Visualization Techniques for Geospatial Data

Vaibhav P. Vasani

Assistant Professor

Department of Computer Engineering

K. J. Somaiya College of Engineering

Somaiya Vidyavihar University

vaibhav.vasani@gmail.com

Geospatial Data

- Geospatial data is different from other kinds of data in that spatial data describes objects or phenomena with a specific location in the real world.
- Geospatial data arises in many applications, including credit card payments, telephone calls, environmental records, and census demographics.
- In this theme, we provide an overview of the special characteristics and methods that are needed for the visualization of geospatial data, sometimes called *geovisualization*.

Geospatial Data

- We introduce the most important basics of geospatial visualization, such as map projections, and discuss visualization techniques for point, line, area, and surface data.
- Due to the large scope of visualization techniques in geographic information systems (GIS) and cartography, we only provide a basic introduction from a visualization perspective.
- We should have a general understanding about state-of-the-art visualization techniques for geospatial data and should be able to implement and use them.

Visualizing Spatial Data

- Large spatial data sets can be seen as a result of accumulating samples or readings of phenomena in the real world, while moving along two dimensions in space.
- Often, spatial data sets are discrete samples of a continuous phenomenon.
- Nowadays, there exists a large number of applications where it is important to analyze relationships that involve geographic location.

Visualizing Spatial Data

- Examples include global climate modeling (e.g., measuring temperature, rainfall, and wind speed), environmental records (e.g., measuring CO2 and other pollution levels), economic and social measures and indicators (e.g., unemployment rate, education level), customer analysis, telephone calls, credit card payments, and crime data.
- Because of its special characteristics, the basic visualization strategy for spatial data is straightforward; we map the spatial attributes directly to the two physical screen dimensions, resulting in map visualizations.

Visualizing Spatial Data

- Maps are the world reduced to points, lines, and areas.
- The visualization parameters, including size, value, texture, color, orientation, and shape, show additional information about the objects under consideration.
- According to the U.S. Geological Survey (USGS), map visualizations are defined as a set of points, lines, and areas, all defined both by position reference to a coordinate system (spatial attributes) and by their nonspatial attributes.

Spatial Phenomena

From the definitions, it becomes clear that we may distinguish spatial phenomena according to their spatial *dimension* or *extent*:

- *point phenomena*—have no spatial extent; they can be termed zero-dimensional and can be specified by a longitude and latitude coordinate pair, along with a set of descriptors or attributes.
- Examples are buildings, oil wells, aggregated measures, and cities.

Spatial Phenomena

- *line phenomena*—have length, but essentially no width; they can be termed one-dimensional and can be specified by an unclosed series of longitude and latitude coordinate pairs for each phenomenon.
- Examples are large telecommunication networks, roads, and boundaries between countries.
- Attributes associated with line phenomena might include capacities, traffic levels, and names.

Spatial Phenomena

- *area phenomena*—have both length and width; they can be termed two-dimensional and can be specified by a series of longitude and latitude coordinate pairs that completely enclose a region, along with a set of attributes for each phenomenon.
- Examples are lakes, parks, and political units such as states or counties.

Spatial Phenomena

- *surface phenomena*—have length, width, and height; they are termed two-and-half-dimensional and can be specified by a series of longitude, latitude, and height coordinate vectors with a set of attributes for each (longitude, latitude) pair.

Map Types

- Maps can be subdivided into map types based on properties of the data (qualitative versus quantitative; discrete versus continuous) and the properties of the graphical variables (points, lines, surface, volumes).
- Examples of the resulting maps are
  - symbol maps (nominal point data);
  - dot maps (ordinal point data);
  - land use maps (nominal area data);
  - choropleth maps (ordinal area data);
  - line diagrams (nominal or ordinal line data);
  - isoline maps (ordinal surface data);
  - surface maps (ordinal volume data).

- Note that the same data may be visualized by different map types.
- By aggregating point data within areas, a choropleth map may be generated out of a dot map, or a land use map out of a symbol map.
- We may also generate a density surface from a dot map and display it as an isoline map or a surface map.
- If we aggregate the point data within areas and map the number of points within the areas to their size, we obtain cartogram visualizations.

Interaction with Maps

- In exploratory geovisualization, interaction with maps is crucial.
- In contrast to traditional cartography, the classification and mapping of the data can be interactively adapted by the user, and interactive querying as well as manipulation of the display are possible.
- A number of techniques and systems have been developed that make extensive use of such interaction capabilities.

Interaction with Maps

- They allow, for example, a linking of multiple maps or a combination of maps with standard statistical visualizations, such as bar charts and line charts, or even with complex multidimensional visualization techniques such as parallel coordinates or pixel techniques.
- In addition, they usually provide an advanced browsing or querying interface.
- An example of such as system is the CommonGIS system.

Map Projections

- In visualizing geospatial data, map projections play a critical role.
- Map projections are concerned with mapping the positions on the globe (sphere) to positions on the screen (flat surface).
- A map projection is defined as $\Pi : (\lambda, \phi) \rightarrow (x, y)$.
- The data format for degrees of longitude (λ) is fixed to the interval [–180, 180], where negative values stand for western degrees and positive values for eastern degrees.
- The degrees of latitude (ϕ) are defined similarly on the interval [–90, 90],where negative values are used for southern degrees and positive values for northern degrees.

Map Projections

Map projections may have different properties:

- A *conformal projection* retains the local angles on each point of a map correctly, which means that they also locally preserve shapes. The area, however, is not preserved.
- A map projection is called *equivalent* or *equal area* if a specific area on one part of the map covers exactly the same surface on the globe, as another part of the map with the same area. Area-accurate projections result in a distortion of form and angles.

Map Projections

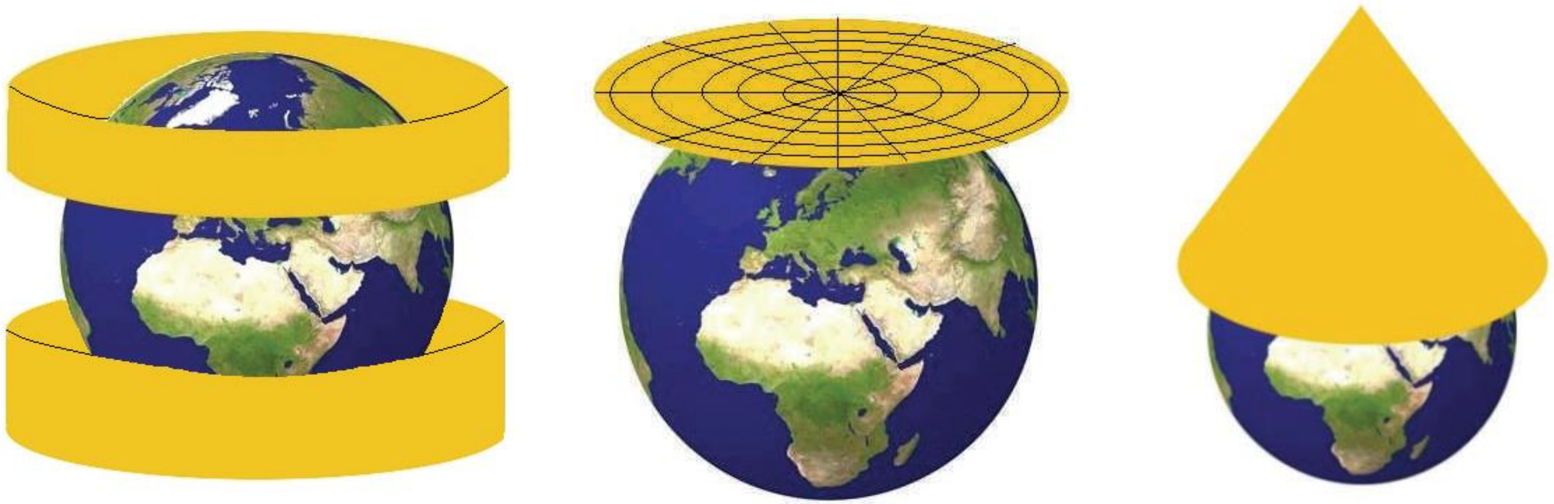
- A projection is called *equidistant* if it preserves the distance from some standard point or line.
- *Gnomonic projections* allow all *great circles* to be displayed as straight lines. Great circles are the largest circle that can be drawn on a given sphere and cut the sphere into two halves of equal size. Gnomonic projections preserve the shortest route between two points.

Map Projections

- *Azimuthal projections* preserve the direction from a central point. Usually these projections also have radial symmetry in the scales, e.g., distances from the central point are independent of the angle and consequently, circles with the central point as center result in circles that have the central point on the map as their center.
- In a *retroazimuthal projection*, the direction from a point S to a fixed location L corresponds to the direction on the map from S to L.

Map Projections

- Map projections may also be classified by the type of surface onto which the sphere is projected.
- The most important surfaces are (see Figure 6.1) as follows:



• Figure 6.1. Cylinder, plane, and cone projections.

Cylinder projections

- *Cylinder projections* project the surface of the sphere on a cylinder that is put around the sphere.
- Each point of the sphere is projected outward on the cylinder.
- Cylinder projections allow the entire spherical surface to be visible.
- Most cylinder projections preserve local angles and are therefore conformal projections.
- The degrees of longitude and latitude are usually orthogonal to each other.
- Pseudo-cylindrical projections represent the central meridian and each parallel as a single straight line segment, but not the other meridians.

Plane projections

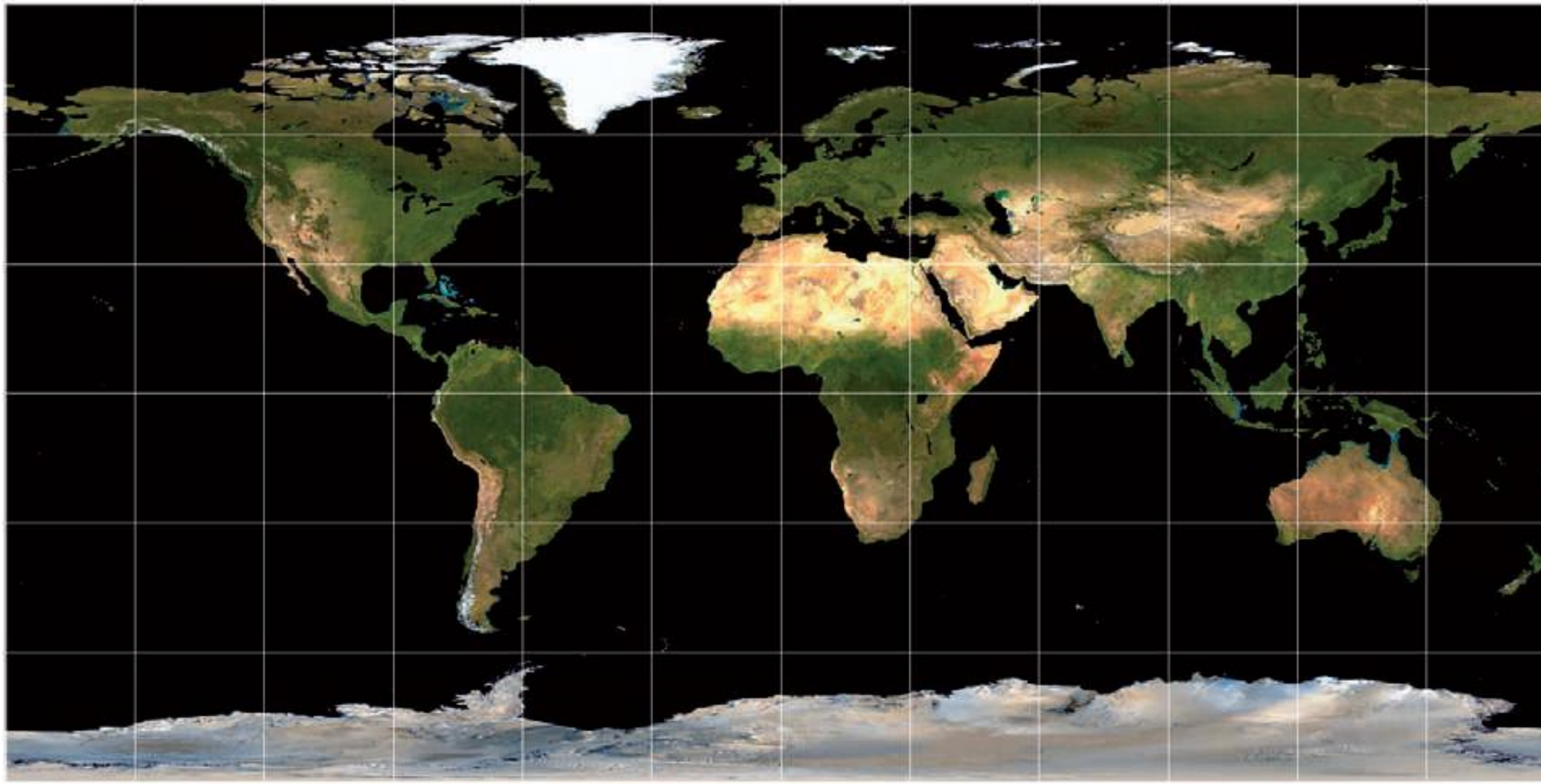
- *Plane projections* are azimuthal projections that map the surface of the sphere to a plane that is tangent to the sphere, with the tangent point corresponding to the center point of the projection.
- Some plane projections are true perspective projections.

