

Towards Geo-Spatial Hypermedia: Concepts and Prototype Implementation

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ABSTRACT

This paper combines spatial hypermedia with techniques from Geographical Information Systems and location based services. We describe the Topos 3D Spatial Hypermedia system and how it has been developed to support geo-spatial hypermedia coupling hypermedia information to model representations of real world buildings and landscapes. The prototype experiments are primarily aimed at supporting architects and landscape architects in their work on site. Here it is useful to be able to superimpose and add different layers of information to, e.g. a landscape depending on the task being worked on. We introduce a number of central concepts to understand the relation between hypermedia and spatial information management. The distinction between metaphorical (and abstract) versus literal (and concrete) spaces is introduced together with a workspace composition semantics and a distinction between direct and indirect navigation. Finally, we conclude with a number of research issues which are central to the future development of geo-spatial hypermedia, including design issues in combining metaphorical and literal hypermedia space, as well as a discussion of the role of spatial parsing in a geo-spatial context.

KEYWORDS: Spatial Hypermedia, 3D, GIS, Geo-Spatial Information Management.

INTRODUCTION

This paper introduces the notion of geo-spatial hypermedia by taking the abstract notion of spatiality, so far explored in the hypermedia community, as the starting point for exploring literal spatial information management, where geographical location plays an important role. The geo-spatial hypermedia prototypes are developed in the EU IST project *WorkSPACE* aimed at providing a computer-based

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environment for architects and landscape architects. The environment allows them to work collaboratively when they are surveying and inspecting in the field.

The work combines experiences and techniques from three main fields: Spatial Hypermedia [1][14][15], Geographical Information Systems (GIS) [11], Collaborative Virtual Environments (CVE)[5][6], but fields such as Collaborative Buildings [30], Augmented Reality (AR) [12] and CSCW in general, have also influenced the work. In the following, we briefly provide an overview of the previous work, which has been our main source of inspiration for the geo-spatial work.

Spatial hypermedia

The notion of spatial hypermedia was introduced in the early 90'es to support information analysis tasks [14][13]. In the following we briefly give an overview of the development of spatial hypermedia leading to the notion of geo-spatial hypermedia introduced in this paper.

Traditional Spatial Hypermedia

Traditional spatial hypermedia can be thought of as using a big 2D space (a canvas) for sorting information or organizing brainstorm notes for writing. Spatial hypermedia systems support this metaphor of organization by allowing items or "cards" to be generated and placed on a "table" (space). Cards may be tailored by changing their size, shape, color, or other visual characteristics. Cards may contain content or point to external content. Additionally, some systems (e.g., Aquanet [15]) allow cards to be "opened" to reveal another space that also may contain many different cards. Some systems (e.g. VIKI [13][14]) provide a 'spatial parser' that recognizes certain structures (such as piles, lists, etc.) and allow users to manipulate these structures as whole units (e.g., by allowing all the cards in a pile to be moved at the same time). Some systems (e.g. VIKI) allow repeated structures to be "formalized" (i.e., assigned a name, a description of a semantic role, etc.), which might allow the system to provide more functionality regarding such formalized structures (e.g., search for other instances, etc.).

Finally, an open collaborative spatial system called CAOS [1] has been developed at University of Aarhus. One of the features of CAOS is an *incremental* parser that recalculates

different types of spatial structures such as clusters, lists and tables upon client modification of realized spaces.

In addition to the research prototypes a few commercial products exist for spatial organization of Web-based materials. An example is WebSquirrel [www.eastgate.com/squirrel/] from Eastgate Systems, another example is The Brain [www.thebrain.com]. The Websquirrel system has strong similarities with the classical VIKI system, whereas The Brain provides a **dynamic graph-based graphical organization**.

