

Introduction to Spatial Data

HES 505 Fall 2023: Session 3

Matt Williamson

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?

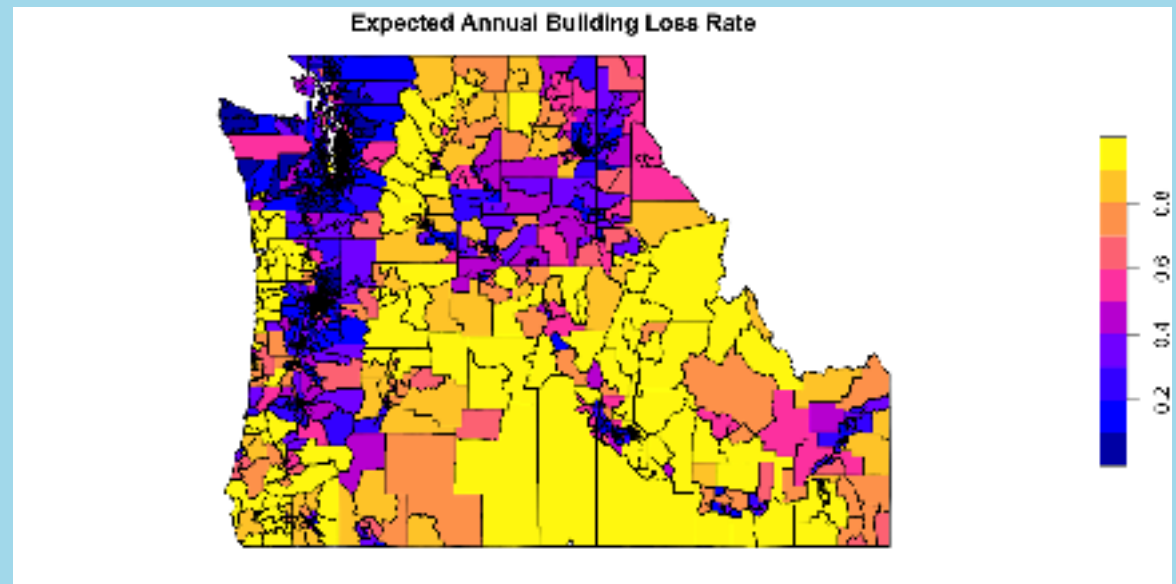
Spatial data as a stochastic process

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

Areal Data

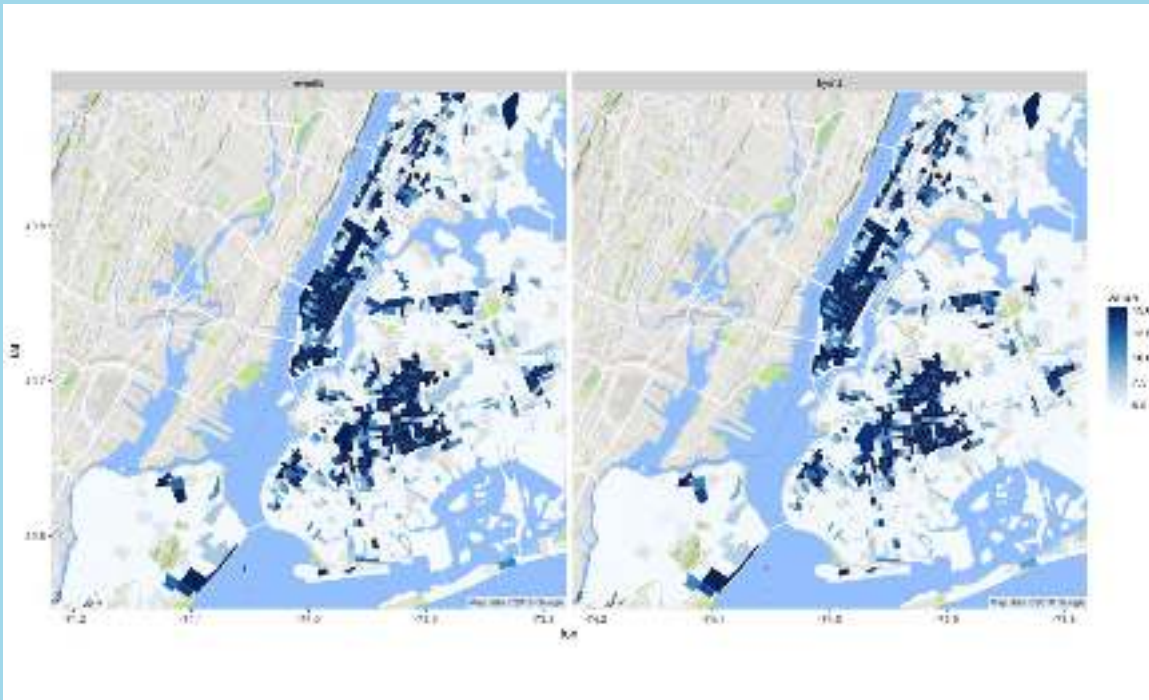
$$Z(\mathbf{s}) : \mathbf{s} \in D \subset \mathbb{R}^d$$

