Mapping and Distance

Ellipses

Determining the shape of the earth is the first step in developing a Coordinate reference systems (CRS). An ellipse is a simple model describing the basic shape of the Earth. All mapping and coordinate systems are based on this shape.

The Earth is almost spherical, however there is a tiny bulge at the equator that makes it ~0.33% larger than at the poles.

The ellipsoid is an approximation and does not fit the Earth perfectly. There are different ellipsoids in use, some are designed to fit the whole Earth (WGS84, GRS80) and some are designed to fit a local region (NAD27). Local ellipses can be more accurate for the area they were designed for, but are not useful in other parts of the world. The modern trend is to use a global ellipsoid for compatibility, such as WGS84. The local-best fitting ellipsoid is now considered an old-fashioned concept, but many maps are based on these ellipsoids.

Projected vs. Unprojected

There are two general options: (1) unprojected (a.k.a. Geographic): Latitude/Longitude for referencing location on the ellipsoid Earth, and (2) projected: Easting/Northing for referencing location on 2D representations of Earth (the creation of maps).

Unprojected/Geographic:

Lat/Long Locations on Earth’s three-dimensional spherical surface are referenced using Latitude and Longitude. The Latitude and Longitude coordinates for a particular location will differ depending on the CRS and when the measurement was taken.

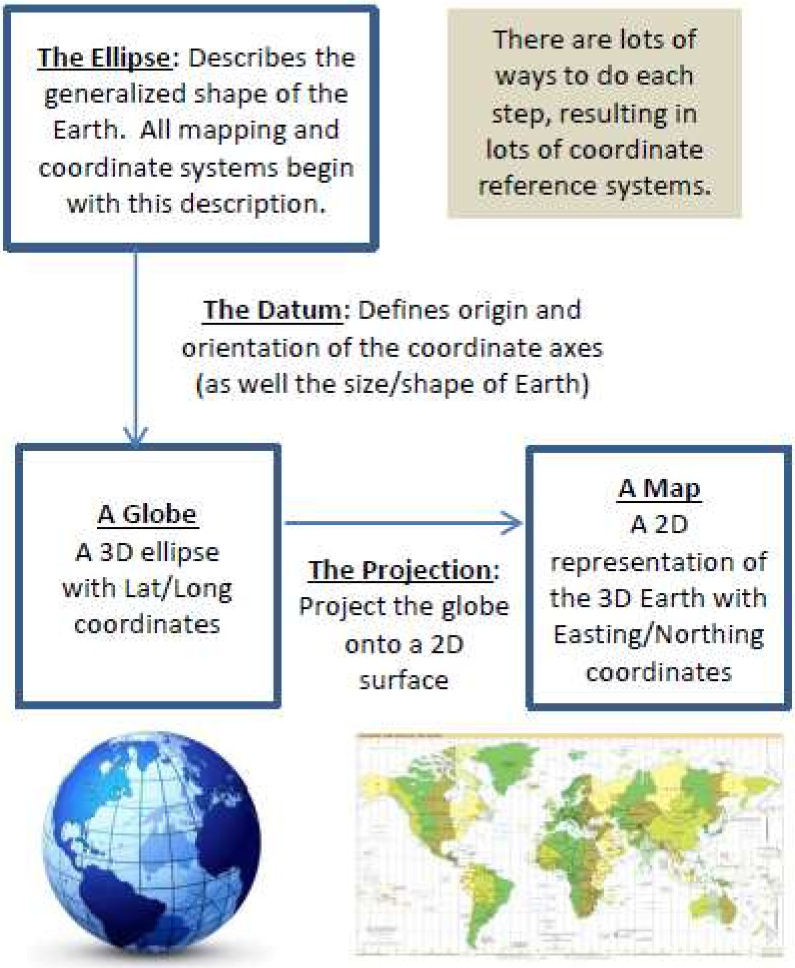
Projected: Easting/Northing

The elliptical Earth can be projected onto a flat surface (i.e., a paper map). Map coordinates of a point are computed from its ellipsoidal latitude and longitude by a standard formula known as a map projection. It is impossible to flatten a round object without distortion, and this results in trade-offs between area, direction, shape, and distance. For example, there is a trade-off between distance and direction because both features can not be simultaneously preserved. There is no "best" projection, but some projections are better suited to different applications.

Universal Transverse Mercator (UTM)

The UTM projection is commonly used in research because it tends to be more locally accurate, and furthermore, it has attributes that make the estimating distance easy and accurate. Positions are described using Easting and Northing coordinates.

