stores a variety of information, including transportation routes, rivers, and names of water bodies.

Reference map of China. This map is considered a reference map because it shows many different features of interest, such as rivers, roads and boundaries. [1]

Thematic maps highlight specific themes. Their chief goal is to focus the user's attention on specific features or characteristics. The figure below has two thematic maps that each draw the user's attention to a single idea or theme. The other information, such as the outlines of states, is only provided to help understand the main theme—vegetation and population, respectively.



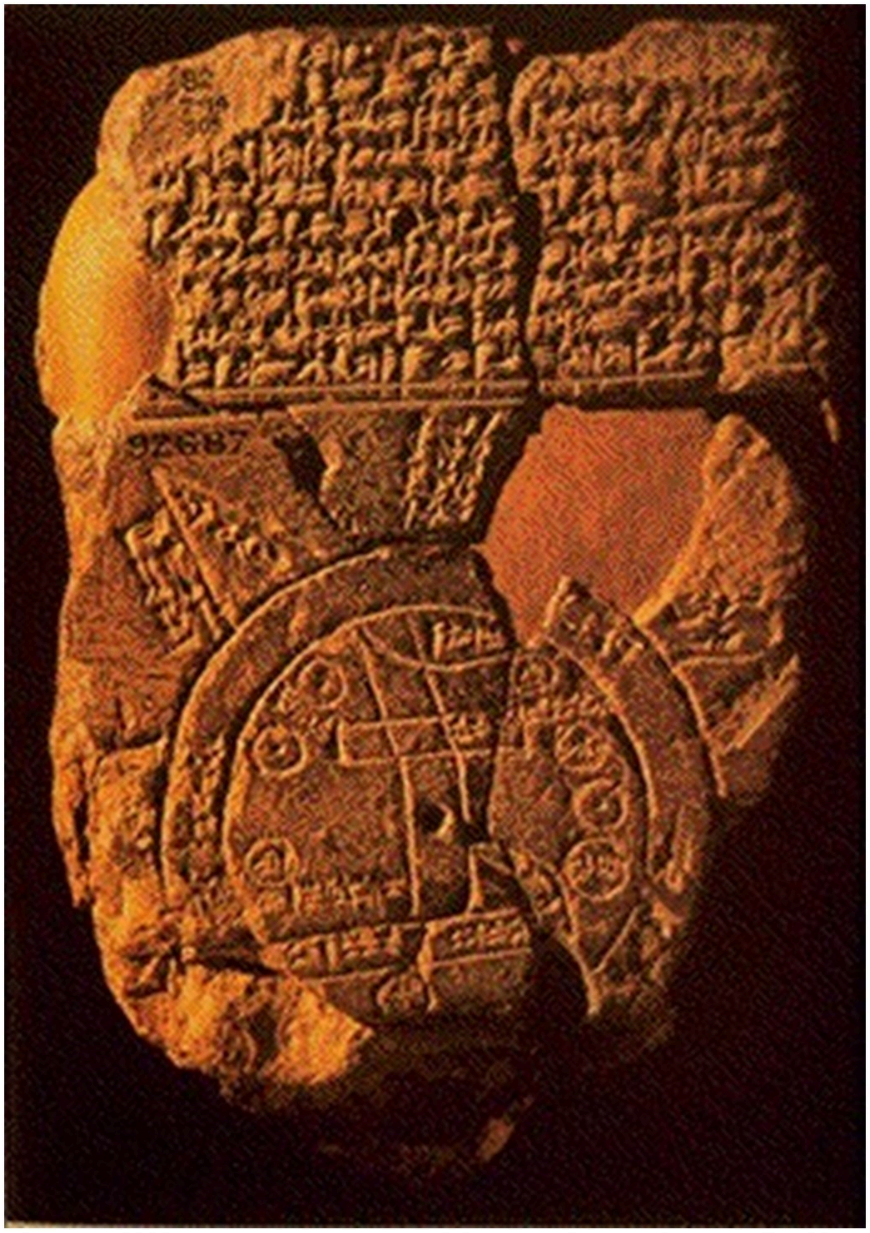
Thematic maps of Thailand. These maps are considered thematic because they focus on a single item or theme. On the left is a categorical thematic map showing nominal classes of vegetation in 1974, and on the right is a quantitative thematic map showing ordinal classes of population density in 1974. [2]

Regardless of whether a map is thematic or reference, it is essentially a technology in that it is the manifestation of knowledge gained from many fields and forms of knowledge. These include cartography, land surveying, remote sensing, computer science, information science, and social science. A map is also a social entity, in that society affects everything from the underlying data used in the map through how it is processed into information, converted into knowledge about the world, and ultimately turned into intelligence that is used for action.

1.2 A Very Short History

The history of mapping is long, rich, and complicated. There are hundreds, if not thousands, of books on the history of mapping and maps. Here, we look at a very general outline; note that we are only looking at a few representations, and are focusing primarily on European and North American maps. There are long histories of mapmaking in most regions of the globe. In thinking about maps, it helps to distinguish between *literal maps*, which were meant to show actual things and places, and *figurative maps*, which show conceptual or imagined places.

Early Maps (25000 BCE+). People have probably been scratching maps into the dirt with sticks for longer than they have been using words. The figure below shows a few maps made in around 600 BCE (Before Common Era) that traces relationships between cities and mythical places and ideas.



Babylonian Map of the World. This map traces relationships between cities and mythical places and ideas (~600 BCE). [3]

Greeks (800-100 BCE). The Greeks were producing fairly high-quality and accurate (so, literal) maps of the region around the Mediterranean Sea and were among the first peoples to discover earth's circumference. Eratosthenes (276-195 BCE) is widely credited for this achievement.

World According to Hecataeus. Reconstruction of the literal map that the Greeks produced of the Mediterranean Region.[4]

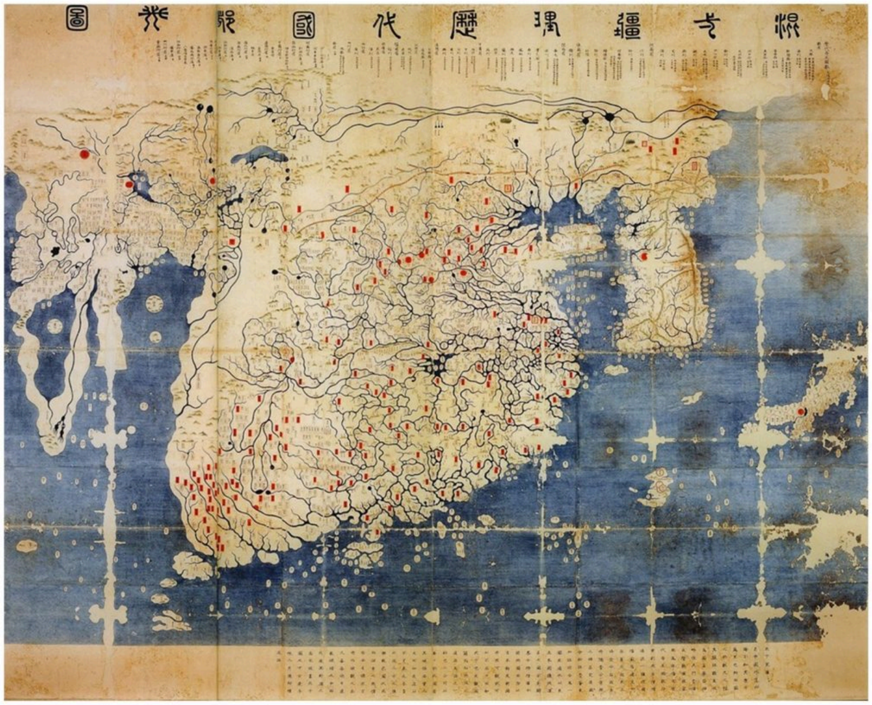
Medieval Maps (1100-1400s). In Europe during the Dark Ages, maps took a turn towards the figurative, often in aid of advancing religious viewpoints of the world. An example is the *T and O Map* below, where the T is the Mediterranean, the Nile, and the Don Rivers dividing the continents of Asia, Europe, and Africa; and the O represents the encircling ocean. Given its religious significance, Jerusalem was generally placed in the center of the map and because the sun rose in the east, Paradise (representing the Garden of Eden) was considered as being in remote Asia. This map captures aspects of reality, such as the relative locations of water bodies and continents, but is a step back from past maps in terms of realism.

T and O map. This map by Isidore of Seville where the T is the Mediterranean, the Nile, and the Don Rivers dividing the continents of Asia, Europe and Africa; and the O represents the encircling ocean. [5]

At this time, non-European cartographers were developing literal maps. Abu Abdullah Muhammad al-Idrisi al-Qurtubi al-Hasani as-Sabti, or simply Al-Idrisi (1100–1165), was an Arab geographer, cartographer, and Egyptologist who lived in Sicily at the court of King Roger II. He traveled the Mediterranean world and developed advanced maps of the world, like the one here.

Al-Idrisi's map of the world. Al-Idrisi was a geographer, cartographer and Egyptologist who lived in Sicily at the court of King Roger II. He traveled the Mediterranean world and developed advanced maps. [6]

Age of Exploration (late 1400s+). European countries embarked on a period of exploration in the 1400s that reshaped the world. Many nations from around the globe had intrepid explorers before this time, but this period saw a rapid increase in maps being made for the explicit purpose of navigation. Chinese cartographers were developing maps for navigation but also as a way to understand history, as below, where Ch'üan Chin and Li Hui developed the Map of Historical Emperors and Kings and of Integrated Borders and Terrain.

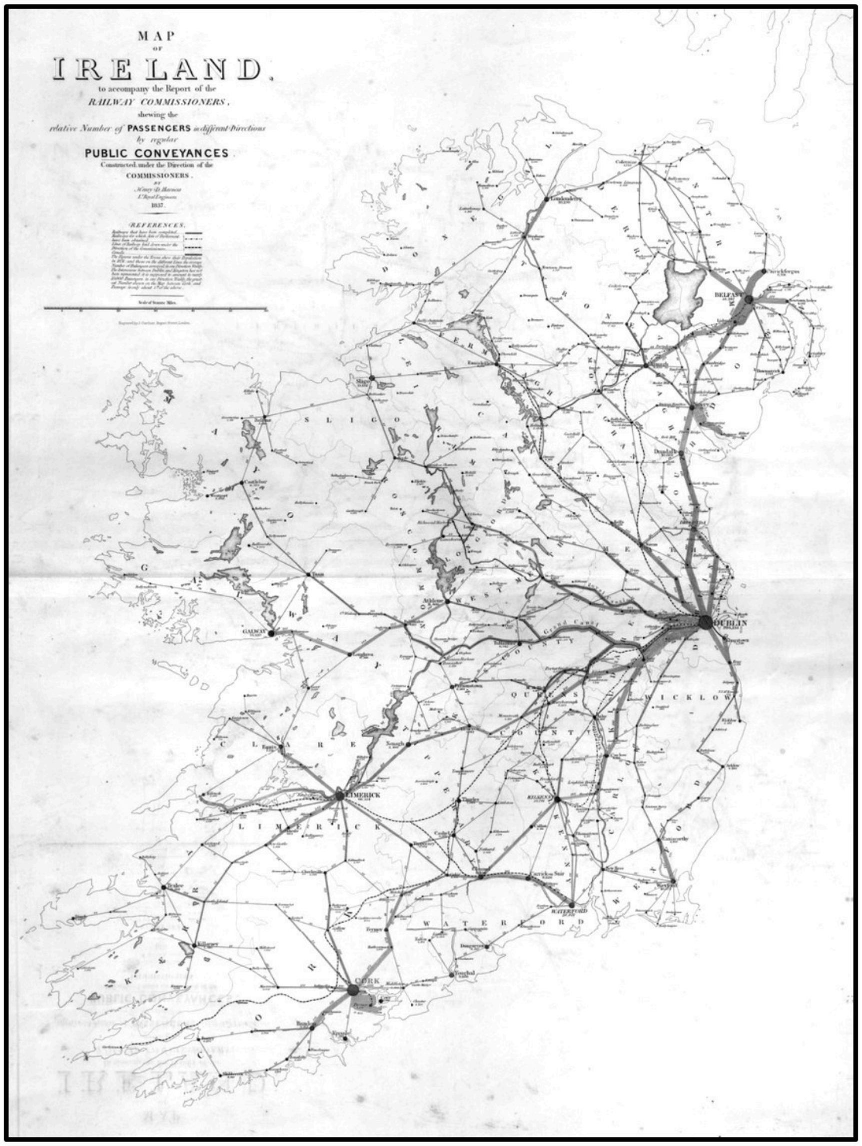


Historical map. Chinese cartographers developed this map in 1402 of historical empires, borders, and terrain. [7]

The Cantino Map, shown below, is one of the earliest surviving maps showing Portuguese discoveries around the world. It is named after Alberto Cantino, who successfully smuggled it from Portugal to Italy in 1502. The Cantino Map, like others of its kind at the time, held military, political, and economic significance. Given that such maps were being used to sail ships and lay claim to places, mapping became more concerned with providing literal and accurate representations of reality.

Cantino Planisphere. Portuguese discoveries as of the year 1502. [8]

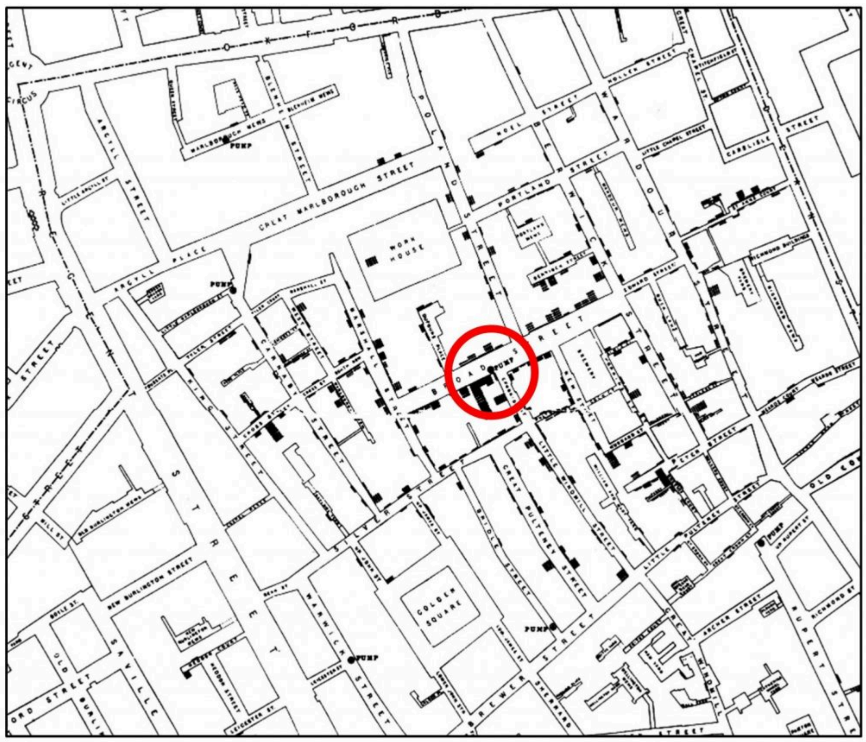
Thematic Mapping (late 1600s+). From the 17th century onward, more people made thematic maps. As discussed above, thematic maps focus on a particular idea or theme, as opposed to serving multiple goals as a reference map. The map below shows travel flows out of Dublin and was one of the first maps designed to convey a sense of flow or movement, namely, where the width of lines was proportional to the number of passengers traveling by rail.



Rail flows out of Dublin. One of the first maps that conveys a sense of flow or movement (1837). The width of the lines are proportional to the number of passengers traveling by rail. [9]

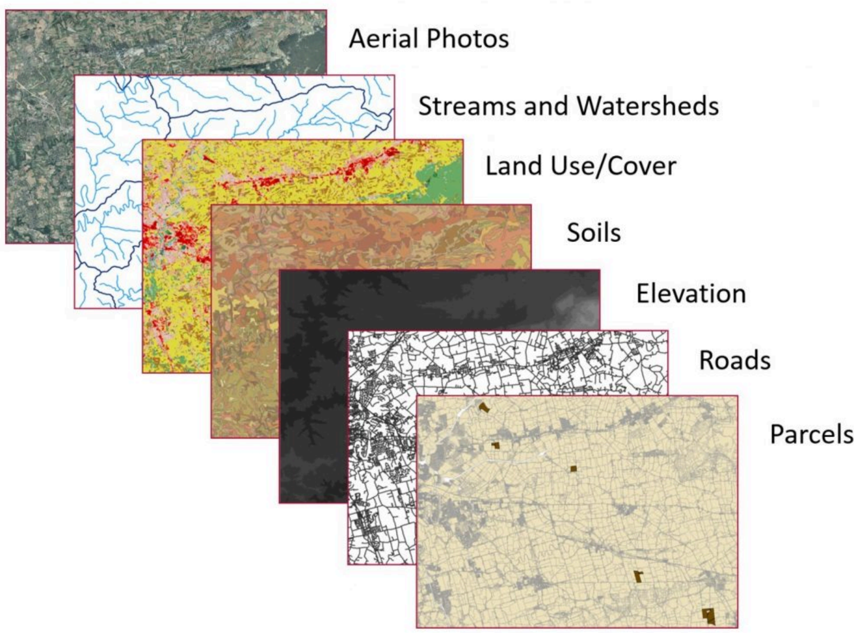
Analytical Mapping (1800s+). Related to thematic mapping is analytical mapping, where maps are used to explore the role of location and space to answer questions. One of the most interesting early examples of analytical mapping was the case of John Snow, an English physician. He investigated the outbreak of cholera in London in 1854. At the time, no one knew it was a water-borne disease.

Dr. Snow spoke with residents and determined that many of the afflicted were drawing water from a public well in Broad Street. He established that people with the disease were clustered around the pump and convinced the authorities to discontinue its use. Dr. Snow is credited as being among the first scholars to consider how a spatial pattern could result from a specific process and to produce maps about his findings.



Snow's map of cholera. John Snow developed this 1855 map to investigate a cholera outbreak. The Broad Street Pump is circled in red. [10]

Geographic Information Science (1960s+). The advent of computing in the 1940s and 1950s led quickly to the foundation for the use of computers in mapping. A Geographic Information System (GIS) is a computer system used to store, display, and analyze spatial information. The field concerned with this use of computers became known as Geographic Information Science (GIS) and has become synonymous with mapping for many practitioners, although technically Cartography is considered the art and science of making maps. As we examine later in the text, GIS can be used to make some truly terrible maps while a cartographer can make beautiful and useful maps using a variety of approaches. GIS excels at bringing together many layers of data for a location and conducting a sophisticated analysis.



GIS layers. These maps show attributes for part of the state of Wisconsin, United States. Geographic information systems are very helpful in that they allow investigators to store, manipulate, and analyze data on a large variety of phenomena. [11]

1.3 Maps & Liberal Education

Liberal education explores how creative insights and knowledge are acquired and used, as well as how they change over time. Mapping is an important way of knowing and changing the world. Liberal education engages you, as both a student and a global citizen, through multiple forms of learning that include reading, fieldwork, group experiences, lab work, writing, and other creative activities. These are important components of a broader education that gives you the ability to see multiple sides of an issue, develop critical reasoning abilities, and create an ethical compass to guide you in your lifelong participation in society as a knowledgeable, thoughtful, and engaged citizen.

1.3.1 Inquiry and Mapping

Artists, scientists, and policy makers are among the many people who use mapping technologies to describe and analyze human experiences and behavior. We examine how individuals and organizations use maps, both as tools and objects of analysis.

Mapping relies on a number of fundamentals, from data collection to science approaches, ranging from mapping data, using symbolization to best represent data, simplifying and classifying data via visual and statistical methods, and then finally analyzing data and maps with a range of methods.

We identify key mapping resources and evaluate their quality. We examine the science and policy dimensions of data and mapping technologies in order to better understand their promise and pitfalls. More broadly, we discuss the role of various individuals and organizations in providing map-based analyses on a range of issues.

We examine the roles that individuals play in their cultural, social, economic, and political worlds. We ask questions about what surveillance practices mean for individuals and society one week, for example, while in another we consider how individuals can take advantage of the ubiquity of mobile mapping technologies to change the way they understand and effect change in the world. Mapping offers a multidisciplinary framework with which to understand a range of local, national, and global issues. It also involves engaging in a process of critical evaluation of maps produced by various individuals, social groups, and researchers.

1.3.2 Society, Technology, and Mapping

We examine the measurable impacts mapping technologies have on society. Mapping is a trillion-dollar enterprise that fuses fast-evolving technologies with rapidly changing societal practices. What does it mean for individuals and society that most mobile phones and many web-applications like Facebook can track your location in a way that was not possible just a few years ago? Should the government track our every movement? Should parents or schools track their children? Companies their employees or customers? These are not hypothetical questions. Tens of millions of people are being tracked right now, including you if you are reading this on a computer or phone or any other internet-connected device.

We examine the science and engineering behind mapping technologies to better understand their promise and pitfalls. How does GPS tracking work, and what are the limitations of its functionality? Importantly, are these limitations clear to its users? How do crowd-sourced maps compare to more traditional atlases in their accuracy and adaptability? How do these different methods of gathering mapped data affect the way these maps are used?

We discuss how society has fostered the development of mapping technologies. What does it mean that mapping technologies such as satellite imaging of the earth, GPS units, or the spatially-aware internet owe their existence and continued evolution to military research?

We examine how various social groups put mapping technologies to use. We explore how maps are used in many ways, including to tell lies, sell products, win elections, and save lives. We look at mapping from multiple perspectives, from developers of technology to users and other people affected by the technology. Mapping is a useful lens through which to understand interactions between society and technology, as mapping technologies are driven by social imperatives, and these technologies in turn change with society.

1.4 Conclusion

Mapping is an essential form of inquiry across a wide range of domains. Mapping also represents the interplay of society and technology, which has been going on for thousands of years. From the earliest forms of writing to modern satellite imaging and web-based social networks, mapping methods spring from, play out in, and shape our social context.

With the advent of GIS, people experience how spatial data, analysis, visualization, and thinking are transforming our society in myriad ways. Billions of people use technologies such as Global Positioning Systems (GPS), Google Maps, Yelp, and Uber. Governments use mapping to identify crime hot-spots, plan social interventions, and identify routes to evacuate vulnerable populations from harm. Companies use spatial analysis to site stores, evaluate supply chains, and determine how much to charge for goods and services. Researchers combine spatial data gleaned from maps, satellites, smart phones, sensor networks, and social media. They help commuters plan how to minimize travel time; farmers to best plant and protect crops; epidemiologists to identify emerging disease hot-spots; emergency planners to develop smarter evacuation routes; policy makers to visualize spatiotemporal climate-change scenarios; and first responders to use high-resolution imagery to map areas of need.

Resources

For more information about mapping and GISc:

- Intergovernmental Committee on Surveying and Mapping (ICSM)
- ESRI
- OGC (Open Geospatial Consortium)

Notes

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10. Public Domain. John Snow; Published by C.F. Cheffins, Lith, Southampton Buildings, London, England, 1854 in Snow, John. On the Mode of Communication of Cholera, 2nd Ed, John Churchill, New Burlington Street, London, England, 1855. https://commons.wikimedia.org/w/index.php?curid=2278605
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2. Data

Melinda Kernik and Dudley Bonsal

When admiring a well-designed map, it is easy to forget that it is made from data that came from somewhere. An individual or group of people has asked one or more questions, gathered data in response, and processed the raw numbers before putting it all on the map. These data are necessarily just a small portion of what can be measured because it is impossible to measure all characteristics for all places for all times. Instead, we focus on how and why data were collected for what, where, and when.

This chapter will introduce you to:

- Elements and common types of spatial data.
- Metadata, or data about data.
- How data in the US census – a survey that underlies many of the examples and activities in this book – are collected and aggregated.

Resolution, accuracy, and interoperability – important concepts that are part of metadata and are important to keep in mind when choosing appropriate data for a project.

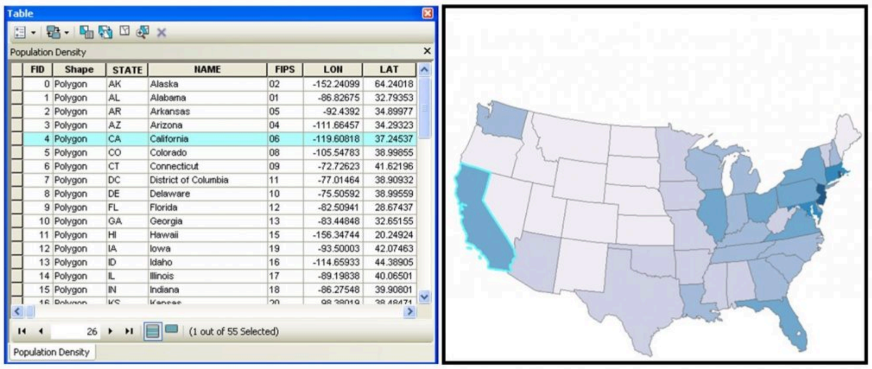
By the end of this chapter, you should be able to ask thoughtful questions about the data used in mapping.

2.1 What are Spatial Data?

Map data have three key characteristics:

- Spatial – **where** an object is located or an event has occurred
- Temporal – **when** the location and attributes were accurate (i.e. when collected)
- Attribute – **what** characteristics the object or event has

Imagine we have data about US states. **Spatial** characteristics of data, namely location of state boundaries, are necessary to put the data on a map or use. More broadly, spatial information can take the form of a street address, latitude-longitude coordinates, or the area in which data was collected (e.g., residential block, city, state, country). **Temporal** characteristics refer to how data represent a "snapshot" of what things were like at the time the data were collected, such as census data from the year 2000. Finally, **attribute** characteristics describe the nature of a location. In the case of the states, we could be concerned with population or income or any of hundreds of other characteristics.



FID	Shape	STATE	NAME	FIPS	LON	LAT
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1	Polygon	AL	Alabama	01	-86.82675	32.79353
2	Polygon	AR	Arkansas	05	-92.4392	34.89977
3	Polygon	AZ	Arizona	04	-111.66457	34.29323
4	Polygon	CA	California	06	-119.60818	37.24537
5	Polygon	CO	Colorado	08	-105.54783	38.99855
6	Polygon	CT	Connecticut	09	-72.72623	41.62196
7	Polygon	DC	District of Columbia	11	-77.01464	38.90932
8	Polygon	DE	Delaware	10	-75.50592	38.99559
9	Polygon	FL	Florida	12	-82.50941	28.67437
10	Polygon	GA	Georgia	13	-83.44848	32.65155
11	Polygon	HI	Hawaii	15	-156.34744	20.24924
12	Polygon	IA	Iowa	19	-93.50003	42.07463
13	Polygon	ID	Idaho	16	-114.65933	44.38905
14	Polygon	IL	Illinois	17	-89.19838	40.06501
15	Polygon	IN	Indiana	18	-86.27548	39.90801

Data table and map. This attribute table and linked map show state boundaries with data from the U.S. Census Bureau on population density. The table and map represent two key elements of spatial data: location and attributes. A third important piece, not shown, is the time at which these data were collected. [1]

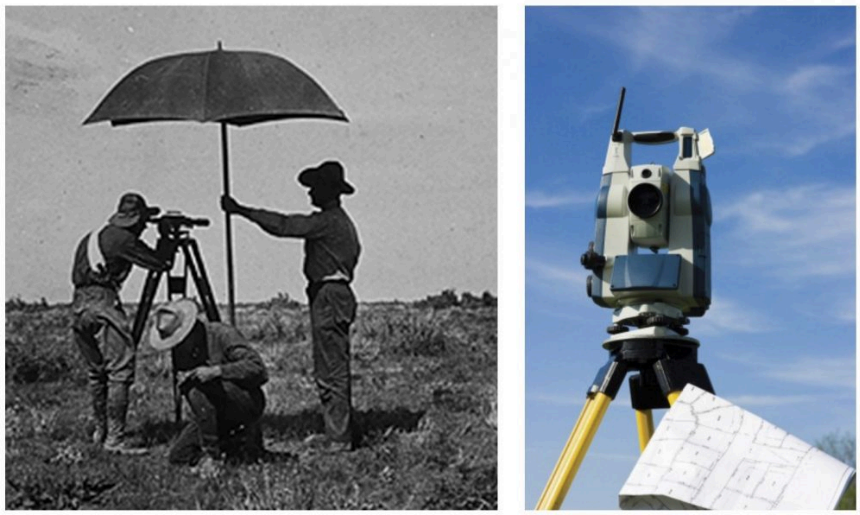
2.2 Collecting Spatial Data

Two main methods of spatial data collection, or gathering information about places, are ground surveying and remote sensing. *Ground surveying* involves a person or mechanism that observes or interacts with people or the environment in a particular place. *Remote sensing* refers to collecting data from afar, often by taking pictures from a plane or satellite.

2.2.1 Ground Surveying

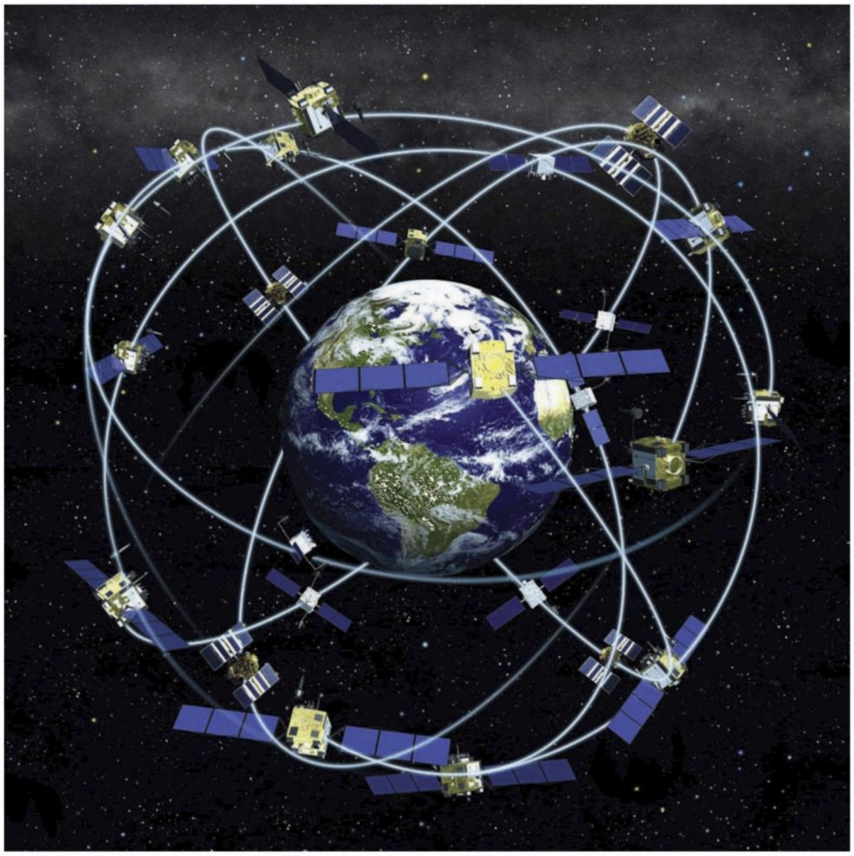
Ground surveying is conducted through an individual or mechanism interacting with a particular place. This can include a person collecting locational data with a handset that works with a global positioning system (GPS), a constellation of satellites that beam signals to earth where they can be used to determine position. Surveys involve talking to people or traveling to different locations to gather information. Another kind of ground surveying occurs at weather stations that measure temperature and other climatological information at a given location. This is similar to a process called geocoding, where data with a locational element such as an address or zip code, are matched to their respective ground coordinates that are known already.

Land surveying is one of the longest-standing methods of determining location. In essence, land surveyors use a variety of tools to determine the precise positions of locations by triangulating from the position of known locations, or in other words, using the mathematics of angles and distances to find locations. Surveying has existed for thousands of years, probably originating as a way to determine the boundaries of land and help construct large buildings. From the 1800s onward, land surveyors helped map out many countries, working outward from known to unknown locations.



Land surveying. The foundation for modern mapping was laid by people walking and measuring the land with specialized telescopes (left) and modern GPS enabled total stations (right). [23]

Global positioning systems (GPS) are constellations of satellites that orbit the earth. These satellites transmit signals to the earth's surface that indicate their position in space and a very precise time signal. A device equipped with an appropriate GPS receiver can interpret these signals and determine the device's location on the earth. We consider using a GPS unit to find location a form of ground surveying because the satellites themselves do not collect information; it is the handset or GPS unit that is determining position from the satellite signals.



GPS constellation. The Global Positioning System is a system, or constellation, of satellites orbiting the earth that allow handsets to establish location. [4]

For decades, locating objects accurately with GPS units required expensive equipment and specialized training. It was undertaken primarily by the military, scientists, and government organizations. With technological developments making computer chips smaller and faster, GPS receivers are now standard in mobile phones. It is possible for any person to record, or tag, the location where a picture was taken or track daily movements without special expertise. This ease of use substantially expands who is able to create spatial data and the amount of spatial data that exists and must be stored.

GPS have their drawbacks. Since handsets must receive signals from satellites orbiting the earth, these signals can be blocked by solid objects, such as trees, buildings, or landscape features such as the sides of tunnels or ravines. Getting a strong signal in a moderately forested area can be difficult, as can getting one in a city with tall buildings. There are a limited number of satellites orbiting the earth, and there are times when the handset is in a non-optimal position relative to these satellites. A GPS handset should receive signals from at least four satellites, and ideally more, that are spread out evenly in the sky, but there are times when these sources are bunched up relative to the handset position and the coordinates it provides will be inaccurate. Finally, depending on the quality of the handset, GPS coordinates can also be inaccurate when the handset is moving quickly, such as in a car or airplane. Note that, generally speaking, heavy weather such as snow, rain, or clouds do not interfere with GPS signals.

GPS handset. Handsets have specialized radios and computers that receive signals from GPS satellites and then determine location. [5]

Geocoding is the process of attaching a geographic location to some sort of address information, such as a house address or zip code, or a verbal description such as “the intersection of Elm Avenue and Main Street.” Geocoding takes a number of different forms, but most use some form of database of addresses whose locations are precisely known. Unlocated addresses are matched to these known addresses in the database.

Geocoding involves matching street addresses to known addresses or best guesses based on ranges of street addresses along streets already on a map. [6]

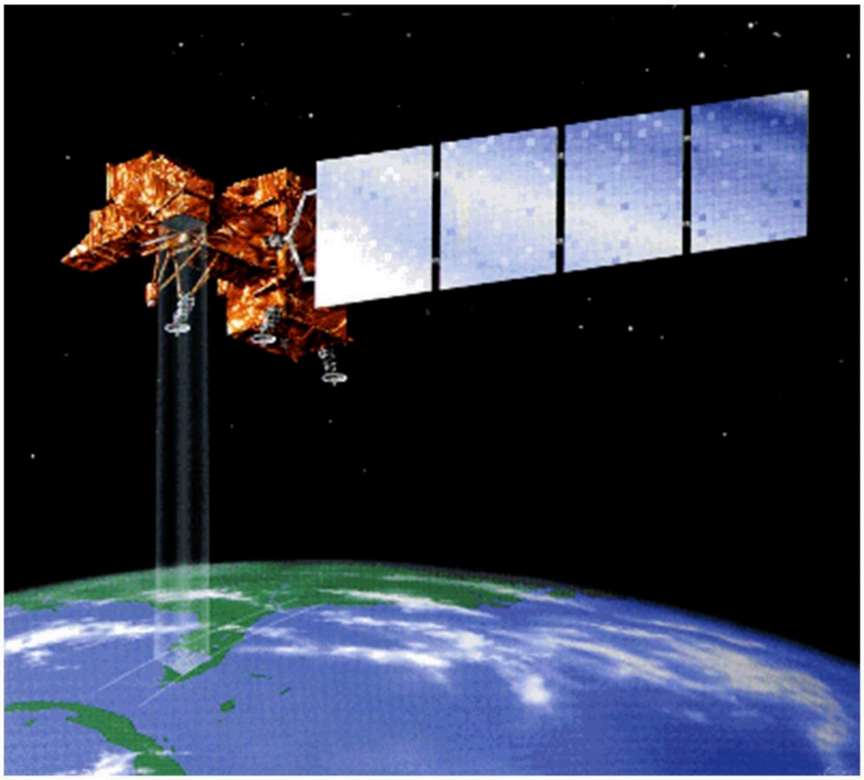
Surveys gather attribute information about individuals, households, businesses, or areas. Not all surveys collect spatial information, but when they do, the data can be linked to a location on a map. Surveys can be mailed to households, gathered in person, or conducted over the phone. They usually focus on a specific subpopulation or activity (e.g., students’ perceptions of safety walking home). A census is a special type of survey that collects data on all members of a population (e.g., with the goal of all inhabitants of a country). Note that survey information is usually attributed information, and determining the location requires geocoding (as with a mail survey that records the address of the person surveyed) or use of a GPS handset by the person taking a survey. Another kind of survey occurs when companies like Google equip cars with GPS receivers and cameras and drive around recording pictures of their surroundings.

Sensors. There is a growing number of sensors used to measure a wide array of human and environmental facts. We have long had climate stations, for example, which measure many variables including temperature, sunlight, and precipitation. The locations of these sensors are determined by GPS, ground surveying, or geocoding.

Climate observation station. Ground-based stations such as these collect information on weather. [7]

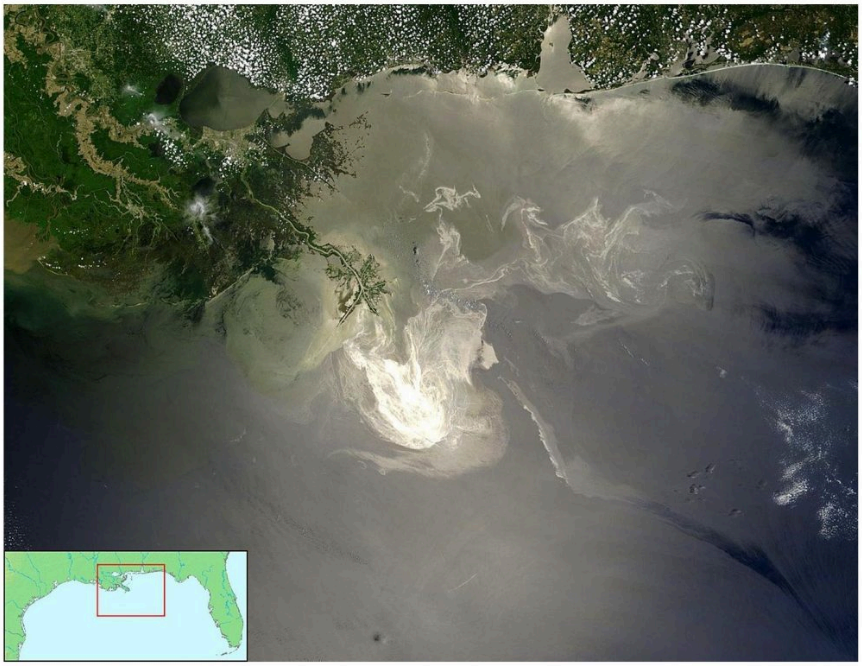
2.2.2 Remote sensing

As the name suggests, remotely-sensed data are collected at a distance from the object they are studying. These data are usually collected by sensors mounted on airplanes, satellites, or drones. Some sensors collect imagery with cameras that work on essentially the same principles as you would find in a handheld film camera or digital cell phone camera. These cameras collect visible light that human eyes can recognize. Other sensors detect different nonvisible parts of the electromagnetic spectrum, such as infrared (heat). Still others can actively scan the earth with technology like radar.



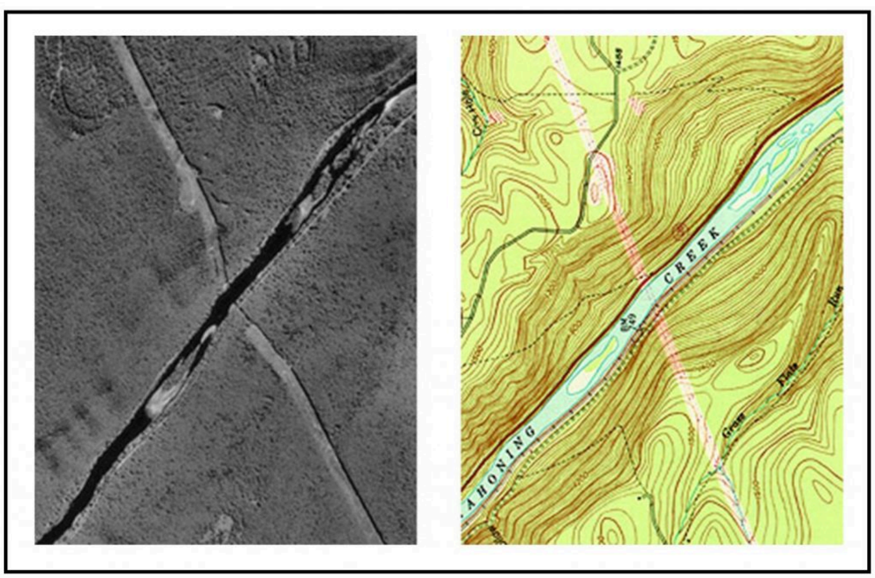
Satellite imaging. Painting of the Landsat 7 remote sensing satellite. Note that the satellite does not really cast a four-sided beam of light upon the Earth's surface, this is just artistic licence. Instead, the satellite's sensors record electromagnetic energy reflected or emitted by the Earth. [8]

You have likely seen remotely sensed data as a basemap for Google maps or other online maps. This imagery is also used for a wide array of purposes, especially monitoring changes in the environment over large areas such as deforestation in the Amazon or oil spills.



Satellite image of an oil slick. A picture from space of an oil slick from the Deepwater Horizon accident in the Gulf of Mexico (May 24, 2010). [9]

Photos are also taken by airplanes and drones. One of the most common uses is to take photos of the earth's surface. These photos are then converted by mapping professionals into maps of the ground.



Aerial photogrammetry. Photogrammetry is the process of taking measurements of the ground from photos of the earth in order to make the data necessary for maps. [10]

2.3 Metadata

When working with maps, you will often use data that you did not create. Metadata helps you determine whether the data on the map are appropriate for your question or project. *Metadata* are data about data. We are usually most interested in spatial, temporal, and attribute data characteristics, but metadata go further and provide information including:

- Who collected the data?
- How were the data collected and classified?
- When were the data collected?
- How accurate are the data?
- What is the resolution of the data? (More on this below!)

Be cautious using a map if you cannot find metadata. This caution is particularly important because metadata lets you assess how well the data can work with other data. Below, we look at issues of resolution, accuracy, and interoperability among datasets. Cartographers explore these issues and then add them to the metadata attached to a map.

