CHAPTER 6

Map design

Today, nearly anyone can make professional-looking maps. Mapmaking software and apps are widely available at low or even no cost. Sophisticated mapping techniques built into the software and apps guide users through the mapmaking process. Data for mapping is often cheap or free, and its access is made easier through online repositories and hubs. Today's mapmakers can create maps to print, use in a publication or presentation, view in a browser, access on a mobile device, embed in a website, include in a story map, and share in email or social media. The result is a paradigm shift called the **democratization of cartography**, which involves making maps available to wider audiences and empowering more people with the tools and knowledge to create and use maps effectively.

Mapmaking has broken out of the dusty corner office and out of the hands of the highly trained cartographer, who was one of the few people with access to the tools and data to make authoritative, high-quality maps. But if nearly anyone can make good-looking maps, how do we know whether the maps are useful, accurate, trustworthy, and reliable? This is the conundrum that comes with the democratization of mapmaking. In this chapter, we explore some of the most important design aspects of the intricate art and science of making maps with the intent of not only helping you succeed in making your own maps but also helping you to recognize when someone else has produced something that should only be used with caution or not at all. This requires that you have a basic understanding of **map design**—the process of arranging and presenting geographic information on a map to communicate spatial information clearly and efficiently to map readers.

Purpose, audience, and other considerations

Before designing a map, the cartographer needs to determine who will use the map, what they will use it for, and how they will use it. The **map audience** is the individual or group of people who will use or interact with the map. The **map purpose** is the primary function of the map, which, as we saw in the introduction, might be to act as a geographic refence, convey a theme, aid navigation, and more. The conditions of use are the circumstances under which the map will be used. These conditions can relate to the map's medium (for example, paper or digital screen), viewing conditions (including distance and lighting), and resolution (amount of detail shown on the display). Technical constraints, such as size of the map, ability to carry it with you, and requirements for black and white or color display, also have implications for the map's design. Designing for accessibility challenges faced by the map reader, such as visual, auditory, motor, or cognitive impairments, may also be a requirement.

A tour map, for example, is designed very differently from a utility map, although both may show similar features, such as roads and buildings. The 3D tour map of Philadelphia, Pennsylvania, in figure 6.1A is intended to entice visitors to explore an area that may be new to them. Landmarks are prominent features on the map, helping readers to navigate a potentially unfamiliar landscape. Other features on the map include historical sites (tan) and green spaces (green); tourist facilities, such as visitor centers; restaurants (wine glass), restrooms (Ⓡ), post offices (✉), and other points of interest. Transportation features include streets of historic or architectural interest (★), parking facilities (Ⓟ), traffic directions (↖), and bike rental locations (🚲). Dashed bus and colored metro stations and lines help people travel to and through the area. The map is visually captivating, drawing readers in to explore the area even if they are not there physically.

The field crews who will use the water utility map in figure 6.1B are trained professionals who are already familiar with the map's design and symbology, as well as the geographic area. The map is intended to display the complex utility network, its features, and their characteristics in a simple and straightforward manner. The map shows three utility systems simultaneously: water (blue), wastewater (green), and stormwater (orange). Aerial imagery (see chapter 11) serves as a detailed basemap over which the brightly colored line and point symbols can be easily seen. This map is designed to provide a thorough picture of specialized information to a small but expert audience so that they can perform their map use tasks efficiently and

