The Global Spatial Data Model (GSDM):
Bridge Between Abstract and Real

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Abstract:

Spatial reasoning includes mental activities that involve geometrical elements and modeling involves the process of relating abstract concepts to physical world experience. When referring to spatial data, the collective processes include various levels of cognitive abilities and mathematical concepts. Within that context and equally applicable worldwide, the global spatial data model (GSDM) provides an efficient understandable connection between measurements in the real world, graphical representation of those data, and storage of that information in an electronic database. The GSDM also provides tools for handling various spatial data accuracies – datum accuracy, network accuracy, and local accuracy.

Key words: digital revolution, geometrical geodesy, spatial data, spatial data accuracy, map projections, spatial reasoning, spatial modeling

Introduction:

The digital revolution has impacted many segments of society – not the least of which is use of spatial data. Global positioning system (GPS) positioning has been a driving force for disruptive innovation in the use of 3-D digital geospatial data, but other sensors and positioning technologies also contribute to defining physical locations. A distinction can be made between spatial data (generic) and geospatial data (Earth-referenced). The generic form as used herein is intended to include both "spatial" and "geospatial" although the word "geospatial" is occasionally used for specificity.

A model can be defined as a connection between abstraction and reality. The global spatial data model (GSDM) is a formal arrangement of fundamental mathematical concepts defining the spatial data infrastructure. The spatial data infrastructure, in turn, provides context for various considerations such as:

- Geographic Information System (GIS) Spatial Analysis
- Spatial Modeling & Reasoning
- Geographic Information Visualization
- Integration of Remote Sensing and GIS

Each category above can be the legitimate focus of targeted research and can include a wide range of issues - concrete to abstract. Society stands to benefit from such research to the extent those considerations are not conducted in isolation. This paper describes the GSDM and shows how an integrated spatial data model supports efficient use of 3-D digital spatial data while bridging the gap between abstract and real. The GSDM can be used beneficially in each of the four areas listed above as it accommodates spatial data in many disciplines worldwide. The focus in this paper is spatial modeling and reasoning.

Background:

A web search on "spatial reasoning" yields a list of links leading to many sources of information. Some of those links are more related to "learning" as related to one's ability to understand and use geometrical relationships. And, learning occurs at many levels throughout life. In the big picture, Brown, Roediger, and McDaniel [1] note that "spatial intelligence" is only one of the following eight kinds of intelligence; (1) logical-mathematical, (2) spatial, (3) linguistic, (4) kinesthetic, (5) musical, (6) interpersonal, (7) intrapersonal, and (8) naturalistic intelligence. It would be a mistake to focus on one category to the exclusion of others, so the reader is reminded again that the focus of this paper, while recognizing vast opportunities otherwise, is intended to serve those activities (surveying, mapping, engineering, navigation, remote sensing, and spatial data management) prefaced on using the spatial data infrastructure. With that said, the difference between spatial and geospatial could be important – especially when addressing issues of local accuracy. Context is often a good discriminator.

It is not intended to disparage previous research such as that reported by Egenhofer and Golledge [2] but rather to recognize that those and similar advancements must accommodate both abstract entities (points, lines, shapes, etc.) and their representations in the physical world. The GSDM provides a bridge whereby “big picture” abstract concepts can be seamlessly integrated with, in the extreme, simple flat-Earth applications without sacrificing mathematical rigor or geometrical integrity.

The Model:

The GSDM includes two primary components - a functional model of geometry which defines location and a stochastic model which handles spatial data accuracy. All GSDM equations for both the functional model and the stochastic model are in the public domain however the format of the cloud-compatible database for efficient storage of spatial data and its accuracy is trademarked as a BURKORD^{TM} file.

When speaking of spatial data models, traditional options include:

1. Time that can be included with each of the following as an added temporal dimension.
2. A flat-Earth model in which either 2-D or 3-D rectangular coordinates define location.
3. A curved-Earth geography model that considers the Earth to be a sphere.
4. The rigorous 3-D geodesy model that includes near-space and the flattened-Earth worldwide.
5. A 2-D map projection model that portrays a given portion of the Earth on a flat map.
6. Elevations for the “height” dimension referenced to the geoid (approximately mean sea level).

