Conceptual Development of True 3-D Vis-à-vis Pseudo 3-D

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Assertion/abstract: Adoption of a standard model for spatial data will provide many benefits.

Abstraction is a concept wherein general rules and concepts are derived from the usage and classification of specific examples, literal signifiers, first principles, or other methods. "An abstraction" is the outcome of this process – Wikipedia.

The digital revolution facilitates convergence of abstraction/technology/policy/practice. Of many areas possible, the use of spatial/geospatial data (location) is considered. In promoting use of "a 3-D model for 3-D data," abstraction in this article is prefaced on input from spatial data users as documented in Appendices A and B of Burkholder's 1980 graduate thesis[1], input from surveying professionals and state DOTs as listed in the Appendices of a 1991 technical paper,[2] applying first principles of logic and geometry to manipulation of spatial/geospatial data, and personal experience/practice.

Impacts of the digital revolution are felt in many facets of modern civilization – two of many possible examples include the telecommunications industry (AT&T)[3] and imaging (Kodak)[4]. Another significant area involves the analog/digital transition as related to spatial/geospatial data (Google Earth)[5]. Sensors have been miniaturized and deployed everywhere from space to human blood vessels. If not for increasing storage capacity for digital data, the sheer volume of location data thus collected could be overwhelming. The challenge for users is to extract relevant information from the measurements and to use those data for beneficial purposes. Spatial data management is facilitated by the underlying geometry of the context in which they were collected. As it turns out, two categories of uses include flat-Earth **(true 3-D)** computations and computations that use map projections to accommodate Earth's curvature **(pseudo 3-D)**. Both camps have a legitimate history, and users in each camp often prefer to avoid the "disruptive innovations" associated with modernization. The 3-D global spatial data model (GSDM) accommodates both camps and is viewed as a candidate for worldwide standardization. At the very least, the 3-D "elephant-in-the-room"[6] should be discussed, and policies/practices clarified for all users. Admittedly, transition from pseudo 3-D to true 3-D will take time and resources, but the benefits of standardization will eventually justify the effort.

I. Introduction

This article chronicles development of "true 3-D" vis-à-vis "pseudo 3-D" concepts with the goal of establishing the global spatial data model (GSDM)[7] as legitimate intellectual property (IP). The geometry and all equations used in the GSDM are in the public domain but the arrangement of existing geometrical elements and the collection of mathematical processes into an identifiable spatial data model qualifies the GSDM for IP recognition.

It has been argued that an assembly of off-the-shelf components does not necessarily deserve patent protection. Robert Kearns,[8] inventor of the intermittent windshield wiper, successfully countered that argument in his lawsuit against the Ford Motor Company. Kearns' position was subsequently supported all the way to the U.S. Supreme Court. The movie, "Flash of Genius," is a documentary of Kearns' lengthy legal battle to have his invention recognized.

The digital revolution, currently manifest in the race to implement artificial intelligence (AI), has driven convergence of abstraction/technology/policy/practice in many disciplines – including use of spatial/geospatial data. Geospatial data are defined mathematically, are used to describe location anywhere in the world, and – if you will – constitute a worldwide geometrical sandbox shared by everyone. While technology/practice continues to advance, the GSDM is stable.

Modern spatial data measurements collected in a 3-D environment are manipulated efficiently using rules of solid geometry – true 3-D. Traditional local practice references spatial data to separate horizontal and vertical datums. The problem is, those datums have disparate origins, meaning geoid modeling is needed to convert ellipsoid heights to elevations. The resulting latitude, longitude, and elevation coordinates are called pseudo 3-D. Several problems can be avoided if a true 3-D datum is used in place of traditional horizontal and vertical datums – geoid modeling is rarely needed, and computations (including AI) can be performed in a mathematically consistent true 3-D environment. The GSDM includes the geometrical environment and the equations needed for both pseudo 3-D and true 3-D. As illustrated by the Timeline shown in Appendix A, the GSDM contributes to evolving practice and modern spatial data applications.

The GSDM also includes a stochastic model for handling spatial data accuracy.[7,9,10] Using standard error propagation procedures, the uncertainty of the observations and/or measurements is used to determine covariance matrices of stored coordinate values. Although error propagation procedures are unambiguous, the ultimate value of any computed standard deviation depends on the user knowing and understanding, "accuracy with respect to what?" With integrity of the input data established, the GSDM can provide reliable answers for datum accuracy, network accuracy, and local accuracy. These accuracies are particularly useful when applied to targeting (military), robotics/drones/mapping, and collision avoidance (airplanes or staying in your lane).

II. Setting the Stage

A. Definition of the Earth-centered Earth-fixed (ECEF) system was formalized by the U.S. Department of Defense and carried forward in publication of the World Geodetic System 1984 (WGS 84).[11] The WGS84 name is constant but updates to the WGS84 have been promulgated by the National Geospatial-Intelligence Agency (NGA). Sometimes the abbreviation WGS 84 includes a space. Other times it does not (WGS84).

B. Conceptually, the origin of the ECEF system is at the Earth's center of mass (CM) because the CM is the physical point about which satellites orbit. As the physical defining point, the CM does not move (except for diurnal rotation and in yearly orbit about the Sun). In reality, points on the Earth's surface do move with respect to the CM. However, a global network of precisely located points (defined by ECEF coordinates) has been established and is used worldwide. Given that "everything moves," one practice is to hold the published global network values fixed and to describe subsequent relative movement as the CM moving with respect to the global network. Those small differences are monitored continuously by high-level scientists and geodesists.

