Introducing Coordinate Systems and Transformations

ROB JUERGENS
BOJAN ŠAVRIČ
Where is my data?

Problem
Transformations

Projections

Vertical

Horizontal

Coordinate Systems
What does a coordinate system tell us?

Distance

Location

Direction
Distance

Q: How far is it from San Francisco to Los Angeles?

- 352.34 miles
- 690.67 kilometers
- 567.03 kilometers
- 620111.549 yards
Q: How far is it from San Francisco to Los Angeles?
A: It depends on the coordinate system.

- 352.34 miles
- 690.67 kilometers
- 567.03 kilometers
- 620111.549 yards
Q: What are the coordinates for Los Angeles?

(-118.25, 34.05)
(1276.333, 2421.545)
(2054060.514, 3897101.109)
(-13163527.521, 4035514.817)
Q: What are the coordinates for Los Angeles?
A: It depends on the coordinate system.

(-118.25, 34.05)
(1276.333, 2421.545)
(2054060.514, 3897101.109)
(-13163527.521, 4035514.817)
Direction

Q: In which direction is the North Pole?

- Down
- To the right
- Up
- Can’t, not on the map
Q: In which direction is the North Pole?
A: It depends on the coordinate system.

- Down
- To the right
- Up
- Can’t, not on the map
Two Kinds of Horizontal Coordinate Systems

- Geographic coordinate system
- Projected coordinate system
Geographic Coordinate System (GCS)

- 3D spheroidal surface

- Point P has:
  - Longitude 80° E
  - Latitude 50° N
Geographic Coordinate System (GCS)
Projected Coordinate System (PCS)

- $X < 0$ and $Y > 0$
- $X > 0$ and $Y > 0$
- $X < 0$ and $Y < 0$
- $X > 0$ and $Y < 0$

The origin $(0,0)$ is located at the center of the coordinate system.
Horizontal Coordinate System
Horizontal Coordinate System

Geographic Coordinate System

Prime Meridian

Datum

Angular Unit

Spheroid
Two Ways to Specify a Coordinate System

Well-known ID

Well-known text
Well-Known ID (WKID)

• All predefined coordinate systems have a WKID
Well-Known ID (WKID)

• WKID ≤ 32767: EPSG
  - EPSG Geodetic Parameter Dataset
  - http://www.epsg-registry.org/
Well-Known ID (WKID)

- **WKID ≤ 32767: EPSG**
  - EPSG Geodetic Parameter Dataset

- **WKID > 32767: Esri**
Well-Known ID (WKID)

- WKID \leq 32767: EPSG
  - EPSG Geodetic Parameter Dataset
  - http://www.epsg-registry.org/

- WKID > 32767: Esri

- Any WKID may change
Well-Known Text (WKT)

GEOGCS["GCS_ETRS_1989",
    DATUM["D_ETRS_1989",
        SPHEROID["GRS_1980",6378137.0,298.257222101]],
    PRIMEM["Greenwich",0.0],
    UNIT["Degree",0.0174532925199433]]
Well-Known Text (WKT)

PROJCS["ETRS_1989_UTM_Zone_32N",
    GEOGCS["GCS_ETRS_1989",
        DATUM["D_ETRS_1989",
            SPHEROID["GRS_1980",6378137.0,298.257222101]],
        PRIMEM["Greenwich",0.0],
        UNIT["Degree",0.0174532925199433]],
    PROJECTION["Transverse_Mercator"],
    PARAMETER["False_Easting",500000.0],
    PARAMETER["False_Northing",0.0],
    PARAMETER["Central_Meridian",9.0],
    PARAMETER["Scale_Factor",0.9996],
    PARAMETER["Latitude_Of_Origin",0.0],
    UNIT["Meter",1.0]]
Vertical Coordinate Systems
Q: How high is Mount Everest?

- 8844.43 meters
- 29029 feet
- 8.850 kilometers
- 29017.16 feet
Q: How high is Mount Everest?
A: It depends on the vertical coordinate system.