3D Spatial Hypermedia

Several 3D environments for document and task management have been developed in recent years. Data Mountain [25] is a 3D environment for organizing web pages. Data Mountain explored how to exploit human spatial memory (i.e. the ability to remember where you put something) in organizing a large number of web pages and verified that users were able to use this ability in a 3D virtual environment. The Task Gallery [26] is a 3D window manager for organizing tasks (a task being a collection of documents and applications) that exploits human spatial memory to keep track of a large number of tasks at once. Manufaktur [3][4][17] was a first attempt at developing a 3D spatial hypermedia system. Manufaktur facilitates a digital 3D spatial arrangement of objects. The objects can be moved, rotated, etc; light effects may be applied; documents can be made (semi-) transparent; organized into groups, and much more. It is a 3D environment, with an abstract and unbounded space, which can be furnished with various objects for particular projects and/or activities. Manufaktur is both a Spatial Hypermedia system and a document-centered collaborative virtual environment (CVE) in that it provides a shared document space between distributed users, who can navigate and manipulate document arrangements in 3D workspaces. The Topos system discussed in this paper is a successor to Manufaktur. The 3D Wunderkammer prototype [2] employed a 3D environment to browse a set of inspirational materials for architectural use.

The former Apple Project X HotSauce product [www.xspace.net] is another example of 3D support for document organization. It provided 3D support for the organization and grouping of Web-based bookmarks, as well as addition of meta-data. The spatial support, and the functionality were quite similar to WebSquirrel, but instead of a flat 2D canvas an unbounded 3D space was used for the organization of bookmarks.

The final example is GeoVRML - a standard for presenting geo-spatial data in 3D described in [23]. It is an extension to the well-known VRML language [www.web3d.org] with the declared goal to make it possible for users to see 3-dimensional geo-spatial maps and data on the web.

Geographical Information Systems (GIS)

Today, Geographical Information Systems (GIS) are widely used and the theory behind these is well founded as e.g.

described by Laurini and Thompson [11].

Basically, a GIS makes it possible to put different layers of information on top of a digital map. Each layer represents one type of information and they can be combined arbitrarily. The information represented by a layer could be anything from cities and roads to the nesting places of an animal species. The wide usage has led to numerous commercial systems such as ESRI's ArcView [www.esri.com/software/arcgis/arcview/index.html], MapInfo [www.mapinfo.com/] and GeoMedia [www.intergraph.com/gis/geomedia/], but also to the development of an open standard, OpenGIS [www.opengis.org], for publishing GIS layers on the WWW.

Stockus et al. [29] treat some of the problems in integrating a Global Positioning System (GPS) receiver with a GIS and retrieving server-based GIS-information through a low-bandwidth connection (a cellular phone). Kraak [8] describes some visualization techniques to be used when integrating multimedia components with GIS.

Laurini and Thompson [11] also introduced the concept of hypermaps. This covers documents that can be reached by clicking an area (on a map) that corresponds to a set of geographical coordinates to which the documents are related. The Geotags Search Engine [geotags.com] among others uses this technique to narrow a keyword search to an area selected by the user.

Location Based Services

A location-based service uses the geographical location of the user to provide some service. This includes systems that tell you the way to your destination like the StreetFinder from Rand McNally [www.streetfinder.com], which utilizes a GPS receiver to get the location; as well as tourist information systems that via WAP or SMS tell you about nearby sights based on the location of your cell phone.

Augmented Reality

Augmented reality focuses on mixing the physical world with digital information and functionality. Typical applications are to link digital annotations to objects and places by means of some identifying code (barcode etc.). An example is the Cybercodes by Rekimoto [24] that allows information to be linked to objects tagged with a two-dimensional bar-code label, which is interpreted by a camera-based reader. Another example is the augmented paper by Mackay [12], where digital layers of information can be attached to physical paper. A final example is the FindEntity system [www.thax.de/english/frame.html], which provides support for locating physical material inside buildings and offices using Radio Frequency Identification (RFID), which is the most common method for locating materials in space. Materials to be located are augmented with a postage stamp sized electronic battery-free tag, then small antennas located under tables, behind shelves, in drawers etc. can help the user to follow links on the computer to physical material residing in a specific location in the building.

