DATA VISUALIZATION

Chapter(4)

Spatial Data Visualization

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OVERVIEW

- Scalar fields
- Isocontours (Topographic Terrain maps), scalar volumes, Direct volume
- Rendering (Multidimensional transfer functions)
- Maps (dot, pixel)
- vector fields
- Defining marks and channels

SPATIAL DATA VISUALIZATION

- **Spatial data** is any type of **data** that directly or indirectly references a specific geographical area or location.
- Sometimes called geospatial data or geographic information, spatial data can also numerically represent a physical object in a geographic coordinate system.
- There are several spatial data types, but the two primary kinds of spatial data are geometric data and geographic data.
  1. **Geometric data** is a spatial data type that is mapped on a two-dimensional flat surface. An example is the geometric data in floor plans. Google Maps is an application that uses geometric data to provide accurate direction. In fact, it is one of the simplest examples of spatial data in action.
  2. **Geographic data** is information mapped around a sphere. Most often, the sphere is planet earth. Geographic data highlights the latitude and longitude relationships to a specific object or location. A familiar example of geographic data is a global positioning system.

SPATIAL DATA VISUALIZATION

- Spatial data visualization is the process of using visual elements such as maps, graphs, charts, and other visual representations to help understand and analyze geographic data.
- These visualizations focus on the relationship between data and its physical location to create insight.
- visualizations highlight the physical connection between data points. This makes them susceptible to a few common pitfalls that may introduce error:
    1. Scaling - Changes in the size of the map can affect how the viewer interprets the data
    2. Auto-correlation - A view may create an association between data points appearing close on a map, even for unrelated data
- It involves creating a visual representation of geographic data, which enables us to identify patterns, relationships, and trends that may not be apparent in raw data.
- Spatial data visualization is widely used in many fields, including urban planning, public health, environmental science, and business.

SPATIAL DATA VISUALIZATION

- spatial visualizations can tell stories about human existence.
- Historically, doctors and scientists have used this kind of presentation to map illness, resources, and even simple navigation.
- In recent years, the most prevalent use of geospatial visualizations is likely through Google Maps and similar apps.
- They allow us to find the fastest way to travel from point A to point B or to identify where something is on Earth.

SCALAR FIELDS

- A scalar field is a mathematical function that assigns a scalar value to each point in a given space.
- A scalar field is a function that gives us a single value of some variable for every point in space.
- In other words, it associates a single value (a scalar) with each point in space. Scalar fields are widely used in physics, engineering, and other fields to describe quantities such as temperature, pressure, density, and potential.
- Some examples of scalar fields include:
  1. Temperature: A scalar field that describes the temperature at each point in space.
  2. Pressure: A scalar field that describes the pressure at each point in space.
  3. Density: A scalar field that describes the density of a fluid at each point in space.
  4. Potential: A scalar field that describes the potential energy at each point in space.
- Scalar fields are used in many fields of science and engineering to model physical phenomena.
- For example, in fluid dynamics, scalar fields such as temperature and pressure are used to describe the behavior of fluids.
- In electromagnetism, scalar fields such as electric potential and magnetic potential are used to describe the behavior of electric and magnetic fields

SCALAR FIELDS

- For example, consider a dataset that contains information about the average temperature at different locations in a city. Each data point in the dataset represents the temperature at a specific location, and the temperature can be considered a scalar value. A scalar field can be created by mapping the temperature values to the corresponding location in space.
- A contour plot can be used to visualize the scalar field. In a contour plot, lines of constant value (called contours) are plotted on a map to show areas with similar values. In the example of temperature data, a contour plot can be used to show areas with similar temperatures. The lines connect points with the same temperature, and the density of the lines can indicate the rate of change of temperature.
- A heat map is another way to visualize scalar fields. In a heat map, the scalar values are mapped to colors or shades of color, and the resulting image is a map of the distribution of the scalar field. In the example of temperature data, a heat map can be used to show the variation of temperature across the city. Warmer areas would be represented with warmer colors, while cooler areas would be represented with cooler colors.

ISOCONTOURS

- Isocontours, also known as contour lines or topographic lines, are lines on a map that connect points of equal elevation or value.
- These lines provide valuable information about the shape, slope, and relief of the terrain or any other variable being represented on the map

ISOCONTOURS

- **Definition:** Isocontours are lines that connect points with the same value. In the case of topographic maps, these lines connect points with the same elevation. Each contour line represents a specific elevation, and the spacing between the contour lines indicates the steepness of the terrain. Closer contour lines indicate steeper slopes, while widely spaced lines represent flatter areas.
- **Elevation Representation:** On a topographic map, each contour line represents a constant elevation above a reference point, usually mean sea level. For example, if the contour interval is set to 10 meters, every contour line will represent a point that is 10 meters higher or lower than the adjacent lines. The contour interval is usually indicated on the map's legend.
- **Characteristics:** Contour lines never intersect or branch out. They can form closed loops to indicate hills, depressions, or mountains. In closed loops, the innermost contours represent higher elevations than the outer contours. V-shaped or U-shaped contour lines depict valleys or ridges, respectively. Steep slopes are indicated by closely spaced contour lines, while gentle slopes have widely spaced lines.
- **Gradient and Slope:** By observing the spacing and pattern of contour lines, it is possible to determine the slope of the terrain. Close contour lines indicate a steep slope, while widely spaced lines suggest a gentle slope. The steepest slope on a topographic map is where the contour lines are closest together or when two contour lines merge into one, forming a cliff or a vertical slope.

ISOCONTOURS

- **Index Contours:** Index contours are contour lines labeled with their corresponding elevations. These lines are usually bolder or thicker than the other contour lines on the map. Index contours are spaced farther apart, typically at regular intervals (e.g., every fifth line), to provide a quick reference for elevation values.
- **Supplementary Contours:** In addition to the regular contour lines, topographic maps may include supplementary contour lines that represent intermediate elevations. These lines are usually shown as dashed or dotted lines and help provide a more detailed representation of the terrain.
- **Topographic Map Symbols:** Topographic maps use various symbols and markings to represent natural and man-made features, such as rivers, roads, buildings, forests, and more. These symbols are usually included in the map's legend or key, enabling readers to interpret the map accurately.
- **Applications:** Topographic maps and isocontours have numerous applications. They are crucial for land surveying, urban planning, hiking, mountaineering, civil engineering, environmental studies, and various scientific research. They provide essential information about the terrain, including elevation changes, slope analysis, drainage patterns, and identification of potential hazards.

