5 Georeferencing

OVERVIEW

- Lays out the principles of georeferencing
- Discusses commonly used systems, including placenames and street addresses, and moving to the more accurate scientific methods that form the basis of geodesy and surveying.
- Considers conversions between georeferencing systems, GPS, georeferencing of computers and cellphones, and gazetteers.

LEARNING OBJECTIVES

- **Know the requirements for an effective system of georeferencing;**
- **Be familiar with the problems associated with placenames, street addresses, and other systems used every day by humans;**
- **Know how the Earth is measured and modeled for the purposes of positioning;**
- **Know the basic principles of map projections, and the details of some commonly used projections;**
- **Know about conversion between different systems of georeferencing**
- **Understand the principles behind GPS, and some of its applications.**

KEY WORDS AND CONCEPTS

Georeference, placenames, linear referencing systems, cadaster, PLSS, latitude, longitude, spheroid, ellipsoid, WGS84, NAD83, NAD27, great circle, projections, easting, northing, Cartesian coordinates, conformal property, equal-area property, tangent projections, secant projections, Plate Carrée, UTM, State Plane Coordinates, GPS

OUTLINE

CHAPTER SUMMARY

5.1 Introduction

Several terms are used to describe the act of assigning locations including georeference, geolocate, geocode, or tag with location.

- Authors use *georeference* in this chapter

Lists several characteristics that georeferences must have

Table 5.1 Some commonly used systems of georeferencing - summarizes on dimensions of domain of uniqueness, metric, and spatial resolution.

5.2Placenames

- Any distinctive feature on the landscape can serve as a point of reference, and these are often named
- Language extends the power of placenames through words like ‘between’ or ‘near’ or by the addition of directions and distances
- Placenames are limited as georeferences

5.3 Postal addresses and postal codes

Postal addresses rely on several assumptions

- Postal addresses fail in locating anything that is not a potential destination for mail, such as a natural feature

- Canadian FSAs, US ZIP code areas and UK postcodes can be changed whenever the post office decides. However, they are sufficiently constant to be used for many purposes

5.4 IP Addresses

- Every device (computer, printer, etc.) connected to the Internet has a unique IP (Internet Protocol) address
- The IP address of the user's computer is provided whenever the computer is used to access a Web site, allowing the operators of major sites to determine the user's location

5.5 Linear referencing systems

- A linear referencing system identifies location on a network by measuring distance from a defined point of reference along a defined path in the network
- Linear referencing systems are widely used in managing transportation infrastructure and in dealing with emergencies
- However, there may be difficulties in defining distances along the network accurately, especially if roads include steep sections where horizontal distance is different from three-dimensional distance

5.6 Cadasters and the U.S. Public Land Survey System

- The *cadaster* is defined as the map of land ownership in an area, maintained for the purposes of taxing land, or of creating a public record of ownership.
- The US Public Land Survey System (PLSS) defines land ownership over much of western North America, and is a useful system of georeferencing.
    - The structure of the PLSS is explained in this section

5.7 Measuring the Earth: latitude and longitude

- The system of latitude and longitude is often called the *geographic* system of coordinates
- Explains how latitude and longitude are determined and defines various terms such as axis of Earth's rotation, the Equator, meridian, parallel
- Before defining latitude further, this section briefly touches on the topics of the figure of the Earth, spheroid, ellipsoid, flattening of the spheroid
    - The distance between the Poles is about 1 part in 300 less than the diameter at the Equator

        - WGS84, NAD83, and NAD27 are mentioned
    - Latitude is often symbolized by the Greek letter phi (φ) and longitude by the Greek letter lambda (λ)
    - Some statistics
        - two points on the same north–south line of longitude and separated by one degree of latitude are 1/360 of the circumference of the Earth, or about 111 km, apart
        - One minute of latitude corresponds to 1.86 km, and also defines one nautical mile
        - One second of latitude corresponds to about 30 m.
        - One degree of longitude along 60 degrees North is 55 km
- On a spherical Earth the shortest path between two points is a *great circle*, or the arc formed if the Earth is sliced through the two points and through its center

Some trivia: the French originally defined the meter in the late 18th century as one ten millionth of the distance from the Equator to the Pole. On the spherical Earth, the actual value Equator to Pole would be 10,018 km.