The 3-D GSDM is built on the assumption of a single origin (Earth’s center of mass) for spatial data and provides a unique location for any point on or near the Earth in terms of Earth-centered Earth-fixed (ECEF) rectangular X/Y/Z geocentric coordinates as defined by the U.S. Department of Defense and utilized by the international scientific community in the realizations of various defined datums (e.g., NAD 83, WGS 84, ITRF, or other). A Helmert transformation can be used to move X/Y/Z values from one datum to another but the GSDM applies specifically to spatial data relationships one datum at a time. As such, the GSDM:

1. Uses rules of solid geometry to perform computations in 3-D space.
2. Permits the user to select any point from which to “view” the world or point cloud.
3. Provides undistorted distances (slope, horizontal, etc.) and true azimuths point to point.
4. Includes simple geometrical equations worldwide: no map projections, zones, or scale factors.
5. Supports simple local rectangular computations within the tolerance of curved-Earth limitations.
6. Plots an orthophoto map, referenced to a point-of-beginning (P.O.B.), of image pixels from a point cloud.
7. Obviates the need for geoid modeling when ellipsoid heights are used for the third dimension.

The following articles by Burkholder document various aspects of the GSDM.

1. Definition and description of the GSDM (1997): www.globalcogo.com/gsdmdefn.pdf
2. Definition of spatial data accuracy (1999): www.globalcogo.com/accuracy.pdf
3. Elevations and the GSDM (2002): www.globalcogo.com/elevgsdm.pdf
4. EOS article on characteristics of GSDM (2003): www.globalcogo.com/gsdm-eos.pdf
5. Abstract context for 3-D digital spatial data (2004): www.globalcogo.com/setepaper.pdf
6. Opportunity for surveying profession (2011): www.globalcogo.com/WestFed.pdf
7. Civil engineering education and practice (2012): www.globalcogo.com/ASCE3D2012.pdf
8. Discussion of network/local accuracy (2013): www.globalcogo.com/StdDevLocalNetwork.pdf
9. Underground mapping with the GSDM (2014): www.globalcogo.com/underground-mapping.pdf
10. BIG DATA and the GSDM (2014): www.globalcogo.com/BIGDATA.html
11. Impact of disruptive innovation (2015): www.globalcogo.com/DisruptiveInnovation.pdf
12. COGO Report Card and the GSDM (2015): www.globalcogo.com/COGO-report.pdf
13. AGU overview of migration to using 3-D model (2016): www.globalcogo.com/poster.pdf
14. Example of local accuracy on NGS baseline (2017): www.globalcogo.com/EFB-SaGES-ALTA-NSPS.pdf

The GSDM is also described in detail by Burkholder [3]. The 2nd Edition [4] includes additional information on policy issues, network and local accuracies, linear least squares adjustments, and a dozen application examples.

Potential Applications:

On March 18, 2014, the National Oceanic and Atmospheric Administration (NOAA) posted a Request for Information (RFI) in EOS Vol. 95, No. 11 asking for advice to make it easier to use many data collected by the agency. The RFI (see link #5 above) includes the following statement of intent:

> *"to determine whether capability and interest exists for establishing partnerships with NOAA for the purpose of intelligently positioning NOAA's vast data holdings in the cloud, to be co-located with easy and affordable access to computing, storage, and advanced analytical capabilities."*

Link #10 also includes the response from Global COGO, Inc. suggesting that the best thing NOAA could do to enhance the commercial value of those holdings would be to adopt a single standard global spatial data model for those data. The benefits of that vision are still to be realized.

The American Society of Civil Engineers (ASCE) publishes a Report Card for America's infrastructure every 4 years. The 16 infrastructure categories include, among others, bridges, rail, and drinking water. But, the ASCE Report Card does not include the spatial data infrastructure. The Coalition of Geospatial Organizations (COGO) is "a coalition of 13 national professional societies, trade associations, and membership organizations in the geospatial field, representing more than 170,000 individual producers and users of geospatial data and technology." A unique feature of COGO is that no policy is promulgated without unanimous support of all organizations. In February 2015 COGO published a "Report Card on the U.S. National Spatial Data Infrastructure" which is available at:

http://cogo.pro/uploads/COGO-Report_Card_on_NSDI.pdf

The National Spatial Data Infrastructure (NSDI) is another example of a comprehensive program that stands to enjoy enormous benefit from adopting and using the GSDM – see item #12 above.

