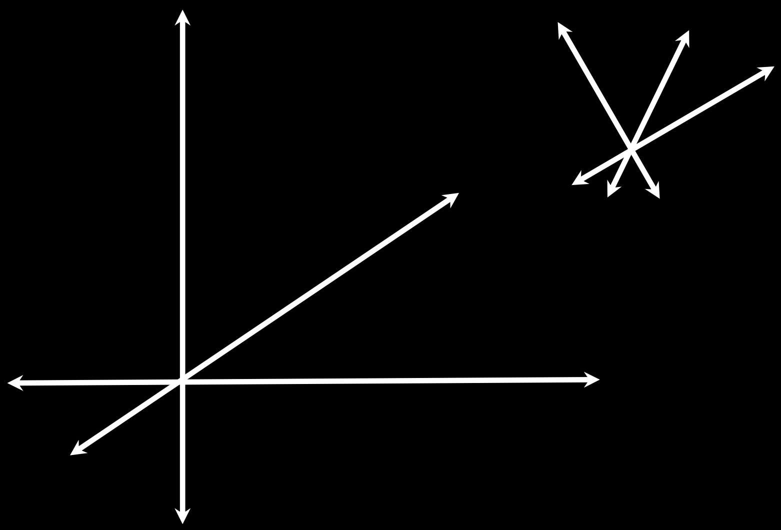


GEOM90007

SPATIAL VISUALISATION

LECTURE 8B

CARTOGRAPHY:
COORDINATE SYSTEMS &
PROJECTIONS

REVISION

- **Cartography 2 Multivariate**
  - Standardisation techniques
    - Proportion, density, rate
  - Univariate (our focus so far)
    - Two-up comparison, multiple comparison
  - Bivariate
    - Combine variables graphically
    - Category/category, quantity/category, quantity/quantity
    - Conjunctions (sepable/integral)
  - Multivariate
    - Use of colour, pattern, glyphs
    - Combo, e.g., univariate choropleth + multivariate glyph
  - Multi-modal variables (e.g., sound)
  - Introduction to cluster analysis

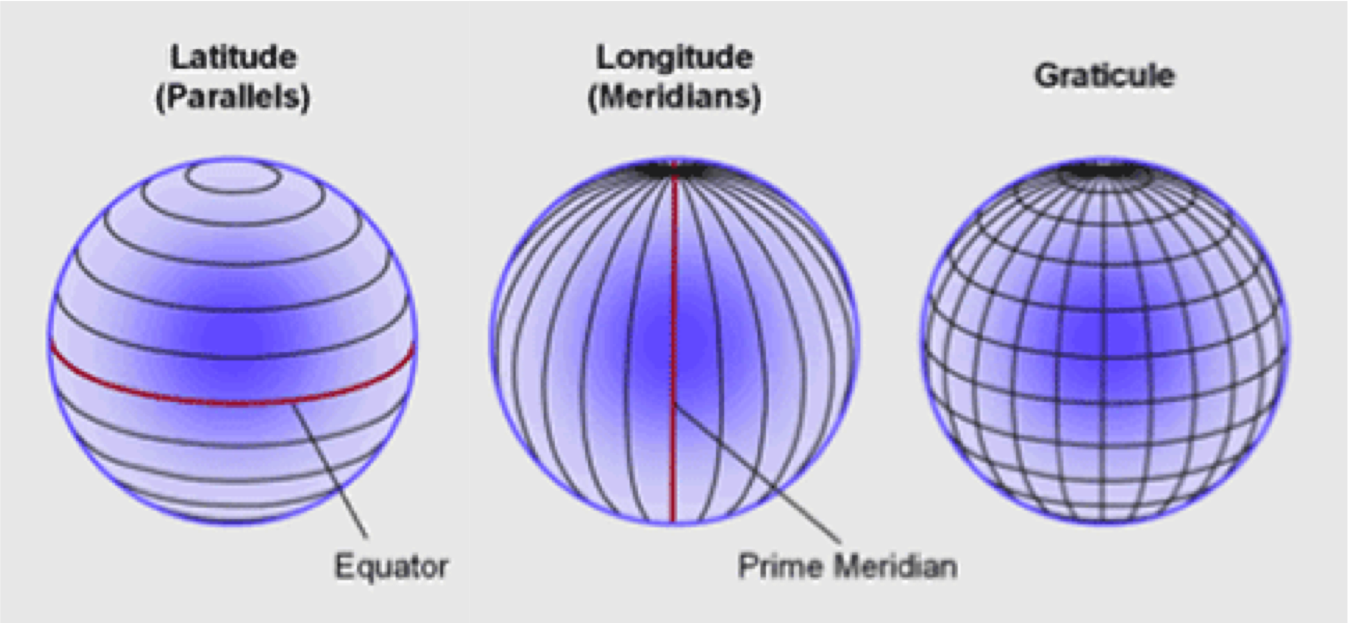
OVERVIEW

- Coordinate systems
- Transformations
  - Plane transformations
  - Map projections
- Common coordinate systems and map projections
- Interactive tool links

EARTH SIZE AND SHAPE

- **The graticule**
  - A spherical system composed of latitude and longitude
  - Angular measurements: *degrees*, *minutes*, *seconds* (a°b'c")
    - Sexagesimal, each component (DMS) is base 60
  - Use of both angles can define a point on the Earth

Image: GIS Commons



GEOGRAPHIC COORDINATE SYSTEM

- Latitude (ϕ)
  - *Equator* is the origin point (0°) from which angles are subtended with the centre of the Earth (geocentric)
  - 90° positive (North, N) or 90° negative (South, S)

- Longitude (λ)
  - *Prime meridian* is the origin point (0°)
  - 180° positive (East, E) or 180° negative (West, W)
  - International date line
    - Divides calendar days due to the Earth's rotation
    - Partially coincides with $\pm$180°

GEOGRAPHIC COORDINATE SYSTEM

- Converting from DMS to DD requires division
  - $DD = Degrees\ .\ (\frac{Minutes}{60} + \frac{Seconds}{3600})$
  - E.g.

    DMS: 90°20’30”, DD: 90.341667

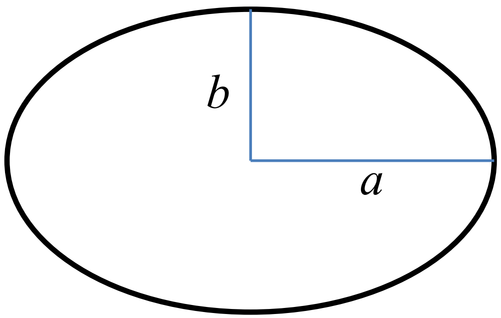
- Computing distances
  - Shortest distance between two points is in arc
    - *Great circle* (plane coincides with the Earth’s centre)
    - *Small circle* (otherwise)
  - Angle between arc and each meridian called the *azimuth*

GEOGRAPHIC COORDINATE SYSTEM

- Reference ellipsoids (smooth models)
  - Sphere is simplistic
  - Ellipsoid is more accurate (early triangulation, later GPS)

Ellipsoid Name	Epoch	Semi major *a* (m.)	Semi minor *b* (m.)	Flattening Constant	Best fit?
WGS	1972	6 378 137.0	6 356 750.5	1/298.26	USA
GRS	1980	6 378 137.0	6 356 752.31	1/298.257	World
WGS	1984	6 378 137.0	6 356 752.31	1/298.257	World