5.8 Projections and coordinates

- Projections are needed because many technologies for working with geographic data are flat, including paper and printing, which evolved over many centuries long before the advent of digital geographic data and GIS.
- The Cartesian coordinate system assigns two coordinates to every point on a flat surface, by measuring distances from an origin parallel to two axes drawn at right angles.
- We often talk of the two axes as x and y, and of the associated coordinates as the x and y coordinate, respectively.
- Because it is common to align the y axis with North in geographic applications, the coordinates of a projection on a flat sheet are often termed *easting* and *northing*.
- A map projection transforms a position on the Earth's surface identified by latitude and longitude (φ, λ) into a position in Cartesian coordinates (x, y).
- Every recognized map projection can be represented as a pair of mathematical functions:

  $x = f(\varphi,\lambda)$

  $y = g(\varphi, \lambda)$
- Two datasets can differ in both the projection and the datum, so it is important to know both for every dataset.

- Two important properties of projections are
    - The conformal property ensures that the shapes of small features on the Earth's surface are preserved on the projection
    - Useful for navigation because a straight line has a constant bearing
- The equal area property ensures that areas measured on the map are always in the same proportion to areas measured on the Earth's surface.
- Useful for analyses involving areas
- Major classes of physical models used are cylindrical, azimuthal, and conic
- Where the developable surface coincides with the surface of the Earth, the scale of the projection is 1
    - Tangent projections are where the developable surface coincides with the surface of the Earth along only one line (or at one point)
    - Secant projections attempt to minimize distortion by allowing the paper to cut through the surface, so that scale can be both greater and less than 1
- The grid of latitude and longitude is known as the *graticule*

5.8.1 The Plate Carrée or Cylindrical Equidistant projection

- The simplest of all projections maps longitude as x and latitude as y, and for that reason is also known informally as the unprojected projection.
- Discusses the serious problems that can occur when doing analysis using this projection and talks about the Tissot indicatrix (without using that term)

5.8.2 The Universal Transverse Mercator projection

- Based on the Mercator projection, but in transverse rather than Equatorial aspect,
- There are 60 zones in the system, each zone being 6 degrees wide
- The UTM system is secant, with lines of scale 1 located some distance out on both sides of the central meridian.
- Scale is 0.9996 at the central meridian and at most 1.0004 at the edges of the zone
- The system for defining the coordinates in meters measured from the Equator and central meridian is described
- Mentions the problem that maps will not fit together across a zone boundary
- Are good for analysis because distances can be calculated for points within the same zone with no more than 0.04% error

5.8.3 State Plane Coordinates and other local systems

- In the 1930s each US state agreed to adopt its own projection and coordinate system, generally known as State Plane Coordinates (SPC), in order to support high-accuracy applications.
- The UK uses a single projection and coordinate system known as the National Grid that is based on the Oblique Mercator projection.

5.9 Measuring latitude, longitude and elevation: GPS

- Very briefly explains the constellation of satellites
- Positioning in three dimensions (latitude, longitude, and elevation) requires that at least four satellites are above the horizon
- If elevation is not needed then only three are needed
- Simple GPS can get horizontal accuracies within 10m, differential GPS can improve it to 1m or better
    - Vertical accuracies are much poorer
- A variety of vertical datums are used, even within single countries.

5.10 Converting georeferences

Technical Box 5.3 Geocoding: conversion of street addresses

Requires a database containing records representing the geometry of street segments between consecutive intersections, and the address ranges on each side of each segment

5.10 Summary

ESSAY TOPICS

1. From Lewis Carroll's Hunting of the Snark:

'What's the good of Mercator's North Poles and Equators,
Tropics, Zones, and Meridian Lines?"
So the Bellman would cry: and the crew would reply
They are merely conventional signs!'

    a. How would you answer the Bellman and crew?
    b. What are the desirable properties of a georeference?

