Abstract

Spatial data are 3-dimensional (3-D) and modern measurement systems collect data in a 3-D environment. Computer databases store 3-D digital spatial data. Human perception of spatial relationships is primarily visual and, due to gravity, our natural reference for spatial perception is horizontal (2-D) and vertical (1-D). Various models are used to establish a conceptual connection between the measurements, digital spatial data, and its representation - data visualization. Digital spatial data are also used to make analog products such as maps, charts, and other hardcopy diagrams. The point is, once spatial data are put into digital form, they can be manipulated at the whim of the user. To preserve the integrity and value of spatial data, there should be a common storage format and the data manipulation processes should be well-defined, unique, bi-directional, and three-dimensional. Of course, the challenge is to identify a common format for 3-D data that is at the same time simple, rigorous, and global. The data storage format must also accommodate reliable statistical measures of spatial data accuracy.

The global spatial data model (GSDM) described in this presentation is a collection of concepts and procedures which can be used to collect, organize, store, process, and manipulate 3-D spatial data. The GSDM uses one set of solid geometry equations which are equally applicable around the world. This simple standard preserves global interoperability and each discipline, agency, corporation, or individual spatial data user is free to implement any derivative use or application.

The GSDM includes both a functional model and a stochastic model. The functional model encompasses the geometry of spatial relationships and the stochastic model defines the process for establishing, tracking, and reporting the accuracy of spatial data using existing standard mathematical procedures.

Introduction

An appropriate introduction to the global spatial data model (GSDM) might be to list several challenges facing geo-spatial data users. According to Vice President Al Gore (1998) in a speech titled, The Digital Earth: Understanding our planet in the 21st century,
"the hard part of taking advantage of this flood of geo-spatial information will be making sense of it - turning raw data into understandable information." The following challenges all come under the umbrella of Gore's statement, but are listed separately for purposes of this discussion. Challenges for spatial data users include:

1. Handling vast amounts of 3-D digital spatial data efficiently.
2. Describing spatial data accuracy without ambiguity.
3. Finding the best (appropriate) combination of tools, talents, and resources to accomplish the task at hand.

The third challenge is very open ended and relies heavily on the judgment of the user but the first two challenges are addressed specifically by the GSDM and supported by an underlying BURKORD® database (see www.zianet.com/globalcogo ). The functional model portion of the GSDM includes geometrical equations that permit each user to work with local rectangular (flat earth) coordinate differences while preserving true geometrical integrity on a global scale. The stochastic model portion of the GSDM includes rigorous error propagation procedures that accommodate input of measurement uncertainties and provide output of standard deviations for each 3-D coordinate position and/or other derived quantities. It has been said, "No job is difficult if you have the right tools." The goal of this paper is to examine features of the GSDM with the idea of finding better tools for handling digital spatial data. If the GSDM is an appropriate tool, and if it can be used beneficially by various disciplines, then the larger issue is becoming more familiar with the fundamental concepts, using and building on those concepts, and sharing that knowledge with others. As Al Gore concluded in his speech, "Working together, we can help solve many of the most pressing problems facing our society..."

**Definition of the Global Spatial Data Model (GSDM)**

The GSDM, formally defined by Burkholder (1997), is a collection of existing mathematical concepts and procedures that can be used to manage spatial data both locally and globally. It consists of a functional model that describes the geometrical relationships and a stochastic model that describes the probabilistic characteristics of spatial data. The functional part of the model includes equations of geometrical geodesy and rules of vector algebra (solid geometry) as related to various coordinate systems (see Figure 1, Diagram Showing Relationship of Coordinate Systems). The primary coordinate system used by the GSDM is the earth-centered earth-fixed (ECEF) geocentric X/Y/Z coordinate system as defined by the Department of Defense (DMA 1991). The GSDM is intended to be consistent with the 3-D Geodetic Model described by Leick (1995) with the following exception; the GSDM, being strictly spatial, does not include gravity measurements, but presumes the effect of gravity is accommodated before data are entered into the spatial model.
The BURKORD™ 3-D Diagram