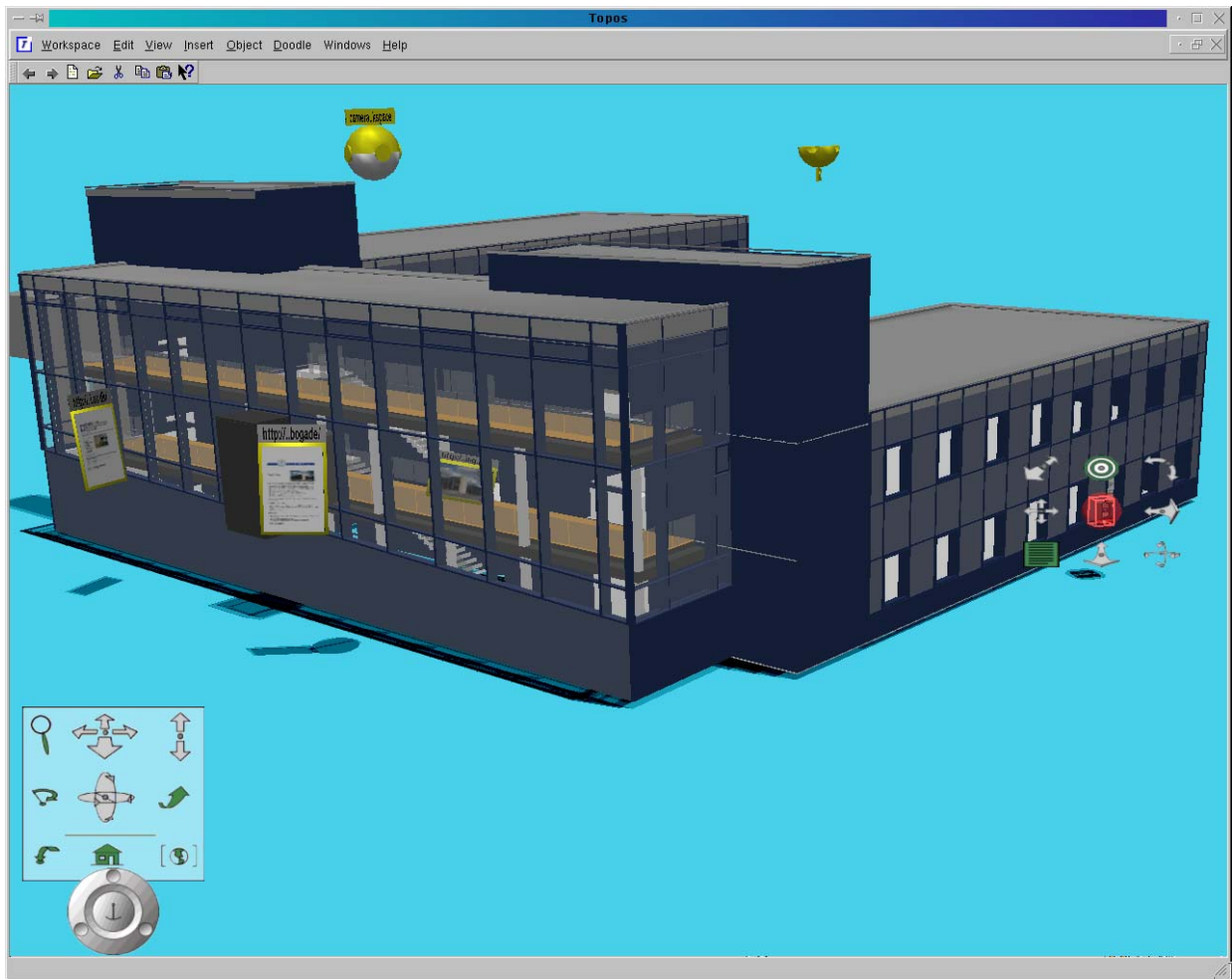


Figure 3: An example of the geo-spatial Topos interface. A layer, which superimposes homepages of institutions and people in our lab building, has been opened on top of the 3D model of our lab. The selected camera to the right represents a mobile user's location in the real world.

