From Latent Semantics to Spatial Hypertext
— An Integrated Approach

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Abstract
In this paper, we describe an integrated approach to the development of virtual reality-enabled spatial hypertext. This approach integrates several fundamentally related tasks into a cohesive and automated process, including latent semantic indexing, transformation between semantic and spatial models, and virtual reality modelling. The design of the visual user interface draws upon the theory of cognitive map. Initial empirical evidence suggests that the spatial metaphor is intuitive and particularly useful when an inherent organisation structure for the data is implicit, or a highly flexible and extensible virtual environment is required. Search patterns associated with the spatial hypertext found in our recent spatial ability study are also discussed with reference to the spatial design.

Keywords: Spatial hypertext, latent semantic indexing, virtual structure

INTRODUCTION

Generating flexible and extensible hypertext systems is a challenging task [22, 15]. There has been a rapidly growing interest in open hypermedia services (e.g., [3]), in which dynamic node-link binding strategies are often used to achieve desired flexibility and maintainability.

The notion of spatial hypertext relies on implicit structures that can be derived from how text is spatially organised by people. Marshall and Shipman [19] used the term linkless structure to describe how people use spatial layout to imply structure in three hypertext systems. They argued that the ability to find and use
implicit structures is important to users in spatial hypertext. In this paper, spatial hypertext refers to hypertext systems in which data are organised and accessed on the basis of a spatial metaphor.

In our previous work, we developed a framework that integrates several structuring mechanisms for generating virtual hypertext link structures [6]. In this paper, we describe how to develop spatial hypertext with such virtual structures, how to accommodate search and browsing in the same semantic space, and how to make these virtual structures more accessible using virtual reality techniques. We also briefly describe some empirical findings concerning the spatial user interface.

This paper is organised as follows. First, we describe the context of the work and introduce techniques used in our approach, especially Latent Semantic Indexing (LSI) and Pathfinder network scaling. Second, we describe the theory of cognitive map and its relations to our virtual reality modelling. These techniques are used to increase the flexibility of visual navigation in a complex semantic space. Users are able to search and browse seamlessly in the same semantic space. Finally, we discuss the implications of this approach for the design of hypertext systems.

RELATED WORK

An important requirement in our work is an integrated, iterative design framework that allows us to extract and represent latent semantic structures in spatial hypertext. A key element in our integrated approach is the use of Pathfinder associative networks [24]. This integrated approach addresses a number of interrelated issues: (1) deriving proximity estimates automatically from the source documents, (2) network scaling, (3) spatial-semantic mapping and (4) virtual reality modelling.

Existing applications of these techniques have focused on one or two components. For example, SemNet [13] and BEAD [4] essentially focused on spatial-semantic mapping. Pathfinder traditionally focuses on network scaling. LSI focuses on automated semantic indexing. In this study, we emphasise the significance of deriving a semantic structure and utilising the structure for building spatial hypertext.

There are apparent similarities between our visualisations and self-organised feature maps produced by artificial neural network techniques (e.g., [17]). The major difference between our approach and neural network-based approach lies in the way that the network structure is derived and represented. Comparing the two approaches more closely is certainly an interesting area of further research. In our previous work [6], we followed the classic tf×idf vector space model [23], whereas in this study Latent Semantic Indexing (LSI) is used instead (see Figure 1). We will explain ramifications of this change shortly. Orendorf and Kacmar [20] described a spatial approach to organising digital libraries, but their work took advantage of an existing geographical layout in their organisation, which may not always be available or appropriate for generic data visualisation (see also [18]). Structuring abstract digital documents in general presents a challenging issue which our work aims to tackle.
Marshall and Shipman [19] studied how people used spatial layout to imply structure in three spatial hypertext systems. They suggested that spatialised text allows authors to create volatile, implicit extensional hypertext, and allows users to interpret interrelationships according to perceptual conventions.

Information visualisation techniques, such as Fisheye Views [12] and Cone Trees [21], provide solutions to the problem of balancing local detail and global context. Many visualisation techniques are based on explicit attributes of a document or a set of documents, such as file size, file names, file system structure, or existing hierarchies of documents.

The focus of our work is on characterising and representing implicit but inherent structures. For example, how should large hypermedia systems be organised to maximise its usability and maintainability? What is the role of virtual reality in improving the accessibility of underlying structures?