- 8,844.43 meters
- 29,030 feet (approximately)
- 8.850 kilometers
- 29,017.16 feet
Vertical Coordinate System (VCS)

- Defines the origin for height or depth
The Origin for Height or Depth

Geometric model

Earth’s surface

ellipsoid
The Origin for Height or Depth

- Geometric model
- Gravity related model

Earth's surface
Ellipsoid
Geoid
Gravity-Related Earth Model

• Geoid
  - Global representation of mean sea level
  - Complex shape
  - Modeled with geoid height / undulation (N)
Vertical Coordinate System
Datum vs. Vertical Datum

• Datum
  - Ellipsoidal datum
  - Ellipsoidal height (h)

• Vertical datum
  - Gravity-related datum
  - Gravity-related height (H)
Direction and Shift

- **Direction**
  - axis direction is positive for heights or depths

- **Vertical Shift**
  - parameter for a built-in offset from the VCS definition
Well-Known Text and ID

- **WKT:**
  
  VERTCS["NAVD_1988",
  VDATUM["North_American_Vertical_Datum_1988"],
  PARAMETER["Vertical_Shift",0.0],
  PARAMETER["Direction",1.0],
  UNIT["Meter",1.0]]

- **WKID:** **EPSG:5703**

Vertical coordinate system
Define Projection Tool

- Overwrites the coordinate system info of a dataset
- When it is unknown or incorrect

```python
import arcpy
infcs = r"C:\data\My_Data.shp"
sr = arcpy.SpatialReference("NAD 1983 UTM Zone 11N")
arcpy.DefineProjection_management(infcs, sr)
```
Projections
Projecting to a Different Coordinate System
### Map Projections in Esri Software

<table>
<thead>
<tr>
<th>Category</th>
<th>Projections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aitoff</td>
<td>Equidistant conic</td>
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<tr>
<td>Albers</td>
<td>Equidistant cylindrical</td>
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<td>Aspect-adaptive</td>
<td>Flat polar quartic</td>
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<tr>
<td>Azimuthal equidistant</td>
<td>Fuller</td>
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<td>Behrmann</td>
<td>Gall stereographic</td>
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<td>Berghaus Star</td>
<td>Gauss Kruger</td>
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<td>Bonne</td>
<td>Geostationary satellite</td>
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<td>Cassini</td>
<td>Gnomonic</td>
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<td>Compact Miller</td>
<td>Goode Homolosine</td>
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<td>Craster Parabolic</td>
<td>Hammer-Aitoff</td>
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<td>Cube</td>
<td>Hotine oblique Mercator</td>
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<tr>
<td>Cylindrical equal-area</td>
<td>IGAC Plano Cartesiano</td>
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<tr>
<td>Double stereographic</td>
<td>Krovak</td>
</tr>
<tr>
<td>Eckert Greifendorff</td>
<td>Laborde oblique Mercator</td>
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<tr>
<td>Eckert I</td>
<td>Lambert azimuthal equal-area</td>
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<td>Eckert II</td>
<td>Lambert conformal conic</td>
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<td>Eckert III</td>
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<td>Loximuthal</td>
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<td>Eckert VI</td>
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<td>Natural Earth II</td>
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<td>Patterson</td>
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<td>Van der Grinten I</td>
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<td>Miller cylindrical auxiliary sphere</td>
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<td>Miller cylindrical auxiliary sphere</td>
<td>Orthographic auxiliary sphere</td>
</tr>
<tr>
<td>Orthographic auxiliary sphere</td>
<td>Vertical near side perspective</td>
</tr>
</tbody>
</table>
Why are there so many map projections?

• Shape
• Area
• Direction
• Distance

Illustration by Charles Preppernau, geographer.xyz
Web Mercator Projection

Q: Which is bigger?

- South America
- Greenland
- Antarctica
Q: Which is bigger?

- South America ~ 17,840,000 km$^2$
- Greenland ~ 2,166,000 km$^2$
- Antarctica ~ 14,000,000 km$^2$
Q: Which projection is the best?

- Albers equal-area
- Stereographic
- Azimuthal equidistant
- Transverse Mercator
Q: Which projection is the best?
A: It depends on what you are doing.