  - Ellipse formula



$$f = \frac{(a-b)}{a}$$

GEOGRAPHIC COORDINATE SYSTEMS

- **Latitude, longitude** (degrees)
- **X, Y, Z** (ECEF, metres)

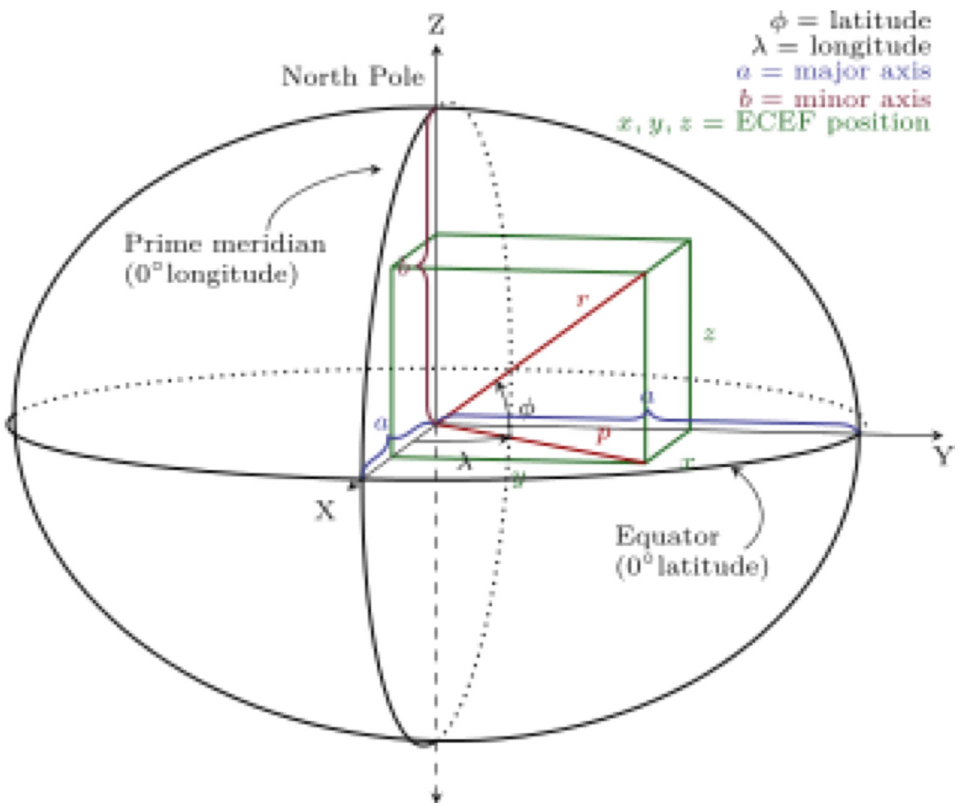


Image: Wikimedia Commons

DATUMS

A datum defines the relationship between an ellipsoid and a coordinate system, allowing coordinates to be "positioned"

- Horizontal
  - Geocentric Datum of Australia (GDA)
    - Realised 1994 (GDA94)
- Vertical
  - Australian Height Datum (AHD)
  - Mean sea level assigned zero

GDA94 specifications

- **Datum:** Geocentric Datum of Australia (GDA)
- **Geographical coordinate set:** Geocentric Datum of Australia 1994 (GDA94) **(latitude and longitude)**
- **Grid coordinates:** (Universal Transverse Mercator, using the GRS80 ellipsoid) Map Grid of Australia 1994 (MGA94)
- **Reference Frame:** ITRF92 (International Terrestrial Reference Frame 1992)
- **Epoch:** 1994.0
- **Ellipsoid:** GRS80
- **Semi-major axis (a):** 6,378,137.0 metres
- **Inverse flattening (1/f):** 298.257222101

Link: http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/geodetic-datums/australian-height-datum-ahd

THE GEOID

- Necessary for geodesy
- Equipotential surface
  - Gravitation and rotation
- Undulations (i.e., not smooth)
- *AusGeoid09* estimates difference between GDA94, AHD, and the geoid

Gravitational map

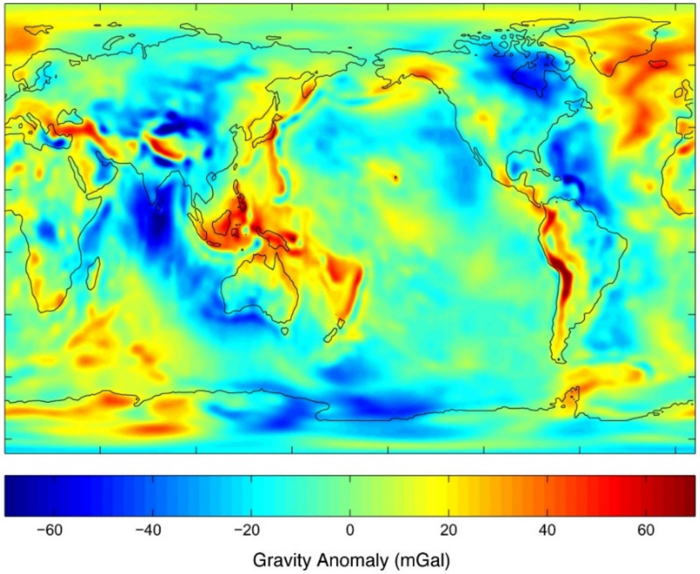


Image: NASA (2016)