In our previous work, virtual hypertext link structures were derived from interrelationships among documents. For example, content-based similarities were computed using the classic $tf \times idf$ vector space model in information retrieval [23]. However, this model relies on an assumption that terms in document vectors are independent. It has been realised that this assumption may be sub-optimal [e.g., 11]. Therefore, in this paper, we use Latent Semantic Indexing (LSI) to generate content-based similarities instead. We will explain why LSI and Pathfinder network scaling are used in the following sections.

**LATENT SEMANTIC INDEXING and Pathfinder**

Latent Semantic Indexing (LSI) is designed to overcome the so-called vocabulary mismatch problem faced by information retrieval systems [11]. Individual words in natural language provide unreliable evidence about the conceptual topic or meaning of a document. LSI assumes the existence of some underlying semantic structure in the data that is partially obscured by the randomness of word choice in a retrieval process, and that the latent semantic structure can be more accurately estimated with statistical techniques.

In LSI, a semantic space is constructed based on a large matrix of term-document association observations. LSI uses a mathematical technique called Singular Value Decomposition (SVD). One can approximate the original, usually very large, term by document matrix by a truncated SVD matrix. A proper truncation can remove noise data from the original data as well as improve the recall and precision of information retrieval.
Perhaps the most compelling claim from the LSI is that it allows an information retrieval system to retrieve documents that share no words with the query [11]. Another potentially appealing feature is that the underlying semantic space can be subject to geometric representations. For example, one can project the semantic space into an Euclidean space for a 2D or 3D visualisation (Figure 2). However, large complex semantic spaces in practice may not always fit into low-dimension spaces comfortably.

Figure 2. Scatter plots of CHI (left) and the CACM collection (right).

The notion of semantic similarity has been commonly used by structural modelling and scaling techniques, such as Multidimensional Scaling [16], Pathfinder [24] and Latent Semantic Indexing [11]. On the other hand, Pathfinder network scaling relies on a distinctive concept known as triangular inequality, which specifies that the distance between two points should be less than or equal to the distance from one point to another via a third point. Pathfinder network scaling selects links that satisfy the triangular inequality constraint into the final network representation. The idea is that these links are likely to capture the underlying structure.

The spatial layout of a Pathfinder network is determined by a force-directed graph drawing algorithm [14]. Such graph drawing techniques are increasingly popular in information visualisation due to its simplicity and intuitive appealing.

INTEGRATED APPROACH

Our integrated approach was applied to the three most recent ACM conference proceedings on Computer-Human Interaction (CHI) and the ACM Hypertext Compendium™ (HTC) [1]. The CHI collection includes 169 papers from CHI’95, CHI’96 and CHI’97. The HTC collection includes 128 papers and panels from conference Hypertext’87, Hypertext'89, ECHT’90 and other sources.

Latent Semantic Indexing (LSI) was used to generate a document-document similarity matrix based on the title, author names and the abstract of each document. Some common English words, known as stopwords in information retrieval, were excluded from the indexing process. These stopwords were commonly used by information retrieval systems, especially the SMART system. Document vectors in LSI used the logarithm of term-document occurrences as local weightings and the entropy as global weighting. This is a recommended choice [11].

We then generated the most restricted Pathfinder networks by imposing the tightest triangular inequality \((q=N-1)\) so as to produce associative networks with the least number of links. If the number of links in the resultant network is still too large, a Minimum Spanning Tree (MST) option is supported in our software based on [27]. On the other hand, a Pathfinder network has a very desirable feature — the structural representation is unique in that a Pathfinder network is the set union of all the possible MSTs.

Finally, the result of force-directed graph drawing of the network was automatically transformed into virtual reality models in Virtual Reality Modeling Language (VRML).
In addition to virtual structures of each individual data set, a coherent virtual structure was generated across a few different data sets. As can be seen from Figure 4, the affordances provided by this integrated visualisation have several possibilities. For instance, we have ongoing projects investigating the application of these techniques to standard text retrieval test collections, such as the CACM and Cranfield collections. One possible application is to use this method for visual analysis of an information retrieval process because researchers now can simulate and see how queries, relevant documents and retrieved documents are located in the semantic space. Therefore, the integrated view has many practical implications, for example to benefit performance in the area of information filtering and building personalised digital libraries that grow organically with use over time.

In this paper, the concept of a cognitive map is used in our user interface design to optimise the cognitive mapping between users' understanding of the environment and the abstract information space. The following section explains relevant concepts.

