The 3-D Global Spatial Data Model (GSDM) Supports Modern Civil Engineering Practice and Education

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Earl F. Burkholder, PS, PE, F.ASCE[1]

[1]Global COGO, Inc., P.O. Box 3162, Las Cruces, NM 88003, PH (575) 532-6185, url: http://www.globalcogo.com, email: eburk@globalcogo.com

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ABSTRACT

This paper discusses concepts and procedures that civil engineers use to handle both generic 3-D spatial data and geospatial data referenced to the Earth. A consequence of the digital revolution is that spatial data are now characterized as digital and 3-D. The principles used by Gerard Mercator (1512-1594) in conformal mapping and René Descartes (1596-1650) in solid geometry are brought forward in the context of information management as envisioned in the 1955 Grinter Report and more recently realized in geographic information systems (GISs) and 3-D applications such as GPS, laser scanning, and LIDAR. The 3-D global spatial data model (GSDM) provides a computational environment that preserves 3-D geometrical integrity, is standard world-wide, supports existing "flat-Earth" applications, and serves as a foundation for the global spatial data infrastructure (GSDI). While spatial data computations are standard in civil engineering practice, the concepts related to geospatial data should also be included in civil engineering practice, education, and curriculum design.

INTRODUCTION

Generic spatial data are described by rules of solid geometry. Spatial data referenced to the Earth are called geospatial data. The terms "spatial" and "geospatial" are often used interchangeably and many rely on context to discriminate between the two. While the rules of solid geometry are applicable to both categories, this paper describes using the global spatial data model (GSDM) as a way to handle 3-D digital geospatial data in addition to spatial data. A paper on geometry and spatial data relationships may fail to gain traction because the rules of solid geometry are well-proven and have remained unchanged for generations. Engineers learn coordinate geometry (COGO) computations, use COGO in many applications, and many take COGO for granted. But, there is more. This paper updates spatial data concepts as related to the use of 3-D digital geospatial data in civil engineering applications. In years past, a civil engineering educational program typically contained 3 or 4 surveying courses with focus on various concepts ranging from simple flat-Earth computations based on plane Euclidian geometry to higher level surveying courses on route surveying, control surveying, municipal surveying, photogrammetry, and maybe even geodetic surveying. Cross disciplinary courses such as cartography, map projections, and/or geography were typically included as electives or found only in a graduate program. Courses devoted to land (boundary) surveying were either missing or offered only as an elective. It has been felt by many that land surveying concepts and practice could be learned on the job as an apprentice. Although eloquently argued otherwise over the years, even today, a college degree is not required to be eligible for licensure as a surveyor in 39 states (Thompson 2011).

With publication of the Grinter Report (ASEE, 1955), the focus for many civil engineering programs began to shift to a greater emphasis on engineering sciences including mechanics of solids, fluid mechanics, thermodynamics, transfer and rate mechanisms, electrical theory, and nature and properties of materials. Surveying came to be viewed as a "hands-on" topic and, over the past 50 years, has been dropped from many civil engineering programs. To pick up the slack, leaders in the surveying profession (Gibson 2009) pushed for establishment of separate surveying programs to serve the broad spectrum of surveying activities and practice. There have been many successes over the years and there are currently more than 25 reputable ABET accredited surveying programs in the U.S.A. (Burkholder, 2011). To its credit, the surveying profession has grown to embrace much more than just land surveying and the term Geomatics is being used to represent a broader discipline. But, with regard to surveying engineering, two unfortunate trends have also occurred; 1) surveying has ceased to be part of many civil engineering programs and 2) the engineering component of most surveying engineering programs has taken a back seat to other topics. Very few EAC accredited surveying engineering programs prepare graduates to take and pass the NCEES Fundamentals of Engineering exam.

