Verhoeven, A. and Warendorf, K. *External Navigation Control and Guidance for Learning with Spatial Hypermedia.*
Journal of Interactive Media in Education, 99 (1)
[www-jime.open.ac.uk/99/1]

Published
15 March 1999

ISSN: 1365-893X

External Navigation Control and Guidance for Learning with Spatial Hypermedia

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Abstract:

The World Wide Web has become a widely available platform for learning with hypermedia. However, WWW hypermedia is often limited in both guidance and navigation support. To improve hypermedia in these aspects, we propose a spatial hypermedia browser for educational purposes. A prototype browser, named HyperMap, has been designed to integrate guided explorative browsing with external control over a learnerís navigation. The flexible control by authors over navigation allows the integration of traditional courseware elements into hypermedia. We explain how the direct manipulation authoring environment in HyperMap simplifies the construction of a curriculum in spatial hypermedia. Object libraries and scripting of adaptive hypermedia objects help a HyperMap author to be productive. We include recent follow-up field-tests at NTU that confirmed the effectiveness of learning with HyperMap spatial hypermedia. The theoretical prospects of further integration of hypermedia with rules for intelligent tutoring are outlined as well.

Keywords:

Adaptive Hypermedia, Spatial Hypermedia

Interactive demonstration:

A Java applet of the *HyperMap* system is embedded in this article for which you will need a Java-aware web browser compatible with Sun's JDK 1.1.4 or higher (Internet Explorer 4.0 and Netscape Navigator 4.5 work without difficulty). A local copy of the system can be downloaded for offline execution, from the JIME site or from http://members.xoom.com/tverhoeven.

Commentaries:

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0. Scope of this paper

This paper describes experiences with an experimental browser for spatial hypermedia, named *HyperMap*. As such, it is mainly an 'ideas and experiences' paper. The HyperMap prototype was de-signed to investigate the suitability of spatial hypermedia for education in general. This paper ad-dresses the issues regarding spatial hypermedia for learners as well as for authors, and how the Hy-perMap browser addresses them. Because HyperMap is a work in progress, not all of its design and features have been completely validated by rigorous empirical testing. However, recent data from a HyperMap field-test with 53 subjects showed a moderately positive assessment of HyperMap by learners. The data confirm our experiences that education with a non-WWW spatial hypermedia browser in the classroom is a feasible option. Discussed on a more theoretical level are the benefits of spatial hypermedia to guide hypermedia learners, whereby a natural form of external control of authors over a learner's navigation is possible. Not every implementation of these new approaches has been field-tested yet. The major focus of this paper is on the HyperMap approach, based on spatial hypermedia, to address the authoring bottleneck, a critical factor for the usability of any custom hypermedia standard. Hy-perMap has been influenced by earlier evaluations of educational WWW systems. The benefits from spatial hypermedia for hypermedia authors are illustrated by practical examples from the direct ma-nipulation environment of HyperMap. The theoretical aspects discussed are three levels of spatial guidance, and prospects for the future integration of spatial hypermedia with didactic intelligent tu-toring features; the HyperMap prototype does not yet support these features. The main goal of this pa-per is to show the feasibility of spatial hypermedia in education, based on encouraging experiences with the HyperMap prototype.

1. The growing importance of hypermedia for education

Over the past years, educational hypermedia applications, different from ordinary World Wide Web sites, have appeared on theWWW. These *adaptive* hypermedia systems, categorised by Brusilovsky (1996), have in common that users are guided towards the paths that are considered optimal for learning. The goal of including guidance in adaptive hypermedia is to prevent disorientation. When users are occupied with learning tasks, guidance is a critical factor in the effectiveness of educational hypermedia system. Adaptive hypermedia guides a learner through a hypermedia-based curriculum, applying a tutoring style that matches the personal learning style and knowledge level of the learner. An adaptive hypermedia system maintains a student model and generates individualised adaptive hypermedia content. This approach to learning with hypermedia is reflected in several systems on the WWW. In the domain of computer programming, examples are systems from Brusilovsky, Schwarz and Weber (1996) and from Soga, Kashihara and Toyoda (1995).

Although advantageous for system developers because of its familiarity, the technology of HTML browsers has a number of limitations. The accuracy of external navigation control over a learner and the level of adaptation is limited. The general-purpose user interface of WWW browsers, with no systematic navigation support available, is likely to further increase the occurrence of disorientation in learning tasks (Verhoeven and Warendorf (1997).

For authors of adaptive hypermedia, the limited control over a learner's navigation path, often with no real-time user modelling, is also limiting (Brown and Benford, 1996). One approach to overcome this is through hybrid architectures consisting of a WWW browser expanded with applets or plug-in browser helper applications. However, there are technical and practical drawbacks, especially for distance education, as concluded in Verhoeven and Warendorf (1998). One drawback is that applets and plug-ins often lead to inconsistent user interfaces that may hinder learning.

We propose spatial hypermedia, with a custom browser and hypermedia format, to address the following major factors in the effectiveness of educational hypermedia:

1. ease of use of the graphical user interface;
2. accuracy in user modelling;
3. frequency of interaction with hypermedia content;
4. support for navigation;
5. guidance and external control over navigation.

Addressing the above requirements well can improve educational hypermedia in several respects. Detailed user modelling will improve the quality of didactic guidance. External measures to control navigation will benefit from this refinement. Also, with flexible control over the navigation style of learners, increased interaction between system and learner is likely. Two major problems associated with educational hypermedia—disorientation, and the enforcement of navigation paths that conflict with a learner's preferences—can thus be prevented.

Without ignoring the benefits from unguided exploration of hypermedia, there is also a form of learning that benefits from a more strictly controlled navigation. Empirical research by Jones and Berger (1995) has pointed out the adverse effects which random browsing behaviour has on learning with hypermedia. To prevent random browsing, educational hypermedia must be able to guide or enforce navigation restrictions on learners, especially when the order of the hypermedia content is essential. Still, unrestricted hypermedia browsing can motivate learners, and should be allowed wherever effective.

1.1 Scenarios for learning with spatial hypermedia

To give an overview of the potential of the HyperMap prototype hypermedia browser for education, two scenarios for learning follow here. 'Learning' is an activity with many dimensions. 'Learning with hypermedia', is in this context not targeted at a particular knowledge domain, age or level of the student. Learners can be twelve to adult; the domain can be primary geography or a university level software engineering course. One starting point in the HyperMap design is that the huge variation in structure, guidance, and content in educational hypermedia material for different populations of learner can in most cases be expressed sufficiently in the spatial hypermedia format of HyperMap, without fundamental differences in the authoring process.

In the following paragraphs, two scenarios of HyperMap application in formal education are outlined. The first scenario is a hypothetical geography hypermedia application, built with the HyperMap authoring environment. The second scenario, university level software engineering education, is based on an actual field-tested prototype application developed at the School of Applied Science at Nanyang Technological University (NTU). Actual screen snapshots and data from a survey are included as proof of concept of the HyperMap design.

1.1.1 A hypothetical scenario: spatial hypermedia in Primary Six

A primary sixth grade teacher is preparing her geography lesson for tomorrow. Her aim is to illustrate the position and relative distances of a number of cities in the Netherlands, and present related WWW pages. The time slot to prepare the hypermedia page is about half an hour.

To start, the teacher uses a scanned picture of a map of the Netherlands into HyperMap as the background of a HyperMap page. Next, she selects the WWW links as additional information for the geography lesson. She places the WWW link symbols on the map close to the cities they relate to. Then she adds a hyperlinked menu of all cities in the top left corner of the map. The menu is constructed from an adapted component copied from a HyperMap library page. She then stores the final result (Figure 1) on the school's WWW server to cater for distance education. Students will start the application as an applet from a WWW browser or a stand alone Java platform.

Figure 1: *Geography class with HyperMap – Shown here is a geographical HyperMap page aimed at primary six students. Students can navigate over the map locate cities, which contain WWW links a traditional WWW browser.*

1.1.2 A field-tested scenario: spatial hypermedia at university level

HyperMap has been field-tested in a Software Engineering laboratory class, as part of a final year research project by Ho and Peh (1998). The subjects were 53 students from the School of Applied Science at NTU. The sample consisted of 32 first- and 21 fourth-year Computer Engineering students. The course material consisted of HyperMap maps filled with examples and explanations on data structures. Figure 2a-c displays two HyperMap pages from the course material, including a survey.

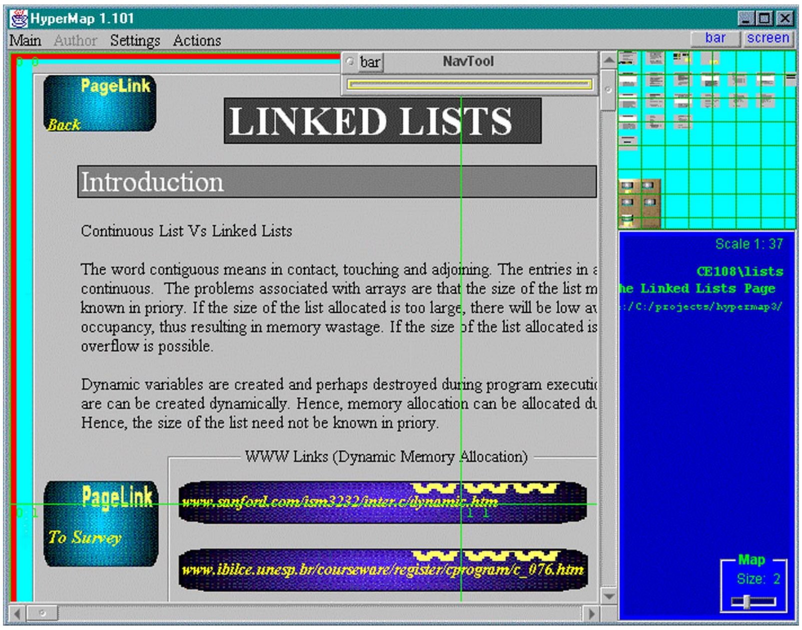


Figure 2a

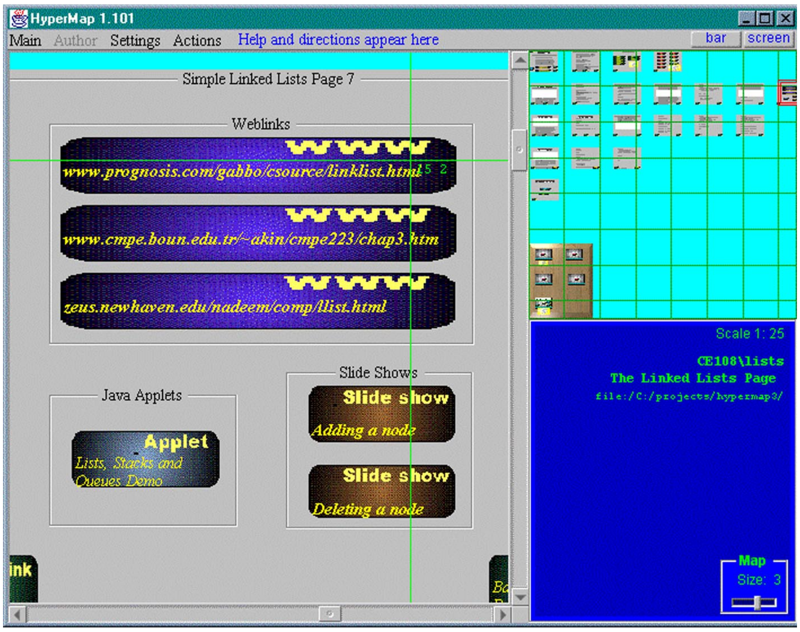


Figure 2b

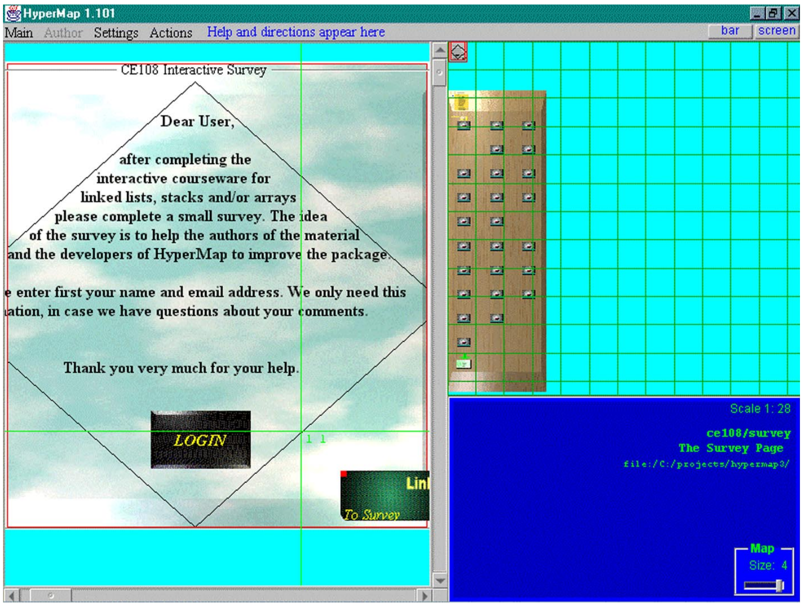


Figure 2c

Figures 2(a-c): *A software engineering course in HyperMap. Snapshot 2a displays the introductory top left corner of a HyperMap page. It contains 22 large hypermedia elements. 2b displays the page area with clickable resources such as WWW links, applets, and slide shows. 2c displays the survey with multiple and open-ended questions, answered as part of the field test.*