Cognitive Map

The concept of a cognitive map plays an influential role in the study of navigation strategies, such as browsing in hyperspace and wayfinding in virtual environments [9]. A cognitive map is the internalised analogy in the human mind to the physical layout of the environment [25, 26]. The acquisition of navigational knowledge proceeds through several developmental stages from the initial identification of landmarks in the environment to a fully formed mental map [10].

Levels of Knowledge

Landmark knowledge is often the basis for building our cognitive maps [1, 10]. The development of visual navigation knowledge may start with highly salient visual landmarks in the environment such as unique and magnificent buildings or natural landscapes. People associate their location in the environment with reference to these landmarks.

The acquisition of route knowledge is usually the next stage in developing a cognitive map. Route knowledge is characterised by the ability to navigate from one point to another using acquired landmark knowledge without association to the surrounding areas. Route knowledge does not provide the navigator with enough information about the contextual structure to enable the person to optimise their route for navigation. If someone with route knowledge wanders off the route, it would be very difficult for that person to backtrack to the route.

The cognitive map is not fully developed until survey knowledge is acquired [26]. The physical layout of the environment must be internalised by the user to form a cognitive map.

Dillon et al. [10] have noted that when users navigate through an abstract structure such as a deep menu tree, if they select wrong options at a deep level they tend to return to the top of the tree altogether rather than just take one step back. This strategy suggests the absence of survey knowledge about the structure of the environment and a strong reliance on landmarks to guide navigation. As hypertext designers, we are interested in exploring ways to help users overcome a reliance on landmarks so that they can discover optimal routes or paths during navigation. Fortunately, some studies have suggested that there are ways to increase the likelihood that users will develop survey knowledge. For instance, intensive use of maps tends to increase survey knowledge in a relatively short period of time [9, 25]. Other studies have shown that adding strong visual cues as to where paths, boundaries and nodes exit will benefit a user’s navigation and understanding of the structure of a virtual space [9]. Additional studies have shown that browsing through a table of contents is a preferred method over more analytical methods such as query formulation. Chimera and Shneiderman [7] compared three generally used interface methods for browsing hierarchically organised online information, including stable, expand/contract and multipane tables of contents. The expand/contract and multipane interfaces are designated to display the high-level information contiguously and give users the choice of viewing specific section and subsection levels on demand to provide a balance of local detail and global context [7]. Chimera and Shneiderman's experiments confirmed the superiority of
dynamic visual representations to static ones during browse tasks. Their findings also highlighted the role of structures in guiding people in visually navigating a large database or information space.

In sum, visual navigation relies on the cognitive map and the extent to which users can easily connect the structure of their cognitive maps with the visual representations of an underlying information space. On the one hand, the concept of cognitive map suggests that users need information about the structure of a complex, richly interconnected information space. On the other hand, if all the connectivity information is displayed, users would be unlikely to navigate effectively in spaghetti-like visual representations. How do designers of complex hypertext visualisations optimise their user interfaces for navigation and retrieval based on this conundrum?

One problem faced by designers is that information on explicit, logical structure may not be readily available. An explicit organising structure may not always naturally exist for a given data set, or the existing structure may simply be inappropriate for the specific tasks at hand. What methods are available for hypertext designers to derive an appropriate structure? How can we connect such derived structures with the user's cognitive map for improved learning and navigation?

In this paper, we focus on the situation when an explicit logical structure of a large collection of documents is not available or not appropriate for visual navigation. We also emphasize the need of an extensible and reconfigurable virtual environment.

In the following section, we will address issues concerning how to single out important structural characteristics to make visual navigation easier, as well as how to filter out redundant information in order to increase the clarity and simplicity of the visual environment.

**Virtual Information Spaces**

In this section, we introduce the design of visual representations of various semantic entities. We identify relationships between the user's cognitive map and visual representations of abstract entities that users may encounter as they navigate through the environment. In Table 1, we classify visual representations of objects in accordance with the three types of cognitive knowledge about the underlying environment, namely landmark, route and survey knowledge.

Visual representations in information visualisation systems often fall into two categories. A natural representation relies on an existing explicit structuring model, for example, data organisation according to a geographical layout. A metaphorical representation usually does not have an inherited organisation model to convey latent, implicit structures in the data, such as semantic structures. Our study essentially belongs to the latter category.

