MULTI-MODEL ADAPTIVE SPATIAL HYPERTEXT

A Dissertation

by

LUIS FRANCISCO-REVILLA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2004

Major Subject: Computer Science

MULTI-MODEL ADAPTIVE SPATIAL HYPERTEXT

A Dissertation

by

LUIS FRANCISCO-REVILLA

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Approved as to style and content by:

Frank M. Shipman, III (Chair of Committee)	Richard K. Furuta (Member)
John J. Leggett (Member)	Donald H. House (Member)
Valerie Taylor (Head of Department)	

December 2004

Major Subject: Computer Science

ABSTRACT

Multi-Model Adaptive Spatial Hypertext. (December 2004)

Luis Francisco-Revilla, B.S., Universidad Iberoamericana;

M.S., Texas A&M University

Chair of Advisory Committee: Dr. Frank M. Shipman, III

Information delivery on the Web often relies on general purpose Web pages that require the reader to adapt to them. This limitation is addressed by approaches such as spatial hypermedia and adaptive hypermedia. Spatial hypermedia augments the representation power of hypermedia and adaptive hypermedia explores the automatic modification of the presentation according to user needs. This dissertation merges these two approaches, combining the augmented expressiveness of spatial hypermedia with the flexibility of adaptive hypermedia.

This dissertation presents the Multi-model Adaptive Spatial Hypermedia framework (MASH). This framework provides the theoretical grounding for the augmentation of spatial hypermedia with dynamic and adaptive functionality and, based on their functionality, classifies systems as generative, interactive, dynamic or adaptive spatial hypermedia.

Regarding adaptive hypermedia, MASH proposes the use of multiple independent models that guide the adaptation of the presentation in response to multiple relevant factors. The framework is composed of four parts: a general system architecture, a definition of the fundamental concepts in spatial hypermedia, an ontological classification of the adaptation strategies, and the philosophy of conflict

management that addresses the issue of multiple independent models providing contradicting adaptation suggestions.

From a practical perspective, this dissertation produced WARP, the first MASH-based system. WARP’s novel features include spatial transclusion links as an alternative to navigational linking, behaviors supporting dynamic spatial hypermedia, and personal annotations to spatial hypermedia. WARP validates the feasibility of the multi-model adaptive spatial hypermedia and allows the exploration of other approaches such as Web-based spatial hypermedia, distributed spatial hypermedia, and interoperability issues between spatial hypermedia systems.

In order to validate the approach, a user study comparing non-adaptive to adaptive spatial hypertext was conducted. The study included novice and advanced users and produced qualitative and quantitative results. Qualitative results revealed the emergence of reading behaviors intrinsic to spatial hypermedia. Users moved and modified the objects in order to compare and group objects and to keep track of what had been read. Quantitative results confirmed the benefits of adaptation and indicated a possible synergy between adaptation and expertise. In addition, the study created the largest spatial hypertext to date in terms of textual content.

DEDICATION

To my family

ACKNOWLEDGEMENTS

Reflecting upon my studies here at Texas A&M University, I realize that I am taking with me much more than just academic knowledge. This time in College Station has been a truly enriching experience for me. Certainly, I have been very lucky to meet, interact and befriend many people. This has impacted my life in many positive ways and I would like to express my gratitude to each and every person who contributed to this work. However, if I unintentionally fail to remember anyone, please forgive me and know that I am very grateful to all of you.

First, I want to thank my family, to whom I have dedicated this dissertation. Without their encouragement and support (in so many different ways) I would have never gotten this far. This dissertation is as much theirs as it is mine. I also want to give special thanks to Sandra. Her support and encouragement were, in the end, what allowed me to finish this dissertation. She inspired me and being with her has improved my life in all regards.

I would like to express my gratitude to all my professors. Particularly I want to thank my advisor Dr. Frank M. Shipman, III for all the support he has given me. I really appreciate his show of confidence in me throughout my studies, guiding me when necessary while at the same time giving me lots of freedom to pursue my own interests. I want to express my thanks to Dr. Richard K. Furuta, who also played a critical role in my studies, offering me advice and support. Finally, I want to thank Dr. John J. Leggett and Dr. Donald H. House for their valuable guidance and feedback.

Work in the Center for the Study of Digital Libraries has been a very enjoyable experience. In the CSDL I found a place to interact, collaborate and share ideas (even if unrelated to Computer Science) with many interesting and diverse persons, making every day an interesting day. While agreement was often unattainable, all the interactions, conversations, discussion, arguments and squabbles forced me to reevaluate many assumptions, greatly enriching my overall experience. While I extend my gratitude to everyone in CSDL, I do want to mention, Haowei, Pratik and Michael in addition to all my officemates. Also, I want to thank Unmil in particular who not only offered me his comments, suggestions and criticisms (often constructive), but in addition he offered me his friendship, having become one of my best friends.

When I arrived at Texas A&M University I was gladly surprised to find myself immersed in a very diverse and multi-cultural community. Ironically, it was my coming to College Station, this little town in the middle of Texas, which allowed me to discover and explore the world. Here I met and befriended people from all over the world. The interactions with all of them are amongst my most treasured memories and experiences.

My friends have played a very important role in my life and deserved to be mentioned here. However, the space constraints literally do not allow me to explicitly name each and every one of my friends – yes, I have been very lucky to have MANY friends: from the Pachucos group, from México and Latin-America, and other groups. I want to say to ‘all y’all’: thank you for your friendship and support. You made this experience one of the best in my life.

TABLE OF CONTENTS

Page

Page

Page

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

TABLE Page

TABLE Page

TABLE Page

1 INTRODUCTION

For years scientists have been interested in finding better ways to deliver and present information to people. Information handling is a complex subject because information varies greatly in nature, size and how much it is interconnected. Throughout time different theories, approaches, technologies and systems have been developed.

A popular approach is hypermedia. It allows different pieces of information to be interconnected, which facilitates access and navigation of large collections of information. Hypermedia implementations such as the Web allow integrating information from distributed locations and delivering it to people in remote locations.

However, information delivery on the Web is often characterized by rigid presentations that require the reader to adapt to general purpose Web pages. In response to this issue, the research fields of spatial hypermedia and adaptive hypermedia have investigated alternative approaches that yield more powerful and flexible presentations. On the one hand spatial hypermedia augments the representation capabilities of hypermedia, while on the other adaptive hypermedia explores the automatic modification of the presentation according to user needs.

This dissertation investigates extending and merging of spatial hypermedia and adaptive hypermedia. It defines, instantiates, and evaluates the new approach of multi-model adaptive spatial hypermedia. This work does not limit itself to the joining of the previous approaches, but also proposes and explores a critical extension to the process of

---

This dissertation follows the style of *ACM Transactions on Information Systems.*

adaptation: the use of multiple independent models as a guiding mechanism in the adaptation of spatial hypermedia presentations. The motivation for this work is presented in section 2, along with a discussion of the problem characteristics associated with this new approach.

Once the motivating problem has been discussed, section 3 continues by presenting relevant work previously conducted in the areas of adaptive hypermedia, spatial hypermedia, multi-model adaptive hypermedia, visual design and conflict resolution.

The design and development of the Multi-model Adaptive Spatial Hypermedia (MASH) approach required the creation of a theoretical framework that grounded the concepts and philosophies involved. The MASH framework is presented in three parts. First, section 4 presents a generic architecture that facilitates the classification and analysis of different hypermedia systems. Section 5 gains depth by defining the fundamental concepts in spatial hypermedia and providing a high level ontological classification of the different types of adaptation in spatial hypermedia. Subsequently, section 6 introduces the approach of conflict management, a strategy capable of supporting the process of adaptation using multiple independent models.

The dissertation moves from the theoretical consideration to the practical implementation by presenting WARP in section 7. WARP is the first MASH-based system, providing a proof by example of the feasibility of the MASH approach. The description of the system includes a discussion of the most novel features such as spatial transclusion links and object importation and exportation.

Section 8 describes a user evaluation comparing two versions of WARP, one adaptive and the other non-adaptive. The results of the study are then shown in section 9. Section 10 presents future areas of work and new research opportunities. Finally, the conclusions presented in section 11 bring the dissertation to a close.

2 PROBLEM

The Web is a highly interconnected and information-rich environment where a great variety of people access and consume a vast quantity of available information. In this fluctuant environment, authors need to create Web pages for an unpredictable audience. The result is general-purpose Web pages, which require that readers adapt to them in order to accomplish their informational goals.

This approach to information presentation is excessively rigid. When generating general-purpose Web pages, authors face decisions about whether a particular piece of information or a particular link should be included or not, regardless of the different possible implications for the reader.

In hypermedia, two approaches have been developed that alleviate the rigidity in hypermedia presentations: spatial hypermedia and adaptive hypermedia.

Spatial hypermedia's response to rigidity is to augment the expressiveness of the medium such that more subtle nuances can be represented. Spatial hypermedia is based in observations of how people used systems such as Aquanet [Marshall and Rogers 1992]. These observations revealed that often only the relative spatial position between objects is used to imply the relationship between objects [Kolb 2001; Kolb et al. 2002; Rosenberg 2001]. By employing the visual relationships between objects, spatial hypermedia can represent explicit and implicit links with varying degrees of formality and ambiguity [Shipman and McCall 1994; Shipman et al. 2001]. This augmented expressiveness allows the creation of a wider variety of presentations that can address larger and more diverse audiences.

In contrast, the adaptive hypermedia approach ameliorates rigid schemas by presenting only the *right* pieces of information based on an understanding of the current context. This requires the ability to differentiate the relevant from the irrelevant. However, this is not a straightforward process, as the assessment of what is relevant varies from person to person. Consequently, research in adaptive hypermedia has focused on customizing the presentation according to a user model, which represents significant user characteristics such as goals, knowledge and preferences [Brusilovsky 1996, De Bra et al. 1999].

Spatial hypermedia and adaptive hypermedia propose different approaches capable of complementing each other. The creation of an adaptive spatial hypermedia approach can provide an exceptional information delivery medium that has powerful representational capabilities and is capable of modifying the content and presentation as appropriate. However, to our knowledge, no work has been done in regard to the augmentation of spatial hypermedia with adaptive behavior beyond the access constraints in HyperMap [Verhoeven and Warendorf 1999]. The creation of a framework that aids in the analysis and design of adaptive spatial hypermedia systems is a key step into the implementation of the software platforms necessary for the exploration of this approach.

Adaptive spatial hypermedia requires not only merging both approaches but also extending them. The use of a single user model in adaptive hypermedia is one candidate for revision because human actions are situated and depend heavily on the particular context [Suchman 1987]. In reality it is impossible to enumerate or predict every possible situation and hence it requires the additional consideration of other relevant factors that also demand the adaptation of the presentation, such as domain [Fischer and Steinmetz 2000] and environment [Cheverest et al. 2000]. As a result, factors external to the user are often included in the user model, increasing its complexity and entangling user-based heuristics with situation or activity-based heuristics.

Part of the research agenda within adaptive hypermedia has been the creation of systems capable of migrating through domains and applications [Encarnação 1997; Stephanidis et al. 1997]. However, the use of a single user model often results in rigid adaptation strategies that render the systems brittle to context and thus limit their ability to scale and migrate across domains and time. To cope with this difficulty, researchers have augmented this approach by employing multiple models [Brusilovsky and Cooper 2002, Francisco-Revilla 1998, Francisco-Revilla and Shipman 1999, Francisco-Revilla and Shipman 2000].

These systems are designed to function using a fixed set of models. This characteristic suffers from similar drawbacks since it is impossible to predict how many models suffice in every case. A better approach is to use multiple independent suggestion mechanisms that use independent models.

The multiple model approach allows adding or fine-tuning the independent mechanisms, making it possible to extend and adapt the system as required. There is, however, a drawback that results from using multiple independent suggestion mechanisms. As the different mechanisms use independent models, there is the possibility that the adaptation suggestions require the use of techniques that oppose or contradict each other. Thus, it is necessary to complement the multi-model adaptation approach with a flexible conflict management approach that supports the required model independence.

The conflict management mechanisms must not depend intrinsically on the number or nature of the models. This greatly facilitates the independent addition, modification or removal of suggestion mechanisms, making it possible to extend and adjust the system as required.

The conflict management approach needs to be flexible. A single conflict resolution strategy is not enough because, in different domains and applications, the suggestion mechanisms can interact with each other in different ways. Hence, supporting a variety of resolution strategies is necessary in order to function in a wider range of domains and applications.

Simple conflict resolution is an overly narrow approach for many situations. A comprehensive approach to conflict management, one that detects the conflicts and simplifies their resolution by identifying their context and how they affect other suggestions, needs to be developed in order to enable the implementation of functional multi-model adaptive spatial hypermedia systems.

3 RELATED WORK

Several research areas have directly or indirectly influenced the approach evaluated in this dissertation. Previous work in spatial hypermedia, adaptive hypermedia, multi-model adaptive hypermedia, visual design, agents, and conflict resolution played very influential roles in the conceptualization, design and implementation of multi-model adaptive spatial hypermedia. The influence and contribution of each of these areas to this work is discussed in the following sections.

3.1 Spatial Hypermedia

Harbingers of Spatial Hypermedia such as Aquanet [Marshall et al. 1991] and gIBIS [Conklin 1987] started appearing as early as the mid 1980's. Aquanet was an argumentation system that allowed the user to define and fill in visual templates that represent information structures, e.g. Toulmin-based argumentation. However, observations of how people actually used the system revealed that often only the relative spatial position was used to imply the relationship between objects [Marshall and Rogers 1992; Marshall and Shipman 1993; Shipman et al. 1995]. This prompted the development of VIKI [Marshall et al. 1994], the first system to describe itself as a spatial hypermedia system. Spatial hypermedia systems not just allow, but support, the visual and spatial expression of inter-document relations.

VIKI emphasized the manipulation of the information structures implicit in the layout of objects. These structures were recognized by a spatial parser enabling VIKI to provide users easier manipulation of their expressions. VIKI was not a presentation-oriented system. It largely assumed the authors and readers to be the same and so did not emphasize document aesthetics and provided limited support for understanding the hypertext. This prompted the development of VKB [Shipman et al. 2001].

VKB is a second-generation spatial hypertext system. It is a presentation-oriented system and includes higher support for collaboration between different authors and readers. One interesting feature that returns in VKB is the possibility of including explicit links within a single spatial hypertext and between spatial hypertexts. This is a crucial feature for adaptation as it allows varying the formalization degree and relocating previously adjoining objects to different parts of the document without losing their relationships.

Spatial hypermedia research has proved to be a prolific field, as more researchers started to explore these ideas and develop new systems in order to overcome shortcomings of traditional hypermedia [Apple 1996; Bernstein 2001; Eastgate 2001; Eastgate 2003; Golovchinsky 2001; Grønbæck et al. 2002; Hsieh and Shipman 2000; Mancini and Shum 2001; Microsoft Research 1999; Mogensen and Grønbæck 2000; Nakakoji and Yamamoto 2001; Nielsen and Ørbæk 2001, Simpson 2001].

This work contributes to hypermedia research by addressing the call for greater automation of spatial hypertext and greater ability to represent ambiguity [Rosenberg 2001]. In particular, this is the first to add adaptation to spatial hypermedia.

3.2 Adaptive Hypermedia

The goal of adaptive hypermedia is to reduce information overload without restricting access to available information. It attempts to achieve this by customizing the presentation to user parameters such as goals, knowledge, and preferences. This adaptive behavior is based on models that represent different characteristics of the user. Most adaptive hypermedia systems use knowledge-based representations for user models, although statistical and sub-symbolic representations (e.g. neural nets and fuzzy logic) are also possible. In 1996 Brusilovsky defined Adaptive Hypermedia using the following definition:

> …by adaptive hypermedia systems we mean all hypertext and hypermedia systems which reflect some features of the user in the user model and apply this model to adapt various visible aspects of the system to the user.

This definition has been used by other researchers [De Bra et al. 1999] and has guided adaptive hypermedia research to user-centered adaptation. From a broad perspective, the current dissertation could be classified as adaptive hypermedia. From a narrower point of view, this work does not fit the definition, as it does not adapt solely to the user.

Adaptive hypermedia, as noticed by Calvi [2001], has been focused mainly in the domain of education. However AH has also produced systems in areas such as intelligent tutoring [Fisher and Steinmetz 2000], context-sensitive help [Encarnação 1997] and information retrieval [Höök 1997].

ORIMUHS [Encarnação 1997] is an adaptive hypermedia context-sensitive help component used for medical imaging and CAD applications. It attempts to infer user preferences and needs. An interesting feature of ORIMUHS is that it can be integrated into new and existent applications, having been tested in the areas of medical imaging and CAD.

Finally, in regard to the issue of domain migration, some AH researchers have been concerned with designing systems that can be portable to different applications. Stephanidis et al. [1997] provide a rationale for designing flexible adaptive systems capable of being reused for different domains and user groups with minor modifications. They suggest the characteristics which determine the adaptation, such as goals and rules, from the particular adaptation strategy employed at the user interface. This approach informed the design and evaluation of the WARP system developed as a part of this dissertation.

Adaptive hypermedia is a field in its own right, having produced a large corpus of documented work and holding periodical international conferences (AH 2000, AH 2002, and AH2004).

3.3 Multi-Model Adaptive Hypermedia

The approach of using multiple models for adaptation follows from my prior work [Francisco-Revilla 1998, Francisco-Revilla and Shipman 1999; Francisco-Revilla and Shipman 2000]. Since users are not inside a box, isolated from their environment, ignoring their circumstantial factors does not serve them well. Therefore the logical consequence is to extend the single model approach to use multiple models to guide the adaptation process. This extension has been previously explored particularly in the Mars Medical Assistant (MMA) [Francisco-Revilla 1998]. MMA is an adaptive hypermedia application in the area of medical informatics. In MMA the medical information is segmented into fine-grained components that are then arranged and presented based on the requirements of the user, task and situation. MMA is particularly relevant for the current dissertation, as it is the ideological predecessor of the approach presented here. As such, many of the features introduced in MMA (such as segmenting information into fine-grained information components) are being used again.

MMA's idea of using fine-grained information segmentation is present in the work of other researchers. In PUSH, Höök introduces the use of fine-grained Information Entities (IE's) for the purpose of adaptive information retrieval [Höök 1997]. Höök's work presents an evaluation of user acceptance to the modification of the presentation based on IE's. The evaluation of PUSH reported positive results of using fine-grained components for adaptive purposes. She concluded that this approach not only facilitates the adaptation process, but it also makes it possible to include more information in each page, resulting in a reduced information space that is easier to navigate.

As multi-model adaptive hypermedia emerged from traditional adaptive hypermedia it has increasingly attracted the attention of more researchers. In the late 1990's researchers began exploring the simultaneous use of user, task, and situation models in adaptive hypertext systems [Francisco-Revilla 1998, Francisco-Revilla and Shipman 1999, Francisco-Revilla and Shipman 2000]. The use of multiple models has now become common place [De Bra et al. 2002]. For example, researchers reused the approach of employing domain, task and user models for adaptive hypermedia performance support [Brusilovsky and Cooper 2002].

These projects began the investigation into the benefits and issues associated with the simultaneous use of multiple models. By assuming a fixed set of coordinated models, these systems were implemented in order to provide a consistent functionality. This approach suffers the weakness that development of the models must be done in concert. Given the impossibility of predicting all potential use situations, model extensions required to support additional domains and applications potentially create the need to revisit all existing models. This dissertation further extends this direction by exploring the use of an open-ended number of models.

3.4 Visual Design

As noted by Bertin, useful information is drawn from the relationships between data items and efficacious graphic representations can convey these relationships through spatial perceptions [Bertin 1981, Bertin 1983]. Due to the visual nature of spatial hypermedia and its intrinsic effort to infer the relationships between objects, it is important to relate the specific methods and techniques in adaptive spatial hypertext to robust graphic design guidelines.

The work done by Tufte [1995] presents and explains the goals and effects behind different design practices. These design policies were converted into possible adaptation methods and techniques. In particular Tufte points at the possibility of augmenting the dimensionality of the information space, using of small multiples, designing for micro and macro readings, layering the information, using color, and creating space and time narratives. These concepts facilitated the design and analysis of spatial hypermedia. For instance, an increased dimensionality of the information space translates into the representation of more than two flat dimensions on the screen. Such is the case of piles of overlapping objects and the use of collections as a hierarchical structure of space. Similarly, small multiples designs allow the comparison and identification of differences between objects and facilitate the representation of ordered sequences of objects in the form of vertical or horizontal lists in a manner similar to the frames in a movie.

In his seminal paper, Mackinlay [1986] addresses the problem of how to use rules, based on robust graphic design guidelines, in order to automatically generate presentations for relational data. More explicitly, his work provides useful information on what and how graphical features can be used to present concepts in expressive and effective ways.

In Mackinlay's approach, graphic presentations are considered sentences of graphical languages. He then uses a basic set of primitive graphical languages and a *compositional algebra* in order to create more complex graphic designs. While in his work the compositional algebra is used in order to create more complex designs, it is also possible to use such rules in order to decompose existing designs. This is used in the context of this dissertation as a kind of spatial parser that attempts to infer the goals behind the arrangement of objects in a given spatial hypermedia document. The adaptation process then uses these inferred goals in determining specific adaptations.

Finally, Mackinlay's work deals with generating designs that can be accurately interpreted. It does not attempt to generate designs according to multiple effectiveness criteria (such as visual impact, speed of perception, or cost-effective rendering) due to the possibility of conflict. To apply this approach to multi-model adaptation required the consideration of trade-offs in visual design given multiple design objectives.

3.5 Agents

The field of agents and in particular of Multi-Agent Systems is related to the current work from the system architecture point of view. No agreed upon definition of agent exists (for different perspectives on the issue refer to Ferber [1999], Nwana [1996] and Wooldridge and Ciancarini [2001]). However there are a few characteristics that tend to be seen as essential, such as goal-oriented, autonomous, and situated behavior. In addition there are other characteristics that also seem to be often involved in agent systems, these are: collaboration and adaptivity.

Similarly, the approach in this dissertation considers the construction of independent entities – in this case the multiple contextualizing models – that are goal-oriented in their behavior. The architecture is based on “situated-ness” in that the agents interact within an environment that they can perceive and act upon.

The multi-agent approach used in this dissertation requires the creation of a cooperation framework between the agents. Cooperation, as defined by Ferber [1999], is the result of collaboration, coordination of action and conflict resolution:

Cooperation = Collaboration + Coordination of Actions + Conflict Resolution

This dissertation draws from work on multi-agent systems to inform the architecture and representation of adaptation models.

3.6 Conflict Resolution

Of the factors identified by Ferber, within the context of this dissertation, conflict resolution can be the most troublesome, especially since the system architecture follows a horizontal layering approach [Wooldridge 1999]. While the use of ambiguity can reduce the number of conflicts, it does not eliminate the possibility of conflict. This is a frequent issue in Multi-Agent Systems (MAS). There has been previous research on solving the issue of competing suggestions offered by different mechanisms [Ferber 1999; Sandholm 1999]. Different schemas have been suggested, including voting or priority based strategies [Conry et al. 1988; Durfee et al. 1989; Weiss 1999]. Approaches based on economic models such as negotiation [Sycara 1989], contracts, and bids (Weiss [1999] provides a description of several of these approaches). Most of these approaches have in common that they try to disambiguate and obtain a single response. In some situations this approach is the best one, while in other cases supporting ambiguity might be more appropriate [Rosenberg 2001]. This dissertation explores the power of ambiguity in expression to ameliorate conflicts between models and goals.

4 GENERAL ARCHITECTURE

The first activity in the design of the Multi-model Adaptive Spatial Hypermedia (MASH) approach was developing a theoretical framework that provided solid grounding for the concepts involved and their interrelations. The MASH framework consists of three components, each addressing a different theoretical perspective. First, the framework includes a generic architecture that facilitates the classification and analysis of different hypermedia systems. Second, it defines the fundamental concepts in spatial hypermedia and provides a high level ontological classification of the different types of adaptation in spatial hypermedia. Third, the approach introduces the philosophy of conflict management as a strategy capable of supporting the process of adaptation using multiple independent models. Each component of the framework is discussed in more detail in the following sections, starting with the general architecture in this section, continuing with the content and adaptation ontology in section 5, and ending with the philosophy of conflict management in section 6.

The generic architecture proposed by the MASH framework is shown in Figure 1. It decomposes systems into blocks that consider different functional aspects of spatial hypermedia. This architecture allows the comparison and classification of systems by reviewing which functional blocks they include. Note that this architecture represents an abstract partition of the functionality. Different systems, particularly early ones, coalesce blocks into single units.

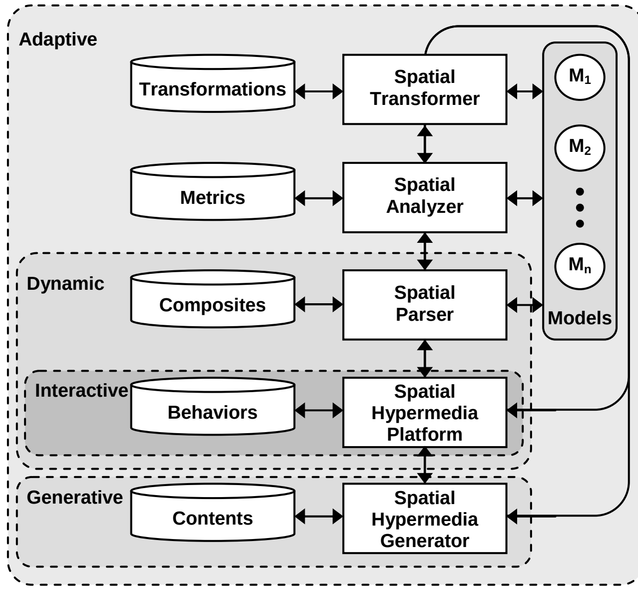

Figure 1. Spatial hypermedia framework

4.1 Generative Spatial Hypermedia

This component of the architecture refers to the creation of spatial hypermedia. The Spatial Hypermedia Generator provides the functionality required to author or automatically generate the documents. Contents might previously exist or they might be authored at document-creation time.

Early on within the field of spatial hypermedia, the systems developed (such as VIKI) assumed that the author of the document also was the document reader [Marshall et al. 1994]. As a result, many systems blended the generative aspect with the interactive aspect of spatial hypermedia [Bernstein 2001; Eastgate 2003; Golovchinsky 2001; Marshall et al. 1994; Nakakoji and Yamamoto 2001; Simpson 2001]. This was a natural union since reading a spatial hypermedia document often requires interacting with it, moving and modifying objects and relationships.

It is at the arrival of second-generation systems and Presentation Oriented Spatial Hypermedia (POSH) that a functional separation between the generative and interactive components starts being observed in the systems' implementation [Shipman et al. 2001]. For example, VITE's mapping engine converts the contents of a relational database table into a spatial hypertext where visual manipulations of objects in the workspace change the semantic contents in the database [Hsieh and Shipman 2000].

4.2 Interactive Spatial Hypermedia

Reading a spatial hypermedia document often requires people to interact with it, moving and/or changing objects and relationships. Therefore, when referring to people who read/interact with spatial documents the terms "user" and "reader" are equivalent.

Interactive Spatial Hypermedia provides the required platform on which users can interact with and read spatial documents. Interaction behaviors such as moving or modifying objects and maximizing and minimizing collections are considered part of interactive spatial hypermedia, even though they change the visual presentation and have a dynamic nature.

4.3 Dynamic Spatial Hypermedia

All spatial hypermedia systems that support reading and interacting with the spatial hypertext by modifying and moving the document's components could be considered dynamic. However, from a narrower point of view, Dynamic Spatial Hypermedia focuses on systems that support manipulation of and with inter-object structures as dynamic navigational hypertext supports manipulation of and with the link structure of nodes. For instance, dynamic behaviors can tether objects together, such that moving one object causes the other object to follow. This kind of relationship is a useful way to enforce and maintain implicit object relationships. The spatial parsers found in some spatial hypertext systems [Bernstein 2003, Francisco-Revilla and Shipman 2003, Hsieh and Shipman 2000, Marshall et al. 1994, Nakakoji and Yamamoto 2001, Nielsen and Ørbæk, P. 2001, Shipman et al. 2001] determine the structures that need to be preserved or exported.

Behaviors can modify the document's space, objects' relationships or composites. *Space behaviors* modify the underlying space directly. Objects are affected only by how they are positioned in the space. They include panning, scrolling zooming, fish eyes or any other function that acts upon the underlying space.

Object behaviors can mutate objects by changing their size, color, location, etc. Examples of how these mutations can be used in order to emphasize or de-emphasize the particular objects are shown in section 7.

Relationship behaviors act upon the relationships between the objects. They modify the relationship quality, association or scope. For instance they can change an implicit relationship to become explicit.

Composite behaviors act upon structures of objects and their relationships. An example is turning a list into a stack. A key component required to support composite behaviors is the Spatial Parser. It dynamically recognizes implicit relationships between objects in the space and infers new composite objects. This is a necessary step for behaviors that mutate implicit composites.

Behaviors are the basis for adaptable spatial hypermedia. Adaptable spatial hypermedia allows users to manually adapt the spatial document. This empowers users with the ability to override possible mistakes from the (automatic) adaptive mechanisms. In addition, behaviors can be used as mechanisms to avoid conflicts that can potentially result between competing model suggestions. This is illustrated later in section 5.

4.4 Adaptive Spatial Hypermedia

Adaptive spatial hypermedia systems (as opposed to adaptable hypermedia systems [schraefel 2000]) adapt the presentation of the document automatically. This includes transforming objects, composites, relationships and space itself.

The essential goal of the adaptation process is to obtain a *better* alternative presentation of the information. This entails evaluating the initial presentation according to the desired metrics and then generating an improved presentation through transformations. The MASH architecture encapsulates the evaluation functionality within the Spatial Analyzer and the functionality of generating an improved version in the Spatial Transformer. In practice, adaptive spatial hypermedia systems may wish to merge these two functions.

The Transformer and Analyzer interact and iterate in order to improve the presentation of the information. On one hand, the Spatial Analyzer evaluates the document based on the metrics available, while on the other hand, the Spatial Transformer attempts to maximize the desired document aspects by applying the appropriate transformations to the document.