1.1.3 Empirical results from learners' experiences with HyperMap

The outcomes from the survey of 53 students by Ho and Peh indicated a general positive learning experience with HyperMap to learn data structures. Forty students (75%) replied 'Yes' when asked if the HyperMap user interface was easy to use. Thirty-one students found that HyperMap stimulated their interest in data structures. Critical comments were mostly in the area of the relatively slow navigation speed, a consequence of HyperMap's implementation in Java.

It is noteworthy that the survey of HyperMap was done with HyperMap. The HyperMap authoring environment allows the construction multiple choice questions, which can be closely integrated with learning material for direct testing and guiding. The survey showed that students appreciate the usefulness of direct feedback. A significant proportion of the surveyed students considered feedback from multiple choice and open questions a good test of their knowledge of the topics. More precisely, 84% of first year and 57% of fourth-year students supported this statement.

A final finding from the survey mentioned here is the added value of HyperMap for understanding data structures, compared to lectures. Forty-seven percent of the fourth year students thought learning with HyperMap had added value, while 29% found HyperMap not effective. For first year students the response was 56% positive versus 22% negative. Qualitative comments were in majority on the slow speed of scrolling. Considering the slow application speed, the general attitude of learners is encouraging.

1.2 Aspects of Spatial Hypermedia applied in education

To achieve a close integration of the five aspects mentioned, our hypermedia design has been based on *spatial* hypermedia. Marshall and Shipman III (1995) introduced spatial hypermedia as an environment that provides computer support for co-operative projects. The potential of spatial hypermedia for educational applications has not been fully investigated yet. We regard spatial hypermedia as a promising hypermedia paradigm that allows the construction of flexible and individualised curriculum in educational applications. This is in general not well supported by traditional browsers; usually the hypermedia document format technically limits these features as well.

Spatial hypermedia allows an abstract information space to be represented as a two dimensional plane with hypermedia objects located on it. Objects are organised in configurations. Hierarchies, categorisations, and informal groupings of objects convey semantic relationships between them. The means to organise objects into a curriculum allows spatial hypermedia authors to incorporate a flexible tutoring style. The style is based on a combination of external control over navigation and of guidance of learners. Creating a flexible tutoring style that changes per subject and/or learner can increase the motivation of learning and the effectiveness of learning through hypermedia. From the various tutoring styles for intelligent tutoring systems, such as scaffolding, cognitive apprenticeship, and free exploration in microworlds, we aim to create a dual-initiative tutoring style. Elsom-Cook (1998) combines tutoring with exploration in educational adaptive hypermedia. With the current generation of authoring tools it is not straightforward to include a tutoring style into educational hypermedia. Our design of a browser with a hypermedia document type aims to provide *dual initiative* tutoring in spatial hypermedia environments, discussed further in Section 7.3.

1.3 HyperMap authoring through direct manipulation

A major focus of this paper is on the authoring of educational spatial hypermedia through direct manipulation. Lowering the barrier for classroom teachers to swiftly publish learning material in hypermedia format is a condition for widespread integration of hypermedia in schools and elsewhere. An optimal authoring environment does not only help transformation of textbooks into hypermedia format. It also means that a teacher is able to quickly add the answers from today's questions into the hypermedia material due for tomorrow's class.

To minimise the learning curve for hypermedia authoring, a major aim of HyperMap design was to make the authoring process more intuitive through object-oriented hypermedia. Each hypermedia object allows customisation through direct manipulation, after being copied from hypermedia object libraries. The authoring process resembles working with commercial presentation packages. A second HyperMap feature to help an author is an authoring environment that is similar in appearance to the HyperMap user environment and closely integrated to it.

Because the structure of hypermedia is very much dependant on the type of learning material, the classroom setting, and the target population, we do not prescribe a 'one-size-fits-all' approach to authoring with HyperMap. Usually, an author has the best view on her particular teaching objectives and how to achieve them. Support may come from HyperMap maps to provide skeletons for a HyperMap page.

Authoring in HyperMap does have its distinct character because of its object-oriented structure and its design for education. Typical authoring actions are copying, editing, pasting and cutting of large and small hypermedia objects. In addition, because the author can restrict navigation to guide the learner, authoring is different from HTML authoring in various aspects. To illustrate a typical practical order in the activities of authoring a large HyperMap, section 6 describes the construction of a large spatial hypermedia document in six stages.

1.4 Three levels of external control over hypermedia navigation

Central concepts in the HyperMap approach to spatial hypermedia are external navigation restriction and guidance of learners towards an optimal learning path. Navigation control is immediately avail-able for HyperMap hypermedia authors during the construction of course material in spatial hyperme-dia. Three levels of navigation control have been identified, explored in detail in sections 3, 4, and 5. The first level of navigation control is based on properties of hypermedia objects. The second level describes navigation control through questions. The third and last level describes knowledge-based control of navigation and guidance. Through section 6, the prototype of HyperMap illustrates the practical implications of constructing hypermedia content that is extended with external navigation control and guidance. Also the benefits from linking with an intelligent tutoring system, not yet im-plemented, are discussed in section 5.

2. Navigation in Spatial Hypermedia

Spatial hypermedia is the general design framework behind the design of a spatial hypermedia browser prototype with its custom hypermedia document format. A design starting from scratch allowed us to avoid the restrictions of available general-purpose hypermedia standards. The approach to hypermedia design and implementation followed s described by Verhoeven and Warendorf (1998) as the *Minimalistic Java Approach* for rapid prototyping Internet clients in Java. The five aspects of effective adaptive hypermedia for education have influenced the HyperMap browser design.

The HyperMap design combines several novel approaches to the role of external navigation control and guidance in spatial hypermedia. In this context, *external control* refers to the restrictions of the navigation of learners to improve the effectiveness of learning from hypermedia. Usually these measures are added to a hypermedia server. In the HyperMap browser these are integrated to allow responsive standalone applications.

Spatial hypermedia was selected as the hypermedia paradigm for HyperMap for the following reasons:

- The direct map metaphor of spatial hypermedia offers direct navigation support. The map relates directly to daily experiences with guidance from a map. All hypermedia navigation is translated into 2D movements over a large information space. To access different locations in the information space, the user has several mechanisms to scroll the information space.

- Navigation based on scrolling allows the implementation of tutoring with automatic scrolling and restriction of scrolling.

- A custom hypermedia format allows definition of a more extended hypermedia link model. Extended link models support intervention of browsing through a rule based or other knowledge source.

- A Multimedia presentation can be integrated naturally in the spatial hypermedia document as a slide show. There is no interruption caused by leaving the spatial hypermedia paradigm. Sound and pictures can also be combined into a spatial hypermedia tour, which relies on scrolling.

- Applications with a small map embedded in the user interface have become commonplace in gaming software. Young students will expecially benefit from this familiarity.

Hypermedia Objects	Educational function
Non-interactive objects	
1. Text displays	Convey information
2. Image displays	
3. Arrows	Express an explicit yet informal semantic relation between subjects
4. Memos	
5. Collections of nested hypermedia objects	Organises information in a hierarchy
Interactive objects	
1. Navigation restricting Collection	Impose explicit navigation restrictions
2. Link to hypermedia object	Allow Exploration / continuation
3. Link to a new HyperMap	
4. Navigation restricting Conditional Link	Prevent haphazard browsing behaviour
5. Collection of nested hypermedia objects	Structure interactive learning material
6. Navigation restricting Collection	Prevent random browsing behaviour
7. Open-ended question	Test the learner's knowledge level
8. Multiple choice question	
9. Evaluation	Provide feedback and references for further browsing
10. Help pop-up object	Offer non-intrusive help
11. Sound	Offer sound clips or voice-overs
12. Slide Show presentations	Integrate multimedia presentation in Hypermedia
13. Guided tours	Offer navigation support on first entry
14. Applet	Integrate external simulation environments ("micro worlds") within spatial hypermedia
15. WWW page	Integrate external HTML resources in spatial hypermedia

Table 1: *The hypermedia objects of HyperMap. Currently there are five non-interactive and fifteen interactive object types implemented*

Table 1 displays the set of the visual hypermedia objects currently available in HyperMap. In its most basic form, a HyperMap object is a static display of text or graphics. The object may be a collection, in which case it contains several objects and may be part of a hierarchy resembling a *book-chapter-page* hierarchy, resembling textbook content.

Depending on the object type and properties added by the hypermedia author, the object will respond to a mouse click. On activation, a slide show will display slides. A hypermedia link will cause scroll-ing of the page. Each object type has a specific property editor that allows basic hypermedia authoring without programming. For questions and evaluation objects, a simple scripting language is used.

2.1 Navigation in spatial hypermedia with HyperMap

All navigation and spatial orientation in HyperMap is based on continuous visibility of a scaled map of the information space. The map outlines the position of the currently visible part within the information space, and conveys immediately the structure and type (pictures, text, exercises, etc.) of the content. It also offers a straightforward navigation method through pointing, clicking and scrolling. The map resembles a real-world topographical map, complete with a grid and grid co-ordinates. Small details are displayed on the map in exact scale, with large captions and titles still readable to provide maximum information on the structure of the information space. In Figure 3, the size of the information space has been limited for reasons of clarity. A HyperMap page can be scaled up by several factors, the largest of which displays only an area the size of the screen. Outside areas become visible after scrolling the HyperMap under the visible window. The similarity with topological maps is usable for topological applications, as illustrated in Section 1 (Figure 1). However, abstract application domains can also be created as two-dimensional maps. The results from the field-testing in the domain of software engineering support this claim.

The effectiveness of maps for hypermedia navigation in educational settings is a topic that has been investigated extensively by various hypermedia researchers. Field tests with subjects show that the benefits of maps in hypermedia systems do not always help navigation in educational assignments. Dias and Sousa (1997) suggest that cognitive maps may have an adverse effect on navigation and orientation in hypermedia. These conclusion are, however, not predictive for the HyperMap browser. The role of a map in the HyperMap browser is different from abstract cognitive maps. One difference is that the HyperMap map is a topological map of the information space, with all items scaled identically. As suggested by Dias and Sousa (1997), the test results with cognitive maps do not necessarily apply for topological maps. A second difference is that in HyperMap the map is continuously visible. As a result, there is no navigation back and forth between the map and the educational material, which would interfere with learning. The HyperMap browser design offers instant orientation without requiring additional effort from the user.