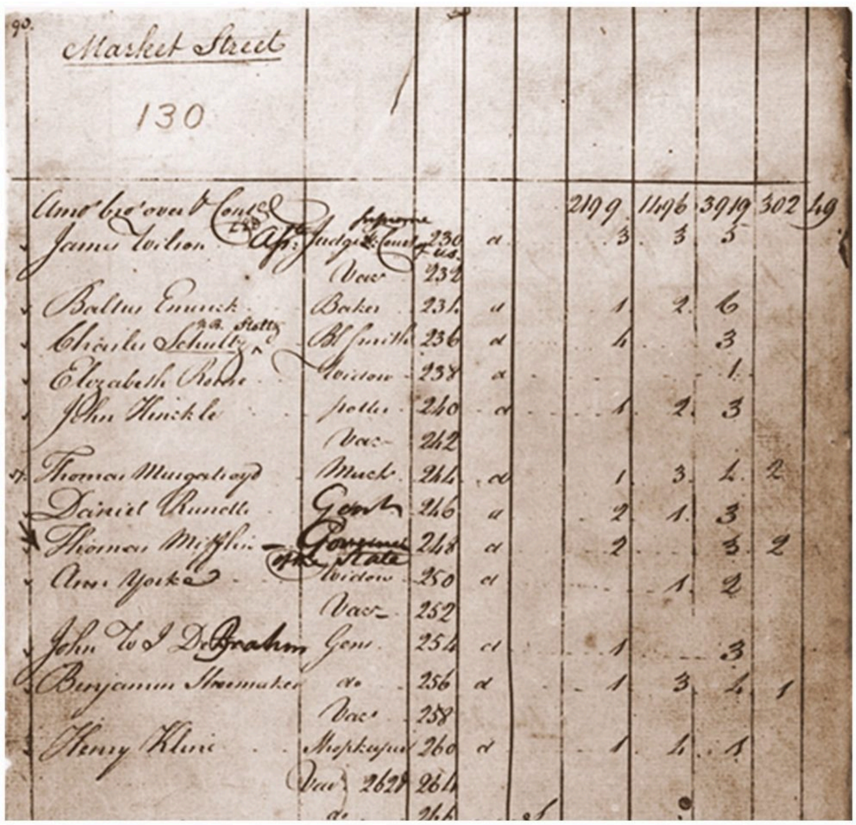
2.4 Census Data

An important form of survey data are census data, or those collected by national governments on their populations. We use the example of census data collected by the United States Census Bureau because the census is the primary source of social data used by government, nonprofits, and businesses. These data are created using well-documented procedures and are available at a variety of scales for the entire nation. Finally, many free online mapping tools provide census data, making it possible to explore mapping concepts without rigorous technical training.

2.4.1 Background to the Census

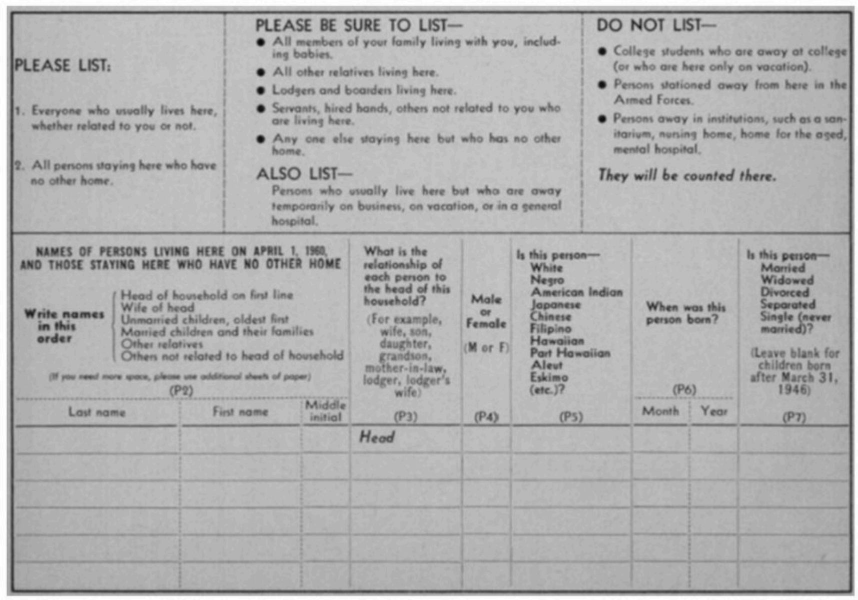
The United States census is conducted every ten years with the goal of counting every person in the country, although, as described below, it is almost impossible to reach this goal. The census collects information about the race, age, and housing situation of the population. The primary purpose of the census, as established in the Constitution, is to determine the number of seats each state will have in the US House of Representatives, the legislative branch of government. Voting district boundaries must then be redrawn in states that have gained or lost seats between census years (we will take a closer look at how redistricting is done and the spatial challenges of the process in later chapters). Censuses also determine how hundreds of billions of dollars in federal funding are distributed for many important purposes, including education, health care, environmental protection, transportation, and other forms of federal aid to states and cities.

The first US census, carried out in 1791 by sixteen US marshals and 650 assistants, counted around 3.9 million people. They asked only a few questions: the number of free persons, the number of slaves, and the sex and race of each individual.



Census form 1791. This form for the first census in the United States was filled out by a census taker who asked a few questions. [11]

By 1960, with the population approaching 180 million, it was no longer feasible to have a census taker visit each household. Instead, questionnaires were mailed to every household, and temporary employees followed up in person with the households that did not respond.



PLEASE LIST:

1. Everyone who usually lives here, whether related to you or not.

2. All persons staying here who have no other home.

PLEASE BE SURE TO LIST—

- All members of your family living with you, including babies.
- All other relatives living here.
- Lodgers and boarders living here.
- Servants, hired hands, others not related to you who are living here.
- Any one else staying here but who has no other home.

ALSO LIST—

Persons who usually live here but who are away temporarily on business, on vacation, or in a general hospital.

DO NOT LIST—

- College students who are away at college (or who are here only on vacation).
- Persons stationed away from here in the Armed Forces.
- Persons away in institutions, such as a sanitarium, nursing home, home for the aged, mental hospital.

They will be counted there.

NAMES OF PERSONS LIVING HERE ON APRIL 1, 1960, AND THOSE STAYING HERE WHO HAVE NO OTHER HOME Write names in this order: Head of household on first line; Wife of head; Unmarried children, oldest first; Married children and their families; Other relatives; Others not related to head of household (If you need more space, please use additional sheets of paper) (P2)			What is the relationship of each person to the head of this household? (For example, wife, son, daughter, grandson, mother-in-law, lodger, lodger's wife)	Male or Female (M or F)	Is this person— White, Negro, American Indian, Japanese, Chinese, Filipino, Hawaiian, Part Hawaiian, Aleut, Eskimo (etc.)?	When was this person born? (P6)		Is this person— Married, Widowed, Divorced, Separated, Single (never married)? (Leave blank for children born after March 31, 1946)
Last name	First name	Middle initial	(P3)	(P4)	(P5)	Month	Year	(P7)
			Head					

Census form 1960. This is a blank copy of the 1960 Census form that was mailed to each household to be filled out. [12]

Questions asked of all households now include the number of persons by age, gender, ethnicity, homeownership, and household composition. Between 1940 and 2000, one in six households also received a more detailed “long form” survey which asked questions about a much wider range of topics including income, occupation, commute length, and military service. The Census Bureau then used this sample to estimate the characteristics of the rest of the population.

Demand for more timely social data led to the development of the American Community Survey (ACS), which replaced the long form census survey in 2010. The ACS is conducted every year in order to provide more frequent “snapshots” of demographic, economic, and housing characteristics of the population. However, only 2-3 million households receive the survey per year (less than 2% of the population), which introduces substantial statistical errors in estimates for the whole population. Data for the census and ACS are collected from each household, but in order to preserve privacy and to make the data easier to use, the Census Bureau aggregates the data to larger geographic areas.

While data are available for a large number of different geographical areas, we will work primarily with census tracts and counties in this course. Census tracts have a population size between 1,200 and 8,000 people, with an optimum size of 4,000 people. Census tract boundaries generally follow environmental or political features, but the spatial size of census tracts can vary a great deal depending on the density of settlement and population. Census tract boundaries and shapes are drawn with the goal that they will stay pretty much the same over a long time so that statistical comparisons can be made from census to census.

2.4.2 Limitations of Census Data

The census is the most comprehensive source of demographic information available for the United States, but it still has important limitations.

The primary challenge is accuracy and undercounting. The census attempts to take a snapshot of how many people there are and where they are living on April 1st of the census year. The method for collecting data assumes that every person lives in a housing unit with a postal address and that they will respond accurately to surveys. The Census Bureau estimated that approximately 10 million people were missed in its 2010 count.

Census 2010. The first enumeration of the 2010 Census took place in Noorvik, Alaska. An early start allows census takers to reach remote villages before residents leave to hunt and fish or travel for warm-weather jobs following the spring thaw. [13]

Undercounting is not random because it is more prevalent in certain areas and subpopulations. Those who are homeless or have unstable housing at the time of the census are often missed. Those residing in remote rural areas can be hard to contact by mail or in person. The census is also less likely to receive responses from those who distrust the government, such as people fear that their answers will be used by immigration enforcement to deport undocumented family members.

Because the census is only taken every ten years, the counts have long-term consequences for states and cities. The accuracy of counts can be very contentious in cash-strapped cities. For example, Detroit challenged the findings of the 2010 census, having come up 40,000 people short of a population cutoff point for many major sources of federal funding. Since poor and marginalized populations are among the hardest to count, districts with the most need are also the most at risk of underfunding and underrepresentation.

Beyond accuracy issues, while the census and ACS provide an extensive set of social data, plenty of topics are not covered. For example, there are no questions about religion, consumer spending, or political party affiliation. The quantity and wording of questions asked in the census have changed over time, and data are not always available for all places or for all geographic areas.

Remember that there are many other social surveys that collect information about different attributes, areas, or periods. For example, the Association of Statisticians of American Religious Bodies conducts the "Religious Congregations and Membership Study" (RCMS) every 10 years to track patterns of religious affiliation. Local governments gather data for projects in their specific region. There are also censuses conducted in countries around the world with varying levels of detail and accuracy.

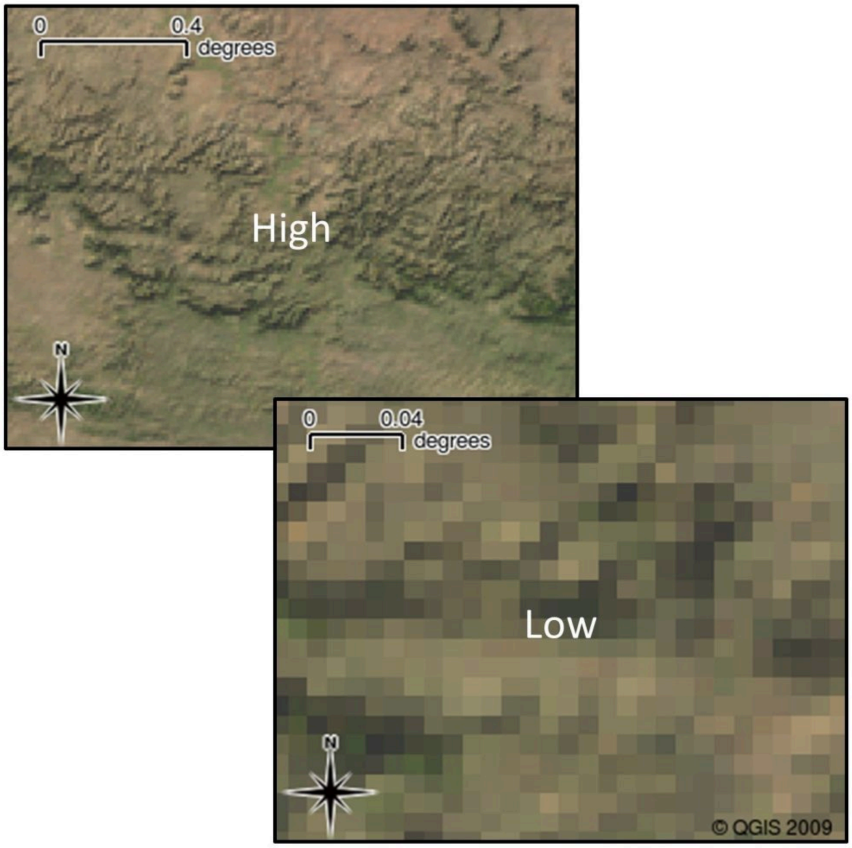
2.5 Data Concepts & Problems

When choosing data to analyze a specific problem, there are some key concepts to bear in mind: 1) resolution, 2) accuracy, and 3) interoperability. We will look at each of these concepts with respect to the three elements of spatial data (location, attributes, time). Each of these concepts can be rolled in under the term metadata in that they are information about data (or data about data). Developing and understanding metadata involves looking past the basics of 'data' in terms of spatial location, attributes measured, and time collected.

2.5.1 Resolution

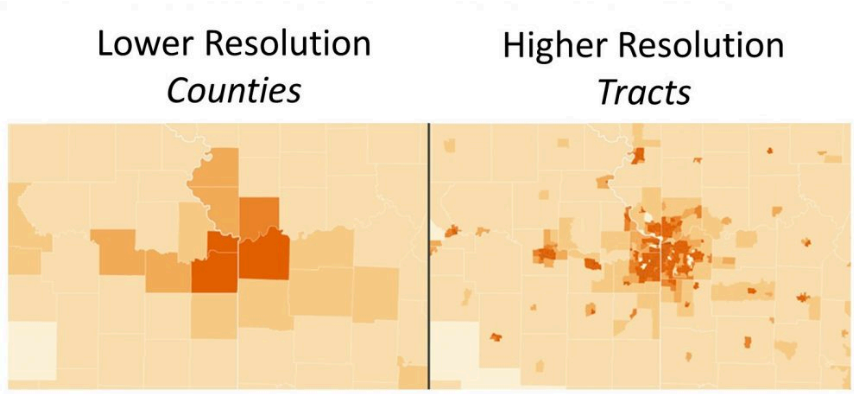
Resolution describes the breadth or specificity of the data you are examining. There are three main types of resolution – spatial, attribute, and temporal. Higher resolution corresponds with smaller areas over which data are aggregated, narrower distinctions between categories, or shorter times between data collection. But before we get into examples of resolution related to mapping social data, think about the concept in relation to everyday technology.

Spatial Resolution. You have probably seen the term "resolution" used to describe the quality of a computer screen or mobile phone camera. Each picture is composed of many smaller squares or pixels. When the pixels that make up the larger picture are small, more detail can be distinguished and the image is said to have higher resolution. As the size of the square pixels increases, it becomes more difficult to make out small details, such as the water droplets on the flower petals. This can be important if you copy an image from a website and then resize the image. Depending on the resolution of the original picture, you may suddenly be able to see pixels that previously were too small to see.



Spatial resolution. Comparing higher resolution and lower resolution in a photograph of leaves (top) or in a grid (bottom). [14]

Spatial resolution can also refer to the question, “What is the smallest unit of area measured?” It is similar to pixel resolution, except that the map often is not split into equally sized squares. Instead, the map might be split up between administrative boundaries (such as census tracts, counties, or states) which have varying shapes and land areas. The greater the area over which data have been aggregated, the lower the resolution and the more difficult it is to make out small details in the data. In the figure below, small areas of high population density are not visible with lower spatial resolution.



Census data resolution. Comparing population density data aggregated by county (left) to data aggregated by census tract (right). [15]

Consider an example. If you were trying to determine whether there had been increasing median income on your block in the last 4 years, but the only data you could find was zip code level resolution, it would be hard to establish the pattern. Zipcodes are substantially larger than blocks. Changes of median income in other parts of the zip code might obscure or falsely enhance what is happening on your block.

Attribution resolution deals with the degree to which distinctions are made between categories. Data split into many categories provide more detailed distinctions and therefore higher attribute resolution. For example, imagine you are interested in data about the age of individuals. If the data are grouped into only two categories – individuals who are under 18 years old and individuals who are over 18 years old – the data would have low attribute resolution. By comparison, splitting ages into more categories (e.g., 0-18, 18-34, 34-64, 65+) would give us higher attribution resolution. If you need to know the number of individuals who are old enough to vote in national elections, using the lower resolution data would be sufficient. But if you are interested in the number of senior citizens, you would need to have higher data resolution.

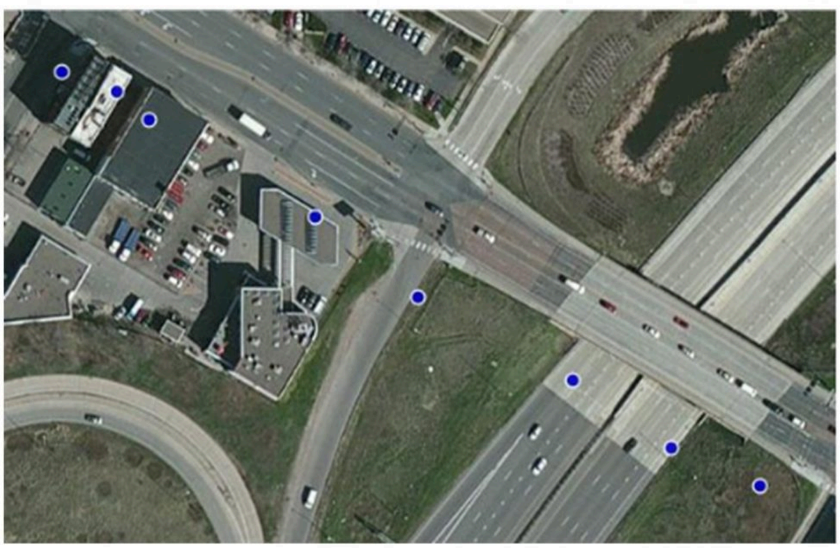
Temporal resolution is the frequency with which data are collected, and in essence, addresses the question, How often or over what period of time is a measurement taken? In the section above, we noted that the US Census Bureau collects data every ten years, whereas the ACS conducts a survey every year. The census is more accurate than the ACS because it draws on a larger proportion of the population, but at the cost of having a coarser temporal resolution. It would not be possible to make an argument about how your neighborhood had changed demographically over a period of five years given the temporal resolution of the census, because the census will only give you a snapshot of your neighborhood every ten years.

In summary, when looking at data, ask yourself the following questions: Are you looking at the correct area for the question being asked? Are the categories in the data specific enough for your argument (or do you need to broaden your claims)? Are data collected frequently enough for the time period you want to analyze?

2.5.2 Accuracy

Accuracy describes how well data on a map align with objects in the world. There are three main types of accuracy – spatial, attribute, and temporal.

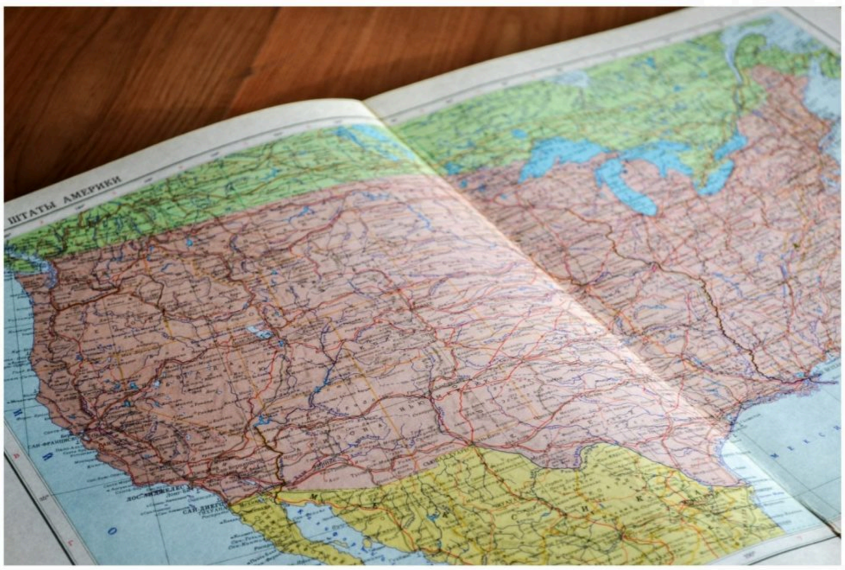
Spatial accuracy answers the question of how well an object's location on the map matches its location in the world. There are many reasons why the locations of something on a map do not exactly correspond to those on the ground in reality. Boundaries between countries may be drawn incorrectly. Points marked using GPS can be offset from their actual location if the signal is blocked by trees or tall buildings. The figure below shows the example of a person whose movements are being tracked with GPS in a vehicle. The map appears to show the person walking through several buildings and then running across a nine-lane freeway. It only appears that way on the maps because of an error in how the GPS measurements were collected.



Spatial accuracy. Blue dots mark the path taken by an individual carrying a GPS tracking device in a vehicle. [16]

Attribute accuracy asks whether characteristics reported about an object are true about that object in the world. Attribute inaccuracies can show up in survey data if participants do not respond, misunderstand the instructions, or purposefully provide false information. Inaccuracies may also occur when estimating values for a small area based on a small number of responses. Remember that the ACS polls around 2% of the population each year – 4 out of every 200 people – and then estimates the characteristics of the rest of the population from their responses. The ACS has a better attribute and temporal resolution than the census (more categories that are collected more often), but the census is more accurate in the sense that it counts more people.

Temporal accuracy is concerned with whether details about an object are up-to-date with respect to changes in the world. While data may be accurate and complete at the time they are collected, details may soon be inaccurate because of changes to the social and physical landscape. For example, the objects on a printed reference map will become less accurate over time as new roads are constructed, removed, or given name changes.



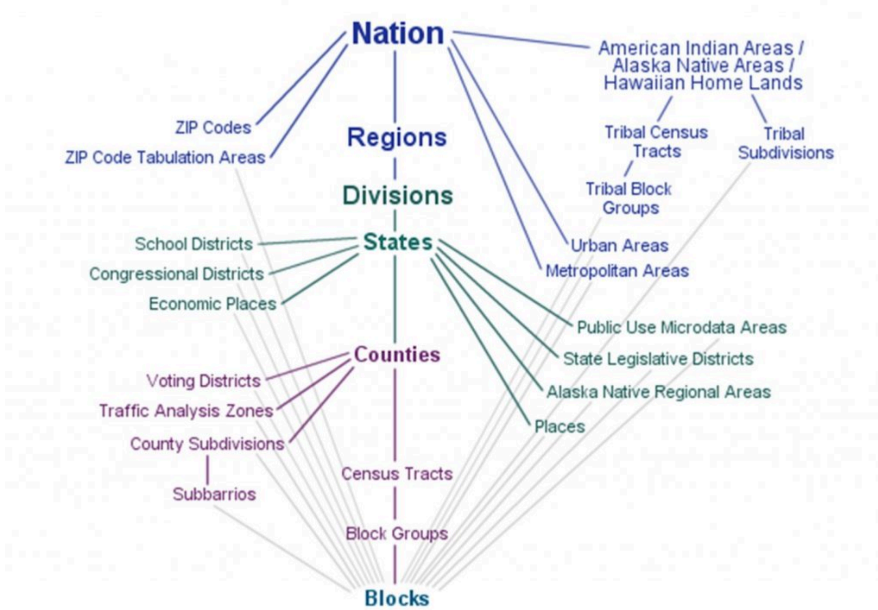
Temporal accuracy. Static road maps are updated much less frequently than Google maps. [17]

2.5.3 Interoperability

Interoperability describes how well two different datasets work with each other. There are three main types of interoperability – spatial, attribute, and temporal.

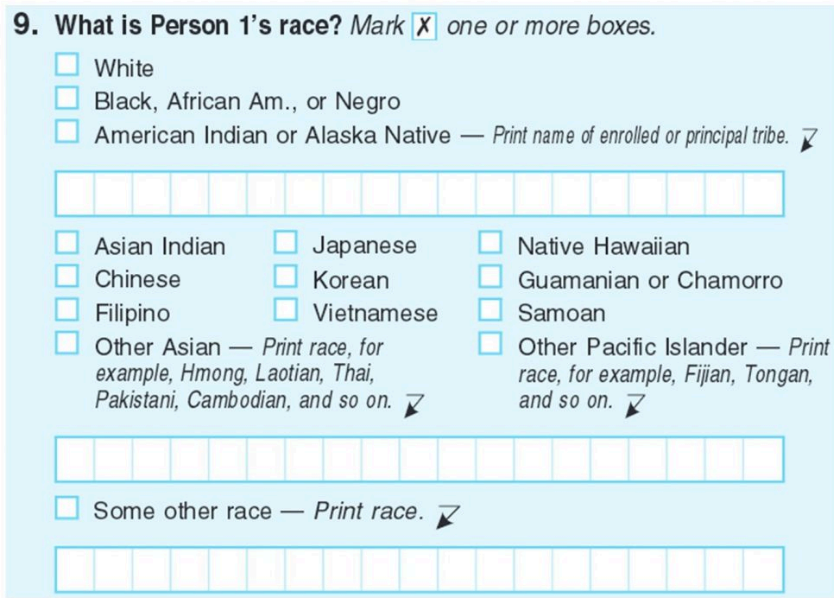
Ask yourself the following questions: Are they comparing the same area? Do they use the same categories and define them in the same way? These questions are especially relevant when using data collected by different organizations or across multiple time periods.

Spatial interoperability. How well do spatial units match up? This is the question that concerns spatial interoperability. For example, zip codes and census tracts are spatial units for which data are frequently aggregated, but their boundaries are rarely the same. A census tract may fall within multiple zip codes and vice versa. Zipcode level data and census tract-level data have poor interoperability because they do not show characteristics for the same group of people.



Census Geographies. Census Geographies. Geographic areas for which the US Census Bureau makes data available, ranging from the state level down to blocks. [18]

Attribute interoperability asks the question: how well do the categories of two datasets match? For example, in the 2010 census, individuals could pick from between fifteen different racial categories with the option of selecting multiple categories. By comparison, in the 1850 census, individuals were divided into only three racial categories: “white,” “black,” or “mulatto.” These two datasets have poor attribute interoperability because they have very different attribute resolution and do not have matching categories.



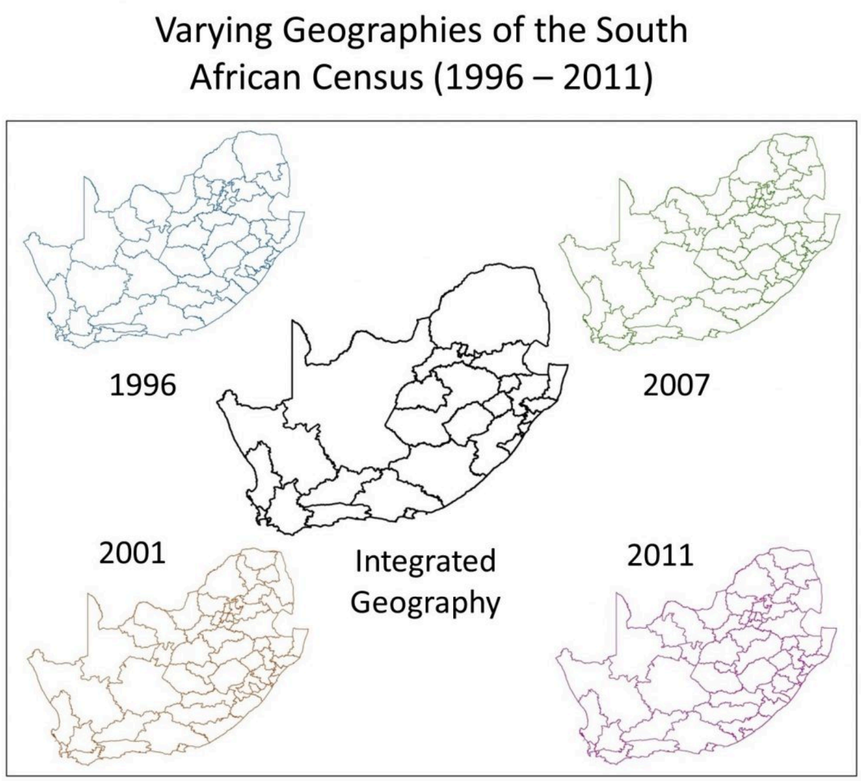
9. What is Person 1's race? *Mark* ☒ *one or more boxes.*

- ☐ White
- ☐ Black, African Am., or Negro
- ☐ American Indian or Alaska Native — *Print name of enrolled or principal tribe.*
- ☐ Asian Indian
- ☐ Chinese
- ☐ Filipino
- ☐ Other Asian — *Print race, for example, Hmong, Laotian, Thai, Pakistani, Cambodian, and so on.*
- ☐ Japanese
- ☐ Korean
- ☐ Vietnamese
- ☐ Native Hawaiian
- ☐ Guamanian or Chamorro
- ☐ Samoan
- ☐ Other Pacific Islander — *Print race, for example, Fijian, Tongan, and so on.*
- ☐ Some other race — *Print race.*

Census form 2010 on race. In the 2010 Census, individuals could pick from between fifteen different racial categories with the option of selecting multiple categories. [19]

Even a category that has a similar name between two census years may measure different attributes. The category "Chinese" used in the 1870 census was applied to individuals from any part of Asia, rather than just China. It is therefore not interoperable with "Chinese" as used in the 2010 census.

Temporal interoperability. How well do reported times match up? Temporal interoperability is of most concern if you are making an argument about what things are like at one point in time but your data are not from the same point in time. For example, imagine you are working at a nonprofit that is trying to compare the number of children ages 0-5 to the number and location of early childhood centers in an area. The most accurate count of children is from the 2010 census, but your organization has information about childhood centers collected in 2015. These two datasets have poor temporal interoperability because no children who were 0-5 at the time of the census would still be in that age bracket in 2015. It would be hard to determine whether childhood centers are appropriately located based on this data. Per below, sometimes you have to worry about both spatial and temporal interoperability!



Spatial and temporal interoperability. Boundaries for different census years in South Africa do not align between years because new regions were added over time. One solution is to create a new map that groups together regions; this integrated geography allows data to be compared between maps. [20]

In summary, when looking at multiple sets of data, ask yourself: Does it make sense to compare these data? Are the data generated for the same area using the same spatial units? Are the attribute categories defined the same way by the organization(s) that produced the data and over time? Were the data produced over a comparable time frame?

2.6 Mapping Tools

There are many software programs for making maps and most offer a range of data to their users. While these programs have traditionally been developed for desktop computers, a large and growing number of websites and web applications are allowing people to view and make maps online. These maps and tools have been developed with the goal of making data more accessible to researchers, politicians, and members of the public.

Social Explorer is an example of an online mapping tool, developed to make it easier to access and use data generated by the US Census Bureau. Keep in mind that many organizations are focused on getting maps online and had no role in collecting the underlying data. Instead, online maps and mapping tools act like libraries by bringing together information from multiple sources. Note that Social Explorer is not the source of the data being mapped; it is our tool for exploring data created by the Census Bureau.

2.7 Conclusion

Whenever you look at a map, it is important to think about how the data that has been visualized were generated. Who created the map? How were the underlying data collected? What questions were asked of whom? How accurate is the map? What is missing? Even the most carefully created data contain errors and have a context within a social, political, and cultural landscape. To be a responsible map user and map maker, you must think about what you can and cannot show given the resolution, accuracy, and interoperability of the available data. It is important to cite the sources of the data you include on your map so that your audience can find additional information.

As we move on to explore how to symbolize and simplify data, to make an appealing map, and to analyze the spatial relationships of data, remember: a map can only be as good as the data that go into it.

Resources

For more information about the history of census questions and procedures, and what the census does and does not ask:

- US Census
- Social Explorer

For more information about GPS:

- Pennsylvania State University Geography 482: The Nature of Geographic Information
- Adam Goetsch at USC

Notes

1. CC BY-NC-SA 3.0. Adapted from Dibiase et al. (2012) Mapping our Changing World. https://www.e-

education.psu.edu/geog160/node/1930. Jennifer M. Smith, Department of Geography, The Pennsylvania State University; Data from U.S. Census Bureau.

2. CC BY-NC-SA 3.0. Adapted from David Dibiase (1998) Nature of Geographic Information. https://www.e-education.psu.edu/natureofgeoinfo/c5_p8.html; originally Hodgson, C. V. A leveling crew at work in 1916. NOAA Historical Photo Collection (2004). Retrieved on April 20, 2006, from http://www.photolib.noaa.gov/.
3. CC BY-NC-SA 4.0. Adapted from J. Campbell and M. Shin (2012). https://2012books.lardbucket.org/books/geographic-information-system-basics/index.html;
4. CC BY-NC-SA 4.0. Adapted from J. Campbell and M. Shin (2012) https://2012books.lardbucket.org/books/geographic-information-system-basics/index.html
5. CC BY-NC-SA 4.0. Adapted from J. Campbell and M. Shin (2012) https://2012books.lardbucket.org/books/geographic-information-system-basics/index.html
6. CC BY-NC-SA 3.0. Adapted from Dibiase et al. (2012) Mapping our Changing World. https://www.e-education.psu.edu/geog160/node/1941. Data from the U.S. Census Bureau.
7. Public Domain. NOAA's National Centers for Environmental Information (nd) Measuring instruments used for current observations and data reporting. https://www.ncdc.noaa.gov/data-access/land-based-statio n-data
8. CC BY-NC-SA 3.0. Adapted from David Dibiase (1998). Nature of Geographic Information. https://www.e-education.psu.edu/natureofgeoinfo/c5_p8.html
9. Public Domain. By NASA/GSFC, MODIS Rapid Response AND demis.nl AND FT2 - 1/ File:Deepwater Horizon oil spill - May 24, 2010.jpg (based upon Original image with cropping)2/ Locator by FT2 from File:Map of USA topological.png (Public domain by author demis.nl)., Public Domain, https://commons.wikimedia.org/w/index.php?curid=10671450.
10. CC BY-NC-SA 3.0. Adapted from David Dibiase (1998) Nature of Geographic Information https://www.e-education.psu.edu/natureofgeoinfo/c5_p8.html.
11. Public Domain. US Census Bureau. https://www.census.gov/history/www/sights_sounds/photos/1790_photos.php
12. Public Domain. US Census Bureau. https://broadcast.census.gov/pio/photos/1960/1960a_hi.jpg
13. Public Domain. https://www.census.gov/history/www/sights_sounds/photos/ 2010_photos.php#
14. GNU Free Documentation License, Version 1.2. Adapted from Sutton, O. Dassau, M. Sutton (2009). A Gentle Introduction to GIS. Chief Directorate: Spatial Planning & Information, Department of Land Affairs, Eastern Cape. http://docs.qgis.org/2.14/en/docs/gentle_gis_introduction/introducing_gis.html
15. CC BY-NC-SA 4.0. Steven M. Manson (2015)
16. CC BY-NC-SA 4.0. Steven M. Manson (2015)
17. Unsplash license. https://unsplash.com/search/map?photo=gtCWBwbZNpM, John-Mark Kuznietsov
18. Public Domain. US Census. http://factfinder.census.gov/faces/nav/jsf/pages/using_fact finder.xhtml?page=census_geography
19. Public Domain. US Census Bureau website - http://www.census.gov/prod/cen2010/briefs/c2010br-02.pdf
20. CC BY-NC-SA 4.0. Adapted from IPUMSI, created by Sula Sarka and Ding Fei. https://international.ipums.org/international/

3. Scale and Projections

Laura Matson and Melinda Kernik

Scale and projections are two fundamental features of maps that usually do not get the attention they deserve. Scale refers to how map units relate to real-world units. Projections deal with the methods and challenges around turning a three-dimensional (and sort of lumpy) earth into a two-dimensional map.

This chapter will introduce you to:

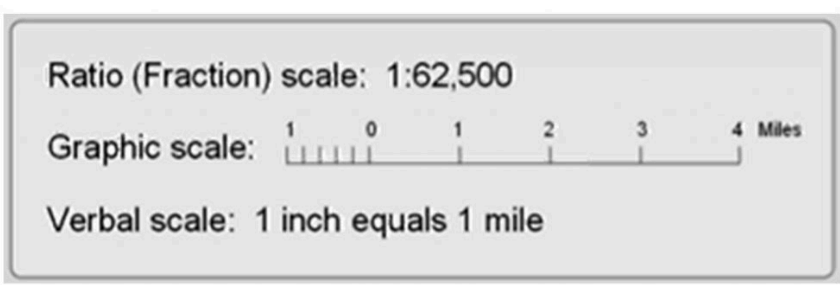
- Scale and ways of telling the map user what the map is measuring on the ground
- Projection mechanics, types of projections, and their characteristics

By the end of this chapter, you should be able to read map scales and identify common projections along with their basic features and uses.

3.1 Scale

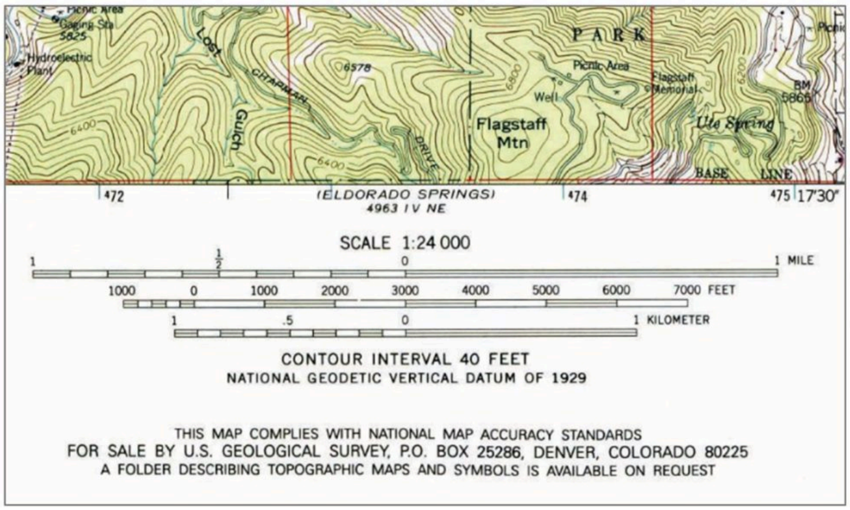
The world is vast. The earth's surface has an area of over 500 million km^2 and any picture of the earth that you can easily carry can only show general outlines of continents and countries. When we visually represent a region of the world on a map, we must reduce its size to fit within the boundaries of the map. Map scale measures how much the features of the world are reduced to fit on a map; or more precisely, map scale shows the proportion of a given distance on a map to the corresponding distance on the ground in the real world.

Map scale is represented by a representative fraction, graphic scale, or verbal description.



Map scales. A map can have a representative fraction, graphic scale, or verbal description that all mean the same thing. [1]

Representative fraction. The most commonly used measure of map scale is the representative fraction (RF), where map scale is shown as a ratio. With the numerator always set to 1, the denominator represents how much greater the distance is in the world. The figure below shows a topographic map with an RF of 1:24,000, which means that one unit on the map represents 24,000 units on the ground. The representative fraction is accurate regardless of which units are used; the RF can be measured as 1 centimeter to 24,000 centimeters, one inch to 24,000 inches, or any other unit.



Representative fraction. Representative fraction and scale bars from a United States Geological Survey (USGS) topographic map. This topographic map has an RF of 1:24,000, which means that one unit on the map represents 24,000 units on the ground. [2]

Graphic scale. Scale bars are graphical representations of distance on a map. The figure has scale bars for 1 mile, 7000 feet, and 1 kilometer. One important advantage of graphic scales is that they remain true when maps are shrunk or magnified.

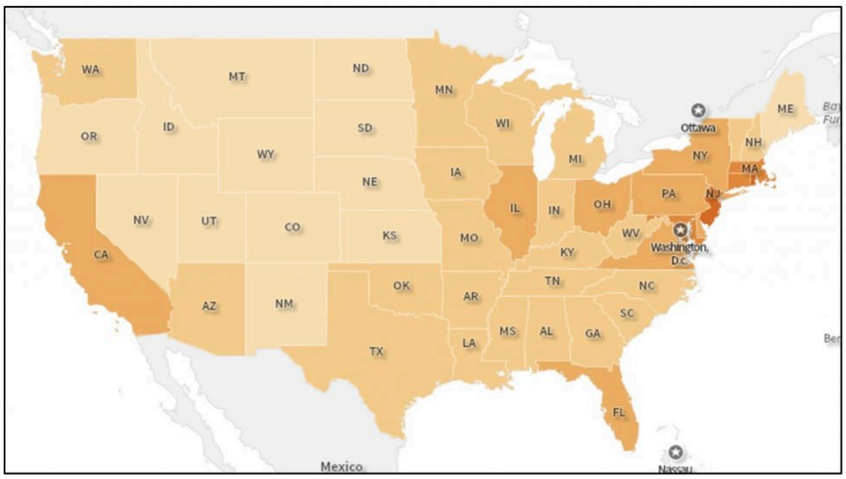
Verbal description. Some maps, especially older ones, use a verbal description of scale. For example, it is common to see "one inch represents one kilometer" or something similar written on a map to give map users an idea of the scale of the map.

Map makers use the term scale to describe maps as being small-scale or large-scale. This description of map scale as large or small can seem counter-intuitive at first. A 3-meter by 5-meter map of the United States has a *small* map scale while a UMN campus map of the same size is *large*-scale. Scale descriptions using the RF provide one way of considering scale, since 1:1000 is larger than 1:1,000,000. Put differently, if we were to change the scale of the map with an RF of 1:100,000 so that a section of road was reduced from one unit to, say, 0.1 units in length, we would have created a **smaller-scale** map whose representative fraction is 1:1,000,000.

When we talk about large- and small-scale maps and geographic data, then, we are talking about the relative sizes and levels of detail of the features represented in the data. In general, the larger the map scale, the more detail that is shown.

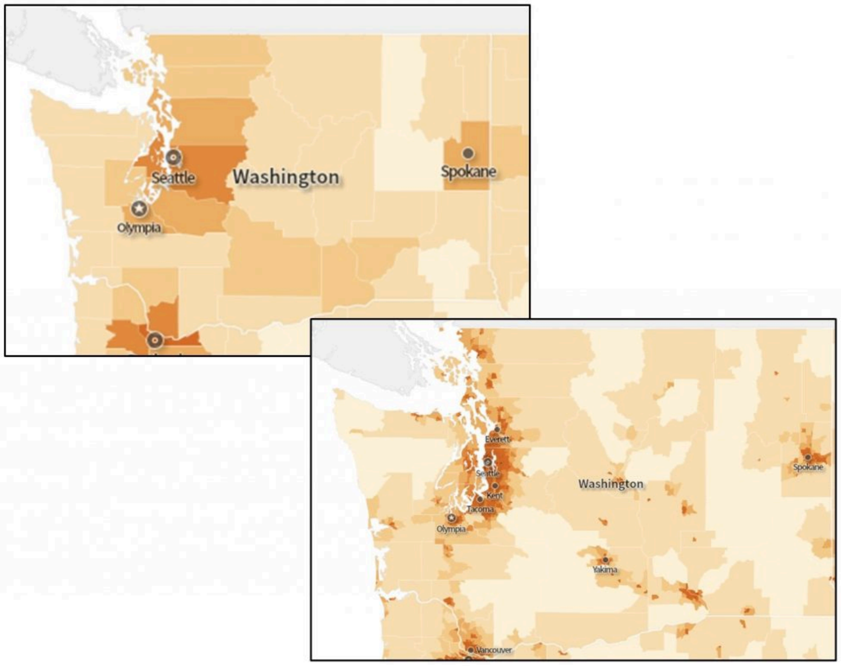
3.2 Extent vs. Resolution

The extent of a map describes the area visible on the map, while resolution describes the smallest unit that is mapped. You can think of the extent as describing the region to which the map is zoomed. The extent of the map below is national as it encompasses the contiguous United States, while the resolution is the state, because states are the finest level of spatial detail that we can see.



Map resolution and extent. This map shows a national extent and a state resolution. The extent of the map is national while the resolution is at the state level because they are the finest level of spatial detail that we can see. [3]

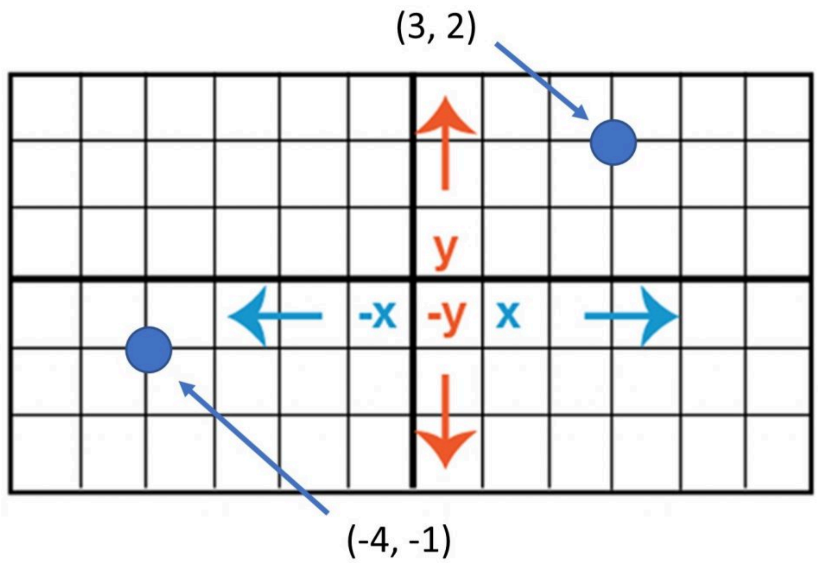
We often choose mapping resolutions intentionally to make the map easier to understand. For example, if we tried to display a map with a national extent at the resolution of census blocks, the level of detail would be so fine and the boundaries would be so small that it would be difficult to understand anything about the map. Balancing extent and resolution is often one of the most important and difficult decisions a cartographer must make. The figure below offers two more examples of the difference between extent and resolution.