Geoid

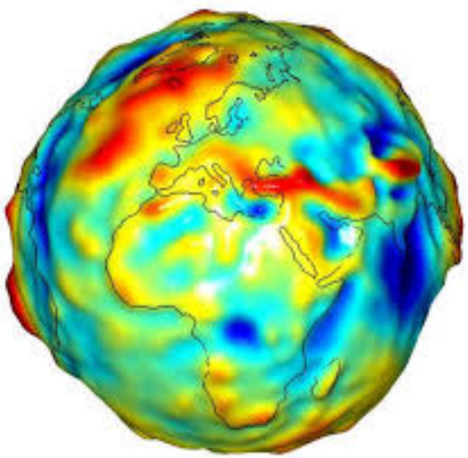


Image: NGS NOAA

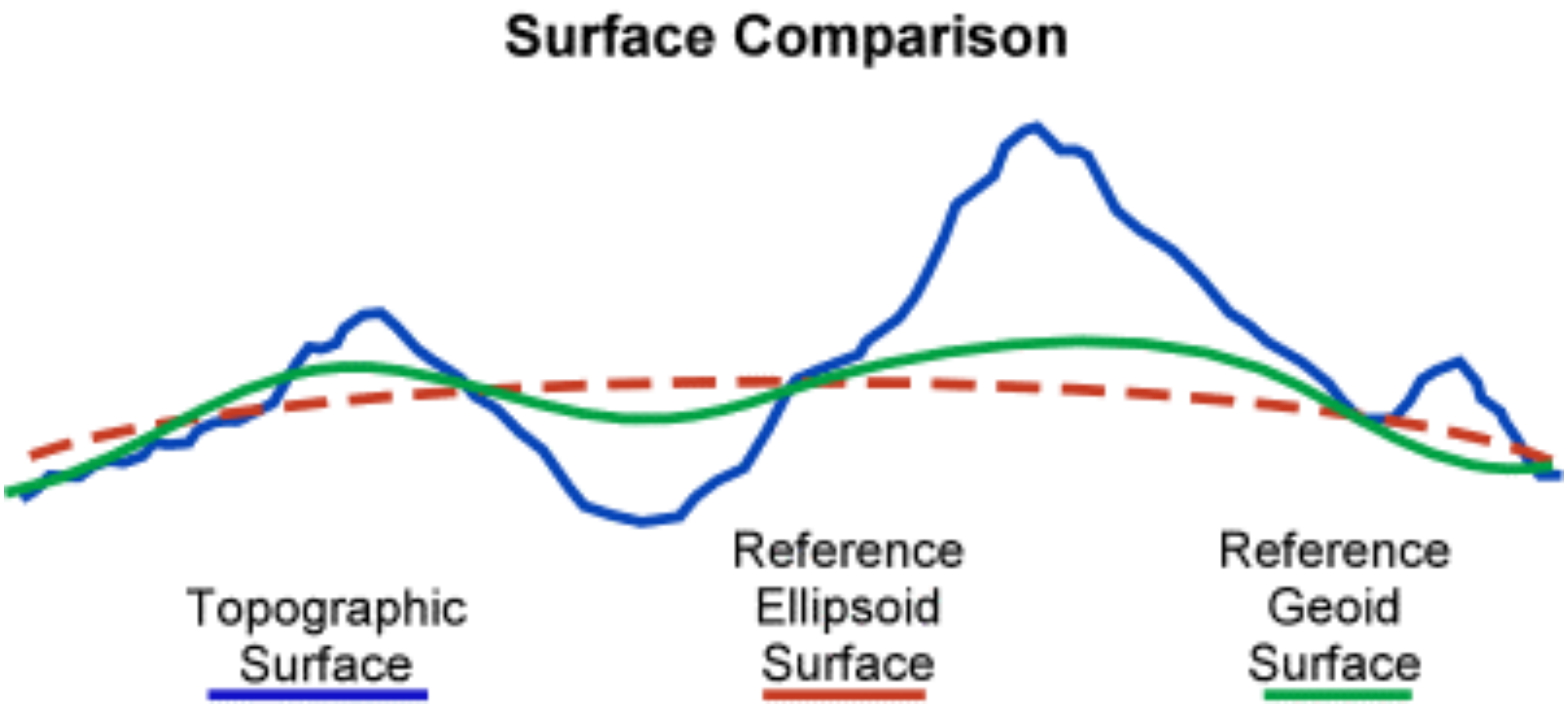


Image: unavco.org

Beware different values for height when mapping in 2.5D or 3D
(factors may be used to correct geoid/ellipsoid heights)

COORDINATE TRANSFORMATIONS

1. Plane transformations
2. Map projection

1. PLANE TRANSFORMATION

Similarity transformation: Conformal mapping (angle preserving)

$\mathbb{R}^{\mathbf{2}} \rightarrow \mathbb{R}^{\mathbf{2}}$

4 parameters

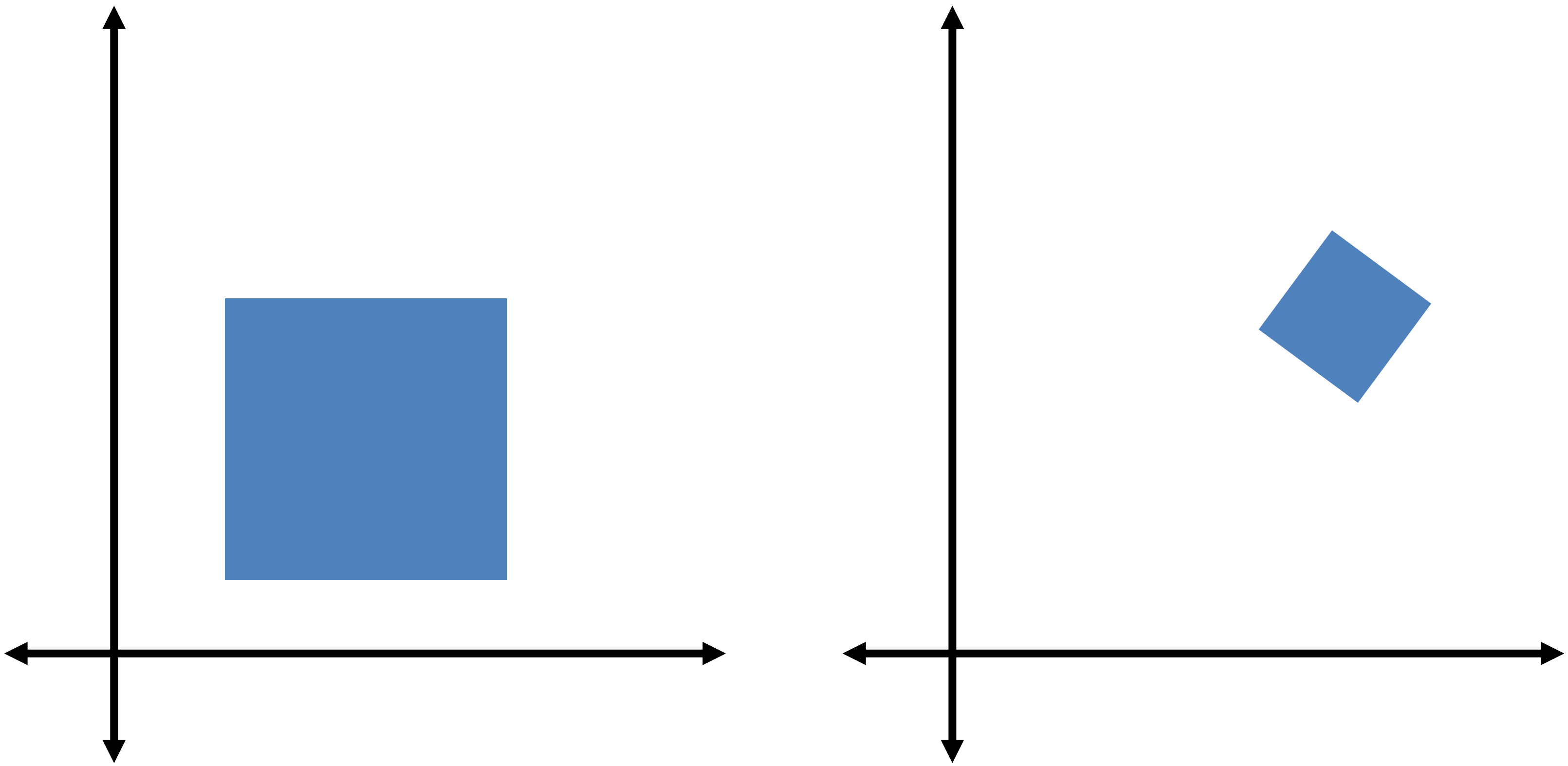
Scale

Rotate

Translate

1. PLANE TRANSFORMATION

Similarity transformation example (angle preserving)



1. PLANE TRANSFORMATION

Affine transformation

$\mathbb{R}^2 \rightarrow \mathbb{R}^2$

6 parameters

Scale

Rotate

Translate

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} s_x & 0 \\ 0 & s_y \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

