Is *Google Earth*, "Digital Earth?"—Defining a Vision

Karl E. Grossner[1]
Department of Geography, 3611 Ellison Hall
University of California, Santa Barbara
Santa Barbara, CA 93106
Phone: (805) 893-3663; Fax: (805) 893-3146
grossner@geog.ucsb.edu

Abstract. The recent wave of interest in the geographic referencing of information and in geographic displays generally, highlighted by the mid-2005 release of the *Google Earth* "geobrowser," suggests the time is right to revisit the vision of a "Digital Earth" project proposed in 1998 by then US Vice-President Al Gore. Digital Earth was an ambitious global undertaking to build a multi-faceted computing system for education and research. I present a short history of the federal Digital Earth Initiative that followed the speech and the related, ongoing activities world-wide. I describe the Digital Earth vision, contrast it with *Google Earth*, and report on research aimed at defining a *digital earth system* in the terms of both a digital geolibrary and a proposed comprehensive digital historical atlas.

1. Introduction

In a January, 1998 speech at the California Science Center in Los Angeles, then US Vice-President Al Gore called for an ambitious global undertaking to build a multi-faceted system for education and research, which he termed "Digital Earth." In proposing this "multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data," (Gore, 1998) he was elaborating on ideas first broached in his 1992 book, *Earth in the Balance* (Gore, 1992). The following passages from the speech exemplify its visionary tone:

> *"Imagine, for example, a young child going to a Digital Earth exhibit at a local museum. After donning a head-mounted display, she sees Earth as it appears from space. Using a data glove, she zooms in, using higher and higher levels of resolution, to see continents, then regions, countries, cities, and finally individual houses, trees, and other natural and man-made objects. Having found an area of the planet she is interested in exploring, she takes the equivalent of a "magic carpet ride" through a 3-D visualization of the terrain. Of course, terrain is only one of the many kinds of data with which she can interact. Using the systems' voice recognition capabilities, she is able to request information on land cover, distribution of plant and animal species, real-time weather, roads, political boundaries, and population."*
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> *"A Digital Earth could provide a mechanism for users to navigate and search for geospatial information–and for producers to publish it. The Digital Earth would be composed of both the "user interface"–a browsable, 3D version of the planet available at various levels of resolution, a rapidly growing universe of*

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networked geospatial information, and the mechanisms for integrating and displaying information from multiple sources."

The results of a current Internet search on the term "digital earth" present an incoherent picture of its status—or perhaps, a clear picture of incoherence. One might have presumed that a phrase with so much cachet several years ago would describe the portfolio of a significant educational or research undertaking by now. But in fact, most of the links returned by that search are for pages and sites representing defunct efforts. I contend this is unsurprising and masks the fact that much progress towards realizing Digital Earth has taken place and that it remains, as Mr. Gore recently remarked, a superior "organizing metaphor for digital information" (Butler, 2006). The disconnect between this good idea and its unrealized potential stems from the huge scope of the envisioned Digital Earth project and resembles the classic "describing the elephant" problem: what it is depends on where you stand—what your frame of reference and area of interest are.

For some, the idea of a Digital Earth seems to be nearly fulfilled in the *Google Earth* geobrowser software released in June, 2005. It is after all "a browsable, 3D version of the planet available at various levels of resolution," albeit displayed on a 2D screen, and anyone with a late-model PC can "zoom in, using higher and higher levels of resolution, to see continents, then regions, countries, cities, and finally individual houses, trees, and other natural and man-made objects," just as Gore described. Furthermore, it is to some degree a viable platform for sharing data. This represents a major stride towards one aspect of a digital earth interface, but so far is simply that. What Tim Foresman of the International Society for Digital Earth (ISDE) calls the "charismatic concept of Digital Earth" (2006) involved integrating "the full range of data about our planet and our history" (Gore, 1998), accessible within a few mouse clicks, in a massively distributed complex of applications for education and research. *Google Earth* is fun, and it is breakthrough technology with terrific potential, but it is not that.

