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

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Keywords: digital earth, virtual globe, geolibrary, GIS

INTRODUCTION

The recent wave of interest in the geographic referencing of information and the growing number of web-based geographic applications is highlighted by the success of *Google Earth* and other "geobrowsers." This category of software bears a more than passing resemblance to the vision of a "Digital Earth," a project proposed in 1998 by then US Vice-President Al Gore, as an ambitious global undertaking to build a multi-faceted computing system for education and research. We first present a short history of the federally sponsored Digital Earth Initiative that followed the speech and related, in cases ongoing activities world-wide. We enumerate the functional, content, interface and system architecture elements of the Digital Earth vision, and contrast them with those of *Google Earth*. While Google Earth is clearly not yet Digital Earth, we offer for discussion a geographic approach to advancing from a vision and a promising interface to the definition of a particular, comprehensive and buildable *digital earth system*.

In proposing a "multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data," (Gore 1998) Mr. Gore 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."*

> *"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 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. We 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.

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 sought 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[1]. Major standards associations involved included the Open Geospatial 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). As two distinct but related categories of purpose, education and research suggested numerous particular challenges, but the shared requirement for a vast "networked universe of geospatial information" 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

[1] 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)

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 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.

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). The upcoming San Francisco conference in 2007 has the theme, “Bringing Digital Earth Down to Earth.” The fact 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 quad tree-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, eight 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. In our view, successful realization of a digital earth system will require strong leadership, able to elicit a clear definition and plan from the global community of interest, and to guide progress towards its completion.

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*.

By the time *Google Earth* appeared, 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 the 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 the free *Google Earth* client 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. By June, 2006 the company had logged 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, high quality imagery and a growing array of interesting content. The open-source *World Wind*, which has similar speed and somewhat lesser functionality, is targeted at users in the scientific community. Microsoft entered the market in November, 2006, with the *Virtual Earth 3D* application, by most accounts comparable to Google Earth in terms of functionality but obviously lagging in the size of active user and developer communities. In the same time frame, GIS software developer ESRI released *ArcGIS Explorer*, a client for its *ArcGIS Server* product, and a true GIS application. It allows "queries and analysis on the underlying data," something the others do not.

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 have lagged 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. The expanding assortment of base data layers includes the David Rumsey historical map collection and links to georeferenced *Wikipedia* and *National Geographic* articles. Numerous organizations have released thematic GIS data layers in KML format that can be displayed on the *Google Earth* globe, and KML has become a *de facto* standard for sharing global mapping data.

GOOGLE EARTH VS. DIGITAL EARTH

Google Earth is without question a "multi-resolution three-dimensional representation of the planet," and its users can display what will ultimately be "vast quantities of geo-referenced data." The language for those core capabilities comes directly from Vice-President Gore's 1998 Digital Earth speech, so is Google Earth, Digital Earth? We argue that the envisioned Digital Earth system—one that would "put the full range of data about our planet and our history at our fingertips"—remains a distant, albeit ever more reachable goal. The project aimed at defining and designing such a system was essentially interrupted in 2000. With the goal of renewing that effort, or at least assessing its feasibility and worth, we have undertaken a preliminary analysis of the of the speech text, with the view not that it may contain precise or complete specifications, but that is a useful starting point for defining a very complex system.

To that end we are adapting aspects of the *unified process* (UP) for software design, which has been successfully applied to many large projects (Larman 2002; Abler 2004, 2006). In *Table 1* we list some high-level requirements—for functionality, content, user interface and system architecture—described or implied in the speech and note whether they are found in Google Earth's free, "Plus" and "Pro" versions as of this writing. An "Enterprise" version offers enhancements we have been unable to appraise directly.

