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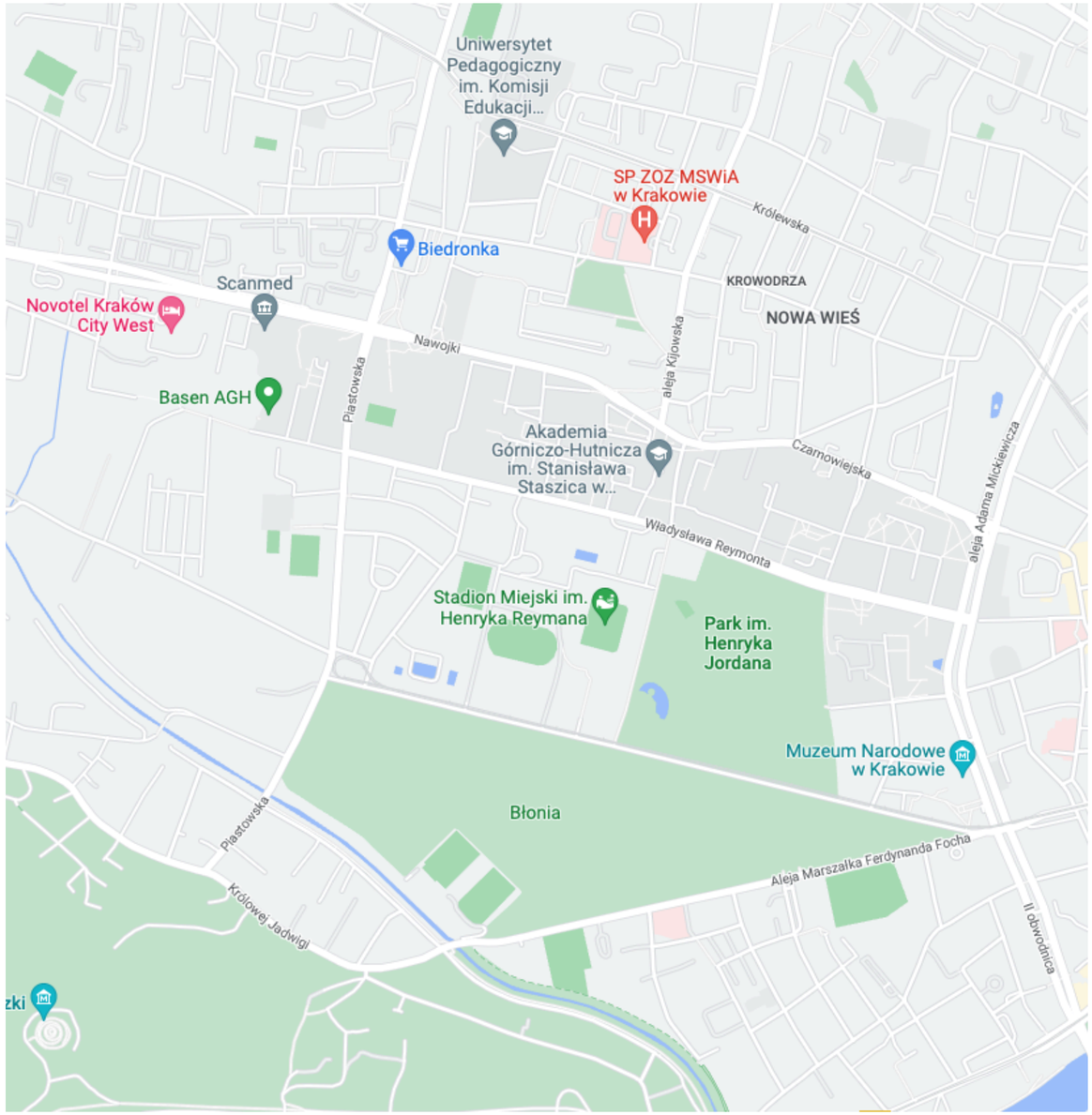
Processing Spatial Data

Data Engineering

Introduction

Dealing with geographic data

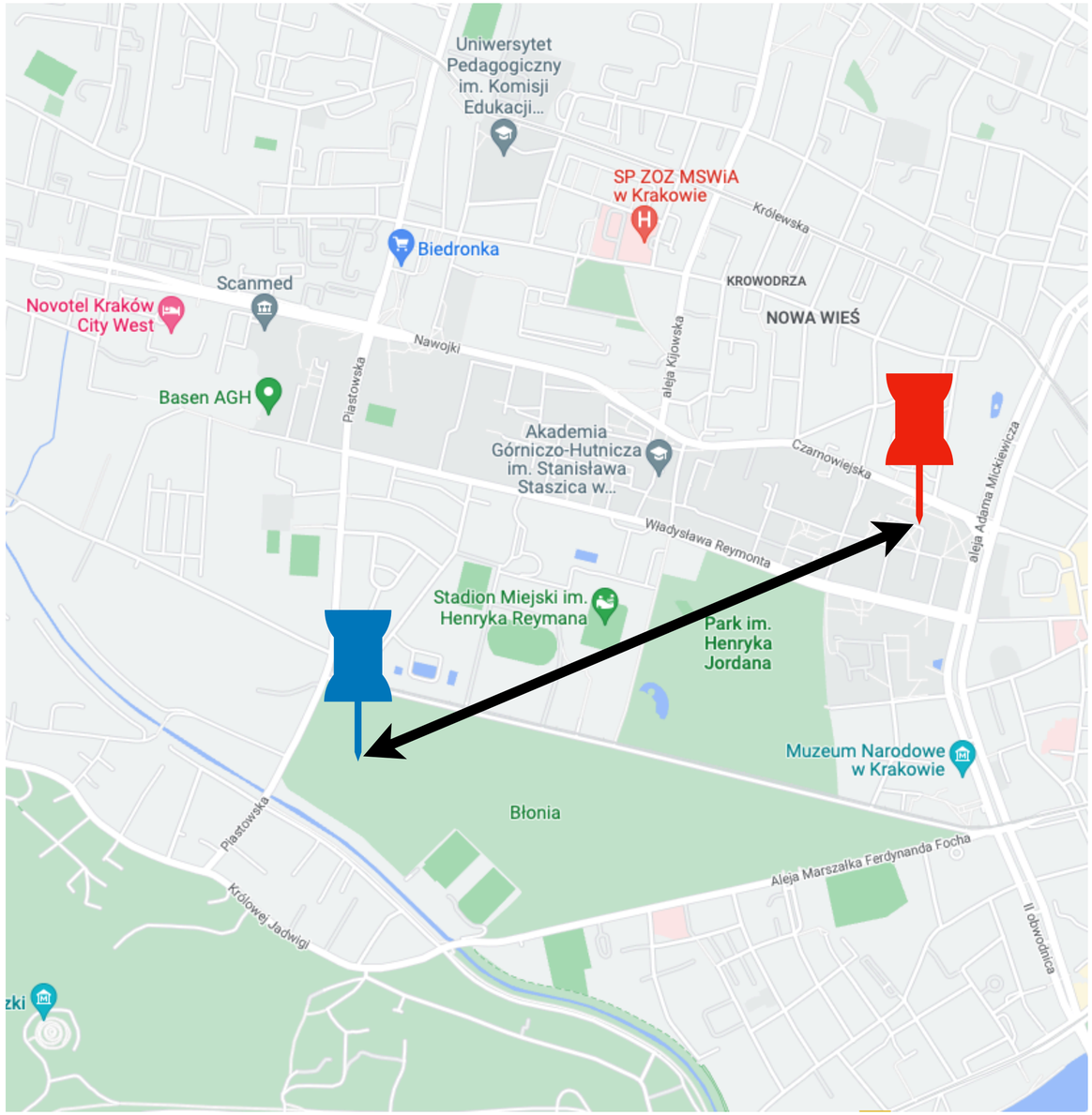
- Geographic data is usually expressed as pairs (2D) or triples (3D) of coordinates (numbers)
- They could be stored as separate *float* columns, but there are drawbacks…



