THE NATIONAL ATLAS OF KOREA

Comprehensive Edition

Preface

Publishing a national atlas is the first step toward achieving the educational goal for students to understand their nation and its geography. In 2007, the National Geographic Information Institute published *The National Atlas of Korea* for the first time. Revisions of the atlas have been made to document and illustrate the rapid transformation of and changes to the land and the details of Korea's physical and human environments.

As a national record, *The National Atlas of Korea* is an official reference for defining and explaining Korea's territory and territorial water to the world. It is a valuable source of information for developing government policies for balanced national development, a necessary educational guide to promote an accurate understanding of the land, and a useful means of introducing dynamic changes and developments in Korea and Korean society to the world.

Reflecting a commitment to staying up-to-date and relevant, The National Geographic Information Institute presents *The National Atlas of Korea: Comprehensive Edition* as a useful educational resource for our adolescents to better understand their nation. I hope that *The National Atlas of Korea: Comprehensive Edition* becomes a valuable reference for our future generations to learn the value and importance of the nation. The National Geographic Information Institute pledges to continuously publish the most updated geographical information of Korea.

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Core Skills: Interpreting and Understanding Maps

Introduction – All Maps Are Not Created Equal

The task of reading a map is similar to reading a book or an essay in the sense that book readers should generally keep an open mind during the reading process and be ready to accept concepts and ideas presented by the author while maintaining a healthy skepticism of what is being written so that questions can be raised or an idea rejected if the reader does not agree with the author. Map reading should follow the same path. However, there is a fundamental difference between reading a book and reading a map. A book uses words, sentences, and paragraphs in a well-structured sequence to convey information and ideas of the central theme of the book. A map uses graphics and symbols on a surface (paper or digital display) to simultaneously present a symphony of complex **spatial phenomena.** These phenomena imply spatial relationships between map components or the map elements. Reading a map is not sequential like reading a book; thus, each map reader may have a different set of strategies or sequences for viewing different parts of the map than another map reader. In so doing, they may come up with different visions, interpretations, and conclusions about the same map.

Many of us are too quick to accept the validity of a published map without questioning its truthfulness or accuracy. To this end, the Internet and any book or map publisher provide a common platform for maps created by both trained and untrained cartographers. A danger exists here when a teacher, or anyone, blindly accepts and adopts an erroneous map, published on the Internet or otherwise, for use in the classroom. Any mistake that may have been included in an erroneous map should not be passed on as fact to the students. Thus, it is important that teachers convey to students that all published maps are not necessarily accurate representations of the world.

The intent of this section is to systematically and clearly outline many of the fundamental concepts on how maps are created from the cartographer's perspective, and to provide some clues on how a reader should interpret and analyze them. All individual maps are different and there is no single magic formula that will clearly or definitively indicate "this map is wrong" or "that map is well constructed." Such evaluations will have to be entirely based on the specific content of the map itself, the integrity of the data used to construct it, and on how well it was designed and presented. Thus, all maps are not created equal. In this respect, the map is perhaps more subject to interpretation than a book would be. The very nature of the map itself is a complex matter as it represents a vast stretch of space and a large number of different spatial relationships. With this section, the authors attempt to briefly introduce the nature of the map in simple terms, and provide insight into the many decisions that a cartographer has to make. Specific examples shall be used to provide guidelines for teachers to consider when determining the pedagogic value of a particular map or group of maps. Since it is impossible to write about all cases and scenarios, this section is meant to invoke the student's and the teacher's spatial thinking skills. It is a task that is impossible to achieve without a thorough understanding of the nature of maps and the possible and embedded spatial information that a map can convey, however simple it may appear. The rest of this section shall be systematically organized by various topics to provide a synopsis of the very fundamental concepts about maps to assist readers in using this atlas.

Major Types of Maps

Various authors have categorized different types of maps in alternate ways. However, there are several distinct broad types of maps. Some may fall into more than one type in this classification. There may also be some maps that do not fit into these types. Nevertheless, each type is clearly distinguishable from another because of their properties and intended functions.

- Reference Maps – The primary function of reference maps is for locating specific places. Each reference map has at least one complete set of coordinate grids, including a geographic coordinate system such as latitude and longitude, or the Universal Transverse Mercator (UTM) grid system, or in the case of the United States, the State Plane Coordinate System. Latitudes, also called parallels, are lines drawn horizontally around the globe that are parallel to the Equator. They reduce in length as they approach the poles. For example, 90° N Latitude and 90° S Latitude are actually points instead of lines (the North and South Poles). Both Korea and the United States are situated north of the Equator and are therefore designated with North Latitudes. Australia, on the other hand, is situated south of the Equator and thus designated with South Latitudes. Longitudes, also called meridians, are lines drawn vertically on the globe and each one runs through both the North and South Poles. The Prime Meridian, or 0° Longitude, at the Greenwich Observatory just outside London, England was recognized as an international standard as a result of The International Meridian Conference held in Washington, D.C. in 1884. It sets a reference for all other longitudes, up to 180° East or West. Korea is situated to the east of the prime meridian and its location is therefore designated in East Longitudes; the United States, however, is situated to the west of the prime meridian and its location is therefore designated in West Longitudes. When a longitude runs through the North Pole and descends on the opposite side of the globe, it then constitutes a great circle. Great circles divide the globe into equal halves. The Equator is also a great circle because great circles do not have to pass through either Pole.

There are many other lesser known grid systems because almost every country in the world defines their own local reference system. Topographic maps are the most popular reference maps. All the maps in Chapter 5 of the National Atlas of Korea I (Choe, 2014) are reference maps. The degree of accuracy of reference maps is generally higher than most other kinds of maps because they are produced through photogrammetric, surveying, and GPS-based methods and are generally made at a larger scale than most other types of maps. Some of these reference maps are so accurate that civil engineers use them to assist in building roads, bridges, and other kinds of infrastructures. Of course, the scale at which these maps are made may also dictate the degree of accuracy. Some atlases can also be considered reference maps even though they may not be as accurate as topographic maps simply because they record as many place features complete with their names for reference purposes.

- Cadastral Maps – Cadastral maps are very large-scale maps generally created by local governments, particularly in the United States, to record ownership of land parcels. These are carefully surveyed maps made by

Photographs showing the physical Prime Meridian at the Greenwich Observatory. Here, husband and wife are geographically separated by the hemispheres. He is in the East, she is in the West.

professional surveyors that show great localized detail so that the boundaries of parcels can be clearly delineated and identified. In the past, paper parcel maps were kept primarily in county courthouses so that they were ready to be copied, used, and re-recorded because of the sale of properties. In many cases, cadastral maps are also used to determine the amount of tax that should be levied on a property because these maps show the size of each piece of property. Today, most counties in the United States have converted these paper maps into digital format so that they can be retrieved and updated easily.

• Route Maps – Route maps are those that are specifically created to guide us from one place to another. They provide us with clues to move about and reach our intended destinations. Since humans travel on land, on water, and in the air, these route maps include navigation or sailing charts, aeronautic charts, and the traditional folded paper maps that were kept in our cars for many decades. Today, with GPS technology, people often opt for the convenience of voice-guided GPS navigation maps and systems that are built into our cars' dashboards or delivered from our cell phones. They are very effective in guiding us through our routes. However, as accurately as GPS maps may perform, they are not 100% fool-proof. Roads, highways, and bridges continue to be constructed on our daily landscapes; the frequency with which GPS map databases are updated can dictate how well they work. In addition, a GPS referenced map can unfortunately be made based on an inaccurate map. Thus, it is always advisable to exercise some caution when using GPS maps and directions. It is important to learn to realize situations when you have been led to the wrong place by GPS instructions.

• Thematic Maps – Thematic maps are maps with specially selected topics. These may be poor in reference information, but are to illustrate a particular theme to highlight a particular event in a particular space at a specific time. A map depicting population density (or any special topic or theme) is considered a thematic map. If there is a way to collect data or information about a topic that can be represented spatially, a thematic map can be created. Some of the largest government agencies specialize in producing large volumes of thematic maps. The census bureaus and statistical agencies are often the largest departments in nations. While statistics provide large amounts of information in tabular or spreadsheet format, thematic maps have the distinctive advantage of showing spatial patterns that allow us to quickly visualize concentrations and sparseness. Thematic maps can also be non-statistical; for instance, an urban land use-themed map may depict areas of land in an urban setting, defining the zones of commercial and retail land, single-family housing, multi-family housing, transportation corridors, institutional land (schools, colleges, hospitals, prisons, etc.), recreational land, and so on. Yet, none of these land classification categories are statistical. Because of the great usefulness of thematic maps in geography and the magnitude and variety of property details that can go into thematic maps, a continued explanation of thematic maps in greater detail continues below. • PhotoMaps –Phillip Muehrcke, in his book titled Map Use (Muehrcke, 1978, 1st edition), first labeled this group of maps as PhotoMaps. In later editions, the term "Image Maps" is used. Regardless of nomenclature, these are meant to include all non-line-drawn maps or non-line-art maps such as aerial photographs, satellite images, radar images, thermal images, and other realistic images of the land. Since then, the sophistication of these images has increased so much that most mapping scientists and the general public would treat image maps as maps. The most popular form of this class of maps is Google Earth. They show no statistics and are mostly devoid of line drawings, containing only the actual image of the land sensed from above at whatever resolution afforded by the sensing instruments. Interpretation of these images requires a totally different kind of training than the interpretation of reference maps or thematic maps.

• Animated and Interactive Maps – The availability of advanced computer graphics and Geographic Information Systems (GIS) software allows the cartographer to create dynamic maps that include animations and interactive learning activities. Some of these are even created in real-time, virtual reality, and in three-dimensions with rotational views. They may even be linked to remote video cameras. Animated maps have been appropriately applied to spatial phenomena that occur over time as well as phenomena that move from one space to another. The use of multimedia to illustrate maps can be very effective. These maps have been used in secondary education to some extent and their use continues to be encouraged. The fact that these maps can be delivered to our tablets and cell phones makes them some of the most versatile spatial education tools.

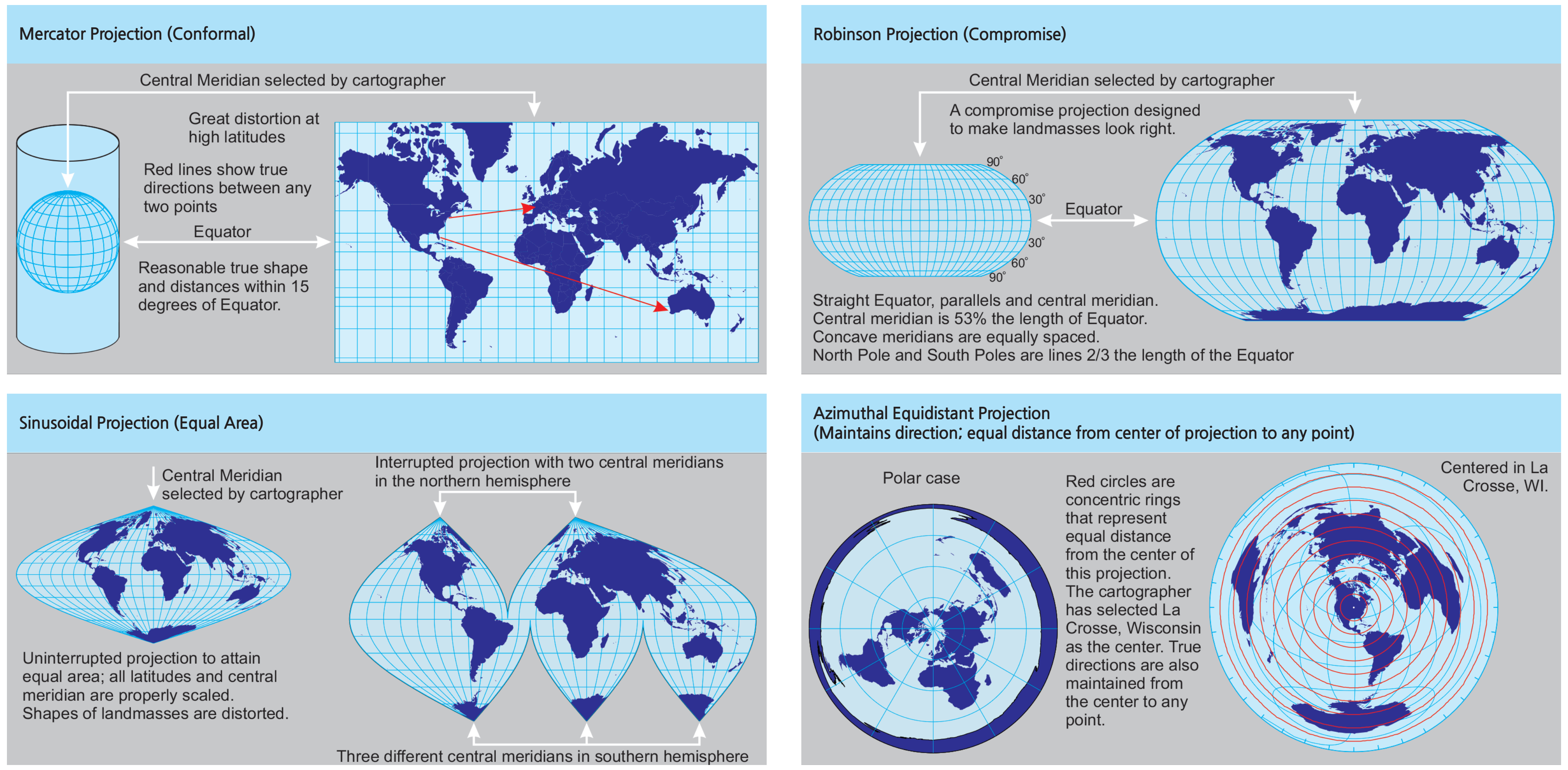
• Other Specialty Maps – In addition to the major types of maps above, there are certainly other forms of maps that are quite specialized. It would be difficult to list all specialty maps since innovations continue to appear on the scene regularly. Researchers have identified several broad groups of specialty maps that are worth mentioning here: tactual or tactile maps, mental maps, and cartograms. Tactual or tactile maps are those made especially for people with visual difficulties. Mental maps are maps or images of places in our minds based on our experience of having seen the place before or based on the ability of our minds to conceptualize the space that can be described to us. A Cartogram is a map type that distorts geographic space by sizing each geographic unit to show a special concentration of that particular set of data; for instance, on a population cartogram of the world, China would be the largest because it has the largest population and India would be second largest even though Russia is the largest in area.

The Earth Is Not (Perfectly) Round

In order to have maps made accurately, cartographers need to know the exact shape of the earth. The axis between the North Pole and the South Pole is shorter than the axis between opposites ends of the Equator. No single mathematical formula can describe the shape of the earth because of the discrepancy between axes (due to the earth not being perfectly round) and because of the unique surface of the earth with uneven distribution and elevation of landmasses and oceans. Alexander Ross Clarke (1828-1914), a British geodesist (a scientist who makes precise locational measurements of the surface of the earth) made measurements of the earth from many different locations around the world. His measurements were mathematically documented with a set of complex formulae and would become the foundation of The Clarke Spheroid of 1866 (a spheroid is a unique description of an imperfect sphere). The Clarke Spheroid became a very important set of mathematical descriptions of the shape of the earth for international cartographers and scientists to use. It was adopted by the U.S. Geological Survey as the basis for the 1927 North American Datum (NAD27) as a standard for producing U.S. topographic maps. In the case of the mapping sciences, the word "datum" is used to refer to a set of base information carefully measured and documented. This set of base information is used as a standard for measuring associated land. The 1927 North American Datum was the standard by which all land in the United States was referenced between 1927 and 1983. It consisted of a horizontal datum and a vertical datum. The horizontal datum began with an east-west stretch of flat land and a north-south stretch of flat land at Meade's Ranch in Kansas, roughly the geographic center of the continental United States. Careful triangulations of these stretches of land were recorded. All land measurements in the continental U.S. are referenced to these triangulation results at Meade's Ranch. The vertical datum was derived from over 35 years of measurements of variations in sea level to find the Mean Sea Level (MSL). The MSL then became the basis for measuring all elevations in the United States.