In this paper, I briefly review the history of the federal Digital Earth Initiative that followed the Gore speech, and compare the envisioned system with the current functionality and use of the *Google Earth* geobrowser. I conclude by discussing ongoing research aimed at defining a category of *digital earth systems*, and presenting an outline of its components and data requirements. Since 1998, sufficient progress has been made on interoperability standards and virtual globe software technology that a major geographic educational and research application such as Gore proposed can be undertaken as the first permanent, evolving exemplar of such a system. It would merge the concepts of geolibraries and knowledge organization systems (KOS), as a suitable framework and testbed for addressing a number of core GIScience research challenges. These include representation of dynamic processes and data quality (visually and with object-level metadata), geographic ontologies, and cognitive approaches to interface design.

2. The Federal Digital Earth Initiative

A US Vice-President can motivate action, and for the three years between 1998 and 2001, a US Government-sponsored "Digital Earth Initiative," coordinated by the Interagency Digital Earth Working group (IDEW), and chaired by the National Aeronautics and Space Administration (NASA), sought to realize the Gore vision according to priorities outlined in the speech: "In the first stage, we should focus on integrating the data from multiple sources that we already have" (Gore, 1998).

The federal Digital Earth Initiative was a collaborative grouping of entities and individuals from government, industry, academia, and the public sectors with a stated mission to "accelerate key areas of technology and associated policy infrastructure that are hampering full realization of the Digital Earth vision" ("The Big Picture"). Specifically, it would seek to "improve the integration of and application of geospatial data for visualization, decision support, and analysis" (Ibid). As such, IDEW activities focused on interoperability, infrastructure and organizational issues far more than design of a system like the one described in the Gore speech. Government participants included representatives from NOAA, USGS, USACE, EPA, USDF and NSF[2]. Major standards associations involved included the OpenGIS Consortium (OGC), the Global Spatial Data Infrastructure (GSDI) and the International Standards Organization (ISO).

Scenarios from the 1998 speech describe an educational, or knowledge organization system, which Gore suggested could also "become a 'collaboratory' – a laboratory without walls – for research scientists seeking to understand the complex interaction between humanity and our environment" (Gore, 1998). These two distinct but related categories of purpose suggest numerous particular challenges, but shared the requirement for a vast "networked universe of geospatial information," so that was tackled first.

The three-year IDEW effort had several results, including collaborative development of the current widely accepted Web Mapping Service (WMS) standard, and a Digital Earth Reference Model (DERM), intended to "define the standards and architecture guidelines of Digital Earth." Additionally, a series of Digital Earth Alpha Version projects were undertaken, including climate and weather applications based on "user context scenarios" for museums, classroom education, government and journalism ("Digital Earth Alpha Versions"). The effort was not directly funded and stalled in late 2001, shortly after the milestone demonstration of a unified interface for distributed WMS datasets.

The Digital Earth Initiative banner raised by the US Government after Gore's speech in 1998 flew over a spectrum of activities that had been under way for some years prior, many of which continue to this day and will likely survive changes to working group names and bureaucratic structures. When that banner was lowered in late 2001, the coordination of related activities was taken up by the Geospatial Applications and Interoperability (GAI) working group, a part of the US Federal Geographic Data Committee (FGDC), itself formed in 1990. The GAI charter included language evocative of, but not explicitly mentioning, Digital Earth:

> *"(responsibility to) develop and maintain the framework for digital representations of the Earth that enable a person to explore and interact with the vast amounts of natural and cultural information gathered about the Earth. Developments to support this framework should facilitate the integration of multi-dimensional, multi-scale, multi-resolution, seamless data that is readily accessible and enhanced through distributed value-added services."*

The GAI working group was in fact a self-described "outgrowth of the Digital Earth Initiative," and remained active until mid-2004. Over the next two years, the GAI working group produced a Geospatial Interoperability Reference Model (GIRM), the most recent version of which (1.1) was released in December, 2003. The model is described as a tool, rather than a set

[2] National Oceanographic and Atmospheric Administration (NOAA); US Geological Survey (USGS); US Army Corps of Engineers (USACE); Environmental Protection Agency (EPA); US Department of Agriculture (USDA); National Science Foundation (NSF)

of prescriptive, rigid standards. Its authors explicitly steered clear of "policies such as human interface guidelines, data content or portrayal requirements, or conventions for data storage or georeferencing," which *were* the purview of the parent FGDC, but outside the scope of GIRM (Evans, 2003). The GAI group's work and responsibilities have since been distributed within the parent Federal Geographic Data Committee (FGDC). To all appearances, the "interoperability" part of the GAI acronym remains a key focus; it is unclear whether "applications" are still of interest. Certainly, mention of Digital Earth applications has vanished, at least from government material available on the Web.

