From pins to computers

Crime mapping has long been an integral part of the process known today as *crime analysis.* The New York City Police Department, for example, has traced the use of maps back to at least 1900. The traditional crime map was a jumbo representation of a jurisdiction with pins stuck in it (figure 1.1). The old pin maps were useful for showing where crimes occurred, but they had serious limitations. As they were updated, the prior crime patterns were lost. While raw data could be archived, maps could not, except perhaps by photographing them.[1] The maps were static; they could not be manipulated or queried. For example, it would have been difficult to track a series of robberies that might overlap the duration (a week or month) of a pin map. Also, pin maps could be quite difficult to read when several types of crime, usually represented by pins of different colors, were mixed together. Pin maps occupied considerable wall space; Canter (1997) noted that to make a single wall map of the 610 square miles of Baltimore County, 12 maps had to be joined, covering 70 square feet. Thus pin maps had limited value—they could be used effectively but only for a short time. However, pin maps are sometimes still used today because their large scales allow patterns to be seen over an entire jurisdiction in detail. Today, "virtual" pin maps can be made on the computer, using pins or other icons as symbols (figure 1.2).

Figure 1.1

Pin maps.

Source: Keith Harries, University of Maryland, Baltimore County, Baltimore, Maryland.

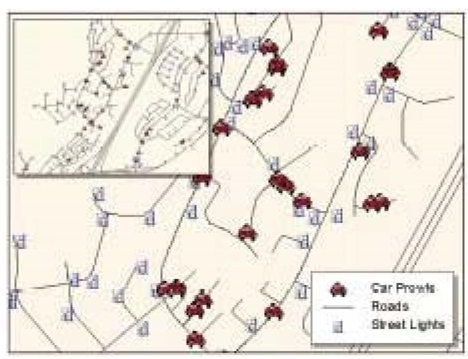


Figure 1.2

A "virtual" pin map.

Source: SanGIS and the San Diego Police Department Crime Analysis Unit.

The manual approach of pin mapping gave way during the past decade or so to computer mapping-specifically, *desktop* computer mapping. For decades before desktop computer mapping, the process was carried out on gigantic mainframe computers using an extremely labor—intensive process. First, much labor was involved in describing the boundaries of the map with numbered coordinates on punched cards. Then came the labor of keypunching the cards, followed by a similar process of coding and keypunching to put the data on the map.

Recognizing all the work needed to produce a map on the computer, many potential *cartographers*[2] (mapmakers) concluded that computer mapping was too labor intensive. They were right—it was a "royal pain." It was productive only if many maps were needed (making it worthwhile to prepare the *base map,* or boundary map, of the jurisdiction), and if the personnel necessary to do the data coding and keypunching were available. Few organizations could afford the luxury.

Since the mid-1980s, and particularly since the early 1990s, when computer processing speed increased dramatically, desktop mapping became commonplace and fast, aided and abetted by the concurrent availability of cheap color printers. What a partnership! Only a generation earlier, maps on paper (as compared with the pin maps on walls in police departments) had been drawn by hand using india ink[3] and special pens, with templates for lettering. If a mistake was made, the lettering had to be scraped off the paper with a razor blade. If shading was needed, Zipatone® patterns were cut to fit the area and burnished to stick. Those were the days? For character building, perhaps!

What does all this have to do with mapping crime today? A newfound access to desktop mapping means that more individuals than ever before have the task—or opportunity—to produce computer maps. Also the huge demand for maps means that most crime analysts, police officers, and others involved in mapping crime have received no formal training in mapmaking-the science called *cartography*. A body of accepted and useful principles and practices has evolved over the long history of mapmaking. Most cartography texts contain those principles but have no regard for the special needs of the crime analyst, police officer, manager, or community user of crime maps. The goal of this guide, therefore, is to provide a guide to cartography that is adapted to specialized needs and speaks the cartographer's language.

Ancient history: Cartography and crime mapping

Conclusive evidence from clay tablets found in Iraq proves that maps have been around for several thousand years—perhaps tens of millennia (Campbell, 1993). Evidently, the need to display geographic data is basic and enduring. Nowhere is the need for maps more compelling than in the field of navigation, whether for an epic around-the-world voyage or for a rookie cop's struggle to find an address in a city map book. Maps for navigation can be matters of life and death, and the inability of early navigators to locate themselves accurately on the surface of the Earth have often spelled disaster, as described vividly in Dava Sobel's book *Longitude* (1995).

Fortunately, crime mappers do not have to be concerned about such epic matters. However, mapping crime is a scientific activity—an application of the broader scientific field of cartography, which has undergone a transformation with the advent of geographic information systems (GIS). Many mapmakers now see cartography as a branch of information technology. A decade or so ago, cartography was much broader in scope than GIS with applications in fields as diverse as surveying, navigation of all kinds (including orienteering and highway mapping), geology, space exploration, environmental management, tourism, and urban planning. Today, however, the convergence of cartography and GIS is nearly complete. Both are tools in a broad range of applications, reflecting the most important use of maps—to communicate information.

Crime mapping, as noted at the beginning of this chapter, has quite a long history. Phillips (1972) pointed out that "hundreds of spatially oriented studies of crime and delinquency have been written by sociologists and criminologists since about 1830. . ." and recognized three major schools:

- The **cartographic** or **geographic** school dominated between 1830 and 1880, starting in France and spreading to England. This work was based on social data, which governments were beginning to gather. Findings tended to center on the influence of variables such as wealth and population density on levels of crime.
- The **typological** school dominated between the cartographic period and the ecological period that would follow in the 20th century. The typologists focused on the relationship between the mental and physical characteristics of people and crime.
- The **social ecology** school concentrated on geographic variations in social conditions under the assumption that they were related to patterns of crime.

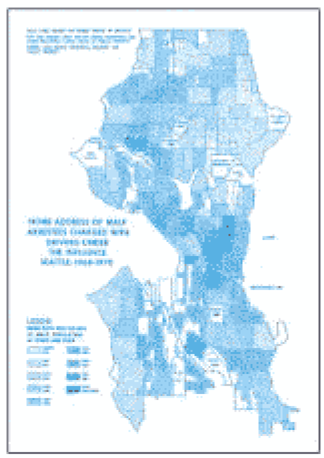
The social ecologists recognized and classified areas in cities with similar social characteristics. Shaw and McKay (1942) produced a classic analysis on juvenile delinquency in Chicago. This work is generally recognized as the landmark piece of research involving crime mapping in the first half of the 20th century. Shaw and McKay mapped thousands of incidents of juvenile delinquency and analyzed relationships between delinquency and various social conditions. Work by the "Chicago school" of researchers also delineated an urban model based on concentric zones, the first attempt to develop a theory to explain the layout of cities (Burgess, 1925). Other significant contributors to the ecological school included Lander (1954), Lottier (1938), and Boggs (1966).

Most likely, the first use of computerized crime mapping in applied crime analysis occurred in the mid-1960s in St. Louis (McEwen and Research Management Associates, Inc., 1966; Pauly, McEwen, and Finch, 1967; Carnaghi and McEwen, 1970; for more discussion, see chapter 4). Ironically, professional geographers were late getting into the act. Early contributions came from Lloyd Haring (who organized a seminar on the geography of crime at Arizona State University around 1970), David Herbert in the United Kingdom, Harries (1971, 1973, 1974), Phillips (1972), Pyle et al. (1974), Lee and Egan (1972), Rengert (1975), Capone and Nichols (1976), and others. Among the most remarkable (and little known) pieces of research emphasizing crime mapping were Schmid and Schmid's *Crime in the State of Washington* (1972) and Frisbie et al.'s *Crime in Minneapolis: Proposals for Prevention* (1997)(figures 1.3 and 1.4). The latter, in particular, was notable for bridging the gap between academic crime mapping and analysis/applications specifically aimed at crime prevention. Early computer mapping efforts used line printers as their display devices, so their resolution was limited to the physical size of the print characters. This precluded the use of computer maps for the representation of point data, at least until plotters that were able to draw finer lines and point symbols came into more general use. (For an excellent review of early map applications in crime prevention, see Weisburd and McEwen, 1997, pp. 1-26.)

Figure 1.3

A map showing home addresses of male arrestees charged with driving under the influence, Seattle, Washington. 1968–70.

Source: Schmid and Schmid, 1972, figure 7.14, p. 311.



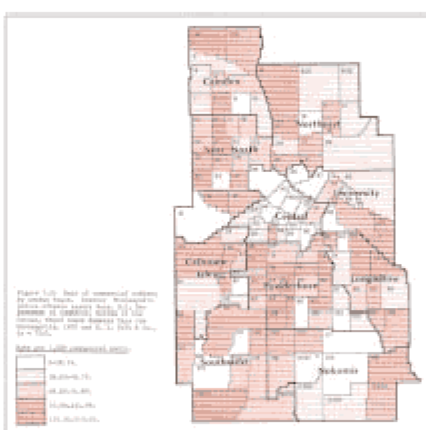


Figure 1.4

A map showing the rate of commercial robbery by census tract, Minneapolis, Minnesota. Line printer technology.

Source: Frisbie et al., 1977, figure 7.2, p. 122.

Even as late as 1980, the breakthrough into widespread GIS-style crime mapping was about a decade away. It was necessary to wait for improvements in desktop computer capacity, printer enhancements, and price reductions before desktop mapping could become an everyday, broadly accepted phenomenon.

To illustrate how matters have improved, a snippet of personal history is offered. In April 1984, the author bought his first personal computer, a Kaypro 10 manufactured by Digital Research, Inc. This wonder ran at 4 megahertz and had 64 kilobytes of random access memory (RAM) and a 10-megabyte hard drive. ("How could you ever use all that storage?" friends asked.) It also had a tiny monochrome display and ran on the CP/M operating system, the precursor of Microsoft DOS. And all this for the rock-bottom price of $2,795 in 1984 dollars. The Silver Reed daisy wheel printer purchased to complement the computer was $895 (extra daisy wheels were $22.50 each, tractor feed for paper was $160), and the 300k-baud rate modem was $535. After adding a few other knickknacks, getting started in personal computing cost almost $5,000 (again, in 1984 dollars).

By comparison, the typical RAM in 1999 is perhaps 1,000 times larger (64 megabytes), the processor speed is 100 times faster (at least 400 megahertz), and hard drives routinely are 100 times bigger (10 gigabytes), all at a lower price. It was this type of computing environment that would facilitate the entry of GIS into law enforcement (and elsewhere) and permit cartographic principles and practices to be used on a day-to-day basis. Mapping crime has come into its own primarily because of advances in computing that, in turn, have facilitated GIS applications. Apart from all the obvious advantages, a major benefit is that computer mapping allows free rein to experiment, a luxury denied in the old days of manual mapping. Are you wondering what a certain map design would look like? Try it out. You don't like it? Start over and have a new map in minutes.

Mapping as a special case of data visualization

Desktop computing has put graphic tools within the reach of virtually everyone. Preparing a publication-quality graphic, statistical or otherwise, was an arduous process a generation ago. Today it is much easier, although the process still demands considerable care and effort. This new ease and flexibility have broadened our perspective on graphics as tools for the visualization of information. This has happened because people no longer have to devote themselves to one specialized, time-consuming methodology, such as cartography. Now, maps can be produced more easily, and the computer has in effect freed people to produce *other* kinds of graphics as needed, such as bar charts, scatter diagrams, and pie charts.

The downside to such ease of production is that it is just as easy to produce trash as it is to create technical and artistic perfection. Famous graphics authority Tufte (1983, chapter 5) referred to what he called "non-data-ink," "redundant-data-ink," and "graphical paraphernalia"—all summed up by the term "chartjunk," a concept equally applicable to maps and charts. An exemplary map, according to Tufte, was prepared by Joseph Minard in 1861 to depict the decline of Napoleon's army in Russia in 1812-13 (figure 1.5). Tufte noted that "it may well be the best statistical graphic ever drawn" (Tufte, 1983, p. 40). What makes it so good is that it shows six variables with extraordinary clarity and without the use of color variation. The width of the bands is proportional to the number of troops, starting with 424,000, which was reduced to 100,000 by the time they reached Moscow. The map shows attrition on the return trip (with vertical rays expressing temperatures on selected dates) that left only 10,000 men still alive when the army returned to the starting point. The fact that the map illustrates the devastating loss of life further adds to its drama.

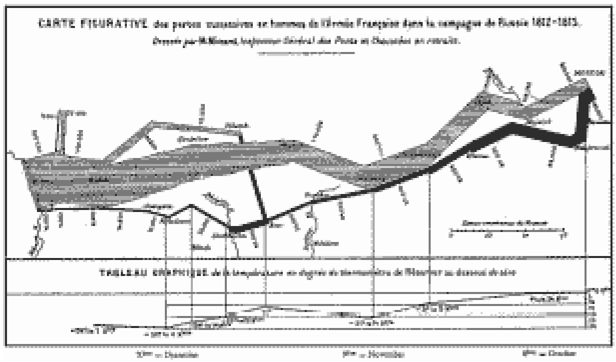


Figure 1.5

Minard's 1861 map of Napoleon's advance to and retreat from Moscow.

Source: Tufte, 1983, p. 41. Reproduced by permission.

Today's simplified graphics-producing environment helps put maps in perspective. Maps are but one way of representing information, and they are not always the most appropriate mode. If information about places is being represented, maps may be the best format. However, if no geographic (place-to-place) information is present, such as when all the data for a city are combined into one table, there is nothing to map. The whole jurisdiction is represented by one number (or several numbers, each representing the city as a whole), so the map, too, could portray only one number. In this situation, a bar chart simply showing the relative levels of each crime category would be the best choice.

What does it mean to say that maps are a form of visualization? Simply that a map is data in a form that we can see all at once. Books or tabulations of data are also visualizations in the sense that we assimilate them visually, but they are labor-intensive visualizations. Maps and other graphics are essentially pictures of information, those proverbial pictures "worth a thousand words." If they are well done, they convey their message more or less at a glance.

Mapping as art and science

Like other forms of visualization, maps are the outcome of scientific activity: hypothesis formulation, data gathering, analysis, review of results, and evaluation of whether the initial hypothesis should be accepted or rejected in favor of a modified version. This cycle, known as the *hypothetic-deductive process*, is used throughout science as a fundamental tool. It is a universal paradigm, or model, for scientific investigation.

Constructing a map involves taking a set of data and making decisions consistent with the hypothetic-deductive process. Decisions need to be made about the kind of map to be prepared, how symbols or shading will look, how statistical information will be treated, and so forth. These decisions must be based on the objective to be achieved, including consideration of the target audience. Certain scientific principles can be applied. For example, if we are preparing a shaded map with a range of statistical data to be divided equally, then a simple formula can guide us:

Range in data values ÷ Number of classes.

Thus, if the range (difference between maximum value and minimum value) of data values is 50 and it has been determined that 4 classes, or "subranges," of data would be appropriate, each will span 12.5 units. This simple example demonstrates an elementary cartographic principle.

However, this science provides no help with elements of map design, such as choice of colors, symbols, or lettering, and the arrangement of map elements on the page or within a frame. These elements are pieces of the art of cartography and are just as important to the overall purpose and effectiveness of the map as the scientific elements. A map that is scientifically perfect may be ineffective if it is an artistic disaster.