Since the U.S. military's 1983 declassification of Global Positioning Satellites (GPS) for the purpose of civilian use, geodesy (the science of precisely locating point positions on the surface of the earth) has greatly increased in accuracy over the 1927 North American Datum. The surface of the earth can now be "remapped" based on GPS methods. Thus, new datums are constantly evolving. In 1983, the World Geodetic Survey (WGS) started to use the WGS83 Datum, followed immediately by the WGS84 Datum. Subsequently, more datums were created, some to meet an individual country's specific needs, others to define specific coordinate grid systems. Nevertheless, all these datums are mathematically documented so that transforming from one datum to another can be calculated. These calculations are

Examples of some commonly used projections



normally embedded in GIS software and such calculations can be performed with a few strokes or clicks on the mouse. To learn more about datums, coordinate systems, and GPS, please read Chapters 1, 4, and 14 of Map Use (Kimerling 2016).

Now that the measurement of the land surface has been accomplished, another problem needs to be addressed. Remember that a map is a transformation from the real, (not perfectly) round, three-dimensional world onto a two-dimensional flat piece of paper or digital display surface. This transformation cannot occur without geometric error. This is where the understanding of map projections is important. Map projections make use of a network of coordinate systems or grids (the most popular one being The Geographic Coordinate System, which uses latitudes and longitudes) such that "casting" or "projecting" this network of grids onto a flat surface may allow us to document the amount of distortion introduced in every map projection transformation. Depending on the method used to cast latitude and longitude onto a flat surface, every resulting projection cannot accurately maintain both size and shape properties of the landmasses simultaneously. One or the other or both properties must be sacrificed. For this reason, there are equal-area map projections which maintain the truthfulness of area measurements at the expense of distorting the shape of landmasses. There are also conformal map projections that maintain the shape of the landmasses at the expense of distorting the truthfulness of area sizes. A compromise or conformal map projection (by far the largest category) may sacrifice both area and shape properties to a lesser degree in order to present a more "realistic look" of the world's landmasses. Most map projections which centered on the North and South Poles can maintain true directions. To learn more about map projections, please read Chapter 3 of Map Use (Kimerling 2016).

Map Scale

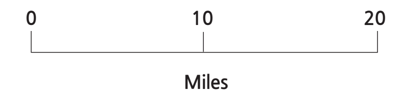
The scale of a map is critical to the map reader as it may imply how accurate a map can be and how much spatial information can be effectively presented on that map. There has been some confusion about the terminologies that relate to map scale. This section is an attempt to clarify all this confusion.

Since a map drawn on a piece of paper cannot have a one-to-one size relationship with the land, the map is thus a one-to-many size relationship with the real world that it represents. In other words, one unit of measurement on the map is designated to represent many of the same units of in the real world. Thus, the map scale is actually a mathematical ratio. Map scale can be expressed in three ways:

• As a Representative Fraction or a ratio: e.g. 1: 10,000. This expression means that, for example, one inch on the map represents 10,000 inches on the ground. Notice that there is no unit of measurement on a ratio. Because scale expression is a ratio or a fraction, it will work with all units of measurement; therefore, it also works for metric measurements, such as one centimeter on the map represents 10,000 centimeters on the ground. The units of measurement on both sides of the ratio, however, must remain the same.

• As a Verbal Statement: e.g. One inch on the map represents one mile. Notice that units of measurements are different (inch and mile) from a representative fraction. This is perfectly acceptable; but the map reader has to recognize these non-matching units. If a map reader measures the distance of a journey taken from home to work to be 2.5 inches on the map, then it can be deduced that the real-world distance between home and work is 2.5 miles. Verbal statement scales can certainly be converted back into ratios. In this case, it is necessary to find out how many inches there are in one mile since a representative fraction or ratio requires that the units be the same on both sides of the ratio. There are 1760 yards in one mile, 3 feet in one yard, and 12 inches in one foot. From these, we can multiply 1760 by 3 by 12 to derive the number of inches. The result is 63,360. Therefore, the verbal statement of "one inch represents one mile" is the same as 1:63,360. Remember that once it becomes a ratio, it will work for all other units of measurement, even in the metric system. Thus, it is also truthful to say that one centimeter on the map represents 63,360 centimeters on the ground.

• As a Graphic or Bar Scale: See the following example:



This graphic scale provides the map reader the opportunity to physically measure a distance on the map and line it up against this graphic scale to read off the real-world distance. Straight line distances can be easily measured with a ruler. Curved line distances can be measured either with a piece of string to simulate the curves on a map or with the straight edge of a piece of paper by holding down at turning points of the curve with a pencil until the entire curved distance is "hugged" by the edge of the paper. Once the curved map distance is simulated on the string or the edge of a piece of paper, they can be lined up parallel to the graphic or bar scale to read off the real-world distance.

There are some misconceptions or confusion about the terms large scale and small scale. Large-scale maps refer to those that cover a small area of land and showing a great deal of local detail. An example would be a cadastral map. Small-scale maps, on the other hand, cover large areas of land and cannot include local details. An example would be a world map on a regular book page.

Since scales are fractions, it is possible to compare the fractions between large and small scales to determine which is a larger scale and which is a smaller scale. A typical large-scale cadastral map may have a scale of 1: 2,000 and a small-scale world map may have a scale of 1: 40,000,000. The fraction, 1/2,000 (0.0005) is a larger number than the fraction 1/40,000,000 (0.000000025). Therefore, the cadastral map has a larger scale than the world map.

The comparison of map scales is always relative. The scales that are in between large and small scales can be considered as intermediate scales. Again, intermediate scale is only a relative term, depending on whether it is compared to a large-scale map or small-scale map.

Obviously, small-scale maps are at a disadvantage on the matter of including or showing a lot of ground detail but at the same time have an advantage over large-scale maps because they provide a wider geographic picture of a much wider view of the landmasses. The opposite is true of large-scale maps, as they can provide a much greater amount of local detail at the disadvantage of being very limited in overall land coverage.

Today, with the advent of a very high volume of storage in computer servers with very high speed delivery, the very popular Google Maps incorporates several datasets in storage such that when a user zooms in to view an area in greater detail (theoretically changing from a smaller scale into a larger scale), the small-scale dataset is switched over to a larger-scale dataset. Upon zooming in further, it changes again into yet another larger-scale dataset. These operations are performed so smoothly and in real time that readers may not realize that there have been switches of the datasets. Next time when you use Google Maps, try to zoom in at different levels at the same time watching the changes in the scale bar and the amount of details being shown on the Google Maps and the changing size of the land coverage. Also notice that the more it is zoomed in, the higher the densities of place names that appear. To learn more about map scales, please read Chapter 2 of Map Use (Kimerling 2016).

The Map Making and Communication Processes

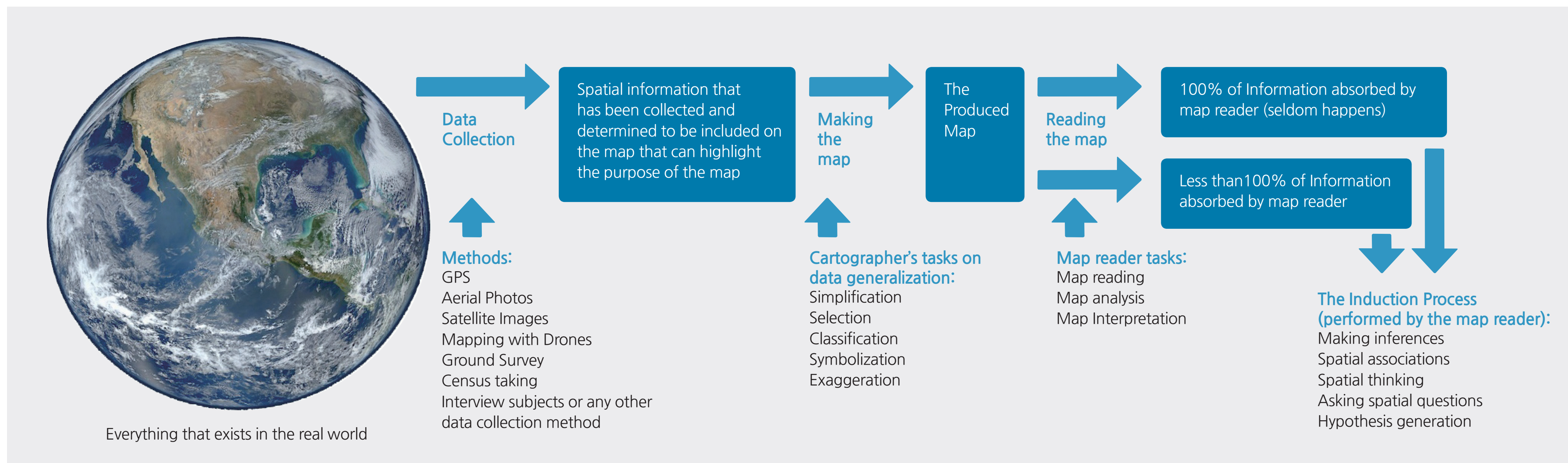
To summarize the entire map making process in just paragraphs is impossible. Communicating map information is also a complex process. This section is meant to provide a theoretical approach to the process of making maps and how map information is processed and communicated to the map reader and the role each stakeholder plays. A great deal of research was performed on these topics by research cartographers in the 1960s and 1970s; their communication models are still applicable today.

The ideal map is supposed to be a representation of everything that exists in the real world. But this is impossible simply because in order to do so, the map will have to be almost as big as the real world. By representing the real world in a reduced scale, certain amounts of information must be left out. The following diagram is an attempt to synthesize the major cartographic processes and map reading processes that take place.

To make a map, a cartographer must first define some parameters. The first map-making step is to define the purpose of the map. Once this is done, the next step is to gather or collect information or data about what we wish to map at an appropriate scale. Are there existing data available from government agencies? If no data are available, how difficult is it to specifically gather the relevant data for the map? The general methods of data collection include recording GPS locational data, using aerial photography and satellite images, using drones for low altitude mapping, conducting ground surveys, taking a census, interviewing subjects, or any other data collection method that involves a geographical component.

Once data have been gathered, there is a set domain of information that is ready for the mapping process. At this point, the cartographer needs to make several important decisions. The amount of data collected can be massive or inadequate. For massive datasets, the main question to consider is whether the scale and other parameters of the map can accommodate such a large amount of data. If not, the data must be generalized. For inadequate datasets, the concern here is whether the limited amount of information can truly represent a spatial phenomenon meaningfully. Would there still be uncertainties in the dataset that may affect the mapping processes? Is the source of the data reliable? These are just some important decisions for the cartographer to make because they can ultimately affect the quality and integrity of the map. There are still many other decisions, but it is apparent that the map making process is very complicated.

A functional map-making and map information communication model



Would the average map reader be able to spot these data quality questions? Generally speaking, spatial data collected by government agencies tend to be meticulous and truthful, but still not without errors. Data collected by researchers may have to depend on the researchers' efforts, their funding, and other parameters. The number of data points collected may indicate the quality of the dataset. The U.S. Bureau of the Census and equivalent census bureaus or central statistical offices of other governments tend to acquire complete information on their complete respective populations. Surveys of other topics may only be based on sampling methods rather than a complete survey: for example, taking a 10% or 20% sample of the entire population and extrapolating (taking a small amount of data and projecting them or making inferences proportionally to represent the entire population) these samples to represent 100%. Unless the map legend specifically indicates how a dataset was derived, the map reader generally may not know. Today, in an environment of digital reality and digital piracy, the act of data mining (taking someone else's dataset —with or without permission—to incorporate into one's own dataset) can be a tricky, if not dangerous, maneuver, however common.

It is clear that the cartographer bears a great deal of responsibility to make careful selections of data that are available for the mapping process. Selecting the proper data may also mean that some less relevant data may be purposely omitted. Data must also be classified into meaningful categories so that they will become manageable or can be presented in an easily comprehensible way.

Datasets can also be complicated. Depending on whether the intended scale of the map can accommodate the presentation of all available data, map data normally must be generalized and simplified. For instance, many maps may only show major roads in an urban setting to provide an adequate vision of the layout of the urban area. That does not mean that other smaller roads, streets, or cul-de-sacs are not present; these smaller and less important features have been simplified so that they will not visually clutter the map and subsequently interfere with the map reader's visualization process. Generalization of map data can be performed in many different ways. The map reader has to be aware that generalization is a common occurrence on maps. The degree of generalization dictates the accuracy of the spatial phenomenon being displayed, as intended by the cartographer.

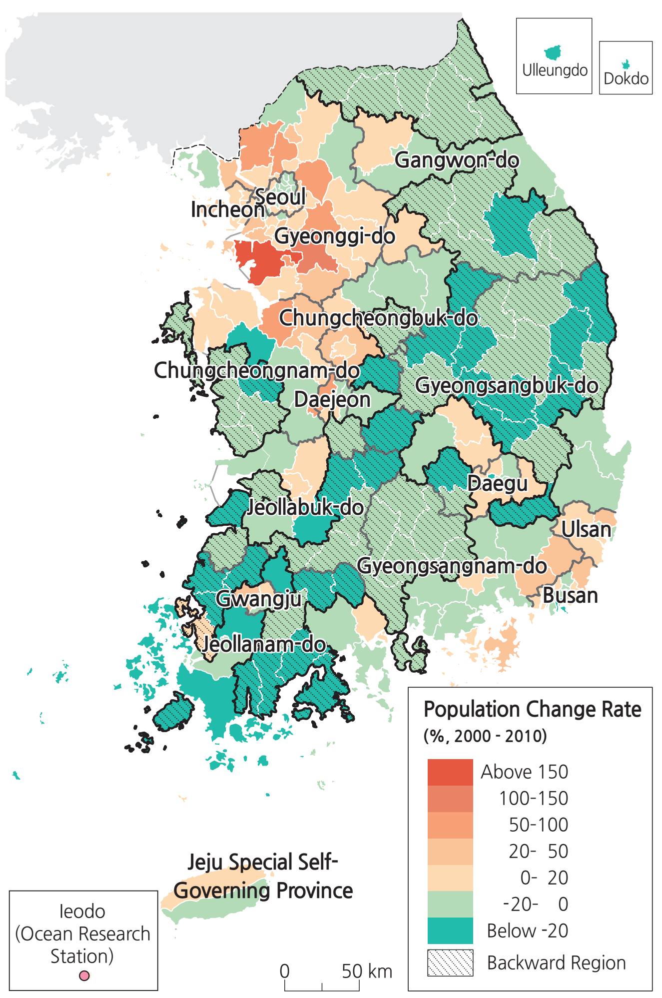
Finally, all map information must be symbolized into graphic forms that can be displayed on the map. The application of the proper map symbols would also contribute to the ease of visualization by the map reader. Some symbols are more intuitively interpreted than others. Other symbols are so small that if truly mapped to scale, the cartographer will exercise some judgment in exaggerating the size of the symbol so that it can at least be visible to the map reader. Using the wrong symbol or visually non-conspicuous symbols will lead to the wrong mental image of the map as interpreted by the map reader.

Thus, the cartographer is really entrusted with the generalization processes in the simplification, selection, classification, symbolization, and exaggeration of map data or information before the final map can be properly designed with the optimal graphic settings and produced to achieve its intended purpose. Once the map is finalized and produced, it is ready to be disseminated, whether by being published in sheet, book, or atlas formats or digitally for display and analysis on the Internet or any other display screens.