A

B

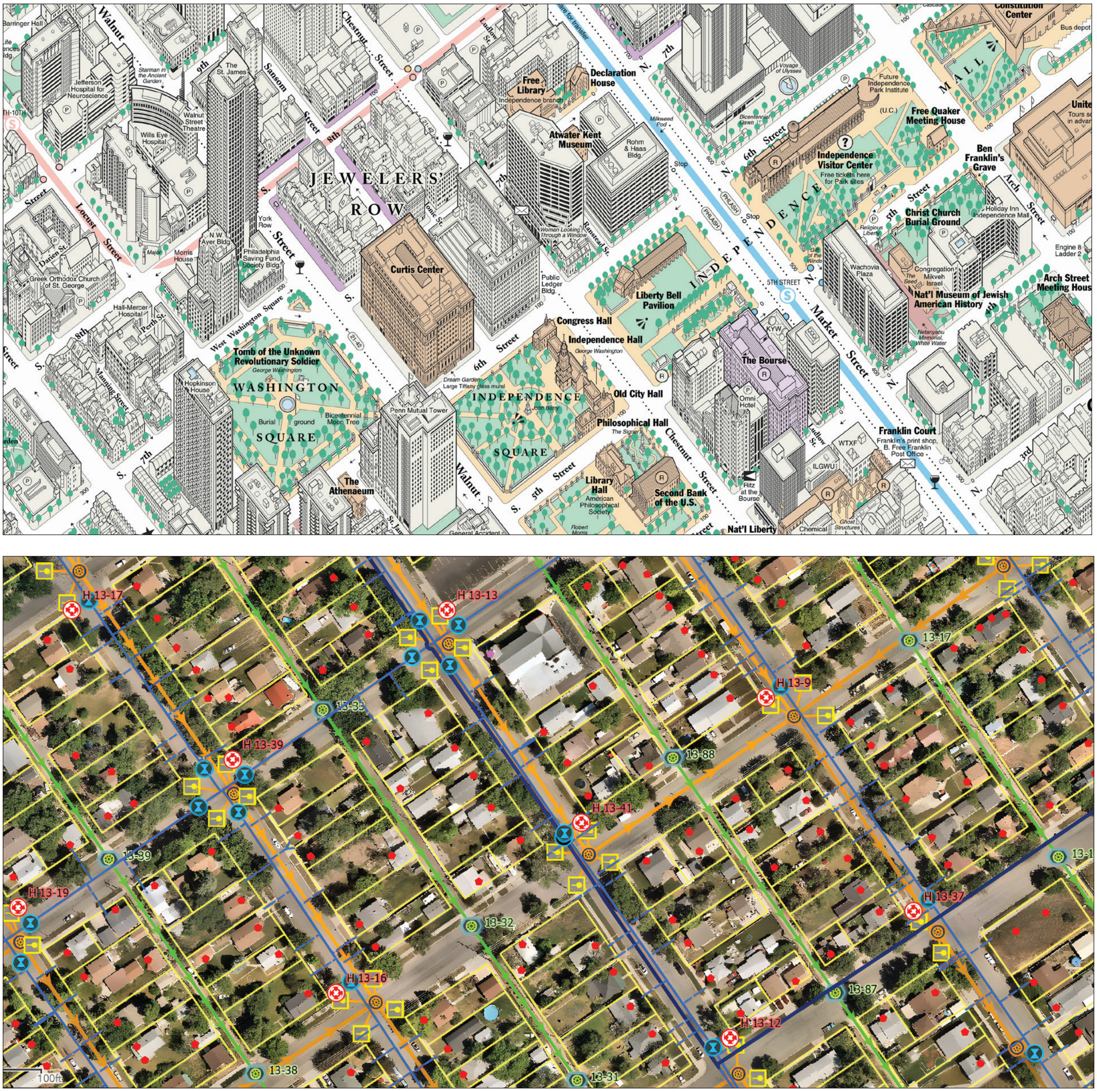


Figure 6.1. Although both of these maps show many of the same features, they are designed for different purposes, audiences, and conditions of use. As a result, the tour map (*A*) is pictorial and eye-catching, whereas the water utility map (*B*) is minimalist and utilitarian. Courtesy of Bill Marsh, Marsh Maps (*A*), and Jeff Sprock, City of Billings, Montana (*B*).

effectively. The tour map might be designed for print so that people can carry it with them, and the utility map might better be shown digitally on a computer monitor in the office or on a mobile device in the field.

Data for map compilation

Many maps today are compiled from existing GIS datasets, but they also may be produced from original surveys, field operations, photogrammetric compilations, and **primary data** that comes from direct measurement or data collection. Data that is captured by converting maps and other geographic data sources to a format that can be used for mapping is called **secondary data**.

