# UNIT 4: SPATIAL DATA VISUALIZATION

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# OUTLINE

- 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

- is the data that has an implicit or explicit spatial or spatio - temporal attribute.
- Geospatial is a dataset includes information that connects each piece of data to a specific location on the Earth's surface.
- Represents a object in a geographic coordinate system.

**E.g.,** Geospatial Dataset

| city | latitude | longitude | population |
|---|---|---|---|
| Kathmandu | 27.70° N | 85.32° E | 862400 |
| Pokhara | 28.21° N | 83.99° E | 513504 |
| Lalitpur | 27.67° N | 85.31° E | 294098 |
| Biratnagar | 26.45° N | 87.28° E | 243927 |
| Birgunj | 27.02° N | 84.88° E | 272382 |
| Bharatpur | 27.68° N | 84.43° E | 369268 |

# SPATIAL DATA VISUALIZATION

- Geospatial data refers to information about the *physical location and shape of objects or features on Earth.*

# SPATIAL DATA VISUALIZATION

## Geometric data

- represents spatial information on a flat, two-dimensional (2D) Cartesian coordinate system.
- This system uses simple X and Y coordinates to define locations, shapes, and distances.
- E.g., a floor plan of a building or a map of a small town would use geometric data.


## Geographic data

- describes objects and their positions relative to Earth's surface i.e., in geographic coordinate system
- Typically represented using latitude (y) and longitude (x) coordinates.

# SPATIAL DATA VISUALIZATION

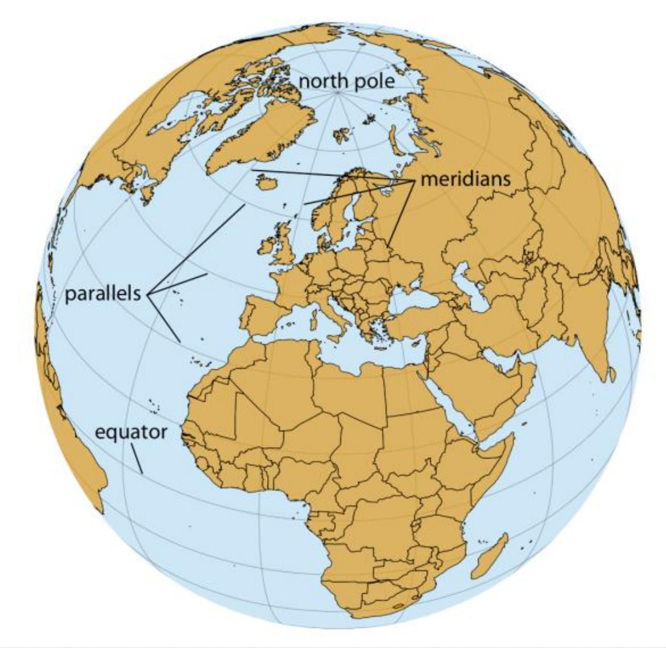
## Geospatial data visualization

- is a field that focuses on graphically representing data that has a geographic component.
- The data being worked is tied to a specific location, either directly or indirectly.
- This connection to a location allows for the creation of maps and other geographical displays.
- **E.g.,:** A dataset of earthquake events that includes the exact latitude and longitude of each epicenter. These points can be plotted on a world map to visualize their distribution.

# PROJECTIONS

- The earth *is approximately a sphere* , and more precisely an oblate spheroid that is slightly flattened along its axis of rotation.

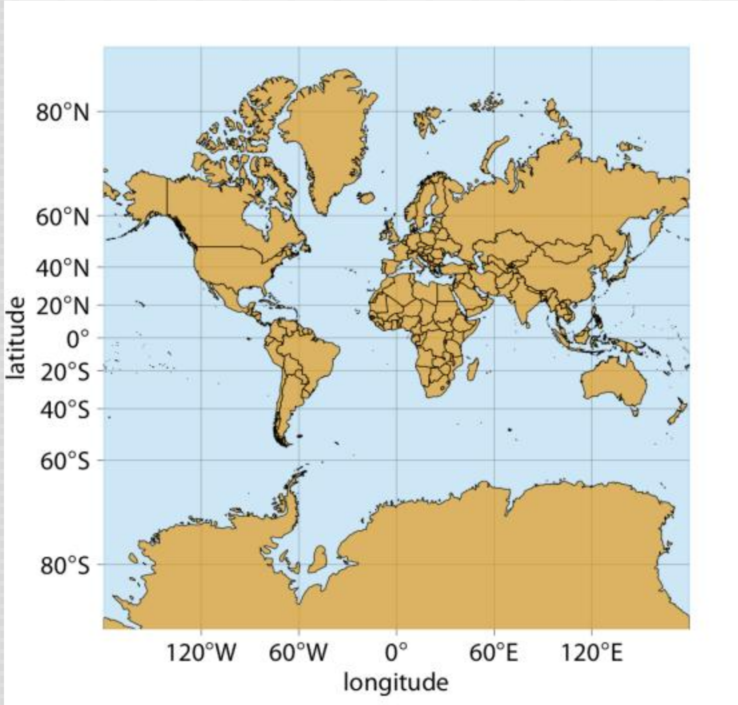
- To uniquely specify a location on the earth, three pieces of information are needed:
  - how close to either pole when moving perpendicular to the equator (the latitude),
  - location along the direction of the equator (the longitude)
  - and how far from the earth's center (the altitude).

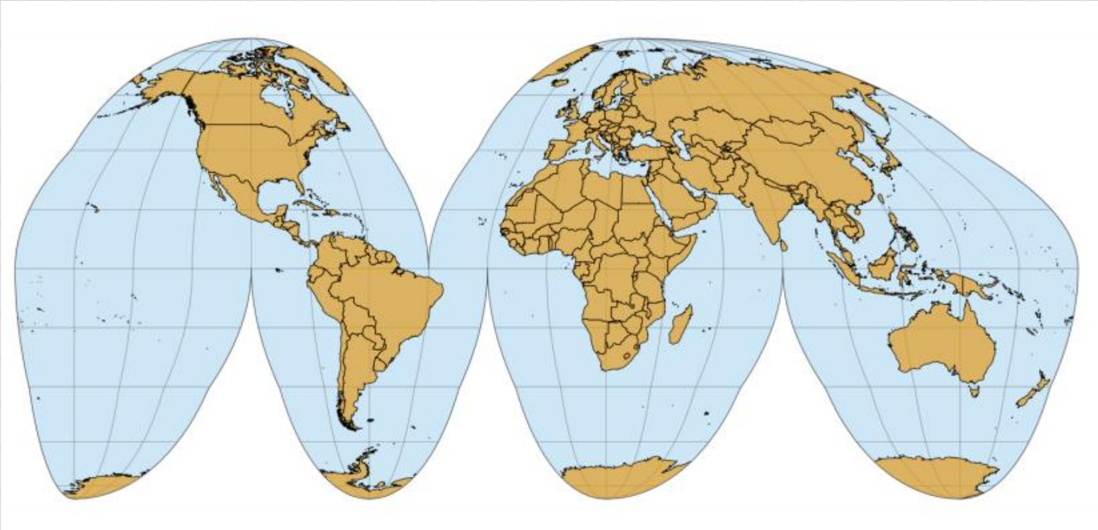



- For e.g., a location might be described as **40° N, 75° W**, which means it's 40 degrees north of the equator and 75 degrees west of the prime meridian.

