The 3-D Global Spatial Data Model:

Foundation of the Spatial Data Infrastructure

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The purpose of this first chapter is to provide a concise overview of the global spatial data model (GSDM). The reader is not expected to understand everything in this chapter the first time through. But, with the framework of the GSDM in place, it will help each reader understand the appropriate context for spatial data concepts as they are presented in the rest of the book.

7. Remote sensing

G. Errorless spatial data must also be accommodated
H. Primary spatial data are based upon:
    1. Measurements that contain errors
    2. Errorless quantities
I. Derived spatial data are computed from primary spatial data
J. Establishing and preserving the value of spatial data
K. Summary
L. References

This chapter defines spatial data, identifies three fundamental coordinate systems, lists types of spatial data, examines the measurement/observation process by which spatial data are generated, looks at errorless spatial data, makes a distinction between primary and secondary spatial data, and closes by suggesting that efforts to preserve the value of spatial data deserve consideration along with efforts devoted to generating spatial data.

III. Summary of Mathematical Concepts

A. Introduction
B. Conventions
C. Logic
D. Arithmetic
E. Algebra
F. Geometry
G. Solid geometry
H. Trigonometry
I. Spherical trigonometry
J. Calculus
K. Probability & statistics
L. Hypothesis testing
M. Matrix algebra
N. Models
O. Error propagation
P. Error ellipses
Q. Least squares
R. Applications to the GSDM
S. References

This chapter identifies mathematical concepts that are relevant to use of spatial data. Written concisely at a fairly comfortable level, it will be a review for many readers. But, as each reader finds his/her own level, it should become obvious that there are some fairly sophisticated mathematical tools that are available for manipulating spatial data. Those needing more than summary information will be directed to other more extensive texts on the various topics. The applications section summarizes concepts that are critical to successful use of the GSDM.

IV. Geometrical Models for Spatial Data Computations

A. Introduction
B. Conventions
C. Two-Dimensional Cartesian Models
D. Coordinate Geometry
   1. Forward/Inverse
   2. Intersections
   3. Perpendicular offset
   4. Area by coordinates
E. Circular Curves
   1. Definitions
   2. Degree of curve
   3. Elements and equations
   4. Stationing
   5. Metric considerations
   6. Area formed by curves
   7. Area of unit circle
F. Spiral Curves
   1. Spiral geometry
   2. Intersecting a line with a spiral
   3. Computing area adjacent to a spiral
G. Radial Surveying
H. Vertical Curves
I. Three-Dimensional Models for Spatial Data
   1. Volume of rectangular solid
   2. Volume of sphere
   3. Volume of cone
   4. Prismoidal formula
   5. Traditional 3-D models
      a. Local flat-Earth
      b. Spherical Earth
      c. Geodetic ellipsoidal Earth
      d. Map projection and elevation
   6. The 3-D GSDM
J. References

Admittedly, this chapter begins by stating the obvious. But the concepts are organized to provide each reader an overview of spatial data manipulation. There is the math/science coordinate system (counter-clockwise rotation from the x-axis) used as the default standard. Then, when using spatial data, there is the engineering/surveying coordinate system used for land based bearings (azimuths) and distances. The GSDM accommodates both. The underlying rectangular *geocentric ECEF coordinate system uses the math/science system convention, but the local tangent plane (flat earth) coordinate system follows established conventions of clockwise azimuth from north. This chapter also helps bridge the gap between working primarily in 2 dimensions to the more general frame of visualizing and working with 3-D spatial data.*

V. Overview of Geodesy

A. Introduction: Science & art
B. Fields of geodesy
C. Goals of geodesy
D. Historical background
E. Developments during the 19th & 20th centuries
F. Forecast for 21st century
G. References

The purpose of this chapter is to provide an historical perspective of geodesy and to describe its contributions to spatial data concepts. An attempt is also made to view the role of geodesy in a broader context than just that of pure science.

VI. Geometrical Geodesy

A. Introduction
B. Two-dimensional ellipse
C. Three-dimensional ellipsoid
    1. Normal section and radius of curvature
    2. Geometrical mean radius
D. Rotational ellipsoid
    1. Equation of ellipsoid
    2. Geocentric and geodetic coordinates
    3. BK1 Transformation – converts lat/long/height to X/Y/Z
    4. BK2 Transformation – converts X/Y/Z to lat/long/height
        a. Iteration
        b. Once through using Vincenty equations
    5. Meridian arc length
    6. Length of parallel
    7. Surface area of sphere
    8. Ellipsoid surface area
E. Geodetic line
    1. Description
    2. Clairaut’s constant
    3. Geodetic azimuths
        a. Target height correction
        b. Geodesic correction

F. Geodetic position computations – forward & inverse
   1. Puissant forward – BK18
   2. Puissant inverse – BK19
   3. Numerical integration
      a. BK18 Forward
      b. BK19 Inverse
   4. Geodetic position computation using state plane coordinates
   5. GSDM 3-D Geodetic Position Computation
      a. BK18 Forward
      b. BK19 Inverse

G. References

This chapter begins with simple fundamental relationships of the 2-dimensional ellipse as found in the meridian section of the earth. From there it expands into three-dimensional relationships of the ellipse rotated about its minor axis--the ellipsoid. Classical geodetic position computations of forward and inverse are discussed and the topic of surface area is summarized. Newer methods of numerical integration and the GSDM are introduced.