Metrics and Transformations determine the strength of the adaptation process. Metrics represent different parameters associated with the space, object or relationships. They can be computed (the screen real estate for a list can be computed at run-time) or absolute (the degree of ambiguity of a matrix may be assigned by an author as "*medium*"). Transformations are methods and techniques that change the space, objects or relationships. Behaviors and transformations are not the same. Transformations are *abstract functions* that "translate" spatial expressions while behaviors *implement functions* that perform actions. While it is possible to code a behavior that triggers a transformation, they remain separate in nature.

The definition of the goal for the Spatial Transformer is the responsibility of the adaptation models (e.g. user model, activity model, situation model). In addition the models can add, modify or delete available metrics and transformations. Models suggest adaptation methods, such as to emphasize an object. Behaviors may be used as adaptation techniques and multiple behaviors may be used by the same adaptation method. For example, the "emphasize" method may be instantiated via highlighting, enlarging font or object size, or changing the object's color.

4.5 Multi-Model Approach

Allowing a variable number of adaptation models enables the adaptation of content in response to multiple aspects of the use context. The Multi-model Adaptive Spatial Hypermedia architecture allows these to be independent models, meaning they need no knowledge of one another. There are no assumptions about the nature of the models, allowing the independent development of the models' inner-workings. This creates a flexible adaptation mechanism, which facilitates migration across domains, applications and time. It also distributes the creation and control of the models, which is crucial to supporting the combination of author-created and user-created models desirable for maintaining personal information privacy.

Having multiple adaptation models results in the need for conflict management. This activity is the responsibility of the Spatial Transformer. Due to the variety of expression in spatial hypermedia, the Spatial Transformer can select alternative behaviors to instantiate transformations in order to minimize conflict and also adjust the level of ambiguity in the presentation in order to represent the tension between the models to the reader.

5 CONTENT AND ADAPTATION

Successful adaptation of information in a context of use requires understanding how content is represented and the methods for modifying that representation in that context. The high-level abstraction in MASH presents a generalization of the spatial hypermedia content, which is fundamental for the framework. MASH also incorporates a theoretical ontology of spatial adaptations that supports the comparison of different strategies.

5.1 Space, Objects and Relationships

When considering the intrinsic components of spatial hypermedia – Objects and Relationships – it is tempting to adopt navigational hypermedia concepts such as nodes and links. While this aids in correlating navigational and spatial hypermedia, it faces the problem that there is more than one possible way to map these concepts. For instance, one possibility is to map objects and relationships to nodes and links respectively. This perspective seems logical when considering a single space/document. However when considering the existence of multiple, interconnected spaces/documents this perspective seems to fall short. Another perspective is to consider spatial hypermedia documents as nodes. In this perspective, most links become internal to the same node; they connect one part of a node to another part of the same node. However this creates a discrepancy with the intuitive notion that links mostly connect nodes to nodes.

Rather than translating navigational hypermedia concepts to spatial hypermedia, spatial hypermedia is best considered in terms of Space, Objects and Relationships.

5.1.1 Space

Spatial Hypermedia, as it names suggests, uses space as the basis for establishing relationships between objects. However, as Kolb [Kolb 2001] points out, philosophers discussing the nature of space have developed different conceptualizations of what "space" is.

While finding a universally accepted definition of space has eluded mankind, there have been some initial studies about the nature of space in the context of spatial hypermedia [Grønbæck et al. 2002; Kolb 2001; Kolb 2002; Robertson et al. 1998]. These studies influenced the selection of the primary characteristics of space used in the MASH framework.

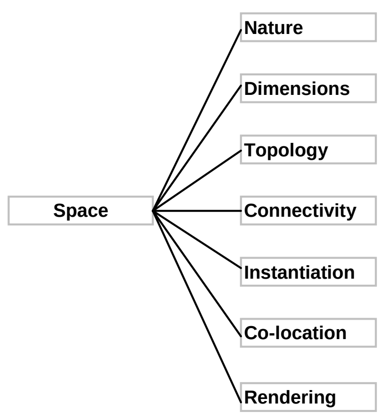

Figure 2. Space

Space can pragmatically be defined in terms of: Nature, Dimensions, Topology, Connectivity, Instantiation, Co-location, and Rendering, as shown in Figure 2.

5.1.1.1 Nature

As Kolb [2001] notes, there are two competing views about the nature of space. On one hand, space can be described as absolute. Space is an entity on its own, independent of whatever it might contain. Perfectly empty space is conceivable, and its contents have no effect on its structure. On the other hand, space can be described as relational. In this view, space is an emergent phenomenon of the relationships between objects.

While node-and-link hypermedia systems function primarily as a relational space, spatial hypermedia systems additionally implement an absolute space.

5.1.1.2 Dimensions

A key feature of space is that it provides a "place" for objects to be located and moved. The dimensions of the space determine the variety of possible locations and movements. Different spatial hypermedia systems implement 2, 2½ or 3 dimensional spaces. The decision of how many dimensions to implement is critical and depends on the specific application. Several studies have been conducted that compare the use of dimensionalities [Cockburn and McKenzie 2001; Modjeska and Waterworth 2000; Roberson et al. 1998].

5.1.1.3 Topology

Space is not necessarily a homogenous, amorphous entity. A space might have a shape (e.g. flat, curved, tilted, shaped as a fish bowl, etc.) and can have zones or areas with different properties. The particular shape and areas of a space define its topology.

Sometimes the virtual space (the system's representation of space) can map to a real space (such as a building or a city). This is the case in Manufaktur [Grønbæck et al. 2002; Mogensen and Grønbæck 2000] and other augmented reality systems. In these cases, the real space determines the topology of the virtual space.

5.1.1.4 Connectivity

Space connectivity determines how areas interconnect. For instance a space might be an infinite or a bounded surface. Reaching a limit might prevent the reader from navigating any further, or might take the reader to the opposite extreme of the space (i.e. an object moving pass the right boundary can appear on the left boundary as if they were connected).

5.1.1.5 Instantiation

This refers to how many instances of the same object can exist in different locations at the same time (e.g. VIKI allowed the "same object" to appear in multiple places in the spatial hypertext).

5.1.1.6 Co-location

This refers to how many objects can occupy the same location at the same time. In the real world we normally work under the assumption of *1 thing at 1 place at 1 time* – only one book can be at a particular point on the bookshelf at a given time.

5.1.1.7 Rendering

In Spatial Hypermedia the question of how to render the space is critical. Rendering variations such as fixed vs. variable viewpoints or immersive vs. non-immersive environment affect the reader's perception of the space [Haik et al. 2002].

5.1.1.8 Combining Spatial Characteristics

The differences between systems' conceptual spaces are significant because the characteristics of the space define the set of relationships that can be represented in it. For instance, a 2-dimensional (2-D) flat space has a different representational power than a 2½-D space. 3-D spaces can represent relationships incapable of being represented in 2½-D spaces. While much research in spatial hypermedia has focused on exploring the use of 2½-D homogeneous space, there has been relevant experimentation with space deformations [Shipman et al. 1999] and with 3-dimensional spaces [Apple 1996; Grønbæck et al. 2002; Microsoft Research 1999; Mogensen and Grønbæck 2000].

5.1.2 Objects

Objects represent the encoded information. They can be of three kinds: atomic, document or composite, as shown in Figure 3.

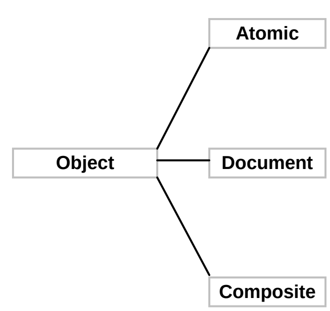

Figure 3. Objects

5.1.2.1 Atomic Objects

Atomic objects are text, images or any other type of information encoding that the system supports. The MASH framework does not attempt to enumerate all possible types since they will evolve as technology advances.

5.1.2.2 Document Objects

Document objects are spatial hypermedia documents that can be related to the current document. These external documents can be included by reference in the current document or linked to as an external resource.

5.1.2.3 Composite Objects

Composites are constructions of one or more objects (atomic, document, and/or composites) that are related in a specific manner. This relationship can be explicitly stated or implicitly inferred by the system.

There is a diversity of composite objects that varies according to the characteristics of the space. However, from an abstract point of view, there are three main ways to create composite objects. One way to create a composite is based on recognizing piles or stacks of co-located (overlapping) objects. This kind of object, often used in 2½ D spaces, is more complex to represent in 3-D spaces and thus used less frequently. The second way to create composites is based on the proximity of the objects. This results in three kinds of composites: 1-to-1, 1-to-many, and many-to-many composites. The last way to create composite is to group objects into a composite object. This composite contains the objects. This kind of composite is often referred to as a Collection (in 2-D and 2½ D systems) or Construct (in 3-D systems).

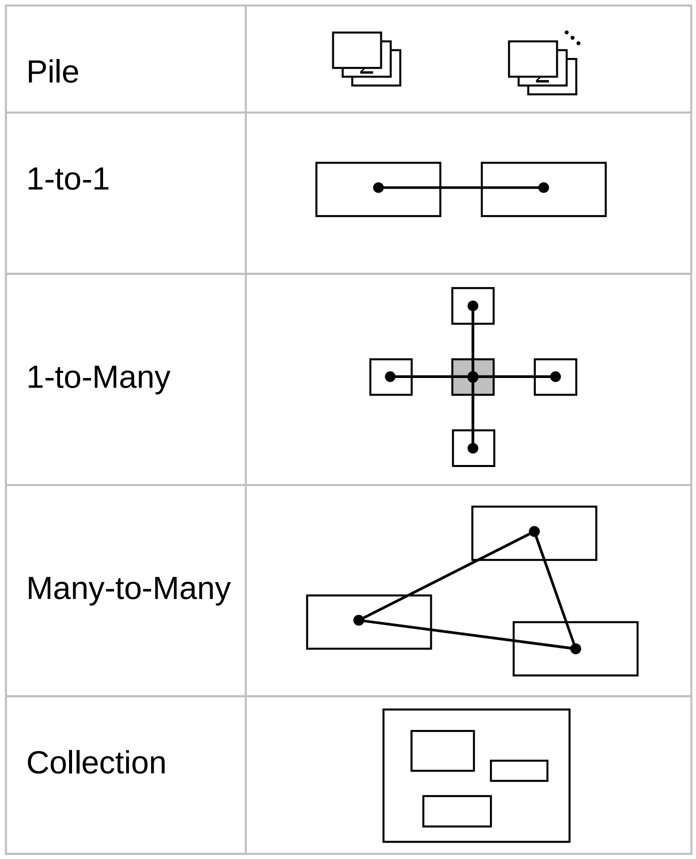

Figure 4. Basic composites

The basic composites, shown in Figure 4, provide only a generic composition of objects. Special cases of these composites are often more useful. Some special case composites of interest because of their frequent use, list and matrices, are shown in Figure 5. List composites are constructed by a set of objects positioned along some direction. Matrices represent a multi-dimensional variation of Lists (the representation and use of matrices in 3-D spaces is more complex than in 2-D spaces).

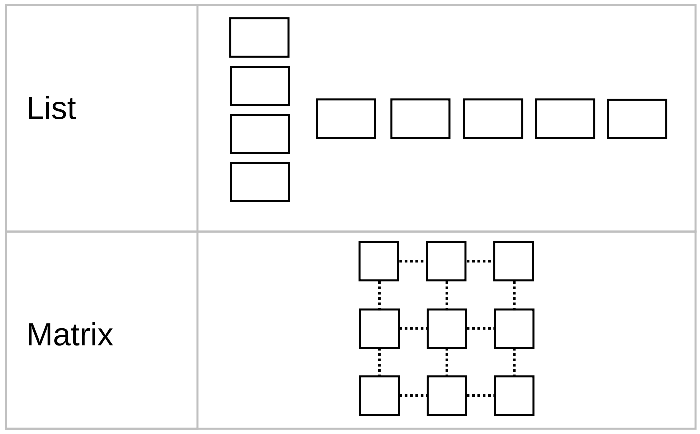

Figure 5. Special case composites

Human perception and algorithmic recognition of which objects make up a composite object often involves not only the relative position but also the type and visual characteristics of the components. The above composites are made of visually similar objects. Alternatively, in some applications, it is desirable to distinguish schematic composites containing a particular set of objects, each with specific features, which are arranged in a specific configuration. For instance, it might be desired to recognize labeled lists or Toulmin structures [Marshall et al. 1991]. However, schematic composites can vary greatly, making them difficult to standardize across domains and applications. Hence, while acknowledging their existence, the MASH framework refrains from classifying them.

5.1.3 Relationships

Relationships in MASH are important. Rather than attempting a fine-grained taxonomy of relationships such as provided by [Conklin 1987; DeRose 1989; and Trigg and Weiser 1986], MASH limits its jurisdiction to the abstract features of relationships that are intrinsic to spatial hypermedia. In this context, MASH classifies relationships according to the three dimensions: quality, association and scope (as shown in Figure 6).

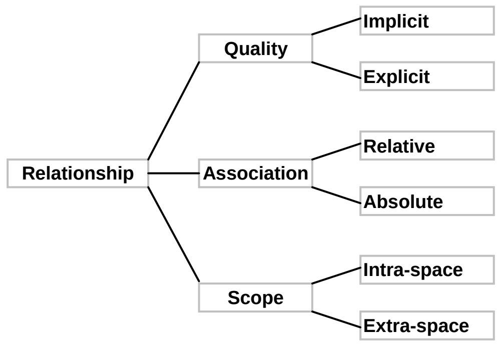

Figure 6. Relationships

5.1.3.1 Quality of Relationships

Quality refers to the instantiation of the relationships. Implicit relationships are inferred by the system while explicit are declared by either the author or the user/reader.

5.1.3.2 Association of Relationships

This dimension represents how the relationship emerges. Relative associations are based on the relative position of the related entities. Absolute relationships have a visual representation independent of the relative position of the related entities (the navigational and semantic links in VKB [Shipman et al. 2001] are one example).

5.1.3.3 Scope of Relationships

This dimension refers to whether the related entities are part of the same spatial hypermedia document or if they belong to different documents.

5.2 Spatial Adaptation Ontology

Ontology, as the Merriam-Webster dictionary defines it, means *a particular theory about the nature of being or the kinds of existents*. Accordingly, the spatial adaptation ontology provides a theoretical framework that facilitates the understanding of the different kinds of adaptations available in spatial hypermedia.

This ontology extends previous classification schemes of adaptation mechanisms developed for traditional hypermedia such as the ones proposed by Brusilovsky [1996] and De Bra et al. [1999].

As spatial hypermedia is best comprehended using objects, relationships and space, the classification of the kinds of adaptation in spatial hypermedia is best accomplished using these dimensions. This results in the four kinds of adaptations shown in Table I.

Table I. Kinds of Adaptations in Spatial Hypermedia

Semantic	Modifies *what information* is shown. Brusilovsky refers to this kind of adaptation as adaptive presentation and De Bra as content-adaptation.
Relational	Modifies *what interconnections* (links in traditional hypermedia, relationships in spatial hypermedia) exist between the different parts of the presentation. Brusilovsky calls this adaptive navigation and De Bra link-adaptation.
Spatial	Modifies *what affordances and constraints* are supported by the underlying space. This dimension does not exist in Brusilovsky’s or De Bra’s models.
Meta-adaptation	Modifies *what adaptations* can be applied to the adaptation mechanism itself. This is an emergent characteristic of the multi-modal approach and does not exist in Brusilovsky’s or De Bra’s models.

Meta-adaptation is a complex issue. While it is important, discussion of the different adaptations possible is outside the scope of this work. Hence, the following sections focus mainly on semantic, relational and spatial adaptations.

5.2.1 Methods and Techniques

Similar to Brusilovsky's [1996] and De Bra's [1999] frameworks, the MASH ontology for spatial adaptations abstracts the different adaptation approaches into high-level methods and low-level techniques. Tables II, III, and IV show methods and techniques for the semantic, relational and spatial dimensions, respectively.

Table II. Semantic Adaptation

Methods	**Techniques**
Provide explanations (Additional, prerequisite, comparative)	• Show/Hide objects • Show/Hide composites • Transform objects • Transform composites • Layer objects and composites
Use explanation variants	• Instantiate objects • Instantiate composites • Show/Hide objects • Show/Hide composites
Create Groups	• Strengthen constraints of objects in the group such that their features vary only within a given range (i.e. position or color) • Layering objects • Instantiate explicit composites • Adjust and equalize objects' visual features (transform objects) • Transform composites • Transform space
Sort	• Instantiate explicit composites • Adjust the features of objects in a group to match a given order • Transform composites
Highlight	Increase object's relative weight
Soften	Decrease object's relative weight

Reviewing the adaptation methods and techniques shown in Table II it is possible to observe that semantic adaptation strategies provide the tools to adjust what and how spatial hypermedia objects are presented. While adjustments to the objects can obviously affect relationships between objects, these methods and techniques are aimed at managing the meaning encoded by the objects while maintaining the relationships between objects.

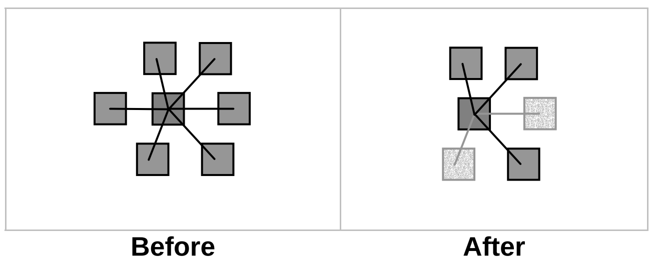

Figure 7. Example of a semantic adaptation

Figure 7 shows a possible application of the explanation variants method using hiding and layering techniques. Relevant information is maintained, while less relevant information is grayed out and inappropriate information is hidden.

Table III. Relational Adaptation

Methods	**Techniques**
Support Global Navigation	• Instantiation of explicit composites • Instantiation of explicit relationships • Instantiation of explicit, absolute relationships • Transform composites
Support Local Navigation	• Instantiation of explicit composites • Instantiation of explicit relationships • Adjust object's implicit relationships • Transform composites
Support Global Orientation	• Show/Hide (transient) milestones • Transform space
Support Local Orientation	• Show/Hide (transient) milestones • Transform space • Panning • Zooming
Support Personalized Views	• Transform objects • Transform composites • Transform space

Relational Adaptations classify different adjustment mechanisms for representing relationships in spatial hypermedia. These mechanisms, although they can affect individual objects, are focused on the spatial, navigational, and semantic relationships between objects. An example is shown in Figure 8.

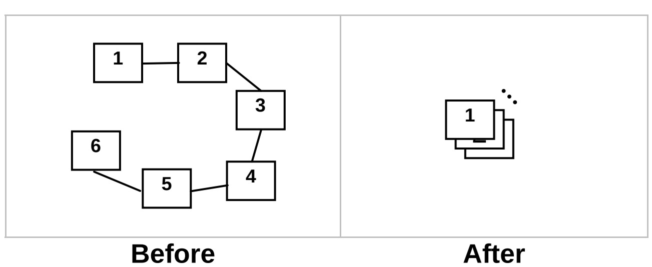

Figure 8. Example of a relational adaptation

Figure 8 shows how an explicit list is transformed into a pile. This transformation provides the user with an alternative way to visualize the relationships between the objects. This is an example of a local navigation method using a composite transformation technique because the change affects only how the user navigates through the relationships between the objects within a local area of the document.

Strategies available in spatial hypermedia for modifying the underlying space are shown in Table IV. These methods and techniques affect space characteristics such as continuity, linearity, uniformity, rendering, and affordances and constraints supported by the space.

Continuity refers to the discrete or continuous nature of space. Linearity refers to how the unit's of each axis (dimensions) increase as they move away from the origin (for instance in a linear or logarithmic way). Uniformity refers to the homogeneity of the space: in a uniform space its characteristics are similar everywhere. The space rendering affects how the space is represented on screen.

Table IV. Spatial Adaptation

Methods	**Techniques**
Deform space (change topology)	• Modify linearity (e.g.. fish-eye views) • Modify continuity (e.g. snap to grid)
Use alternate renderings	• Zoom in/out • Modify angle of view
Set affordances and constraints	• Apply constrains and affordances to the global space (e.g. set a gravity force) • Apply constraints and affordances to local area (e.g. set gravity points)

Finally, Table V shows the adaptation methods for the meta-adaptation dimension.

Table V. Meta-Adaptation

Methods
• Model modification • Model substitution • Inter-model interaction modification • Redefinition of Metrics • Redefinition of Transformations

The meta-adaptation dimension has a more abstract nature as it is not directly coupled with the presentation. As it is concerned with changing computational procedures, there are plentiful meta-adaptation strategies. Therefore, rather than imposing artificial limits, no technique level is presented.

5.2.2 Adaptation Goals

When deciding on an adaptation, there are two aspects to consider: what to present and how to present it. There are a variety of desirable and undesirable attributes for a presentation. Examples of presentation attributes include formal, detailed, visible, etc. These attributes can theoretically be achieved via each adaptation type.

Two attributes worth noticing, although they are not strictly mandatory, refer to the formality and ambiguity. These are important because Spatial Hypertext has often dealt with issues of incremental formalization [Shipman and McCall 1994].

The terms "informal" and "ambiguous" can be confused. Hence, before proceeding, it is important to define and differentiate them.

Formality refers to how "established" the presentation appears. An informal presentation appears flexible and inviting to interact with, for example, by making modifications and adjustments. A formal presentation appears better organized and more reliable. Figure 9 illustrates the difference between formal and informal presentations.

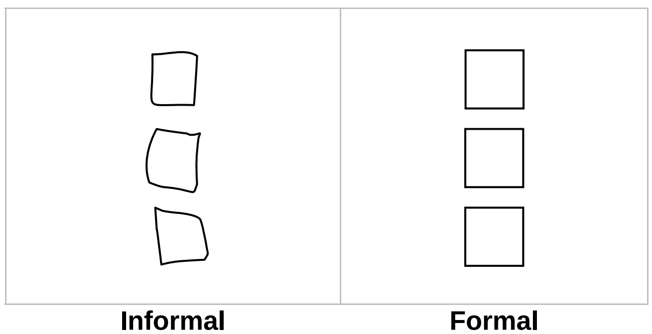

Figure 9. Informal vs. formal spatial presentations

In the informal case, the objects' shapes and alignment loosely indicate a list. However this seems more "experimental" than the formal case, where objects have strict shapes and alignment.

Ambiguity refers to the clarity of the presentation. In an unambiguous presentation, relationships between the objects are clear and easy to interpret. In contrast, in an ambiguous presentation, relationships are not always clear and there is more than one interpretation of the underlying structure. Figure 10 illustrates the contrast between ambiguous and unambiguous presentations

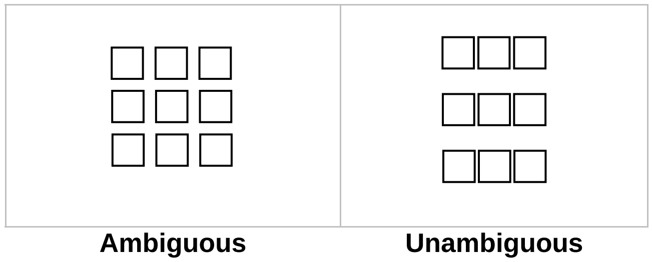

Figure 10. Ambiguous vs. unambiguous spatial presentations

In the ambiguous case it is impossible to know if there are three rows of objects or three columns or both. However in the unambiguous case, the relative position clearly shows that there are three rows of objects, each with three objects.

Table VI shows the different methods and techniques that can be used in order to make the presentation more formal or informal.

Table VI. Formality Adaptation

Methods	**Techniques**
Normalize objects, relations and space (increase formality)	• Strengthen constraints in groups of related objects. • Equalize objects' characteristics like size, position, etc. (align objects).
De-normalize objects, relationships and space (decrease Formality)	• Relax similarity constraints in groups of related objects • Allow larger differences in space uniformity and constraints.

Table VII shows the different methods and techniques used for modifying the ambiguity of the presentation.

Table VII. Ambiguity Adaptation

Methods	**Techniques**
Clarify relationships (*disambiguate*)	• Create explicit relationships • Create explicit composites • Transform composites
Blur relationships (*ambiguate*)	• Destroy explicit relationships and imply relationships by the use of similar or relative object features • Transform composites
Emphasize Structure	• Activate negative space between objects • Augment border's relative weight • Transform composites
Emphasize Content	• Augment object's relative weight • Deactivate negative spaces • Decrease border's relative weight • Transform composites

These examples show how the goals of adaptation relate to different presentation characteristics. They also show how adaptation methods and techniques can be matched to the presentation goals.

5.3 Theoretical Platform for Spatial Hypermedia

Clear comprehension of how information is represented in spatial hypermedia and how it can be adapted is essential for the design of adaptive spatial hypermedia systems. In this regard MASH provides a robust theoretical grounding in the form of a conceptual abstraction of the fundamental concepts and an ontological study of the adaptation methods, techniques and goals.

6 CONFLICT MANAGEMENT

The philosophy of managing conflict, as opposed to simply resolving conflicts, is fundamental for the support of the approach to adaptation using multiple independent models. Conflict management is a process that encompasses three steps: *conflict avoidance*, *conflict detection* and *conflict resolution*. This apparently straightforward process has its intricacies. Conflict detection can be troublesome as conflicts can be created indirectly and determining the context of conflict is often difficult.

The following example provides a base for the discussion of the complexities involved in conflict management and how some spatial hypermedia features can be used for addressing these complications.

Consider a multi-model adaptive system that takes various sources of news and then adapts their presentation for individual stockbrokers who work in a given brokerage firm. The system employs a user model in order to identify relevant news using information about the user's investment portfolio. If an article or news item is about a company part of the portfolio, then it is marked as *very relevant*. The news item is marked as *so-so relevant* if it is not about any company in the portfolio, but it talks about an industry that encompasses at least one of the companies in the portfolio. All other articles and news items are marked as *not relevant*.

In addition to the user model, the system also uses a competitor model that classifies the news in a similar way based on the market performance of a competing trader.

Finally, the firm's management included a risk model that classifies the news pieces based on the confidentiality of the information and the risk that the use of this information might prompt accusations of insider trading. This model classifies the news items as *very risky*, *so-so risky*, and *not risky*.

Once the models classify the news items, the system adapts the presentation by emphasizing the relevant and de-emphasizing the irrelevant ones. Similarly, news items are annotated based on how risky they are. In addition, very risky news items are protected from viewing.

Based on the models described above, consider a news item containing confidential information about a company that belongs to an industry in which the user does not own any stock but the competitor does. In this case the system needs to deal with suggestions for the same object to de-emphasize (from the user model), emphasize (competitor model) and protect it from viewing (risk model). The following sections reflect on similar situations as a way to explain the processes of avoidance, detection and resolution.

6.1 Avoidance

In multi-model adaptive hypermedia, conflicts occur when different models suggest adaptations that the presentation medium cannot represent simultaneously. As an example, consider the suggestions from the competitor model and the risk model mentioned in the previous example. Imagine that the only way to emphasize a news item is to highlight its text and the only way to protect it from viewing is hiding (not showing) the object. This creates a conflict because it is impossible to highlight the news item if the object is hidden.

Based on the previous discussion it follows that augmenting the expressiveness of the medium can sometimes prevent the conflict from occurring or avoid the need of resolving it.

6.1.1 Avoiding Conflicts

Conflicts can be anticipated by mapping the suggestions of each model to high-level adaptation methods capable of being expressed through different adaptation techniques. In the example above, the system attempts to “emphasize” very relevant news items and to “protect from viewing” very risky items. Different techniques can implement these methods. For instance, emphasizing can be expressed by changing the background color or adding an icon. Similarly, instead of hiding the object, a news item can be protected from viewing by occluding the text while keeping a placeholder for the object. These adaptation techniques can simultaneously represent both suggestions.

6.1.2 Avoid Resolving Conflicts

Supporting ambiguity in the presentation is another useful approach that, while not preventing the conflicts from occurring, avoids having to resolve them.

In the previous example, consider the conflict between the user model and the competitor model. One suggests de-emphasizing the news item while the other suggests emphasizing it. If a system that supports ambiguity, each “emphasize” could be expressed through different techniques. For instance, the de-emphasize method can reduce the size of the object while the emphasize method can change the background color. The decision of whether supporting ambiguity or not is important and needs to be addressed at the time of system design.

6.2 Detection

Detecting conflicts when different models make suggestions regarding the same object is trivial. However, because information objects in the presentation are often interrelated, conflicts can be indirectly created as by-products of suggestions regarding different objects. For instance, in the example of the adaptive news system, one news item might include a picture while another item might contain comments about the picture. Hiding the picture might make the comments meaningless. The main problem is identifying the relationships between objects in the presentation.

6.2.1 Context of Conflicts

In spatial hypermedia, a key functionality is the ability to parse the document in order to recognize the implicit and explicit information structures that emerge as a result of the relative positioning of the objects.

The objective of the spatial parsing is to recognize specific visual arrangements, such as piles and lists, which are often used by presentation authors in order to express meaningful relationships. The parsing process takes a set of objects (atomic objects) and groups them *into* composite objects, where composites can “contain” objects or other composites. This process continues grouping composites and atomic objects until it achieves an overall document hierarchy in the form of a tree or forest.

Given the parser's hierarchical structural interpretation of the spatial hypermedia document, "context" can be defined as a function of "containment". This definition allows conflicts to be classified into the following categories:

- Object conflicts. This kind of conflict occurs when suggestions about an object oppose each other; for instance, when one model suggests hiding an object while another suggests to showing it.
- Sibling conflicts. Sibling conflicts occur when suggestions for one object affect or contradict the presentation of another object in the same context; for instance, a suggestion to show and highlight a text that annotates a picture conflicts with the suggestion to hide the picture.
- Parent conflicts. Composites are computed based on the visual appearance of the objects that make them up. Modifications of an object's visual appearance can affect the parent composite, potentially destroying it. For instance, a list of objects can be broken up into two lists if one object in the middle is hidden. There are different actions that might be appropriate when facing these conflicts. Sometimes it might be best to maintain the broken lists while other times it might be better to "contract" the list, repositioning the other objects in such a way that it still is recognized as a list.
- Parent-child conflicts. Parent-child conflicts occur when suggestions for the adaptation of the parent composite oppose suggestions for the components of the composite (children). For instance, suggestions of hiding a list of objects conflict with suggestions of highlighting objects in the list. Parent-child conflicts differ

from parent conflicts, in that the former ones are the result of contradicting suggestions at different levels of the document hierarchy, while the latter ones are by-products of suggestions for a single object.