Art and science may merge imperceptibly and confound one another in unfortunate ways. For example, oversized symbols or lettering may draw attention to parts of the map that should be understated or less emphasized from a purely scientific perspective. A poor choice of colors or intervals for statistics can also make a big difference. Thus the scientific mission of the map can be subverted through inappropriate artistic choices, and poor choices on the science side can similarly affect the artistic elements. In cartography, as in medicine, art and science are inseparable. The perfect map blends art and science into an effective tool of visual communication. Figure 1.6 shows elements of weaker (middle figure) and stronger (bottom figure) map design. The chart (top figure) known as a *histogram* accompanying the maps shows an approximately normal (bell-shaped) distribution of scores on an index representing the association between violence and poverty in a neighborhood of Baltimore. The scores have a mean, or average, of zero and a measure of spread around the mean (standard deviation) of 1.0. Technically, this means that the census block groups in the range -1.0 to +1.0 are not significantly different from the average. Those with scores lower than -1.0 or higher than +1.0 are considered relatively extreme. We may wish to map the extremes because they could convey information of value in community policing-areas with a strong link between poverty and violence may warrant special allocations of crime prevention and social service resources.

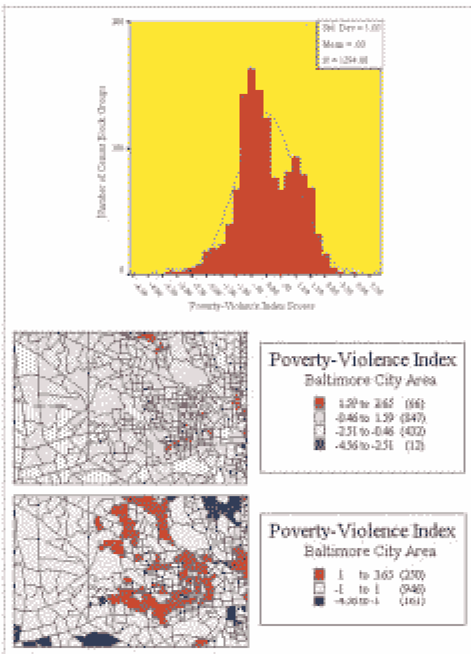


Figure 1.6

Examples of maps with differing impact depending on design.

Source: Keith Harries.

If the objective of the map is to represent the high and low extremes, then the bottom figure does a much better job than the middle one, both in terms of how the data are divided and how they are symbolized with colors. The bottom figure divides the data into standard deviation units such that the blue and red values are the focus of attention. In the middle figure, the visual message is almost lost in a combination of a poor choice of colors and shading symbols and a confusing division of the data into classes. The visual messages conveyed by the maps are different, yet the underlying geographies and statistics are identical. This example emphasizes the importance of the map as a medium for the interpretation of information. Subjective choices relating to both the art and science content of the map are critical.

Figure 1.6 also reminds us that it is just as easy to lie with maps as it is to lie with statistics. (Remember the three kinds of lies: lies, damn lies, and statistics—and maps, perhaps?) "Lying" may be a bit strong. It is more likely that the compiler of the map misleads readers by choosing inappropriate designs rather than by intentionally falsifying information. This may happen on several levels, the most basic being that the author of the map created it to achieve an objective different from that experienced by the readers. Next are issues related to data manipulation and cartographic art. Ultimately, the possibilities for misrepresentation and misinterpretation are virtually infinite. The key question is whether these problems are fatal flaws with respect to specific maps.

Maps as abstractions of reality: Benefits and costs

Maps try to display some aspect of reality. But like books, movies, television, or newspapers that try to do the same, they fall short (figure 1.7). The only perfect representation of reality is, after all, reality itself. ("You had to be there.") All else is, to a greater or lesser degree, an abstraction. Abstractions present choices. How much abstraction can we tolerate? How much information can we afford to lose? The fundamental tradeoff is:

- More abstraction equals less information (farther from reality).
- Less abstraction equals more information (closer to reality).

The tradeoff can also be viewed this way:

- More abstraction equals greater simplicity and legibility (more effective visual communication).
- Less abstraction equals greater complexity, less legibility (less effective visual communication).

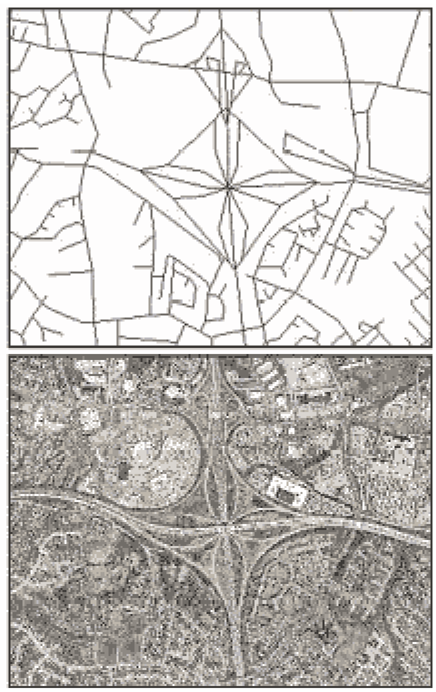


Figure 1.7

Maps showing the contrast between more abstraction ("stick" streets—top) and less abstraction (an aerial photograph of the same area—bottom).

Source: Orthophotography: Baltimore County, Maryland, GIS Unit, March 19, 1995 (Phase II), pixel size 1", compilation scale 1" = 200'. Reproduced by permission.

In our quest to represent reality as faithfully as possible, we may be tempted to put too much "stuff" in our maps or other graphics. This may give us maps that have a lot of information but that may be illegible junk heaps. Usually, the abstraction-reality tradeoff should tilt us in the direction of simplicity. Better to have one or two important points clearly understood than to have utter confusion pushing readers toward anger and frustration. Worse yet, that confusion may cause readers to draw incorrect conclusions. That outcome could be worse than no map at all.

Consideration of this tradeoff should be part of the map production process. With practice, it will become "second nature" and will not need much thought. But for the novice, it is an important issue calling for thought and perhaps discussion with colleagues. Reading Tufte (1983, 1990) will raise awareness.

Crime incidents: Measuring time and space

Crimes happen—everything happens—in *both* time and space. Vasiliev (1996) has suggested that time is a more difficult concept than space. Spaces and locations can be seen and measured quite easily by means of simple reference systems, such as x-y coordinates. Time, however, is harder to grasp, and maps have represented time in multiple ways (Vasiliev, 1996, p. 138), including:

- Moments. Providing times of events in geographic space. When did crime incidents occur and where?
- Duration. How long did an event or process continue in a specific space? For example, how long did a crime rate remain above or below a certain level in a particular area? How long did a hot spot (an area of high crime) persist?
- Structured time. Space standardized by time (for example, shift-based patrol areas, precincts, and posts).
- Distance as time. We often express distance as time. "How far is it?" "About 20 minutes." More to the point, perhaps, is concern with response times. In practice, a fixed, maximum permissible response time corresponds to the maximum distance feasible for patrol units to drive. Another application would be an investigation to see whether a suspect could have traveled from the last place he was seen to the location of the crime within a certain time period.

Specialized activities, such as policing, have their own unique perspective on time and space; thus, the elements of Vasiliev's typology will vary in their relevance from time to time and place to place.

There is no question that time is an important element in crime mapping owing to the time-structured way in which things are organized in police departments—by shifts. Patrol area boundaries may differ by shift, commanders may call for maps of crime by shift, and resources may need to be allocated differently by shift. Maps may need to be prepared on a weekly, monthly, quarterly, or annual basis to illustrate trends. Time-based maps may be further refined temporally by adding the shift dimension. Crime data could be mapped vertically, in effect stacking (merging) maps on top of each other, using different symbols for different time periods. Alternatively, a different map could be prepared for each time period. All these modifications can be automated by using GIS.

The importance of selecting appropriate time periods for mapping cannot be overemphasized. For example, a map covering a month may mask noteworthy week-by-week variations. Or weekly maps could hide day-to-day changes. Mapping intervals selected for administrative convenience may not be the best for analytical purposes. For example, the calendar week may be best for police department convenience, but local events, such as an industrial holiday, a sporting event, a plant closure, or some seasonal phenomenon may cut across administrative time units and may also have relevance to crime frequencies. Related questions are, How much time elapses before a map is out of date? All data are obsolete sooner or later, but when is sooner? When is later? These decisions are quite subjective and call for a "feel" for the data under review.

Another aspect of mapping crime in time and space relates to the representation of change. One of the most crucial questions asked in police departments is, How has crime changed in this neighborhood in the last week or month or year? Maps can help answer this question by symbolizing change in several possible ways, such as by showing crime as a "surface" with peaks representing high levels of occurrence (gray areas) and valleys low levels (red areas) (figure 1.8). This approach borrows from the methodology of the topographic map, on which the land surface is represented by contour lines, each joining points of equal elevation. On the crime surface map, areas of declining crime can be shaded differently from those with increases. Crime mappers are limited only by their imagination when representing time and space in two dimensions or simulated three dimensions.

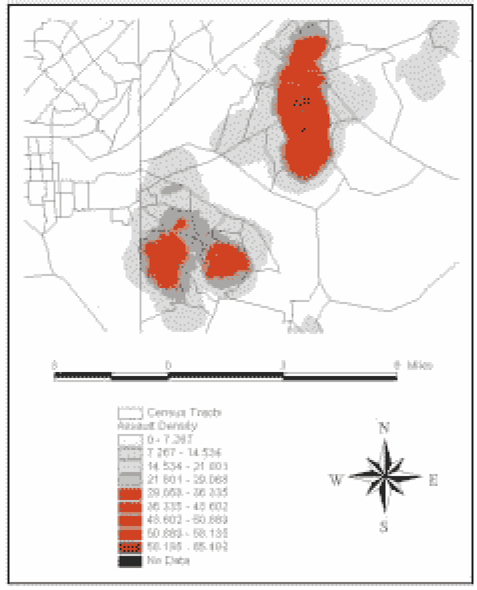


Figure 1.8

A representation of the aggravated assault "surface" in part of Baltimore County, Maryland. Red and darker shading indicate higher assault densities.

Source: Keith Harries.

As usual, we should keep an open mind. Some space-time data may be best represented with a "non-map" graphic, or a combination of map and statistical graphics, such as precinct bar charts or pie charts embedded in a map of precincts. Here we come full circle, back to cartography as art and science and to the abstraction/detail tradeoff. Only crime mappers can decide, probably on the basis of some experimentation, which graphic representations are best for themselves and for their audiences.

Map projection

What is it?

A fundamental problem confronting mapmakers is that the Earth is round and the paper we put our maps on is flat. When we represent the round Earth on the flat paper, some distortion (perhaps a lot, depending on how much of the spherical Earth we are trying to show) is inevitable. Map projection is so called because it assumes that we have put a light source in the middle of a transparent globe (figure 1.9). The shadows (grid) made on a nearby surface are the *projection*.[4] Their characteristics will vary according to where the surface is placed. If the surface touches the globe, there will be no distortion at that point or along that line in the case of a cylinder being fitted over the globe, touching along the Equator. Away from the point or line of contact, distortion increases. Among the most common projections are the cylindrical (already described) and the conical, for which a cone is fitted over the globe, like a hat, with the top of the cone over the pole (see figure 1.9). The cylinder or the cone is cut and flattened to create the map. The cylindrical projection tends to have much more distortion at high latitudes (closer to the poles) compared with the conical.

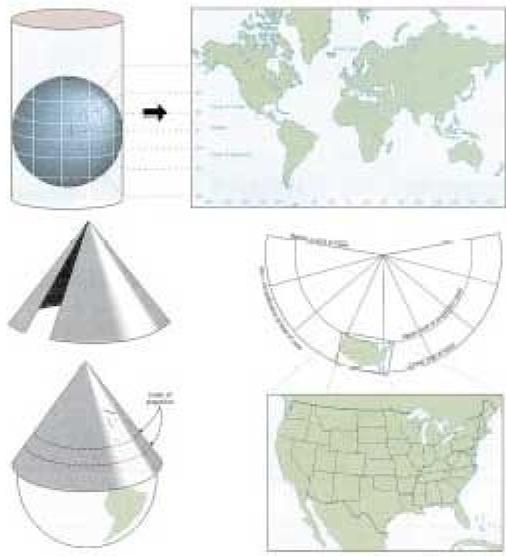


Figure 1.9

Diagrams showing cylindrical and conical projections. Shadows of the globe's grid lines on wraparound paper; a cylindrical projection results (top). Construction of a conic projection (middle and bottom).

Source: H.J. Blij, *Human Geography: Culture, Society, and Space*, Fifth Edition. New York, NY: John Wiley & Sons, Inc., ©1996, Figures R7 and R8, pages R6 and R7. Reprinted by permission of John Wiley & Sons, Inc.

The better known projections include the venerable *Mercator*[5] (useful for navigation), the *Albers conical equal-area*[6], and the *Lambert conformal conic*[7] (the last two are frequently used for U.S. maps). Another well-known format is the *Robinson*, now the default world map projection used by the National Geographic Society. Its advantage is that it minimizes high-latitude distortion of areas compared with most other cylindrical projections. U.S. States are typically represented by either the Lambert conformal conic or the *transverse*[8] Mercator, depending on the size and shape of the State. For example, Dent (1990, pp. 72-73) noted that for Tennessee a conical equal-area projection would be appropriate, with its standard parallel (the line of latitude where the projection cone touches the State) running through the east-west axis of the State. Projections are a highly technical branch of cartography, and readers who want to learn more are referred to standard texts in cartography such as Campbell (1993), Dent (1990), and Robinson et al. (1984).

Why we don't need to worry

Map projections are vitally important for cartographers concerned with representing large areas of the Earth's surface owing to the distortion problem and the myriad choices and compromises available in various projections and their numerous specialized, modified forms. But crime analysts do not need to be overly concerned with map projections because police jurisdictions are small enough so that map projection (or Earth curvature) is not a significant issue. However, there is the possibility that analysts will deal with maps with different projections and that those maps will not fit properly when brought together. Streets and boundaries would be misaligned and structures misplaced. However, this misalignment can also occur for reasons unconnected with projection, as explained below. Although crime analysts do not need to worry about projections per se, a related issue, *coordinate systems,* generally needs to be given more attention because the analyst probably will encounter incompatible coordinate systems.

What are the differences between projections and coordinate systems? *Projections* determine how the latitude and longitude grid of the Earth is represented on flat paper. *Coordinate systems* provide the x-y reference system to describe locations in two-dimensional space. For example, latitude and longitude together are a coordinate system based on angular measurements on the Earth's sphere. But there are other ways of referring to points. For instance, all measurements could be based on distances in meters and compass directions with respect to city hall. That would also be a coordinate system. Distances in feet and directions could be based on the police chief's office as a reference point. The following discussion provides some details on commonly used coordinate systems.

Coordinate systems

What is it?