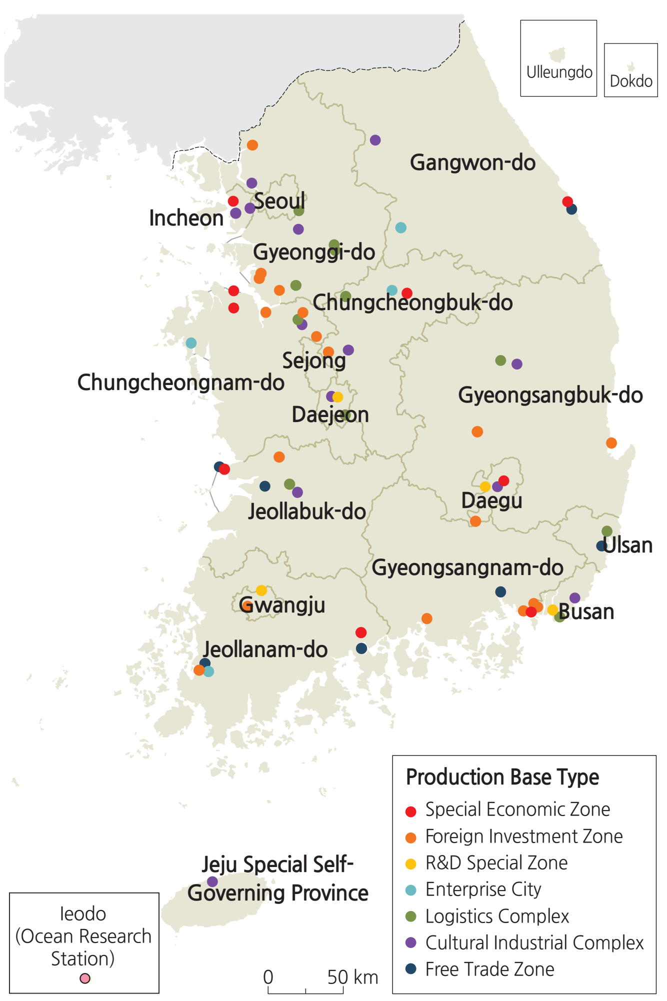
Realistically, the cartographer is seldom available for consultation by the map reader. The only communication channel that links the conceptual framework and purpose of the map to the map reader's understanding of the map elements is the set of symbols, legend, title, and any other peripheral information that are skillfully designed and displayed on the map. The legend is especially important to the translation of the mapped information to a mental image. It would then be up to the map reader's sole efforts to visualize, analyze, and interpret the map that determines ultimately how much of the cartographer's intended map message is to be absorbed and understood by the map reader. Different map readers have varying ability in conducting these map-reading tasks. Today, with the interactive nature of the Internet, maps published on the Internet may finally provide a blogging mechanism for map readers to ask the map publisher questions and to provide feedback to the cartographer. To learn more about the selection, classification, generalization, and symbolization of map data, please read Chapter 10 of Map Use (Kimerling, 8th edition).

To lead the map reader to understand the intent of a map is an ultimate goal of the cartographer. However, there is an additional higher level intellectual process that a map reader can perform: making inductions and inferences from the elements presented on the map. To make an induction or inference is to mentally relate one thing to another, one spatial entity to another, or one spatial entity to the same spatial entity on a different map (in the case of an atlas) or for different time frames. These can be performed by techniques such as thinking spatially, making spatial associations, visualizing the area mapped, and deriving new spatial knowledge from the map. Two seemingly unrelated maps from the National Atlas of Korea I (p.82 and p.93) illustrate this idea of spatial association.

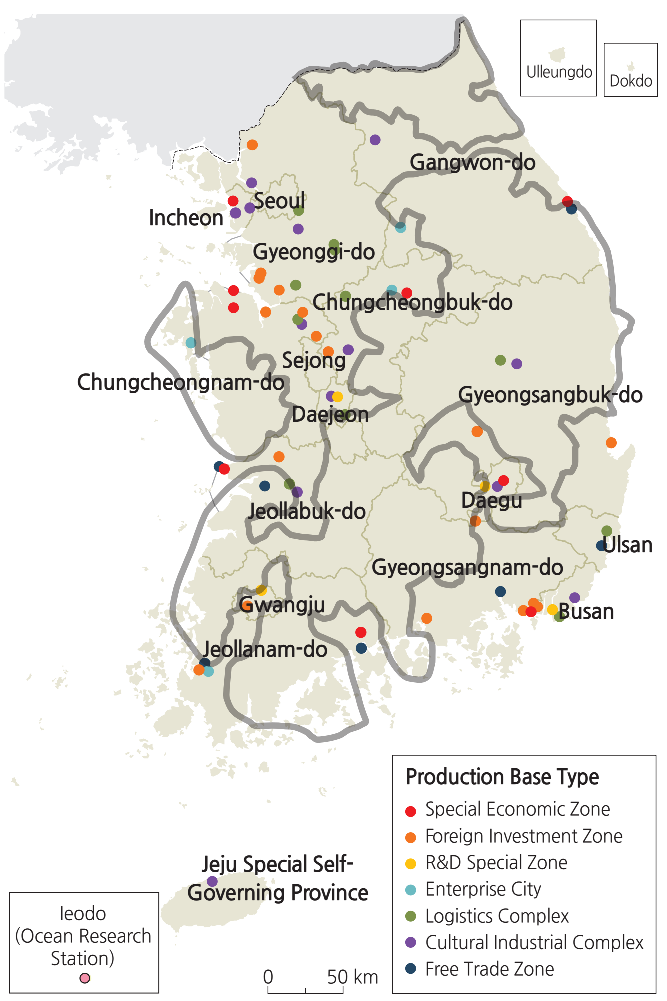
Annual Average Population Change and Backward Region



New Industrial Production Bases



New Industrial Production Bases with Backward Region Boundary Superimposed



The map on the left appears on Page 82 of the National Atlas of Korea I with the title "Annual Average Population Change and Backward Region." The map in the middle appears on Page 93 of the same Atlas, with the title "New Industrial Production Bases." From reading the titles, these two maps appear to be totally unrelated. The map on the right illustrates the technique of spatial association (taking one spatial entity and associating it with other spatial phenomena). Taking the "Backward Region" boundary from the map on the left and superimposing it over the map in the middle results in the map on the right. Thus, using the spatial entity (Backward Region) from one map and associating it with spatial phenomena on another map quickly indicates that there are only four dot locations which are defined as "new industrial production bases." The majority of the dots lie outside the "Backward Region." With this spatial association, a map reader can immediately raise some questions: Why are there so few industrial bases (only 4) in the Backward Region? Did the loss of population in the Backward Region contribute to undesirable conditions for the government planner to place new industrial bases in this region? What geographic factors contribute to the loss of population and less than ideal conditions to develop industrial bases? The list of intellectual questions can be many. Could there be answers to these questions? Could these answers lead to a better understanding of the conditions in the region? More research needs to be done, but at least curiosity has been piqued, which is a major element of all map reading.

Raising these questions typifies the process of spatial thinking. In addition to raising these questions, the next step in a scientific inquiry is to generate a hypothesis. Hypotheses that can be generated and proven will inherently add to a knowledge base. Increasing the number of spatial thinking activities performed will enhance the chances of discovering possible hypotheses.

The Nature of Map Data

As can be imagined, not all map data are created equal. In order to evaluate the accuracy of a map, it is helpful to have a better understanding of the nature of map data. Map data can be classified by several different categories that have very different real and visual characters, as follows:

• By dimensions: point data has no dimension, but each point occupies a location; line data are considered one-dimensional; area data are two-dimensional; volumetric data are three-dimensional; volumetric data through time can be considered four-dimensional.

• By time-frame (or temporality): temporal data are considered historic or something that happened in an instant in the past, and they can be dated or out-dated; real-time data (such as continuous satellite scans of the earth) are as current as can be. When a map is made, it is important for the cartographer to provide a clue as to when the data were captured and then mapped (either in the map title or in the map legend).

• By spatial aspects: spatial data or geographic data specifically define the location of data points (e.g., GPS locations, latitude and longitude descriptions); non-spatial data include attribute data or thematic data about a geographic feature (e.g., all the wells in La Crosse County, Wisconsin can be located as spatial data, while the degree of contamination of the water taken from each well is a set of thematic data). By putting locations with water contamination data, a map can be made of the overall spatial pattern of contaminated water for the whole county.

• By continuity: data can be discrete (countable in whole numbers), such as one house, two houses. Data can also be continuous, such as with time or population density. For example, the number of persons divided by the area of a geographic entity might be 356.23451083 persons per square mile; notice that this particular number is carried out to 8 digits beyond the decimal. Chances are it can be more than 8 digits; however, in the map legend, it is normally rounded off as 356 or placed in a category of 300-400 persons per square mile. Regardless, such a number is still continuous data.

• By numerical aspects: quantitative data refer to actual numbers in a dataset (e.g., a population density map is a quantitative map showing higher and lower densities). Qualitative data refer to things that are not described numerically (e.g., a geologic map is considered a qualitative map because it shows all different types of geology without the use of numbers). Other qualitative map examples are planning maps (where to locate dams, transportation routes, electricity generating plants, etc.; an example is the National Territorial Planning Map on p. 77 of the National Atlas of Korea I).

• By appearance: Concrete data refer to things that can be seen and directly enumerated, such as an urban land use setting that delineates which parts of the city are devoted to greenways or commerce or residential or industrial land use—all of which are easily observable objects. Abstract data are things that one cannot generally see, such as population density or barometric pressure patterns. These things may have to be calculated or measured with instruments.

• By origin: observed data refer to data that are enumerated or collected by field methods or with the use of instruments. Derived data are those that are calculated or computed, for example, taking the population of Greater New York City (available from the Census Bureau) and dividing it by the area of Greater New York City (based on ground surveys) results in derived data in the form of population density.

• By measurements: these refer to nominal data, ordinal data, interval data, and ratio data. Nominal data refers to named information like a house, a light house, or a dam, and so on; these data are qualitative and do not possess any rankings because they are individual geographic entities. Ordinal data refer to data that have a ranking but no specific numerical certainties. For example, with a map showing areas of low, medium, or high crime rates in a city, the reader may not know precisely what is considered low, medium, or high, or the thresholds of these categories. Other rank order examples are: hot-warm-cool-cold, or dense-medium-sparse. Interval data refers to assigned numeric data values but with no baseline for comparison. For example, water freezes at 32° F and boils at 212°F but at the same time it can be measured in Centigrade for the same coldness or hotness at 0°C for freezing or 100°C for boiling. There is no baseline for comparing the degree of coldness or hotness between Fahrenheit and Centigrade. Ratio data provide a baseline for comparison; the 1 on the left side of the ratio sets the standard for comparison; thus, a scale of 1:2,000 is definitely a larger scale than 1:10,000 because these are fractions for which 1 being divided by 2,000 results in 0.0005, a number that is larger than 0.0001, which is the result of dividing 1 by 10,000.

• By data structure: In digital mapping, there are two basic data structures, rasters and vectors. Rasters are generally referred to as a collection of pixels. Each pixel is one single graphic data point. Much like in digital photography, the higher the number of pixels, the better the resolution or data representation. Aerial photographs, satellite images, and some elevation data are in a raster data structure. Vectors are data that are defined in a coordinate system that have x- and y- values in a two-dimensional plane or with z-values in a three-dimensional structure. X-, y-, z- values can all be continuous and can be represented in infinitely small numbers (many digits after the decimal). Each data point has a specific location in the coordinate system. Two data points make up a line (or an arc in GIS terms) and a minimum of three data points make up an area (polygon). The vector data structure is very beneficial in a GIS because it allows GIS software to build a topology, a mathematic that computes the true and definable spatial relationship between data features. Topology is the fundamental part of an engine that drives the computerized spatial analysis and modeling routines in a GIS software program.

The raster-vector diagram illustrates the differences between raster and vector structures. While the raster structure is mainly used to represent satellite images and aerial photographs and does show some spatial relationship between features, the vector structure is a more efficient topological detector of spatial relationships. Imagine taking two points in a vector dataset; if a direction can be established between these points, it is then possible to identify certain relationships. From the vector diagram, assume that we take Point A as an origin (the "from-node" in GIS terminology) and Point E as a destination (the "to-node"), we can now calculate the distance and direction of travel from A to E. In addition, we can also describe Point K in relation to the direction of travel between A and E by acknowledging that K is to the right-hand side of the direction of travel. This simple routine is exactly how the U.S. Bureau of the Census can perform address-matching with its TIGER (Topologically Integrated Geographic Encoding Resources) software by identifying even or odd address numbers to the right or left. In the TIGER database, each street intersection is assigned a node, thus making it possible to pinpoint street addresses. By the same token, we can take any two points and join them as a line (or an arc in GIS terminology) or take any number of points and join them as an area (or a polygon in GIS terminology). In the raster-vector diagram, the shaded area ABCDEA is a closed area; thanks to the use of topology, we can definitively conclude that Point K is clearly contained in this area and Point J is clearly outside this area. If point, line, and area features can be located in space (based on a coordinate system), buffers can also be built to surround each feature. These buffers can be used to encompass other thematic features in a relational database. For example, TIGER can use the buffer to round up all the number of people who live within that specified buffer zone. If a river is determined to have a potential flooding of 100 feet from its banks, a linear buffer can be specified in a GIS to identify all the houses within the buffer that are prone to flooding. Thus, we can really see the benefits of performing spatial analysis and advanced spatial and statistical modeling using topological concepts. In addition, we can also add spatial layers to the GIS, thus providing us with a lot more flexibility and analytical power to perform spatial analysis across layers.

Map Accuracy and Map Errors

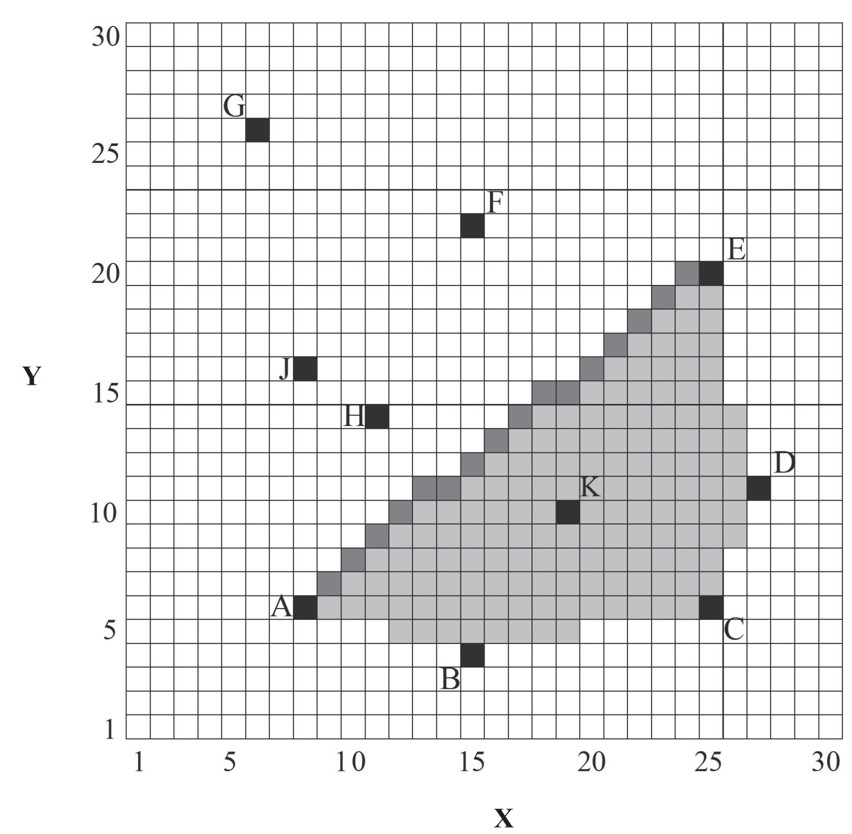
The term "map accuracy" must always be taken as a relative term because some maps are more accurate than others; they can also be more accurate in certain aspects and not in other aspects. Generally speaking, large-scale maps are expected to have a higher accuracy than small-scale maps. Making a map to be as accurate as its parameter dictates is of vital importance. Inaccurate and/or missing information on a map has actually led to transportation fatalities. Legal issues have always surrounded matters of map accuracies. It is impossible to make a general or overall checklist of everything about accuracy or inaccuracy. Nevertheless, map inaccuracies can be so difficult to detect but have real consequences.

Map accuracy is governed by several factors. Maps produced by national geodetic surveys such as the U.S. Geological Survey or Korea's National Geographic Information Institute tend to be very accurate because they use state-of-the-art instruments to produce reference maps. Databases created by such government agencies can also be used for other purposes. The U.S. Bureau of the Census combines its census-taking techniques with U.S.G.S. geographic databases to form one of the most sophisticated non-military mapping systems in the world.