2. What the practical problems associated with the use of latitude and longitude as a global georeference?
3. What are the deficiencies of postal codes when they are used as georeferences?

4. What are the deficiencies of IP addresses when they are used as georeferences?
5. What features of some linear referencing systems allow geographical analysis, and what are the limitations of these systems?
6. Summarize the arguments for and against use of a single ellipsoid such as WGS84.
7. How would you go about identifying the projection used by a common map source, such as the weather maps shown by a TV station or in a newspaper?
8. Identify the map projections that would be best for measurement of (1) area, (2) length, (3) shape.
9. To what extent does the use of unusual projections present cartographers with another 'visual variable'?

MULTIPLE CHOICE QUESTIONS (MCQ)

1. Eastings in map co-ordinates are conventionally associated with which axis of a Cartesian system, *x*or *y*?
2. What is the value of the polar flattening of the Earth relative to a perfect sphere? Is it 1 part in (a) 500, (b) 300 or (c) 200?
3. Which of the following is NOT an essential requirement of a georeference?
    a. Uniqueness
    b. Shared meaning
    c. Persistence
    d. A time and date

10. Which of the following are not metric georeferences?
    a. Post/ZIP codes
    b. Latitude/longitude
    c. Postal address
    d. House number
    e. State plane co-ordinates
    f. National grid reference
11. What are the two most important characteristics of a geographical data set that <u>must</u> be known before any analysis?
    a. the datum
    b. the scale
    c. the projection
    d. the key
12. Complete the following sentence by choosing from the bracketed alternatives. "UTM has (180/100/60/10) zones each of 3/6/12 degrees width; from 174E to 180E which is Zone

number (1/30/60); from 180W to 174W which is Zone number (1/30/60) The scale at the central meridian is (1.004/0.9996) and at most (1.0004/0.9996) at the zone edges".

13. A cadaster is
    a. a land subdivision
    b. the boundary of some property
    c. part of the Public Land Survey System
    d. a map of land ownership
14. Match each of the places in the table to its latitude and longitude (rounded to the nearest integer):

City		Latitude	Longitude
Narsarssuaq, Greenland		51°N	0°W
Hong Kong		49°N	2°E
Paris, France		61°N	45°W
London, England		37°S	175°E
Auckland, New Zealand		22°N	114°E

15. In the US PLSS a township has what area?
    a. 40 square miles
    b. 36 square miles
    c. 1 square mile
16. Which of the following 'surfaces' does not define a class of map projections?
    a. sphere
    b. cylinder
    c. plane
    d. cone

CLASS AND INDIVIDUAL ACTIVITIES

1. Where do you live? Ask a class to take five minutes to write down how they would answer someone who asks 'where do you live?' Compare the responses to the methods listed in Table 5.1. Two simple additions to this exercise are (a) to use a WWW location-finding utility such as in UK the one at www.streetmap.co.uk to perform searches using each and every georeference the system uses (street name, telephone code, OS (x,y), post code, place name, and latitude/longitude), and (b) qualify the question by some imagined location, such as overseas, in your country, and in your locality. The first will demonstrate that the same place can be georeferenced in many ways, whilst the second shows that the one used is frequently context dependent.

2. Visit your local map library, and determine: (1) the projections and datums used by selected maps; and (2) the coordinates of your house in several common georeferencing systems

3. The advent of GPS has revolutionized the geo-location process, but using the system is not without its problems. Even simple, low-cost hand-held units without differential correction can be used by students in projects that collectively will give them a good idea of the technology and its limitations. Most GPS either come with, or have as an optional extra, a cable that connects to either the USB Serial or COMs port of a PC. For some useful shareware to up- and down-load data to and from most easily obtainable GPS see htpp://www.gpsu.com.