Coordinate systems allow users to refer to points in two- or three-dimensional space. You may have heard of Cartesian geometry, named for the 17th-century French mathematician Descartes, the founder of analytic geometry and the Cartesian coordinate system. In two dimensions, we usually refer to two principal axes, the *x* (horizontal) and *y* (vertical). If necessary, we add the *z* axis for the third dimension. Points are located by referring to their position on the scales of the x and y (and z) coordinates. Diagrams usually known as scatter diagrams, or scatter plots (figure 1.10), are based on Cartesian coordinates, with their origin in the lower left corner. Things get a bit more complicated when the coordinate system is applied to the spherical shape of the Earth.

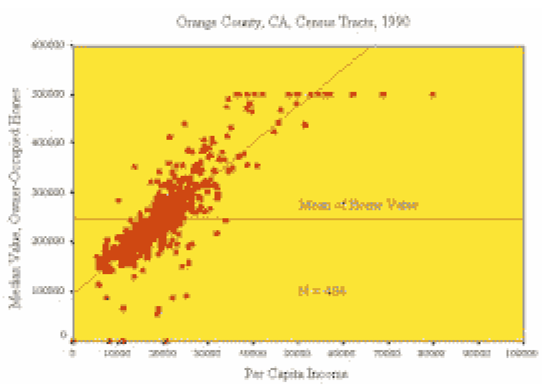


Figure 1.10

A scatter diagram showing the relationship between per capita income and median value of owner-occupied homes by census tract in Orange County, California, that illustrates the use of x-y coordinates.

Source: Keith Harries.

Latitude/longitude

For the Earth's sphere, angular measurements must be added to the x-y coordinate system. *Latitude* angles are measured from the center of the Earth between the Equator and poles, 90 degrees north and south, with the Equator as 0 degrees and each pole 90 degrees. *Longitude* angles are also measured from the center of the Earth, 180 degrees east and west of the Prime Meridian running through the Royal Naval Observatory in Greenwich, England,[9] a location fixed by international agreement in 1884. So all of the United States is described in degrees north latitude and west longitude. For example, New Orleans is located at approximately 30 degrees north latitude and 90 degrees west longitude. Latitude lines are also known as *parallels* because they are, in fact, parallel to one another, and longitude lines are called *meridians*, as in "Prime Meridian." State boundaries west of the Mississippi River are predominantly made up of segments of meridians and parallels. For example, the longer western border of Oklahoma is a segment of the 100th meridian.

State Plane and Universal Transverse Mercator

As noted previously, appropriate map projections have been adopted for each State, yielding "Earth" projections with coordinates based on latitude and longitude, the universal reference system. But these "latitude/longitude" references, as they will be referred to, are quite cumbersome, given that they are in degrees, minutes, and seconds.[10] Two principal alternative coordinate systems are found in addition to latitude/longitude: the *State Plane Coordinate System and the Universal Transverse Mercator* (UTM).

The State Plane Coordinate System was devised for greater user convenience, with a rectangular grid superimposed over the latitude/longitude graticule, producing *State plane coordinates* expressed in meters, yards, or feet. In effect, this system assumes that the individual States are flat so they can be described by plane geometry rather than the spherical grid. For local applications, this use of plane geometry is acceptable because error due to failure to take Earth curvature into account is not significant over relatively small areas such as police jurisdictions.

Large States are divided into zones with separate grids for each to avoid the distortion problem. Texas, for example, is divided into the North, North-Central, Central, South-Central, and South zones; Louisiana into North, South, and Coastal. Typically, the origin, or zero point, for a State plane system is placed in the southwest corner, just like the scatter plot shown in figure 1.10, to avoid the inconvenient possibility of having to express coordinates in negative numbers. The origin is also placed outside the study area for the same reason.

The UTM system is used to refer to most of the world, excluding only polar regions, and consists of 60 zones, north-south, each 6 degrees of longitude wide. Each zone has a central meridian, and origins for each zone are located 500,000 meters west of the central meridian. A sample location in Texas (the capitol dome in Austin) is shown in figure 1.11. This example specifies that the dome is 621,161 meters east of the central meridian of zone 14 and 3,349,894 meters north of the Equator, the latitude of origin. The acronym NAD will appear in references to the State plane and UTM coordinate systems. NAD stands for *North American Datum*, a reference system that was based at a Kansas ranch in 1927. Demands for greater accuracy and more accurate surveying made possible by satellites led to a new NAD in 1983, hence the reference in figure 1.11 to NAD 83 UTM coordinates.

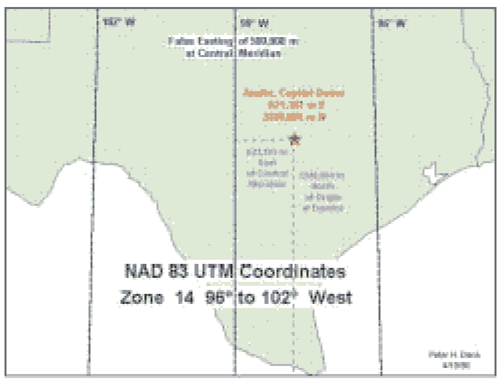


Figure 1.11

An example of a Universal Transverse Mercator (UTM) location.

Source: Peter H. Dana, The Geographer's Craft Project, Department of Geography, University of Texas at Austin. Reproduced by permission. Visit Dana's Web site dealing with coordinate systems: http://www.utexas.edu/depts/grg/gcraft/notes/coordsys/coordsys.html.

Why we do need to worry

Crime mappers using computerized data from different sources may run into a problem resulting from different data sets being digitized (assigned their x-y coordinates) in, or converted to, incompatible coordinate systems or even incompatible projections. The most frequent conflict is likely to be between latitude/longitude and State plane coordinates owing to the likelihood that locally developed data (often in State plane coordinates) will be mixed with data from more general sources, probably expressed in latitude/longitude. We saw that New Orleans is referenced as 30 degrees north latitude and 90 degrees west longitude in the latitude/longitude system. But if we refer to it using the State plane system, it is in the Louisiana South Zone, with coordinates 3,549,191 feet east of the origin and 592,810 feet north of the origin. Clearly, if we try to put the State plane data on a map set up for latitude/longitude, ugly things will happen. (What usually happens in a GIS is that the map goes blank.[11])

Data sets placed together on a map should have compatible projections and compatible coordinate systems. Fortunately, GIS software permits conversion from one projection to another and from one coordinate system to another, so the problem, if it does arise, is reasonably easy to fix. But if incompatibilities are not recognized at the outset, they can be quite frustrating. Positive action to check the projection and coordinate properties of a new data set is recommended because the coordinate system may not be apparent initially.

Map elements: The usual bits and pieces

Generally, maps have the following elements that help provide consistency and comprehensibility for readers.

- **A title** (or caption) to describe the map.
- **A legend** to interpret the content of the map, such as the symbols and colors.
- **A scale** to translate distance on the map to distance on the ground.
- **Orientation**[12] to show compass direction.

However, a review of maps in cartography texts and elsewhere reveals the inconvenient fact that these conventions are often overlooked. Context should dictate whether some or all of these elements are included.

For example, in a situation in which maps of the same jurisdiction, or parts of it, are produced and distributed to the same audience on a repetitive basis, a label telling readers the area would be a waste of ink. But if the map were intended for wider distribution to audiences that might not know what they were looking at, a caption or heading would be appropriate. Similarly, scale may be redundant when the users of the map are educated to the spatial relationships on the map, often through years of field experience. Orientation, too, is unlikely to be critical in locally used crime maps, for which north is almost always "up." It may be worth noting that Minard's map of Napoleon's army (see figure 1.5) has no orientation, and if you want to be picky, it has no legend per se.

Indeed, a legend is perhaps the only somewhat (but not entirely) indispensable map element. Readers need to be absolutely sure what map data mean, and the legend is the only reliable guide to this information. Some maps may be so simple that a legend is not necessary. An example would be a map showing points, each of which represents a residential burglary. The heading or caption of the map (such as, "Locations of residential burglaries in St. Louis, September 2000.") can contain the necessary information and override the need for a legend.

This discussion may imply that one can be slapdash about map elements, but that implication is not intended. Careful consideration should be given to whether a particular element should be included; if an element is included, it must contain complete and accurate information.

Types of map information

Maps can provide a rich variety of information, including but not limited to location, distance, and direction as well as pattern for maps displaying point or area data. Each type of data means different things to different users.

- **Location** is arguably the most important of all the types of information to be represented on, or gleaned from, a map from the perspective of a crime analyst. Where things have happened, or may happen in the future, is the most sought after and potentially useful piece of information because it has so many implications for investigators and for the allocation of patrol and community resources, in addition to utility in the realms of planning and politics.
- **Distance** is not much use as an abstract piece of information. It comes to life when translated into some kind of relationship: How far did the victim live from the place where she was robbed? What is the maximum distance police cars can travel within a specific urban environment to provide acceptable response times? How far could a suspect have gone in a particular time period?
- **Direction** is most useful when considered in conjunction with distance, although it is not typically an important piece of map information in crime analysis unless it relates to other relevant processes or conditions. It is generally used in a broadly descriptive context, such as "the hot spot of burglaries is spreading to the west," or "serial robberies are moving southeast," or "the east side is becoming a high-crime area." In the example shown in figure 1.12, serial robbers were found to have a tendency to migrate south from Baltimore along the major highways.

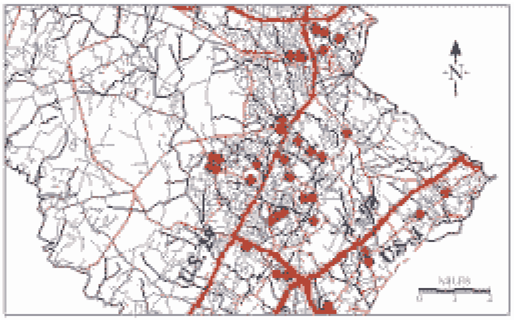


Figure 1.12

A map of selected robberies in Howard County, Maryland, concentrating along the U.S. 29, U.S. 1, and I-95 highway corridors. The Baltimore-Washington area Regional Crime Analysis Program has used maps like this to help apprehend serial robbers who cross county lines. For a full account of this process, see Mishra, 1999.

Source: Keith Harries.

- **Pattern** is an especially useful concept in crime analysis, as so much of what crime analysts do involves describing or analyzing the pattern of crime occurrences. Pattern can be a powerful investigative tool because the way points are arranged may tell us something about the process driving that arrangement. Patterns are usually classified as *random, uniform, clustered,* or *dispersed*. In a random arrangement, points are just as likely to be at any place on the map as at any other. Points are distributed haphazardly around the map. A uniform distribution has points that are equally spaced. Alternatively, we can say that in a uniform distribution the distance between neighboring points is maximized. In a clustered pattern, points are clumped together with substantial empty areas.

It is tempting to assume that the nonrandom distributions (uniform and clustered) automatically mean that some interesting underlying process is at work, providing useful information about crime. This may or may not be true. For example, burglaries show up in a cluster, suggesting a hot spot. But further investigation shows that the cluster corresponds to a neighborhood with a dense population, so the high frequency is no more than an expression of the geography of risk. The terms describing the types of patterns are subject to some semantic confusion. For example, what does *dispersed* mean? A dispersed pattern could be random or uniform. Is "less dispersed" the same as "clustered"? Various indexes have been developed to measure regularity, randomness, and dispersion. For additional reading, see, for example, Taylor (1977, chapter 4) and Hammond and McCullagh (1974, chapter 2).

Line data (for networks, for example) and both *discrete* and *continuous* areal distributions are additional types of data.

- **Line data.** Linear features or processes can be abstracted on maps. The Minard map (see figure 1.5) did this by symbolizing the flow of troops to Moscow and back. The street maps used to map crime also contain line data that show points on streets, indicating the linear arrangement of incidents. A map connecting places where vehicles are stolen to the places where they are recovered is prepared with lines connecting the places. Or a line map might connect victim addresses to suspect addresses. Traffic flow can be shown with lines proportional in thickness to the flow (again like Minard's map in figure 1.5).
- **Discrete distributions.** When point data are combined within unit areas such as precincts, patrol areas, census tracts, or neighborhoods, each area is separated from the others; it is "discrete." Mapping by discrete areas can be used to reorganize the point data into a context that may have more meaning for a specific purpose. For example, commanders may want to see the distribution of drug offenses by patrol beat to decide how workloads should be assigned. This could be measured by *density*, which expresses how often something happens within an area. A common application is *population per square mile*, for example. Density also is used increasingly frequently to describe crimes, and population density data can provide additional explanation of the risk or rate concepts in public forums. Graphic representations of this general type, mapping data by administrative or political areas, are known as *choropleth*[13] maps. (A more detailed explanation is given in chapter 2.)
- **Continuous distributions** are used less in crime analysis than discrete distributions, but they can be useful and are finding more frequent application in conjunction with, for example,

commonly used software such as *ArcView®* *Spatial Analyst*. Continuous distributions are phenomena found in nature, such as the shape of the land (topography), temperature, and atmospheric pressure. All places on Earth (above and below sea level) have topography and temperature, and all places above sea level (and a few on dry land below sea level) have atmospheric pressure. Thus it makes no sense to represent these conditions on maps divided into areas such as counties or cities, except for reference purposes.

What does this have to do with crime mapping? It is sometimes useful to assume that crime can be represented as a continuous distribution to prepare a generalized statistical surface representing crime density. This can provide a "smoother" picture of crime that can be enhanced by adding three-dimensional effects (figures 1.13 and 1.14). This implies an acceptance of the tradeoff between loss of detailed locational information from the point map and the smoothed, generalized picture provided by the quasi-continuous presentation. This smoothed version may have the advantage of better legibility than the original detail. Another advantage of a surface smoothed across jurisdictions is that it may vividly illustrate that political boundaries have little or no meaning for criminals.

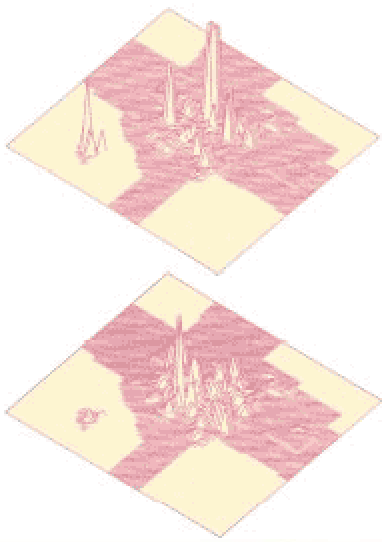


Figure 1.13

Early (1976) three-dimensional maps of Tulsa, Oklahoma, using the SYMVU program. The robbery rate is based on the population (top) and number of persons per dwelling unit (bottom). The bottom map illustrates the point that the denominator in crime rates does not have to be population.

Source: Harries, 1978, figures 43 and 44.

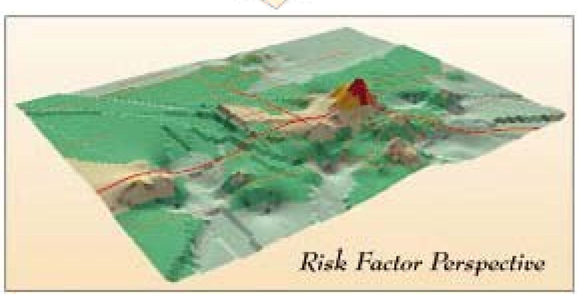


Figure 1.14

A contemporary three-dimensional map of Redlands, California. The vertical dimension portrays the relative risk of crime across the city.