More map extent and resolution. Maps showing an extent of the Pacific Northwest. The top image has a spatial resolution of the county and the bottom has a spatial resolution of census tracts. [4]

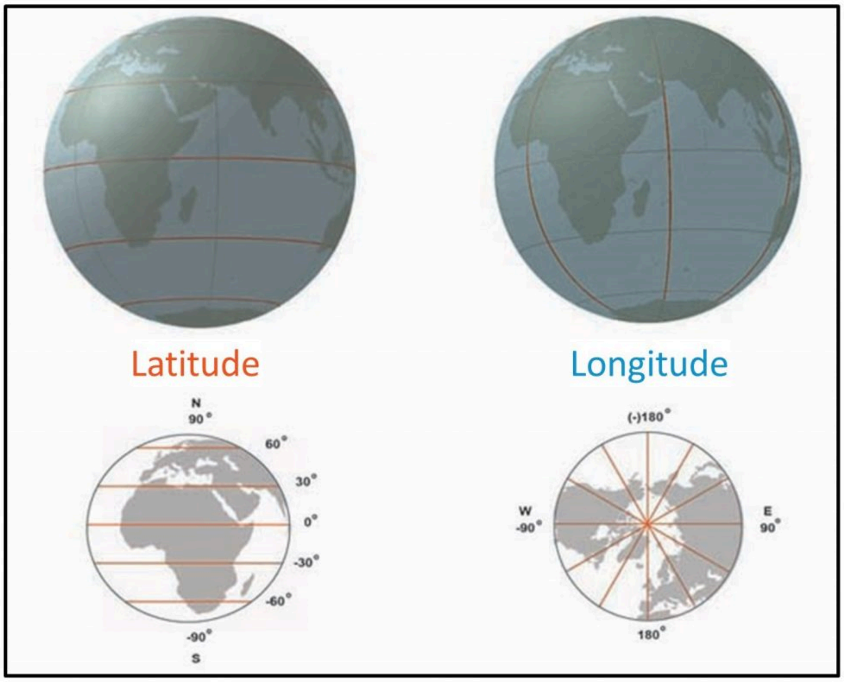
3.3 Coordinates & Projections

Locations on the earth's surface are measured in terms of *coordinates*, a set of two or more numbers that specifies a location in relation to some reference system. The simplest system of this kind is a Cartesian coordinate system, named for the 17th century mathematician and philosopher René Descartes. A Cartesian coordinate system, like the one below, is simply a grid formed by putting together two measurement scales, one horizontal (x) and one vertical (y). The point at which both x and y equal zero is called the *origin* of the coordinate system. In the figure, the origin (0,0) is located at the center of the grid (the intersection of the two bold lines). All other positions are specified relative to the origin, as seen with the points at (3, 2) and (-4, -1)



Coordinate system. Locations on the Earth's surface are measured in terms of coordinates, a set of two or more numbers that specifies a location in relation to some reference system. [5]

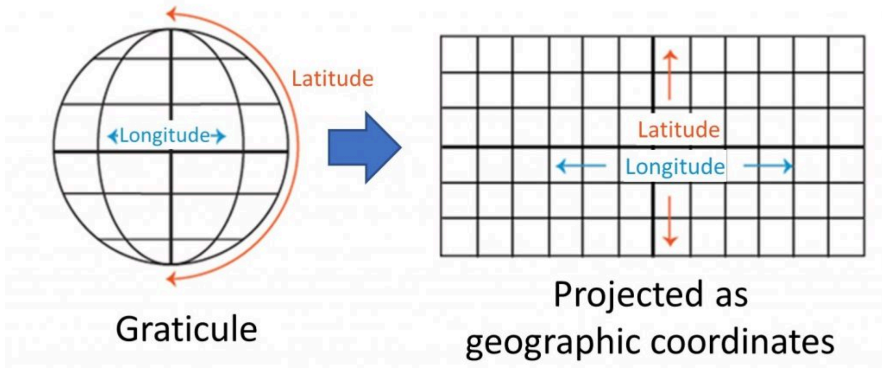
The geographic coordinate system is designed specifically to define positions on the Earth's roughly-spherical surface. Instead of the two linear measurement scales x and y, as with a Cartesian grid, the geographic coordinate system uses an east-west scale, called longitude that ranges from +180° to -180°. Because the Earth is round, +180° (or 180° E) and -180° (or 180° W) are the same grid line, termed the International Date Line. Opposite the International Date Line is the prime meridian, the line of longitude defined as 0°. The north-south scale, called latitude, ranges from +90° (or 90° N) at the North pole to -90° (or 90° S) at the South pole. In simple terms, longitude specifies positions east and west and latitude specifies positions north and south. At higher latitudes, the length of parallels decreases to zero at 90° North and South. Lines of longitude are not parallel, but converge toward the poles. Thus, while a degree of longitude at the equator is equal to a distance of about 111 kilometers, that distance decreases to zero at the poles.



Longitude and latitude. The graticule is based on an east-west scale called longitude and a north-south scale called latitude. [6]

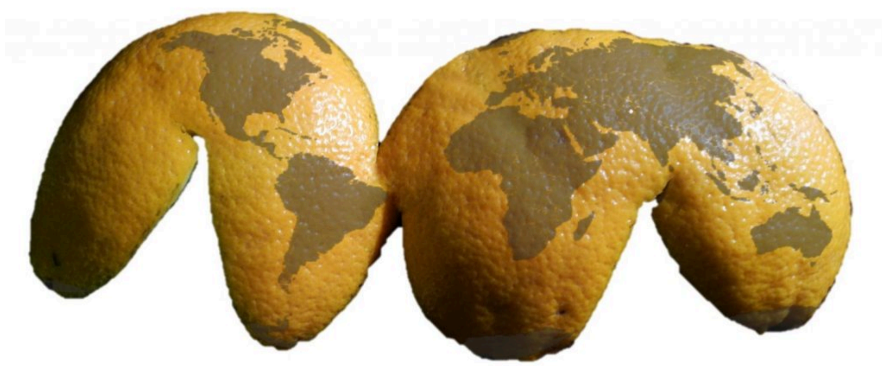
The graticule specifies positions on the globe with latitude and longitude coordinates. The graticule refers to longitude and latitude on a three-dimensional globe. When we use longitude and latitude on a two-dimensional map, we refer to these as geographic coordinates. Maps can have an enormous array of different coordinate systems depending on who developed and used them.

Projection is the term for turning a three-dimensional globe into a two-dimensional map. As noted above, the graticule on a globe is helpful, but how do we go from three-dimensional graticule to two-dimensional geographic coordinates, as per the figure below? We will discuss the process of how objects on a 3-dimensional surface (the earth) come to be represented on a flat piece of paper or computer screen. Our emphasis will be on the properties that different projections distort or maintain – area, shape, and distance.



Graticule projected. The longitude and latitude of the graticule become two-dimensional geographic coordinates through projection. [7]

Projection is the process of making a two-dimensional map from a three-dimensional globe. We can think of the earth as a sphere. In reality, it is more of an ellipsoid with a few bulges, but it is fine to think of it as a sphere. To get a sense of how difficult this process can be, imagine peeling the skin from an orange and trying to lay the skin flat.

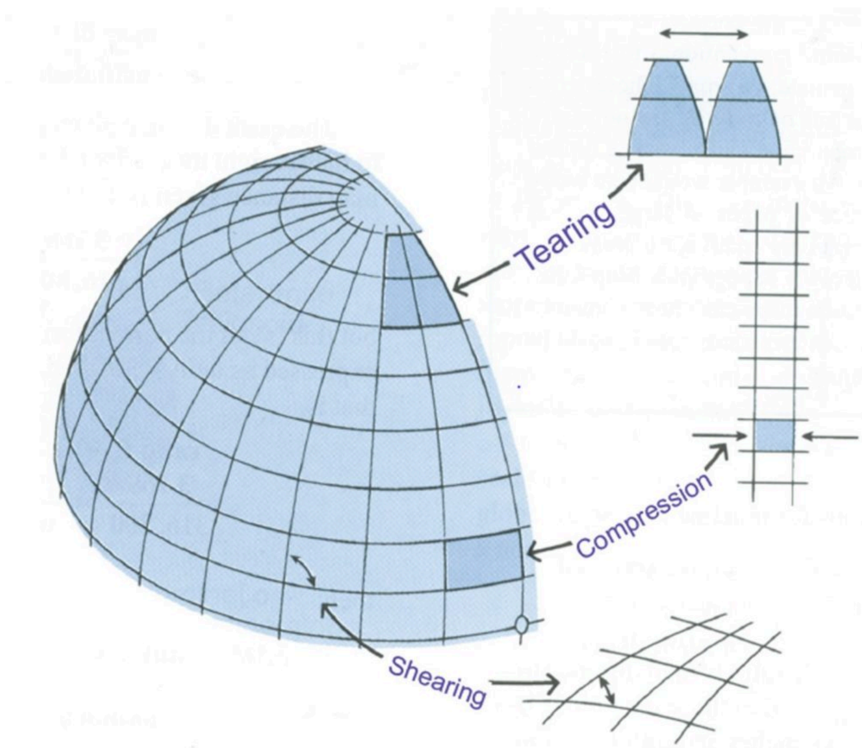


Flattened orange peel. You can imagine the difficulty of moving from a 3d to 2d surface by considering how difficult it is to peel the rind from an orange and try to lay the skin flat. [8]

As you peel and flatten the skin, you will encounter several problems:

- Shearing – stretching the skin in one or more directions
- Tearing – causing the skin to separate
- Compressing – forcing the skin to bunch up and condense

Cartographers face the same three issues when they try to transform the three-dimensional globe into a two-dimensional map. If you had a globe made of paper, you could carefully try to ‘peel’ it into a flat piece of paper, but you would have a big mess on your hands. Instead, cartographers use projections to create useable two-dimensional maps.

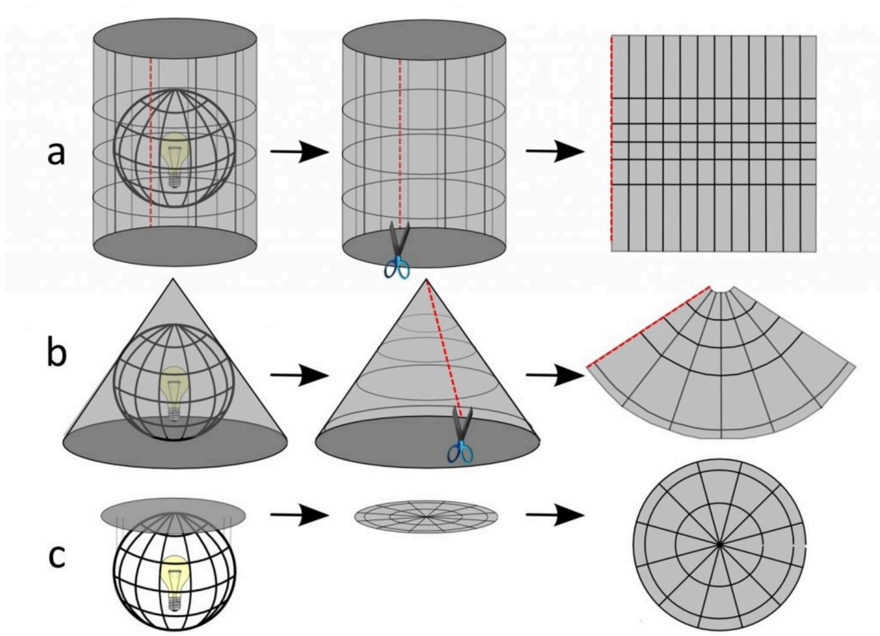


Shearing, tearing, compression. Cartographers face these three issues of shearing, tearing, and compression on a globe when they try to transform the three-dimensional globe into a two-dimensional map. [9]

3.4 Projection Mechanics

The term "map projection" refers to both the process and product of transforming spatial coordinates on a three-dimensional sphere to a two-dimensional plane. In terms of actual mechanics, most projections use mathematical functions that take as inputs locations on the sphere and translate them into locations on a two-dimensional surface.

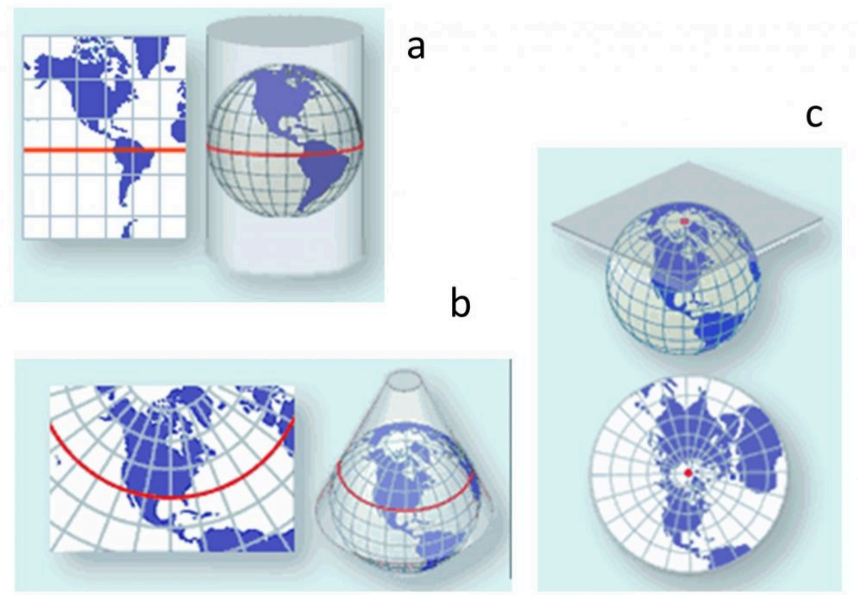
It is helpful to think about projections in physical terms. If you had a clear globe the size of a beach ball and placed a light inside this globe, it would cast shadows onto a surrounding surface. If this surface were a piece of paper that you wrapped around the globe, you could carefully trace these shadows onto the paper, then flatten out this piece of paper and have your projection!



Thinking of projections in physical terms. You can conceptualize projection as working with a clear globe, a light bulb, and tracing paper. If you had a clear globe the size of a beach ball and placed a light inside this globe, it would cast shadows onto a surrounding surface. This surface can be a (a) cylinder, (b) cone, or (c) plane. [10]

Most projections transform part of the globe to one of three "developable" surfaces, so called because they are flat or can be made flat: plane, cone, and cylinder. The resultant projections are called planar, conical, and cylindrical. We use developable surfaces because they eliminate tearing, although they will produce shearing and compression. Of these three problems, tearing is seen as the worst because you would be making maps with all sorts of holes in them! As we see below, however, there are times when you can create maps with tearing and they are quite useful.

The place where the developable surface touches the globe is known as the tangent point or tangent line. Maps will most accurately represent objects on the globe at these tangent points or lines, with distortion increasing as you move farther away due to shearing and compression. It is for this reason that cylinders are often used for areas near the equator, cones used to map the mid-latitudes, and planes used for polar regions.



Tangency. Red lines or dots mark the tangent line or point respectively. The flat surface touches the globe and it is the point on the projected map which has the least distortion. the place where the developable surface touches the globe is known as the tangent point or tangent line. These surfaces can be a (a) cylinder, (b) cone, or (c) plane. [11]

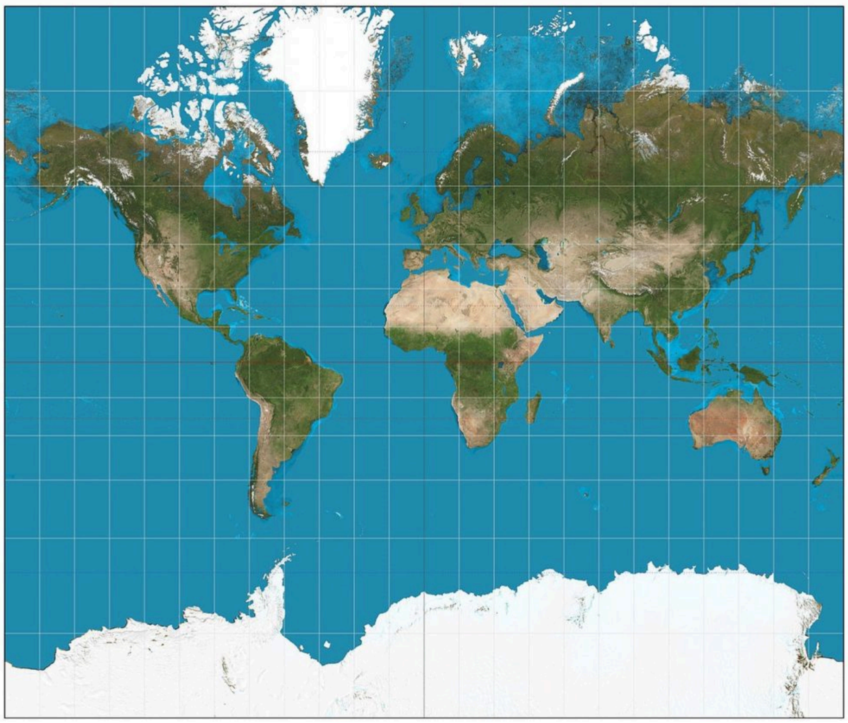
For beginning mapmakers, understanding the exact mechanics of projections doesn't matter as much as knowing which map properties are maintained or lost with the choice of projection – the topic of the next section.

Projections **must** distort features on the surface of the globe during the process of making them flat because projection involves shearing, tearing, and compression. Since no projection can preserve all properties, it is up to the map maker to know which properties are most important for their purpose and to choose an appropriate projection. The properties we will focus on are shape, area, and distance.

Note that distortion is not necessarily tied to the type of developable surface but rather to the way the transformation is done with that surface. It is possible to preserve any one of the three properties using any of the developable surfaces. One way of looking at the problem is with distortion ellipses. These help us to visualize what type of distortion a map projection has caused, how much distortion has occurred, and where it has occurred. The ellipses show how imaginary circles on the globe are deformed as a result of a particular projection. If no distortion had occurred in projecting a map, all of the ellipses would be the same size and circular in shape.

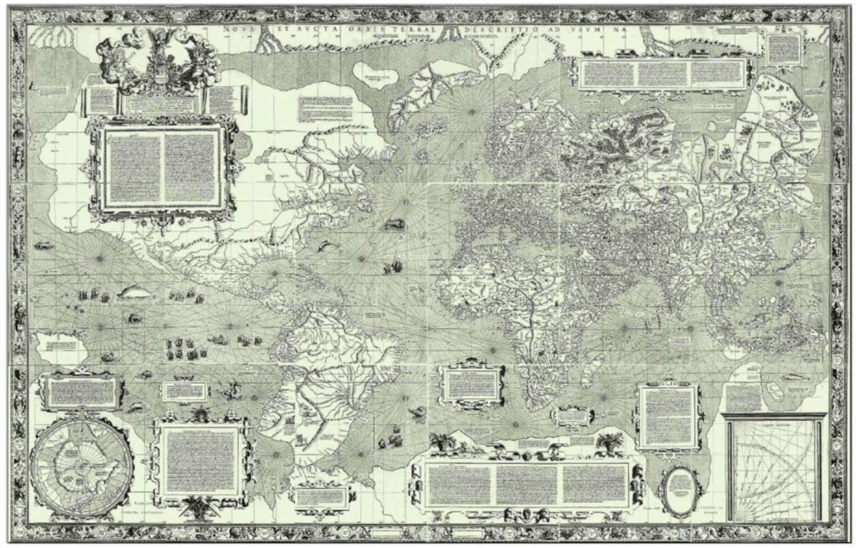
3.4.1 Conformal

Conformal projections preserve shape and angle, but strongly distort area in the process. For example, with the Mercator projection, the shapes of coastlines are accurate on all parts of the map, but countries near the poles appear much larger relative to countries near the equator than they actually are. For example, Greenland is only 7-percent the land area of Africa, but it appears to be just as large!



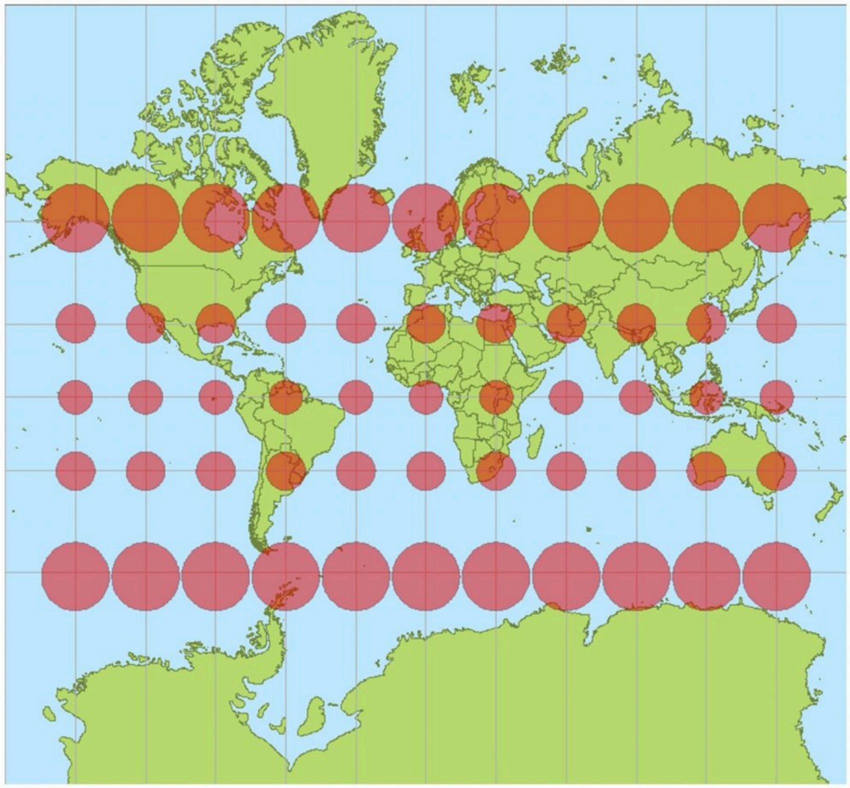
Mercator projection. The Mercator projection is conformal because it preserves shape and angle but strongly distorts area. [12]

Conformal projections should be used if the main purpose of the map involves measuring angles or representing the shapes of features. They are very useful for navigation, topography (elevation), and weather maps.



Mercator projection. One of the first maps of the world developed was by Mercator (Carta do Mundo de Mercator, 1569). [13]

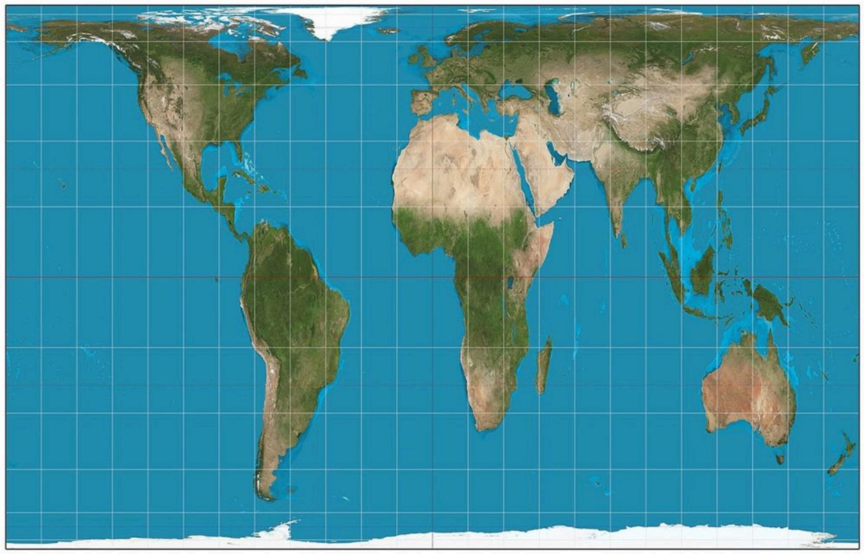
A conformal projection will have distortion ellipses that vary substantially in size, but are all the same circular shape. The consistent shapes indicate that conformal projections (like this Mercator projection of the world) preserve shapes and angles. This useful property accounts for the fact that conformal projections are almost always used as the basis for large scale surveying and mapping.



Mercator distortion. The Mercator projection is conformal because it preserves shape and angle but strongly distorts area. [14]

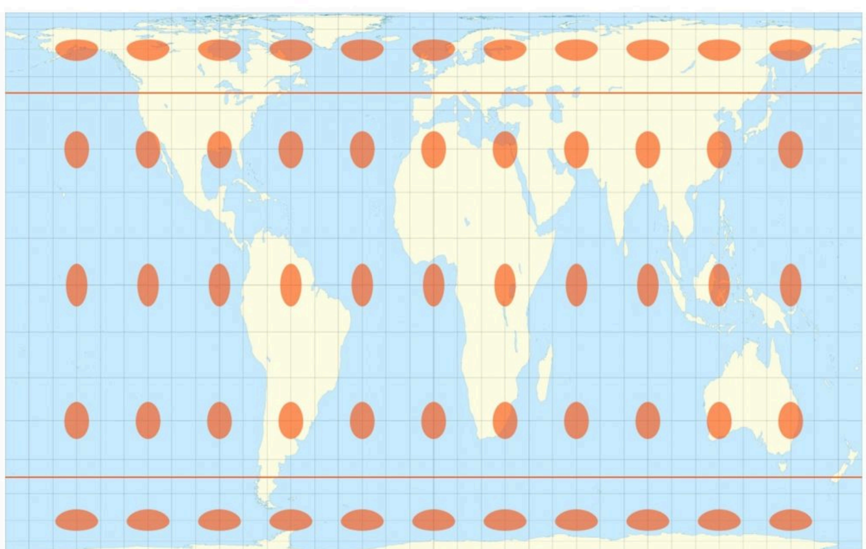
3.4.2 Equal Area

On *equal-area projections*, the size of any area on the map is in true proportion to its size on the earth. In other words, countries' shapes may appear to be squished or stretched compared to what they look like on a globe, but their land area will be accurate relative to other land masses. For example, in the Gall-Peters projection, the shape of Greenland is significantly altered, but the size of its area is correct in comparison to Africa. This type of projection is important for quantitative thematic data, especially in mapping density (an attribute over an area). For example, it would be useful in comparing the density of Syrian refugees in the Middle East or the amount of cropland in production.



Gall-Peters projection. The Gall Peters projection is equal area. Note how the shape of Greenland is significantly altered, but the size of its area is correct in comparison to other regions such as Africa. [15]

As we can see with an equal-area projection, however, the ellipses maintain the correct proportions in the sizes of areas on the globe but that their shapes are distorted. Equal-area projections are preferred for small-scale thematic mapping, especially when map users are expected to compare sizes of area features like countries and continents.



Gall-Peters distortion. The Gall Peters projection is equal area. Note how the shape of Greenland is significantly altered, but the size of its area is correct in comparison to other regions such as Africa. [16]

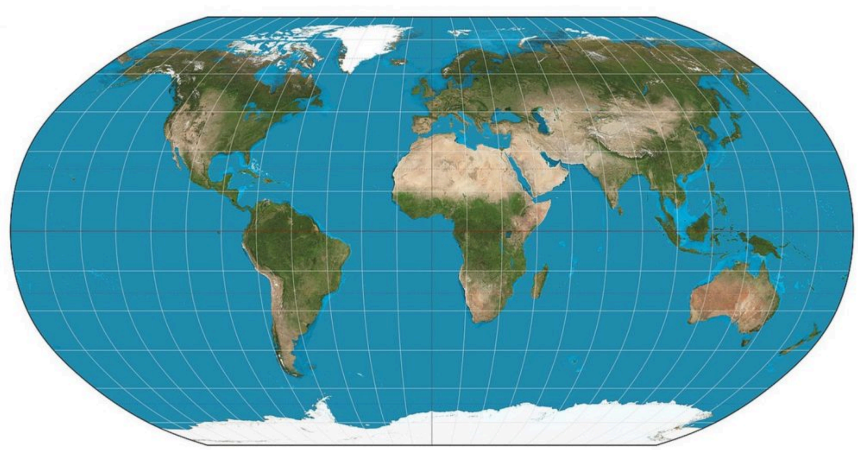
3.4.3 Equidistant

Equidistant projections, as the name suggests, preserve **distance**. This is a bit misleading because no projection can maintain relative distance between all places on the map. Equidistant maps are able, however, to preserve distances along a few clearly specified lines. For example, on the Azimuthal Equidistant projection, all points are the proportionally correct distance and direction from the center point. This type of projection would be useful visualizing airplane flight paths from one city to several other cities or in mapping an earthquake epicenter. Azimuthal projections preserve distance at the cost of distorting shape and area to some extent. The flag of the United Nations contains an example of a polar azimuthal equidistant projection.

Azimuthal Equidistant projection. In this equidistant projection, all points are the proportionally correct distance and direction from the center point. This projection is used on the map of the United Nations. [17]

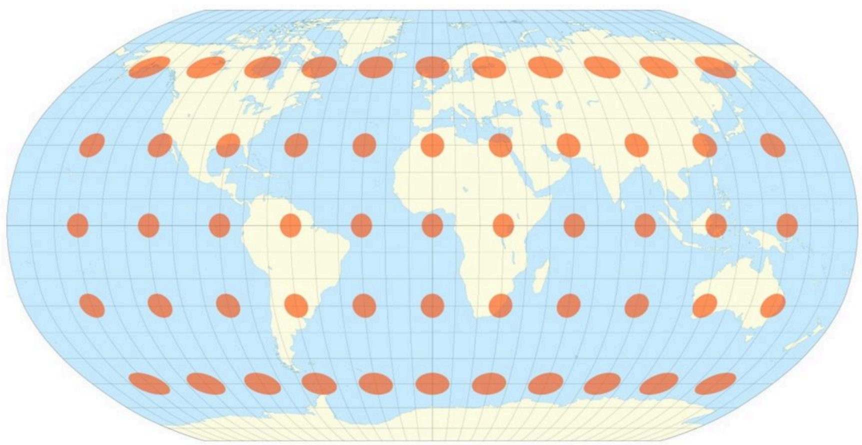
3.4.4 Compromise, Interrupted, and Artistic Projections

Some projections, including the Robinson projection, strike a balance between the different map properties. In other words, instead of preserving shape, area, or distance, they try to avoid extreme distortion of any of these properties. This type of projection would be useful for a general purpose world map.



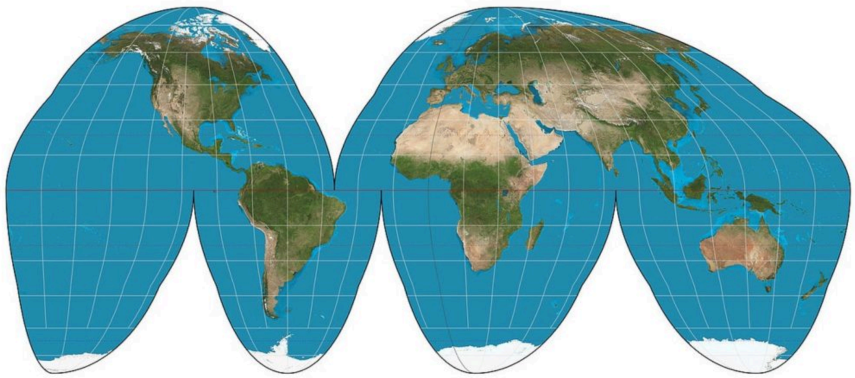
Robinson Projection. Some projections, including the Robinson projection, strike a balance between the different map properties. In other words, they do not preserve shape, area, or distance, but instead try to avoid extreme distortion. [18]

Compromise projections preserve no one property but instead seek a compromise that minimizes distortion of all kinds, as with the Robinson projection, which is often used for small-scale thematic maps of the world.



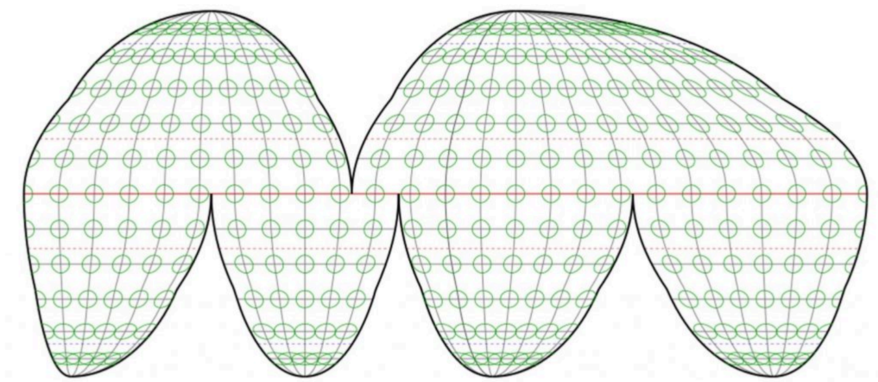
Compromise distortion. Note that some maps may not preserve either shape or area but do a pretty good job at both. [19]

Other projections deal with the challenge of making the 3D globe flat by tearing the earth in strategic places. Interrupted projections such as the interrupted Goode Homolosine projection represent the earth in lobes, reducing the amount of shape and area distortion near the poles. The projection was developed in 1923 by John Paul Goode to provide an alternative to the Mercator projection for portraying global areal relationships.



Goode homolosine projection of the world. This equal-area projection is interrupted in the sense that it uses lobes or sections. [20]

The Interrupted Goode Homolosine preserves area (so it is equal-area or equivalent) but does not preserve shape (it is not conformal).



Interrupted distortion. This equal area projection preserves area but distorts shape, but not as much as it would if it were not interrupted. [21]

There are also many projections that are aesthetically pleasing, but not intended for navigation between places or to visualize data. Examples of these artistic projections include the heart-shaped Stabius-Werner projection.

Artistic projections. Many projections are interesting and beautiful, like this Stabius-Werner Projection, but are not intended for navigation between places or to visualize data. [22]

3.5 Conclusion

In this chapter, we have explored the concepts of scale, resolution, and projection. There are hundreds of projections, each which distorts the world in a slightly different way. Keep in mind that all maps have a scale and there are a few important ways to indicate this scale. All maps also use a projection that can be formed from a developable surface and can preserve one or two properties at most.

Resources

- GIS Commons
- Spatially Integrated Social Science

References

Parts of section 3.1 are adapted from Campbell and Shin (2011). Essentials of Geographic Information Systems.

Parts of section 3.3 are adapted from DiBiase (1998). The Nature of Geographic Information: An Open Geospatial Textbook.

Notes

1. CC BY-SA 3.0. Adapted from Michael Schmandt (nd). GIS Commons: An Introductory Textbook on Geographic Information Systems http://giscommons.org/output/
2. CC BY-NC-SA 4.0. Adapted from J. Campbell and M. Shin (2012) https://2012books.lardbucket.org/books/geographic-information-system-basics/index.html; Based on USGS topographic maps (PD)
3. CC BY-NC-SA 4.0. Steven Manson 2017. Data from SocialExplorer and US Census.
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4. Design and Symbolization

Eric Deluca and Dudley Bonsal

“Design is so simple, that’s why it is so complicated.” Paul Rand, graphic designer

The difference between an ordinary map and one that is persuasive and interesting depends on how well the cartographer incorporates principles of good design and symbolization. Data, in isolation, cannot tell a story. It is up to the cartographer to make the data convincing by turning mundane information into artistic expressions. The concepts in this chapter are fairly basic to understand, yet they take years to put to good practice. Map design requires patience, trial and error, and careful attention to detail.

This chapter will introduce you to:

- Basic map elements: key elements, such as a title or source, are found on most maps and understanding their purpose will give you a solid foundation for cartography.
- Design principles: there are many principles of good design, but we start with the two of hierarchy and balance, which make the difference between boring maps and maps that pop out at the reader.
- Symbolization: cartographers have many tools to make data more memorable and convincing, and among these are symbolization basics including geometry and visual variables.

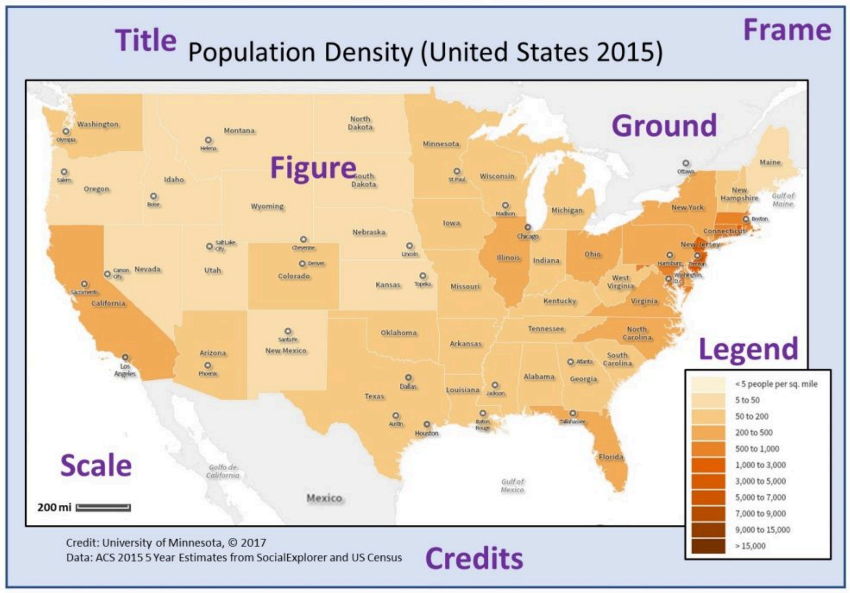
By the end of this chapter, you should understand the basic principles of design and symbolization, and tools you can use to make interesting, aesthetically pleasing, and effective maps.

4.1 Map Elements

Maps are composed of a varying number of elements. There are potentially dozens of map elements but we focus here on a few key ones.

- Figure. The thing or place being mapped is called the *figure* of the map. In the map below, the figure of the map is the continental United States.
- Ground. The figure is juxtaposed against the *ground* of the map, or in other words, the background. In this case, it is the countries outside of the United States and the oceans.

- Frame. Maps often have a *frame*, a line drawn around the figure and ground, that acts as a picture frame does for a picture. The more technical term *neatline* is also used.



Map elements. Key map elements include figure, ground, and frame. Additional elements that make for a basic map are title, legend, credits, and scale. [1]

Other elements are informative enough to be used almost always, including a title, scale, legend, and source information.

- Title. The *title* is a short, descriptive text typically at or near the top of the map. A good title should provide some detail about the map's content without being too wordy or descriptive. Map titles often include all or some of the following components: the subject of the map, the year, the spatial extent, the mapping resolution, and the data source.
- Legend. The *legend* lists the symbols used and explains what is being mapped. It is important to include the symbols on the legend exactly as they appear on the map. Legends include both text and graphics, and they sometimes contain additional details such as the source of the data or the year the data were collected. Labeling the units in the legend is important so the audience can properly understand the data being mapped. If your map of counties shows the number of bicycles per thousand people, then the legend should say so.
- Source/Credits. Think back to the data chapter and recall how important it is to know where the mapping data come from and what sort of biases are inherent in the data. For transparency purposes, it is necessary to provide attribution to the *source* of the data— the place, company, person, or agency that made the data. These are also known more generally as *credits*. Including the source makes it possible for the audience to explore the

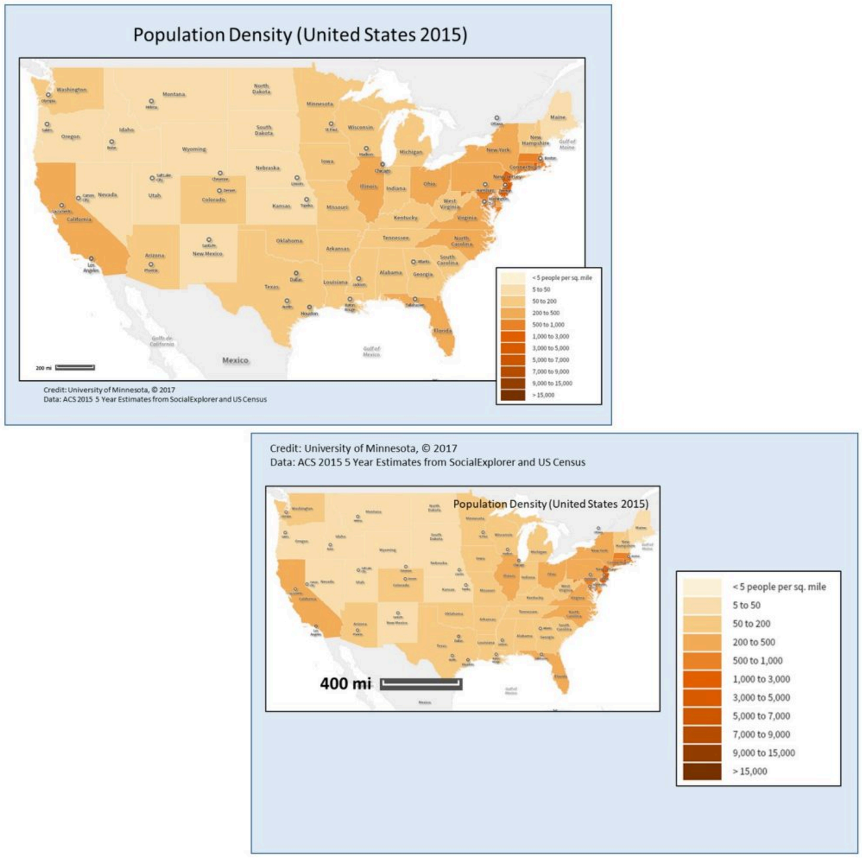
data further if necessary. Knowing who made the map can help the reader better gauge the accuracy and reliability of the data. Sometimes, the mapmaker is highly regarded for accurate and unbiased use of data; other times, he or she is known for having a political agenda that would raise doubts about data accuracy. Source attribution can be as simple as a short text annotation near the bottom of the map, or it can include more detailed information.

- Scale. Almost all maps include a scale because maps are smaller than the reality being mapped. Providing the map audience with information about what scale you are using is important so they can have some understanding of relative size and distance. The scale is often provided in a less prominent part of the map and is typically displayed with graphics or text. There are times when the scale is so obvious that it is omitted from a map. For example, a map of the entire world does not typically have a scale bar on it, because everyone has a general understanding of how large the world is. Keep in mind from the section on projections, however, that many maps distort area, so the sizes that you see on a map might not always be spatially accurate. In this case, listing the projection with the scale is helpful.

There are many other possible elements that cartographers may include and that you may see used in maps. These other elements, while not as frequently included, often represent good mapmaking practice, especially if you want the reader to understand how the map was created. These elements include the cartographer's name or company, the production date, and the projection. Some elements of the map, such as the north arrow, follow conventions, or commonly understood rules. Typically, we equate the orientation "up" with "north," so cartographers will often omit the north arrow on a map unless the map breaks that convention.