The central concept in Topos is the *workspace*. Workspaces are sets of spatially related and placed materials (documents, CAD drawings, 3D models, notes, other workspaces, etc.).

There are two ways to compose workspaces in Topos. A *proxy* refers to another workspace, which can be brought into the context of the surrounding workspace by opening the proxy. The materials of the sub-workspace can be manipulated either individually or as a whole. Several proxies can refer to a single sub-workspace even from within the same workspace. Visually, this appears as several synchronized copies of the materials of the sub-workspace. The graph consisting of workspaces, proxies and materials constitute a directed acyclic graph, as depicted in Figure 2.

Composing workspaces via proxies corresponds to transclusion [19] in traditional hypertext. The second way

to compose workspaces in Topos is by traditional *linking* between workspaces. Activating a link in workspace W transfers the user to the workspace pointed to by the link (C), and the entire spatial context of W is gone and replaced by C. In the Discussion section we will expand on the various ways to compose workspaces in Topos.

THE TOPOS GEO-SPATIAL PROTOTYPE EXPERIMENTS

The Topos prototype is being developed together with a group of landscape architects, using scenarios from their work practice as inspiration for the prototype development. The current support for geo-spatial hypermedia in the Topos prototype was developed to support the following scenario (among others): During construction at a site, architects and landscape architects frequently visit the construction site to keep an eye on things, discuss changes and solve problems with the contractors constructing the buildings or planting the trees etc.

Our ethnographic studies have shown that in many cases the architects on site need to consult co-workers back at their office to clear up details. Often, it is important for the co-worker to know where the architect on site is standing and which way he is facing to get an understanding of the context he is referring to.

Topos is intended as an information organization tool and hence we envision that e.g. an architect on site will bring the electronic documents and models relating to the project with him, using Topos to organize them on his laptop or PDA.

The prototype implementation lets the Topos client running on the laptop listen to a GPS receiver and a digital compass. The Topos client is configured at run-time to let the GPS coordinates control the location and direction of an object inside a Topos workspace. This object may reside on the local database on the laptop or on a shared database back home. As a special case the controlled object may be a camera object that any one of the architects may enter to see the virtual world from the perspective of the architect on site.

For the purposes of this discussion, let us assume that the GPS controlled object belongs to the database on the laptop. Whenever the GPS location changes, the object in the database is updated, and a collaboration event is transmitted to the collaboration server at the office via a wireless link (e.g. mobile phone). If the co-worker subscribes to update events on this object (by having the relevant workspace open), his Topos client will retrieve the location from the laptop database via the wireless link and his display will be updated with the new location so that he can see the location of his colleague.

In order to save bandwidth and increase response time, only the modified location parts of the controlled object are retrieved.

Also, the on-site architect and his co-worker may choose to share only a small workspace consisting solely of the controlled object. A copy of the documents and workspaces can be brought along on the laptop. This can save a lot of

bandwidth when opening the workspace and allows totally disconnected use. Changes to the copied workspaces can later be re-synchronized when a high bandwidth connection is available.

Having a 2D map or a 3D model of the site inside a workspace may be used to organize electronic materials and documents geographically. The architect may for example place pictures relating to a building close to that building on the map. Using the GPS receiver to control the location of his camera/avatar in the workspace he may virtually "bump into" the documents when he walks up to the building on site.

In the following we expand on the technical parts of the prototype implementation:

- GPS integration, and coordinate mapping.
- Collaboration and protocol compression.
- Composition of workspaces on different databases.
- Workspace synchronization.