- Parent-parent conflicts. Objects can belong to multiple composites. Consider a vertical list intersecting a horizontal list of objects. The object in the intersection is contained in both lists. Hiding this object produces parent conflicts in both lists. However, the parent lists are limited in the corrective actions that they might use. It is not possible to contract both lists. As two objects would be “pulled” into the same position. Alternatively, instead of hiding the object in the intersection, it might be better to replace it with a “ghost object” or placeholder that while occluding the object it still conveys the meaning that an object is there and that there are two lists.
- Global conflicts. In addition to the previous types of conflicts, conflicts might arise between adaptation suggestions regarding objects in different parts of the document tree and at different levels in the hierarchy. These global conflicts can occur even in the absence of other kind of conflicts. As an example of this kind of conflict consider the case where the models require the adaptation process to enforce a consistent structure within all substructures (e.g. the same schematic layout). Initially all collections contain similar substructures. A global conflict would occur if the contents and visual arrangement of one collection change and become different than all other collections.

6.3 Conflict Resolution

Conflicts can propagate across the object relationships. For instance, sibling conflicts can spread from sibling to sibling. Therefore, it is desirable to solve conflicts early before they propagate any further.

6.3.1 Flexibility

Depending on the situation, conflicts need to be resolved differently. It is necessary to be flexible and support different resolution strategies. Consider the example of the financial news system. Assume that an object conflict is detected between the user model suggestion of emphasizing a particular news item and the risk model suggestion of protecting the item from viewing. If the management wants to minimize the chances of facing an insider trading lawsuit, then the best conflict resolution strategy might be to assign priorities to each model. In this way the risk model suggestion can overrule suggestions from the other models. However, an object conflict between the user model suggestion of de-emphasizing an object and the suggestion of the competitor model to emphasize it might be resolved differently. For this conflict a better approach might be to take the suggestion that assigned the highest relevance to the news item.

It is often not enough to provide flexible strategies based on the type of conflict. In some cases, the same kind of conflict might require different resolution strategies, depending on the particular objects that are involved. Hence, it is desirable to provide flexible conflict resolution also at the object level.

6.3.2 Provide a Default Strategy

Flexibility is a necessary feature of conflict resolution that can be challenging to make both general and usable. In adaptive hypermedia systems designed as presentation mediums, authors cannot be expected to specify the adaptation strategy for all objects. A better approach is to bootstrap the system by providing a default strategy for objects and types of conflicts (e.g. suggestion averaging or model voting). The default strategies are not always appropriate and authors and users need to be able to override the conflict resolution strategy in order to meet their preferences.

6.4 Managing Conflict

Multi-model adaptive hypermedia addresses issues arising due to the complexity of developing single models that represent all relevant aspects of the use context and concerns over control and access to adaptation model content. Systems supporting independent models need to manage conflict among the models. We have explored a combination of conflict avoidance, conflict detection, and conflict resolution, which uses the spatial parser to recognize the context of conflicts and takes advantage of the highly expressive nature of spatial hypermedia.

7 WARP SYSTEM

WARP is the first multi-model adaptive spatial hypermedia system. It is implemented as a Web-based application written in Javascript and Java Applets. This facilitates the exploration of distributed spatial hypermedia and collaborative spatial hypermedia. Additionally, because it executes inside Web browsers, WARP avoids having strong dependencies on operating systems and hardware platforms.

Designed in accordance with the MASH framework, WARP's functionality includes the interactive, dynamic and adaptive aspects of spatial hypermedia. The generative aspect is performed in collaboration with VKB [Shipman et al. 2001]. VKB provides the authoring environment for the creation of presentation-oriented spatial hypermedia documents, which may then be exported in WARP format. WARP presents the spatial hypertext on-line and provides the required platform for people to read and interact with them. Since WARP and VKB do not map one-to-one, this schema allows the testing of novel system interoperability concepts in spatial hypermedia systems.

7.1 WARP Functionality

In order to illustrate WARP's functionality, a scenario of use is provided. Consider a user in the process of creating a conference presentation about spatial hypermedia. In the spatial hypertext shown in Figure 11, the user has organized objects into collections representing references, conferences and earlier presentations.

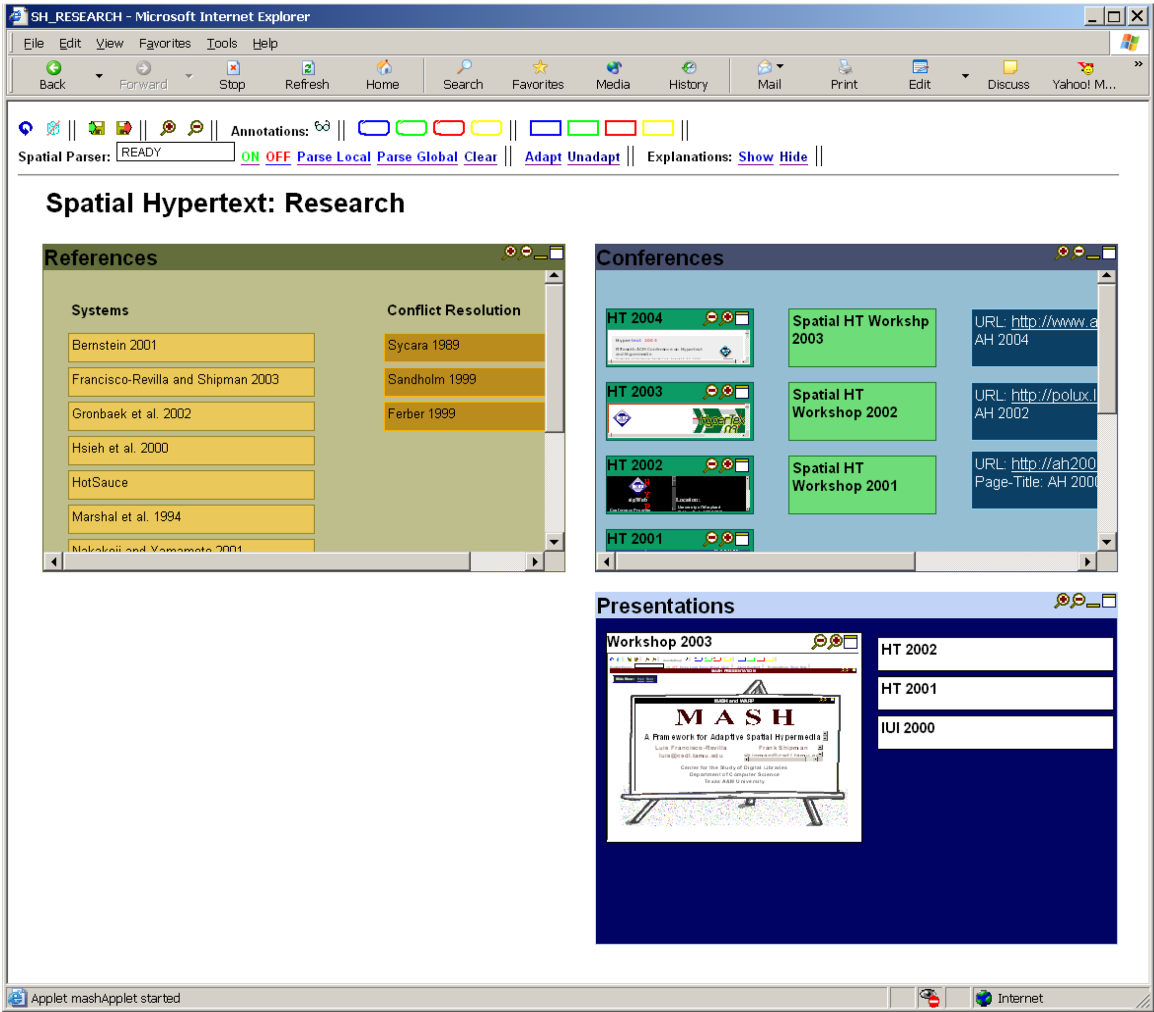

Figure 11. WARP

The collection titled "References" contains groups of references arranged by topic ("Systems", "Conflict Resolution", etc.). All of these are text objects. The "Conferences" collection has different kinds of objects that represent some of the conferences and workshops in which the user has previously participated. These objects are examples of the two types of explicit links that WARP currently supports. Transclusion links are illustrated by the ACM HT conference objects. They show the actual conference Web pages as local sub-areas that can be zoomed in or out in order to improve the overall perception of the contents. In contrast, the blue objects on the right are text objects that contain traditional navigational links to the AH conferences. It is up to authors to choose the appropriate way to represent their links.

The "Presentation" collection shows another example of a transclusion link. The document object for the "Workshop 2003" presentation is another spatial hypertext located elsewhere on the Web. This is an active space that allows the user to read and interact with it as if it were a part of the parent document. Transclusion links are discussed in more detail in section 7.2.

WARP functionality includes behavior support. Behaviors can be assigned to objects, relationships or the space. Correspondingly, behaviors can act upon objects, composites or space. Figure 12 illustrates how behaviors can preserve the visual relationships between objects. In this example there are explicit relationships between the HT conference objects in the "Conferences" collection. These relationships have an associated behavior that enforces a fixed distance between objects. Thus, the resizing of the "HT 2003" object "pushes" the other document objects up or down, preserving the implicit vertical list.

Also visible in Figure 12 is the c*ontext menu*. This menu appears when the user right-clicks on any object (e.g. the "HT 2003" object). This is one of the ways that WARP allows the user to manually adapt the document components using general adaptation methods, such as emphasize and explode, or specific adaptation techniques such as glow and resize.

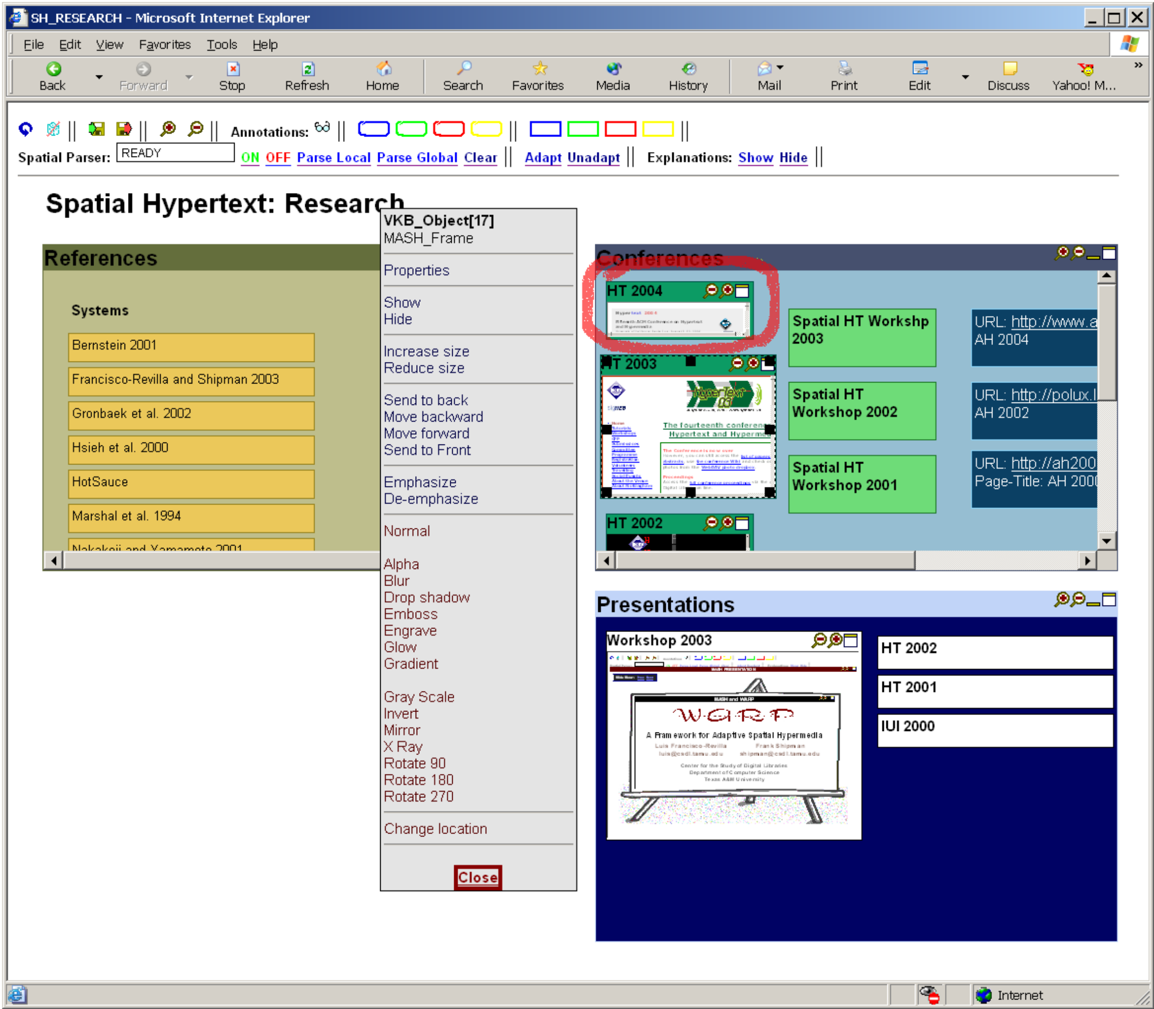

Figure 12. Behaviors and interaction

Behaviors are the basis for WARP's adaptable capabilities, which empowers users with the ability to adapt the document as they see fit and correct inappropriate adaptations performed by the system.

7.2 Personal Access or Shared Access

WARP, by virtue of being a Web-based application, circumvents some of the distribution issues typically associated with proprietary spatial hypermedia systems. In

WARP, documents can be published and may include, by transclusion links, other documents available on the Web, whether they are spatial hypermedia documents or not. As a result, it is necessary to consider some interesting aspects regarding the interaction and access of multiple users to multiple distributed spatial hypermedia documents.

Reading a spatial hypermedia document often requires the user to interact with it. This can be considered a modification of the document. These possible “modifications” can have repercussions that raise issues about ownership of the document and collaborative access to the document. WARP supports personal access to the document, as opposed to shared access. This means that the interacting/reading activity of a user does not interfere with the interacting/reading of any other users.

In WARP, the first time that a user accesses a document, s/he gets a copy of the original spatial hypertext. The document author can specify interaction affordances and constraints that define the user’s ability to modify properties of the objects such as their position or their default conflict resolution strategy.

In addition, WARP supports the creation of user annotations on the document by creating new objects. These are personal annotations. An example of a user annotation is shown in Figure 12, which shows a red circle that the user has created around the “HT 2004” conference. The purpose and meaning of annotations depend completely on the user. Annotations in WARP are private and, for the moment, cannot be shared.

Reading spatial hypertexts is an active process that often extends through time. Hence, WARP allows users to save the state of the spatial hypertext as a cookie on the local machine. This allows users to return to their personal version of the document the next time they access it.

7.3 Transclusion

WARP, as previously mentioned, allows users to view and interact with spatial documents that have been linked by transclusion. Furthermore, WARP supports the import and export of objects across spatial documents linked by transclusion. This is illustrated in Figure 13. While interacting with the 2003 Spatial Hypertext Workshop document, the user moves (imports) a collection and all its contents into the present space/document (and thus copies it from the “Workshop 2003” space).

To the user, WARP’s import-export operation is identical to dragging an object out of a collection. This results in a transparent interaction that blends different spaces into a seamless one. From the user’s perspective, it is a unified space. While for this user the collection has been moved into a different document/location, for other users this collection is still where it was in the “Workshop 2003” document.

Transcluded spaces are more than distributed collections. Each space can have particular behaviors, explicit relationships, transformations and spatial characteristics. The import and export operations need to deal with these issues in order to be useful. For instance, the collection titled “MASH and WARP” shown in Figure 13 has an associated behavior that moved the collection to the back of the pile whenever the user clicked on another object in the space. When the object is exported, the behavior needs to be dissociated from the object in the new document.

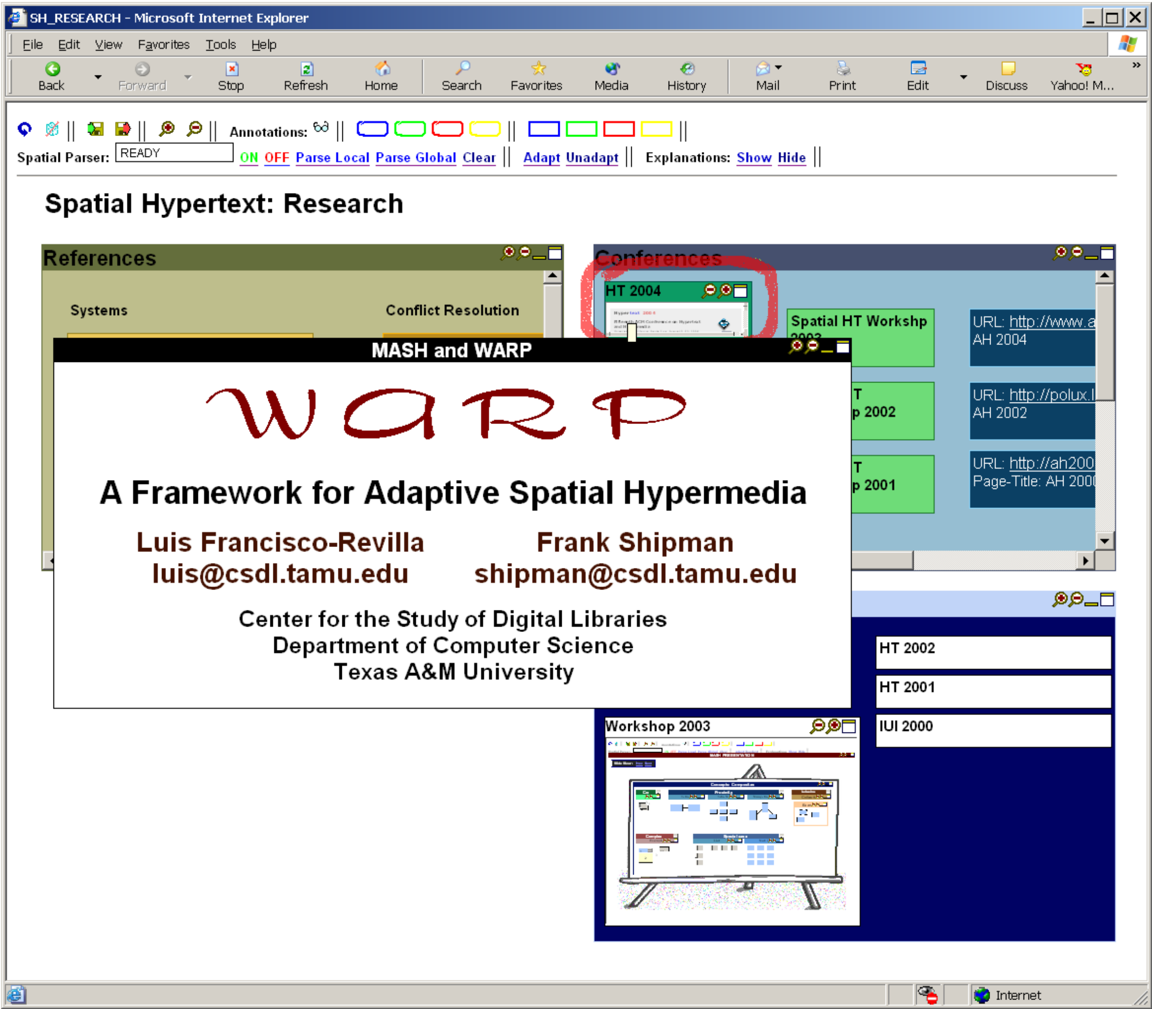

Figure 13. Transclusion and collaboration in WARP

While WARP attempts to empower the users in order to enrich their reading/interaction with the document, WARP also attempts to respect the rights of the document/space authors. In the use scenario illustrated in Figures 11 to 13, the user is assumed to be the reader and author of the documents and has full access to the spaces. However, in some cases authors may want to control access to and interaction with their spatial documents. WARP addresses this by allowing authors to attach access control and rights metadata to objects. This metadata can include copyright notices or specific constraints that guide the import and export operations. While this is only a first step, it provides an initial approach that can be revised with experience.

7.4 Adaptation

WARP's approach to adaptation is designed to take an existing spatial hypertext and produce, guided by the suggestions of a set of models, an improved version of it. The adaptation process is elaborate and can vary. It is best understood by tracing its functionality through a scenario of use.

At the spatial hypermedia platform, objects are simply located in space. For instance, Figure 14 shows an abstract example containing five objects. There might be implicit relationships but the system has not yet inferred them. As previously mentioned, these implicit relationships define the context of the objects and recognizing them is critical for the resolution of conflicts. Hence, the first step for WARP's adaptation is to pass the objects to the spatial parser in order to recognize the composite objects created as a result of the implicit relationships between objects.

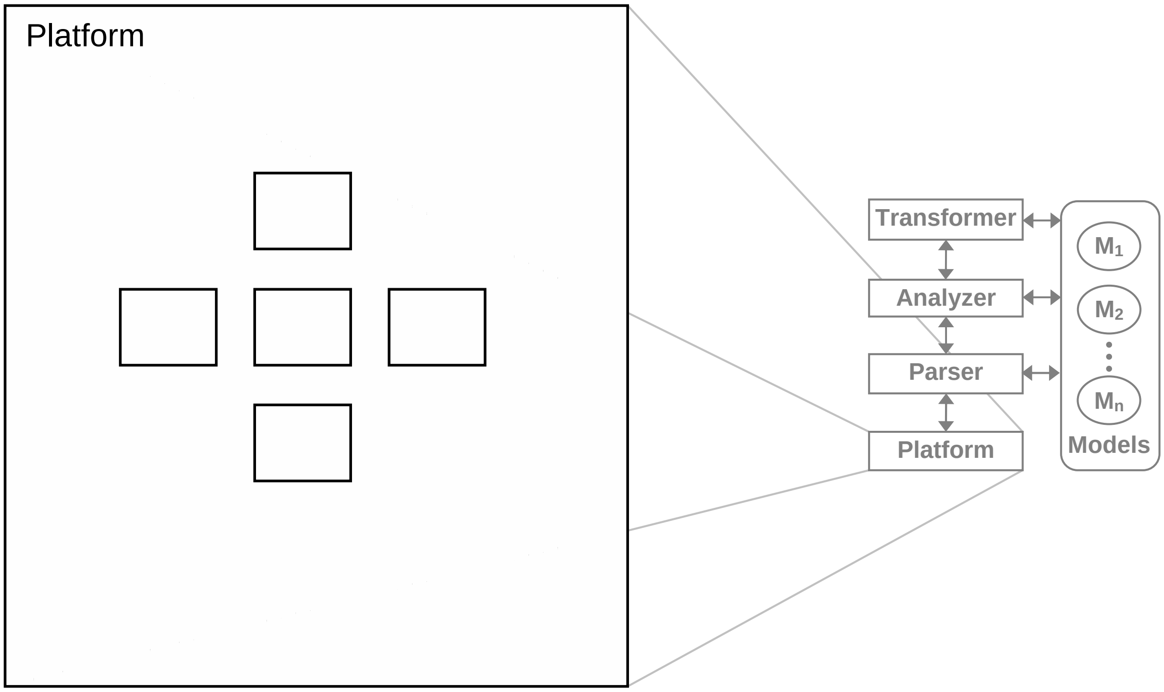

Figure 14. Adaptation process

WARP uses a novel fuzzy-logic approach to spatial parsing that can encode human rules of composite recognition. For instance, when trying to assess if two objects belong to the vertical list, the parser employs rules like:

> If the objects are *close* to each other and their vertical alignment is *good*,
> then the possibility that they form a vertical list is *strong*.

Terms such as “close”, “good” and “strong” are fuzzy variables that define the membership degree of ranges of values. A value can belong to more than one fuzzy variable with a degree of membership ranging from 0 (does not belong) to 1 (belongs 100%). A Fuzzy Set defines all fuzzy variables for a range (open or closed) of values. For instance, Figure 15 shows the fuzzy set of variables that classify the proximity of two objects. The values of the horizontal axis represent the vertical distance between objects measured as percentages of the height of the shortest object.

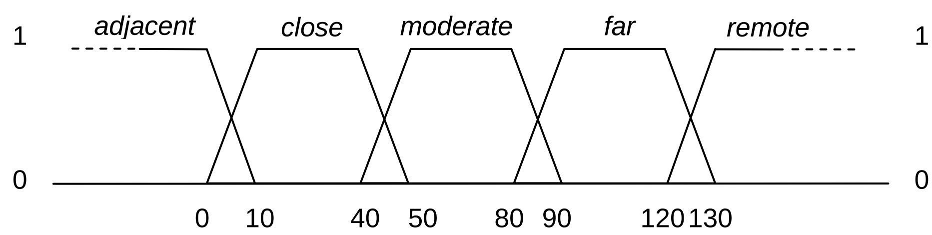

Figure 15. Vertical list proximity fuzzy set

Similar fuzzy sets define the fuzzy variables such as “good” for the alignment and “strong” for the possibility of forming a vertical list. This allows the translation of human heuristics to system rules in order to recognize structures perceivable to humans. Additionally, WARP allows the author and users to modify the default specifications in order to better calibrate the spatial parser. (A review of fuzzy logic can be found in [Yen and Langari 1999].)

Currently, WARP’s spatial parser recognizes implicit composite objects including vertical and horizontal lists, piles and heaps, 1-to-1 relationships, 1-to-many relationships, and many-to-many relationships. Figure 16 shows the parsing results for the objects shown in Figure 14.

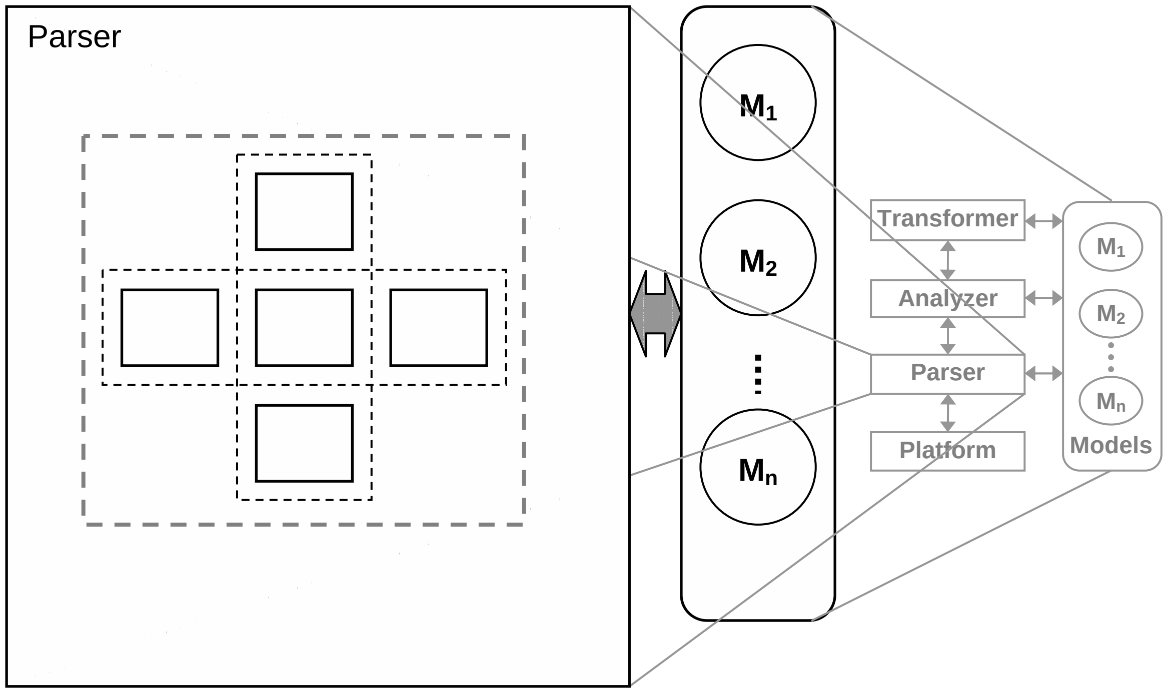

Figure 16. Parsing and adaptation

A feature of WARP's spatial parser is its support for the manipulation of many of its functional parameters, including the type of objects to be recognized, which characteristics of the objects are considered, and the precision level required for recognizing ambiguous relationships between objects. For instance, it is possible to see in Figure 16 that the parser has recognized a horizontal list, a vertical list and a pile composed of the horizontal and vertical lists. This exemplifies one difference from the VIKI/VKB spatial parser – objects and composites may be a component in more than one higher-level recognized structure. It could also have recognized the pile as a 1-to-many relationship. In this example, the spatial parser disregards piles of implicit composite objects.

Changes in parsing behavior at run-time are the result of suggestions provided by the models. The number of models and which ones are used for generating parsing suggestions is variable. The default behavior in WARP is to consider, with the same degree of confidence, all suggestions from all the models. However, the author can modify this and specify the individual degrees of confidence and scope of action for the models.

Once the parser has finished, it passes the resulting object structure, comprised of all composite and atomic objects, to the spatial analyzer. This is shown in Figure 17.