In later sections, we will show an integrated environment in which users have a wider range of options for accessing information. They are able to utilise visual representations for both search and navigation strategies to match the visual navigation to their specific cognitive knowledge.

**Table 1. Visualising the cognitive map.**

<table>
<thead>
<tr>
<th>Cognitive Map</th>
<th>Visualisation</th>
<th>Natural</th>
<th>Metaphorical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landmarks</td>
<td>Reference Points</td>
<td>Document Size</td>
<td>User Profiles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Creation Time</td>
<td>Retrieval Queries</td>
</tr>
</tbody>
</table>
VIRTUAL REALITY MODELLING

Virtual reality modelling is an integral part of our approach. It transforms the blueprint provided by Pathfinder and force-directed graph drawing algorithms to virtual worlds in VRML so that users can visually explore the virtual structure. Several direct manipulation tasks are supported in such virtual worlds, such as walk, spin, slide and examine. When users click on a document sphere, the document, whether it is local or remote, will be downloaded to their client-side browsers.

Table 2. Visualisation model.

<table>
<thead>
<tr>
<th>Digital Objects</th>
<th>Geometric Model</th>
<th>Attribute</th>
<th>Semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>document sphere</td>
<td>radius</td>
<td>size</td>
<td></td>
</tr>
<tr>
<td>document sphere</td>
<td>colour</td>
<td>source of data</td>
<td></td>
</tr>
<tr>
<td>link cylinder</td>
<td>radius</td>
<td>semantic similarity</td>
<td></td>
</tr>
<tr>
<td>link cylinder</td>
<td>length</td>
<td>latent semantic distance</td>
<td></td>
</tr>
<tr>
<td>query cylinder</td>
<td>height</td>
<td>matching similarity</td>
<td></td>
</tr>
<tr>
<td>query cylinder</td>
<td>colour</td>
<td>keyword</td>
<td></td>
</tr>
</tbody>
</table>

Direct manipulation-based user interfaces are easy to learn and use [7]. Virtual reality models provide new ways of interacting with the semantic space, such as walking back and forth through the space, which effectively overcomes the traditional focus-versus-context problem [12, 21]. VRML supports the notion of Level of Detail (LOD)—as the user approaches to an object in the virtual world, the virtual world increasingly reveals more information about the object.

By explicitly representing salient relationships between two documents in a virtual link structure, users are able to see the connectivity patterns in the entire semantic space. Virtual link structures of different natures, be they hyperlinks, content similarity, navigation patterns or bibliographic citations, can be combined and animated to help users to make sense of the complex semantic structure.

VIRTUAL STRUCTURES and spatial hypertext

We present the following examples to illustrate the use of these virtual structures for spatial hypertext.
Figure 3 shows the virtual space of the recent CHI proceedings (1995—1997). This virtual space is based on the latent semantics characterised by LSI and link structures determined by Pathfinder network scaling. When the user moves the mouse cursor over a document sphere in the structure, the title of the document will appear at the point of the cursor. If the user clicks on the sphere, the abstract of the document will appear in the right-hand side frame.

Figure 3. The virtual structure is used with a WWW browser.

**Landmarks**

In our spatial hypertext, predominant landmarks are related to search relevance rankings. A cylinder will appear on a document if the document is sufficiently similar to the query. If the query has a number of distinct terms, the resultant cylinder will consist of cylinders for terms that reached sufficiently high rankings. These landmark bars are coloured and labelled to enable users distinguish them easily. Neighbouring documents are often likely to contain more keywords, in our experience. The structuring techniques used to build the information visualisation tend to group documents on similar topics near to each other.

Once the user identifies the document with the highest cylinder landmark (indicating the most relevant neighborhood of documents to search through), then he/she can use this document as a starting point to explore the semantic space. For example, some documents nearby may not contain particular terms used in the query, but since they are grouped together by LSI they are likely to have something in common, and thus are worth exploring. The user may simply want to click on the bar’s corresponding node and read the most relevant retrieved paper directly.

