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For Information that Supplements the Contents of this Unit:

[Links to the following resources have been omitted.]

- Coordinate Systems (Dana/Geographer's Craft) -- Global systems: latitude, longitude, height, UTM; Local systems: public land rectangular surveys, metes and bounds; Miscellaneous systems: postal codes, navigational systems.
- Geodetic Datums (Dana/Geographer's Craft) -- Introduction to geodetic datums; Figure of the earth: geometric models, reference ellipsoids, global coordinate systems, earth surfaces; Geodetic datums.
- Global Positioning Systems (Dana/Geographer's Craft) -- US Department of Defense Satellite Navigation System; US GPS positioning services; GPS satellite signals; GPS data; position and time from GPS; GPS error sources; etc.
- Latitude and Longitude (illustrated)
- Modified UTM Grid Projections -- Article on applications for field and computer generated coordinate systems (McDowell).

F. DETERMINING POSITION

- REFERENCES

- DISCUSSION AND EXAM QUESTIONS

- NOTES

This unit begins the module on coordinate systems. An understanding of this important topic is critical when students begin to build databases from many different sources. If you find it difficult to draw a good diagram illustrating latitude and longitude, any introductory Geography textbook will have at least one figure showing this.

UNIT 26 - GENERAL COORDINATE SYSTEMS

A. INTRODUCTION

- coordinates are used to identify locations on the earth's surface

- are based on measurements of displacement from a given location

- are of two types:
    - plane
    - global

B. PLANE COORDINATE SYSTEMS - CARTESIAN COORDINATES

Determining Coordinates

- Cartesian coordinates are determined as follows: 1. locate an origin 2. set two axes through origin in fixed directions, at right angles to each other
    - by convention these are usually:
    - identified as x and y
    - x is horizontal and y vertical
    - i.e. y is anticlockwise from x
    - x is east, y is north 3. measure linear displacement from the origin in directions defined by the two axes 4. produce an ordered pair - (x,y)

Measuring Distance

- Cartesian coordinates can be used directly to calculate distance between two points

    1. Euclidean (Pythagorean) Distance

    - distance defined in a straight line from point (x1,y1) to point (x2,y2):

    $D2 = (x1 - x2)2 + (y1 - y2)2$

    2. Manhattan Metric

- assumes a rectilinear route paralleling the x and y axes:

  $$D = |x1 - x2| + |y1 - y2|$$

- alternate routes all have the same length
- assumes travel is parallel to the axes
  - if not parallel, error in distance can be as much as 41% (/2 - 1)

3. Distance with Barriers

- in this case, distance is calculated assuming there are barriers to go around
- barriers may be areal (i.e. lake) or linear (river)

- is difficult to solve if there are many barriers and many alternate routes

C. STORING COORDINATES

- since, in a GIS, coordinates must be stored in the computer as numbers, there are two important concepts that need to be considered:
  - integer vs real numbers

  - questions of precision

Integers vs real numbers

- integers are whole numbers, optionally preceded by "-" to indicate negation
  - are discrete since mathematically there is a distance of 1 between consecutive numbers

- real numbers can be expressed as decimal numbers
  - are continuous

- real numbers are often expressed as floating point numbers
  - usually expressed as two sets of digits (a,b)
    - the first set gives the significant digits
    - the second set gives the exponent, which determines the position of the decimal place
    - the number is the product (a x 10b)
- e.g. +1234 +2 would indicate 0.1234 x 102 or 12.34

Computer Precision

- in the computer, the number of digits which can be stored for each value is limited by the hardware

- integers are normally stored using 16 bits of memory
  - can have a range from -32767 to +32767

floating point numbers can use single or double precision
- single and double precision are used to refer to the number of digits that can be stored for a single value
- single precision commonly allocates 32 bits, or 4 bytes, of memory for each value
  - equivalent to 7 significant decimal digits
  - actual numeric ranges vary between computer implementations
  - in QuickBasic the exponent range is -45 to +38
- double precision commonly allocates 64 bits or 8 bytes
  - equivalent to 15 or 16 significant decimal digits and, in QuickBasic, an exponent range from -324 to +308

- questions of precision are important when doing calculations since extra digits produced by division and multiplication operations may exceed the precision capacity of your system

Precision of Cartesian Coordinates

- the number of significant digits required for a specific project when using Cartesian coordinates depends on two measures:
  - size of the study area
  - resolution (accuracy) of measurement

- for example, if the study area is 10 km across and the resolution of measurement is 10 cm
  - this would create a range of values from 0 to 10^5
  - requires 5 significant decimal digits or approximately 15 binary digits

    - can calculate approximate number of binary digits by multiplying number of decimal digits by 3 ($\log_2 10$)

- since the computer system usually offers more resolution than needed by the data
  - data is stored at higher precision than is justified by its accuracy

- GIS designers are reluctant to throw away extra significant digits
  - because designers may not be aware of the resolution of the data that will be used
  - people are reluctant to throw away "data", even if it is spurious

- coordinate systems based on a global scale where the size of the area is 10,000 km and the resolution is 1 mm would need 10 decimal digits or 30 binary digits
  - this will require double precision coordinates, which few GIS systems offer

Propagation of coordinate errors

- for an area the size of the US, it takes about 6 decimal digits to specify locations to the nearest meter
  - e.g. coordinates might be x = 272640, y = 146430
  - these coordinates might be stored using 6 digits of precision