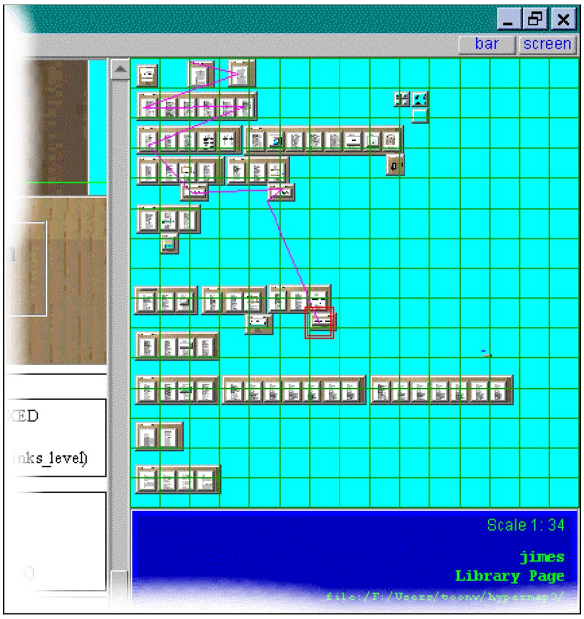


Figure 3: *Navigation support. A map is the central navigation and orientation tool of the HyperMap browser. (In this figure, we have zoomed in on the map in the the top right corner of the screen shown.) Also shown is navigational support from a trace of where the user has been, visible as the line connected to the central box in the centre showing the current visible area.*

2.2 Collections and hypergraphs in spatial hypermedia

In spatial hypermedia groups of hypermedia objects are organised into spatial *collections*, a term from Marshall and Shipman III (1995). Collections cluster the hypermedia content into semantically connected groups, with implicit and explicit links. The specific lay-out of a group of objects can be informal, hierarchical, or have any other configurations that conveys well the relations between the hypermedia objects.

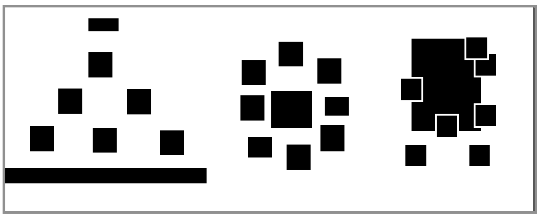
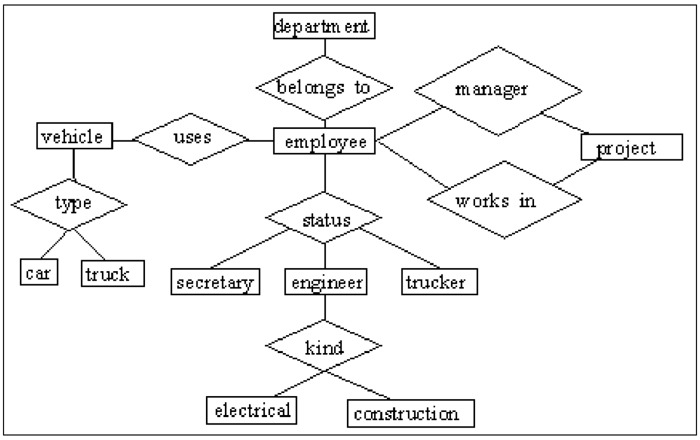


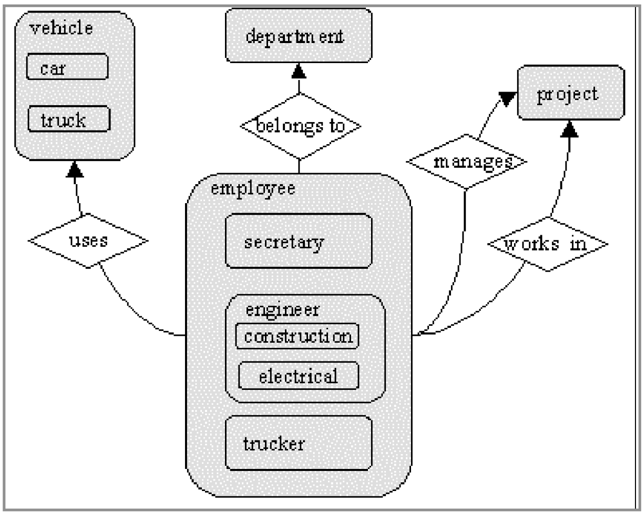
Figure 4: *Collection as structure in hypermedia objects – The relation between objects in a 2D space can be structured as hierarchical, around a central concept, or more informal (after Marshall and Shipman III, 1995)*

In addition to the above structuring, the spatial hypermedia format of HyperMap has been influenced by *hypergraphs* as well. Hypergraphs are visual notation formalism proposed by Harel (1988). Harel claims that a classical entity-relationship (ER) diagram can be expressed more clearly as a hypergraph when it is beyond a critical size. The usage of hypergraphs in spatial hypermedia has the advantage that the logical navigation paths, either implicit or explicit, are more immediately apparent through the use of arrow symbols of different size, depending on the place in the hierarchy.

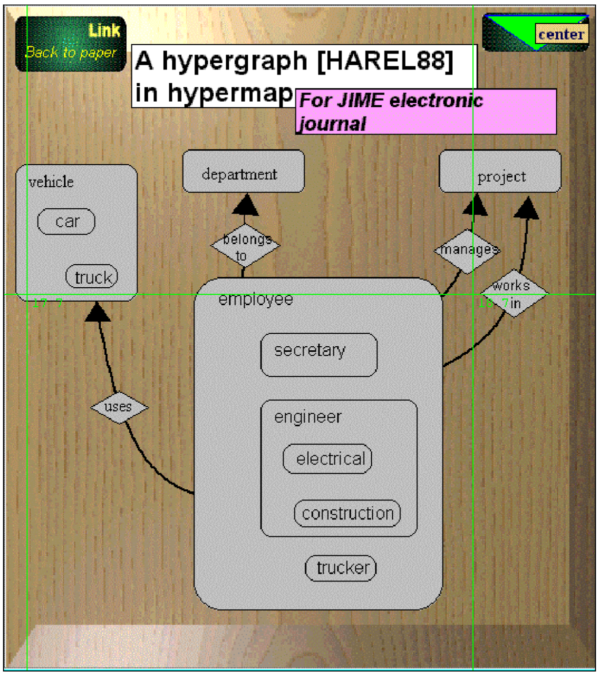
Hypergraphs are promising for spatial hypermedia because they may improve the expressiveness of spatial hypermedia collections after zooming out. With patterns or colours, the overall structure of a zoomed out hypergraph remains clearer when compared to ER diagrams that consist of small items only. In contrast, more central concepts in a hypergraphs will also have larger dimensions since they contain related entities. The result is that more expressiveness can be achieved on large HyperMaps than with ER diagrams. Figure 5 illustrates the relation between ER diagrams, hypergraphs, and hypergraphs displayed as spatial hypermedia objects. Because the example diagram fits on a screen, no distinctive colouring scheme has been used in this example.



A



B



C

Figure 5: *Hypergraphs - An Entity-Relation diagram (A) can be transformed into a Hypergraph (B). A hypergraph can be expressed in HyperMap through collections and arrows to add in the visual clarity of hypermedia documents.*

The arrows in hypergraphs are not to be interpreted as explicit hypermedia links that completely prescribe temporal order in hypermedia browsing. Hypergraphs are introduced here to increase the number of visual cues that remain visible on a small map, thus robust for scaling, where small textual information is invisible. In multi-screen sized hypergraphs, some overview can b retained by colouring substructures to be identifiable on the map.

An advantage for hypermedia authors is that hypergraphs can be efficiently constructed from object oriented hypermedia structures. Because a top-level hypergraph structure contains its own substruc-tures, the automatic copying and pasting of these substructures helps fast generation of large hyper-graphs. Although there is no intrinsic restriction on the size of hypergraph structures, a hypergraph without additional cues such as colours and font sizes should be kept small to remain understandable. Rigorous empirical testing of the benefits of hypergraphs is required before specific guidelines on the application and effects of hypergraphs in hypermedia can be given.

2.3 Navigation in spatial hypermedia -- implicit and explicit links

2.3.1 Implicit hypermedia links

In spatial hypermedia, hypermedia links can be implicit or explicit. Implicit links exist between hypermedia objects that are in close proximity to each other; this indicates a weak semantic relation between them. The objects can consist of text, picture, sound, or a combination of these. With no or minimal scrolling activity required, the user is encouraged to explore information related to the current topic of interest. A main difference with HTML based hypermedia is that implicit spatial navigation does not rely on explicitly defined hypermedia links, but instead on the spatial configuration of the objects.

For navigation between distant objects that are closely located, a HyperMap user selects a location on the page with a mouse click on the scaled map. As a result, the two-dimensional information space scrolls with high speed until the desired location is visible. A trace on the map displays the path that has just been traversed. The map allows fast navigation to any location when the hypermedia content is organised to be visually consistent and well structured. Colouring and grouping of hypermedia objects into meaningful collections further facilitates navigation, as can be seen in Figure 6.

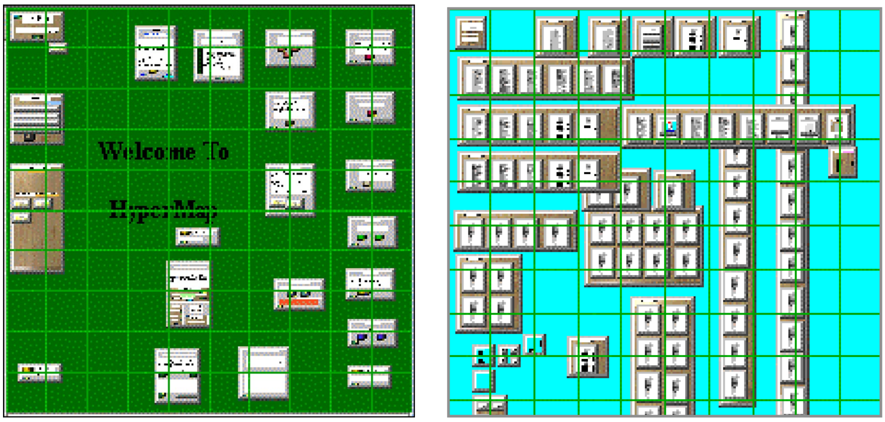


Figure 6: *Structure in spatial hypermedia - The organising effect from colouring and grouping facilitates map-based navigation. The HyperMap page on the left does have a highly non-linear structure. The page on the right is linearly structured, with clearly visible super structures.*

2.3.2 Explicit hypermedia links

The HyperMap browser also support explicit navigation. The activation of an object type that is clearly recognisable as a link button. After mouse clicking, the information space scrolls until the link destination is visible. Explicit links usually have a title that gives information about the link's destination. Sometimes a more elaborate description next to them, located next to text areas. A HyperMap link does not have the inherent textual character of HTML links. The link destination can be a single paragraph or picture, or a collection of objects. During navigation, the links visited are shown in a separate navigation window, the *navTool.* Added to the history list of links are dynamically updated time stamps of time passed since, as is shown in Figure 7A.