The mercator projection **preserves angles and direction, but distorts distance**. To minimize this distortion, the **UTM** divides the Earth into sixty zones, and uses a secant transverse Mercator projection in each zone.



https://www.maptiler.com/google-maps-coordinates-tile-bounds-projection

Coordinate reference systems. (CRS)

CRS provide a standardized way of describing locations. Many different CRS are used to describe geographic data. The CRS that is chosen depends on when the data was collected, the geographic extent of the data, the purpose of the data, etc.

The majority of web map applications use the Spherical Mercator (Pseudo-Mercator, Web Mercator) (EPSG:3857), which shows the world as a square that can be further thought of as a pixel.

On the other hand, World Geodetic System 1984 (WGS84, EPSG:4326) is showing the world as a rectangle with an aspect ratio of 2:1.

This geographic coordinate system (using latitude and longitude calculated from the mass center of the Earth) is accurate thanks to the new system of earth position gathering based on satellites on Medium Earth orbit - Navstar GPS (Global Positioning System).

Any other coordinate system than Spherical Mercator (EPSG:3857) is possible to use only the OpenLayers library which handles reprojecting.

Some CRS :

EPSG:4326
WGS 84 -- WGS84 - World Geodetic System 1984, used in GPS

Coordinate system: Ellipsoidal 2D CS. Axes: latitude, longitude. Orientations: north, east. UoM: degree

EPSG:3857
WGS 84 / Pseudo-Mercator

Spherical Mercator, Google Maps, OpenStreetMap, Bing, ArcGIS, ESRI

Alternatives codes : 900913 3587 54004 41001 102113 102100 3785

Scope: Web mapping and visualisation.

Remarks: Not a recognised geodetic system. Uses spherical development of ellipsoidal coordinates. Relative to WGS 84 / World Mercator (CRS code 3395) gives errors of 0.7 percent in scale and differences in northing of up to 43km in the map (21km on the ground).

Coordinate system: Cartesian 2D CS. Axes: easting, northing (X,Y). Orientations: east, north. UoM: m

World between 85.06°S and 85.06°N.

EPSG:5634
REGCAN95 / LCC Europe (Lambert Conic Conformal)

Coordinate system: Cartesian 2D CS. Axes: northing, easting (N,E). Orientations: north, east. UoM: m

Area of use: Spain - **Canary Islands** onshore and offshore.

EPSG:4083
REGCAN95 / UTM zone 28N

Coordinate system: Cartesian 2D CS. Axes: easting, northing (E,N). Orientations: east, north. UoM: m.

Area of use: Spain - **Canary Islands** - east of 18°W, onshore and offshore.

References
https://docs.qgis.org/3.28/fr/docs/user_manual/working_with_projections/working_with_projections.html

https://epsg.io/ and https://spatialreference.org/ref/epsg/

Distance

Planar distance is straight-line Euclidean distance calculated in a 2D Cartesian coordinate system.

Geodesic distance is calculated in a 3D spherical space as the distance across the curved surface of the world. It is the shortest path between two points along the ellipsoid of the earth.

Geodesic distance always produces a more accurate result.

The difference between planar and geodesic calculations of distance and direction varies with map projection and size of the study area.

It increases proportionally with distance from the source. If you are working in a small geography, such as a city or county, the difference between planar and geodesic is proportionally smaller than if you are working at the scale of a country.

Distance analysis and map projections

The earth is a three-dimensional slightly flattened sphere, or ellipsoid.

To represent the earth on maps, cartographers created map projections, which are mathematical transformations between 3D and 2D space.

These projections distort the data in different ways, affecting measurement of distances, angles, and areas.

Many projections have been developed in attempts to preserve one or more of these characteristics, often for particular parts of the map such as specific meridians or parallels, or a few points.

Although some map projections preserve some characteristics accurately, none preserve all distances correctly.

Projections have been developed that preserve true direction, but none fully preserve both distance and direction.

For the Spatial Analyst distance tools to calculate distance and direction accurately in any direction between any locations geodesic distance must be used.

When you reproject to a projected coordinate system, the distance method is probably using a planar calculation. 5634, for instance, uses Lambert conformal conic and is centered in Europe so more distance distortion than the UTM zone. UTM isn't distance-preserving either and 3857/900913 is notoriously bad at distances. Look for a geodesic or in a pinch a great circle method; then the CRS doesn't matter.

Other Solution :

Adapt projection to the points. I prefer transverse plate carrée over transverse Mercator, but over small enough areas ("large scale"), almost any projection "**centered**" near the region of interest will give good accuracy.

Distance in Python

Modules : **Shapely, Geopandas**

Shapely geometries are, by design, agnostic (unaware) of the reference system used to represent them. Distances and surface area calculated using the built-in shapely methods will always: a) assume a flat, Cartesian, Euclidean space, and b) return the calculated value in the unit of the coordinates (e.g., meters, or degrees).

