Introduction to Spatial Data

HES 505 Fall 2024: Session 3

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Today’s Plan

1. Ways to view the world
2. What makes data (geo)spatial?
3. Coordinate Reference Systems
4. Geometries, support, and spatial messiness

How do you view the world?

…As a Series of Objects?

- The world is a series of *entities* located in space.
- Usually distinguishable, discrete, and bounded
- Some spaces can hold multiple entities, others are empty
- Objects are digital representations of entities

…As a Continuous Field

How did the data arise?

Spatial data as a stochastic process

$$Z(\mathbf{s}) : \mathbf{s} \in D \subset \mathbb{R}^d$$

There is some attribute ($Z(\mathbf{s})$) that we observe at a location (s). That location (s) is an element of a domain of data (D), which is a subset of real coordinate numbers ($\mathbb{R}^d$, $d = 2$).

Three types of spatial data are defined by the differences in domain (D).

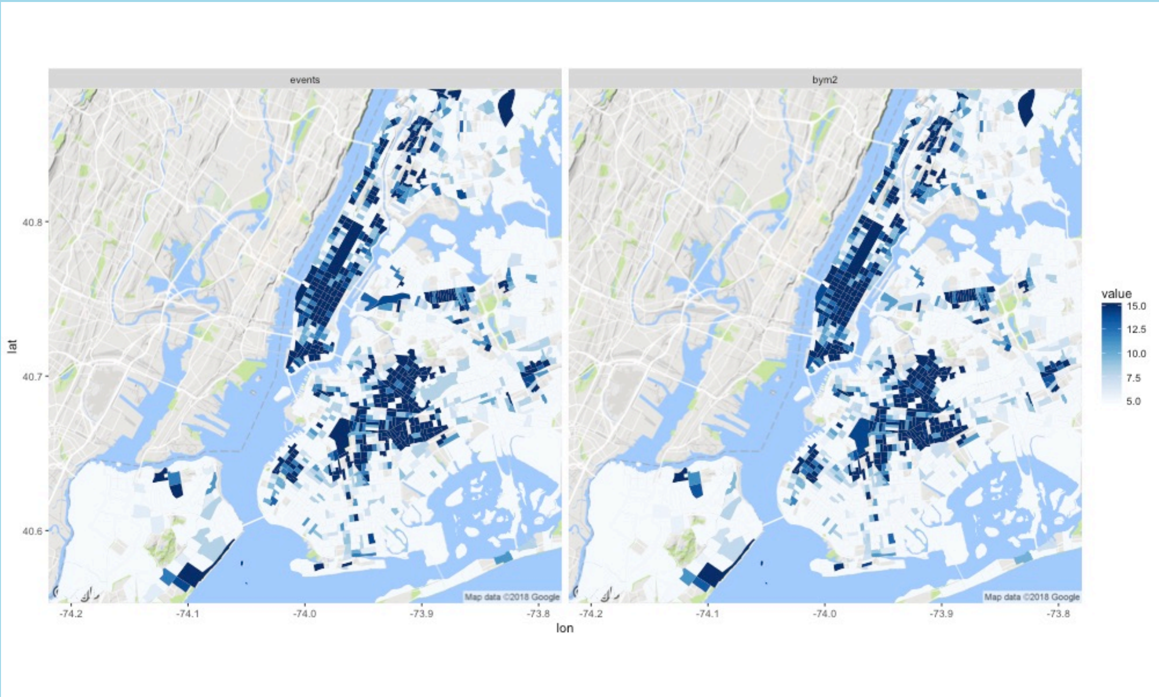
Areal Data

$$Z(\mathbf{s}) : \mathbf{s} \in D \subset \mathbb{R}^d$$

- D is fixed domain of countable units
- Typically involve some aggregation

Geostatistical data

$$Z(\mathbf{s}) : \mathbf{s} \in D \subset \mathbb{R}^d$$



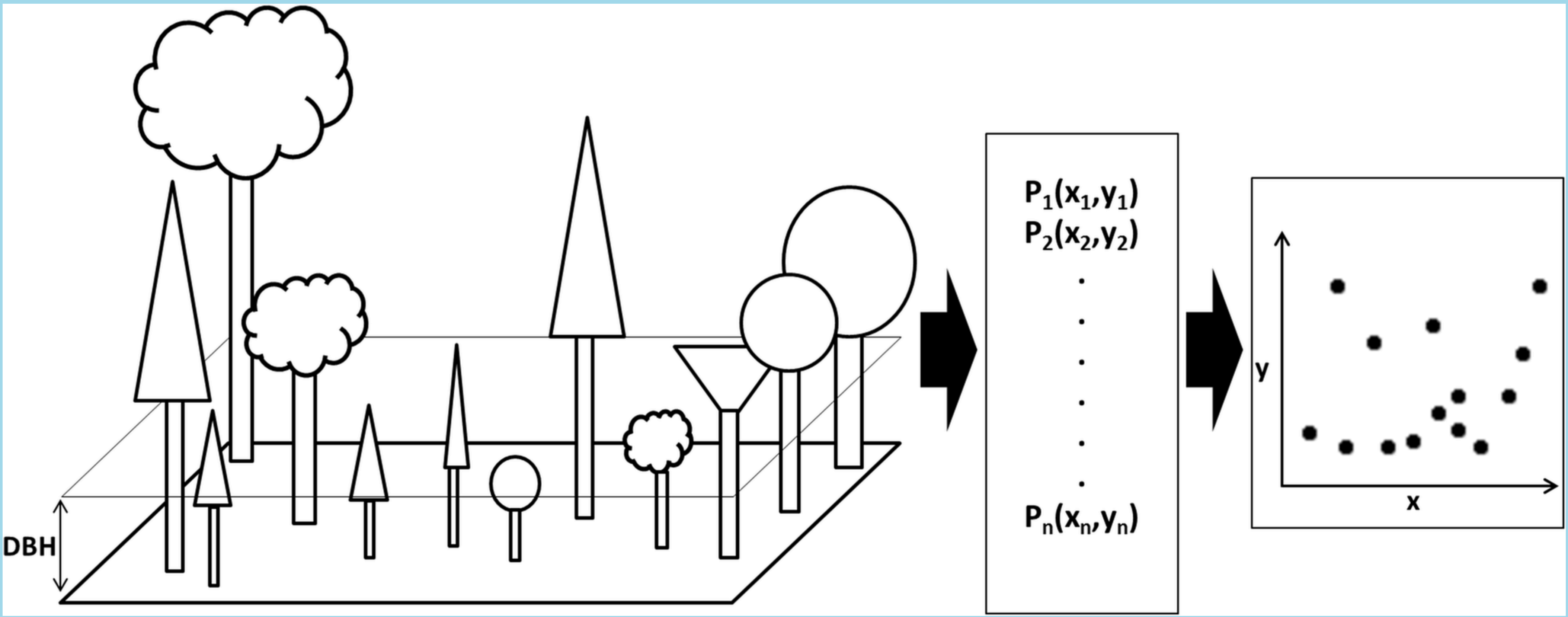
- D is a fixed subset of $\mathbb{R}^d$
- $Z(\mathbf{s})$ could be observed at any location within D.
- Models predict unobserved locations

Mitzi Morris

Point patterns

$$Z(\mathbf{s}) : \mathbf{s} \in D \subset \mathbb{R}^d$$

- D is random; where $\mathbf{s}$ depicts the location of events



How is the data stored?