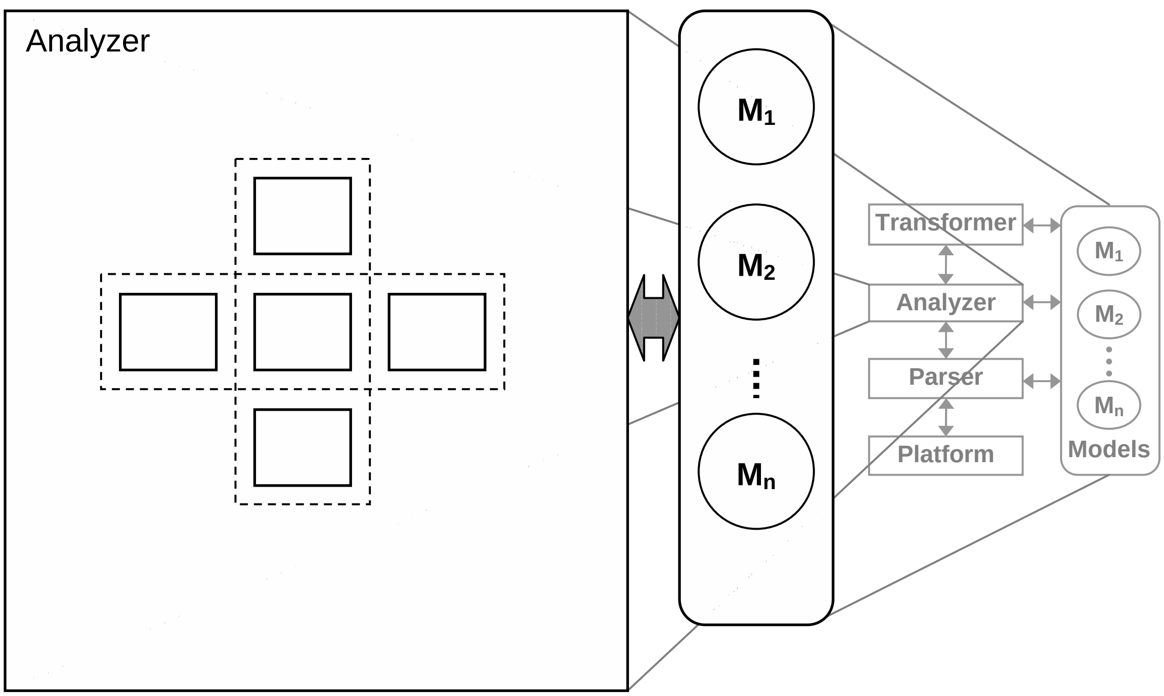

Figure 17. Context inference and conflict avoidance

At this stage, the inferred structure is analyzed and the context for possible conflicts is inferred. This is the stage where conflict avoidance techniques can be used.

For instance, the analyzer can automatically instantiate behaviors that enforce a minimum distance between objects in order to prevent the possibility of unintentionally overlapping objects due to adaptations that move or resize the objects.

After deciding which conflict avoidance strategies to use – guided by the suggestions from the models – the analyzer passes the objects and recognized structures to the transformer.

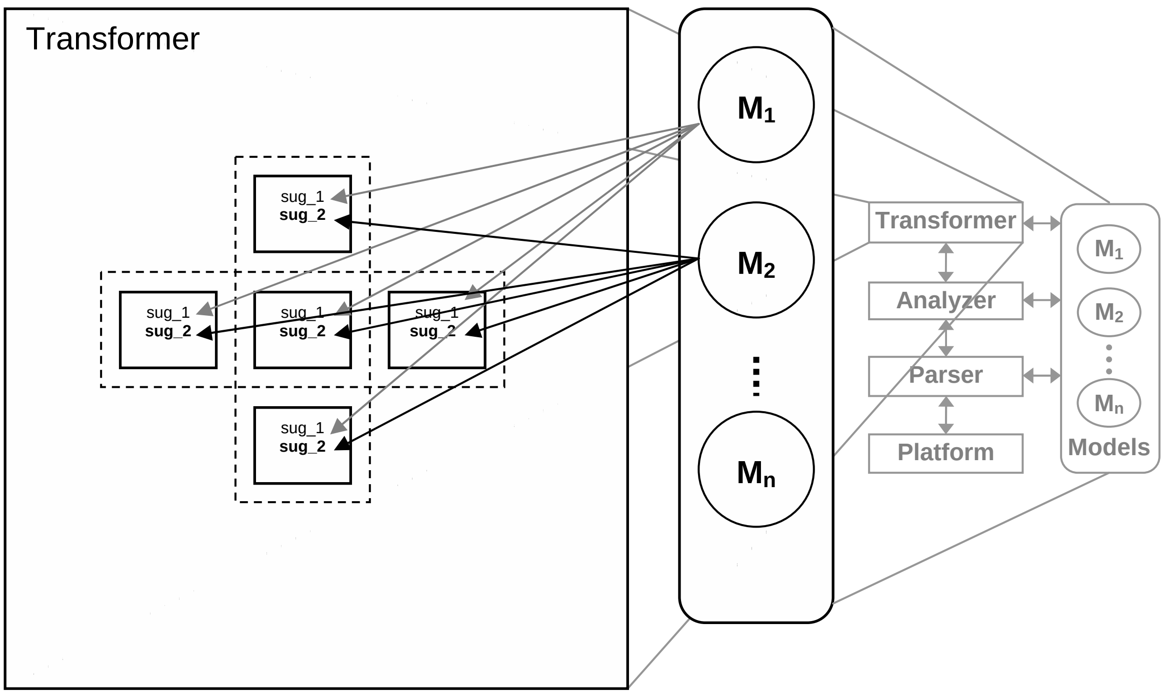

Figure 18. Gathering adaptation suggestions

WARP's adaptation process executes in consecutive rounds that progressively adapt the document according to different aspects. It is the job of the transformer to execute these adaptation rounds.

By default, WARP adapts the objects based on their relevance but it can also execute additional adaptation rounds that address requirements for explanation variants, layout optimizations, and navigation and orientation alternatives. The author can specify the order in which WARP attends to each one of them and even specify additional adaptation aspects.

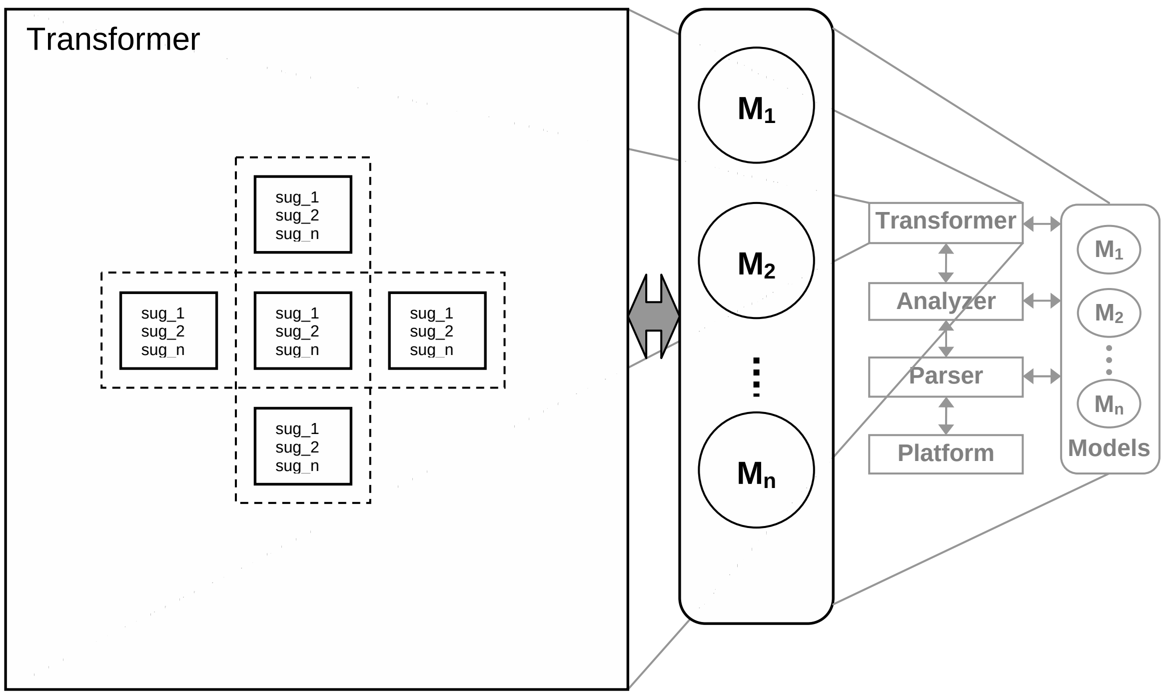

Figure 19. Suggestion integration and resolution of object conflicts

In each adaptation round the transformer asks the models to evaluate each object, atomic or composite, explicit or implicit, and make an adaptation suggestion. The scenario of use assumes a single round of adaptation based on object relevance. Figure 18 illustrates how the models return their relevance suggestions to the objects.

Each adaptation suggestion has two values: a strength assessment (ranging from -1 to 1) and the model's confidence of that assessment (ranging from 0 to 1). Each object has a list of the models from which it accepts suggestions. The model list also specifies the degree of confidence or relevance that the object attributes to each model (ranging from 0 to 1). By default objects accept suggestions from all models defined for the document. Authors can override the defaults for individual objects or for the whole document. Figure 19 shows the objects after registering all the suggestions. The composite objects have also received suggestions from the models, but they are not shown for clarity sake.

Once all suggestions are collected, each object combines the suggestions using a suggestion integration strategy. There are different strategies available to each object. The strategy employed can be the default strategy, an alternative strategy explicitly specified by the author, or a strategy recommended by the models. This is WARP's core mechanism for solving object conflicts. WARP's set of suggestion integration strategies include:

- Weighted average: averages the strength of the suggestions, weighted by the object's confidence in the model and the model's confidence in the suggestion.
- Maximum strength: uses the suggestion with the highest strength.
- Minimum strength: uses the suggestion with the lowest strength.
- Maximum confidence in model: uses the strength suggested by the object's most trusted model. If the object trusts more than one model with the maximum confidence, then suggestions from these models are weight-averaged.

- Maximum suggestion confidence: uses the suggestion from the model with the highest confidence in the suggestion. If more than one model trusts its suggestion with the maximum confidence, their suggestions are weight-averaged.
- Heuristic best: uses the suggestion with the highest heuristic value. The heuristic value is the product of the object's confidence in the model multiplied by model's confidence in the suggestion.

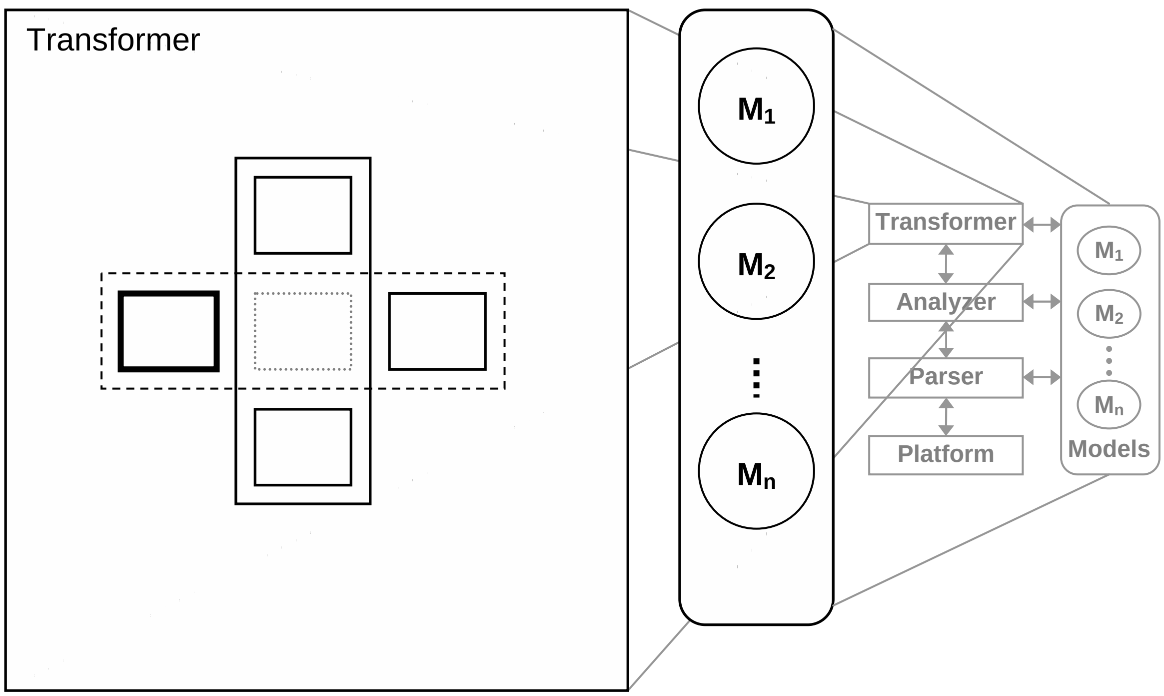

Figure 20. Transformation and adaptation

Once each object integrates its suggestions, it is possible to translate the suggestions into object transformations. These transformations operate at the adaptation method level. The mapping of methods to techniques is executed later. As an example, consider Figure 20. The object in the center has integrated all the suggestions and concluded that it has a low relevance (strength = -0.5) and that it needs to be de-emphasized. The object on the left has consolidated its relevance suggestions into a strength of 0.5, requiring additional emphasis. Similarly, the vertical list has consolidated its relevance suggestions to a strength of 0.4, also requiring greater emphasis.

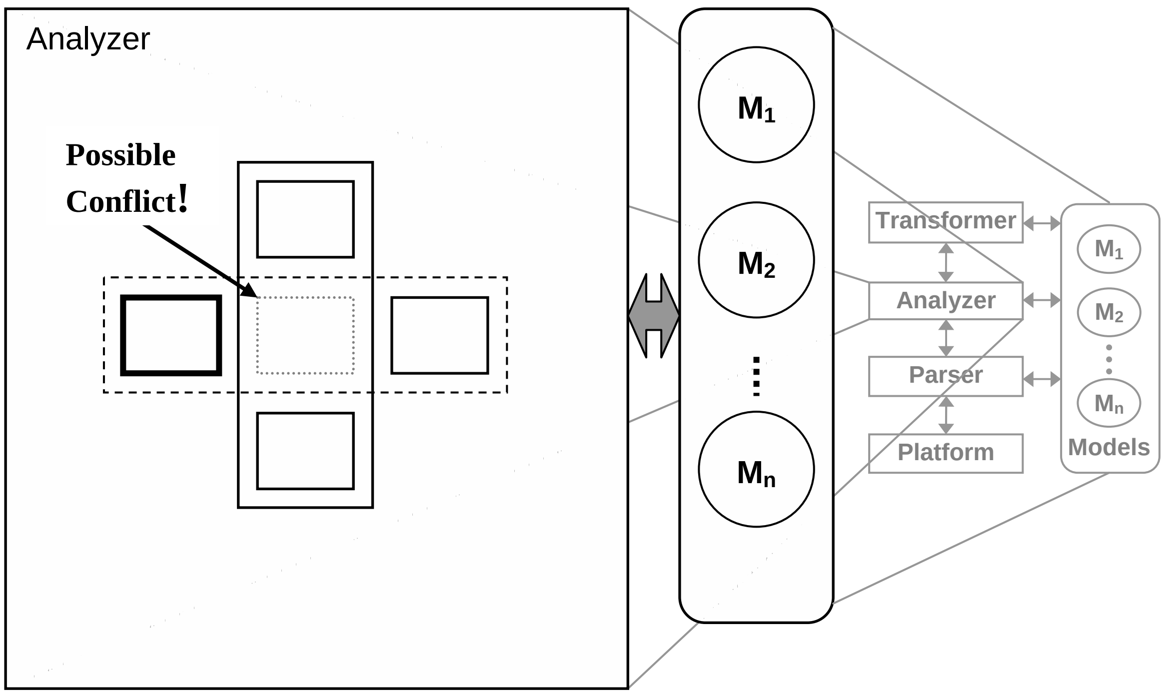

Figure 21. Extended conflict detection

The default mappings from emphasis to specific adaptation techniques can vary across objects. In the case of the left object, the default is to increase the border width, but in the case of the implicit vertical list the default is that it instantiate an explicit list object. The default mapping from the central object de-emphasizing is to hide it.

Default mappings of adaptation methods may, or may not, be the best alternatives. Hence, the transformer requests the analyzer to evaluate the resulting effect of all the object transformations, as shown in Figure 21.

Given the context provided by the inferred spatial structure, WARP can detect possible conflicts including: parent, parent-child, parent-parent, and overall conflicts. The goal of the analyzer is, in addition to detecting conflicts, to identify a set of constraints that can be used to guide the process of mapping adaptation methods to techniques. For instance, in Figure 21, the analyzer has detected a parent-parent conflict. Hiding the central object results in breaking the visual appearance of both lists. In order to search for better alternatives, the analyzer returns the objects to the transformer along with the identified mapping constraint to not hide the central object.

WARP's adaptation flexibility resides in the high-level nature of the suggestions, the knowledge of the degrees of confidence, and the recognition of the adaptation constraints. Given these, the transformer can look for alternative mappings that meet the constraints set by the analyzer. This can result in different configurations, such as those shown in Figure 22. The two alternative configurations result from two different mappings for the de-emphasize method. The top alternative chooses to gray-out the central object, reducing its weight but maintaining its presence in the space. The construction of the second alternative is more elaborate. The transformer asks each parent composite (the vertical and horizontal lists) to react to the hiding of one of their members. As a result, both of them "contract" moving their visible members together. The transformer also moves the lists in order to avoid overlapping of the lists.

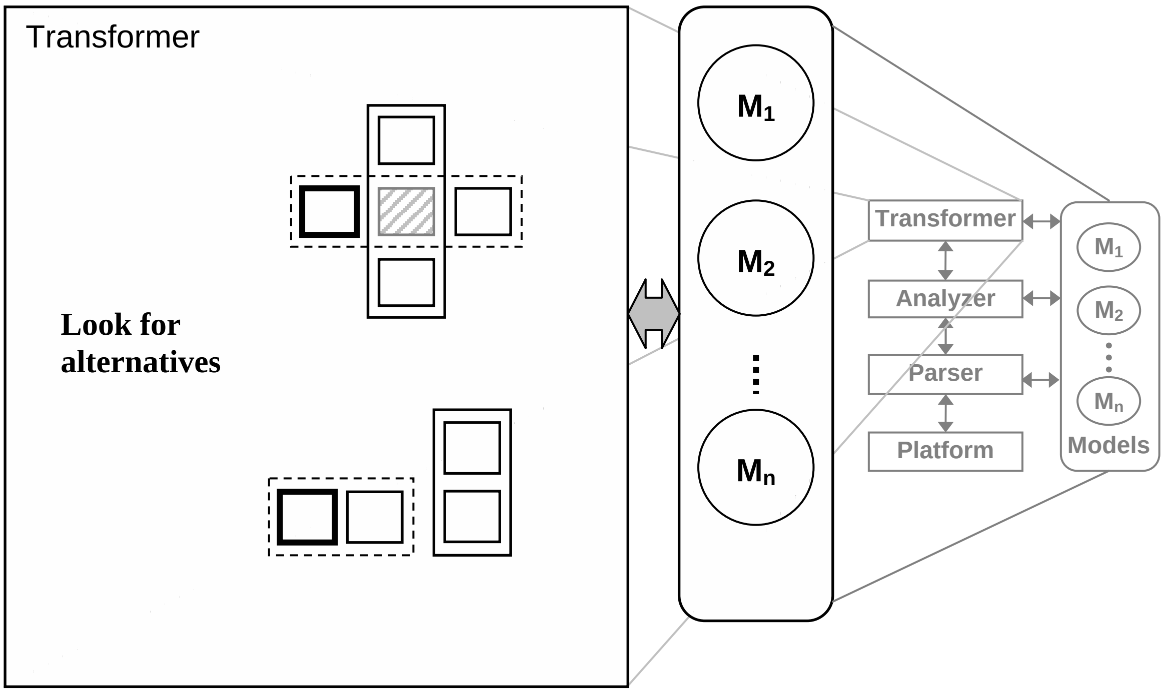

Figure 22. Alternative transformations

Normally the transformer selects the best mapping (going from the simplest to the more complex) that does not require the use of the mapping constraint ("hiding" in the case of the scenario of use). If more than one mapping is equally desirable, the transformer can compute more than one alternative and submit all of them to the analyzer.

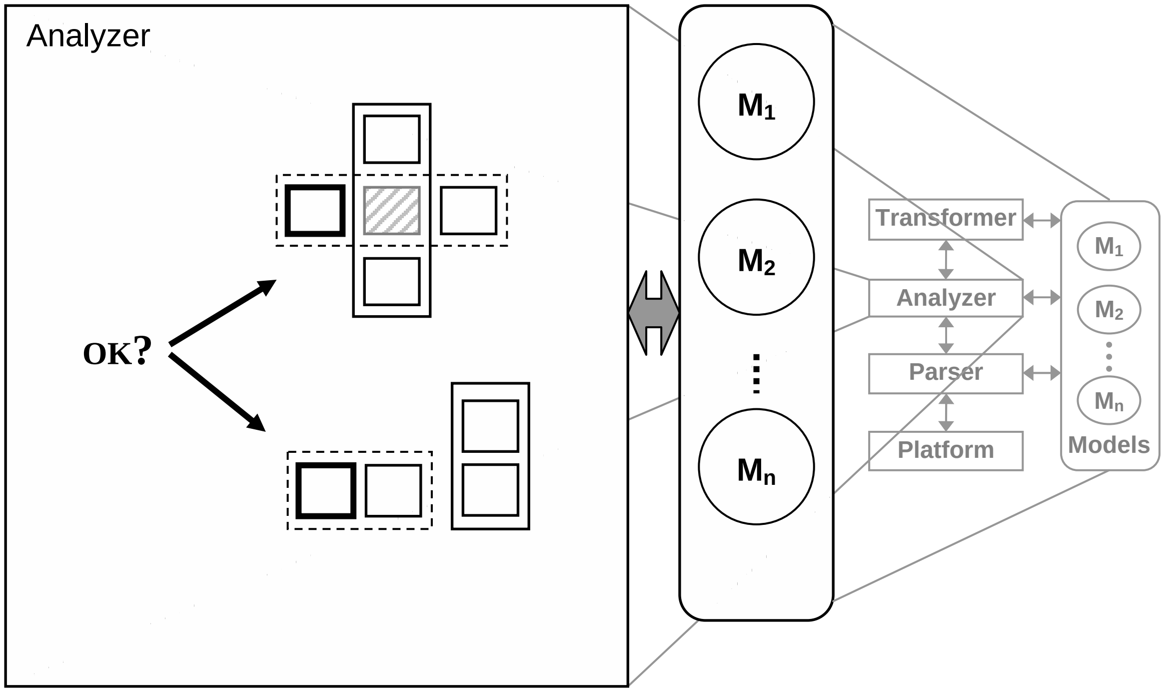

Figure 23. Evaluation of alternative adaptations

The analyzer evaluates the alternative adaptation. The analyzer deems the adaptations acceptable if it does not detect conflicts. If the adaptation is not acceptable, the process iterates, requesting a new alternative from the transformer.

Once the adaptation is appropriate, or the transformer is incapable of finding better alternatives, the analyzer passes the adapted structure with the highest score back to the parser, which in turn gives it to the spatial hypermedia platform. In Figure 23 the analyzer returns a higher score for the top alternative, as it is simpler and requires fewer modifications to the original layout.

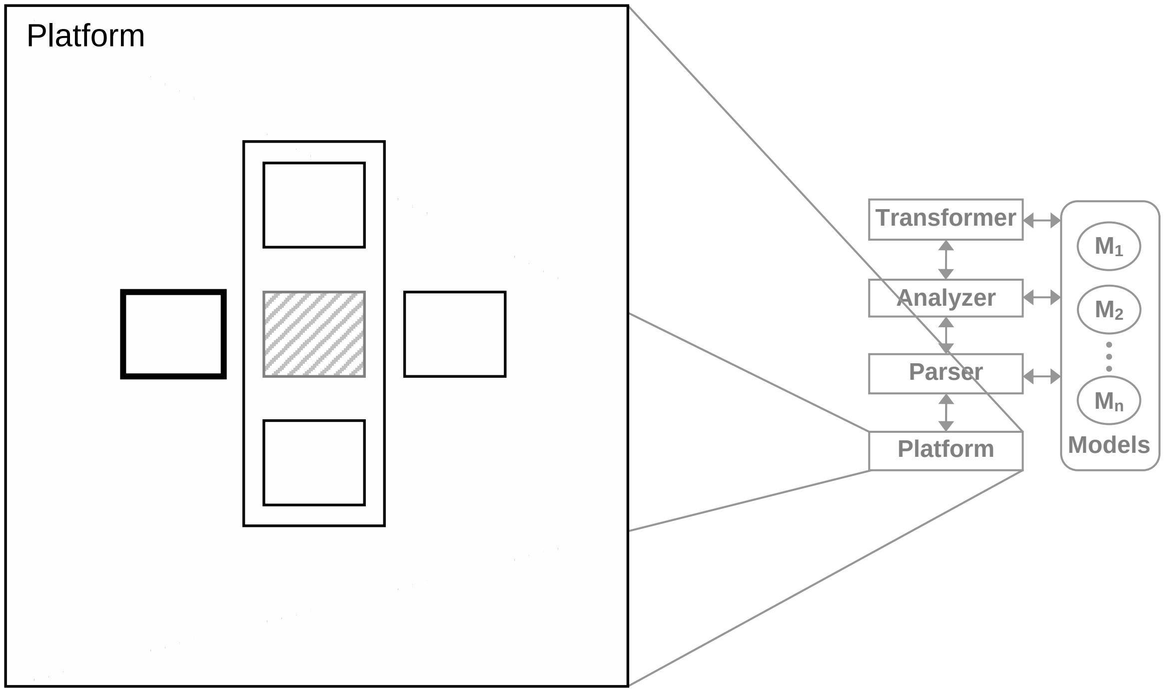

Figure 24. Final adaptation stage

In the last stage of the adaptation process, the spatial hypermedia platform then instantiates the adaptation techniques and presents the results to the user, as illustrated in Figure 24.

7.5 Model Creation

The implementation of multi-model adaptive systems, such as WARP, help visualize the differences between the single user model approach used in adaptive hypermedia to the multi-model approach. In WARP, the design and implementation of a model is done once. Each model represents a coherent aspect of the context as determined by system developers and authors. In the financial news example, the models can be represented as in Figure 25.

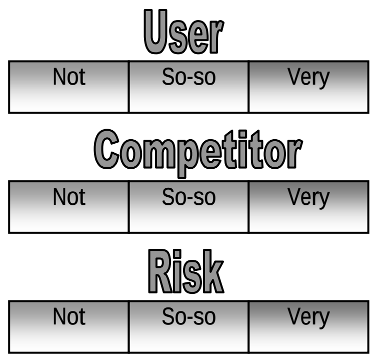

Figure 25. Multiple models of the financial news system

In single model adaptive systems, all aspects need to be modeled in the same model. The model needs to specify the behavior for all possible combinations of aspects, as shown in Figure 26.

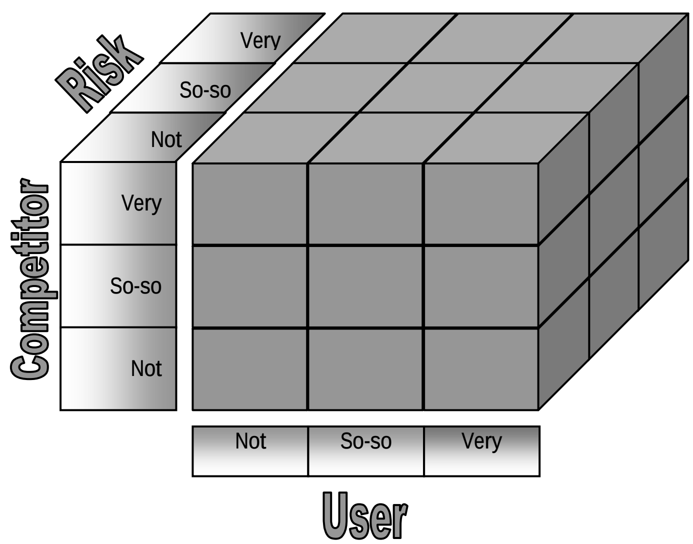

Figure 26. Single model of the financial news system

From this perspective it is clear that the multi-model approach reduces the load for system designers and authors by simplifying the specification of the models. Even if the single model is internally implemented in a simple way, it is still an integrated module that cannot be broken up into parts. It creates stiff adaptation mechanisms. In contrast, the multi-model approach allows the system to use any set of models. Models can be included or excluded from the adaptation mechanism, creating a flexible adaptation mechanism. In addition, models can be reused and combined in new applications and domains. Finally, while it is still not completely implemented in WARP, users can share and exchange models using transclusion links.

The experimental evaluation presented in the next section required the implementation of two models, a user model and an activity model. The user model is implemented using an overlay approach while the task model is implemented using a stereotype approach. A detailed discussion of the models implemented for the experiment is presented in section 8.5.

8 EVALUATION

This dissertation investigates the feasibility, effects and benefits of adaptation in spatial hypermedia. WARP provides a proof-by-example of the feasibility of multi-model adaptive spatial hypermedia. However, assessing the benefits of the adaptation and its effects on the process of reading/interacting with spatial hypermedia documents required experience with use. Consequently, an experiment was conducted in order to study the nature and use of reading strategies in adaptive and non-adaptive spatial hypermedia documents. The study evaluated and compared the effectiveness of adaptive to non-adaptive spatial hypermedia as a medium for information delivery.

8.1 Experimental Goals

The experiment had two objectives. The first objective was to evaluate Adaptive Spatial Hypermedia, specifically the hypothesis that the quality of information support is lower when using a non-adaptive version than when using an adaptive version of the document. The second objective was to observe reading behaviors in Spatial Hypermedia and in Adaptive Spatial Hypermedia. As a side-effect of the experiment, the largest informational spatial hypertext to date was designed and implemented.

Based on the conditions described a balanced experiment was designed with two factors and two levels each, as shown in Table VIII.

Table VIII. Experiment Factors and Levels

Factor	**Levels**
Adaptation	Non-adaptive, Adaptive
Expertise	Novice, Advanced

8.2 Research Procedures

The experiment required the authoring of a spatial hypermedia document containing information about HTML and XHTML. Two versions of the document were created: a non-adaptive version and an adaptive version.

The adaptive version used two models in order to guide the adaptation process: a user's knowledge model and a task requirements model.

- The user's knowledge model abstracts how much the user knows about the HTML topics and subtopics presented in the document.
- The task requirements model abstracts what topics are necessary for the authoring of different kinds of Web pages.