The virtual space in Figure 4 visualises the result of a search of keywords *digital library* and *spatial map* on the basis of the overall semantic structure of CHI proceedings. In the landscape view, for example, vertical bars highlighted papers that have good match to these words. The height of each bar is proportional to the strength of the match. For example, the best match for *spatial map* (similarity=0.724) is at the far end of the scene in Figure 4b with the highest vertical bar.
There are two general types of hypermedia networks—homogenous or heterogeneous. In a homogenous network, all the nodes are of the same type; for example, the network contains papers and nothing else. In a heterogeneous network, one may deal with different types of nodes; for example, the network not only contains papers, but also contains user profile of their information interests and sample queries (even though many studies have regarded queries as a special type of documents). These nodes can be regarded as a special type of landmarks, or reference points. There is a similar notion known as unfolding in psychology [16], in which subjects and stimulus are embedded into the same space.

Figure 5 shows three independent data sets embedded into the same coherent virtual structure. CHI papers are coloured in light blue (1995), light green (1996) and light red (1997). Red spheres are HTC papers and the dark blue ones are papers by one of the authors. Users now can access the three data sets from the single virtual structure, while the original data sets remain intact.
Figure 5. A coherent virtual structure of 304 papers from three sources, including 169 CHI papers, 127 ACM HTC papers and panels, and 8 papers from the first author.

The merged virtual structure allows us to visually analyse cross-domain interconnections. Neighbouring documents in the space should be of particular relevance to the person. One can use software agents to import other papers into their current personalised digital library automatically.

**Route Knowledge**

Links preserved by the Pathfinder network are explicitly displayed in our current visualisation techniques. A route from one paper to another has the minimum cost, or the strongest connecting strength. The presence of a route in the virtual environment therefore suggests to the user that papers on the route between two relevant papers may be worth browsing.

Papers from different years were coloured differently. This colouring scheme was designated to detect emerging trends in research questions and application domains addressed by papers in consecutive years of conferences. For example, if we see a group of papers gathered together in blue (i.e., papers from the latest conference), it suggests that new topics are introduced into the conference series. If a group of papers clustered in the network includes every colour but blue, then this may suggest that a particular area was not addressed by papers accepted for the conference.

Self-organised node placement in our approach is based on the spring embedder model, which belongs to a class of graph drawing heuristics known as force-directed placement [14]. The positions of nodes are guided by forces in the dynamic systems. The satisfactory placement is normally obtained when the spring energy in the entire system reaches the global minimal.

General aesthetic layout criteria include minimising the number of link crossing and overlapping, symmetrical displays and closeness of related nodes. We use the term *self-organisation* in this paper to emphasis the role of these heuristics in satisfying several potentially contradicting aesthetic requirements. Although the spring embedder algorithm does not explicitly support the detection of symmetries, it turns out that in many cases the resulting layout demonstrates a significant degree of symmetrical arrangements.

In addition to the layout heuristics, a good navigation map should allow users to move back and forth between local details and the global context, to zoom in and out the visual display at will, to search across the entire graph. More advanced features may include simulation and animation through consecutive views. Our initial studies show that many of these requirements can be readily met by Virtual Reality Modeling Language (VRML), especially VRML 2.0.

**Survey Knowledge**

Visual navigation in our virtual environment starts with an overview from a distance. Users then approach the centre of the virtual world for further details. Users have a number of options, such as *walk*, *spin* and *point*. In next section, we start with how an overview of an underlying information structure is presented to the user who is visually navigating in our virtual environment.

In the following section, we discuss some preliminary findings from our empirical study in the context of the overall design experience.

**search parttens and spatial ability**

Previous studies in hypertext suggested that spatial ability may be a significant factor affecting users’ satisfaction and performance with spatial hypertext systems. We have recently conducted an empirical study to investigate the interaction between users' spatial ability and their search patterns with the spatial
hypertext. Here we will summarise some interesting findings of our empirical study. A more detailed report of the empirical study will be available shortly.

In the empirical study, subjects were asked to find papers related to particular topics within a 30-minute interval. For example, in one task, subjects were asked to find as many papers as they could on information visualisation. In particular, the recall and precision measures were used based on our own relevance ratings. Recall was positively correlated with spatial ability based on a spatial pretest’s paper folding scores in two search tasks ($r = 0.42$ and $0.37$, respectively). Precision was strongly negatively correlated with spatial ability in these tasks ($r = -0.53$ and $-0.18$, respectively). We spend some time discussing this interesting pattern of findings [5]. The important point is that spatial ability strongly influences users’ search patterns in these virtual spaces. Individual differences should be considered when designing information visualisations such as ours, and perhaps adapting the users’ abilities over time would be ideal.