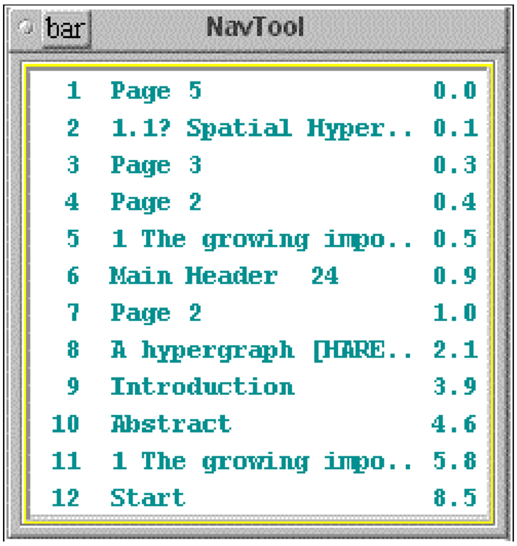


Figure 7A: *Support for navigation history - Visits to named destinations are added to an expanding history list. A time stamp tag is added. Locations can be revisited through a mouse click on the list, scroll-restrictions permitting.*

Additional support for orientation and navigation with explicit links is provided through tracing. The complete path travelled during the current session in the information plane is visible as a trace, both on the scaled map as well as on the information space itself. In addition, every object element that has been visited is earmarked with a green square in the upper left corner of the object, as shown in Figure 7B.

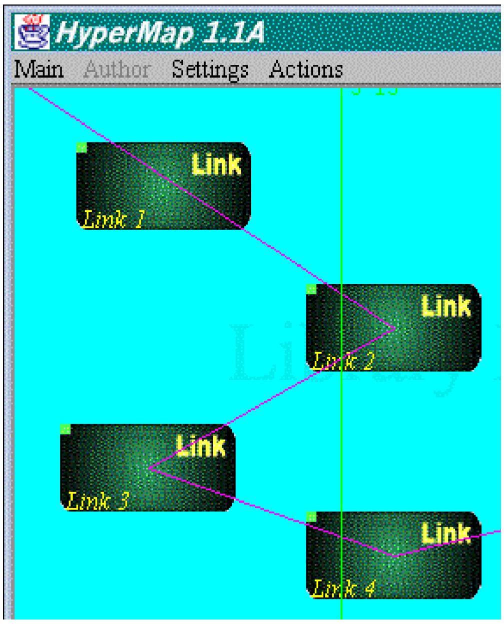


Figure 7B: *Navigation support through visual marking - Earmarks on hypermedia objects (left side) together with navigation traces on the map (right side) offer visual navigation support.*

3. Level I: Navigation control through static link conditions

However well supported free navigation through hypermedia can be for information gathering, for educational assignments that go beyond information retrieval, unrestricted navigation alone is insufficient. . Classroom education with hypermedia is likely to benefit from checkpoints at strategic positions to test a learner's knowledge level and guide or restrict when appropriate. In most educational adaptive hypermedia systems [e.g. Brusilovsky et al. (1996)], some degree of external control over navigation is achieved through limiting or ordering the number of links available to the learner. In WWW based educational hypermedia consisting of real-time generated multi-page HTML documents, users are sometimes able to circumvent checkpoints, while revising generated pages can be difficult.

In spatial hypermedia, the external control over navigation is based on control of the scrolling mechanism. Scroll limitations cannot be bypassed. This first level of navigation control is implemented through *conditional hypermedia links* and *scroll-restricted collections*. When applied together, they enable hypermedia authors to add navigation restrictions with a small granularity for specific audience and curriculum.

3.1 Conditional hypermedia links

A basic method to enforce order in the navigation of hypermedia content is to set conditions on which the state of the link, active or inactive, is dependent. When the link is in an active state, activation by the user through a mouse click will result in scrolling. When the link is inactive, a message informs the user that the link cannot be used currently. Conditional links contain a list of hypermedia objects located on the same page. When the link is accessed, each object in the list is checked for validation. When not every object on the list has been validated yet, the link remains inactive. Validation of an object can also through a previously answered question. In HyperMap, validation of a non-conditional object is achieved by manipulating the object with a mouse click. The validation leaves a visible earmark in the top left corner of the object. Figure 8 illustrates the effect of conditional links on navigation.

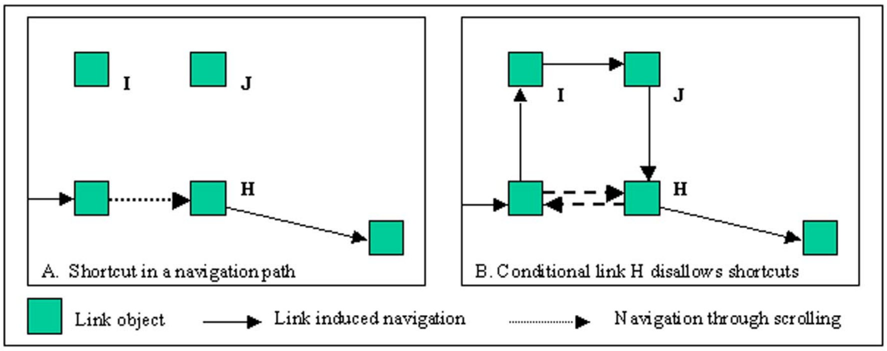


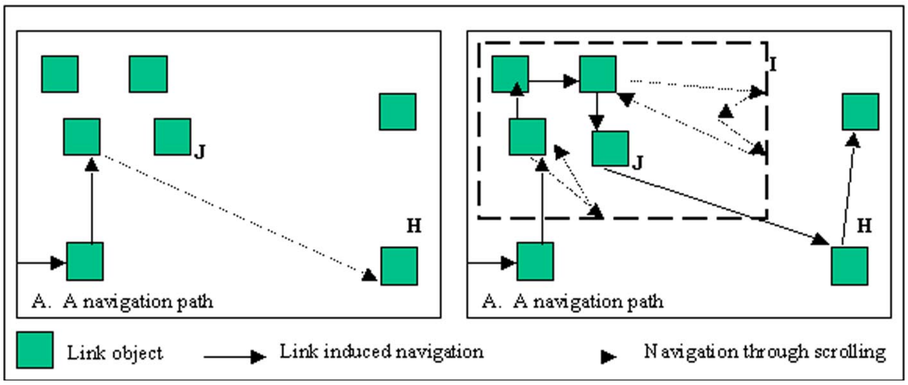
Figure 8: *Conditional hypermedia links - Unconditional linking allows shortcuts, i.e. to node H in picture A. A conditional hypermedia link responds only to user events when each of its conditional objects are validated. The conditional hypermedia link H responds only to activation when all of its conditional objects (links I and J in picture B) are validated. Conditional links prevent disorientation through structuring for learners the access of hypermedia content.*

Conditional links provide a measure to curb haphazard browsing strategies. Random navigation strategies often lead to complete disorientation. Including conditional links does still permit unguided exploration within a sub-section. When more stringent external navigation control is required, the destination of a conditional link can be placed on a separate page. The effect is that the conditional link becomes a gateway that has to be entered to continue on the next page. Otherwise, scroll-restricted collections can help.

3.2 Scroll-restricted collections of hypermedia objects

When navigation restrictions apply on specific groups of objects, conditional links in individual objects alone are insufficient. A set of objects within a collection is better served through a single scroll-restriction of the top-level collection. A reason to impose navigation restriction on a collection might be *"once topic A has been reached, no further browsing is permitted until all subtopics of A have been visited"*. An additional restriction would be to control the point of exit to other locations, e.g. *"After topic B has been reached, the student should continue with either topic C or D"*. In this case, unrestricted navigation is still allowed within collection B, which may contain numerous objects. Because of the scroll-restriction, the exit is now certain to be either topic C or D.

In the HyperMap authoring environment, the author can define scroll-restrictions for each collection. When a learner enters a scroll-restricted collection area, no scrolling beyond the collection boundaries is allowed. Exiting is only possible through explicit links that point to outward destinations. Navigation inside the collection borders remains completely unrestricted. Thus applied, scroll-restricted collections allow subspaces, where exploration is curbed but not



eliminated (see Figure 9).

Figure 9: *Scroll restriction - The effect of scroll-restricted collections on the number of possible navigation paths. Here collection I restricts the navigation to link H to single navigation route which includes link J under all circumstances.*

With the addition of conditional links, an information space can be partitioned into areas with different purposes. Areas open for exploration serve information retrieval activities well. Other areas in the information space provide less freedom in a traditional courseware approach. These areas for testing of knowledge levels will contain sequences of scroll-restricted questions. Many gradations between these two extremes are possible. The spatial hypermedia format of HyperMap aims to support the combination of both tutoring styles within the same hypermedia environment.

4. Level II: Navigation control through dynamic feedback

A second level of guidance and external navigation control in educational hypermedia is adaptive feedback to learners. The feedback follows on completion of an exercise or question. In the current version of HyperMap, feedback only follows after questions. The purpose of these questions, multiple choice or open-ended, is a direct assessment of a learner's knowledge level. The feedback on a question usually contains explanations with corrections of common mistakes. The basic mechanism for feedback on exercises, simulations and *microworlds* would be identical.

Aside from text, the feedback can also contain one or more hypermedia links. The links guide the student to locations on the current page that solves their misconceptions or offer the most efficient continuation of the curriculum. An example of guidance by a multiple-choice question is displayed in Figure 10. When the learner is in a scroll-restricted area, there is no other alternative then to follow the feedback link. Otherwise, a learner can choose to ignore the guidance.

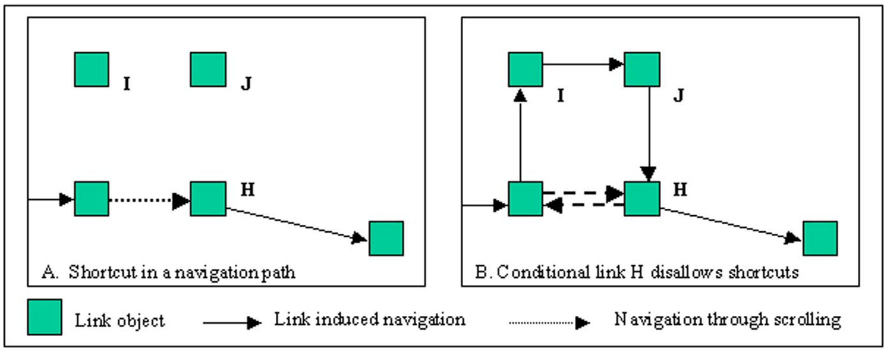


Figure 10: *Questions and feedback windows - On answering a question follows immediate feedback. The feedback window can offer several hypermedia links.*

When the learner chooses not to act on guidance and instead intends to explore other parts first, a different scenario arises. Exercise and feedback windows retain their exact location on the HyperMap page, until explicitly closed. This serves variation in learning strategies because a learner can choose from several feedback links.

The permanent availability of past questions, answers, and feedback contrasts with various systems that are based on dynamic generation of HTML pages or applets. Often, when an HTML page has been left, previous user data is lost for the learner. In HyperMap, the learner decides when past information can be discarded.

5. Level III: Navigation control through evaluation of knowledge level

After a user answers a question, the answer is stored in the model of the student, maintained by the HyperMap browser. The complete set of answers is the major part of the student model as maintained in HyperMap. The student model provides the input for an evaluation of a learner's knowledge level. The high level feedback from evaluations forms the third level of external guidance and control of HyperMap.

An evaluation can comment on the learner's achievements, or alternatively inform the learner about the curriculum itself, i.e. what to expect on the next page. The specific application and number of evaluations in a hypermedia document depends on the attitude of the hypermedia author towards learning and on the target audience. As with the feedback objects, evaluations contain reference links as well. This allows evaluation to be applied as signposts at crossroads in the information space that help to select one of several alternative learning strategies. When a topic is available in different versions, each based on different learning styles, an evaluation may offer a learner free choice in where to continue.

As with link objects, an evaluation object in HyperMap is directly recognisable as an interactive button so as not to confuse a learner with the unexpected popping up of windows. On activation, the evaluation first matches the set of all previous answers with a set of defined cases that are relevant for the purpose of the evaluation. The case that matches with the data stored in the student model is selected and displayed in a window, see fig. 11. Similar to feedback windows, an evaluation remains accessible until discarded by the user.