What is a data model?

- **Data:** a collection of discrete values that describe phenomena
- Your brain stores millions of pieces of data
- Computers are not your brain
  - Need to organize data systematically
  - Be able to display and access efficiently
  - Need to be able to store and access repeatedly
- Data models solve this problem

2 Types of Spatial Data Models

- **Raster:** grid-cell tessellation of an area. Each raster describes the value of a single phenomenon. More next week…
- **Vector:** (many) attributes associated with locations defined by coordinates

The Vector Data Model

- **Vertices** (i.e., discrete x-y locations) define the shape of the vector
- The organization of those vertices define the *shape* of the vector
- General types: points, lines, polygons

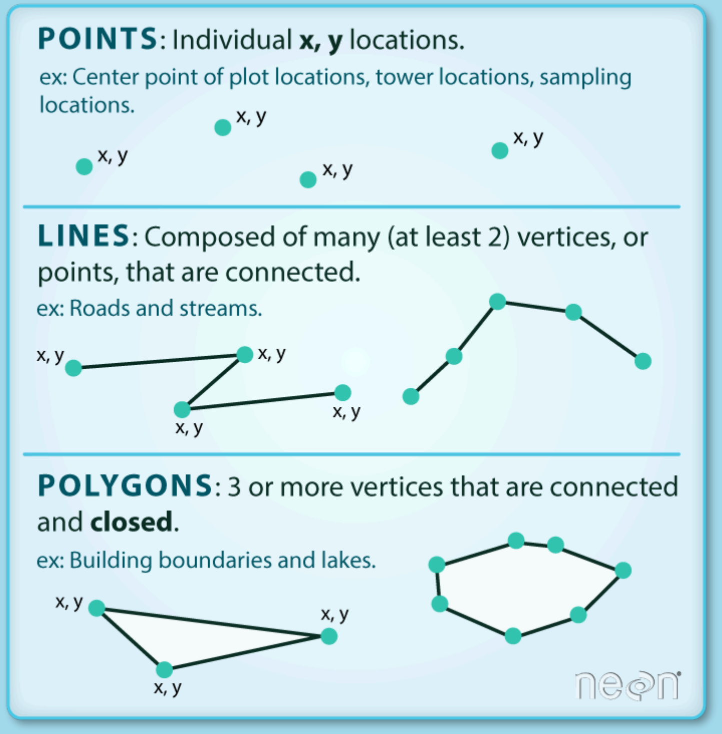
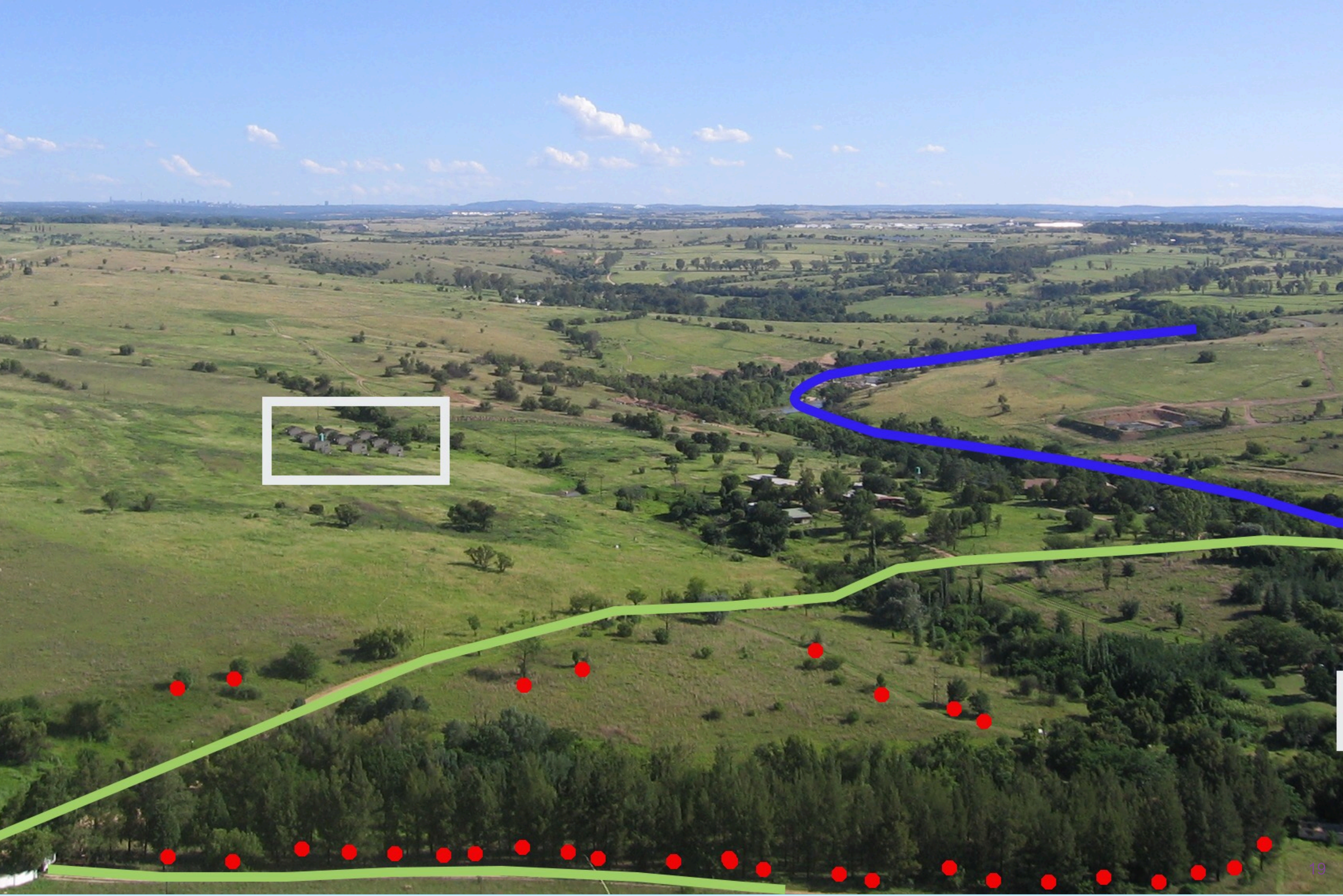