- the distance from this point to a second point at x = 272720, y = 146430 is 80 m

- the accuracy of the coordinates was 1 part in 1,000,000 but the accuracy of the distance is only 1 part in 100

- if distance is also stored as a floating point number with 6 digits of precision, the last 4 digits will be meaningless

- in GIS operations, it is important to keep track of how results, like distances, are affected by database accuracy
    - in this example, distance is much more uncertain, in proportional terms, than the coordinates

D. PLANE COORDINATE SYSTEMS - POLAR COORDINATES

- use distance from origin (r) and angle from fixed direction (q)
    - usually fixed direction is north and angle is measured clockwise from it

- polar coordinates are useful for measuring from some fixed point such as the center of the city or when using data from sources such as ground surveys and radar

- to translate from (r, q) to (x,y)

    $x = r \sin(q)$ $y = r \cos(q)$

    $r = \sqrt{(x2 + y2)}$ $q = \arctan(x/y)$

E. GLOBAL COORDINATES - LATITUDE AND LONGITUDE

Determining Coordinates

- start with a line connecting N and S pole through the point
    - called a meridian

- latitude (j) - measures angle between the point and the equator along the meridian1
    - has range: -900 (S pole) to +900 (N pole)

- longitude (l) - measures the angle on the equatorial plane between the meridian of the point and the central meridian (through Greenwich, England)
    - has range: -1800 (westerly) to +1800 (easterly)

Important Terms

- meridian - line of constant longitude _____ 1This definition of latitude does not hold on an allipsoid. See Robinson et al.

- parallel - line of constant latitude

- great circle - imaginary circle made on the earth's surface by a plane passing through the center of the earth

- small circle - imaginary circle made on the earth's surface by a plane that does not pass through the center of the earth

Measuring distance

- using latitude and longitude, can calculate great circle distance between two points:

  $d = R \arccos(\sin(j1) * \sin(j2) + \cos(j1) * \cos(j2) * \cos(l1-l2))$

  where R is the radius of the earth

- this assumes the earth is a sphere

Question of Precision

- since latitude and longitude are measured in degrees, minutes and seconds
  - have problems storing dms units
  - therefore, often store lat/long as decimals of degrees

- one second of latitude is equal to about 30 m

- how many bits are needed to store global data at one second resolution?
  - on the globe there are 60 x 60 x 360 = 107 seconds of longitude
    - this requires 7 decimal digits or 21 bit precision
    - therefore, with 32 bit precision can get resolution better than 30 m

- since lines of longitude converge at the poles, precision of longitude will increase toward the poles
  - each km on the ground equals more and more seconds of longitude as you approach the poles

F. DETERMINING POSITION

- it is often necessary to establish the location of some point on the earth's surface, i.e. its coordinates

- the most common method is to identify a nearby object, and find a map which shows the object
  - the map must also show the coordinate system, e.g. with a lat/long grid

- in surveying, we measure the distance and direction from some object whose location is known precisely, i.e. a monument, then use coordinate geometry (COGO) to compute the location of the desired point

- GPS (Global Positioning System) is a satellite-based system for determining position (see Unit 7)
  - when all 24 planned satellites have been deployed, it will be possible to determine location anywhere on the earth's surface to high accuracy
  - with the current set of satellites (early 1990) and available receivers it is possible

to determine location in the continental US to within meters and even cm within seconds, and using an instrument weighing a few pounds

REFERENCES

Goodchild, M.F., 1984. "Geocoding and Geosampling," in G.L. Gaile and C.J. Willmott, eds., Spatial Statistics and Models, Reidel Publishing Company, Dordrecht, Holland, pp. 33-53.

Robinson, A.H., R.D. Sale, J.L. Morrison and P.C. Muechrcke, 1984. Elements of Cartography, 5th edition, Wiley, New York. See pages 63-71.

Strahler, A.N. and A.H. Strahler, 1987. Modern Physical Geography, 3rd edition, Wiley, New York. See pages 3-8 for a description of latitude and longitude and various appendices for information on coordinate systems.

The magazine GPS World is a good source of frequent update on the state of GPS technology and its applications.

DISCUSSION AND EXAM QUESTIONS

1. Determine the location of your current residence using a standard topographic map, in:

a. Cartesian coordinates, using the lower left corner of the map as origin and the bottom and left edges as axes

b. polar coordinates, using the lower left corner as origin and the left edge as the reference direction

c. latitude and longitude.

Estimate the accuracy of your results in terms of distance on the ground. How is this affected by the scale of the map? For each of the three sets of coordinates, estimate how many (a) decimal and (b) binary digits would be needed to store your answer. Assume that the range of Cartesian and polar coordinates is defined by the map sheet, but the range of latitude and longitude is defined by the globe.

2. You are designing a database for Los Angeles County to store the boundaries of each land parcel. The required accuracy is 1 m. Assuming that Los Angeles County has dimensions on the order of 100 km by 100 km, estimate how many bits you will need to store each coordinate pair.

3. Discuss the relative advantages of integer and real (floating point) representations of coordinates in spatial databases. When would you choose one and when the other, and why?

4. Describe Cartesian and polar coordinate systems. What advantages do polar coordinates have, and in what types of applications might you expect them to be used?

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