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



Geostatistical data

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



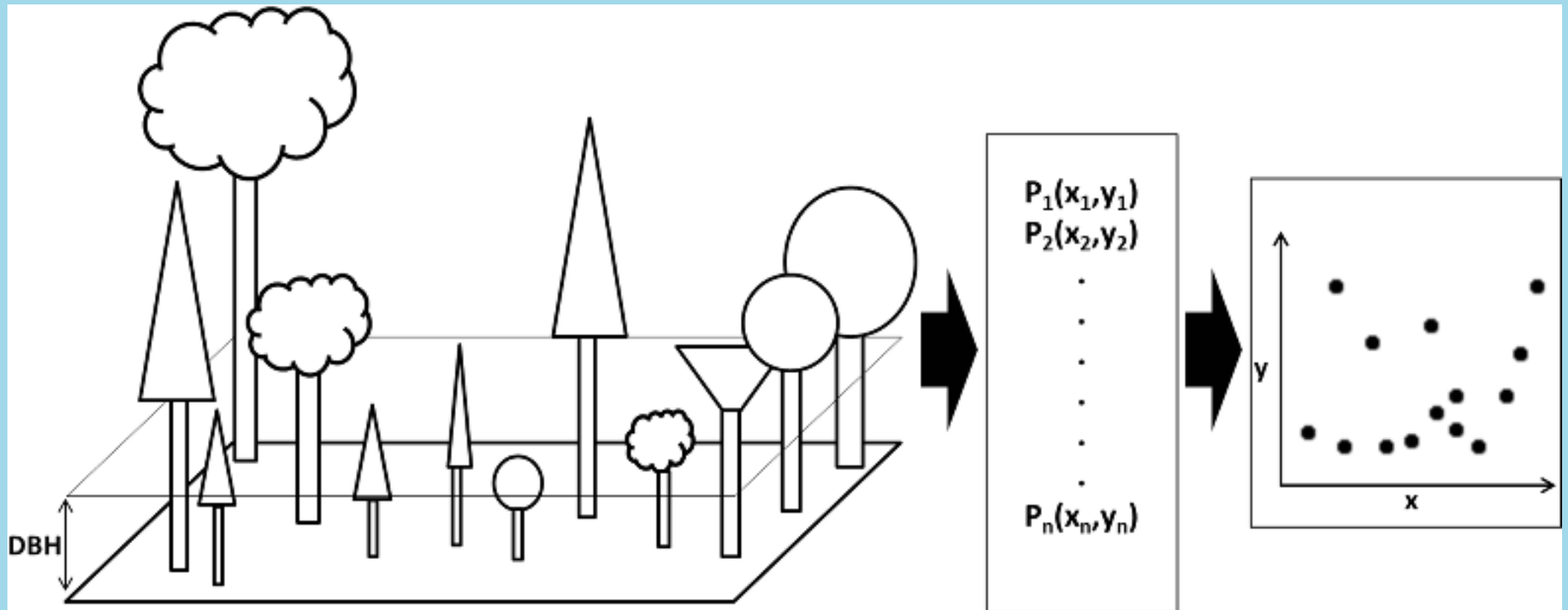
Mitzi Morris