TOPOGRAPHIC TERRAIN MAPS

- Topographic terrain maps, also known as topographic maps or contour maps, are maps that represent the physical features of a specific area, such as mountains, valleys, rivers, and other landforms.
- These maps use contour lines to depict the elevation and relief of the terrain
- Here are some key elements and features you may find on a topographic terrain map:

Contour Lines:

Contour lines are curved lines that connect points of equal elevation. They provide information about the shape of the land and its steepness. Contour lines that are close together indicate steep terrain, while lines that are farther apart represent flatter areas.

Elevation Markings:

Topographic maps often include elevation markings along the contour lines, indicating the elevation at specific points on the map. These markings help determine the height of mountains, valleys, and other landforms.

Relief Shading:

Relief shading is a technique used to provide a visual representation of the terrain's three-dimensional characteristics. It involves using shadowing or coloring to simulate the effects of light and shade on the landscape, helping to visualize the highs and lows of the land.

TOPOGRAPHIC TERRAIN MAPS

Vegetation and Land Cover:

Topographic maps may include symbols or colors to depict different types of vegetation and land cover, such as forests, grasslands, wetlands, and urban areas. These symbols help identify the types of environments and land use in the area.

Water Features:

Rivers, lakes, streams, and other bodies of water are usually depicted on topographic maps. They are often indicated by blue lines or symbols.

Man-Made Features:

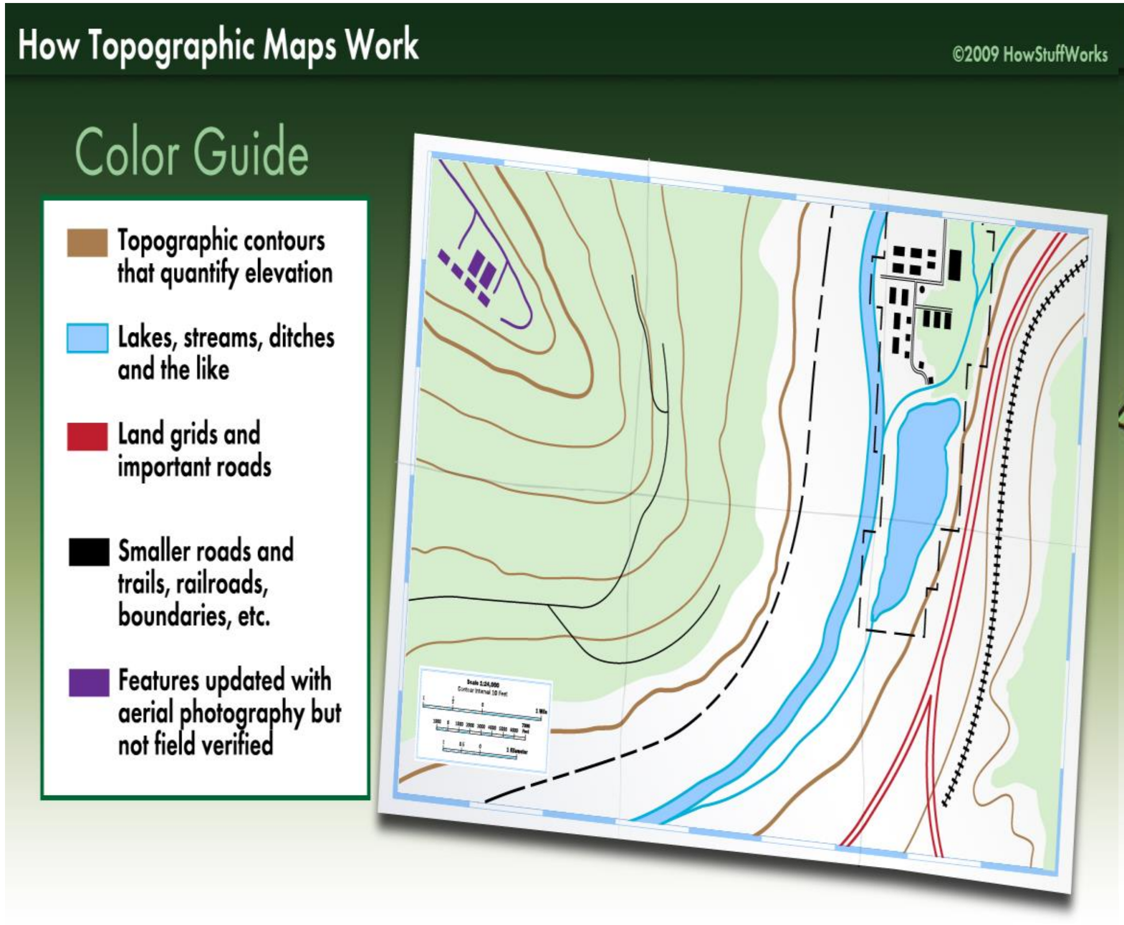
Topographic maps can also show man-made features, such as roads, highways, buildings, bridges, railroads, and other infrastructure. These features are essential for navigation and understanding the human influence on the landscape.