Introduction

Problem #1: distance

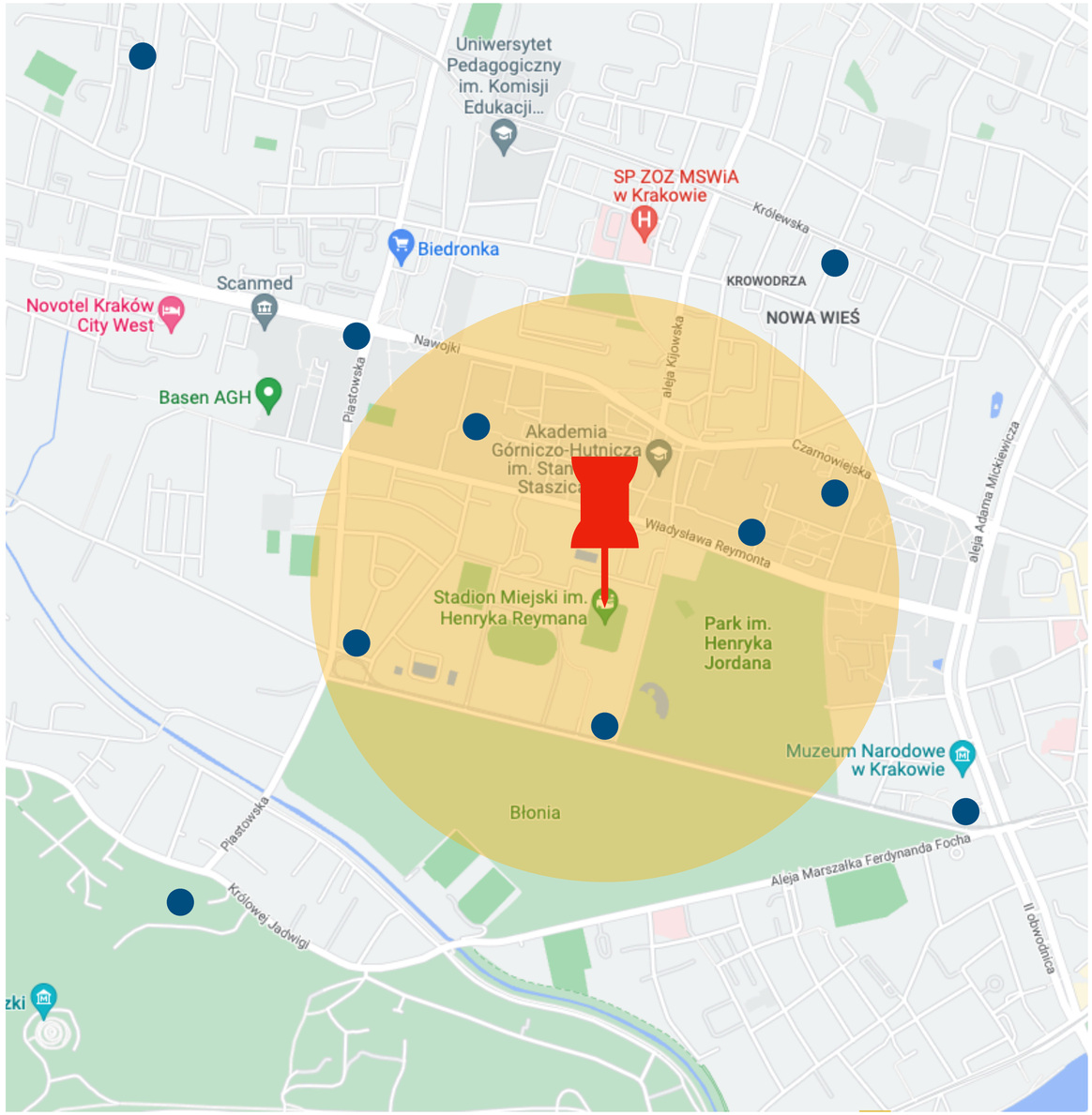
- Calculating the **distance** is pretty straightforward
- We can use a **simple formula** to calculate the distance between two points



Introduction

Problem #2: points in radius

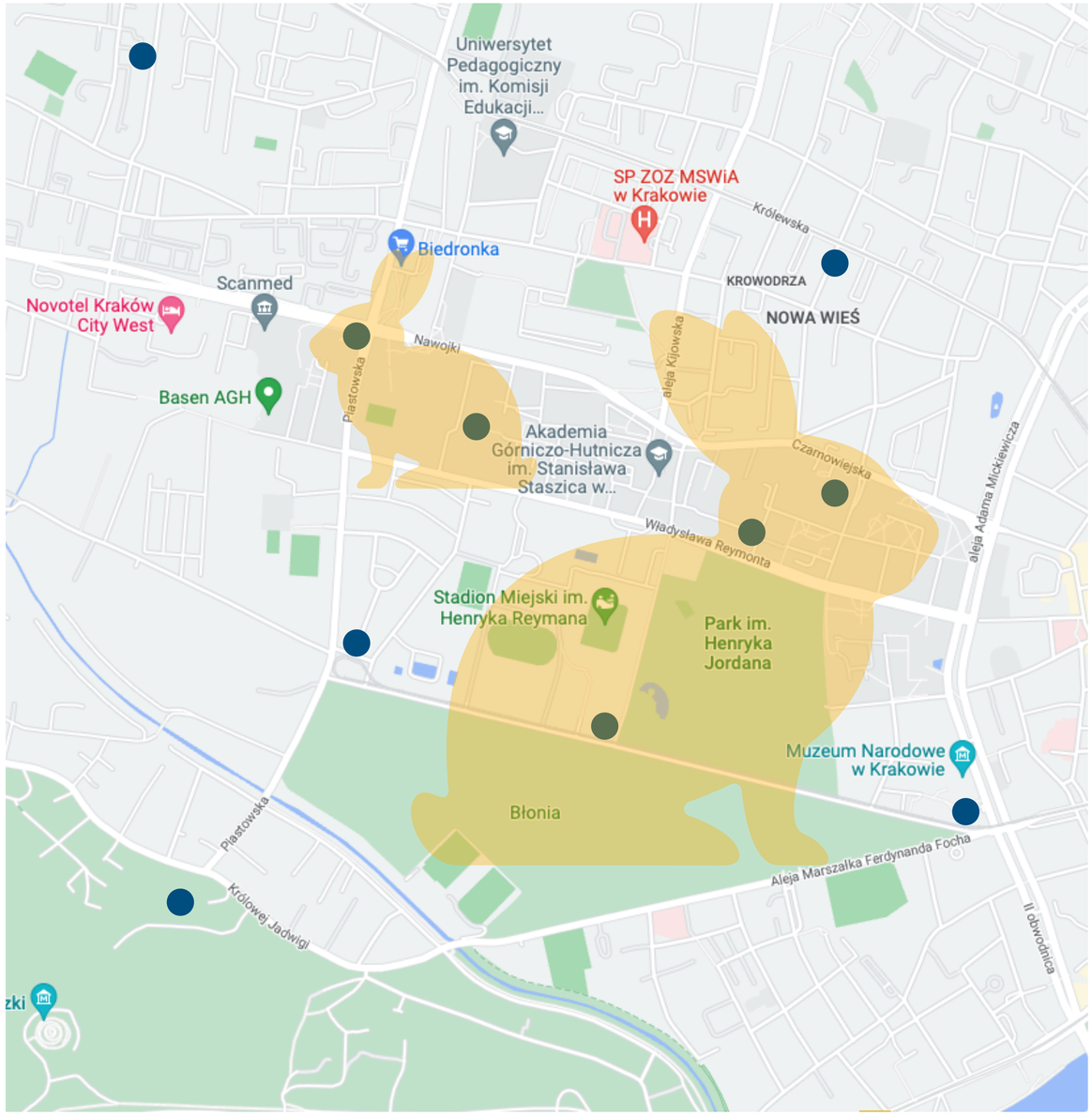
- The **formula** stays roughly the same
- But now we need to use it as a **selection predicate**
- This means calculating **many distances**



Introduction

Problem #3: spatial join

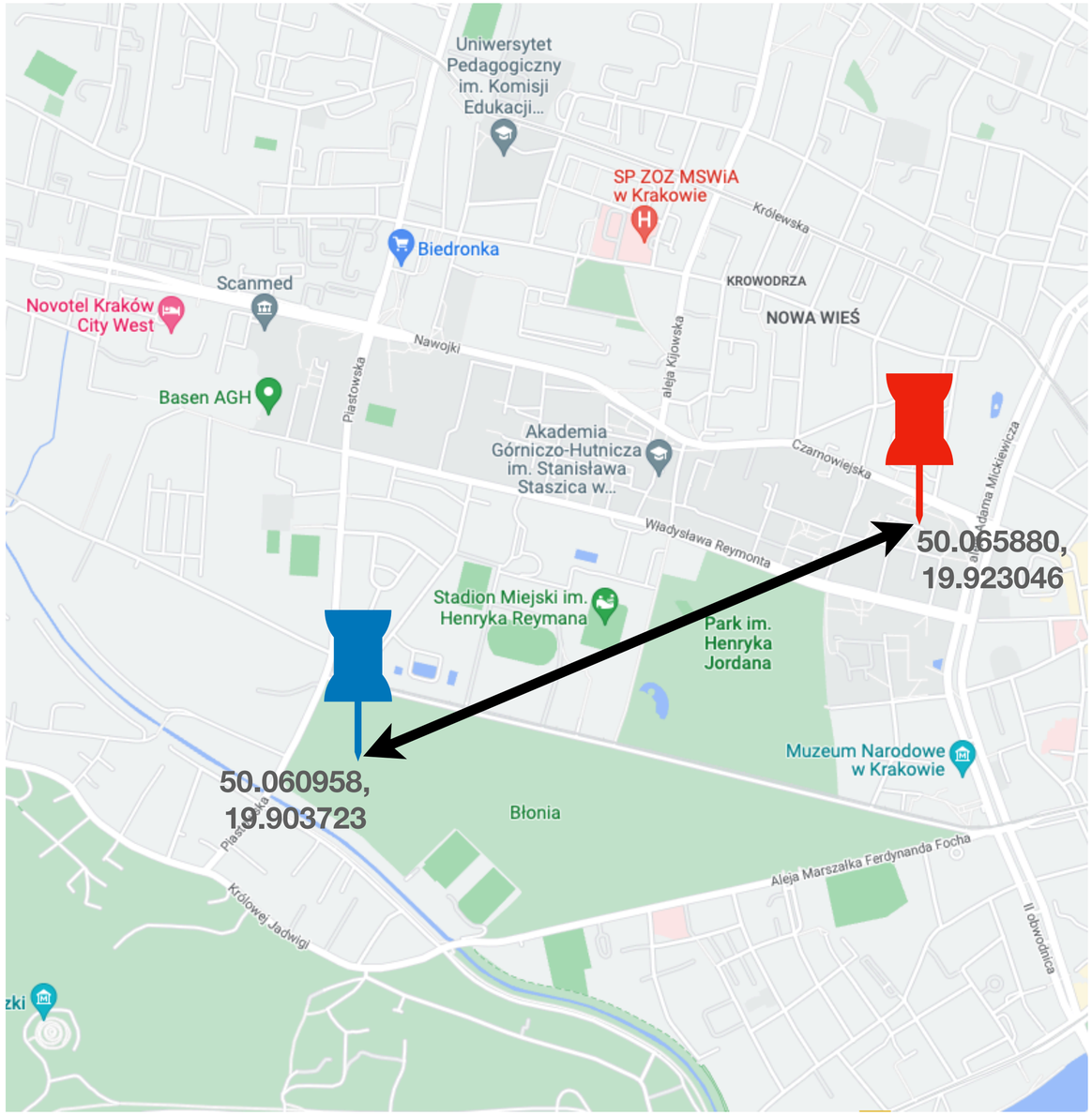
- Now we **two datasets** – two sets of shapes
- The **formula** is no longer that simple…



Introduction

Problem #4: units

- What **units** are the coordinates expressed in?
- What is the unit of the **result**?
- How to convert it to **meters**?