Image Source: Colin Williams (NEON)

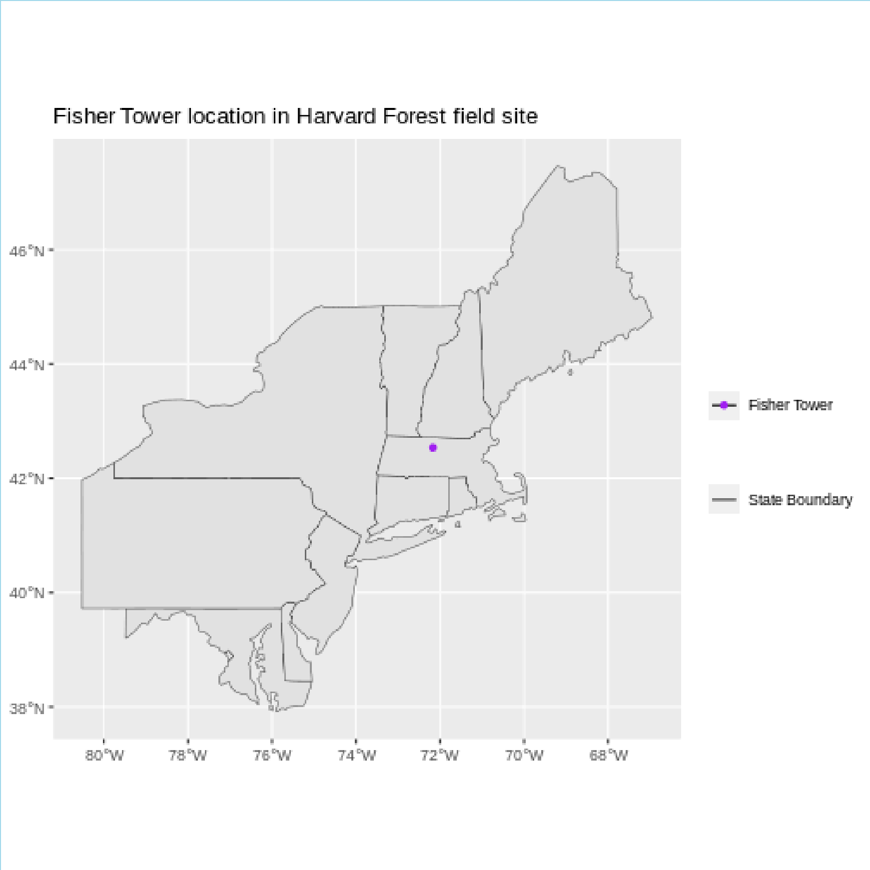


Vectors in Action

- Useful for locations with discrete, well-defined boundaries
- Very precise (not necessarily accurate)

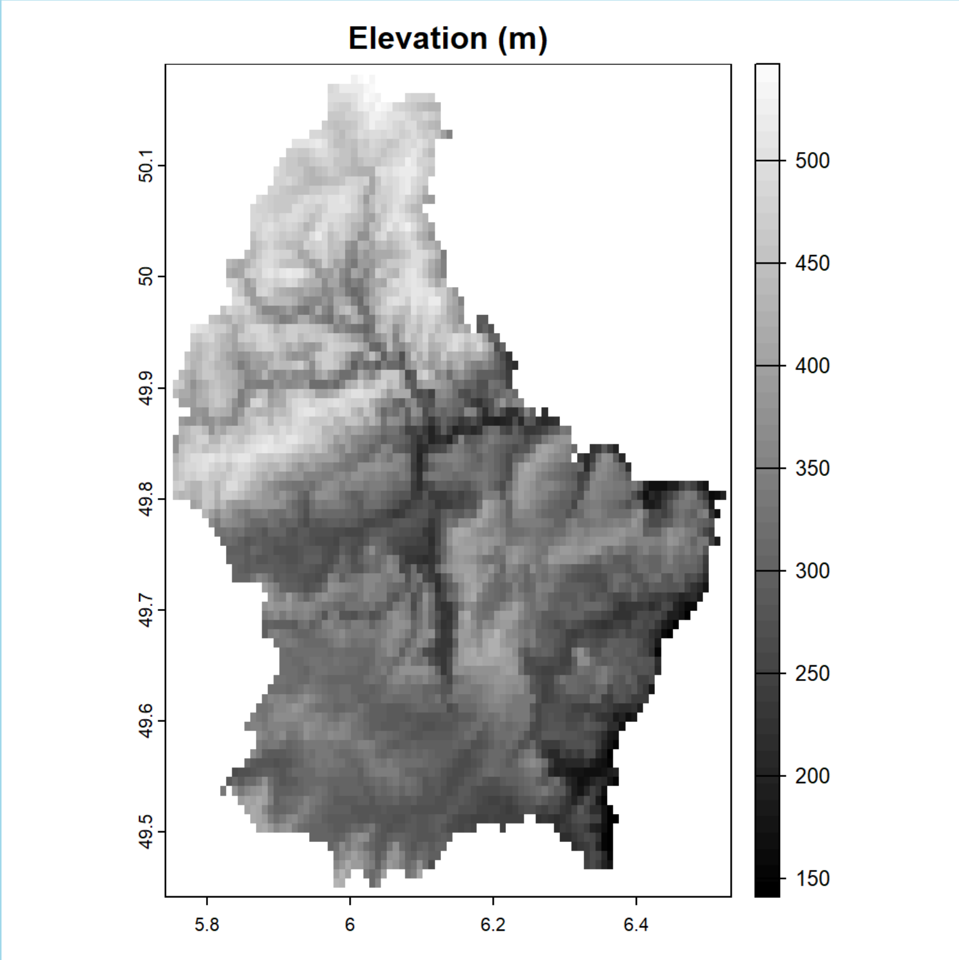
Vector Challenge!

The plot below includes examples of two of the three types of vector objects. Which ones are they?