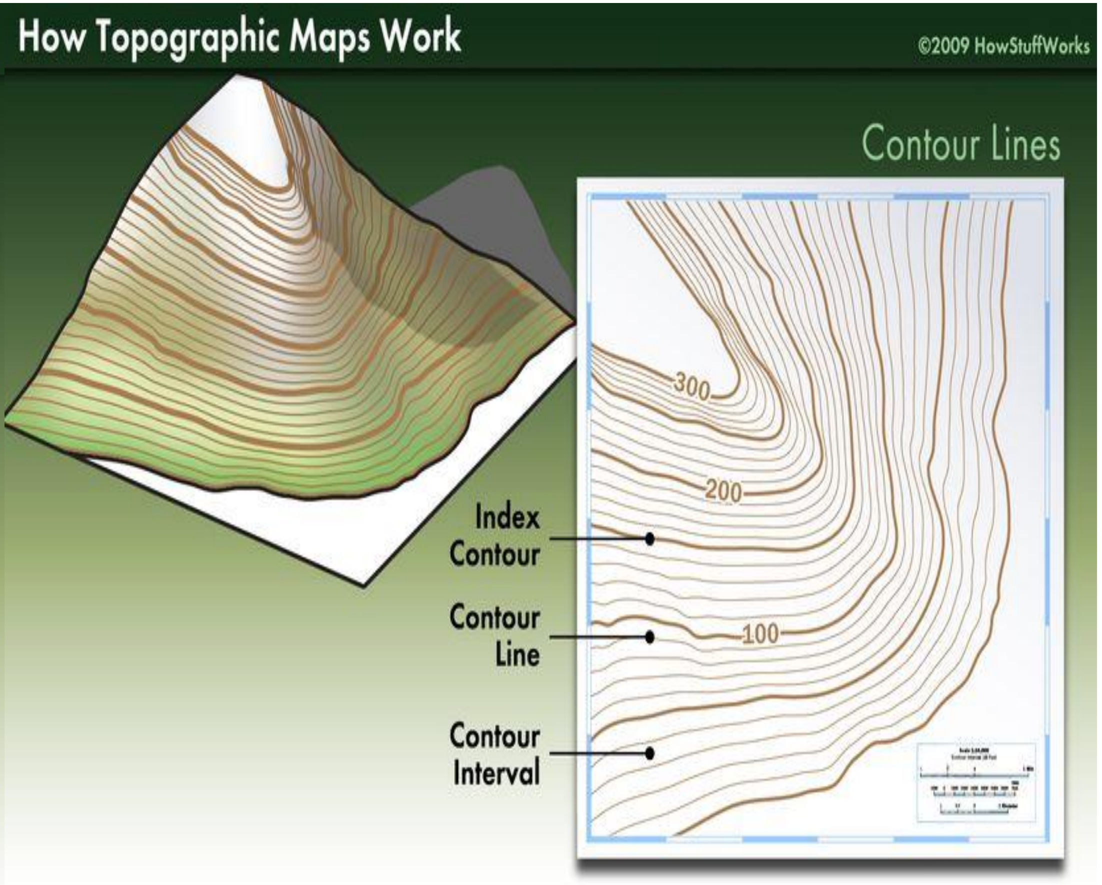
Scale and Legend:

Topographic maps include a scale bar to determine distances on the map. A legend or key is provided to explain the symbols, colors, and other elements used on the map.

Topographic terrain maps are widely used in various fields, including geography, geology, outdoor recreation, urban planning, and environmental studies. They are valuable tools for hikers, surveyors, scientists, and anyone who needs to understand the physical characteristics of a specific area.

TOPOGRAPHIC TERRAIN MAPS





SCALAR VOLUMES

- Scalar volumes refer to three-dimensional datasets where each point in space is associated with a scalar value.
- In other words, scalar volumes represent volumetric data where a single scalar quantity, such as temperature, density, or intensity, is defined at each point in the volume.

Example: A medical CT scan of the brain can be represented as a scalar volume, where each voxel corresponds to a specific location and contains a scalar value representing tissue density.

- **Scalar Volume Representation:**

  In a scalar volume, the scalar values are typically represented on a regular grid, forming a three-dimensional array.

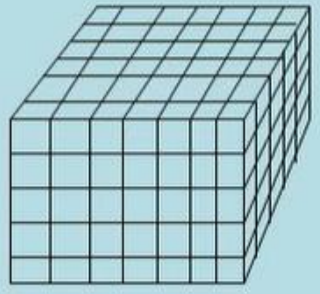
  Each grid point, also known as a voxel (volume pixel), contains a scalar value.

  The grid's dimensions in each direction (x, y, and z) determine the spatial resolution of the scalar volume.

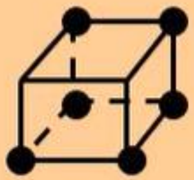
- Here's an example to illustrate scalar volume representation:

  Suppose we have a scalar volume representing temperature distribution in a cubic region. The volume has dimensions of 100 x 100 x 100 voxels. Each voxel contains a temperature value ranging from 0 to 100 degrees Celsius.

What is a Voxel? – Two definitions



A voxel is a cubic cell, which has a single value cover the entire cubic region



A voxel is a data point at a corner of the cubic cell
The value of a point inside the cell is determined by interpolation

SCALAR VOLUMES

Example:

For example, let's consider a CT scan of the head. The scalar volume derived from the CT scan represents the X-ray attenuation coefficients at each spatial point, reflecting the density of tissues in the head. By visualizing this scalar volume, medical professionals can examine the brain, skull, blood vessels, and other structures in three dimensions..

Example:

- Scientific Simulation In scientific simulations, scalar volumes are employed to represent physical properties in a computational domain. For example, in a simulation of fluid dynamics, a scalar volume can represent parameters such as pressure, velocity, or temperature at each point in the simulated fluid. Researchers can analyze the scalar volume to study flow patterns, identify areas of high pressure or temperature, and gain insights into the behavior of the fluid under different conditions

DIRECT VOLUME RENDERING (MULTIDIMENSIONAL TRANSFER FUNCTIONS)

- Direct volume rendering (DVR) is a visualization technique used to generate images of volumetric data, such as medical CT or MRI scans, scientific simulations, or 3D models.
- It allows for the direct exploration and analysis of data without the need for intermediate geometric representations like surfaces or contours.
- In DVR, the volumetric data is represented as a 3D grid of voxels (volume elements).
- Each voxel contains scalar or multi-component values, such as density, temperature, or velocity, which define the properties of the volume at that particular location.
- To generate a 2D image from the volumetric data, DVR employs a process called ray casting.
- The basic idea is to cast rays from the viewpoint of the camera into the volume and accumulate the properties of the intersected voxels along the ray path. These properties are then used to determine the final color and opacity of the pixels in the output image.