Geocentric Coordinates: X, Y, Z
- True 3-D, Computations follow rules of solid geometry
- Linear adjustment model
- Meter length units

(A) Geocentric Coordinate Differences
\( \Delta X, \Delta Y, \Delta Z \) (Meters)
GPS Results

(B) Geodetic Coordinates
(Degrees, minutes and seconds)

Ellipsoid heights
(length units)

(Approx. geoid hgt.
(3-D integrity lost))

(Accurate Geoid
Heights)

(C) Rotation Matrix

Local Geodetic Horizon Coordinate Differences
\( \Delta e, \Delta n, \Delta u \) (Meters)

(D) P.O.B. Datum Coordinates
(Feet/meters)
- Survey Plats

Mark-to-Mark (total station)
Observations
- slant distance
- azimuths
- zenith directions

2-D

1-D

True 3-D Coordinates

Project Datum Coordinates

(Pseudo 3-D Coordinates)

State Plane
(Map projection)
Coordinates

Orthometric Heights
(levels)

Figure 1 Diagram Showing Relationship of Coordinate Systems
The stochastic model component of the GSDM uses fundamental error propagation concepts as described in Chapter 4 of Mikhail (1976) and Chapter 5 of Wolf/Ghilani (1997). The GSDM stores stochastic information in the variance/covariance matrix associated with each point defined by ECEF coordinates and in the correlation between point-pairs. The local perspective (e/n/u) covariance values and standard deviations need not be stored but are computed upon demand from the geocentric values. The accuracy defined by each point covariance matrix, whether geocentric or local, is called **datum accuracy**. A BURKORD® 3-D database accommodates storage of both the geocentric covariance values for each point and point-pair correlation. As described by Burkholder (1999), that capability supports and allows one to exploit the rigorous mathematical definitions of **local accuracy**, **network accuracy**, and **P.O.B. accuracy** when computing the position of one point with respect to another. Note: In surveying, P.O.B. stands for “Point of Beginning” and is accepted as the local origin for a survey or project.

Figure 2 is a diagram of the GSDM and lists the core concepts surrounded by various disciplines that, to one degree or another, use geographic information systems based upon the National Spatial Data Infrastructure (NSDI) as defined by President Clinton’s Executive Order 12906 (Clinton 1994). The GSDM fully supports the NSDI and is compatible with details of that Executive Order.

**Features of the Global Spatial Data Model (GSDM)**

It is not possible or feasible to describe all the features of the GSDM here, but several of the more prominent features are:

1. The GSDM uses standard existing mathematical equations of solid geometry and vector algebra for defining the location of a point and for manipulating spatial data. Many complicated geometrical geodesy equations, needed when working with the mathematical ellipsoid model, can be avoided. Instead, using a rotation matrix, the GSDM provides an efficient way to view any set of global X/Y/Z points in terms of local "flat earth" coordinate differences. Additionally, no geometrical integrity is lost (due to the model) and traditional coordinate systems (latitude/longitude or map projection) can still be used as or if desired.

2. The GSDM utilizes rigorous error propagation concepts in all three dimensions and provides a standard set of tools that can be used by various disciplines to describe spatial data accuracy with statistical reliability. Metadata are still important but, in many cases, standard deviations are more efficient because they provide a numerical filter for categorizing the accuracy of each point; horizontal, vertical, or both.
Global Spatial Data Model - GSDM
(A Universal 3-D Model for Spatial Data)

The Global Spatial Data Model provides a simple, universal 3-dimensional mathematical foundation for the National Spatial Data Infrastructure (NSDI) which supports Geographic Information System (GIS) database applications in disciplines such as:

3. In particular, the GSDM:
   a. provides a globally unique location tag for each point.
   b. uses one set of equations world-wide. No zone constants are required.
   c. preserves geometrical integrity both locally and globally.
   d. solves the grid/ground distance dilemma.
   e. combines horizontal and vertical into a single 3-D database.
   f. permits each user to know the 3-D positional accuracy of each point.
Model and Perspective

The best model is one that is simultaneously simple and appropriate. Current horizontal and vertical models as used in geodesy and other spatial data applications are really not very simple but, given the traditional use of horizontal and vertical datums, have been used because they are more appropriate than the flat earth model. Burkholder (1998) describes various models used for spatial data, gives background and details of the GSDM, and includes equations for using the GSDM.