GPS integration

The Global Positioning System (GPS) consists of a number of satellites in low earth orbit sending time-coded signals to the ground. By knowing the orbital elements of the satellites and receiving the very precise time codes from the satellites one is able to compute ones geographical location and height above sea level to within 10 meters provided more than 4 satellites are visible at the same time. To improve accuracy even further, differential GPS employs correction signals received via mobile phone or radio link to increase the accuracy to within a few meters. Our prototype uses the CSI GBXpro differential GPS receiver. Our software communicates with the GPS receiver over a serial link using the NMEA-0183 protocol [18]. It is a simple, standardized, text based protocol making it easy to retrieve latitude, longitude and altitude data from a GPS receiver.

Mapping geographical coordinates to model space

Having received a set of GPS coordinates our software converts the latitude-longitude coordinates into local Euclidian coordinates. This is necessary for two reasons: internally, Topos works with 3D Euclidian coordinates, and these coordinates are represented as IEEE single precision floating point values. GPS coordinates cover such a large range that when representing global coordinates double precision must be used to maintain accuracy. We alleviate this by allowing a workspace to carry a "geo base" property: the latitude and longitude of the center of the workspace. These base coordinates are subtracted from the GPS coordinates, so that single precision will be enough on a local scale (within some kilometers). The same issue is discussed and solved similarly in the GeoVRML specification [23]. The GPS coordinates are then transformed to Euclidian coordinates using a simple tangent plane projection, as this will work accurately enough within a typical construction site. A Topos workspace also contains a scale factor for GPS coordinates to transform the coordinates to the scale factor of the models and maps

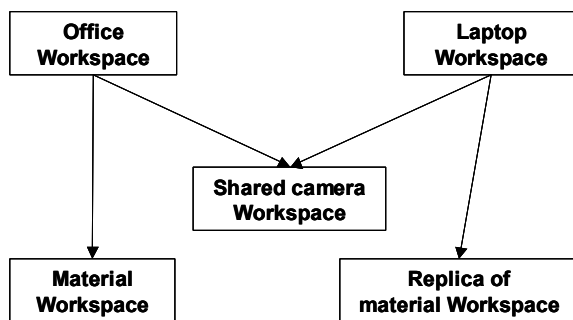


Figure 4: Relationships among workspaces when maintaining collaboration between a mobile computer in the field and a computer in the home office

within the workspace.

In tests it proved hard to control the position of GPS controlled objects precisely using only the geo-base and scale of the workspace, caused by the lack of precision in the geo-base coordinates and free hand placement of maps and models in the workspaces. To solve this we therefore allowed user placement of the GPS controlled object as a means of calibration: When the architect arrives at the site he uses his mouse (or pen) to place the GPS controlled object precisely on the map or model of the site inside Topos corresponding to his real world location. This sets an offset in the object relating the GPS location to the Topos location, and thus allows easy calibration.

The current prototype only allows each Topos client to GPS-control a single object. This corresponds to the client being in only one place at any one time. Several Topos clients can of course GPS-control several objects at once. Support for GPS-controlling a number of objects at once might be useful to control ones position on several maps and models at once, and could easily be added.

Collaboration

Any Topos client application connects to a database that holds the workspaces and the objects within. When collaboration is switched on clients also connect to a collaboration server. Each client notifies the collaboration server about any changes to the database and the server then distributes these events to other clients subscribing to the relevant workspaces. The other clients then retrieve the parts of the database state that has been changed, as indicated in the collaboration message. In order to provide interactive performance when moving around objects in a shared workspace, location coordinate changes are handled specially: As long as the position is changing (while the user is dragging the object) coordinate changes are only transmitted over the collaboration protocol and not committed to the database. When the user lets go of the object, the new coordinates are committed to the database and a final update event is sent. The collaboration server also keeps track of users and selection highlights, but this is not discussed in this paper.