The statement "everything moves" is a consequence of physical mass transfers by:

1. Tectonic plate movement.
2. Earthquakes.
3. Melting of glaciers and polar region icecaps.
4. Impoundment of water in large reservoirs.
5. Open pit mining/extraction of oil and ground water.
6. Construction/concentration of massive structures – cities, etc.
7. Other – such as water vapor in the atmosphere.

C. The U.S. National Geodetic Survey (NGS) is responsible for maintaining the U.S. National Spatial Reference System (NSRS) and is currently in the process of "modernizing the NSRS." The spatial data user community is indebted to NGS for staying abreast of measurement technology and crustal movements associated with the underlying reference system. In addition to the WGS 84 (defined and maintained by the U.S. DoD), the international scientific community observes and publishes a duplicate global network, the International Terrestrial Reference Frame (ITRF). The two systems, observed and computed independently, are compared daily. Since observed differences between the two are statistically insignificant, the implication is that the ITRF and the WGS 84 can be used interchangeably without detrimental consequence. The important point is that having modern reliable standardized reference systems readily available to all disciplines is an enormous benefit to spatial data users worldwide.

D. In fulfilling its scientific mission, the NGS makes survey observations and publishes authoritative control values for the latitude, longitude, height, and gravity at numerous points in the network as well as values for scale and orientation throughout the NSRS. Historical practice has rightfully included publishing values for latitude and longitude related to a horizontal datum while elevation is referenced to a vertical datum. The geometrical consequence is that horizontal and vertical have disparate origins and the horizonal/vertical combination of published control values lacks 3-D mathematical consistency. The resulting triplet of latitude/longitude/elevation coordinates is called pseudo 3-D. The solid geometry equations associated with the ECEF system are referenced to a single origin and true 3-D computations are performed in an integrated 3-D datum. High-level users routinely use true 3-D. Such use is not an issue. The point is that a 3-D model should be used for 3-D data and that those users who prefer using separate horizontal and vertical datums should consider the advantages of making the transition from using pseudo 3-D to using true 3-D. The GSDM accommodates that transition and provides additional features that enhance existing uses of true 3-D, e.g., finding the azimuth of a vector, computing spatial data accuracy, and utilizing a linear adjustment for terrestrial networks. A common universal spatial data model can be beneficial to all users worldwide.

III. Characteristics of and Tools for Manipulating Spatial Data

A. At the risk of over thinking the issues, a distinction is made between spatial data and geospatial data. In some cases, the two terms are used interchangeably. The conceptual difference between spatial and geospatial data is using the Earth as a reference. Generic spatial data (rectangular coordinates) are often used in the context of a flat-Earth, but curvilinear coordinates of latitude and longitude are more convenient for referencing points on the curved Earth (geospatial data). The following definitions are used here:

1. **Spatial data** are those entities and/or objects assembled from geometrical elements of points, lines, surfaces, and volumes. Spatial data are given meaning by being referenced to a predefined coordinate system. If the coordinate system is three-dimensional, the rules of solid geometry are applicable throughout, and computations are called true 3-D. The system is called 4-D if time is included.

   Two standard mathematically defined coordinate systems are:

   a. Rectangular Cartesian coordinates (length units) are referenced to an origin and three mutually perpendicular axes. Location of the origin and orientation of the axes may both be arbitrary (spatial data) but in the context of the ECEF, X/Y/Z coordinates are geospatial data.

   b. Curvilinear coordinates are measured as angles from two axes – two dimensions. The third dimension (to the surface of a sphere) is given as the radial distance from the origin. The location of the origin and orientation of the axes may be arbitrary as chosen by the user. These coordinates are true 3-D spatial. In the context of the ECEF system, latitude is measured north or south from the Equator and longitude is measured eastward from the Greenwich Meridian. The third dimension is ellipsoid height measured in meters along the ellipsoid normal. These coordinates are true 3-D geospatial.

2. As noted in the previous section, **geospatial data** are those spatial data referenced to the Earth – typically in terms of latitude/longitude/ellipsoid height. The geometry of the ellipsoid is well defined and solid geometry equations based on latitude/longitude/ellipsoid height support <u>true 3-D</u> computations.

3. Geospatial data are also expressed in terms of latitude/longitude/elevation. Since elevation is referenced to the geoid (approximated by sea level) and not the ellipsoid, horizontal and vertical components have disparate origins and subsequent coordinates are called <u>pseudo 3-D</u>.

4. Are geospatial data a subcategory of spatial data or are spatial data a subcategory of geospatial data? Arguments can be made either way:

a. Mathematically, geospatial data are a sub-set of spatial data.
b. Geographically, spatial data are a sub-set of geospatial data.

B. Math has an undeserved reputation for being difficult to understand. On the contrary, mathematical tools enable efficient handling of important, in this case, geospatial data. Tools facilitating the use of spatial/geospatial data include vectors and matrix algebra.