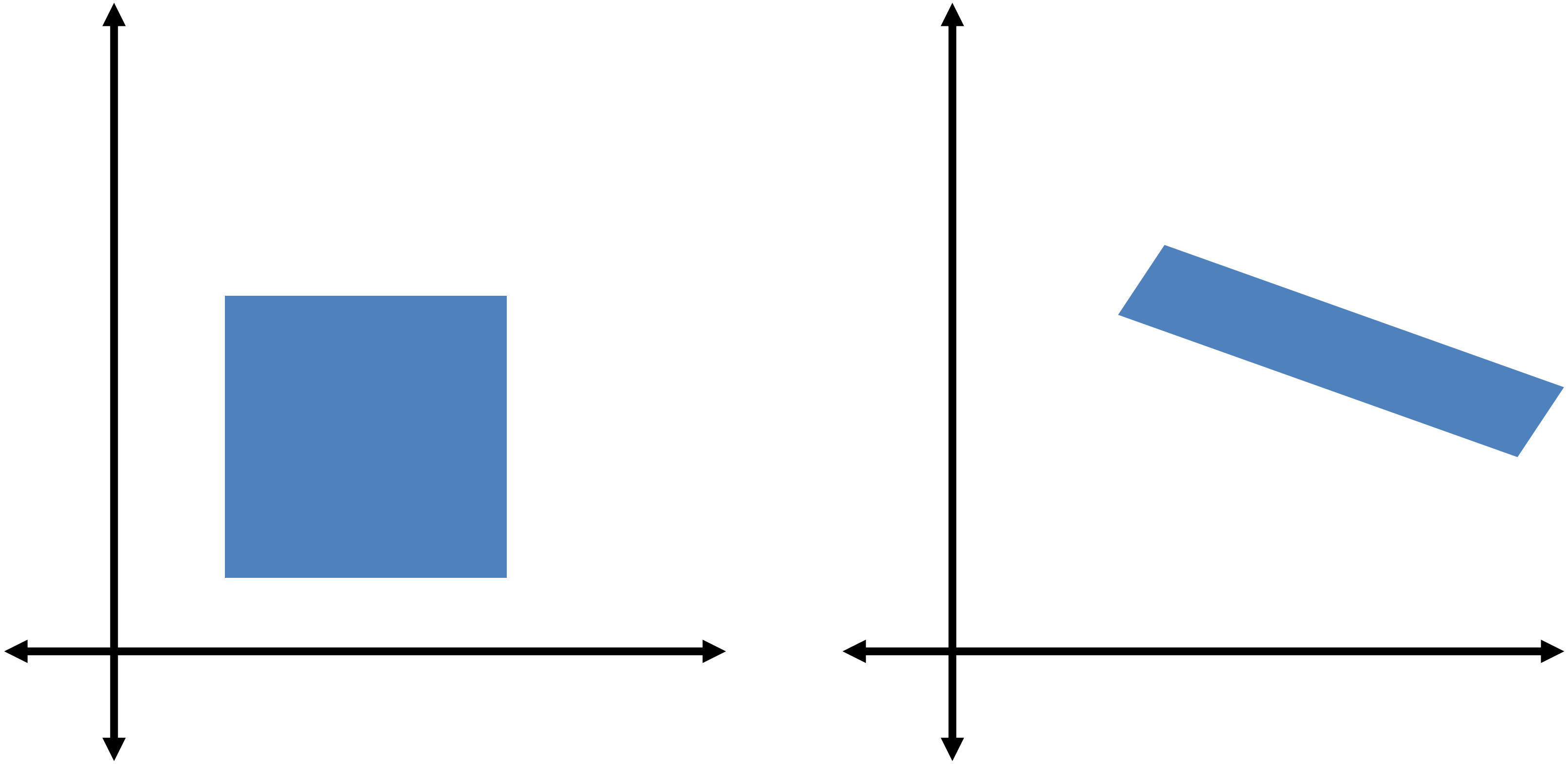
$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \Delta_x \\ \Delta_y \end{bmatrix} + \begin{bmatrix} x \\ y \end{bmatrix}$$

Commonly used for **georeferencing**

1. PLANE TRANSFORMATION

Affine transformation example (shearing)



Chain of transformations – don't get them wrong!

KNOW YOUR COORDINATE SYSTEM

Know your dataset's coordinate system

- EPSG Codes can help with transformations (e.g., PostGIS)
  - WGS84: 4326 (lat, long)
  - GDA94: 4283 (lat, long)

```
GEOGCS["WGS 84",
   DATUM["WGS_1984",
      SPHEROID["WGS84",6378137,298.257223563,
               AUTHORITY["EPSG","7030"]],
      AUTHORITY["EPSG","6326"]],
   PRIMEM["Greenwich",0,
      AUTHORITY["EPSG","8901"]],
   UNIT["degree",0.01745329251994328,
      AUTHORITY["EPSG","9122"]],
   AUTHORITY["EPSG","4326"]]
```

```
GEOGCS["GDA94",
   DATUM["Geocentric_Datum_of_Australia_1994",
      SPHEROID["GRS 1980",6378137,298.257222101,
         AUTHORITY["EPSG","7019"]],
      TOWGS84[0,0,0,0,0,0,0],
      AUTHORITY["EPSG","6283"]],
   PRIMEM["Greenwich",0,
      AUTHORITY["EPSG","8901"]],
   UNIT["degree",0.01745329251994328,
      AUTHORITY["EPSG","9122"]],
   AUTHORITY["EPSG","4283"]
```

KNOW YOUR COORDINATE SYSTEM

Transforming between coordinate systems

- Need to know your data! (did I mention this?)
- Processing v3:

```
proj.transformCoords(new PVector(lat1,long2))
```

More information: http://www.gicentre.net/utils/mapprojection

2. MAP PROJECTIONS

Traditionally, spherical representations were unportable ‘globes’

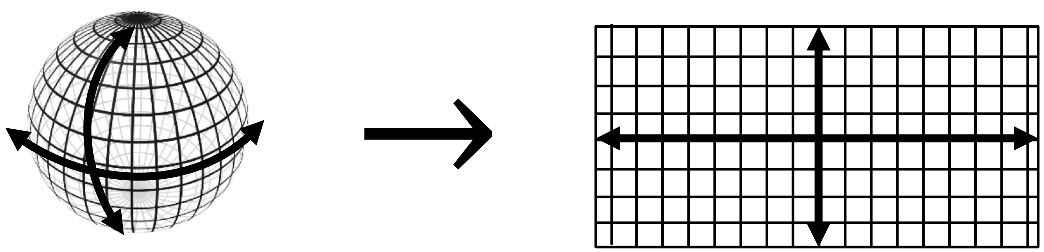
Map based representations generally have four advantages:

- Easier to work with, greater detail, cheaper, understandable dimensions

Image: Wikimedia Commons

Map projection is transferring a curved surface to the plane

$\mathbb{R}^{3} \rightarrow \mathbb{R}^{2}$



Where is the origin? (0,0)?