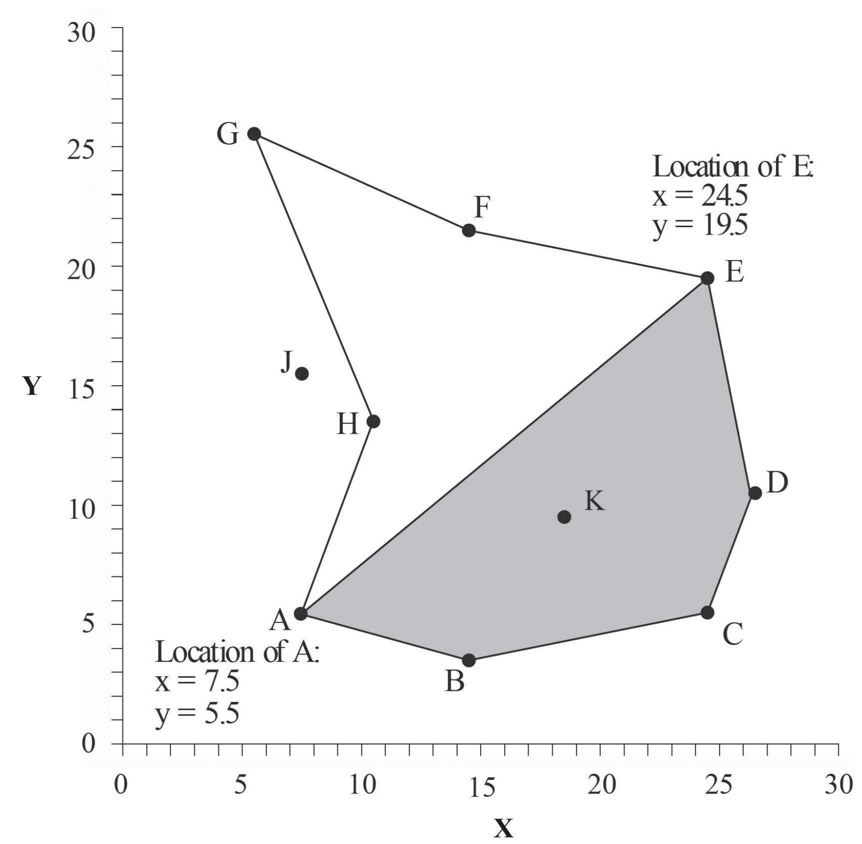
The accuracy of thematic maps, however, may depend on several other factors, such as the data collection methods, data portrayal methods, and size of mapping units. Variations in these factors may not contribute to errors, but they definitely affect the level of accuracy. The section on thematic maps below shall include more detailed discussions on matters of accuracy specifically relating to thematic maps.

Theoretically, there are always errors on maps. The mere transformation of the three-dimensional earth on to a two-dimensional piece of paper or digital display screen inherently introduces map error. The degree of error for such a transformation depends on the map scale, size of the area of coverage that was transformed, and many other factors. In addition, the mapping process requires such procedures as selection of data, generalization schemes, and other maneuvers by the cartographer. These are also sources

Raster data structure



Vector data structure



of introducing error on to maps. It is up to the map maker as well as the map reader to educate themselves about where and how map errors can occur. Once again, this is a topic on which it is impossible to provide all scenarios. This section is intended to provide only some of the more common examples of map errors in the map-making/map communication processes. For example:

• Temporal error: Using or reading a map that is out-dated; a lot of changes could have taken place during an elapsed time period.

• Scale error: using an inappropriate scale for the purpose of the map.

• Displacement error: using a symbol that is too large for the area being covered.

• Symbol placement error: a map symbol being placed in the wrong part of the map.

• Distance displacement error: a topographic map distance is orthogonal (a flat plane as its base, also technically referred to planimetric) while its contours indicate elevation. Traveling from one point to another across contour lines is really traveling up- or down-hill, which has a greater actual distance than the orthogonal or planimetric distance that most people measure from the topographic map. The Pythagorean Theorem should be used to compute the hypotenuse distance caused by height over planimetric distance.

• Factual and data input errors: entering the wrong data or information on a map.

• Instrumentation error: entering data from malfunctioning instruments.

• Data computation error: using the wrong computation methods to derive data.

• Line generalization error: a computerized line generalization routine (such as smoothing) can lead to unintended errors (such as changing the topology of features). There is a fine line between generalization and over-generalization of data.

• Data selection error: selecting the wrong data points or omitting relevant ones can affect the outcome of the map patterns.

• Resolution change errors: Reducing the resolution of a raster structure can lead to merging of the pixels that can result in data representation error.

• Modeling error: many of today's maps are based on computer and statistical modeling methods. In modeling a statistical surface (a land surface or a spatial surface filled with continuous statistical data), many modeling methods such as Kriging, Spline, Polynomial, Inverse Distance to the Power, Shepard's Method, Nearest Neighborhood (and more) can be applied. Each method has its own unique mathematical formula to perform modeling of the data; each will yield a different result, but some are more appropriate than others. While a viewer may see a television weather broadcast map of wind patterns, these patterns have been "modeled" in the most appropriate modeling methods by the meteorologists. Much of the time, these generated weather maps are quite accurate, but they also have been known to be wrong or distorted on rare occasions.

• Perceptual error: reading off the wrong symbols or map legend clues from the map, or misinterpreting the title and purpose of the map. Just like reading a book, extracting information from a map has to be a careful process.

Obviously, this list is non-exhaustive and there are many more types of map errors. The map reader must exercise some caution and alertness in reading maps and develop at least a sense, if not a variety of techniques, to detect map errors so that a full and overall meaning and intended function of the map can be realized.

Thematic Maps and Their Interpretation

Like many other atlases, this *National Atlas of Korea: Comprehensive Edition* is mostly filled with thematic maps. As defined above, a thematic map is one that focuses on a theme; this can be a population map, a land use map, a natural resources map, or any other theme that renders geographic information. Thematic maps are created because they can tell a great deal about the spatial distribution of important social, economic, demographic, environmental, and political characteristics about an area or a nation. Visualizing the concentration or sparseness of hot spots of a thematic pattern will assist policy makers to make better decisions about these places. Thematic maps can be great decision-making tools.

The number of topics that can be mapped is unlimited so long as data are available. This is why they are so popular. With the available software programs today, it is very easy to create thematic maps, often by pressing a few buttons or with a few clicks of the mouse. However, making a good and meaningful thematic map is also a complicated process. This section is an introduction to the different kinds of thematic maps as well as an attempt to demonstrate the extensive methods and the complexities of creating thematic maps and the equally complex circumstances in their interpretation. The two principal types of thematic maps can be categorized as qualitative and quantitative.

With the current emphasis on technology and learning how to use GIS to make thematic maps in secondary school level geographic education, there are several often neglected or forgotten and yet simple questions that need to be asked in order to promote spatial understanding.

• For what reason or purpose do we make a particular map?

• How well does a map convey its geographic meaning?

• How well does a student understand the intended message of the map?

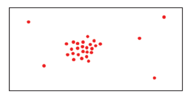
• What is the proficiency or ability of a student's interpretation of a map given that there are so many kinds of maps and so many ways a cartographer can make it?

• How great is the effort on the part of the teacher to teach map reading, analysis, and interpretation?

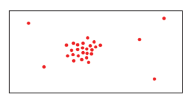
Obviously, there is no simple answer to any of these questions or others that have not been specifically raised here yet. But these questions do relate to spatial thinking and spatial understanding. Map interpretation is unquestionably a key issue for the improvement of geographic education.

Since each map is unique, so is its interpretation. Some of the common, unwritten rules relate to the analysis of the logic between title, legend, scale, data, mapping method, and visual presentation. Experienced cartographers and map designers manage a symphony of all these components in the creation of a map. As a map reader, adding some common sense is almost a requirement, but the greatest asset a map reader can have is a general, or even specific, knowledge of the geography of the place being mapped. Applying the element of geographic knowledge as an aid to map interpretation can be very helpful. Several examples are provided below to illustrate this connection.

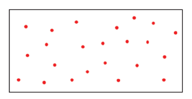
Recognition of Spatial Attributes and Patterns: Geographic or spatial patterns provide clues to the interpretation of maps. Many real-world phenomena exhibit specific patterns that can be readily identifiable on maps. Few features in nature have straight lines or sharp corners; such occurrences are clues that these features are artificial. Railroads are always in straight lines or in gentle smooth curves rather than sharp curves or in angular turns simply because trains do not run through sharp curves. Based on our knowledge of how certain things are distributed, we can summarize some of the workings of many spatial patterns. The following are typical examples.



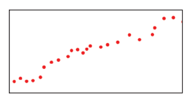
A Clustered distribution - Typical of a rural community surrounded by farmland, such as a traditional European spatial arrangement.



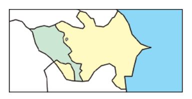
An Isolated distribution - Outside of the central cluster, there are five isolated entities. Spatial isolation suggests greater distance to travel for necessities, less efficient communication, less active community participation affairs, and greater operational costs.



A Scattered or Randomly Distributed Pattern - Typical of an area with extensive farming practice where individual farm owners are spaced apart, as is the case in the U.S. Great Plains.

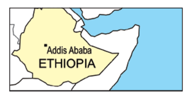


A Linear Pattern normally signifies human activities along a road or a river. Land area that is away from the narrow band of linear pattern suggests harsh environments or no incentive or the need for development.

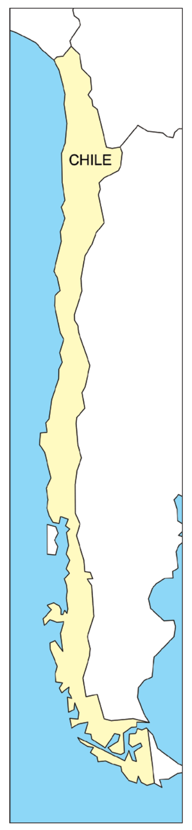


Exclaves - Yellow is Azerbaijan with a large exclave in Armenia (green) while Armenia also has exclaves in Azerbaijan. Several other exclaves from both countries are too small to show at this map scale.

Enclaves - Two countries, Swaziland and Lesotho, are enclaves embedded inside the country of South Africa. Such a spatial pattern suggests confinement, added logistics for crossing borders, and tariff assessments. Political tensions or accessibility problems may also occur.



Compactness refers to the shape of an area being compact without branched out areas such that distances from the center to its perimeter or border are all approximately the same. The perfect compact shape is obviously the circle, but in the real world, no perfectly circular country exists. Ethiopia is considered very compact with only one protrusion into the East. Other examples of a compact country are Poland, Romania, and Uruguay.

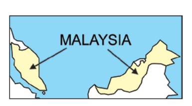


Elongated - Chile has a very long, elongated shape that is caused by the orientation of the Andes Mountains of South America. There is a narrow coastal plain but then the topography rises towards the Andean ridgeline. An elongated shape normally suggests great travel distances between one end of the country and another.

Contiguity is another spatial attribute that refers to one area or country touching or sharing a common border with other areas or countries. In the case of Ethiopia, we can say that it is contiguous to Eritrea, Djibouti, Somalia, Kenya, South Sudan, and Sudan. Contiguity may suggest easy trade with neighboring countries or conflict between them. Short contiguous borders suggest easy control, such as those between British Gibraltar and Spain or China and Macau. Borders may also be impenetrable due to rugged topography.

Land locks. A country is said to be landlocked if it has no access to the sea. Ethiopia again is an example. There are many others, Afghanistan, Chad, Bolivia, Hungary, and Mongolia to name a few. These countries are economically disadvantaged because they do not have access to ocean shipping facilities to assist in their economies. Other small landlocked countries such as Liechtenstein and Luxembourg turn to finance, high tech, and service industries that require digital communications rather than access to the sea for shipping-related businesses.

Widely Scattered - There are 17,000 islands in Indonesia scattered around the Sunda Sea and other Seas. Such a scattered pattern suggests governing and accessing all the islands is an expensive logistical nightmare.



Separation - Two major parts of separated landmasses make up Malaysia. Separation may lead to differences in the country's developments, resources, or environmental settings and concerns.

Obviously, not all possible spatial patterns can be presented here; training oneself to carefully observe what the pattern implies will undoubtedly help in spatial reasoning. In addition to spatial patterns, the matter of temporality should also be considered. Understanding a time frame's effect on spatial arrangement can also be critical in map reading. For example, a zigzagging road with hairpin turns normally implies a steep grade that goes up a mountain; while seemingly a good access to the mountain top, the time of year may play a factor as snow may make it impassible. The same can happen with intermittent streams during alternating dry and rainy seasons. Nevertheless, using common sense in addition to spatial thinking skills will enhance map reading and interpretation success.

Qualitative thematic maps: These maps show the locations and spatial distributions of specific geographic features. Examples are planning maps, geologic maps, soils maps, transportation network maps, distribution of flora and fauna species, and so on. They are not quantitative in nature and are not meant to have a rank order of all features that are mapped. They can be very effective in showing concentrations or dispersions of a particular feature.

Interpreting qualitative maps appears to be a simple and straightforward process since no numerical data are involved. For each qualitative map, the map legend and its definition of symbols play the most important role. Matching any map symbol to the legend should always reveal what that symbol represents. But the map interpretation process goes beyond the ability to identify which symbol represents what. The map reader should visualize all members of the same symbol that appear on the map. The Distribution of Endangered Plants map is a good example of a qualitative map. Various symbols depict different endangered species on this map; the green square symbol represents Anconitum coreanum, commonly known as Korean monk's hood. Spatial questions can easily be raised about the location of Korean monk's hood. That leads to inquiry which subsequently may lead to possible answers. Is the distribution of Korean monk's hood showing a distinct pattern such as linear, scattered, clustered, or skewed in one direction and not another? A map reader can easily identify them on this map and come to the conclusion that they are somewhat clustered in remote high mountain places. The power of spatial reasoning is what leads to further understanding of the geography of the land.

Quantitative thematic maps: Quantitative thematic maps are based on the concept of treating the surface of the earth as having statistical data points, or a statistical surface. All point locations on the surface of the earth can be described (or located) by latitude and longitude (x and y values in a two-dimensional coordinate system). It is also true that any point location on land that is above sea level has an elevation; the elevation of a point is considered as the third dimension or designated as a z-value. Besides elevations, there are many other data that can be mapped with z-values, such as amount of rainfall as measured by the locations of rain gauges. If there are instruments to measure carbon dioxide concentrations, one can literally collect data points of carbon dioxide concentration at every street intersection in a city and they will create a statistical surface of carbon dioxide for that city. Thus, we can proceed to map a pattern of carbon dioxide concentrations for that city by using modeling methods. Statistical surfaces are as wide as all the instruments that take measurements of any attribute, or censuses and surveys conducted over an area. Thus, quantitative thematic maps are as wide as our data collection techniques allow for gathering spatial information.

The discussions of quantitative thematic maps begin with the least common and least used mapping method called "dasymetric maps," followed by a common method called "isarithmic maps," and then by a widely used method of "dot maps and graduated symbol maps," and finally the most popular thematic mapping method called "choropleth maps," which warrants a lot of in-depth explanation.

• **Dasymetric maps:** The dasymetric mapping method is a rarely used mapping method because it is unconventional and requires ancillary spatial information such as other supporting maps to help determine if the use of this method is valid. The classic example is John K. Wright's Cape Cod: Population Maps. He first mapped population density by townships (left map below); then he mapped the uninhabitable areas of Cape Cod (center map) because of their absence of population. Then he combined these two sets of data and recalculated population density based on subdivisions of townships, a finer mapping area unit. This resulted in the dasymetric map (right map), which is a much more accurate representation of Cape Cod's true geography of its population density that also correlates to the density of homes along the coastal lines and the commercial businesses along Highway 6 that runs in the middle of the curved peninsula.