Table 1 - Digital Earth/Google Earth comparison

Functionality	
Embed georeferenced data in any quantity (i.e. contribute, publish)	Embed: no; contribute: potentially; publish, yes
View the Earth, i.e. multi-resolution imagery, photographs and other data (to 1m per pixel) at multiple scales, from multiple viewpoints and able to simulate motion; e.g. animated, still; zoom, pan; orthogonal, oblique	Yes; resolution varies
Locate information at various levels of granularity by means of browsing (maps, lists), direct queries and hyperlinks to associated data stores	In part
Create visualizations of uploaded data	By means of georeferenced overlays
Travel through time; display conditions at a place for any time period the system is aware of, incl. from Mesozoic into the future in the case of predictive models	Time-enabled browsing i.e. filtering by timestamp intervals
Take "virtual tours" of museums	No
Listen to oral histories (and music, presumably)	No
Collaborate with others in scientific inquiry	Yes, in some degree
"Predict the outcomes of complex natural phenomena"	No embedded computational analysis functions as in GIS; georeferenced output from other applications may be overlaid on the Earth surface or at elevation
"Simulate phenomena that are impossible to observe"	
Create intelligent software agents that aggregate information automatically	
Send content and/or links to content to email recipients	Yes

Content	
Vast quantities of georeferenced information about environmental and cultural phenomena on and near the Earth's surface	Potentially; the central data store resides on Google's servers; distributed user data in the form of Internet-accessible KML files represents a large, unmanaged "virtual" data store
Landsat photography	Base imagery is derived from Landsat
"A digital map of the world at 1 meter resolution."	Base imagery varies in resolution from sub-meter in many populated areas to multi-meter in large regions
A global digital elevation model (DEM)	Yes
Data layers with global coverage for:	
• roads	Yes
• political boundaries	Yes
• land cover • distributions of plant and animal species • population • real-time weather	As noted, users' georeferenced layers in several standard raster and vector formats may be overlaid on the globe base map
Directly sensed or observed environmental data with coverage of individual research projects, including "citizen science" efforts like GLOBE	By virtue of KML, GE is becoming an effective platform for sharing many type of geospatial data
Hiking trails and other features in national parks	Yes (United States)
"Value-added information services"	Emerging, by means of distributed KML files with embedded hyperlinks and web-

	accessible database interaction
Virtual reality tours of museums such as Louvre	No
Historical data and media content with global coverage for political and cultural topics, e.g. newsreel footage, oral histories, newspaper articles and 'other primary sources.'	Information with scattered coverage is part of the 'primary database.' Increasingly, individuals and organizations are publishing KML data
Pre-historical data, e.g. about dinosaurs	
Modeled thunderstorms	No

User interface	
A "browsable 3D version of the planet"	Yes
In public exhibits, such as at a museum, head-mounted display and data glove for immersive experience	Some experimental large-scale interfaces are in development by 3rd parties
Hyperlink navigation	Yes
Speech recognition capability	No
Audio capability	Not directly

System architecture	
Databases, content stores, application software are all distributed—maintained by thousands of organizations worldwide; some is in the public domain, some in a digital marketplace	There is a global, distributed "virtual store" of information in terms of publicly accessible KML files; it is not organized except for bulletin board-type forum folders; standard web search methods apply
In aggregate, "quadrillions of bytes of information"	There is no upward limit on what may be accessed in a public, distributed, peer-to-peer architecture
Participating servers and access points all on a "high-speed network" (given presumptions of bandwidth limits in 1998)	GE is a public Internet application; the Enterprise version can reside on private high-speed networks
Standard formats, protocols, software and metadata requirements that allow "information generated by one kind of application software to be read by another"	KML has become a standard for sharing data for display in virtual globe software; the GE primary database cannot be accessed by any non-Google software applications
Allows display, integration, and fusion of data from multiple sources	Display, yes; integration and fusion: not within the GE application itself
Individuals are able to "publish" to the system	Contribute to the loosely organized "Google Earth Community"
Two levels of functionality—the full level for users on Internet2, and "a more limited level" for consumer-grade internet access.	Enterprise level hardware requirements exceed those of the consumer versions

This list indicates Google Earth resemble the featured user scenario in the Digital Earth speech, that of the schoolgirl in the museum. However, that narrative and the remainder of the speech really describe a comprehensive knowledge organization system, with global coverage for a wide range of data types, from land use to population characteristics to cultural and political history. This is quite distinct from the distributed, peer-to-peer "virtual store" of information, explored primarily via search engines, that appears to be at the center of Google's development strategy. Key definitional elements of the Digital Earth vision are missing and unlikely to ever be realized in the Google Earth product, even though its popularity and widespread adoption as a visualization tool make it certain to expand and improve. A passing or increasing resemblance is in our view too low a bar. We argue that a true *digital earth system* is necessarily a global public undertaking, comprising (1) a geographic computing "platform," including a distributed network of compatible servers, and (2) multiple compatible end-user client software applications.