Cone projections

- *Cone projections* map the surface of the sphere to a cone that is tangent to the sphere.
- Degrees of latitude are represented as circles around the projection center, degrees of longitude as straight lines emanating from this center.
- Cone projections may be designed in a way that preserves the distance from the center of the cone.
- There are also a number of pseudo-conical projections that, for example, retain the distances from the pole, as well as the distances from the meridian.

Equirectangular Cylindrical Projections

- The equirectangular projection (see Figure 6.2), one of the oldest and simplest projections, is a cylindrical projection. It maps meridians to equally spaced vertical straight lines and circles of latitude to evenly spread horizontal straight lines.
- The spherical coordinates are transferred one-to-one to a rectangular surface: $x = \lambda$, $y = \phi$.
- The projection does not have any of the desirable map properties and is neither conformal nor equal area. Because of the distortions introduced by equirectangular projections, it has little use in navigation, but finds its main usage in thematic mapping.

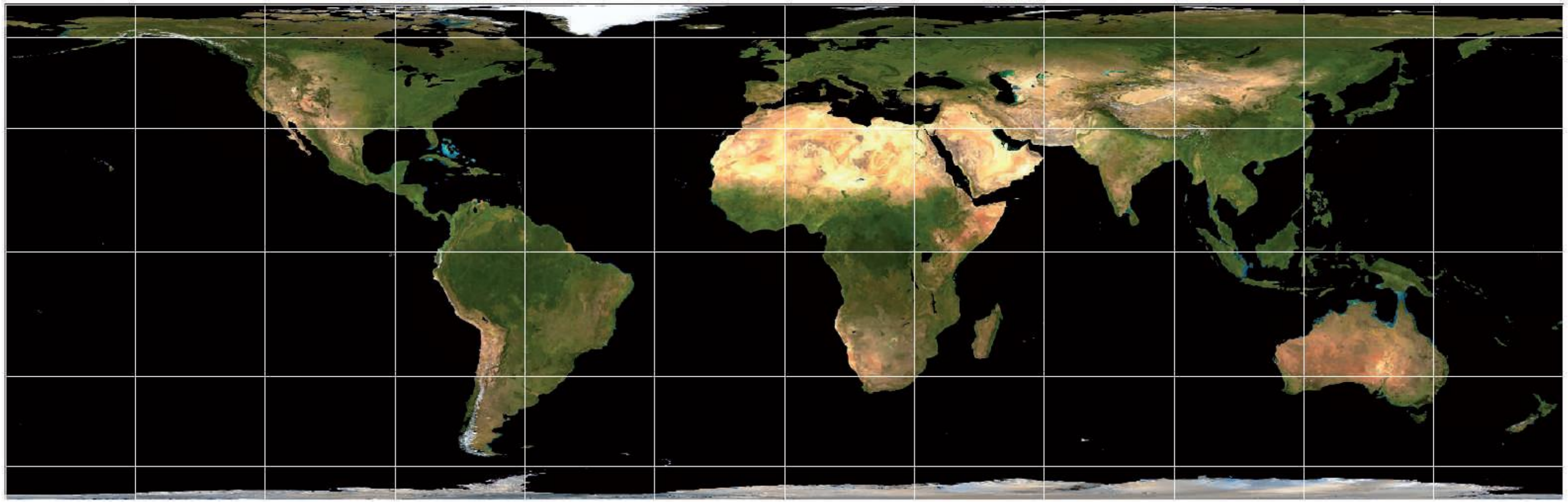


- Figure 6.2. Equirectangular projection.

Lambert Cylindrical Projection

- The Lambert cylindrical projection (see
- Figure 6.3) is an equal area projection that is easy to compute and provides nice world maps.
- The mapping is defined as

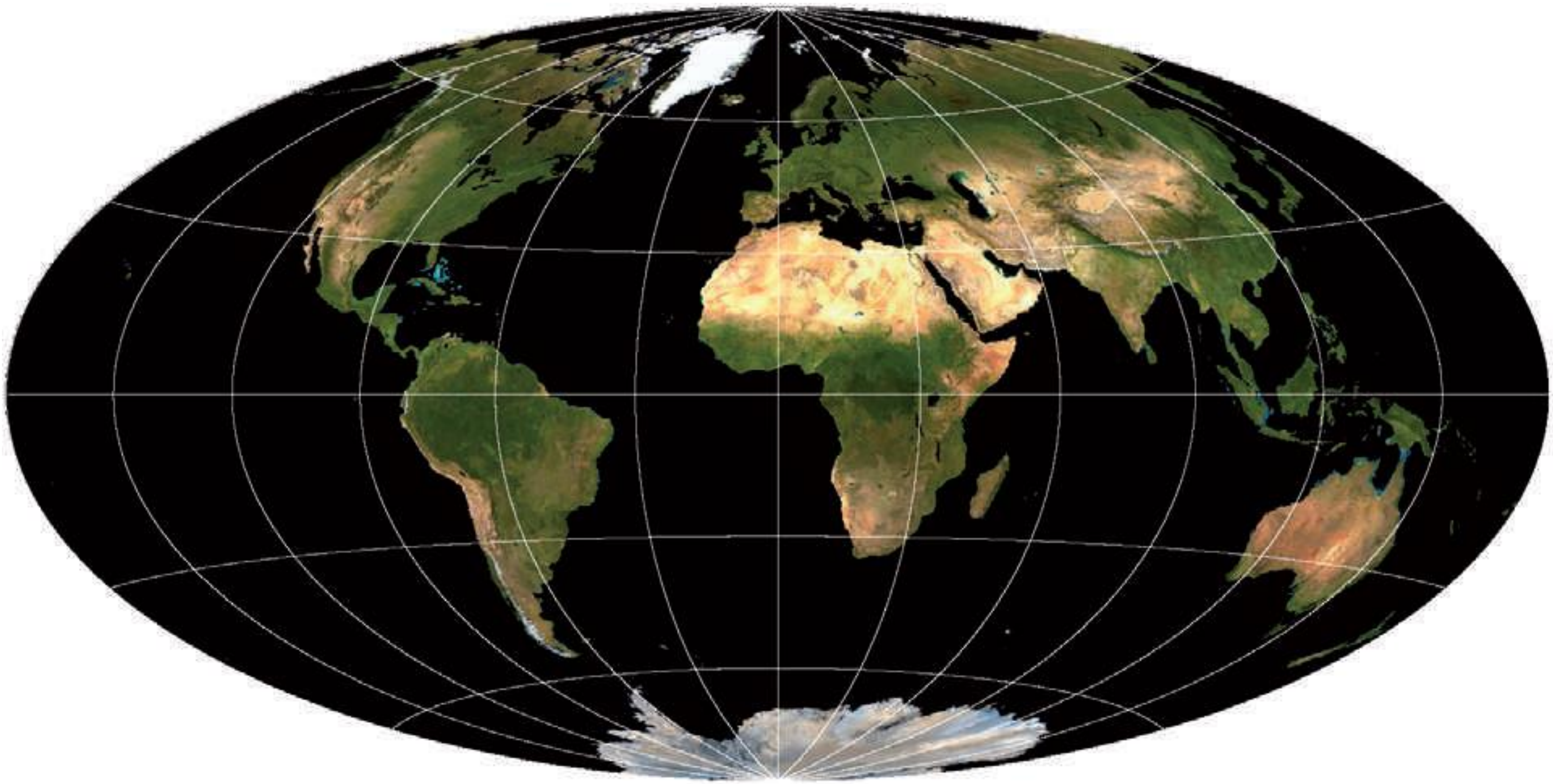
$x = (\lambda - \lambda_0) * \cos\phi_0$, $y = \sin\phi / \cos\phi_0$.



• Figure 6.3. Lambert cylindrical projection.

Hammer-Aitoff Projection

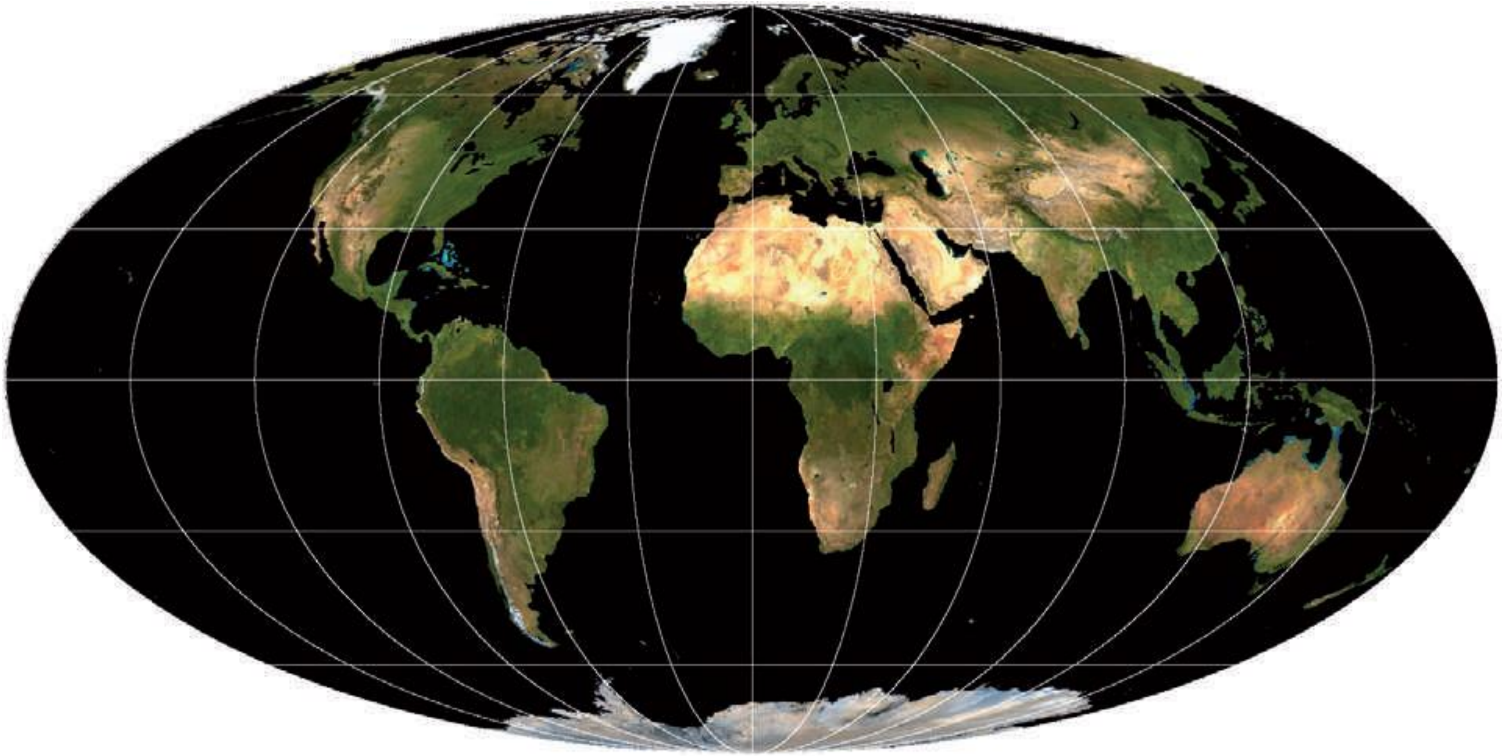
- The Hammer-Aitoff projection is a modified azimuthal projection.
- The central meridian and the equator are straight lines, with the meridian being half as long as the equator.
- The other meridians and equator-parallels are unequally spaced curves (see Figure 6.4).