3. Other Digital Earth Efforts

The only academic and industry organizations mentioned in early IDEW documents as having an official involvement were, respectively, the University of Maryland and GIS software developers, ESRI. However, quite a bit of related academic and commercial activity has occurred between 1999 and today. Much of this has been reported at the series of bi-annual international conferences hosted by the International Society for Digital Earth (ISDE). These Digital Earth Symposia have been held in Beijing (1999), New Brunswick, Canada (2001), Brno, Czech Republic (2003) and Tokyo (2005). Upcoming venues include Auckland (2006) and a San Francisco conference in 2007 with the theme, "Bringing Digital Earth Down to Earth." That 345 registered participants from 37 countries met to share progress and ideas at the 2005 Tokyo Symposium would seem to indicate that a fairly robust global interest in the Digital Earth vision remains, as attendees are involved with projects self-identified as being related to the original Gore vision. However, a survey of conference programs indicates that over time, relatively fewer papers are directly tied to a Digital Earth concept.

Significant projects in academia have included the NSF-funded *Alexandria Digital Earth Prototype* (ADEPT), a "virtual learning system" developed by researchers at the University of California, Santa Barbara between 1999 and 2004. International academic conferences on discrete global grids were held in 2000 and 2004. Researchers at Georgia Institute of Technology developed a novel quadtree-based data model for managing navigation within a global grid (Faust et al, 2000). Many academic researchers have presented at the bi-annual ISDE Symposia, largely on issues related to managing and sharing large geospatial data stores.

In "Cartographic Futures on a Digital Earth" (1999), University of California, Santa Barbara's Michael Goodchild suggested the Digital Earth vision was a framework that could "help to orient…the current community interested in geographic information, in pursuit of a common goal and the research problems that will have to be solved to reach it." He identified a number of those problems, and several in the realm of virtual globes are, six years later, well on the way to being solved by researchers and the GIS industry. Others, involving novel cartographic techniques and management of enormous, globally distributed geographic database structures and *knowledge organization systems* (KOS) remain a focus of research initiatives worldwide.

4. Geobrowsing

By the time the Digital Earth name had disappeared completely from Federal geospatial data initiatives, no comprehensive definition of a Digital Earth application had emerged publicly. However, several commercial developers and NASA *were* hard at work building digital "virtual globes" upon which one could drape satellite photographs and other imagery. Keyhole's *Earthviewer* and the GeoFusion *GeoPlayer* appeared in 2001, and NASA's own *World Wind* was first released in 2003. These received notice in the still fairly small community of interest for virtual globes. Then in October, 2004, Google acquired Keyhole Corporation, foreshadowing a major development—the June, 2005 release of *Google Earth*.

When *Google Earth* appeared on the market, viewers of cable television news broadcasts were already familiar with its capability. Zooming from a birds-eye (or satellite's) 3D view of the planet to hovering helicopter-like over a precise site of a news event had become commonplace, thanks to breakthrough display technology licensed from Keyhole. *Earthviewer* delivered only data needed to render the current view frame, and only to the necessary resolution. The release of *Google Earth* brought similar visual wizardry to anyone with a recent-vintage desktop PC. Its functionality is very reminiscent of the "magic carpet ride" found in the 1998 Gore speech and has undoubtedly increased the interest in—and market for—information systems that reference content geographically The reverberations from this milestone in visual communication are many and their significance, like the elephant begging description earlier, depends on where you stand.

While *Google Earth* was not the first virtual globe geobrowser software, it has been easily the most successful. In June, 2006 the company claimed 100 million product activations. It has captured an enormous interest for a few key reasons: (1) it is free; (2) it is fast; (3) it has its own markup language (KML), which allows anyone to display and easily share their own data; and (4) it is by all accounts fun; this stems from its speed, an easy-to-use interface and its high quality imagery. The open-source *World Wind*, which has similar speed and somewhat lesser functionality, is targeted at users in the scientific community. GIS software developer ESRI has announced the release of *ArcGIS Explorer* for mid-2006—a true GIS application allowing "queries and analysis on the underlying data," something the others do not. Microsoft looms as well, promising greater functionality for their *Virtual Earth* application.