1. An ECEF vector. . .
    a. is a directed line segment having magnitude and direction.
    b. is used to handle spatial data manipulations in 3-D space.
    c. contains fewer digits in components derived from coordinate differences.
    d. is independent of gravity because it is referenced to the ellipsoid normal.
    e. can be rotated to local e/n/u perspective without loss of rigor or integrity.
    f. can be combined with other connecting X/Y/Z vectors (laid head to tail to form a chain, a loop, or a network) and used in true 3-D computations.

2. Matrix Algebra. . .
    a. is that branch of mathematics dealing with "n" vector spaces.
    b. gets "dicey" in the abstract when dealing more than 3-D vector space.
    c. arranges elements in arrays of "m" rows and "n" columns.
    d. arrays can be added, subtracted, and multiplied if compatible.
    e. does not define division but instead defines a matrix "inverse."
    f. uses the product of an inverse and its original as a "check" computation.
    g. is used extensively in error propagation and adjustment computations.

IV. Defining a Formal 3-D Model

A. Without identifying or mentioning "abstraction," my Purdue graduate committee (which included Ralph Moore Berry, at the time Deputy Director of NGS) was adamant that persons and organizations potentially impacted by publication of a new (NAD 83) datum should be asked for input to my graduate thesis,[1] see Appendices A and B. In hindsight, the common elements of those responses laid the foundation for the focus of my professional career – insisting that surveyors can make and are making significant contributions to society in the use of spatial data.

B. Spatial data users in all disciplines worldwide can enjoy direct access to and the benefits of using the ECEF for 3-D spatial data manipulation. There is a single origin for 3-D data, positions are expressed using ECEF metric coordinates, and all solid geometry (including vectors and matrix algebra) equations for manipulating spatial data are in the public domain. The large magnitudes of ECEF coordinate values may be awkward to use but most applications can be accomplished using coordinate differences. Those vector components generally contain fewer digits (easier to handle) than "parent" coordinates.

C. Visualizing an ECEF vector in 3-D space does not come naturally for most humans. Not to worry, a rotation matrix is used to generate a local view of an ECEF vector. The user chooses the location for the rotation – often the "tail" of a single vector or a common origin for an assembly of vectors. Vectors related to a common local origin, called a Point-of-Beginning (P.O.B.), can be manipulated in true 3-D space – in stark contrast to more traditional procedures associated with performing computations in the pseudo 3-D environment. Those are the fundamental assumptions underlying the definition of the "3-D global spatial data model (GSDM)" described in a document filed with the U.S. Copyright Office in 1997.[7]

D. Executive Order 12906[12] establishing the National Spatial Data Infrastructure (NDSI) was signed by (then) President Clinton and released April 11, 1994. This landmark order designated the Federal Geographic Data Committee (FGDC) as the agency responsible for "developing standards for implementing the NSDI, in consultation and cooperation with State, local, and tribal governments, private and academic sectors, and. . ." Note that incorporating input from the private sector is accommodated by the enabling order. At the time I was self-employed as a Consulting Geodetic Engineer as well as the Editor of the ASCE Journal of Surveying Engineering (JSE). I wrote an Editorial[13] for the August 1995 issue of the JSE in support of the NSDI alerting readers to the expanding scope of spatial data. Among others, the Editorial proposed a global spatial data system (GSDS) "in which all points are uniquely and precisely defined" in the ECEF reference frame. The closing paragraph of the Editorial begins, "The convergence of modern technology has created both the tools and demand for working with spatial data on a global scale."

E. The defining document for the GSDM cites sources for constituent concepts and, insofar as possible, gives credit to those whose ideas were incorporated into the definition of a "new" 3-D model for spatial/geospatial data. The defining document also states that the GSDM will become the "Grand Unification Theory (GUT)" for spatial data to the extent it is adopted and used worldwide. That forward-looking view still appears realistic.

F. Acknowledging non-exclusive definitions of spatial and geospatial, the following true 3-D spatial data types are listed in Burkholder (2001)[14] and loosely categorized as follows.

1.	Absolute geocentric X/Y/Z coordinates.	Geospatial
2.	Absolute geodetic coordinates latitude/longitude/height.	Geospatial
3.	Relative geocentric coordinate differences.	Geospatial
4.	Relative geodetic coordinate differences.	Geospatial
5.	Relative coordinate differences	Spatial, but traceable to Geospatial
6.	Absolute local coordinates	Spatial, but traceable to Geospatial
7.	Arbitrary local coordinates.	Strictly Spatial

G. Anytime elevation is used along with plane coordinates for a 3-D position, the result is called pseudo 3-D because the origin for the third dimension (elevation) is a curved surface. The exception is if Earth's curvature is ignored – meaning the coordinates are treated as arbitrary local spatial true 3-D coordinates. **Gaming applications and many graphical displays typically use true 3-D (no gravity). Furthermore, many infrastructure and civil works projects have been completed successfully using locally defined x/y/z coordinates subject to flat-Earth assumptions**. A subsequent challenge is to incorporate these spatial data into a geospatial 3-D environment. Never say "never," but in many circumstances the best (most defensible) solution may be to re-observe and/or re-compute the survey as true 3-D geospatial rather than attempting a transformation.

H. State plane (and other map projection) coordinates are viewed as absolute local spatial data. But since they are traceable to latitude/longitude positions, they can also be classified as geospatial data. Spatial and geospatial data can both be 3-D, but map projections are strictly 2-D. Therefore, data sets of map projection coordinates paired with either elevations or ellipsoid heights are categorized as pseudo 3-D. It might be tempting to label map projections coordinates paired with ellipsoid heights as true 3-D, but the geometrical integrity of that combination also suffers because the "height" of a point from the plane of a map projection is not mathematically defined.