Adaptation of the spatial hypertext in response to the user knowledge translates to the automatic emphasizing or de-emphasizing of topics and subtopics that best fit the knowledge level of the user. Adaptation of the document in response to the task requirements is based on what topics and subtopics are useful for authoring different types of Web pages.

The document versions were presented to a set of 16 volunteers from Texas A&M University and the neighboring areas of Bryan and College Station. All volunteers were proficient in English and their ages ranged from 20 to 40 years old. Specific demographics of the population such as gender, ethnicity or age were not expected to affect the study. The experimental set of 16 subjects contained 8 novice and 8 advanced subjects. Classification of subjects as beginner or advanced depended on the following three factors:

1. Previous programming experience
2. Previous Web-based experience (in topics such as authoring, scripts, applets, etc)
3. Previous HTML/XHTML knowledge

Participants were randomly divided into 2 groups of 8 members, each group having 4 novice and 4 advanced subjects. Group N used the non-adaptive version, and Group A used the adaptive version of the document. This is illustrated in Table IX.

Table IX. Distribution of Subjects

	Non-Adaptive (N)	Adaptive (A)
Novice	4 subjects	4 subjects
Advanced	4 subjects	4 subjects

In order to perform the experiment, the participants were first trained in the use of the software applications (WARP, and the authoring environment). Then they answered a questionnaire about their computer and Web expertise for demographic information. Next, they answered a second questionnaire regarding their knowledge of HTML. This questionnaire was used to initialize the user knowledge model. Then, the subjects were asked to author a Web page in HTML or XHTML using a text editor. The spatial hypertext document provided the informational support necessary for the authoring process. The non-adaptive version presented the information as it was originally created, while the adaptive version adjusted the presentation according to the knowledge and task. In order to infer the knowledge of the user, the system presented subjects with a questionnaire about HTML and analyzed their answers.

Once the subjects finished the Web page, or the allotted time expired (90 minutes), the participants completed a third questionnaire about their experiences using the software system. Finally a free-form interview was conducted in order to collect additional commentary about the experiment and the usability of the system. The approximate times required for each task in the experiment are shown in Table X.

Table X. Approximate Experimental Times

Time	**Activity**
15 minutes	Training in software tools (WARP and authoring environment)
5 minutes	Completing the computer and Web expertise questionnaire
20 minutes	Completing the HTML and XHTML questionnaire
90 minutes	Authoring Web page
10 minutes	Completing the questionnaire about use of the system
10 minutes	Interview
2:30 hours	

The study's goal of investigating the nature and use of reading strategies in adaptive and non-adaptive spatial hypermedia documents was obtained by observing the subjects use the system and by analyzing their comments and interviews.

The assessment of the effectiveness of each version of the spatial hypermedia document was obtained by comparing the quality of the Web page and the time required to author it depending on the version used. The assumption was that Web pages can be created in less time with better quality as a result of having a contextualized presentation of the supporting information. In order to obtain a numerical assessment of the quality the Web page, the subjects were provided with detailed specifications about the required content and presentation. Each individual item had a value that signified the difficulty to fulfill it. The sum of all the fulfilled requirements provided a numerical assessment of the whole Web page quality. The task was challenging enough to require most people to take more time than was provided in order to complete the Web page. However, if a participant finished before the time expired, extra points where awarded for every remaining minute.

8.3 Spatial Hypertext Content

Due to the influence of the particular spatial hypertext on the evaluation, care was taken by the experimenter to select a domain with extensive content and to appropriately represent it using spatial hypermedia. Creation of the spatial hypertext required reflection on the inherent structure of the information in the document and the visualization of the relationships between the different components. Additionally, careful consideration was required in deciding the dynamic and adaptive behaviors of the document and which aspects should be considered for adaptation. The following subsections describe the design of the spatial hypertext used in the evaluation.

8.3.1 Topic and Source of Information

The experimenter's first decision was to select a domain and collect the information to be delivered. An extensive domain was desirable, as it would help to test the limits of the approach. Availability of previously-authored and reputable sources of information that ensured the quality of the contents was a must. Finally, the domain should facilitate easy evaluation conditions.

After considering and discarding several domains, content authoring in HTML/XHTML was selected as it facilitated the desired experimental conditions, and required the presentation of relatively large amounts of information. Also, high quality content was readily available on the Web.

Several reputable sources were evaluated and finally O'Reilley's *HTML & XHTML: The Definitive Guide* [Kennedy and Musciano, 2002] was selected. Its coverage of the domain and clear writing fit readers of all levels. Additionally, by virtue of being available on-line through O'Reilley's Safari digital library, it provided a navigational interface that aided in the design of the spatial hypertext document.

There was a challenge that needed to be tackled. For the spatial hypertext document to be useful to novice and expert readers, it needed to contain the whole book, or at least a large portion of the on-line book. This content was distributed over a 100 Web pages with text and images in the Safari digital library. This was an excellent test of spatial hypertext's ability to properly encode and support navigation of large information spaces within a single document. Due to system and time constraints, we included 10 of the 17 sections and one of the seven appendices.

8.3.2 Reflecting Structure of the Information

Instructional information, such as that used in the experiment, often has a strong hierarchical nature that divides the contents into sections and subsections. Many Web sites serving instructional information provide a list of links that reflect this inherent structure. For instance, the Safari digital library provides a “Table of Contents” Web page for each of its on-line books. Clicking on an item in the table of contents returns the associated Web page containing the selected section or subsection. This approach forces readers to discover the underlying structure of the information through navigation and inference. In contrast, spatial hypertext visually reflects the structural organization of the information. For instance, hierarchy can be mapped into a hierarchical arrangement of collections containing collections, as shown in Figure 27.

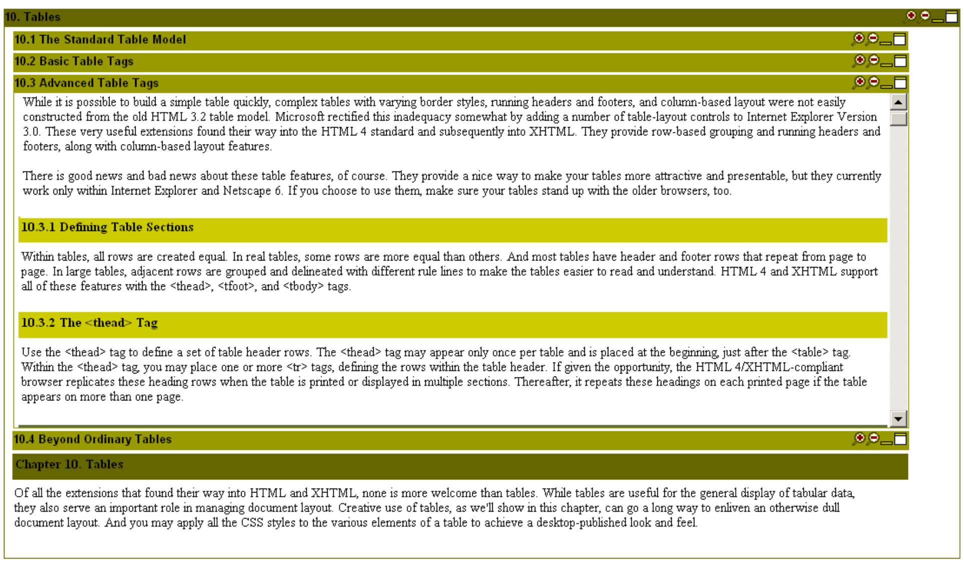

Figure 27. Hierarchy and containment

Sections and subsections are encapsulated into collections and sub-collections. As a result, readers directly perceive the structure. Visualization of the relationship between objects and their location within the information hierarchy can be reinforced by color coding such that major sections have darker colors than sub sections.

From a user perspective, maximizing a collection is similar to traversing a link. Both cause the currently visible information to be replaced by alternate information either within the collection or at the other end of the link. However, collections and transclusion links [Nelson 1995] in spatial hypertext are powerful alternatives to links in navigational hypertext. While the latter requires the readers to traverse links in order to discover what lies ahead, the former offers readers a view of the destination, allowing them to make informed decisions about whether they should traverse the link or not.

8.3.3 Document Layout

Design of the document layout commenced by considering the transfer of layouts frequently encountered in navigational hypertext. This resulted in experimenting with layouts such as the one shown in Figure 28, which shows the document structure on the left with the particular content displayed to the right.

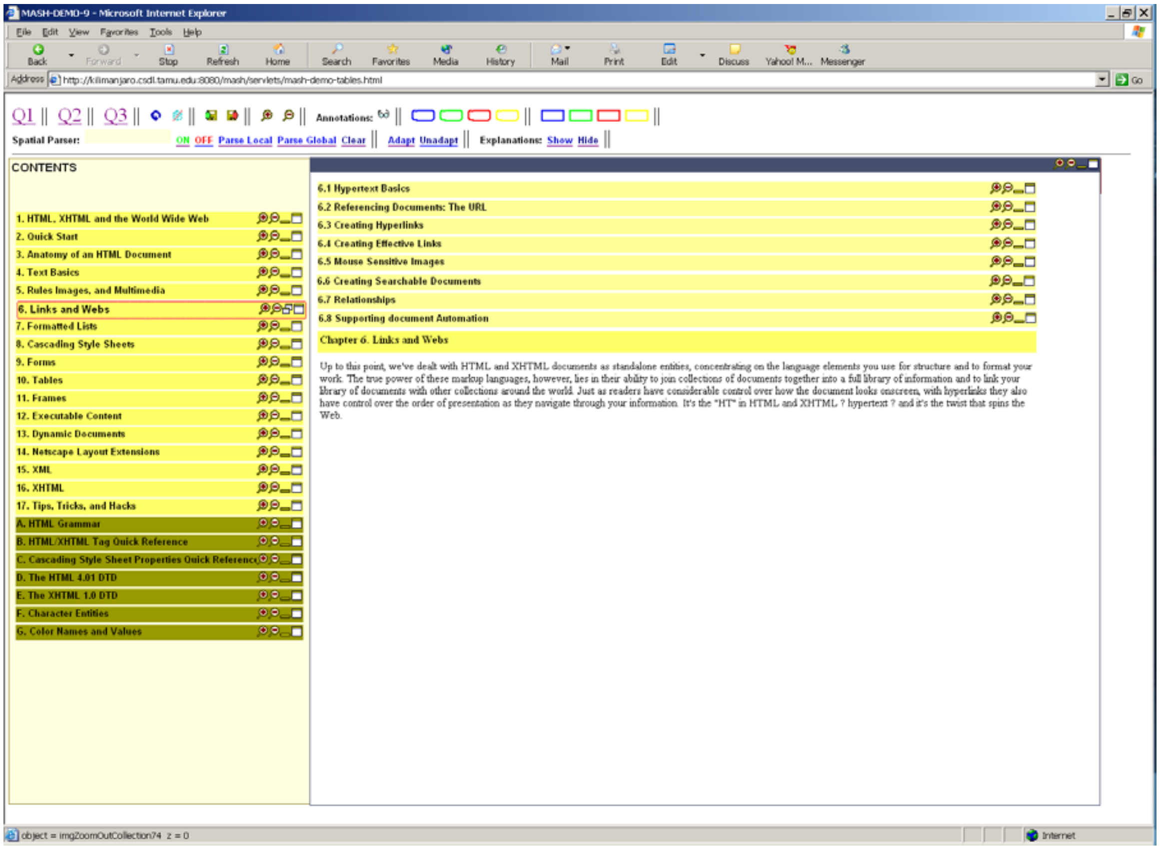

Figure 28. Emulating navigational hypertext in spatial hypertext

In order to imitate the functionality of Web pages, behaviors attached to objects automatically move and open the collections inside the work area (shown on the right side of Figure 28). However, this approach did not take advantage of many features of spatial hypertext and required the implementation of additional dynamic behaviors. Thus, alternative layouts that exploited the medium’s spatial features were designed in order to eliminate the need for navigational controls extraneous to spatial hypertext. The simplest and most obvious arrangement, shown in Figure 29, was to represent one section as a collection and arrange all sub sections as a vertical list of collections.

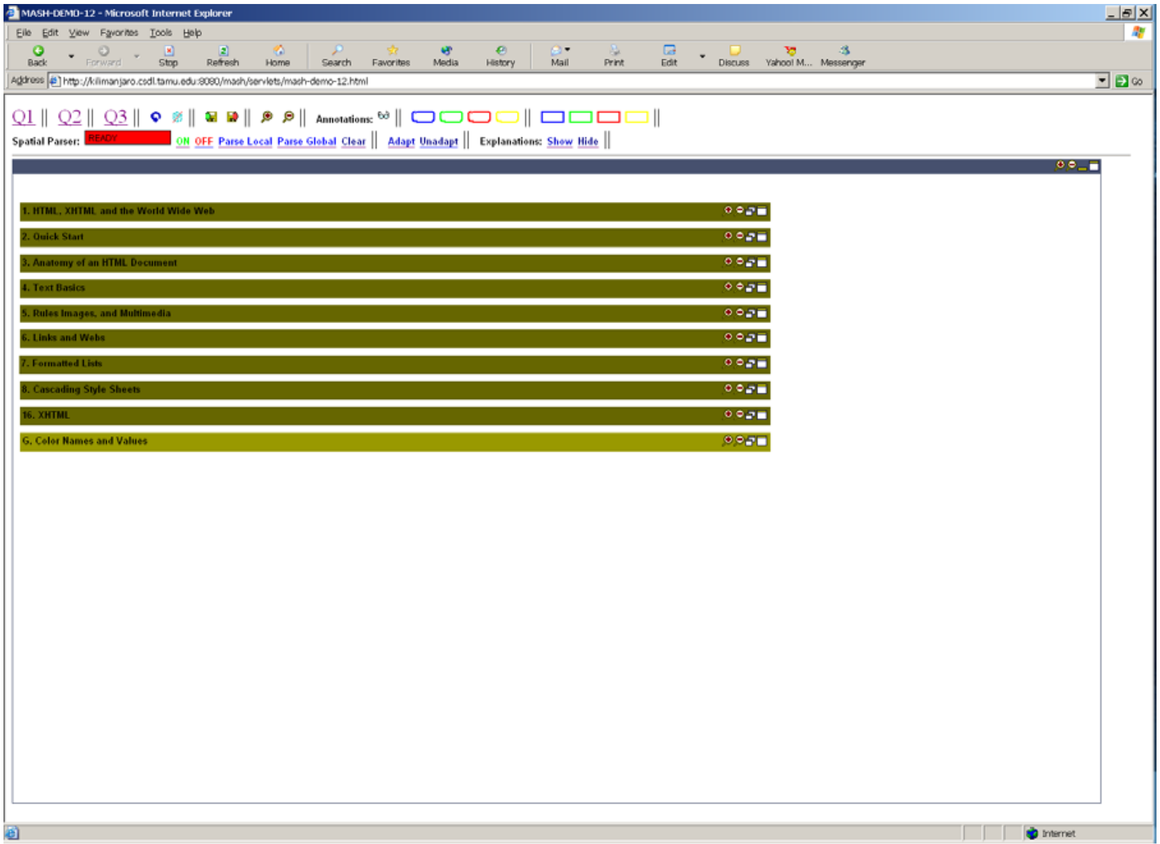

Figure 29. Basic spatial arrangement of a hierarchical information space

Using minimized collections that only take a single line allow all sections in the same hierarchical level to be shown as a list, which implicitly expresses the sequential ordering of its elements. This basic construct of hierarchically nested lists of collections fits very well with the ordering of sections and subsections of a book.

8.3.4 Dynamic Behaviors

While minimized collections provide a compact way to represent the information contained in a given level of the hierarchy, people reading the spatial hypertext need to "open" the collections in order to access their contents. Collections can be opened by maximizing or resizing them. However, opening a collection will obscure collections that follow it in the list. Rather than occluding other collections, it is often preferred to *push* the list down, as shown in Figure 30.

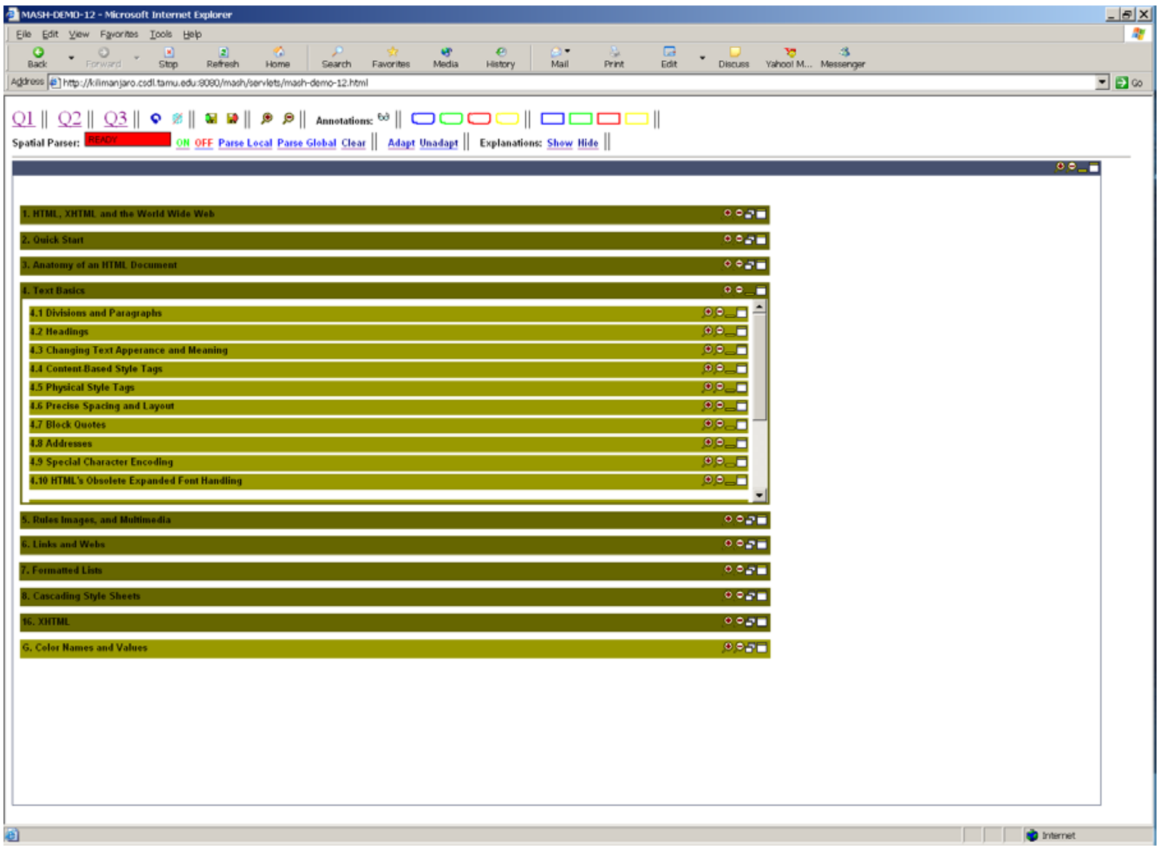

Figure 30. Stretch lists

This emulates Nelson’s notion of stretch text for the document structure [Nelson 1995]. In spatial hypertext, stretching can be performed simultaneously on the vertical and horizontal dimensions. Stretch space is one example of dynamic behaviors available in spatial hypertext. There is a vast range of useful behaviors that enhance the presentation of information by animating typically static media such as text [Lee et al. 2002]. However, dynamic behaviors risk becoming excessive, as they can distract readers from the reading process itself. Thus, only stretch space was initially selected.

8.3.5 Adaptive Behaviors

Differentiating relevant from irrelevant information often plays a critical role in the reading of instructional information. Systems that adapt documents in such a way that relevant information is more noticeable than irrelevant information facilitate the assimilation of the required knowledge for the task. Consequently, we decided to focus on documents that adapt in response to the user's knowledge and task requirements.

Part of the adaptive document creation was deciding how to "emphasize" and "de-emphasize" objects. The philosophy was to employ multiple visual cues that could represent varying degrees of relevance. After some experimentation, relevant objects were marked with a red glow, increased screen size and font size, and a higher zoom factor. Objects deemed irrelevant were visually altered by fading them out, reducing their size and font size, and zooming them out.

As mentioned before two models used to guide the adaptation process: A task model and a user model. The task model is a stereotype model. It assigns relevance values to sections and sub sections depending on the type of Web page being created. As part of the experimental setup, it was set for Web pages containing text, links, tables, images, but no formatted lists. Given that all users were authoring the same page, the model always returned the same suggestions.

When the task model was asked to provide a relevance suggestion for an object, it compared it with its list of relevant and irrelevant objects and provided a suggestion-strength equal to the value pre-assigned to it. The model's confidence on the suggestion was also pre-computed. For topics that were clearly necessary, the confidence in the suggestion was set to a high value, such as 1.0. For concepts that could be useful, but not strictly necessary, the confidence was lower. In cases when the object could not be found on the list, the task model returned a suggestion with strength equal to 0 and confidence equal to 0. This was taken by the object as a no-opinion suggestion.

The user model evaluated the objects according to the user's knowledge of the topics and subtopics. The model was initialized with the users' answers of the HTML and XHTML pre-task questionnaire. The model then evaluated the responses in order to infer how much the user knew about each topic and subtopic.

The user model implemented an overlay approach in which each topic and subtopic was mirrored in the model. The system then compared the user knowledge with the overlay structure and assigned the strength value as follows. Basic topics, those that the user knew well, were assigned a low or negative strength (i.e. 0.2 to -1.0), because the model deemed these objects as unnecessary help. However, topics were considered appropriate when the user knew them only partially. These topics were assigned a strength value from moderate to high (i.e. 0.4 to 1.0).

Advanced topics for which the user had most of the prerequisite knowledge to learn were assigned a moderate strength value (i.e. 0.4 to 0.6). This prompted the user to look into advanced sections in order to increase their points in the task. Topics were considered too advanced if the user did not know them and did not know the supporting prerequisite topics for that topic (for instance, document level Cascading Style Sheets for users with no previous knowledge of HTML). These topics were assigned a low to negative strength value (0 to -1.0).

Finally, confidence in the suggestion was computed based on correct answering of the questionnaire. Correct answers supported the inference that the user knew a topic. When multiple responses supported the knowledge (or lack of knowledge) of a topic, the confidence in the suggestion was set to 1.0. When different answers supported contradicting inferences, the confidence was set to a lower value (i.e. 0.5).

Given the importance of the HTML/XHTML questionnaire, each question had the option to answer “I don’t know”. Additionally, users were reminded that the questionnaire was not a way to test them, but it was a way to initialize the system so it would provide appropriate help.

8.3.6 Final Interface

During the process of authoring, the spatial hypertext was naturally rearranged in order to keep track of the progress and to compare sections. During this task it became clear that the previous layout shown in Figure 30 was too linear, not taking advantage of the second spatial dimension. Therefore, it was decided to create a horizontal list of vertical lists. The resulting document is shown in Figure 31.

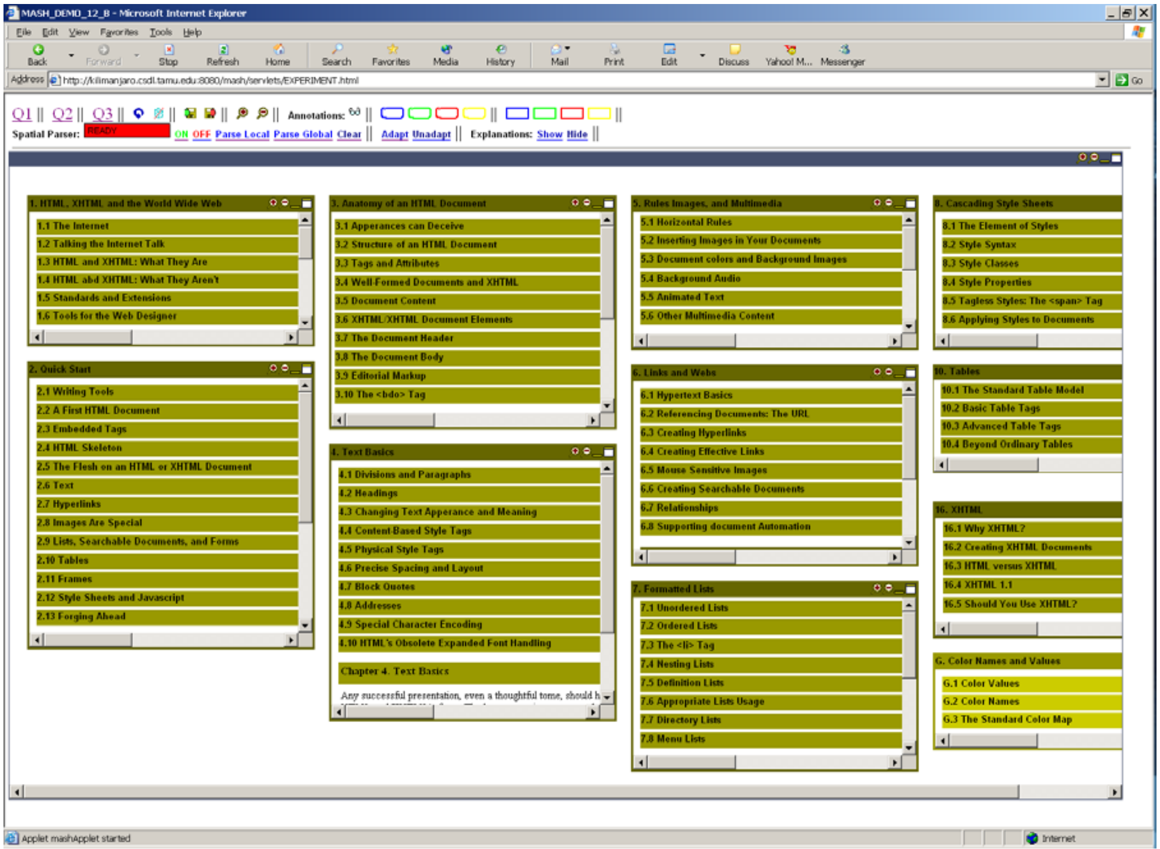

Figure 31. Initial interface for the non-adaptive version

Interaction with the space revealed some trade-offs associated with stretch space. As all collections expanded vertically, the stretch list improved the management of the space. However, it also restricted the reader's flexibility to re-arrange objects, and hindered the simultaneous view of all sections. The reduction of collection width allowed the simultaneous presentation of all sections and subsections, but also resulted in the instantiation of horizontal scrollbars.

The final content used in the study consolidated the information normally shown in 90 individual Web pages into a single WARP document. The experiment's HTML file was over 3 MB. It used 19 Javascript files, totaling more than 10,000 lines of code, which provided the functional support for WARP. The HTML declared over 4600 objects, including about 100 GIF images (amounting to 2MB of disk space) and 160 Collections. These 4600 objects of the same topics and subtopics were grouped together and encapsulated into the collections. While Figure 31 shows the initial interface for the non-adaptive case, Figure 32 shows the interface after adapting it to fit the subject.

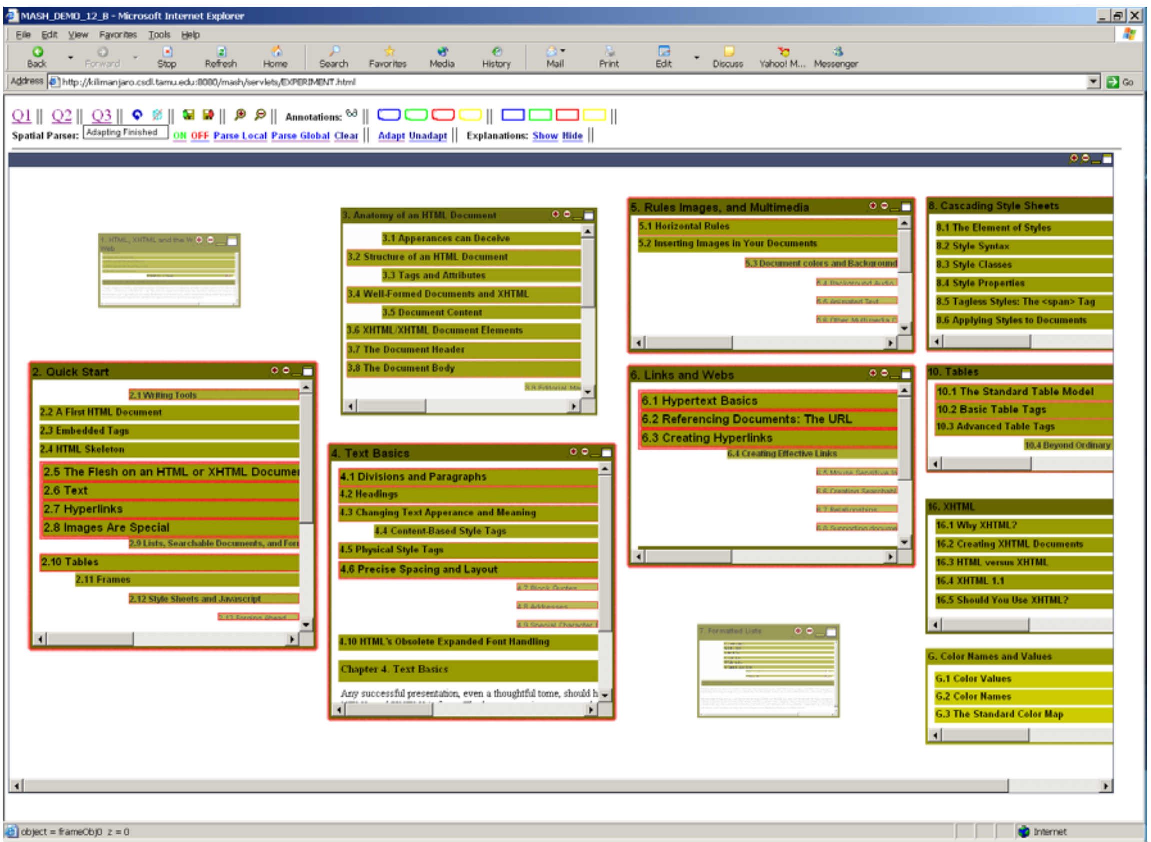

Figure 32. Initial interface for the adaptive version

9 RESULTS

Results are presented in the following two sections. First are the results obtained from observations, interviews, on-line questionnaires, and comments provided by the experiment participants. These include discoveries about the process of reading spatial hypertexts and differences between adaptive and non-adaptive spatial hypermedia. Next, results from the comparative study are presented. These include the quantitative analysis and assessment of the benefits of non-adaptive and adaptive spatial hypermedia.