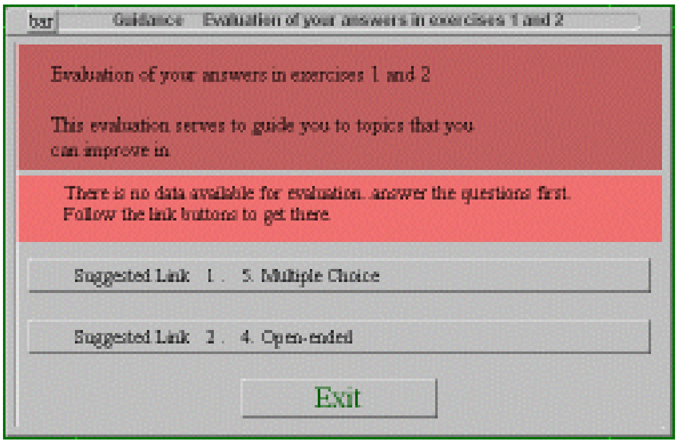


Figure 11: *An evaluation window - Evaluations provide knowledge level feedback to motivate the learner.*

An advantage of evaluations is that they adapt to a learner's knowledge level. In addition, they do not interrupt explorative hypermedia navigation although evaluations can be directive when applied on scroll-restricted areas. Also, there is always only one external window. All feedback windows are internal windows located on the HyperMap page. Graphical user interfaces that rely on multiple external windows often bring about window clutter, a downside of the desktop metaphor graphical user interface for multiple window applications [Henderson and Card (1986)]. The result of searching through stacks of overlapping 'guiding' windows will most likely increase disorientation.

6. Construction of a large spatial hypermedia page

A crucial factor in the practical application of educational hypermedia is the effort that is required to create new hypermedia content. Development with proprietory hypermedia packages often suffers from an authoring environment that does not scale up sufficiently to maintain large hypermedia applications. Müldner, Müldner and van Veen (1997) presented a case study with the various practical problems that surface when authoring and managing a large educational hypermedia curriculum.

Another reason for the authoring bottleneck lies in deficient authoring environments. According to Nanard and Nanard (1995), the large role of creativity in the authoring process is often overlooked, affecting hypermedia authoring. Creativity requires maximum support that is often lacking in traditional hypermedia authoring tools.

In addition, the complexity of some authoring environments discourages educators with minimal hypermedia experience. The learning curve is often too steep for casual authors, such as teachers interested in educational hypermedia content to support a non-standard course. These and other problems associated with the authoring process pose a bottleneck for hypermedia projects that are more demanding than a regular WWW site.

The HyperMap browser addresses the authoring bottleneck through a visual authoring environment. Features of authoring spatial hypermedia content in HyperMap are:

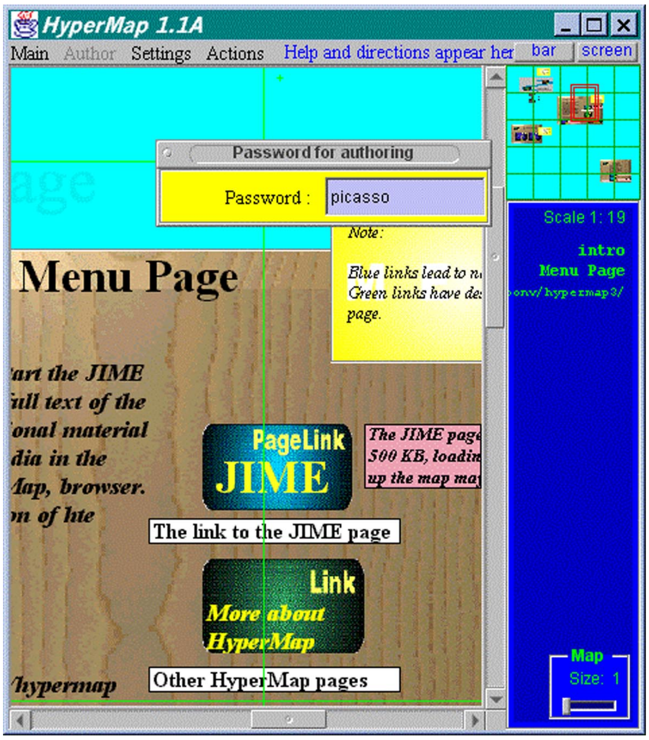
- A simple environment based on direct manipulation to support authors with limited authoring experience

- No external mapping tools such as introduced by Zizi (1995) or formalisms are required.

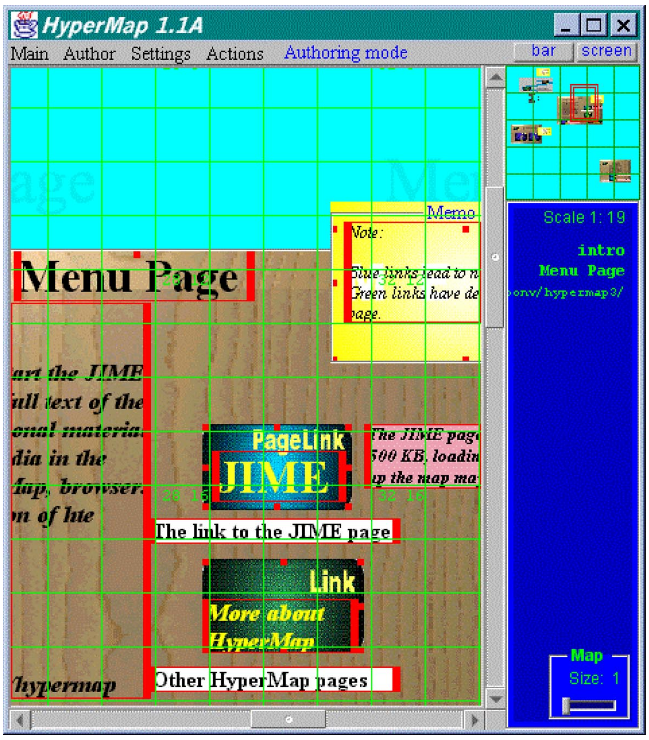
- Authoring consists of manipulating visual hypermedia objects, as shown in Figure 12. Hypermedia objects are copied and pasted, preferably from libraries. The scripting language for interactive objects has an equally simple syntax.

- The hypermedia content is fully object-oriented. Navigation restrictions and non visual object properties are set with s small set of specialised editors.

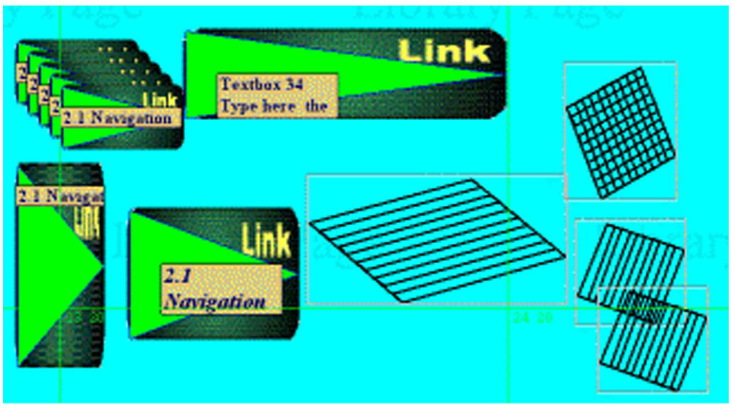
- Authors are able to build personal repositories with frequently used objects or page layout templates.



A



B



C

Figure 12: *Entering the Authoring Environment – A HyperMap user enters authoring mode with a password (A) to enable all authoring functions (B). Then, each object can be resized, rotated, cloned, and repositioned (C) through direct manipulation with the mouse and drag, cut copy, and paste actions.*

6.1 Creation followed by customisation and modification

There now follows a case example to illustrate the authoring process of spatial hypermedia with the HyperMap authoring environment. There is no single HyperMap development approach that fits all domains and educational goals. Various factors contribute to the large variety of authoring scenarios. Factors include not only the level and age of the students, but also the availability of hypermedia repositories, and the particular modes of thinking within the domain. The following list mentions several authoring scenarios, with teachers as the most likely adapters of their self-developed course material. The list order is based on an estimation of the probability of occurrence, for instance, adaptation will occur more frequently than a complete layout from scratch.

- *Adaptation of externally available material*, limited to updating it with small addition and deletions. The addition of last minute information just before deployment falls in this category. The duration of authoring may be as little as a few minutes.

- *Reordering of previously created hypermedia material*, a scenario based on externally available course material that requires further adaptation. For example, the target students are of a different age, a teacher may add an extra layer of guiding hypermedia elements to an existing HyperMap page, to accommodate the different age group.

- *Improvement of previously created hypermedia material*, based on either explicit or implicit feedback that a teacher receives from observation of students during hypermedia-based learning. It can be foreseen that in practice, personal preferences, didactical preferences, and intuitions will play a role in a teacher's design of hypermedia based courses.

- High level integration of spatial hypermedia components, a scenario based on a reuse culture among a group of hypermedia authors. Once the effectiveness of certain map layouts for designated target audiences has been established, authors are able to assemble hypermedia content by configuring constellations of objects, where only blanks have to be filled in. Candidate structures for reuse are hierarchies, timelines as used in history, and specific elements such as the periodic table for chemistry content. Geographic maps as shown in Figure 1 are also potential component structures.

- *Complete construction of hypermedia material from scratch, for new content where reuse is not possible; a scenario for hypermedia professionals*. Despite the direct manipulation user interface, without a base of material to build upon, the construction of a large is still labour intensive. Most likely, only professional hypermedia authors will start from scratch. Especially for large HyperMap pages, design will probably start by outlining large areas for designated functions. Each area is later subdivided and embellished with content.

This last development scenario has been extended to describe HyperMap authoring in more detail. The 'complete construction' scenario is selected because it makes most aspects of the authoring process visible. However, it is not the most frequent authoring scenario.

The 'complete construction' case focuses on the complete construction from a blank HyperMap page. As a realistic test case of the authoring environment, the goal was to transform the full content of the first version of this paper unabridged into a large, single page HyperMap document. The end result was a spatial hypermedia document consisting of over 2000 objects, available as the JIME HyperMap page.

No rigid design method other than a top down oriented approach was followed. Afterwards, five distinct authoring phases could be determined. There follows a description of the phases. Although some phases roughly apply to spatial hypermedia development in general, most are specific for the HyperMap spatial hypermedia format. No other methods or tools, except the HyperMap browser, were involved.

6.1.1 Phase 1: Layout of the high level structures

The first step in design was identification of the size and number of large top-level collections. Next, an estimation was made of the size and other requirement of top-level components, which are comparable to the sections of the first version of this paper. This in turn determined the total page size. For a sufficient visual organisation of large pages, the sections have a wood texture, along with a descriptive title.

The layout was based on a basic sketch of the page layout that was imported into HyperMap as an enlarged backdrop image on the page. The sketch marked the locations of the main areas and their educational function, as a marker where to place the various types of hypermedia objects in following design phases. The page shown in Figure 13 is organised as largely linear on the left and areas for freestyle navigation collections on the right, with a scroll-restricted survey areas.

