The Digital Revolution Begets The Global Spatial Data Model (GSDM)

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Regardless of when the digital revolution began, profound changes have occurred during the past 50 years in the way spatial data are collected, stored, manipulated, and used. In years past, maps were made using plane table methods and other manual surveying techniques. But, mapping and automation of spatial data collection has progressed enormously since the 1950's and 1960's when photogrammetric mapping techniques greatly simplified design activities for the U.S. interstate highway system. Similarly, the electronic calculator replaced the slide rule in the 1970's and surveyors have been using electronic total stations since the early 1980's. During the past 20 years, the global positioning system (GPS), geographic information systems (GIS's), and the world-wide-web (WWW) have joined the technological onslaught so that now spatial data can be characterized as digital and three-dimensional (3-D). Regretfully, development and implementation of the conceptual models used to handle spatial data have not kept pace. But a comprehensive 3-D global spatial data model (GSDM) has been defined which accommodates new technology, existing practices, and any location on earth or within the birdcage of orbiting GPS satellites. Spatial data users in many disciplines all over the world stand to benefit from adopting and using a comprehensive standard 3-D model.

In 1569 Gerhardus Mercator published his 21-sheet map of the world based upon latitude and longitude spacing that became known as a conformal map projection. The universal transverse Mercator (UTM) projection is still used all over the world and the state plane coordinate system in the United States uses three different conformal projections. But, a map projection is strictly a 2-D model and spatial data are 3-D. Furthermore, the ubiquitous digital computer is now part of everything we do. With advent of the digital revolution, analog maps have given way to electronic digital data bases, GPS provides instantaneous position to novice and expert alike, and remote sensing satellites are capturing images of our planet earth 24 hours a day 7 days a week. In a speech on "The Digital Earth" www.isde5.org/al_gore_speech.htm given by then Vice President Al Gore, at the California Science Center, January 31, 1998, he said, "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 National Spatial Data Infrastructure (NSDI) and associated geographic information systems (www.fgdc.gov/nsdi/nsdi.html) are promoted as being the best way to handle geo-spatial data. The NSDI offers many advantages, (e.g., specificity and standardization) but the NSDI has two serious flaws – 1) without reliable geoid heights, the NSDI is not a true 3-D data base and 2) meta data do an incomplete job of describing spatial data accuracy. The analogy is putting new (digital) wine into old bottles.

The GSDM represents a "new bottle" model that accommodates 3-D digital spatial data, is standard the world over, is compatible with modern measurement systems, provides local tangent plane distance and azimuth between points, permits each user maximum flexibility with regard to the use of spatial data, and offers a reliable numerical filter for discriminating spatial data accuracy. The GSDM is already defined, the technology is already in place, and using the GSDM is essentially a matter of deciding to do so. The challenge is organizing implementation.

Any agency or discipline anywhere in the world that uses spatial data stands to benefit from using the GSDM. Mercator's 2-D projection has served well (and will continue to serve 2-D uses), but the time has come to begin using a modern 3-D model that accommodates new technology and modern practice. The GSDM is defined in an article posted at www.zianet.com/globalcogo/gsdmdefn.pdf. Two other articles that contain the mathematical equations for both the functional model (www.zianet.com/globalcogo/ionpaper.pdf) and the stochastic model (www.zianet.com/globalcogo/accuracy.pdf) are posted as well.

Current spatial data users can begin using the GSDM immediately because it accommodates existing 2-D and 1-D practices in a derivative manner. Once a point is competently defined within the 3-D environment, 2-D and 1-D applications are fully supported. The reverse is not true. It is awkward, if not impossible, to build a true 3-D data base from 2-D and 1-D spatial data that do not share a common origin. Therefore, the effort required to implement spatial data manipulation practices built on the GSDM will not be trivial. But, modern measurement systems already generate 3-D spatial data that can and should be stored in an appropriate 3-D data base.

The GSDM is based on, and is viewed as compatible with, the earth-centered earth-fixed (ECEF) system designed by the U.S. Department of Defense (DoD 1997). Spatial data professionals in scientific disciplines are already using the ECEF system. Hopefully, the spatial data user community will soon come to realize that the same model that accommodates the high-level functional and stochastic requirements of the scientists will simultaneously (and without loss of rigor) support the rectangular "flat earth" simplicity desired by local users. The challenge of making such a change is probably best described by Kuhn (1970) who writes about "the structure of scientific revolutions." Acceptance of such a new paradigm is not viewed as immediate or automatic – see www.zianet.com/globalcogo/figpaper.pdf.