I. The GSDM also supports additional computational procedures such as

1. Adjusting a network of conventional terrestrial data using a linear model.[15]
2. Computing offsets in a vertical plane rotated to an arbitrary direction. [16]
3. Finding the direction to anywhere (Mecca?) from anywhere, $\alpha = tan^{-1}\left(\frac{\Delta e}{\Delta n}\right)$.

J. The stochastic portion of GSDM [9] is based on the error propagation principles as expressed in the well-known matrix expression given as:

$$\Sigma_{YY} = J_{YX}\, \Sigma_{XX}\, J_{XY}^{t} \qquad \text{where. . .}$$

Σ_{YY} = Covariance matrix of computed result.
Σ_{XX} = Covariance matrix of variables used in computation.
J_{YX} = Jacobian matrix of partial derivatives of the result with respect to the variables.

The stochastic feature of the GSDM . . .

1. Puts the user in control of data quality. User gets to know, "with respect to what?"
2. Stores X/Y/Z coordinates from which coordinate difference can be computed.
3. Uses a matrix to rotate an ECEF vector to a local perspective vector.
4. Stores uncertainty data. . .
   a. in the covariance matrix for each stored point.
   b. in the correlations of vector components between points.
5. Can be used to compute standard deviation of any derived geometrical element:
   a. Coordinate or component thereof.
      i. In the ECEF perspective.
      ii. In the local (user) perspective.
   b. Inverse directions between points.

c. Distances between points – slope, horizontal, and/or vertical according to:
   i. Network accuracy.
   ii. Local accuracy.
d. Areas and volumes.

6. Permits use of a numerical filter to exclude non-qualifying data.
7. Has been challenged in technical literature but successfully defended.[17]

V. Spatial Data Accuracy - possibly the most significant part of the GSDM

The GSDM supports a simple mathematical definition of spatial data accuracy as derived from well-known error propagation procedures. The underlying stipulation is that the user is responsible for knowing/deciding, "with respect to what?" The big picture view is "with respect to ECEF." However, the mathematical concepts and procedures apply equally for the control decisions made by the user. For example, a project or local network could be implemented such that computed standard deviations of points within the area would be "with respect to the City, County, Section, or Project network" as established by the user. As described in Burkholder,[9,10] the following designations are applicable as determined by the user and the manner in which elements of the covariance matrices are used. A detailed example of "local accuracy" is included in Burkholder.[18] It is specifically noted that metadata associated with such use is essential. Subsequent users must be able to rely on data management decisions made by the data originator. Within the context of user decisions:

- Datum accuracy of a point is defined by the covariance matrix of the point.
- Network accuracy is the standard deviation of an inversed distance between endpoints based on the covariance matrices of statistically independent endpoints.
- Local accuracy is the standard deviation of one point with respect to another based on the full covariance matrix (includes correlation) of an inverse between endpoints.
- P.O.B. accuracy uses the covariance matrix of any point while holding P.O.B. errorless. (If "normal" statistics are available, it may be that P.O.B. accuracy is rarely used.)

Regarding copyrights, the following spatial data accuracy documents are readily available in addition to the material in two editions of "The 3-D Global Spatial Data Model" by CRC Press:

A. Spatial Accuracy documents filed with the U.S. Copyright Office:
   1. Mathematical definition of spatial data accuracy, Burkholder – 1997.[7]
   2. Fundamentals of Spatial Data Accuracy and the GSDM, Burkholder – 2004.[10]
   3. Standard Deviation and Network/Local Accuracy, Burkholder – 2013.[19]

B. ACSM article, Spatial Data Accuracy as Defined by the GSDM," Burkholder – 1999.[9]

C. ASCE holds the copyright for the following published items:
   1. Rigorous Estimation of Local Accuracy, Soler/Smith – 2010.[20]
      a. Discussion, Burkholder – 2012.[21]
      b. Closure, Soler/Smith – 2012.[22]
   2. Local Accuracies, Soler/Han/Smith – 2012.[23]

3. Rigorous Estimation of Local Accuracies Revisited, Soler/Han 2017.[24]
   a. Discussion, Burkholder – 2019.[25]
   b. Closure, Soler/Han – 2019 (authors declined to respond).[26]

D. Additional accuracy items posted on Global COGO, Inc. website:
   1. Appendix E, "Evolution of Meaning of Terms Network Accuracy and Local Accuracy," 2016.[27]
   2. "Concepts of Spatial Data Accuracy Need Our Attention," SaGES Conference, Corvallis, Oregon – July 30 to August 3, 2017.[18]

VI. Intellectual Property Considerations

Even though Intellectual property considerations are difficult to enforce, an overall doctrine of fairness should not be ignored. For example, should former New York City Mayor, Rudy Guiliana, be allowed to castigate the 2020 Georgia election workers with impunity? The answer is "No." There is no patent (or "patent pending") on the GSDM and all equations used in the GSDM are in the public domain. The only protection enjoyed by the author is copyrights of original works (sometimes assigned to the publisher) and the BURKORD™ trademark which covers "computer software for mathematically manipulating spatial data and for location referencing in the field of three-dimensional coordinate geometry."