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

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

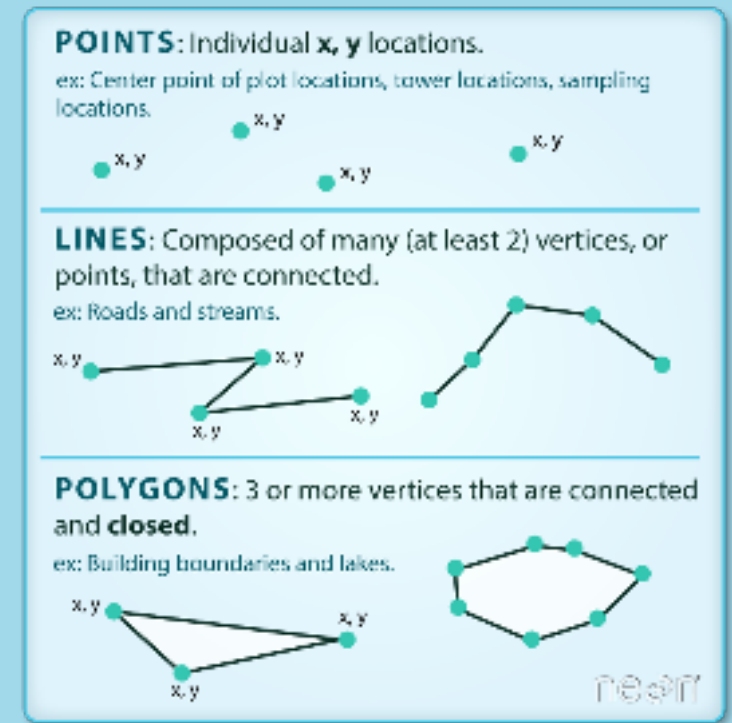
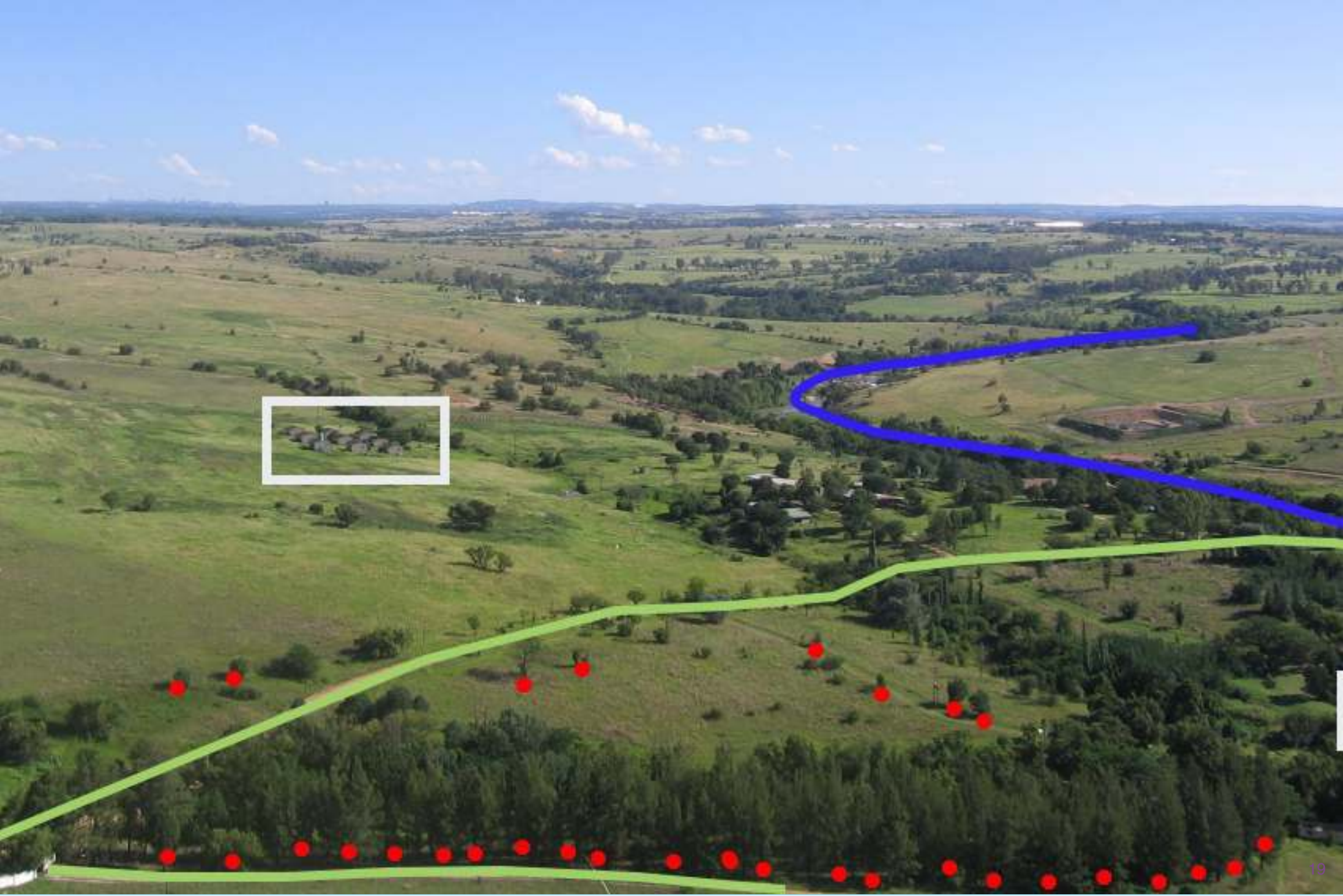


Image Source: Colin Williams
(NEON)