The collaboration protocol utilizes differential message compression so that parts of messages that are equal to the corresponding part of the previous message are not sent. However, to enable newly connected clients to understand the messages sent by the other clients, one in every 30

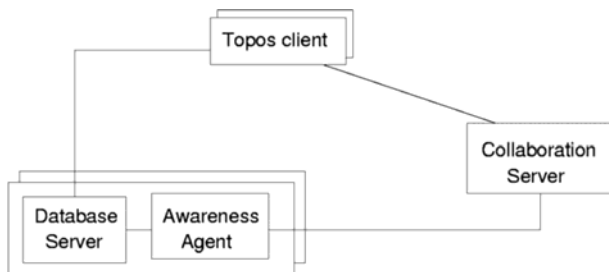


Figure 5: Topos client, collaboration server and database server.

messages are sent uncompressed to allow new clients to be able to decompress future messages.

Distributed Workspace composition

Workspaces from different databases can be composed by letting proxies or links refer to workspaces in other databases. This makes it possible to share only the camera between the worker on site and the office workers in the above scenario. Databases, materials and workspaces are referred to by an URL-like notation, and can therefore be shared across the Internet. The clients keep track of open connections to databases, so that only one connection is open to a given database at a time.

Workspace synchronization

To support disconnected use of Topos we implemented a workspace synchronization feature akin to the synchronization features of PalmOS and Windows CE PDA's. Whenever a copy of a workspace is pasted into another workspace (possibly on another database) the copy of the workspace is marked as a *replica* workspace with a reference to the original. Changes made to the replica can at a later point be re-synchronized into the original, and changes to the original can also be re-synchronized into the replica. All modifications to objects and workspaces update a time stamp on the object/workspace and the most recently changed object wins when synchronizing. We do not attempt to merge differences among properties of individual objects as that would require time stamps on every property on every object.

CONCEPTUAL DISTINCTIONS IN SPATIAL AND GEO-SPATIAL HYPERMEDIA

This section tries to position the work conceptually in the context of Spatial Information Management. The concepts and distinctions represent the results of our investigations into spatial information management with potentials for supporting the architectural application domain with information management tools.

For the purposes of positioning our geo-spatial work in the context of spatial hypermedia, we introduce a primary distinction in spatial information management, namely between: metaphorical/abstract spaces and literal/-concrete spaces.

Metaphorical and abstract spaces

Spatial hypermedia in this category provides an abstract space for users to organize their materials according to some metaphor, such as cards on a table, documents on walls or thoughts in a brain. Examples in this category are the traditional 2D systems mentioned in the introduction such as Viki, and VKB, but also web based systems like WebSquirrel, and TheBrain. The first three systems apply a "card on tables" metaphor whereas the last system applies a more abstract "thoughts in brains metaphor"

The 3D spatial hypermedia systems Manufaktur and Topos as well as Task Gallery [26] are examples of systems applying an abstract room metaphor, where materials may be placed free-floating or glued to virtual walls or floors.

HotSauce [www.xspace.com] is another example of 3D support for document organization, but in more abstract and unfurnished open spaces than Manufaktur/Topos and Task Gallery.

Literal and concrete spaces

Spatial information systems in this category provide support for users to organize and navigate information according to a concrete digital representation of some real world space, such as a room, a building, a city, a landscape, a country, a planet, or the universe. There are many uses of physical object location in concrete spaces: This category includes interactive GPS based travel guides, cell phone location based tourist information, augmented reality based navigation (and addition) of digital materials linked to physical objects. The geo-spatial support in Topos falls in this category.

These uses may be distinguished further between whether we use a known location as the starting point for information retrieval or we retrieve a computed destination location.

- *Starting from known location.* This category includes interactive travel guides, cell phone location based tourist information (given the position of the users s/he may receive information about the nearby sights), digital materials linked to the physical object or environment (as in augmented reality systems) and narrowing searches to geographic regions as in the Geotags system.
- *Retrieving a computed location.* This category supports locating people, physical materials or computers. Application examples include person pagers, locating folders in a physical file cabinet (e.g. FindEntity), and simple pinpointing on a map.