DEFINING DIGITAL EARTH: A PARTICULAR GEOGRAPHIC COMPUTING SYSTEM

A comprehensive high-level definition of a *digital earth system* is the subject of ongoing research; we introduce here some concepts framing that effort. The term Digital Earth has come to represent a global technological initiative—in a sense, an intellectual movement. The Digital Earth concept encompasses those of the distributed geolibrary (Goodchild 1998), the digital atlas (see for example Geospatial One-Stop at www.geodata.gov), and to some extent, geographic information system (GIS) software. We can say then a *digital earth system* is a hybrid that doesn't 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." Addressing again 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 house complete coverage of the globe for a set of base thematic data layers at a uniform scale or set of scales (Level I). It will also contain such additional thematic layers of georeferenced data at any geographic scale, level of detail or coverage extent as are made available according to published standards and accepted for inclusion (Level II). A third tier of content (Level III) 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 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 attempting to house all information with a geospatial element, but that any entity, event or process with a particular geographical location could 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. We are 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.

DEFINING DIGITAL EARTH: ESSENTIAL COMPONENTS

Some important required components not generally present in existing distributed geospatial data systems, can be grouped as follows:

Data model

An approach that is fundamentally different from a typical GIS is required. It must be semantic and ontology-based; that is, structured to allow feature and event attributes to represent meaning in class rules and relationships. Attribute changes over time must be trackable, to permit visualizations of dynamic processes. Furthermore, the model must enable integration of object and field data sources.

Object-level metadata

Since both observational data and derived knowledge (concepts which may have contested or simply variant meanings) are to be managed, effective means of distinguishing the two and of representing provenance and quality are essential (Peuquet, 2003; Gahegan, 2006). Complete and highly granular metadata is required—more accessible and visible than is currently the norm.

Multi-tiered distributed database

The volume of information concerned means contributions must be facilitated, but a high standard of authenticity is necessary for the system's core data layers. It is important that the distinction between observational data and derived knowledge be fundamentally clear. These requirements can be met with a 3-tiered database system, described very briefly above.

Integrated authority lists

Existing clearinghouse and portal systems can present unified listings of distributed GIS data layers, but the types of queries to be served by a *digital earth system* require a central, integrated set of authority lists, including a place name gazetteer, time period directory, biographical directory and a central, extensible categorization framework of domain ontologies.

SUMMARY: A WAY FORWARD

We have argued that *Google Earth* is not "Digital Earth"—although there is a more than passing resemblance—and that the commercial forces driving *Google Earth* development make it unlikely to become so. However, it is a notable advance in virtual globe interfaces and geographic visualization that will inform any *digital earth system* going forward. 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. Since 1998, sufficient progress has been made on interoperability standards and virtual globe software technology that the development process interrupted in 2001 can and should resume: design of a major geographic educational and research application can be undertaken as the first permanent, evolving exemplar of such a system, and is critical feedback for design of the underlying platform to support all *digital earth applications*. It would merge the concepts of geolibraries and knowledge organization systems (KOS), as a suitable framework and testbed for addressing most of the core GIScience research challenges (McMaster & Usery, 2005). A partial list of these includes representation of dynamic processes and data quality (visually and with object-level metadata), geographic ontologies, and cognitive approaches to interface design.

ACKNOWLEDGEMENTS

Karl Grossner's graduate studies are funded by the National Science Foundation's IGERT in Interactive Digital Multimedia, Grant # DGE-0221713

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