• Figure 6.4. Hammer-Aitoff projection.

Mollweide Projection

- The Mollweide projection is an equal-area pseudocylindrical projection that represents the earth in the form of an ellipse (see Figure 6.5).
- All equator-parallels are straight lines, and all meridians except the central meridian are equally spaced elliptical arcs.



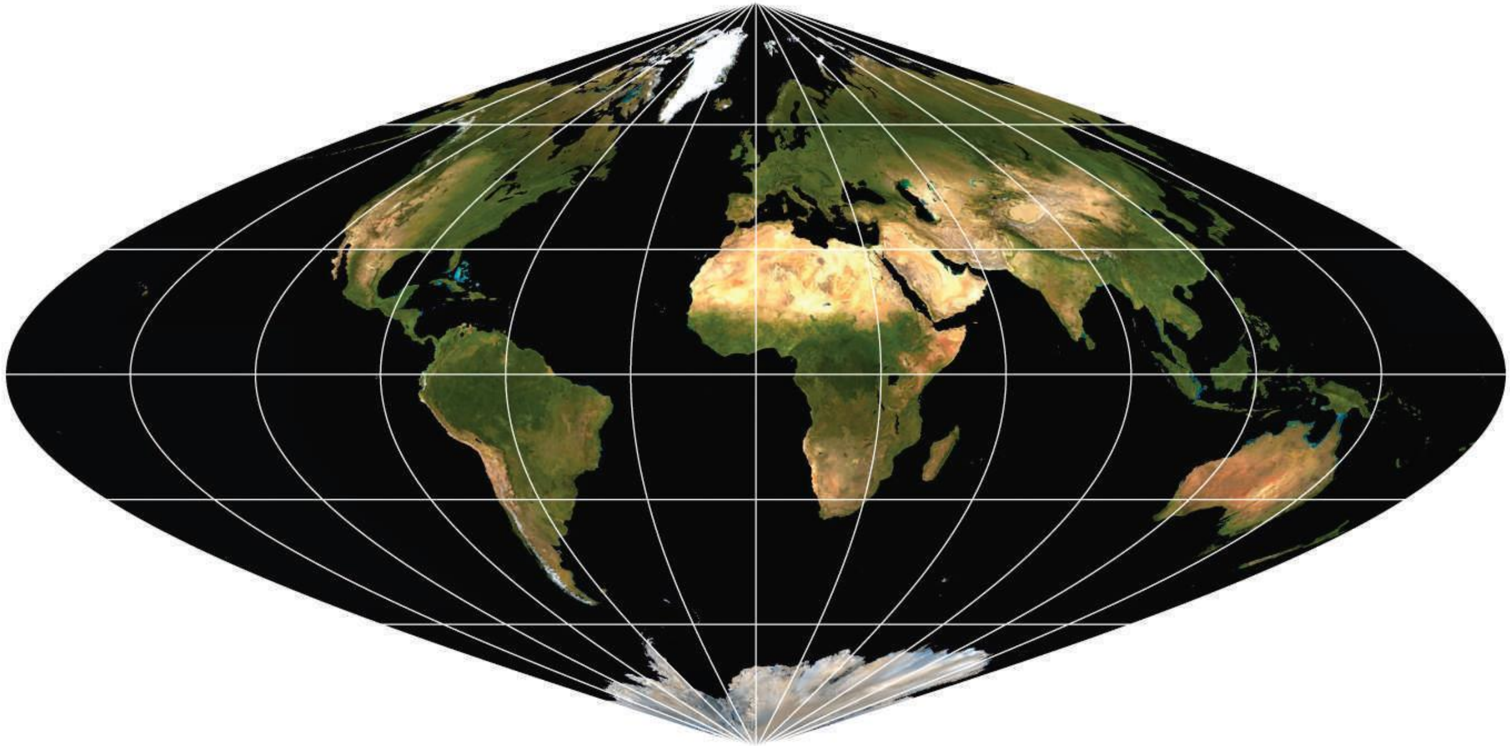
• Figure 6.5. Mollweide projection.

Cosinusoidal Projection.

- The Cosinusoidal projection is a simple pseudocylindrical equal-area projection that can be quickly computed.
- It has a unique form and surprisingly good local properties (see Figure 6.6).
- The mapping is defined as

$$x = (\lambda - \lambda_0) * \cos \phi, \; y = \phi.$$

- It is an equal area projection, and its elliptic form gives the viewer a reference to the spherical shape of the earth.



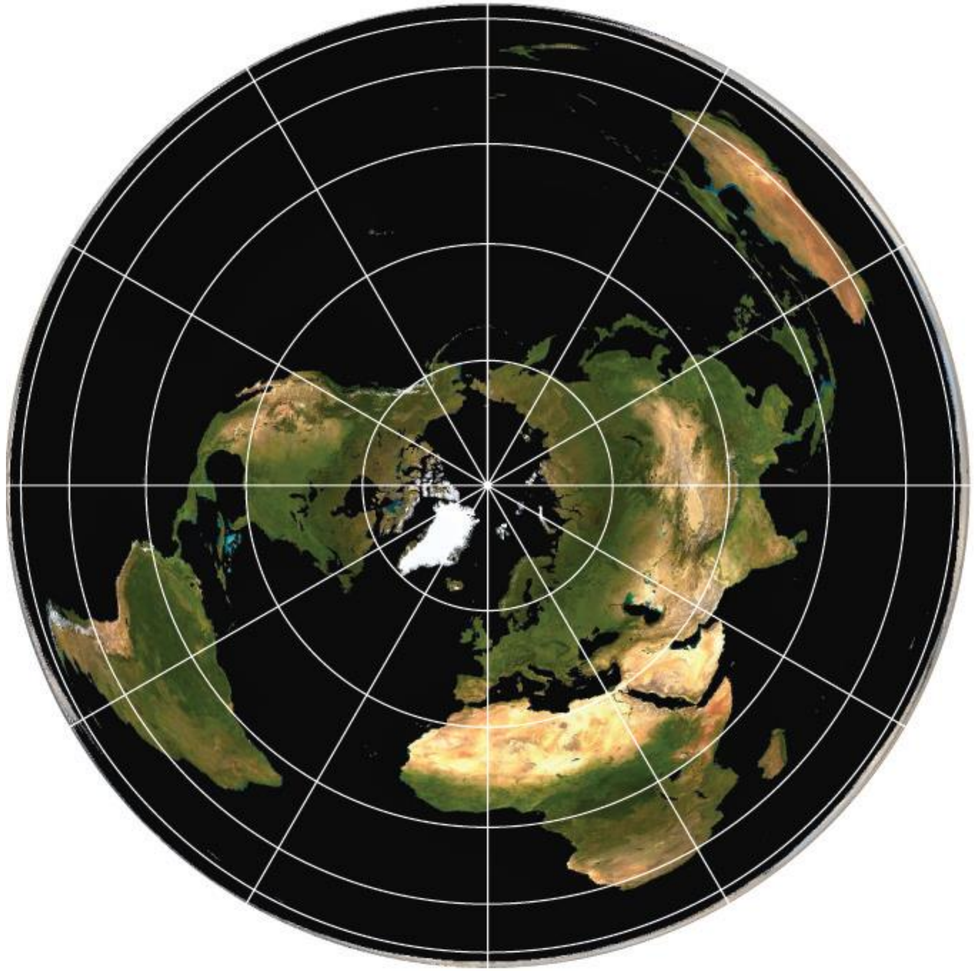
• Figure 6.6. Cosinusoidal projection.

Albers Equal-Area Conic Projection

- The Albers equal-area conic projection is an area-accurate cone projection.
- Its basic idea is to use two standard parallels (defined by β_1 and β_2) to reduce some of the distortions resulting from projection with only one standard parallel.
- The meridians are equally spaced straight lines intersecting in one point.
- The equator-parallels are unequally spaced concentric circles.

Albers Equal-Area Conic Projection

- Neither shape nor distances are correct, but the distortion of these properties is minimized in the region between the two standard parallels.
- The distances are most accurate in the middle latitudes, and therefore the projection is mostly used for smaller regions with east-west orientation located in the middle latitudes (see Figure 6.7).



• Figure 6.7. Albers equal-area conic projection.

Visual Variables for Spatial Data

Maps are used in many different ways: for example, to provide specific information about particular locations, to provide general information about spatial patterns, or to compare patterns in multiple maps.

The mapping of spatial data properties to the visual variables must reflect this goal.

The visual variables for spatial data are:

- *size*—size of individual symbols, width of lines, or size of symbols in areas;
- *shape*—shape of individual symbols or pattern symbols in lines and areas;
- *brightness*—brightness of symbols, lines, or areas;
- *color*—color of symbols, lines, or areas;

Visual Variables for Spatial Data

- *orientation*—orientation of individual symbols or patterns in lines and areas;
- *spacing (texture)*—spacing of patterns in symbols, lines, or areas;
- *perspective height*—perspective three-dimensional view of the phenomena with the data value mapped to the perspective height of points, lines, or areas;
- *arrangement*—arrangement of patterns within the individual symbols (for point phenomena), patterns of dots and dashes (for line phenomena), or regular versus random distribution of symbols (for area phenomena).