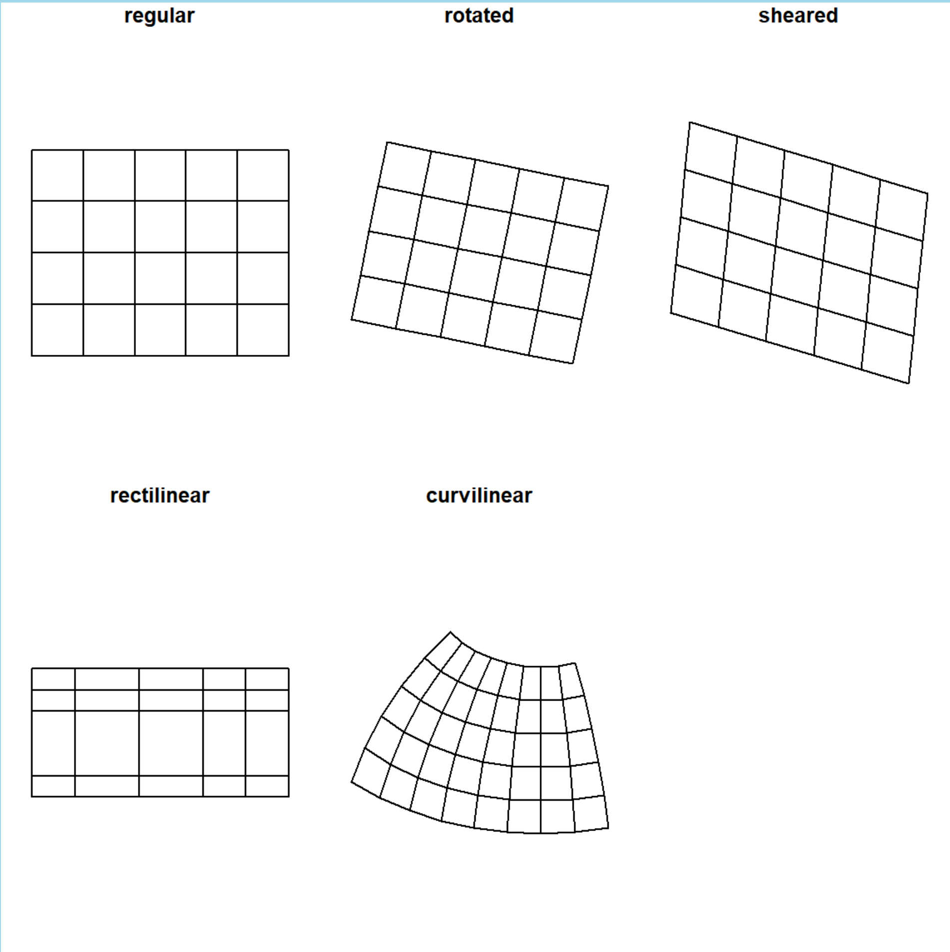


The Raster Data Model

- **Raster data** represent spatially continuous phenomena (NA is possible)
- Depict the alignment of data on a regular lattice (often a square)
- Geometry is implicit; the spatial extent and number of rows and columns define the cell size



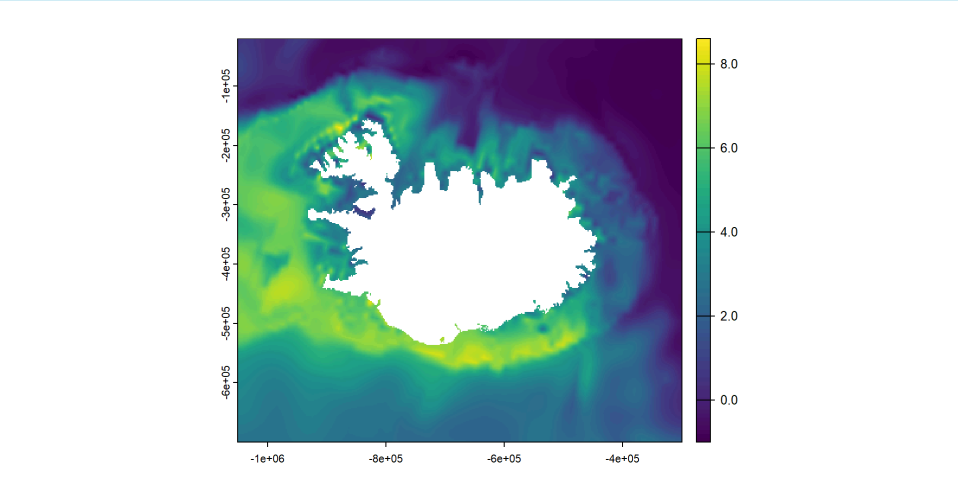
Types of Raster Data

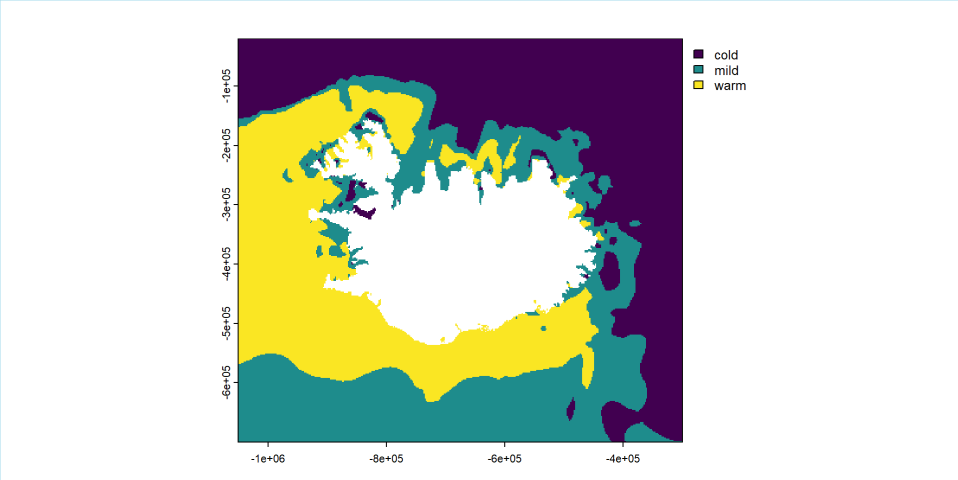


- **Regular**: constant cell size; axes aligned with Easting and Northing
- **Rotated**: constant cell size; axes not aligned with Easting and Northing
- **Sheared**: constant cell size; axes not perpendicular
- **Rectilinear**: cell size varies along a dimension
- **Curvilinear**: cell size and orientation dependent on the other dimension

Types of Raster Data

- **Continuous**: numeric data representing a measurement (e.g., elevation, precipitation)
- **Categorical**: integer data representing factors (e.g., land use, land cover)





What makes data (geo)spatial?