GEOGRAPHIC
Angular coordinates (ϕ, λ)
DMS

CARTESIAN
Grid coordinates (x, y)
Typically metres

CONCEPT

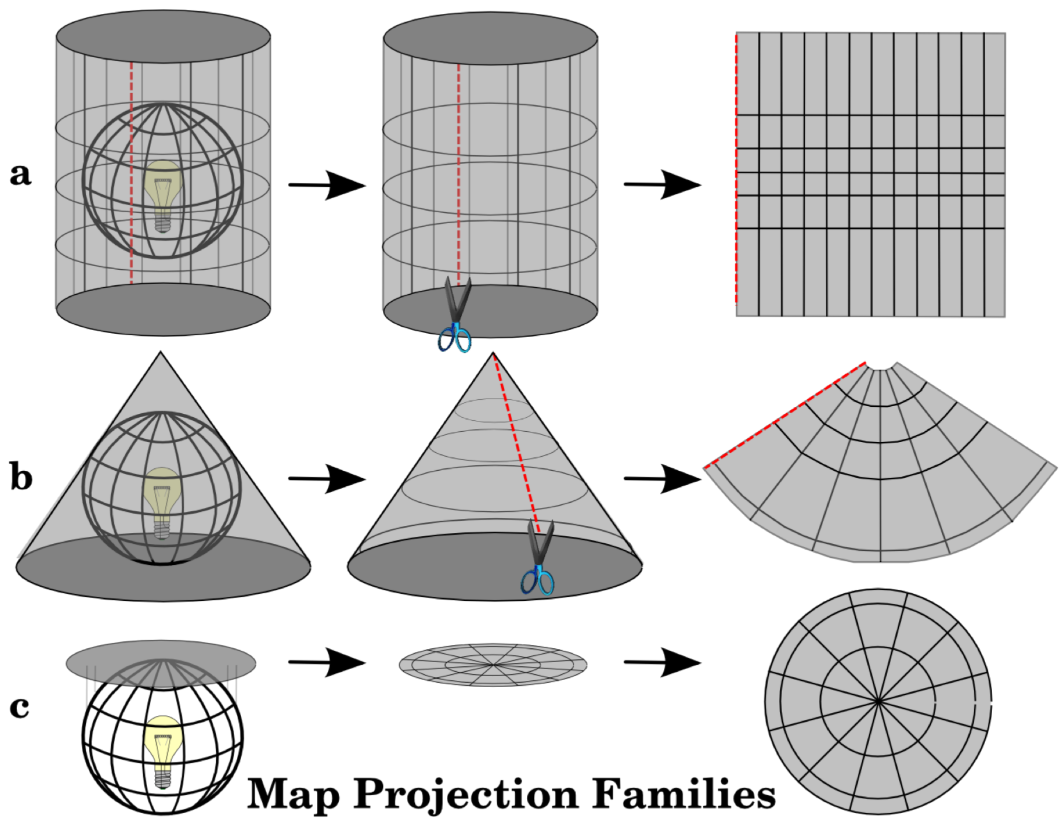
Transform a point on a curved surface (ϕ, λ) to a point (x, y) on a map

Three major classes:

Cylindrical

Conic

Planar (Azimuthal)



e.g.
Equidistant,
Equal-area,
Mercator or UTM

e.g.
Lambert Conformal,
Albers Equal-area,
Polyconic

e.g.
Orthographic,
Gnomonic,
Stereographic

Image: QGIS, http://docs.qgis.org/

DISTORTION

- Every map projection will contain some distortion (none perfect!)
- This may be measured using quantitative distortion analyses

Scale factor:

1. Calculate scale factor

$$SF = \frac{distance\ on\ the\ projection}{distance\ on\ the\ ellipsoid}$$

2. Compare at different locations

SF will be different at different points, and potentially at different directions (distortion along parallels different to distortion along meridians)

PROJECTION PROPERTIES

Map design must consider what spatial relationships are preserved
Otherwise the message may be distorted!

1. **Areas preserved** (Equivalent or Equal Area)
   - SF changes must be controlled, angular distortion only

2. **Angles preserved** (Conformal)
   - SFs change at the same rate, areal distortion only

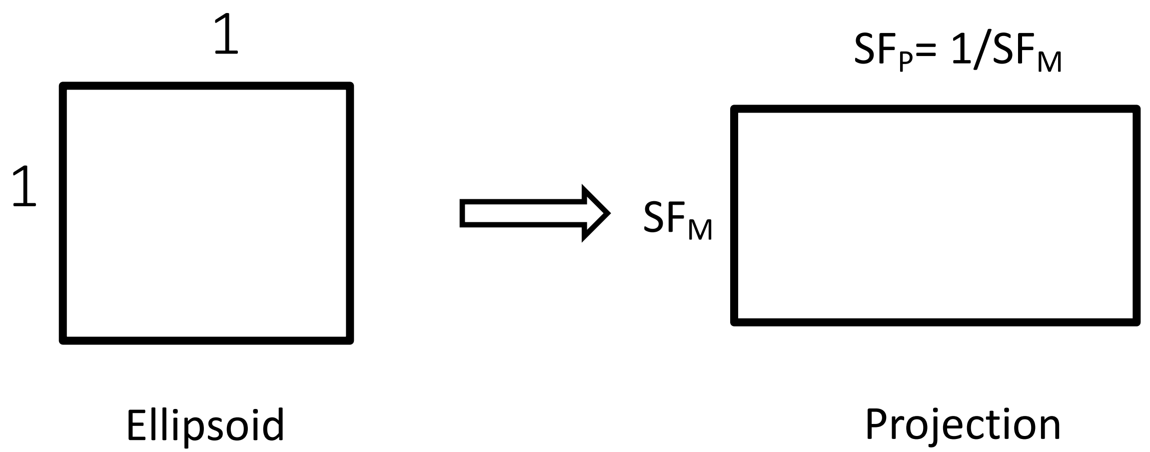
3. **Distances preserved** (Equidistance or Equirectangular)
   - Distorts areas and angles, however correct scale within some limit

4. **Directions preserved** (Azimuthal or planar)
   - Great circles represented as lines (but SF = 1 only at centre)

PROJECTION PROPERTIES

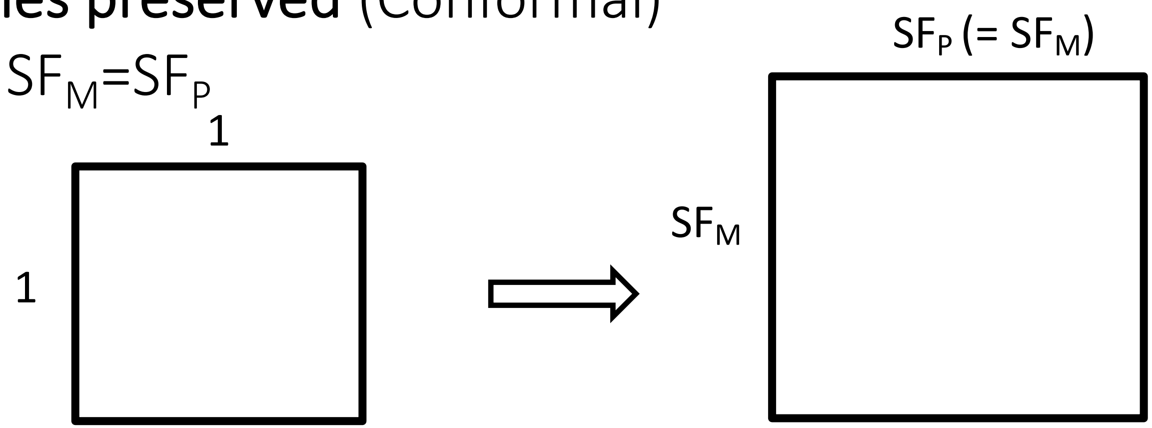
1. Areas preserved (Equivalent or Equal Area)