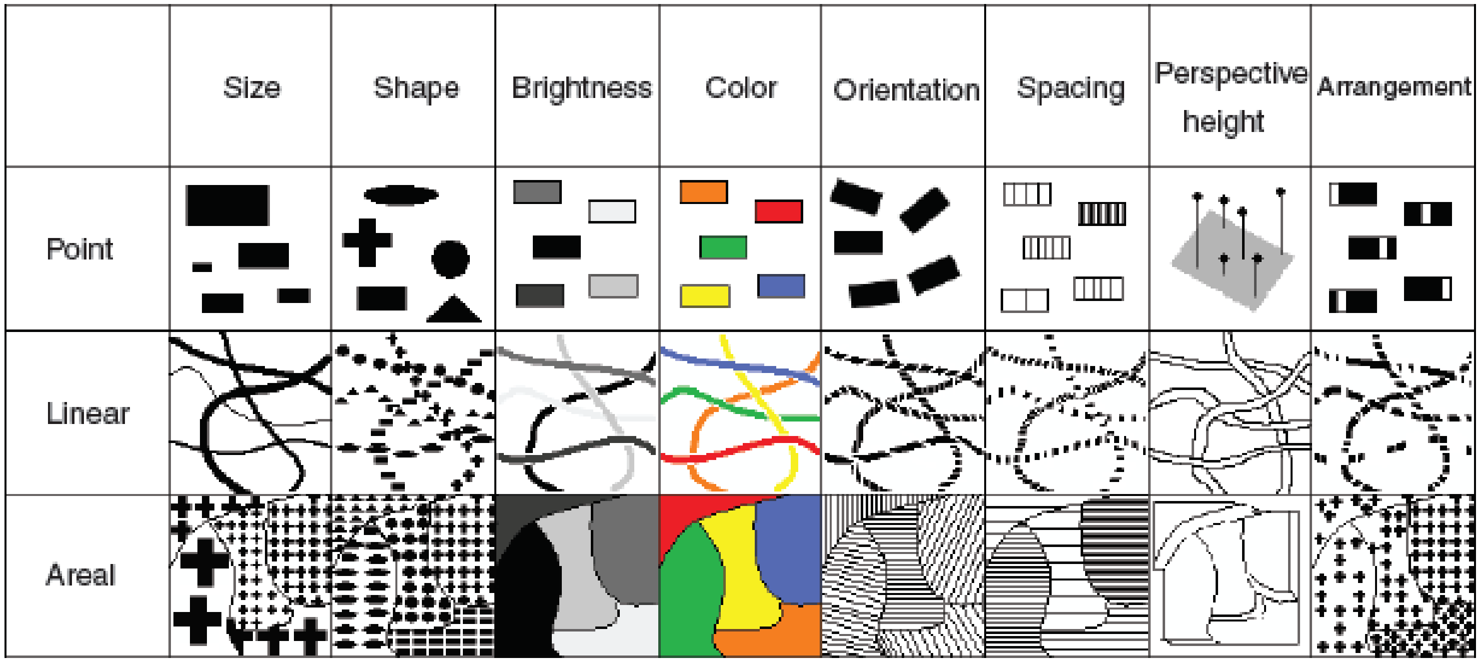


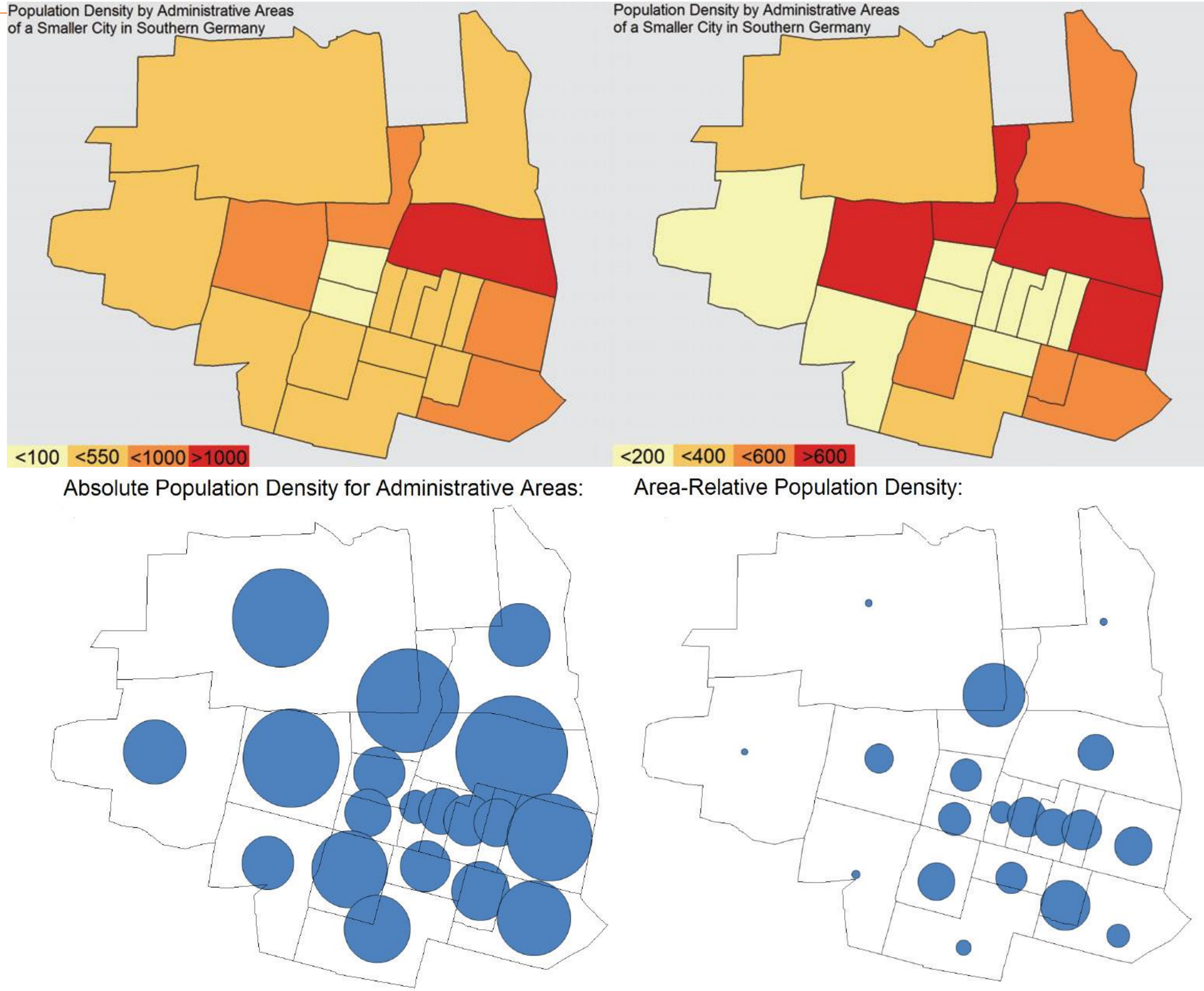
Figure 6.8. Visual variables for spatial data.

Visual Variables for Spatial Data

- Cartographic design has been studied intensively for several decades, and there are well-established guidelines for map design.
- All are based on the results of perceptual research, and the same basic mapping principles as discussed before must be observed.
- Note that in spatial data mapping, the chosen class separation, normalization, and spatial aggregation may have a severe impact on the resulting visualization.
- In Figure 6.9 (top), for example, two visualizations of the same data are shown.

Visual Variables for Spatial Data

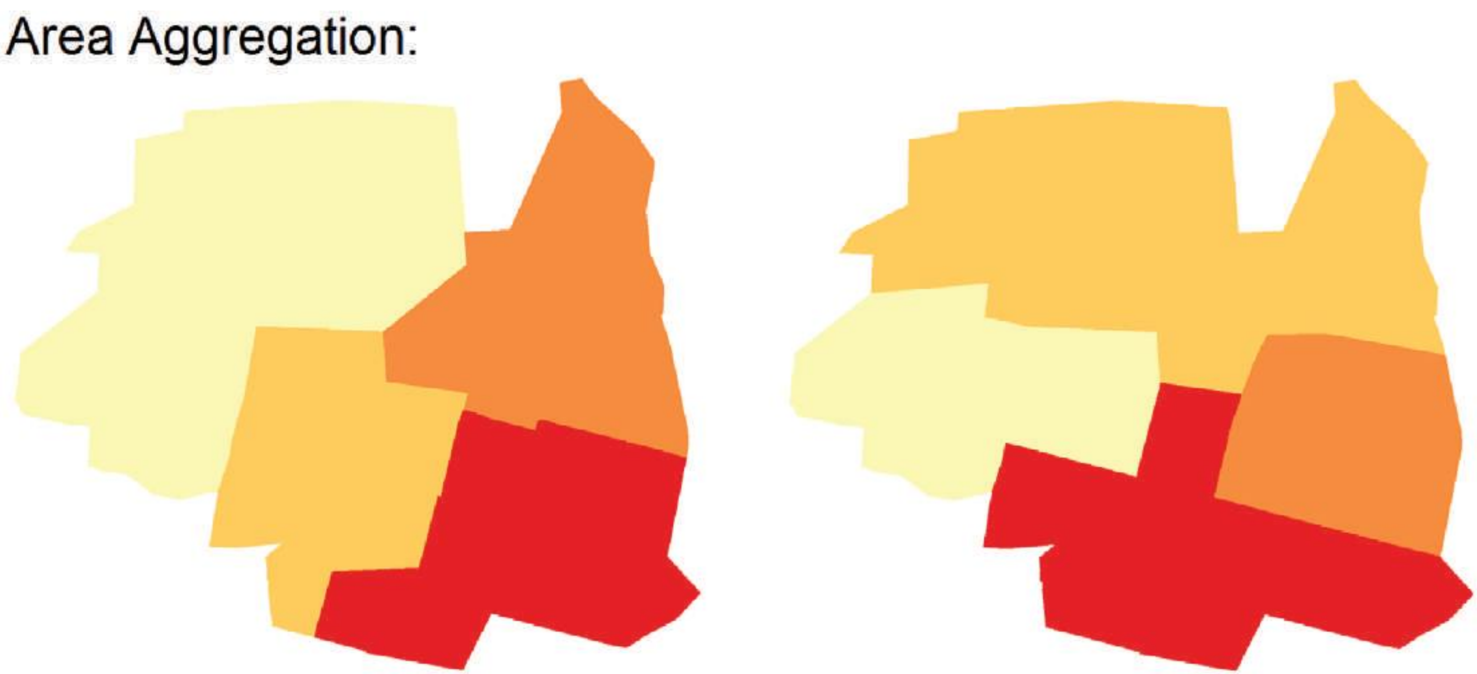
- The only difference is that the class separation chosen has been slightly modified, with a significant impact on the generated map. Figure 6.9 (bottom) shows the significant change resulting from an absolute versus relative mapping.
- On the left side, the absolute numbers are shown, while on the right side, the numbers are displayed relative to the population numbers.
- Note that due to the large population differences in some areas, an inverted visual effect results.
- The visualization also heavily depends on the extent of the areas for aggregation.



- Figure 6.9. Mapping problems: (top) different class breaks yield different choropleth maps; (bottom) absolute versus relative mappings yield different choropleth maps.