A February, 2006 *Nature* magazine article spotlighting the virtual globe software phenomenon, reported that the Digital Earth project "died…in 2001 after Gore lost the 2000 US presidential election" (Butler, 2006). Gore's electoral misfortune did presage the gradual "quiet death" of the federal Digital Earth Initiative, which had always been focused on standards for interoperability and to a lesser degree, technical issues regarding digital globe software interfaces (de La Beaujardiere, 2006). One could say that the vision of a particular Digital Earth system for education and research had been fading all along. However, as Michael Goodchild noted in the same *Nature* article, "scientists' (current) use of virtual globes is breathing new life into Gore's dream" (Butler, 2006). By all accounts, the number and range of such scientific applications is expanding exponentially. To cite one example, the James Reserve environmental observatory (http://www.jamesreserve.edu/), a research unit of University of California's CENS (Center for Embedded Network Sensing), recently published a *Google Earth*-based interface for their observation network. Tower-mounted sensors and cameras monitor the microclimate and various plant and animal activities in the area, and the data and images produced are typically updated within the interface every few minutes.

Cultural and historical applications developed for Google Earth and other virtual globes arguably lag in sophistication to those in the sciences. Google hosts a public repository of collections of placemarks, many with external links to informational windows and web sites. For example an "Official World Heritage List in *Google Earth*," was recently published by UNESCO (http://whc.unesco.org/en/list/kml/). More sophisticated applications are gradually appearing. One enterprising cartographer has mapped all of the places the author Jane Austen lived, the place names found in her published works, and provided photographs of the locales used in film adaptations of the novels. There are also numerous experiments with overlaying of historical maps and GIS data layers on the *Google Earth* globe.

5. Google Earth v. Digital Earth

A consensus definition put forth by federal IDEW in 1999 distilled Al Gore's earlier words thus: "Digital Earth will be a virtual representation of our planet that enables a person to explore and interact with the vast amounts of natural and cultural information gathered about the Earth." *Google Earth* is, so far, a geographic visualization platform consisting of a virtual globe upon which anyone may place certain kinds of images and symbolization. The growing central data store—limited compared to the "the vast amounts" suggested for a Digital Earth—holds photographic imagery, the underlying digital elevation model, administrative boundaries, place names, hydrological and transportation features and a variety of placemarks for public and commercial entities of various kinds. The coverage varies by feature type and is uneven globally. The highest resolution imagery is disproportionately for North America and Europe, and the same holds true for numerous vector and label data layers.

The Digital Earth of the Gore speech would coordinate and facilitate access to data from "thousands of different organizations," (Gore, 1998) and that does not appear to be in the *Google Earth* development plans. The Digital Earth Initiative undertook the "government-sponsored testbed involving government, industry and academia" (Ibid.) towards that end. While it may not be feasible or wise for another large bureaucratic undertaking to lead the way, an international consortium without a profit motive would almost certainly be required to coordinate collaborative work of the imagined scope.

As a single public corporation, we can assume Google's principal motivation is maximizing profit and return for its shareholders. Google's very successful business model involves displaying advertising alongside the information it delivers. While the *Google Earth* mission is to "organize the world's information geographically" (Jones, 2005), so far that information amounts to whatever placemarks or data anyone, anywhere wants to post, as opposed to anything resembling a knowledge organization system. A key factor in the program's exploding popularity is the concurrent release and continued improvements to the Keyhole Markup Language (KML). The ability for users with even limited technical skills to display and share information of interest to themselves and their individual audiences, has contributed to the kind of organic, exponential growth reminiscent of the Wikipedia encyclopedia, the blog phenomenon and the Internet itself.

The Digital Earth Initiative focused on the sharing of geospatial data via web-based GIS; the first and only Alpha Version prototype in 2001 was a demonstration of a single interface for distributed WMS GIS databases. Although GIS data files can be imported and displayed in *Google Earth*, little if any analytical functionality listed as definitional for GIS by Chrisman (2003) for example, is possible and is unlikely ever to be. Despite major differences between the current *Google Earth* product and the Digital Earth vision, it does represent major progress towards the exciting visualization possibilities with virtual globes.