Maps may also be compiled from data used to make other maps, usually of a larger scale. Many national mapping agencies have developed workflows to create their smaller-scale map series from the data they compiled for their larger-scale maps. These resulting products are sometimes referred to as **derived maps**, and they may include information from secondary sources, in addition to the maps from which they are principally drawn. Thus, maps may include information from a variety of sources. For example, road maps are compiled from road surveys, topographic maps, and aerial photography, whereas city maps are often compiled from surveyors' maps originally created to support engineering plans and land development. This presents a challenge for both the mapmaker (in collating the data) and the map reader (in assessing the value of each data source as well as the mapmaker's ability to manage the data).

Map scale

Map scale, described in chapter 2, is critical to map design because it affects how much detail can be shown on the map. Map scale guides decisions about selection, generalization, and classification, as well as symbols, color, and type, all of which we explore in more detail in this chapter. Map scale is proportional to the amount of detail that can be shown. For example, as map scale decreases from 1:24,000 (figure 6.2A) to 1:100,000 (figure 6.2B), the number and types of features decreases, as does the level of detail.

Recall from chapter 2 that map scale is the ratio between distances on the map and their corresponding distances on the ground. When ground features are displayed on a map, distances between them must be reduced simply because the size of the symbols on the map is greater than the actual size of the features on the ground. If we were to map physical features in the landscape at their ground sizes, many would be so small that you could not see them on the map, depending on the map's scale. If we try to shrink a larger-scale map to a smaller scale, the symbols may become too small to see or too difficult to differentiate from other symbols (figure 6.2C). Cartographers must therefore carefully balance the variety, complexity, and density of features with the map scale. This becomes an even greater challenge for many web maps because these decisions must be revisited for each zoom level, discussed in chapter 2.

Map projection

You saw in chapter 3 that map projections are designed for particular purposes and have certain properties, so choosing the right projection is a critical mapmaking decision. Map projection selection is often one of the first decisions made in map compilation—a wrong choice can result in a bad map, no matter what other decisions the cartographer makes. And savvy map users who spot a map with the wrong projection will be dubious about the map as a whole.

A general rule of thumb relates to equal-area versus conformal projections (see chapter 3). In general, equal-area projections should be used for maps of statistical distributions, such as population density, so that the relative sizes of areas can be properly compared. Conformal projections should be used to map locations, routes, landforms, and other geographic data for which shape and angles are important. Sometimes the map projection has been decided by mapping standards, client requirements, or other considerations that are out of the hands of the mapmaker. When a choice is possible, the map selection guidelines in chapter 3 and the summary of projection uses in table 3.1 can assist you.

Default map projection parameters sometimes need to be modified for appropriate use of the projection at different scales or geographic extents. A good example is redefining the central meridian, or the origin of the x-coordinates in the map projection (see chapter 3), to the center of the mapped area. Take as an example the Lambert conformal conic map projection for the conterminous United States map in figure 6.3A. With the central meridian at 96° W, the longitude line aligns to north in the center of the map. Zooming in to Oregon, the map appears rotated about 15° clockwise (figure 6.3B). Redefining the central