A single surveying (Geomatics) course can be a valuable component of a CE program if it reinforces engineering concepts such as measurements, coordinate systems, spatial data models, error analysis, and non-trivial computations. But, it is difficult to cover all of those topics adequately in one course. Two conflicting views are that a single Geomatics course should be included early in the CE curriculum to help the student gain a broader perspective of fundamental engineering concepts. An alternate view is that a single Geomatics course should come much later in a baccalaureate CE program and, building on student maturity in engineering sciences, include higher-level computational concepts such as spatial data modeling, coordinate systems, network adjustment, error propagation, and functional analysis. The ideal scenario would be to include at least two separate Geomatics courses in all CE programs. But, recognizing the pressure to reduce total credit hours for a BS degree, if offering two or more courses is not a possibility, the first choice should be to offer at least one higher-level Geomatics course in each CE undergraduate program.

With regard to the use of geospatial data, the impact of the analog/digital transition described herein needs to be incorporated in both civil engineering practice and in civil engineering education. Specific recommendations are: 1) ASCE should become pro-active by including modern spatial data concepts in continuing education efforts. 2) ASCE should promote inclusion of high-level spatial data concepts in all civil engineering programs, and 3) ASCE should lobby for enhanced EAC surveying engineering criteria in the ABET accreditation process. Consideration, adoption, and use of the GSDM can enhance the success of all three recommendations.

BACKGROUND

Surveying has been around ever since ancient Egyptian “rope stretchers” re-established boundaries following annual floods of the Nile River. Others describe development of surveying as beginning with Euclidian geometry or activities of the Roman Empire engineers. This discussion begins with the works of Gerard Mercator (1512-1594) because Mercator developed what is now known as a conformal map projection. In addition to being able to represent the curved Earth on a flat map, the unique feature of a conformal map is that angles on the spherical Earth are projected without distortion onto a flat map. The beneficial consequence in Mercator’s day was that navigators could plot a course on a Mercator map from one port to another as a straight line and sail a constant bearing to travel port to port (Crane, 2002). Note – even though a straight line on the map was not the shortest possible route, the Mercator map greatly simplified navigation. Mercator projections are still used extensively in the Universal Transverse Mercator (UTM) projections and for numerous state plane coordinate zones in the United States. Mercator projections are also used by various GPS vendors as the basis for “localization” when using GPS derived coordinates on local sites. Being familiar the advantages and limitations of a map projection and associated plane coordinates can be very important for many civil engineers – especially those who work with GPS, LIDAR, or machine control.

René Descartes (1596 – 1650) was a noted philosopher and mathematician. As a philosopher, Descartes is best known for the quote “I think, therefore I am.” However, Descartes (who gave us the rectangular Cartesian coordinate system) also made huge contributions in mathematics by systematically organizing geometry concepts and publishing his “Discourse on the Method of Reasoning Well and Seeking Truth in the Sciences” in 1637 (Aczel, 2005). Even today, rules of solid geometry, analytical geometry, and calculus are routinely studied and used within the context of Cartesian coordinates. There is little to get excited about in engineering so long as the use of 3-D rectangular Cartesian coordinates is limited to assumptions of a flat-Earth (spatial data). But, as everyone knows, the Earth is not flat and, over the past 400 years, methods of triangulation and geodetic surveying have been employed to perform rigorous latitude/longitude computations. Geospatial data (geodetic) computations are conducted at a higher level of complexity and geospatial data considerations now include issues of ellipsoids, map projections, datums, coordinate systems, geoid modeling, and spatial data accuracy.

DIGITAL REVOLUTION

The digital revolution of the past 50 years has had an enormous impact on many facets of life – one being the collection, manipulation, and use of 3-D spatial data. In years past, survey measurements were recorded in field books, computations were performed by hand (often using logarithms), drawings were created on a drafting board, and original maps were stored in flat files for use and re-use. The analog map was both the end product of the survey and the storage medium for the information. All that changed with the advent of the digital computer, the invention of electronic measuring devices (EDM), refinement of photogrammetric mapping processes, organization of spatial data in geographic information systems (GISs), the arrival of GPS positioning, and integration of sensors/microprocessors into elaborate 3-D measurement, imaging, processing, and data storage systems. Laser scanning, LiDAR, machine control, point clouds, Google Earth, and 4G networks are currently riding the technology wave. In all cases, spatial data are characterized as digital and 3-D and stored in electronic files. The current challenge is realizing geometrical consistency in the manner in which 3-D spatial data also include geospatial data and are used in various disciplines all over the world. The 3-D global spatial data model (GSDM) described by Burkholder (2008) is built on geometric/mathematical fundamentals, supports existing horizontal/vertical applications, accommodates modern 3-D digital measurements, and offers significant benefits for standardization and interoperability for the global community of spatial data users. The difference between spatial data and geospatial data can become significant in practice. But, given an appropriate tie between them, the GSDM accommodate can both.