VII. Geodetic Datums

A. Introduction

B. Horizontal Datums
   1. Brief history
   2. North American Datum of 1927
   3. North American Datum of 1983
   4. High Accuracy Reference Networks – HARN
   5. Continuously Operating Reference Stations (CORS)
   6. Datum conversions

C. Vertical Datums
   1. Definitions
   2. Mean Sea Level Datum of 1929
   3. International Great Lakes Datum
   4. North American Vertical Datum of 1988 – NAVD 88

D. 3-D Datums

E. Datum transformations

F. References

When referencing spatial data to existing coordinate systems, it is important for purposes of consistency to make sure all the data are on the same datum and to document which datum is being used. This chapter includes a discussion of datums routinely encountered in the United States and describes how data are moved from one datum to another. Summary details will also be included as to establishing compatibility between datums in other parts of the world. Concepts of a combined 3-dimensional spatial datum will also be presented and intended computational efficiencies will be described in terms of the GSDM.

VIII. Physical Geodesy

A. Introduction
B. Gravity
C. Definitions
   1. Elevation – generic
   2. Equipotential surface
   3. Level surface
   4. Geoid
   5. Geo-potential number
   6. Dynamic height
   7. Orthometric height
   8. Ellipsoid height
   9. Geoid height
D. Gravity and the shape of the geoid
E. Laplace correction
F. Measurements and Computations
   1. Interpolation/Extrapolation
   2. Gravity
   3. Tide readings
   4. Differential levels
   5. Ellipsoid heights
   6. Time
G. Use ellispoid height in place of orthometric heights
H. The need for geoid modeling
I. Geoid modeling and the GSDM
J. Using a geoid model
K. References

High-level material on physical geodesy is left to the scientists. However, the concept of gravity and a description of the measurement environment determined by the local plumb line must be included so spatial data users can understand the difference between elevation and ellipsoid height. The concept is not that difficult, but it is quite specific. On-going research into geoid modeling has provided excellent tools for computing geoid heights, but the limitations and procedures both need to be discussed carefully. This will be an important chapter in the book.

IX. Satellite Geodesy & Global Navigation Satellite Systems (GNSS)

A. Introduction
B. Brief history of satellite positioning
C. Modes of positioning
   1. Elapsed time

2. Doppler shift
3. Interferometry

D. Satellite signals
   1. C/A code
   2. Carrier phase
E. Differencing
   1. Single
   2. Double
   3. Triple
F. RINEX Data
G. Processing GPS data
   1. Spatial data types
   2. Autonomous
   3. Vector
   4. Multiple vectors
   5. Traditional networks
   6. Advanced processing
H. The future of survey control networks
I. References

The advent of GPS is driving widespread use of spatial data. Earlier, understanding and using GPS data was primarily the domain of geodesists and other technical disciplines. However, low cost and ease of use have brought GPS technology into the purview of many spatial data users. This chapter will present the overall concepts of GPS positioning and extend those to a careful description of two very different GPS products, e.g., the precise baseline vector (based upon carrier phase observed differences) and the less precise GPS point position based upon pseudoranging. The chapter ends with a description of results (positions and covariance) obtained from combining GPS vectors into networks.

X. Map Projections

A. Introduction: round Earth - flat map
B. Projection criteria
C. Projection figures
D. Permissible distortion and area covered
E. U.S. state plane coordinate systems (SPSC)
   1. History
   2. Features
   3. NAD27 and NAD83
   4. Sidebar – meter/foot relationship
   5. Current status
      a. Advantages
      b. Disadvantages
F. Procedures

1. Grid Azimuth
2. Grid Distance
3. Traverses

G. Algorithms for traditional map projections
   1. Lambert conic conformal projection
   2. Transverse Mercator projection
   3. Oblique Mercator projection

H. Low distortion projections

I. References

Almost all spatial data users have encountered map projection (in the US, state plane) coordinates. This chapter will present the fundamental concepts of a map projection and describe some of the advantages obtained by using a map projection to "flatten the world." Details will be included so that those needing to can implement and use map projection (state plane) coordinates in defined areas. Focus will be on U.S. state plane coordinate zones, but details for other parts of the world will also be included. The advantages and disadvantages of using the map projection 2-dimensional model will be discussed.

XI. Using Spatial Data

A. Introduction

B. Forces driving change

C. Transition

D. Consequences

E. Spatial data accuracy
   1. Introduction
   2. Definitions
   3. Spatial data components and their accuracy
   4. But everything moves
   5. Observations, measurements and error propagation
   6. Finding the uncertainty of spatial data elements
   7. Using points stored in the X/Y/Z database
   8. Example
   9. Network accuracy and local accuracy

F. References

This chapter provides a summary describing how the form of spatial data has evolved in recent years from analog hardcopy maps to electronic digital data. The chapter will also look at how spatial data are used with consideration given to the preservation of their economic value. Blind acceptance of default models creates problems that have been addressed, in part, using modified map projection models, i.e., surface coordinates. Continued use of a 2-dimensional model for 3-dimensional data is inappropriate for geometrical integrity and computational efficiency. Examples will be given.

XII. Using GSDM

A. Introduction
B. Features
    1. Functional model
    2. Stochastic model
C. Database issues
D. Implementation issues
E. Applications/examples
F. WBK software
G. References

Parts of this chapter will be a summary because the fundamental pieces have all been defined previously. The definition and description of a global spatial data model will show how the various pieces fit together and how the functional model and stochastic model support each other relative to preserving the value of spatial data. Implementation issues will be discussed and several examples presented, but the focus will be on the features of the model. Many persons in various disciplines will use the model as the underlying standard for many other applications that go far beyond the scope of a book devoted to definition of the model.

XIII. Appendices

A. Rotation matrix derivation
B. State plane coordinate zone constants
C. Spreadsheet for computing network and local accuracies