4.2 Design Principles

While a title, legend, source, and scale are necessary elements of all maps, they need be applied according to map design principles in order to properly convey the information. Poorly designed maps, like the one below, can be both difficult to read and confusing.

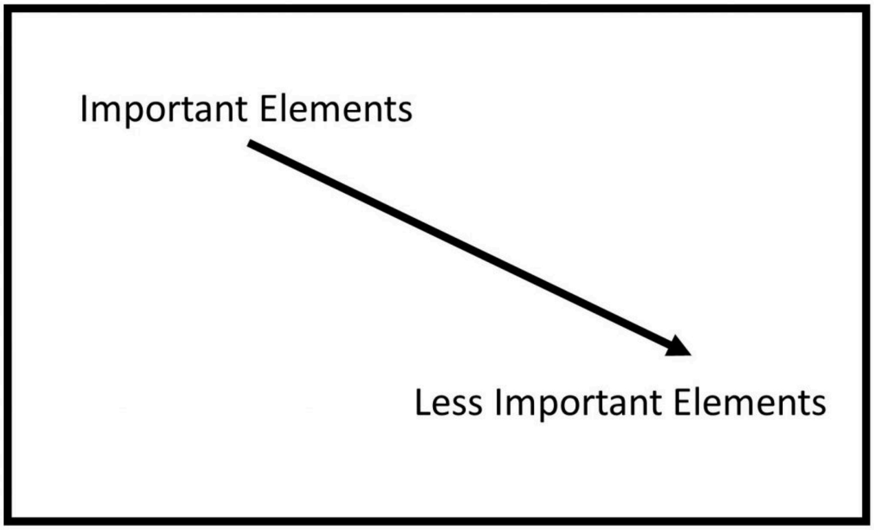


Poor map design. While the bottom map contains necessary elements (such as title, legend, scale, and source), it fails to practice principles of good design. It is unbalanced, disorganized, and uses white space poorly. [2]

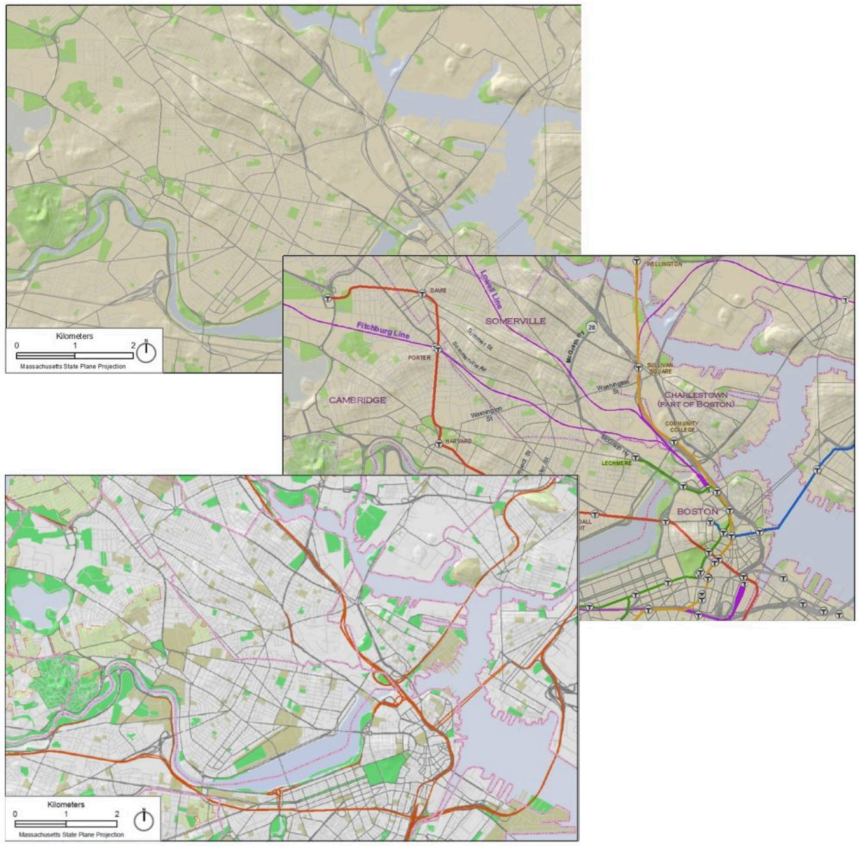
Designing maps to be visually appealing is an art form, and there are entire courses in cartography devoted to these principles. Two of the foundational elements of design that all good maps must incorporate are hierarchy and balance.

4.2.1 Hierarchy

Not all information on a map is of equal importance. A title is more important than the north arrow, so making them the same size would lead to an inadequate emphasis on the title. It also does not make sense if a legend is so large that it overwhelms the actual figure that you are mapping. *Visual hierarchy* is the design principle that takes these factors into consideration. A map with a good hierarchy emphasizes important information and figures by positioning them strategically on the map and by using visual variables appropriately. Typically, the top of the map is a good place for important information like the title. Size and color are two other important tools in creating a strong visual hierarchy, as the more important text and figures can be larger in size.



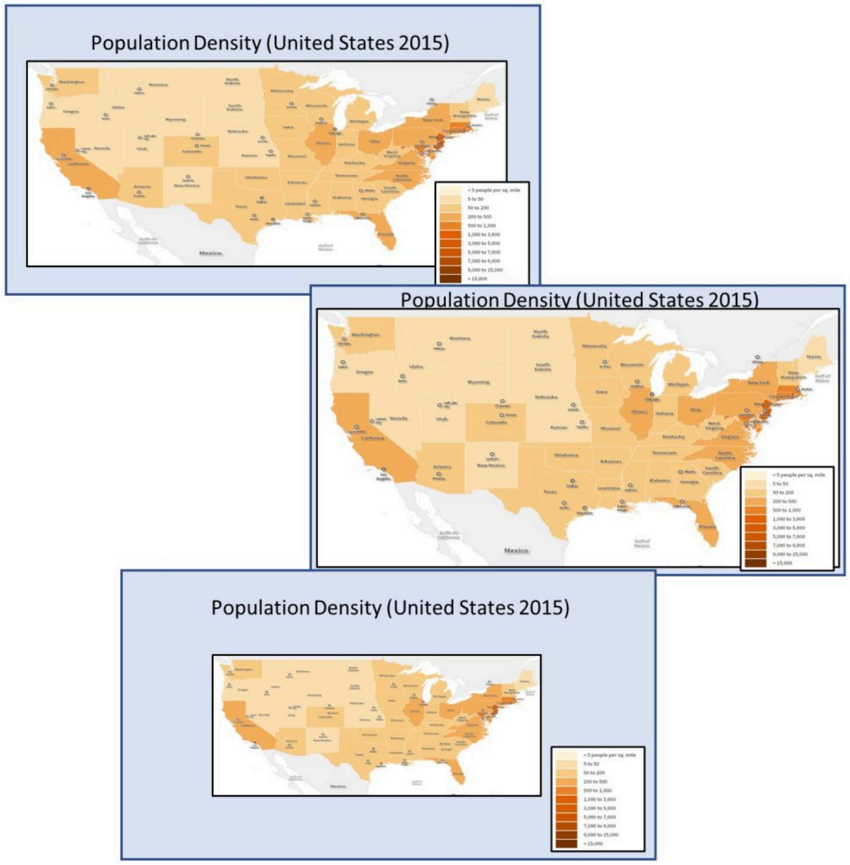
Visual hierarchy. Typically, the top left of the map is a good place for important information like the title. If this frame represents the layout of a map, it is often helpful to put your most important information on the top or the top left side of the page. Information near the bottom of the page seems less important to the map audience. Bear in mind that the "top-left to bottom-right" rule is relevant in the western context, but different cultures have different rules of visual emphasis so it is important to understand the audience of your map. [3]



Visual hierarchy examples. These three maps use various techniques of visual hierarchy. None of them are necessarily "correct," but you can see how certain techniques help to emphasize the important features. Note how these images use hues, sizes of lines, and texture in different ways to emphasize certain roads and parks. [4]

4.2.2 Balance

Not everything that is important can be in large text at the top of the map. After you satisfy the requirements of visual hierarchy, the next step is to make sure that your map looks *balanced*. This entails aligning text with other text or elements so everything looks neat and organized. If your map is too cluttered it will be difficult to see the information, so maintaining a sufficient amount of white space is helpful.



Hierarchy and balance. These are three examples of incorporating hierarchy and balance to varying degrees of effectiveness. The map on the top offers good hierarchy and balance as the image is well-sized, and there is sufficient white space. The map in the middle does not leave enough room for the legend and title. The map on the bottom has too much white space so it is difficult to make out the figure. [5]

4.3 Symbolization

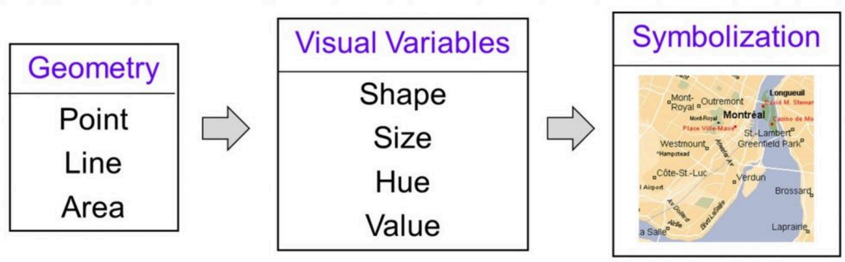
Symbolization is the term used to describe how the features on a map are visualized. Unless you are looking at an aerial photographic image, everything on a map is a symbol of something in the real world. A mapmaker must constantly decide how a map feature should be symbolized in a way that helps the reader to quickly understand what it represents and its degree of importance relative to other features on the map.

Before we continue, we need to consider a basic distinction between kinds of data, namely whether they are quantitative or qualitative.

- *Qualitative* data deal with descriptions of a real-world phenomenon that relate to the quality (which is where 'qualitative' comes from), or in other words, differences in **kind** or **existence**.
- *Quantitative* data are those that deal in measurements (or quantities, which gives us the term 'quantitative') that deal with differences in **amount**.

A qualitative map of cities, for example, would show whether a city exists or not in a given place, while a quantitative map would show the location of the city as well as some measurement, such as the number of people living there. A qualitative map of wildlife could indicate where different kinds of animals live, while a quantitative map would show the amounts of different animals.

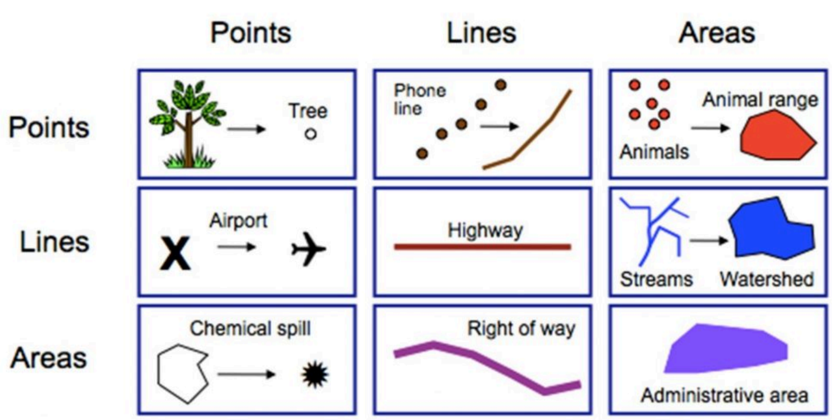
We look at two key components of symbolization: geometry and visual variables. Per the figure below, these components all work together to make map symbolization.



Symbolization components. Basic building blocks of symbolization are geometry (points, lines, and areas) and visual variables (shape, size, hue, and value).[6]

4.3.1. Geometry

Most map symbols are essentially variations on three simple geometric features: the point, the line, and the polygon.



Geometry. Points, lines, and areas and how they can be used interchangeably. Each row represents a different mode of symbolization, and each column represents a different kind of real-life thing or place.[7]

Points are typically used for discrete features, such as a tree or the location of a store. Lines are often used to represent roads, telephone lines, or other long, continuous features. Areas or polygons are typically used to represent boundaries such as counties or parks, but they can also be used to help generalize data such as the concentration of many individual animals. It is very common for all three of these geometric objects to be used in a single map, such as the map of Montreal below which contains the locations of roads (lines), cities (points), and parks (areas).

Power of symbolization. Satellite Image on the left compared to a map incorporating point, line, and area symbolization on the right.[8]

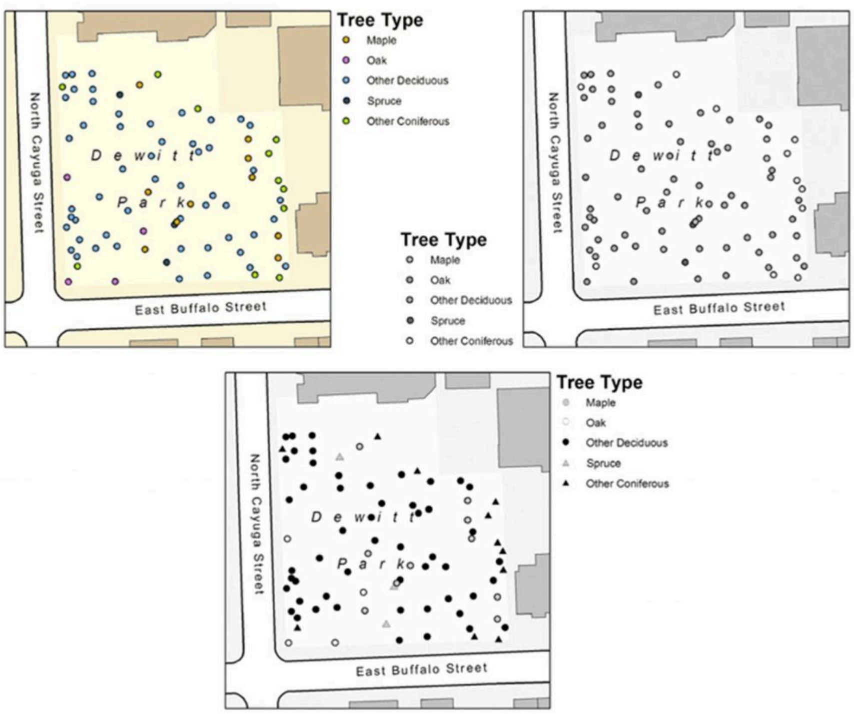
4.3.2 Visual Variables

We can modify the appearance of basic geometries of maps (points, lines, and polygons) in many ways. The modifications or variation of these points, lines, and polygons are referred to as *visual variables* because they describe how a given visual entity, like a line, for example, varies from dark to light or big to small. Visual variables are important in displaying both qualitative and quantitative data. The four main visual variables that are commonly manipulated on maps are shape, size, hue, and value. The figure below highlights the main tenants of these visual variables as well as what types of data they are best suited for.

Visual Variable	What Type of Data is it Used For?
Shape	Qualitative
Size	Quantitative
Hue	Qualitative
Value	Quantitative

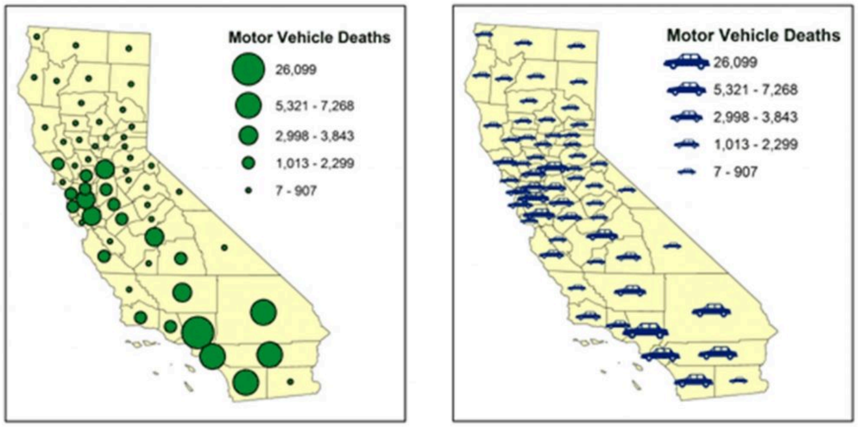
Quantitative and qualitative data. Different visual variables are suited to quantitative data and qualitative data. [9]

Shape. Shapes often indicate differences in kind, so they are good for qualitative data. There are certain conventions of shape use, such as an airplane for an airport, or a cross for a hospital. Shapes can also have much more specific representations. A wildlife map might show simple pictures of different species of animals to show the location of their habitats. Corporate logos can also be used, indicating the locations of dealerships for different models like Honda or Ford, or someone looking for a nearby fast food restaurant can easily distinguish between the locations of a McDonald's or a Burger King.



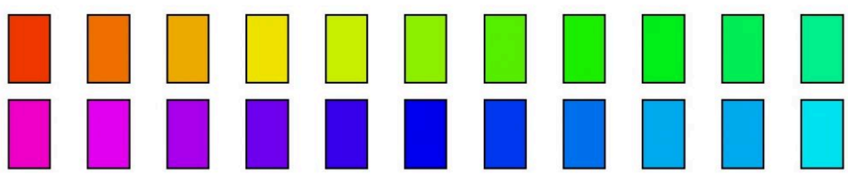
Qualitative data and shape. This map uses shapes to indicate different kinds of tree species. [10]

Size. Size is a visual variable especially well-suited for quantitative attributes. Large sizes are often understood to represent something of high value or importance, while small sizes represent low or less important values. Size is limited by the ability of the map audience to estimate the difference between sizes.



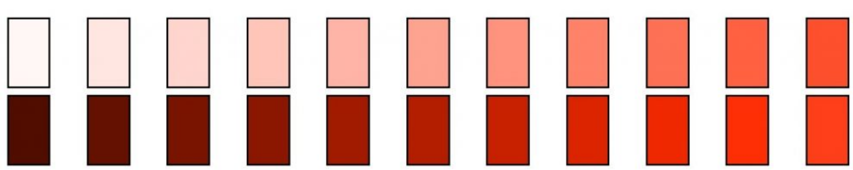
Quantitative data and visual variables. This map uses one hue and incorporates changes in size to demonstrate quantity. Cartographers sometimes like pictographic symbols because they can be more interesting (like the cars in the map at the right), but the complicated shapes of these symbols may make their areas more difficult to estimate and create greater problems with symbol overlap than more simple shapes like the circles in the map on the left. [11]

Hue. When people speak about color on a map they usually refer to what is technically known as hue. Hue is most commonly used to distinguish between qualitative data. Decisions are based on psychological and social factors because we associate certain colors with certain real-world things: blue (water), green (forest), and red (fire or heat). It is also common for red to be used to signify intensity or importance while calming colors such as blue or grey help to signify something of less intensity.



Hue. Different hues (colors) are used to demonstrate discrete qualitative data. [12]

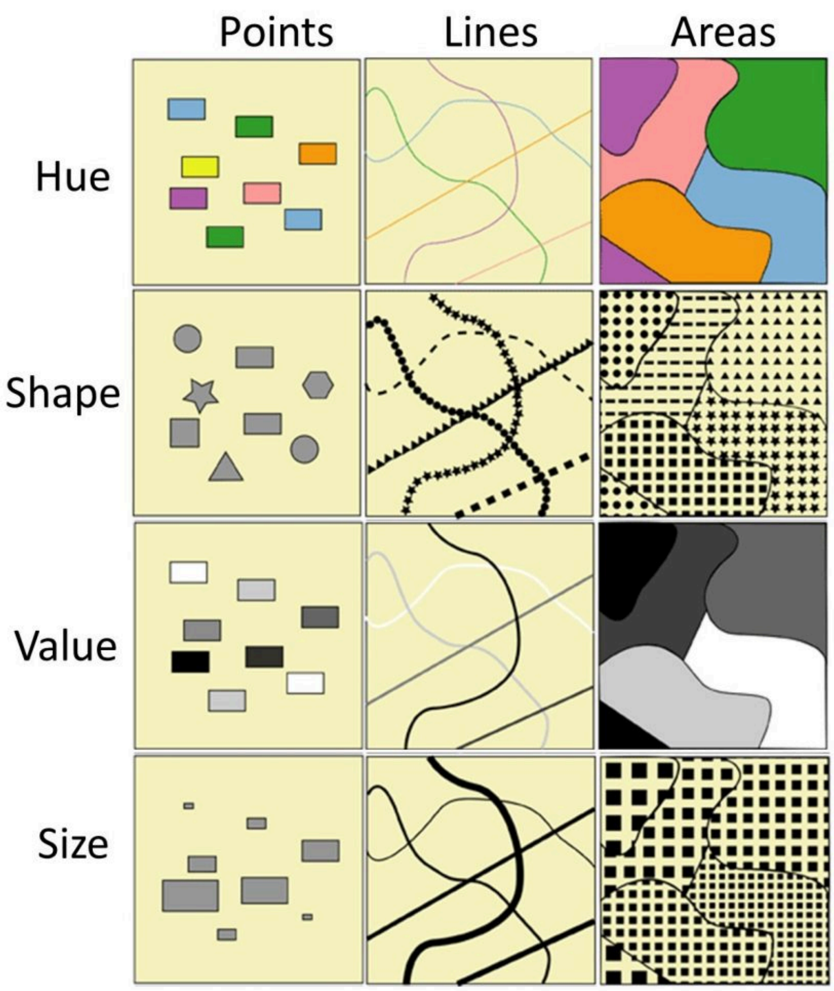
Value. Value refers to the lightness or darkness of a hue. It is most commonly used for quantitative data as it can demonstrate relative importance or amount on a continuous scale. While the distinction between light and dark is fairly obvious, be careful not to use too many different values on a map. The human eye has difficulty distinguishing more than about eight values on a map.



Value. Note the range of values across these 22 different shades of red. High value refers to a color that is very light, while low value refers to colors that are dark. [13]

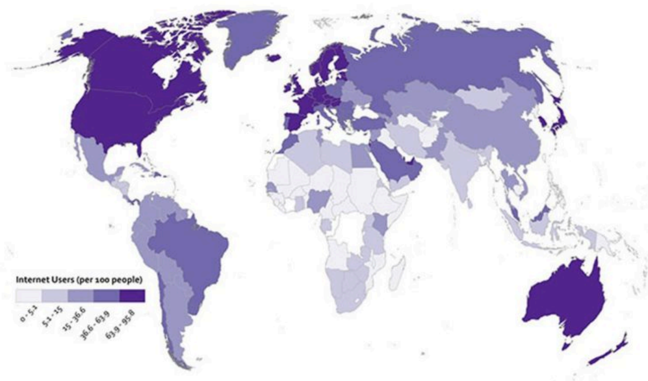
4.3.3 Recap

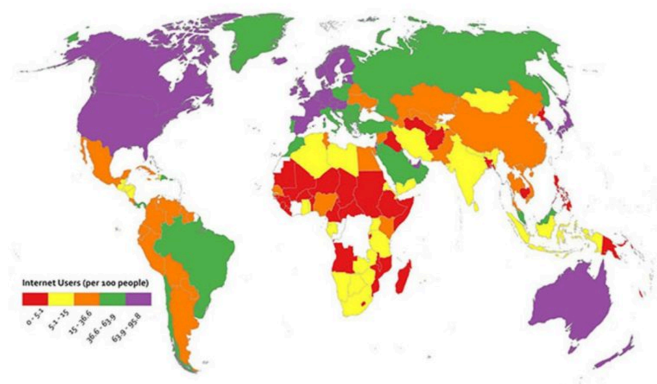
In very general terms, we use size and value for quantitative data and we represent qualitative data with hue and shape. This applies to points, lines, and areas, per this figure.



Visual variables with quantitative and qualitative data. Different visual variables are suited for quantitative data and for qualitative data. Cartographers tend to use size and value for quantitative data and represent qualitative data with hue and shape. [14]

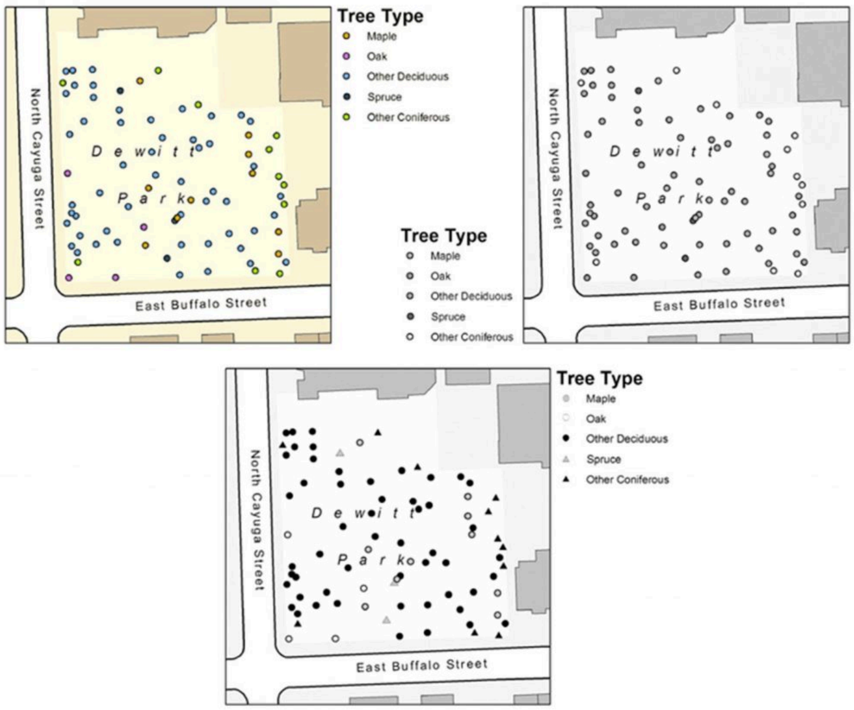
Note that the kinds of data, qualitative or quantitative, makes a difference in color choice. Consider the two maps below, which show internet users per 100 people by country. The first uses a single hue – purple – and different values. This first one is easier to understand because darker colors indicate higher values. The second one uses different hues – such as green or red or orange – to indicate different values. This one does not work as well because you have to study it intently to assess which places are high and low in terms of internet users.





Mapping quantitative data. These two maps use hue and value differently, with an impact on map readability. [15]

Symbolization choices may also be tied to the potential uses of your map. You may want to design a map in color but your map users may want to reproduce it in black-and-white, as when a color map gets photocopied on a black-and-white photocopier or printed on a monochrome printer. If you know that your color map may become reproduced in black-and-white, you may choose to adjust your color design so that important features do not become lost in the translation. The figure below explores these transitions for tree mapping.



Symbolization choices. In the top left map, different tree types are symbolized using different hues. If this map is photocopied (top right), it will be very difficult to tell most classes of trees apart. However, by using shape and value differences instead of hues (bottom map), the map reader can easily differentiate all five classes of trees. [16]

4.4 Conclusion

In this chapter, we have looked at the basics of symbolization. Basic map elements include the figure, ground, and frame as well as ones commonly seen on maps such as title, legend, scale, and source. These elements are then integrated with design principles, particularly hierarchy and balance, and the tools of symbolization, such as geometry and visual variables including shape, size, hue, and value.

Resources

For more information about symbolization:

- Basic Elements of Map Composition at the University of Colorado
- Visual Variables at the University of Muenster

For more information on cartography:

- The Geographer's Craft at the University of Colorado

References

Portions of section 4.3 were adapted from Adrienne Gruver (2016). Cartography and Visualization and David DiBiase and Jim Sloan (2016). Mapping Our Changing World.

Notes

1. CC BY-NC-SA 4.0. Steven Manson 2017. Data from SocialExplorer and US Census
2. CC BY-NC-SA 4.0. Steven Manson 2017. Data from SocialExplorer and US Census
3. Steven Manson 2017
4. CC BY-NC-SA 3.0. Steven Manson 2017. Adapted from Paul Cote (2009). Fundamentals of GIS. http://www.pbcgis.com/courses
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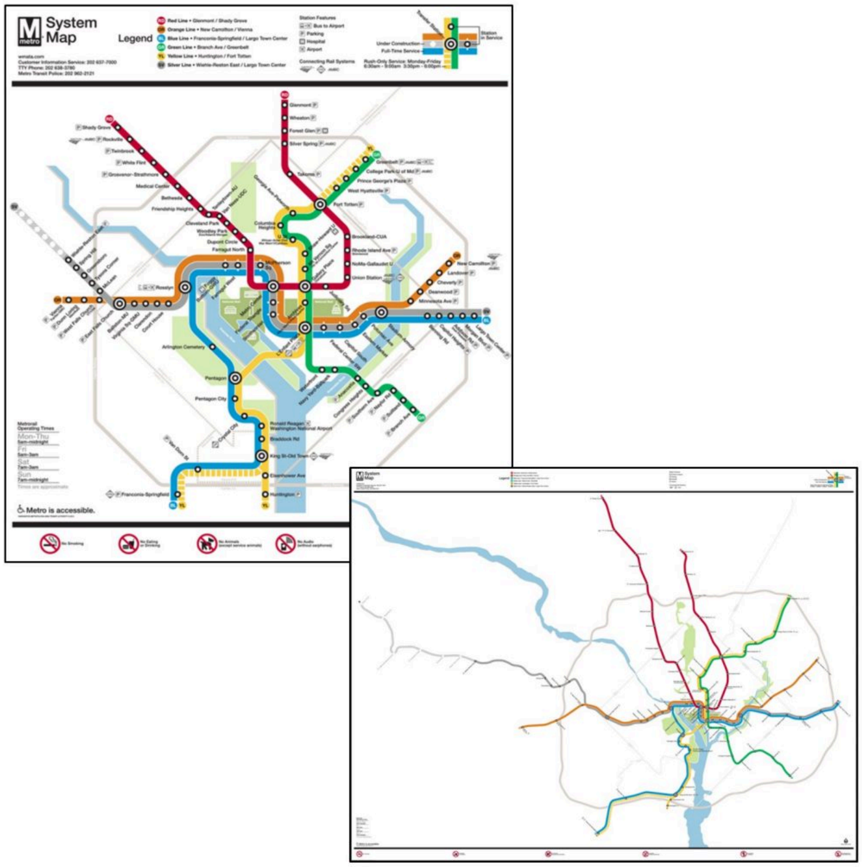
16. CC BY-NC-SA 3.0. Adapted from Adrienne Gruver (2016). Cartography and Visualization. https://www.e-education.psu.edu/geog486/l1_p7.html

5. Simplification

Melinda Kernik and Eric DeLuca

> “What a useful thing a pocket-map is!” I remarked.
>
> “That’s another thing we’ve learned from your Nation,” said Mein Herr, “map-making. But we’ve carried it much further than you. What do you consider the largest map that would be really useful?”
>
> “About six inches to the mile.”
>
> “Only six inches!” exclaimed Mein Herr. “We very soon got to six yards to the mile. Then we tried a hundred yards to the mile. And then came the grandest idea of all ! We actually made a map of the country, on the scale of a mile to the mile!”
>
> “Have you used it much?” I enquired.
>
> “It has never been spread out, yet,” said Mein Herr: “the farmers objected: they said it would cover the whole country, and shut out the sunlight ! So we now use the country itself, as its own map, and I assure you it does nearly as well.”
>
> Lewis Carroll, Sylvie and Bruno Concluded, Chapter XI, London, 1895

Maps are by necessity smaller than what they portray in the real world. Because of this, only a limited number of features can be represented on them. Choices have to be made about how to simplify the complexity of the world to be understandable on the map. Knowing who your audience is and having a clear sense of what you want to explain to them are crucial for deciding what to include and what to leave out. For example, subway maps prioritize the names of stops and connections between subway lines over the geographical location of the stops.



Subway map. The official subway map for the Washington DC metro (left) compared to a map of the subways drawn to scale (right). Subway maps prioritize the names of stops and connections between subway lines over the geographical location of the stops. [1]

Simplification is used in both thematic and reference maps. The first part of this chapter will look at different kinds of thematic maps and the concept of *classification*, paying close attention to how different classification schemes break up data between classes. We will also reflect on the ways in which selecting a classification scheme and the number of classes impact the data patterns that are visible. The second part of this chapter will look at how maps simplify the shape or number of objects on a reference map – a process known as *generalization*.

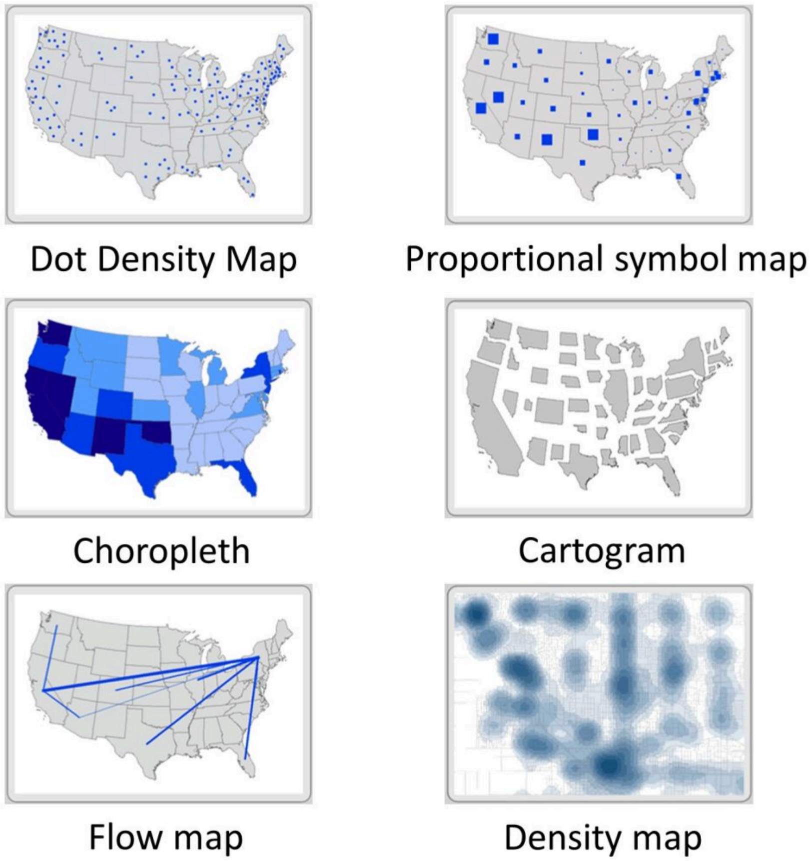
This chapter will introduce you to:

- the advantages and disadvantages of three common classification schemes
- situations in which data standardization is appropriate
- four major types of generalization on reference maps

5.1 Thematic Map Types

We use a variety of different kinds of maps. We will take a quick look at several key kinds and then focus on a few in particular.

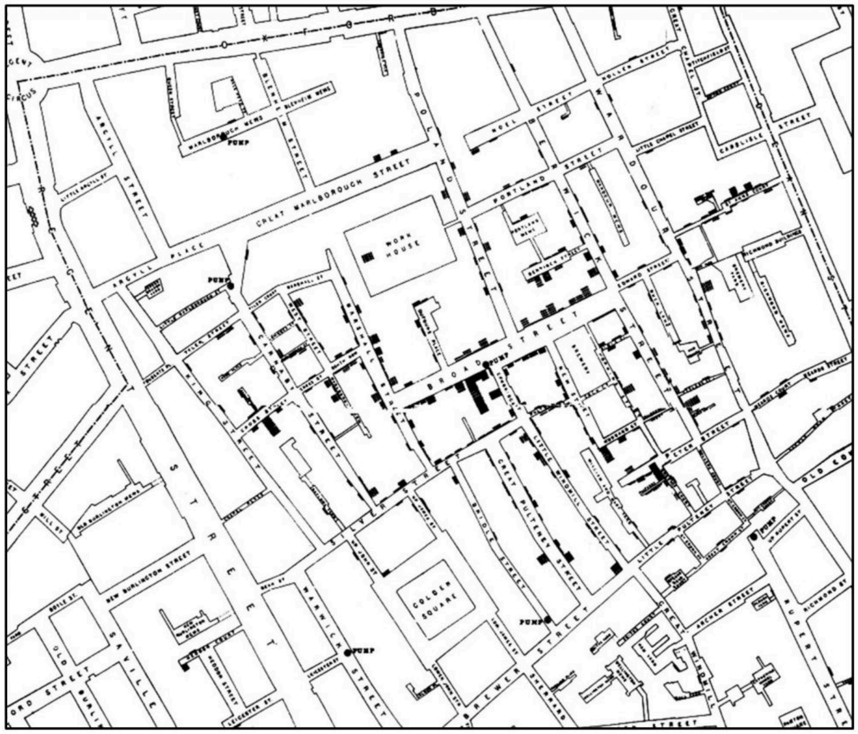
- *Dot density maps* use dots or points to show a comparative density of features over a base map. The dots are all the same size.
- *Proportional symbol maps* use symbols that occur at points across a map, but unlike dot maps, the symbol size varies based on the quantity or magnitude of the thing being measured. Generally speaking, higher values get larger symbols.
- *Choropleth maps* are among the most commonly used thematic maps. They use varying colors to show measures that are for areas or regions on the map.
- *Cartograms* distort the shape of areas to depict the magnitude of the attribute being measured. A relatively high value within a typically small geographic unit like a state will be depicted as disproportionately large on a cartogram because the size of the region is based on its attributes and not its actual size.
- *Flow maps* show the movement of goods, people, and ideas between places. Usually they depict the size of flows by changing the width of the lines connecting places.
- *Density maps* depict the concentration of point measures. You can think of this map showing how each location spreads out its presence beyond its immediate location to include adjacent areas.



Map types. There are six common kinds of thematic maps that are used to simplify data. [2]

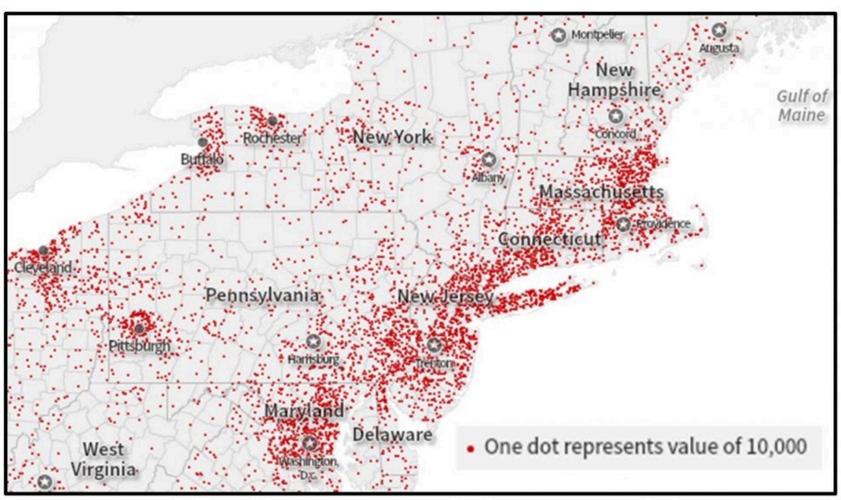
5.1.1 Dot Map

On a dot map, each dot represents a fixed quantity. For one-to-one dot maps each dot represents one object or person. For example, John Snow’s famous map had one dot for each reported death from cholera around the Broad Street pump.



One to one cholera map. John Snow’s famous one-to-one map of cholera deaths centered around the Broad Street pump.[3]

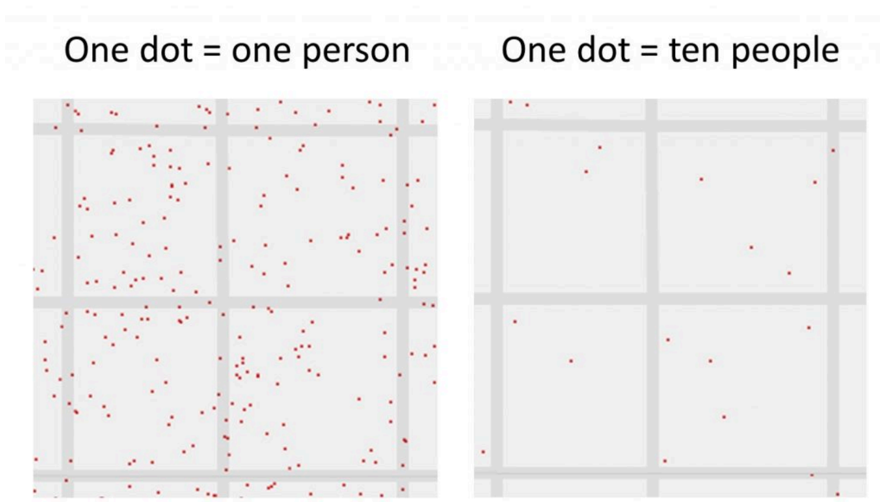
Alternatively, one dot can stand in for multiple objects or people. The figure below shows an example of a many-to-one map in which one dot represents 10,000 people.



Many-to-one dot map. This map portrays the total population of the Northeastern United States. Each dot represents 10,000 people. [4]

Dot maps are useful for quickly visualizing patterns of clustering and density. They do not require color to communicate, which avoids issues arising from differences in how people perceive color such as color blindness. Though they are versatile and intuitive, it can be hard to determine precise numbers based on a dot map. One area may have more dots than another, but to know how many more would require you to painstakingly count hundreds or thousands of dots.

Privacy can also be an issue for one-to-one maps. For example, you might not want exact locations known when mapping sensitive subjects such as where patients with sexually transmitted diseases live. To get around this, dots are often displaced from their actual location. By simplifying the number of dots on the map, many-to-one maps avoid privacy problems but instead face the challenge of where to place the dots. Dots are generally positioned at an average location of the multiple objects represented.



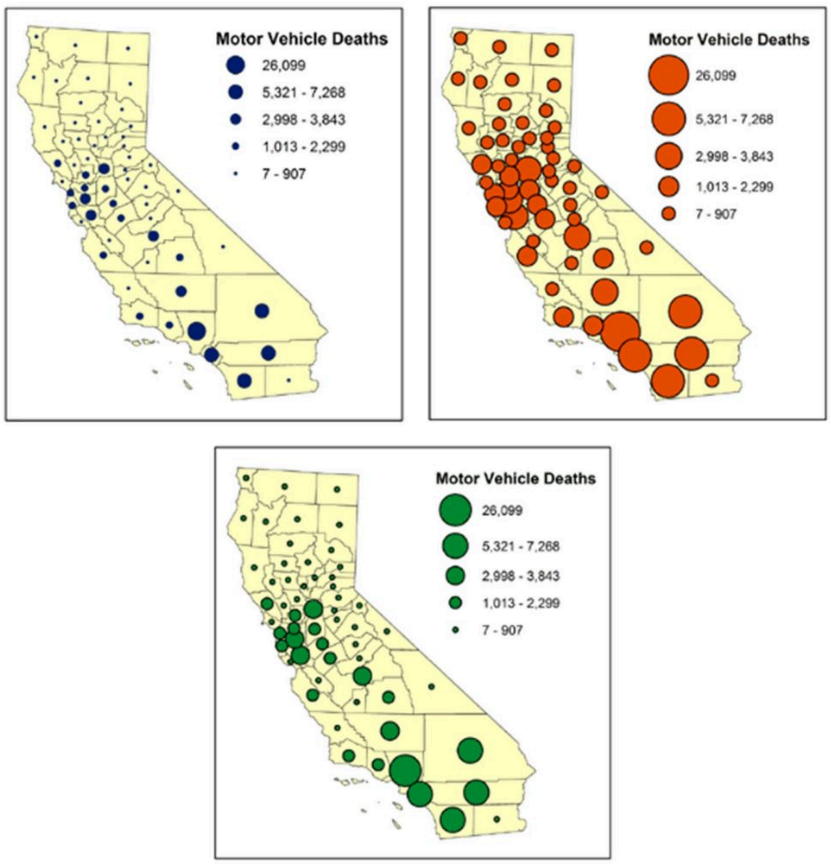
Dot map simplification. The placement of dots in the middle of roads and uneven distribution around the block are evidence that the dots in the one-to-one dot map have been displaced. The many-to-one map of the same blocks simplifies the amount of data shown and places dots at an average location. [5]

Note that it is crucial that dot maps be drawn using an equal area projection, or the density of the dots will be distorted.