TRANSITION – ANALOG TO DIGITAL

The transition of practice from analog to digital with regard to use of spatial data has not been instantaneous or without glitches. It has taken time to evolve from using journals and field books to using recorders and electronic data collectors. Once analog maps were meticulously drafted by hand or compiled on a photogrammetric plotter and printed to exacting specifications on large printing presses. The importance of high-quality maps is not to be discounted and a collection of maps can be a valuable investment. On the other hand, maps are now generated on a computer screen from a file of digital data. A disposable map is used and discarded. Or if hard-copy is needed, a map can be run off on a color printer by the user.

Mapping procedures have been automated over the years. Efficiency and productivity have both soared accordingly. During the transition, existing maps have been scanned and/or digitized so that analog data previously stored on a map can be shared in digital format. Although costly by some measures, the benefits of such conversion justified the expense. **Impressive as the analog-digital transition for spatial data has been, a final significant step involves the adoption and use of an integrated 3-D spatial data model.** Traditionally, horizontal and vertical data have been modeled separately – even so far as maintaining separate horizontal and vertical datums – a practice which fails to exploit fully the wealth of data available. As stated in the Foreword (Burkholder 2008), “In a sense, the spatial data user community continues to put new (digital) wine into old bottles. The global spatial data model (GSDM) is a new bottle model that preserves the integrity of 3-D spatial data while providing additional benefits. . .” A recent paper by Burkholder (2012) describes the development of spatial data models and compares the features of a low distortion projection (LDP) with those of the GSDM.

LESSON FROM THE GRINTER REPORT

Published over 50 years ago, some of the issues discussed in the 1955 Grinter Report are dated but the big-picture view of educational concepts emerging from the report remains relevant and can help avoid “re-inventing the wheel” when looking for the best way forward with regard to meeting the current challenges of adapting to the digital spatial data world. Gibson (2009) correctly notes that the Grinter Report recommends that “engineering education should leave the hands-on practical approach and adopt the highly mathematical and scientific approach.” Gibson also notes that surveying was considered “hands-on and practical” and identified for elimination in a 1959 meeting of CE Department Chairs. As noted in the Introduction of this paper, the surveying profession has matured considerably over the past 50 years as a separate distinct profession and makes huge contributions to society. Without detracting from the value of existing surveying programs, the fact remains that civil engineers also need and use spatial data concepts in the conduct of civil engineering practice. There is a lot of overlap in the use of spatial data and everyone should understand that the practice of surveying and engineering are not mutually exclusive. An important point in this paper is that while the Grinter Report fails to anticipate the impact of the digital revolution, it does accommodate current justification for including spatial data modeling and concepts in civil engineering education.

In summary, among others, the Grinter Report (ASEE, 1955) emphasizes that:

- Engineering education should focus heavily on science and math.
- New areas of knowledge (i.e. characteristics and use of digital spatial data) should be included.
- Information theory (spatial data management) is an area showing significant promise.
- Developing frontiers based on new concepts (GPS) give increased vitality to older fields.
- Measurements and their analysis are essential elements of the laboratory experience.
- Mathematical proficiency is a must and learning to learn is paramount.

It seems, given the pervasive role of spatial data in most civil engineering applications and the benefits associated with efficient use of digital spatial data, that effort and attention devoted to exploiting the fundamental characteristics of digital spatial data has the potential of paying enormous dividends to the civil engineering profession.