Visual Variables for Spatial Data

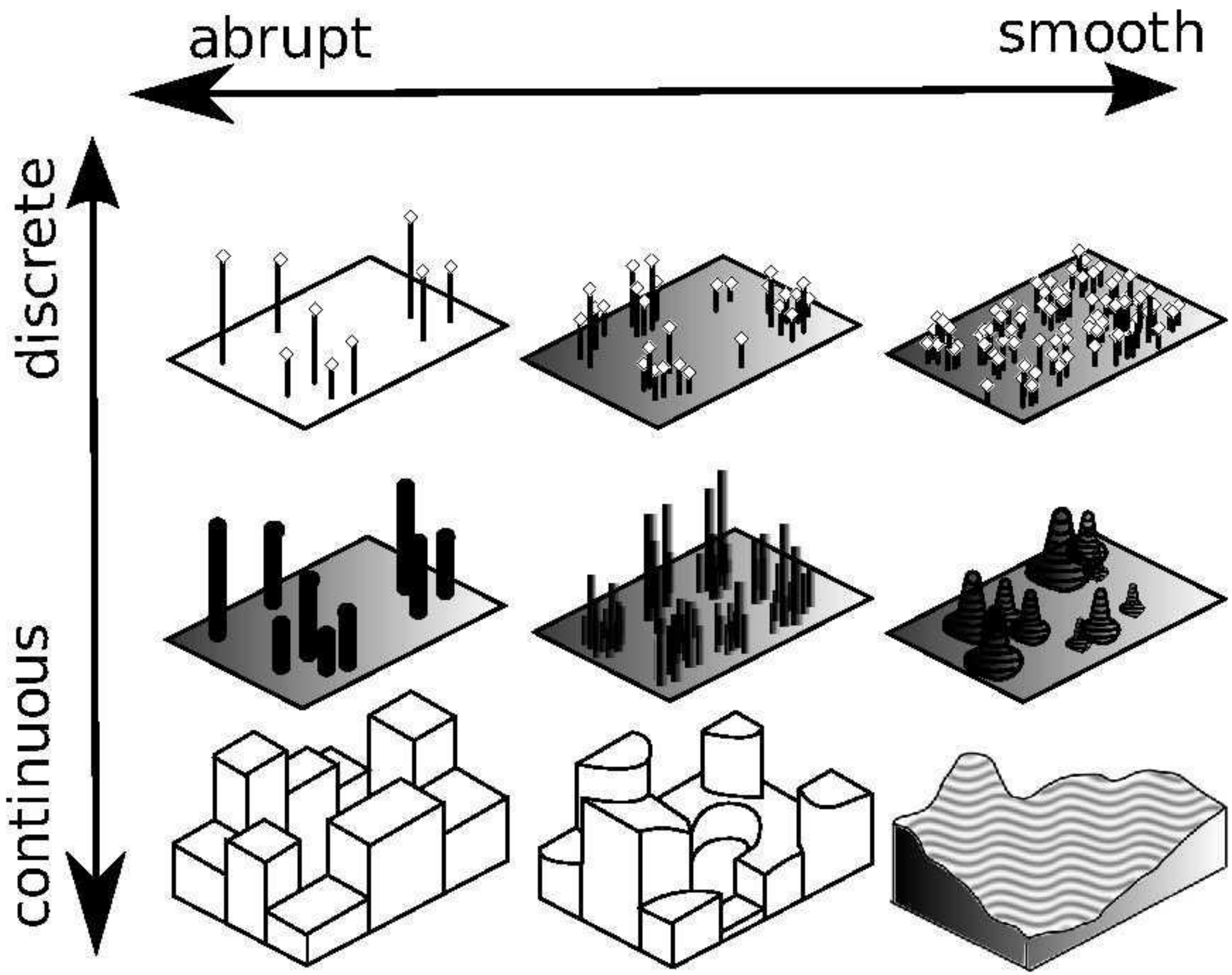
- Figure 6.10 shows the well-known London cholera example with different area aggregations, resulting in quite different maps.



- Figure 6.10. Different spatial aggregation yields different choropleth maps.

Visualization of Point Data

- The first important class of spatial data is *point data*.
- Point data are discrete in nature, but they may describe a continuous phenomenon, for example, temperature measurements at specific locations.
- Depending on the nature of the data and the task, the designer must decide whether to display the data continuously, versus discrete and smooth, versus abrupt.
- Figure 6.11 show the different options.
- *Discrete data* are presumed to occur at distinct locations, while *continuous data* are defined at all locations.
- *Smooth data* refers to data that change in a gradual fashion, while *abrupt data* change suddenly.



- Figure 6.11. Discrete versus continuous and smooth versus abrupt.

Dot Maps

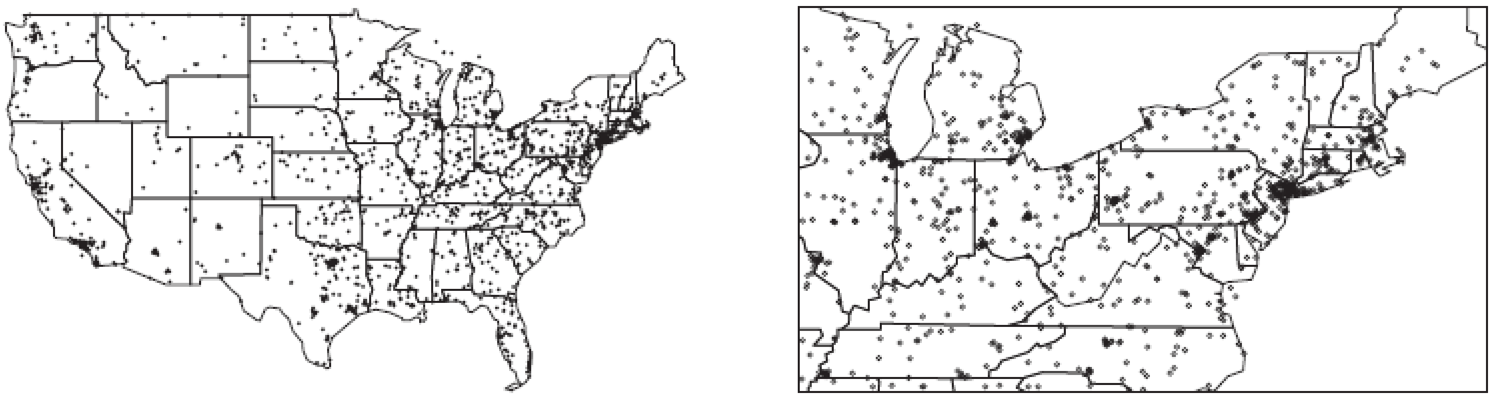
- Point phenomena can be visualized by placing a symbol or pixel at the location where that phenomenon occurs.
- This simple visualization is called a *dot map*.
- A quantitative parameter may be mapped to the size or the color of the symbol or pixel.
- Circles are the most widely used symbol in dot maps, but squares, bars, or any other symbol can be used as well.
- If the size of the symbol is used to represent a quantitative parameter, a specific question is how to scale the symbols.

Dot Maps

- Calculating the correct size of the symbols does not necessarily mean that the symbols will be perceived correctly.
- The perceived size of the symbols does not necessarily correspond to the actual size, due to problems in size perception.
- The perceived size of the symbols depends on their local neighborhood (e.g., the Ebbinghaus illusion), therefore no global formula for perceptual scaling is possible.
- If color is used to represent a quantitative parameter, the problems of color perception must be taken into account.

Dot Maps

- Dot maps are an elegant medium for communicating a wealth of information about the relationships of spatial point phenomena in a compact, convenient, and familiar format.
- However, when large data sets are drawn on a map, the problem of overlap or overplotting of data points arises in highly populated areas, while low-population areas are virtually empty (see Figure 6.12), since spatial data are highly nonuniformly distributed in realworld data sets.
- Examples of such spatial data sets are credit card payments, telephone calls, health statistics, environmental records, crime data, and census demographics.



- Figure 6.12. USA dot map: every circle represents the spatial location of an event. Even in the zoomed-in version there is a large degree of overlap.

Dot Maps

- Note that the analysis may involve multiple parameters that may be shown on multiple maps.
- If all maps show the data in the same way, it may be possible to relate the parameters and detect local correlations, dependencies, and other interesting patterns.
- There are several approaches already in common use for coping with dense spatial data.
- One widely used method is a 2.5D visualization showing data points aggregated up to map regions.

Dot Maps

- An alternative that shows more detail is a visualization of individual data points as bars, according to their statistical value on a map.
- A problem here is that a large number of data points are plotted at the same position, and therefore only a small portion of the data is actually visible.
- Moreover, due to occlusion in 3D, a significant fraction of the data may not be visible unless the viewpoint is changed.

PixelMaps

- One approach that does not aggregate the data, but avoids overlap in the two-dimensional display, is the *PixelMap* approach.
- The idea is to reposition pixels that would otherwise overlap.
- The basic idea of the repositioning algorithm is to recursively partition the data set into four subsets containing the data points in four equal-sized subregions.
- Since the data points may not fit into the four subregions, we must determine new extents of the subregions (without changing the four subsets of data points), such that the data points in each subset can be visualized in their corresponding subregion.

PixelMaps

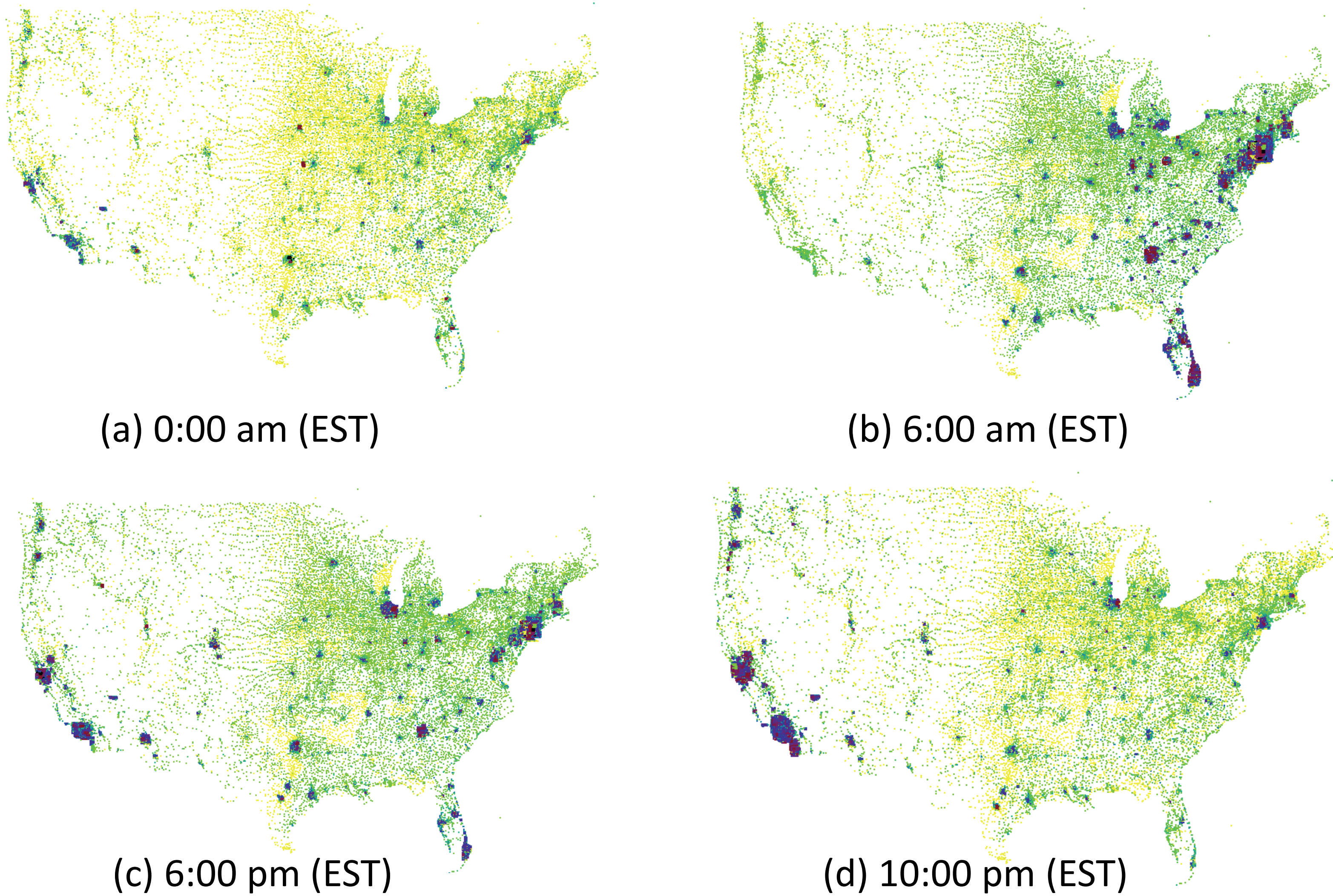
- For an efficient implementation, a quadtree-like data structure manages the required information and supports the recursive partitioning process.
- The partitioning process works as follows.
- Starting with the root of the quadtree, in each step, the data space is partitioned into four subregions.
- The partitioning is made such that the area occupied by each of the subregions (in pixels) is larger than the number of pixels belonging to the corresponding subregion.