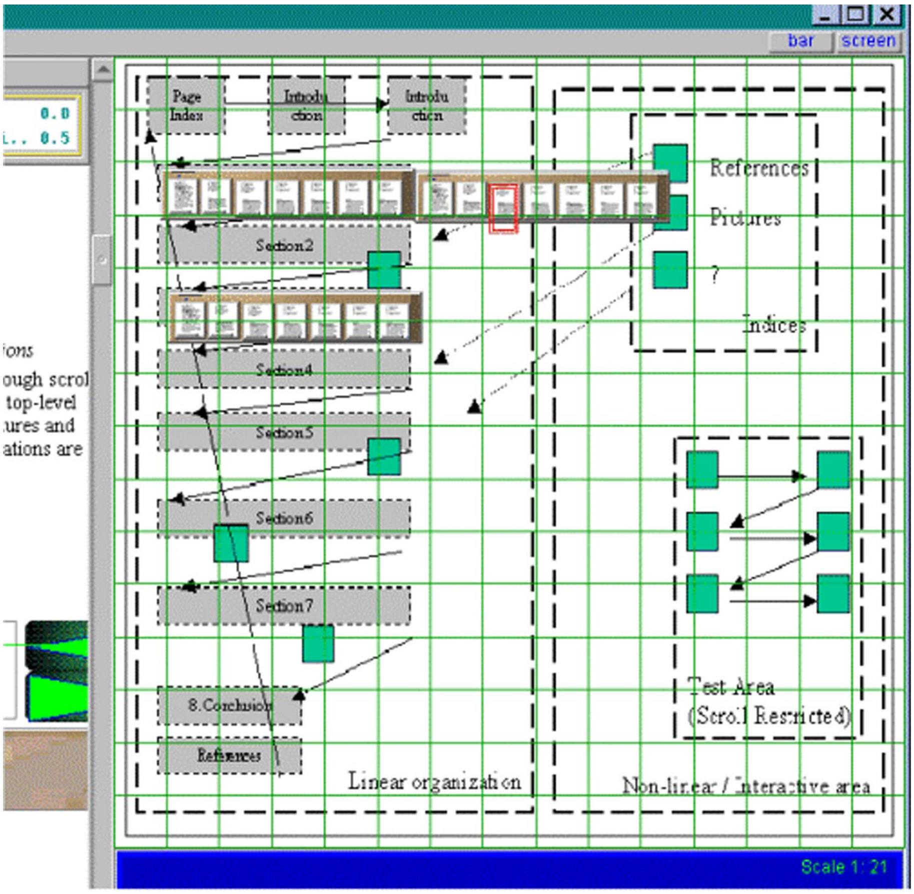


Figure 13: *Phase 1 of spatial hypermedia creation – The screenshot from the map with scale 1:21 shows three large hypermedia objects on top of an otherwise still empty page design draft.*

6.1.2 Phase 2: Specification of static multimedia objects

The specification of large areas started with the layout of static objects. Here layout is based on a textbook format: titles, section headers, and paragraphs are grouped in a structure of textbook pages. At this stage, some sub-level collections were kept unspecified (containing only default content) until a more specific specification was clear.

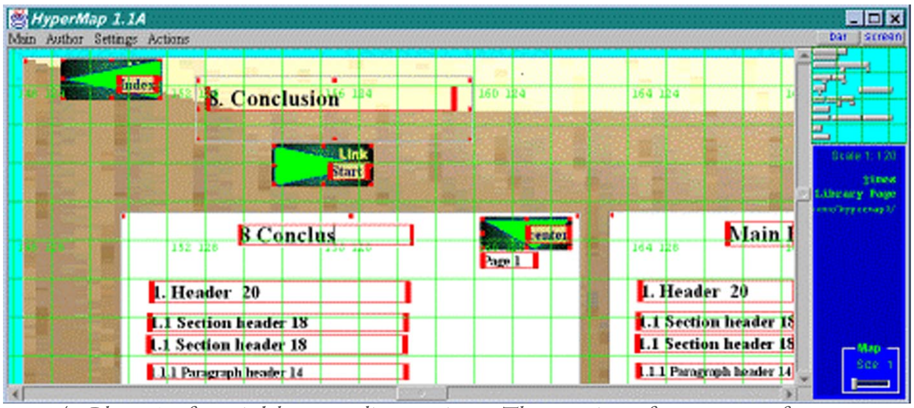


Figure 14: *Phase 2 of spatial hypermedia creation - The creation of a text page from a prototype. Building with repository objects helped to keep fonts, colours, and link positioning consistent.*

6.1.3 Phase 3: Definition of the high level links with conditions

The main activity of the next phase was the addition of external navigation control through scroll-restricted conditional links to connect the top-level collections. All major links added in this phase have already been planned in the layout sketch of phase 1. They are visible as the arrows in Figure 13. A major determinant for the duration of this phase is the author's view on the degree of freedom to permit for navigation. In our case, the top-level structures are not linked conditionally, leaving the order unspecified. With a stricter design, each horizontal top level structure would have an evaluation element to test the knowledge level before proceeding. The addition of scroll-restrictions would create evaluations that cannot be avoided.

6.1.4 Phase 4: Specification of additional navigational paths

After the main structure of the curriculum had been established, a second layer of minor links was added. The function of these links is to increase true hypermedia navigation to address variation in learners' knowledge levels and learning styles. As is visible in Figure 15, the links are added as shortcuts to references located elsewhere. To prevent haphazard navigation strategies, an option is to make shortcuts conditional. To further increase the educational effect of browsing, questions with feedback and evaluations are added at positions where guidance is expected to support a specific learning activity.

The usual goal of evaluations, help links, and questions is to provide guidance to learners. In the case presented here, there has not been empirical testing of the final page layout with subjects. However, it is expected that during normal usage, feedback from users may result in repeating the activity of phase five, perhaps several times. Classroom experience of hypermedia authors will be decisive factor in the final quality of HyperMap design. Future empirical experience will certainly shape this phase further. The layout followed here should be interpreted as just one layout from many possibly completely different designs. The target learner population will drive the selection of design alternatives.

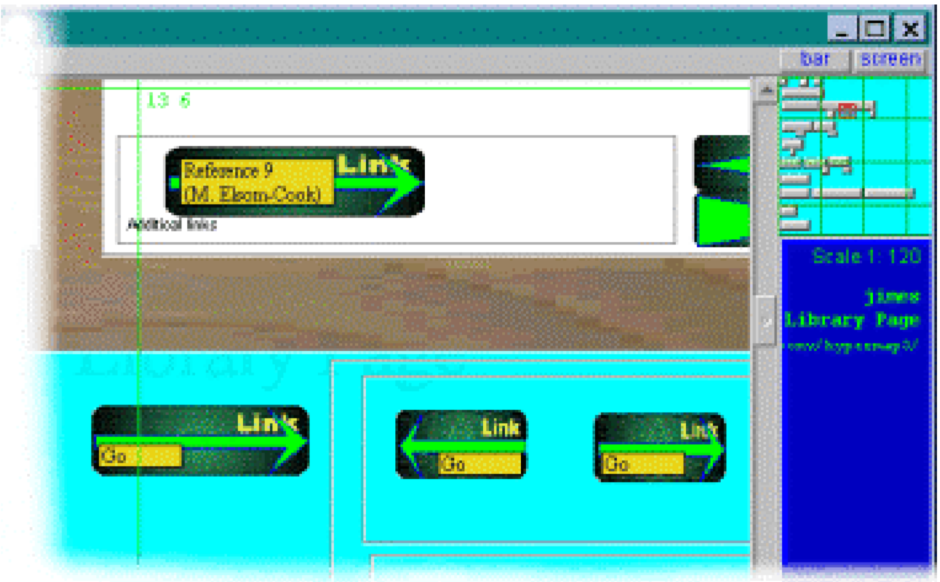


Figure 15: *Phase 4 of spatial hypermedia creation – Shown here is addition of reference links to the bottom of text pages. The design shown here adds all referential links in the bottom left corner of each page.*

6.1.5 Phase 5: Improvement based on test feedback

Before deployment in classrooms or university labs, it is desirable that some level of validation of the design is obtained through tests. Preferably, the test subjects are learners with various knowledge levels and navigational styles. Feedback from subjects may indicate that certain links are positioned wrongly for common navigation paths of which the author was unaware. Unrealistic link conditions and overly restrictive feedback may also surface in this phase. Addition of links, help and evaluation objects can address these problems. It is expected that an experienced author with relevant teaching experience will arrange evaluation objects such that common misconceptions are addressed. To give an evaluation-specific behaviour, a simple scripting language is used to specify evaluation categories (Figure 16).

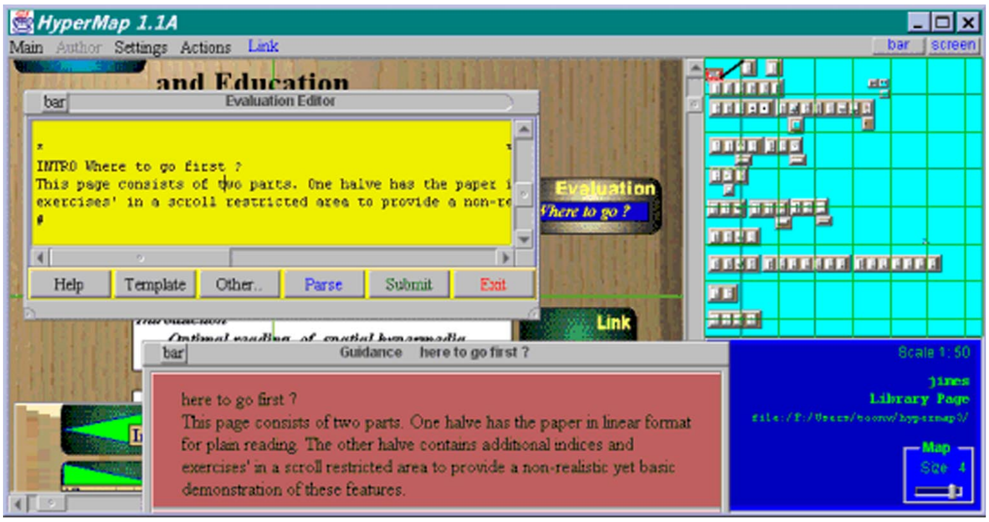


Figure 16: *Phase 5 of spatial hypermedia creation – The strategic addition of evaluation objects as further improvement of pages. Shown is the scripting of an evaluation object to improve guidance*

Because this particular HyperMap page was not used in education, no further evaluation data is available. However, the qualitative evaluation of the HyperMap pages for software engineering laboratory classes (Section 1.1.3) does highlight the importance of evaluation during deployment. One such finding was that for a large proportion of the test users, the speed of the application was a major concern.

6.1.6 Phase 6: Continuous adaptation and further improvements

Although only a largely theoretical phase in this case, 'real-world' hypermedia will have to be adaptive to changes in order to remain usable in education. Curricula change over time, better examples will replace old ones, and new didactics need to be incorporated into existing hypermedia pages. Without adaptability to changing demands, the initial effort to set up a hypermedia curriculum will not be readily invested. Critical to this is the ease of use of the authoring environment.

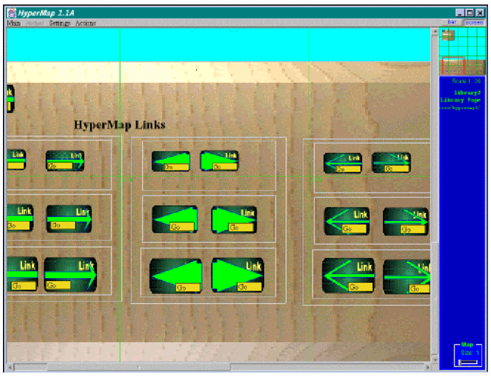
The original design drivers behind the HyperMap authoring environment support continuous adaptation. Simple updating, through memo addition, does not require any authoring skills. Large modifications in spatial hypermedia can be achieved in a gradual manner, by copying and pasting entire subsections of a page. This allows a map to be completely usable even when under construction. During such reconstruction activities, scroll-restrictions may be applied to create off-limit areas. Gradual authoring over a longer time spans encourages more experimenting with variation in HyperMap designs.