Location vs. Place

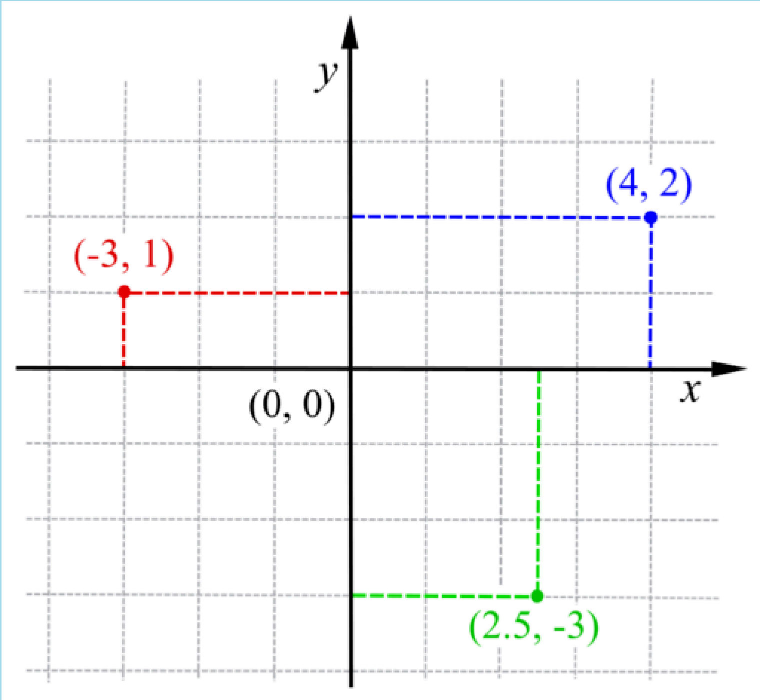
- **Place:** an area having unique **physical** and **human** characteristics **interconnected** with other places
- **Location:** the actual position on the earth's surface
- **Sense of Place:** the emotions someone attaches to an area based on experiences
- Place is *location plus meaning*

- **nominal: (potentially contested) place names**
- **absolute: the physical location on the earth's surface**

Describing Absolute Locations

- **Coordinates:** 2 or more measurements that specify location relative to a *reference system*

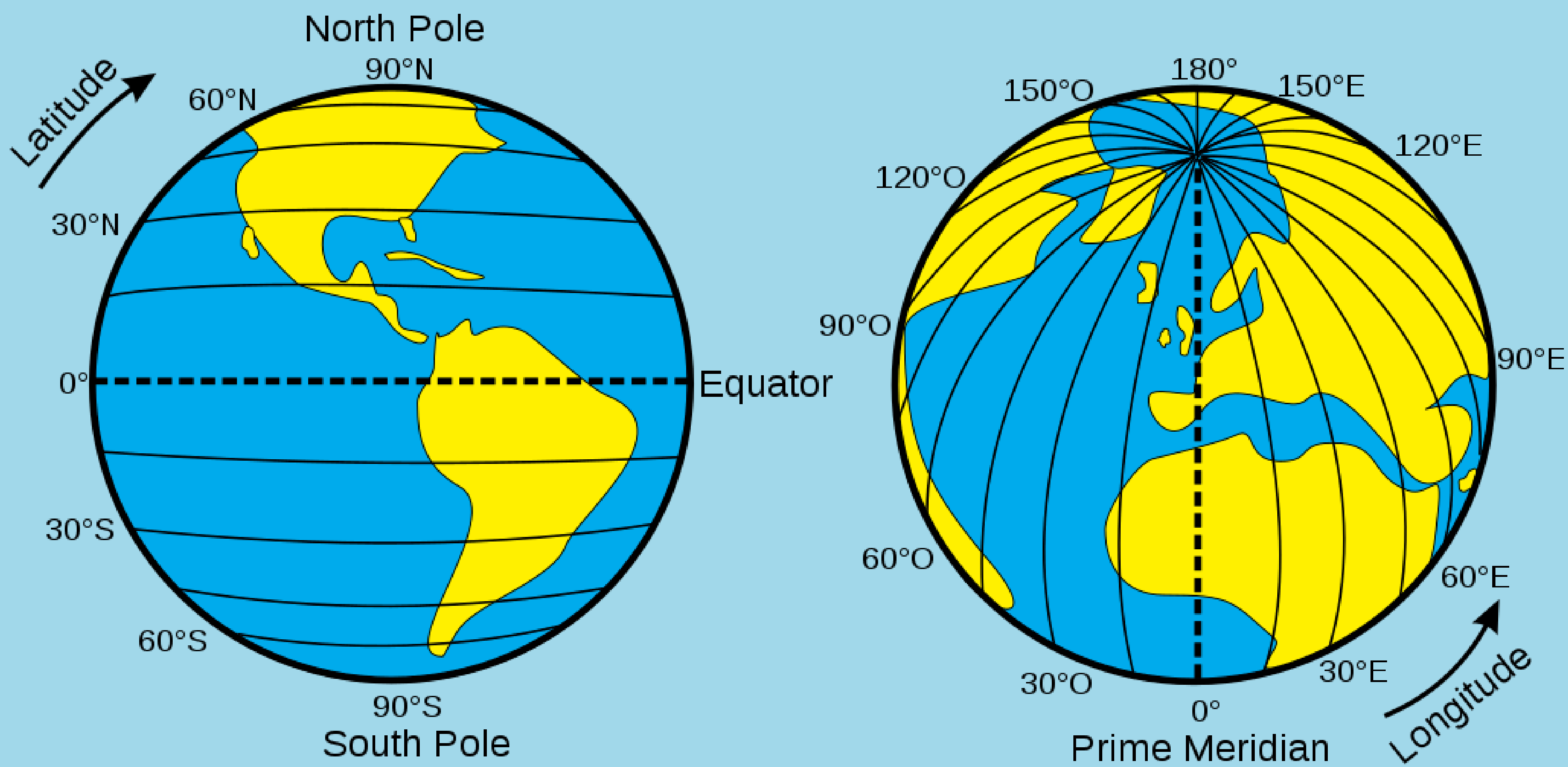
- Cartesian coordinate system
- *origin (O)* = the point at which both measurement systems intersect
- Adaptable to multiple dimensions (e.g. *z* for altitude)