PixelMaps

- If—after a few recursions—only a limited number of data points are left in a subregion, the points are positioned by a pixel placement algorithm that positions the first data item at its correct position, and subsequent overlapping data points at nearby unoccupied positions, resulting in a placement that appears locally quasi-random.
- A problem of PixelMaps is that in areas with high overlap, the repositioning depends on the ordering of the points in the database.

PixelMaps

- Figure 6.13 presents four time steps of such visualizations, showing the U.S. Telephone Call Volume within a 10-minute interval of the time denoted.
- The time sequence shows the development of the call volume over time.
- The visualizations allow an intuitive understanding of the development of the call volume, showing the wake-up from east to west and the drop down in call volume at commuting and lunch time, for example.



(a) 0:00 am (EST)

(b) 6:00 am (EST)

(c) 6:00 pm (EST)

(d) 10:00 pm (EST)

Figure 6.13. The figures display U.S. Telephone Call Volume at four different times during one day.

Visualization of Line Data

- The basic idea for visualizing spatial data describing linear phenomena is to represent them as line segments between pairs of endpoints specified by longitude and latitude.
- A standard mapping of line data allows data parameters to be mapped to line width, line pattern, line color, and line labeling.
- In addition, data properties of the starting and ending points, as well as intersection points, may also be mapped to the visual parameters of the nodes, such as size, shape, color, and labeling.

Visualization of Line Data

- The lines do not need to be straight, but may be polylines or splines, in order to avoid clutter in the display.
- Which mapping is best depends on the application and the task.
- Note that the choices in visualizing line data are similar to those in graph drawing, except that the position of the nodes in the display is fixed in geospatial applications, whereas it is part of the mapping and optimization process in graph drawing applications.

Network Maps

- Network maps are widely used in a variety of applications.
- Some approaches only display the connectivity of networks for understanding their general behavior and structure.
- Eick, and Wills used functions such as aggregation, hierarchical information, node position, and linked displays for investigating large networks with hierarchies and without a natural layout.
- They used color and shape for coding node information and color and line width for coding link information.

Network Maps

- Researchers at NCSA added 3D graphics to their network maps to display animations of Internet traffic packets within the network backbone.
- Becker, Eick and Wilks describe a system called *SeeNet* , which is motivated by research in dynamic statistical graphics.
- The basic idea is to involve the human and let him/her interactively control the display to focus on interesting patterns.
- They use two static network displays to visualize the geographic relationships, and a link matrix, which gives equal emphasis to all network links.

Network Maps

- Another interesting system for visualizing large network data is AT&T's SWIFT-3D System.
- This system integrates a collection of relevant visualization techniques, ranging from familiar statistical displays to pixel-oriented overviews, with interactive 3D-maps and drag+drop query tools (see Figure 6.14)

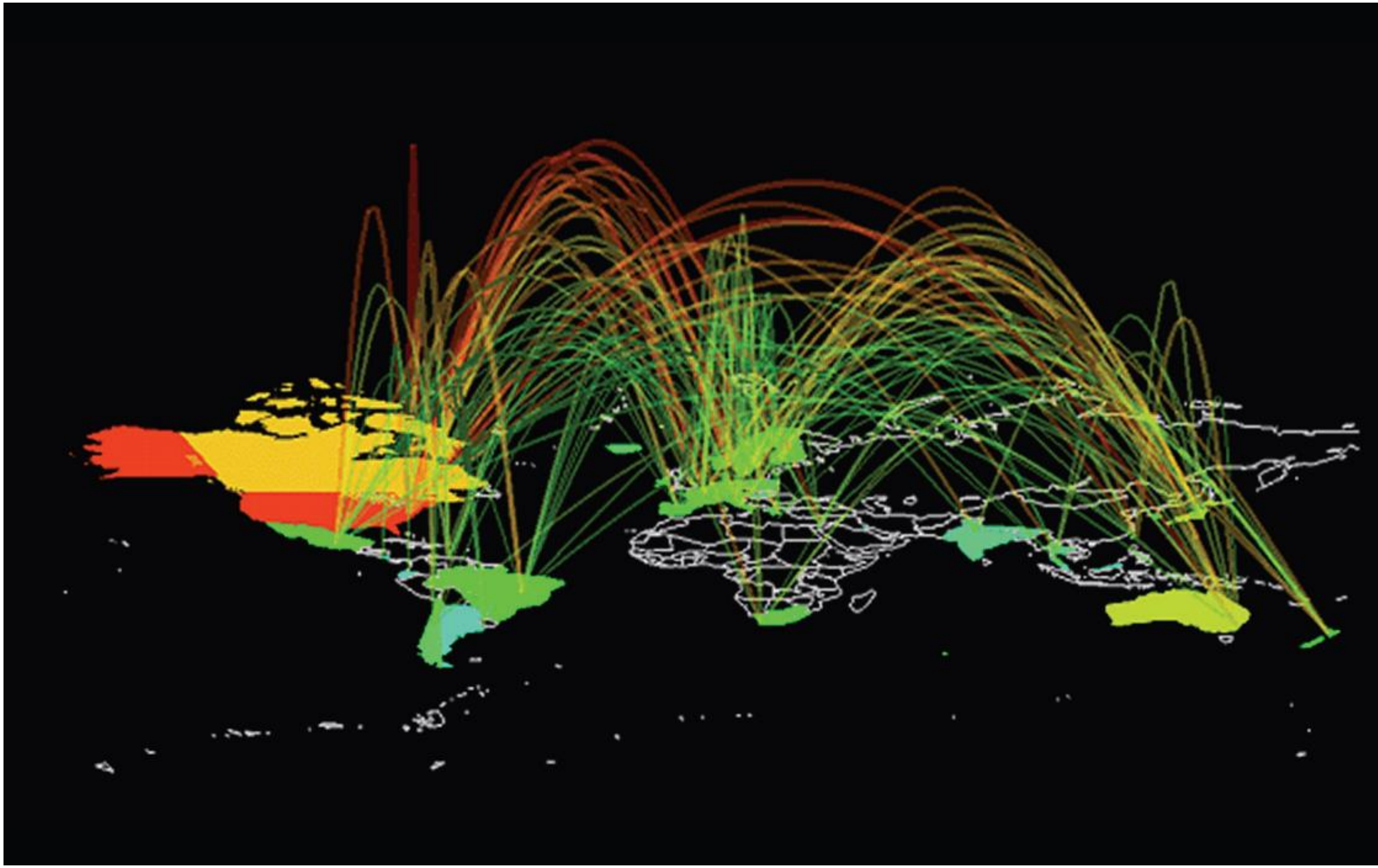
- Figure 6.14. Swift-3D.

Network Maps

- The visualization component maps the data to a set of linked 2D and 3D views created by different visualization techniques: statistical 2D visualizations, pixel-oriented 2D visualizations, and dynamic 3D visualizations.
- In all mentioned approaches, however, the visualization of large networks on maps leads to the overlap problem of line segments in dense areas.

Flow Maps and Edge Bundling

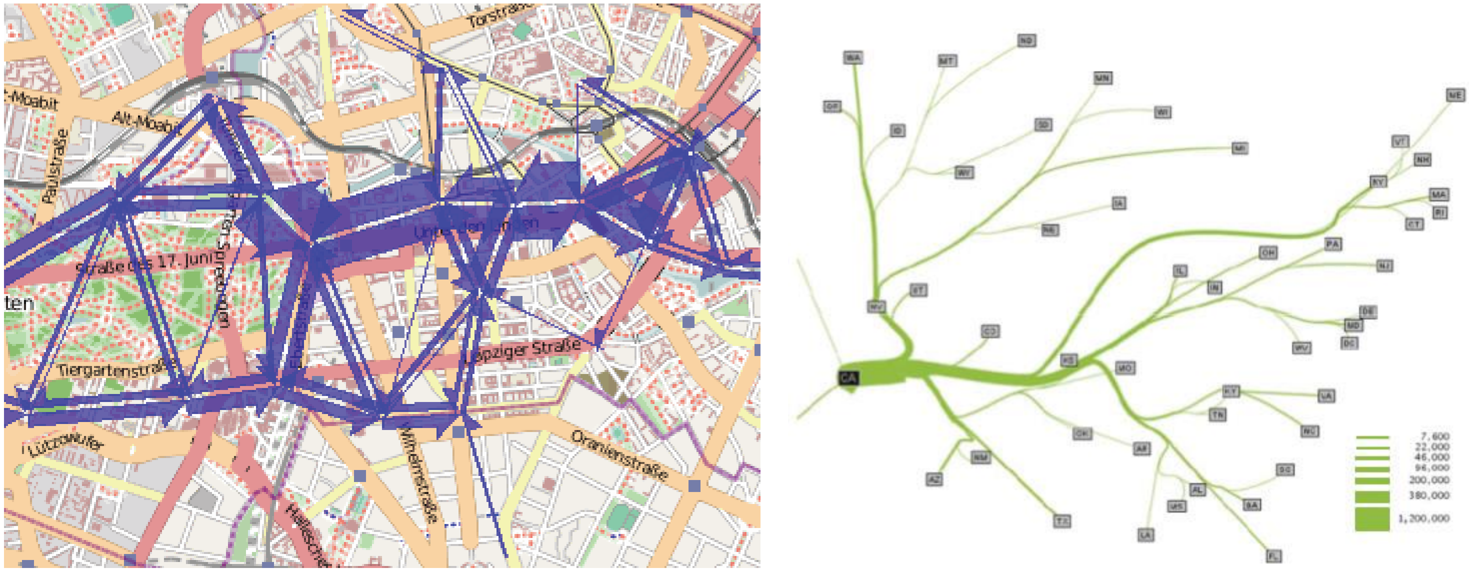
- There are a number of approaches that try to avoid the overlap problem of traditional network maps by using curved lines instead of straight lines (see Figure 6.15).
- While this has been done mostly manually by cartographers in the past, a number of approaches for an algorithmically generated visualization of network maps with curved lines have been proposed.
- Two prominent examples are Stanford flow maps and Danny Holten's edge bundling.



• Figure 6.15. ArcMap.

Flow Maps and Edge Bundling

- The *flow map* technique is inspired by graph layout algorithms that minimize edge crossings and node position distortions, while retaining their relative positions.
- Algorithmically, a hierarchical clustering based on node positions and flows between the nodes is performed to compute a useful merging and rerouting of flows.
- In comparison to other computer-generated flow maps (Figure 6.16(a)), the results of the Stanford system show a much clearer picture, with the clutter being significantly reduced (Figure 6.16(b)).