This is perfectly fine for small-scale geo-spatial operations, if you keep yourself aware of the expected output unit. Most packages built on top of shapely, for instance **GeoPandas** bring their own functions and take the coordinate reference system into consideration.

A geographic coordinate system, **EPSG:4326**, is not particularly well-suited for showing the countries of the European Union. Distortion is high. Rather, we could use a Lambert Azimuthal Equal-Area projection, such as **EPSG:3035**, the map projection officially recommended by the European Commission.

Canaries : 4083, 5634, Açores : 5015, 3063, Web mapping : 3857

shapely.geometry.distance and **geopy.distance.distance** use different algorithms for calculating distances. Shapely's distance method computes the Euclidean distance between two points in Cartesian space (assuming the points are in a flat coordinate system), whereas geopy's distance calculations are based on geodetic formulas that consider the Earth's curved surface.

If you need accurate distances on the Earth's surface, especially over longer distances, it's generally recommended to use geodetic calculations. Shapely is more suitable for planar geometry and doesn't account for the Earth's curvature.

The geodesic method uses the geodesic distance, which is the shortest path between two points along the Earth’s surface. It is more accurate than the Haversine and spherical law of cosines methods, as it accounts for the Earth’s ellipsoidal shape. The **Geopy** library provides an easy-to-use implementation of this method.

Web mapping

Degrees Geodetic coordinates WGS84 (EPSG:4326)

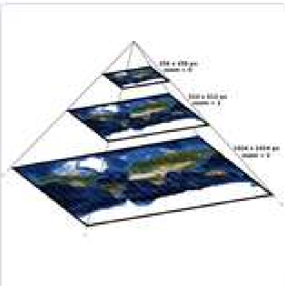
Longitude and latitude coordinates are used by GPS devices for defining position on Earth using World Geodetic System defined in 1984 (WGS84).

HINT: WGS84 geodetic datum specifies lon/lat (lambda/phi) coordinates on defined ellipsoid shape with defined origin ([0,0] on a prime meridian).

Meters Projected coordinates Spherical Mercator (EPSG: 3857)

Global projected coordinates in meters for the entire planet. Used for raster tile generation in GIS and WM(T)S services.

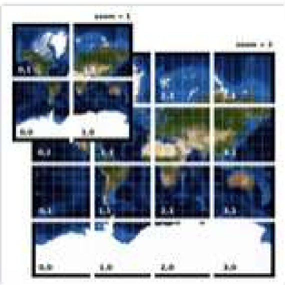
HINT: Simpler spherical calculations are used instead of ellipsoidal. Mercator map projection deforms size (Greenland vs. Africa) and never shows poles.



Pixels Screen coordinates XY pixels at zoom

Zoom-specific **pixel coordinates** for each level of the pyramid. Top level (zoom=0) has usually 256x256 pixels, next level 512x512, etc.

Devices calculate pixel coordinates at defined zoom level and determine visible viewport for an area which should be loaded from servers.



Tiles Tile coordinates Tile Map Service (ZXY)

Coordinates of a **tile in the pyramid.** There is one tile on the top of the pyramid, then 4 tiles, 16 tiles, etc. All raster tiles have the same size, usually 256x256 or 512x512 pixels. Vector tiles work a bit differently.

Only the relevant tiles are loaded and displayed for the area of interest/ viewport.

Python

Ipyleaflet (https://ipyleaflet.readthedocs.io)

Ipyleaflet is a Jupyter widget for Leaflet.js , enabling interactive maps in the Jupyter notebook. Every object in ipyleaflet (including the Map, TileLayers, Layers, Controls, etc.) is interactive: you can dynamically update attributes from Python or from the browser.

Folium

Python data, leaflet.js maps (https://python-visualization.github.io/folium/latest/index.html)

Folium builds on the data wrangling strengths of the Python ecosystem and the mapping strengths of the Leaflet.js library. Manipulate your data in Python, then visualize it in a Leaflet map via Folium.

A key difference between **ipyleaflet** and **folium** is that ipyleaflet is built upon ipywidgets and allows bidirectional communication between the front-end and the backend enabling the use of the map to capture user input, while folium is meant for displaying static data only (source).

Leafmap : (https://leafmap.org). A Python package for geospatial analysis and interactive mapping in a Jupyter environment. Leafmap has six plotting backends, including folium, ipyleaflet, plotly, pydeck, kepler.gl, and heremap.

Resources

https://jakevdp.github.io/PythonDataScienceHandbook/04.13-geographic-data-with-basemap.html

https://pro.arcgis.com/en/pro-app/3.1/tool-reference/spatial-analyst/geodesic-versus-planar-distance.htm (exist in fr)