Spatial data

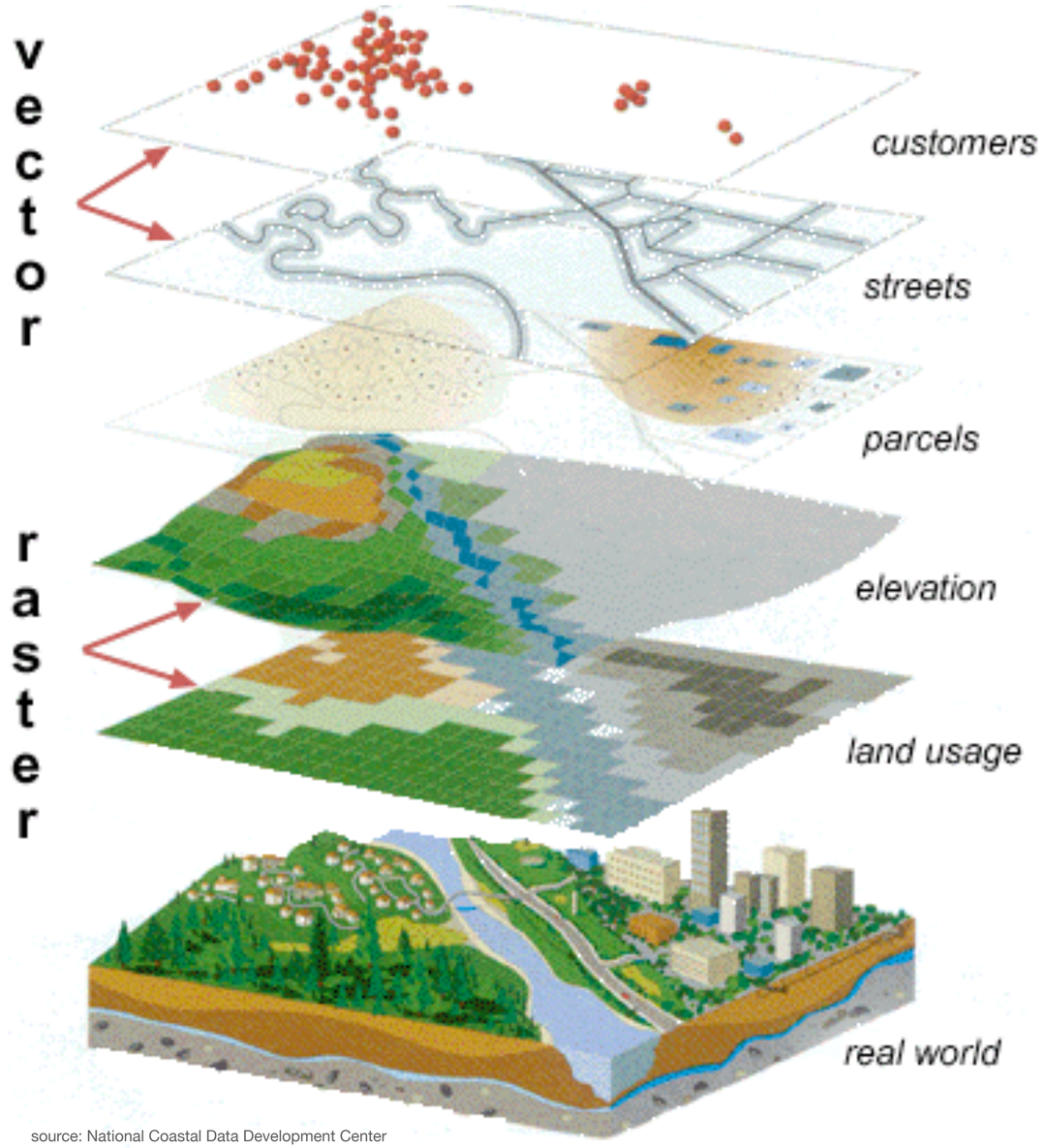
What is spatial data?

- Spatial datasets usually contain two components:
  - spatial component – geometry: location, shape
  - attribute component
- Also called *geospatial data* or *georeferenced data*.

Spatial data

Types of geometry layers

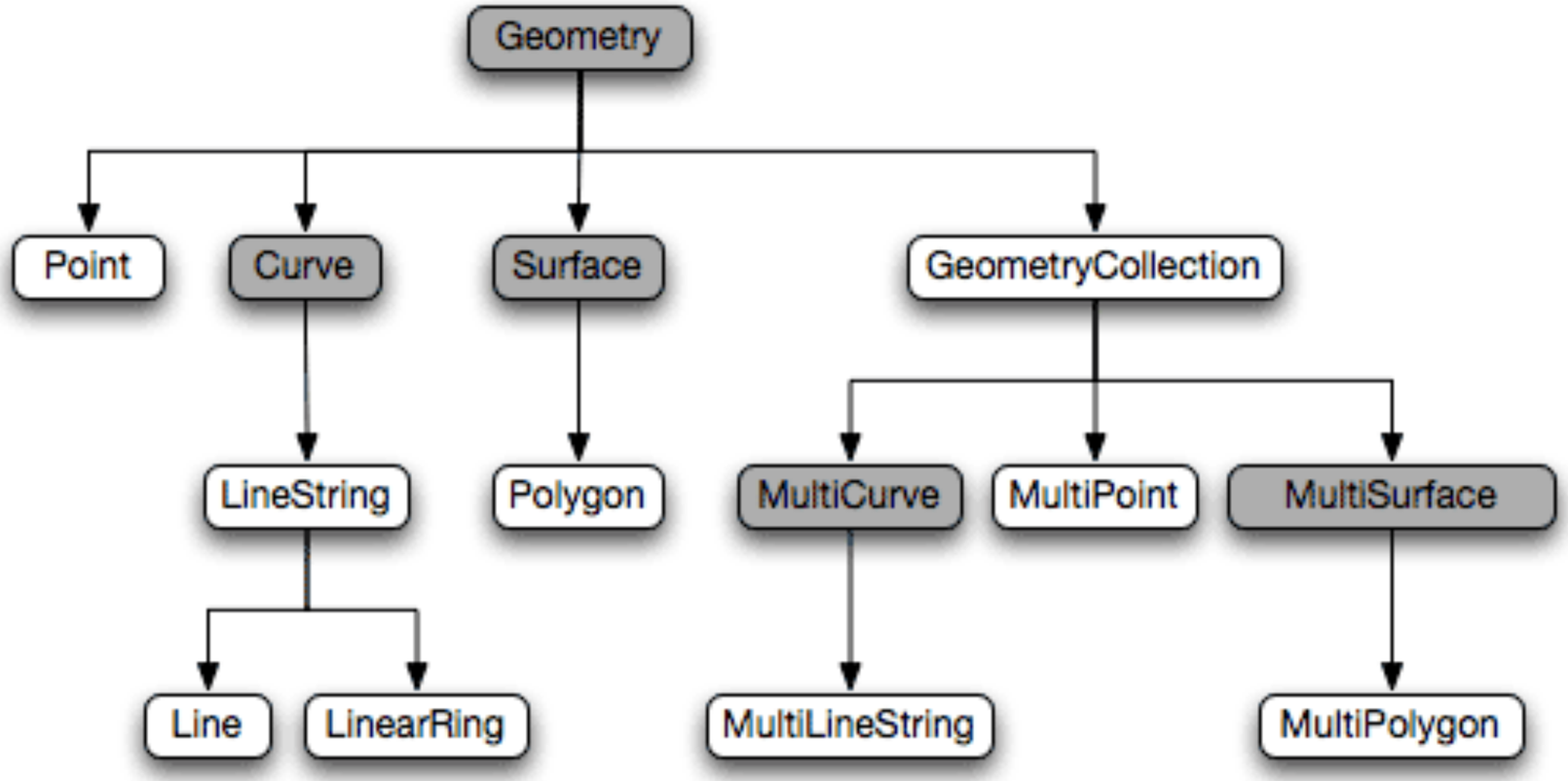
- raster layers:
  - area is divided into a grid of equally-sized ‘pixels’
  - each field is assigned a value
- vector layers:
  - objects are described using basic geometric shapes (point, line, polygon)



