Hypermap in the Digital Earth

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Abstract

This paper addresses the issues on hypermap development and management in the Digital Earth. The integration of remote sensing and hypermap is presented. Finally, The future development of hypermap is discussed.

1. Introduction

The essence of knowledge is, having it, to apply it; not having it, to confess your ignorance.
(Confucius)

1.1 Hypermedia

The term 'hypermedia' is becoming more and more widespread. But what exactly is hypermedia? Before trying to identify or develop a useful definition, let us divert for a moment and consider the way that human memory works.

Human memory is associative: we associate pieces of information with other information ad create complex knowledge structures. We often remember information via association, i.e. a person starts with an idea which reminds them of a related idea or a concept, which triggers another idea. The order in which a human associates an idea with another idea depends upon the context under which the person wants information i.e. a person can start with a common idea and can end up associating it to completely different sequences of ideas on different occasions.

What is hypermedia? For many people the most common experience of hypermedia is the World Wide Web. Although Websites are only a single type of hypermedia application (and an often criticised one at that), they do demonstrate many of the fundamental characteristics of a hypermedia application.

In addition to being able to access information through association, hypermedia applications are strengthened by a number of additional aspects, including an ability to incorporate various media, interactivity, vast data sources, distributed data sources and powerful search engines. These make hypermedia a very powerful tool to create, store, access and manipulate information.

Hypermedia is an application which uses associative relationships among information contained within multiple media data for the purpose of facilitating access to, and manipulation of, the information encapsulated by the data (Lowe and Hall 1999).

With hypermedia we (i.e. the developer of the hypermedia applications) provide multiple possible paths through the information; we do not constrain the reader to a predetermined path. Instead, the user can interactively browse through the information following any of the possibly very large number of paths. A number of good overviews of hypermedia applications exist (for example, see Nielsen (1995)).

Current hypermedia applications are beginning to mature in their ability to support the first aspect of the above quota – 'The essence of knowledge is, having it'. The more advanced current applications do provide reasonable access and retrieval of information, albeit often within a constrained domain.

1.2 Hypermap and Digital Earth

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. In another word, Digital Earth is a multi-resolution, four-dimensional (three spatial dimensions and one time dimension) representation of the planet, into which we can embed vast quantities of geo-referenced data. For Digital Earth, there was the need to combine the maps with the non-geo-referenced data.

Hypermedia, introduced the integrated use of non-geo-referenced data in many applications. Maps provided their users with access to geo-referenced data. Here the map can play an additional role, it can function as an interface to these (hypermedia) data. This approach introduces the hypermap concept.

A hypermap, then, can be described as geo-referenced approach to hypermedia (Kraak and Vandriel 1997, Voisard 1999). The hypermap is based on hypertext and hyperdocument principles. Hypermaps introduce spatial referencing to all components in the system and allow for spatial and thematic navigation around the data. Although, as with hypermedia in general, links are predetermined, individual users do not necessarily follow the same paths.

A hypermap can structure the individual hypermedia components with respect to each other and the map. Hypermaps will let users navigate hypermedia data sets not only by theme but also spatially. The hypermap, thus, allows the user to make a geographic search, in addition to a thematic search. Using a hypermap, e.g. retrieve spatial information based on associative and logical combinations, is expected to be an efficient and easy method to understand the environment (Laurini and Thompson, 1992). Kraak and Vandriel (1997) outlined the basic functions required for a hypermap:

- Access documents by spatial hypermap navigation;
  Several access methods are available, which are (a) Click anywhere on the map; (b) Select a map symbol; (c) Define an area of interest and (d) Providing location.
- Access documents by thematic hypermap navigation;
- Access documents by temporal hypermap navigation;
- Update the hypermap;
- Storing hypermap data.