Cartesian Coordinate System

Locations on a Globe

- The earth is not flat…



Latitude and Longitude

Locations on a Globe

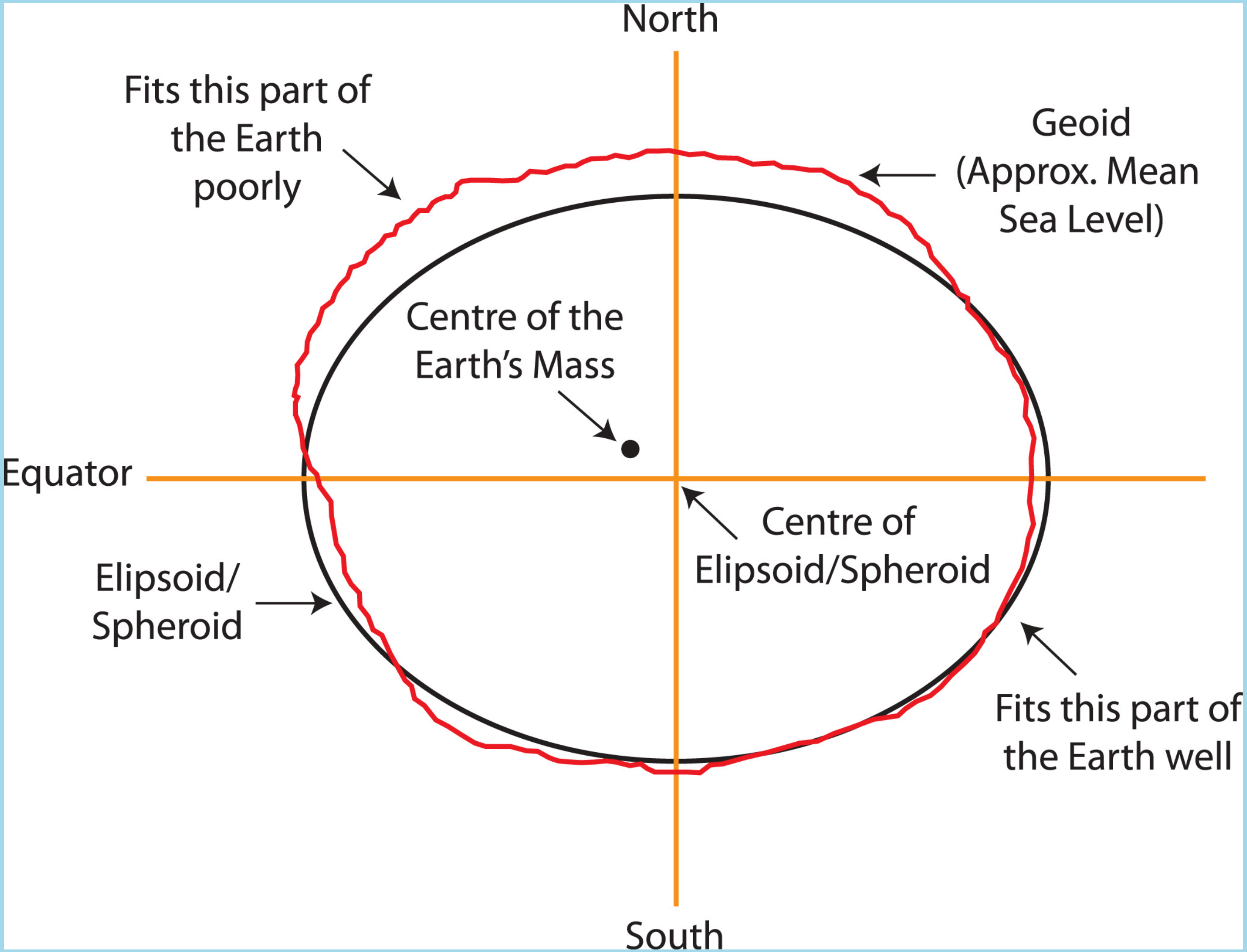
- The earth is not flat…
- Global Reference Systems (GRS)
- *Graticule*: the grid formed by the intersection of longitude and latitude
- The graticule is based on an ellipsoid model of earth's surface and contained in the *datum*

Global Reference Systems

The *datum* describes which ellipsoid to use and the precise relations between locations on earth's surface and Cartesian coordinates

- Geodetic datums (e.g., `WGS84`): distance from earth's center of gravity
- Local data (e.g., `NAD83`): better models for local variation in earth's surface

Global Reference Systems

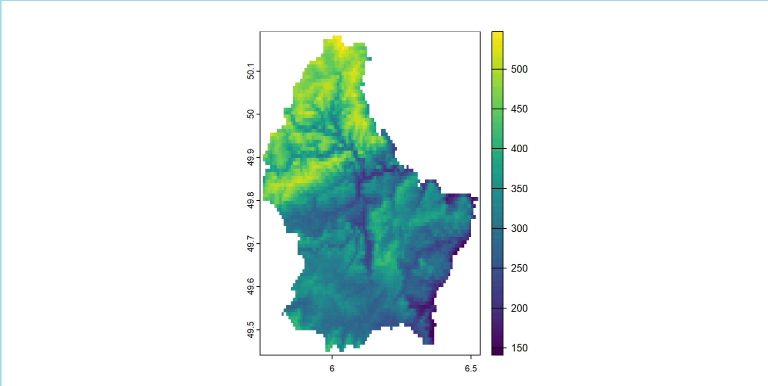


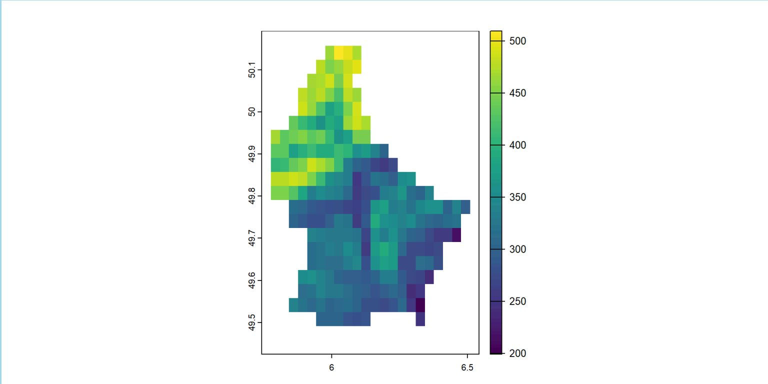
Describing location: extent

- How much of the world does the data cover?
- For rasters, these are the corners of the lattice
- For vectors, we call this the bounding box

Describing location: resolution

- **Resolution:** the accuracy that the location and shape of a map's features can be depicted
- **Minimum Mapping Unit:** The minimum size and dimensions that can be reliably represented at a given *map scale*.
- Map scale vs. scale of analysis