- Albers equal-area
- Stereographic
- Azimuthal equidistant
- Transverse Mercator
Preserve Area

- Albers equal-area conic
Preserve Area

- Albers equal-area conic
Preserve Angles

- Stereographic
  - Only at infinitesimal scale
Preserve Direction and Distance

- Azimuthal equidistant
  - Only from the center
Project Tool

- Projects spatial data from one coordinate system to another

```python
import arcpy
input = r"C:\data\My_Data.shp"
output = r"C:\data\My_Data_Project.shp"
out_cs = arcpy.SpatialReference("NAD 1983 UTM Zone 11N")
arcpy.Project_management(input, output, out_cs)
```
What is happening when we project data?

• Case 1: Both PCSs contain the same GCS

\[(x, y) \quad \text{PCS A1} \quad \text{PCS A2} \quad (x, y)\]

\[(\lambda, \phi) \quad \text{GCS A}\]
What is happening when we project data?

- Case 1: Both PCSs contain the same GCS
What is happening when we project data?

- Case 1: Both PCSs contain the same GCS
What is happening when we project data?

- Case 2: Each PCS contains a different GCS
What is happening when we project data?

- Case 2: Each PCS contains a different GCS
What is happening when we project data?

- Case 2: Each PCS contains a different GCS

\[
\begin{align*}
\text{PCS A1} & \quad (x, y) \\
\text{GCS A} & \quad (\lambda, \phi) \\
\text{Unproject} & \\
\text{Geographic (Datum) Transformation} & \\
\text{PCS B1} & \quad (x, y) \\
\text{GCS B} & \quad (\lambda, \phi)
\end{align*}
\]
What is happening when we project data?

• Case 2: Each PCS contains a different GCS

- Project
  - Geographic (Datum) Transformation
  - Unproject
Transformations
Transforming Means Changing Datum

Earth-centered datum (WGS 1984)
Transforming Means Changing Datum

Earth-centered datum (WGS 1984)

Local datum (NAD 1927)
Why do we need to transform our data?
Why do we need to transform our data?
Two Kinds of Transformations

Geographic (datum) transformation

Vertical transformation
Geographic (Datum) Transformation

NAD 1927  NAD_1927_To_WGS_1984_1  WGS 1984
Geographic (Datum) Transformation

NAD 1927

NAD_1927_To_WGS_1984_1

WGS 1984

NAD 1927

~NAD_1927_To_WGS_1984_1

WGS 1984
Defined for Certain Area

- 33 transformations:
  - NAD 1927
  - WGS 1984
How do I find transformations?
Vertical Transformation

Ellipsoidal Heights (NAD83)

NAD_1983_To_NAVD88_CONUS_GEOID12B_Height

Orthometric Heights (NAVD 88)
Vertical Transformation Methods

Geoid models
- EGM2008
- EGM84 and EGM96
- GEOID12B
- VERTCON

Vertical offset
Vertical offset and slope
# ArcGIS Coordinate Systems Data

The ArcGIS Coordinate Systems Data is a collection of resources that provide spatial reference information for geospatial data. This page allows users to download specific coordinate systems data for various ArcGIS products.

<table>
<thead>
<tr>
<th>Coordinate Systems Data</th>
<th>Additional Information</th>
<th>Version</th>
<th>File Size</th>
<th>Action</th>
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<td>902.99 MB</td>
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</tbody>
</table>

## Access to Coordinate Systems

- **Navigate to MyEsri**
- **Select My Organizations**
- **Downloads**
- **Data and Content**
ArcGIS Coordinate Systems Data

- 1.5 GB additional data install

- GEOCON v1.0

- NTv2 (CA, ES, CH, UK)

- VERTCON / GEOID12B
- Geoids for Japan and New Zealand
- EGM2008 (1' x 1', 2.5' x 2.5')
What You Should Know About Geographic (Datum) and Vertical Transformations?

Demo Theater Presentation

Today, 2:30 - 3:00 pm
Demo Theater 3: Oasis 1-2
Now you understand…

Coordinate Systems

Transforming your data

Projecting your data
Where is my data?
Solution
Resources

http://resources.arcgis.com/en/help
- **ArcMap** → **Map** → **Map projections**
- **Developer Help**
  - **List of ArcGIS APIs**

**Lining Up Data in ArcGIS**, Margaret Maher

ESRI Technical paper: **Understanding Coordinate Management in the Geodatabase**

ESRI Technical paper: **Understanding Geometric Processing in ArcGIS**
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