source: National Coastal Data Development Center

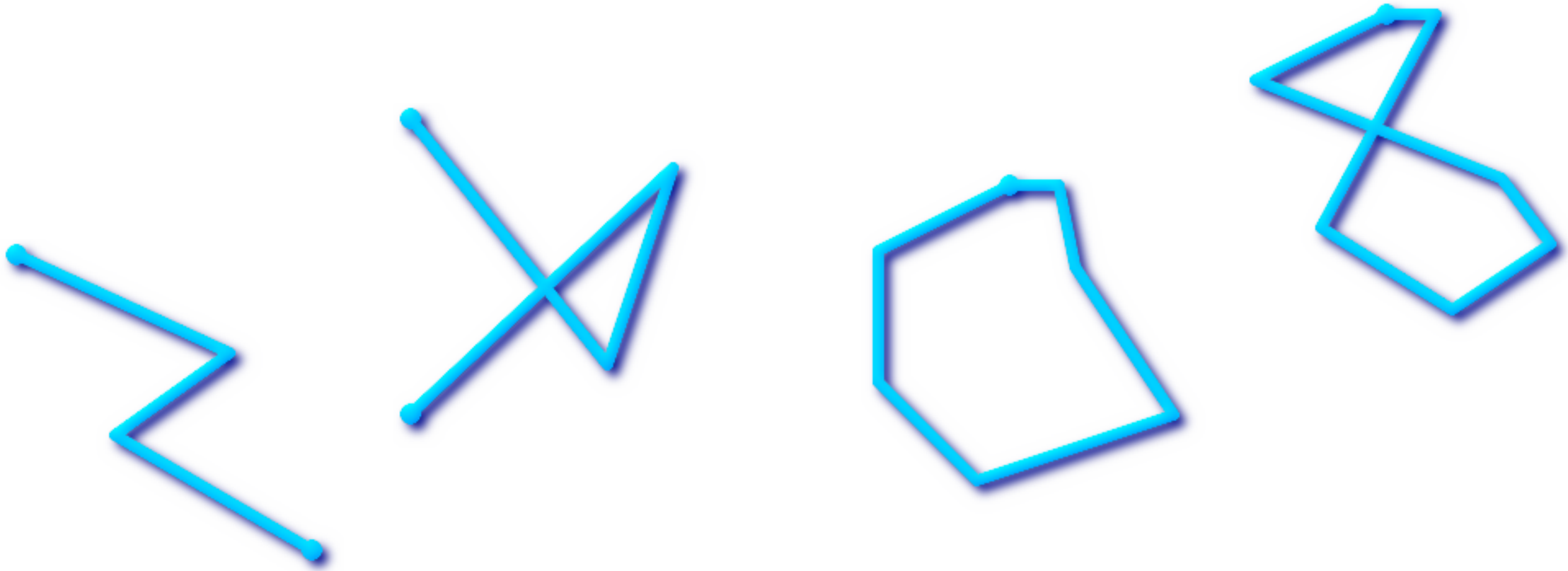
Spatial data

Types of geometric primitives



Spatial data

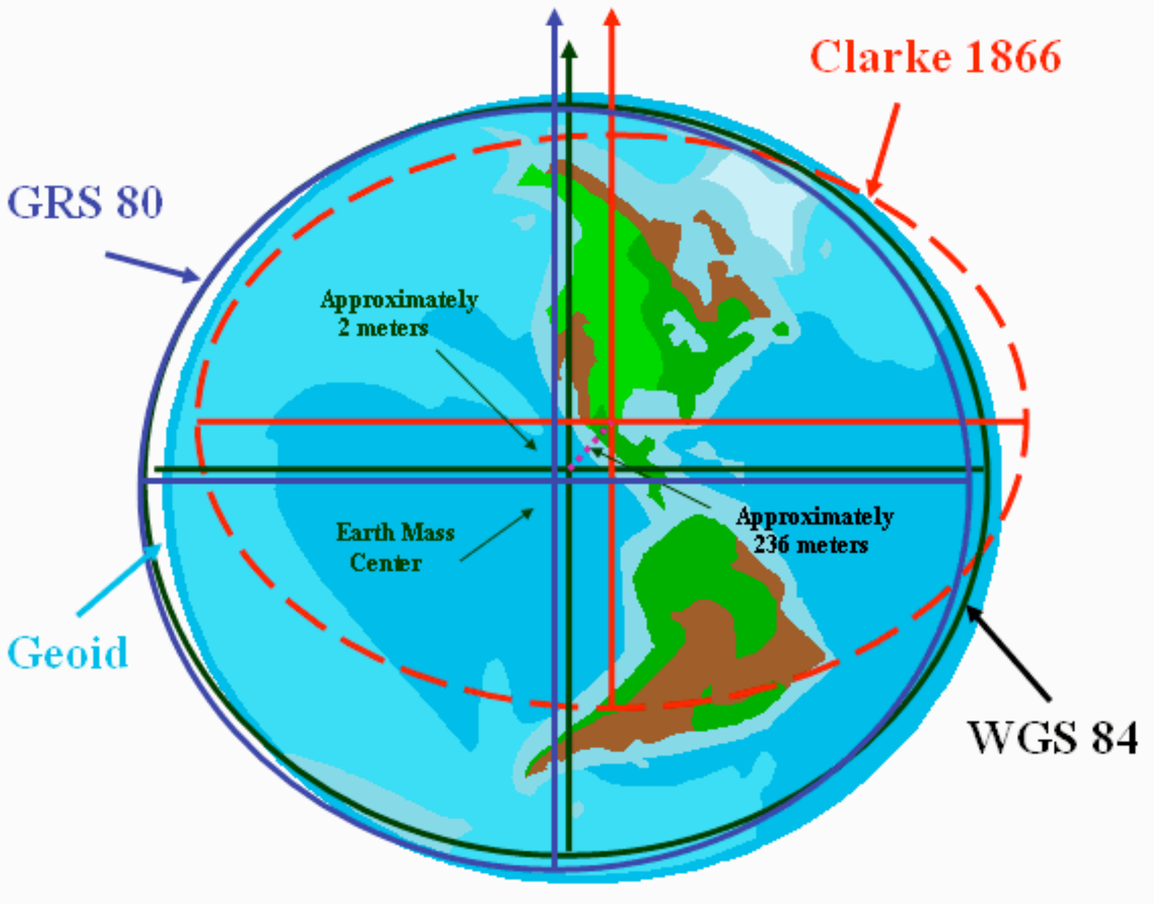
Which of these are proper linestrings?



Spatial data

Coordinate reference systems

- *Spherical* systems (degrees) vs. *planar* systems (meters)
- Catalogued by EPSG (European Petroleum Survey Group)
- Referred to using SRIDs
- Common SRIDs: EPSG codes (format: *EPSG:xxxx*)

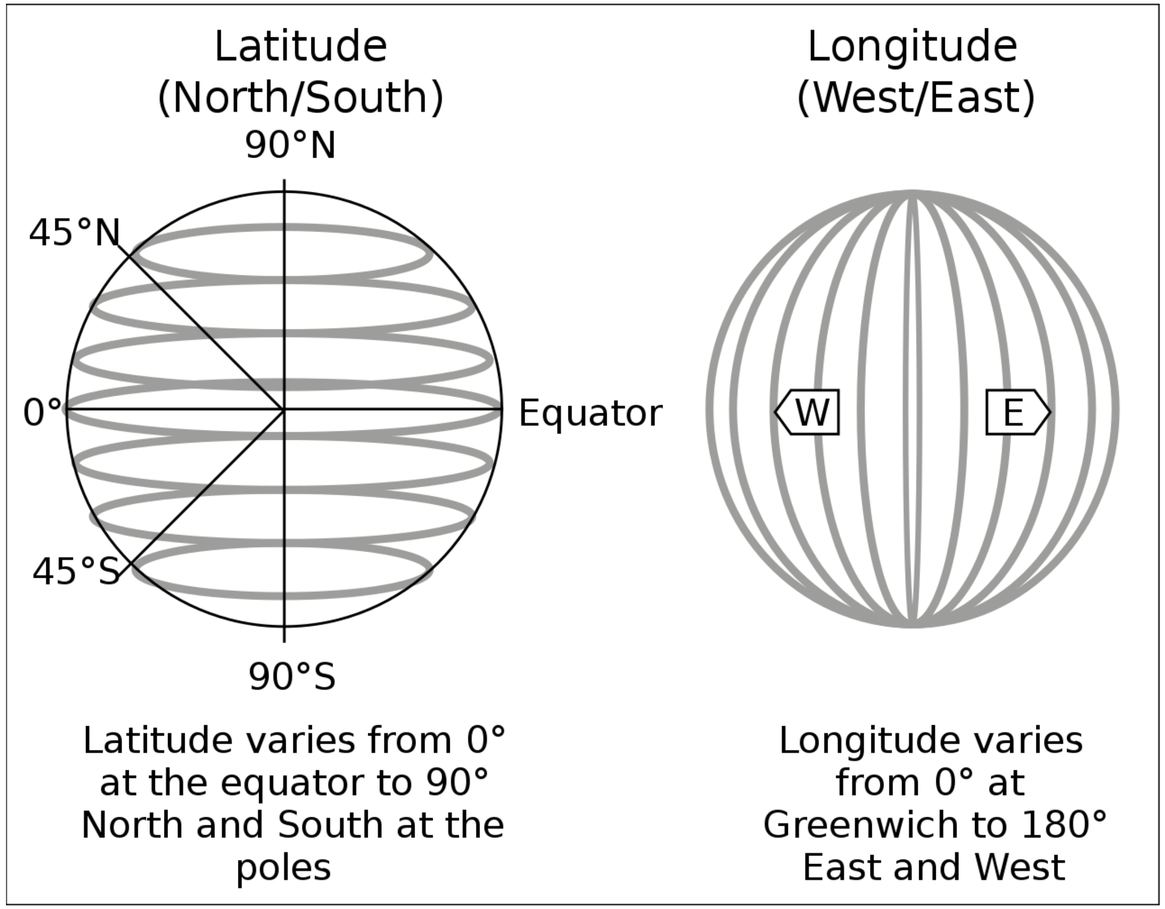


source: National Oceanic and Atmospheric Administration

Spatial data

Spherical CRSs

- Locations defined by providing two coordinates (*latitude* and *longitude*) in *degrees*
- Sometimes: also *elevation* (in *meters*)
- Can express any location on Earth…
- …but pretty useless for measurements: *“What is the distance from Krakow to Katowice in degrees?”*
- Most popular spherical CRS: EPSG:4326 (WGS-84)