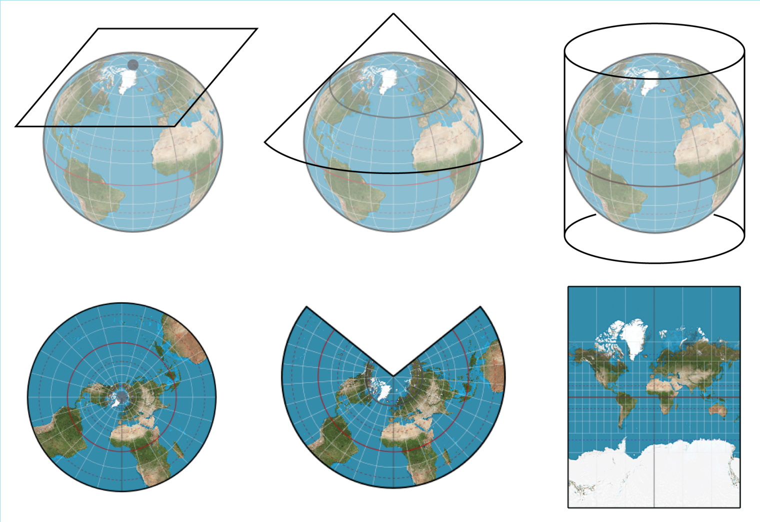




The earth is not flat…

Projections

- But maps, screens, and publications are…
- **Projections** describe *how* the data should be translated to a flat surface
- Rely on 'developable surfaces'
- Described by the Coordinate Reference System (CRS)

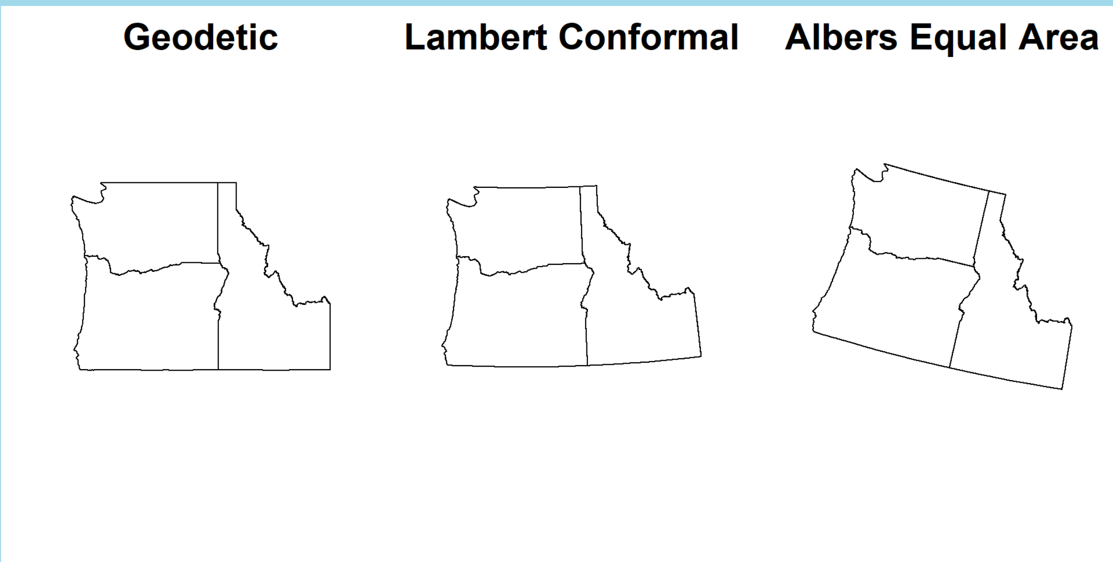


Developable Surfaces

Projection necessarily induces some form of distortion (tearing, compression, or shearing)

Coordinate Reference Systems

- Some projections minimize distortion of angle, area, or distance
- Others attempt to avoid extreme distortion of any kind
- Includes: Datum, ellipsoid, units, and other information (e.g., False Easting, Central Meridian) to further map the projection to the GCS
- Not all projections have/require all of the parameters



The Orange Peel Analogy

A datum is the choice of fruit to use. Is the earth an orange, a lemon, a lime, a grapefruit?

A projection is how you peel your orange and then flatten the peel.

Choosing Projections

Neil Kaye/@neilrkaye

The Mercator Map Projection with the true size and shape of the country overlaid.

- Equal-area for thematic maps
- Conformal for presentations
- Mercator or equidistant for navigation and distance

Geometries, support, and spatial messiness

Geometries

- Vectors store and aggregate the locations of a feature into a geometry
- Most vector operations require simple, valid geometries