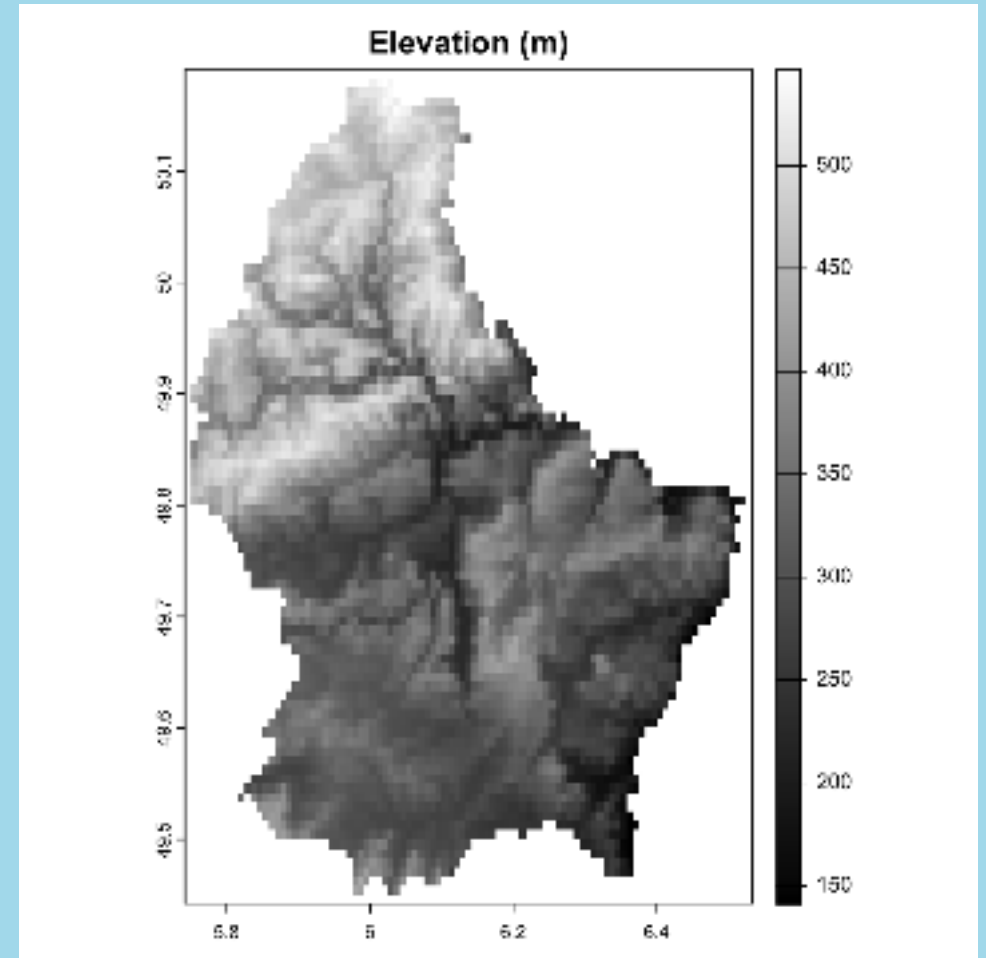
Vectors in Action

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

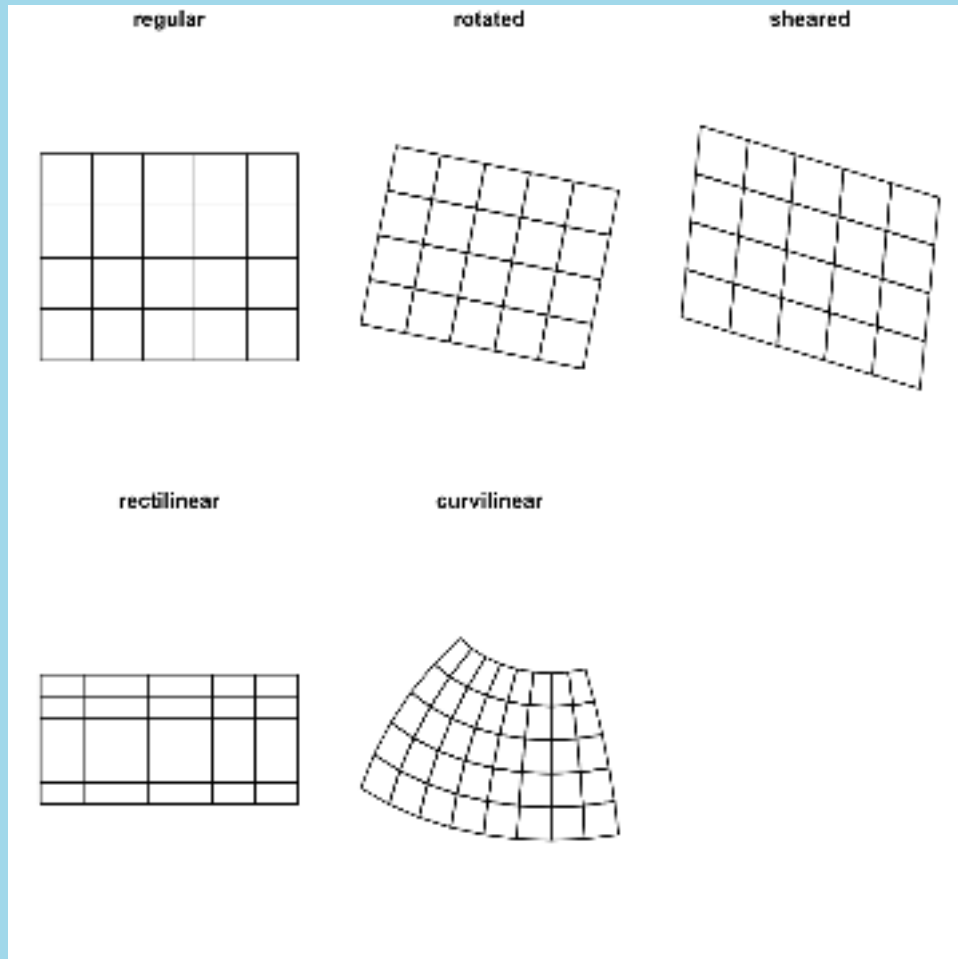


The Raster Data Model

- 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



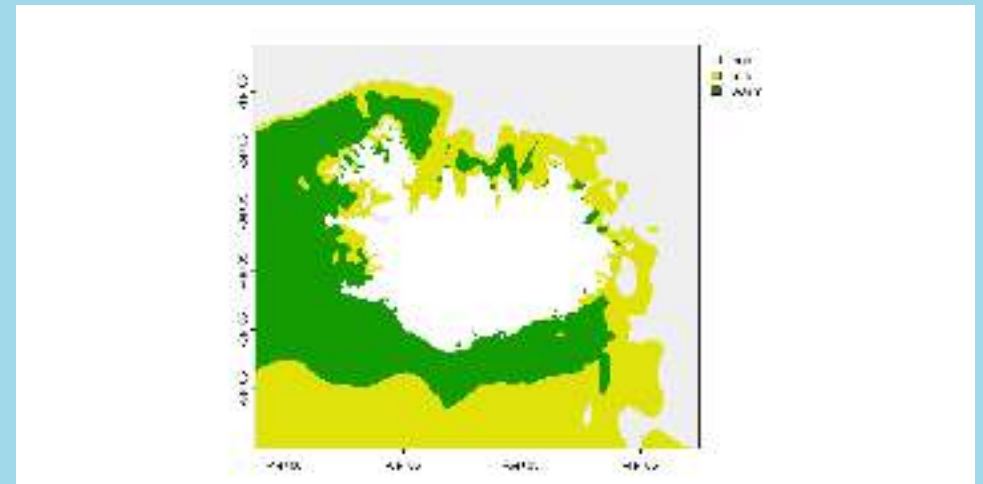