In *Table 1*, I have parsed Gore's motivational 1998 speech and consider whether *Google Earth*, in the current technological landscape, fulfills each element. Italicized items *are* in place, to varying extents.

Table 1. Components of Vice-President Gore's Digital Earth

Infrastructure	
Organizational	*Grassroots effort of thousands of individuals, companies, researchers and government organizations*
	Organic Internet-like growth
	Government-sponsored testbed involving government, industry and academia
	Data from "thousands of different organizations"
Hardware	High-speed (10Gbps) networks
	Huge mass storage requirements
	Satellites providing imagery
	Public access points for highest bandwidth access, e.g. museums
Software standards	*("some level of…") interoperability enabling data transfer between disparate systems*
	Metadata
Interface; principal application	
Software	*3D globe*
	Zoom in, out to multiple resolutions; fly through
	Control overlays, including terrain
	Virtual tour of museums
	Personal compilations; email
	Timeline
	Collaboration tools for researchers
	Generate and/or *display model results, e.g. land use planning; ecological scenarios*
	A path between scientists' results and the public, particularly regarding environmental science
Hardware	Virtual reality helmet, glove
	Voice recognition
Data	
	"Vast quantity"
	Historical, insofar as possible
	Public access and marketplace
	Global " 1 meter imagery"
	Digital Elevation Model ("visualize terrain")
	Land cover and land use
	Plant and animal species' distribution
	Soils, climate
	Real-time weather
	Physically sensed (e.g. GLOBE)
	Roads
	Political boundaries
	Population
Other content	
	Newsreel footage
	Oral histories
	Maps
	Newspapers

6. Of Libraries and Atlases

A fairly recent technological development with features and functionality reminiscent of the Gore's 1998 vision is the geolibrary. The term was introduced coincidentally in the same year, defined as "a library filled with georeferenced information" (Goodchild, 1998). A geolibrary allows users to retrieve any information having a specific, related geographic footprint by matching it with the footprints of items in the library. Geolibraries are necessarily digital, because making that match entails spatial mathematics essentially impossible in a physical library. Goodchild emphasizes that georeferenced information is superset of geographic information, which "(are) representation(s) of some part of the Earth's surface" (p. 59). Georeferenced information *refers* to "specific places on the Earth's surface, and yet are not normally included in discussions of geographic databases" (Ibid).

A summary report from a 1998 US National Research Council workshop panel on distributed geolibraries, self-described as "a vision and not a blueprint," made the following observation ("Distributed Geolibraries"):

> *"Like distributed geolibraries, Digital Earth is about making use of the vast but uncoordinated masses of geoinformation now becoming available via the Internet and about presenting it in a form that is readily accessible to the general user. Like distributed geolibraries, its central metaphor for the organization of information is the surface of the Earth and place as a key to information access."*

Also, this seemingly prescient suggestion:

> *"While the prevailing metaphor for human-computer interaction is the office or desktop, that metaphor may not be particularly helpful in organizing information about the Earth. Instead, access to a geolibrary could be through the visual metaphor of the Earth's surface itself; a student interested in Thailand would manipulate a globe on the screen until it centers on Thailand and then zoom in for more detail, as in the Digital Earth vision."*

The Alexandria Digital Library (ADL), developed in the 1990s and operational now at University of California, Santa Barbara, was a pioneering effort at building a geolibrary. Its catalog now contains over 15,000 entries for a variety of geographic information objects, including scanned maps, remotely sensed images, digital elevation models and air photographs. Users can identify a place by name or spatial footprint and ask, either broadly or with one or more narrowing filters, "What do you have about there?" A small number of geographic information clearinghouses have emerged with the similar ability to search one or more collections by geographic location. Two noteworthy and distinctly different examples are the US Government's Geospatial One-Stop (www.geodata.gov) and the Electronic Cultural Atlas Initiative (ECAI, at www.ecai.org), an international consortium of humanities and information systems scholars who have as one goal, "to make virtual collections of scholarly data from around the globe accessible through a common interface {by providing) a means for making data interoperable across formats, disciplines, institutions, and technical paradigms" ("ECAI"). Geospatial One-Stop is a clearinghouse for public domain GIS datasets. What these systems have in common is that their response to queries about a place, or about a theme at a given place is effectively, "here are some digital objects with metadata matching your criteria—good luck."