9.1 Reading Spatial Hypermedia Documents

The study produced several results in regard to the activity of reading spatial hypermedia documents. The results show that while some reading strategies apply to spatial hypertext in general, others are used depending upon whether the spatial hypertext is adaptive or non-adaptive.

9.1.1 Spatial Layout

The two-dimensional arrangement of information was well received by participants using the adaptive and non-adaptive interfaces. When asked if they had any comments, participants often began with expressions like: *"it was very well organized"* and *"this is so much better than Tables of Contents"*. Even if the reduced width of the collections resulted in a limited view of the contents, requiring users to scroll horizontally, participants appreciated the fact that they could quickly see the complete structure of information, saying: *"I really like that I can see all of the chapters"*.

9.1.2 *Moving and Rearranging*

The participants' appreciation of the layout did not prevent them from moving objects around the space. Overall, 69% of the participants moved the collections during their reading of the space. Examples of the interfaces after completion of the task are shown in Figures 33 and 34.

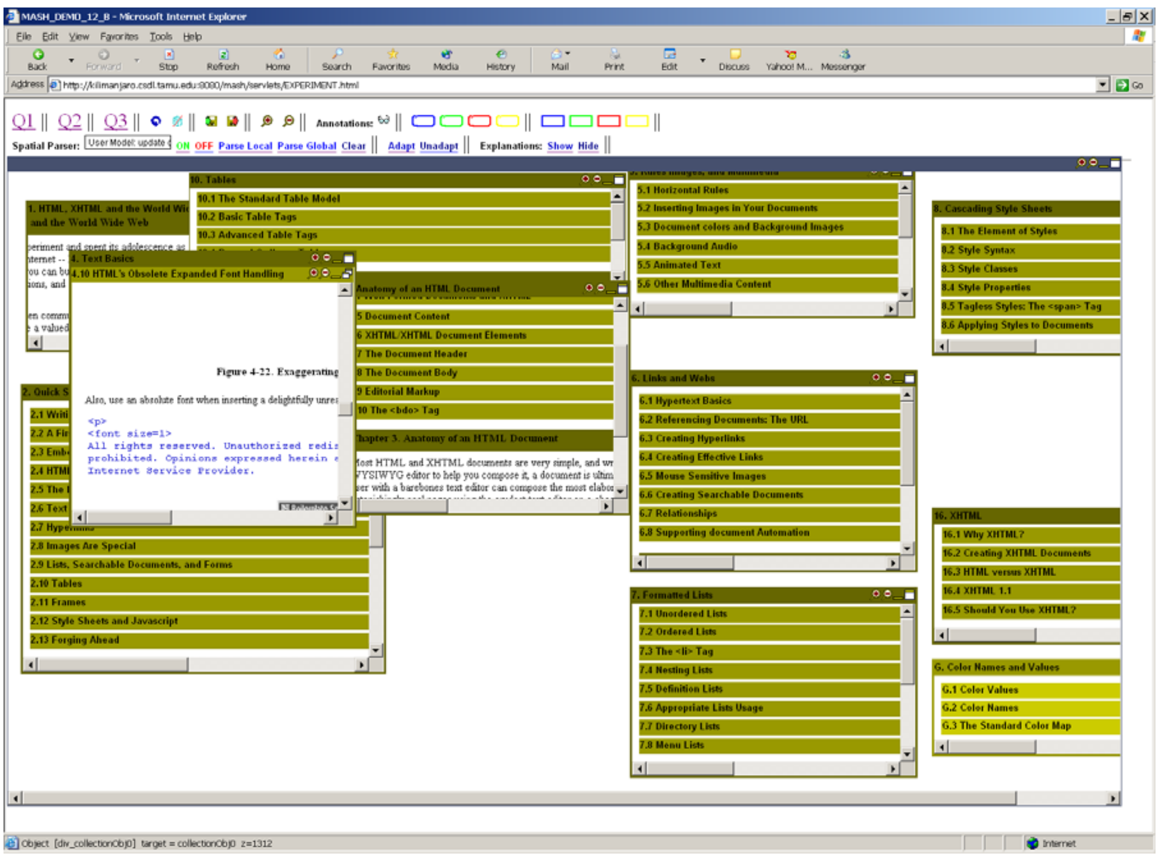

Figure 33. Non-adaptive interface after completing the task

The moving of collections was often more related to the act of reading than to the restructuring of the space. For instance, participants often dragged objects to the center of the screen *"for convenience"*, or moved objects around as they resized collections. In a couple of cases, after completing their exploration of the collection's contents, subjects went to considerable lengths in order to maintain the pristine state of the document. After completing the task, their interfaces looked exactly the same as in the beginning.

Other participants, however, consciously moved collections in order to group *"what is more important*", to *"see both and compare"*, and to signify what is being read or had been read *"for reference"*. For instance, in Figure 33 the participant has moved (and piled) several collections in the top left corner. In the process of reading, the subject has resized these collections and scrolled to display the relevant information. In contrast, other collections remain in their original location and initial state.

More participants using the non-adaptive interface rearranged the layout than those using the adaptive interface (75% vs. 63%). The difference was not statistically significant but it can be observationally explained. In the case of the non-adaptive interface, all collections are potentially relevant. Thus, when relevant information is found, participants wanted a visual cue that facilitated revisiting that information. As moving is the easiest action to visually change a spatial hypertext and is often used in the course of the normal reading activity, users chose to move collections as a way to identify the important information. In contrast, the adaptive interface already provided a visual encoding of objects' relevance, diminishing the incentive for additional user actions. This interpretation was made obvious by several participant's interviews and comments. For instance, a participant deliberately rearranged the layout by locating the relevant objects on the left side of the screen and moving the irrelevant ones to the right.

Another subject explained that rearranging the layout *"...because this way you only have what you need"*.

9.1.3 Navigation and Collections

The experiment centered heavily on the use of containment as a metaphor for navigation. This proved quite powerful as all participants were comfortable with the concept and understood the structure of the information. On a scale from 0 to 6 – 0 being the worse and 6 the best – the participants' evaluation averaged 5.44 regarding the ease of understanding of how information was contained in collections.

Participants reported that they could navigate with ease through the entire document even though the document included content originally divided across 90 Web pages. On average they judged the ease of navigation to be 4.69 on the 0-6 scale. However, some participants expressed that they lowered their score in response to a glitch in the software, namely the animation to open and close collections was too slow.

9.1.4 Informed Link Traversals

The study revealed that collections can be used in many ways that had not been anticipated. The original assumption was that subjects would tend to proceed by first maximizing a section, then exploring its contents, and finally maximizing the subsections as appropriate. However, rather than maximizing a collection and then reviewing its contents with the extra space provided by a full screen display, most participants explored the contents using the normal size of the collection. Even the necessity to scroll horizontally did not appear to obstruct their tasks. Furthermore, relevant subsections were often maximized inside the normal-sized parent collection, as shown in Figure 33.

When asked about this, participants commented that they wanted to review the contents before committing to opening collections that would fill the entire screen. This strategy allowed them to quickly explore and compare multiple collections, selecting to open only useful collections. One participant clearly expressed this as:

> You are not clicking on a bunch of links that may or may not have what you are looking for

The ability to partially take a link by maximizing a sub-collection within a parent collection instead of the entire window was important to the reading practices participants developed.

The perceived equivalence between maximizing/minimizing and traversing a link was confirmed by experimental observations and subjects' comments. One particular case illustrates this. During the course of authoring the Web page, one of the subjects, clicked the "Back" button in the browser (causing the WARP document to disappear and requiring a reload). When asked about why he did that, the user commented that: "*I clicked back intending to minimize the collection*".

9.1.5 Using Collections as Bookmarks

Another practice that emerged from the handling of collections and sub-collections is the use of collections as bookmarks. Having located relevant information in certain subsections, users often left them open to that location, while they browsed on other collections for additional information.

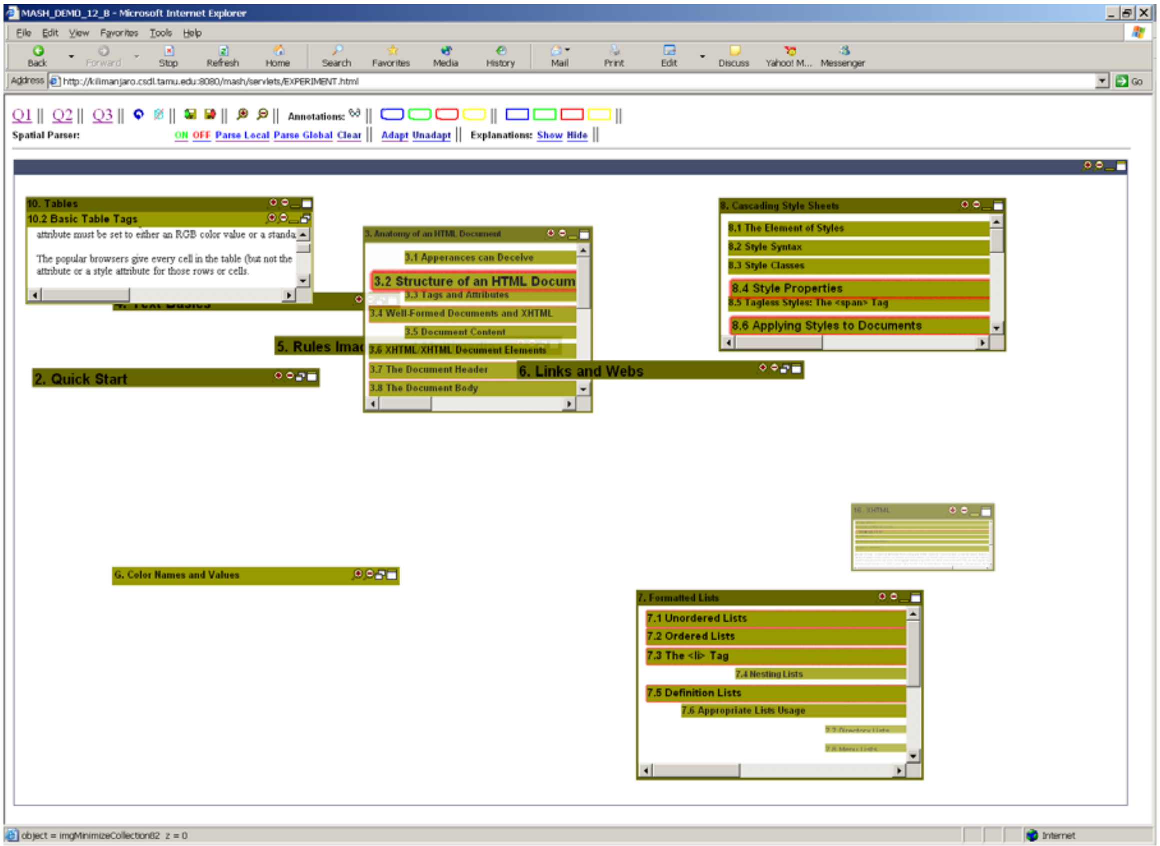

Figure 34. Non-adaptive interface after task completion

Figure 34 shows an example of this practice. In this case, the participant identified relevant content inside section 10.2. The sub-collection containing 10.2 is maximized. However, not only is section 10 not maximized but its size has been reduced and it has been located out of the way in the top left corner. The participant employed this strategy in order to conduct other reading activities such as browsing and exploring other collections while keeping track of the content and the fact that section 10 was valuable.

9.1.6 Minimizing

This bookmark strategy was not limited to normal sized collections. Investigators also noticed that many minimized collections, such as the ones visible in Figure 34, also contained maximized sub-collections. After interviewing and observing several participants it was discovered that this was an intentional extension of the bookmark strategy. After finishing working in a section, participants minimized the collections in order to make space for the reading of new sections. However, predicting that they might need to access those same contents later, they decided to keep the sub-collections open. This behavior is in stark contrast with cases when the participants assumed that they would not need to revisit the section any time soon. In such cases, participants tended to either restore the original structure of the section or document or chose to minimize the section or sub-section.

Interviews also revealed that participants consciously used the minimization of collections to signify completion of a section. An example is provided in Figure 35, which shows how the subject minimized sections 2, 4, 8 and 10. Notice that the participant preserved the document's overall structure and did not reuse the available space. In this case, as the subject stated, minimizing meant *"I am done with that"*.

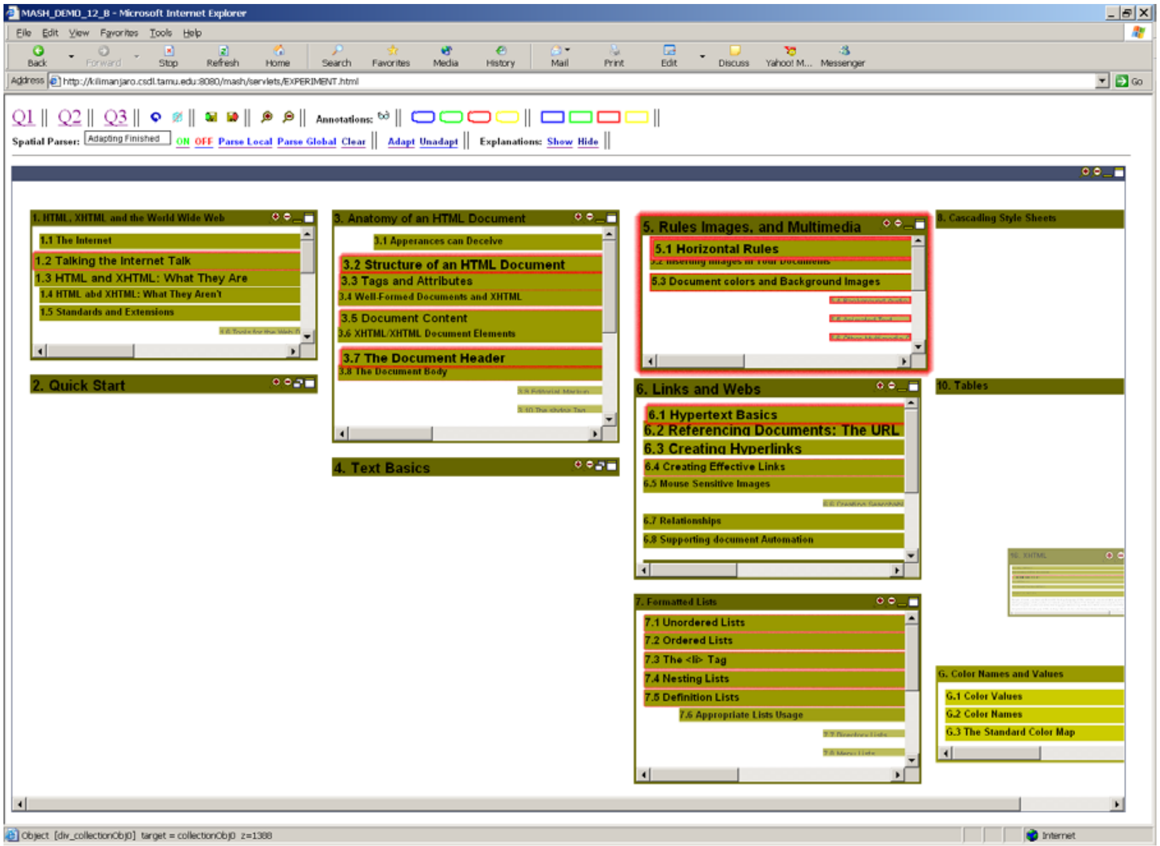

Figure 35. Simple use of minimization to signify completion of reading

9.1.7 *Adaptation*

In addition to the moving of collections previously mentioned, the experiment revealed other behavioral differences between adaptive and non-adaptive spatial hypertext. These included the changing of the object's visual appearance and zooming.

When using the adaptive document, 63% of the participants changed the visual look of objects. As for participants using the non-adaptive version, only 38% changed the original appearance of objects. In regards to the use of the zooming, 88% of the participants in the adaptive case used the zoom feature while only 38% of the subjects in the non-adaptive case used it.

This is not unexpected, as the additional effort from the subjects was motivated by visually excessive adaptations, such as extreme font sizes (large or small) and zoom factors. The glow effect was effective as an initial way to get the attention, but it became obtrusive subsequently. Hence participants chose to cancel it out. Changes of objects' visual features in non-adaptive cases focused on resizing collections, although one participant experimented with emphasizing important objects, before starting to re-locate important objects in the top left-corner of the screen.

The design decision to use multiple cues was validated by the participant interviews. Participants distinguished relevant from irrelevant objects very easily (5.1 on the 0-6 scale). However, not all participants were conscious about the different visual cues used, asking questions such as *"What red glow?"* Having multiple cues facilitated the use by different people. However, different participants complained about liking or disliking the modification of different features. Discussion with the participants led to the conclusion that adaptation should take into consideration the user's preferences for the selection of appropriate and meaningful visual cues.

Irrelevant objects also played an important role. The adaptation mechanisms were designed to never hide objects. Instead objects were de-emphasized in such a way that they were visually less prominent than the rest of the objects in the document. This approach was very successful as most readers always chose to explore and navigate into emphasized collections before de-emphasized ones. This was the case even when the participants thought that they were navigating the list of sub-collections sequentially. An explanation for this is that perceptually, participants were filtering out the de-emphasized collections before making cognitive decisions about exploration and navigation. This hypothesis seems validated by participants' comments like: *"There were not many de-emphasized objects"*, where in fact about 30% of the collections visible were de-emphasized to a large extent.

Finally, adaptation is not valued or desired by all users. For instance, one participant actually *fought* the adaptation, commenting that *"I didn't like that the system was trying to make me look into certain sections, so I decided to check all of them sequentially"*. This was lamentable failure on the presentation, as the design of the spatial hypertext and the adaptation was trying to present the adaptations as suggestions rather than commands. The participant's comment serves to stress the important observation that document adaptation should be optional and, when used, clearly presented as such.

9.2 Comparison of Non-Adaptive and Adaptive Spatial Hypermedia

The experiment measured and compared the quality of the Web pages authored using non-adaptive and adaptive spatial hypermedia. The overall quality measure is the summation of the quality assessment of the Web page's contents and presentation. The metrics for the evaluation of Web pages is presented in Appendix A. When a component looked as specified it was awarded 100% of its weight for the visual appearance score. Similarly, when a component was encoded correctly (i.e. there were no HTML/XHTML syntax errors) 100% of its weight was awarded to the encoding score. In cases where there were syntax errors or the visual appearance varied slightly, partial credit was given. Only when the component did not show at all, or was not even present on the Web page code, was it scored as 0. In order to ensure consistency, before evaluating the Web pages, evaluation standards were predefined. These standards defined the percentage of the components' weights to be awarded when specific error conditions were encountered. These percentage penalizations represented the seriousness of the mistakes. For instance, hyperlinks that pointed to the wrong URL had a lower penalization than attempts to create hyperlinks without using the <a> tag or any other valid alternative (as some people created a navigational bar that looked as specified, but containing plain text and not hyperlinks).

In order to maintain consistency, the evaluator did not consider which case was being evaluated. The evaluator proceeded by evaluating each component in all Web pages, instead of evaluating all the components of a Web page before moving to the next page. Once all components were evaluated, the total score was entered for each Web page, correlating the random number assigned to each participant with the proper case (adaptive or non-adaptive, novice or advanced).

The complete data collected during the experiment, including the comments and answers to the questionnaires are presented in Appendix B. The following sections discuss the experimental results presenting only a summarized view of the data relevant for the particular discussion.

9.2.1 Quality of Web Pages

The experiment discovered significant differences between novice and advanced subjects and between non-adaptive and adaptive hypermedia.

Tables XI and XII show the quality assessments for all Web pages. Similarly Figures 36 and 37 show the graphical representation of the results.

Table XI. Measurement of Web Page Quality Using Non-adaptive Spatial Hypermedia

	Content	Presentation	Overall
Advanced	1802.50	1055.00	2857.50
	1610.00	1157.50	2767.50
	1687.50	1070.00	2757.50
	1435.00	850.00	2285.00
Novice	1535.00	812.50	2347.50
	1235.00	665.00	1900.00
	1166.25	630.00	1796.25
	760.00	420.00	1180.00
Mean	1403.91	832.50	2236.41
Standard Dev	337.97	253.96	582.72
Variance	114222.07	64494.64	339565.82

Table XII. Measurement of Web Page Quality Using Adaptive Spatial Hypermedia

	Content	Presentation	Overall
Advanced	2180.00	1315.00	3495.00
	2060.00	1187.50	3247.50
	1885.00	1287.50	3172.50
	2005.00	1105.00	3110.00
Novice	1356.25	667.50	2023.75
	1190.00	727.50	1917.50
	1295.00	610.00	1905.00
	1091.25	527.50	1618.75
Mean	1632.81	928.44	2561.25
Standard Dev	441.43	326.73	759.69
Variance	194857.48	106751.67	577124.55

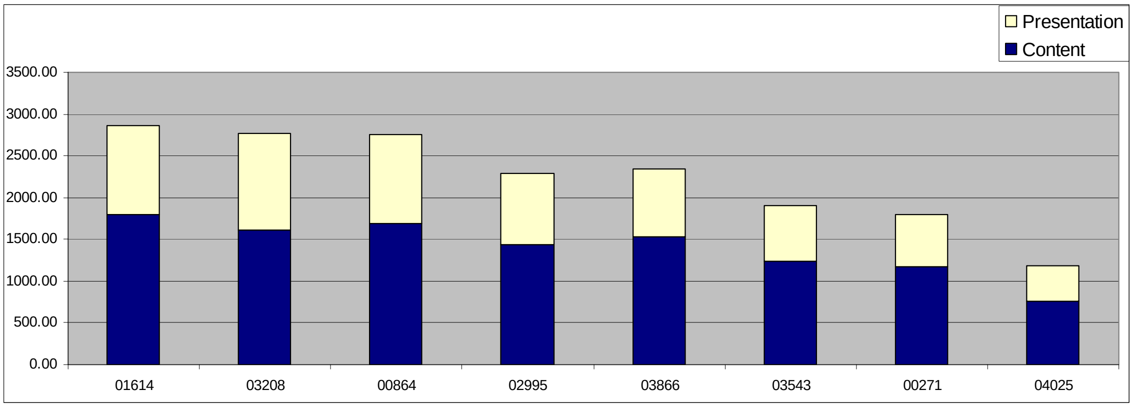

Figure 36. Web page quality using non-adaptive spatial hypermedia

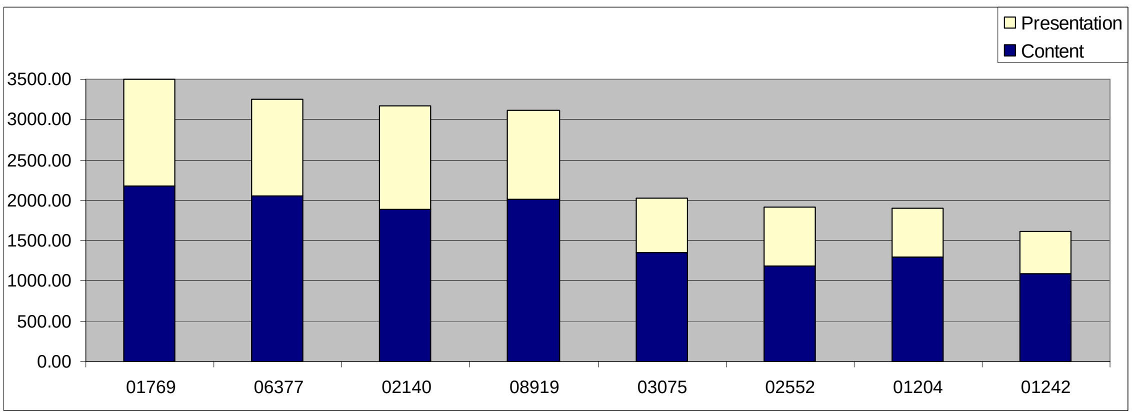

Figure 37. Web page quality using adaptive spatial hypermedia

An ANOVA was performed on the results collected. Not surprisingly, the differences between Novice and Advanced subjects were all significant. Table XIII provides the p values for the overall, content and presentation measurements of Web page quality (For details on the calculation, see Appendix B).

Table XIII. Differences between Novice and Advanced Subjects

Overall	p = 0. 000003456
Content	p = 0. 00003351
Presentation	p = 0. 000003227

Comparing Adaptive to Non-adaptive yielded significant differences, except for the presentation scores, as shown in Table XIV.

Table XIV. Differences between Adaptive and Non-adaptive Subjects

Overall	p = 0. 040472625
Content	p = 0. 03800957
Presentation	p = 0. 142204242

The value of the Interaction between subject expertise and adaptation was not significant, as shown in Table XV, but it is low enough to raise the question whether further experimentation would prove a stronger interaction. Looking at the data of Tables XI and XII, it seems that advanced users benefited more than novice users.

Table XV. Interaction between Expertise and Adaptation

Overall	p = 0.103946086
Content	p = 0.109338754
Presentation	p = 0.147016452

9.2.2 Knowledge Distribution

One challenge for the experiment was the determination of the subjects' expertise level because it did not depend only on specific knowledge about HTML/XHTML, but also depended on other knowledge about Web technologies and programming in general. Thus the expertise level was calculated using the following formula:

Expertise = HTML knowledge * (1 + Previous knowledge)

The HTML Knowledge was the ratio of right answers to total questions in the HTML/XHTML pre-task questionnaire. It acts as a weighting factor for the Previous Knowledge. The 1 provides a lower bound limit to avoid a Previous Knowledge that equals zero to cancel the HTML Knowledge. The previous knowledge can range from 0 to 10 and is composed 50% by Web knowledge (ranging from 0 to 5) and 50% by Programming knowledge (being a boolean value of either 0 or 5). Given that evaluating the programming skills of the subjects was out of the scope and resources available for the experiment, it was determined during the participants' interviews. The formulae for calculating the Web Knowledge and Programming knowledge are:

Previous knowledge = 5 * (Web + Programming)
Web = (E + T + J + C + A) / 5

E = previous authoring of Web pages using a text editor
T = previous authoring of Web pages using tools (e.g. Composer)
J = previous knowledge of Javascript
C = previous authoring of cgi's_or_servlets
A = previous authoring of applets

Table XVI. Participant Expertise

	ID	(T) tools	(E) text-editor	(J) javascript	(C) cgi, servlet	(A) applets	Programming	Web	HTML	Expertise	Score
Adaptive	01769	1	1	1			5	8	56.25%	6.0625	3495.00
	06377	1	1	1	1	1	5	10	65.63%	8.2188	3247.50
	02140	1					5	6	56.25%	4.9375	3172.50
	08919	1	1	1	1	1	5	10	71.88%	8.9063	3110.00
	03075							0	9.38%	1.0938	2023.75
	02552							0	0.00%	1.0000	1917.50
	01204							0	0.00%	1.0000	1825.00
	01242	1						1	9.38%	1.1875	1618.75
Non-adaptive	01614	1					5	6	25.00%	2.7500	2857.50
	03208	1	1	1	1	1	5	10	65.63%	8.2188	2767.50
	00864		1	1		1	5	8	65.63%	6.9063	2757.50
	02995	1			1	1	5	8	46.88%	5.2188	2285.00
	03866						5	5	9.68%	1.5806	2347.50
	03543							0	6.25%	1.0625	1900.00
	00271	1	1					2	25.00%	1.7500	1796.25
	04025							0	0.00%	1.0000	1180.00

Table XVI shows the Expertise levels for all subjects (ID's have been randomly assigned in order to preserve the participants' anonymity). Advanced participants have an expertise level of 2.00 or higher and are shown in Table XVI with a gray background. Novice participants, depicted with a white background, have an expertise level lower than 2.00.

Figure 38 plots the overall Web page quality against the participants' expertise. While adaptive spatial hypermedia tends to cluster, non-adaptive spatial hypermedia is more dispersed. However, the correlation between expertise and overall score was lower than expected, as shown in Table XVII.

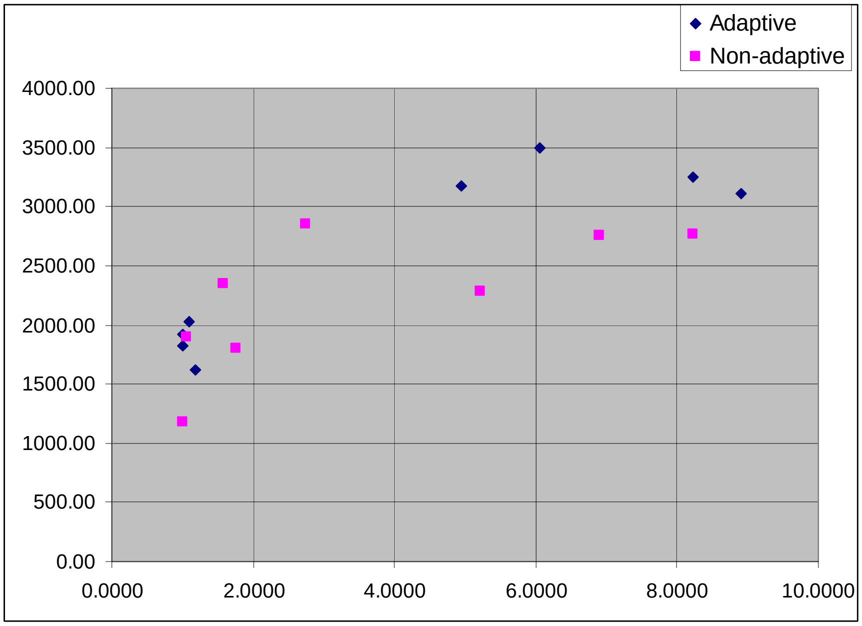

Figure 38. Expertise versus overall Web page quality

Table XVII. Correlation between Expertise and Overall Web Page Quality

Non-adaptive Spatial Hypermedia	0.894939384
Adaptive Spatial Hypermedia	0.684398811

9.3 Summary of Evaluation

By observing how people use and interact with spatial hypertexts, it was discovered that people reading spatial hypertext documents use navigation and orientation strategies unique to spatial hypermedia. These strategies include the change of objects' appearance and/or location in order to group important objects, to compare objects and to keep track of what has been read.