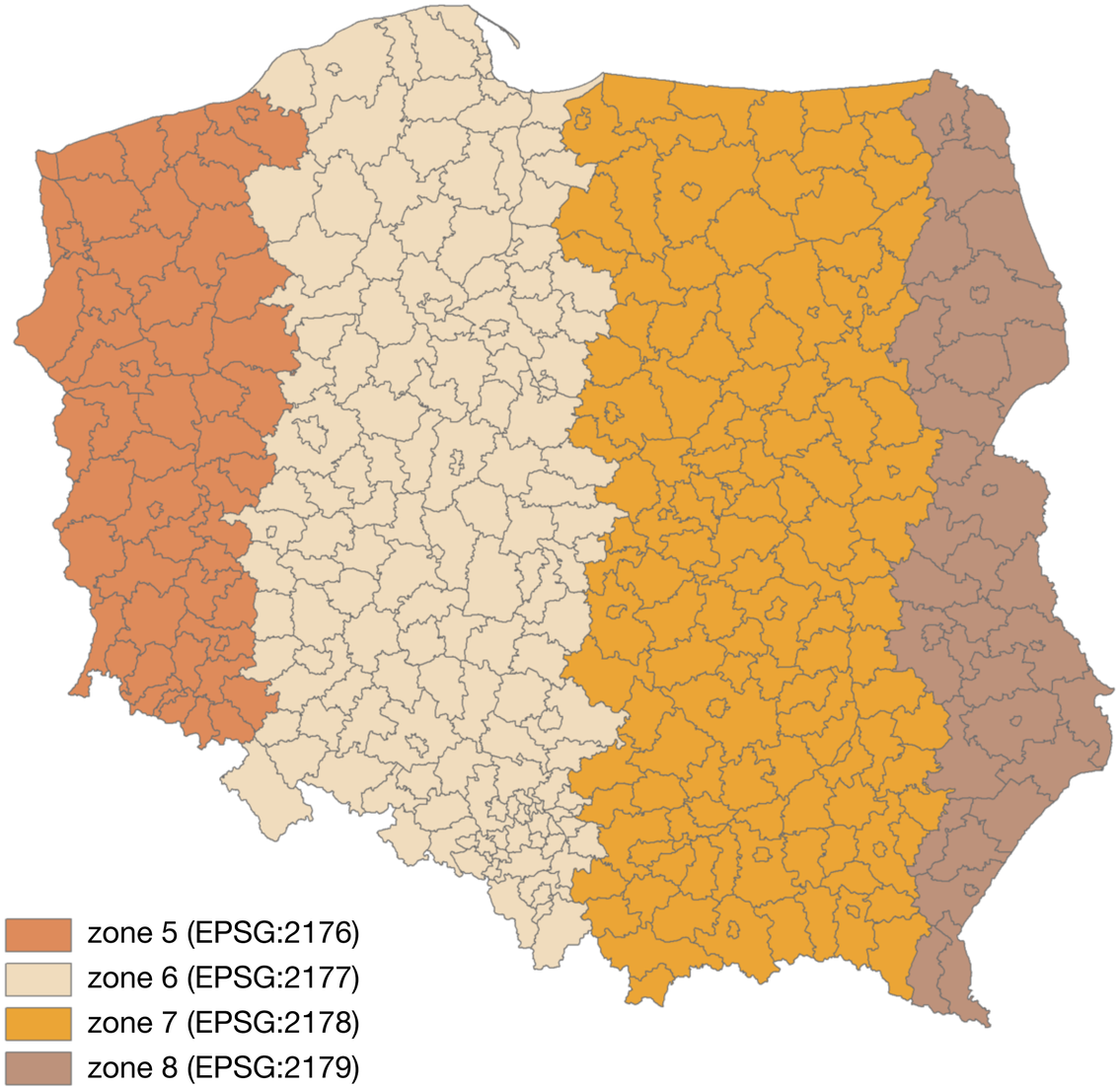


Spatial data

Planar CRSs

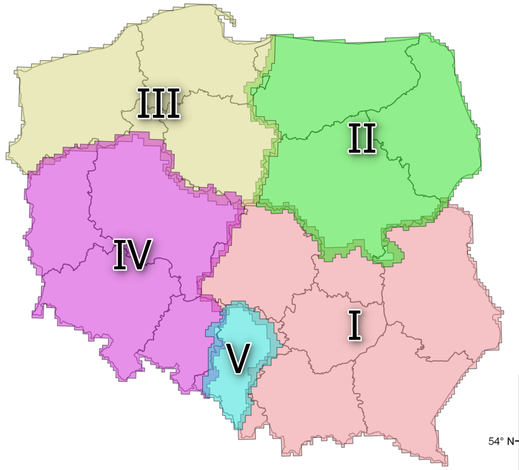
- Project *a certain area* onto X/Y (isometric) coordinates, usually in *meters* (sometimes, also Z for elevation)
- Enable easy measurements
- Precision varies

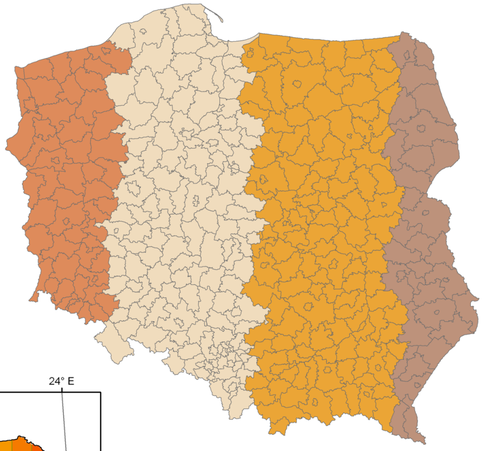
Four zones of the Polish 2000 Coordinate System (PUWG 2000)

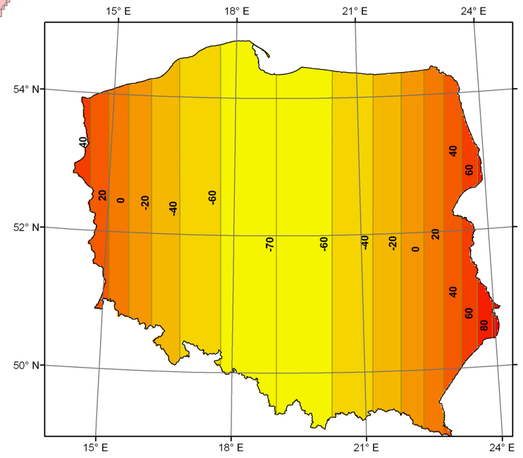


Spatial data

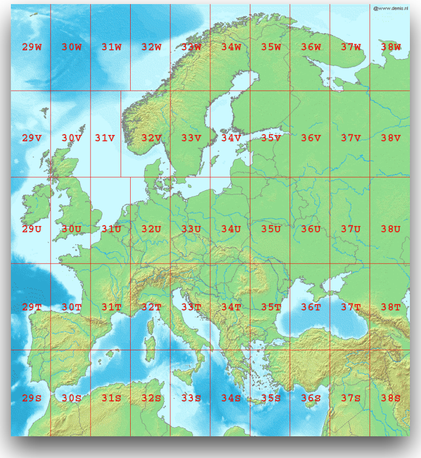
Precision of planar CRSs

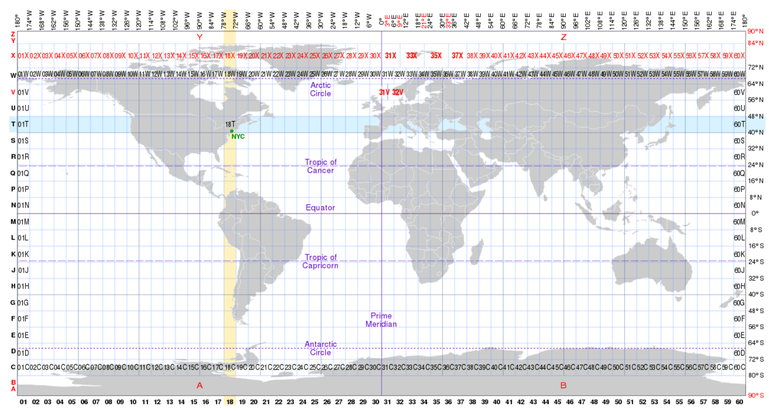






- **Polish CS 1965** (EPSG:3120, EPSG:2172–2175): distortion up to **20 cm/km (0.2 ‰)**
- **Polish CS 1992** (EPSG:2180): distortion up to **90 cm/km (0.9 ‰)**
- **Polish CS 2000** (EPSG:2176–2179): up to **7.7 cm/km (0.077 ‰)**
- **Universal Transverse Mercator** (60 zones): below **1 cm/km (0.01 ‰)**