With that said:

A. The concept of an integrated 3-D model for 3-D data, called "The 3-D Global Spatial Data Model (GSDM)," is original as stated in the defining document[1] filed with the U.S. Copyright Office in 1997. The intent in that document was to recognize the input and contributions of many, both living and dead, with apologies to anyone left out or overlooked. The influence of both Moritz[7] and Burns[7] is noteworthy.

   1. The 1991 paper,[2] "Using GPS Results in a Coordinate System Designed for Transportation & Engineering Projects," is the "parent" for the definition of the GSDM. Figure 6 in the 1991 paper is a block diagram of 3-D concepts, and shows the geometrical relationship between true 3-D and pseudo 3-D.

   2. Appendix III of that 1991 paper contains a Questionnaire sent to all and responses received from 46 of 50 state DOTs. Given the advent of GPS for surveying in the 1980s, the Questionnaire focused on the difference between grid distance and ground distance when using state plane coordinates.

   3. The 1991 paper was subsequently published in the Journal of Surveying Engineering[28] under the title, "Using GPS Results in True 3-D Coordinate System," Vol. 119, No. 1.

B. With publication of the NAD 83 horizontal datum and the NAVD 88 vertical datum, among others, NGS encouraged the Southeastern Wisconsin Regional Planning Commission

(SEWRPC) to adopt the new datums. The 7-county SEWRPC region had, since 1961, installed high-quality horizontal and vertical control networks throughout the region "as a basis for the compilation of large-scale topographic and cadastral maps, as a basis for the conduct of land and engineering surveys, and as a basis for the development of county and municipal automated land information and public works management system."

Rather than incur the expense and inconvenience of making a transition to the NAD 83 and the NAVD 88, the SEWRPC commissioned two separate studies to document reliable mathematical transformations that others could use to move NAD 27 coordinates and NGVD 29 elevations to the new datums for their own purposes. The Commission was resolute in not migrating coordinates and elevations in their existing database to NAD 83 and NAVD 88. Those studies were conducted by Earl F. Burkholder, PS, PE, Consulting Geodetic Engineer and published by the Commission for use in the Region.[29,30]

While developing the scope of those two transformation projects, the point was made that since the digital revolution was driving the transition of analog to digital, the horizontal and vertical datums should be combined into a single 3-D database using a "3-D model for 3-D data." That discussion was intense but short lived. The following two reports were developed and published.

SEWRPC Technical Report No. 34, "A Mathematical Relationship Between NAD27 and NAD83(91) State Plane Coordinates in Southeastern Wisconsin," December 1994.

SEWRPC Technical Report No 35, "Vertical Datum Differences in Southeastern Wisconsin," December 1995.

Following completion of those first two reports, a third study was commissioned to investigate the feasibility of combining the two separate databases (horizontal and vertical) into a single 3-D database. That 3-D report,[31] published in 1997, contains the first description of the Global Spatial Data Model (GSDM) and includes the rationale for implementing a 3-D datum. The report highlights disciplines that stand to benefit from using the 3-D model, lists equations for performing spatial data computations, and provides computational examples including GPS data and geoid modeling.

SEWRPC, "Definition of a Three-Dimensional Spatial Data Model for Southeastern Wisconsin," January 1997.

Incidentally, Dr. Kurt W. Bauer, Executive Director of SEWRPC, retired at the end of 1996 and the report was shelved. Although seminal, the report was not implemented.

C. Based in part on the 1991 GPS paper, the formal definition and description of the global spatial data model (GSDM)[7] was developed during the 3-D study for SEWRPC. The GSDM definition resulted from stepping back, looking at the fundamental characteristics of spatial data, and assembling constituent components within the ECEF framework as defined by the DoD. That meant using a single origin for 3-D data, implementing the rules of solid geometry, and taking advantage of computational enhancements such as vector algebra, matrices, enhanced computer capability, and "unlimited" storage capacities.

D. Researchers have long known that the internet, film documentaries, and ChatGPT can't be relied upon as a source for authoritative information. Citing un-overturned court cases is much more reliable. Information from Wikipedia lies somewhere between those two on the "reliability" spectrum and can be quite valuable. According to Wikipedia –

> ***Wikipedia is an online encyclopedia written and maintained by a community of volunteers, known as Wikipedians, through open collaboration and using a wiki-based editing system called MediaWiki.***

1. From Wikipedia: The Netflix documentary,[32] "Billion Dollar Code" (parts of the documentary were admittedly fictionalized) describes the unsuccessful lawsuit Art+Com brought against Google claiming that Google Earth infringed upon their patented software product, TerraVision. The Art+Com patent was invalidated as unoriginal.

   In addition to the Netflix documentary, information found on the Wikipedia site leads to various other sources describing the intellectual contest about who was first with the idea for using "multi-resolution pyramid of imagery" for zooming from high to lower altitudes. It seems that Stephen Lau, former employee of Stanford Research Institute (SRI) developed an "earth visualization application" (ultimately used by Art+Com) in 1994. It could be said that the "zooming" feature for visualization is a direct offshoot from Figure 6 of Burkholder's 1991 ASCE article which details use of a "user selected" origin. In practice, it appears that both TerraVision and Google Earth implementations consist of rapid successive applications of the "selectable origin" of Figure 6. Of course, it could be a coincidence that the SRI material was also original and developed independently of the concepts presented in Figure 6 at the ASCE conference in 1991.