**Navigation Strategies**

In order to study navigational patterns in the spatial semantic space, we superimposed the frequencies of accessing papers that are judged relevant in the first search task, according to a pre-determined relevance judgement, over the visualised semantic structure (see Figure 6). Relevant papers are marked as boxes and the number of dots beside each box indicates how many different individuals successfully found that target.

Task performance scores suggest that subjects did reasonably well if targets were located in some structurally significant positions in the spatial hypertext. However, if task-relevant papers were located in outskirts of the structure in the user interface, subjects were less successful. In addition, subjects seemed to be affected by the varying visibility of topical keywords (i.e., whether a search word appears in the title, or is hidden in the abstract, or there is a complete vocabulary mismatch) across the semantic space. This could be a serious issue if one cannot easily recognise the relevance of a paper, especially when they are located in a key position, such as a gateway or a branching point. (We found that these positions, or hotspots, were typically examined by subjects in their first few moves; the navigation route would be different if one failed to recognise a relevant paper because he/she is likely to look for elsewhere, instead of exploring targets locally.) We will further discuss this issue in later sections.

![Figure 6. The locations of search targets.](Image)
ignored during the initial search. Then subjects would check a number of positions on the circle, especially
points connecting to branches. Over time, subjects would gradually expand their search space outwards to
reach nodes farther away from the central area. An example of a good strategy observed was that one
subject sampled a single node in each cluster and moved on to other clusters quickly during the initial
stage. This strategy maximised the likelihood of not becoming lost in a local minimum.

Some subjects hopped from one cluster to another in long jumps, whereas other subjects carefully
examined each node along a path according to the virtual semantic structure. Subjects who made longer
jumps apparently realised that they might be able to rely on the structural patterns to help with their
navigation. Navigational patterns also highlighted the special role of distinctive structural patterns such as
circles, stars, and long spikes as we expected. We will be analysing the video more thoroughly to gather
more detailed data about navigation strategies and report our findings in the near future.

Spatial Memory

The spatial memory test provided an alternative viewpoint to look at the interaction between visualised
semantic structures and individuals' understanding of how the semantic space is organised. By identifying
what subjects learned about the structure and how the their remembered user interface details vary from
one area to another, we were able to understand more about various characteristics of our visual semantic
structure.

Figure 7. Subjects' sketches of the semantic information space searched during the study.

Figure 7 shows the sketches of the semantic space from two subjects. These sketches show not only that
these subjects have focused on different areas in the semantic space, but also that subjects can remember
the semantic structures inherent in the user interface quite vividly. These figures are partially related to the
differences in interactions between subjects’ navigation strategies and their emerging cognitive maps. One
interesting question that awaits future research is whether subjects’ maps would converge over repeated
exposure and use of the information space.

Most subjects clearly remembered the shape of the central circle. In (a), the subject highlighted the central
circle and three sub-areas around the circle. The video analysis confirmed that these had been the most
often visited areas in his search. In (b), the subject was able to remember more details about the branches
surrounding the central circle. In addition, he added some strokes inside the circle, although they were not
as accurate as other structural patterns in his sketch. While this provides an brief hint of how subjects’
spatial memory may be influenced by this information visualisation, as well as their individual differences
in ability and strategy, we will continue to analyse these structures for meaningful implications for 3D user
interface design.

CONCLUSION

In this paper, we have described an integrated approach to the development of spatial hypertext. We have
emphasised the integral parts played by Latent Semantic Indexing (LSI), Pathfinder networking scaling and
virtual reality modelling. A number of powerful techniques are naturally integrated into a generic,
extensible and fully automated methodology. The use of virtual structures transcends the boundaries of the
source data originally stored — they leave all the original data intact. We have also demonstrated that searching and browsing can be accommodated within the same semantic space.

The design practice and our preliminary empirical evaluation have provided some valuable experience and insights into the spatial hyperspace. We are planning to conduct more studies in related areas, such as evaluating the usability of such virtual environments and investigating the role of individual differences in the use of spatial user interfaces, especially spatial ability and cognitive styles.

We are undertaking a project to create a semantic space on the WWW for all the abstracts of the British Computer Society's HCI conference proceedings since 1985. We will explore practical issues in our ongoing projects. We will investigate dynamic space transformation in response to usage patterns of users. We will explore more opportunities of applying this approach to real world situations as a part of an iterative development of the methodology.

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