6.2 Creation of hypermedia artefacts

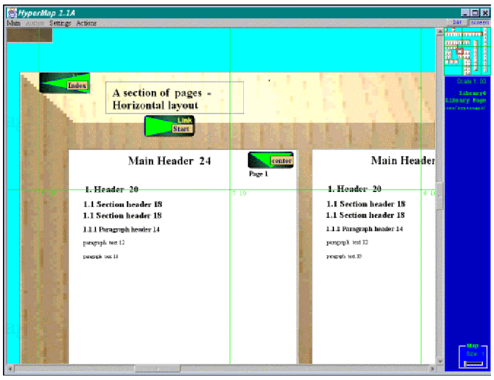
6.2.1 Creation from libraries

For regular HyperMap artefacts and collections, creation of new HyperMap objects consists of two activities. First, a library is selected that contains similar object (which may be a compound object i.e. a collection). For this purpose four thematic prototype libraries have been created, visible in Figure 17:

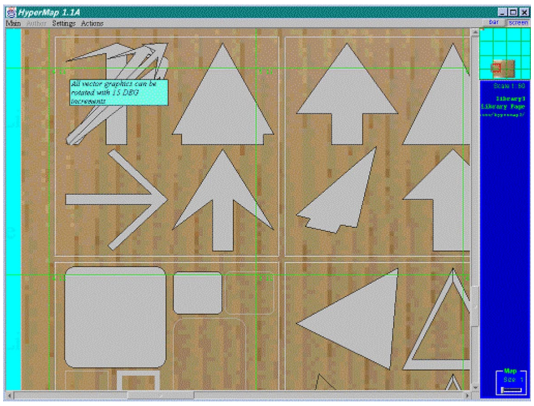
- Icon designs for hypermedia links and other interactions
- Compound information containers, such as grouped and linked pages.
- Vector graphic clipart for light-weight rotatable annotation symbols
- Bitmap Clipart for illustrations and collection backgrounds



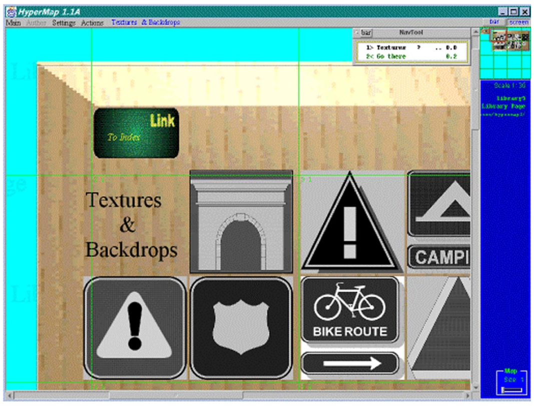
A.



B.



C.



D.

Figure 17: *Libraries of HyperMap objects - Libraries are standard HyperMap pages accessible for authors. Currently libraries have been defined with icon designs (A), compound information containers (B), vector graphics (C), and pictures and textures (D).*

To use a library, an author will usually go through three steps. First she will save her current page. Next, she opens the HyperMap clipboard window for temporary object storage. The author then copies one or several reusable elements onto the clipboard with copy and paste actions (Figure 18).

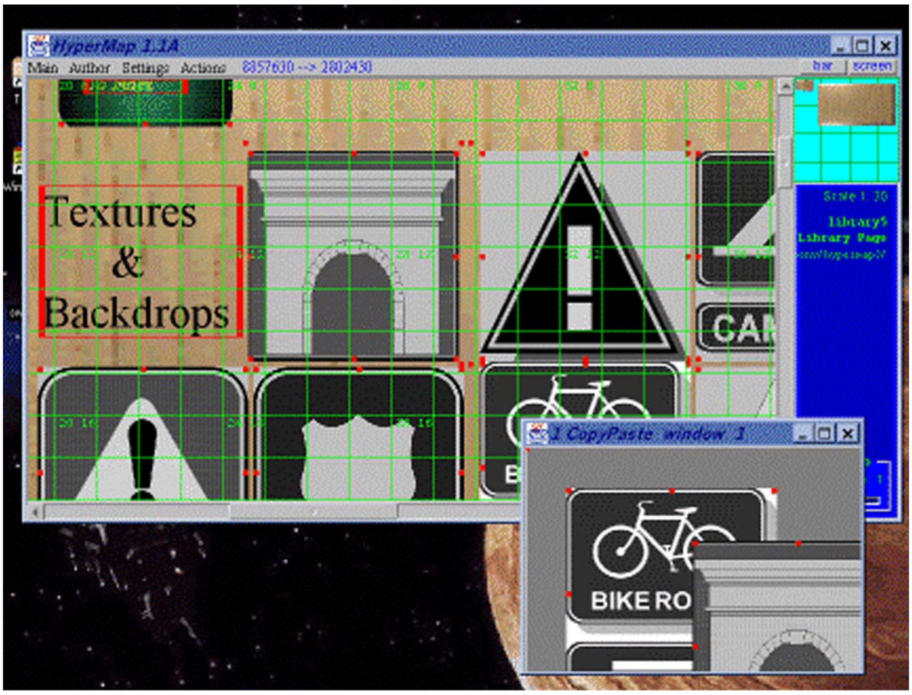


Figure 18: *Library usage –Two pictures have been copied onto the clipboard.*

Finally, the author returns to her original page and copies the collected material in it. Resizing or reshaping of the pictures will take place after insertion in the target document.

6.2.2 Creation with specialised editors

With only ready-made library objects available, an author is not fully able to create a unique HyperMap page design. Modification by direct manipulation is insufficient. In addition, the orientation of learners will not benefit when there are only monotonous sets of objects without visually apparent locations. HyperMap has a set of editors to facilitate the creation of new HyperMap objects or adapt copies from library objects (Figure 19).

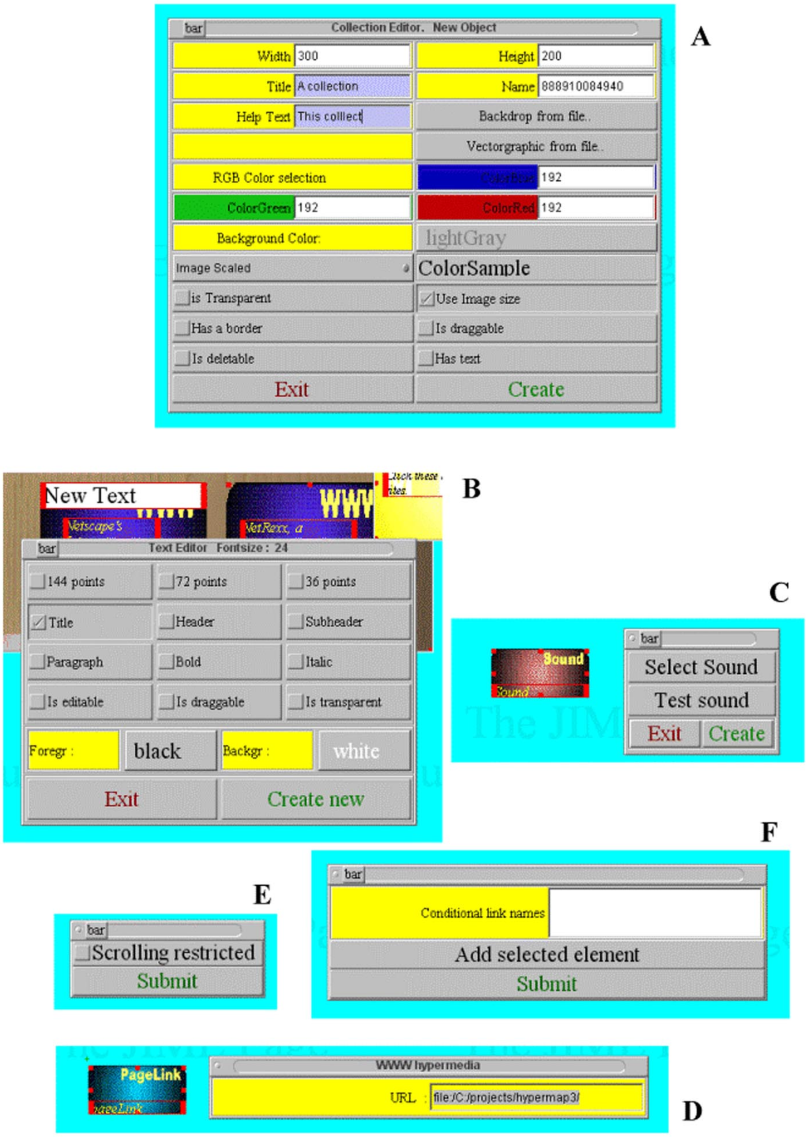


Figure 19: *Editors for objects - General editors are available for graphical (A) and text layout (B), sound (C), URLs (D), and navigation restrictions (E and F).*

The most frequently used are to modify colour, change the backdrop image, and add variable sized text, sound and URLs in any combination. An additional type of object for which an editor exists is a *miniature object.* A miniature object allows a link button to contain a dynamically generated picture of the collection it points to. Miniatures can be added as small Roadmap signs at junctions of navigation paths. Two other editors mentioned here is the *nn* editor to embed Java applets directly within a HyperMap page (without the intervention of a WWW browser), and a *Slide show* editor to create sequences of slides that popup after activation of a Slide show object.

```
INTRO
Evaluation of your answers in exercises 1 and 2

This evaluation serves to guide you to topics that you
can improve in.
#

OPTION inconsistent_1
question1 egg
question2 chicken
#

OPTION inconsistent_2
question1 chicken
question2 egg
#

OPTION chicken
question1 chicken
question2 chicken
#

OPTION egg
question1 egg
question2 egg
#

OPTION false_1
question1 false
#

OPTION false_2
question2 false
#
```

```
(continued)

FEEDBACK inconsistent_1
First you answered egg, then chicken....
#

FEEDBACK inconsistent_2
First you answered chicken, then egg...
#

FEEDBACK egg
You have been consequent in your choice for 'egg'
#

FEEDBACK chicken
You have been consequent in your choice for
'chicken'
#

FEEDBACK false_1
You have answered one out of two questions wrong.
Your first anser was wrong.
#

FEEDBACK false_2
You have answered one out of two questions wrong.
Your second anser was wrong.
#

FEEDBACK_DEFAULT 7468140 2900320
There is no data available for evaluation..answer the
questions first.
Follow the link buttons to get there.
#
```

Figure 20: *An Evaluation script - In this script, two user input variables are compared: the answers of two questions, question1 and question2. Then six OPTIONS follow, which are the evaluation criteria. In the second column, the corresponding feedback cases are defined, some with links attached. The editor for testing and validation can be seen in Figure 16.*

6.2.3 Creation of scripts for Evaluation Objects

To give questions and evaluations their specific feedback, a script can be added. The scripting is supported in the authoring environment in two areas. First, during script testing there is error feedback from the internal script editor. Second, the author may immediately 'test-drive' the resulting behaviour, without leaving authoring mode. The scripting language grammar is kept simple, as can be seen in the sample test script in Figure 20, taken from an evaluation object. The resulting objects are then tested, as shown in Figure 21.