(a) (b)

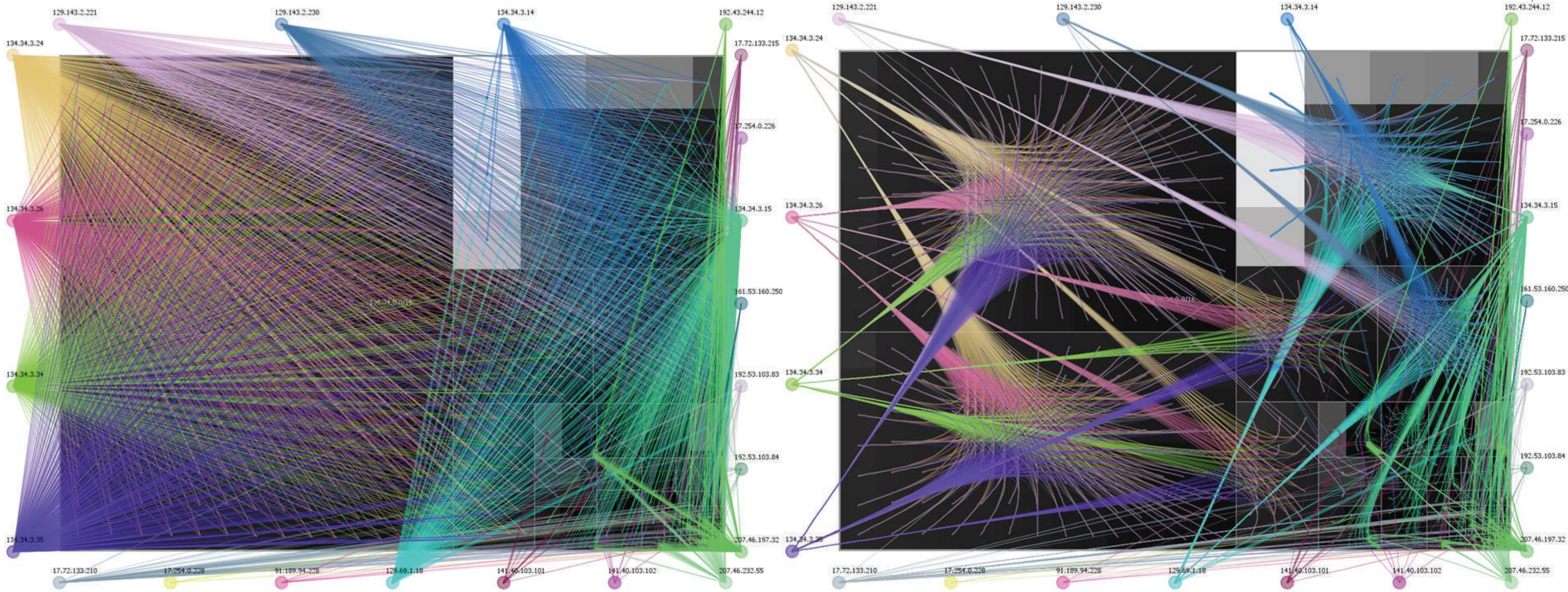
- Figure 6.16. Flow maps: (a) flows of tourists in Berlin; (b) produced by the Stanford system showing the migration from California

Flow Maps and Edge Bundling

- Edge bundling also aims at reducing the clutter in line drawings.
- If a hierarchy is defined on the nodes, the edges can be bundled according to the hierarchy by using the hierarchy as defining points for B-splines connecting two nodes.
- Nodes connected through the root of the hierarchy are maximally bent, while nodes within the same subhierarchy are only minimally bent.
- Hierarchical bundling significantly reduces visual clutter.

Flow Maps and Edge Bundling

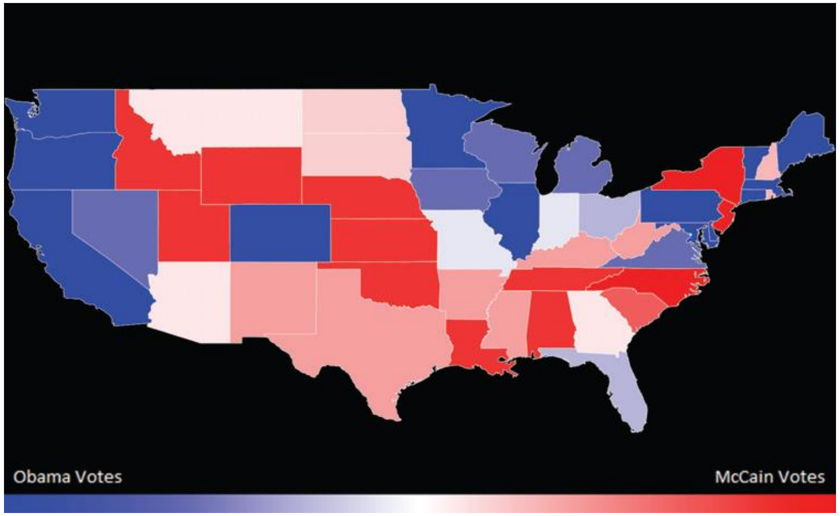
- It is a generic method that can be used in conjunction with a number of visualization techniques, including traditional maps, but also standard tree visualizations, circular trees, treemaps, and many others.
- The example in Figure 6.17 displays edge bundling being applied to a visualization of IP traffic data.
- The visualization shows the traffic from external nodes that are on the outside, to internal nodes that are visualized as a treemap.
- The comparison between the standard visualization of the connections by straight lines and the edge bundling visualization clearly shows the advantage of the technique.



- Figure 6.17. The visualizations show IP flow traffic from external nodes on the outside to internal nodes, visualized as treemaps on the inside. The edge bundling visualization (right side) significantly reduces the visual clutter compared to the straight line visualization (left side).

Visualization of Area Data

- Thematic maps are the main approach to visualizing area phenomena.
- There are different variants of thematic maps.
- The most popular type of thematic maps are *choropleth maps* (Greek: choro = area, pleth = value), in which the values of an attribute or statistical variable are encoded as colored or shaded regions on the map.
- Choropleth maps (Figure 6.18(a)) assume that the mapped attribute is uniformly distributed in the regions.
- If the attribute has a different distribution than the partitioning into regions, other techniques, such as dasymetric maps, are used.



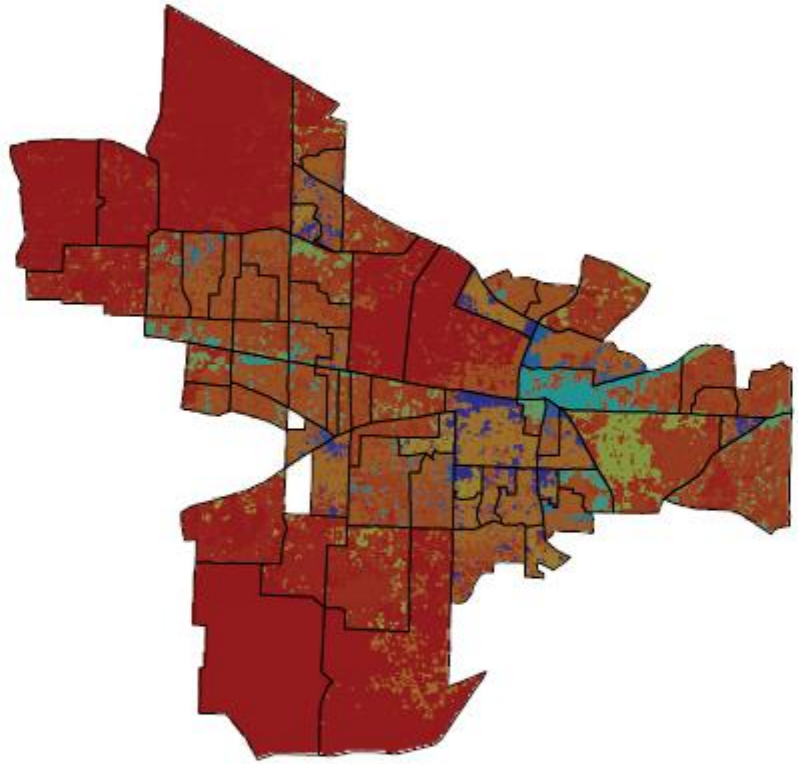
(a)

(b)

- Figure 6.18. Thematic maps:
- (a) A choropleth map showing U.S. election results of the 2008 Obama versus McCain presidential election.
- (b) An isarithmic map showing the number of pictures taken on Mainau Island, using a heatmap, where the colors range from black to red to yellow, with yellow representing the most photographs.

Visualization of Area Data

- In *dasymetric maps* (Figure 6.19), the variable to be shown forms areas independent of the original regions, e.g., in contrast to choropleth maps, the boundaries of the areas derived from the attribute do not need to match the given map's regions.
- A third important type of map is an *isarithmic map* (Figure 6.18(b)), which shows the contours of some continuous phenomena.
- Widely used examples of isarithmic maps are contour maps or topographic maps.



- Figure 6.19. A dasymetric map showing the population distribution in Beaverton Creek, Oregon, USA.

Visualization of Area Data

- If the contours are determined from real data points (such as temperatures measured at a specific location) the maps are called *isometric maps*; if the data are measured for a certain region (such as a county) and, for example, the centroid is considered as the data point, the maps are called *isopleth maps*.
- One of the main tasks in generating isarithmic maps is the interpolation of the data points to obtain smooth contours, which is done, for example, by triangulation, or inverse distance mapping.

Visualization of Area Data

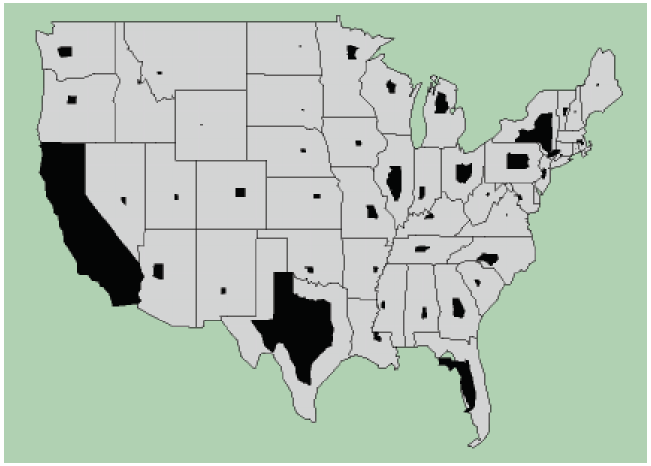
- A complex, but less frequently used mapping technique, is *cartograms*, in which the size of regions is scaled to reflect a statistical variable, leading to unique distortions of the map geometry.
- There are different variants of cartograms, ranging from continuous cartograms that retain the topology of the polygon mesh, to noncontinuous cartograms that simply scale each polygon independently to rectangular or circular approximations of the areas.

Cartograms

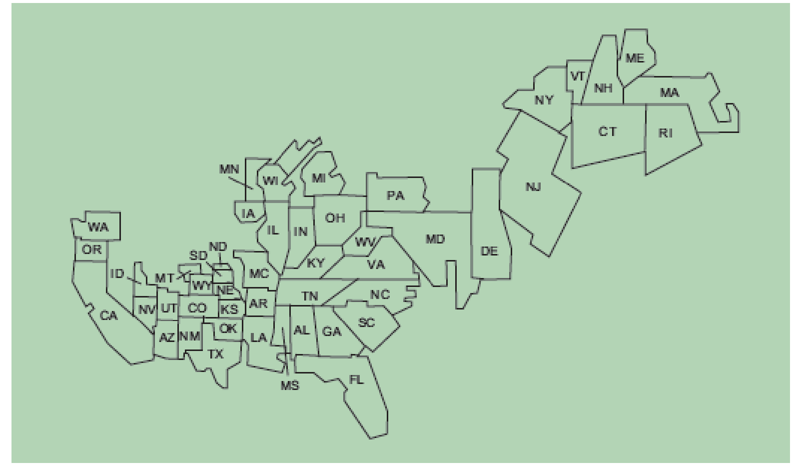
- *Cartograms* are generalizations of ordinary thematic maps that avoid the problems of choropleth maps by distorting the geography according to the displayed statistical value.
- Cartograms are a specific type of map transformation, where the regions are resized according to a geographically related input variable.
- Example applications include population demographics, election results, and epidemiology.