Spatial data formats

Well-known text (WKT)

- Simple, text representation of vector geometries
- Designed to be human-readable
- Has a binary counterpart: **WKB (Well-known binary)**
- Often used inside SQL queries or when browsing spatial data in non-visual interfaces

```
GEOMETRYCOLLECTION(POINT(4 6),LINESTRING(4 6,
7 10))
POINT ZM (1 1 5 60)
POINT M (1 1 80)
POINT EMPTY
MULTIPOLYGON EMPTY
TRIANGLE((0 0 0,0 1 0,1 1 0,0 0 0))
TIN (((0 0 0, 0 0 1, 0 1 0, 0 0 0)), ((0 0 0,
0 1 0, 1 1 0, 0 0 0)))
POLYHEDRALSURFACE Z ( PATCHES
    ((0 0 0, 0 1 0, 1 1 0, 1 0 0, 0 0 0)),
    ((0 0 0, 0 1 0, 0 1 1, 0 0 1, 0 0 0)),
    ((0 0 0, 1 0 0, 1 0 1, 0 0 1, 0 0 0)),
    ((1 1 1, 1 0 1, 0 0 1, 0 1 1, 1 1 1)),
    ((1 1 1, 1 0 1, 1 0 0, 1 1 0, 1 1 1)),
    ((1 1 1, 1 1 0, 0 1 0, 0 1 1, 1 1 1))
  )
```

Spatial data formats

EWKT/EWKB

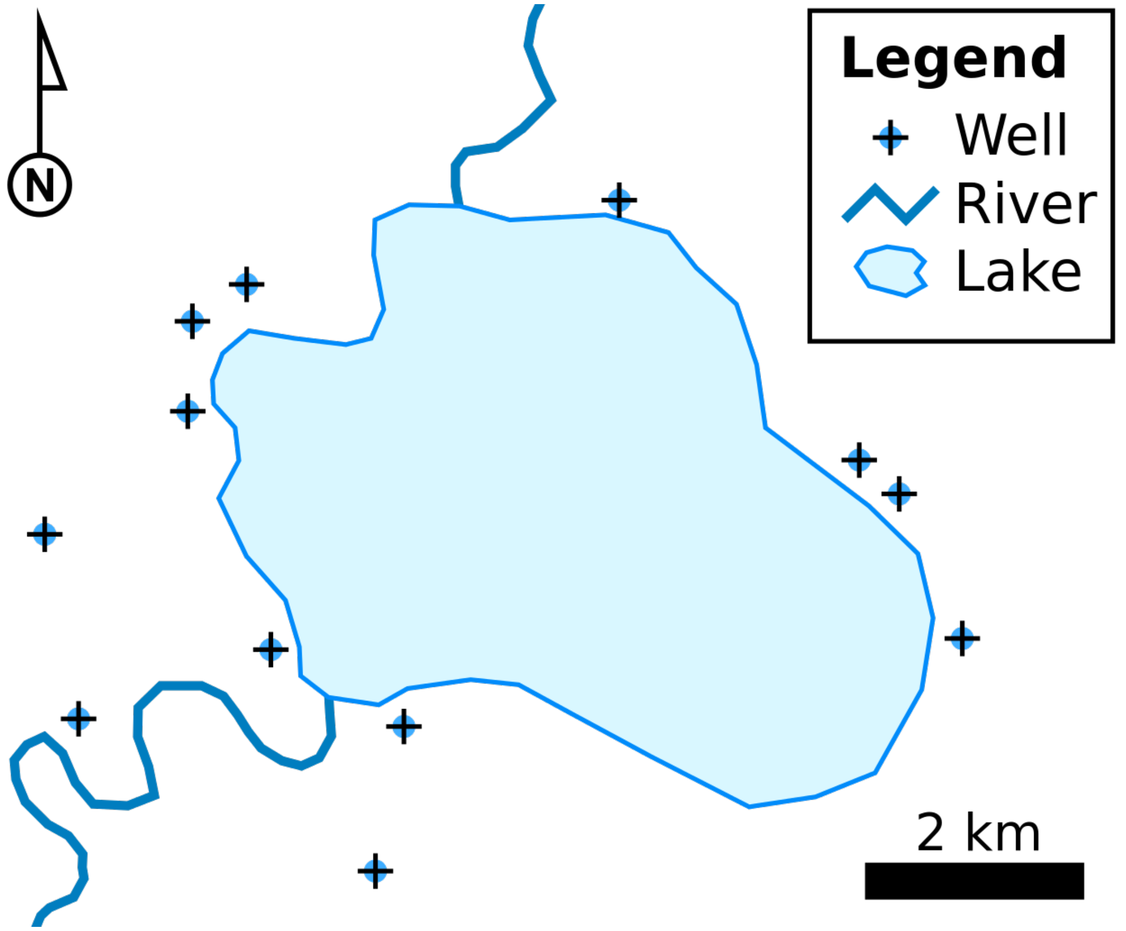
- Variation of WKT/WKB introduced by PostGIS
- Adds SRID, e.g.: SRID=4326;POINT(-44.3 60.1)
- Supports up to four ordinate values (XYZM)

```
GEOMETRYCOLLECTION(POINT(4 6),LINESTRING(4 6,
7 10))
POINT ZM (1 1 5 60)
POINT M (1 1 80)
POINT EMPTY
MULTIPOLYGON EMPTY
TRIANGLE((0 0 0,0 1 0,1 1 0,0 0 0))
TIN (((0 0 0, 0 0 1, 0 1 0, 0 0 0)), ((0 0 0,
0 1 0, 1 1 0, 0 0 0)))
POLYHEDRALSURFACE Z ( PATCHES
    ((0 0 0, 0 1 0, 1 1 0, 1 0 0, 0 0 0)),
    ((0 0 0, 0 1 0, 0 1 1, 0 0 1, 0 0 0)),
    ((0 0 0, 1 0 0, 1 0 1, 0 0 1, 0 0 0)),
    ((1 1 1, 1 0 1, 0 0 1, 0 1 1, 1 1 1)),
    ((1 1 1, 1 0 1, 1 0 0, 1 1 0, 1 1 1)),
    ((1 1 1, 1 1 0, 0 1 0, 0 1 1, 1 1 1))
  )
```

Spatial data formats

ESRI Shapefile

- Commonly-used vector geometry interchange format, introduced in the 1990s
- Dataset consists of several files
- Attribute names limited to 10 characters
- Mandatory files:
  - `.shp` – geometry itself
  - `.shx` – shape index
  - `.dbf` – attributes (dBase IV format)
- Additional files: projection (.prj), indexes, code page specification, etc.



Spatial Data Formats

GeoPackage

- “New standard” format, defined in 2014
- Supports vector and raster data
- Everything in a single file (`.gpkg`)
- Extended SQLite 3 database file underneath

Spatial data formats

GeoJSON

- JSON-based standard format for geographic data interchange
- Defined by RFC 7946
- Supports commonly-used primitives and collections
- Each feature can have arbitrary JSON properties

```
{
  "type": "Feature",
  "geometry": {
    "type": "Point",
    "coordinates": [125.6, 10.1]
  },
  "properties": {
    "name": "Dinagat Islands"
  }
}
```

Spatial data formats

Geography Markup Language

- Abbreviated as GML
- Primary use: vector features
- Also supported:
  - coverages (bitmap layers)
  - sensor data streams

```
<gml:Polygon>
  <gml:outerBoundaryIs>
    <gml:LinearRing>
      <gml:coordinates>
        0,0 100,0 100,100 0,100 0,0
      </gml:coordinates>
    </gml:LinearRing>
  </gml:outerBoundaryIs>
</gml:Polygon>
<gml:Point>
  <gml:coordinates>
    100,200
  </gml:coordinates>
</gml:Point>
<gml:LineString>
  <gml:coordinates>
    100,200 150,300
  </gml:coordinates>
</gml:LineString>
```

Spatial data formats

OpenStreetMap XML

- Not really a GIS format, but a format for OpenStreetMap data
- More on OpenStreetMap will follow
- XML-based text format (`.osm`) that represents all OpenStreetMap (but not OGC) primitives
- Files can be huge!
- Has a binary counterpart: PBF (Protocolbuffer Binary Format)