Two other areas in which the GSDM could provide significant "common model" benefits include:

1. Flying drones (airborne).
2. Intelligent driverless (land-based) vehicles.

Whether airborne or land-based, common challenges, which can be solved in part using the GSDM, include:

1. Using GPS or other positioning technology, the location of the moving receiver needs to be determined very quickly in real time. A separate challenge is to know the spatial data accuracy of the "instantaneous" position.
2. Terrain features in the database need to be known on the same datum. Furthermore, the quality (accuracy) of the database positions is also very important in supporting quality operations. Using both the instantaneous observed location and the database position, the accuracy of the "closing distance" can be determined efficiently in terms of the GSDM.
3. Or, in some cases, both receiver and target are mobile. The relative position between them is critical.
4. Two kinds of accuracy – network accuracy and local accuracy – are encountered in such operations. Network accuracy is with respect to the underlying network while local accuracy gives the relative positional accuracy between local endpoints. The GSDM supports both accuracies depending on how the covariance matrix of the inverse distance is implemented.

Challenges Addressed by the GSDM:

1. Distances are computed from solid geometry equations (e.g., equation by Pythagoras).
2. A linear adjustment can be used in the GSDM to avoid time-consuming iterations.
3. The GSDM provides accuracy of a position with respect to the datum.

(Datum accuracy is used in navigating to a general area.)

4. The accuracy of a computed distance with respect to the network (common datum values at both ends). (Network accuracy is obtained for the distance computed between uncorrelated points.)
5. Accuracy of an observed (computed) position with respect to another "nearby" point. (Local accuracy is critical when avoiding vehicle collusions or landing on a porch to deliver a package.)

Many of the GSDM features and challenges are described in the EOS article - #3 on list above [5].

1. Geoid modeling is not needed if ellipsoid height is used for third dimension.
2. Time, and polar motion are used analogies to geoid modeling.
3. Monitoring real-time movement of the Earth's crust – Earth tides are already being monitored.
4. Definition of n-simplexes need to be connected to "real world." That is what the GSDM does.
5. An orthophoto map can be plotted from local components of each image pixel with respect to the P.O.B.
6. The radial component (third dimension) of a GPS position could be stronger than a horizontal distance.
7. Storage logistics and costs are becoming less of an obstacle.

Conclusions:

1. The GSDM is an umbrella concept/model. Existing models can be used subordinate to the GSDM.
2. The value of abstraction is enhanced to the extent it leads to specific knowledge and application.
3. None of the geometry used in the GSDM is new but performing computations in 3-D space is a new way of approaching many problems.
4. Spatial data standards and specifications need to be updated in light of using the GSDM.
5. Spatial data accuracy (datum, network, and local) is critical in many applications.
6. Algorithms for linear adjustments enhance computational efficiency – especially in real-time constraints.
7. The difference between spatial and geospatial data must be acknowledged and accommodated.
8. Learning and education need to be incorporated into development of professional capability.

References:

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[2] Egenhofer, M. J. and R. G. Golledge, Ed., (1998) *Spatial and temporal reasoning in geographic information systems,* Oxford University Press, New York & Oxford.

[3] E.F. Burkholder, (2008) *The 3-D global spatial data model: Foundation of the spatial infrastructure*, CRC Press – Taylor & Francis Group; Boca Raton, London, New York.

[4] E.F. Burkholder, (2018) *The 3-D global spatial data model: Principles & applications*, 2nd Ed., CRC Press – Taylor & Francis Group; Boca Raton, London, New York.

[5] E.F. Burkholder, (2003) "The Digital Revolution Begets the Global Spatial Data Model (GSDM)," *EOS* Transactions, American Geophysical Union, Vol. 84, No. 15.