- $SF_M \times SF_P = 1$



2. Angles preserved (Conformal)

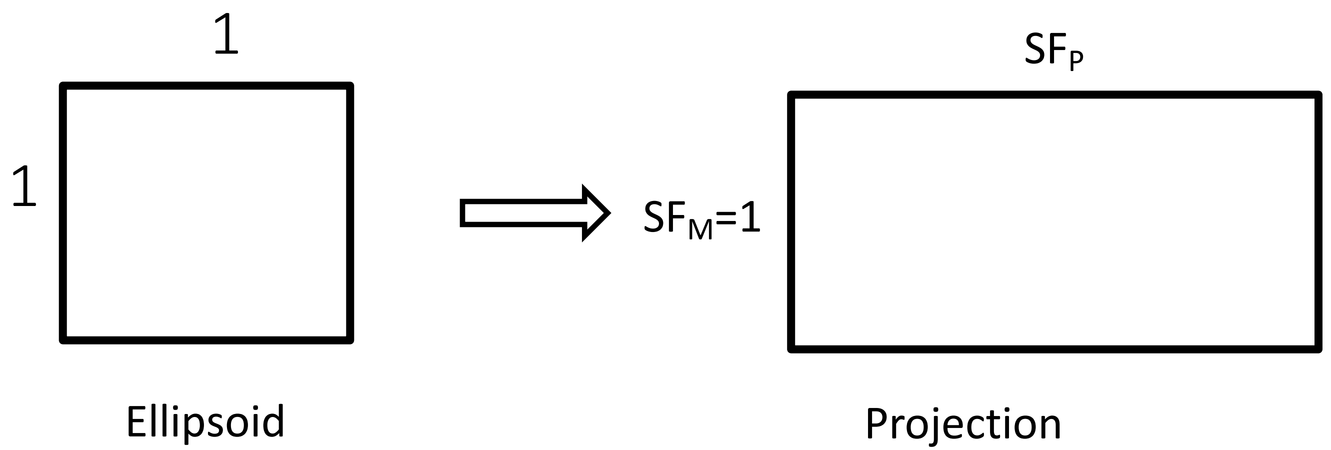
- $SF_M = SF_P$



PROJECTION PROPERTIES

1. **Distances preserved** (Equidistant or Equirectangular)

- E.g., $SF_M = 1$

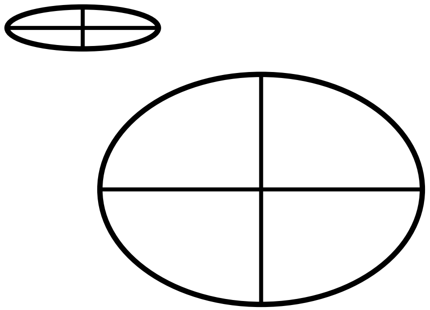


DISTORTION

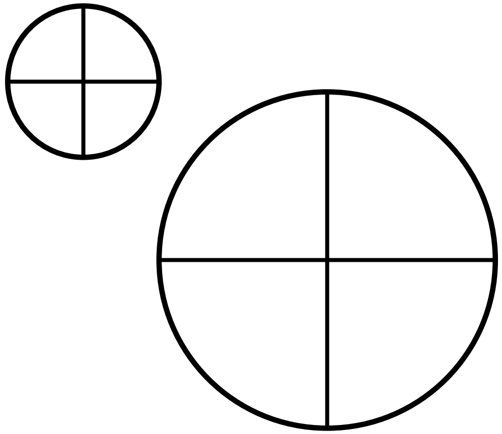
Tissot's Indicatrix:

Represent scale factors using a unit circle (radius of 1) at infinite points

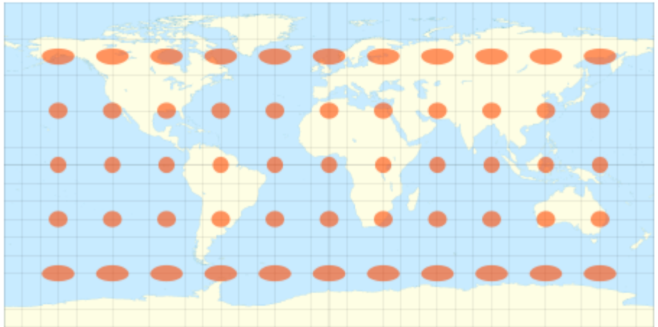
Angular distortion:
Unequal scaling of
semi-major and minor axes



Areal distortion:
Equal scaling of
semi-major and minor axes

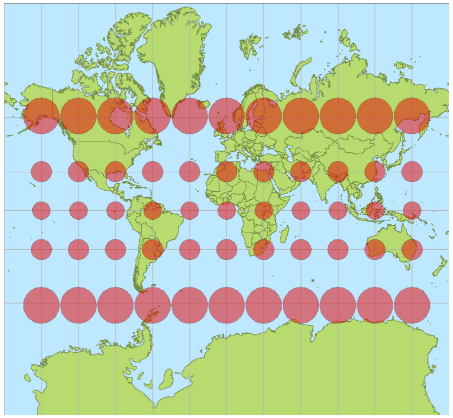


DISTORTION: Tissot’s Indicatrix



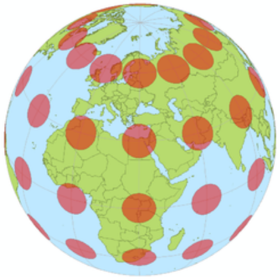
Equirectangular
(preserves distance)
Image: Wikimedia Commons

✓Thematic mapping
✓Raster (pixels)



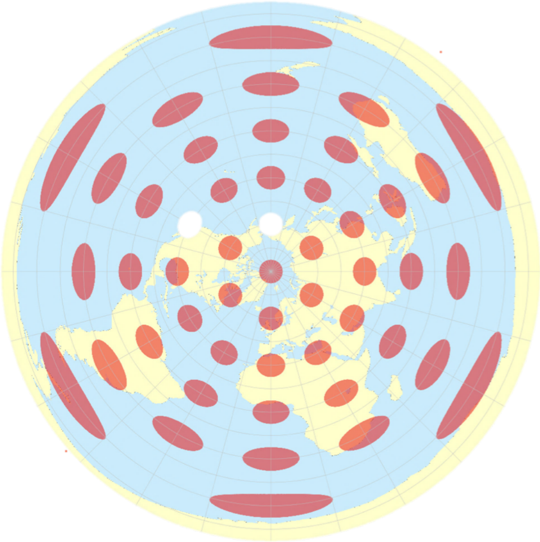
Transverse Mercator
(preserves angles,
size distorts with latitude)
Image: Wikimedia Commons

✓Navigation



Spherical
(preserves areas and angles)
Image: Wikimedia Commons

✓Virtual globes



Azimuthal Equidistant*
(*along meridians only)
Image: Tobias Jung
http://www.map-projections.net