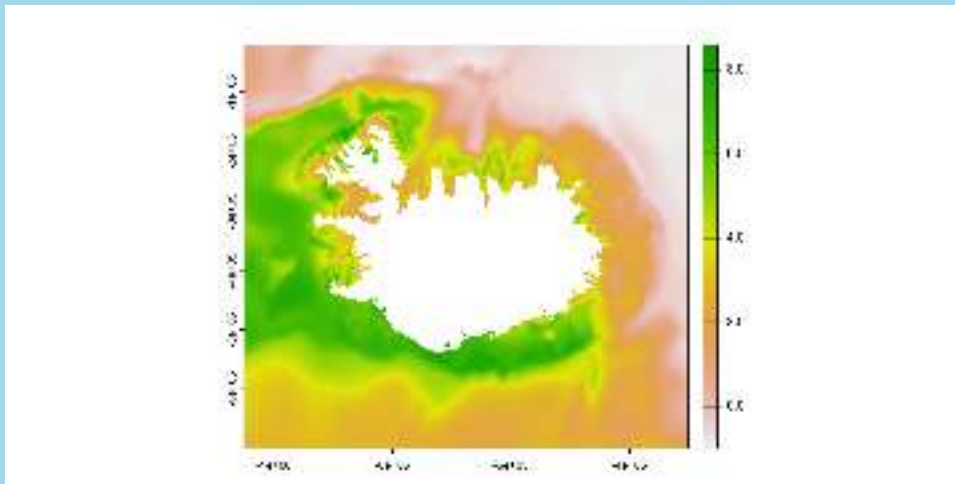
Types of Raster Data



- **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 parallel
- **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)



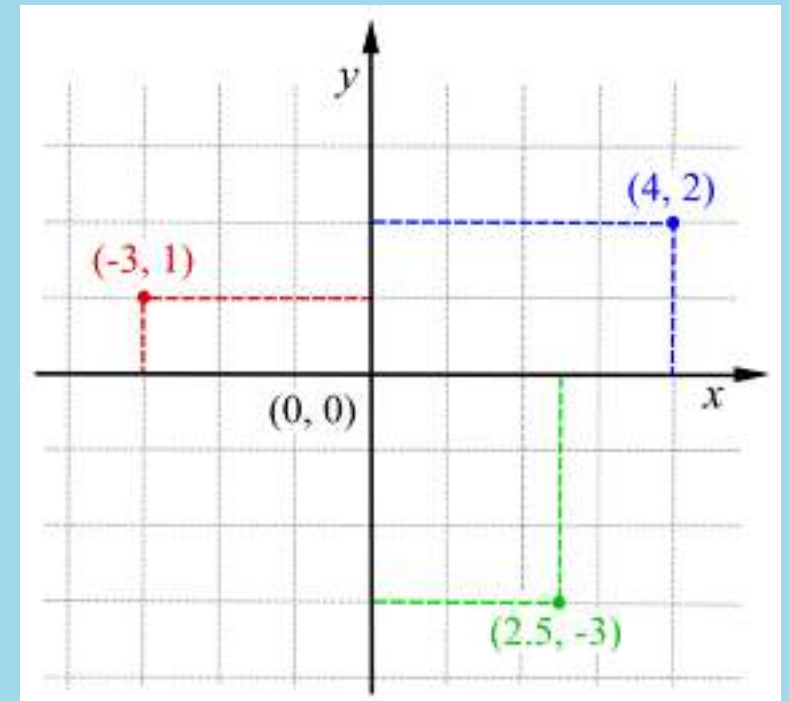
What makes data (geo)spatial?