DIRECT VOLUME RENDERING (MULTIDIMENSIONAL TRANSFER FUNCTIONS)

- Here are five key points that explain direct volume rendering:
  - Volumetric Data Representation:

    Direct volume rendering operates on volumetric datasets, which are typically represented as a regular grid of voxels (three-dimensional pixels). Each voxel contains scalar values representing properties such as density, temperature, or concentration. These values can be sampled at various positions within the volume.
  - Ray Casting:

    The most common algorithm used in direct volume rendering is ray casting. It simulates the behavior of light rays traversing through the volume. For each pixel on the image plane, a ray is cast into the volume, and its interaction with the data is calculated to determine the final pixel color.
  - Transfer Function:

    A transfer function maps the scalar values of the voxels to optical properties, such as color and opacity. It determines how the voxel values contribute to the final rendering. For example, in medical imaging, a transfer function can be designed to assign different colors to different tissue types or highlight specific structures of interest.
  - Compositing Techniques:

    Direct volume rendering employs various compositing techniques to combine the contributions from multiple voxels along a ray. The most commonly used compositing method is the alpha blending technique, where the colors and opacities of voxels are blended based on their positions along the ray.
  - Lighting and Shading:

    To enhance the visual quality and perception of depth, direct volume rendering often incorporates lighting and shading techniques. These techniques simulate the interaction between light sources and the volumetric data, allowing for the depiction of highlights, shadows, and gradients.

DIRECT VOLUME RENDERING (MULTIDIMENSIONAL TRANSFER FUNCTIONS)

- **Example:** Let's say we have a volumetric dataset of a human head, obtained from a CT scan. The dataset consists of a 3D grid of voxels, with each voxel storing the Hounsfield unit value, which represents tissue density. Here's how direct volume rendering could be applied in this example:

1. **Volumetric Data Representation:** The dataset contains information about the density of different tissues in the head, such as bones, muscles, and brain matter. Each voxel in the grid represents a small three-dimensional element of the head.
2. **Ray Casting**: For each pixel on the image plane, a ray is cast into the head volume. As the ray traverses the volume, it samples the voxel values along its path.
3. **Transfer Function:** A transfer function is defined to map the Hounsfield unit values to optical properties. For instance, low-density regions like air can be assigned high transparency, while bone can be assigned high opacity and a specific color.
4. **Compositing Techniques:** As the ray intersects with voxels, their colors and opacities are combined to determine the final pixel color. In regions where multiple structures overlap, the compositing technique blends their contributions accordingly.
5. **Lighting and Shading:** To enhance the rendering, lighting and shading techniques can be applied to the final image. For example, ambient lighting can provide overall illumination, while specular reflections can be used to highlight certain structures like bone surfaces.

- let's consider an example of using a multidimensional transfer function for volume rendering of a brain MRI scan. The volumetric data contains intensity values and gradient magnitudes. We can construct a transfer function that assigns different colors and opacities based on the intensity and gradient magnitude of the voxels. Regions with high intensity and high gradient magnitude can be assigned a bright color and high opacity, while regions with low intensity and low gradient magnitude can be assigned a darker color and low opacity.
- Here is a simplified step-by-step process for performing direct volume rendering with a multidimensional transfer function:
  1. Load the volumetric data: Read the volumetric data from a file or generate it from a simulation.
  2. Define the multidimensional transfer function: Determine the properties of interest and their respective ranges. For example, in a brain MRI scan, we might have intensity values ranging from 0 to 255 and gradient magnitudes ranging from 0 to 100. Create a transfer function that assigns colors and opacities based on these ranges.
  3. Ray casting: Cast rays from the camera viewpoint into the volume. For each ray, sample the voxels it intersects along the ray path.
  4. Accumulation: Accumulate the properties of the sampled voxels along the ray. For each voxel, retrieve the intensity value and gradient magnitude.
  5. Apply the transfer function: Use the multidimensional transfer function to assign a color and opacity to the voxel properties. This can be done through interpolation or lookup tables.
  6. Compositing: Combine the color and opacity values of the voxels using techniques like alpha blending or compositing to obtain the final pixel color and opacity along the ray.
  7. Repeat steps 3-6 for all rays: Perform the ray casting and accumulation process for each pixel in the output image.
  8. Display the image: Output the final rendered image, which represents a 2D projection of the volumetric data.

MAPS (DOT)

- Dot maps, also known as point maps, use individual dots or symbols to represent discrete data points or events on a geographic map.
- Each dot typically represents a specific count or occurrence of a phenomenon at a particular location.
- Dot maps are particularly useful for displaying discrete data with a clear spatial distribution.
- Here are some key aspects of dot maps in data visualization:

Patterns and Density:

Dot maps excel at revealing patterns and density variations across a geographic area. By placing individual dots on the map, viewers can identify areas of high concentration or clustering. This can be valuable for visualizing data like population density, crime incidents, disease outbreaks, or the locations of specific events.

Symbol Size and Quantity:

The size or quantity of the dots can encode additional information. For example, larger dots might represent higher counts or values, emphasizing areas with greater magnitude. This technique is useful when visualizing data such as the number of sales or the intensity of an event.