   In addition to the "selectable origin" as shown in Figure 6 of the 1991 paper and implemented in Google Earth, that 1991 paper was written to look at the difference between ground and grid distances arising from use of GPS and state plane coordinates. As it turns out, pseudo 3-D is associated with using map projection coordinates while "true 3-D" computations are performed in 3-D space. A thorough literature search might reveal that others have addressed the true 3-D versus pseudo 3-D issue – maybe under a different name or label. Current searches have failed to disclose prior discrimination between true 3-D and pseudo 3-D spatial data. Although the GSDM is a collection of tools for performing routine spatial data computations in 3-D space and it seems that current professional and technical leaders are reluctant to discuss the true 3-D versus pseudo 3-D difference. A possible exception can be inferred from the USGS webinar, "3D

National Topography Model Data Collaboration Announcement Webinar" which (minutes 3:37 to 5:02) shows development of a future 3D Integrated Datum for the 3D National Topography Model (3DNTM).[33]

2. As mentioned in the Introduction, the movie, "Flash of Genius"[8] gives a dramatic example of "David versus Goliath" with Robert Kearns' suing the Ford Motor Company for recognition of his invention, the intermittent windshield wiper. The documentary may have taken liberty with the court room argument (A Tale of Two Cities) put forward by Kearns but, according to Wikipedia, Kearns prevailed in the lawsuit and his argument was supported all the way to the U.S. Supreme court.

3. The British thriller, "Eye in the Sky"[34] was filmed in 2015 and explores the ethical challenges of drone warfare. The reader is invited to watch the movie and/or to access the Wikipedia description of its making. While thought-provoking, the film also demonstrates the then-existing use of leading-edge geospatial technology for military purposes. Exploiting the characteristics of spatial data for military purposes is not new. In the past 10 years, drones have become commonplace (in both military and civilian applications), autonomous vehicles routinely appear on our highways, and ChatGPT is being implemented in all walks of life – including spatial/geospatial. The evolution of technology is impressive, **but the underlying geometry of spatial/geospatial data, as reflected in the GSDM, is unchanging**. An integrated 3-D datum, such as the GSDM, will ultimately be the glue for global digital twins – uniting our physical world by providing a rigorous underlying model that supports exchange of spatial data between all disciplines worldwide.

4. More importantly, the ECEF values in the 3-D database can be converted into other coordinate systems. That means the user is free to continue using a "preferred system" for local applications. **The caveat is that such a conversion must be bidirectional with the understanding that any data generated by data collection (survey) or as part of the design process must conform to true 3-D geometrical standards before being added to the database**. Any/all subsequent users will benefit to the extent they can depend on the stored X/Y/Z values of points stored in a 3-D database. A BURKORD™ database is but one of many possible candidates.

5. The point is also made that the GSDM provides greater flexibility for the end user. The 3-D database contains the ECEF coordinate values and covariance information for each stored point. The user can access all the Information in a selected area/project, or the user can impose a numeric filter on standard deviations to screen out any non-qualifying data. Additional database and implementation issues regarding the GSDM are included in Chapter 15 of the 2nd Edition.[15]

E. Summary of IP issues

1. All equations in the GSDM are all in the public domain.
2. Documents filed in the U.S. Copyright Office provide “public notice” status.
3. Global COGO, Inc. was incorporated in 1997 in the State of Ohio.
4. The trademark BURKORD™ was first registered in 1997. The trademark wording is, “Computer software for mathematically manipulating spatial data and for location referencing in the field of three-dimensional coordinate geometry.”
5. A patent is issued for 20 years. If renewed, the life of a trademark can be indefinite.
6. Copyrights protect “originality of expression” and should serve to deter plagiarism.
7. After an intellectual property attorney declined to get involved, my publisher made a formal request (it was honored) in 2014 for plagiarized portions of the book, “The 3-D Global Spatial Data Model: Foundation of the Spatial Data Infrastructure” to be removed from a web site. See http://what-when-how.com/. Scroll down that page and click on link to “The 3-D Global Spatial Data Model.” Once there, use “GSDM” in the search function to see list of 71 pages removed.
8. A BURKORD™ database is unique in that it stores the X/Y/Z coordinates for each named point along with the (optional) covariance matrix. Another optional feature is that the correlation between points can also be stored. In both cases, the user has the option of storing variances only on the diagonals or storing the full covariance matrix – which includes correlations. Details of a BURKORD™ database are posted at http://www.globalcogo.com/burkord.html. A paper presented at the SaGES Conference[18] in Corvallis, Oregon, in 2017 includes an example of using covariances to compute local accuracy from values in a BURKORD™ database.

VII. Incidentals

This section includes miscellaneous information related to development of the GSDM that doesn’t seem to fit elsewhere.

A. Few scientific developments have had the global impact of John Harrison’s clock.[35] While the technical complexity of the GSDM falls far short of the elegance of “longitude by time,” there appears to be a parallel between the reluctance of the Board of Longitude to accept Harrison’s clock and the hesitation of current professionals to adopt a “3-D model for 3-D data.” Appendix A of this paper contains a Timeline reflecting this author’s involvement in developing the GSDM. As a reminder, the GSDM is prefaced on the assumption of a single origin for 3-D data and is built on long-standing rules of solid geometry. Is it too simple?