To make ADL and the other systems mentioned more nearly like the educational system in Al Gore's vision would require further inclusion of that 'larger body of georeferenced information' discussed earlier, expanding the system's role from simply enabling search and delivery of information objects, to breaking open those objects in some degree, and processing what they contain (Goodchild, 2004). This would allow adding to the currently answerable query, "what *do you have* about that place?" another, vastly broader one, "what *is so* about that place?" and even, "what *has been so* there?" An advanced distributed geolibrary, and *digital earth system* for that matter, will be able to field such questions both from information both in its local collection, and seamlessly, from a distributed web of collections worldwide. This would effectively and for all practical purposes marry the concepts of digital libraries and knowledge organization systems. ECAI is moving in that direction by fostering the development of digital cultural atlases, which are GIS-driven geo-historical reference works comprehensive within given knowledge domains.

The Perseus Digital Library at Tufts University (www.perseus.tufts.edu) has for several years also been at the forefront of research efforts looking to 'open and process' historical materials. They have digitized the contents of a large number of classical and other source texts and have georeferenced and mapped the place names therein. Its founder and director, Gregory Crane, recently addressed the potential impact of the enormous collections promised by the Google Print project and others of Yahoo, Microsoft and the European Union (2006). Crane identified three core issues involved in making best use of such collections: advances in optical character recognition (OCR) technology to better recognize and interpret document structure as well as letters on a page; machine translation between languages; and the two-fold task of first extracting references to people, places, dates and organizations, then automatically generating "atomic propositions" from them, e.g. "PERSON arrived at PLACE" (Ibid).

Educational digital earth systems with content stores comprising georeferenced million-volume collections is an extraordinary concept—one that is within sight technologically. As Google is learning in its legal battles the most difficult issues may turn out to be those of copyright and of intellectual property rights generally. Crane (2006) says hopefully, "Sooner or later some form of compulsory licensing, similar to that used by radio stations which broadcast copyrighted content, will probably emerge as a reasonable solution" (p.3).

7. DEFINING DIGITAL EARTH: A GEOGRAPHIC VIEW

The term Digital Earth has come to represent a global technological initiative—in a sense, an intellectual movement. I propose here a starting point for defining a (lower-case) *digital earth system*. The Digital Earth concept is inclusive of the geolibrary, the global digital atlas, and to some extent, geographic information system (GIS) software. A *digital earth system* is then a hybrid of these which does not yet exist, "a digital geolibrary for which the principal user interface is a global atlas having at least some of the typical functionality of a GIS." Phrased another way, it is "a comprehensive, massively distributed geographic information and knowledge organization system." To again answer the question posed in the title of this paper, *Google Earth* is not that—to date, anyway.

It is necessary to parse that definition and define some terms: it is *comprehensive* in that it will contain complete, "blanket" or "Level I" spatial coverage of the globe for a set of base thematic layers at a uniform scale or set of scales. Further, it will contain such additional thematic layers of georeferenced data at any geographic scale, level of detail (LOD) or coverage extent as are made available and accepted for inclusion by a designated review committee (Level

II). A third (Level III) tier of content will be un-reviewed material submitted by the global public at large—either explicitly as a candidate for Level II status or simply posted for others to view.

This digital earth system is *distributed* because, (1) there are necessarily multiple, geographically dispersed data stores providing content and (2) the processing load of server-based query and analytical processes should be shared for performance reasons.

Geographic information is "very broadly…information about well-defined locations on the Earth's surface; in other words, information associated with a geographic footprint" (Goodchild, 2000). Since all entities and events have spatial (and temporal) extents, by implication, the potential content of a Digital Earth System is almost infinite. The intent here is not to house all information with a geospatial element, but that any entity, event or process with a particular geographical location *may be* represented in a comprehensive digital earth system; obviously, not all could or should be.