Source: Redlands Police Department. Reproduced by permission.

Scale

Maps are miniature representations of part of reality. *Scale* tells us how miniature they are. Scale is commonly expressed as a ratio, in words, or as a bar graph located somewhere in the map frame. A ratio states the scale as a unit of map distance compared with distance on the ground. This is referred to as the *representative fraction* (RF). Thus an RF of 1:10,000 means that 1 unit of linear measurement on the map represents 10,000 of those units on the ground. Units are interchangeable; for a 1:10,000 map, 1 inch on the map equals 10,000 inches on the ground, 1 centimeter on the map equals 10,000 centimeters on the ground.

Scale terminology can be confusing. For example, large-scale maps and aerial photographs used by local governments (and quite likely to be used by crime analysts) are often at a scale of 1:2,400. If expressed in inches and feet, this is equivalent to 1 inch equaling 200 feet. Hence users often refer to the maps simply as "200 scale."

Large scale or small scale?

The distinction between large scale and small scale is also a source of confusion, but there is a simple rule to help us understand. Look at the representative fraction. If it is a large fraction, the map scale is large, and vice versa. For example, I open my National Geographic *Atlas of the World* and flip through it until I come to a map of the world. The scale is expressed in words as follows: "Scale 1:66,300,000 at the Equator." This is extremely small scale, as 1/66,300,000th of something is not much. A few pages farther, I come to a map of the upper midwestern States of the United States. Its scale is expressed as "1:2,278,000"-a fraction 29 times larger than that for the world map. As scales get larger and larger, we move from the realm of "maps" to what we customarily refer to as "plans," such as 1:20, where 1 unit on the map (plan) equals 20 units on the ground or the floor plan. These very large-scale renderings are the domain of the architect or engineer rather than the cartographer.

Scale has implications for the interpretation and meaning of maps. Implicit in the concept of scale is the now-familiar tradeoff between abstraction and detail. Small scale implies more abstraction, large scale less. Evidence from cognitive psychology cited by MacEachren (1995) suggests the importance of progressing from small scale to large scale when presenting maps of different areas, the principle of g*lobal-local precedence*. In other words, if you were to prepare maps for the entire jurisdiction and also for a small part of it, the best mode of presentation would put the smaller scale map (the entire jurisdiction, perhaps in the form of a satellite image) first. The smaller area (larger scale) would follow this.

Rules of Thumb for Map Scale

- Small-scale maps show large areas.
- Large-scale maps show small areas.

Another implication of scale is that crime data will look different at different scales, such as citywide and beat levels. The same data will appear to be more spread out (less dense) at the scale of the beat and more crowded (more dense) at the citywide scale. But in reality densities (crimes per unit area) are the same on both maps. What has changed is scale.

Scale also has implications for data collection. If maps are to be large scale, detailed data collection is appropriate. But small-scale maps are incapable of representing fine detail, so if the only scale available for a specific purpose is small, collecting data at the micro level is pointless. The detail will be lost on a map incapable of showing it. The converse is also true. Gathering data at the ZIP Code level will be too coarse a scale on a map showing street addresses.

Maps of crime: Thematic maps

What is a thematic map? Quite simply, as the label suggests, it is a map of a theme or topic. Thematic maps have almost infinite variety and include most of the maps in the media showing, for example, the spread of fire ants, the status of sales taxes by State, or world population density. Thematic maps are like a comprehensive toolkit—we can select a topic and then choose from many possible ways of converting the data into a legible map that effectively communicates with the intended audience. Thematic maps may be *quantitative* or *qualitative*.

- **Quantitative** maps portray numerical information, such as numbers of crimes in an area or crime rates.
- **Qualitative** maps show nonnumerical data like land use types or victim/ offender characteristics, such as male or female, juvenile or adult.

Crime analysts use both quantitative and qualitative maps. Thematic maps can include four kinds of measurement data: *nominal, ordinal, ratio,* and *interval*. (For a more detailed explanation, see any basic statistics textbook, such as Burt and Barber, 1996.)

- **Nominal** measurement names or labels items in unordered categories, such as race. If a map shows homicide victims by race, it is a qualitative thematic map. Mapping by race, age group, or marital status puts labels on groups without ranking them as higher or lower or better or worse. (Quantitative information can also be inferred from this type of map. For example, the number of incidents affecting racial groups by areas can be counted, thus combining qualitative and quantitative interpretations. Types of measurements are often mixed on maps.)
- **Ordinal** measurement classifies incidents, victim or offender characteristics, or some other attributes (perhaps areas) according to rank. Thus patrol areas or precincts might be ranked according to their crime rates, their incidence of complaints, or the average seniority of officers. This involves only sorting and evaluating the data according to their relative values so that subjects can be ranked. How much the subjects differ is not considered. Thus we can put qualitative characteristics on an ordinal scale, such as a hierarchy of police areas based on size, with districts above precincts, which are in turn above patrol beats.
- **Ratio** scales, such as distance in inches, feet, yards, millimeters, meters, and so forth, start at zero and continue indefinitely. Zero means there is none of it and 20 means there is twice as much as 10. For example, the homicide rate is 3 per 10,000 persons in the city. Crime analysts will use nominal, ordinal, and ratio scales for these data but are very unlikely to use the fourth kind of measurement, interval.
- **Interval** scales show values but cannot show ratios between values. Temperature is a good example. We can measure it, but we cannot say that 80 degrees is twice as warm as 40 degrees, since the starting points of both the Fahrenheit and Celsius scales are arbitrary—that is, they are not true zeros. A possible exception to the assertion that crime analysts will not use interval scales could be *seriousness weighting*. (See Wolfgang et al., 1985a and 1985b, for more on this topic.)

Thematic maps come in considerable variety and will be examined in more detail in chapter 2. Each type represents some kind of data best. Information with address-level detail calls for one kind of thematic map, whereas data measured only at the neighborhood, precinct, or census tract level require a different approach. Examples of various ways in which thematic maps can be designed are contained in the following categorization of thematic maps:

- **Statistical** maps use proportional symbols, pie charts, or histograms to visualize the quantitative aspects of the data. Typically, the statistical symbols are placed in each subdivision on the map, such as patrol areas, census tracts, neighborhoods, or wards. Such maps can be quite difficult to read if they contain a large amount of detail, particularly when many geographic subdivisions and several attributes of the information are being mapped. Nominal data, such as the race of victims as proportions in precinct-based pie charts, can be represented on a statistical map.
- **Point** (pin) maps use points to represent individual incidents or specific numbers, such as when five incidents equal one point. (Aggregating multiple incidents to single points would be done only on a small-scale map.) A map showing locations of drug markets by types of drugs prevalent in each is an example of a point map with nominal scale data. Point maps are probably the most frequently used maps in policing, as they can show incident locations quite precisely if address-level data are used.
- **Choropleth** maps show discrete distributions for particular areas such as beats, precincts, districts, counties, or census blocks. Although point data can give us the best detail in terms of where events happen, information may be needed for areas in summary form that has meaning in

terms of planning, management, investigation, or politics. Note that point data and choropleth representations can both be put on the same map, if it is appropriate and the result is not a garbled mess. For example, burglary (point) data could be put over neighborhood boundaries (choropleth data) or any areas representing police geography. Also, choropleth maps can be given a three-dimensional appearance by making each area into a raised block, with the height of the block representing the relevant data value.

- **Isoline** is derived from "iso," the Greek prefix for equal, and refers to maps with lines that join points of equal value. Physical geography is replete with isoline maps that use the following: *isobars* (equal barometric pressure), *isohyets* (equal rainfall), *isotherms* (equal temperature), *isobaths* (equal depth), and, in a rare departure from use of the iso prefix, *contour* lines to join points of equal elevation. The form most likely to be used in crime analysis is the *isopleth* (equal crowd), in which data for areas, such as crimes per neighborhood or population density, are calculated and used as control points to determine where the isolines will be drawn.[14] (See Curtis, 1974, for an example of an isopleth map of homicide, rape, and assault in Boston.)
- **Surface** maps can be regarded conceptually as a special case of an isoline presentation. Such maps add a three-dimensional effect by fitting a raised surface to data values. Typically, an arbitrary grid is placed over the map and the number of incidents per grid cell are counted. These counts form the basis for what is, in effect, an isopleth map that is given its third, or *z* (vertical), dimension derived from the isoline values. The resulting map is rendered as if it were being viewed from an oblique angle, say 45 degrees. (If it were to be viewed from overhead, like a normal map, the surface would be lost and the map would appear to be a flat contour map.) Such continuous surface maps can make a powerful visual impact, but they have dual disadvantages in that data values are hard to read on the map and detail behind data peaks is lost (see figures 1.13 and 1.14).
- **Linear** maps show streets and highways as well as flows using linear symbols, such as lines proportional in thickness to represent flows. Apart from base maps of streets and highways, crime mappers use linear maps infrequently—the most common application is vehicle theft investigation showing connections between the place of theft and place of recovery.

Data, maps, and patterns

The stage is set. We have a truckload of data, computers, software, and printers. Provided our data have been gathered in a form that permits computer mapping (or have been converted to such a format; see chapter 4), we are at least technically ready. It should be noted at this point that computer mapping is not "plug and play" but is more akin to word processing—the data have to be entered and sentences (read "maps") composed. Similarly, we will not be able to do computer mapping until we have data in a format that the program can understand. Also, many choices will have to be made. Automated mapping is automated only up to a point. (When you put your car on cruise control, someone still has to steer!)

Before we plug it all in and start mapping, it might be helpful to pause and think about the reasons underlying the patterns we observe and map. Those patterns must be generated by specific conditions and processes, and theories can be employed to help us understand them.

Each type of crime tends to be influenced by different conditions. For example, shoplifting is the outcome of circumstances different from those that produce homicide. Even within crime types, there are qualitative differences in circumstances. For example, a drug-related homicide may be the result of a conflict over turf or unpaid debts, whereas a domestic homicide may be the product of long-simmering animosities between partners.

Crimes may have distinctive geographic patterns for two underlying reasons that often overlap:

- First, crimes must have victims, and those victims (or their property) have definite geographic coordinates at any given moment, although these coordinates can shift, as in the case of vehicles.

- Second, some areas in cities, suburbs, or rural areas have persistently high rates of crime, so that for certain neighborhoods there is a rather permanent expectation that crime is a major social problem. For example, Lander's (1954) research on Baltimore revealed high rates of juvenile delinquency to the east and west of downtown from 1939 to 1942. Some 60 years later, the pattern has changed a little but is basically the same.

A broad-based discussion of the causes of crime is beyond the scope of this guide, and the reader is referred to the substantial literature of criminology for guidance. However, we can consider issues with more obvious geographic implications, and we can do this by moving along a continuum of scale from the *macro* to the *micro* level.

On the *macro* scale, interpreted here to mean national or regional, geographic variation is apparent for some crimes, notably homicide, in the United States. Although the pattern has decayed somewhat in recent decades, a stream of research has addressed what has been called by some the southern violence construct (SVC), the tendency for high rates of homicide to be concentrated in the South. Similar regional variations are seen in other countries. In India, for example, high homicide rates are seen in the densely populated northern states.

On the *intermediate* scale, we see variations in crime rates among cities, although much of the apparent variation can be explained by boundary effects. In other words, "underbounded" central cities (where the urbanized area spills over beyond the city limits) tend to have high rates, since their territories exclude low-crime suburbs. Conversely, "overbounded" cities (such as Oklahoma City) tend to have low rates. However, by no means are all explanations of rate variation necessarily found in boundary anomalies. Cities differ in social structure, traditions, mores, the strength of various social institutions, and other conditions relevant to potential criminality. These include economic conditions, the impact of gangs, and gun and drug trafficking. The wide variation in homicide rates among cities is represented by figure 1.15, which also reinforces the point that similar *numbers* of incidents may yield vastly different *rates*. (For an interesting example of interurban comparisons examining multiple factors, including gangs, guns, and drugs, see Lattimore et al., 1997.)

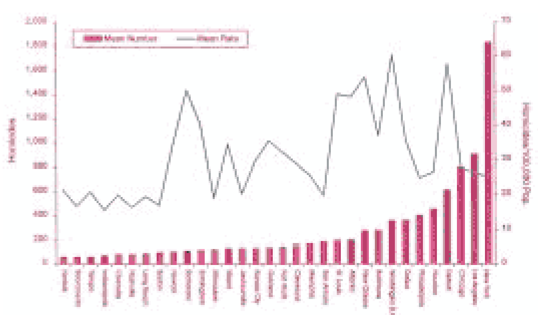


Figure 1.15

A chart showing mean annual homicide counts and rates for 32 U.S. cities, 1985–1994.

Source: Lattimore et al., 1997, figures 2–4, p. 10.

On the *micro* or intraurban scale, a broad array of environmental factors must be taken into account if crime patterns are to be understood. Arguably, the most important general principle is usually known as *distance decay*. This is a process that results from another behavioral axiom, the *principle of least effort*, suggesting that people usually exert the minimum effort possible to complete tasks of any kind. Distance decay (see also chapter 6) is the geographic expression of the principle of least effort. As shown in figure 1.16, the relationship between the number of trips and distance is represented by a line showing that people take many short trips but few long ones. This principle has been observed to apply to a broad range of behaviors, including shopping, health care, recreation, social visiting, journeying to work, migration, and last but not least, journeying to crime. It is possible to create families of distance-decay curves to represent different classes of movement behavior. For example, shopping trips can be divided into *convenience* and *comparison* types. Convenience shopping is characterized by many very short trips because most people will get items such as milk and bread from the closest possible source. Comparison shopping occurs when buyers need big ticket items such as appliances, cars, houses, and college educations. Longer trips in search of more expensive goods and services are thought to be worthwhile because price savings produced by better deals will pay for the longer distances traveled, at least in theory.

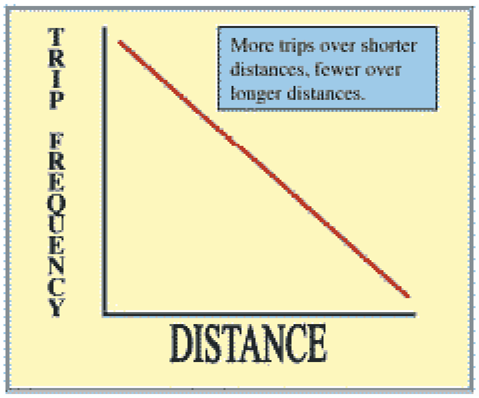


Figure 1.16

A diagram representing the relationship between distance and the intensity of interactions, also known as the *distance-decay concept*.

Source: Keith Harries.