# PROJECTIONS

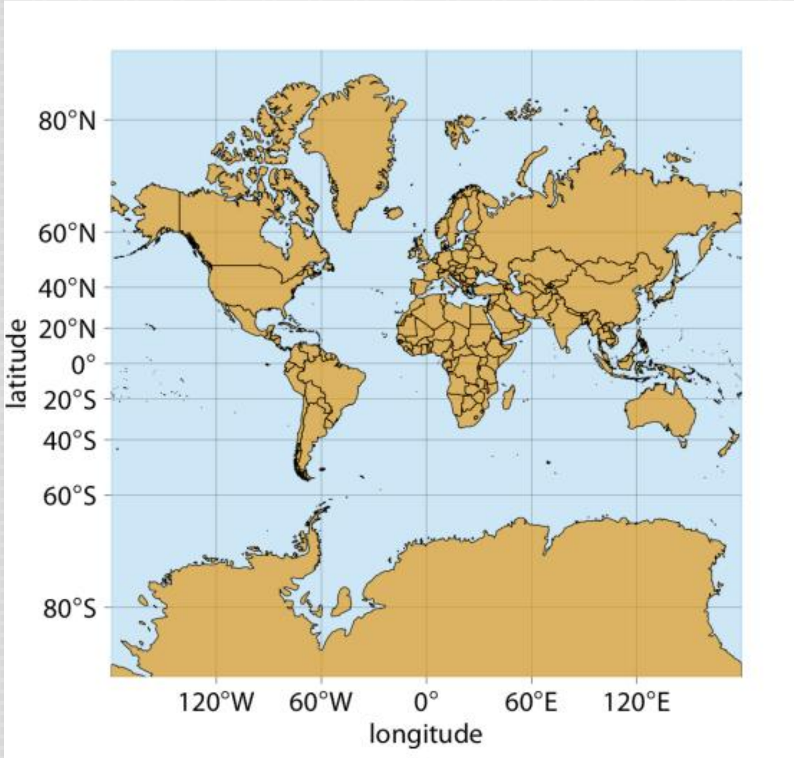
- To create the flat map, the 3D geographic data must be transformed using a **map projection.**
- Map projection is the mathematical process that takes the curved geographic coordinates and translates them into flat, 2D geometric coordinates.
- Map projection introduces distortions, the projection can preserve either angles or areas but not both.



# PROJECTIONS

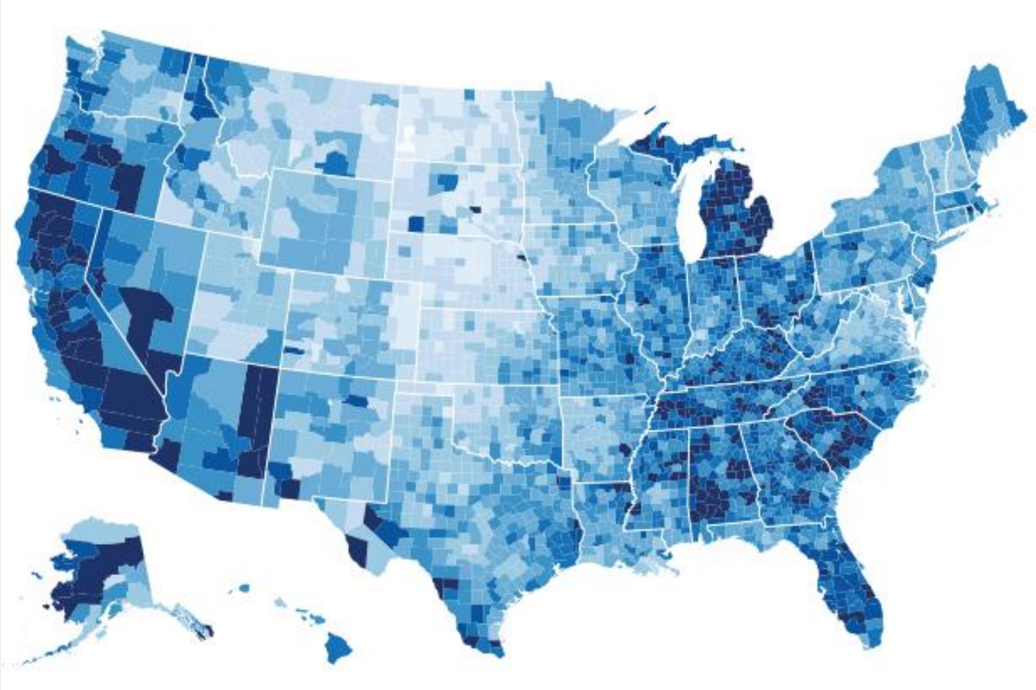
- **Mercator projection:** accurately represents shapes but introduces severe area distortions near the poles.



# SPATIAL DATA VISUALIZATION

## Choropleth Maps

- shows a quantitative attribute encoded as color over regions delimited as area marks, where the shape of each region is determined by using geometry.
- Can do so coloring individual regions in a map according to the map according to the data attribute which to be displayed.



**What Data?**

- Geographic geometry data. Table with one quantitative attribute per region

**How to Encode?**

- Use given geometry for area mark boundaries. Color: sequential segmented colormap.