B. Thomas Kuhn wrote a book,[36] “The Structure of Scientific Revolutions,” in which he describes the process of “discovery” and the tests to be conducted before a new process is accepted. The digital revolution is the driving force behind “disruptive innovations” in the use of spatial data. The GSDM embodies more efficient computational processes for spatial/geospatial data. Both the functional and stochastic models of the GSDM have survived “falsification by the scientific method" as described in Chapter 1 of Pruneau.[37] The GSDM is both "simple" and adequate for using spatial data.[38] The following examples reinforce Kuhn's arguments.

1. Walter Isaacson[3] wrote, "The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution," He discusses the reluctance of AT&T to "go digital" on pages 252 to 254

2. Kodak[4] is another example of an industry that faced the challenge of "adapt or die" as society transitioned to digital images and media. A web search on "Kodak digital" returns many relevant links – several of them are listed.

3. AT&T and Kodak are not the only entities to resist change. Many individuals objected to deprecation of the U.S. Survey Foot,[39] maybe not realizing that the U.S. Survey Foot will continue to exist as a legacy unit along with "chains and links."

4. The existence of the "Higgs Boson" was confirmed at CERN in 2012 (many advances have occurred since then). A fascinating story leading up to that confirmation (which represents an enormous breakthrough in particle physics) is told by Dr. Leon Lederman,[40] Director of the Fermi National Accelerator Laboratory in Batavia, Illinois, from 1978 to 1989. In particular:

    a. Dr. Lederman was a strong advocate for the Superconducting Super Collider (SSC) planned to be built in Waxahachie, Texas. SSC groundbreaking was in 1989 but Congress defunded and terminated the project in 1993.
    b. Dr. Lederman coined the phrase and wrote the book, "The God Particle: If the universe is the answer, what was the question?" The book includes an overview of the development of science leading up to confirmation of the Higgs Boson.
    c. Scattered throughout the book, addressed particularly in "Interlude C," and echoing Kuhn (above), Dr. Lederman discusses how scientific advances are incremental with new research being added to the collective knowledge base.

5. "Night Comes to the Cretaceous"[41] by James L. Powell describes evaluation of evidence purporting to identify evidence about the death of the dinosaurs some 65 million years ago. About 1980, Nobel prize-winning physicist Luis Alvarez and his son, geologist Walter Alvarez hypothesized that high levels of iridium found in the K-T boundary (geological periods) worldwide meant that a huge meteorite struck the Earth and caused mass extinction. Experts from various disciplines look for justifiable reasons to question the evidence and logic leading to profound conclusions. Powell's account seems incontrovertible, but a recent internet search reveals additional speculation about consequences of the meteorite impact. Kuhn takes the word "paradigm" to be "universally recognized scientific achievements." A paradigm shift occurs when the collection and evaluation of evidence leads to a revised view of previously

accepted reality. Science (sometimes messy) is an on-going dynamic process which provides society with a credible foundation for knowledge and decision making.

C. The trademark BURKORD™ grew out of the ASCE GPS '88 Specialty Conference in which numerous vendors were vying for leadership in the emerging commercial GPS market. As Editor of the Journal of Surveying Engineering (JSE) at the time, it was my responsibility to secure credible reviews of the various articles prior to publication. Fairly new in that capacity, I had much to learn in making sure the "commercial" focus of a given article did not overshadow the academic value of sharing the information in the broader community. I devoted untold hours to finding the right balance and ASCE staff, along with numerous reviewers, provided guidance in navigating that maize. Never-the-less my efforts were not viewed kindly by everyone. Formal complaints were filed. I was very grateful that ASCE supported my efforts and "circled the wagons" on my behalf. Those Specialty Conference papers are published in JSE Volumes 114 (4), 115(1), and 115(2).

D. The Global COGO, Inc. webpage was established in 1996. The functionality of the site has been improved over the years, but many improvements could and should be made to support a growing audience of spatial data users. The following features are envisioned:

   1. Sign-in for those wishing to leave a record of their visits.
   2. Zoom webinars devoted to promoting the GSDM.
   3. Establishing an interactive "blog" for the benefit of interested persons.
   4. Making it easier to find and download relevant articles and software.
   5. Other.

E. The original dream for Global COGO, Inc. included developing, selling, and supporting software for manipulating 3-D spatial data. To that end, the BURKORD™ trademark was secured in 1997. It became obvious (based on consultations with the SCORE office in Columbus, Ohio) that launching a successful software business required more entrepreneurial vision and talent than I had available. The resistance to "disruptive innovation" throughout the professional community was also greater than anticipated. Recognizing that teaching and research are a better match for my talents and given the opportunity, I returned to teaching in the Surveying Engineering program at New Mexico State University in 1998. Teaching, professional involvement, and 3-D research made for a satisfying career while permitting pursuit of my hobby – geometry, computers, and GPS.

   While self-employed, I was able to develop a modest DOS-based, menu-driven program – BURKORD™, written in FORTRAN. A Windows version, called WBK[42], was written by S.R. Hashimi and released in 2008 about the same time as publication of the first edition of, "The 3-D Global Spatial Data Model: Foundation of the Spatial Data Infrastructure." The DOS version and the Windows version of BURKORD™ are both successful prototypes, which, for various reasons, have not been marketed commercially. Hint – the overwhelming reluctance by practicing professionals to adopt the GSDM is a significant factor. It is noted that AT&T and Kodak both took time to "go digital." The window for adoption of the GSDM is still open.