5.1.2 Proportional Symbol Map

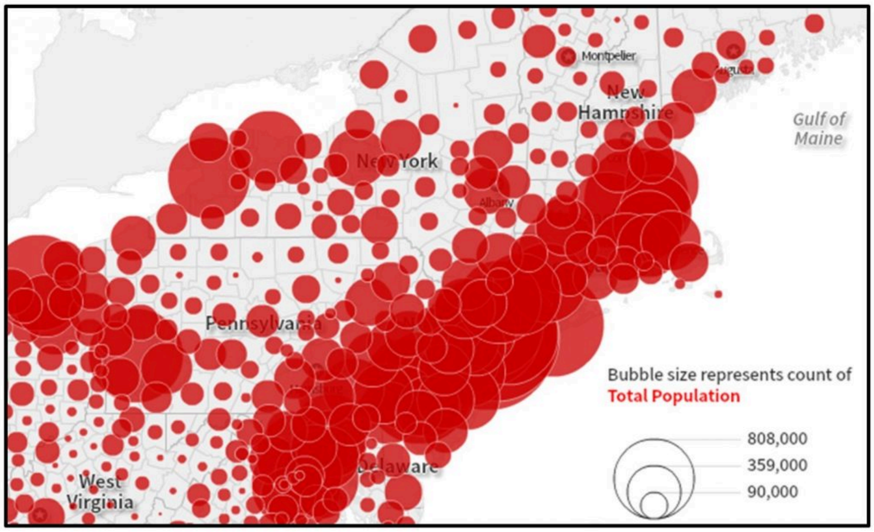
This type of map adjusts the size of simple symbols proportionally to the data value found at that location. The larger the symbol, the "more" of something exists. Proportional symbols can be used to represent data at precise locations (points) or data averaged over a geographic area. A key advantage of this type of map is that the perception of data value is not affected by the size of the area that the symbol represents. In choropleth maps, states with small geographic areas (such as Rhode Island) may be overlooked even if they have a large data value. By contrast, the sizes of symbols in a proportional symbol map are not tied to the land area.

The downside to this is the greater likelihood of visual clutter. Symbols may overlap if locations with large values are close together. As in the figure below, the relative sizes of symbols can matter. If you choose symbols that are overall too small, it will be more difficult for the map reader to see patterns in the data (top left) but if they are too large, many symbols will overlap and make it difficult to see patterns in the data (top right). Ideally, the symbols have a slight overlap between symbols in the most crowded area of the map (bottom) without there being so much overlap that symbols are hidden.



Symbol size. Proportional symbol map of motor vehicle deaths in California, United States. Note how the relative sizes of symbols must be chosen with care. [6]

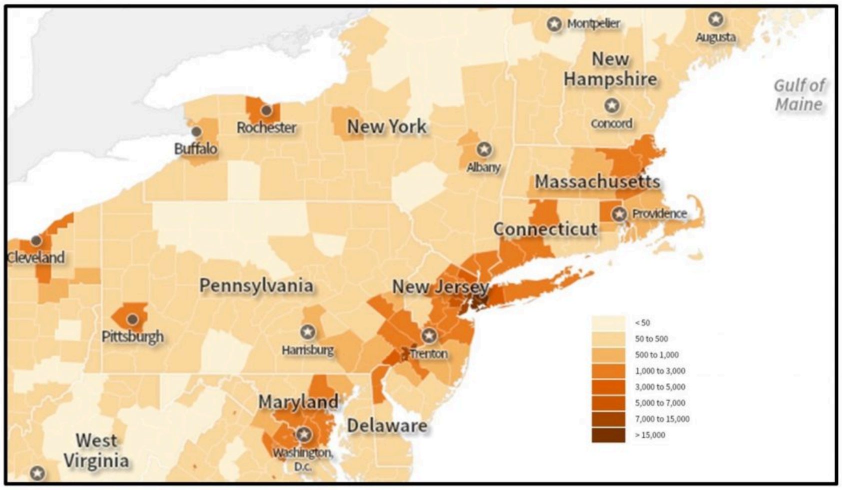
This problem of overlap in proportional symbol maps can get to the point where people have trouble accurately comparing symbol sizes, in the figure below. Many people underestimate differences in symbol size, especially when the difference is large. The proportional symbol map maker must strike a balance between having a range of symbol sizes and limiting their overlap.



Proportional symbol map. With this map of the population by county, it is difficult to make out which county each symbol represents in areas with many small populated counties. [7]

5.1.3 Choropleth Map

On choropleth maps, areas are shaded using hue or value to represent different quantities. Usually darker hues or values signify larger quantities. Choropleth maps are easy to make and to interpret, which has made them very popular among map makers. They can, however, be very misleading if incorrectly standardized or if the geographic phenomena being mapped are not intrinsically tied to the areas being shaded. For example, rainfall totals, soil type, and length of a commute do not vary according to county or zip code boundaries. Phenomena being mapped rarely change abruptly at human-defined boundaries as they appear to do on a choropleth map, and there may be a lot of variation within an area symbolized with a single color. When working with choropleth maps, a mapmaker must try to maintain important patterns while simplifying unnecessary complexity.

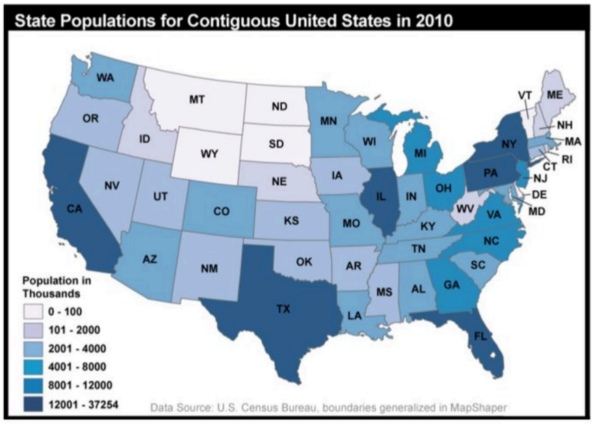


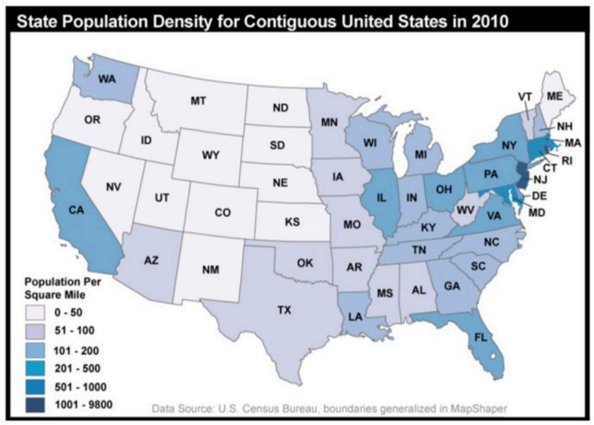
Choropleth map of population density. This map of population density by county from the 2010 Census relies on users correctly interpreting the way the data are divided into groups. [8].

5.2 Standardization

An important consideration in thematic mapping, especially in choropleth maps, is whether data are visualized as a count (e.g., number of people) or as a density (the number of people per square mile). The primary reason to standardize data is to allow the map reader to compare places that are very different in terms of size or shape. Comparing a large place like Russia to a smaller place like Ireland is only really possible by looking at population density instead of population total. Russia has far more people than Ireland but has a lower population density because it is so large.

Some forms of standardization are spatial such as population density – the number of people per square mile. Consider the figure below. The map on the top simply shows the count of the number of people in each state in 2010. Texas and New York have a much larger population than North or South Dakota, so it should be unsurprising that they also have a darker shading. By contrast, the map on the bottom is standardized – showing the number of births per square mile. This map is more interesting because it focuses on people and not state size.





Standardization and population. The top map shows the count of the number of people in each state in 2010. The bottom map is standardized – showing the number of births per square mile. Jennifer M. Smith, Department of Geography, The Pennsylvania State University; Data from U.S. Census Bureau. [9]

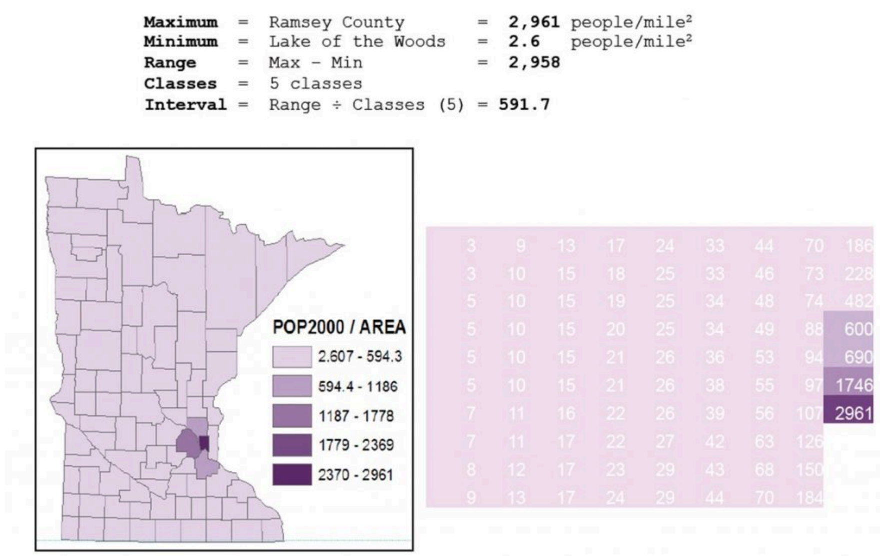
Other types of standardization are non-spatial, such as dividing the cost of housing by the total household income or dividing the number of students receiving free or reduced-price lunch by the total number of students at that school. Both the raw count and standardized numbers can be useful, depending on what you are trying to accomplish. If you are calculating the cost of providing meals through the free or reduced-price lunch program, you would need to know the number of students who qualify. If you are trying to understand how much of a student body faces food insecurity, having a standardized number – the percentage of students receiving free or reduced-price lunch – would be more useful. When mapping social data, unless the areas being compared are similar in size and population, it is usually best to standardize numbers.

5.3 Classification

Classification is at the heart of simplification and thematic mapping. Classification can be used to simplify a wide range of values into something that can be more easily interpreted by the map audience. Rather than symbolizing each data value with a unique hue or size, values are grouped together into a smaller number of categories. There are many classification schemes – methods for breaking up the data into these categories. We will focus on three of the most frequently used classification schemes: 1) equal interval, 2) quantile, and 3) natural breaks.

5.3.1 Equal Interval

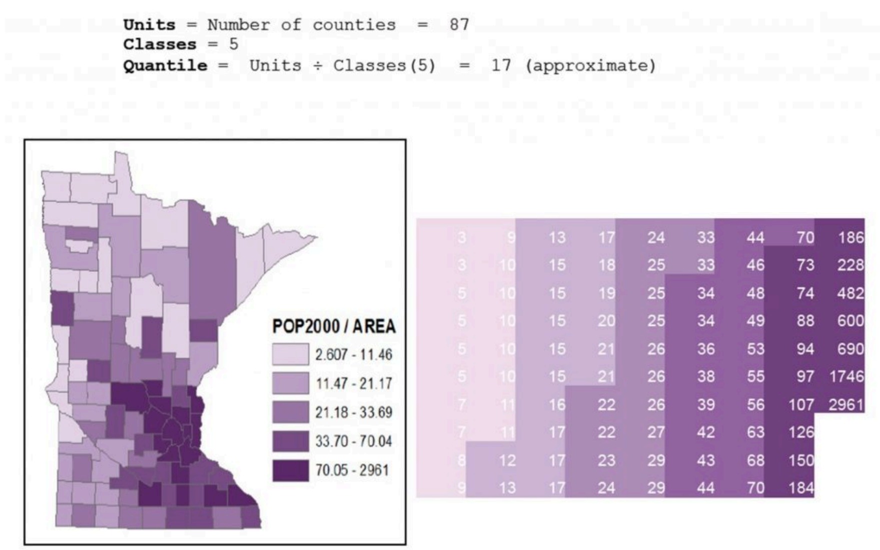
Using the equal interval method, data is split into classes that have an equal range of values (e.g., 0-100, 100-200, 200-300, and so on). Equal interval is easy to interpret and to compare with other maps in a series. However, it does not work well for all data distributions. If there are gaps in the data values, some classes may be empty. If the data are strongly skewed or has outliers, you may end up with a map where almost all areas are in a single class. Equal interval works best when data are relatively evenly distributed between the minimum and maximum value, and there are no outliers.



Equal-interval classification. Population density by county in Minnesota in the United States using equal-interval classification. [10]

5.3.2 Quantile

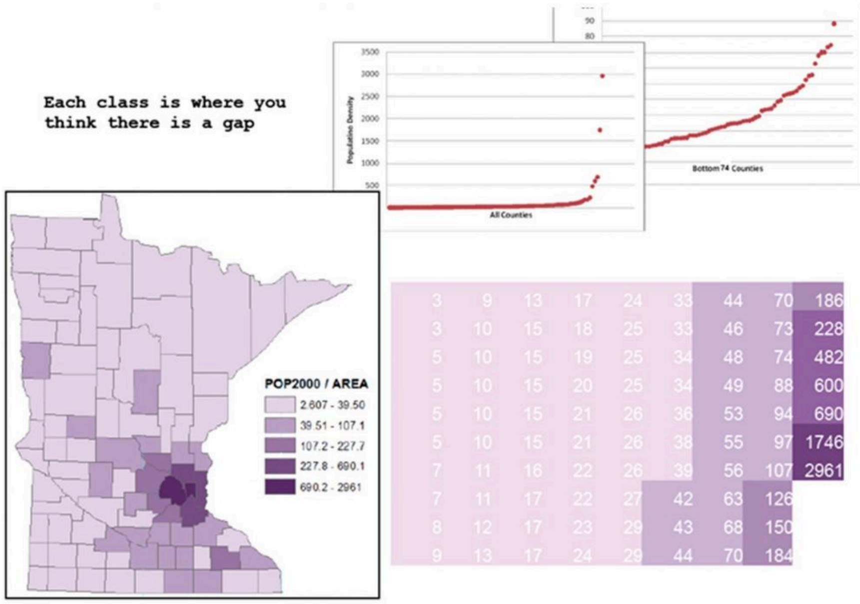
With the quantile method, data are split so that there is an equal number of observations in each class. For example, if you have 100 cities and 5 classes, there would be 20 cities in each class. This method yields attractive, visually balanced maps and can be useful if you are working with ordinal data or those that are ranked (in this case from largest to smallest). Because it puts the same number of observations in each class without reference to the value of those observations, quantile sometimes groups very different values in the same class (e.g. 0-11,12-21,22-33,34-70,71-2961). This effect is especially notable with outliers, or especially low or high values that are out on their own. If one were to create a quantile classification that is technically exacting, it could put observations with the same value into different classes; however, mapmakers will often manually change the classification so that observations of equal value are not separated, which makes it more like a natural breaks classification (below).



Quantile classification. Population density by county in Minnesota, United States using quantile classification. [11]

5.3.3 Natural Breaks

The natural breaks method attempts to maximize differences between classes and minimize differences within classes. There are multiple algorithms for how to do this, usually by putting breakpoints where there are the largest gaps between observation values. This method works especially well for data with clusters or outliers. One drawback to natural breaks is that it establishes unique breakpoints for each dataset and thus is difficult to use if you need to make a comparison across multiple maps (e.g. population change in a city between 1970 and 2010).

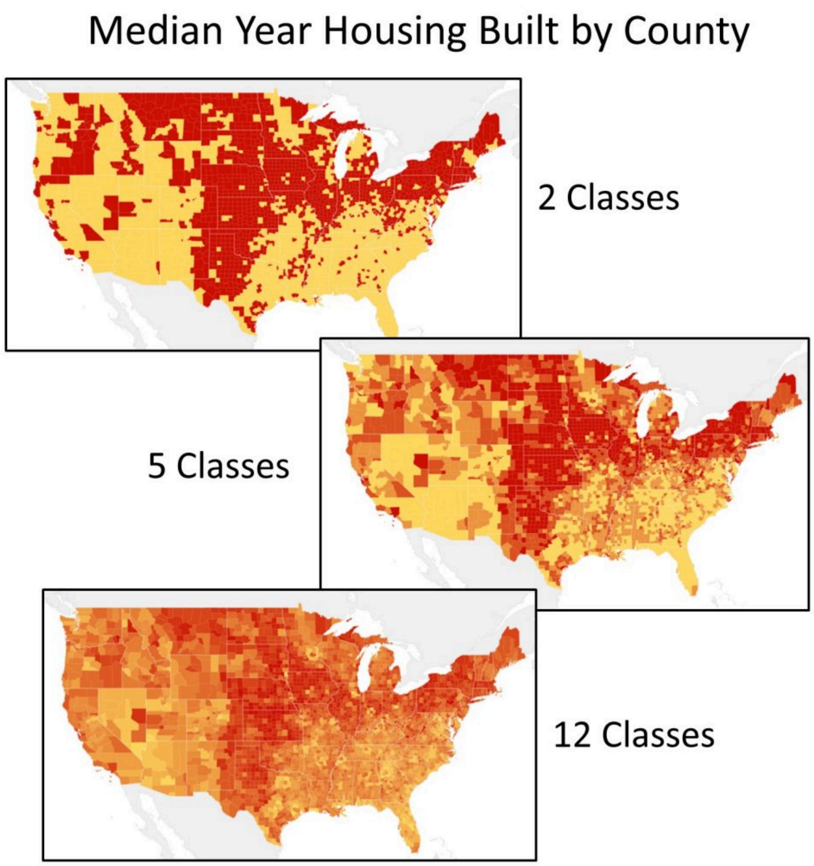


Natural breaks classification. Population density by county in Minnesota, using natural breaks classification. The smaller graphs above are scatter plots of the actual data points and show the population density of the counties range from lowest on the left to highest on the right. You can see how the graph of all counties has many low values and just a few higher values on the right-hand side, which are the populous Twin Cities counties such as Hennepin and Ramsey. [12]

5.3.4 Number of Classes

In addition to selecting a classification method, mapmakers need to decide how many classes or categories to divide the data into. Having only a few classes can hide important details and draw attention to geographical patterns that are not actually there. Having too many classes, however, can make a map confusing.

With more classes, it can be hard to distinguish between different colors, increasing the likelihood that values in the legend will be misread. There is no ideal number of classes that will work for every choropleth map. It depends on what you are trying to convey and how your data are distributed.



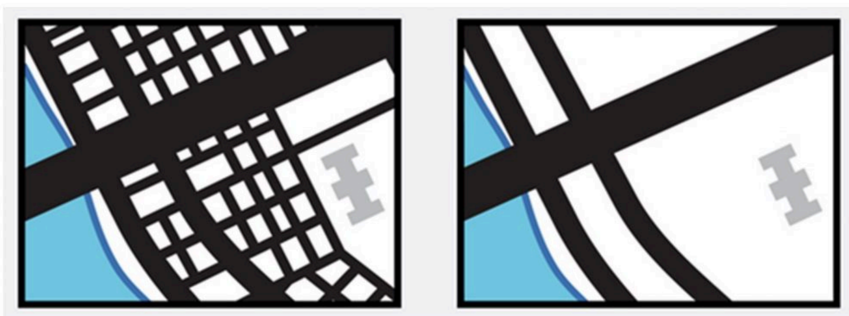
Different classifications. These three maps use the same classification scheme (quantile) and data (ACS 2010 5-yr estimate), but show different patterns and locations of where older housing stock exists. [13]

In summary, depending on choices made about standardization, classification scheme, and the number of classes, the same data can be visualized very differently. These differences can have a huge influence on the social and political conclusions drawn from a map. When making maps or looking at a map someone else has made, be very thoughtful about how your data has been divided into categories.

5.4 Generalization

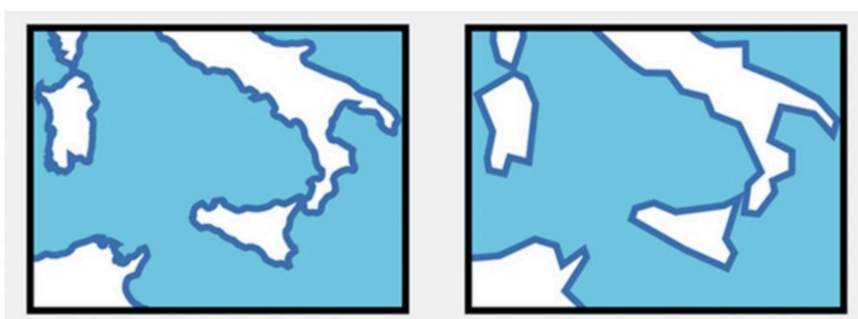
We have been looking at simplifying data for thematic maps (i.e., grouping data into a smaller number of categories or areas). Simplifying data and information is also important when making reference maps, a process known as generalization. Generalization is especially necessary on small-scale maps. For example, as you zoom out on Google Maps, it becomes increasingly impractical to show small details like residential streets. Even if you wanted to include every building and street name, objects eventually will be too small to be displayed on your computer screen. A mapmaker has to choose what features of the map are most important to include and what can be simplified.

Eliminate. Removing objects from a map. A mapmaker may remove features completely if they become too small to see, too close together to be meaningful or provide unnecessary detail. For example, small residential streets have been eliminated from the image on the right.



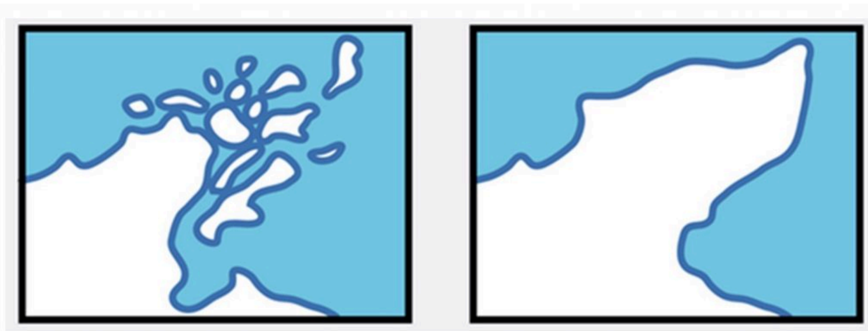
Elimination. Map generalized by eliminating streets. [14]

Simplify. Smoothing or removing the geometry of features on a map. Shorelines, rivers, and borders between countries often have lots of curves and bends. When working at small scales, a mapmaker may choose to simplify the shapes of objects or smooth out wiggly lines. Note: yes, this can be confusing – generalization is a kind of simplification, but generalization also uses an approach called simplification.



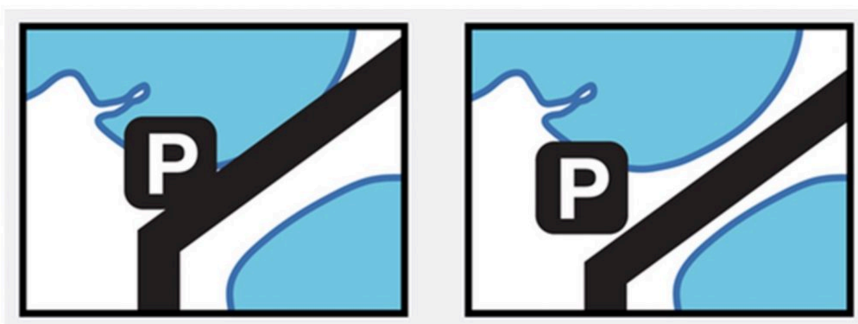
Simplify. Map generalized by smoothing shorelines. [15]

Combine. Merging, aggregating, or amalgamating features. A mapmaker might also choose to combine small objects into a larger object that will be visible when zoomed out at small scales.



Combine. Map generalized by combining islands with the mainland. [16]

Displace. Moving or enhancing an object. If an object is important for the purpose of the map but very small or not visible at a selected scale, a mapmaker might enhance the size of the symbol. The symbol will appear on the map larger than it would be in reality. If multiple important objects are so close together that their symbols overlap, the map maker might also move them apart. For example, the road and parking lot in the image on the right has been shifted slightly from their actual location so that the map is easier to read.



Displace. Map generalized by moving the road to enhance separation from the shoreline. [17]

5.5 Conclusion

The key to making good choices about simplification is to know what you are trying to say with your map. Now you are familiar with several types of thematic mapping including dot maps, proportional symbol maps, and choropleth maps. You also have a sense of how standardization and classification influence what data looks like when it is visualized on a map. We have examined simplifying data by dividing it into classes (via the process of classification) with three basic approaches: 1) equal interval, 2) quantile, and 3) natural breaks. We also took a gander at simplifying geometry by generalizing the actual point, lines, and areas via elimination, combination, simplification, and displacement. Most importantly, you should be on the lookout for simplification and curious about its impact on the message of the maps you encounter.

Resources

For more information about Thematic Map Types:

- Indie Mapper
- Map Types at University of Muenster

For information on classification:

- Choropleth Mapping with Exploratory Data Analysis at Directions Magazine

Notes

1. CC BY-NC 4.0. Peter Dovak 2013. https://www.behance.net/gallery/Washington-Metro-Map-to-Scale/10965947
2. CC BY-SA 3.0. Adapted from http://giscommons.org/output/
3. Public Domain. John Snow; Published by C.F. Cheffins, Lith, Southampton Buildings, London, England, 1854 in Snow, John. On the Mode of Communication of Cholera, 2nd Ed, John Churchill, New Burlington Street, London, England, 1855. https://commons.wikimedia.org/w/index.php?curid=2278605
4. CC BY-NC-SA 4.0. Sara Nelson 2015. Data from SocialExplorer and US Census.
5. CC BY-NC-SA 4.0. Sara Nelson 2015. Data from SocialExplorer and US Census.
6. CC BY-NC-SA 3.0. Adapted from Adrienne Gruver (2016). Cartography and Visualization. https://www.e-education.psu.edu/geog486/l1_p7.html
7. CC BY-NC-SA 4.0. Sara Nelson 2015. Data from SocialExplorer and US Census.
8. CC BY-NC-SA 4.0. Sara Nelson 2015. Data from SocialExplorer and US Census.
9. CC BY-NC-SA 3.0. Adapted from Dibiase et al. (2012) Mapping our Changing World. https://www.e-education.psu.edu/maps/l5_p5.html
10. CC BY-NC-SA 4.0. Steven M. Manson and Jerry Shannon, 2012
11. CC BY-NC-SA 4.0. Steven M. Manson and Jerry Shannon, 2012
12. CC BY-NC-SA 4.0. Steven M. Manson and Jerry Shannon, 2012
13. CC BY-NC-SA 4.0. Steven Manson 2015. Data from SocialExplorer and US Census
14. CC BY-NC-ND 4.0. Roth, R.A., Brewer, C.A., and Stryker, M.S. (2011). A typology of operators for maintaining legible map designs at multiple scales, Cartographic Perspectives NorthAmerica, 68, Mar. 2011. Available at: http://www.cartographicperspectives.org/index.php/journal/article/view/cp68-roth-et-al/18. Date accessed: 24 Sep. 2015.
15. CC BY-NC-ND 4.0. Roth, R.A., Brewer, C.A., and Stryker, M.S. (2011). A typology of operators for maintaining legible map designs at multiple scales, Cartographic Perspectives, NorthAmerica, 68, Mar.

2011. Available at: http://www.cartographicperspectives.org/index.php/journal/article/view/cp68-roth-et-al/18. Date accessed: 24 Sep. 2015.

16. CC BY-NC-ND 4.0. Roth, R.A., Brewer, C.A., and Stryker, M.S. (2011). A typology of operators for maintaining legible map designs at multiple scales, Cartographic Perspectives, NorthAmerica, 68, Mar. 2011. Available at: http://www.cartographicperspectives.org/index.php/journal/article/view/cp68-roth-et-al/18. Date accessed: 24 Sep. 2015.
17. CC BY-NC-ND 4.0. Roth, R.A., Brewer, C.A., and Stryker, M.S. (2011). A typology of operators for maintaining legible map designs at multiple scales, Cartographic Perspectives, NorthAmerica, 68, Mar. 2011. Available at: http://www.cartographicperspectives.org/index.php/journal/article/view/cp68-roth-et-al/18. Date accessed: 24 Sep. 2015.

6. Analysis

Laura Matson and Eric Deluca

Analysis is a way of interpreting what is going on in the maps that you encounter and create. Analytical tools provide ways of engaging with data, understanding spatial patterns, and giving us a vocabulary for discussing what we see when we look at a map. There are many ways to spatially analyze the data displayed in maps – too many to mention here. In this chapter, we will focus on a few particular techniques for analyzing maps, and we will touch on some of the social, economic, and political implications of map analysis.

This chapter will introduce you to four kinds of analysis:

- point pattern
- autocorrelation
- proximity
- correlation

These categories differ in several ways. They can differ in whether they are looking at location alone, or location and attributes at the same time. They sometimes differ in whether they look at points *and* areas, or just points *or* areas. These analytical approaches also differ in whether they are looking at just one theme (say, just population) or more than one theme at a time (such as two maps of counties, one of population density per county and another of median income).

Depending on the focus of inquiry and the number of themes being analyzed, some maps can be analyzed using more than one of these methods, and other maps are best analyzed using just one. In this chapter, we will teach you the differences between these four types of spatial analysis, and ask you to use these analytical methods to understand maps. Keep in mind that although we draw distinctions between these types of analysis throughout the chapter, there are many overlaps and situations in which different analytical methods (particularly proximity and correlation) can be used in tandem. At the end of this chapter, you will have the basic skills to analyze and interpret maps and spatial data.

Type of Analysis	Focus of Inquiry	Geometric Feature	Number of Themes
Point Pattern	Location	Point	1 Theme
Autocorrelation	Location and Attribute	Area	1 Theme
Proximity	Location	Point/Area	2+ Themes
Correlation	Location and Attribute	Point/Area	2+ Themes

Analysis. Four common methods for analyzing maps. They differ in whether they are looking at location alone or location and attributes at the same time. [1]

6.1 Point Pattern Analysis

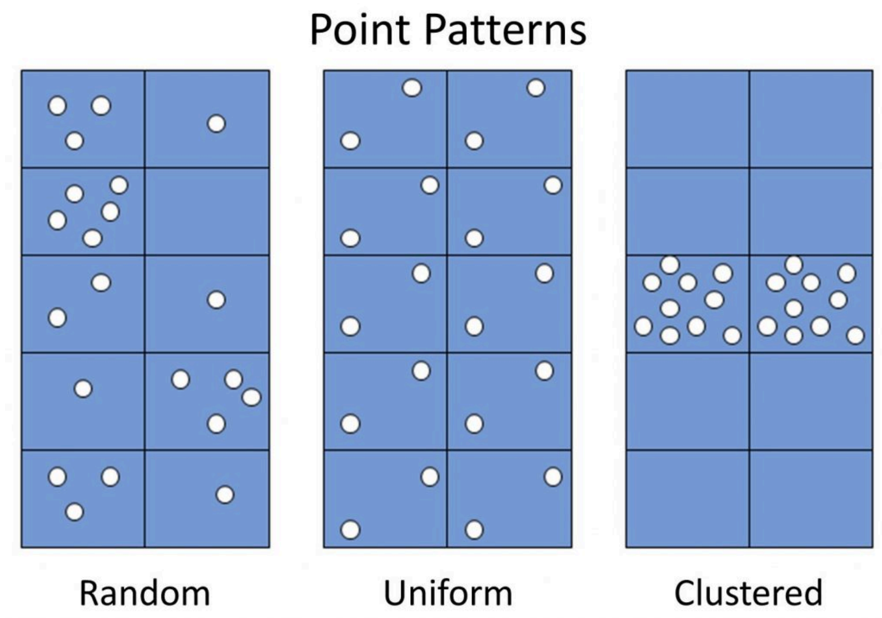
Point pattern analysis looks at the spatial arrangement of the locations of objects or events within a single theme and does not consider how their attributes vary. In particular, this kind of analysis looks at the relationship between the locations of objects or events in space relative to the locations of other objects or events.

The map below looks at the distribution of burglaries near the Thames River in London. Here we are looking at the locations of specific events—burglaries—which occur when someone enters a building illegally with the intent to steal something. Note that technically there is a qualitative attribute being considered – did a burglary occur at a given location or not? – but we are really just interested in the location of these events. We are not interested in the attributes of any given burglary itself, such as what was stolen, what was it worth, whether the thief caught, or any number of other kinds of attributes we could measure or questions we could ask.

London burglaries. This map portrays the distribution of burglaries near the Thames River in London. [2]

We use point pattern analysis to describe the pattern of this one particular theme of interest—locations of burglaries—over the mapped area. Point pattern analysis can help us to see where spatial patterns of burglaries are occurring, such as if burglars are targeting a particular block in recent days. As you would guess from the name, point pattern analysis is interested in finding patterns in locations, in this case where there are any patterns in burglaries. We need a language to describe these patterns, which is what we explore next.

There are three main types of point patterns – or spatial distributions of locations of entities or events – in a map: random, uniform, and clustered.



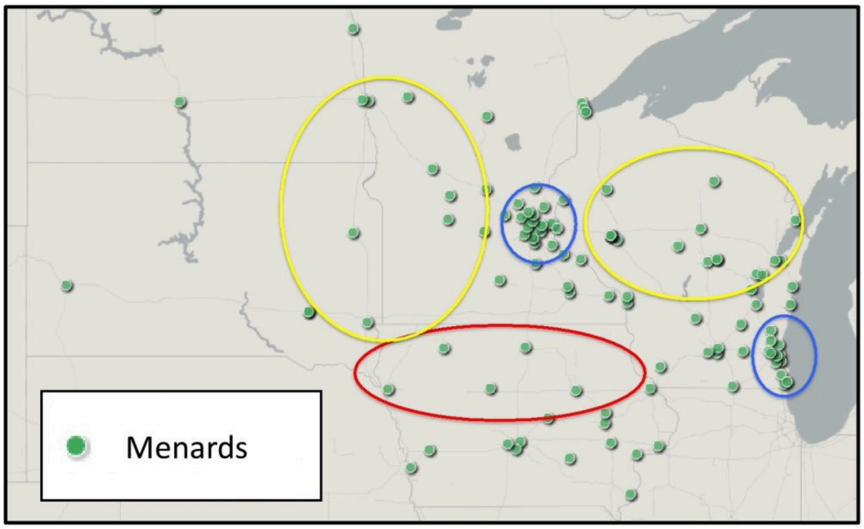
Point patterns. Three general point patterns are random, uniform, and clustered. [3]

Random. A random pattern is where locations are distributed seemingly randomly, or in other words, where the position of any one point is unrelated to the locations of other points. Marketing firms that conduct phone surveys often want a random distribution of people, for example, so they use methods to ensure that they choose random locations where people live in a city, state, or nation.

Uniform. A uniform pattern is one in which locations are evenly distributed through space. Maps of fire stations in a county often display a uniform pattern because fire stations are deliberately spaced out across a city or county in order to ensure that firefighters can quickly and efficiently access fires across the area. Another example is the location of wolf packs, in that packs spread out as much as possible as each pack tries to keep a lot of space between itself and the other packs in order to reduce conflict over game.

Clustered. A clustered pattern describes when a number of locations are very close to one another, or in clusters – closer than you would expect if they were randomly patterned. Burglars who target a particular neighborhood will create a cluster of burglaries on a community's crime map. Disease is often clustered in space because the location of one event, such as the flu, makes it more likely that other flu cases will be nearby, as the flu is spread through close contact among people.

Keep in mind that you will often find multiple point patterns on the same map. The figure below shows a map of locations of hardware stores in the Midwest of the United States. Looking at this map with point pattern analysis, you could describe store distribution as uniform in northern Iowa (circled in red), random in central Wisconsin and the Minnesota/Dakotas border area (yellow), and clustered around Milwaukee and the Twin Cities (blue).

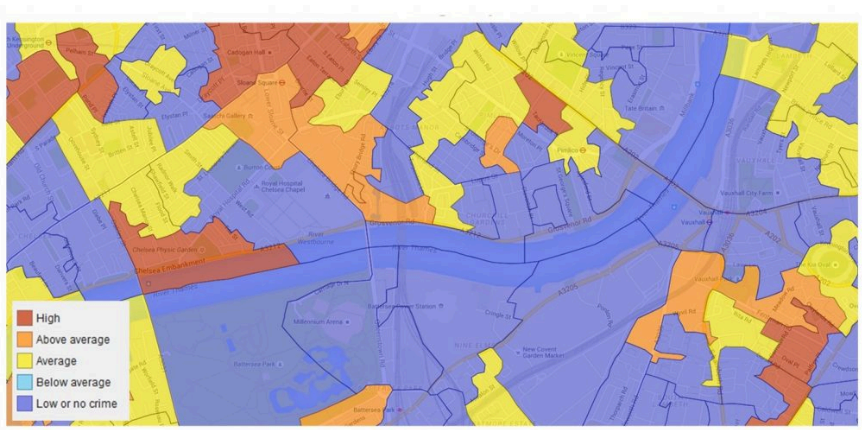


Clustering in stores. Clustering comparison for the locations of Menards hardware stores in the US Midwest. You could describe store distribution as uniform in northern Iowa (circled in red), random in central Wisconsin and the Minnesota/Dakotas border area (yellow), and clustered around Milwaukee and the Twin Cities of Minnesota (blue). [4]

6.2 Autocorrelation Analysis

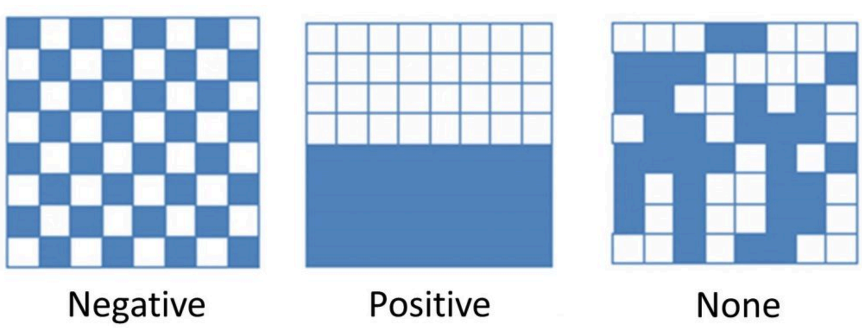
While point pattern analysis is concerned with the relationships among locations on the map, autocorrelation pertains to both the spatial distribution of **location** and **attributes** over an area. Census data, for example, are well-suited for autocorrelation analysis. Though census data may be collected at the level of individual households, the demographic data are ultimately aggregated and mapped over an area, rather than tied to specific household locations. *Autocorrelation* looks at the relationship of one attribute to itself; or in other words, autocorrelation is a way of analyzing the degree to which things of the same kind are related.

Recall the map of London burglary locations discussed above. The figure below demonstrates the difference between a point map (like that above), which is best examined using point pattern analysis, and an area map, which is better suited to an autocorrelation analysis. The point map above shows specific locations where burglaries were reported in London while the one below reports these data as burglary rates for specific neighborhoods, which allows us to compare burglaries among neighboring areas. These two types of maps are useful for different purposes. If you want to understand the particular houses or blocks that burglars target in a neighborhood, the point map is better for gleaning information about the spatial clustering of burglaries. If you work for the city of London and you are trying to decide how to distribute resources to various police precincts, it is more helpful to you to know where the most crime is happening across different precinct areas. In that case, knowing the locations of specific households would not be as useful as having spatial data over an area. If you are considering buying a house in the neighborhood, either of these maps may help you to understand your general risk of burglary.



Burglaries by area. Reported burglaries in London aggregated over an area. [5]

There are three ways to describe autocorrelation patterns: negative autocorrelation, positive autocorrelation, or no autocorrelation. These descriptive terms call to mind what has been termed Tobler's First Law of Geography: "Everything is related to everything else, but near things are more related than distant things." The figure below offers a highly simplified example of how these autocorrelation descriptions might appear on a very stylized map.



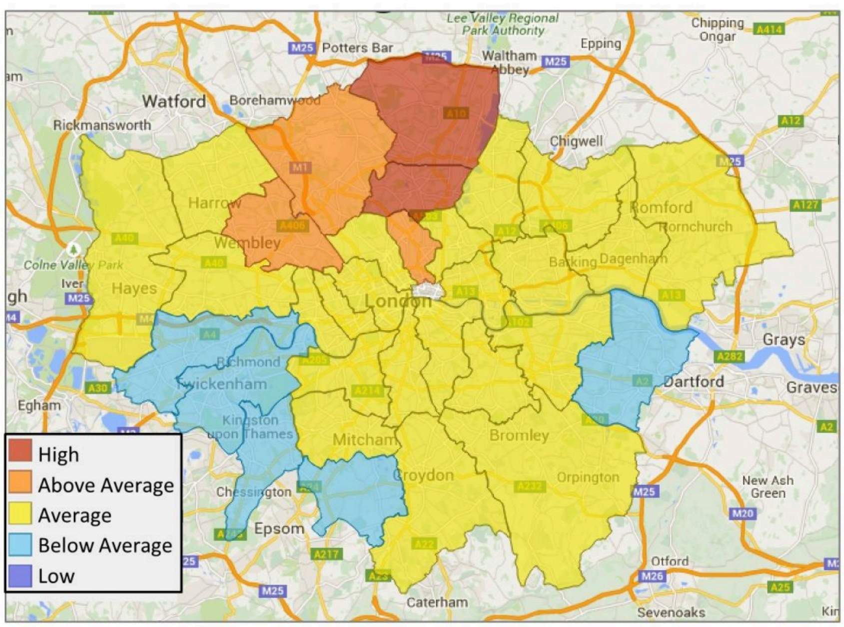
Autocorrelation. Negative, positive, and neutral or no autocorrelation. [6]

- *Negative autocorrelation* describes a pattern that defies Tobler's Law – the attribute is uniformly distributed across the area, intersects uniformly with dissimilar attributes, and is not concentrated.

- *Positive autocorrelation* corresponds with Tobler's law – the areas nearest to each other will display similar patterns or densities of the attribute, and the areas farther away display different densities of the attributes.
- *No autocorrelation* indicates that there is no discernible pattern in the distribution of the attribute.

Another way of thinking about autocorrelation is to ask whether the values of an attribute in one place are likely to be similar to those in nearby places (positive autocorrelation), very different from neighboring locations (negative autocorrelation), and whether there is basically no connection between neighboring places in terms of the attribute (no autocorrelation).

Much of the demographic data that we deal with in this course will display positive autocorrelation. For instance, a map that shows the burglary rates for all of London demonstrates that boroughs with high burglary rates are generally located nearer to other boroughs with high or above-average burglary rates. Boroughs with low burglary rates are generally nearer to other boroughs of low or below average burglary rates.