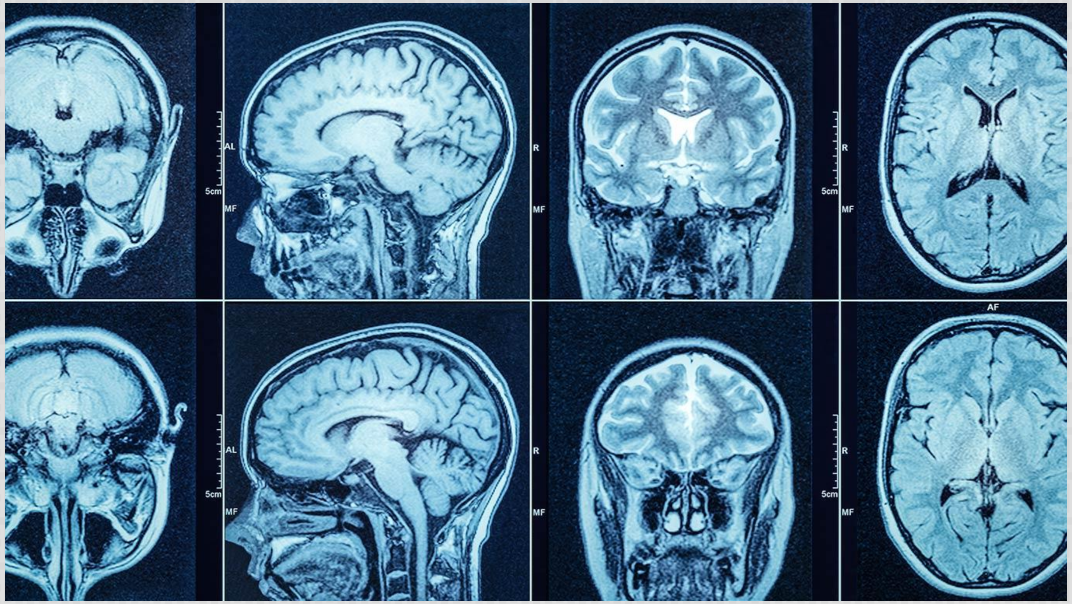
# SCALAR FIELD

- A scalar spatial field has a single value associated with each spatially defined cell.
- The data has a magnitude but no direction.
- A scalar spatial field represents a dataset that has a single numerical value (a scalar) to every point within a given spatial region.
- **E.g.,** The temperature at every location is a scalar value; it has a magnitude (e.g., 25°C) but no direction.
- **E.g.,** Elevation, Air pressure, population density

| District | Popn Density |
|---|---|
| Kathmandu | 4935.1 |
| Morang | 618.4 |
| Sunsari | 737.4 |
| Jhapa | 505.0 |
| Kaski | 297.5 |
| Surkhet | 169.4 |
| Ilam | 164.1 |
| Taplejung | 33.1 |
| Manang | 2.5 |

# SCALAR FIELD

- Visualizing scalar field is crucial in fields such as medical imaging, scientific visualization, and engineering.
- **Computed Tomography (CT) scans** use X-rays to measure **radio-opacity**, which is how much a tissue absorbs radiation.
- Each cell in a field contains measurements or computations from continuous domain



- A high scalar value : high radio-opacity
- A low scalar value

# SCALAR FIELD

Techniques for visually encoding scalar field

- **Color Mapping (or Heat Maps):**
  - Uses a color gradient to represent the range of scalar values.
  - Scalar values are mapped to a continuous or discrete color scale, which allows to perceive variations and identify regions of high or low values.
  - E.g., a temperature map might use blue for cold values, green for moderate, and red for hot.

- **Isocontours**
- **Direct Volume Rendering**

# SCALAR FIELD

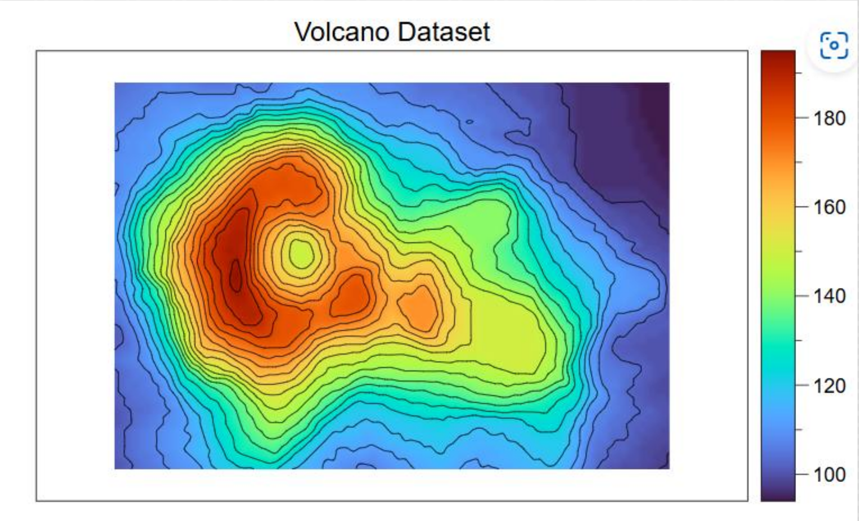
## Isocontours

- A set of isolines, namely, lines that represent the contours of a particular level of the scalar value, can be derived from a scalar spatial field.

- Contours are imaginary lines joining places having the same or equal elevation.

- an isocontour is a line of equal value.

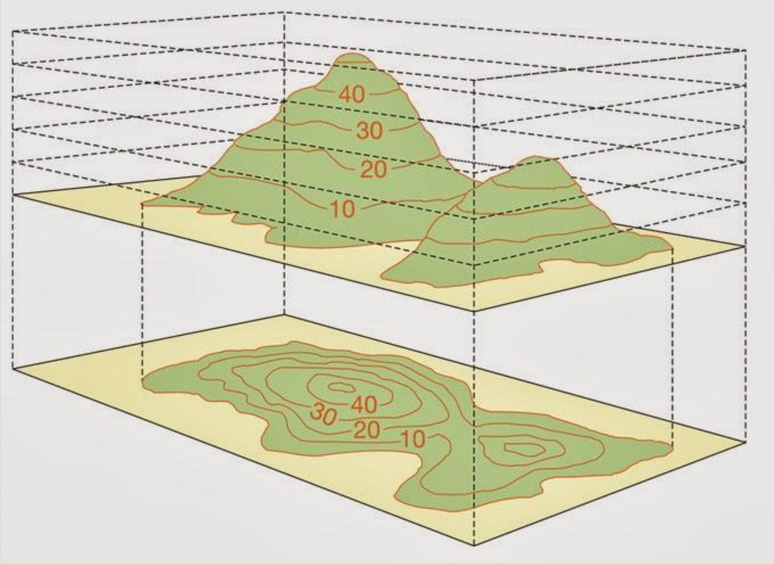
- These lines provide valuable information about the shape, slope of the terrain or any other variable being represented on the map.