2. Hypermap and Earth Observation (Remote Sensing)

Hypermap would be ideally suited to do what is known in the data trade as fusion: taking different data sets and combining them to produce something new and, one would hope, more informative (Williams). Fusion is the essential of mapmaking. A networked hypermap can explore a potential infinity of data and can go anywhere in the world to get it. The amount of digital geographic data in the world is also finite, but the difference is that it is growing. The hypermap concept carries with it the idea that as data is newly minted from cartographers and orbiting satellites, then all the world's hypermaps immediately gain the new depth. Thanks to earth observation technology, the quantity of geographic data is increasing even faster than the violent increase in computer speed that is changing society so quickly. When up-to-date maps of essentially infinite detail are combined with 3G wireless telecommunication technologies and high-accuracy global positioning systems (GPSs), can be the concept of an expedition into the wilderness survive.

Within the scope of science and technology, only earth observation technology from the space can provide a global, repeat and continuous data coverage for the earth surface. These data are used to understand the earth system. The earth is a comprehensive system involving all fields related to every discipline about geosciences. The earth observing technology from the space and complex computer simulation works are playing an irreplaceable role in the study of the earth system, and are key techniques in building up the digital earth (Guo, 1999).

Earth Observing System (EOS) is part of NASA's "Mission to Planet Earth". One rational for EOS is to provide the data needed to predict the effects of global warming in specific, quantitative, local detail for long-range planning purposes. EOS will bring in satellite-based remote sensing data about Earth's land, ocean and atmosphere at a vast number of Gigabytes per day. The wide availability of high-resolution geographic data will change our view of Earth, making it at the same time more familiar, more mundane, more complex and more precious.

3. Development of Hypermap Applications

Hypermap applications typically have various primary characteristics. The most significant of these is non-linearity (hence *hyper*media). Other characteristics include the use of multiple forms of media (hence hyper*media*), especially geo-referenced maps (hence hyper*map*), and multiple types of access mechanisms.

A more useful categorisation of hypermedia applications to us at the moment is shown in Figure 1.1. In this categorisation we have separated applications along two axes: application size and application development focus.

The Category Four of applications is characterised by a large scale, a focus on content and how it is effectively conveyed and managed, and a long lifespan during which ongoing change to content and technology is likely to occur. These applications are often referred to as mission critical, because they can provide information which is critical to the day-to-day operation of many organisations. With this type of application, several new issues become important, including the fact that the application size means that issues such as navigability become important, and the long lifespan means that maintainability and reuse are relevant.

Hypermap applications in the Digital Earth are large-scale hypermedia applications. The defining characteristic of large-scale hypermedia applications is, obviously, size. The size of an application has significant implications for how we develop and use the application. Small-scale applications can often be satisfactorily developed using an ad hoc approach. This is not true of large-scale applications. As the application size grows, not only does the number of links grow, but the overall structure becomes more complex, making it more difficult to create each link.

Other factors also come into play when developing hypermap applications which are not significant for other applications. As the size grows, the range of media being used and how these media are combined grows, both of which create difficulties which must be addressed during development. Another factor is the increasing complexity of information access mechanisms; as the application grows it becomes more important to provide sophisticated mechanisms to assist users in managing the complexity. This can take the form of assisting users in understanding the structure of the information, navigating around the information, and providing mechanisms for identifying specific information within the application.

Another important aspect of hypermap applications which must be considered is that they will usually have long lifetimes and involve progressive or iterative development and refinement. The investment in a hypermap application is much greater. The result is that, with large-scale hypermap applications, ongoing maintenance, updates and refinement becomes important. Consequently, the applications should be developed with this in mind. The application framework or structure must be extensible, and mechanisms for carrying out the maintenance understood.

Given all of the above, it becomes possible to define a set of typical characteristics of hypermap applications, including both functional characteristics (those associated with the function or behaviour of the application) and non-functional characteristics (those associated with the form of the application). Typical functional characteristics include support for:

- Effective navigation
- Content-based Searching and indexing
- Map Information contextualisation
- Handing of information security and cost
- Appropriate presentation mechanisms
- Support for customisation
- Effective use of resources
- Handling of temporal media

Typical non-functional characteristics include:

- Link and content validity (covering aspects such as correctness, relevance, completeness and integrity)
- Suitable organisation of concepts
- Consistency and seamlessness of the structure
- Efficiency
- Maintainability and evolvability
- Reusability of information
- Reliability and robustness
- Testability, ability to be validated and verified
- Interoperability, flexibility, portability and genericity