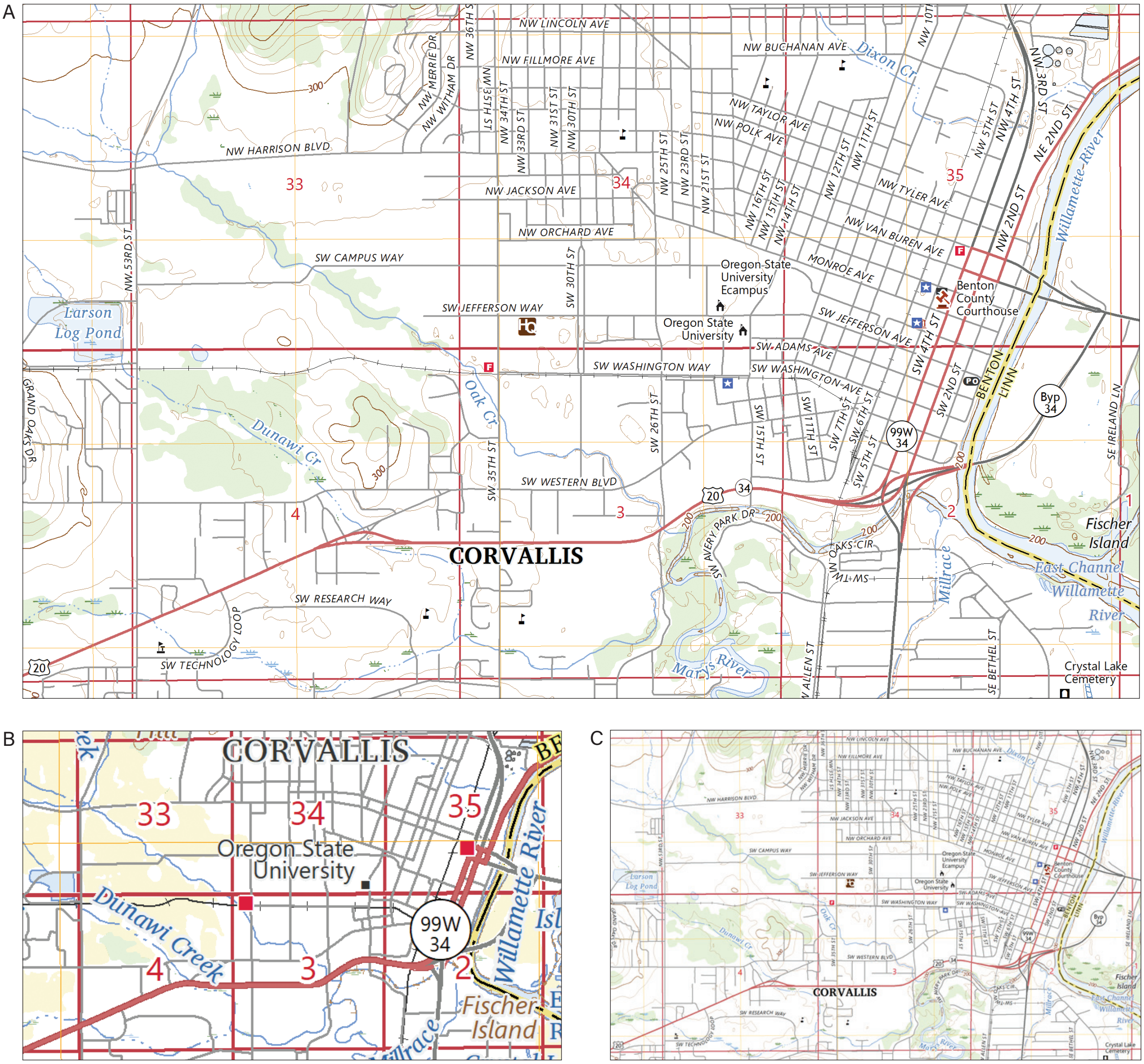


Figure 6.2. These USGS topographic maps show, at their relative map scales, the same six PLSS sections in the Corvallis, Oregon, vicinity. The detail on the 1:24,000-scale map (*A*) must be reduced by showing fewer numbers and types of features with less complexity than on the 1:100,000-scale map (*B*). Simply shrinking the map (*C*) from a larger scale to a smaller one results in a product that is illegible and useless. Courtesy of the US Geological Survey.

meridian at, or near, the center of the east–west extent of the state adjusts the map so that north is up at the center of the map extent (figure 6.3C). An eyeball estimate can be used to guess that 120° W might be a good choice for Oregon, but this can also be calculated by subtracting the easternmost longitude from the westernmost longitude, dividing by two, and adding that value to the easternmost longitude. For Oregon, the precise result is 120.513° W. The difference between 120° W and 120.513° W will be too small to see, so eyeballing the central meridian would be perfectly acceptable in this case.