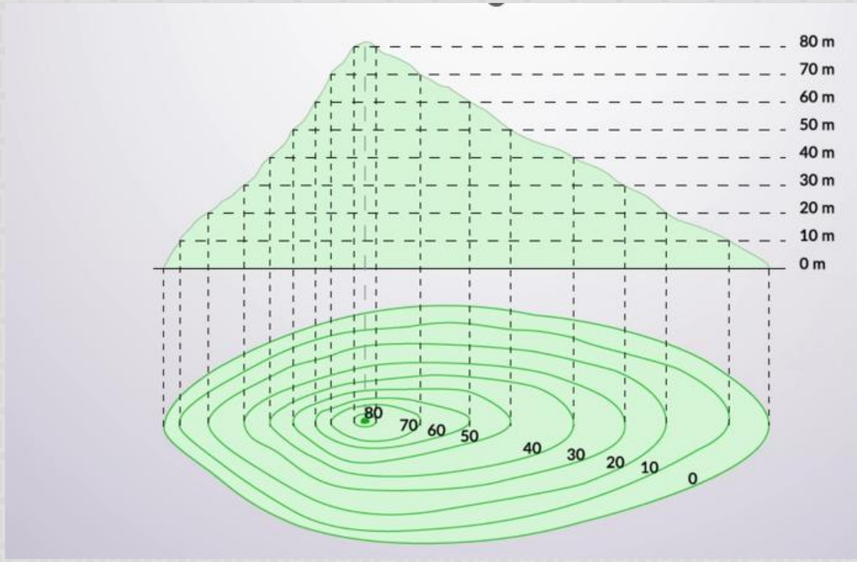


# SCALAR FIELD

## Topographic Terrain maps

- A topographic map is a two-dimensional representation of a three-dimensional land surface, showing both natural and man made features.
- It uses contour lines to depict elevation changes, which allows to visualize the terrain's shape, including mountains, valleys, and slopes, as well as other features like bodies of water, transportation routes, and buildings.

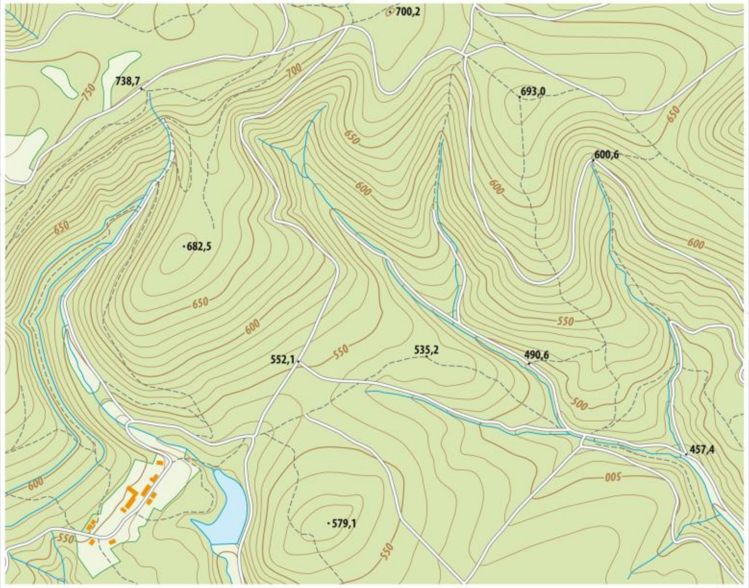


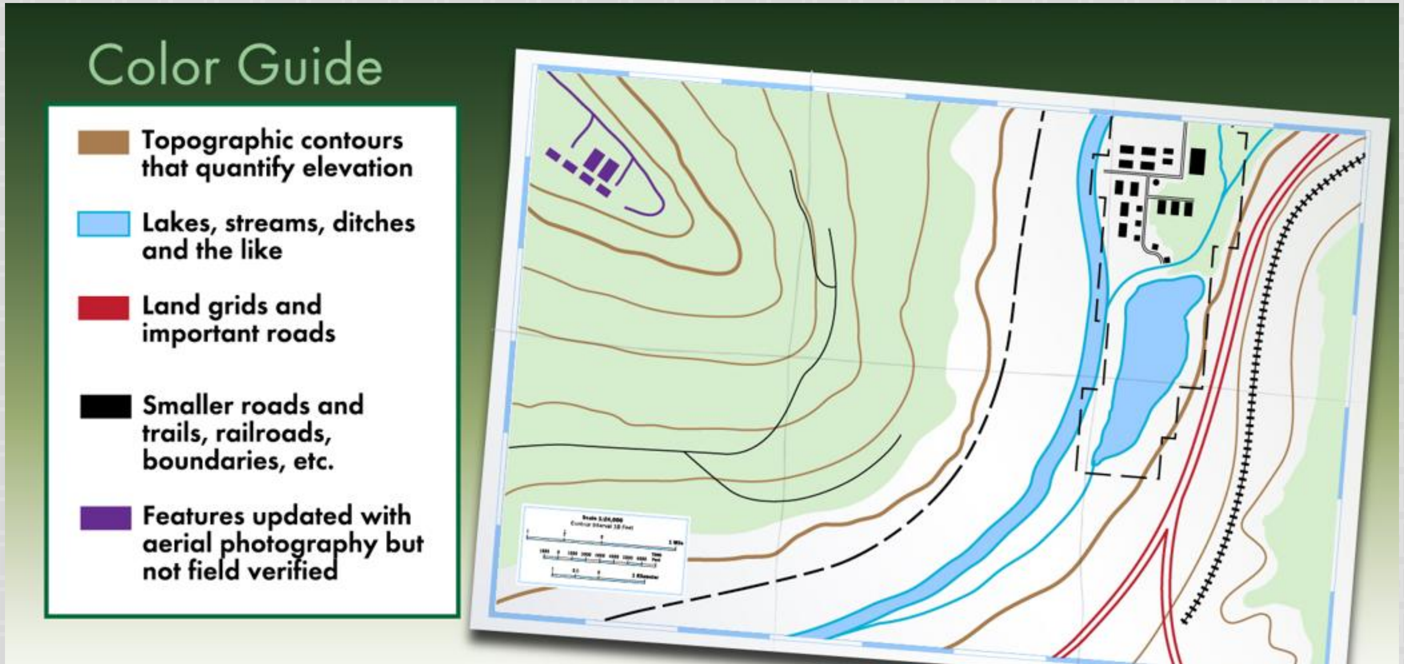



# SCALAR FIELD

**Topographic Terrain maps**

- **Contour Interval**: The difference in elevation between adjacent contour lines is called the contour interval. A smaller interval indicates a steeper slope, while a larger interval means a gentler slope.
- Contour lines *never intersect or branch out (exception hanging cliff)*. They can form closed loops to indicate hills, or mountains.