- Appropriate handling of political and social aspects
- Cost-effectiveness

In developing applications, most of these characteristics become progressively more difficult to manage as the application size and scope grows. Any approach to development should ensure that applications contain the appropriate balance of these characteristics. The different stages for the development of hypermap applications has been identified:

- Conversion of paper maps into digital form
- Conversion of raw remotely-sensed data into vector maps
- Determination of relationships between geo-objects
- Specification of a simple model based on these relationships
- Implementation of a prototype
- Analysis of prototype and user behaviour
- Specification of a generic hypermap model
- Implementation of the generic hypermap model

Unfortunately, hypermap development is currently at the stage software development was at thirty years ago. Most hypermap applications are developed using an *ad hoc* approach. There is little understanding of development methodologies, measurement and evaluation techniques, development processes, application quality and project management. The focus in much of the development is on technical issues such as interface implementation – rarely is the quality of end applications adequately considered or understood (Lowe and Hall 1999).

4. Hypermap Management

Hypermap systems, indeed information in general, contains various types of relationships between elements of information. Hypermap allows these relationships to be instantiated as links which connect the various information elements, so that these links can be used to navigate within the information space. Lowe and Hall (1999) divided relationships (and hence links) into those based on the organization of the information space (structural links) and those related to the content of the information space (associative and referential links). Let us take a brief look at these links in more details.

- Structural links
  The information contained within the hypermedia application is typically organized in some suitable fashion represented using structural links. We can group structural links together to create different types of application structures.

- Associative links
  An associative link is an instantiation of a semantic relationship between information elements. In other words, completely independently of the specific structure of the information, we have links based on the meaning of different information components.

- Referential links

A third type of link which is often defined (and is related to associative links) is a referential link. Rather than representing an association between two related concepts, a referential link provides a link between an item of information and an elaboration or explanation of that information.

Different types of media will provide varying levels of support for operations on the media. Table 1.1 lists some of the more common (and important types of operations which can be applied to different media. The most significant class of operations (in term of supporting hypermedia functionality) is those that analyze media in some way. This includes operations such as indexing and searching.

The information structures created during the development processing can be calculated in various ways. Four common structures are linear, hierarchical, network or graph and matrix (see Figure 1.2). Applications can use more than one information structures.

Linear structures can be used in a number of ways within a hypermedia application. They can be used to retain the sequential structure of an original paper document. *Hierarchical structure* can be used to retain the original structure of the information contained in a hypermedia application. The third type of structure available in hypermedia applications is *the network or graph structure*. This structure is composed of associative links, which are of a semantic or pragmatic nature and are truly non-sequential. The ability to use these associative links and the resulting network in effective browsing of the information space is one of the main advantages of hypermedia applications. In many cases we will have categorizations of information, but the categorization is not single dimensional. *Matrix structures* allow us to capture the multidimensionality of various sources of information.

To a large extent, hierarchical links are used to represent information structure, while network links are used to represent semantics. In practice, a combination of these is often used to form a hybrid structure. A matrix structure will often be appropriate to be used as a top level of a hypermedia structure, providing an indexing mechanism to lower levels of detailed information.

One of the unique points for hypermap is the use of geo-referenced videos, images and maps. Integration of videos, images and maps into hypermap for the Digital Earth is a key issue in hypermap management.

Geographic objects in video image could be translated into point data in hypermap, and these data were topologically related to two-dimensional digital maps and video image files (Kim *et al*. 1998). Video images incorporated with digital map database structure, geo-referencing method and DGPS (Differential Global Positioning System applied database assembling method. When video image data integrated to hypermaps is well constructed, it is possible to verify the status of remote location without being at eh specific site, making it useful establishing various basic plans in the fields of landscape planning, city planning and environmental planning. It is also expected to be applied to education related to geographical space and to tourism industry.