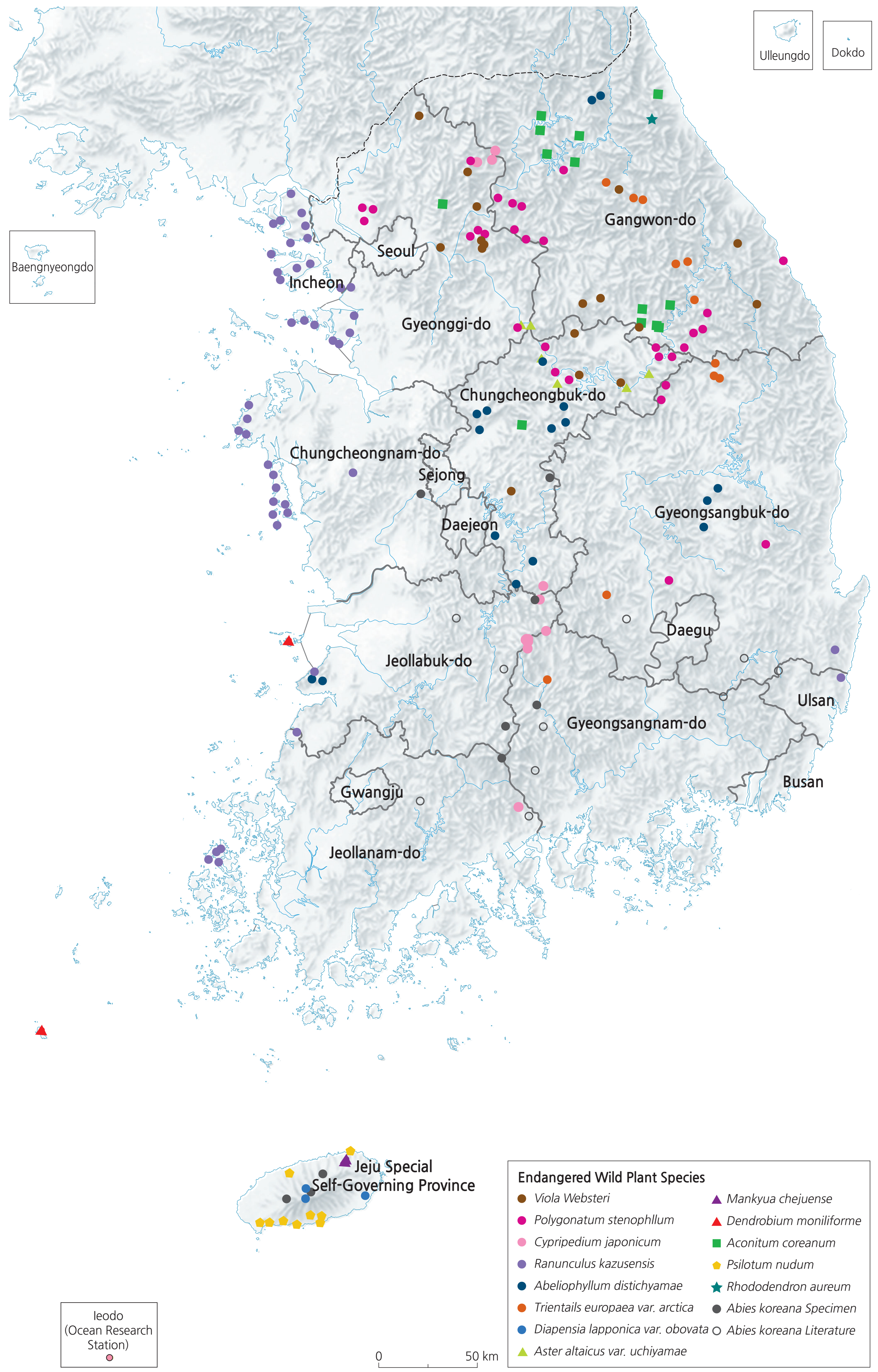
Recent computer programs have been written to facilitate such calculations that are meant to combine more than one map into the making of daysmetric maps; the U.S.G.S. has produced some accurate maps of the San Francisco Bay Area population density based on this method (USGS, 2017).

• **Isarithmic maps:** The term "isarithm" refers to a line that connects all data points of the same value. For example, a contour line joins all points of the same elevation; an isohyet joins all points of equal rainfall; an isobar joins all points of equal air pressure. There are two types of isarithmic maps: the isoline map and the isopleth (or isoplethic) map. The contours, isohyets, and isobars are typical isoline maps since they represent real physical data surfaces, but there are many others – any set of point data relating to the same attribute (say, housing values) can be mapped by isolines. Isolines are generated with the process of interpolation.

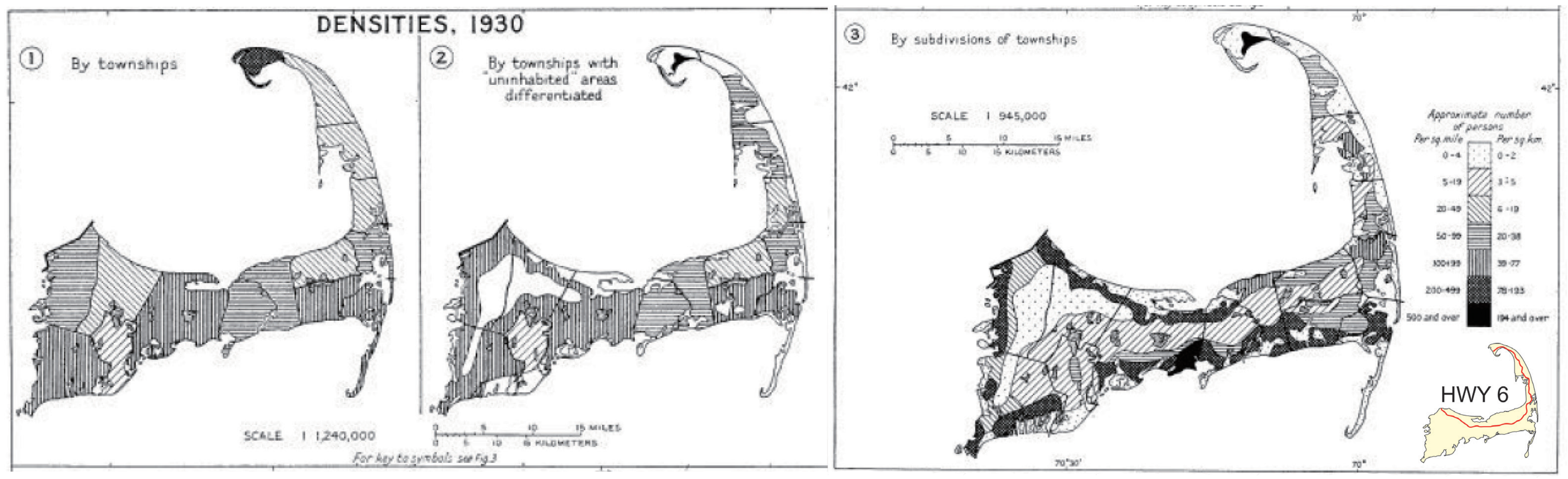
The Interpolation Process

Interpolation begins with a set of existing data points in two-dimensional space. Each data point has a spatial relationship with each other data point, however many there may be. The red lines on Map A (below) of the Interpolation Process show such spatial relationships. Between the points with values of 234 and 449 is a line with a proportionally graduated scale of equal parts; the values 300 and 400 fall on this line and the tic marks for 300 and 400 indicate where the isoline with those values will pass through. This is the interpolation process. Map B shows all the data points that are linked with either or both the 300 or 400 values: their tic marks are also indicated. Map C follows with the actual model that the blue isolines are generated through with these tic marks.

Distribution of Endangered Plants: A Good Example of Qualitative Map

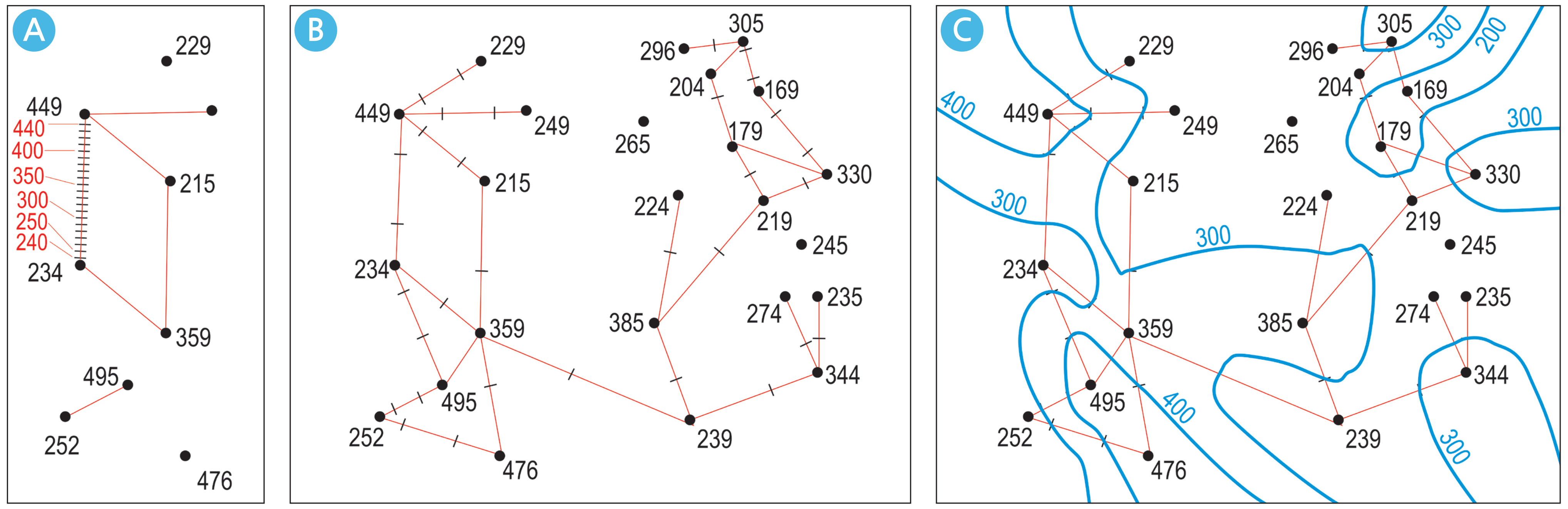


National Institute of Biological Resources (2015)



From: Wright, John K. 1936. "A Method of Mapping Densities of Population with Cape Cod as an Example." Geographical Review. American Geographical Society. NY. 26: 103-110 (published with the kind permission of The American Geographical Society).

The Interpolation Process

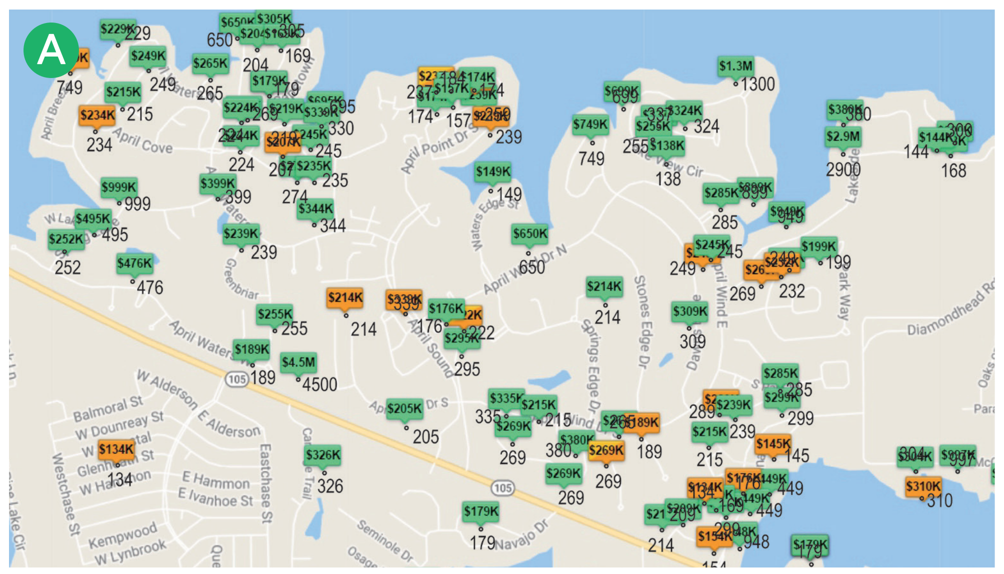


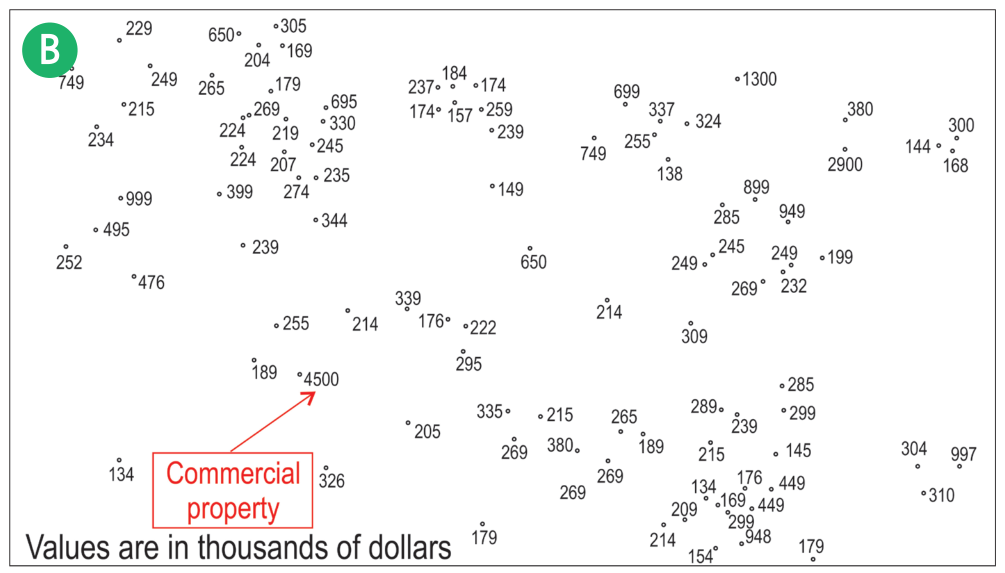
A major characteristic of the isoline map is that it represents a continuous surface where any data point in between two isolines can be interpolated with a relatively high degree of accuracy. Unlike the contour representation of land elevation, isopleth maps employ the same technique of generating isolines; however, the value in between isolines cannot be precisely determined. In such a case, an average or interval value can apply.