# SCALAR FIELD

## Characteristics of Isocontours

- All points on a contour line are of the same elevation.
- No two contour lines can meet or cross each other except in the rare case of an overhanging vertical cliff or wall
- Closely spaced contour lines indicate steep slope
- Widely spaced contour lines indicate gentle slope
- Equally spaced contour lines indicate uniform slope
- Closed contour lines with higher elevation towards the center indicate hills.

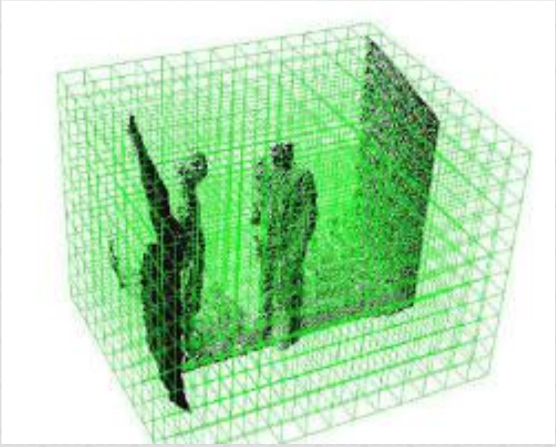
# SCALAR VOLUMES

- Scalar volume refers to a 3D dataset where each point in space (voxel) is associated with a single numerical value, representing a scalar quantity

- Scalar volume visualization involves representing three-dimensional scalar fields. A scalar field assigns a scalar value (like temperature, pressure, or density) to each point in a three-dimensional space.

- Visualizing scalar volumes is crucial in fields such as medical imaging, scientific visualization, and engineering.

- Scalar volume data is typically organized as a 3D array or grid of voxels.

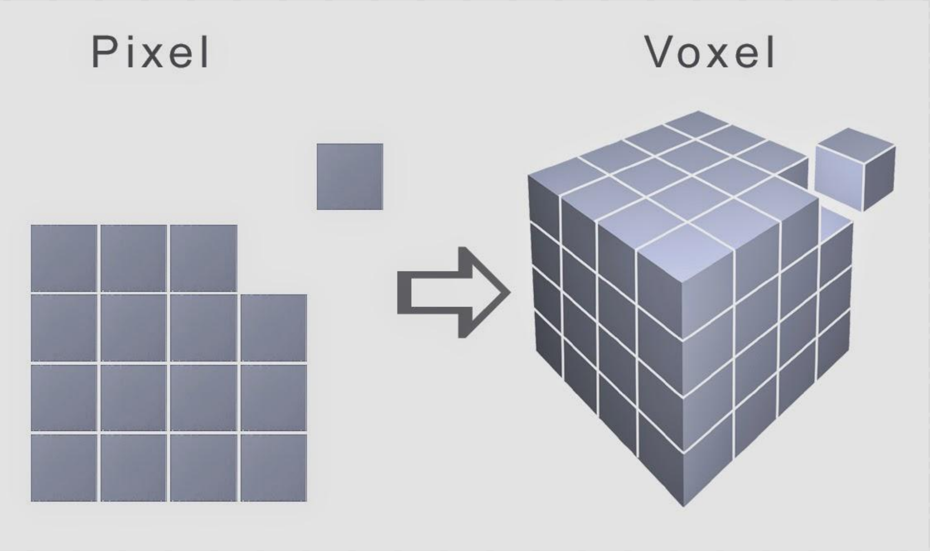


# SCALAR VOLUMES

- a **voxel** is a representation of a value on a three-dimensional regular grid, akin to the two-dimensional pixel.

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

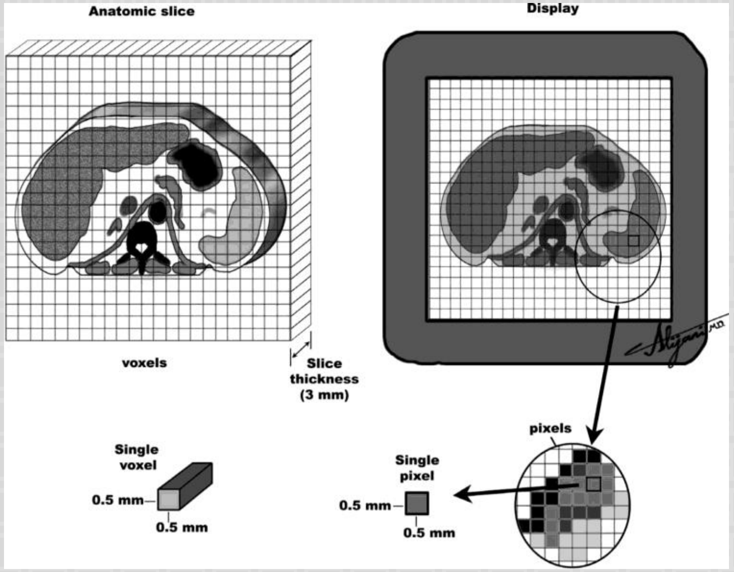
- Each grid point, also known as a **voxel**, contains a scalar value.

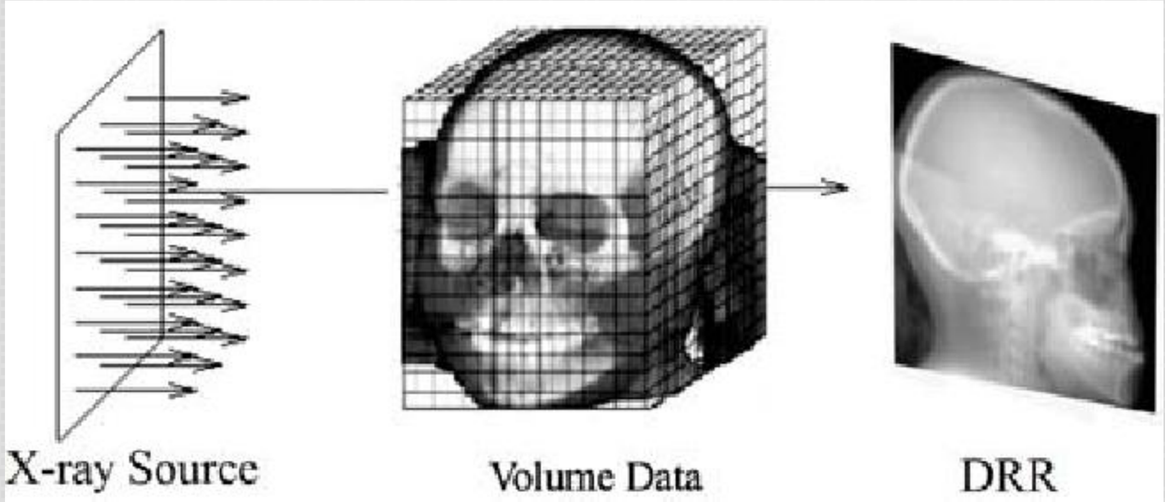



- While a pixel represents a single point in a 2D grid, a voxel represents a single value on a 3D grid, essentially a tiny cube of information.