Cartograms

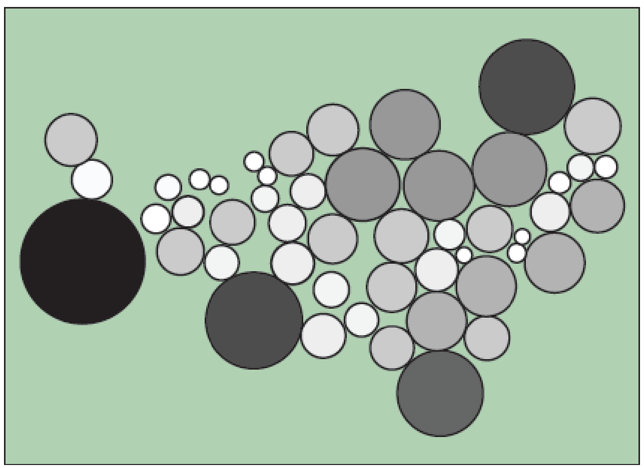
- Several categories of cartogram problems exist.
- As shown in Figure 6.20(a), *noncontinuous cartograms* can exactly satisfy area and shape constraints, but don't preserve the input map's topology.
- Because the scaled polygons are drawn inside the original regions, the loss of topology doesn't cause perceptual problems.
- More critical is that the polygon's original size restricts its final size.
- Consequently, you can't make small polygons arbitrarily large without scaling the entire map, so important areas can be difficult to see, and screen usage can be poor.



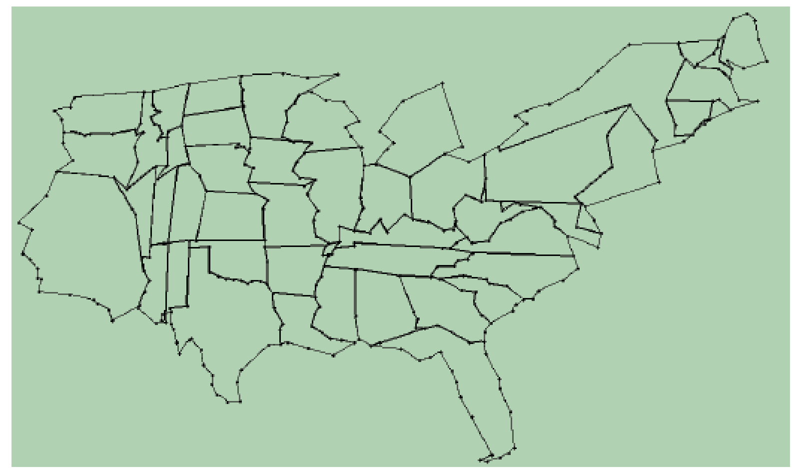
(a) Noncontinuous cartogram.



(b) Noncontiguous cartogram.



(c) Circular cartogram.



(d) Continuous cartogram.

- Figure 6.20. Different types of cartograms.

Cartograms

- *Noncontiguous cartograms*, shown in Figure 6.20(b), scale all polygons to their target sizes, perfectly satisfying the area objectives.
- Shapes can be slightly relaxed, so polygons touch without overlapping, and the map's topology is also highly relaxed, because polygons don't retain their adjacency relationships.
- Noncontiguous cartograms provide perfect area adjustment, with good shape preservation.
- However, they lose the map's global shape and topology, which can make perceiving the generated visualization as a map difficult.

Cartograms

- *Circular cartograms*, shown in Figure 6.20(c), completely ignore the input polygon's shape, representing each as a circle in the output.
- In many cases, area and topology constraints are also relaxed, so circular cartograms have some of the same problems as noncontiguous cartograms.
- The final category is *continuous cartograms*, shown in Figure 6.20(d).
- Unlike the other categories, continuous cartograms retain a map's topology perfectly, but they relax the given area and shape constraints.

Cartograms

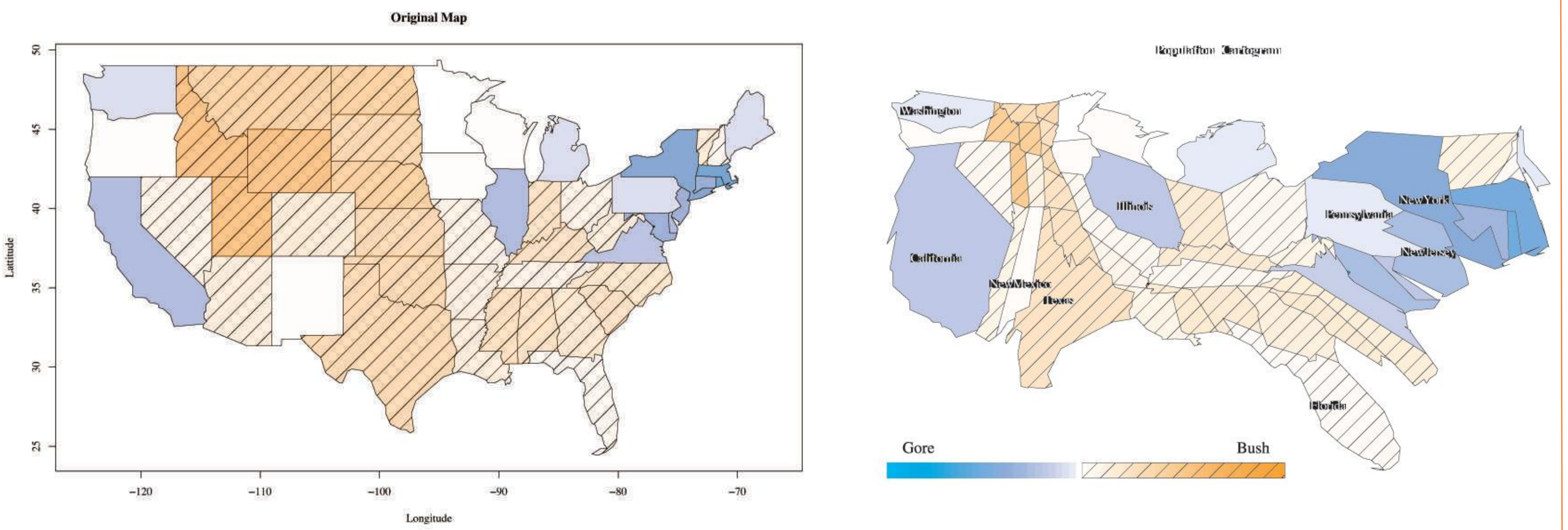
- In general, cartograms can’t fully satisfy shape or area objectives, so cartogram generation involves a complex optimization problem in searching for a good compromise between shape and area preservation.
- Although continuous cartograms are difficult to generate, the resulting polygonal meshes resemble the original map more than other computergenerated cartogram variants.
- The rest of this section therefore focuses on continuous cartograms.

Cartograms

- Because cartograms are difficult to make by hand, the study of computergenerated automated methods is of special interest.
- Cartograms can also be seen as a general information visualization technique.
- They provide a means for trading shape against area to improve a visualization by scaling polygonal elements according to an external parameter.
- In population cartograms, more space is allocated to densely populated areas; patterns that involve many people are highlighted, while those involving fewer people are less emphasized.

Cartograms

- Figure 6.21 shows a conventional map of the 2000 U.S. presidential election, along with a population-based cartogram presenting the same information.
- In the cartogram, the area of the states is scaled to their population, so it reveals the close result of a presidential election more effectively than the original choropleth map.
- For a cartogram to be effective, a human being must be able to quickly understand the displayed data and relate it to the original map.



- Figure 6.21. A U.S. state population cartogram with the presidential election results of 2000. The area of the states in the cartogram corresponds to the population, and the color (shaded and not shaded areas) corresponds to the percentage of the vote. A bipolar color map depicts which candidate has won each state.

Cartograms

- Recognition depends on preserving basic properties, such as shape, orientation, and contiguity.
- This, however, is difficult to achieve, and it has been shown that the cartogram problem is unsolvable in the general case.
- Even when allowing for errors in the shape and area representations, we are left with a difficult simultaneous optimization problem for which currently available algorithms are very time consuming.

The Continuous Cartogram Problem

- The *continuous cartogram problem* can be defined as a map deformation problem.
- The input is a planar polygon mesh (map) *P* and a set of values *X*, one for each region.
- The goal is to deform the map into *P* so that the area of each region matches the value assigned to it, doing this in such a way that the overall shape of the regions is preserved, and that they all remain recognizable.

The Rectangular Cartogram Problem

- The idea of rectangular cartograms is to approximate familiar land-covering map region shapes by rectangles, and to find a partition of the available screen space where the areas of these rectangular regions are proportional to given statistical values.
- In order to support the understanding of the information represented by a cartogram, the rectangles are placed as close as possible to their original positions, and as close as possible to their original neighbors.

The Rectangular Cartogram Problem

- The problem may be defined as an optimization problem with a number of constraints and optimization criteria, including the area, topology, relative polygon position, proportion of the rectangle, and empty space.
- In defining a specific instance of the problem, these criteria may be set as required constraints or as a weighted part of the optimization function.
- For some of the variants of the rectangular cartogram problem, efficient approximation algorithms such as the RecMap algorithm exist.

Other Issues in Geospatial Data Visualization

- Prerequisite to generating useful visualizations of spatial phenomena are a number of well-known techniques from cartography, including map generalization and map labeling.
- *Map generalization* is the process of selecting and abstracting information on a map.
- Generalization is used when a special-purpose small-scalemap is derived from a large-scalemap containing detailed information.
- The goal is to adapt the objects on the map in such a way that the objects of interest may be easily perceived in the resulting visualization.

Other Issues in Geospatial Data Visualization

- Note that map generalizations are application- and task-dependent, e.g., good map generalizations emphasize the map elements that are most important for the task at hand, while still representing the geography in the most accurate and recognizable way.
- It is important that the visibility and recognizability of the objects displayed on the map outweigh the lost details of items that are generalized.
- The goal is to preserve the distinguishing characteristics of what makes the map useful in the particular application.

Examples for typical map generalizations

- *Simplify points*—remove or combine points that are not relevant or not separately visible on the small-scale map.
- *Simplify lines*—remove small fluctuations and bends or collapse dual lines to centerlines. Lines that are in danger of touching each other in the scaled version of the map may be removed.
- *Simplify polygons*—remove small fluctuations and bends while preserving the essential shape feature. This includes the removal or simplification of building footprint boundaries while preserving the essential shape and size, as well as the combination of disjoint but adjacent polygons into a new area based on a specified tolerance distance.

Other Issues in Geospatial Data Visualization

- Map labeling deals with placing textual or figurative labels close to points, lines, and polygons.
- This seems to be an easy and straightforward task, but it has been shown to be a difficult problem.
- There are a large number of label placement algorithms that differ in their effectiveness, e.g., quality of the results, and their efficiency, e.g., speed of calculating the label placement.
- Map labeling algorithms are based on heuristics, and in most cases use a rule-based label placement followed by an optimization algorithm, such as local search, greedy algorithms, simulated annealing, random placement, and genetic algorithms.

Other Issues in Geospatial Data Visualization

- Many other issues are related to the design of effective *geographic information systems* (GIS).
- A GIS essentially allows users to create interactive queries for dynamic search and exploration, to compare and edit spatial data on different geographic map layers, and finally to present the results of all these operations.
- Geospatial data visualization is just a part of GIS.
- The advance of visualization and other relevant GIS functions could benefit each other to make the whole system more powerful and useful.

Other Issues in Geospatial Data Visualization

- In recent years, with the advance of fast-growing web technology and APIs (e.g., Flex, AJAX, and the Google MAP API), as well as public availability of digitized geographic data and various economic, social, environmental measures and indicators data via the Internet, the GIS community has developed a large number of interactive high-performance tools for spatial data visualization.
- These tools significantly increase the awareness and better understanding of public issues among large populations of people.
- It turns out that the visualization of geospatial data has become exciting to many people.

Other Issues in Geospatial Data Visualization

- For an advanced GIS, there is a trend that the geospatial data visualization needs to integrate with temporal data visualization, such that the system could more easily and systematically track and model the information as it changes over time.
- As GIS needs sufficiently integrate data from different sources for facilitating interoperability (e.g., comparing data whose metadata might be slightly different) and data is reused among GIS applications, it is important for geospatial visualization to work with associated ontologies, which provide a semantic approach to allow different specifications of the same concepts and relationships in a given domain to work in a uniform workspace.

Question
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