✓Site specific

DISTORTION

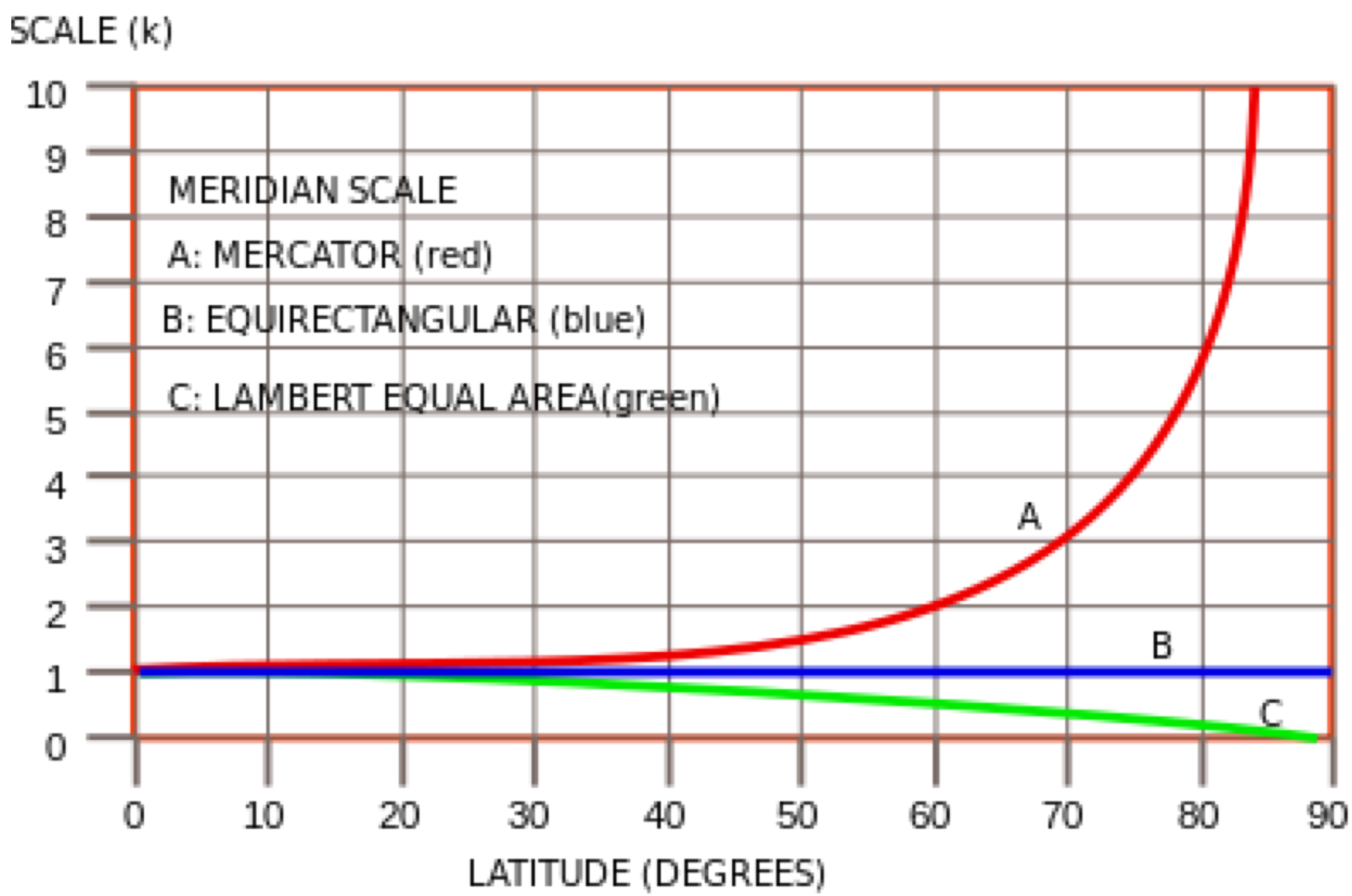
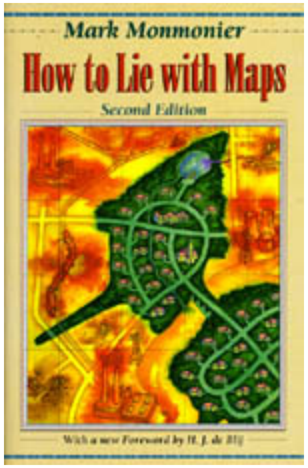


Image: Wikimedia Commons

DISTORTION – Accidental, deliberate



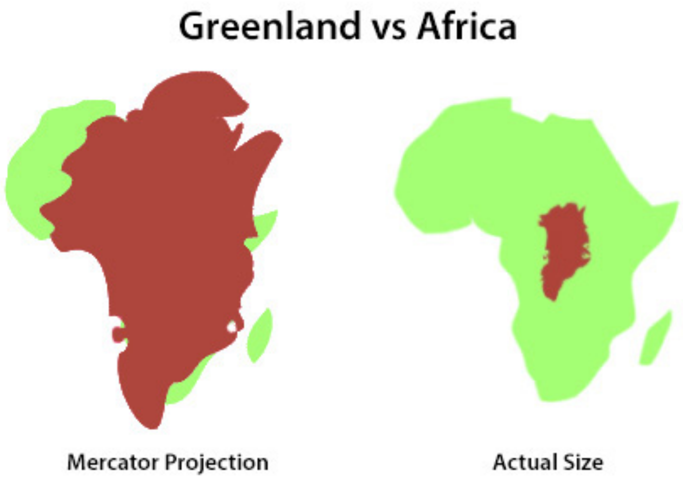


Image: Geoff Boeing
http://geoffboeing.com/2015/08/map-projections-that-lie/

Warning: Bigger things attract more attention
- Particular problem for choropleth maps!
- Likely to effect the 'value message'

BuzzFeed clip:
https://www.youtube.com/watch?v=KUF_Ckv8HbE

SPECIAL CASE: UNIVERSAL TRANSVERSE MERCATOR (UTM)

Uses the transverse Mercator (cylindrical and conformal) at different zones (spaced ~6° longitude)