Similar reasoning might be applied to criminal movements, although not enough data have been published to permit much in the way of generalization. The pioneering work of Frisbie et al. (1977), in Minneapolis, showed that more than 50 percent of residential burglary suspects traveled less than half a mile from their homes to their targets. Commercial burglars went somewhat farther, with some 50 percent of incidents occurring within 0.8 miles. Stranger-to-stranger assaults had a wider range, with the cumulative 50-percent threshold not accounted for until a radius of about 1.2 miles from the offenders' homes. Commercial robbers also reached the cumulative 50 percent of incidents at about 1.2 miles. However, a larger proportion of the commercial robbers traveled longer distances compared with those who committed the other crimes, presumably to locate suitable targets and also to avoid the recognition that may come with robbing the corner store. Travel distances tend to reflect population density and other characteristics of the physical environment (such as the geography of opportunities)[15], so it is unlikely that distance-decay curves for crimes could ever apply universally. Nevertheless, the concept of distance decay is still a useful one, even if curves for specific crimes cannot be calibrated very accurately.

Although journeys to crime vary among crime types and with the demographic characteristics of offenders, targets or victims tend to be chosen around the offender's home, place of work, or other often-visited locations. If your home is burglarized, the chances are that the burglar is a not-too-distant neighbor. The long-established prevalence of violence among intimates is further confirmation of the idea that most interactions—including negative ones—occur at short range.

Distance decay is a useful general concept, but a detailed understanding of the fine points of local crime patterns demands detailed local knowledge. Where are the neighborhoods that are experiencing the greatest social stress? What are the patterns of mobility of the population? Who are the movers and shakers in the drug and gang scenes, and do their movements affect crime patterns? What changes are going on?

Other theoretical perspectives

Two of the more compelling theoretical perspectives deal with *routine activities* (Cohen and Felson, 1979; Felson, 1998) and *criminal spatial* behavior (Brantingham and Brantingham, 1984). In the routine activities interpretation, crimes are seen as needing three ingredients: a *likely offender*, a *suitable target*, and the *absence of a guardian* capable of preventing the criminal act. Guardian is broadly interpreted to mean anyone capable of discouraging, if only through his or her mere presence, or interceding in, criminal acts. The mention of guardians begs discussion of the *density paradox*. This refers to the idea that, on the one hand, high population densities create a high potential for crime because people and property are crowded in small spaces. There are many likely offenders and suitable targets. On the other hand, surveillance is plentiful, and criminal acts in public spaces are likely to be observed by others, who, however unwittingly, take on the role of guardians. Crime can be prevented or reduced by making people less likely to offend (by increasing guilt and fostering development of the "inner policeman" who tames criminal impulses), by making targets less available, and by making guardians more numerous or effective. The process of making targets less available in various ways has become known by the generic term *situational crime prevention* (Clarke, 1992).

Putting the routine activities approach and its sibling, situational crime prevention, into a geographic context involves asking how each element is distributed in geographic space. Where are the likely offenders? (What is the geography of the youthful male population?) Where are the suitable targets? (What is the geography of convenience stores, malls, automated teller machines, poorly illuminated pedestrian areas?) Where are the guardians? (What is the potential for surveillance, both formal and informal, of targets or areas that may contain targets? Where are the public or quasi-public spaces that lack surveillance and are ripe for graffiti and other incivilities?)

The perspective that focuses on criminal spatial behavior develops a scenario in which the motivated (potential) criminal uses cues, or environmental signals, to assess victims or targets. Cues, or clusters of cues, and sequences of cues relating to the social and physical aspects of the environment are seen as a *template* that the offender uses to evaluate victims or targets. Intimately tied to this process is the concept of *activity space*, the area in which the offender customarily moves about and that is familiar to him or her (Brantingham and Brantingham, 1984).

At the micro level of analysis, these concepts are useful in that it is known that activity spaces vary with demographics. For example, younger persons tend to have constricted activity spaces. They do not usually have the resources to travel far. Historically, women have had more geographically limited activity spaces than men due to the higher probability that men would work farther from home and that their jobs would be more likely to give them greater mobility. This is less true today but is still valid to some degree.

Analysts considering crime patterns from a theoretical perspective might think in terms of putting the crimes of interest through a series of "filter" questions. The most obvious is the question, How important is geography in explaining this pattern? (Is the pattern random, or not? If not, why not?) Can routine activity theory or criminal spatial behavior theory help explain this pattern? Is this pattern normal or unusual for this area? If the pattern is an anomaly, why is this? What resources can be brought to bear to better understand the social and other environmental dynamics of the area of interest? Analysts can take their intimate knowledge of the local environment and develop their own set of diagnostic questions, which could be the foundation of an analytic model.

The basic point of this section is to suggest that a systematic approach to analysis rooted in theory may yield more consistent results with a deeper level of explanation. This is not to say that analysts need to be preoccupied with whether their work is consistent with all the research ever done but, rather, to advocate a thoughtful research design consistent with some of the more widely accepted concepts in the field. As noted, this short explanation cannot do justice to the rich array of material dealing with theory in this realm. Readers who may wish to follow up should consult Eck and Weisburd (1995) and the other references cited previously.

A note on cartograms

Maps that distort geography to emphasize a specific type of information are called *cartograms* to imply a combination of map and diagram. The media often publish maps showing world or U.S. population data as cartograms, with the areas of countries or States proportional to their populations. Cartograms may also represent linear data by showing travel time, for example, rather than physical distance between places.

Cartograms have not found widespread application in crime mapping, although they could be useful. For example, urban subdivisions could be shown with their areas proportional to the number of crime incidents. The major limitation in using cartograms for crime data is the lack of software availability to permit their easy preparation. Historically, cartograms have been labor-intensive projects, each needing to be custom drawn. When viewed from a cost-benefit perspective, the novelty and impact of cartograms for crime data have not been seen as worth the cost.

Reminder: Information is inevitably lost in the process of abstraction

Cartographer Mark Monmonier (1991) pointed out that the three fundamental elements of maps—scale, projection, and symbolization—can each be distorted. In creating the abstraction called a map, loss of information is taken for granted. Given that there will be information loss, the question is whether we are properly representing the "residual" information left after the data are reduced to manageable proportions. As noted earlier in this chapter, our maps may "lie" as a result of sins of omission or commission. We may forget to do something and get errors as a result, or we may do something that creates errors—or both.

Because all abstractions lie in some way, we come full circle to the awareness of both art and science in cartography. As crime mappers, we should maintain a background awareness that we may make artistic (design) decisions that obfuscate. We may make scientific decisions that misinform. Could our map sidestep a degree of accuracy that it might otherwise have achieved? (How should these data be *pre*processed? Should the mean or median be used to characterize these data?) More often than not, only the analyst/cartographer knows for sure how truthfully a map conveys its message, so she or he has considerable ethical responsibility.

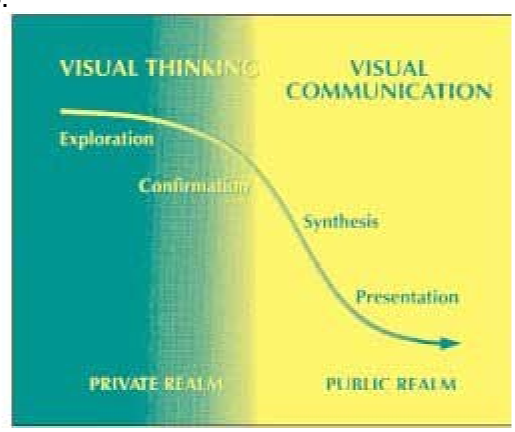
What crime maps do

Maps are often thought of solely as display tools. In fact, maps have a wide-ranging role in the process of research, analysis, and presentation. Mapping is most effective when those broad capabilities are recognized and used to their fullest extent. The map is the end product of a process that starts with the first-responding officer's report that is processed by data entry personnel, entered into a database, and transformed into a symbol on paper. In this narrow interpretation, a map is merely a picture or part of a database. But maps can be useful in other ways. MacEachren (1994) and MacEachren and Taylor (1994), following DiBiase (1990), noted the distinction between visual thinking and visual communication in the use of maps and graphics (figure 2.1).

Figure 2.1

The roles of graphics in the research process: Visual thinking and visual communication.

Source: DiBiase, 1990. Reproduced by permission.



Visual thinking

In *visual thinking*, the map is used to generate ideas and hypotheses about the problem under investigation. By inspecting a map, for example, we may notice a relationship, or correlation, between environmental factors that otherwise might have gone unnoticed. This correlation may be *vertical* in the sense that we see connections between different phenomena, such as crimes, land uses, and demographics. Alternatively, we may see a *horizontal* relationship in which we recognize a common factor across a particular crime type, such as graffiti in similar types of crime locations. Visual thinking is a *private* activity involving exploration and confirmation.

In the *exploratory* phase, maps may be crude and are not intended for display or publication. A computer-printed map of burglary patterns for the most recent week might be marked with handwritten information provided by investigators or with other data not in digital form. Information might be transcribed from a mental map to a paper map. Another possibility is that the tools of exploratory spatial data analysis (ESDA) are used to find anomalies in data, such as an unexpected cluster of incidents, that could point to unexpected relationships.

Visual Thinking versus Visual Communication

- Visual thinking is abstract and internal. Some ideas for putting data into maps, charts, or other media may never see the light of day.
- Visual communication is a tangible expression of visual thinking. It is putting thoughts about data and processes into a format others can see and understand with minimal effort.

At this stage the analyst may generate a formal *hypothesis*, or educated guess, to explain the process producing the observed crime pattern. Did the observed cluster of burglaries pop up by chance? Is there some recognizable cause? Is a serial burglar operating in the area? Do officers in the field have insight to offer? By developing a hypothesis, the analyst is in the mainstream of scientific research, using a venerable methodology—the so-called (and awkwardly called) *hypothetic-deductive* method.

Maps and other graphics are integral tools for exploration and hypothesis testing. Do preliminary maps confirm the hunch that a burglary pattern is likely the product of a repeat offender who is using a bus route, and apparently a specific bus stop, to visit a neighborhood and commit his offenses? If so, the preliminary information will help the hypothesis gel into something useful.

At the core of this method is a potentially repetitive process involving:

- **Development of a hypothesis** on the basis of the best available information derived from both theory and field data.
- **Development of a method** for testing the hypothesis, perhaps involving statistical and graphic testing or modeling.
- **Analysis** of the data.
- **Evaluation** of the results.
- **A decision** to accept or reject the original hypothesis.
- **Reevaluation** of the original hypothesis, if it was unsatisfactory. It may be modified to take into account new knowledge. If so, the process begins anew.

The *confirmation* stage tells the analyst whether the hypothesis does indeed have a factual basis that will withstand scrutiny. If it does not, we reevaluate and make necessary adjustments, perhaps gathering more information to add depth to what is already known and to shore up the hypothesis, which itself may now have been modified to take new data into account.

What's Hypothesis Got to Do With It?

Will the typical crime analyst go through the rigmarole of visual thinking and visual communication—plus the process of hypothesis testing? It's not likely, since most analysts work under though deadlines with inadequate resources. (Just like everyone else!) Also, much of the work is prescribed, routine, and repetitive, leaving little flexibility for research.

So, what's the point? The formal structure outlined here is an ideal model for map-related research—a *paradigm* or *modus operandi*. Thus it is unlikely to be replicated often in practice. Like other models, it provides an ideal guide and enables the analyst to apply whatever parts of the process can be applied in the time available.

MacEachren (1994) cautions that investigators should realize that maps and other graphics are prone to error resulting from their underlying data, inappropriate design, or even the margin of error introduced by the normal process of abstraction. If possible, the analyst should not rely on any one data source, whether it be a map, field observation, or survey, if other sources can be used to complement each other.

Visual communication

As we move from visual thinking to visual communication, we go from the private realm to the public activities of synthesis and presentation. *Synthesis* implies merging various types of information-in this case, geographic information system (GIS) layers-into a coherent final product. Although synthesizing is essentially scientific, human judgment is at the core of this filtering and refining process.

Synthesis is assisted by the ability to find overlaps (intersections) between layers in a GIS. But even then decisions have to be made about what to put in, what to leave out, and what importance to attach to each layer. A *presentation* puts all the relevant pieces together in a map. The map can be highly persuasive if it provides information germane to the question at hand and is well designed. As MacEachren (1994, p. 9) noted, "People believe maps."

How crime maps do what they do

A detailed discussion of how maps communicate through processes of visual comprehension is beyond the scope of this guide. However, a few points are made here to explain the underlying process and underscore the idea that people see maps differently due to differences in, for example, their eyesight, aptitude for visual comprehension, and prior training. A background problem that goes largely unrecognized in the community of mapmakers is that, for some people, maps have no meaning. They may grasp neither scale nor symbolization. As a result, they have no sense of distance, relative or absolute, and are unable to draw meaningful conclusions from a map.

This problem is, in part, a legacy of the disappearance (until recently) of geography from school curriculums. But it may go deeper, seemingly having to do with gender- and race-specific differences in personal mobility that, in turn, may hinder the development of *spatial experience* and reduce individuals' abilities to take advantage of maps as tools. For example, in the past, women's traditional roles in childrearing have limited their mobility, thus denying them opportunities to learn geography by directly experiencing places. Race has had a similar indirect effect through the mechanisms of discrimination and depressed economic status. Insofar as minority groups have experienced disproportionate levels of poverty, their mobility has been limited and their geographic learning correspondingly stunted. (See Montello et al., 1999, for a discussion of related questions.) While the police are very geographically aware, in part due to much field experience, individual members of the community may not be. An argument might be made for giving special attention to maps intended for the community. For example, digital photos of landmarks could be embedded in a community map as visual anchors to show residents how the map relates to their environment.

All messages, including maps, are laced with nuance. "The medium is the massage," wrote McLuhan and Fiore (1967), arguing that literate people had been rendered visually incompetent by an excessive dependence on text. Since that famous remark, personal computers have provided an interactive platform, allowing what is, in effect, environmental manipulation on the fly. Maps, text, and data have moved from the realm of the passive to the active and interactive, encouraging perception of the map as a tool rather than as a mere display device.

Peterson (1995) has outlined several theories and models that have been advanced to explain how visual information is processed:

- **Stage model.** Visual information moves through three memory stages. The first (*iconic*) is very short and deals with initial recognition. The second (*short-term visual store*) is longer but has less capacity so complexity becomes an issue. Moving from iconic to short-term demands attention. The information is then sent to *long-term visual memory*. Long-term images provide cues to help with recognition of new visual stimuli.
- **Pattern recognition theory.** Iconic images are converted into something recognizable through pattern matching.
- **Computational model.** This sophisticated three-dimensional model is similar to the process of abstraction in cartography. (For additional discussion, see Peterson, 1995, chapter 1.)

These theoretical considerations are reminders that producing a map is only half the story. We also have to be concerned with how it is interpreted by the intended audience. The storage of cues for the interpretation of visual images in long-term memory means that familiarity provides a substantial advantage in the interpretation of maps. We may be oblivious to the fact that our map is extremely familiar to us but means little or nothing to those who have no reference points in their long-term memory or who have had insufficient time to study and process the details.

Another way of visualizing the process of moving a concept from the analyst to the map user is illustrated in figure 2.2, showing that the cartographer's and map user's realities are both abstractions of reality. The cartographer creates a cartographic abstraction and translates this into a map that is read by the map user and transferred to the user's mind.