# SCALAR VOLUMES

- Volume data is generally a sampling of a continuous phenomenon, and can be either acquired via sensors *(e.g., tomographic data sets)* or generated via simulations (e.g., computational fluid dynamics).
- Voxels are crucial for visualizing and analyzing data that exists in a three-dimensional space.



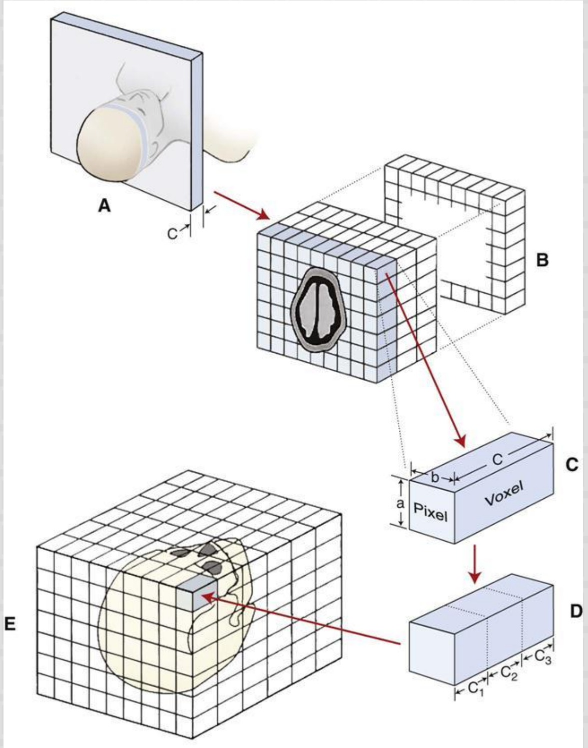



# SCALAR VOLUMES

- Instead of a flat image, a voxel-based visualization is a digital representation of a physical volume.

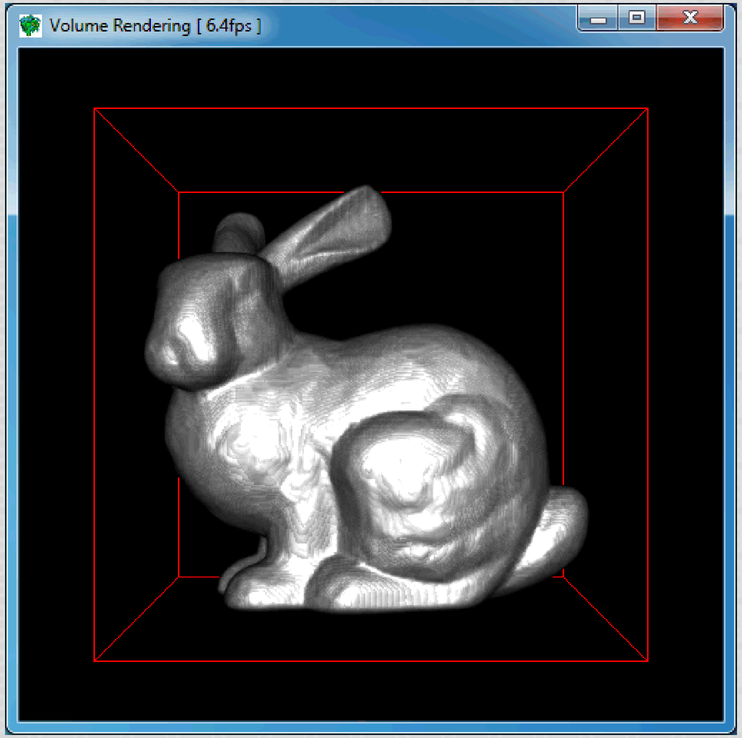
- This allows to explore the internal structures of an object or an environment.

- The main difference from other 3D models (like those based on polygons) is that voxel data is a continuous grid.
- This makes it ideal for showing things like internal changes or varying material properties, as the data for every point in the volume is explicitly stored.



# DIRECT VOLUME RENDERING

- Direct volume rendering (DVR) is a technique used to visualize 3D volumetric data by projecting it directly onto a 2D image, without converting the data into geometric primitives like surfaces.
- used to generate images of  volumetric data, such as medical CT or MRI scans, scientific simulations, or 3D models.
- is a technique that uses this entire 3D dataset to create a single, continuous 3D image.
- The image is rendered from a specific viewpoint, and the user can manipulate parameters like color and transparency to see different structures.



# DIRECT VOLUME RENDERING

- It creates images by accumulating color and opacity values along viewing rays, providing a way to see inside the volume and visualize internal structures.

- 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.

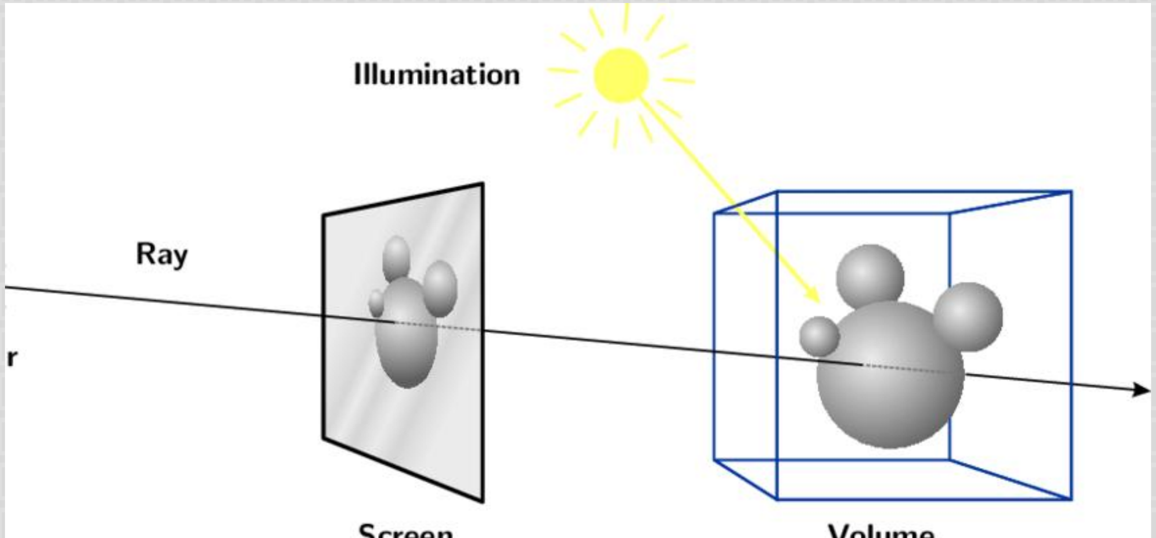
- A crucial visual encoding design choice with direct volume rendering is picking **the transfer function** that maps changes in the scalar value to opacity and color.