Egenhofer and Golledge's work (1998) grew out of Research Initiative 10 of the U.S. National Center for Geographic Information and Analysis (NCGIA) and "reflects the state of the art in research focusing on spatio-temporal reasoning." It is a collection of articles by 25 different contributors and is an example of research that attempts to gain a better understanding of spatial data. The underlying premises for those articles are more abstract than ideas represented by the GSDM but some of those developments are severely limited by "in the box" assumptions with regard to geodetic datums. For example, in Chapter 2, Worboys (page 32) describes the 0-simplex, the 1-simplex, and the 2-simplex only with respect to a 2-dimensional Euclidean plane. It appears that representation of purely spatial objects is not "connected" to the real 3-D world except by traditional 2-D and 1-D datums and reference frames as described by contributor Smyth (Egenhofer and Colledge, 1998, Chapter 14, p. 202).

Smyth also gives a definition of spatial primitives in terms of n-simplexes (Egenhofer and Colledge, 1998, Chapter 14, p. 202). A 0-simplex is a point, a 1-simplex is a line, a 2-simplex is a triangle and a 3-simplex is a tetrahedron. He goes on to say, "Physical form is modeled by polyhedral approximation based on geometrical simplicial complexes. This representation is complete and consistent for point, linear, surface, and volume features embedded in Euclidean 3-space." This last quote may be true, but close examination of the context reveals a flaw – Euclidean space is not connected to the physical world other than by the above-mentioned datums.

Such abstractions are elegant, but not suitable for a comprehensive integrated 3-D spatial data model because their spatial data primitive is not logically connected to the real world. It appears instead that connections to the physical world are confined to assumptions of traditional horizontal and vertical datums. There is a better way. Burkholder (2001) www.globalcogo.com/ascespatial.pdf offers a concise, specific definition for 3-D spatial data and spatial data types. That definition is compatible with rigorous solid geometry equations that can be used for spatial data manipulation. Additional research is needed to reconcile the GSDM with abstract definitions of the spatial data primitive.

The goal in defining the GSDM was to start with the fundamental ECEF geocentric rectangular system as defined by the DoD and add pieces/measurements/procedures consistent with rules of solid geometry and standard error propagation equations. Consequences of that design process include:

1. The GSDM can be attached to any well-defined 3-D reference frame. Several obvious candidates are the World Geodetic System 1984 (WGS84), the International Terrestrial Reference Frame (ITRF), or the North American Datum of 1983 (NAD83).

2. The 3-D location of each point is defined by ECEF metric X/Y/Z coordinates. That means there is a single origin for 3-D data. Current 2-D and 1-D practice presumes two disparate origins – earth's center of mass and the geoid. In either case, time is included as the fourth dimension.

3. The covariance matrix of each point defines its spatial (datum) accuracy.

4. The respective covariance matrices also define the accuracy of any derived quantity. For example, a point-pair inverse uses the covariance matrix of each point and the correlation matrix between points (if it exists). Local accuracy is obtained by using the full inverse covariance matrix and network accuracy presumes no correlation between points. For more information, see - www.zianet.com/globalcogo/accuracy.pdf.

5. The 1-D elevation or 2-D location of any point can be equivalently described as derived by computation in any reputable defined coordinate system such as geodetic coordinates, state plane coordinates, or UTM coordinates.

6. Ellipsoid heights are numbers that look like elevations (orthometric heights) but differ by the quantity known as geoid height. With improvements in geoid modeling, the absolute elevation of any point can be determined to a comparable level of accuracy. Eventually, elevation should be defined as ellipsoid height - see

www.zianet.com/globalcogo/elevgsdm.pdf.

Although many issues related to the GSDM have been studied, other issues need additional study. For example, vertical results are often stated to be weaker than horizontal results when using GPS. That may be true if one uses only the satellites visible from one side of the earth. Given the bird-cage of orbiting GPS satellites and the fact that signals from the satellites travel to a "solid" earth, it stands to reason that vertical should be the strongest observed component – if data from all satellites are used simultaneously. If an earth-fixed world-wide network is treated as a deformable solid, then collective interpolation of points within the bird-cage should be strongest in the radial (vertical) component. The GSDM provides an appropriate computational environment within which to test that hypothesis. Later, if not sooner, it will be possible to record (or watch on a monitor in real time) the precise movement of a well-monumented point throughout the day. Reliable 3-D statistics for such (earth-tide) movement can be generated simultaneously with the observed/adjusted position.

In addition, even though requiring enormous data storage, the process of generating an orthophoto map has been automated so it is now done quickly and efficiently. Even so, the hypothesis is that the GSDM provides a better method for generating an orthophoto map. Given a collection of 3-D points (shared by all users) defined by their ECEF geocentric coordinates – the process is the same regardless of the number of points in the data base – an orthophoto is generated by plotting the local Δe and Δn of each pixel with respect to any point selected by the user. A different map or adjoining area is plotted by selecting a different P.O.B. (see Burkholder 1993), but plotting points of interest from the same seamless 3-D data base. The challenge, which some say is solved, is documenting the procedures by which reliable X/Y/Z coordinates for each pixel are generated. The stochastic properties of each pixel can be exploited to define the spatial accuracy of any point or feature on the map.

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