Aggregation and Generalization:

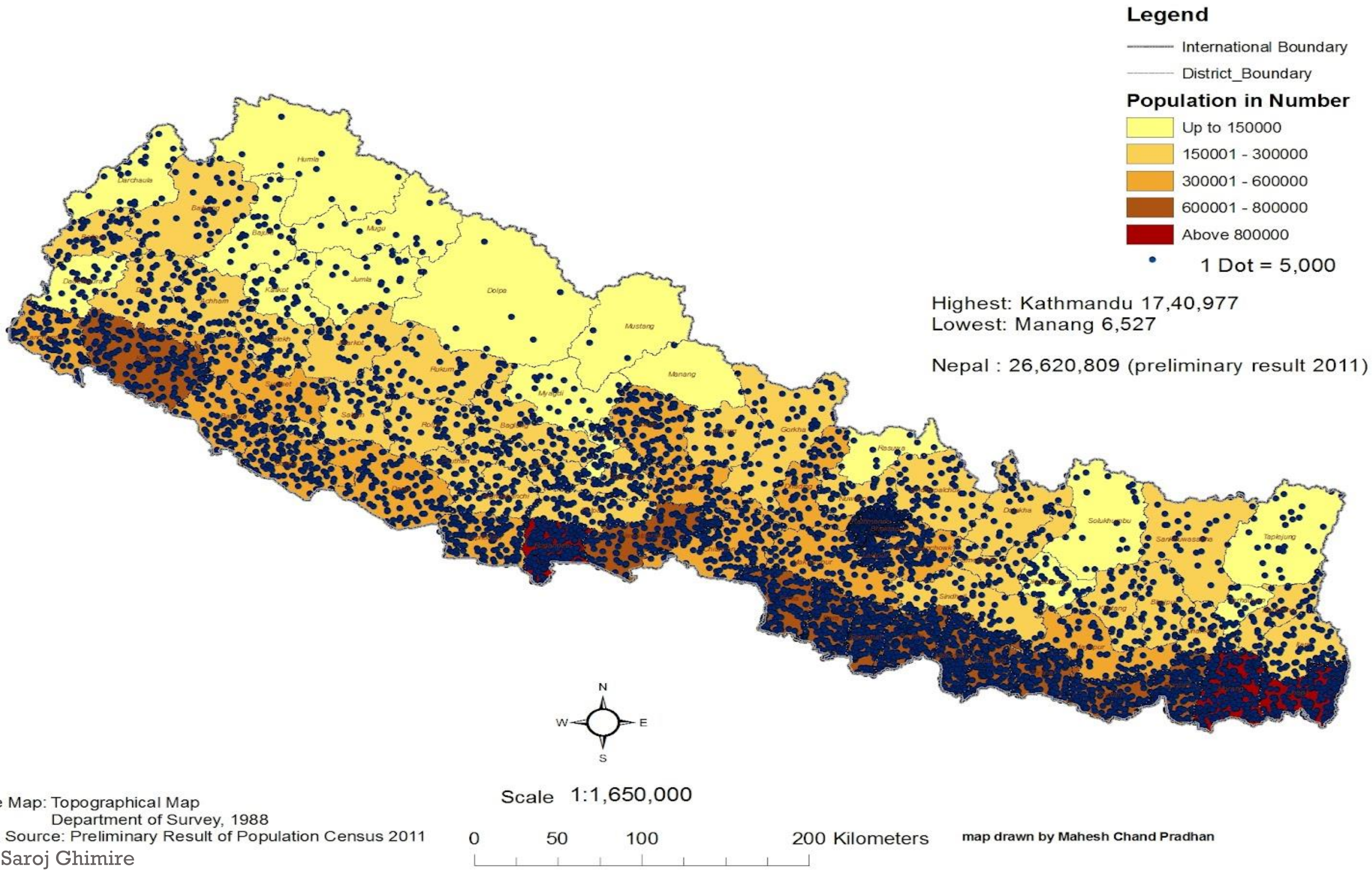
When working with large datasets, dot maps can become cluttered. In such cases, aggregation techniques can be applied to group the data into larger geographic units, such as neighborhoods or counties, reducing visual complexity while preserving patterns. Aggregation can involve using larger dots or aggregating counts into color-coded choropleth maps, where areas are shaded based on data values.

Limitations:

Dot maps have limitations when it comes to displaying very small-scale or precise information, as individual dots lack specific geographic boundaries. Additionally, the placement of dots may introduce a level of randomness or uncertainty, especially when representing point locations with high density.

Population Distribution of Nepal 2011

1



Base Map: Topographical Map
Department of Survey, 1988
Data Source: Preliminary Result of Population Census 2011

map drawn by Mahesh Chand Pradhan

MAPS (PIXELS)

- Pixel maps, also known as raster maps, use a grid of individual pixels to represent continuous data over a geographic area.
- Each pixel corresponds to a specific location on the map and represents a value or attribute associated with that location.
- Pixel maps are commonly used to display data that varies continuously across space, such as temperature, elevation, or satellite imagery
- Here are some key considerations for pixel maps in data visualization:

Continuous Data Representation:

Pixel maps are ideal for representing continuous data that changes gradually across space, such as temperature, precipitation, elevation, or vegetation indices. Each pixel represents a specific location on the map and contains a value that corresponds to the attribute being represented.

Color and Shading:

The color or shading of the pixels is used to represent the data values. A color scale or gradient can be applied, where different colors or shades are associated with specific data ranges. This allows viewers to perceive variations in the data and identify patterns or anomalies.

Interpolation:

Pixel maps require interpolation when the data resolution differs from the map resolution. Interpolation techniques, such as nearest neighbor, bilinear, or cubic interpolation, are employed to estimate values for pixels based on neighboring data points. This ensures a smooth representation of the continuous data.