VIII. Status September 2023

Gravity is one of the four fundamental forces in the universe. Although the force of gravity is too small to be included in the Standard Model of Particle Physics,[43] scientists claims that gravity is so strong in a black hole that even light can't escape.[44] The human experience with gravity lies between those extremes – in this case, the impact of gravity on location. The difference between true 3-D and pseudo 3-D is ultimately caused by gravity as discussed in a paper,[45] "Reconciling Gravity and the Geometry of 3-D Digital Spatial Data." The issue is huge and various user communities have strong reasons for preserving status quo applications.

In looking for an independent entity having the credibility (and resources?) to study the issue and make recommendations; it appears that the mission of the U.S. National Institute of Standards and Technology (NIST) as listed on their website and quoted in a proposal [46] sent to them (and others) in January 2003 might be a good fit. Disappointed at not getting any response from NIST, a colleague noted, "you may be pretty good at geometrical geodesy, but you are very naïve when it comes to political geodesy." So much to learn!

IX. Corporate

Global COGO, Inc. is a family-held S Corporation and is the repository of intellectual property generated or owned by Earl F. Burkholder. While there is no restriction on use of existing mathematical equations or procedures, the combination of processes as constituted in the global spatial data model (GSDM) is valuable intellectual property as supported by copyright, established descriptions, and priority of publication. The BURKORD™ trademark is a separate but identifiable part of the overall intellectual property package.

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Appendix –
Timeline Showing Evolution of True 3-D and Pseudo 3-D Geospatial Data

300 BCE	Euclid – geometry, theorems, and logic.
276 – 195 BCE	Pythagoras – hypothenuse and sides of a right triangle.
1512 – 1594	Mercator – conformal map projection of the world
1596 – 1650	Descartes – rectangular coordinate systems.
1688	Love – Geodesia or the Art of Surveying and Measuring Land Made Easy.
1735 – 1741	Meridian arc surveys proved that the Earth is flattened at poles.
1790 – 1800	Meter is defined as 1/10,000,000 of arc distance Equator to North Pole.
1807	Ferdinand Hassler named first Director of U.S. Survey of the Coast.
1816-1817	Hassler began observations following acquisition of equipment and delays.
1856-1857	Precise levels run to study tides and currents in New York Bay & Hudson River.
1866	Meter defined as legal standard for length in the United States
1877	First geodesic leveling benchmark set in Hagerstown, Md.
1878	Global 3-D polyhedron network proposed by H. Burns.
1879	First national horizontal datum established in the United States
1884	Greenwich Meridian designated as Prime Meridian of the World
1927	NAD 1927 served as horizontal datum in the U.S. for nearly 60 years.
1929	NGVD 1929 served as vertical datum in the U.S. for more than 60 years.
1933	State Plane Coordinates enable plane surveyors to use geodetic control.
1950s	Photogrammetric mapping blossoms as tool for Interstate Highway System.
1986	Publication of NAD 83 – published as a 2-D horizontal datum.
1986 – 1997	HARNs observed state by state, first truly three-dimensional HARN - 1997.
1991	**Figure 6 of ASCE paper on true 3-D http://www.globalcogo.com/Tru3d.pdf.**
1994	ASCE/ASPRS/ACSM Glossary of the Mapping Sciences, no ECEF and no GPS.
1994	Executive Order 12906 establishing NSDI signed by President Clinton.
1994	Silicon Graphics markets algorithm for displaying 3-D graphics.
1994	TerraVision and ART+COM developed cascading resolution for images. (Cascading algorithm utilizes mobile POB (Fig 6 above) from 1991 paper.)
1994	Google developed Google Earth and distributes gratis to users worldwide.
Note:	*(No mention is found where Silicon Graphics, TerraVision, ART+COM, or Google distinguish difference between true 3-D and pseudo 3-D. Current Google Earth displays give the user a choice of ground distance or map distance – implying the displayed results are pseudo 3-D.)*
Now:	***View Netflix documentary, Billion Dollar Code (it is fictionalized a bit).***
1995	Editorial in JSE advocates a global spatial data system (GSDS) for the NSDI.
1997	Definition of GSDM based on 1993 paper is filed in U.S. Copyright Office.
1997	SEWRPC 3-D Report – proposes use of integrated 3-D datum, the GSDM.
2008 (3-D book)	The 3-D Global Spatial Data Model describes true 3-D/pseudo 3-D in detail.
2014	NGS modernization of NSRS promotes continued use of separate datums.
2015	Eye in the Sky – "science fiction" documentary showing military use of 3-D.
2017 (2nd ed. Book)	No new "geometry" but adds updates and material on accuracy/projects.
2020	Webpage www.tru3d.xyz contains various items promoting use of tru3-D.
2022	Digital twins arrive. See http://www.globalcogo.com/GSDM-and-DT.pdf
2022	ASCE "Future World Vision," – proposal to discuss "elephant-in-the-room."
2022	High-definition maps needed for autonomous navigation – use GSDM?
2023	Proposal to NIST to study GSDM – www.globalcogo.com/NIST-memo.pdf.
2023	AI and ChatGPT hit the stage – www.globalcogo.com/ChatGPT.html.