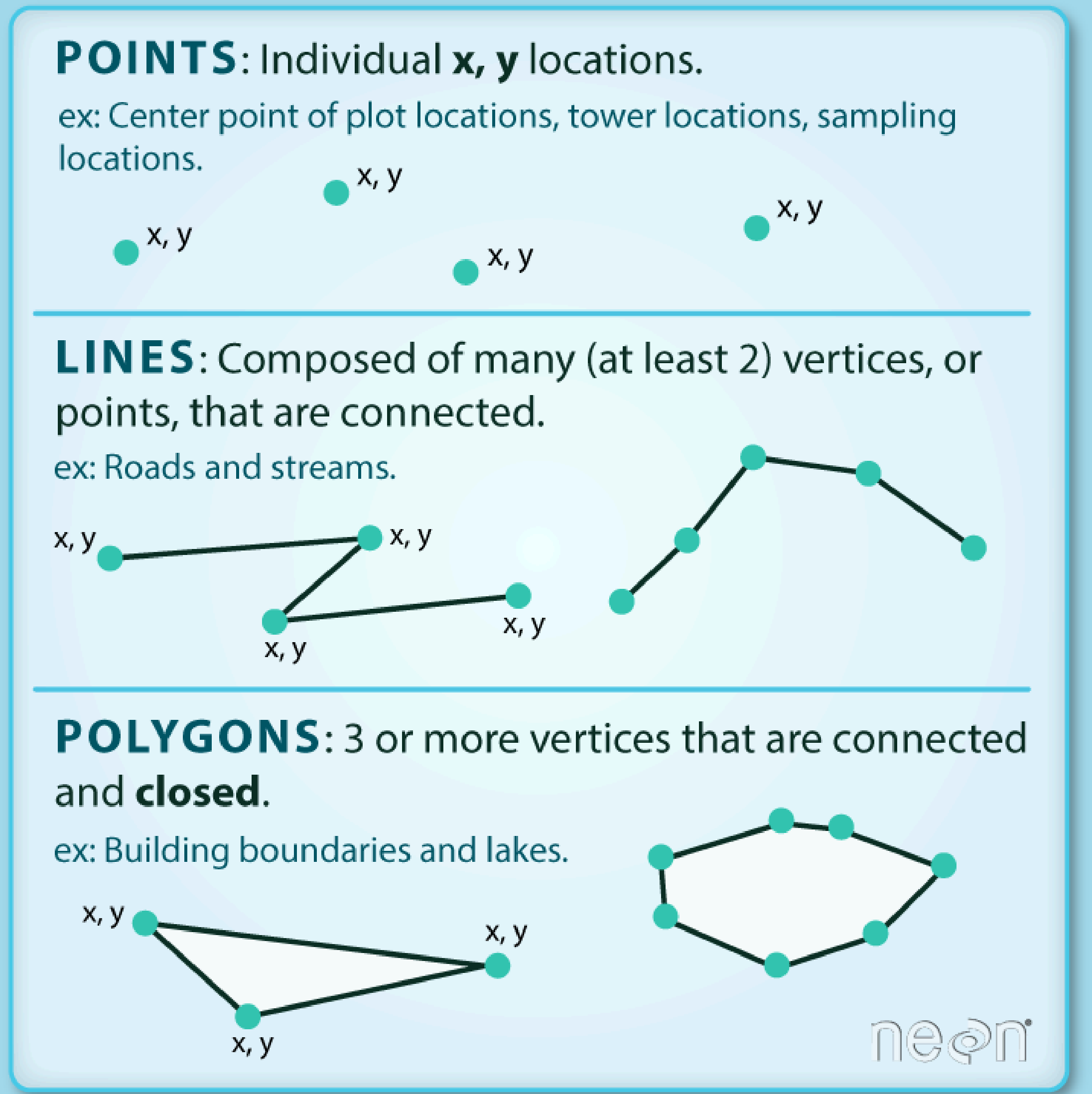


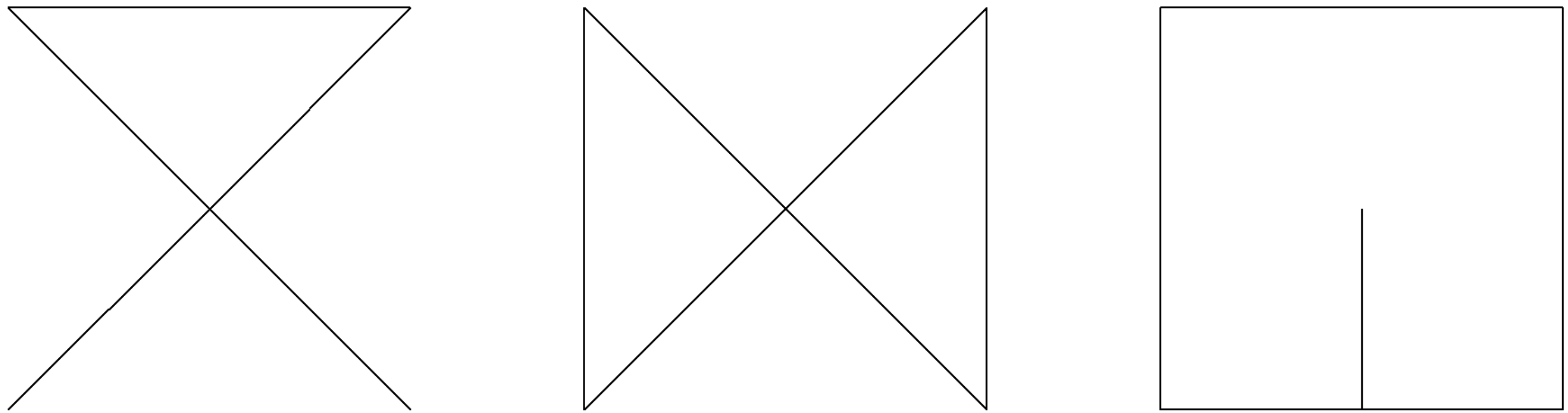
Image Source: Colin Williams (NEON)

Valid Geometries

A `linestring` is *simple* if it does not intersect

Valid polygons:

- Are closed (i.e., the last vertex equals the first)
- Have holes (inner rings) that inside the the exterior boundary
- Have holes that touch the exterior at no more than one vertex (they don’t extend across a line) - For multipolygons, adjacent polygons touch only at points
- Do not repeat their own path



Empty Geometries

- Empty geometries arise when an operation produces `NULL` outcomes (like looking for the intersection between two non-intersecting polygons)
- `sf` allows empty geometries to make sure that information about the data type is retained
- Similar to a `data.frame` with no rows or a `list` with `NULL` values
- Most vector operations require simple, valid geometries

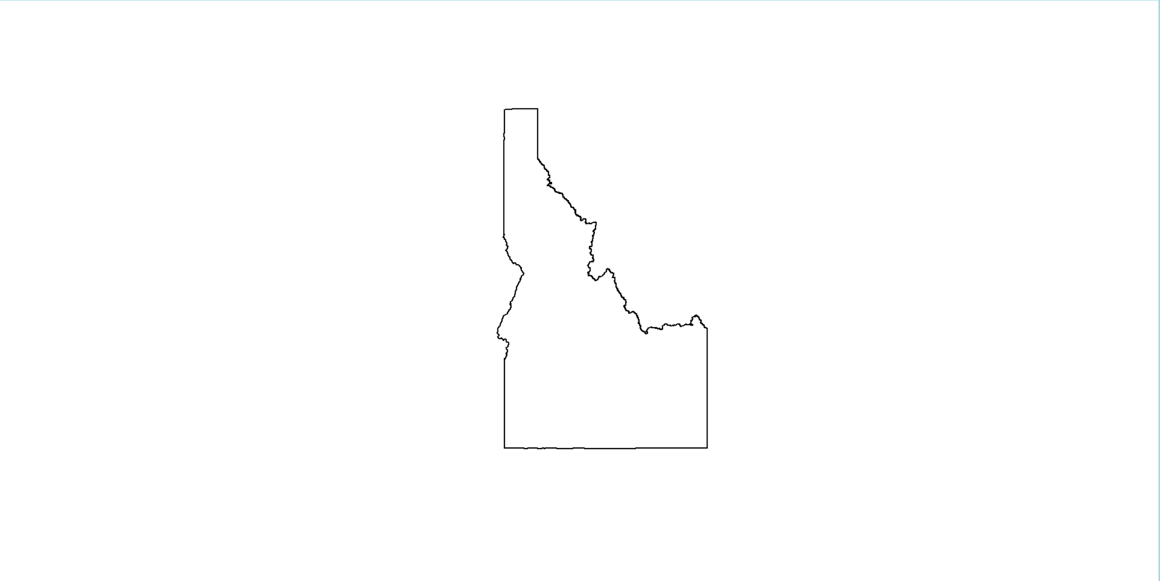
Support

- **Support** is the area to which an attribute applies.

Types of support for vectors

Give an example of:

- constant support
- identity support
- aggregate support



Spatial Messiness

- Quantitative geography requires that our data are aligned
- Achieving alignment is part of reproducible workflows
- Making principled decisions about projections, resolution, extent, etc

End