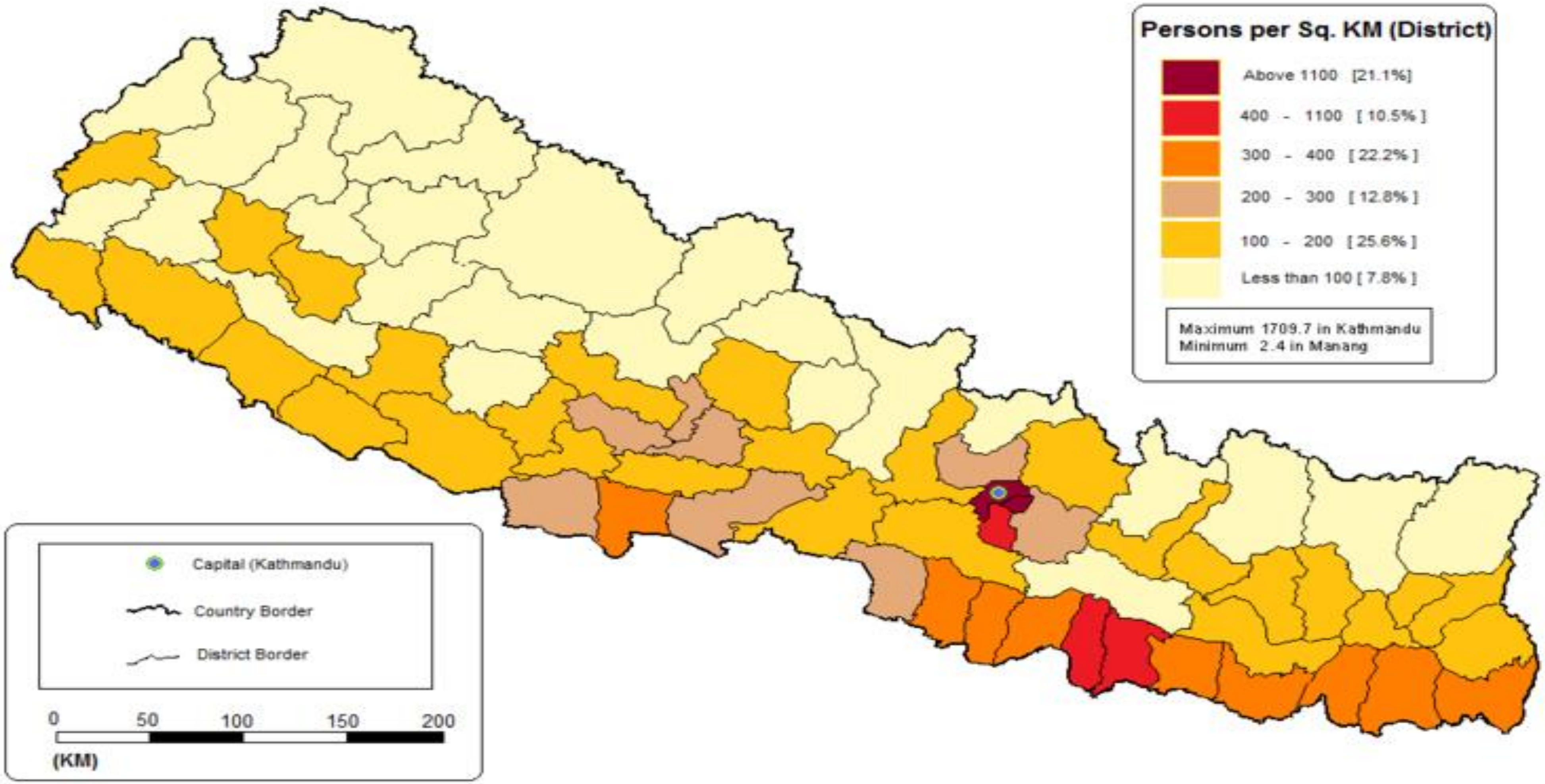
Zoom and Resolution:

Pixel maps have fixed resolutions, and zooming in or out can lead to pixelation or loss of detail. Careful consideration is necessary when choosing the appropriate resolution for the map based on the data's granularity and the desired level of detail.

Limitations:

Pixel maps may not accurately represent small-scale or detailed geographic features due to their fixed resolution. They are better suited for displaying broad patterns and trends. Additionally, pixel maps may require substantial memory and computational resources for large datasets or high-resolution imagery.

MAPS (PIXELS)


Persons per Sq. KM (District)
Above 1100 [21.1%]
400 - 1100 [10.5%]
300 - 400 [22.2%]
200 - 300 [12.8%]
100 - 200 [25.6%]
Less than 100 [7.8%]
Maximum 1709.7 in Kathmandu
Minimum 2.4 in Manang
Capital (Kathmandu)
Country Border
District Border
0 50 100 150 200
(KM)

VECTOR FIELDS

- A vector field assigns a vector (magnitude and direction) to every point in space.
- Each vector represents a specific attribute, such as velocity or force, at a particular location.
- Vector fields are commonly used in scientific simulations, fluid dynamics, weather forecasting, and many other fields where understanding the behavior of vector quantities is essential.
- Visualizing vector fields involves representing the vectors in a meaningful and understandable way.

DEFINING MARKS AND CHANNELS

- Marks and channels are fundamental concepts in data visualization that help encode data attributes into visual properties. They are defined as follows:

  Marks:

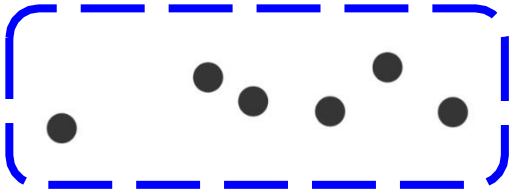
  Marks are the visual elements used to represent individual data points in a visualization. Examples of marks include points, lines, bars, areas, or shapes. Each mark corresponds to a specific data point or observation.

  Channels:

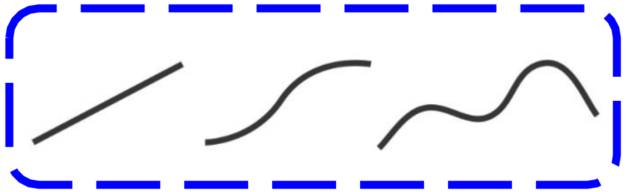
  Channels are the visual properties or attributes of marks that can be mapped to the data attributes. Common channels include position (x, y, z), size, color, shape, and opacity. By mapping data attributes to different channels, we can visually represent and differentiate various aspects of the data

DEFINITIONS: MARKS

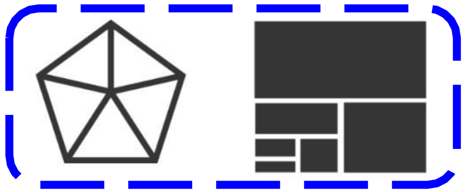
- A **mark** is a basic graphical element in an image.
- Marks are geometric primitives classified according to the number of dimensions they require.
- Examples: points (0D), lines (1D), areas (2D) and volumes (3D).
- Volume marks are not commonly used.