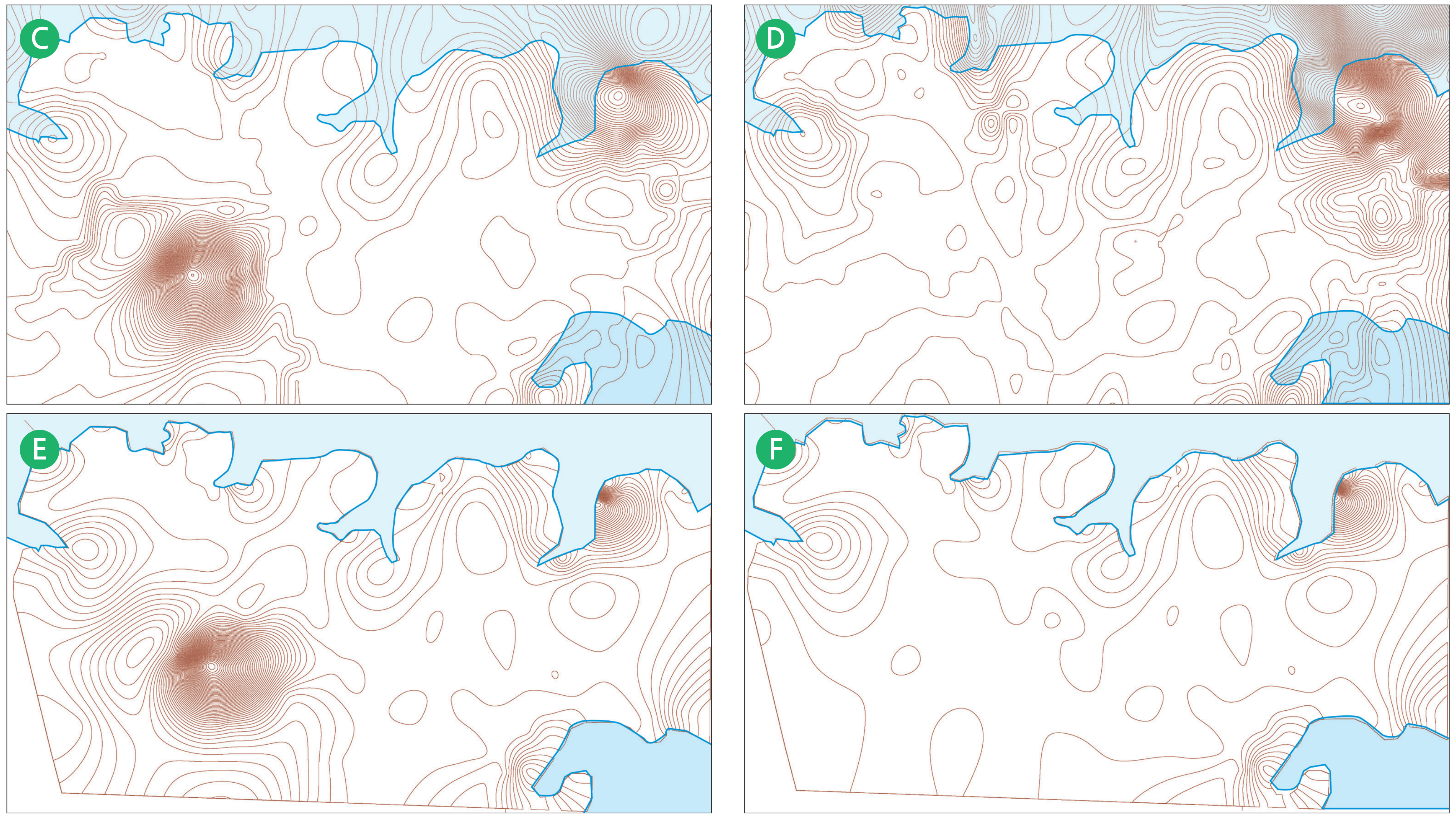
Map A below is an actual map from a real estate website depicting properties that were listed for sale in the City of Montgomery, Texas on the shore of Lake Conroe. Each house lists a specific asking price in thousands of dollars. The individual data points are re-drawn on Map B thus showing a statistical surface, but with one data point for a commercial property listing at $4.5 million. Four isoline maps depicting house prices are generated using the "spline interpolation" method, each with a different parameter. It is apparent that all four have different patterns.

The isolines for Maps C and D were generated with a default computer routine without regard to the geographic reality that the shoreline is there. The routine assumes the extensions of the isolines over the lake. Map C also included the presence of the commercial property, which definitely skews the real estate asking price pattern. This data for this property was deleted to generate only the residential properties for Map D.

The isolines Maps E and F were generated by using the shoreline as a barrier such that no isoline will cross over the shoreline into the lake area where there is actually no data point. The resulting maps are more realistic. The data point for the commercial property on Map E was purposely left remaining just to show how one data point can skew the entire isoline pattern. Map E is the ideal one for this dataset since both the shoreline barrier is applied and the commercial property deleted.

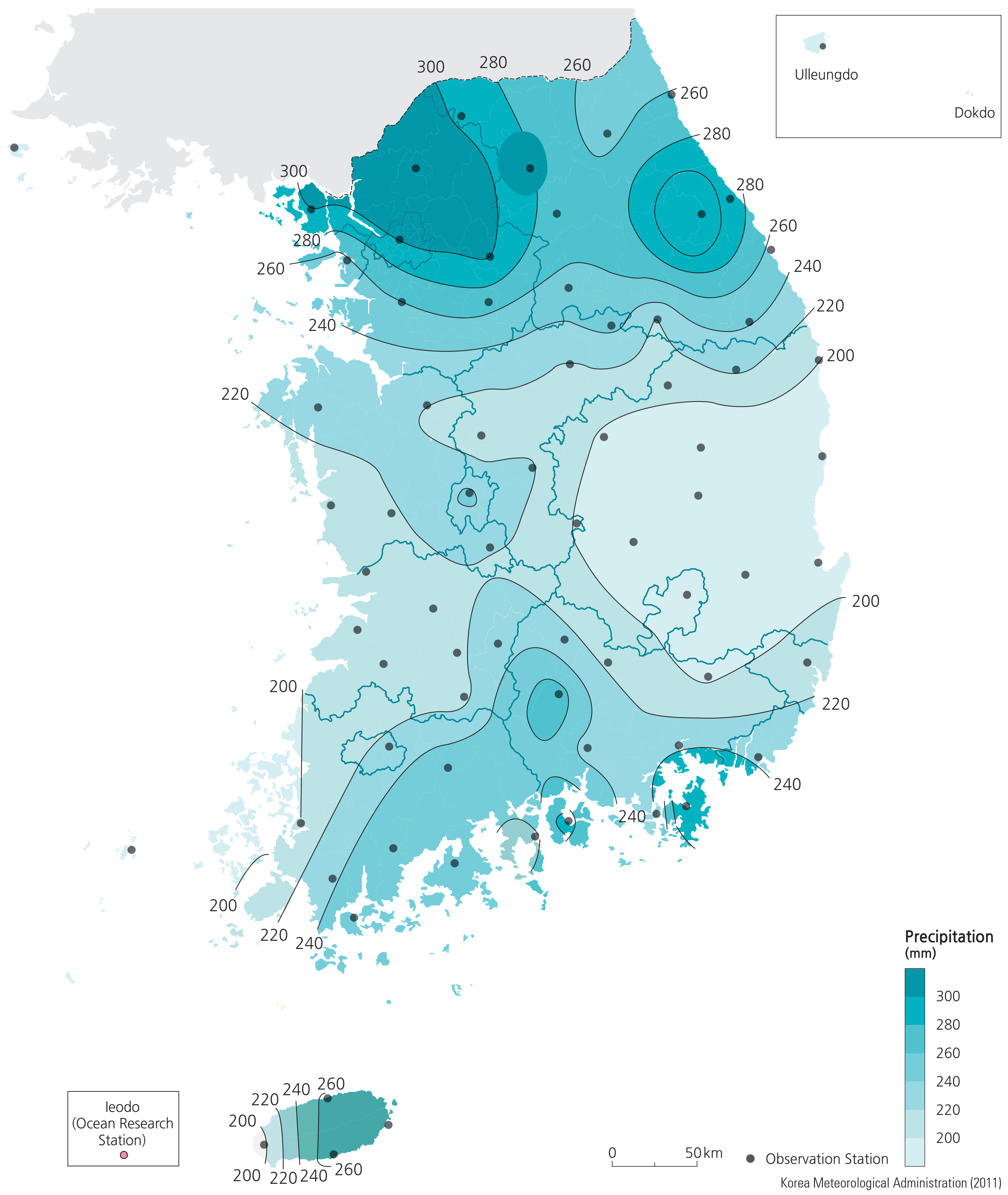






Four different methods of generating isolines from the same dataset create four different geographic patterns. Map readers must be careful in understanding which one is realistic (courtesy of J.C. Nelson, Upper Midwest Environmental Sciences Center, USGS).

Annual 5-Day Consecutive Maximum Precipitation (1981-2010)



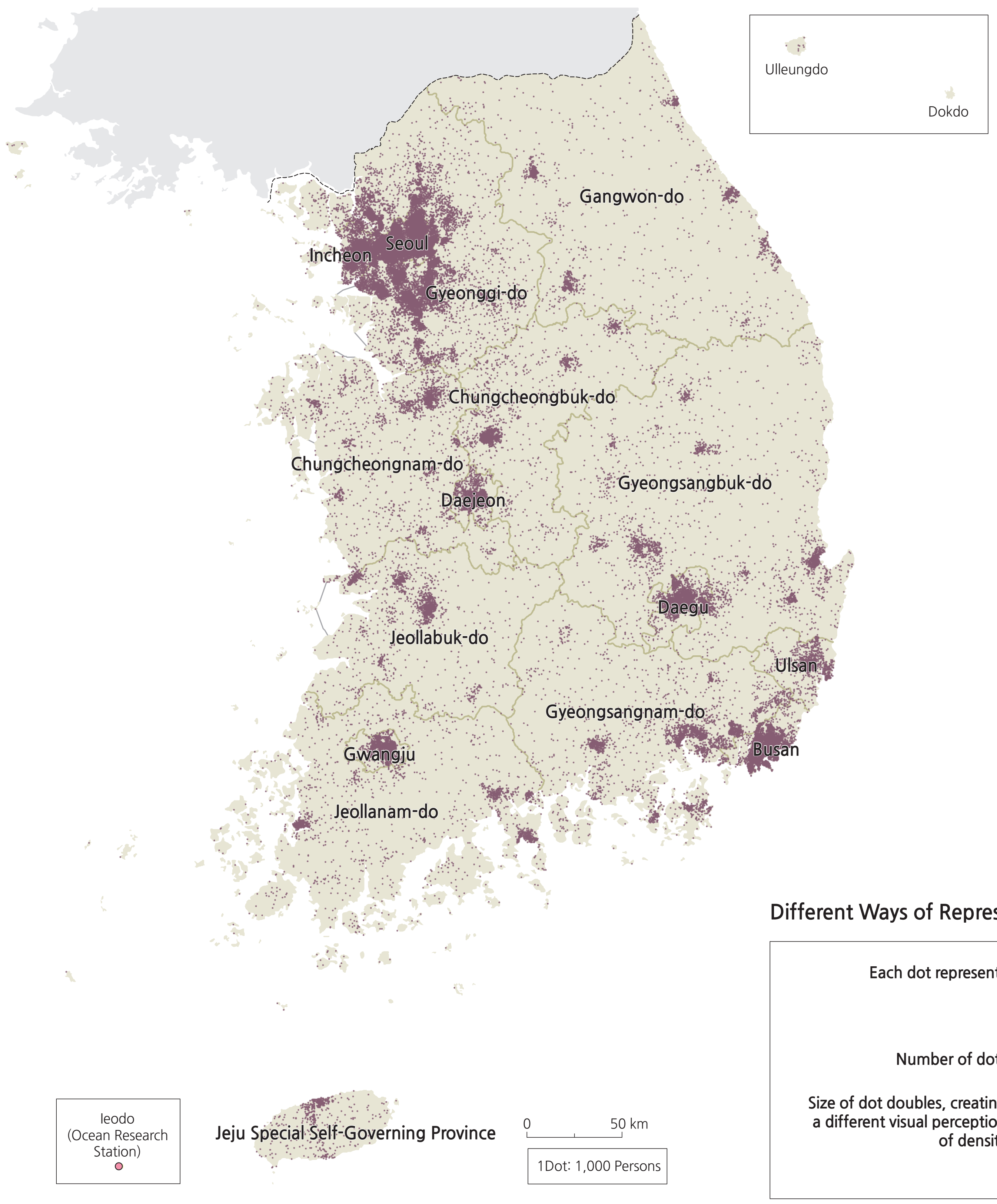
Unlike the isoline map, an isopleth map is used to show a dataset that cannot be assumed to be continuous. The Annual 5-Day Consecutive Maximum Precipitation Map (1981–2010) inserted from p.138 of The National Atlas of Korea II is an example of an isopleth map (left). Unlike the isoline map, precipitation values cannot be considered continuous. In other words, a map reader cannot perform interpolation procedures in-between the isolines and expect the in-between points to be proportional to the distance between two isolines. For example, a point situated exactly midway in a perpendicular distance between 220 mm and 240 mm isohyets does not necessarily represent 230 mm. The shaded colors are used in an isopleth map to convey the fact that a map reader can only assume the in-between values to be in the range of 220–240, not a precise precipitation value.

Example of an isopleth map depicting the precipitation pattern of South Korea (courtesy of The National Atlas of Korea II, page 138, published by the Korean National Geographic Information Institute.)

- **Dot maps and graduated symbol maps:** A dot map is a simple and easily comprehensible statistical map that depicts the distribution of a certain population. A graduated symbol map is also an easily comprehensible map that uses the proper scaling of the size of a statistical symbol to represent the data.

In a dot map, the cartographer selects what is being considered as an "appropriate" value of the population data (e.g., each dot represents 200 persons). So, for a place that has a population of 1,000,000 persons, the map will show 5,000 dots. But if the cartographer selects 250 as the appropriate value that each dot represents, there will then be 4,000 dots. Subsequently, a value of 1,000 will yield 1,000 dots and a value of 100 will yield 10,000 dots on the map. There is no right or wrong way for selecting any one of these values: 100, 200, 250, and 1,000. However, what makes the dot map easily comprehensible are several other factors that the cartographer must consider. The physical dimension of the map itself, the size of the dot symbol, and the pattern of concentration of the data will all contribute to how a dot map looks or how easily it can be interpreted. A smaller page size or map dimension will warrant the cartographer to consider a higher value for each dot so that the total number of dots is at 1,000, but the map will suffer in dot placement accuracy. A larger dimension can afford more map space to accommodate more dots so that the cartographer may select 200 as the dot value, which would yield 5,000 dots, thereby increasing the accuracy of dot placement and contributing to a more accurate population pattern.

Population Distribution of Korea (2010)

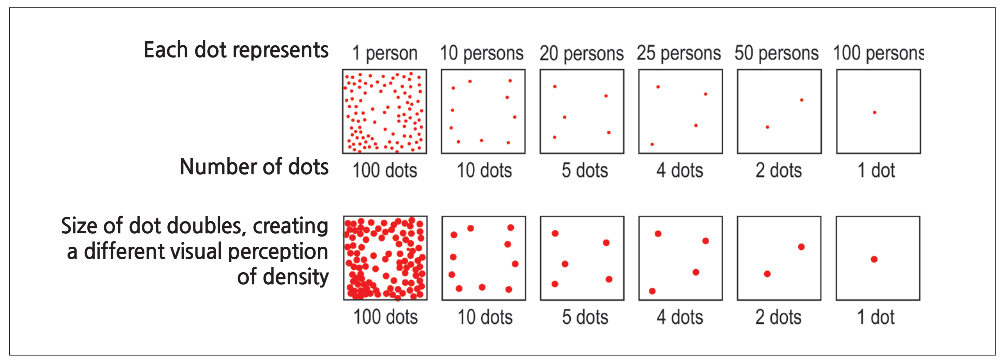


While the average map reader may not realize how the dot map was created, the cartographer certainly carries a great deal of responsibility in making the best selections and decisions. Sound decisions present the dot map with its best chance to communicate an accurate geographic pattern of population to the map reader. There is yet another level of difficulty for making a dot map, which relates to the placement of the dots. Suppose the dot value on a dot map is 1,000 people. As small as the size of one dot symbol may be, it is highly unlikely that all 1,000 persons live in a space at the placement of one dot, let alone all the dots in the entire map. In order to be accurate, the cartographer must have detailed knowledge of the area being mapped into dots and needs to exercise sound judgment to place the one dot in the centroid (center of gravity) of the clustered location of those 1,000 persons that the dot represents. Map readers need to understand this. While the production of the dot map is straight forward, the amount of research required to accurately place the dots in their proper locations can be tremendous and time-consuming. This is one reason why there are far less thematic maps portrayed as dot maps than other kinds of mapping methods.