    a) Track a location over time.
    b) Log a self-evidently 'straight' line
    c) Develop a database of where places are in your locality.
    d) Visit http://confluence.org to catch up with some very, curious folk who want to visit and photograph every point of intersection of whole number lines of latitude and longitude. Actually, as a record of the landscape at the beginning of the century, there is some purpose to the project
    e) Visit http://www.gpsdrawing.com/gallery/land/oxdon.htm for some real fun. This is for people who have nothing better to do than use various forms of transport and their GPS to trace out on the ground huge drawings of the outlines of familiar objects. One example, chosen semi-randomly, is the outline of the face of an Oxford Don, 'drawn' over a length of over 100km and superimposed on an aerial photograph.
    f) Make your own maps. It's possible to make crude maps, using a hand-held GPS as a rough surveying instrument but, for anything other than a fairly large piece of terrain, the inaccuracies might well be embarrassing.

4. In addition to the examples given in the chapter, there are projections that vary locally in scale (sometimes called magnifying-glass projections because the effect is similar to running a magnifying glass across the mapped area). For a good example see: Fairbairn, D. and Taylor, G. (1995) Developing a variable scale map projection for urban areas. *Computers & Geosciences*, 21(9): 1053-1064.

5. It is also possible to reference on the sphere by recursive subdivision using a shape that nests onto it, so that the spatial location is a list of the subdivisions in which the point resides. In his Quaternary Triangulated Mesh (QTM) system, the American cartographer Geoff Dutton has developed an approach that does just this. It is useful to visit his website to examine the principles involved, which is at http://www.spatial-effects.com. Having visited the site, make a list of the 'pros' and 'cons' of his method.

6. A very good way to introduce the distortion properties of map projections is to use the computer to examine the graticules (grids of parallels and meridians), continental outlines, and, if the software used allows, the Tissot Indicatrix for a variety of projections. A simple 'upside-down' Mercator projection, or moving the central meridian from the Atlantic to somewhere else, radically alters one's perception of the planet. Software to support such an exercise can be found in many GIS.

7. During the preparation of this supplement, one of the team flew from London England round the world by way of Los Angeles (CA), Auckland (New Zealand), Sydney, Perth (Australia) and Singapore. Assuming that on every leg of this journey the aircraft took the shortest route, how far was the journey? This can be done using the usual formula,

$$Distance = R\arccos[\sin \varphi 1 \sin \varphi 2 + \cos \varphi 1 \cos \varphi 2 \cos(\lambda 1 - \lambda 2)]$$

in which φ_1 and φ_2 are the latitudes and λ_1 and λ_2 the longitudes. *R* is an accepted value for the Earth radius such as 6378km. You should get a distance of around 39,507nm, which is, of course, considerably more than the equatorial circumference of the Earth. Many globetrotting travelers keep to the service networks of airline alliances, in order to accrue frequent-traveler benefits. Would our author have been able to travel more nautical miles with members of the Oneworld Alliance (www.oneworld.com, including American Airlines, British Airways and Qantas) or the Star Alliance (www.staralliance.com, including Air New Zealand, Singapore Airlines, and United Airlines), assuming he minimized any distance traveled on non-alliance airlines?

8. Most metric coordinate systems use a Euclidean distance as their basis. Such distances have five key properties:

They are *non-negative.* You cannot have a minus distance.
If they are zero, then the distance from a place to itself is zero
There is one and only one *shortest* distance
They are symmetrical: the distance from A to B is the same as that from B to A.

They obey the so-called *triangle inequality*. This says that if we imagine a triangle with vertices labeled A, B, and C then one side (say AC) will be no longer than the sum of the other two.

Spend a few moments thinking about other 'distances' that might be used instead, and then search your map library and the literature for examples of maps based on other sorts of 'distance' such as cost and time. The book by Anthony Gatrell (1983) Distance and Space: a geographical perspective (Oxford: OUP) is a good place to start. Is it legitimate to call these graphics 'maps'?