With the advent of modern data collection instruments, electronic storage media, and geographic information systems (GIS's) the demand for spatial data has mushroomed. Productivity in map-making skyrocketed because traditional manual processes were computerized and increases in productivity continue by using automated data collectors and faster computers. But the question must be asked, "Are the underlying spatial data models really appropriate?" For the way humans visualize the world, the answer might be "yes." But for automated data collection, electronic processing, and digital storage, the answer is "no." Modern GIS's have evolved from 2-dimensional databases (state plane coordinates) to 2.5-dimensional systems where elevation is an attribute of location to pseudo 3-D systems in which state plane coordinates are used with elevations (called pseudo because elevations are referenced to an irregularly curved surface - the geoid). The next step is to use a truly 3-dimensional model that is both simple and appropriate—the GSDM which accommodates new technology, modern practice, AND permits each user to view the world from any perspective.

Perhaps user perspective is the most novel idea associated with the GSDM. The origin of a local rectangular coordinate system travels with the user and is placed (or moved) at will. The unique three-dimensional location of each point is stored in the database but, given a data set of points (10, 50, 1000 or millions), the user selects any point as the Point of Beginning (POB) and all other points are brought out of the database with respect to the chosen POB. The technology of data visualization is already in place and, using a moveable POB, it is possible to walk or fly through a proposed development using virtual reality. With the GSDM, the difference is that all points in the database represent real world points. And, the added benefit is that the GSDM provides an efficient way to describe the spatial accuracy of each point—in three dimensions.

The GSDM is already defined and in place. Using the GSDM is a matter of deciding to do so. It supports interoperability. It is seamless, simple, and rigorous. And, data quality is defined in terms of standard deviations of each component. The phrase "global spatial data model" is generic and can be freely used. The term "BURKORD" has been trademarked and applies to 1) prototype software written by the author for performing 3-D coordinate geometry and error propagation computations and 2) design of a 3-D database for storing geocentric X/Y/Z coordinates and associated covariances and correlations.
Example Using Points On/Near NMSU Campus

A detailed example is posted at www.zianet.com/globalcogo/example.html, but the BURKORD™ computer printout in Figure 3a and 3b shows:

1. Headings and administrative information.
2. Defining input for 2 A-order stations. Station “Reilly” is on the NMSU campus and “Crucesair” is at the airport.
3. A 3-D geocentric coordinate difference traverse (GPS base line) to two other points.
4. A listing of the 4 points as stored in the database (1 line per point). Note, format is point number, X/Y/Z coordinates, covariance values, and point name/description.
5. An expanded listing for point 1001 showing both geocentric and local corvariance matrices.
6. Computed inverses between stated points which show in sequence:
   A. Standpoint geocentric coordinates, latitude/longitude/height, and local standard deviations.
   B. The computed $\Delta X/\Delta Y/\Delta Z$ components along with their standard deviations.
   C. The computed $\Delta e/\Delta n/\Delta u$ components along with their standard deviations.
   D. The local tangent plane distance and azimuth along with their standard deviations.
   E. Forepoint geocentric coordinates, latitude/longitude/height, and local standard deviations.
7. A listing of local tangent plane coordinate differences with respect to a user-selected P.O.B.

Applications to Current Initiatives

Many persons and organizations are doing impressive things with digital spatial data. Decentralization and the freedom to innovate is fundamental to progress, but the importance of a simple standard underlying spatial data model is the point of this paper. The GSDM is a unifying concept that provides each researcher and user the luxury of complete freedom with respect to how spatial data are used. On the other hand, complete interoperability and compatibility are assured to the extent that users are also willing to define the relationship of their database to the GSDM. In most cases, that is already being done by default if not by specific declaration.