The experiment also evaluated how the system could perform similar strategies – modifying the objects' visual characteristics – in order to signify relevance of the objects. In this regard, the results of the study substantiate the approach of using multiple visual cues and allowing readers to select when and how the system can adapt the information space.

The observations of and interviews with people reading the spatial hypertexts illustrated the multiple roles of collections and transclusion links in spatial hypermedia. First, collections and transclusion links provide an effective way to visually convey the structure of the information by encapsulating it into hierarchically ordered spaces. This allows people to readily understand the structure of the information and enables them to navigate through large information spaces. In addition, collections and transclusion links act like links since they provide a transition into other information spaces. However, collections and transclusion links augment links in that they provide a partial view of their contents, which allows readers to make informed decisions about the usefulness of traversing a link. This need to inform readers about the destination of the link before it is traversed is pervasive to hypermedia in general and it has been explored also in the realm of navigational hypermedia [Brown 1987; Schneiderman 1987; and Zellweger et al. 2001].

The experimental results show significant differences between novices and advanced users. The analysis of these results reveals that adaptation is of benefit. While not statistically significant, the data also suggests a possible synergism between adaptation and expertise. More experimentation is needed in order to confirm the effect.

While this experiment allowed the comparison of non-adaptive to adaptive spatial hypermedia, the dynamic behaviors were kept to a minimum in order to facilitate the observation and analysis of the effects and benefits of basic spatial hypertext. Further experimentation will be required to assess the value and effectiveness of other more dynamic behaviors.

10 FUTURE WORK

This dissertation provides a framework, instantiation, and evaluation of adaptive spatial hypermedia. WARP provides a useful platform that enables the exploration of new research directions. While providing answers to some basic question, it raises many more. A natural way to organize these efforts is by classifying how they extend into the intellectual spaces of the different kinds of spatial hypermedia.

10.1 Generative Spatial Hypermedia

The VKB-WARP interaction encourages researchers to reflect on how different spatial hypermedia systems can interact and complement each other. More research in this area can aid in the development of a standard specification for spatial hypermedia documents. This could be within a language like XML that allows spatial hypertexts to be properly rendered by different systems, even if the document contains features not supported by all the system.

Parallel to the exploration of interoperability aspects, a greater range of exploration can be achieved by augmenting WARP with generative capabilities. Having authoring support in WARP benefits authors by expediting the creation of documents and provides readers with powerful annotation capabilities. Additionally, by extending WARP's functionality to allow users to share their annotations, it is possible to augment the interaction and collaboration between authors and readers.

An important feature for the authoring system will be the ability to define and specify metadata associated with individual objects, relationships, and areas in the space.

This will allow authors to assign access rights and copyright information to any element of the document.

10.2 Interactive Spatial Hypermedia

WARP's experimental nature allows for interface and interaction improvements. From a pragmatic perspective, increasing the robustness of the system facilitates the use and exploration of new ideas. From a semantic perspective, augmenting the presentations with other media, such as video and audio, can enrich the readers' experience when using the system. However these new media have a temporal nature that can potentially create interesting challenges.

Support for explicit intra-document links is planned in the short term. This will reduce the functionality gap between VKB and WARP and will increase the interactive power of WARP.

10.3 Dynamic Spatial Hypermedia

In order to facilitate a more sophisticated exploration of dynamic functionality in spatial hypermedia, more behaviors are needed. Currently there are unresolved questions about what to do with behaviors when the object to which they are attached changes. For instance, a behavior that enforces a constant distance with its neighbor object (like in a stretch-text or stretch-list) will be broken if the object is dragged into another collection, but it is unclear what to do if the object returns to the original space. Should objects retain a history of the structures and constraints in which they have participated? Similarly, other behaviors might require a different treatment. More research is needed in order to ensure an interaction coherent with the user expectations.

Besides increasing the number and diversity of behaviors, more research needs to be conducted in authoring dynamic spatial hypermedia documents. Authors need to be able to specify behaviors and users need to be able to access and manipulate them.

10.4 Adaptive Spatial Hypermedia

Deeper investigation into the use of multiple models is required, particularly authoring and interacting with the models. At this moment, creating and modifying a model still requires considerable programming skills. Providing an approach to create models and specify their functionality will increase the use of the system and allow larger audiences to author MASH documents.

Similar to the exploration of dynamic functionality in spatial hypermedia, adaptive spatial hypermedia can benefit from a larger collection of transformations and conflict resolution strategies that increase WARP's flexibility. As the collection increases, it will be possible to study which transformations and resolution strategies work best for different conditions. This could result in the development of heuristics that will greatly facilitate a transparent migration of models and systems across domains.

Research is needed to devise better ways for the adaptation mechanisms to cope with distributed spaces, especially given the availability of transclusion links. When parsing or adapting a space, it is not always clear if the process should proceed into the spatially transcluded document as it does for collections.

10.5 Collaborative and Distributed Spatial Hypermedia

MASH and WARP open the door for the exploration of a number of interesting research issues in the areas of Computer Supported Collaborative Work with Spatial

Hypermedia. As of now, WARP supports personal access to shared documents. However, an avenue of research is to explore concurrent access to multiple spatial hypermedia documents. This will require the study and implementation of new system components such as notification mechanisms and access controls.

11 CONCLUSIONS

This dissertation provides two main contributions. First it proves the feasibility of adaptive spatial hypermedia. Second, it validates the use of multiple-models in order to guide the adaptation process in adaptive spatial hypermedia. More so, the design and development of this work entailed attaining significant theoretical and practical milestones, which represent achievements by their own right.

A theoretical framework for Multi-model Adaptive Spatial Hypermedia (MASH) was devised. This framework provides a solid grounding for the study of dynamic and adaptive spatial hypermedia. The MASH framework is influenced by research into traditional adaptive hypermedia but it deviates from previous taxonomies and models in order to address the expressiveness of spatial hypermedia. The framework is composed of four parts: a general architecture of spatial hypermedia systems, a definition of the fundamental concepts in spatial hypermedia, an ontological classification of the adaptation strategies in spatial hypermedia, and the philosophy of conflict management, as opposed to conflict resolution, which enables the support of multiple-model adaptation systems.

The MASH general architecture provides a way to classify current and future spatial hypermedia systems based on their functionality. Systems can be categorized as generative, interactive, dynamic and adaptive spatial hypermedia. Generative spatial hypermedia systems are those that support the authoring and creation of new spatial hypermedia documents. Interactive spatial hypermedia refers to systems that support the user/reader to interact/read the spatial hypermedia document. Dynamic spatial hypermedia expands the concept of interaction in order to support complex dynamic behaviors that augment the traditional "static" or "passive" spatial hypermedia. Adaptive spatial hypermedia adds the capacity to automatically adapt the presentation in response to relevant aspects abstracted by a set of models.

The basic spatial hypermedia concepts set the common ground required for the analysis of different systems and approaches. This MASH conceptualization departs from the traditional node-and-link model and characterizes spatial hypermedia in terms of objects, relationships and space. The adaptation ontology describes potential spatial hypermedia adaptations within the categories of semantic, relational, formal, and meta-adaptation. Similar to traditional hypermedia, the MASH ontology differentiates high-level adaptation methods from low-level adaptation techniques.

The MASH framework extends the traditional approach of using a single user model to multiple models as a way to guide the adaptation process. Furthermore, the framework also takes into account the possibility of conflicts between the models and presents an approach to deal with them. This approach first analyzes conflicts based on the context in which they occur. The context is computed using the parsing capabilities of spatial hypermedia for recognition of visual relationships between objects.

In comparison to the single model approach, the multi-model approach has important design advantages for adaptation in regard to complexity, scalability, reusability, distribution, and flexibility of the adaptation. In a single-model approach, all relevant aspects that demand adaptation must be encoded together. In general, interactions can exist between the different aspects, making it necessary to specify the response of the model to all the possible combinations. In MASH, the single model is broken up into multiple independent models, each addressing a different aspect that demands adaptation. Interactions between the models are dealt with by the system, which in turn reduces the overall model complexity. This facilitates not only authoring more models, but also authoring more responsive models that take into consideration finer details of the aspect they address.

MASH makes no assumption of the nature or location of the models, thus it is possible to envision powerful model services that execute locally or in remote locations and provide adaptation suggestions to different adaptive systems. This scheme facilitates a very flexible use of models where the adaptation process can be easily modified according to the model availability and appropriateness.

In addition to the classification of current systems, the MASH framework provides useful guidelines for augmenting and developing new spatial hypermedia systems. These guidelines were tested and validated with the implementation of WARP, the first MASH-based system.

Compared to previous spatial hypermedia systems, WARP provides several novel features including spatial transclusion links as an alternative to navigational linking, behaviors supporting dynamic spatial hypermedia, and personal annotations to spatial hypermedia. Additionally, WARP uses a Fuzzy logic approach to parsing, which allows a more flexible recognition of the spatial structures commonly used by humans.

WARP demonstrates, in a proof-by-example manner, that multi-model adaptive spatial hypermedia is a viable approach. Additionally it shows how presentation-oriented spatial hypermedia documents can be delivered over the Web, while allowing users/readers to create, maintain and reuse their own personal models. This ability to support distributed models enables users/readers to include personal or sensitive information in their models without fearing that it might be misused by third parties.

WARP supports personal access to the spatial hypertexts, as opposed to shared access. This means that the interacting/reading activity of a user/reader does not interfere with the interacting/reading of any other users/readers.

The conflict management scheme implemented in WARP supports the use of a variety of resolution strategies, both at the document level and at the object level. In addition, the adaptation approach implemented in WARP includes a flexible mapping of adaptation methods to adaptation techniques, allowing conflict avoidance to be supported.

WARP provides the required platform for the study of different adaptation approaches and several other extensions to spatial hypermedia such as document publication and document access, interoperability issues between different systems, and distributed Web-based spatial hypermedia.

The study conducted as part of this work shows that spatial hypermedia can be an effective medium for the delivery of information on the Web. It facilitated the creation of efficient layouts that allowed readers to navigate through large amounts of information. These layouts are not mere replicas of navigational hypermedia, as they rely on intrinsic features of spatial hypermedia such as the readers' ability to rearrange and manipulate objects.

Spatial hypermedia has often been used in order to organize information, with spatial objects providing links to external documents that contain the desired information. In contrast, the document used in this work contained all the information in itself. To the best of our knowledge this is the largest spatial hypertext to date in terms of sheer textual content.

The study showed the emergence of navigation and orientation strategies performed spontaneously by people reading spatial hypertext. Users often moved and modified the information objects as part of their reading process. Readers used changes in object appearance or location to group important objects, to compare objects and to keep track of what had been read.

The encapsulation of information into hierarchically ordered collections was shown to be an effective way to visually convey the structure of the information. Observations and evaluation of how people interacted with both spatial hypertext versions showed that people readily understood the structure of the information space, and were able to read, browse and explore book-sized documents with ease.

In addition to reflecting the information structure, collections and transclusion links augment traditional links as they support readers making informed decisions about the usefulness of traversing a link. While both collections and traditional links provide a transition into a separate information space, collections and transclusion links provide a partial view of their contents, allowing readers to see what there is at the other side of the links before having to traverse them. Interviews and observations of the interactions with the spatial hypertext document confirmed the readers' appreciation of this feature as they often based their decision about maximizing a collection on the previous exploration of its contents. (Within in navigational hypermedia, the idea of informing readers about the destination of links has been investigated by Brown [1987], Schneiderman [1987] and Zellweger et al. [2001] among others.)

Adaptation of the document by directly relating the visual prominence of objects and collections to their relevance provided an effective way to facilitate the navigation of spatial hypertexts. The study revealed the value of representing these adaptations using multiple visual cues. Comments from participants indicated that document adaptation should be optional and selection of the particular adaptation techniques should be made cooperatively with the reader.

This work also compared non-adaptive spatial hypermedia to multi-model spatial hypermedia in the context of on-line help and instructional content. The results show that the multi-model system performed better than the non-adaptive system for users with and without significant prior domain knowledge.

This dissertation answers some questions concerning the viability and effectiveness of adaptive spatial hypermedia but many questions remain. The MASH framework and WARP provide a starting point for future research into this promising area.

REFERENCES

APPLE. 1996. *HotSauce*:
http://www.abc.it/Apple/Product_Info/MacAdvantage/HotSaucefactsheet.pdf

BERNSTEIN, M. 2001. Notes on the Vitality of Hypertext Systems. In *First Workshop on Spatial Hypertext* (Århus, Denmark, August 14).
http://www.well.com/user/jer/SH1/papers.html.

BERNSTEIN, M. 2003. Collage, Composites, Construction. In *Proceedings of the Fourteenth ACM Conference on Hypertext and Hypermedia*, (Nottingham, U.K. – August 26-30) ACM Press, New York, pp. 122-123.

BERTIN, J. 1981. *Graphics and Graphic Information Processing.* Walter de Gruyter. New York, New York

BERTIN, J. 1983. *Semiology of Graphics: Diagrams, Networks, Maps.* University of Wisconsin Press. Madison, Wisconsin.

BROWN, P.J. 1987. Turning Ideas into Products: The Guide System. In *Proceedings of the ACM Conference on Hypertext*, (Chapel Hill, North Carolina – November 13-15) ACM Press, New York, pp. 33-40.

BRUSILOVSKY, P. 1996. Methods and techniques of adaptive hypermedia. In *User Modeling and User-Adapted Interaction*, Kobsa, A. (Ed.) 6 (2-3) Kluwer Academic Publishers, pp. 87-129

BRUSILOVSKY, P. AND COOPER, D. W. 1999. ADAPTS: Adaptive Hypermedia for a Web-based Performance Support System In *Second Workshop on Adaptive Systems and User Modeling on the World Wide Web* (Toronto, Canada – May 11) available as CSN 99/07, TUE, or at http://wwwis.win.tue.nl/asum99/.

BRUSILOVSKY, P. AND COOPER, D. W. 2002. Domain, Task, and User Models for an Adaptive Hypermedia Performance Support System In *Proceedings of the International Conference on Intelligent User Interfaces '02* (San Francisco, California – January 13-16) ACM Press, New York, pp. 23-30.

CALVI, L 2001. The Future of AH. In *Third Workshop on Adaptive Hypertext and Hypermedia* (Århus, Denmark – August 14-18). http://wwwis.win.tue.nl/ah2001/

CONKLIN, J. 1987. Hypertext: An Introduction and Survey. *IEEE Computer,* 20(9) (September), pp. 17-41.

CHEVEREST, K., DAVIS N., MITCHELL, K., FRIDAY, A,, AND EFSTRATIOU C. 2000. Developing a Context-aware Electronic Tourist Guide: Some Issues and Experiences. In *Proceedings of CHI'2000* (The Hague, The Netherlands – April 1-6) ACM Press, New York, pp. 17-24.

COCKBURN, A., AND MCKENZIE, B. 2001. 3D or not 3D? Evaluating the Effect of the Third Dimension in a Document Management System. In *Proceedings of CHI'2001* (Seattle, Washington – March 31-June4) ACM Press, New York, pp. 434-441.

CONRY, S., MEYER, R. A. AND LESSER, V. 1988. Multistage Negotiation in Distributed Artificial Intelligence. In *Bond, A. and Gasser, L. (Ed.) Readings in Distributed Artificial Intelligence*. Morgan Kaufman, San Francisco, California, pp. 367-384.

DE BRA, P., BRUSILOVSKY, P., AND CONEJO, R., 2002. *Proceedings of the Second International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems,* Springer-Verlag, London, UK.

DE BRA, P., HOUBEN, G-J., AND WU, H. 1999. AHAM: A Dexter-based Reference Model for Adaptive Hypermedia. In *Proceedings of the 10th ACM Conference on Hypertext and Hypermedia: Returning to Our Diverse Roots* (Darmstadt, Germany – February 21-25) ACM Press, New York, pp. 147-156.

DEROSE, S. J. 1989. Expanding the Notion of Links. In *Proceedings of Hypertext '89* (Pittsburgh PA – November 5-8), ACM Press, New York, pp. 249-257.

DURFEE, E. H., LESSER, V. R., AND CORKILL, D. D. 1989. Cooperative Distributed Problem Solving. In *Barr, A., Cohen, P. R., and Feigenbaum, E. A., (Ed.). The Handbook of Artificial Intelligence*. Vol. IV. Addison Wesley, 1989. pp. 83-147.

EASTGATE. 2001. *Web Squirrel*.
http://www.eastgate.com/squirrel/

EASTGATE. 2003. *Tinderbox*.
http://www.eastgate.com/Tinderbox/

ENCARNAÇÃO, L. M.1997. Multi-Level User Support through Adaptive Hypermedia: A Highly Application-Independent Help Component. In *Proceedings of Intelligent User Interfaces '97* (Orlando, Florida – January 6-9) ACM Press, New York, pp. 187-194.

FERBER, J. MULTI–AGENT SYSTEMS. 1999. *An Introduction to Distributed Artificial Intelligence*. Addison-Wesley, Harlow, U.K.

FISHER, S., AND STEINMETZ, R. 2000. Automatic Creation of Exercises in *Adaptive Hypermedia Learning Systems*. In *Proceedings of the Eleventh ACM Conference on Hypertext and Hypermedia* (San Antonio, Texas – May 30-June 4) ACM Press, New York, pp. 49-55.

FRANCISCO-REVILLA L. 1998. *User & Situation Models for Medical Information Delivery*. Masters Thesis. Dept. of Computer Science. Texas A&M University, College Station, Texas.

FRANCISCO-REVILLA, L., AND SHIPMAN, F.M. 1999. Adaptive Medical Information Delivery: Combining User, Task and Situation Models. In *SIGWEB Newsletter* 8, 1 (February) ACM Press, New York, pp. 18-20.

FRANCISCO-REVILLA, L., AND SHIPMAN, F.M. 2000. Adaptive Medical Information Delivery: Combining User, Task and Situation Models. In *Proceedings of IUI 2000* (New Orleans – Jan 9-12) ACM Press, New York, pp. 94-97.

FRANCISCO-REVILLA, L., AND SHIPMAN, F.M. 2003. MASH: A Framework for Adaptive Spatial Hypermedia. In *Third Workshop on Spatial Hypertext* (Nottingham, UK – August 26). http://www.csdl.tamu.edu/~shipman/SpatialHypertext/SH3/luis.pdf

GOLOVCHINSKY, G. 2001. Bridging Paradigms: Spatial Hypertext in the Document World. In *First Workshop on Spatial Hypertext* (Århus, Denmark – August 14). http://www.well.com/user/jer/SH1/papers.html

GRØNBÆCK, K, VESTERGAARD, P., P., AND ØRBÆCK, P. 2002. Towards Geo-Spatial Hypermedia: Concepts and Prototype Implementation. In *Proceedings of the 13th ACM Conference on Hypertext and Hypermedia* (Maryland – June 11-15) ACM Press, New York, pp. 117-126.

HAIK, E., BARKER, T., SAPSFORD, J., AND TRAINIS, S. 2002. Investigation into Effective Navigation in Desktop Virtual Interfaces. In *Proceedings of Web3D'02* (Temple, Arizona – February 24-28) ACM Press, New York, pp. 59-66.

HÖÖK, K. 1997. Evaluating the Utility and Usability of an Adaptive Hypermedia System. In *Proceedings of Intelligent User Interfaces '97* (Orlando, Florida – January 6-9) ACM Press New York, pp. 179-186.

HSIEH, H. AND SHIPMAN, F., 2000. VITE: A Visual Interface Supporting the Direct Manipulation of Structured Data Using Two-Way Mappings. In *Proceedings of ACM Conference on Intelligent User Interfaces 2000*, ACM Press, New York, pp. 141-148.

KENNEDY, B., AND MUSCIANO, C., 2002. *HTML & XHTML: The Definitive Guide*, 5th Edition, O'Reilly & Associates, Sebastopol, California.

KOLB, D. 2001. Places and Spaces: Adjacency Effects. In *First Workshop on Spatial Hypertext* (Århus, Denmark – August 14).
http://www.well.com/user/jer/SH1/papers.html

KOLB, D. 2002. Aristotelian Spatial Hypertext. In *Second Workshop on Spatial Hypertext* (College Park – Maryland, June 12). http://www.well.com/user/jer/SH1/papers.html

LEE, J.C., FORLIZZI, J., AND HUDSON, S.E. 2002. The Kinetic Typography Engine: An Extensible System for Animating Expressive Text. In *Proceedings of UIST'02* (Paris, France – October 27-30) ACM Press, New York, pp. 81-90.

MACKINLAY, J. D. 1986. Automating the Design of Graphical Presentations. *ACM Transactions on Graphics,* 5(2) pp. 110—141.

MANCINI, C., AND SHUM, S. B. 2001. Cognitive Coherence Relations and Hypertext: From Cinematic Patterns to Scholarly Discourse. In *Proceedings of the Twelfth ACM Conference on Hypertext and Hypermedia* (Århus, Denmark – August 14-18) ACM Press, New York, pp. 165-174.

MARSHALL C.C., HALASZ, F.G., ROGERS, R.A., AND JANSSEN W. C. JR. 1991. Aquanet: A Hypertext Tool to Hold Your Knowledge in Place. In *Proceedings of the Third ACM Conference on Hypertext* (San Antonio, Texas – December 15-18) ACM Press, New York, pp. 261-275.

MARSHALL C.C. AND ROGERS R.A. 1992. Two Years before the Mist: Experiences with Aquanet, In *Proceedings for the Fourth ACM Conference on Hypertext* (Milano, Italy – November 30-December 4) ACM Press, New York, pp. 53-62.

MARSHALL C.C., AND SHIPMAN, F. M. III. 1993. Searching for the Missing Link: Discovering Implicit Structure in Spatial Hypertext. In *Proceedings of 5th ACM Conference on Hypertext* (Seattle, Washington – November 14-18) ACM Press, New York, pp. 217-230.

MARSHALL C.C., SHIPMAN, F. M., AND COOMBS, J. H. 1994. VIKI: Spatial Hypertext Supporting Emergent Structure. In *Proceedings of the 6th ACM European Conference on Hypermedia Technology* (Edinburgh, Scotland – September 18-23) ACM Press, New York, pp. 13-23.

MICROSOFT RESEARCH. 1999. TaskGallery. http://research.microsoft.com/adapt/TaskGallery/

MODJESKA, D., AND WATERWORTH, J., 2000. Effects of Desktop 3D World Design on User Navigation and Search Performance. In *Proceedings of the International Conference on Information Visualization IV200* (London, England – July 19-21) IEEE, pp. 215-220.

MOGENSEN, P., AND GRØNBÆCK, K 2000. Hypermedia in the Virtual Project Room-Toward Open 3D Spatial Hypermedia. In *Proceedings of the Eleventh ACM Conference on Hypertext and Hypermedia* (San Antonio, Texas – May 30-June 4) ACM Press, New York, pp. 113-122.

NAKAKOJI, K. AND YAMAMOTO, Y. 2001. Spatial Positioning as a Representation That Helps Us Think. In *First Workshop on Spatial Hypertext* (Århus, Denmark – August 14). http://www.well.com/user/jer/SH1/papers.html

NELSON, T. H. 1995.The Heart of Connection: Hypermedia Unified by Transclusion. In *Communications of the ACM* 38, 8 (August) pp 31-33.

NIELSEN M. B. AND ØRBÆK, P. 2001. Spatial Parsing within the Topos 3D Environment. In *First Workshop on Spatial Hypertext* (Århus, Denmark – August 14). http://www.well.com/user/jer/SH1/papers.html

NWANA, H. S. 1996. Software Agents: An Overview. *Knowledge Engineering Review* 11(3): pp. 205-244.

ROBERTSON, G., CZERWINSKI, M., LARSON, K., ROBBINS, D. C., THIEL, D., AND VAN DANTZICH, M. 1998. Software Data Mountain: Using Spatial Memory for Document

Management. In *Proceedings of UIST'98* (San Francisco, California – November 1-4) ACM Press, New York, New York, pp. 205-244.

ROSENBERG, J. 2001. And *And*: Conjunctive Hypertext and the Structure Acteme Juncture. In *Proceedings of the Twelfth ACM Conference on Hypertext and Hypermedia* (Århus, Denmark – August 14-18) ACM Press, New York, pp. 51-60.

SANDHOLM, T. W. 1999. Distributed Rational Decision Making. In *Multiagent Systems*. Weiss, G. (Ed.) MIT Press, Cambridge, MA, pp. 201-258.

SCHRAEFEL, M. C. 2000. ConTexts: Adaptable Hypermedia. In *Proc. of AH 2000*, (Trento, Italy – August 28-30). Lecture Notes in Computer Science, Vol. 1892, Springer-Verlag, London, UK., pp. 369-375.

SHIPMAN, F., HSIEH, H., AND AIRHART, R., MALOOR, P., AND MOORE, J.M. 2001. The Visual Knowledge Builder: A Second Generation Spatial Hypertext. In *Proceedings of the Twelfth ACM Conference on Hypertext and Hypermedia* (Århus, Denmark – August 14-18) ACM Press, New York, pp. 113-122.

SHIPMAN, F. M., AND MCCALL, R. 1994. Supporting Knowledge-Base Evolution with Incremental Formalization. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Celebrating Independence* (Boston, Massachusetts – April 24-28) ACM Press, New York, pp. 285-291.

SHIPMAN, F. M., MARSHALL, C. C., AND LEMERE, M. 1999. Beyond Location: Hypertext Workspaces and Non-Linear Views. In *Proceedings of the 10th ACM Conference on Hypertext and Hypermedia* (Darmstadt, Germany – February 21-25) ACM Press, New York, pp. 121-130.

SHIPMAN, F. M., MARSHALL, C. C., AND MORAN, T. P. 1995. Finding and Using Implicit Structure in Human Organized Spatial Layouts of Information. In *Proceedings of CHI'95* (Denver, Colorado – May 7-11) ACM Press, New York, pp. 346-353.

SCHNEIDERMAN, B. 1987. User Interface Design for the Hyperties Electronic Encyclopedia (Panel Session), In *Proceedings of the ACM Conference on Hypertext*, (Chapel Hill, North Carolina – November 13-15) ACM Press, New York, pp. 198-194.

SIMPSON, R. M. 2001. Requirements, Characteristics, and Issues for an Information Structures Spatial Hypermedia Environment. In *First Workshop on Spatial Hypertext* (Århus, Denmark – August 14). http://www.well.com/user/jer/SH1/papers.html

STEPHANIDIS, C., KARAGIANNIDIS, C., AND KOUMPIS, A. 1997. Decision Making in Intelligent User Interfaces. In *Proceedings of Intelligent User Interfaces '97* (Orlando, Florida – January 6-9) ACM Press, New York, pp. 195-202

SUCHMAN, L. A. 1987. *Plans and Situated Actions*. Cambridge University Press, New York.

SYCARA, K. 1989. Multiagent Compromise via Negotiation. In *Distributed Artificial Intelligence*. Gasser, L. and Huhns, M. (Eds.) Pitman, Totowa, New Jersey.

TUFTE, E. R. 1995. *Envisioning Information*. Graphics Press, Chesire, Connecticut.

TRIGG R.H., AND WEISER, M.1986. TEXTNET: A Networking-Based Approach to Text Handling. In *ACM Transactions on Office Information Systems*, 4(1) (January), ACM Press, New York, pp. 1-23.

VERHOEVEN, A., AND WARENDORF, K. 1999. External Navigation Control and Guidance for Learning with Spatial Hypermedia. *Journal of Interactive Media in Education*. http://www-jime.open.ac.uk/99/1/

WEISS, G. 1999. *Multiagent Systems*. MIT Press, Cambridge, Massachusetts.

WOOLDRIDGE, M. 1999. Intelligent Agents. In *Multiagent Systems*, Weiss, G. (Ed.) MIT Press, Cambridge, Massachusetts, pp. 22-77.

WOOLDRIDGE, M. AND CIANCARINI, P. 2001. Agent-Oriented Software Engineering: The State of the Art. In *Agent-Oriented Software Engineering, Lecture Notes in AI, ,* Volume 1957, Ciancarini, P., and Wooldridge, M.(Eds) (January), Springer-Verlag, London, UK., pp. 1-27.

YEN, J. AND LANGARI, R. 1999. *Fuzzy Logic: Intelligence, Control, and Information*. Prentice Hall, Englewood Cliffs, New Jersey.

ZELLWEGER, P.T., BOUVIN, N.O., JEHØJ, H., AND MACKINLAY, J.D. 2001. Fluid Annotations in an Open World. In *Proceedings of the Twelfth ACM Conference on Hypertext and Hypermedia* (Århus, Denmark – August 14-18) ACM Press, New York, pp. 9-18.

APPENDIX A

EXPERIMENTAL DOCUMENTATION

Scenario

In order to contextualize the task performed by the subjects in the experimental evaluation of the project, the following user scenario was provided.

> Assume that you work for "Website Development", a company that designs and develops websites. The management usually plans the activities and maintains a steady workload. Recently, however, as the result of a series of coincidences, the workload increased dramatically.
>
> Last night the group of designers and developers had their weekly geek night out. Watching the TV news, while drinking discreet amounts of soft drinks at the local cowboy-styled bar (this soft drink consumption was much to the dislike of the local bartender and usual patrons), they found out that the lottery ticket that they had bought as a group during last week's caffeine rush had won the grand prize. As a result, they proceeded to order beers for celebrating (after that the bartender was happier and the usual patrons stopped paying attention to them). Having not duly trained their neurons and livers during all those years in the university, they followed their first-time experienced alcohol-induced impulses and jumped on an airplane to Bahamas, but not before sending an e-mail from their notebooks (which they usually carried to the bar for conversation support given the bar's wireless network and their innate inability to remember any basketball player's statistics) quitting their jobs.
>
> The e-mail from the developers arrived just before another e-mail from Website Development's main client, "Non-Profit Org", a large non-profit organization for which Website Development has created several websites. A month ago, Non-Profit Org had ordered the design and development of a website for "The Community Center", a community center that they sponsor. The developer, now lucky sun-tanning millionaires, had been working on this website since then and they had come up with a general structure design and the specifications for all the Web pages in the website. The plan was to start the implementation of the Web pages today and to finish them in the next 10 days. However, in this morning's e-mail, Non-Profit Org asked for the website to be published by tomorrow. Apparently, having contacted a millionaire guy, currently

vacationing abroad, who was considering donating a large amount of money, they wanted to impress him by showing him the website with all the activities that they carry out at The Community Center.