A further modification of the projection reduces distortion in the north–south direction. The **1–6 rule** is a cartographer's rule of thumb to determine the two standard parallels of a secant-case conic or cylindrical projection (see chapter 3 for secant-case projections). The rule is to divide

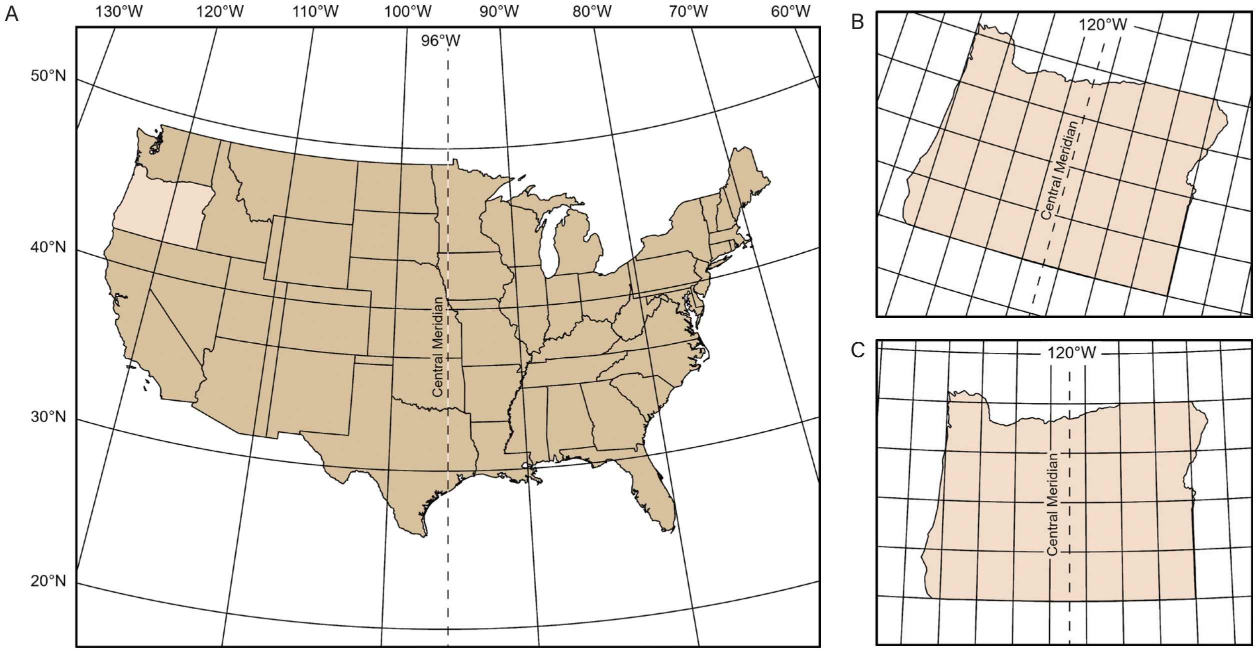


Figure 6.3. When using the Lambert conformal conic map projection for the conterminous United States centered at 96° W (*A*), a map of Oregon appears rotated clockwise about 15° (*B*). Changing the central meridian of the map projection to 120.5° W (near the east–west center of the state) adjusts the map so that north is up in the middle of the map (*C*).

the north–south extent of the mapped area into sixths. The first standard parallel is 1/6 from the bottom of the area, and the second is 1/6 from the top. This modification minimizes distortion between and outside the standard parallels along which, like the central meridian, the scale factor is 1. The result for Oregon is 42.72° and 45.28° N, which can be rounded to 43° N and 45° N.

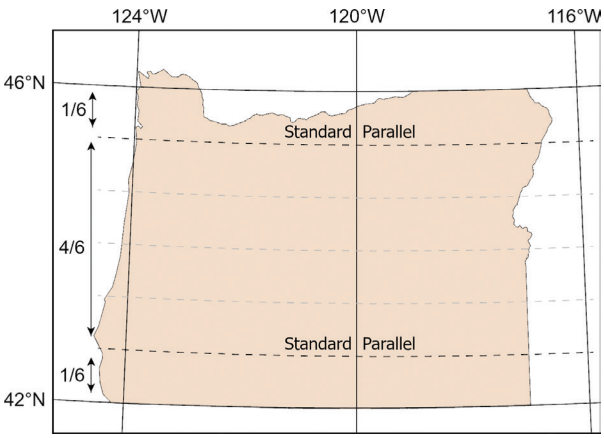


Figure 6.4. The 1–6 rule can be used to define the standard parallels for a secant-case conic or cylindrical map projection to minimize distortion in the mapped area.