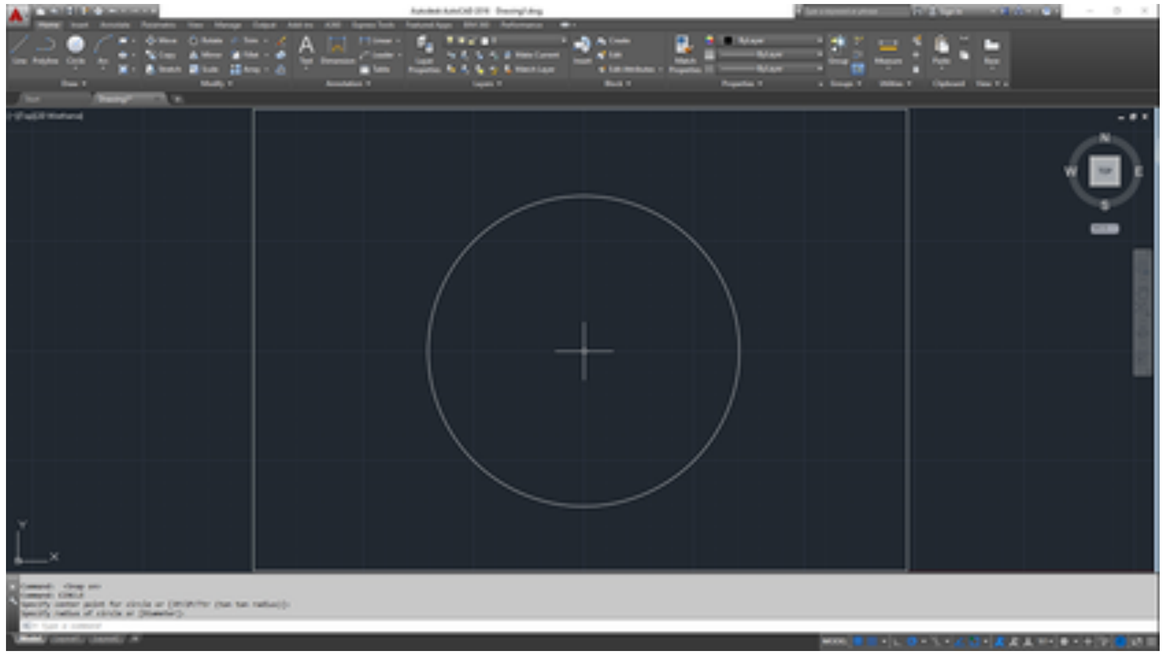
```
<node id="273470204" lat="50.0679716"
lon="19.9312968" version="1"
changeset="302227" user="Rafal Olearski"
uid="12349" visible="true"
timestamp="2008-06-26T19:21:27Z"/>

<way id="25117187" visible="true"
timestamp="2008-06-26T19:21:30Z" version="1"
changeset="302227" user="Rafal Olearski"
uid="12349">
  <nd ref="273470204"/>
  <nd ref="273470207"/>
  <nd ref="262201253"/>
  <tag k="name" v="Kremerowska"/>
  <tag k="highway" v="residential"/>
  <tag k="oneway" v="yes"/>
</way>
```

Spatial data formats

AutoCAD DWG/DXF

- Also not really a GIS format
- CAD drawings can have geographic (planar) coordinates
- Data organised in layers
- DXF is the ‘open’ format; DWG can be converted e.g. using the ODA File Converter tool



Spatial data formats

Converting between formats

- GDAL has ogrinfo & ogr2ogr shell tools
- Python: Fiona
- Shapefiles: shp2pgsql (bundled w/PostGIS)
- OSM data: osmosis, osm2pgsql

Spatial data processing

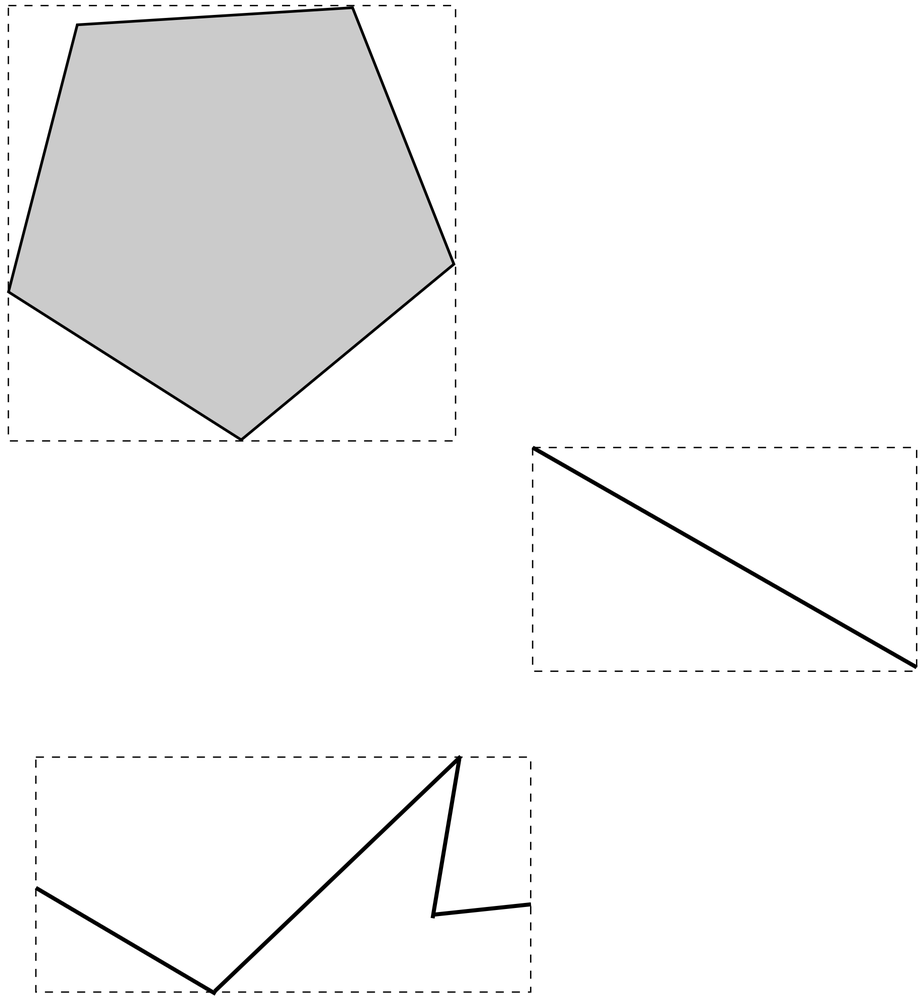
What features do we need?

- **Data types.** The system must support data types which allow for storing map elements.
- **Spatial operations.** We need functions which construct, process and analyse spatial objects (area, distance, joins, etc.).
- **Exchange of spatial data.** The system must be able to exchange spatial data with other systems.
- **Spatial data indexing.** Traditional indexes are not optimised for spatial queries.

Spatial data processing

Data indexing

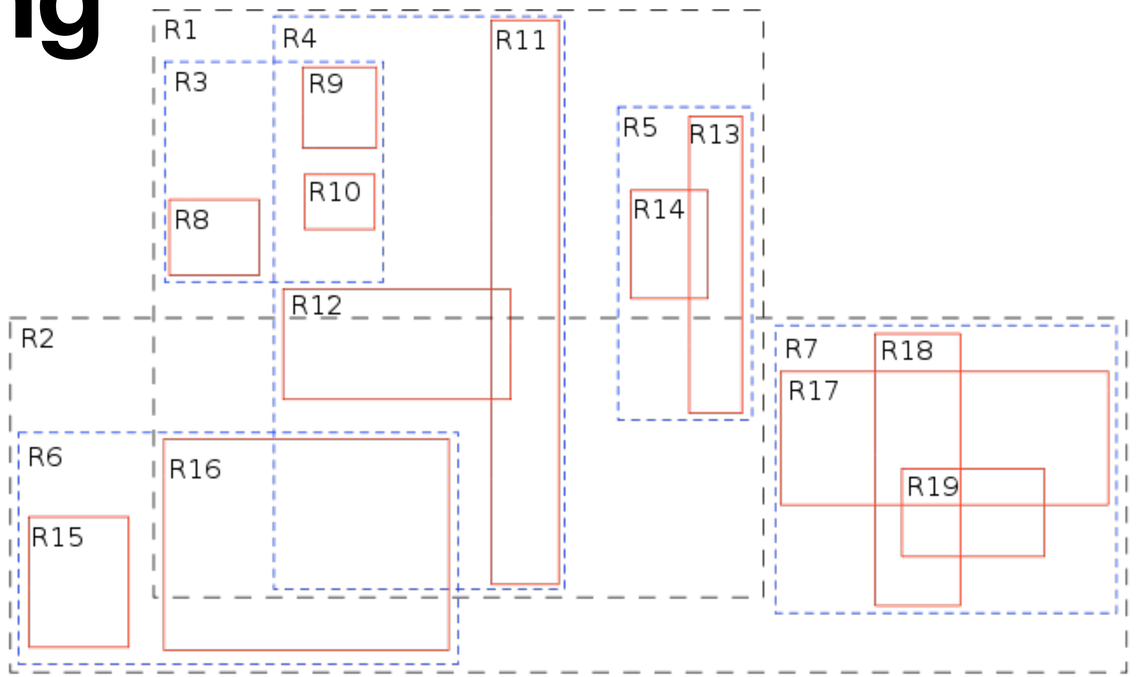
- Classical indexes are usually based on structures like B-trees, only applicable for one-dimensional data.
- Spatial data is usually 2D or 3D.
- We may use two independent 1D indexes, but that limits query flexibility.
- Instead, spatial indexes are based on the concept of the MBR (Minimum Bounding Rectangle)

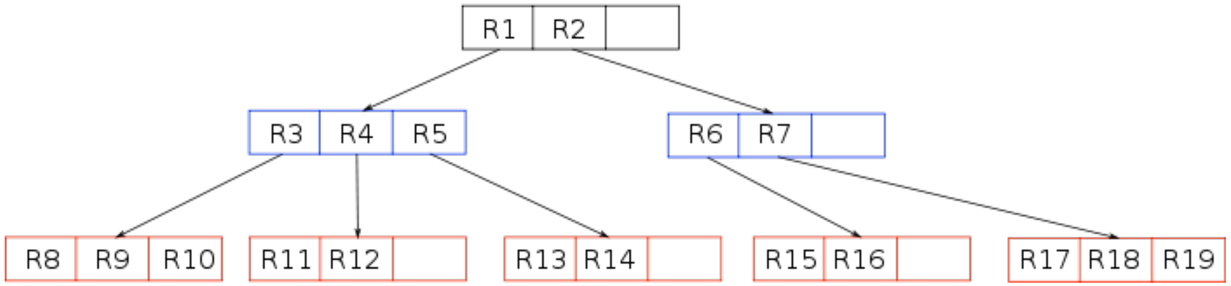


Spatial data processing

Indexing using R-trees

- Similar to B-trees, but used to index multidimensional data.
- Divide space into nested, overlapping regions.
- Close regions are placed in one tree node.