The term *knowledge organization* is explicitly part of this definition for a few reasons. First, distinguishing knowledge from information (and data) is one element of a general statement of epistemological viewpoint. I am comfortable with the formulation of a continuum offered by Longley, et al. (2005) and echoed elsewhere: *data* as "in some sense neutral and almost context-free…raw geographic facts," *information* as data organized for some purpose, and *knowledge* as information to which interpretation has been added, "based on a particular context, experience and purpose" (p.11-12). Secondly, the vast realm of conceptual knowledge, while not itself intrinsically geographic or spatial, may be entered from consideration of any geographically located entity or event. Organizing that realm will therefore be undertaken in this system, at least to the extent of providing reasonable entry points. Finally, while *knowledge organization system* has become an umbrella term "encompass(ing) all types of schemes for organizing information and promoting knowledge management" (Hodge, 2000, p.1), it refers here to a particular combination of classification schema informing data model design and authority files, such as gazetteers and time period directories.

8. Digital Earth Components

A comprehensive high-level definition of a *digital earth system* is the subject of ongoing research, and its components can be outlined as follows.

Distributed database

The core of a digital earth system is a distributed network of GIS databases. A mirrored or replicated "central system" will comprise a database storing "Level I" empirical data and an integrated knowledge organization system of derived and interpretive works. The central database will extend the model of a typical GIS to allow encoding of temporal attributes and semantic meaning for geographic entities, as well as allow integration of object (vector) and field (raster) data types in novel ways. External databases in the network will not necessarily have or use such extensions. I propose a 3-tiered data system, further divided into "empirical" and "derived" categories, summarized as follows:

- Level I ('blanket,' or 'core,' data at a uniform scale, with complete global coverage; replicated on mirrors): VMap1 layers; 1 meter orthophotos and imagery; digital elevation model (DEM).
- Level II (data and information/knowledge objects 'certified' in some respect by a review process; may be held centrally or at distributed locations; various scales and coverage extents)

- Level III (registered in a clearinghouse mechanism, but un-reviewed as in "wiki" systems; may be nominated for certification and Level II status)
- Level I data are empirical; Levels II and III can have both empirical and “derived” or interpretive information/knowledge objects.

Distributed content store

The system will house information objects in a distributed architecture much like the databases described above. A replicated central store will house Level I empirical material of various media types, including source texts, a geographic glossary/encyclopedia for definition of terms, and multimedia objects such as photos, charts and video. External collections of interpretive work can become part of the larger content store simply by publishing and registering a catalog formatted to the system standards with a centralized clearinghouse.

“Middleware” services.

The replicated central servers will provide software that presents the distributed systems of both data and content as a single virtual database system to the application level interfaces, and so to users. It will also comprise authority lists of several kinds, including but not limited to, a place name gazetteer, time period directory, biographical directory and an extensible subject category framework or system of domain ontologies.

User interface

A digital earth system will provide one or several user interfaces. Such a system should have as wide a distribution and accessibility level as possible worldwide, and for that reason, a web browser interface meeting all current W3C standards should be provided. Advanced functionality can be provided via the ubiquitous Flash plug-in. Further capability, such as an interactive *Google Earth*-like virtual globe can be provided via a secondary “thick client,” with the expectation that in time the baseline of common hardware capability will rise sufficiently for near-universal access.

9. Conclusions: A way forward

The simple answer as to whether *Google Earth* is “Digital Earth” is, no—although there is a passing resemblance. The commercial forces driving *Google Earth* development make it unlikely to come to pass. It is, however, a notable advance in virtual globe interfaces that may be useful for any *digital earth system*. The term “Digital Earth” has been and will be applied to many efforts and products, and has come to represent a very loosely organized international effort to build comprehensive digital representations of Earth. However, nearly all organizations self-identified as working on Digital Earth-related projects are addressing only aspects of such representations—particular related technologies, or geographical regions. The potential breadth and depth of a comprehensive Digital Earth, “the full range of data about our planet and our history” (Gore, 1998), is so vast as to make a complete specification unwarranted and probably impossible. What I have undertaken is to begin listing the properties a *digital earth system* should necessarily have, certainly a pre-requisite to any effort at building one. My own doctoral research will be directed at the database design and cartographic challenges particular to a cultural and historical digital earth atlas application. My hope and expectation is that it contribute building blocks for a permanent, continually growing and evolving, global collective project that provides universal access to the world’s information, geographically.

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