Cartographic abstraction

Much of the power of maps lies in **cartographic abstraction**, in which data that has been collected about the environment is converted into a graphic representation that retains the salient aspects of the geographic features and their relationships. To do this, cartographers rely on selection, generalization, classification, and symbolization. They decide what type of and how much information to portray (selection). They eliminate or de-emphasize unwanted or unneeded detail (generalization) and summarize other details into categories (classification). They also make choices about how the information is shown graphically (symbolization). Cartographic selection, classification, generalization, and symbolization are interrelated, so mapmaking is more of an iterative process than a prescriptive one as cartographers continually refine the results they obtain through the cartographic abstraction process.

Selection

Selection in cartography is the process of deciding which features to show on the map and which to leave off. Selection decisions relate to the themes of information on the map, as well as the categories and subcategories of features within the themes. For example, on one map, you might decide to leave off all roads, but on another, you may decide to leave off only the minor roads and other less important road features.

Cartographic selection for general reference maps is much different from that for thematic maps. For reference maps, the challenge for the mapmaker is to decide which features are of greatest interest to a variety of map readers for a range of purposes. Reference maps, such as the road map of Oregon in figure 6.5A must carry a lot of information, although only some of it may be relevant for a particular map use task. Expert decisions about how to categorize and order features and labels on the map allow readers to distinguish the many types of features and their relative size or importance. This map could be used as effectively

A

B

Figure 6.5. The number and variety of features selected to be shown on reference maps, such as the recreation map (*A*), is greater than for thematic maps, such as the protected areas map (*B*). Only the reference information that provides geographic context is included on thematic maps. Courtesy of Benchmark Maps, an imprint of East View Information Services (*A*) and the US Geological Survey (*B*).

for road navigation as for planning a recreational trip or analyzing the distribution of wilderness areas.

With thematic maps, the challenge for the mapmaker is to decide which features to include without detracting from the theme. Only the features that are relevant to the theme or necessary to provide geographic context are included because superfluous information may distract, confuse, or mislead the reader. The map of protected areas in figure 6.5B provides a good example. The only things added are the features and labels for states, large cities, interstate highways, and major hydrographic features.

For any map, it is the responsibility of the mapmaker to select the features wisely. However, it is the map reader's responsibility to understand that all possible features cannot be shown.

Generalization

Generalization in cartography refers to reducing the amount of detail on a map through a change in the geometric representation of features. When the world is reduced to the scale of a map, the challenge is to remove unnecessary detail while preserving the basic geometric form of the simplified features and the salient spatial relationships among them.

The dimensionality (one dimension, two dimensions, and so on) of a feature can be used as an indicator of the appropriate level of generalization. For example, point features should appear as zero-dimensional points on a map, and linear features should appear as one-dimensional lines. When there is too much detail on the map, nearby points may coalesce and appear as blobs, and lines may collapse on themselves and appear as polygons (figure 6.6A). Feature curvature is another indicator. For example, lines that are curvilinear in nature but have sharp angles on the map (figure 6.6B) are clues that the lines are too generalized. Using data that is appropriate for the map scale is ideal (figure 6.6C), but the data might not be available. When that is the case, symbolizing a line with a thinner symbol may eliminate blobs (figure 6.6D), and showing an angular feature with a thicker line can sometimes mask its jagged edges.

Generalization in mapping is a complex topic, and entire books have been written on the subject. Because there is so much information available on generalization and so many ways to approach the subject, we severely limit our discussion here and instead provide a broad overview of generalization methods that can be used for features symbolized with points, lines, and polygons.

Generalization is used to simplify and refine features for display at smaller scales while preserving their basic geographic properties and relationships. For example, when map scale is reduced, two linear features that are next to each other in reality, such as a river and a road, may begin to coalesce on the map. Because the map should graphically communicate the real-world geographic setting, the message to map readers should be that the features are next to each other, not on top of each other. To preserve the integrity of the spatial relationship, the cartographer may offset one or both of the features.