Points – 0D



Lines – 1D

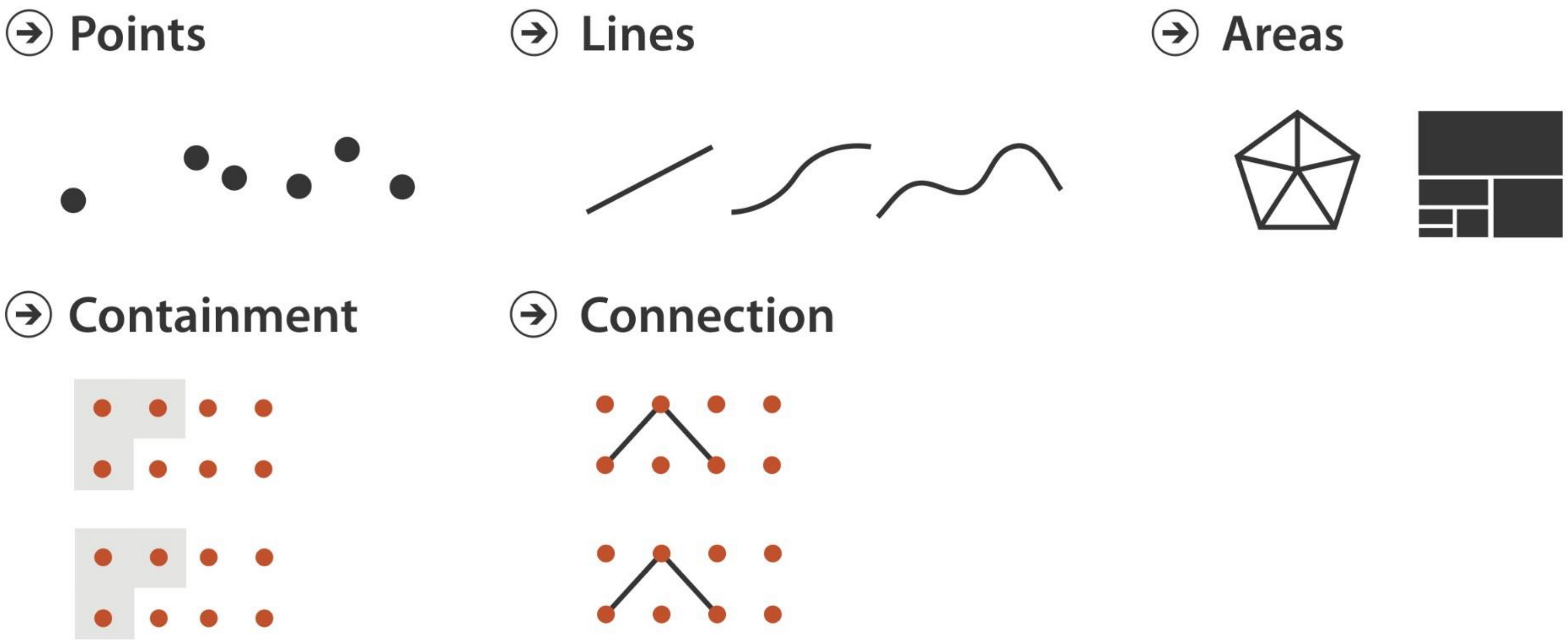


Areas – 2D

MARK TYPES: 1/2

- **In a table dataset, a mark always represents an item. For a network database, a mark may be an item (i.e., node) or a link.**
- **There are two link marks: connection and containment.**
- **A connection mark shows a pairwise relationship between two items, using a *line*.**
- **A containment mark shows hierarchical relationships using areas, and connection marks may be nested within each other at multiple levels.**