In the panic wake of the morning e-mails the management decided to recruit you and all other available employees to help with the development of the website (regardless of your or their previous experience with Web page authoring). As a result you were assigned to author a Web page about the ongoing racquetball tournament.

Given that the website needs to be published today, the management cannot provide any formal training on HTML and XHTML. However, they did find and make available the help documentation usually employed by the developers. This documentation is a spatial hypermedia document that contains the necessary information about HTML and XHTML.

Regardless of their panic attack, management is still concerned about maintaining quality standards. While they understand that given the short notice it might not be possible to maintain all of them, they request you to consider them as guidelines and follow as much as you can while still finishing the Web pages on time. The development guidelines are:

- The Web page must show all the content specified.
- The Web page layout should be similar to the layout showed in the mock-up.
- Preferably use XHTML instead of HTML.
- Use CSS and content-based styles instead of physical styles.
- Images should provide brief descriptions when the mouse lingers over them.

At this point the management will be happy with you providing a Web page that looks the best. However, Non Profit Org requires a minimum quality standard for Web pages such that their Webbots work properly (whatever Webbots are…). Thus, the management is going to evaluate the quality of the Web page, and it is in your best interest to attain the highest score possible as there are rumors flying around about bonuses. But at least they are giving you a fair chance of getting the bonus as they are providing you with the evaluation criteria.

The specifications for the Web page are attached at the end of this document. The developers also had time to make some hand-drawn mock-ups of the Web page. These are included along with all the Web page contents (texts, website addresses, tournament schedule and results).

In order to author the Web page you will have to actually write the HTML or XHTML code using a text editor as the other highly sophisticated software tools typically used for creating Web pages were missing (later it will be discovered that they are in a notebook currently located approximately 4.5 meters below the surface of the Atlantic Ocean). However, in order to expedite the writing and viewing of the Web page, the management is providing you with a software environment that allows you to switch between the HTML/XHTML code and the actual way the Web page shows on a browser.

Lucky for you, earlier today, the network administrator rose to the occasion and made all the possible arrangements to facilitate your work. She created a directory structure that mimics the website structure defined by the developers. She also created empty files such that you can rewrite them and save them directly in the proper directory (the specific file name, directory and URL for the Web pages are specified later). She even loaded the authoring software environment for you! (Honestly, kudos are in order.)

Having given access to the spatial hypermedia documentation, the authoring environment, and the evaluation criteria, you are now asked to first create in the next 90 minutes a Web page for the racquetball tournament.

In order to create the Web page, you can find the html file in:

Y:\sports\racquetball\tournament\index.html

This location is also accessible through the Web as:

http://kilimanjaro.csdl.tamu.edu:8080/center/servlets/sports/racquetball/tournament/index.html

In order to facilitate your work, the whole textual content is included in the file:

Y:\sports\racquetball\tournament\webpage.txt

This file lets you copy and paste the text instead of having to actually type it.

The goal of this page is to provide basic information about the tournament such as dates, locations and the general structure of the tournament. This includes a general text description, the tournament's classification games, and the pictures of the players.

In addition, this page must provide support for people to navigate through the whole Community Center website. Hence it is important to provide appropriate links that connect it this page with other important Web pages of the website.

Specifications

The complete specific requirements for the Web page were also provided to subjects. These are shown in Tables XVIII and XIX.

Table XVIII. Web Page Specifications

Points	**Feature**
50	Web page title: `Winter 2003-2004 Racquetball Tournament`
50	Prominent heading: `Winter 2003-2004 Racquetball Tournament`
50	Subheading with dates of tournament: `November 15 – February 15`
300	Navigational bar at the both top and bottom of the page with links to: • Community Center's Home page • Sports page • Social Activities page • Message Board page • About (should open on a new window)
150	Welcome message. Composed of the following 3 independent paragraphs: `We will be taking Racquetball Entries between October 15, 2003 and November 7, 2003. To enter, you`

can sign the entry form at the reception desk of the Student Recreation Center, or sign up on-line today. **This tournament is FREE to all Community Center members.** You must be affiliated with the Community Center to participate. All entries must be completed by 8:00pm on November 7, 2003. We will contact all participants to inform them of their first match pairing.

The tournament is offered only in the Singles Division. The tournament begins on November 15, 2003 and will run through February 15, 2004. Matches will be held in the racquetball courts of the Community Center. The tournament comprehends two rounds of games. First is the Classification Round, where all players play each other. A player ranking will be determined based on the results of the Classification Round. The player ranking will be then used for seeding the players in the Playoff Round. The playoffs are a single game elimination round that ends with the championship game.

During the Classification Rounds, participants will be responsible for contacting their opponents and arranging a time that is convenient for both to play, then reporting your score before the completion date for that particular round. The last day for Classification games is December 31, 2003. Playoff schedules will be posted on January 10, 2004. For additional information you can E-Mail us, or contact the Community Center Sport Programs at 555-1234.

50 Prominent heading:

Classification Round

50 Short paragraph:

Participants are responsible for contacting their opponents and arranging a time that is convenient for both to play. Please report your score immediately after the match at the Equipment Desk.

300 Classification games

- Table of classification games must be a table (as requested by the client).
- Each cell must provide the score. Scores are always formatted such that the points of the row's player are first and the column's player second.

	Ana	Bernardo	Carrie	David
Ana		15-13	15-11	15-12
Bernardo	13-15		15-8	16-14
Carrie	11-15	8-15		15-13
David	12-15	14-16	13-15	

50 Prominent heading:

```
Players
```

50 Short Paragraph:

```
This page provides the necessary information for
players to get to know each other. Also players can
contact each other by clicking on the picture of
the player in order to send him/her an e-mail.
```

400 Pictures of the players.

- Show the picture of each player.
- The name of the player should be shown under the picture.
- Link each picture to the e-mail of each player
- Resting the mouse over the picture should display the name of the player

1500

Table XIX. Image Details

Name	**File name (relative address)**	**Address**
Ana	./images/ana.png	ana@kilimanjaro.csdl.tamu.edu
Bernardo	./images/bernardo.png	bernardo@kilimanjaro.csdl.tamu.edu
Carrie	./images/carrie.png	carrie@kilimanjaro.csdl.tamu.edu
David	./images/david.png	david@kilimanjaro.csdl.tamu.edu

Evaluation criteria

The criteria used to evaluate the Quality of the Web pages is shown in Tables XX and XXI.

Table XX. Web Page Required Features

Required Features	Points
Shows all the contents specified Partial value each for parts of the contents is specified for each Web page.	1500
Layout is appropriate. The management evaluates this based on how similar the page is to the layout proposed on the hand-drawn mock-ups. Partial value each for parts of the contents is specified for each Web page.	1500

Table XXI. Web Page Additional Features

Additional Features	Points
Document	
Proper HTML	300
Proper XHTML	600
Fonts, Color and Backgrounds	
Content styles only	100
CSS in-line styles	200
CSS document level styles	300
Layout	
Use of CSS positioning for layout	300
Images	
Alternative text describing each image	100
Explicitly specify the width and height of the images	100
Use relative addresses	100
Links	
Use relative addresses for other pages and files within this website	100

APPENDIX B

EXPERIMENTAL DATA AND ANALYSIS

ANOVA for Overall Results

Table XXII. Overall Results

	Adaptive	Non-adaptive
Advanced	3495.00	2857.50
	3247.50	2767.50
	3172.50	2757.50
	3110.00	2347.50
Novice	2023.75	2285.00
	1917.50	1900.00
	1905.00	1796.25
	1618.75	1180.00

Table XXIII. ANOVA for the Overall Results

Advanced	Adaptive	Non-adaptive	Total
Count	4	4	8
Sum	13025.00	10730.00	23755.00
Average	3256.25	2682.50	2969.38
Variance	28493.75	51900.00	128508.48
Novice			
Count	4	4	8
Sum	7465.00	7161.25	14626.25
Average	1866.25	1790.31	1828.28
Variance	30063.54	209754.56	104426.76
Total			
Count	8	8	
Sum	20490.00	17891.25	
Average	2561.25	2236.41	
Variance	577124.55	339565.82	

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	5208379.79	1	5208379.79	65.0617	0.000003456	4.7472
Columns	422093.85	1	422093.85	5.2727	0.040472625	4.7472
Interaction	247817.29	1	247817.29	3.0957	0.103946086	4.7472
Within	960635.55	12	80052.96			
Total	6838926.46	15				

ANOVA for Content Results

Table XXIV. Content Results

	Adaptive	Non-adaptive
Advanced	2180.00	1802.50
	2060.00	1687.50
	2005.00	1610.00
	1885.00	1435.00
Novice	1356.25	2285.00
	1295.00	1900.00
	1190.00	1796.25
	1091.25	1180.00

Table XXV. ANOVA for the Content Results

Advanced	Adaptive	Non-adaptive	Total
Count	4	4	8
Sum	8130.00	6535.00	14665.00
Average	2032.50	1633.75	1833.13
Variance	15008.33	23810.42	62065.63
Novice			
Count	4	4	8
Sum	4932.50	4696.25	9628.75
Average	1233.13	1174.06	1203.59
Variance	13658.85	101832.68	50493.05
Total			
Count	8	8	
Sum	13062.50	11231.25	
Average	1632.81	1403.91	
Variance	194857.48	114222.07	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1585238.38	1	1585238.38	41.0922	0.00003351	4.7472
Columns	209592.29	1	209592.29	5.4330	0.03800957	4.7472
Interaction	115387.60	1	115387.60	2.9911	0.10933875	4.7472
Within	462930.86	12	38577.57			
Total	2373149.12	15				

ANOVA for Overall Results

Table XXVI. Presentation Results

	Adaptive	Non-adaptive
Advanced	1315.00	1157.50
	1287.50	1070.00
	1187.50	1055.00
	1105.00	850.00
Novice	727.50	812.50
	667.50	665.00
	610.00	630.00
	527.50	420.00

Table XXVII. ANOVA for the Presentation Results

Advanced	**Adaptive**	**Non-adaptive**	**Total**
Count	4	4	8
Sum	4895.00	4132.50	9027.50
Average	1223.75	1033.13	1128.44
Variance	9268.75	16947.40	21617.75
Novice			
Count	4	4	8
Sum	2532.50	2527.50	5060.00
Average	633.13	631.88	632.50
Variance	7259.90	26205.73	14342.86
Total			
Count	8	8	
Sum	7427.50	6660.00	
Average	928.44	832.50	
Variance	106751.67	64494.64	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	983816.02	1	983816.02	65.9375	0.000003227	4.7472
Columns	36816.02	1	36816.02	2.4675	0.142204242	4.7472
Interaction	35862.89	1	35862.89	2.4036	0.147016452	4.7472
Within	179045.31	12	14920.44			
Total	1235540.23	15				

Graphic results for adaptive and non-adaptive cases

Figures 39, 40 and 41 provide visual comparison for the overall, content, and presentation quality measurements. While there is no statistical pairing of the different data measurements, these graphics illustrate that adaptive hypermedia tended to produce higher scores than non-adaptive hypermedia.

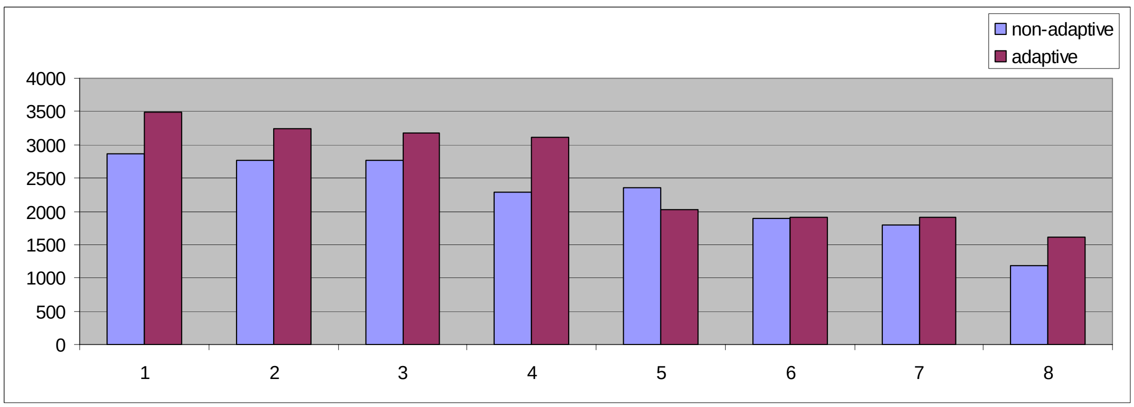

Figure 39. Web page overall quality comparison

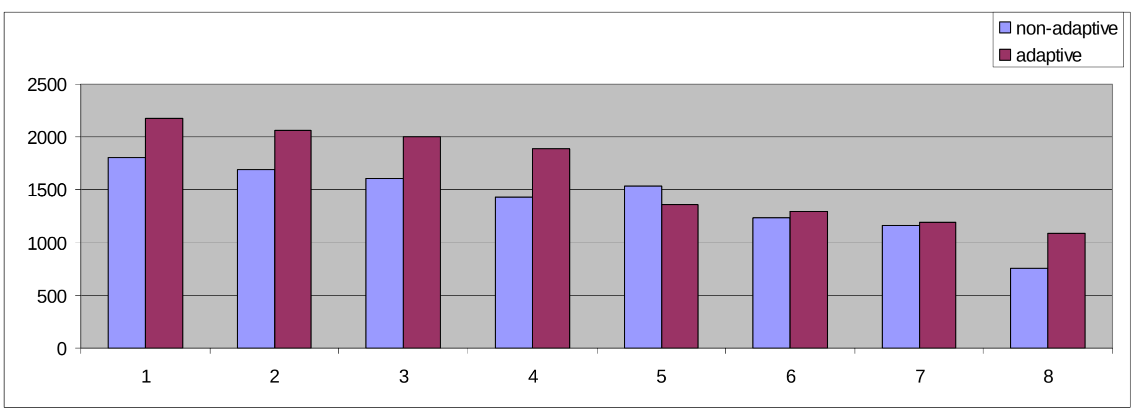

Figure 40. Web page content quality comparison

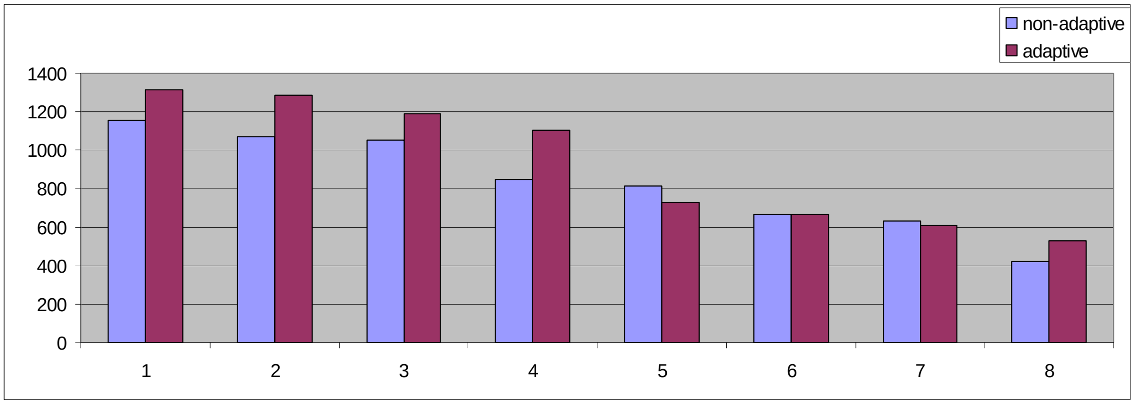

Figure 41. Web page presentation quality comparison

Questionnaire 1: Subjects' Background

Table XXVIII. Questionnaire 1: Questions

Q1	How long have you used computers?
Q2	How often do you use computers?
Q3	For how long have you known about the Web?
Q4	How often do you access the Web?
Q5	Check the technologies with which you have experience authoring Web pages (mark all that apply): • Authoring Web pages using composition tools (FrontPage, Composer, or any other) • Authoring Web pages using HTML and a text editor • Authoring Web pages with Javascript • Writing Servlets or CGI scripts (in Java, C, PERL, or any other) • Writing Java Applets
Q6	For how long have you authored Web pages or develop software for the Web (CGI, Servlets, Scripts, Applets, etc.)
Q7	How often do you author Web pages or develop software for the Web (CGI, Servlets, Scripts, Applets, etc.)

Table XXIX. Questionnaire 1: Answers

ID	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6	Q 7
01614	over-two-years	daily	over-two-years	daily	tools	never	less-than-monthly
03543	over-two-years	daily	over-two-years	daily	no-answer	never	less-than-monthly
04025	over-two-years	daily	over-two-years	weekly	no-answer	never	less-than-monthly
02140	over-two-years	daily	over-two-years	daily	tools	over-two-years	less-than-monthly
03866	over-two-years	daily	over-two-years	daily	no-answer	never	less-than-monthly
03075	over-two-years	daily	over-two-years	daily	no-answer	never	less-than-monthly
01769	over-two-years	daily	over-two-years	daily	javascript text-editor tools	over-two-years	weekly
06377	over-two-years	daily	over-two-years	daily	tools text-editor javascript applets cgi	over-two-years	weekly
08919	over-two-years	daily	over-two-years	daily	tools text-editor javascript cgi applets	over-two-years	daily
02552	over-two-years	daily	over-two-years	daily	no-answer	never	less-than-monthly
01204	over-two-years	daily	over-two-years	daily	no-answer	never	less-than-monthly
03208	over-two-years	daily	over-two-years	daily	tools text-editor javascript cgi applets	over-two-years	daily
01242	over-two-years	daily	over-two-years	daily	tools	over-two-years	less-than-monthly
02995	over-two-years	daily	over-two-years	daily	tools cgi applets	one-year-to-two-years	less-than-monthly
00271	over-two-years	daily	over-two-years	daily	tools text-editor	six-months-to-one-year	monthly
00864	over-two-years	daily	over-two-years	daily	Applets javascript text-editor	six-months-to-one-year	less-than-monthly

Questionnaire 2: HTML and XHTML

Table XXX. Questionnaire 2: Questions

Q1	What is HTML? It is a language that specifies how to display a hypertext document, including layout and hyperlink specifications. It is the protocol used in Internet to send Web pages It is a hyperlink between two text documents on the Web I don't know
Q2	What are the differences between "Clients" and "Servers"? Servers are the reader's computers that run the browsers. Clients are the computers that have the documents and sends them to the clients. Clients are the reader's computers that run the browsers. Servers are the computers that have the documents and sends them to the clients. Client and Servers refer to the user's and authors of hypertext documents respectively I don't know
Q3	What is the main purpose of Web browsers? To interpret the HTML code and then display the Web pages to users To show the HTML code that constitutes a Web page To send Web pages to other people I don't know
Q4	What differentiates tags from text in HTML? Tags are exclusively at the top of the document (in the head section) and text is exclusively in the lower part of the document (the body section) Tags are bracketed inside a < and a >. The content inside the brackets is not shown. Everything that is not a tag or a comment is text There are no differences. Tags and text are the exactly the same I don't know
Q5	Please complete the following sentence: "A basic HTML document..." ...requires that the name of the file is written within the <title> </title> tags ...has two main structures: a head and a body ...always shares it's URL with all the other documents that are pointed to by it I don't know
Q6	In HTML, which tags are commonly used for controlling how the text flows? <flow> <title> <div> <p> <hr> <head> <body>

	I don't know
Q7	How can Web page author ask users to enter information? Using the <form> tag Using the <enter> tag Using the <user> tag I don't know
Q8	How can tables be included in a Web page? Using the <tb> tag Using the <table> tag Using the <include> tag I don't know
Q9	Which of this tags is NOT properly written in HTML? <div id = myDiv>text</div> <diV name = "my div ">text</div> <div name=my div>text</div> I don't know
Q10	Where is the proper place to define the title of an HTML document? Directly inside the <head> tag Directly inside the <title> tag nested inside the <body> tag Directly inside the <title> tag nested inside the <head> tag I don't know
Q11	What is the purpose of the <div> tag? Divide two numbers (i.e.1/2) Divide the document into smaller sections Divide the source code into smaller files I don't know
Q12	What is the purpose of the heading tags To structure the flow of a document into a more readable and manageable document To identify sections of the source code of a Web page making it more readable for programmers To define the contents of the <head> tag I don't know
Q13	What is the purpose of the tag? It specifies the browser name It signals the beginning of a bracket It represents a line break. It breaks the flow of the text I don't know
Q14	Which text features can be changed in HTML? (Select the best answer) color and boldness

	size and face color, size, face and boldness I don't know
Q15	What is the use of the <hr> tag? It is a generic header tag It is the hour tag It creates a horizontal line or rule that visually separates the document into sections I don't know
Q16	Are images, videos or other multimedia content part of the HTML document? No. They are independent files. The HTML file tells the browser how to find them Yes. They are encoded inside the HTML file Only the images are part of the HTML file. All other objects are independent files. I don't know
Q17	What tag or tags can be used for loading images inline with the text? <a> <img> <span> I don't know
Q18	Which is a valid way to change the background color of a HTML document? <body background=#000099> <body background-color=#000099> <body bgcolor=#000099> I don't know
Q19	How are hyperlinks most commonly specified in HTML? Using the <link> tag Using the <hyperlink> tag Using the <a> tag I don't know
Q20	What is the purpose of the <link> tag? Creates a hyperlink between two documents Specifies the relationship between authors and readers Specifies how this document relates to other documents I don't know
Q21	Which one of the following is a relative URL? mash/servlets/mash-demo-10.html \\kilimanjaro.csdl.tamu.edu\mash-demo-10.html:8080 http://kilimanjaro.csdl.tamu.edu:8080/mash/servlets/mash-demo-10.html I don't know
Q22	Select the most accurate statement of the following

	In HTML and XHTML, hyperlinks can contain images but images cannot contain hyperlinks In HTML and XHTML, hyperlinks can contain images and images can contain hyperlinks In HTML and XHTML, images can contain hyperlinks but hyperlinks cannot contain images I don't know
Q23	What is the function of the <meta> tag? Defines the goal of the document Defines the direction of the hyperlinks Defines name/value pairs that can facilitate the automatic process of the HTML/XHTML document I don't know
Q24	In HTML what is the tag used for creating a bulleted list of items? <bl> I don't know
Q25	Is it possible to nest lists in HTML? No Only unordered lists Yes I don't know
Q26	In general what kind of list is best for name/value pairs? <dl> I don't know
Q27	Sort the following alternatives of changing the text based on the preferred way (answer assume the left-most is the better option and the right-most is the least recommended option): A) Content-based styles B) Cascading Style Sheets C) Physical Styles A B C B A C C B A I don't know
Q28	What is a style in HTML? It's a term that refers to a particular genre of Web pages (i.e. academic) It's a genre that refers exclusively to how the author of the Web page comments the

	HTML and XHTML document It's a rule that tells the browser how to display a particular tag's content I don't know
Q29	Which rule is properly written according to CSS2 syntax? h1.color = green; h1 { color:green; } h1 color = green I don't know
Q30	When a particular nesting of tags matches several style rules that define the same property, which rule is used? The last rule The first rule The most specific rule I don't know
Q31	For what are CSS2 classes used? To apply pre-created classic styles to elements (tags) To classify the elements (tags) To create several different styles for the same element (tag) I don't know
Q32	Have you ever created a XHTML document? Yes No I don't know

Table XXXI. Questionnaire 2: Answers

C = Correct
I = Incorrect
U = Unknown
N = No-Answer

	Non-Adaptive								Adaptive							
ID	01614	03543	04025	03866	02995	03208	00271	00864	02140	03075	01769	06377	08919	02552	01204	01242
Q1	C	C	U	C	C	C	C	C	C	U	C	C	C	U	U	C
Q2	C	C	U	C	C	C	C	C	C	C	C	C	C	U	U	N
Q3	C	I	U	C	C	C	C	C	C	U	C	C	C	U	U	C
Q4	C	U	U	U	C	C	C	C	C	C	C	C	C	U	U	U
Q5	C	U	U	I	C	C	U	C	C	U	C	C	I	U	U	U
Q6	U	U	U	I	C	C	U	C	C	U	C	C	C	U	U	U
Q7	U	U	U	I	C	C	I	C	C	U	C	C	C	U	U	U
Q8	U	U	U	U	C	C	U	C	C	U	C	C	C	U	U	U
Q9	U	U	U	U	I	C	U	C	C	U	C	I	C	U	U	U
Q10	U	U	U	U	U	C	C	C	I	U	C	C	C	U	U	U
Q11	U	U	U	U	U	U	U	C	C	U	C	C	C	U	U	U
Q12	U	U	U	U	U	I	U	I	U	U	I	C	C	U	U	U
Q13	U	U	U	U	C	C	U	C	C	U	C	C	C	U	U	U
Q14	I	U	I	I	I	I	I	I	I	I	I	I	I	U	U	I
Q15	U	U	U	U	U	C	U	I	C	U	C	C	C	U	U	U
Q16	C	I	I	U	C	C	C	C	C	U	C	C	C	U	U	C
Q17	C	U	U	U	U	C	U	C	C	U	C	I	C	U	U	U
Q18	U	U	U	U	U	C	U	U	U	U	U	C	I	U	U	U
Q19	U	I	I	U	C	C	U	C	C	U	C	C	C	U	U	I
Q20	U	I	I	I	U	U	I	U	U	I	U	U	C	U	U	N
Q21	I	U	U	U	I	I	C	I	I	C	I	I	I	U	U	U
Q22	C	U	U	N	C	I	U	U	C	U	I	I	I	U	U	U
Q23	U	U	U	U	C	C	U	U	U	U	C	I	C	U	U	U
Q24	U	U	U	U	U	C	U	C	U	U	U	C	U	U	U	U
Q25	U	U	U	U	U	C	C	C	C	U	U	C	C	U	U	U
Q26	U	U	U	U	U	I	U	C	U	U	I	C	U	U	U	U
Q27	U	U	U	U	I	U	U	C	I	U	U	C	C	U	U	U
Q28	U	U	U	U	C	C	U	C	C	U	C	C	C	U	U	U
Q29	U	U	U	U	U	U	U	I	U	U	U	U	C	U	U	U
Q30	U	U	U	U	U	I	U	C	U	U	U	U	U	U	U	U
Q31	U	U	U	U	U	U	U	U	U	U	U	U	C	U	U	U
Q32	I	I	I	U	C	C	I	I	I	I	I	I	I	I	I	U

Questionnaire 3: Comments

Table XXXII. Questionnaire 1: Questions

Q1	Did you create any annotation?
Q2	Did you rearrange the objects in the space?
Q3	Did you change the look of the objects?
Q4	Did you use the zoom feature?
Q5	How easy was to navigate through the information space?
Q6	How easy was to understand the concept of containment in collections?
Q7	How easy was to distinguish emphasized from de-emphasized objects?
Q8	How well did emphasized objects properly classify relevant information?
Q9	How well did de-emphasized objects properly classify irrelevant information?

Table XXXIII. Post-evaluation of Non-Adaptive System

ID	**Q 1**	**Q 2**	**Q 3**	**Q 4**	**Q 5**	**Q 6**	**Q 7**	**Q 8**	**Q 9**
01614	no	yes	no	no	1	0	N	N	N
03543	no	yes	no	no	0	0	N	N	N
04025	no	yes	yes	yes	3	0	N	N	N
03866	no	yes	yes	yes	2	0	N	N	N
03208	no	yes	no	no	1	0	N	N	N
02995	no	yes	yes	yes	1	0	N	N	N
00271	no	no	no	no	1	3	N	N	N
00864	no	no	no	no	0	0	N	N	N
SUM					**9.0000**	**3.0000**			
AVERAGE					**1.1250**	**0.3750**			
ST DEV					**0.9910**	**1.0607**			
VARIANCE					**0.9821**	**1.1250**			

Table XXXIV. Answers of Adaptive Subjects to the Post-evaluation Questionnaire

ID	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6	Q 7	Q 8	Q 9
02140	no	yes	yes	yes	5	6	6	3	3
03075	no	yes	yes	yes	4	5	3	2	2
01769	no	yes	yes	no	4	5	6	5	5
06377	no	no	yes	yes	5	6	6	1	1
08919	no	yes	yes	yes	4	6	5	5	5
02552	no	no	no	yes	4	5	4	4	3
01204	no	yes	no	yes	5	5	6	5	5
01242	no	no	no	yes	5	4	5	5	5
SUM					**36.0000**	**42.0000**	**41.0000**	**30.0000**	**29.0000**
AVERAGE					**4.5000**	**5.2500**	**5.1250**	**3.7500**	**3.6250**
ST DEV					**0.5345**	**0.7071**	**1.1260**	**1.5811**	**1.5980**
VARIANCE					**0.2857**	**0.5000**	**1.2679**	**2.5000**	**2.5536**

VITA

Luis Francisco-Revilla was born on August 1, 1970 in Mexico City. From 1987 to 1992 he attended the Universidad Iberoamericana in Mexico City, where he studied Electronic and Communications Engineering. Along with his thesis partner, he was the first in his class to graduate in October 1994 after completing his bachelor's thesis. From 1992 to 1996, while living in Mexico City, he worked in both academia and industry. He started as a full-time lecturer for the Universidad Iberoamericana. Later, he worked for NCR and AT&T in the areas of Systems, Marketing, and Consulting. In 1996 he moved to College Station to study Computer Science at Texas A&M University, obtaining his Master in Science degree in December 1998. He continued his studies in Computer Science at Texas A&M University, obtaining his Ph.D. in December 2004. During his stay at Texas A&M University, Luis Francisco-Revilla worked as a Graduate Research Assistant for the Center for the Study of Digital Libraries. During this time, he worked several projects including Walden's Paths, Path Manager, VKB, MASH and WARP. He also published several articles in international journals and conferences such as: International Journal on Digital Libraries, ACM/IEEE Joint Conference on Digital Libraries, and Hypertext among others. Luis Francisco-Revilla can be contacted at:

Cerro del Crestón #146

Col. Campestre-Churubusco, 04200

Mexico City, Mexico