# DIRECT VOLUME RENDERING

- The process can be broken down into three main steps:

## 1. Ray Casting:

- For every pixel on the 2D screen, a virtual ray is "cast" into the 3D volume. This can be thought as light rays traveling from the eye through the image plane into the scene.
- It treats the 3D volume as a semi-transparent medium that emits, absorbs, and scatters light. The final image is created by calculating how light travels through this medium and is accumulated at each pixel on the screen.



# DIRECT VOLUME RENDERING

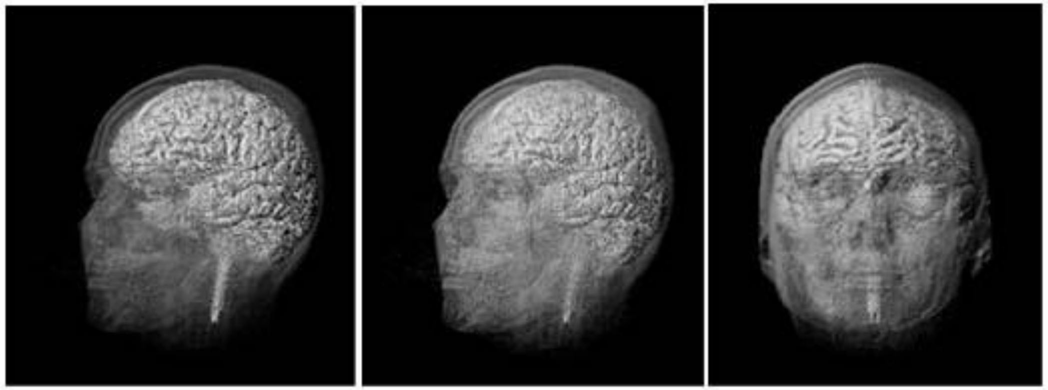
## 2. Transfer Function:

- As each ray travels through the volume, it samples the data at regular intervals (at each voxel it passes through).
- For each sample point, a **transfer function** is applied. This function maps the raw data value (e.g., tissue density) to visual properties like color and opacity.
- This is the crucial step that allows different structures to be highlighted or made transparent.
- For e.g., a transfer function could make bone voxels opaque and white, while muscle voxels are semi-transparent and red.

# DIRECT VOLUME RENDERING

## 3. Compositing Technique

- The classified color and opacity values from each sample point along the ray are then blended together, or "composited," in a front-to-back or back-to-front order.
- This process accumulates the color and intensity, just like light passing through a real-world object. The final, composited color is then assigned to the pixel on the screen.



(a)Brain Opacity: 1.00 Skin Opacity: 0.05 (b) Brain Opacity: 1.00 Skin Opacity: 0.15 (c) Brain Opacity: 1.00 Skin Opacity: 0.15

- DVR is a photograph of the entire house, possibly with some walls made transparent so can seen inside.

# DIRECT VOLUME RENDERING

- **Shows Internal Structure:**
- Instead of showing just the surface of an object, DVR allows to see inside the volume, revealing internal structures and semi-transparent features.
- The image is rendered from a specific viewpoint, and the user can manipulate parameters like color and transparency to see different structures.
- Allows not only to see the surface of a tumor, but its relationship to surrounding tissues and its internal characteristics, such as density variations.
- **No Intermediate Geometry**: It doesn't require a separate step to extract surfaces which can be computationally expensive and may lose data fidelity.

# MAPS (DOT, PIXEL)

- Maps are fundamental tools in spatial data visualization, representing spatial relationships and distributions of data across geographical or conceptual spaces.

- Maps can be created using different elements such as dots, pixels, and other graphical representations to convey information.