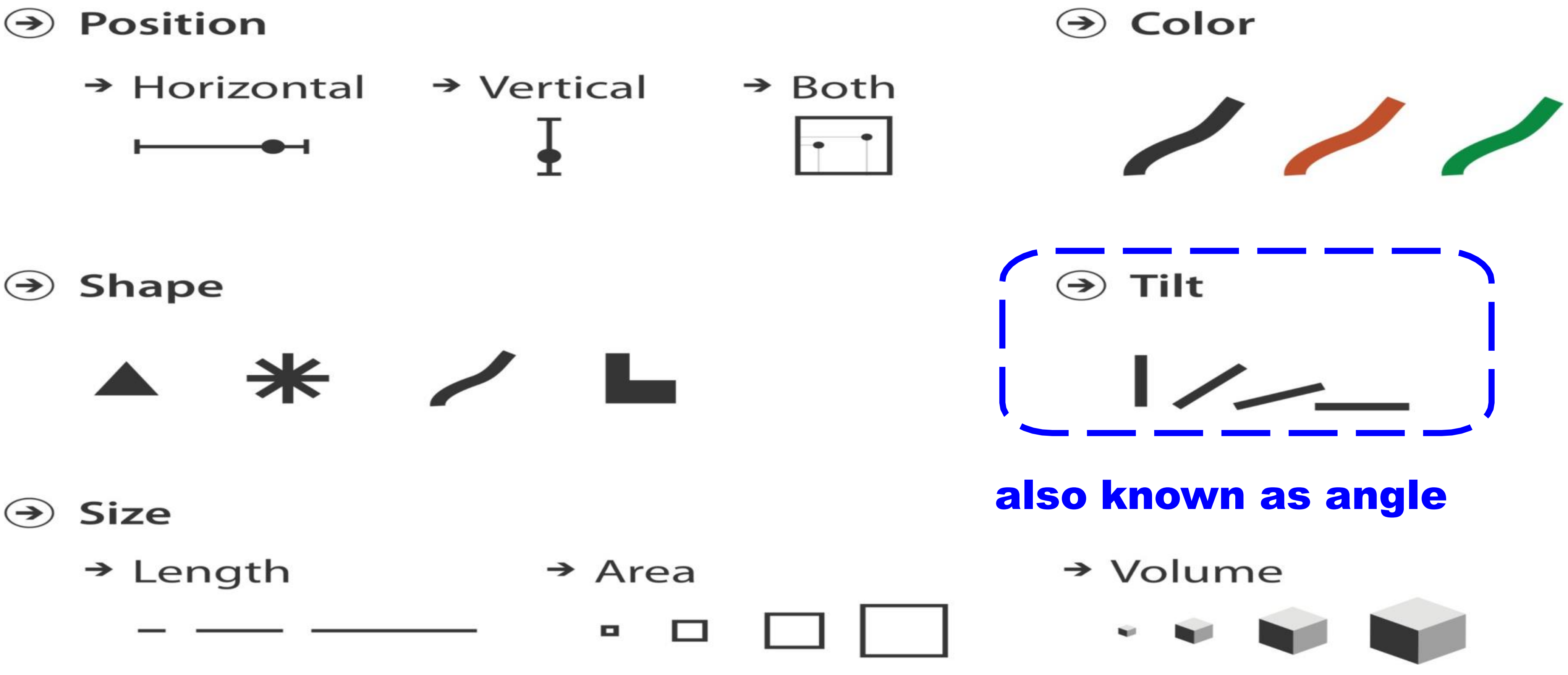
MARK TYPES: 2/2



DEFINITIONS: CHANNELS

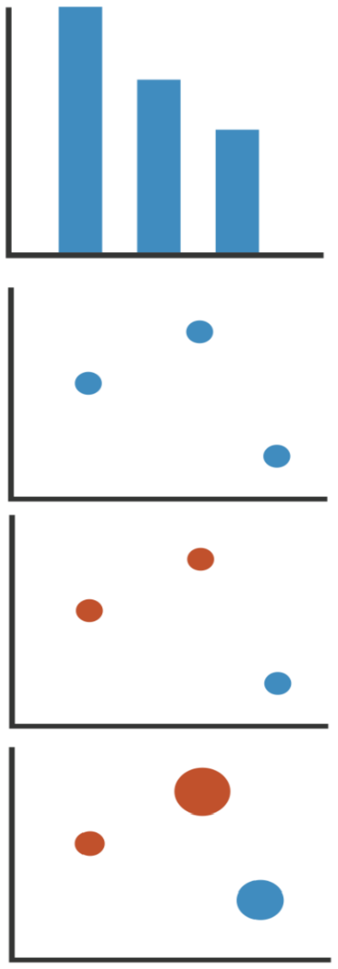
- A visual **channel** is a way to control the appearance of marks, independent of the dimensionality of the geometric primitives.
- There are some commonly seen channel types:
  - **position**, **color**, **shape**, **tilt** and **size**.
- See next slide for examples.
- There are other possible channels such as **depth**, **luminance**, **saturation**, **curvature**, etc.

DEFINITIONS: CHANNELS 2/2



also known as angle

NOTES: 1/3



Bar charts show two attributes,
but only one is quantitative (vertical) and the other is categorical

A second quantitative attribute can be encoded by using the visual channel of horizontal spatial position.
We have a 2D scatterplot.

One more categorical attribute may be added by using the visual channel of hue (i.e., color)

The visual channel of size may be used to add yet another quantitative attribute

NOTES: 2/3

- In these examples, each attribute is encoded with a single channel.
- Multiple channels can be combined to redundantly encode the same channel; however, this approach uses more channels so that not as many attributes can be encoded in total.
- Usually, the size and shape channels cannot be used on all types of marks.
- For example, higher- dimensional mark types may have built-in constraints from their definitions.

NOTES: 3/3

- An **area** mark has both dimensions of its size constrained as part of its shape. For example, an area mark denoting a state within a country on a geographic map already has a certain size.
- A **line** mark that encodes a quantitative attribute using length in one direction can be size coded by changing its width; however, it cannot be sized in its length dimension.
- A **point** mark can be **size** coded for its quantitative attribute and **shape** coded for its categorical attribute.

CHANNEL TYPES

- The human perceptual system has two fundamentally different kinds of sensory modalities.
- The **identity** channels tell us information about *what* something is or *where* it is. **Examples**: circles, triangles, colors, in motion, inside/outside of an area, etc.
- The **magnitude** channels tell us *how much* of something there is.

Examples: longer/shorter, larger/smaller, brighter/darker, etc.

ASSIGNMENT

1. What is a scalar field, and how is it visualized in spatial data visualization?
2. How can color mapping be used to represent scalar fields?
3. Discuss the techniques used to interpolate and visualize scalar fields at different resolutions
4. What are isocontours, and how are they used to visualize scalar fields?
5. Explain the concept of contour lines and contour intervals in the context of topographic terrain maps.
6. Discuss the techniques used to generate and visualize isocontours from scalar field data.
7. What are scalar volumes, and how are they represented and visualized?
8. Explain the concept of volume rendering in the context of scalar volumes.
9. Discuss the techniques used to visualize and explore scalar volumes in three-dimensional space.

ASSIGNMENT

10. Explain the concept of multidimensional transfer functions and their role in direct volume rendering
11. Explain the concepts of dot maps and pixel maps in spatial data visualization.
12. Discuss the strengths and limitations of dot maps and pixel maps in representing spatial data.
13. What are vector fields, and how are they visualized in spatial data visualization?
14. What are marks and channels in the context of data visualization?
15. Discuss different types of marks that can be used to represent spatial data.
16. Explain how channels, such as position, color, size, and shape, can be used to encode data attributes in spatial visualizations. Provide an overview of spatial data visualization techniques, including scalar fields, isocontours, scalar volumes, maps, and vector fields.
17. Discuss the importance of effective visualization in understanding and analyzing spatial data.
18. Give examples of real-world applications where spatial data visualization has been instrumental in gaining insights and making informed decisions.