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

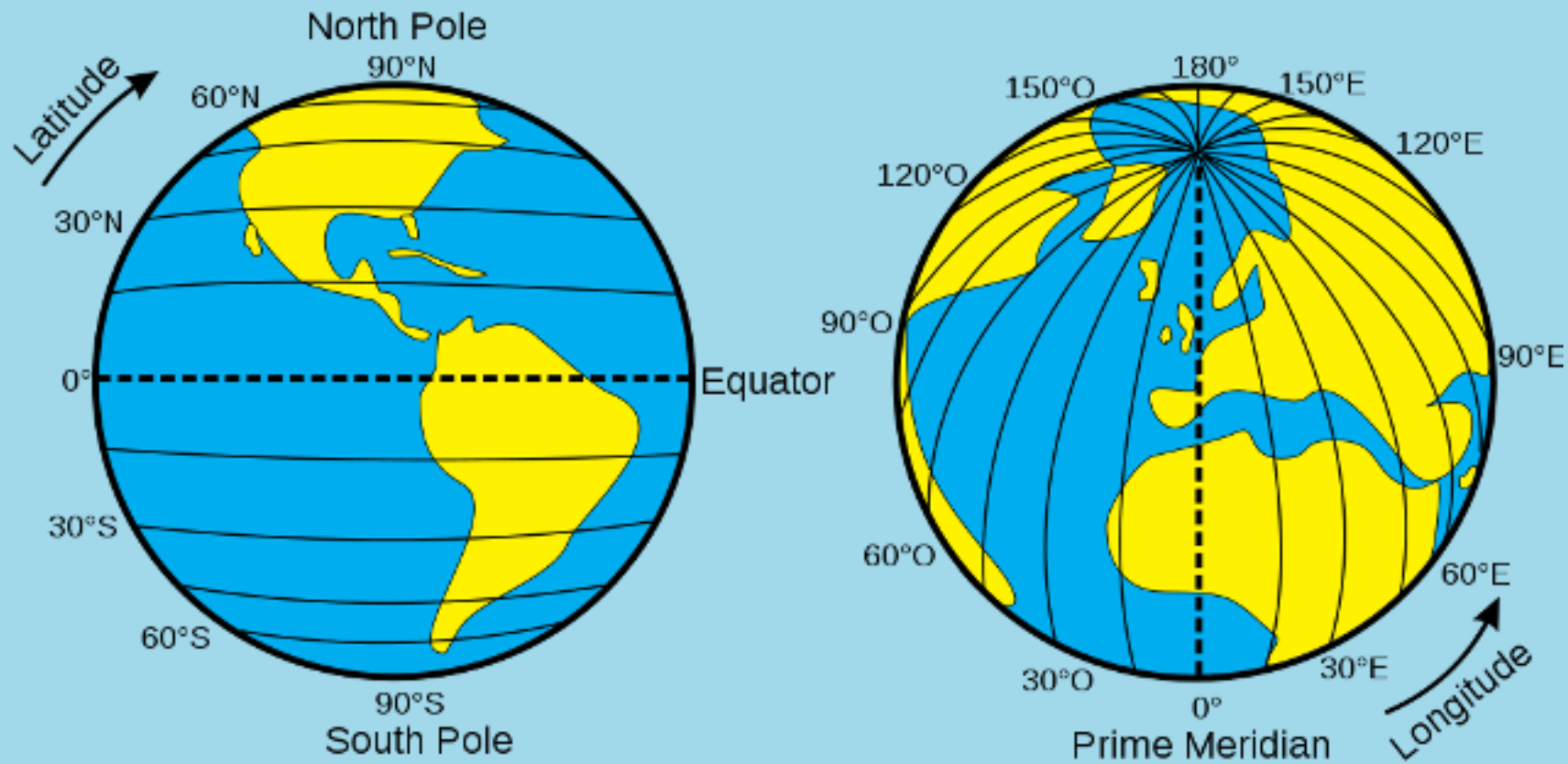
- **Coordinates:** 2 or more measurements that specify location relative to a *reference system*
- Cartesian coordinate system
- *origin* (O) = the point at which both measurement systems intersect
- Adaptable to multiple dimensions (e.g. z for altitude)