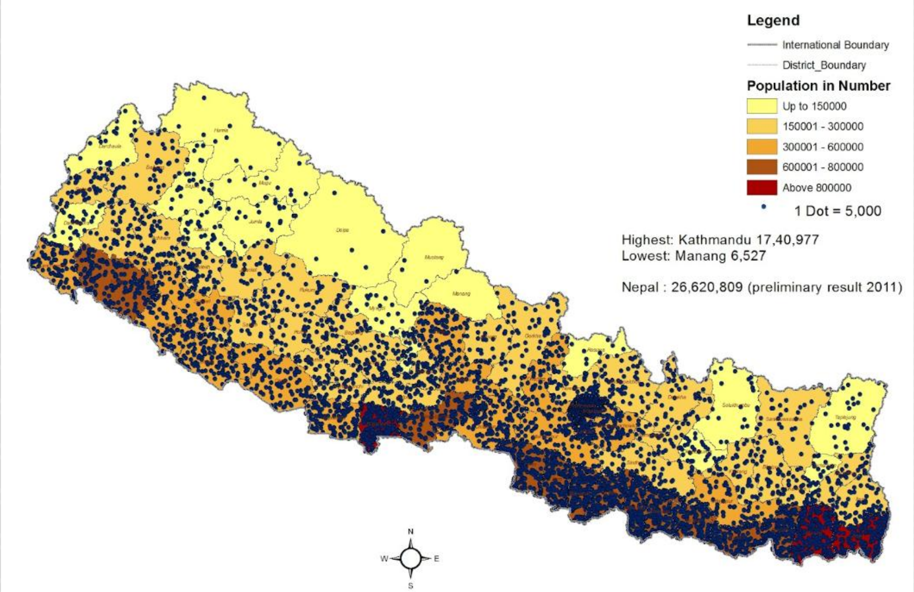
**Types of Maps**

1. Dot Maps
2. Pixel Maps
3. Choropleth Maps
4. Heatmaps

# MAPS (DOT, PIXEL)

## Dot Maps

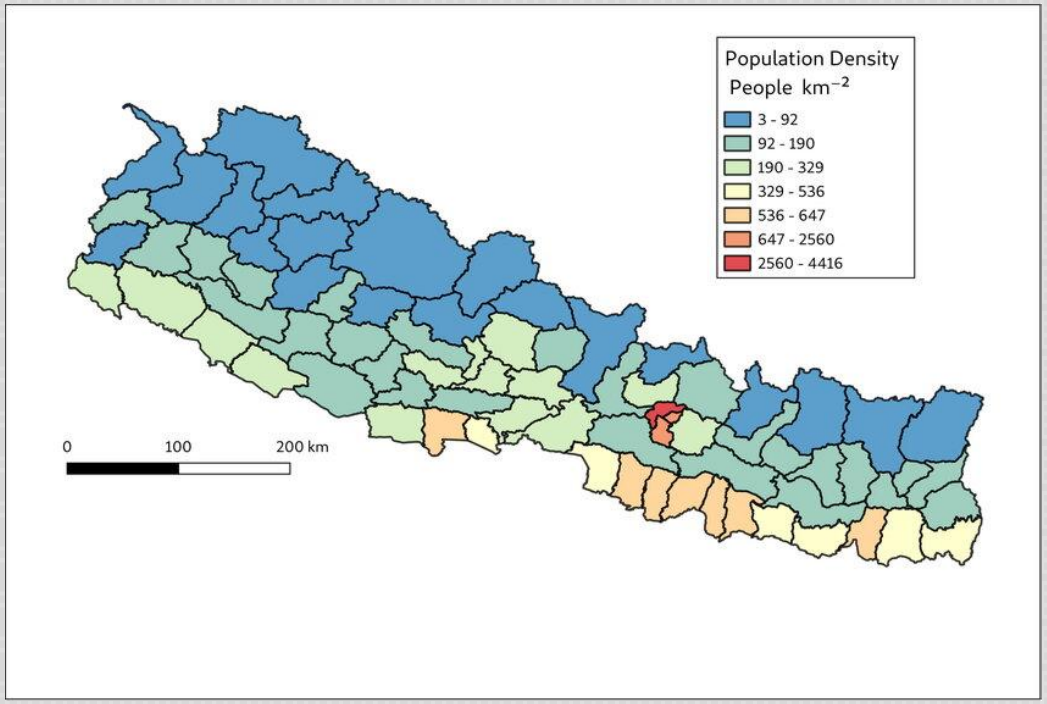
- A **dot map is a map** that uses a single dot to represent one or a fixed number of occurrences of a phenomenon.
- The primary goal of a dot map is to visualize the **density** and **distribution** of data.
- A dot is placed on the map for each individual data point (e.g., one dot per person) or to represent a group of data points (e.g., one dot per 1,000 people). The concentration of dots on the map directly corresponds to the data density in that area.



# MAPS (DOT, PIXEL)

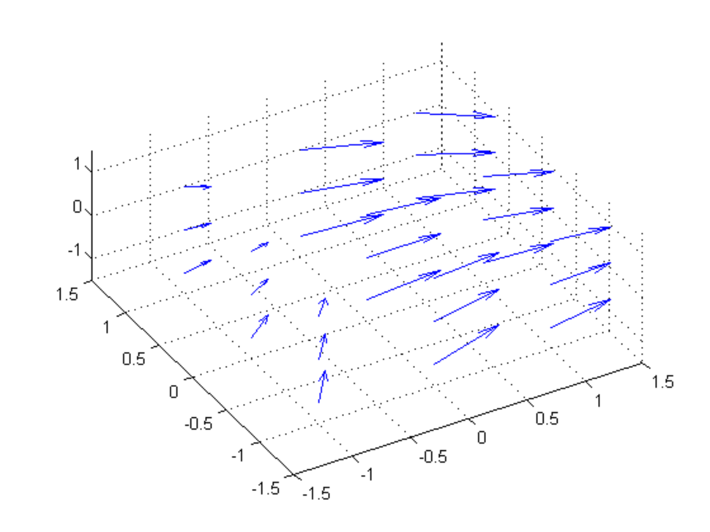
**Pixel Maps**

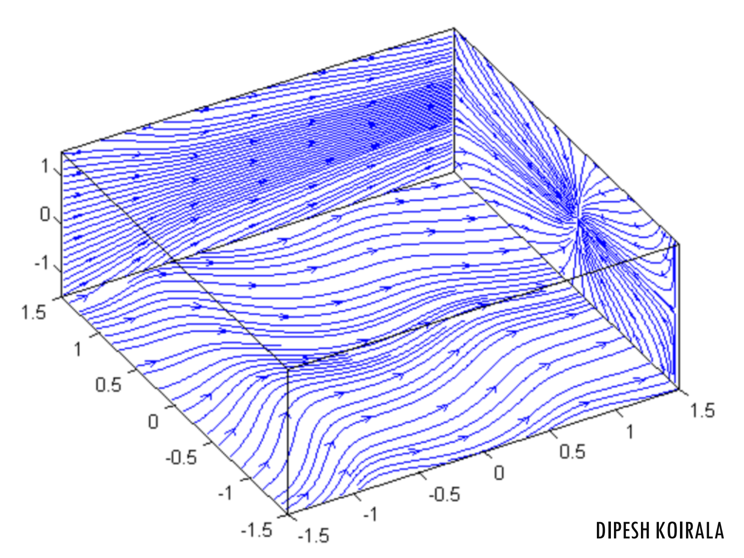
- A **pixel map** is a more modern visualization technique that uses a regular grid of pixels to represent data.
- Unlike a dot map, where a dot represents an entity, in a pixel map, the **color and intensity** of each pixel on the grid is directly encoded with a data value.



# 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.
- used to visualize phenomena such as wind currents, fluid dynamics, or magnetic fields.
- The length of the arrow typically represents the magnitude, while the arrow's orientation indicates the direction of the vector at that specific point.



# VECTOR FIELDS

**Techniques:**

- Velocity Plot (Quiver Plot)
- Velocity Plot (Cone Plot)
- Streamlines
- Streamslice
- Stream Tube and Stream Ribbon

**Source:**
*https://web.mit.edu/8.13/matlab/MatlabTraining_IAP_2012/AGV/DemoFiles/ScriptFiles/html/Part8_VectorFields.html*

# REFERENCES


https://avida.cs.wright.edu/courses/CS399/CS399_4.pdf

# THANK YOU

Dipesh Koirala