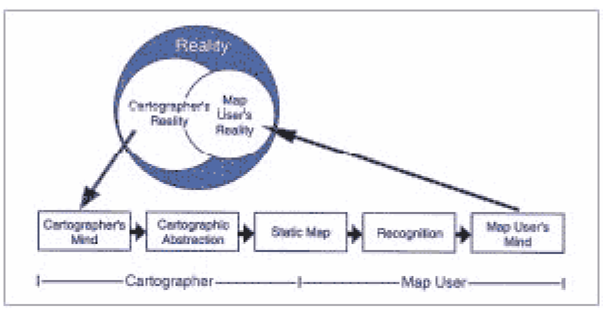


Figure 2.2

A model of cartographic communication.

Source: Peterson, 1995, figure 1.1, p. 5. Adapted by permission of Prentice Hall, Inc., Upper Saddle River, New Jersey.

Choosing a crime map

Chapter 1 characterized thematic maps as falling into the following broad categories: statistical, point, choropleth, isoline, surface, and linear. How do we choose the most appropriate type for mapping crime and crime-related phenomena? Some decisions jump out at us while others are open to interpretation.

For example, if we want to see the precise locations of burglaries for the last month, then we use a point map of addresses of incidents. Or perhaps a city council member has asked the police department for a map summarizing the number of incidents of graffiti per structure by city neighborhoods. This calls for a choropleth map, with neighborhood boundaries making up the geographic units. Links between victim and offender residences demand a linear representation. A generalized picture of crime risk or incidents is seen best with an isoline or surface map, and census information depicting the relationship between poverty and race can be shown using either a statistical or choropleth map.

Because of the infinite potential combinations of crime-related conditions that can be depicted on maps, we can combine map types to put more information on the same map. For example, we can combine *nominal* and *ratio* data, such as a choropleth map of drug-related crime by patrol beats and add the locations of drug markets on the same map. Crime mappers should be aware of the potential for combining thematic map types, provided that the result is not overloaded with information—or just plain incomprehensible. An overloaded map will have so much information that the eye is unable to take it all in. It will prevent the reader from discriminating between what is important and what is not.

Examples of thematic maps

Perhaps the best way to get a feel for the kinds of maps used to display crime data is to look at examples and to think about why each type of map was selected. A good place to start is the Web site of the National Institute of Justice Crime Mapping Research Center (*http://www.ojp.usdoj.gov/nij/maps/*), which provides links to police departments across the United States. Another useful Web site is maintained by Hunter College in New York (*http://www.geography.hunter.cuny.edu/capse/projects/nij/crime.html*). (See the appendix for additional information.)

Thematic maps using point symbols: The dot map

When should point symbols be used? The first prerequisite is that *you have locational detail*—information specific to your points, such as street addresses or coordinates in latitude/longitude or some other system, such as State Plane (explained in chapter 1). The second prerequisite is that *the audience needs locational detail*. If you have point data, but the audience wants information summarized by patrol areas or neighborhoods, then the point data can be added up, or aggregated, to the areas of interest. Examples of point, or dot, maps are shown in figures 2.3 and 2.4.

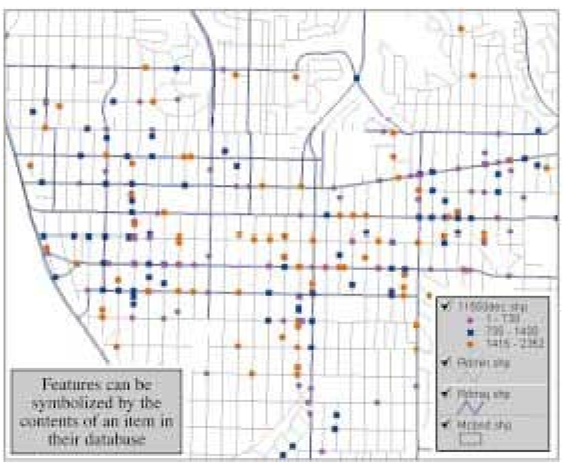


Figure 2.3

A point data map discriminating among three crime categories with different symbols and colors.

Source: San Diego, California, Police Department. Reproduced by permission.

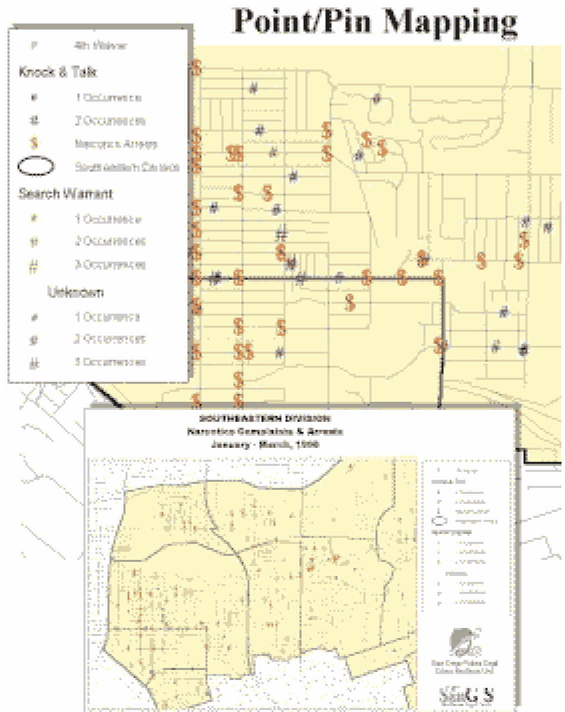


Figure 2.4

A point data map of drug arrests using different symbols and colors.

Source: San Diego, California, Police Department. Reproduced by permission.

When there are too many points to be mapped, using point data may result in a mess of superimposed points that have little or no meaning. This could happen if calls for service are mapped using addresses in a large city. The point data may need to be summarized by areas to make the data legible. Point maps also get too crowded if long time periods are summarized for more frequent crime categories. Thus, even though you have reasonably precise locational information, aggregation by areas in the form of a choropleth map may yield a more legible map than the presentation of each individual point.

Thematic maps using statistical symbols

At its most primitive, a statistical map consists of raw numbers written in the subdivisions of the map. The advantage is that the reader can see exactly what the statistic is. The downside is that maps designed in this way are difficult to read quickly. It could be argued that, in effect, they defeat the purpose of the map, which is to facilitate visualization of the data. Admittedly, this form of map does put data in its geographic context, but in an inconvenient format. Cartographers argue that if you want to see only the raw numbers, then a table, not a map, is needed (see next section, "Thematic maps using area symbols").

Statistical symbols commonly take the form of pie charts, bar charts, graduated circles, or dots representing incident counts (dot density) placed in the relevant map subdivisions (figure 2.5). This allows multiple variables to be mapped at the same time. Examples could include bar charts with bars representing both crime and poverty or graduated circles like those in figure 2.6, showing the U.S. House of Representatives vote on an Omnibus Drug Bill provision requiring a 7-day waiting period for the purchase of handguns. At first glance, the symbols in figure 2.6 look like pies, but circle segments are all 90 degrees. This is actually a graduated circle map, in which the *area* of the 90-degree segments is proportional to the number of yes votes (top part of the circle) or no votes (bottom part of the circle), with the left side of the circle representing votes by Democrats, the right by Republicans.[1] The map shows both nominal data (party affiliation and yes/no votes) and quantitative data (the number of votes), as well as location of votes by State. Although reading this map takes some effort, it is rich in information and gives that information a clear geographic context.

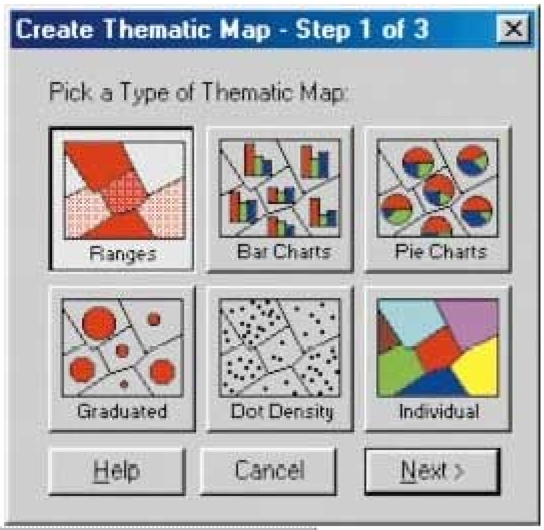


Figure 2.5

Thematic mapping options in MapInfo™, a desktop mapping program.

Source: MapInfo Corporation, Troy, New York.

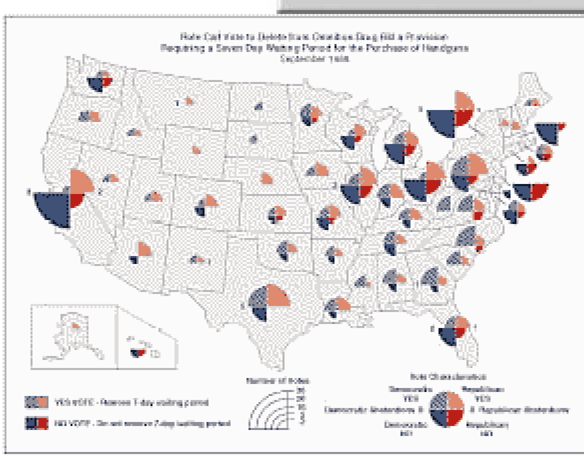


Figure 2.6

A graduated circle map showing a U.S. House of Representatives vote on an omnibus drug bill provision requiring a 7-day waiting period for the purchase of handguns.

Source: T. Rabenhorst, University of Maryland, Baltimore County, Maryland. Reproduced by permission.

More typical graduated symbol maps used in crime analysis applications are shown in figures 2.7, 2.8, 2.9, and 2.10. Note that points and proportional circles can be combined if this helps convey the essential information to readers and avoids overloading the map. Note also that the size range for symbols is a judgment call. If the size range is too small, readers will have difficulty extracting meaning from the map. Also, some symbols are more effective than others in conveying the message. Solid symbols probably work best in most cases because they engage the eye more effectively.

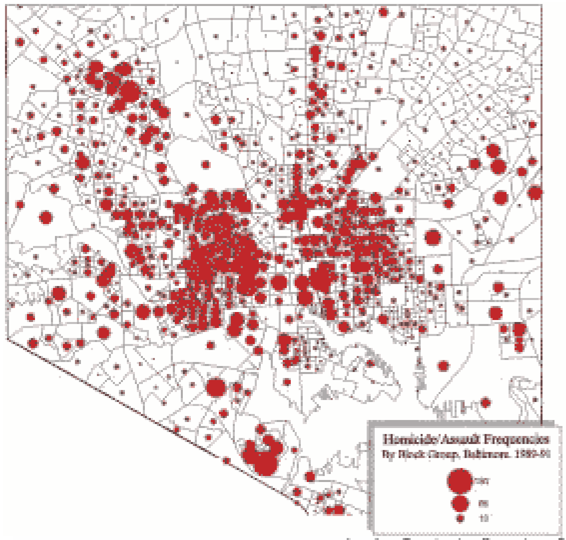


Figure 2.7

A graduated circle map showing aggravated assaults by census block group, Baltimore, Maryland.

Source: Keith Harries from Baltimore City, Maryland, Police Department.

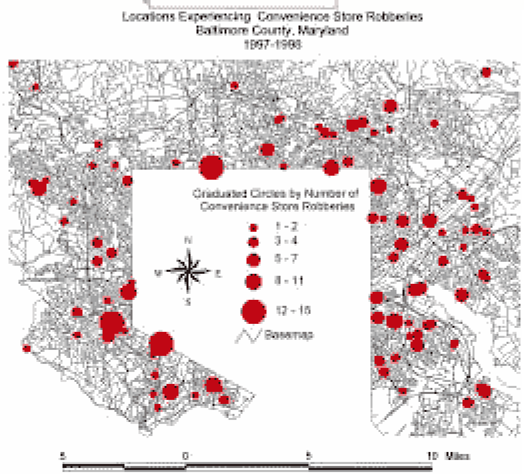


Figure 2.8

A graduated circle map showing convenience store robberies, Baltimore County, Maryland.

Source: Philip Canter, Baltimore County, Maryland, Police Department. Reproduced by permission.

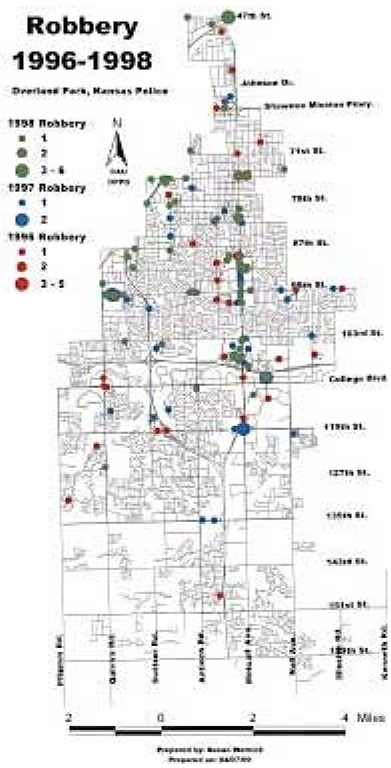


Figure 2.9

A graduated circle map showing robberies in Overland Park, Kansas.

Source: Susan Wernicke, Overland Park, Kansas, Police Department. Reproduced by permission.

Figure 2.10

A graduated symbol map showing calls for service in a San Diego neighborhood.

Source: San Diego, California, Police Department. Reproduced by permission.

A disadvantage of using statistical symbols on maps is that they may overlap one another and result in an illegible mess. Map design must take into account the final size of the map, the scale to be used, and the possibility of overcrowding.

The use of statistical devices of various kinds on maps is limited only by the analyst's imagination. For example, it may be useful to accompany a map with a scatter diagram showing a collateral relationship, such as calls for service by time of day (chart) and calls for service by location (map). Mapping software offers numerous possibilities because the programs usually can make both charts and maps and combine them in layouts in useful ways.

Classifying map information

Generally, information on maps is classified in some way; data are not symbolized individually. For example, all burglaries are shown with the same symbol on a point map. It would be absurd to show each crime with its own symbol.

In effect, maps contain two levels of abstraction:

- The overall level of detail and the scale used to present the data.
- The way data are symbolized, because there is a continuum from highly detailed to extremely generalized in the symbolization process.

To some extent, the choice of scale controls the level of abstraction of the content because it is impractical to load a small-scale (large area) map with local detail. MacEachren (1994, p. 41) argues that for categorical information, "features that end up in the same category should be more similar to one another than features in different categories."

What does this mean for crime maps? A map of drug offenses might group related drug categories together. Generically related robberies could be put together in the same category and symbolized the same way on a general crime or violent crime map. If a map were specific to robberies, however, symbolization might be separated into commercial and street or weapon type or time of day. This type of adjustment is intuitive and naturally occurs in the crime context where data are typically sorted into categories as part of normal processing. But the situation becomes more intricate when moving from nominal and ordinal data to ratio-type data.

It is less obvious how to classify numerical data when several alternatives present themselves. Common mapping software packages offer options, including a default, for grouping numerical data in thematic maps but rarely explain how to choose among these approaches. Dividing up the data range in a way that best represents it involves the abstraction issue again.