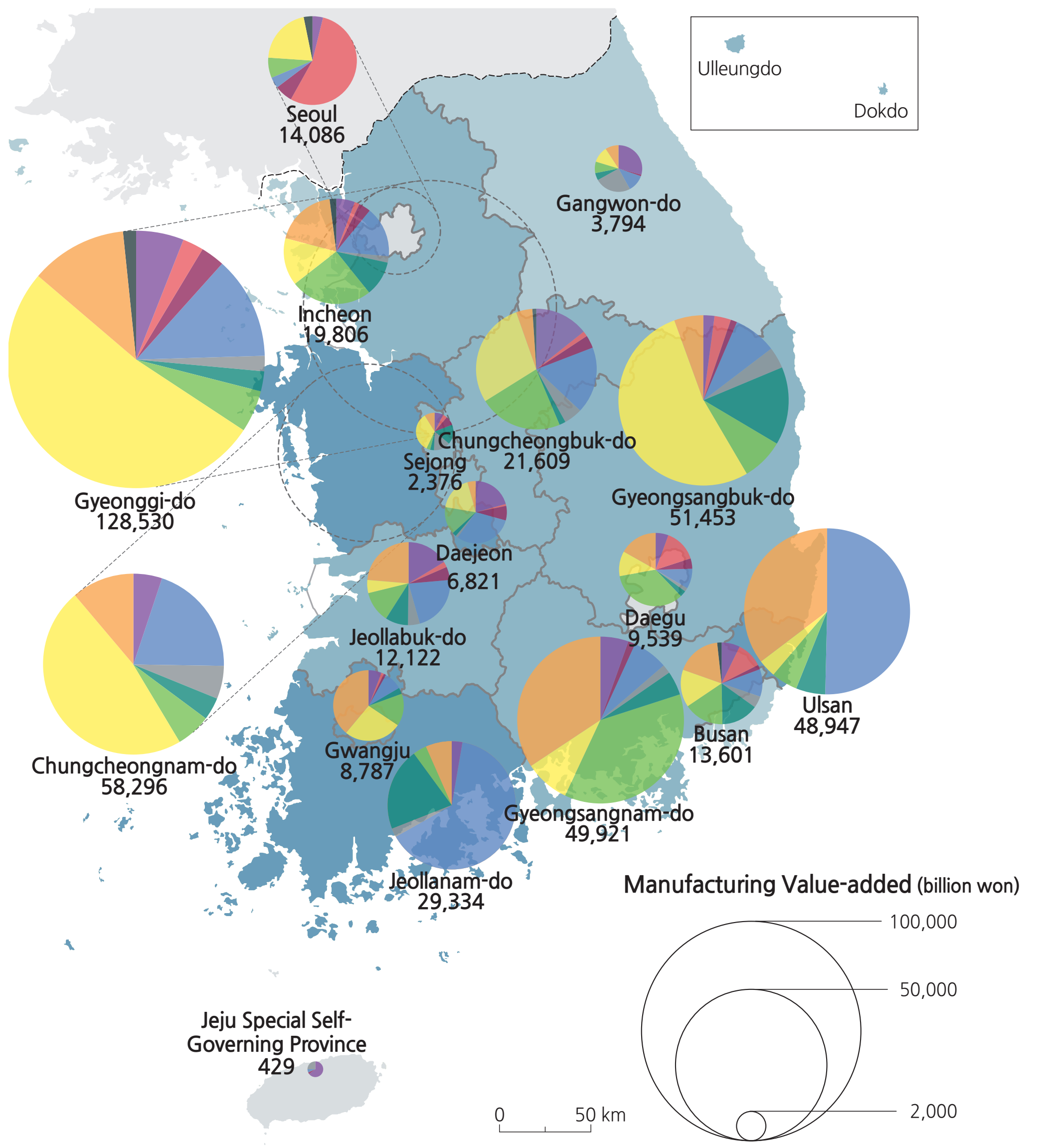
A map design element comes into play here: the selection of the size of each dot symbol. Dot density will look very differently on the same map simply by changing the size of the dots, as hundreds or thousands of dots may appear on a map. If the dot size is too small, it may not convey a desirable "look" for the density. If the dot size is too large, dots may coalesce and impede the visual process and give the reader a false mental perception of the true density.

The ultimate goal here is to convey a realistically portrayed geographic pattern of the population data that has been collected with a great deal of resources and effort. Theoretically, a map reader can count the number of dots in an area and multiply by the value each dot represents to derive the total population on the map; this is highly impractical and improbable as it is such a tedious chore.

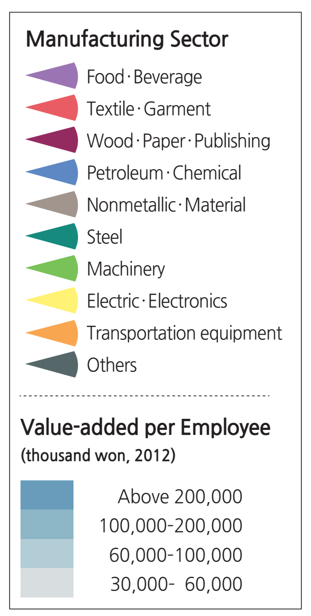
Different Ways of Representing the Same Set of Population Data on Dot Maps



Manufacturing Value-added and Sectoral Composition (2012)

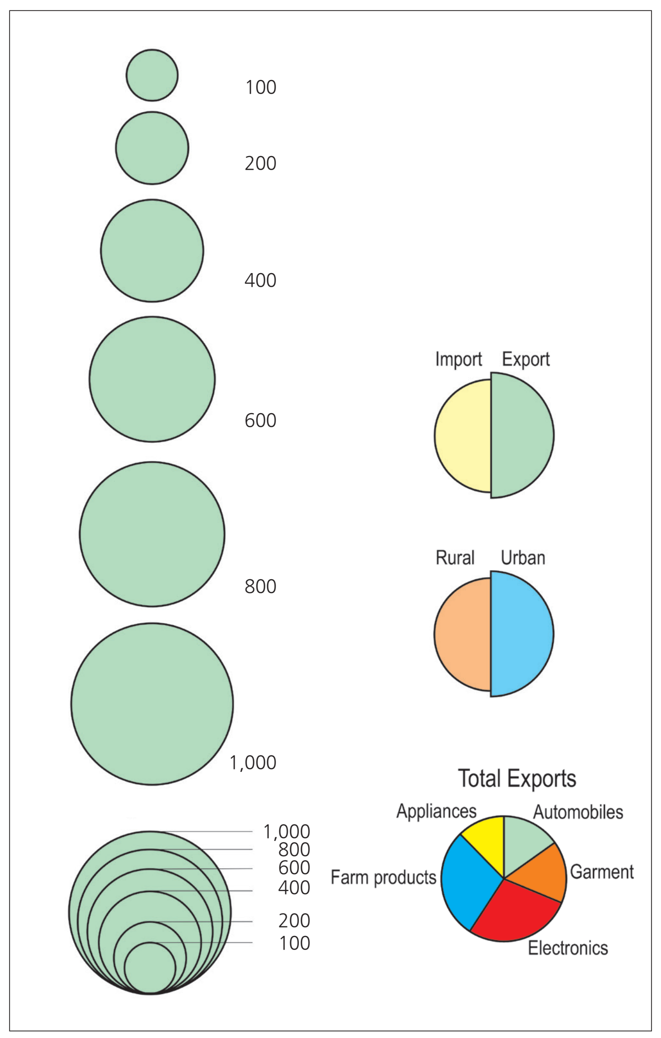


This map on 2012 Manufacturing Value-Added and Sectoral Composition is a good example of a well-designed graduated circle map (from p. 91 of The National Atlas of Korea I). It immediately draws attention to the yellow color that represents Korea's strong electric/electronic manufacturing industry.



Statistics Korea

Legend Designs that Show Typical Graduated Circle Map Legends

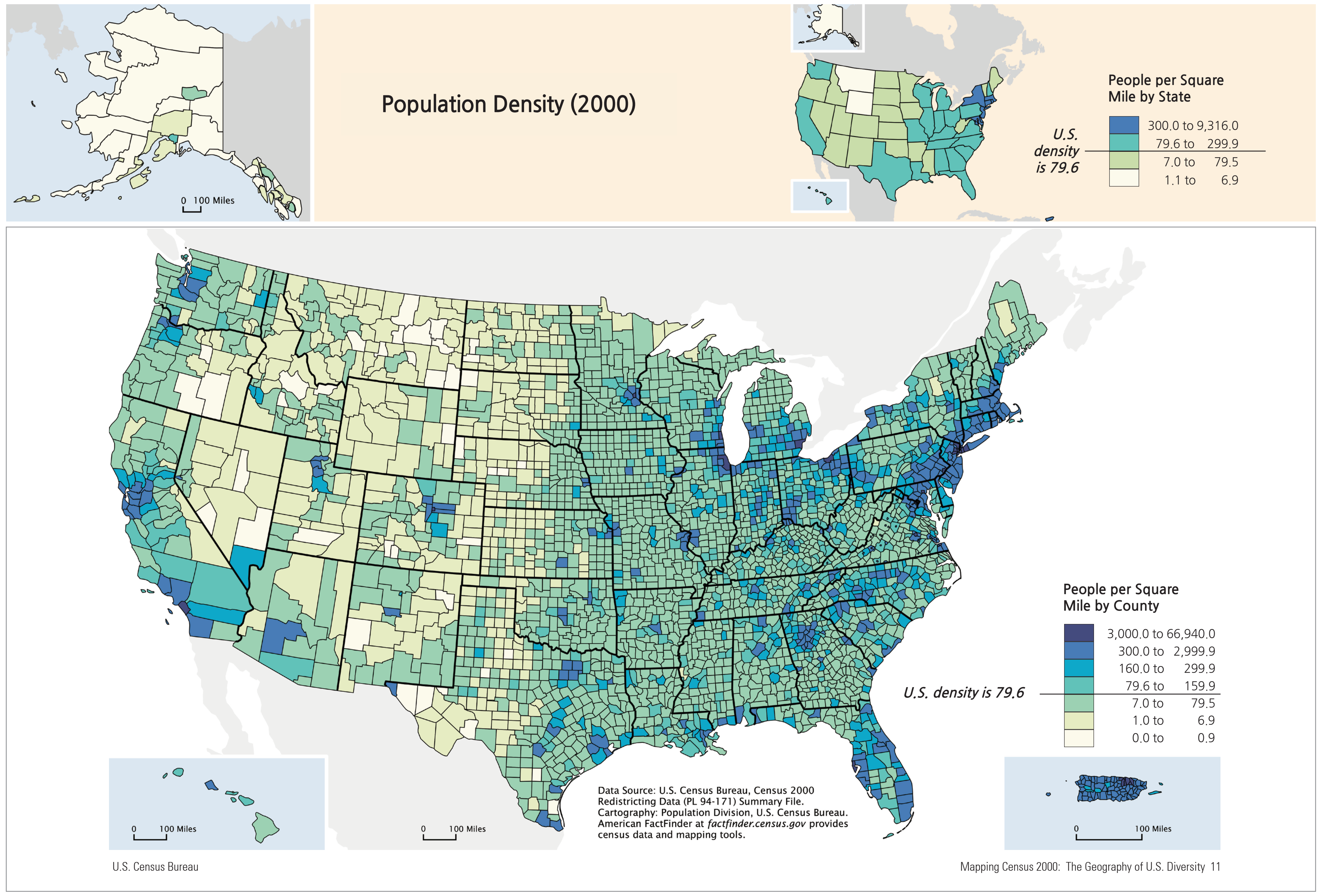


The value of a dot map, when mapped properly, can show effectively the concentrations and sparseness of the population data over a geographic space.

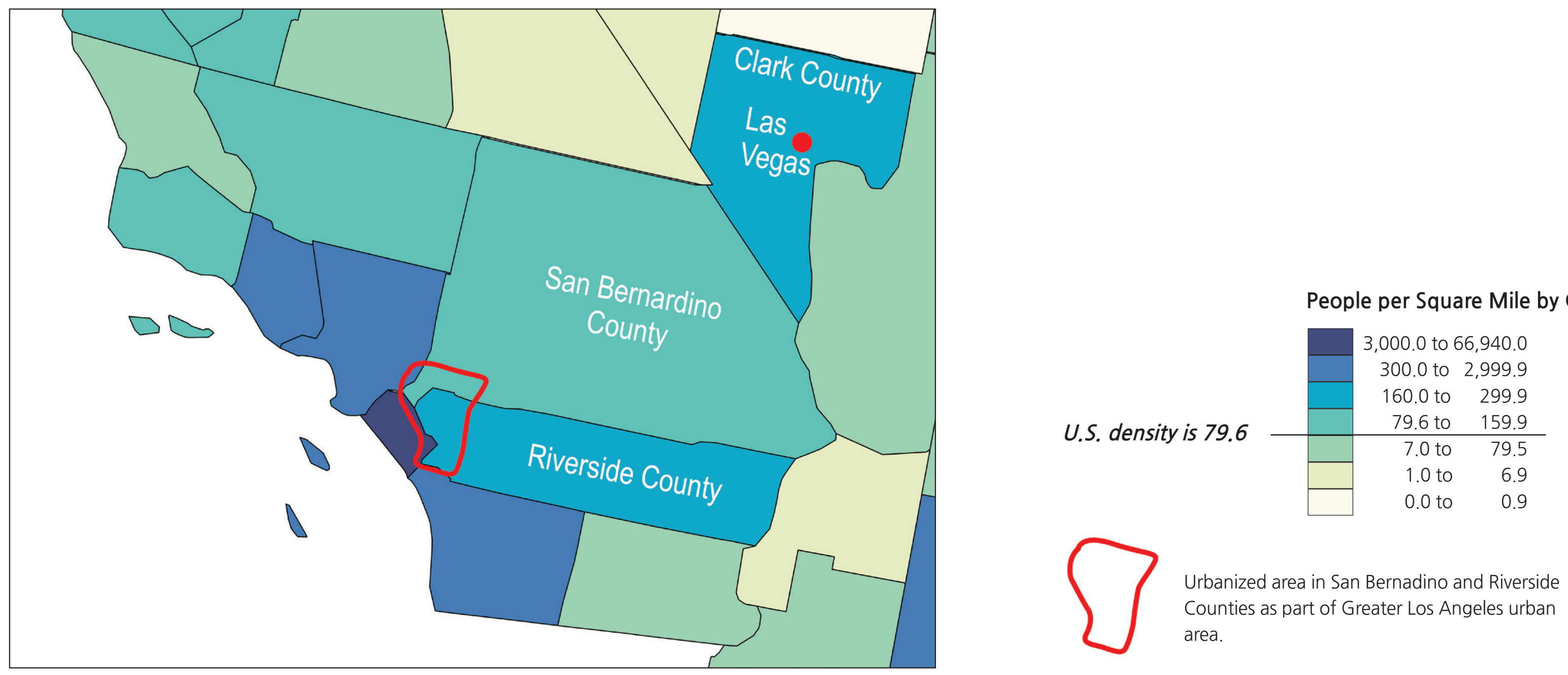
The graduated symbol map is a variation of the dot map where the location of the symbol, sized to reflect the magnitude of the data, is a more detailed but less cluttered method of showing a set of spatial statistics. The symbol, normally a circle, is sized by the area of the symbol to represent a set scale of the data points. The tricky part about the construction of the circle sizes is that people often tend to forget that visualizing area is the main concern and since the area of a circle (A) is equal to πr^2, the radius of the circle is then $\sqrt{A/\pi}$. The mistake of not taking the square root of (A/π) as the radius of the circle has been known to occur frequently on published maps; this causes an improper size representation of the data. The map reader should always be aware of this kind of mistake when viewing a graduated symbol map.

Further breakdowns of a total population data subset (such as different ethnic groups that make up 100% of a population) can be achieved with the graduated circle method. Circles can be proportionally sectored to represent the data subset based on the degrees of a circle that represent a percentage (360 degrees represents 100%). In this respect, more than one variable can be shown simultaneously on the same graduated circle map. A map with more than one variable is called a bivariate map; maps with more than two variables are considered multivariate maps. However, the more variables a cartographer includes on one map, the more difficult it becomes to interpret and derive a geographic pattern.

- **Choropleth maps:** A choropleth map is a statistical map where data collection is based on pre-established area units, cartographically referred to as mapping units. These units have pre-established boundaries, such as a state, county, province, census block, or school district. Data are collected on attributes (such as population, housing units) to cover the entirety of the mapping unit. In other words, a population tally for one county will include every person who lives within that county's boundaries, no matter which part of the county. The U.S. Population 2000 map shows two maps of population of the United States: one based on state boundaries (upper right) and the other on county boundaries (main map).



U.S. Population Density 2000 maps by state and by county, published by the U.S. Bureau of the Census. https://www.census.gov/population/www/cen2000/atlas/index.html item 2: Total Population, page 3 (in PDF format)



Concentrations of population in small areas within a large county often skew the true representation of data and mislead in the visualization process.

There are striking differences between these two maps even though they are created from the same government agency. The upper map was mapped by state statistics; the pattern shows concentrations of population density of the U.S. by states. Because the choropleth mapping method includes every single person within one state, it is not effective in showing any population density variations within that state; the best that a map reader can do is conclude that the eastern half of the United States has a higher population density. Not many other conclusions about this map can be made.