GeoPandas

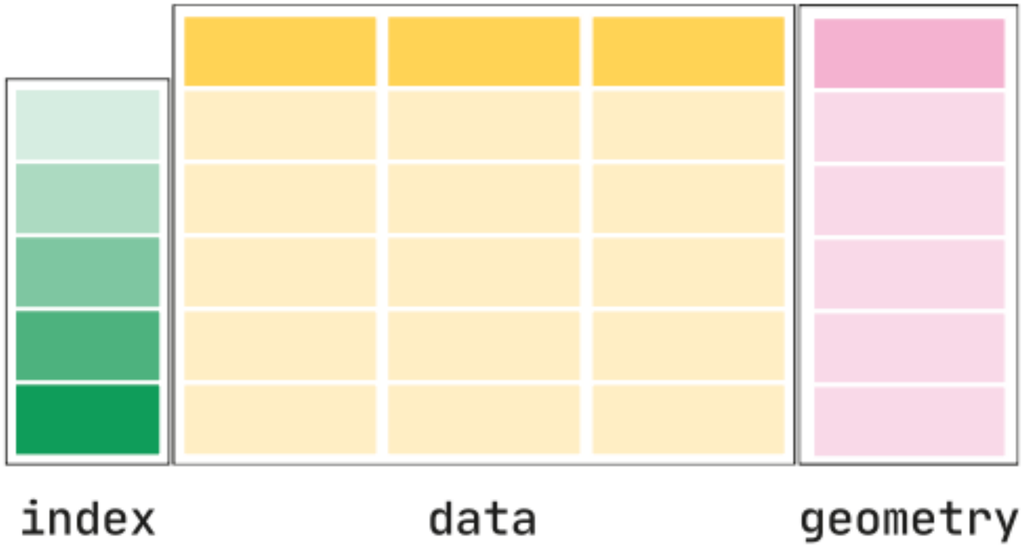
General characteristics

- GeoPandas extends Pandas by adding geometric types and operations
- Uses:
  - shapely for operations
  - fiona for I/O
  - descartes and matplotlib for plotting
- Supports spatial joins, reprojecting CRSs… and all that Pandas can do

GeoPandas

Data structures

- A GeoDataFrame is a DataFrame that has a designated *geometry* column.
- That column is a GeoSeries – a Series composed of Shapely objects.
- A GeoDataFrame can have more GeoSeries as columns, but only one is designated as the geometry.
- Each GeoDataFrame can also have an assigned CRS.



QGIS

Open-source GIS software

- Formerly known as Quantum GIS
- I/O in many supported formats
- Visualisation and editing
- Data filtering, labelling and rule-based rendering
- Supports Linux (repos/binaries for most distributions), Windows (directly or via OSGeo4W) and macOS (use HomeBrew Caskroom!)

OSGeo

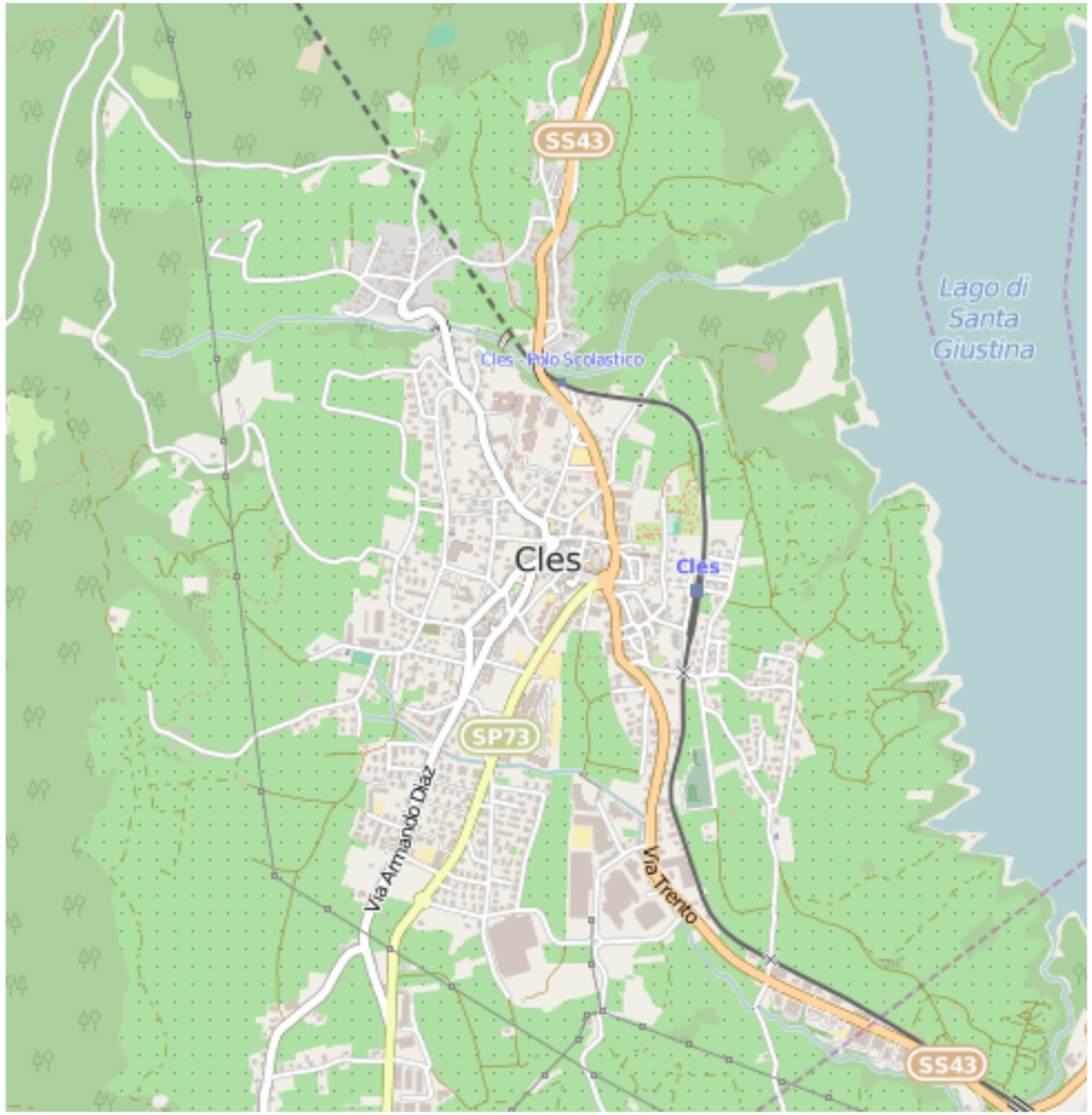
Open Source Geospatial Foundation

- Provides tools, teaching materials and promotes the use of open-source GIS tools
- OSGeo4W, OSGeo4mac, OSGeoLive are easy-to-install sets of GIS tools (including e.g. QGIS)

Mapnik

Open-source map renderer

- Used as “industry standard” for rendering maps
- Many supported input formats
- Cross-platform



OpenStreetMap

A collaborative map of the world

- Edited by the community, just like Wikipedia
- Central repository (uses MySQL), not really interesting for us
- Web interface allows for map browsing, edition and (small) downloads
- Extra tools: converters, editors (more advanced than the web-based one)

OpenStreetMap

The Web interface

- http://www.openstreetmap.org
- Uses Leaflet.js
- Provides basic editing tools
- Can export some OSM XML

OpenStreetMap
Data model

- Basic elements:
  - nodes,
  - ways,
  - relations.
- Parameters for each element (e.g. road class, building type) are assigned as key/value pairs.
- Link: map features and their attributes.

OpenStreetMap

Tracking changes

- OSM keeps all history of changes
- Changesets describe changes introduced in a given editing session by a given user
- Operations: *add*, *modify*, *delete*
- Each changeset has a bounding box

OpenStreetMap

Getting the data

- Download entire globe: *planet.osm*
- Currently approximately 95 GB (XML/bz2), 54 GB (PBF)
- Better solution: download only the region you need, e.g. from GeoFabrik...
- …and crop using the Osmosis utility

OpenStreetMap

Tools

- Editors: Potlatch, JOSM
- Data processing: Osmium, Osmosis
- Data conversion: osm2pgsql, osm2pgrouting, but also Osmosis
- Python support: OSMnx