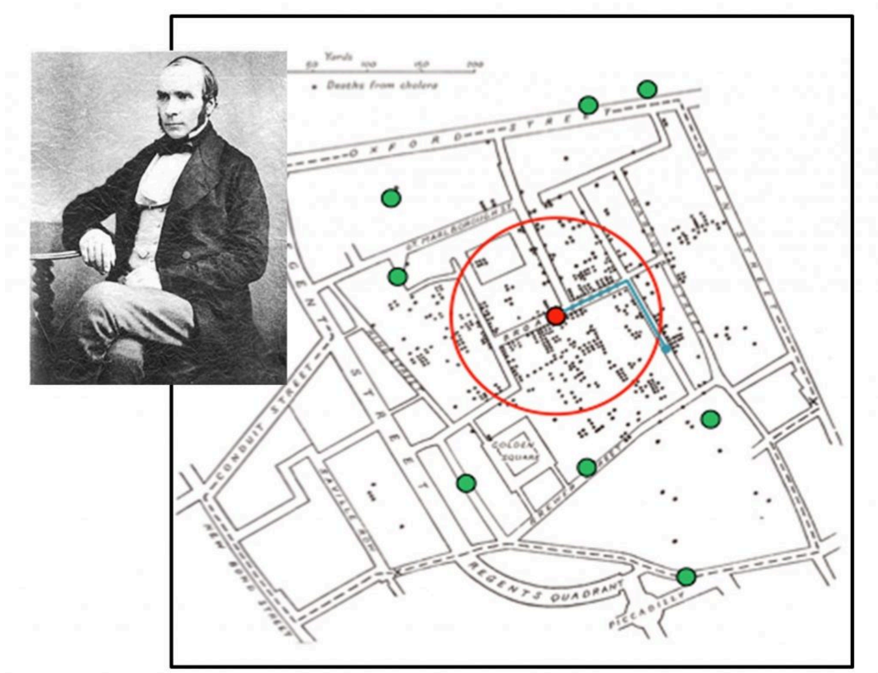


Burglaries by borough. London burglary rates aggregated by borough. Those with high burglary rates are generally located nearer to other boroughs with high or above-average burglary rates. [7]

6.3 Proximity Analysis

Proximity analysis describes the spatial relationships and patterns between locations across two themes – think of it as point pattern analysis with two different kinds of objects or events. Using proximity analysis, you can look at the relationship between houses and streets, crimes and surveillance cameras, patients and disease vectors, or stores and where people live. Beyond the spatial relationship between multiple points, proximity analysis can help us to make sense of the world over time and distance.

Proximity analysis can be tremendously useful for public health—determining how diseases spread, how to predict vulnerability to disease, and how and where to most effectively target interventions. Dr. John Snow developed one of the classic examples of public health proximity analyses. As noted in Chapter 1, a cholera outbreak had ravaged London in 1854 and left many public health advocates and policy makers alarmed and unsure of how to contain the virus. Dr. Snow interviewed residents and discovered that those who contracted cholera obtained their water from the Broad Street pump, as in the figure below. Soon after the handle was removed from that pump, the cholera epidemic subsided.



Proximity and disease. Cholera outbreak and proximity to Broad Street water pump, London 1854, drawn by Dr. John Snow (pictured). The small black dots represent cholera cases, the large green dots represent water pumps, and the red dot is the Broad Street Water Pump. The red circle is the concentration of the greatest number of cholera cases, proximate to the Broad Street pump. [8]

To persuade the medical community that cholera was a waterborne rather than an airborne disease, Dr. Snow created the map shown above to demonstrate the relationship between cholera cases and the Broad Street pump. Dr. Snow's map was one of the earliest examples of proximity analysis conducted to understand spatial disease vectors, and it paved the way for significant expansions of disease mapping.

Proximity analysis can also help us to think about different ways of measuring distance. Most of the time we are interested in *Euclidean distance*, which is the straight-line distance between two points. However, unless you are able to scale and hop across buildings, the distance between point A and point B will be affected by the natural and built environment. Imagine that you are an ambulance driver, and you need to get a critically injured person to the nearest hospital. The "closest" hospital based on time (speed of the roads, traffic) or distance (miles of road) might not be the same as the hospital that is closest in Euclidean distance. *Manhattan distance*, or "taxicab geometry," is a measurement of distance that takes into account the grid-like pattern of city streets (as on the island of Manhattan), and is better suited to understanding navigational proximity. Manhattan distance is not only useful for thinking about proximity in urban environments. It more generally denotes the distance you have to travel over a transportation network in order to reach someplace, or *network distance*.

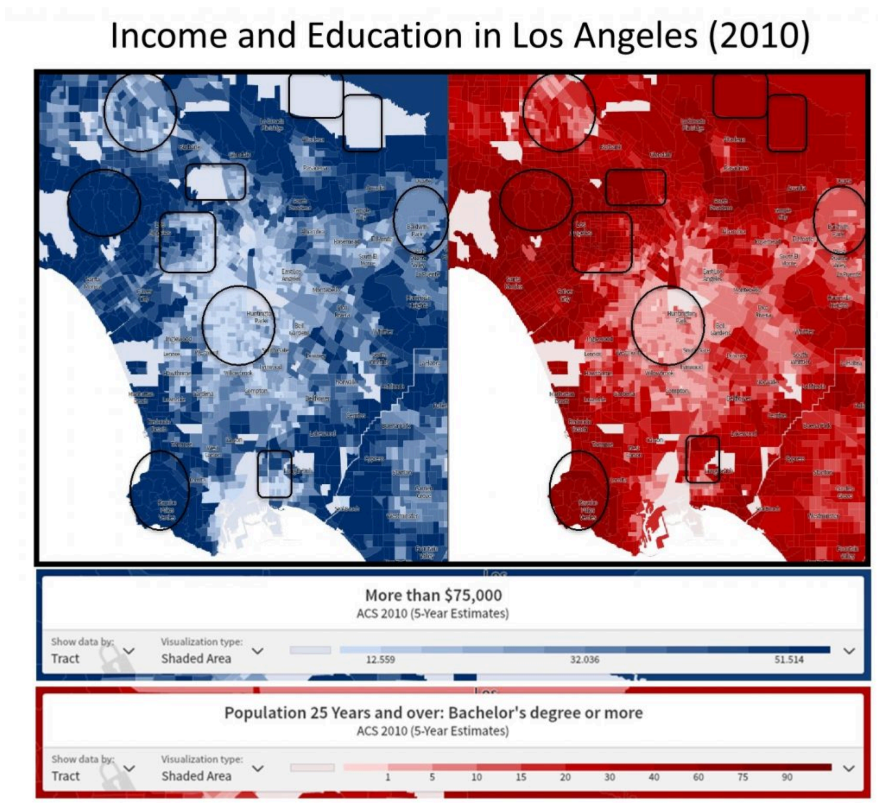
Imagine that you are planning a trip to the beautiful Southern Alps of New Zealand. Fox Glacier and Mt. Cook are two of the most breathtaking sites, and only about 35 km from one another, which is very proximate using a Euclidean measure of distance. Still, to travel between them by car takes over 5 hours because there are few places to pass through the mountains. Your travel plans must take into account network distance, or you will be in for a very long and potentially frustrating day of travel!

Kinds of distance. Google Maps driving directions from Mt. Cook to the Fox Glacier, New Zealand. Travel between them by car takes over 5 hours even though they are close in terms of Euclidian distance. [9]

6.4 Correlation Analysis

Correlation analysis involves analyzing the spatial relationship between multiple attributes or themes. In other words, correlation analysis attempts to measure the degree or extent to which two or more different attributes are spatially related. Although correlation is generally a good method for looking at multiple attributes aggregated over an area, it can also be used to talk about the relationship between an aggregated attribute and a specific point. In this way, sometimes there are overlaps between proximity and correlation analysis. We will deal with these overlaps more comprehensively later. For now, let's look at a typical example of correlation analysis: the spatial relationship between income and education.

Across the world, many governments, NGOs, and media outlets herald the relationship between higher education and increased income. The figure below shows the average incomes of those earning $75,000 or more and the percentage of people with a bachelor's degree or higher for census tracts in the city of Los Angeles. Looking at these two maps side by side, we can see a general correlation between certain areas with relatively high incomes and higher levels of educational attainment. The places where the correlations between the two attributes are strong are highlighted with a circle or oval.



Correlation analysis. Income and educational attainment are correlated in the Los Angeles Area. [10]

There are other areas on this map where the correlation is not so clear, as noted by the squares and rectangles. For instance, in downtown Los Angeles (the square to the upper left of the circle in roughly the center of the map), we see little correlation between education and income. It's important to read your maps carefully when assessing correlation: take a look at the long diagonal census tract in the upper right of each map. This is Los Angeles County Census Tract 9301.01, and we can see from the maps that though there is a large population of educated residents, there is insufficient data as to how many of them are making $75,000 or more per year. This may be because only 119 people live in this whole area of the San Gabriel mountains. Although a number of areas on the map seem to support the proposition that higher education correlates to higher incomes, the map also demonstrates that there are areas that do not adhere to this pattern and that the situation is likely more complicated in reality.

6.4.1 Potential mistakes

When performing a correlation analysis, you need to be careful to avoid two common pitfalls: 1) correlation does not necessarily mean causation, and 2) data are sometimes not interoperable.

Mistake One: Correlation ≠ Causation

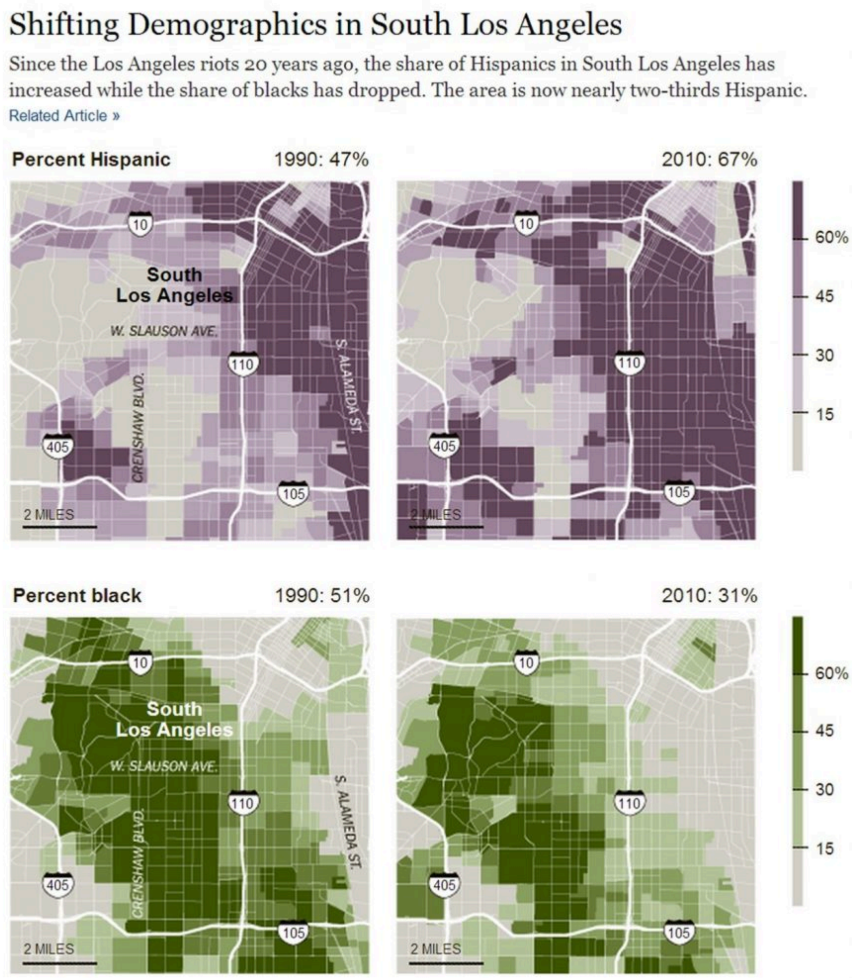
As with the income and education example above, just because you see a correlation in the map does not mean that you have sufficient information to determine causation. Looking back at our maps of income and education in Los Angeles, we do not have adequate information to claim that higher education **causes** higher incomes, or that higher incomes cause higher education. All we can see from the map is that the two are **correlated**. If you wish to make an assertion about causation when doing a spatial correlation analysis, you must consult and cite other robust academic literature that supports your analysis. In short, you must develop a candidate theory or concept that explains the relationship among your variables.

The correlation/causation fallacy is perpetuated throughout the popular media. For instance, in 2014, the New York Times Economy section posted an article with the headline: “A Simple Equation: More Education = More Income.” (Porter 2014). Now, this proposition may be true in certain areas, and at certain levels of aggregation, but we know even from a simple glance at our map that in the Los Angeles area, there are almost as many places where there is little correlation between income and education. We simply do not have enough information to understand why some tracts do not display a correlation between education and income when other nearby tracts do. We cannot make a claim about causation for certain places or spatial scales without introducing additional peer-reviewed data, and even then we must be very careful about causal assertions.

Similarly, the proposition in the New York Times article, which argues that higher education does have a causal relationship to higher income, does not help us to explain these low correlation tracts either. Though there may be widespread correlations between educational attainment and income at the state and county level, a critical reading of our map of income and education demonstrates the complexity of these relationships and the fallacy of a simple correlation equals causation argument. For these reasons, academic literature is required to clearly state its research methodology and is more transparent about how data are collected and how conclusions are drawn than popular media sources. Generally, academic resources are more useful if you are interested in making causal arguments.

Mistake Two: Interoperability oversights

Make sure that the data you are correlating are actually comparable. You’ll want to verify that the maps you are comparing—and the data that are displayed—are based on similar aggregation units, categories, and temporalities. You can only draw effective correlations if your maps and data are interoperable. The figure below shows an example of how correlation analysis can be used to interpret attribute shifts over time. These figures, produced by the New York Times, look at correlations in demographic shifts between black and Hispanic populations in South Los Angeles between 1990 and 2010.

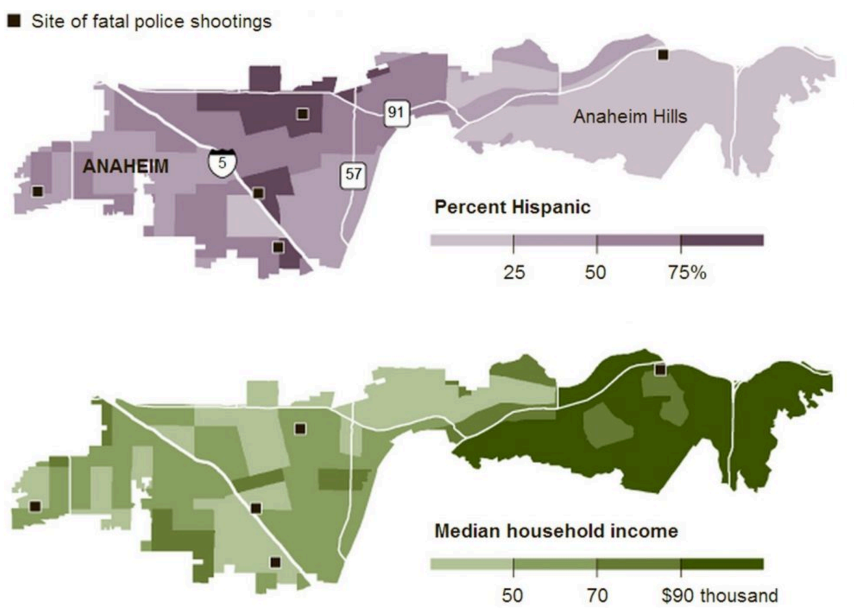


Correlation and interoperability. Spatially interoperable maps that show correlations in demographic shifts over time. [11]

Using what you know about census data, take a look at the temporalities, aggregation units, spatial extent, and attribute categories. Are these maps properly interoperable? In this case, the answer is yes. These maps cover the same time frames (1990 & 2010), in years when racial categories remained consistent (Black and Hispanic have the same meanings in the 1990 and 2010 censuses), both maps aggregate data by census tract (across years when the spatial boundaries of census tracts remained consistent) and focus on the same spatial extent (South Central Los Angeles). These are maps that cover all of the interoperability bases and can be effectively analyzed using correlation. If you have additional questions about interoperability, refer back to the chapter on Data for a more in-depth discussion.

6.5 Combining Analyses

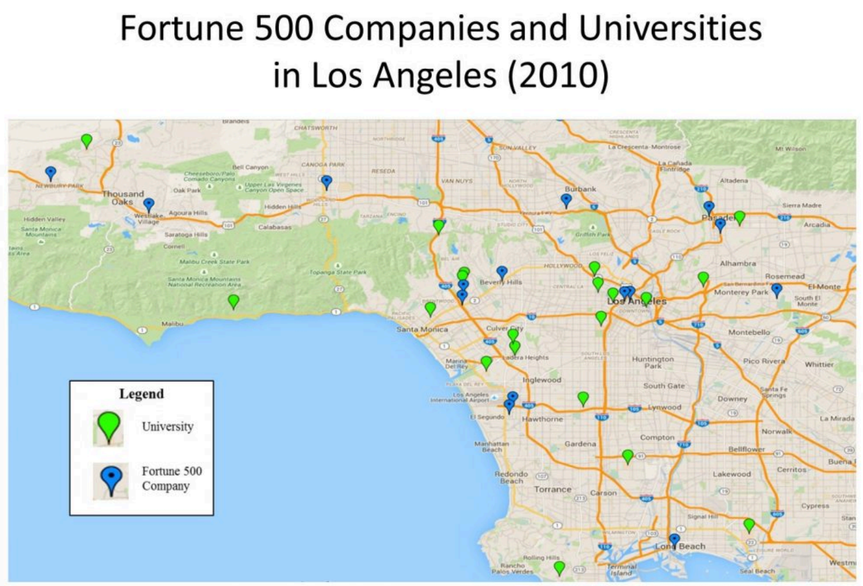
As mentioned above, there are occasionally overlaps between these different analytical methods, and the distinctions are not always so clear. Sometimes you can use these multiple methods to analyze one map. The figure below was published by the New York Times in 2012 as part of a series on fatal police shootings in Anaheim, California.



Mixing kinds of analysis. Locations of fatal police shootings, percent Hispanic demographic data, and Median household income, Anaheim, California, United States. [12]

Using this figure, we can perform a point pattern analysis by observing the distribution of fatal police shooting sites. We could conduct an autocorrelation analysis on the top map by looking at the relationship between the density of Hispanic residents across neighboring tracts (relatively positive levels of autocorrelation), or the bottom map by comparing median household incomes across tracts. We can perform a correlation analysis on the two maps side by side, by attempting to determine whether there is a relationship between the percentage of Hispanic residents and the median household income. Finally, we might use these figures to understand the proximity between fatal shooting locations, the percentage of Hispanic residents, and/or median household incomes. Because there is often overlap between correlation and proximity, you could use either or both analytical methods to understand the spatial relationships between fatal shootings and the aggregated attributes of percent Hispanic population and median household income.

Let's look at another example. In the figure below, proximity analysis is called for, since the focus of inquiry is the location of universities and Fortune 500 companies to one another in the Los Angeles area. In general, we see a relatively high degree of proximity between universities and Fortune 500 companies. Of course, there are some exceptions. For instance, Pepperdine University, nestled in the Santa Monica Mountains on the left side of your map, seems relatively isolated at this scale; however, in Manhattan or network distance terms, it is less than 20 miles, and around a 30-minute drive, from either Dole Foods or Health Net, the corporations located respectively to the northwest and northeast of campus.



Proximity analysis. Proximity analysis between corporations and universities in the Los Angeles area. [13]

6.6 Conclusion

In this chapter, we examined a few methods for analyzing maps. We have narrowed our focus to four general categories of analysis: point pattern, autocorrelation, proximity, and correlation. These categories differ in key ways, particularly in terms of whether they look at location alone or location and attributes at the same time, and whether they are looking at just one theme or more than one theme at a time. They also sometimes differ in whether they look at only points, only areas, or both points and areas. Regardless of approach, it is important to not lose sight of the bigger picture, to remember that you can sometimes use multiple forms of analysis with the same map, and to remain critical of causal claims based only upon correlation.

Resources

For more information about analysis:

- ESRI (the world's largest GIS company) looks a few ways of using maps
- ESRI's chief scientist looks at 'story maps' and spatial analysis
- Eduardo Porter. 2014. "A Simple Equation: More Education = More Income." *The New York Times.*

Notes

1. CC BY-NC-SA 4.0. Steven M. Manson, 2015
2. Map generated with map interface at The London Telegraph (2015)http://www.telegraph.co.uk/finance/newsbysector/constructionandproperty/11328658/Crime-map-Is-your-home-in-one-of-Londons-burglary-hot-spots.html
3. CC BY-NC-SA 4.0. Steven M. Manson, 2015
4. CC BY-NC-SA 4.0. Laura Matson, 2015
5. Public Domain. Metropolitan Police Service (2015) http://news.met.police.uk
6. CC BY-NC-SA 4.0. Steven M. Manson, 2005
7. Public domain. Metropolitan Police Service (2015) http://news.met.police.uk
8. Public Domain. John Snow; Published by C.F. Cheffins, Lith, Southampton Buildings, London, England, 1854 in Snow, John. On the Mode of Communication of Cholera, 2nd Ed, John Churchill, New Burlington Street, London, England, 1855. https://commons.wikimedia.org/w/index.php?curid=2278605
9. CC BY-NC-SA 4.0. Laura Matson, 2015. Google maps.
10. CC BY-NC-SA 4.0. Sara Nelson 2015. Data from SocialExplorer and US Census
11. Fair use. New York Times (April 24, 2012). In Years Since the Riots, a Changed Complexion in South Central
12. Fair use. New York Times (August 2, 2012). A Divided City.
13. CC BY-NC-SA 4.0. Laura Matson, 2015. Google maps

7. Lying With Maps

Eric Deluca and Sara Nelson

You've learned many different ways that you can represent data and modify your maps. Geographer Mark Monmonier argues that all of these little modifications—smoothing of geographic features, choices about classification scheme, aggregation of data, or clever use of hue—represent little "lies." He writes, "To portray meaningful relationships for a complex, three-dimensional world on a flat sheet of paper or a video screen, a map must distort reality…There's no escape from the cartographic paradox: to present a useful and truthful picture, an accurate map must tell white lies." (1996)

White lies include all sorts of cartographic strategies, including symbolization, generalization, and unintentionally misleading mistakes. Then there are the other kinds of lies—propaganda maps, advertising maps, maps for military defense and disinformation, and maps that push a particular political perspective. As a critical map reader and map maker, it is imperative that you be able to identify and understand all of the ways that maps lie. In this chapter, we are going to focus on how and why maps lie, whether innocently or not so innocently.

By the end of this chapter, you should be able to critically read the maps that you encounter in your daily life—whether simple informational maps or maps with a more complex social or political message—and understand the strategies that the mapmakers have chosen to promote a particular message or highlight specific data features. In order to be a critical map reader, pay attention to the guiding questions in the box on the right.

The various mapping strategies that you've learned about in this course all work together to produce a specific result in the final map. The mapping choices that are made can have a big impact on the final product. As we will see a little later in this chapter, these choices—and the lies that they tell—can also have real-world consequences for people and societies.

This chapter will introduce you to guiding questions in thinking about lying maps:

- Who made this map and why?
- What is included and what is excluded from the map?
- What is the source of the data on this map?
- Which modification strategies are at work in this map? What is the effect?

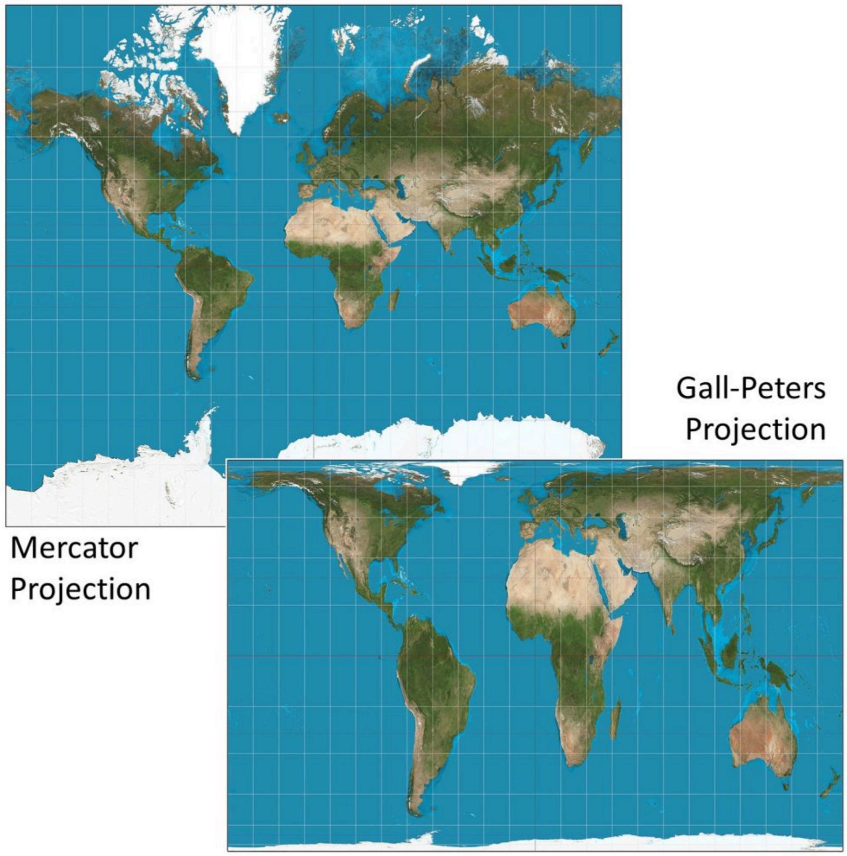
7.1 Little lies

7.1.1 Projection

All maps inherently include white lies and subtle misrepresentations: these white lies are fundamental to the very act of mapping! Think back to our discussion of projection. Recall that only a 3-dimensional object is able to preserve both shape and area, so anytime you translate a 3-dimensional object onto a 2-dimensional surface, you must choose how you are going to distort the object.

This misrepresentation is a form of lying with projection. One example that has garnered much attention is the difference between the Mercator and Gall-Peters projections. The Mercator projection was created by Flemish cartographer Gerardus Mercator in 1569 and is used in many settings, from classrooms to Google Maps and other online services. This map was primarily made for navigation and it preserves angles and shapes well. The major drawback to this projection is that it does not preserve area, so that countries near the poles appear much larger than they should relative to countries near the equator. Greenland has only 7-percent of the land area of Africa, for example, but it appears to be just as large on the map.

In contrast, the Gall-Peters projection preserves area at the cost of shape (e.g., Greenland is significantly distorted but the size of its area is correct in comparison to Africa). Dr. Arno Peters in the 1970s argued that the Mercator projection could introduce bias into the perception of the world, given that countries in the northern latitudes were perceived as much larger than those closer to the equator. As a result, Peters argued, the Mercator projection shows a northern-centric bias and alters the world's perception of the importance of the global south. He offered an alternative, the Peters projection, that better preserved area. It turns out that this project existed long before, having actually been invented by James Gall in the 1800s, but the projection is usually termed the Gall-Peters projection to recognize Peters' argument.

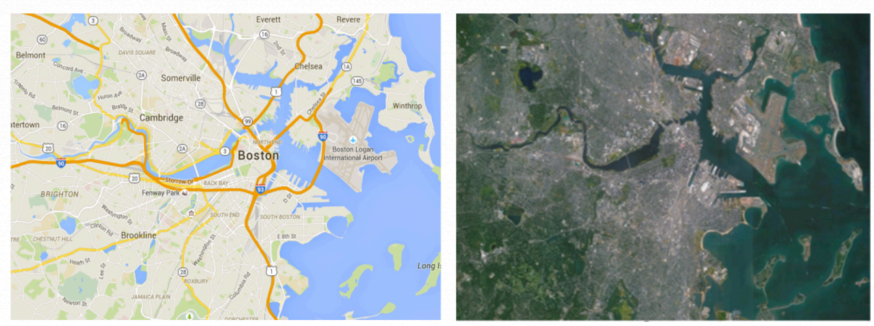


Lying with projections. The Mercator and Gall-Peters projections are both correct in the sense of being good projections but present the world differently. [1]

7.1.2 Symbolization

Because it is impossible to show or even to acquire all of the information that could be mapped in a particular area, symbolization is a common way in which mapmakers “lie” in order to present or highlight certain information.

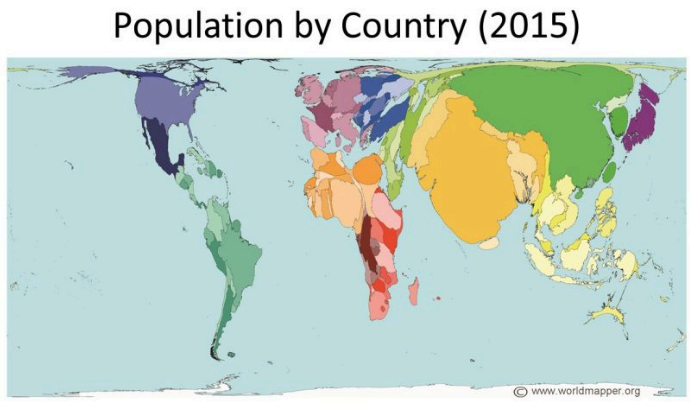
Compare the Google Maps road map of Boston in the figure below to its satellite image equivalent. The image and map represent the same area, but in the road map, Google uses symbolization to tell white lies—highlighting different roadways using size and hue (federal highways in thick orange, state highways in yellow, county roads in thick white, city roads in thin white), different shapes to signify different types of highways, and different label styles for different towns and neighborhoods in the area. These forms of lying with symbolization help to fulfill one of the central purposes of Google Maps: clear presentation of information. You would be hard-pressed to use the raw imagery to do useful things like drive around Boston or find locations like Cambridge. On the other hand, the image could be more useful to make guesses about urban land cover in the Boston region or how deep the water is in the harbor.

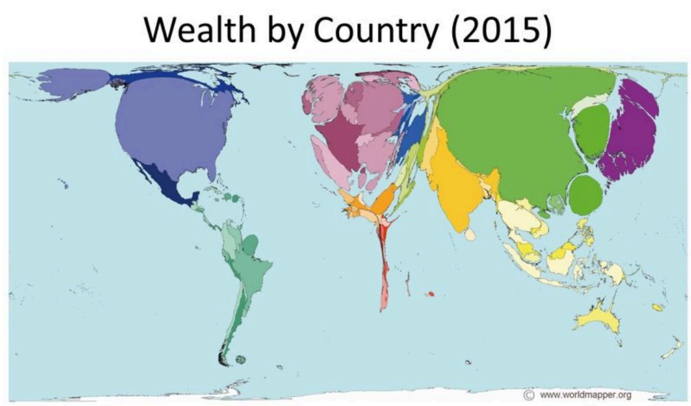


Lying with symbolization. Google Maps view of Boston and satellite view of Boston are of the same area but use symbolization differently. [2]

Cartograms are another way of lying with symbolization. Cartograms are maps that distort area or distance by substituting another thematic variable. Because of the dramatic distortions that cartograms produce, you might consider them to be telling more than white lies. However, cartograms are just different ways of symbolizing the same data in order to tell a story. The big lies that we discuss in the next section are lies that are told for very specific purposes or for eliciting particular reactions. Cartograms are considered white lies here because they are just another set of symbolization choices that affect the representation of data on your map.

The figure below is an example of a map showing the number of people and the amount of wealth per country in 2015. Note how the size of any given country is not displayed in accordance with the land mass of that country, but in fact, corresponds to the number of people living there or its total wealth. This map gives you, very quickly and effectively, a read on which countries have the most people and most money.

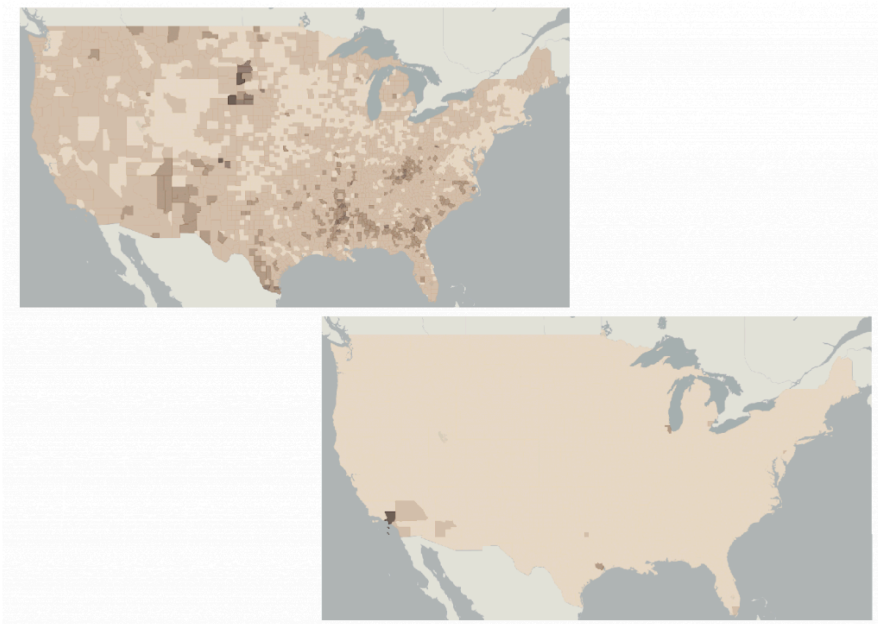




Lying with cartograms. Population total and wealth by country in 2015. Note how the size of countries on the map is not their actual area but instead proportional to the attribute being measured, population or wealth. [3]

7.1.3 Standardization

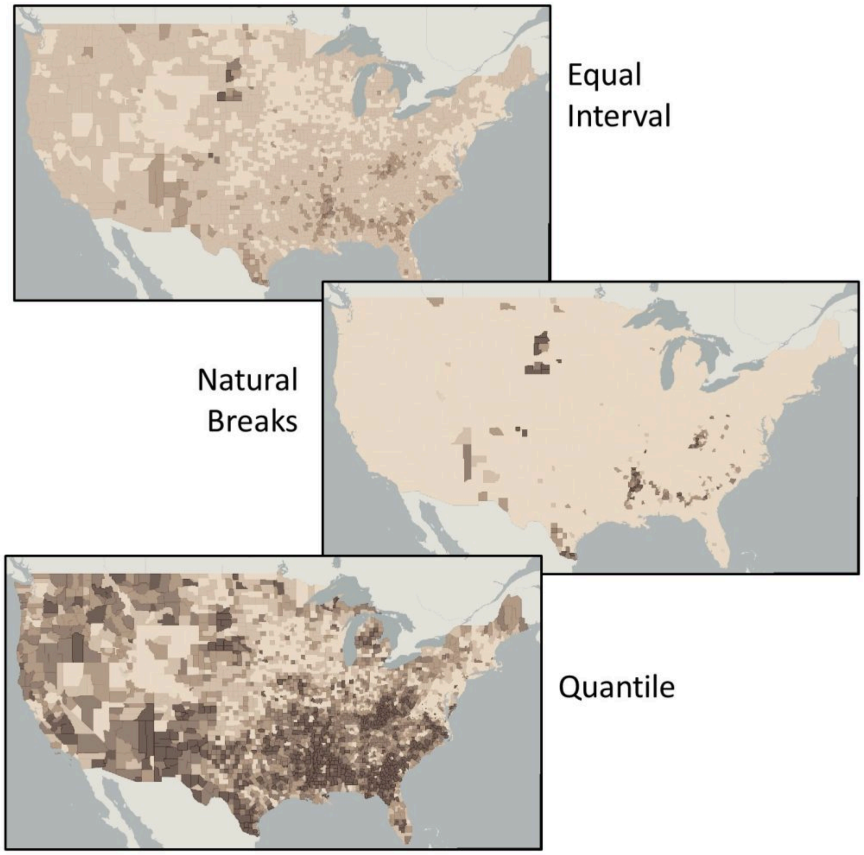
How and whether data is standardized also has a huge impact on the story that the map tells. The maps in the figure below represent poverty data from the 2000 US census. The top map standardizes data by the percentage of the population – the number of people living in poverty relative to the total population of that census tract. The bottom map is based on raw numbers for how many people are living in poverty in the census tract. By failing to account for poverty as a percentage of the total population, the bottom map tells a much bigger lie about poverty levels in the US.



Lying with standardization. Poverty as a percentage versus poverty as a raw number. These maps represent poverty data from the 2000 US Census but differ in their standardization. [4]

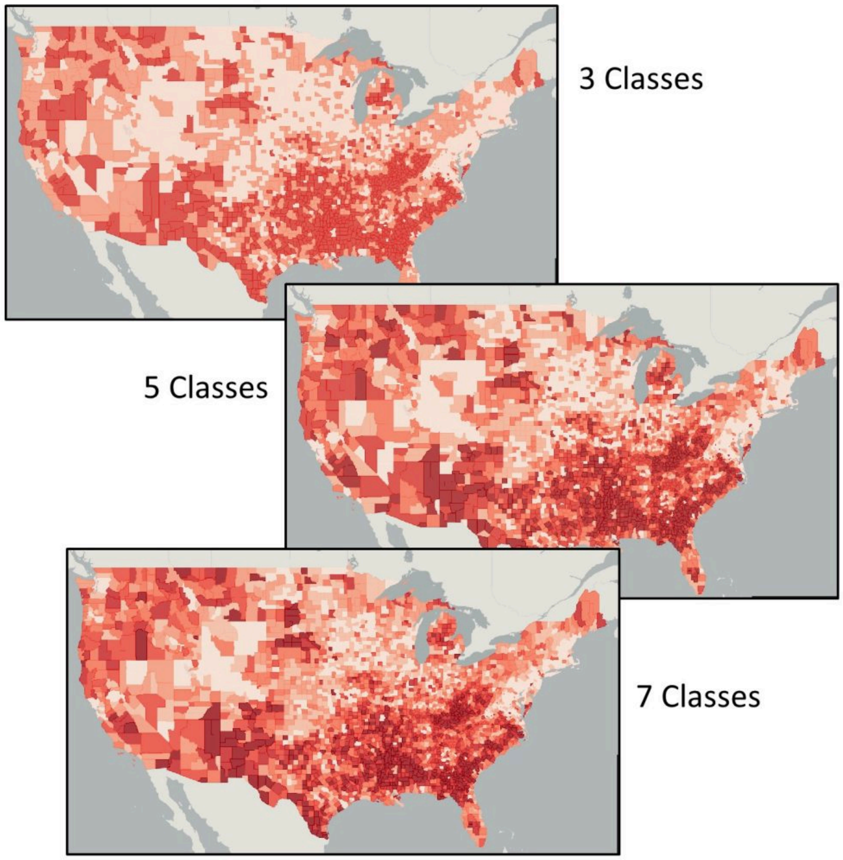
7.1.4 Classification

Classification matters. Choices you make about how to classify your data can have a big impact on the story that your map tells. The maps here show how you can lie with classification. The three maps in the figure below each use the same data, the same number of classes, the same color scheme, and the same standardization, yet each tells a very different story about poverty in the US, depending upon the classification scheme. The first map classifies the data using equal interval, the second using natural breaks, and the third using a quantile scheme.



Lying with classification. Poverty via equal interval, natural breaks, and quantile classifications. The three maps use the same data, the same number of classes, the same color scheme, and standardization, yet each tells a very different story about poverty in the US. [5]

The figure below shows three maps of 2000 census poverty data. Each uses a quantile classification scheme. The only difference is the number of classes. See how the number of classes impacts your perception of poverty levels in the US. Although there are some areas that demonstrate patterns of poverty across the three maps, as you increase the number of classes, you get a more nuanced picture of how poverty is distributed across the country.



Lying with classes. Poverty via quantile classifications with a differing number of classes. The three maps use the same data and color scheme yet tell a different story about poverty in the US. [6]

7.1.5 Aggregation, Classification, and the Ecological fallacy

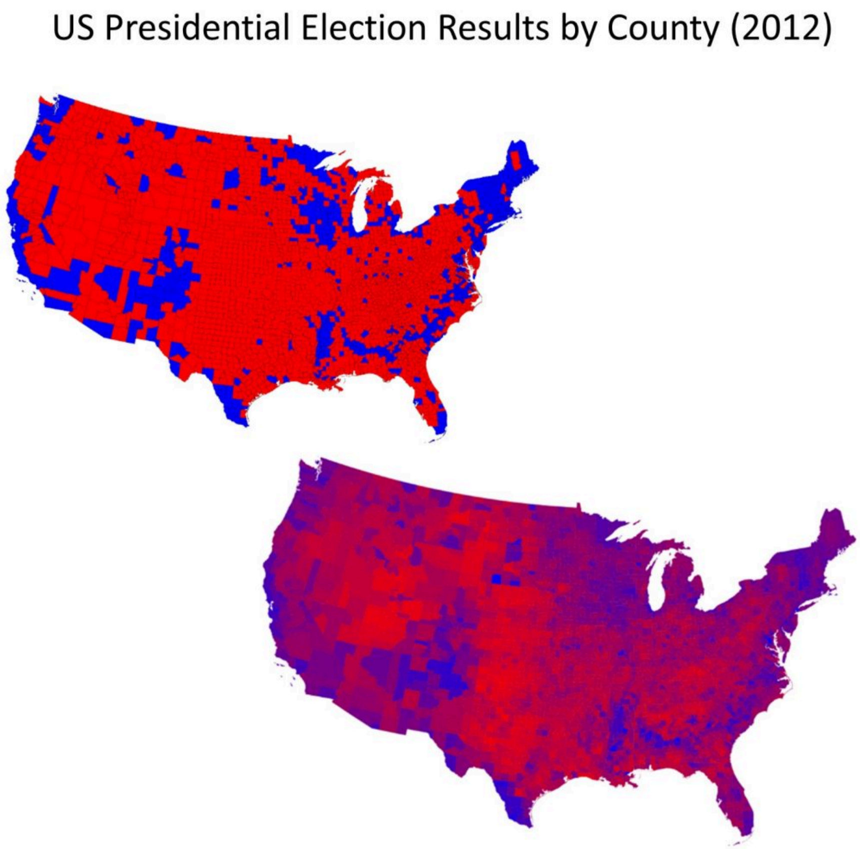
Recall that data are often aggregated. They are often collected at one scale, such as the household or neighborhood, and then reported at much broader scales, such as the census tract or county. This is termed aggregating the data. While aggregation can be very helpful in terms of preserving privacy or presenting a broader and synoptic view, it can also lead to the *ecological fallacy*, or the assumption that a characteristic or value calculated for a group in aggregate can be applied to an individual member of that group. In other words, aggregated data make it hard to assume or guess at the characteristics of any given individual found in that aggregated area.

Imagine you are comparing the income of two blocks, each being composed of five households. Block A has an average household income of $48,000 while Block B has an average household income of $40,000, per the figure below. In which area are you more likely to find a household with a higher income? If you chose Block A—the area with the higher average income total—then you were tricked by the ecological fallacy. In fact, there is no way to know from aggregated data alone what the situation is like for an individual within a group. The figure shows one of many possible scenarios under which four out of five households in Block B have higher incomes than households in Block A.

Ecological fallacy. Consider this scenario in which Block A has a higher aggregated average income but mostly lower individual values than Block B. [7]

Watch out for the ecological fallacy whenever you are interpreting maps, or you might come to false conclusions about the people who live in a neighborhood or other areas!

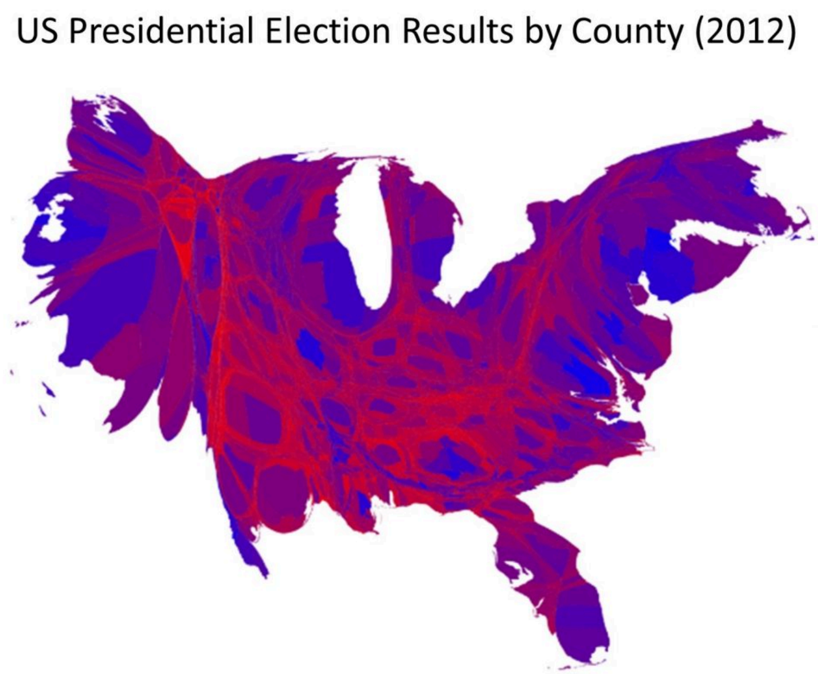
The danger of the ecological fallacy for the map reader is closely tied to the subtle ways that mapmakers can lie with aggregation, often in combination with classification. The figure below illustrates voting returns for the 2012 US presidential election. The map on the left represents counties by their majority vote in the election. Red signifies counties where a majority of residents voted for the Republican candidate, Mitt Romney; blue signifies counties with a majority vote for the Democratic candidate Barack Obama. The map on the right attempts to reveal a little more nuance in voting patterns, by using a red-purple—blue scale to indicate percentages of votes, while the one on the left is simpler and more prone to the ecological fallacy. These maps are both entirely correct. They differ in how they classify their underlying data into either two categories or by not classifying the data and instead of using hue and value to represent fine differences among counties.