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

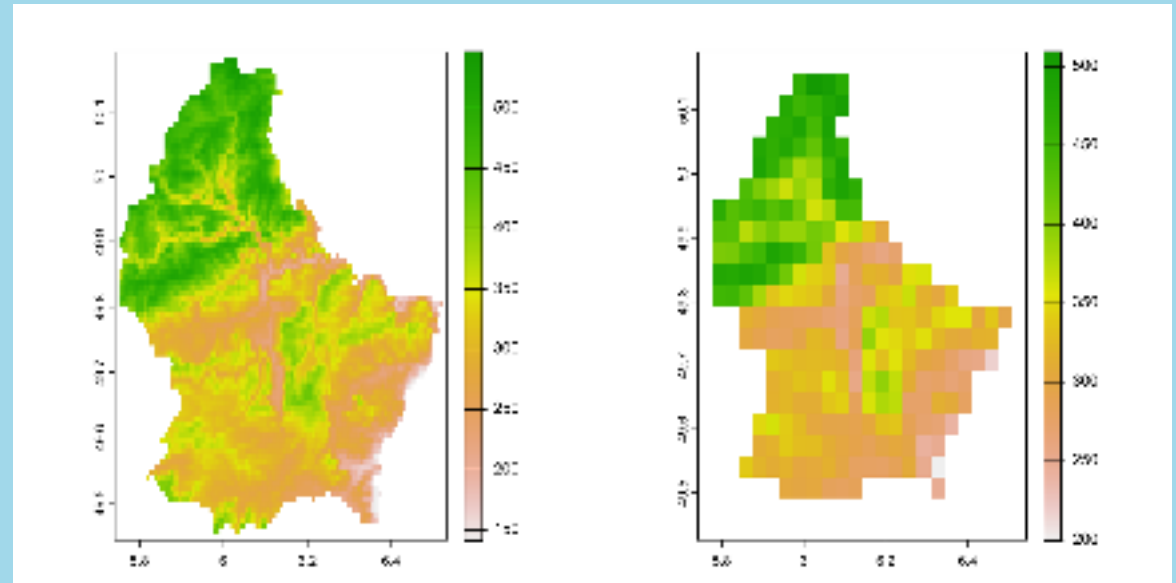
Describing location: extent

- 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 is the size of the smallest object that can be distinguished
- Resolution is determined by the wavelength of the light used
- Resolution is determined by the numerical aperture of the objective lens
- Resolution is determined by the quality of the optics
- Resolution is determined by the quality of the detector
- Resolution is determined by the quality of the sample
- Resolution is determined by the quality of the environment
- Resolution is determined by the quality of the operator
- Resolution is determined by the quality of the data
- Resolution is determined by the quality of the analysis
- Resolution is determined by the quality of the results
- Resolution is determined by the quality of the conclusions
- Resolution is determined by the quality of the communication
- Resolution is determined by the quality of the collaboration
- Resolution is determined by the quality of the culture
- Resolution is determined by the quality of the community
- Resolution is determined by the quality of the country
- Resolution is determined by the quality of the continent
- Resolution is determined by the quality of the world

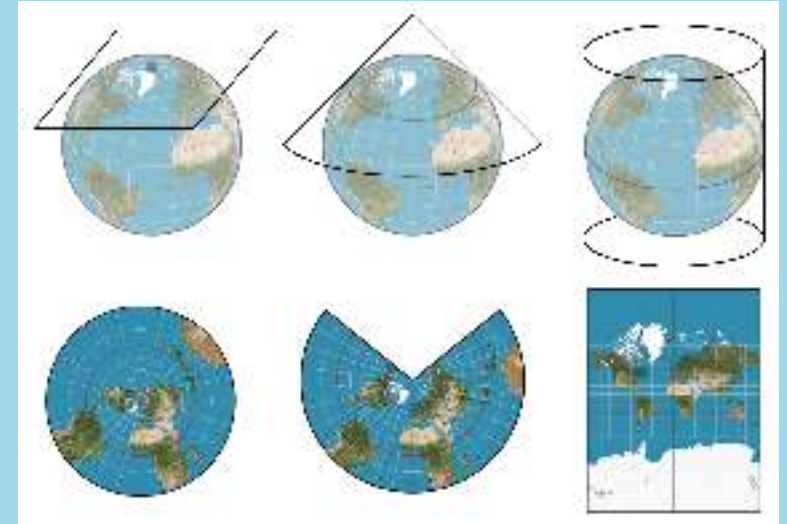
- **Resolution:** the accuracy that the location and shape of a map's features can be depicted
- **Minimum Mapping Unit:** The minimum size and dimensions that can be reliably represented at a given *map scale*.
- Map scale vs. scale of analysis



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)