9. A debate/seminar. Ask the house to debate the motion that 'Euclidean geometry is not a good candidate for representing geographic information, since it relies on the existence of complete co-ordinate n-tuples' (Egenhofer and Mark, 1995). Arguments in favor of the motion will be found in the original paper on what is called 'Naïve Geography', written for a meeting of the COSIT group by Max Egenhofer and David Mark, published in: A. Frank and W. Kuhn (eds.), *Lecture Notes in Computer Science*, Vol. 988, Springer-Verlag, pp. 1-15. The same paper can be downloaded from http://www.spatial.maine.edu/~max/RC20.html. Arguments against the motion can be found in almost all of the materials in Chapter 4. This exercise is a very good way to introduce students to ideas at the research frontier in GIScience.

10. Chapter 5 is all about georeferencing using placenames, various post codes, linear systems, lat/longitude and then coordinates in some projection. A useful thought exercise is to match these to the equivalents that might be used to locate ourselves in time (a tempo-reference?).

FURTHER READING

Bugayevskiy L M, Snyder J P 1995 *Map Projections: A Reference Manual*. London: Taylor and Francis.
A profusely illustrated catalog.
Burrough P A, Frank A U editors 1996 *Geographic Objects with Indeterminate Boundaries*. London: Taylor and Francis ('dip into' all chapters)
Fotheringham A S, Wong D W S 1991 The modifiable areal unit problem in multivariate statistical analysis. *Environment and Planning A* 23: 1025-1044
Keay J 2001 *Great Arc: The Dramatic Tale of How India was Mapped and Everest was Named*. New York: Harper Collins

Tells the heroic, but bizarre, tale of how William Lambton set out to determine the shape of the Earth. Mapping the sub-continent was a side issue! Reading this alongside Dava Sobell's better known book (q.v.) should be compulsory for all those who habitually use latitude and longitude georeferences!
Kennedy M 1996 *The Global Positioning System and GIS: An Introduction*. Chelsea, Michigan: Ann Arbor Press.
Maling D H 1992 *Coordinate Systems and Map Projections* (2nd edn). Oxford: Pergamon.
This is very much the standard work.
Sobel D 1995 *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time*. New York: Walker.
A surprise best seller that led to several TV dramatizations, and that tells the story of Harrison and his chronometers.
Snyder J P 1997 *Flattening the Earth: Two Thousand Years of Map Projections*. Chicago: University of Chicago Press.
Steede-Terry K 2000 *Integrating GIS and the Global Positioning System*. Redlands, CA: ESRI Press.

RELATED READING

Longley P A, Goodchild M F, Maguire D J, Rhind D W (eds) 2005 Geographical Information Systems: Principles, Techniques, Management and Applications (abridged edition). Hoboken, NJ: Wiley.
30. Spatial referencing and coordinate systems, H Seeger
Maguire D J, Goodchild M F, Rhind D W (eds) 1991 *Geographical Information Systems: Principles and Applications*. Harlow, UK: Longman (text available online at www.wiley.co.uk/gis/volumes.html).
10. Coordinate systems and map projections for GIS, D H Maling, pp. 135-46

ONLINE RESOURCES

ESRI Virtual Campus course, *Turning Data into Information* by Paul Longley, Michael Goodchild, David Maguire, and David Rhind (training.esri.com)

Module 1: Basics of Data and Information, Unit: The nature of geographic data
Section 5.5, Module 1: Basics of Data and Information,
Unit: The nature of geographic data,
Sub-unit: Distance decay and spatial interpolation

NCGIA Core Curriculum in GIScience, 2000 (www.ncgia.ucsb.edu/giscc)

1.3. Position on the earth (012), ed. *Ken Foote*

1.3.1. Coordinate Systems Overview (013), *Peter Dana*

1.3.2. Latitude and Longitude (014), *Anthony Kirvan*

1.3.3. The Shape of the Earth (015), *Peter Dana*

1.3.4. Discrete Georeferencing (016), *David Cowen*

1.3.5. Global Positioning Systems Overview (017), *Peter Dana*

1.4.1. Projections and transformations (019)

1.4.2. Maps as Representations of the World (020), *Judy Olson*

NCGIA Core Curriculum in GIS, 1990 (www.ncgia.ucsb.edu/pubs/core.html)

26. Common coordinate systems

27. Map projections

29. Discrete georeferencing