The Topos system can support both of these ways of dealing with location depending on which location technologies are integrated.

For handling of indoor location we see tracking technologies ranging from accurate magnetic, ultrasonic, barcode, and infrared systems over video based systems to Radio Frequency Identification (RFID) tags providing very coarse-grained location. RFID is the most common tracking method for materials in indoor spaces and it is e.g. used by the earlier mentioned FindEntity system.

The Global Positioning System (GPS) and GSM cell phone systems dominate handling of outdoor locations. Examples of existing systems in this category are location based interactive travel guides like StreetFinder, the FieldNote context-aware computing system [22][27] and the GPS-equipped camera used for educational purposes described by Smith et al [28].

Direct versus indirect navigation

We also distinguish between *direct physical* navigation and *indirect representational* navigation.

Direct physical navigation. Physical walking or driving is a typical means of navigation in this category, which includes interactive GPS based travel guides, location based tourist information, augmented reality based navigation (and

addition) of digital materials linked to the physical objects. The geo-spatial navigation support in Topos falls in this category.

Indirect representational navigation. Pointing and searching information on locations physically remote from the user's location is the typical means of navigation in this category. Web-based route planning or searching of hotels/restaurants in a remote city or nearby area falls in this category. Technologies supporting this kind of navigation are e.g. content based mapping of web pages to geographical locations [9][16] and mapping of web pages to locations based on author supplied tags, making location information explicit in the content of the web pages. Geotags [geotags.com] among others uses this last approach. Finally, navigation in abstract/metaphorical spaces, e.g. Viki and Topos, typically falls in this category, where a mouse or a pen is used to navigate and to move objects. However, tracking-based virtual reality systems may support direct physical navigation in abstract spaces with no direct reference to real world environments.

The concepts and distinctions introduced here enable us to map conceptual differences to decisions on how to design a spatial hypermedia system which is open for supporting the different categories of spatial information management applications we have identified. One example of such design considerations is the support for a variety of different composition semantics.

COMPOSITION SEMANTICS

In spatial hypermedia, composition [15] is the main structuring mechanism. As introduced earlier the Topos composite primitive is called a *workspace*. Workspace composites may be created explicitly from the starting point as containers for objects or they may be created post hoc, for instance resulting from spatial parses for object structures. Workspaces may, however, also be composed themselves, and we distinguish between two different ways in which workspaces may be composed by means of proxies.

First, workspaces can be composed and interpreted as *layers* on top of a background model or map. The layers must have a fixed position and scale relative to the underlying map. The overlaid layers have little or no meaning without the underlying map. The geometry of the layers and the underlying model are highly dependent, and a high degree of cohesion is required between layers. A typical example of workspace composition as layers is within GIS systems where a number of layers are overlaid on top of a map.

Secondly, workspaces may be composed more freely by placing sub-workspaces within an otherwise void super-workspace. This form of workspace composition is useful in creating conglomerate contexts, and allows sub-workspaces to be pushed out back to fluidly transfer them between the center of attention in the foreground to the background, while still being peripherally aware of them. This has been the typical use of Topos workspaces described in previous papers. Here sub-workspaces are

dynamically formed to give permanence to groupings of materials.

There are, of course, workspace compositions in between these two extremes. Abstract and sparsely furnished spaces allow users to move materials without completely losing their meaning and relation to the surroundings. An example of this can be found in Data Mountain and Task Gallery where the (relatively fixed) background geometry forms the furnishing of an abstract, but non-void, space.

Links between workspaces constitute an entirely different way of composing workspaces. As the entire context of the linked-from workspace disappears, no spatial relations exist between the two linked workspaces; only a temporal relation remains (viz. the Kuleshov effect [8]). This allows, for example, links from layer-like workspaces into free-form workspaces, which would be awkward using only proxies and transclusion [19]. In referring from free-form workspaces to layer-like workspaces it makes sense to use both transclusions and links.