The lower map, which was mapped by county level statistics, shows population density by the counties. It is definitely a better representation than the map based on states because it shows greater detail in the variations of population density pattern for the entire U.S. For example, the spatial variations of population in the State of Texas clearly shows the high densities around urban counties near Houston, and the counties that make up the urban corridor from San Antonio through Austin to San Marcos to Waco and then the Dallas-Fort Worth areas. Western Texas is correctly shown as a low-density area with sporadic small urban counties around the cities of Lubbock and Amarillo. This rendition of population density is much more accurate than the map shown by state boundaries because the mapping unit here, counties, is smaller than states. Obviously, the collection of data for smaller mapping units requires a much greater effort, but can be rewarded with a map of greater accuracy. Theoretically, since the U.S. Bureau of the Census collects data by census enumeration blocks, a choropleth map based on mapping population or population density by census enumeration blocks – a much smaller mapping unit than the county – can yield a map with even higher accuracy. Practically, this is not a good idea simply because the census enumeration blocks will be so small on the map that any color fill may not be visible.

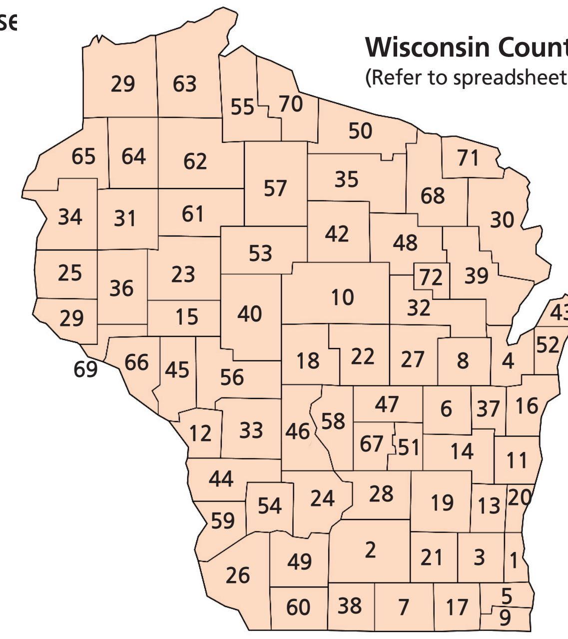
A special caveat needs to be raised here relating to a situation where population is very concentrated in a small area within a large county (or mapping unit). Consider the real population distributions in Clark County, Nevada, and San Bernardino and Riverside Counties in California. The map of population density in these counties does not reflect their true geographies. The majority of population in Clark County lives only in Las Vegas and its suburbs. The landscape outside the Las Vegas urbanized area is practically barren but yet the entire county is shown in the blue shade that represents 160-299.9 people per square mile. If not for the presence of Las Vegas, Clark County would probably be classified as the light yellow, 0.0-0.9 persons per square mile. The vast stretch of land in San Bernardino County is also basically devoid of population and includes the Mojave Desert. But the shape of the County protrudes into the Greater Los Angeles urban area. The very small urbanized area in the southwest corner of San Bernardino County contributes to a high overall population density of 79.6-159.9 people per square mile, even though the dark green color paints over the remaining 95% of the entire land area in the county, including the Mojave Desert. The same case is true for Riverside County.

In addition to the effects of the size of the mapping unit, the choropleth mapping method can also be very complicated in other ways, particularly in the data handling phase of making the map and the visualization phase by the map reader. There are many statistical methods for the cartographer to classify data and determine the best way to handle a particular set of data. Some of the common methods are:

- Equal intervals
- Quartiles, quintiles, sextiles, septiles, etc.
- Natural breaks in dataset
- Targeted breaks in dataset
- Parameters of a normal distribution (e.g., classification by standard deviations)
- The Jenks' method of Goodness of Variance of Fit (Jenks 1967)
- Arithmetic progression
- Geometric progression
- And many more

Once again, important decisions must be made by the cartographer because each one of these methods can be multiplied into several renditions of the choropleth map by varying the number of classes used and the statistical method selected. Consider the following dataset obtained from the U.S. Bureau of the Census for its 1990 Census. It shows the number of households in each county in the State of Wisconsin in 1990. This spreadsheet has been sorted from the highest number of households to the lowest number in each county. Milwaukee County (373,048), Dane

1990 U.S. Bureau of the Census datase on the number of households in Wisconsin counties



	Households	Name
1	373048	Milwaukee
2	142786	Dane
3	105990	Waukesha
4	72280	Brown
5	63736	Racine
6	53216	Winnebago
7	52252	Rock
8	50527	Outagamie
9	47029	Kenosha
10	41547	Marathon
11	38592	Sheboygan
12	36662	La Crosse
13	32977	Washington
14	32644	Fond Du Lac
15	31282	Eau Claire
16	30112	Manitowoc
17	27620	Walworth
18	27473	Wood
19	26853	Dodge
20	25707	Ozaukee
21	24019	Jefferson
22	21306	Portage
23	19077	Chippewa
24	17703	Sauk

	Households	Name
25	17638	St. Croix
26	17169	Grant
27	17037	Waupaca
28	16868	Columbia
29	16374	Douglas
30	15542	Marinette
31	15435	Barron
32	13775	Shawano
33	13144	Monroe
34	13056	Polk
35	12666	Oneida
36	12250	Dunn
37	11772	Calumet
38	11541	Green
39	11283	Oconto
40	11209	Clark
41	11011	Pierce
42	10159	Lincoln
43	10066	Door
44	9725	Vernon
45	9495	Trempealeau
46	8265	Juneau
47	7616	Waushara
48	7563	Langlade

	Households	Name
49	7406	Iowa
50	7294	Vilas
51	7189	Green Lake
52	6756	Kewaunee
53	6692	Taylor
54	6593	Richland
55	6255	Ashland
56	6253	Jackson
57	6054	Price
58	5972	Adams
59	5914	Crawford
60	5876	Lafayette
61	5693	Rusk
62	5569	Sawyer
63	5515	Bayfield
64	5456	Washburn
65	5242	Burnett
66	4123	Buffalo
67	4831	Marquette
68	3290	Forest
69	2612	Pepin
70	2602	Iron
71	1755	Florence
72	1079	Menominee

County (142,786), and Waukesha County (105,990) have far more households than each of the rest of the counties. In fact, there is a large difference between the highest counties and the lowest counties (28 counties with less than 10,000 each) that makes this dataset difficult to map.

To demonstrate how this dataset can be mapped from dozens of statistical methods to create different versions of maps with the same set of data, nine maps are created. They all look different. The immediate question anyone will raise is "which one is correct?" The answer is: all of them are neither correct nor incorrect. The map that best simulates the true geography of the land is the best map and producing it is the responsibility of the cartographer. With the widespread access to GIS and other mapping software, making maps has been said to be democratized. Everyone is equally capable of producing thematic maps or freely disseminating them on the Internet, but not everyone has received the vigorous training that a professional cartographer has. This is why students and teachers alike should learn to be skeptical and keep a critical eye over the quality and integrity of the map that has been presented.

Maps 1, 2, and 3 are created with the most frequently used equal intervals method (e.g., 0–100, 100–200, 200–300, and so on) by dividing the highest data value by the number of intervals, 4, 5, and 6 in these cases. In Map 1, dividing Milwaukee County's 373,048 by 4 yields 93,262 which becomes the range to set the interval sizes (0–93,262, add another 93,262 to make 93,262–186,524 and repeating this to make 186,524–279,786, and finally 279,786–373,048). The same is repeated for Map 2 by dividing 373,048 into 5 classes and Map 3 into 6 classes. Because the dataset is skewed at the top, the equal intervals mapping method did not produce any truly representative patterns on the maps since there are no data points in the middle ranges, thus resulting in mostly the yellow lower-level class intervals and no in-between shades of green. Thus, the equal intervals method is not appropriate for this particular dataset.

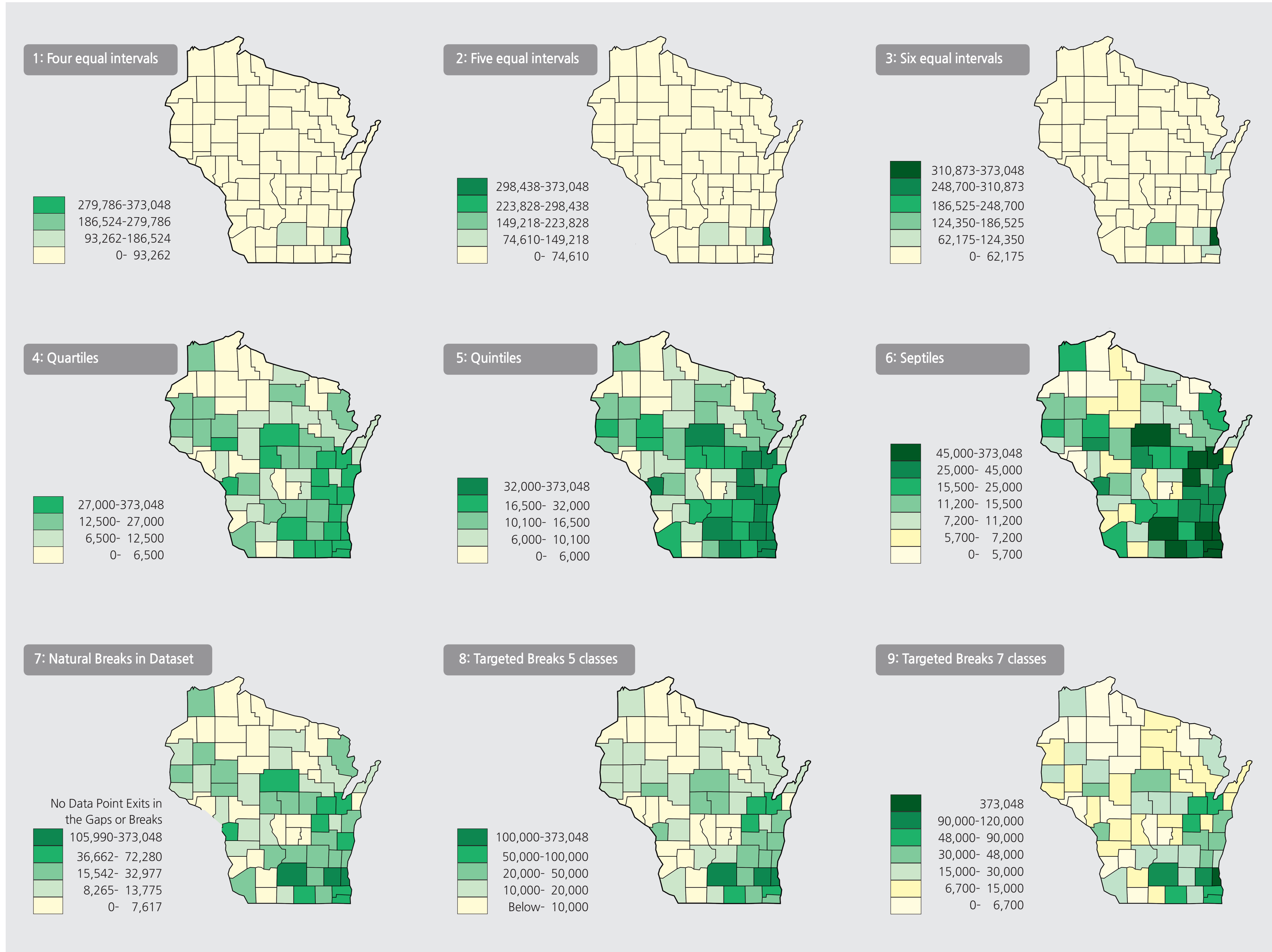
Maps 4, 5, and 6 use a different statistical approach. The quartiles method divides the total number of data points, in this case 72 counties, into 4 groups with 18 data points each (5 groups for quintiles, each with 14.4 or rounded to 14 data points per group, and 7 groups for septiles, each with 10.3 or rounded to 10 data points per group). The resulting maps show a lot more diverse patterns than the equal intervals method. Although having more diverse patterns on these three maps, they still have not achieved the true geography of the distribution. Even with the septiles method, the seven class intervals are still unable to clearly show the skewed concentration of the top counties when Milwaukee County (373,048) is included in the same interval as Marathon County (41,547).

Maps 7, 8, and 9 make use of natural and targeted breaks in the dataset. A break is a large jump in value from one data point to the next in the dataset. Examining the top values in the dataset quickly reveals that there are big jumps from Brown County (72,280) to Waukesha County (105,990) to Dane County (142,786) to Milwaukee County (373,048). Map 7 shows a 5-interval map delineated with natural breaks between 72,280 and 105,990; 32,997 and 36,662; 13,775 and 15,542; and finally, 7,617 and 8,265. This method is an improvement over the quartile, quantile, and septiles methods; it clearly separates the top three counties from the rest.

The natural breaks method is closely associated with the Jenks' Goodness of Variance of Fit statistical modeling of a dataset. Natural breaks are obvious boundaries for delineating interval thresholds in a dataset. As the breaks separate groups of data points, the mean of each group can be calculated and the furthest data points away from the mean would have the greatest variance, while the data points near the mean would have the least variance. It is most desirable to have groups that compute to the lowest variance index which ranges from 0 to 1. An index number closest to 1 has the lowest variance and the best goodness of fit for the classified groups. The statistical formula for the Jenks Goodness of Variance of Fit method is embedded in most current choropleth mapping software programs' classification routines; it should be applied whenever available.

Maps 8 and 9 are targeted approaches to the natural breaks, with 5 and 7 classes, respectively. Map 8 classifies the top three counties into one class and the rest with arbitrary breaks. The result is a good representation of the realistic geography of households in Wisconsin counties.

Nine of the dozens of methods that can be used to create choropleth maps to show the number of households in Wisconsin counties in 1990.



Map 9 goes one step further into 7 classes, with Milwaukee County separated above all others since there is a big jump in the data; isolating Milwaukee County to stand out as having the single most number of households by far is certainly justifiable. Having Dane County and Wakesha County included in the second highest class also separates these two counties from the rest of the counties. Since the top three counties are now classified, the remaining data points are no longer greatly skewed and can be logically grouped into 5 more classes with much less variance.

In these respects, Map 9 with its 7 classes is the best representation of a much-skewed dataset. One might suggest that adding more classes will further improve the accuracy of the map; theoretically, it is true, but by adding more classes, the cartographer runs into a map design problem of finding enough variations of tints to show the classes. Psychologically, it is difficult for a person to see and recognize 8 different shades in the grey scale. It would be counter-productive for a cartographer to design a map that has more than 8 different shades of the same color. This is where cartographic theory intersects with the practicality of map design when the cartographer has to decide how to manage both competing parameters. The map with too many shades creates difficulty for the map readers to visualize the data and distinguish between all the different shades, particularly with small area units filled with a medium shade.

After Thoughts

As the discussion of accuracy of representation continues, the main question that can be asked is whether a cartographer is mapping the true geography of the land or simply mapping a set of data that is conveniently available. A map reader should train himself/herself to recognize the difference. It may not be an easy task, but taking the context of other geographic factors and other supporting maps or geographic information and then applying spatial thinking skills is critical in truly understanding the intended message of the map. Researchers have already shown that secondary school students are capable of achieving some skills in understanding thematic maps; among the researchers are Castner, Gerber, Liebens and Downs, Gersmehl, Lee and Bednarz, Huynh and Sharpe, Duarte, and Chu et.al (see Reference and Bibliography below). The 2006 publication by the U.S. National Research Council, Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum, should be used by teachers as a reference and consultation for their efforts in developing lesson plans or for creating spatial thinking exercises. Four lesson plans developed by a team of U.S. experienced geography teachers from maps and other materials in The National Atlas of Korea Volume I have been taught in classrooms for two years to over 800 students in Utah, Minnesota, Tennessee, Georgia, and several other states with success (Chu et.al.; 2016). These lesson plans can be downloaded by any teacher for use in their classroom since they are in the public domain (http://nationalatlas.ngii.go.kr/). Developing spatial thinking skills should begin at the middle and high school levels.

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