Although myriad generalization operations have been described and developed, there is no set of operations that all cartographers agree on. The operations described here are often used in workflows to derive smaller-scale maps from larger-scale cartographic data, and all are available as geoprocessing tools in table 6.1. Some create new data that is simplified, but many modify the symbology without changing the data. This allows the original data to be preserved and managed without redundancy. Keep in mind that this is not an exhaustive set of methods to generalize features on maps. For example, simple symbology modifications can be used to display less detail, as we saw in figure 6.6D, and selection tools can be used to exclude features by category or size.

Traditionally, generalization operations affected the geometry of each class of features without regard to symbology or relationships with other features. Many of today's generalization operations perform **contextual generalization**, in which multiple features from multiple classes are considered at the same time to maintain the salient geographic pattern, density, and character of the features. This contextual approach also considers conflicts that arise between the symbols of features, which is particularly important when generalizing data for a different map scale. Tools to perform graphic conflict operations (table 6.2) can be used to detect problem areas (detect graphic conflict), move roads so their symbols do not overlap (resolve road conflicts), and move, resize, or hide buildings relative to roads (resolve building conflicts). A workflow might start with reducing the number and complexity of the features. Then conflicts between the symbolized features would be resolved. These steps might be repeated until the desired result is achieved.

To see how these generalization and other types of operations, such as selection, can be used together, we can look at a map that was reduced in scale from the **source scale** (the scale at which the data was originally captured from its