Differences between spatial data and geospatial data were discussed earlier. But, there is more. Many design activities involve use of local spatial data in which 3-D flat-Earth computations competently accommodate sound engineering principles and the thought processes of the design engineer. In that case, it can be argued that a bigger picture of 3-D geospatial data concepts is not necessary. On the other hand, a Geomatics engineer has the responsibility of insuring competent use of 3-D spatial data in a broader context that includes geo-referenced (geospatial) data – whether those data are related to a GIS, a project tied to state plane coordinates, or any project containing elevation data. A broad statement is that geospatial data are those referenced by a well-defined global coordinate system while spatial data are taken to be coordinate differences within the same system. Viewed that way, the use of spatial data is subordinate to the larger context of geospatial data. The reverse argument could also be made to insist that, with respect to rules of solid geometry, geospatial data are a subcategory of spatial data. In either case, an extension of the concepts described in the Grinter Report supports the argument for at least one or two Geomatics courses in every civil engineering BS program.

3-D GLOBAL SPATIAL DATA MODEL (GSDM) IS A SOLUTION

"The global spatial data model (GSDM) is an arrangement of time-honored solid geometry equations and proven mathematical procedures. In that respect, it contains nothing new. But, the GSDM is built on the assumption of a single origin for three-dimensional (3-D) geospatial data and formally defines procedures for handling spatial data that are consistent with digital technology and modern practice. In that respect, the GSDM is a new model (Foreword, Burkholder 2008)." Stated differently, the GSDM provides a well-defined connection between applications of spatial data and geospatial data. The GSDM can preserve the 3-D geometrical integrity of any/all 3-D computations on a global scale while simultaneously accommodating simple 3-D flat-Earth computations.

Details of concepts, algorithms, and computational procedures associated with use of the GSDM are in the public domain and readily available by reference. Relevant sources include:

- During early stages of formulating the concepts, the author had an opportunity to make a presentation to the "First Congress on Computing in Civil Engineering" June 20-24, 1994 in Washington, D.C. (Burkholder 1994).

- A formal definition of the GSDM is given by Burkholder (1997) and is available on the Global COGO web site.

- More recently, the author was privileged to make a presentation to the ASCE Texas Section Meeting in October, 2010, in El Paso on Spatial Data Considerations for Civil Engineers (Burkholder 2010).

- A more comprehensive source is a book by the author, "The 3-D Global Spatial Data Model: Foundation of the Spatial Data Infrastructure" published in 2008 by CRC Press (Burkholder 2008).

- A more philosophical big picture challenge was written for spatial data users worldwide and is posted on the Global COGO, Inc. web site (Burkholder 2007)

- Spatial data users use map projections extensively. However, instead of projecting features to a flat map, the GSDM provides a "user view" of any/all data (point or cloud) from an origin selected by the user. This game changing concept is described in an article "Contrasting a Low Distortion Projection (LDP) with the Global Spatial Data Model (GSDM)" posted on the Global COGO web site (Burkholder, 2012).

CONCLUSIONS

We (society and our professions) are where we are because of where we came from. No apologies are needed for that. With regard to use of spatial data, many disciplines and professionals have become accustomed to long-standing practices of conceptually separating horizontal and vertical concepts in the way spatial data are used. That is our real world experience. So long as simple flat-Earth assumptions remain valid, those spatial data practices remain legitimate. However, with advent of the digital revolution and modern measurement systems, spatial data are now characterized as digital and 3-D. When attached to a global reference system, such 3-D data are best called geospatial data. Much of the existing software used in civil engineering practice still treats horizontal and vertical data separately – even in terms of geospatial considerations. The purpose of this paper is to present a forward looking view and to advocate transition to an integrated 3-D spatial data model which provides a "user view" of the world (whether the data are point data or cloud data). That model is built on the assumption of a single origin for 3-D data and accommodates real-world modeling and visualization much better than do existing models. It all has to do with computing.

In order to stay abreast of these technological innovations, ASCE should:

1. Develop and sponsor workshops/seminars/webinars on 3-D computing.

2. Promote the idea of including high-level spatial data concepts in all BS civil engineering programs.

3. Lobby for enhanced EAC surveying engineering criteria in the ABET accreditation process.

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