Lying with aggregation and classification. Lying, or rather telling different truths, about the United States presidential election in 2012. The map on the left shows counties by their majority vote in the election, where red means counties where a majority of residents voted for the Republican candidate and blue signifies counties voting Democrat. [8]

From your knowledge of the ecological fallacy, you know that even at the level of the county, this map does not accurately represent the party affiliation, beliefs, or voting patterns of each person in the county. The data are aggregated to the county level and are classified differently than the data in the map on the right. This sort of aggregation and classification is useful because it allows us to distinguish between voting patterns in different parts of the country—rural/urban variations, for instance. The map on the right is still lying of course—not all residents in the US voted, and those who did were not necessarily voting for the endorsed Republican or Democratic candidate—but it is trying to provide a more accurate picture of the data. Both maps lie in order to give a picture of the election outcome in particular parts of the country.

Consider the cartogram version of the election map, below. The cartogram distorts area based on county-level election returns, so counties with larger populations appear bigger. The cartogram lies by distorting area, but in some ways, it gives us a clearer picture of election results. In the standard county aggregation map above it appears that the US voted strongly Republican; but the cartogram shows that many Republican-leaning counties have relatively small populations, while counties with larger populations mainly voted for the Democratic candidate.

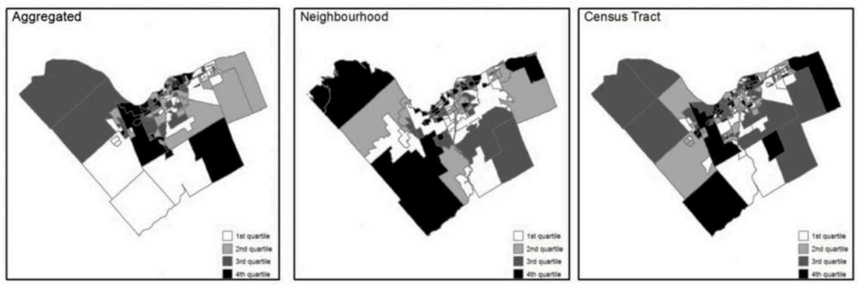


Election cartogram. This cartogram of election results distorts apparent county area by the number of returns, so counties with larger populations appear bigger. [9]

7.1.6 Aggregation and Zonation

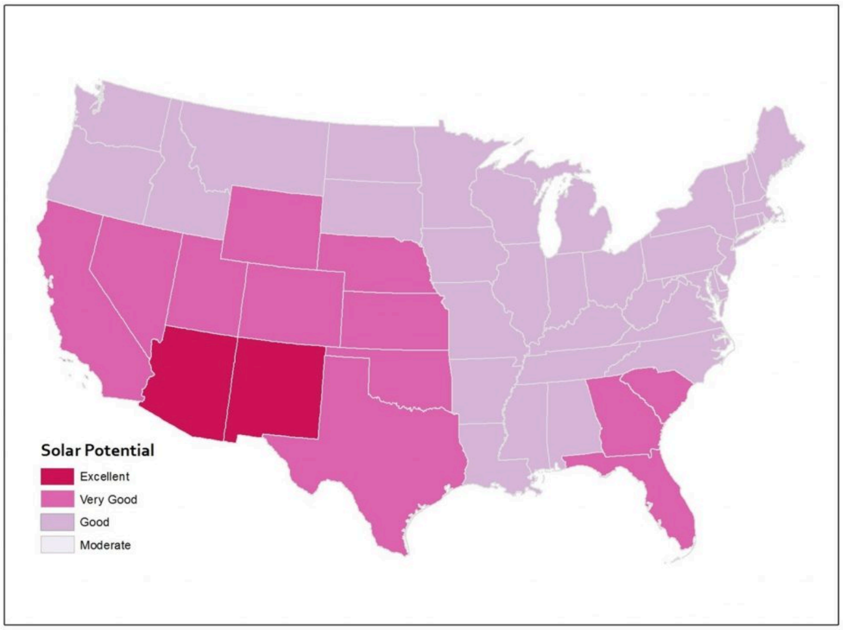
We have looked at how data are aggregated to larger areas and how this process of aggregation can affect how data are interpreted, such as causing the potential for the ecological fallacy. In addition to aggregating data, we can also zone it differently, which is another way of saying we can draw an almost infinite array of differing boundaries for any given aggregation. We often use county boundaries in our analyses, for example, but the boundaries of counties are arbitrary. They were drawn over time according to a range of different principles, such as where a river flowed or where settlement was being encouraged. Population data is often aggregated and reported by county but they could be (and often are) reported via other zonations, such as zip codes, phone-number area codes, school districts, or watershed boundaries.

Importantly, the way in which data are aggregated and where the boundaries of zones are drawn can easily change data patterns and analysis outcomes. Depending on the scale at which you look at a geographic pattern, you can derive completely different results from the exact same underlying data. This is called the *modifiable areal unit problem*. For example, consider the rate of a disease in a population. Individuals at specific locations become sick, but health officials often want to know the broader trends of diseases. For this reason – and to protect the privacy of patients – they may count the number of cases by block, zip code, or another zonation. But artificially breaking up space into these larger areas can change the apparent patterns of disease. The figure below illustrates this for deaths from respiratory problems in Ottawa, Canada. Each map uses the same underlying data but groups or zones cases differently: by a health department aggregation, by neighborhood, and by census tract. Each classes spatial units into quartiles, or in other words, divides the areas into four equal groups by how many people are dying in those areas. Note that these three maps all use the same exact underlying data and are just using different ways of zoning the groups. Nonetheless, these maps look very different, highlighting the challenge of the modifiable areal unit problem.



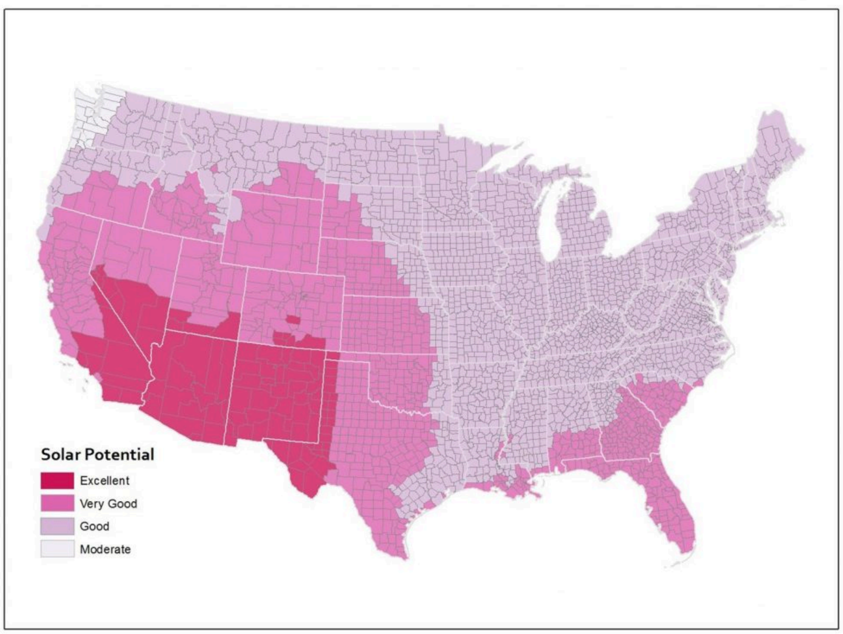
Health and zonation. These maps all show data on where people die from respiratory problems in Ottawa, Canada. Each map uses the same underlying data but groups or zones cases differently. Each categorizes spatial units into quartiles. [10]

In addition to zoning, the modifiable areal unit problem can result from aggregation. Consider the figures below of solar potential in the lower 48 United States. Solar potential refers to the suitability of a particular place to develop solar power. These data are from the National Renewable Energy Laboratory and these maps were created by Anthony Robinson (2010). The first map shows the average annual solar potential by state. In other words, these data are aggregated by state. You can see right away that some states look better than others.



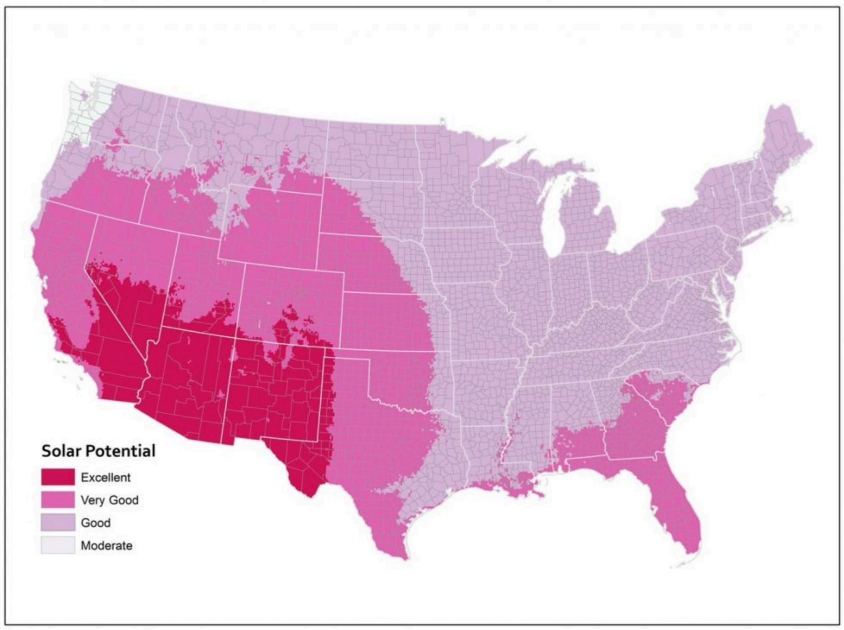
Solar potential by state. Annual solar potential by state, which measures the suitability of a particular place to develop solar power. [11]

The same underlying data aggregated to counties instead makes it look like a lot of states that were shown in one color at the state level actually include several categories of solar potential when you look at the data by county.



Solar potential by county. Annual solar potential by county, which measures the suitability of a particular place to develop solar power. [12]

The third map shows the original underlying data on which the other two maps were based. These original data calculate solar potential in 10-kilometer grid cells. You can see how the state and county boundaries compare to the raw data and how aggregation changes the apparent distribution of phenomena.



Solar potential by grid cell. Annual solar potential given by the original data, which used a 10km grid cell. [13]

7.2 Big Lies

There are other mapping lies that are not so innocent. In the remainder of this section, we are going to focus on some examples of maps that are lying more deliberately—or working hard to represent a very particular story. Keep in mind, though, that there is a fine line between the map-maker intending clarity vs. pushing an agenda. The first example addresses the ways that aggregation and zonation are manipulated to achieve a particular political end.

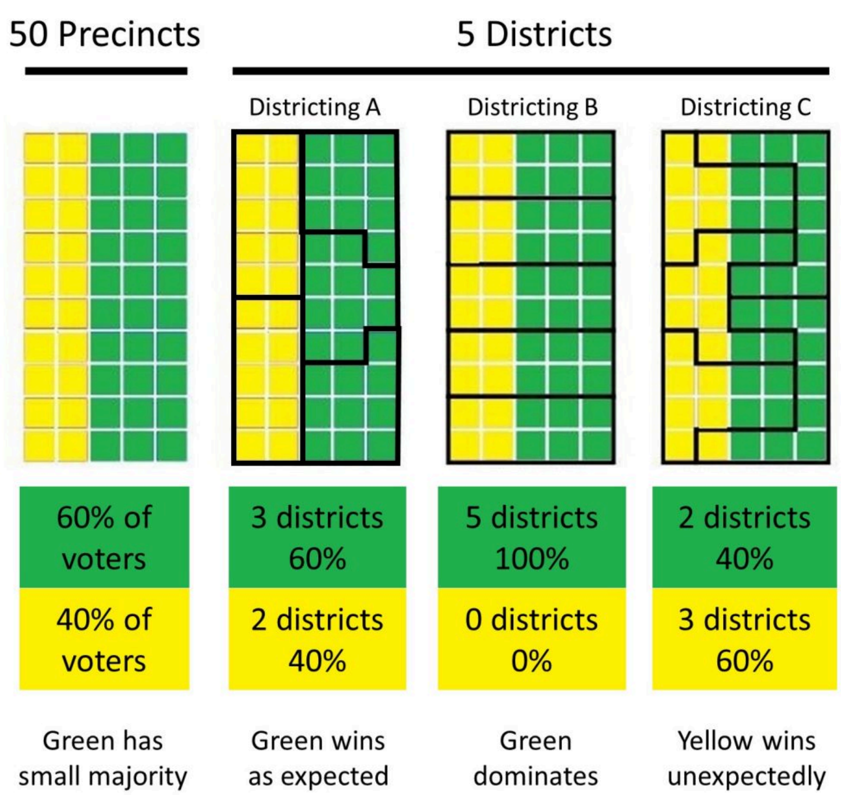
7.2.1 Political Lies: Gerrymandering

There are many ways that maps are modified in order to promote particular political perspectives or outcomes. Political lies in mapping take the form of propaganda, campaign advertisements, and politically-motivated resource maps. One particularly important political lie is gerrymandering, the manipulation of the boundaries of an electoral constituency in order to favor a particular political party or group. Because US Congressional districts are reapportioned in the years following the decennial census, political leaders in power at that time may take the opportunity to redraw borders—even convoluted gerrymandered borders—that favor their party's continued political success.

Gerrymandering has been an important and highly contested part of the US political process for quite some time. The term was coined in the Boston Gazette in reference to the contrived redistricting schemes designed to secure the political power of Massachusetts Governor Elbridge Gerry's Democratic-Republican Party. In 1812, the Gazette published the illustration seen below comparing Gerry's convoluted redistricting to the image of a salamander-like creature. Thus, "gerrymandering" was born. This political technique has a storied history, and is a powerful way of lying with maps: gerrymandering works to consolidate or distribute political power, with such tactics as isolating opponents (known as packing) and breaking up areas of opposition (cracking).

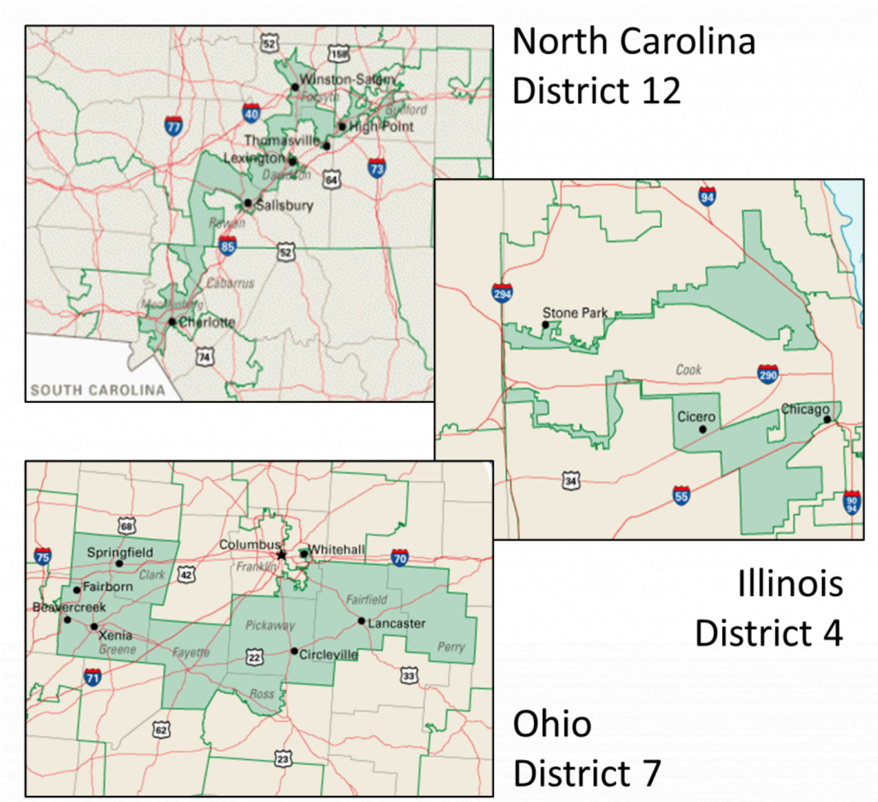
Gerrymandering. The term gerrymandering was coined by Elkanah Tisdale in the Boston Gazette in 1812. The newspaper published an editorial cartoon that showed the elongated shape of the aggregated areas in the form of a salamander. [14]

In the figure below, there are fifty precincts (the smallest area in which votes are tallied) that can be distributed among five districts. At the precinct level, there are proportionally more green voters than yellow (60% versus 40%), and so all other things being equal, you would expect non-gerrymandered districts to reproduce a proportionate outcome. Out of the five total districts, you would expect three to vote majority green and two majority yellow, which corresponds to the 60% versus 40% split of the underlying precincts. Grouping precincts into districts yield different outcomes if principles of gerrymandering are used, namely packing and cracking. Under Districting A, the number of districts won by each party is proportional to the number of voters for each party: 60% for green and 40% for yellow. Districting B cracks the yellow precincts in a way that allows green to dominate all districts, yielding 100% for green and 0% for yellow. Districting C packs and cracks green in a way that lets yellow eke out an upset win with three districts, which is the reverse of the underlying voting patterns of the precincts.



Packing and cracking. Overall, at the precinct level, there are proportionally more green voters than yellow (60% vs. 40%). Three different ways of grouping precincts into districts yield different outcomes. Under Districting A, the number of districts won by each party is proportional to the number of voters for each party. Districting B cracks the yellow precincts in a way that allows green to dominate all districts. Districting C packs and cracks green in a way that lets yellow gain an upset win with three districts. [15]

Gerrymandering is alive and well today. It is widely practiced in the US, as you can see by some of the more outrageous examples of congressional gerrymandering in the figure below. This type of redistricting and reapportionment can have very real consequences for people who live in these areas, limiting their representation, protecting incumbent seats, and compromising access to federal funding. Some have argued that gerrymandering is akin to legal election rigging.

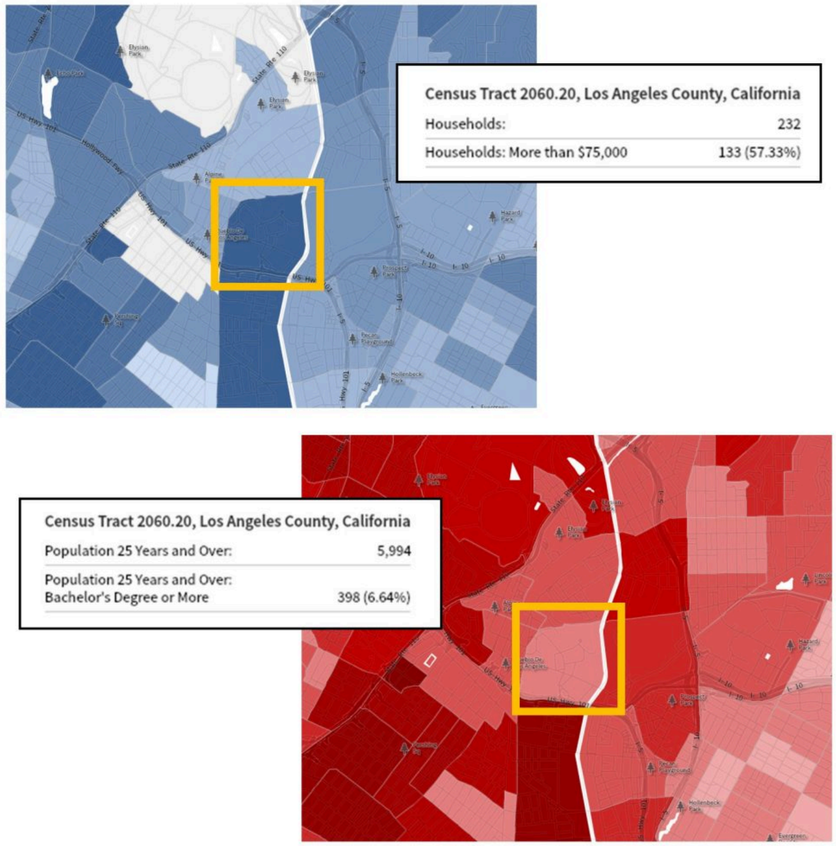


Gerrymandering in the United States. These maps show examples of gerrymandered districts in the United States; these are just a few of many. North Carolina's 12th congressional district in 2016 was an example of packing, with predominantly African-American residents (top). Illinois's 4th congressional district packs two Hispanic areas while meeting the requirement for contiguity running along Interstate 294 (middle). Ohio's 7th is an example of "cracking" where the urban population of Columbus, Ohio is split off into more conservative suburbs. [16]

For incarcerated populations and those who live in districts where prisons are located, gerrymandering may have an even bigger impact. In order to understand how prison-based gerrymandering works, you'll have to think back to what you learned about how census data is collected, analyzed, and aggregated. For certain data categories, the Census Bureau counts incarcerated people as residents of the town where their prison is located, rather than the town where they resided prior to their imprisonment. Because census data are currently used for redistricting at all levels of federal, state, and local governance, the particular cities and census tracts where people are counted is very important for ensuring representation and apportionments.

In the US, the prison population has risen significantly in the past few decades. Advocates for ending prison-based gerrymandering argue that counting prisoners based on their incarceration location—particularly when those prisoners are barred from voting in 48 states—gives exponential political power to the small non-incarcerated population in the area, and their representatives. When this happens, advocates argue, the practice siphons political representation and funding from other districts in the state—particularly those districts that bear the greatest costs of crime.

The prison gerrymandering dynamic is evident in existing census maps. Let's return to the Los Angeles area income and education maps that you encountered in chapter 6. The figure below contains details about Los Angeles County Census Tract 2060.20. The map shows us that income and education are not correlated in this area. Looking at the data, we see that only 5.328% of the population in this tract has a Bachelor's degree, but 91.453% has an annual income of $75,000+. Only when we dig a little deeper does this particular tract begin to make a little more sense. Census Tract 2060.20 is home to the Twin Towers Correctional Facility and the Men's Central Jail. The ACS and census currently tabulate all of the prisoners who live in the Twin Towers and Men's Central jail as residents and takes into account their education level. However, the census does not include incarcerated populations in household income or poverty calculations, so the map on the right only takes into account the incomes of the surrounding community. You can see how this kind of data collection method might make it very difficult to adequately account for population, ensure reasonable representation, and manage appropriations in prison-based communities, as well as the communities from which incarcerated populations come.



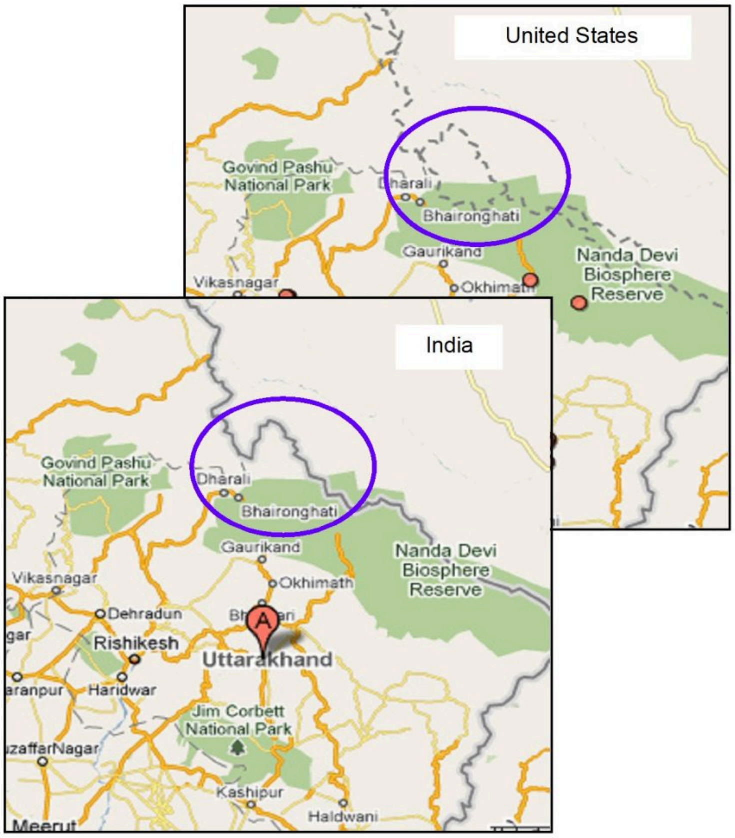
Prison gerrymandering. This detail of Census Tract 2060.20 shows income and education (Left: Income More than $75,000; Right: Education Bachelor's Degree or More). These maps show us that income and education are not correlated in this area. [17]

7.2.2 Geopolitical Lies: Contested Territories

There are other types of lies that have more to do with navigating the complexities of international geopolitics. For instance, in many parts of the world, there are territories that are contested between two or more states. Depending on the political considerations of the mapmaker and the audience, regional maps may represent these territories very differently. Jammu & Kashmir is a territory in the northwestern region of South Asia along the borders of India, Pakistan, and China. Since the 1947 partition of British India created the contemporary states of India and Pakistan, the two countries have been engaged in a territorial dispute over the region. Jammu and Kashmir are geopolitically significant and are the source of the Indus River and its tributaries, which sustain India and Pakistan's water supplies.

Situating Kashmir. Jammu & Kashmir is a territory in the northwestern region of South Asia along the borders of India, Pakistan, and China. [18]

India and Pakistan both claim Jammu and Kashmir. The figure below shows how Google Maps images of the region appear differently whether the search is conducted in the US (which considers the two states' territorial claims on Jammu and Kashmir to be unsettled) or India (which reasserts its claim to Jammu and Kashmir in the map).



Contested Kashmir. Google Maps will show the contested Kashmir region differently depending on whether the user is in the United States or India.[19]

Different media organizations have also favored different representations of Jammu and Kashmir, as seen below.

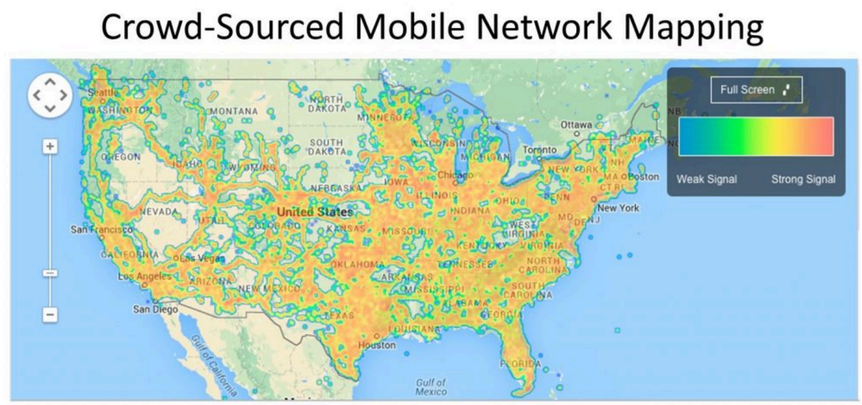
Kashmir in the news. Competing media representations of Kashmir. Different media organizations favor different representations of Jammu and Kashmir. [20]

7.2.3 Commercial Lies: Advertising

In 2009, AT&T filed a lawsuit in federal court against Verizon. The complaint? AT&T alleged that a Verizon ad campaign featuring coverage maps of each carriers' 3G cellular data service misrepresented the actual reach of AT&T's wireless service and misled customers. AT&T sued Verizon over a "lying map." AT&T was concerned that the map would make customers think that its entire wireless network was reflected in the spotty map below, while Verizon contended that the map accurately reflected the differences between the two carriers' 3G networks. AT&T dropped the suit about a month after it was filed, but it raises some important questions about lying maps in advertising.

Lying competition. AT&T alleged that a Verizon ad campaign "There's a Map for That" featured coverage maps of each carrier's cellular data service that misrepresented the actual reach of AT&T's wireless service and misled customers. [21]

For mobile service providers, maps that demonstrate extensive coverage are becoming increasingly important as companies like Verizon and AT&T compete for larger shares of the marketplace. However, many consumers have expressed frustration over what they perceive as inaccurate coverage maps in the advertising materials of mobile phone service providers. In recent years, a number of apps and websites have popped up to crowd-source mobile phone coverage data across the US and paint a more accurate picture of mobile network coverage. The figure below shows a crowd-sourced map from one such site, OpenSignal.com.



Open mapping. This crowd-sourced mobile network coverage map from OpenSignal.com is arguably less biased than those offered by companies because firms have a vested interest in making their product seem better than competing offerings. [22]

7.3 Conclusion

In making maps, we tell many lies. Small lies include all sorts of standard cartographic strategies, including projection, symbolization, standardization, classification, aggregation, and zonation. Then there are the other kinds of lies—gerrymandering, propaganda maps, maps that push a particular political perspective, and misleading advertising maps. As a critical map reader and map maker, it is imperative that you be able to identify and understand the ways that maps lie.

Resources

For more information about lying with maps:

- Mark Monmonier. 1996. How to Lie with Maps (University of Chicago Press)
- Prisoners of the Census:

For more perspectives on gerrymandering:

- Michael Hiltzik, "A gerrymandering attempt that went hilariously awry," *Los Angeles Times* (Aug. 31, 2015).
- Christopher Ingraham, "America's most gerrymandered congressional districts," *Washington Post* (May 15, 2014).

- John Sides & Eric McGhee, "Gerrymandering Isn't Evil: Why independent redistricting won't save us from political gridlock," *Politico* (June 30, 2015).
- Christopher Ingraham, "How to steal an election: a visual guide," *Washington Post* (March 1, 2015).

Notes

1. CC BY-SA 3.0. Adapted from Daniel R. Strebe - Own work.nhttps://commons.wikimedia.org/w/index.php?curid=16115307 https://commons.wikimedia.org/w/index.php?curid=16115242.
2. CC BY-NC-SA 4.0. Steven M. Manson, 2015
3. CC BY-NC-ND 4.0. Benjamin D. Hennig Worldmapper.org
4. CC BY-NC-SA 4.0. Steven Manson 2005 Data from SocialExplorer and US Census
5. CC BY-NC-SA 4.0. Steven Manson 2005. Data from SocialExplorer and US Census
6. CC BY-NC-SA 4.0. Steven Manson 2005 Data from SocialExplorer and US Census
7. CC BY-NC-SA 4.0. Sara Nelson 2015
8. CC BY 2.0. M.E.J. Newman. 2012 Maps of the 2012 US presidential election results. http://www-personal.umich.edu/~mejn/election/2012/
9. CC BY 2.0. M.E.J. Newman. 2012 Maps of the 2012 US presidential election results. http://www-personal.umich.edu/~mejn/election/2012/
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11. CC BY-SA 3.0. Adapted from Anthony C. Robinson. Maps and the Geospatial Revolution https://www.e-education.psu.edu/maps/l4_p4.html
12. CC BY-SA 3.0. Adapted from Anthony C. Robinson Maps and the Geospatial Revolution. https://www.e-education.psu.edu/maps/l4_p4.html
13. CC BY-SA 3.0. Adapted from Anthony C. Robinson. Maps and the Geospatial Revolution. https://www.e-education.psu.edu/maps/l4_p4.html
14. Public domain. By Elkanah Tisdale (1771-1835) Originally published in the Boston Centinel, 1812. https://commons.wikimedia.org/w/index.php?curid=6030613
15. CC BY-SA 4.0. Adapted from Steven Nass - https://commons.wikimedia.org/wiki/File:How_to_Steal_an_Election_-_Gerrymandering.svg, https://commons.wikimedia.org/w/index.php?curid=60129008
16. Public domain. Adapted from nationalatlas.gov. Accessed 2013.
17. CC BY-NC-SA 4.0. Sara Nelson and Steven Manson 2015
18. Public domain. CIA and U of Texas http://www.lib.utexas.edu/maps/middle_east_and_asia/kashmir_region_2004.jpg, https://commons.wikimedia.org/w/index.php?curid=618641
19. CC BY-NC-SA 4.0. Sara Nelson and Steven Manson 2015
20. Fair use. Steven Manson 2015 Maps from bbc.com, foxnews.com, cnn.com
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8. Surveillance

Laura Matson and Steven Manson

We live in a surveillance society and always have. Multiple organizations track our daily activities, and often with the help of geospatial technologies including mobile phones, satellite remote sensing, and sophisticated mapping systems. The practice of tracking populations is not new. Governments in particular have long conducted surveillance of individuals and groups for centuries, although they have been joined by a host of companies and other groups. For most of human history, however, surveillance was limited in scope because it required a lot of human resources. The advent of computers and computing networks has vastly expanded the ability of government agencies, commercial firms, and other organizations to monitor millions of people.

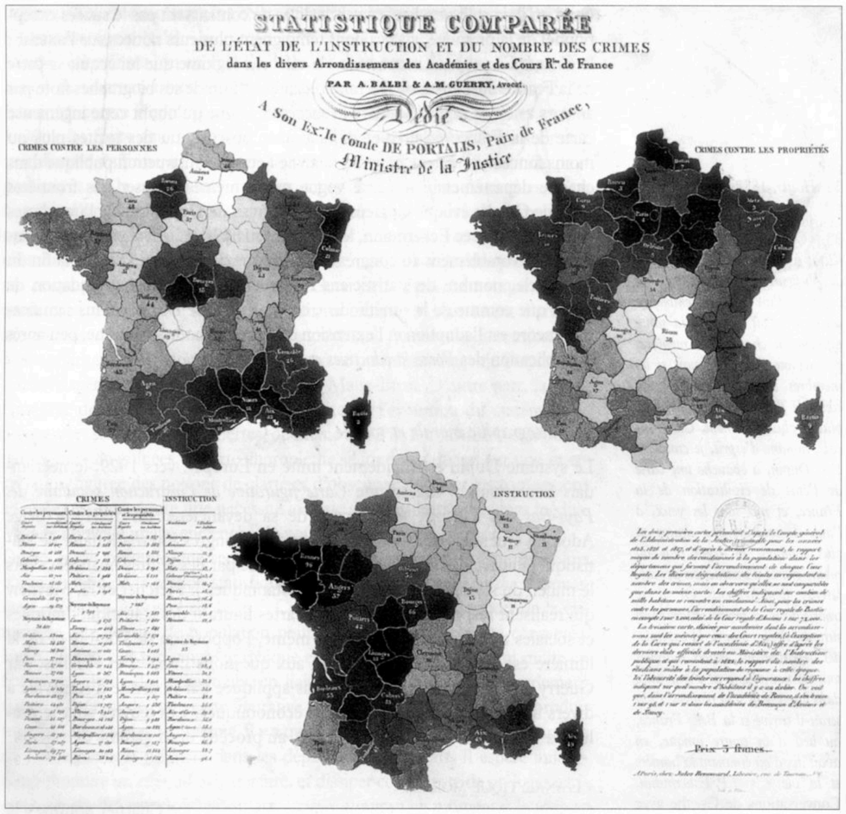
This chapter will introduce you to:

- Surveillance as a concept that has long been a part of human societies
- Drivers of the new surveillance society
- Surveillance from both the inside and outside of our daily lives

8.1 Surveillance

In many ways, we are living in a surveillance society and have been since the earliest of human civilizations. Multiple organizations track our daily activities, often with the help of geospatial technologies. The practice of tracking populations is not new. Governments, in particular, have long conducted surveillance of individuals and groups, and many countries have conducted a population census continually for centuries. From the 1800s onward, most governments have tracked their populations. Besides basic demographics, governments gather health surveys, migration information, data on border crossings, crime, and more (as seen in the map below).

For much of human history, the opportunities for surveillance were physically bound in important ways. For example, governments have always employed people to follow other people around to keep them under observation, but this is expensive and time-consuming. It is also difficult to monitor people passing across borders or to count citizens once a decade at their home via a census. This kind of door-to-door census is tremendously costly to conduct because it involves paying thousands of enumerators to go to homes and talk to people in addition to the money and time spent mailing, reading, and tabulating surveys. Since around the mid-Twentieth century, however, technology has made it much easier for governments, companies, groups, and individuals to surveil large numbers of people.



State surveillance. Map of crimes against persons, crimes against properties and education in France (1829). Governments gather information on health, migration, crime, and more/. [1]

There are three recent drivers of expanded surveillance, which threaten to fundamentally rewrite the rules about how government agencies, commercial firms, and other organizations keep tabs on individuals.

The first major driver is our ever-improving technology which has become less expensive and much faster.

- *Computerization.* From the 1940s onward, the advent of computers heralded new capacities for observing and tracking societies. Computers are very helpful for keeping records and making connections among records, and they can store large amounts of information.
- *Networks*. From the 1980s onward, communication networks made it easier for computers to talk to one another. Organizations could share information more easily and it became easier to collate information from many different places.

- *Miniaturization*. Both computers and networks benefit from miniaturization. Computers are becoming faster and networks are becoming almost omnipresent. Mobile phones exist because computers are now small enough to fit in your pocket while remaining capable of networking with other computers.

The second driver of expanded surveillance is the rise of the politics of fear and security. Although by most measures we are living in a safer world than ever before, many people feel less safe and less secure than in the past. The reasons for this mismatch are numerous and complex, but in general, there is evidence that bad news travels faster than it ever has before. The news is filled with stories of danger and tragedy from around the world, stories we would not have heard about by just relying on the newspaper or evening news. We have also seen an increase of, and desire for, a range of surveillance technologies, such as cameras put in private and public spaces in the name of safety.

These technologies are arguably making us safer in some cases, but at what cost to personal liberty and privacy? These trends are also related to both perceived and actual increases in terrorism, along with related threats such as cybercrime. This has ushered in a new era in which governments have sought more powers of surveillance. The Patriot Act in the US, for example, substantially increased the powers of government to track citizens through their phone records and online activities, often with little or no oversight. While these measures have undoubtedly helped protect people from harm, they have also introduced a new and potentially dangerous level of government scrutiny into the lives of all people.

Surveillance cameras. These cameras have become ubiquitous. This one is part of the Memphis Police Department's Blue Crush Taking Back Our Streets initiative. [2]

The third major driver in the growth of surveillance is the personalization of tracking. In general, we have moved from a situation where a person was observed or tracked in one or two places, like at a border crossing, to a situation where a person can be observed directly or indirectly at almost all times. In some cities, a person can be seen by dozens of cameras a day and their face or license plate number can automatically be matched against databases. Essentially every online interaction you have, be it looking up directions on a map or looking at shoes on a website, is tracked by multiple organizations, ranging from private sector companies to government agencies. If you carry a mobile phone, you are also carrying a device with a microphone, camera, and location tracker. These are just a few of many possible examples of the ways in which you are monitored on a regular basis.

8.2 Inside Surveillance

Often we think of surveillance as happening outside of daily life – we watch movies where secret agents use satellites, telescopes, and microphones to spy on criminals or enemy agents or our hapless heroes. Really, though, much of the surveillance we experience is “from the inside,” in that we willingly purchase spy gear and carry it with us in order to be spied on.

Many of our possessions, including clothing and other items we buy in stores, have radio-frequency identification (RFID) tags built into them, which can continue to be accessed even after their original purpose has been fulfilled. These RFID tags help to prevent shoplifting, but it is possible for anyone to read these chips; so, for example, if you buy a pair of jeans from the Gap, another retailer could read the chip in your jeans months later. Companies constantly experiment with different ways of using these and other kinds of technologies. Your student ID card likely has an RFID chip embedded in it, as do many of the cards you carry. These chips are helpful because they allow users to open locks and doors with the swipe of a card instead of having to use a key for every door. Some universities have gone a step further, however, and have installed special doorways that detect students’ IDs automatically. They are experimenting with using this technology to track attendance in classes, use of the cafeteria, or to make for easy entrance to dorms. Of course, you can imagine many other uses to which this system could be applied. How would you feel knowing that the university knows your every move on campus?

Our mobile phones are tremendously useful, but many different parties – phone companies, marketing firms, government agencies – have varying degrees of access to the microphone, camera, data, and location of your phone. These organizations know who uses the phone, what they use the phone for, and where the phone is at all times. One advantage of this situation is that companies can offer location-based services (LBS), or services and products that take into account where you are. If you search for a coffee shop, for example, your phone will tell you the locations of the nearest shops, give you ratings, and provide directions. Of course, companies like Google or Apple provide search results that are biased toward stores or chains that pay advertising fees. They are also interested in tracking the people you spend time with; features such as facial recognition or the opportunity to ‘tag’ or identify friends and family in photos are often billed as a great way to help organize photos, but they also provide a way for companies to better understand your social networks.

Most of our activities online are tracked by companies and governments. There is always a tug of war occurring behind the scenes over the balance between protecting the privacy of people being tracked versus using this tracking information to learn about people, their activities, and their relationships.

The companies that power the internet, such as Google, Apple, and Facebook, keep track of every person who uses their services. They track what you buy, with whom you communicate, the stories you read, and the people with whom you associate. Much of this is spatially-aware knowledge, in the sense that these companies can track with whom you travel or spend time.

One side effect of many people being tracked is that this continuous and automated collection yields a lot of data that can be used in various ways, some inadvertent. These data are typically used by companies to develop better products and sell advertising while providing a useful service. There are many mobile phone applications (or “apps”) on fitness, for example, that will use your location to help you plan running or biking routes, monitor your exercise routines, or encourage you to push yourself further. Strava is one such application that is used by millions of people around the globe. In addition to using the data for its own purposes, the firm shares its data as maps. One unanticipated side effect of this data sharing is that it became apparent that members of the armed forces and security services of various countries were using the app and inadvertently sharing their data. These data could be used to create high-resolution maps of how, where, and when people moved around on a military base such as the Bagram Air Base, the largest U.S. military base in Afghanistan, pictured here. This level of specificity poses a range of security risks. This is just one example of the many potential uses and misuses, inadvertent or otherwise, that may result from the mass surveillance of people using their mobile devices.

Mobile phone tracking. Users of a fitness app shared their locations and these data in turn were used to make a map that showed details of a military installation. [3]

Most transactions have some sort of receipt or indication of their occurrence and we have many different kinds of records about who we are and what we do: internet activity, credit card purchases, debit card activity, airline tickets, car rentals, medical records, educational transcripts, driver's licenses, utility bills, tax returns, and records of most life events, including birth, marriage, divorce, and death. These records are collected and collated by governments and private firms, and other organizations. Government agencies, political parties, advertisers, and internet companies like Google or Facebook are just a few of many organizations that maintain vast amounts of information on individuals from the moment they are born until when they die. It is very difficult for individuals to gain access to these data or learn how they are used.

Much of the time, this tracking occurs with our blessing: we choose to be tracked in order to get better search results, deals on services, travel directions, and so on. There are other times, however, when these data are misused to breach the privacy of individuals, or when they are stolen by cyber-criminals and used to commit fraud. These same dynamics also hold true for governments. Local, state, and federal authorities use cell phone information in various ways to help catch people suspected of crimes, but these technologies are often also used to monitor citizens for *potential* criminal behavior. There have been many, and will likely continue to be many, instances where these data are misused by trusted authorities in ways that skirt or sometimes just break the law.