One of the most important issues is map retrieval by content, i.e. to retrieve portions of maps based on the information that they convey. In order to support retrieval by content of map images, the maps should be interpreted to some degree when they are inserted into the database. This process is referred to as converting a map image from a physical representation to a logical representation (Samet and Soffer 1996). It is desirable that the logical representation preserves the spatial information inherent in the map image (i.e., the spatial relationship between the objects found in the map image). The process of converting a map image from its physical to its logical representation is the subject of the field of map interpretation. This subject has been studied in the context of the data fusion in the area of remote sensing modelling (for example, Xue and Cracknell 1995), in the context of the data conversion process in the field of GIS research (Chhabra and Phillips 1998), and in the context of the document analysis in computer science research (Amin 2000).

The key to content-based access of hypermap is the efficient and effective creation, encoding and maintenance of associations among geo-objects. The interaction metaphors employ multiple paradigms to facilitate making these associations. The problem of how to use the indices that have been constructed on the spatial, context and meta data in an efficient matter is very complex. This is a question of query optimisation in a spatial database (Ioannidis 1996), a subject that is only recently receiving attention in the database literature.

A further study on special image compression technique is required to reduce computer hardware problems. The recent development of wavelet compression can yield “virtual lossless” images with compression ratio between 10:1 and 20:1, which can reduce the amount of space required to store raster images (Xue and Rees, 1999).

When stereo image is used, upgrade and renewal of topographic information can be possible. Thus, a further elaboration on the use of stereo CCD in auto-extraction of three-dimensional coordinates from video image is necessary (Ahn and Moon, 1993).

For the evaluation of a hypermap system, the first is accuracy of the result. That is, how many result tiles are missed and how many result tiles do not meet the query specification. The second performance metric is query execution time. Two error types are commonly used in document analysis studies. Type I error occurs when an image that the system retrieved for a given query does not meet the query specification (a false hit), and a Type II error occurs when an image that meets the query specification was not retrieved by the system (a miss). Type I errors are detected by visual inspection of the result tiles. In order to count the Type II errors, we need to visually inspect the physical map tiles (in contrast to just looking at the result tiles as done for Type I error) or the paper map and ground truth for the data set and look for all required results in order to determine whether any result tiles were missed. Both error types correspond to the recall and precision metrics, respectively, used in information retrieval experiments.

5. Conclusions

A hypermap is an efficient tool in structuring and navigating a geo-referenced hypermedia database. It could function as a browser of geographical information systems, since it allows access to the data by the spatial data's natural components: location, attribute and time. And, more important, it can provide the user with links between non-spatial hypermedia data and a GIS' spatial data. Depending on visualization needs of the user, the hypermap can function in an exploratory, analytical and presentation environment.

The technical path to the hypermap is fairly well marked at this point. There are enormous challenges awaiting in database management, and in designing means of exploiting and presenting the data that will be useful to the expert and novice alike, but the routes to solving these problems look reasonable clear. More difficult are the political issues inherent in marking available remote sensing data owned by the government. Significantly, the US government has already decided that EOS data will be available not only to the priesthood of scientific digerati, but also to colleges, high schools, and individuals.

As long as these issues could be resolved, hypermap will deliver information that is not only useful but inspiring, enable individuals to see the world through maps.