The following list is incomplete, but intended to be somewhat representative of large-scale efforts that could benefit from adopting the GSDM as a matter of policy. It would not restrict the prerogative of any initiative, but it would insure compatibility between disciplines, between agencies, between government and industry, and between users all over the world.

3. XY Project – www.xyproject.org
Figure 3a  Computer Printout Showing 3-D Coordinate Geometry Computations
AN EXPANDED LISTING OF POINT 1001

1001 Reilly HARN "A"

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>E</th>
<th>N</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>1556177.6150</td>
<td>55.929040</td>
<td>-1556177.6150</td>
<td>15.160703</td>
<td>-5169235.3190</td>
<td>1166.5703</td>
</tr>
</tbody>
</table>

LAT (N+S-) 32 16 55.929040 X: -1556177.6150 X .25E-04 Y .25E-04

E .25E-04

EL HGT 1166.5703 M Z: 3387551.7090 Z .00E+00 .25E-04 .25E-04

INVERSE BETWEEN POINTS

1001 Reilly HARN "A"

X = -1556177.6150  LAT (N+S-) 32 16 55.929040 +/- .0050 METERS N

Y = -5169235.3190  LON (E+W-) -106 45 15.160703 +/- .0050 METERS E STANDARD DEVIATIONS

Z = 3387551.7090  EL HGT 1166.5703 M +/- .0050 METERS U

DELTA X/Y/Z WITH SIGMAS -337.8590M +/- .007M 179.1660M +/- .007M 104.9890M +/- .007M

DELTA E/N/U WITH SIGMAS -375.1645M +/- .007M 128.3724M +/- .007M -6.6293M +/- .007M

LOCAL PLANE INV: DIST = 396.5197M +/- .007M N AZI. = 288 53 23.04 +/- 3.7 SEC

1004 Wakeman

X = -1556515.4740  LAT (N+S-) 32 17 09.55057 +/- .0051 METERS N

Y = -5169056.1530  LON (E+W-) -106 45 29.493587 +/- .0051 METERS E STANDARD DEVIATIONS

Z = 3387656.6980  EL HGT 1159.9833 M +/- .0051 METERS U

DELTA X/Y/Z WITH SIGMAS 305.7260M +/- .007M -230.3410M +/- .007M -199.1870M +/- .007M

DELTA E/N/U WITH SIGMAS 359.1568M +/- .007M -239.1158M +/- .007M 5.5524M +/- .007M

LOCAL PLANE INV: DIST = 431.4742M +/- .007M N AZI. = 123 39 16.14 +/- 3.5 SEC

1003 Bromilow

X = -1556209.7480  LAT (N+S-) 32 16 52.334086 +/- .0052 METERS N

Y = -5169286.4940  LON (E+W-) -106 45 15.772679 +/- .0051 METERS E STANDARD DEVIATIONS

Z = 3387457.5110  EL HGT 1165.5203 M +/- .0053 METERS U

LISTING OF POINTS WITH RESPECT TO MASTER P.O.B: 1001 Reilly HARN "A"

(ASSUMING POSITION OF P.O.B. IS ERRORLESS)

<table>
<thead>
<tr>
<th>NUMBER</th>
<th>NORTH SIGMA</th>
<th>EAST SIGMA</th>
<th>UP SIGMA</th>
<th>STATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1002</td>
<td>-27.496</td>
<td>0.005</td>
<td>-15889.221</td>
<td>0.005</td>
</tr>
<tr>
<td>1003</td>
<td>-110.757</td>
<td>0.005</td>
<td>-16.017</td>
<td>0.005</td>
</tr>
<tr>
<td>1004</td>
<td>128.372</td>
<td>0.005</td>
<td>-375.165</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Figure 3b  Computer Printout Showing 3-D Coordinate Geometry Computations
References