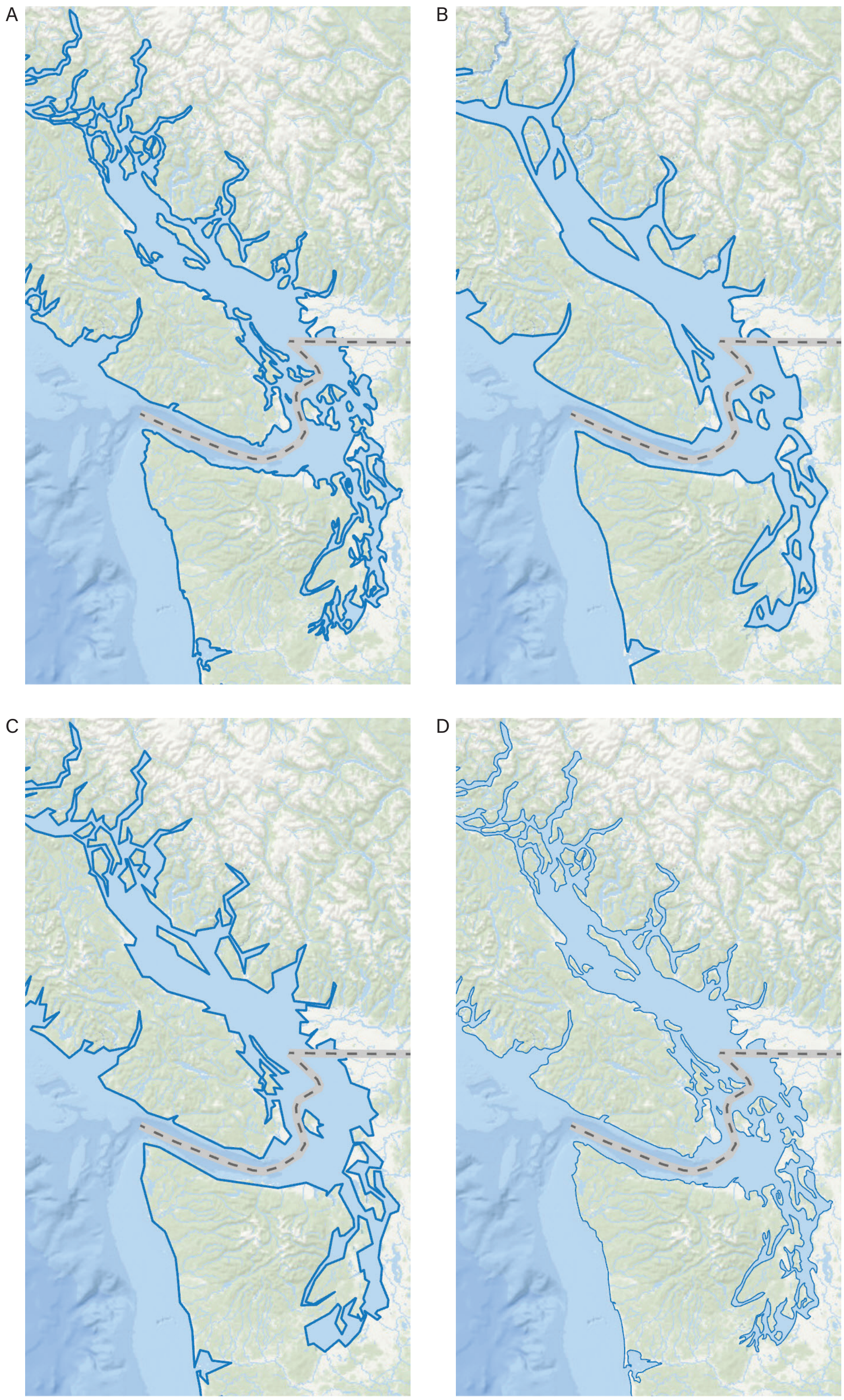


Figure 6.6. The lines in maps *A*, *B*, and *C*, each from a different source, are drawn with a one-point line, and map *D* is drawn with a 0.5-point line. At the same scale, the lines in *A* coalesce in some places, giving the appearance of additional polygons—an indication that the lines are too detailed. The lines in *B* appear too rectilinear, indicating that the data is overgeneralized. The lines in *C* are at an appropriate level of generalization. The more detailed lines in *A* can be visually improved with a thinner line symbol, as shown in *D*.

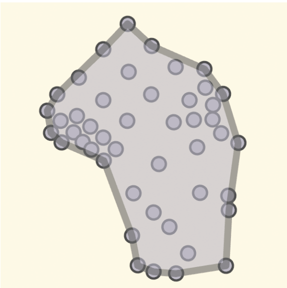
sources) of 1:25,000 to 1:100,000. The map in figure 6.7A shows the source features that were used to make the map at a smaller scale (figure 6.7B). The result is a map with much-reduced detail that still shows the proper geographic relationships among features.

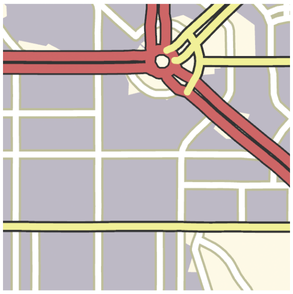
Classification

When we look at the world around us, we naturally try to differentiate, group, and organize what we see to make better sense of it. We associate things that are similar and distinguish things that are different. This type of mental classification is fundamental to comprehension and learning. We can apply the same process to geographic data when we try to represent the world on a map. **Classification** is the process of grouping, ordering, or scaling data into categories or classes based on similarities in attribute values or spatial relationships. The goal is to maximize both within-group similarities and between-group differences. For cartographers, classifying data meaningfully can be a challenge, and mapmakers make better judgments about classification if they understand inherent differences in data types, data distributions, statistical measures, and classification methods. Here, we discuss the most common methods for classifying data for mapping purposes.

Table 6.1. Generalization operations

<table>
<tr><th>Generalization operation</th><th colspan="6"></th></tr>
<tr><td rowspan="3">Aggregate Points / Polygons

Create polygons around clustered points / polygons while retaining their essential character.</td><td colspan="6">In the Aggregate examples, dark gray indicates original features, and light gray indicates generalized features.</td></tr>
<tr><td colspan="2">Points</td><td colspan="2">Orthogonal polygons</td><td colspan="2">Nonorthogonal polygons</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td></td><td colspan="3">Original map</td><td colspan="3">Generalized map</td></tr>
<tr><td>Delineate Built-Up Areas

Create polygons around densely clustered buildings.</td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>Simplify Shared Edges

Reduce the number of inflections in line and polygon features, and in shared edges while retaining connectivity.</td><td colspan="3"></td><td colspan="3"></td></tr>
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