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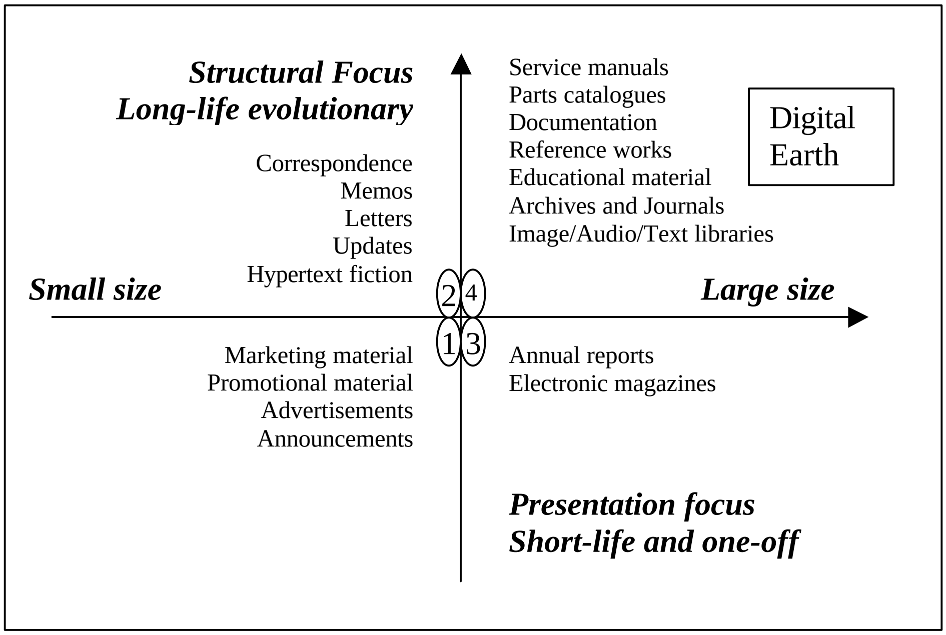

Figure 1. Hypermedia applications can be categorised on the basis of size and development focus (Adapted from Lowe and Hall 1999)

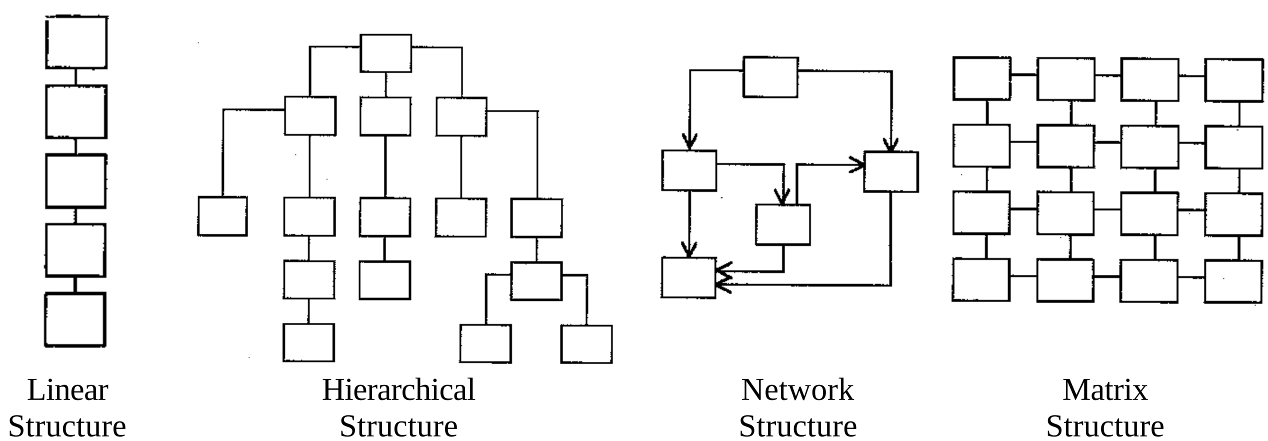

Figure 2. Different information structures which can be sued within hypermedia applications

Text	**Audio**	**Graphic**	**Image**	**Animation**	**Video**
Character manipulation	Sample manipulation	Primitive editing	Pixel operations	Primitive editing	Pixel operations
String manipulation	Waveform manipulation	Structural editing	Geometric manipulation	Structural editing	Frame manipulation
Editing	Audio editing	Shading	Filtering	Rending	Editing
Formatting	Synchronisation	Mapping	Compositing	Synchronisation	Synchronisation
Sorting	Conversion	Lighting	Conversion	Searching	Conversion
Indexing	*Searching*	Viewing	*Indexing*	Indexing	Mixing
Compression	*Indexing*	Rendering	*Compression*		*Indexing*
Searching		Searching	*Searching*		*Searching*
Encrypting		Indexing			Video effects

Table 1. Typical range of operations supported by different media types in the digital domain. The items in italics are still very poorly understood (Adapted from Gibbs and Tsichritzis (1995))