Total abstraction would be represented by the use of one shade for all areas on the map. This says that there are data, but little or no specific information is supplied about them. At the other extreme, each area would have its own shade, and if city blocks were shown, the map would have thousands of shades. Obviously, neither of these alternatives is useful, and the solution lies somewhere between.

Greater accuracy dictates the use of more classes of data, although readers pay a price for this in terms of comprehension as the map moves along the continuum of abstraction toward reality and complexity. The underlying question is, What is this map being used for? MacEachren (1994, pp. 42-43) suggests that if we are in the visual thinking stages of exploration and confirmation, we will need more detail (more classes), but as we progress toward synthesis and presentation it becomes more important to show general trends rather than detail, hence fewer classes. Furthermore, limitations on human visual comprehension must also be taken into account-the limit is about six levels of color or gray scale shading in the context of a map.

Are there natural breakpoints in crime data? For example, in a robbery map of a city we could embed the State, regional, and national robbery rates as breakpoints. This might be informative but could get a political "thumbs down" if the local jurisdiction compares unfavorably. (Conversely, it could be a popular approach.) Choices available to cartographers in common desktop mapping packages are represented by the drop-down menus shown in figure 2.14.

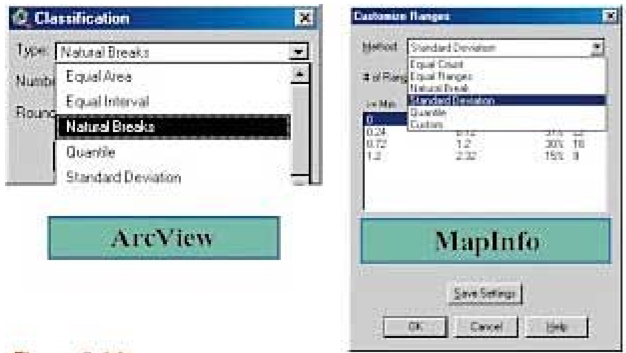


Figure 2.14

Choices for class interval determination as presented in two widely used desktop mapping programs. Left, ArcView™; right, MapInfo™.

Sources: ESRI, Inc., Redlands, California, and MapInfo Corporation, Troy, New York.

The choices available, and the relative ease of using them, invite experimentation. How will a particular database look when mapped in a particular way? What method conveys the crucial information with the least distortion and best visual impact? Good maps are likely to result from a working environment that encourages experiment because it is ultimately through trial and error that most learning is done. This is said not to invite a "shotgun" approach but, rather, to encourage the responsible testing of options under the assumption that alternative methods of representation are tested for a reason other than the sake of doing something different.

How Many Classes in a Map?

Use no more than six—and not less than four—classes, or shading levels, of data in a choropleth map.

Each of the alternatives typically employed in data mapping is introduced here and illustrated in figures 2.15 and 2.16.

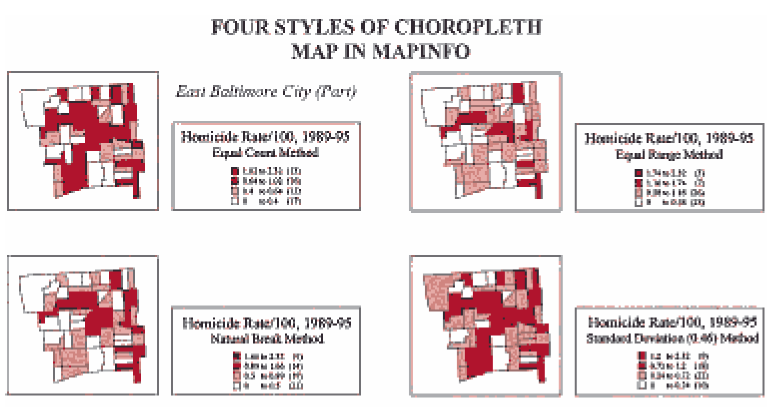


Figure 2.15

East Baltimore City homicide rate in choropleth maps using different methods.

Source: Keith Harries.

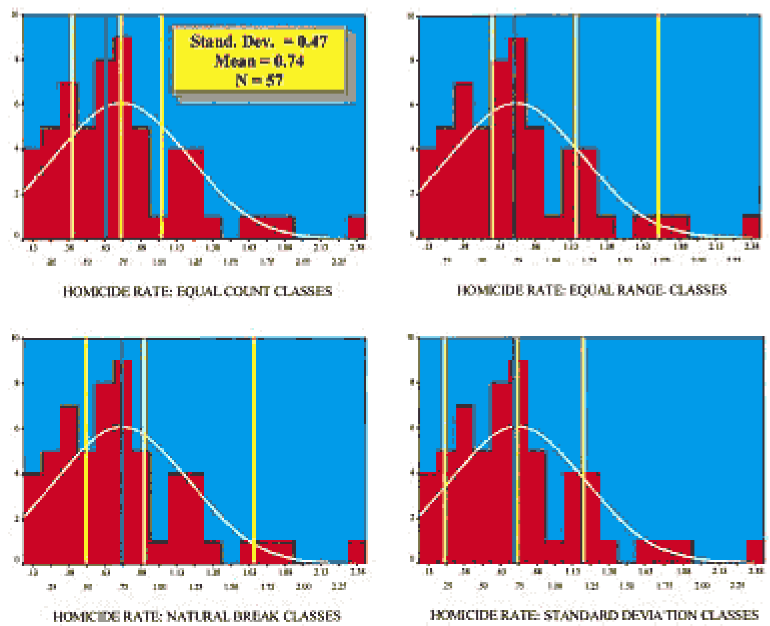


Figure 2.16

Histograms associated with maps in figure 2.15 with class interval breaks (vertical yellow lines) and normal distributions superimposed.

Source: Keith Harries.

- **Equal ranges or intervals.** The data range (difference between maximum and minimum) is calculated and divided into equal increments so that the within-class ranges are the same, such as 1-3, 4-6, 7-9, and so on.
- **Equal count (quantiles).** Approximately the same number of observations is put in each class. The number of classes determines the technical definition of the map (quartile if there are four classes, quintile if there are five classes, and so forth). The term quantile is the generic label for data with observations divided into equal groups. This software option gives the user the opportunity to enter the number of classes desired. (This is the default in MapInfo®.)
- **Equal area.** Breakpoints between classes are based on equality of area rather than equality of range or an observation count. If areas in a choropleth map vary greatly in size, this type of map will differ from an equal count map based on the same data. If areas are roughly equal in size (such as city blocks), the result will be similar to an equal count presentation.
- **Natural breaks.** In this approach, gaps or depressions in the frequency distribution are used to establish boundaries between classes. This is the default in ArcView®, which employs a procedure know as *Jenks' Optimization* that ensures the internal homogeneity within classes while maintaining the heterogeneity among the classes. (For more details, see Dent, 1990, pp. 163-165, and Slocum, 1999, chapter 4.)
- **Standard deviation (SD).** SD is a statistical measure of the spread of data around the mean, or average. In the literature of stocks and mutual funds, for example, SD is often used as a risk index, since it expresses the amount of price fluctuation over time. In the context of crime, SD can be a useful way of expressing extreme values of crime occurrence or portraying various social indicators. Generally, classes are defined above and below the average in units of 1 SD. The drawback is that this method assumes an underlying normal distribution, or bell-shaped curve, something of a rarity in social data.
- **Custom.** As the label suggests, this option allows users to determine class intervals according to their own criteria, such as regional or national norms and thresholds determined for policy reasons.

Table 2.1 summarizes the criteria for selecting methods to define class intervals for maps, providing a guide with respect to data distribution, ease of understanding, ease of computation, and other standards. (For a comprehensive discussion of issues relating to the determination of class intervals for maps, see Slocum, 1999, chapter 4.)

Table 2.1. Criteria for Selecting a Method of Classification

Criterion	Equal Interval	Quantiles	Standard Deviation	Natural Breaks
Considers distribution of data along a number line	P	P	G	VG
Ease of understanding concept	VG	VG	VG	VG
Ease of computation	VG	VG	VG	VG
Ease of understanding legend	VG	P	G	P
Legend values match range of data in a class	P	VG	P	VG
Acceptable for ordinal data	U	A	U	U
Assists in selecting number of classes	P	P	P	G

P=Poor G=Good VG=Very good A=Acceptable U=Unacceptable

Source: Thematic Cartography and Visualization, T.A. Slocum, 1999, figure 4.7, p. 74. Reprinted by permission of Prentice Hall, Inc., Upper Saddle River, New Jersey.

Maps and statistics: Exploratory spatial data analysis

Some statistical methods have been mentioned in the preceding discussion, and consideration of statistical concepts is unavoidable when considering how best to visualize numerical data. As noted earlier, because we can lie with statistics, we can also lie with statistical maps. Indeed, maps have been used throughout history as propaganda tools (Campbell, 1993, pp. 229-235), so potentially we can have honest error as well as pure cartographic deceit. Perhaps the greatest danger in the mapmaking process is that people tend to believe the information in maps (what MacEachren, 1995, p. 337) called the connotation of veracity), and they also believe that maps are unbiased (the connotation of integrity).

But mapmakers, like other elements of society, are culturally conditioned, selectively including and excluding data according to the values of the responsible parties. Given that maps can harbor many possible errors and biases, both intentional and accidental, it is incumbent on the crime analyst to be aware of possible sources of error and to work to avoid them. Nowhere is there more scope for distortion and misinterpretation than in the preparation of maps based on numerical data. This is due to the potential complexity of the information and the infinite set of display permutations, whether in raw form or as some derivative measure such as a rate or percentage.

Mapmakers can gain a preliminary understanding of what the numbers mean through the process of exploratory spatial data analysis. It is quite helpful to understand what the distribution of a set of numbers looks like when expressed graphically. Is this a normal (bell-shaped) distribution with most observations clustering around the mean, or average, and a few very low and a few very high values? Is it a skewed distribution with extreme values to the right (high values) or the left (low values)?

In the unlikely event of a normal, symmetrical, bell-shaped distribution, maps created by all of the classing methods look similar. Almost always, however, real-world data are somewhat skewed, and different classing methods produce maps that look different and convey different visual impressions to readers.

Consider in some detail what will happen when different methods are applied to a data set that has a strong positive skew (figures 2.16 and 2.17).

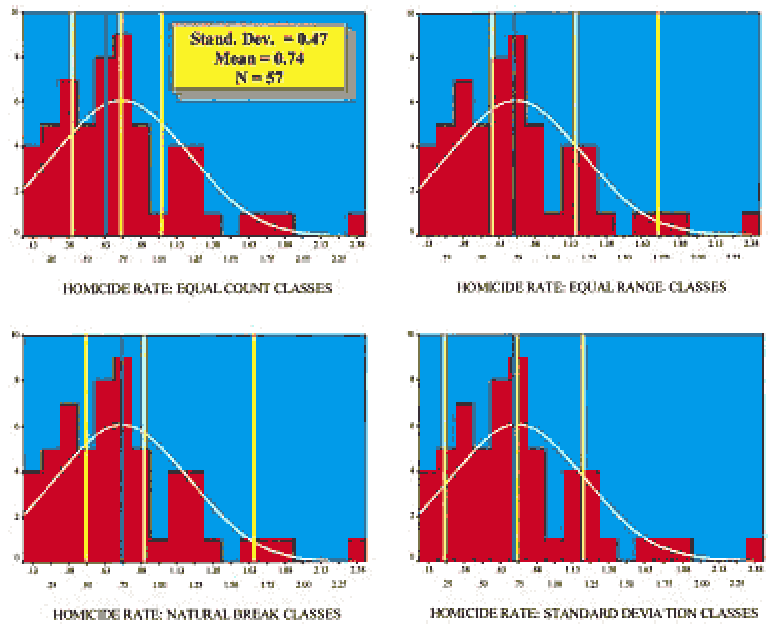


Figure 2.16

Histograms associated with maps in figure 2.15 with class interval breaks (vertical yellow lines) and normal distributions superimposed.

Source: Keith Harries.

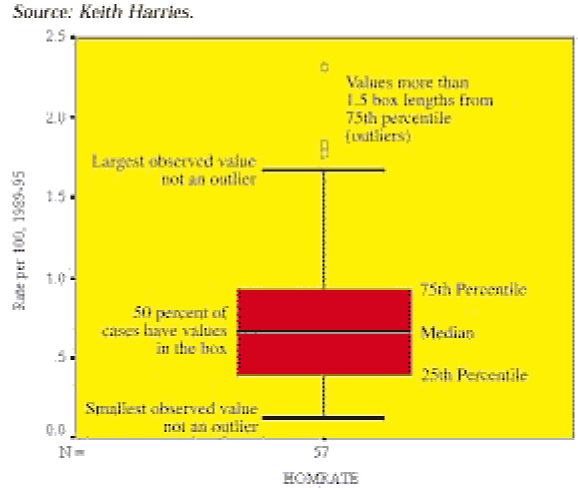


Figure 2.17

A box plot of homicide rate data. Compare with histograms (see figure 2.16).

Source: Keith Harries.

A Note on Skewness

A normal distribution is the familiar bell-shaped curve that is seldom seen in crime data. Most crime data are positively skewed, meaning there is a long right "tail" representing a few high values. Hot spots (high crime areas are geographic expressions of skewness, which presents difficulties in mapping numerical data. See the box, How Much Exploration? and figures 2.15 and 2.16.

Let's review each histogram (or frequency curve) and map in figures 2.15 and 2.16, method by method.

- **Equal count.** On the histogram, the right tail (highest values of the distribution) is prominent because there are few extremely high values. Thus, the program has to seek the lower rank-ordered data values (farther to the left on the histogram) to come up with the 13 observations for the class. (Note that the number of observations per class is uneven, ranging from 13 to 17.) The resulting map tends to visually exaggerate the seriousness of the problem because color saturates more map areas.

Best Choice?

Generally, natural breaks or equal intervals will be the best methods for creating area-type maps in crime analysis.

- **Equal range.** Because the distribution is right-skewed, equal range will tend to favor lower data values. The two lowest classes have 23 and 26 members, respectively, while the higher classes have 7 and 3. The map contrasts with the equal count version, now visually minimizing the problem.
- **Natural break.** This method appears to have struggled to come up with natural breaks, which is a problem, along with breaks in awkward places. The result here is quite similar to the equal range breakdown, with cuts between classes shifted to the left (lower values) as compared with the equal range. It comes as no surprise that the equal range and natural break maps are quite similar.
- **Standard deviation.** Here, the breakdown of class intervals is set with reference to the average, or mean, so that an interval of 1 SD is established to the left of (below) the mean (blue line, 0.47), and above the mean at the same distance. The effect of this on the right-skewed distribution is a symmetrical breakdown, with about as many observations in the lowest (10) and highest (9) classes and in the two middle classes (22 and 18). The visual impression conveyed by the associated map is close to the severity of the equal count method. This is due to the similar number of observations in the top category.