It clearly makes sense to compose concrete workspaces as layers when they refer to the same geo-spatial coordinates, however, it also makes sense to compose abstract metaphorical workspaces as layers, where a layer may contain a special type of documents for example. Also, concrete workspaces may form part of larger abstract workspaces: Users may make a concrete workspace a part of their current workspace, and push it out back to be peripherally aware of co-workers walking around in the field.

We therefore view the layer versus free form composition semantics as independent of the metaphorical versus literal distinction.

OPEN ISSUES AND FUTURE WORK

Experiments with geo-spatial hypermedia of course raise a number of issues and questions, which we have no definite solutions for yet. We will mention a few here.

How to combine metaphorical and literal spatial information management approaches?

As mentioned in the previous section we provide a rich variety of composition semantics, which allow for many ways of composing both metaphorical and literal spaces. However, there are still a lot of open issues in deciding how to visualize the compositions in meaningful ways depending on the context. We can have the same material organized both in abstract project portfolios and mapped literally to locations in the real world. If we wish to work with these two workspaces in an integrated manner (a composite workspace) then it may require special visualization techniques to maintain the user's general view of the material and the different composition semantics. Design decisions may need to be tailored to specific application domains and more research is needed to identify the possibilities and constraints in this respect.

The role of spatial parsing in geo-spatial hypermedia

The Topos system includes a spatial parser [20] based on 3D proximity analysis. The spatial parser can recognize

clusters and more specific arrangements like tabular and list arrangements. This functionality is classical for spatial hypermedia support in abstract spaces. But it is not entirely clear which applications of spatial parsing will be useful in literal spaces with geo-spatial support. Here the placement of objects is typically tied to a specific location, and abstract clustering and automatic arrangement may potentially spoil the geo-spatial relationship to the "background" model of the part of the real world in question. We may, however, be able to use parts of the background model as a spine of a parse such that materials placed along a road may be treated as a structure. We may also need to introduce meta-data attributes, such as colors for the objects in space such that the spatial parser may cluster and highlight objects with similar Meta data. Finally, the spatial parser functionality may be used similarly as the proximity functionality in CVE [7] to provide ongoing calculations of the objects that given specific measures of aura, focus and nimbus relative to a user's camera will be rendered, activated or the like. But we need to do more research in the role of spatial parsing in the future of geo-spatial hypermedia.

Hardware supporting geo-spatial hypermedia

In our experiments with geo-spatial hypermedia, the application domain of architecture and landscape architecture has had a number of implications on our work with the actual physical interface. We envision a tablet computer like device (see mock-up in Figure 6), which is integrated with GPS, digital compass, mobile Internet, and a camera for taking pictures and placing them on absolute coordinates in the literal geo-spatial workspace. Information may be retrieved on the tablet computer and annotations may be entered relative to the actual location of the user in the space.



Figure 6: Geo-spatial hypermedia on a tablet computer



Figure 7: Hardware configuration of the current functional prototype of the geo-spatial version of Topos

Our current functional prototype integrating the necessary technologies in a less elegant design is shown in Figure 7. More research, engineering and design is needed to make this into an easy to use tool, e.g. for architects.

CONCLUSIONS

This paper has made an attempt on taking the abstract notion of spatiality so far explored in the hypermedia community into the area of literal and concrete spatial information management, where geographical location plays an important role. We call this new notion of spatial hypermedia for geo-spatial hypermedia, and we introduce a number of conceptual distinctions. We have also described our experiments with geo-spatial hypermedia in the Topos prototype. We discussed different ways of composing abstract/metaphorical workspaces with literal geo-spatial workspaces. Finally, we have described some open issues that need more research to achieve a more complete understanding of geo-spatial hypermedia.

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