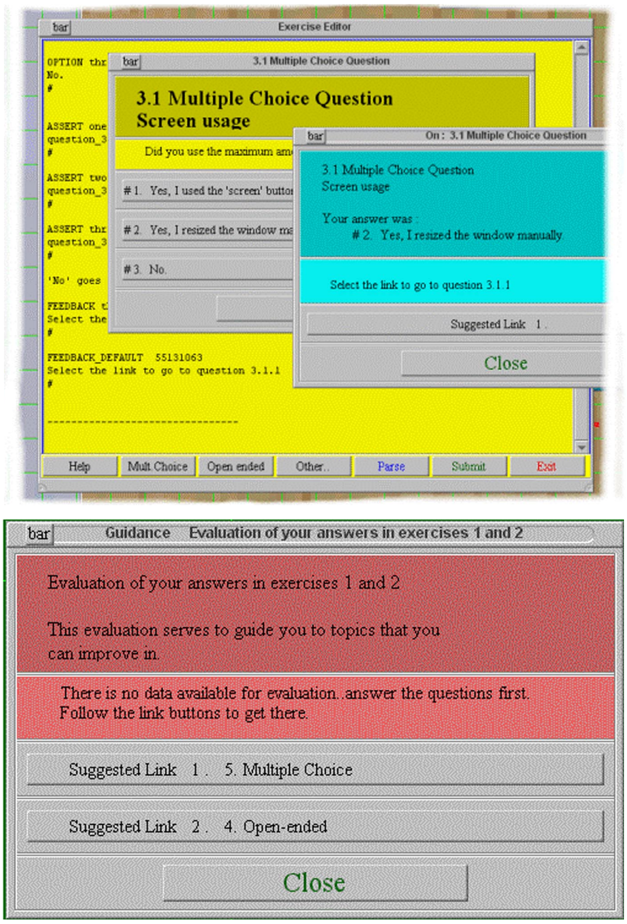


Figure 21: *Creation of questions and evaluations – Shown on the left is the testing of a multiple-choice question with feedback. Shown on the right is an Evaluation popup, which gives feedback on answers given earlier. The evaluation's responses are defined in the script of Figure 20.*

6.3 Comparison with object-oriented methodologies for hypermedia

Rossi, Schwabe, Lucena and Cowan (1995) and Lange (1994) have mentioned the benefits of object orientation for hypermedia development. The majority of publications aim at the implementation of specialised hypermedia applications, and less on object-oriented hypermedia authoring. A comparison between the steps of Object Oriented Hypermedia Development Methodology (OOHDM) (Rossi et al., 1995) with the five phases of HyperMap authoring, reveals similarities in several activities. In the first step of OOHDM, high level concepts are defined and visualised in design graphs. In HyperMap a similar organisation is achieved directly in the graphical layout with collections. Step 2 of OOHDM consists of navigational design of new objects, whereas phase 2 for HyperMap addresses similar aspects through hypermedia links and navigation restrictions.

However, beyond superficial similarities there are various differences. A main difference is that OOHDM is a general design methodology and not specific for a single authoring environment. In contrast, a HyperMap author only develops new hypermedia object types as modifications of existing ones. Objects or clusters of objects are first selected from libraries and then manipulated to tailored in their visual appearance and interactive behaviour, with guidance from specialised object editors. Another difference is that the application domain of HyperMap is targeted at educational hypermedia. This has influenced the following aspects of the design of the HyperMap prototype:

- A design aimed at practical application in a classroom setting by teachers for students of all ages, with extra tools for providing navigation guidance.
- Simplicity in the user interface design and in the authoring environment.
- A strong emphasis on visually oriented knowledge communication

7. From external browsing control towards a tutoring style

7.1 A tutoring style based on navigation control for spatial hypermedia

The three levels of external navigation control described in Sections 3–6 can be interpreted as points on a scale that describes the *role for exploration in learning*. The dimension, seen in Figure 22, measures the importance of exploration as one of the learning activities supported by a system. At the right extreme of this dimension, a learner is not restricted at all in the selection of an individual path through the curriculum. This is typical for hypermedia. At the left extreme, the learner is restricted to an ordered learning style, with no opportunities for exploration at all. This situation resembles learning with traditional courseware systems and intelligent tutoring system that have a directive tutoring style.

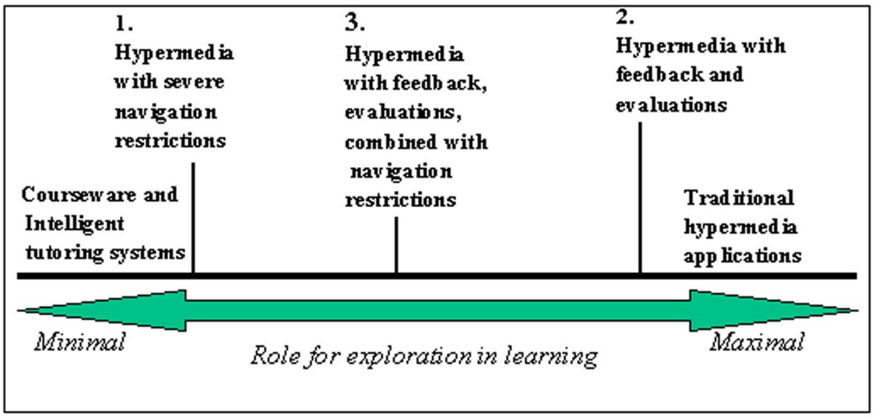


Figure 22: *The role for exploration in learning - While restrictive navigation control (level I) minimise exploration (position 1), feedback and evaluation (level II and III) encourage it (position 2). With both measures applied in balance, they provide an educational hypermedia learning environment with elements from hypermedia, courseware, and intelligent tutoring systems (position 3).*

With adaptive hypermedia that supports guidance and flexible external restriction of navigation, educational hypermedia can take a centre position on the dimension. The degree of exploration in learning will adapt to the learner's progress. When exploration is restricted too severely by completely disabling links or making them conditional, the application will lose its hypermedia characteristics. Overly applying the level I navigation restrictions would have this effect. In contrast, the level II and level III measures for external navigation control and guidance increase the number of hypermedia links and thus encourage a guided form of exploration. A hypermedia author can tune the role for exploration in a hypermedia curriculum a balance in navigation restriction (control level I) and guidance (control levels II and III), until an effective external control on navigation control is achieved.

The degree of navigation control will most likely differ for different parts of a curriculum. An educational hypermedia system of this type will have a middle position on a scale from courseware to hypermedia, as displayed in Figure 22. Such a hypermedia-based system contains navigation restrictions, but leaves a considerable role for exploration in learning.

7.2 A tutoring style for hypermedia based on navigation control

On the subject of the consequences of tutoring style for intelligent tutoring systems, Elsom-Cook (1988) argues that a middle position on the spectrum of external control over a learner's activities is preferable. It has benefits both for learning as well as for the practical development of intelligent tutoring systems. He introduced *dual initiative tutoring*, which is founded on the observation that development of perfectly adaptive intelligent tutoring modules, with access to a complete student model and a various tutoring strategies, is usually not attainable. The input data for student modelling is often insufficient for a completely tutor-driven tutoring style.

A cornerstone of dual initiative tutoring is that the balance of control over the learning process should remain flexible, able to slide back and forth from strict control to free exploration, whatever is most beneficial for learning a particular combination of topic and learner's knowledge level. Although dual initiative tutoring is not specific for adaptive hypermedia systems, the foundation of dual initiative tutoring matches with the effect of navigation control and guidance on exploration in hypermedia, as displayed in Figure 22. A dual initiative tutoring point seems therefore a logical starting point for introducing a tutoring style into an adaptive hypermedia environment.

Usually a course contains sections where prerequisites and knowledge levels have to meet a certain standard before proceeding to a next topic is of any use. For those parts, checking a learner's knowledge level as a prerequisite is useful. Other sections of the course may contain only reference information, where the order and boundaries of topics are not extremely relevant because reference material should be accessible at all times. Together, the three levels of external control over a learner's navigation in hypermedia allow the construction of course material in a spatial hypermedia format that can meet the requirements of different types of learning. The measures to control navigation are based on scrolling and are difficult to translate directly into traditional hypermedia formalisms. The spatial nature of navigation control therefore provides a natural mechanism for dual initiative tutoring in hypermedia.

7.3 Prospects on integrating adaptive tutoring in spatial hypermedia

Although the navigation control implemented in the HyperMap browser provides adaptive hypermedia links, the possible outcomes of an evaluation are static. The possible outcomes of feedback and evaluations are all explicitly defined or 'hard-wired' in the hypermedia document. This limits the adaptability of the system for dealing with individual learning styles. When a course is aimed at two distinctly different populations of learners, the learning material will have to be offered as two separate hypermedia documents. With a flexible tutoring style however, a single hypermedia curriculum would have been sufficient. Through didactic adaptation of the tutoring strategy, different learning and navigation styles are accommodated. In this scenario, a tutoring module with didactic knowledge modifies navigation restrictions, feedback and evaluations in real time. Extension of a hypermedia browser with a knowledge base would allow this: the knowledge base would continuously match the learner's actions with a set of rules containing didactic knowledge and navigation styles, with adaptive guidance based on overall browsing behaviour. Because of ongoing asynchronous activity of the rule base, the hypermedia system would be able to offer guidance without explicitly being asked to. The current version of the HyperMap prototype does not as yet include a rule base that supports the adaptive tutoring style.

The knowledge to provide a tutoring style is usually defined as a rule based system that interacts with a hypermedia system. Merlet (1993) defined a set of didactic rules for hypermedia to optimise learning directly through navigation. The external navigation control measures that are specific for the HyperMap version of spatial hypermedia would allow a further refinement of rule based navigation control. Figure 23 displays rules for rule based navigation control. There are general didactic rules, and rules that regulate navigation, thus specific for spatial hypermedia. With these rules, an educational hypermedia system is able to continuously optimise the amount of unrestricted hypermedia exploration in learning. A haphazard browsing style and repeated false answers would induce a temporary shift to more restrictive navigation control; otherwise exploration is permitted. With standard rule based extensions of hypermedia, the prospects of a fully dual initiative tutoring style for spatial hypermedia environment increase considerably.

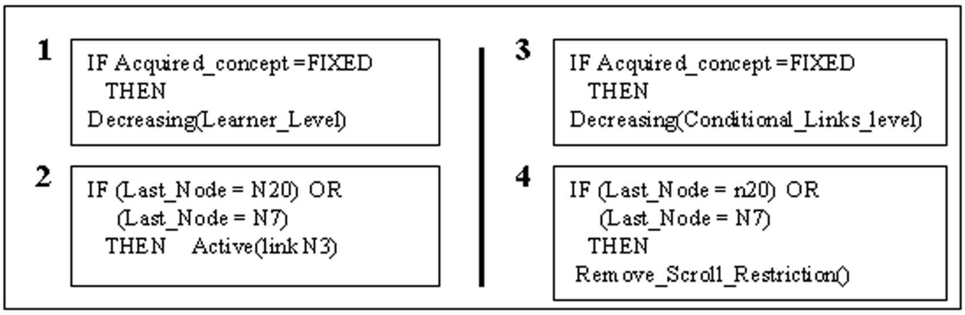


Figure 23: *Rule based navigation control - Rule 1 and 2 are rule-based extension of educa-tional hypermedia from Merlet (1993). Rule 3 and 4 are modified versions of the same rules that integrate scroll-restrictions and link conditions with tutoring from a rule base*

8. Conclusion

We have investigated the potential of adaptive browsing control for educational hypermedia systems, based on a custom spatial hypermedia format. A prototype of a spatial hypermedia browser named HyperMap illustrated the feasibility of hypermedia development that addresses the major problems associated with educational hypermedia for both developers and users:

- to provide navigation support and prevent disorientation with a detailed topological map and tracing;
- to guide a learner with feedback and evaluation, and control navigation directly through scrolling restrictions;
- to overcome the authoring bottleneck with a direct manipulation authoring environment;
- to integrate hypermedia into an intelligent tutoring system.

The empirical data from the field tests with HyperMap have given a first stage validation of the theoretical and practical design foundations under the HyperMap prototype. However, issues for further research remain. One is a direct comparison with WWW hypermedia. With the availability of identical content in WWW browser format, a better evaluation of the practical merits of spatial hypermedia can be made.

Another issue is empirical data of the authoring environment. Practical usage of HyperMap by hypermedia authors will most likely guide improvements of the authoring environment. These can be in the user interface, but also the addition of HyperMap page templates, specific libraries, or new categories of components. Also possible is the addition of domain specific libraries, such as time lines for history class, microworlds for physics and chemistry, and maps for geography.

Additional research into the specific contributions of navigation from a map and external navigation control features of the HyperMap browser is needed. Further field testing through the construction of curricula to test these aspects is a logical next step to obtain empirically founded spatial map design guidelines.

In the area of intelligent tutoring, the prospects for adding dual-initiative tutoring to spatial hypermedia have been outlined. Although not yet implemented, the feasibility of linking HyperMap objects to didactic rules looks promising. Further validation is needed in this area. One future direction is the extension of the hypermedia object set with rule based didactic knowledge.

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