Beyond our phones, there are a variety of ways in which computers, networks, and miniaturization have made it easier to track people. GPS receivers are small and powerful, making it easy for security or investigative agencies to place them on a suspect's car or person and track them for months. Insurance companies offer drivers the opportunity to have GPS trackers placed in their cars in order to get a better idea of how a person drives, which can lead to better rates – at the cost of having a company know your every move. Many new cars have GPS-based services built-in, such as emergency roadside assistance, which can be a real help when you have car trouble. These companies often sell this information, however, to other companies that want to know where you travel or where you live.

These are just a few of many examples of how we are all tracked in the course of our daily lives.

8.3 Outside Surveillance

A growing amount of surveillance also happens from "the outside," by which we mean when you are being observed or tracked in ways that do not rely on devices you carry on your person or are derived from your interactions with computers.

A prime example of surveillance from the outside is remote sensing technology, which is rapidly improving. Until recently, the spatial resolution of these sensors was not good enough to see or track people, but now there are several companies and governmental agencies that offer space-based and airborne sensors that can track individual people and cars with ease. Some commercial systems can track every single person and car in a city over the course of hours, and military and government systems are much better. Military-level surveillance techniques can even be applied to, for example, apprehending suspected criminals in US cities or tracking literally thousands of cars at the same time as they move along city streets.

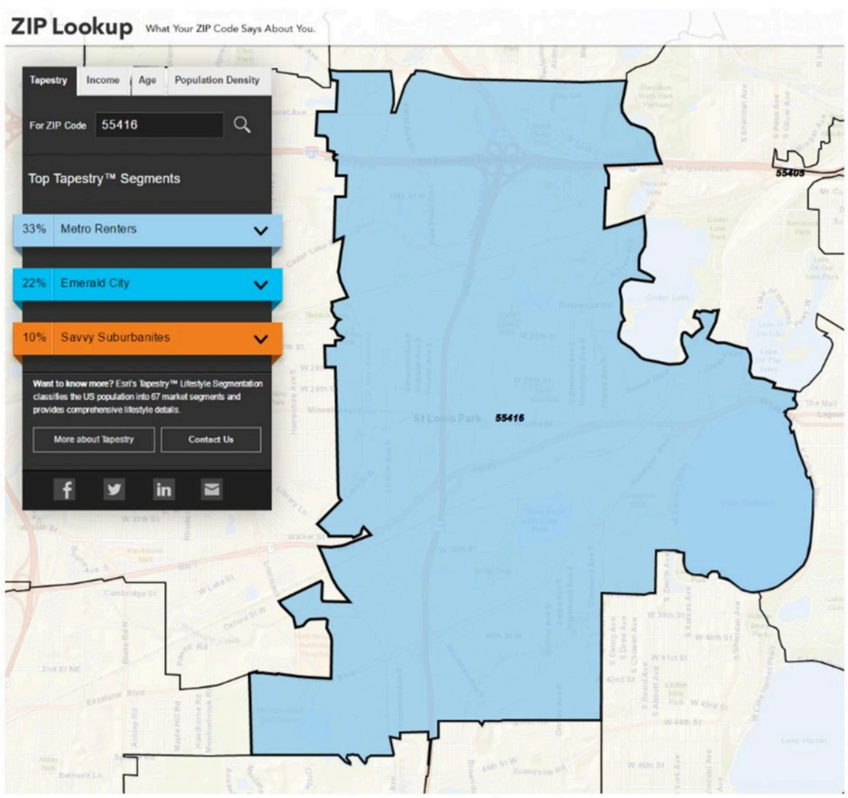
More prosaically, most cities are carpeted with surveillance cameras mounted on any number of objects – stores, houses, light poles, or traffic signs. There are some urban areas where you cannot walk virtually anywhere without being captured on camera. For some people and places, these cameras are seen as a good thing. The site www.videosurveillance.com/communitycam/, for example, argues for more, and better camera coverage in order to safeguard property and protect people from harm caused by crime or automobile accidents. In contrast, the New York Civil Liberties Union's Surveillance Camera Project warns of the dangers of blanketing cities with cameras, especially in how they offer security but at the cost of intruding into the lives of many people by removing their ability to be anonymous, move through the city freely, and associate with other people without fear of being watched.

Another emerging technology that is both useful and troubling is facial recognition. Many of the kinds of data collected about people during the course of their daily lives can be associated with them because they carry a phone or use a computer. In other words, surveillance from the inside. Leaving a phone behind or not using a computer can free a person from this form of surveillance, but it does not prevent other people from taking photos of that person or from cameras from doing so. Increasingly, these photos and videos are processed by computers that can recognize faces and associate these faces with other records. Apps on your mobile phone, like Facebook or Google+, can automatically identify the people in your photos. We are very close to a time when someone can simply point a phone at you and be able to bring up all sorts of information about you without your knowledge and consent.

Consider a program being tested in China, called "Xue Liang" or "Sharp Eyes", a nationwide surveillance system that uses artificial intelligence to match people from a photo database to the video feeds from private and public cameras in streets and in homes and businesses. This system is seen as being helpful because it would allow banks, hotels, airports, apartment buildings, schools, and other places to identify people and allow them entry automatically. Of course, the police and security forces are also very interested in being able to track actual or suspected criminals. Further plans include linking this facial recognition system to medical records, social media posts, travel plans, and purchases in order to create a single system of pervasive and ubiquitous national surveillance. The program will eventually give officials the ability to track what people are doing, where, and with whom.

Perhaps the fastest-growing form of surveillance from the outside is one that is also much like surveillance from the inside namely the profusion of internet-connected devices such as baby monitors and internet-enabled speakers like Google Mini or Amazon's Alexa or Echo. These are devices that are always on, always listening and watching, and always feeding information back to their companies. Of course, people have these devices in their homes because they are helpful—they can search the internet, order groceries, and monitor whether a child is sleeping peacefully. These devices also have drawbacks. Companies record and track every utterance or request, feed this information into their systems in order to use it both in house, and to sell to other companies. Many of these devices—especially cameras and toys—are incredibly insecure and are vulnerable to being hacked or taken over by people in order to spy on you and anyone else who is in your home.

Even when organizations don't have pieces of information about you, in particular, they can make very good guesses about the sort of things you do, buy, and want based on where you live—with even small amounts of information. This way of combining location with attributes of the people who live in a given place is called geodemographics. A product by Esri called "Zip Tapestry" divides the country up by zip codes and other zonations, and then describes a good guess about who lives in each area. You can try it yourself at ESRI's Zip Tapestry.



Geodemographics. Esri's Zip Tapestry website describes the general categories of people living in a given zip code, based on a variety of different data. [4]

These technologies are very helpful to firms because they help narrow down where their customers live. Many college and university students can find elements of their lives in the following description of the "young and restless":

> We're millennials and coming into our own. We're young, diverse, well educated, and are either financing our classes or working in professional/technical sales, and office administration support positions. Most of us rent and will move for a job. We live alone or share a place in densely populated areas of large metro areas in the South, West, and Midwest. We can't do without our cell phones; we text, listen to music, pay bills, redeem coupons, get directions, and research financial information. Not brand-loyal; we shop for the best price. We buy natural/organic food but will also go for fast food. We want to be the first to show off new electronics, but we read online reviews before buying. We go online to bank, buy from eBay, access Twitter and Facebook, and watch TV and movies.

Do you see yourself or someone you know in this description?

8.4 Conclusion

We are steadily moving towards a state of "Total Surveillance," by which we mean that very few aspects of our lives will not be observed in some way. Many of the necessary technologies are already in place and others are getting better with every day.

Issues around the surveillance society are complicated, and it seems as if they will only get more so as time goes on. When thinking about the good and bad aspects of surveillance, it can help to ask three key questions when considering a given case or scenario.

- What power relations are involved?
- Who controls the technology?
- What are the implications for privacy vs. security?

Resources

For more information about the use of airborne cameras developed for the military in Juarez, Mexico, and Dayton, Ohio, listen to this episode of the podcast *Radiolab*, "Eye in the Sky."

To learn more about day-to-day tracking in our lives, read the article by Matthew Hutson in *The Atlantic*, "Even Bugs Will Be Bugged"

The home page of each of these projects examines and track video cameras. Compare and contrast how each project looks at video surveillance.

- NYCLU Surveillance cam mapping project
- Video Surveillance's mapping project

Read the article by Adrienne LaFrance in *The Atlantic*, "Big Data Can Guess Who You Are Based on Your Zip Code." The article talks about ESRI's Zip Tapestry.

The Washington Post story Simon Denyer, "China's Watchful Eye" describes China's efforts to create a surveillance state. January 7, 2018.

Notes

1. Guerry, A. M. and A. Balbi, Statistique comparée de l'état de l'instruction et du nombre des crimes, 1829. French National Library. https://commons.wikimedia.org/wiki/File:Statistique_compar%C3%A9e_de_l%27%C3%A9tat_de_l%27instruction_et_du_nombre_des_crimes.jpg?uselang=fr.
2. CC BY 3.0. Wikimedia commons; https://commons.wikimedia.org/wiki/File:Surveillance_cameras_Tom_Lee_Park_Memphis_TN_01.jpg
3. Fair use. Steven Manson 2015
4. Fair use. Steven Manson 2015

9. Social Maps

Melinda Kernik and Sara Nelson

We will look at ways in which changing mapping technology has become embedded in daily life. With the development of location-aware technology like smartphones, there has been a big shift in *what* is possible to measure, *who* is collecting data, and *how much* data is produced. We will examine how geographic data, produced by diverse groups of people, have been incorporated into scientific research, disaster relief, and local government services. We will consider changes to mapmaking that have been made possible through the rise of online user-friendly geospatial tools and easier access to data. Relatedly, we will think about the "digital divide" between those who have access to mapping technology and those who do not. We will close the chapter by thinking about how technological change shapes the way we navigate between places and find information about businesses and services.

This chapter will introduce you to:

- Volunteered Geographic Information (VGI)
- Democratization of data production and mapping
- Digital divides
- Issues around e-waste
- Various ways maps are used in the real world

9.1 Volunteered Information

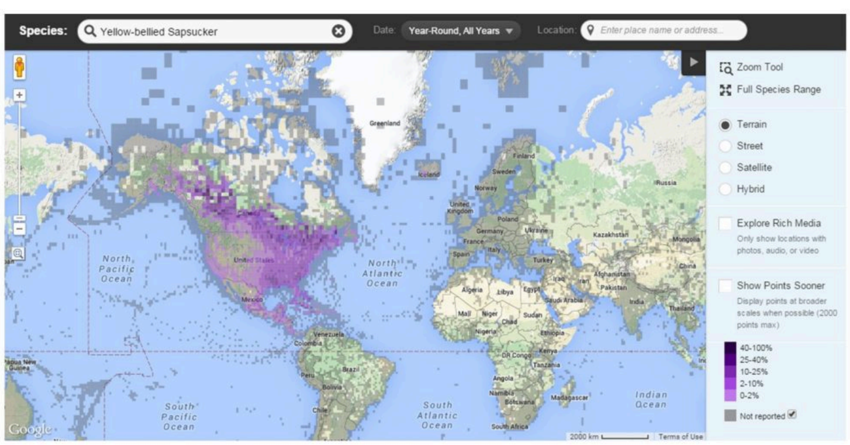
You may remember from your learning about data that spatial data has historically been collected by a small number of experts working for well-funded organizations (government, academia, etc.) and then made available to the public for use through static maps. Until recently, identifying the physical location of objects required special training and equipment. Technological developments in the mid-2000s, however, brought about huge changes in *who* collects data, *how* it is collected, and *what* types of places and events have data collected about them. Rather than a one-way exchange of information, it is now possible to produce spatial data using inexpensive, widely available mobile devices that accurately record spatial location without extensive training.

This form of data, collected by individuals with diverse backgrounds and skill levels, is known as

Volunteered Geographic Information (VGI). VGI makes it possible to map phenomena that take place over such a large area or short time span that they cannot be recorded by conventional data practices. VGI also supports groups that can map aspects of daily life ignored by official agencies. Data collected from cell phones can be used for surveillance, but the examples in this chapter will focus on the more positive and transparent uses of these new technologies. We will look at three different ways that VGI is being incorporated into daily practice, such as for science, disaster relief efforts, and local government.

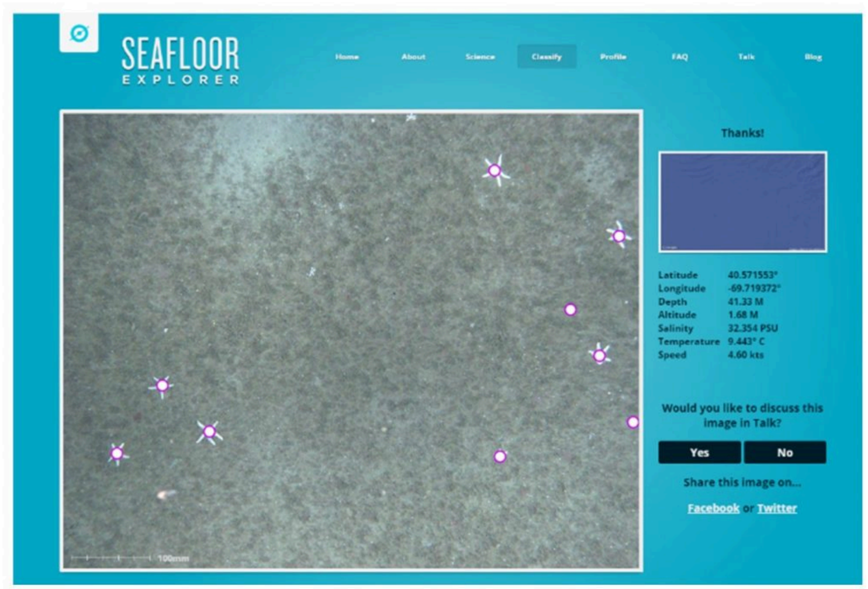
9.1.1 VGI for Science

VGI offers exciting possibilities for scientific research. When collecting information about how a phenomenon occurs over space (e.g., the migration of birds from high to low latitudes in winter), scientists often have a limited number of monitoring sites they can support with trained staff and funding. Scientists increasingly use spatial data volunteered by enthusiastic citizens to expand what they can observe. It should be noted that citizen science projects were popular long before cell phones, but new technologies have increased the number of projects, the spatial accuracy of reported observations, and the ease of participation. With VGI, data can be collected and processed rapidly and at a very low cost. There are trade-offs, however, in terms of data quality. Even with the most well-intentioned volunteers, it can be difficult to establish consistent practices, coordinate data collection for all areas of interest, or assess possible errors in the data. In some cases, the volunteers are the "sensors" – they make observations and report back what they have seen or measured. For example, with [Ebird](), volunteers count the number and type of birds they observe, as below. They enter the information into a website with reports from other birdwatchers. When combined, the data give a picture of species density and migration patterns.



Citizen science mapping. Ebird creates maps of bird distribution as reported by volunteer bird watchers on the site. [1]

In other cases, information has already been collected but volunteers assist scientists in going through large quantities of data to identify important patterns. With Seafloor Explorer, for example, volunteers mark the number and type of species they observe in photographs of the seafloor. The location of each photo is known, helping scientists understand spatial patterns in marine biology.



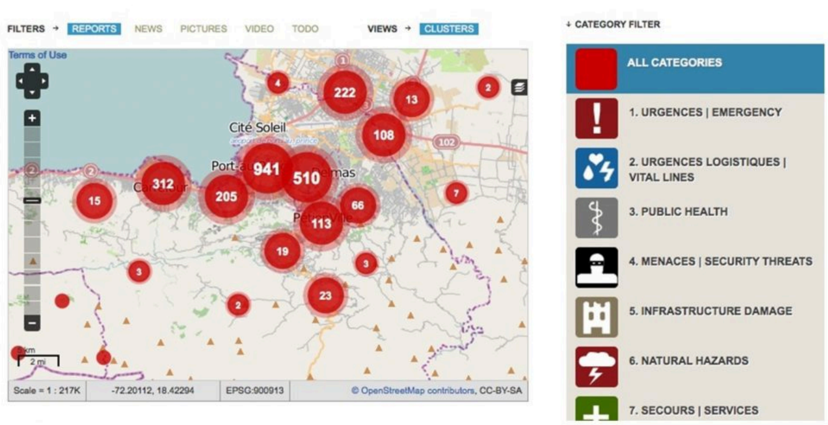
Crowdsourced discovery. Volunteers mark sea star locations in an image from Seafloor Explorer. These locations can then be used by scientists to better track and understand the sea stars. [2]

9.1.2 VGI for Disaster Response

When a disaster strikes, getting good information quickly is essential. By using data created by affected populations, emergency aid workers can get a better understanding of what is happening on the ground and respond appropriately. In January 2010, a massive earthquake shook Port-au-Prince, Haiti, claiming many lives and causing major damage to buildings.

Disaster. A United Nations patrol through the damaged suburb of Bel Air, Haiti (Jan 19 2010). [3]

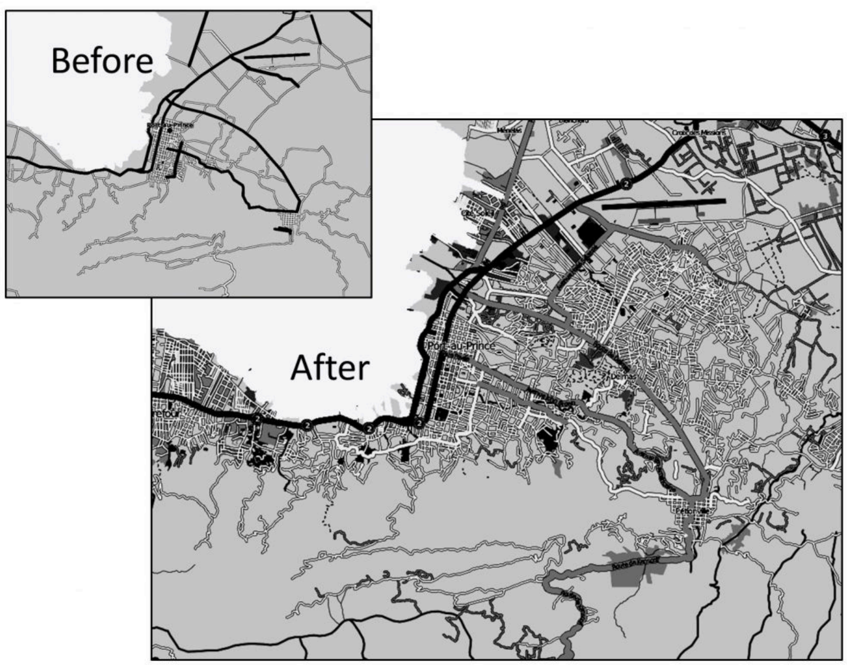
In the days following, a number of VGI and crowdsourcing endeavors emerged to support the relief effort. The group Mission 4636 set up a free number to which individuals could send text messages (SMS) to request supplies or report conditions such as people trapped beneath rubble, infrastructure damage, and food and water shortages. The site *CrowdFlower* coordinated Creole and French-speaking volunteers to translate, categorize, and geolocate over 40,000 received messages. A group of students at Tufts University used a mapping platform known as Ushahidi to sort through the massive influx of incoming data to identify urgent requests, as seen below. They also combined the translated messages with information from official reports and social media to be marked as events on a crisis map.



Crisis mapping. The Ushahidi crisis map for Haiti, built by volunteers and people sending information from the site of the disaster. [4]

Texts and their crowdsourced translations were vital in responding to urgent medical and rescue requests. The geographic and linguistic knowledge of the crowd often far exceeded resources available to UN and US responders. In cases of aggregate need such as food and water shortages, however, the messages were less helpful. Emergency response officials did not trust that the incoming requests showed a complete picture of need, in part because people had to use cell phones to report information, and there may have been areas where people did not have phones.

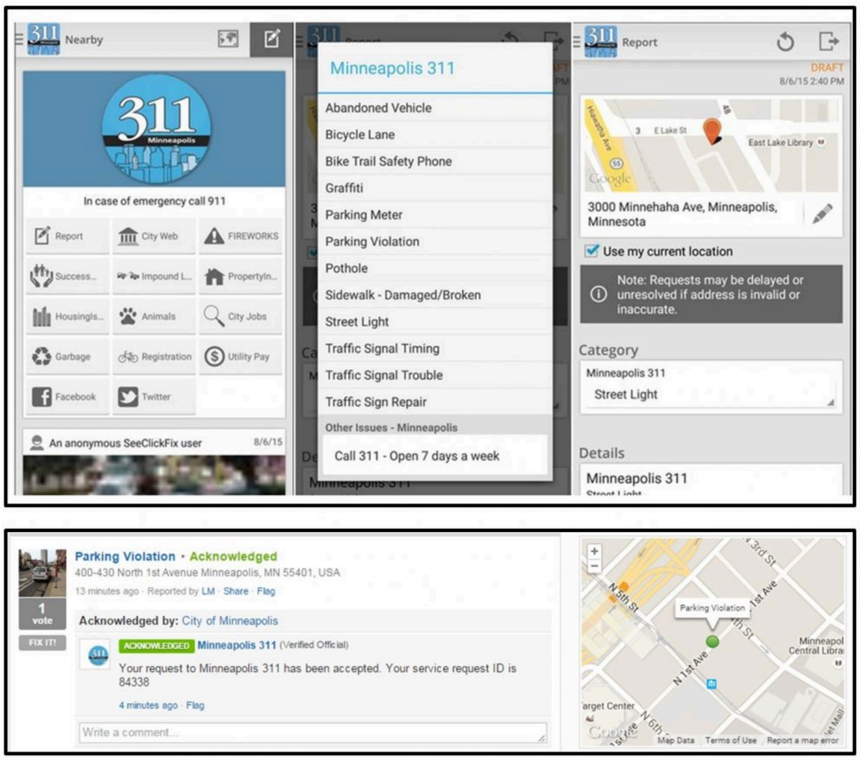
One very useful VGI activity during the Haiti relief effort came from contributions to Open Street Map (OSM). OSM is an open-source map to which anyone can add or edit geographic data. At the time the earthquake hit, existing maps of Haiti were out of date and incomplete. Volunteers from all over the world worked to trace roads and buildings from high-resolution satellite imagery. Within a few days, the crowdsourced map was the most detailed available, as seen below. The United Nations, the World Bank, and search-and-rescue teams quickly adopted it for their work. Crisis maps and OSM have been used during other natural disasters, including Typhoon Haiyan, and the mapping projects are also being done in areas likely to have severe weather or geologic events.



Open street map. The Open Street Map Port-au-Prince before and after the earthquake in Haiti shows how quickly volunteers can create new data and maps. [5]

9.1.3 VGI for Government

Many local governments are using VGI to monitor traffic patterns, plan new bike routes, and interact with citizens. One example of this move towards using ordinary people's observations to improve urban spaces is SeeClickFix. Using this application, individuals are able to report issues they see around their neighborhood such as street light malfunctions, graffiti, or abandoned vehicles, per the figure below. You can select the location of the issue you are reporting and it will appear on a map with concerns posted by other users. City officials monitor these posts and pass the report to road maintenance, police, or another relevant government department. You can also post photos of problems and signal support for issues reported by other people. In some ways, these systems are more transparent than calling a city to file a complaint – everyone can see the unresolved cases on the map. This can be a problem for city staff, though, if they are unable to respond quickly or if the person submitting the request is not satisfied with the fix.

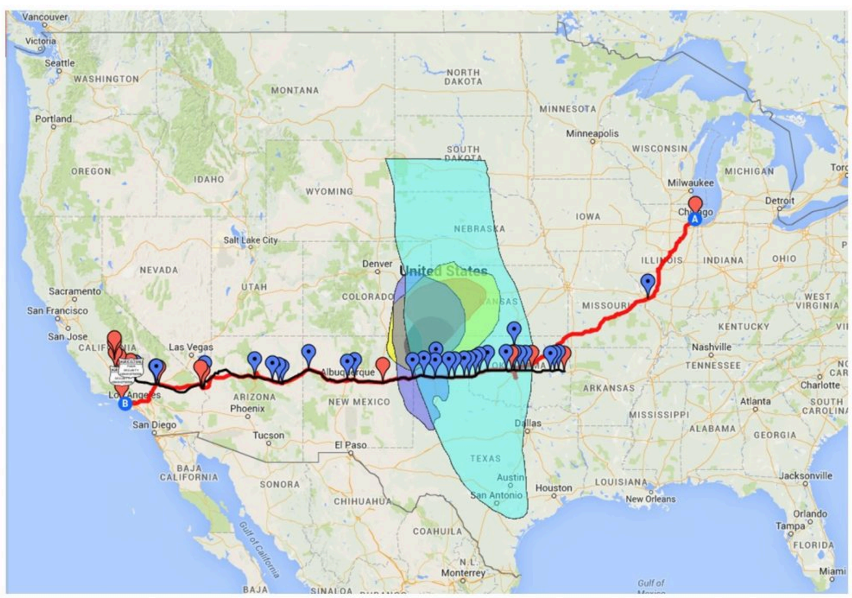


Mobile government. The 311 Mobile Application interface for SeeClickFix in Minneapolis, MN and a report submitted to SeeClickFix from a cell phone. Individuals are able to report issues they see around their neighborhood such as street light malfunctions, graffiti, or abandoned vehicles.[6]

9.2 Neogeography

In addition to expanding the number of people who can create data, shifts in technology have also made it easier to make maps without special training. There are a number of user-friendly online and open-source mapping tools and many government and nonprofit organizations that make their data freely available. This trend has been described as a “democratization” of mapping practice since the public is actively encouraged to participate in describing the world.

Advocates for this “new geography” or neogeography argue that it takes the power to choose how the world is represented out of the hands of the military, government, and academics. Amateur and self-trained neogeographers combine already-existing online tools and data to share information with friends or create a useful synthesis tool. For example, they might use Google Maps to “mash-up” data from several sources, make a story map of a recent vacation using geotagged photos and social media posts, or map the movements of famous fictional characters, as below. By putting data and mapping tools into a more diverse set of hands, a wider range of experiences and concerns become visible.

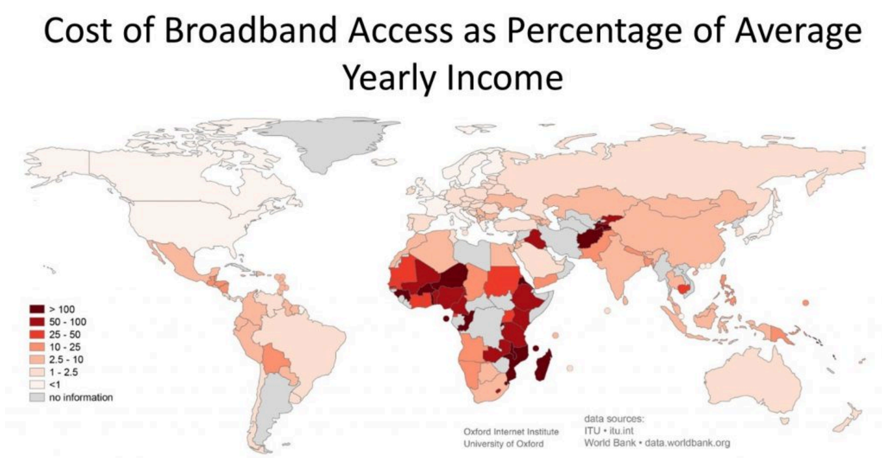


Neogeography. A Google Map made by a neogeographer that marks events and places described in John Steinbeck’s classic novel The Grapes of Wrath. [7]

Some traditionally trained geographers and cartographers have questioned the quality or accuracy of the resulting maps. This guide has spent dozens of pages discussing mapping principles, and only skimmed the surface of cartographic methods. With today’s technology, anyone can make a map, but they may not understand the underlying data, appropriate symbolization choices, or how to handle the “lies” maps inevitably tell.

9.3 Digital Divides

While there are many new possibilities for mapping, there are also huge disparities in terms of who has the technology, skills, and time to create data and maps. The "digital divide" between those who have access to technology and those who don't is evident at multiple scales. Wealthy countries like the United States have faster, cheaper internet service, more comprehensive access to computers, and more resources devoted to the creation of geospatial data than developing nations. It is estimated that up to a quarter of the world's population does not have access to electric power, much less the technology necessary to generate digital data or maps about their experiences.



Digital divide. Map of the cost of broadband subscription as a percentage of average yearly income. [8]

This digital divide has resulted in a large discrepancy in the quantity and quality of data created for different parts of the world (e.g., lower spatial and attribute resolution in poorer countries.) This also means that international organizations continue to have more influence in shaping maps and narratives about developing countries than the people who live there.

The digital divide is also evident in smaller areas within wealthy countries and cities. There are strong differences in the speed of internet connections and the use of new map technology between urban and rural areas. There are also notable divides in the use of technology-based on socioeconomic and demographic characteristics. Who owns smartphones or other devices that leave a digital footprint? Who has the time and resources to volunteer geographic information? Unsurprisingly, data is more often produced by citizens from wealthy, tech-savvy urban neighborhoods than from poor, rural places. This results in inconsistent accuracy in data for different places on the map. In sum, just because new technology provides the possibility for more widespread participation in mapping, that does not guarantee that this participation will be equitable without appropriate technologies and the existence of supportive social, economic, and political institutions.

9.3.1 E-Waste

With rapid changes in new technology, the lifetime of electronic products is often very short. Cell phone and computer companies encourage customers to trade in their devices for newer models every couple of years or even yearly. Hundreds of millions of used computers, monitors, TVs, mobile phones, and other electrical products are thrown away annually. An estimated 50 million tons of electronic waste (also known as e-waste) were generated worldwide in 2012 alone (Vidal 2013). Electronic components frequently contain hazardous substances such as lead, mercury, and cadmium and must be disposed of carefully to avoid negative environmental consequences. So what happens to all of these used and broken electronics?

Trade agreements, such as the Basel Convention (1989), attempt to restrict the flow of e-waste from country to country. There are many loopholes, however, and a thriving black market has developed in some locations. Indeed, border agents checking shipping containers leaving the European Union found that almost one in three contained illegal e-waste. Waste has become particularly concentrated at ports in the developing world such as Guiyu, China, and Agbogbloshie, Ghana. Impoverished individuals in these places have become experts at pulling apart electronic circuitry in order to sell the most valuable components, as seen below. Many techniques for disassembling electronics, such as burning plastics casings to get to the recyclable metals, have serious health effects.

The human toll of e-waste. People working to process electronic waste in Agbogbloshie, Ghana, moving material (left), and burning components for copper (right). [9]

9.4 Digital Maps, Real world

Digital maps shape the way that we move through and think about space. Most of the time this is very helpful, as when we use phones to navigate from one place to another. Digital maps are also increasingly used to help guide us to specific kinds of destinations, such as the nearest gas station or coffee shop, as well as to provide information such as open hours or reviews. There can be downsides to these very helpful technologies, however!

GPS-enabled devices have become vital to the way we navigate from place to place. With the help of a smartphone you can arrive in a new city and, without knowing anything about the area, find your hotel or locate a popular restaurant. Increasingly, people trust the route planning algorithms embedded in online maps rather than their own knowledge of an area or paper maps. There are many examples of obedient drivers following flawed directions from their GPS units into dangerous situations, including driving into lakes, onto airport runways, or on roads not suitable for the size of their vehicle. While you might urge individuals to pay more attention to their physical surroundings, it is undeniable that the internet, our phones, and Google Maps mediate our movements through space. An estimated one billion people use Google Maps every month. We are increasingly reliant on GPS to help us get from one activity to another. In one study in England, four out of five 18- to 30-year-olds confessed to an inability to navigate without electronic help (Ward 2013).

Google and other search engine listings impact where we choose to shop, eat, and spend our free time. When trying to find the nearest restaurant or get information about a business, many people turn to Google maps. So where does Google get its data? The bulk of the information in Google Places (Google's business directory) comes from commercial mailing list databases, but ordinary users can also edit details such as phone number or hours of operation. This means rival companies can spam or hack a listing if it is not actively maintained by the real business owners.

An example of how someone can modify online directories is demonstrated by the fate of the Serbian Crown, a restaurant serving hearty Serbian fare for 40 years at the same location. The restaurant was forced to close in 2013 after seeing a sudden 75% decline in customers on the weekends (Poulson 2014). The puzzled owner eventually discovered that Google Places had been changed to incorrectly report the store as closed on Saturdays, Sundays, and Mondays. This service allows anyone with a Google email address to modify the information about a real place. Most of the time this is helpful because anyone can correct an error, but sometimes this functionality can harm real people. Google has gotten better at monitoring the so-called "community edits," but still has trouble tracking fake map listings.

9.5 Conclusion

Rapid changes in technology have greatly expanded who is able to create data and maps. These changes hold exciting possibilities for scientific research, disaster relief, government practices, social justice, and representing/navigating daily life. But it is also important to acknowledge that the benefits of these innovations are not equally dispersed. Large portions of the global population do not have consistent access to electricity, much less the kinds of spatial data and techniques discussed in this chapter. Maps have a profound impact on the ways we move through the world and perceive space. As we have discussed in this chapter, mapping technology has changed significantly over time, with both positive results, like greater participation in data creation, and negative ramifications, like the 'digital divide.'

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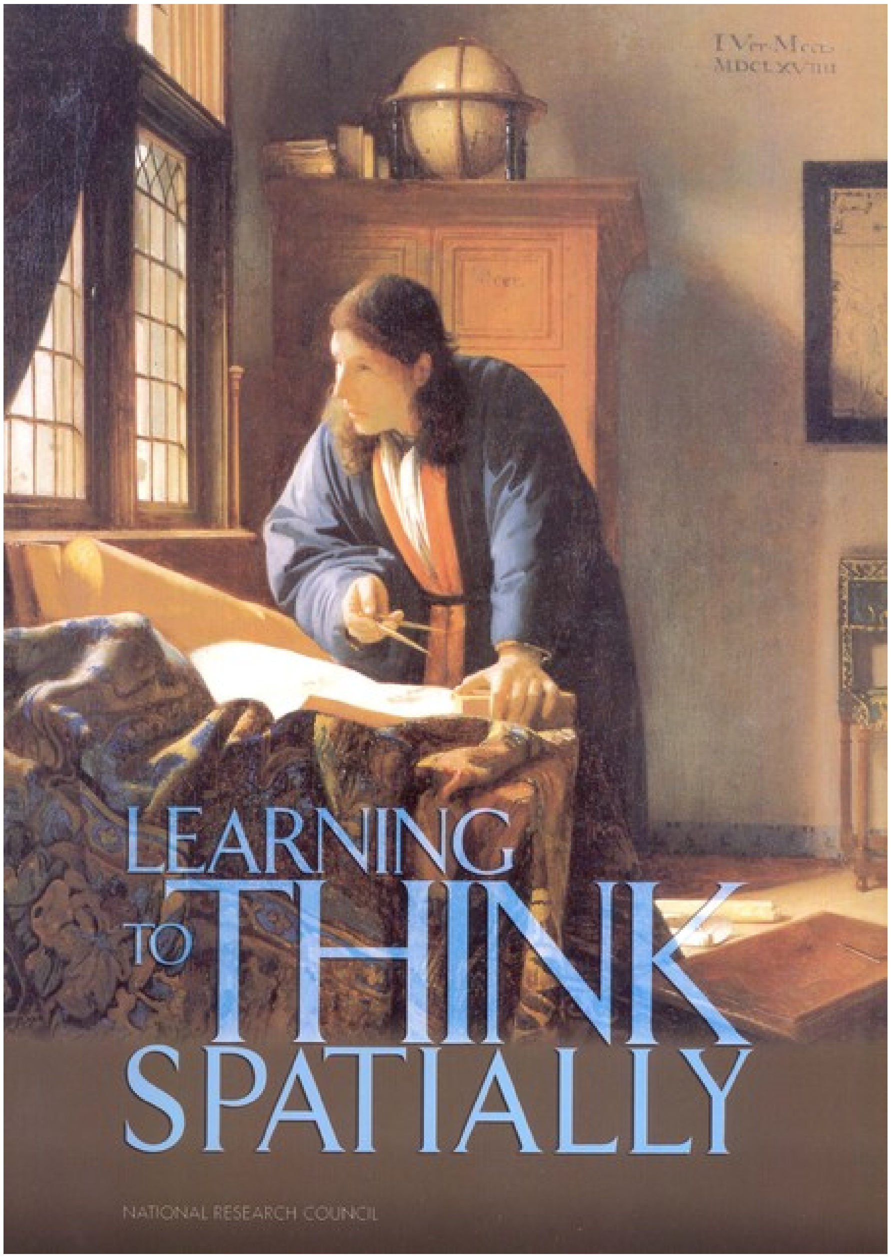
10. Conclusion

Steven Manson

Mapping is central to many things we do as individuals and as groups. Throughout this book, we've seen the ways in which people have used maps for thousands of years, and indeed, it's likely that they were using maps in times before we had evidence in the form of clay tablets or wall drawings. Today, mapping is a large and growing sector of the economy as well as an important social, cultural, and political phenomenon. Mapping is also important for lifelong learning. Spatial thinking skills are used in many fields, careers, and pastimes. The National Research Council report "Learning to Think Spatially" emphasizes that "with advances in computing technologies and the increasing availability of spatial data, spatial thinking will play a significant role in the information-based economy of the twenty-first century." Mapping and related technologies and societal practices are the foundation of spatial thinking.



Learning to Think Spatially. The National Research Council report “Learning to Think Spatially” describes how mapping is central to the information-based economy of the twenty-first century. [1]

We’ve seen how scholars, policy makers, students, workers, and others have employed spatial approaches that recognize the spatiotemporal nature of people, places, and processes. The key to these efforts is using concepts such as location, space, scale, and distance. This work is all part of a broader and vital cross-cutting need for society to broaden and deepen the use of spatial approaches so that we may better see the connections within and among the various challenges and possibilities that people and the environment face. Mapping technologies have always exemplified the interplay between society and technology, but these social and technological components are increasingly inseparable when they come together in mapping.

Maps are useful in part because they allow us to see large areas of the world that we otherwise wouldn't be able to see on our own, whether it be the bus lines on the next block or the entirety of the earth. Maps are helpful because they can present a variety of complex social and environmental information in a way that is easy to interpret. Maps can demonstrate basic spatial relationships and highlight features of interest, but they can also provide information on things that cannot be directly observed even if one were standing in the mapped location. For instance, maps allow us to 'see' invisible phenomena such as mineral deposits below the ground, pollutants in the air, and the day's pollen count. Many of our maps are reference maps, generalist views depicting one world that essentially stores and displays a variety of features for a variety of uses. In contrast, thematic maps highlight specific themes, be it the fastest route to work or the best places to eat.

More broadly, we have seen how maps are both technology—be it pen on paper or pixels on a screen—and an artifact of society derived from the data, analysis, display, and use to which maps are put. As such, it is hard to know what the future holds. Our maps today reflect artistic and scientific standards that are centuries old, such as the underlying projection systems or color conventions used by most online and mobile maps. Like the societies from which they spring, however, maps both drive and are driven by changes in society and technology. Clearly, mapping today is a story of geographic information science and cognate technologies, like GPS, big data, virtual reality, or machine learning. Mapping will remain an important part of this larger evolving mix of society and technology.

What will not change, however, is the need to see maps explicitly in terms of society and technology. Mapping is a way of knowing and changing the world, and as such, mapping can only make sense in the context of a broader education that allows a person to critically and ethically engage with its various dimensions. We have seen how mapping is built on various fundamentals including data, symbolization, simplification, and classification, as well as many forms of spatial analysis. Throughout this book, we have explored the numerous scientific and policy dimensions of maps, particularly in how there is no such thing as just data or maps outside of a broader social and technological context. Even the most basic aspects of science and engineering of mapping technologies pose various kinds of promises and pitfalls, including foundational technologies like GPS, the internet, remote sensing, and crowdsourcing. Many mapping technologies, including satellite imaging, GPS units, and the location-aware internet are grounded in a complicated set of interplays among various parts of society, including the government, military, commercial firms, not-for-profit organizations, and regular people going about their lives.

It will also remain important to examine the continuing roles that individuals play in their cultural, social, economic, and political worlds as it relates to mapping. We must ask questions about what surveillance practices mean for individuals and society or how individuals can take advantage of mobile mapping technologies to change the way they understand and effect change in the world. Mapping offers a multidisciplinary framework with which to understand a range of local, national, and global issues. Mapping also involves critically evaluating maps produced by different individuals, social groups, and researchers. This informed understanding of these social and technological features of mapping is more important now than ever. We have seen how individuals and groups are tracked via their mobile phones by companies like Facebook or by government agencies. If you are reading this book via the internet or as a download on your phone or tablet, you are being tracked by a few different organizations, and likely more than you would expect. Mapping is a useful way to understand relationships between society and technology, as mapping technologies are driven by social needs, and these technologies, in turn, advance and change with societal shifts.

In sum, mapping is an essential and ever-growing human activity. It is the result of the interplay among many facets of society and technology, and has been for most of recorded history (and likely before then as well). With the advent of computerized mapping, people experience how spatial data, analysis, visualization, and thinking are transforming our society in many ways. Billions of people use technologies such as GPS, mapping, location-based restaurant service, and car-hailing companies. Governments use mapping to identify crime hot-spots, plan social interventions, and identify routes to evacuate vulnerable populations from harm. Companies use spatial analysis to find optimal sites for stores, evaluate supply chains, and determine how much to charge for goods and services. We combine spatial approaches with spatiotemporal data gleaned from maps, satellites, smartphones, sensor networks, drone-based cameras, and social media. These technologies help commuters plan how to minimize travel time, farmers to best plant and protect crops, epidemiologists to identify emerging disease hotspots; emergency planners to develop smarter evacuation routes, policy makers to visualize spatiotemporal climate-change scenarios, and first responders to use high-resolution imagery to map areas of need. These are just a few of the many high-impact and relevant ways in which mapping is used in people's lives.

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Notes

1. In the public domain in the United States because it is a work prepared by an officer or employee of the United States Government as part of that person's official duties under the terms of Title 17, Chapter 1, Section 105 of the US Code.

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Timeline

- 2018. Updates to the first edition, including updating sections 2.2.1 and 9.1-9.3 and correcting typos throughout. Added Conclusion (Chapter 10).
- 2017. First edition published by University of Minnesota Libraries Publishing. Steven Manson, Laura Matson, Sara Nelson, and Ashwini Srinivasamohan reviewed text for clarity and typographical errors. Manson remained primary editor, revising several chapters and developing new figures. Brittany Krzyzanowski helped process these images.
- 2016. Second edition of informal course text. Sara Nelson and Dudley Bonsal reviewed all chapters and authored significant revisions for several chapters.
- 2015. First edition of informal course text. Steven Manson worked with teaching assistants Melinda Kernik, Eric DeLuca, and Laura Matson to develop chapters. Jerry Shannon helped with images.

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- Past TAs have helped in many ways. In addition to the chapter authors making their contributions, Ashwini Srinivasamohan reviewed text for clarity and typographical errors; Brittany Krzyzanowski helped process these images and getting the book online and into print, as well as fixing typos; and Jerry Shannon helped with images.
- Susan Tade and Paul Ching from the Center for Educational Innovation offered expert advice and assistance in developing the 2015 version as part of a broader effort to update Mapping Our World.
- Kristi Jensen and Shane Nackerud of the University Libraries, as part of their pioneering Partnership for Affordable Content program, offered expert advice in developing open source materials and providing assistance in publishing the 2017 version and getting it into print in 2018.
- Mark Lindberg for early consultation on mapping and projections.
- As noted in several places throughout the text, portions of text and images were adapted from other open-source works, so an additional ‘thank you’ to their authors.

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Supplementary Materials

Supplementary materials, including labs and activities, are available for *Mapping, Society, and Technology* at:

z.umn.edu/mst