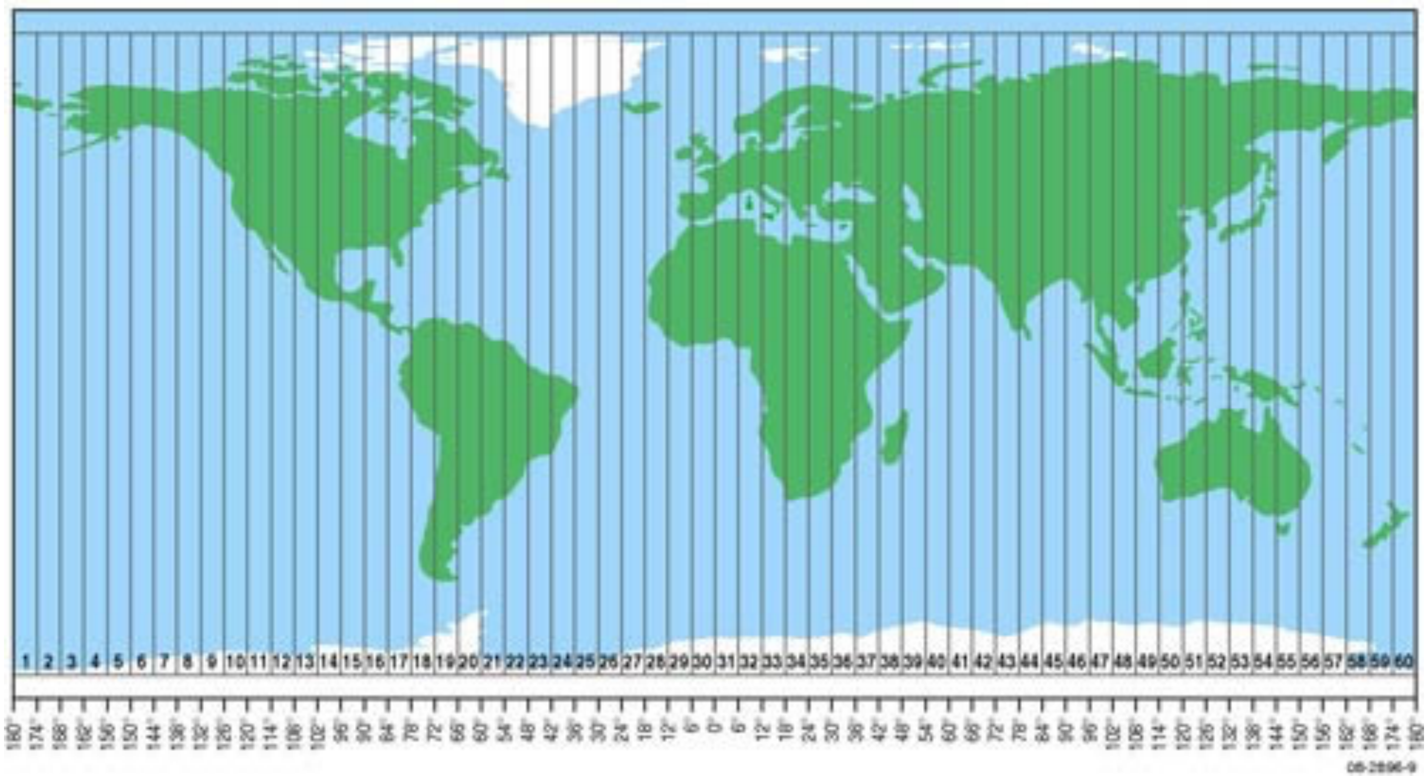


Image: ICSM Australia http://www.icsm.gov.au/mapping/map_projections.html

UTM in Australia

- GDA94 datum (GRS80 ellipsoid)
- Projected using UTM into zones 49-56

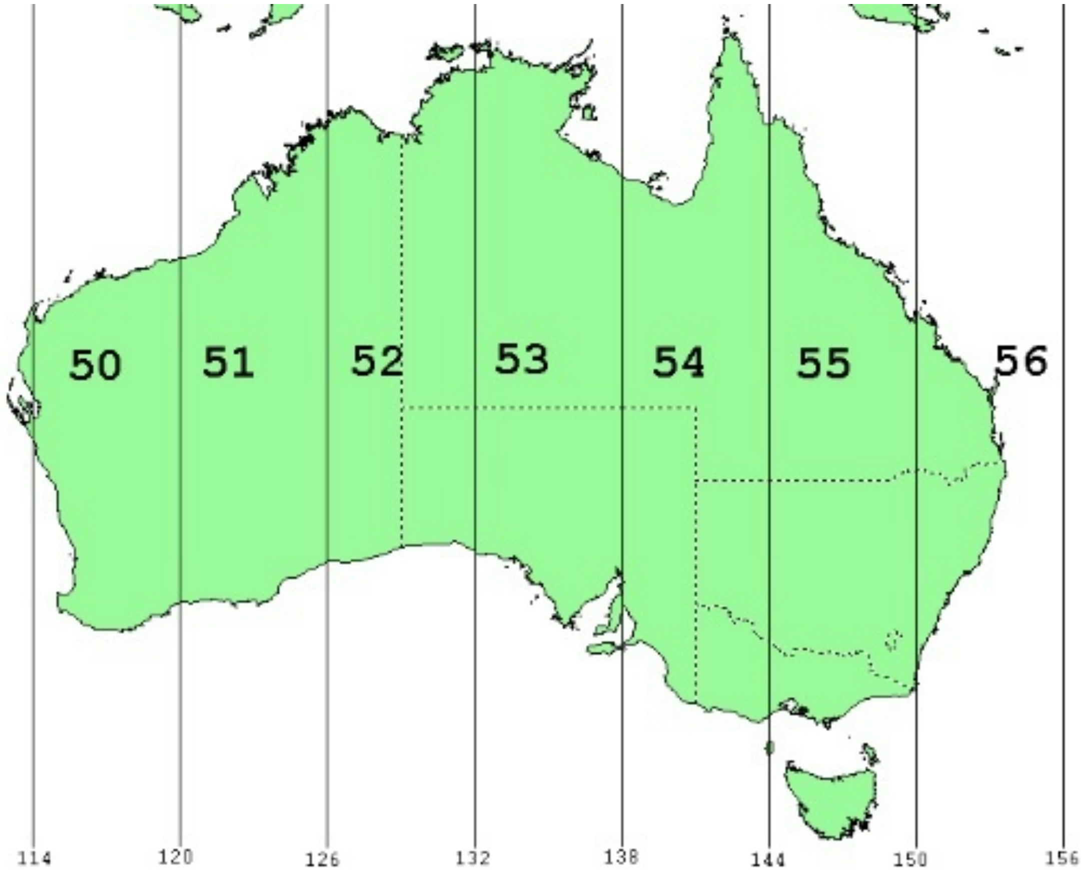


Image: Anthony Dunk
http://www.diamondspirit.net/adunk/software/zonemap.jpg

Projected coordinates: Map Grid of Australia (MGA) are in **metres**

X = Eastings
Y = Northings

LATITUDE DIVISIONS:

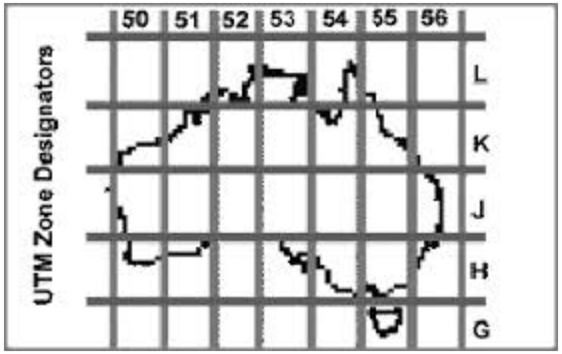


Image: DTPLI (2015)

SPECIAL CASE: WEB MERCATOR (spherical Mercator, auxiliary sphere…)

- Preserves angles, distorts size
- "Hack": Ellipsoidal coordinates (WGS84) with a spherical projection
  - Ignores flattening at poles, very poor towards these areas
  - OK for apps such as Uber or Airbnb*

- EPSG Code: 3857
  - "Projection used in many popular web mapping applications (Google/Bing/OpenStreetMap/etc). Sometimes known as EPSG:900913" http://spatialreference.org/ref/sr-org/7483/

- Processing using giCentre:

```
WebMercator proj = new WebMercator();
```

There's no north pole!

Image: Alastair Aiychison https://alastaira.wordpress.com/2011/01/23/the-google-maps-bing-maps-spherical-mercator-projection/

INTERACTIVE TOOLS

Flex projector
http://www.flexprojector.com/

Map Projector 2.0
http://projections.mgis.psu.edu/

Tissot's Indicatrix global (Mercator)
http://www.jasondavies.com/maps/tissot/

Tissot's Indicatrix on Google Maps (Web Mercator)
http://darrenwiens.net/tissot.html

SUMMARY

Coordinate systems

- Reference ellipsoid (e.g., WGS or GRS)
- Datum (horizontal, vertical)

Transformation:

- Coordinate transformation (overview)
- Map projection
  - Various types
  - Must always be considered in map design (e.g., medium)

Introduction to working with spatial data

- Know your data and your map's purpose / audience
- Iterative design process

NEXT LECTURE

- Cartography 4 – Towards greater interaction

PRACTICAL

- Presenting Data with Processing (PDP) / Interaction and Animation with Processing (IAP)

REFERENCE – How to choose a map projection?

Snyder, J. (1935) Map projections: A working manual, *USGS*
Link: http://pubs.usgs.gov/pp/1395/report.pdf