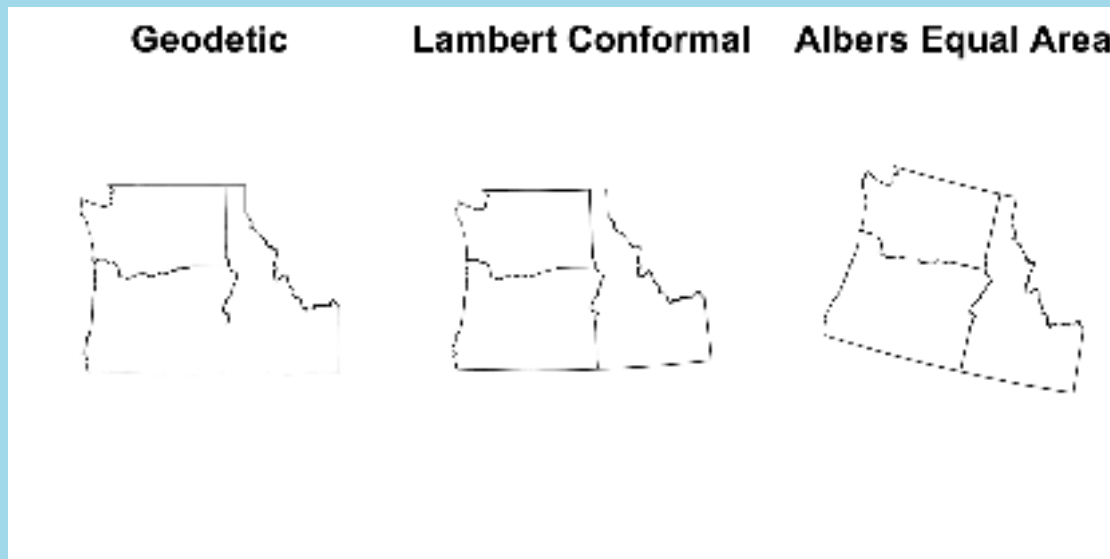


Developable Surfaces

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



Choosing Projections



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

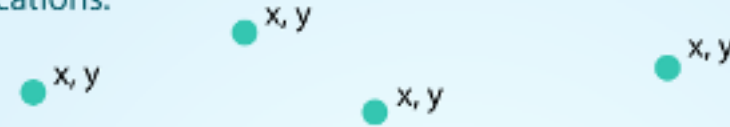
Geometries, support, and spatial messiness

Geometries

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

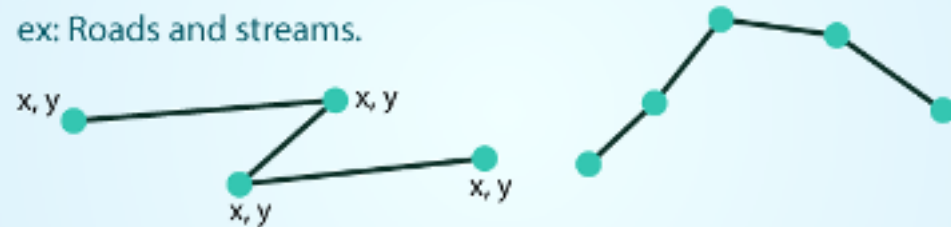
POINTS: Individual x, y locations.

ex: Center point of plot locations, tower locations, sampling locations.



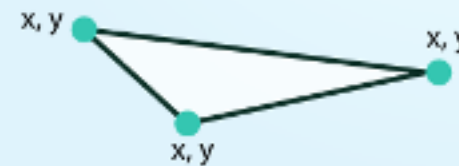
LINES: Composed of many (at least 2) vertices, or points, that are connected.

ex: Roads and streams.



POLYGONS: 3 or more vertices that are connected and **closed**.

ex: Building boundaries and lakes.

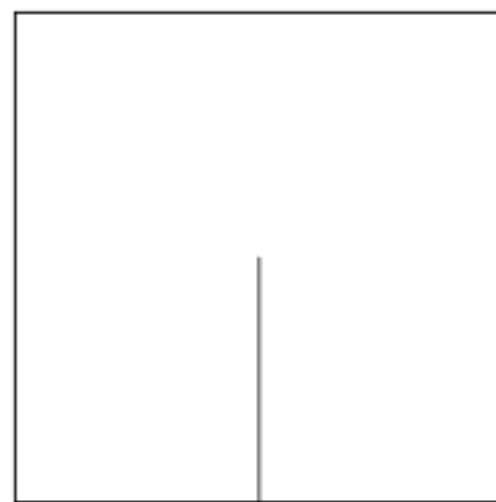
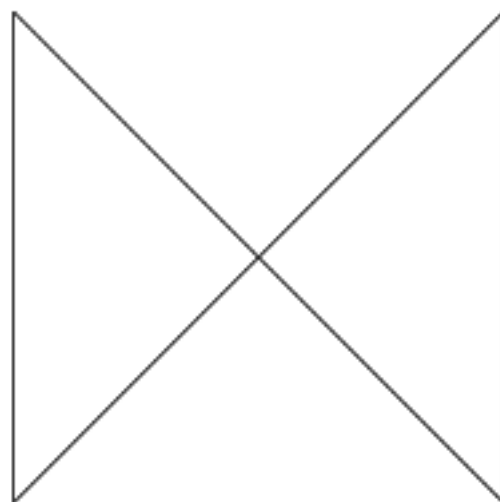
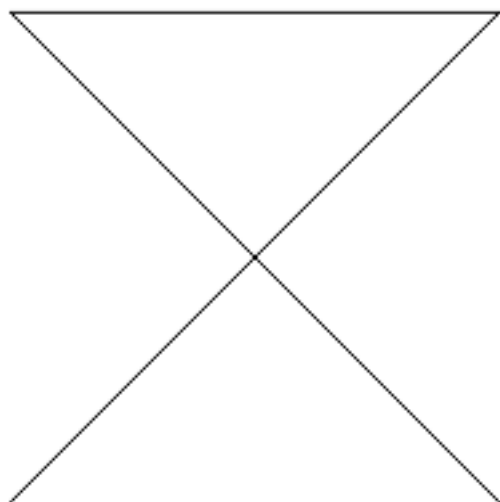


neon

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.

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