The basic point to be made from this discussion is that cases that may fall in a given class by one method may be in a different class by another. The only certainty is that the highest and lowest values will always be in the top and bottom map classes, respectively. What method is preferable? MacEachren (1994, p. 47) noted that, "for any skewed data, quantiles are a disaster for a presentation map!" In the above example, quantiles result in such a large data range in the highest class as to be almost meaningless. Standard deviation classes may be helpful in some situations where the distribution is not extremely skewed.

Note that a frequency curve shows skewness in the rank-ordered data values, but only a map can show skewness in geographic space. Are the high values distributed geographically in a random way or clustered? Either method yields useful information. If the high crime rates are clustered, it may indicate a hot spot. If the high rates are random, the net impact on the community may be about the same, but we are now unable to point to a hot spot.

We can see an empirical relationship between map scale and skewness, which is minimized in a small area (large scale) and maximized in a large area (small scale). Think of it this way: A very small area in the community, say 1 square yard, can have no spatial skewness because only one event can happen there. But as the spatial scope increases (smaller scale maps covering larger areas), the potential for skewness increases because there can be bimodal, or split, distributions in space (as well as time). A clump of events can occur in one small area with the rest empty—an extremely skewed pattern.

This is what the crime scene is like on a regional, national, or global scale. Clusters correspond to opportunities presented by the underlying controlling condition, population distribution. At the smallest scale (region or world), the crime map is for all practical purposes the same as the population map, but at larger scales (city or neighborhood) we refine the view and see that the presence of people actually means variations in rates conforming to varied social and physical environmental conditions. Also, at larger scales we will see different patterns depending on the denominators used to calculate crime rates.

Another way to visualize a distribution is the use of a box plot, which shows how data are spread in relationship to the mean, median, mode, and quartiles, with outliers symbolized in a special way. (Outliers are values more than 1.5 box lengths from either the 25th or 75th percentiles.) If we examine the HOMRATE data set using the box plot routine in the Statistical Package for the Social Sciences (SPSS), the result appears as shown in figure 2.17.[5] Note that the box plot is an alternative way of visualizing the same data shown in figures 2.15 and 2.16. In the box plot in figure 2.17, the red box represents 50 percent of the data values, with the median shown by the bold line across the box. The 75th and 25th percentiles are the top and bottom of the box, respectively. The ends of the Ts represent the smallest and largest observed values that are not defined as outliers. Although the box plot seems to be repetitive, it provides a different perspective on the data—one that complements the more frequently used histogram. (For a detailed explanation, see SPSS documentation, such as *SPSS for Windows Base System User's Guide Release* 6.0, p. 186.)

Only the immediate objective and the available tools limit the amount of exploration and preprocessing crime mappers do. Perhaps the single most important exploratory step is the creation of a histogram, box plot, or comparable graphic with which to visualize the shape of the data and answer the fundamental question: Is it severely skewed or in some other way not normal (e.g., bimodal or double peaked)? How will this affect maps, and what type of map will permit a presentation that minimizes distortion and accurately portrays the data? Again, this examination of the data is the ideal. Not all analysts will have the tools or the time to go through this step. Nevertheless, these possibilities are outlined here to raise awareness of what constitutes the best practice.

Map design

The field of map design has generated substantial literature in cartography focusing on how people comprehend maps and the impact of various design elements such as symbol size, color, and line thickness. Also of interest is the impact of the arrangement of a map within the map frame as well as the merits and demerits of various types of maps.

Debate continues, for example, over the dominance of choropleth maps to represent numbers. Opponents point to the most obvious choropleth defect: its use of one data value to represent an entire area, an absurdity that becomes acute when most of a geographic subdivision contains virtually no human activity because of the terrain or the existence of bodies of water.[6] Muehrcke (1996) quoted Ronald Abler, Executive Director of the Association of American Geographers, who, in 1987, said something to the effect that choropleth maps were an abomination that GIS would soon eliminate through the use of dasymetric mapping.[7] (The death of the choropleth map has been slow!) However, the increased use of density surfaces in various desktop GIS programs is a move away from such heavy reliance on either dot or choropleth modes of representation and is consistent with the concept of areal averaging—without slavish adherence to political or administrative boundaries.

Map design is at once a technical and an artistic effort. Dent (1990) devotes 5 chapters and about 120 text pages to designing thematic maps; we can give only broad consideration to a few issues relating to typical parts of a map and how they should be organized. The reader is referred to the following textbooks for a full explanation, particularly on such details as lettering and labeling: Campbell, 1993; Dent, 1990, 1993; Robinson et al., 1995; and MacEachren, 1994, 1995.

How Much Exploration?

A histogram of the numerical data, as will as statistics for skewness and kurtosis will help determine what kind of map would be most effective and least misleading. Common statistical packages such as SAS® and SPSS® enable the rapid production of these diagnostics. Also, Microsoft Excel and other spreadsheets yield the following statistics as well as a histogram option. (In Excel, see the Tools menu, then Data Analysis.)

HOMRATE*	
Mean	0.74
Standard Error	0.06
Median	0.67
Mode	N/A
Standard Deviation	0.47
Sample Variance	0.22
Kurtosis	1.44
Skewness	1.10
Range	2.20
Minimum	0.12
Maximum	2.32
Sum	42.43
Count (number of block groups)	57.00
Largest (1 case)	2.32
Smallest (1 case)	0.12
Confidence Level (95.0%)	0.12

Interpretation: Values of the skewness and kurtosis are centered at zero. If either is relatively large, a nonnormal distribution is likely. See Norcliffe (1977 for more detail on this, and consult figures 2.15 and 2.16 for graphic interpretations.

*HOMRATE is the homicide rate per 100 persons in a selected part of Baltimore, Maryland. These statistics were used to compile figures 2.15, 2.16, and 2.17

Source: Keith Harries

It may be helpful for newcomers to mapmaking to make a flow chart in which the design of the map is adjusted to ensure that the map fulfills its stated purpose. This activity may become less important over time as intuition and experience take over from reliance on a formally structured process. Dent (1990, p. 316) lists the following elements of the thematic map, which could serve as a checklist for inclusion:

- Title (or caption).
- Legend.
- Scale.
- Credits.
- Geographic content (showing information that may not necessarily be included in the subject matter of the map, such as orientation or north arrow).

- Graticule (spherical coordinate system: latitude/longitude, State plane).
- Borders and neatlines (the lines that bound the body of a map, usually parallels and meridians).
- Symbols.
- Labels.

Most of these elements are necessary in a typical crime map. The principal exception is the graticule (spherical coordinate grid), which normally serves no useful purpose.[8] Also, credits are rarely used because data are likely to be locally derived. However, if data sources are not self-explanatory, credits clarify exactly where the data came from. This information could be listed under the body of the map using the keywords "source" or "data source." We could add author to the list to assist in the process of accountability, inconspicuously noting the name or initials of the analyst-cartographer in a corner of the map.

A useful approach to learning more about design is to look at examples of crime (and other) maps that have been deemed acceptable by their respective audiences. Fortunately, there is no shortage of maps, whether on crime or on other phenomena. The easiest access is via the World Wide Web, and the appendix of this guide lists some useful Web site addresses. Chapter 3 uses examples to discuss various applications of crime mapping. Here we confine ourselves to outlining principles.

Dent (1990, chapter 13) has noted several *elements of map composition*: balance, focus of attention, and internal organization.

- **Balance** refers to the need to arrange parts of the map in a way that enhances its visual symmetry. However, the crime cartographer may have little flexibility with respect to balance owing to inherent content limitations. For example, the jurisdiction may be extremely asymmetrical, making it difficult, if not impossible, to map without leaving considerable white space on the paper. Cities with long "shoestring" annexations, like Los Angeles, or States with long panhandles, like Oklahoma, are good examples of difficult map shapes. This problem sometimes can be solved by chopping the city or other area of interest into its component parts. An inset, or miniature map of the whole, is used to show how the pieces fit back together. Another solution is to routinely map individual precincts or districts under the assumption that the managers of those areas are first and foremost interested in seeing patterns in their areas of responsibility. The drawback to this is that crime patterns do not pay much attention to administrative or political boundaries, so that looking at individual subdivisions in isolation from the rest of the area may cause someone to miss hot spots or other useful patterns by fragmenting them.
- **Focus of attention** is a concept based on the assumption that people read maps like they read the printed page, by moving their attention from upper left to lower right.[9] Hence the optical center of a map is somewhat above the geometric center suggesting that, ideally, the most significant information should be closer to the optical center. Again, this is easier to manage in theory than in practice. Still, it is a useful concept to bear in mind because crime analysts will sometimes have enough discretion in design that the focus of attention can be exploited to advantage.
- **Internal organization** refers to the alignment of the parts of a map or individual maps on a page or within a frame. Map elements should be arranged in a logical way rather than placed haphazardly on the page. The core contents of the map, for example, should dominate the space, and other elements should be secondary.

According to Dent, contrast also is important to visual perception. Line, texture, value, detail, and color are powerful tools because they allow map elements to be differentiated from one another. More contrast makes objects stand out, less allows them to fade into the background. *Line* thickness, or weight, can assist in this process, and using more than one line weight on the map can add interest. *Texture* can add variety and draw attention to an important part of the map. *Value* refers to the use of lighter or darker shades of color, and *detail* draws the eye in. As noted elsewhere, however, detail is a two-sided coin. It adds interest, but when used to excess it can cause clutter and make the map illegible. If a map is to be reduced for publication, fine detail may be completely lost in the reduction process. Experiment with enlarging and reducing on a photocopier to learn more about how this works in practice.

Color is extremely important in the process of area differentiation. It is also a complex issue owing to the physiological, psychological, and physical processes involved. Dent (1990, chapter 16) notes that color has three dimensions: hue, value, and chroma.

- **Hue** is the term given to color labels-red, yellow, and blue, the primary colors-and the millions of permutations derived from them.
- **Value** refers to the degree of lightness or darkness of a color. GIS programs can help you select color values by providing color "ramps" (or series of related shades or values of a hue) in a visually logical sequence ranging along an intensity spectrum. Colors vary along a continuum from light to dark. For example, reds may range from light pink to deep red, and blues may range from sky blue to navy blue.
- **Chroma** is understood through the concept of color saturation. A less saturated color appears to contain more grays, and a saturated color has no gray and appears as the "pure" color. In photography, some films have a reputation for conveying more saturation than appears in natural scenes (bluer blues, greener greens), "larger than life" color that is pleasing to some viewers but excessive to others.

Choices of color in maps need to be made quite carefully because color may have strong emotional connotations for some readers. For example, should red be used for a map of violent crime, given the symbolic connection to blood? It is tempting to overload crime maps with warm colors, such as red and orange, but the analyst should be mindful of the symbolic effect and the impact this may have on the intended audience.

Just as color makes maps and other graphics come alive, color also enhances our ability to mislead people with maps through the use of inappropriate hues and values. For example, a crime category that is a local political "hot potato" could be visually minimized through the use of cool colors in subtle shades lacking saturation. The use of color in maps and graphics is complicated by the fact that a significant portion (8 percent of males and 0.5 percent of females) of the population is at least partially colorblind.

Using Colors and Shades

- Use darker colors or gray shades for more or higher values.
- Use lighter colors for less or lower values.

Crime mappers can take advantage of various models of color sequencing. GIS software typically defaults to a part-spectral plan with shades from yellow to brown. In a full-spectral plan, colors range from warm to cool, and in a double-ended plan, data values representing an increase (or above average) are in one color and a decrease (or below average) in another. Increases (or higher values) are typically shown in warmer colors, decreases (or lower values) in cooler (see Dent, 1990, p. 387). GIS software normally permits the customizing of colors to fit your purpose.

Design, abstraction, and legibility

Map design and abstraction are inseparable. The map design defines the level of abstraction to be imposed. "To represent is to abstract," wrote Muehrcke, and "abstraction frees us from the tyranny of our physical existence" (1996, p. 275). He presumably meant that it gives us license to, so to speak, "mess with reality." Many of the issues that concern cartographers, such as the degree of distortion on world maps, are of little concern to crime mappers. Where should we focus our attention when it comes to thinking about abstraction in our maps? What can we afford to ignore? Are any map elements indispensable on most crime maps?

Abstraction, the reduction of detail on maps, permits us to design our maps in ways that make them attractive and effective. Abstraction is like the sculptor's chisel—it determines what remains of the raw material and what form the finished product will take. As noted earlier, most map elements are dispensable at one time or another, depending on the context.

First and foremost, the analyst must consider the audience and the medium of presentation. Will the map go to one person and be seen at arm's length? Will it be a page in a report? (If so, will it be in color? How would the map look if it was converted to gray scale?) Will it become a transparency for an overhead projector or a 35-mm slide? Will it be incorporated into a digital projector production in Microsoft PowerPoint® or comparable software?

If a map is to be projected, lettering size and line weight become quite critical. You may have a brilliant map with potentially great visual impact, but if two-thirds of the audience can't read the lettering when it is projected, your creativity is wasted.[10] Also consider the "demographics" of the audience to be addressed: are they younger? older? more educated? less educated? predominantly female?

If the audience is not similar to the general population, some adjustments in map design may be needed. Research has shown, for example, that there may be subtle differences in the way men and women read maps (Kumler and Buttenfield, 1996).

This begs the corollary question of exaggeration in maps to gain legibility. Sometimes detail must be retained, but this may result in objects running together owing to the thickness of the lines representing them. Line thickness may need to be adjusted and objects may need to be moved slightly to maintain visual separation. Bear in mind that line work on maps often greatly exaggerates the true dimensions of linear features. A typical State highway map may be used as an example. On this map, interstate highways are 1/16th of an inch wide. The representative fraction (RF) of the map is 1:380,160, or 6 miles to the inch, which represents a width of 660 yards. This is probably, on average, double the width of most interstate highways. By comparison, area features such as a city block, a city, or a county, should be accurately rendered because exaggeration is not needed to make them visible.

Even point data generally exaggerate the size of the location at which a crime incident occurred or the address of the victim or offender. Point symbols are actually markers for general locations and should be interpreted as approximations owing to (a) the size of the point symbol and (b) normal problems with address interpolation touched on in chapter 4 of this guide. It is tempting to see point data as the epitome of accuracy, but this accuracy is relative.

Map Design Questions to Consider

- Is this the best map for the stated objective?
- Is the scale appropriate?
- Does the design account for both data representation and aesthetics?
- Could a flowchart ensure the inclusion of all necessary elements?
- Are the sources of data, authors of the map, and date of preparation shown?
- Are balance, focus of attention, and internal organization considered?
- What colors work best?
- Is the map legible in all the contexts in which it will be used (print, slide, fax, PowerPoint®, and overhead transparency)?

Crime mappers might consider using more *perspective symbol landmarks* or *mimetics*[11] to help readers orient themselves, particularly in metropolitan areas (see figures 1.2, 3.25, and 5.9). These symbols are pictorial and characterize the landmarks they represent, such as the use of an airplane symbol to represent an airport or silhouettes of familiar structures, such as a school, church, ballfield, cathedral, city hall, or highrise tower. Such pictorial devices are more important for lay audiences than for police officers, who are familiar with the area, although the assumption that all cops are equally familiar with entire cities or metro areas is a fallacy. We—even cops—are victims of our daily routines and the neighborhoods they take us through. None of us can comprehend entire metropolises, at least not at the level of street name familiarity.