MASH: A Framework for Adaptive Spatial Hypermedia

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ABSTRACT

Spatial hypermedia provides opportunities for expression not possible in navigational hypertext. However, static spatial hypermedia, just like static traditional hypermedia, has a single presentation for all use contexts. We are exploring the use of multiple adaptation models to alter the presentation of spatial hypertext. Differences between navigational and spatial hypertext expression require developing additional principles that can guide the design of new adaptive spatial hypermedia systems. MASH (Multi-model Adaptive Spatial Hypermedia) is a theoretical framework to help guide the augmentation of spatial hypermedia to include dynamic and adaptive behaviors. The framework provides, in the form of a general architecture, guidelines for designing, analyzing and comparing spatial hypermedia systems. This architecture allows spatial hypermedia systems to be classified based on their generative, interactive, dynamic and adaptive functionality. The MASH framework also presents an ontology of the adaptation methods and techniques that can be used in spatial hypermedia. The theoretical work is then grounded by introducing WARP, a prototype that not only exemplifies this approach but also represents a first incursion into Web-based spatial hypermedia, distributed spatial hypermedia, access issues for Presentation Oriented Spatial Hypermedia (POSH) documents, and interoperability issues between spatial hypermedia systems.

Categories and Subject Descriptors

H.5.4 [**Information Interfaces and Presentation**]: Hypertext/Hypermedia – *architectures, theory, navigation.*

General Terms

Algorithms, Design, Experimentation, Standardization, Theory.

Keywords

Spatial Hypertext, Multiple models, Adaptive, Dynamic.

1. INTRODUCTION

The spatial hypermedia approach has powerful representation capabilities that can handle explicit or implicit relationships in a semi-formal way. Spatial hypermedia can support ambiguities and the fluid formalization of information. Additionally, the use of space, intrinsic to spatial hypermedia, facilitates presenting information in more ways than navigational hypertext. This expressiveness makes spatial hypermedia an interesting approach to create presentations for information-rich domains.

However, static spatial hypermedia, just like static traditional hypermedia, has a single presentation for all use contexts. Thus, supporting a more dynamic approach can enhance the usability and usefulness by allowing the user/reader to alter the presentation of the information. Finally, in an effort to increase the effectiveness of general-purpose presentations, spatial hypermedia systems can automatically adapt the presentations in order to best fit the context.

Current work on spatial hypermedia has centered on exploring the expressiveness of the medium. There has been limited work about augmenting spatial hypermedia to support dynamic and adaptive behaviors. And while there is relevant work on adaptive hypermedia, the differences between the mediums require developing additional principles that can guide the design of new adaptive spatial hypermedia systems.

This work introduces a general framework for the development of adaptive spatial hypermedia systems. This framework proposes a general architecture and an ontology of adaptation methods and techniques for spatial hypermedia. Finally it presents WARP, a prototype that exemplifies this approach.

2. PROBLEM

Hypermedia is a medium for presenting an interconnected body of information. However, delivering information is not a trivial matter in information-rich domains. The simple approach of gathering and presenting all available information overwhelms readers/users. In order to address this issue, different techniques have emerged in order to select and present the most relevant pieces of information.

One problem when attempting to identify the relevant pieces of information from the irrelevant ones is that every person has different needs. Hence the selection process must adapt in order to effectively support individuals. As a result, research in adaptive hypermedia has typically focused on customizing the presentation according to a single model that represents user characteristics such as goals, knowledge and preferences [2, 5].

However, as pointed out by Suchman [34], human actions are situated and depend heavily on the particular context. Systems cannot enumerate or predict every possible situation. Thus, in addition to the user, it is necessary to take into consideration factors such as situation and activity, which also demand the adaptation of the presentation of the information. As a result, factors external to the user are often included into 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 is the creation of systems capable of migrating through domains and applications [8, 33]. However, the use of a single user model often results in rigid adaptation strategies that render the systems brittle to context and thus limit the their ability to migrate and scale through domains and time. To cope with this difficulty, researchers have augmented this approach by employing multiple models [10, 11, 12].

However, these systems have always assumed a fixed number of models. This assumption suffers the same weakness since it is impossible to predict how many models will suffice in every case. A better approach is to use multiple agents or suggestion mechanisms that function based on independent models. This approach allows adding or fine-tuning the independent mechanisms, making it possible to extend and adapt the system as required.

A drawback of using of multiple independent agents is that conflicts can occur. There has been previous research on solving the issue of competing suggestions offered by different mechanisms [9, 27]. Different schemas have been suggested, such as voting or priority based strategies [4, 7, 35]. 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 [26].

While it is necessary to solve conflicts whenever they occur, it is also possible to take more proactive measures. In multi-model adaptive hypermedia, conflicts occur when different models suggest presenting information in ways that the medium does not support. Therefore it would be desirable to proactively circumvent the whole issue of presentation conflicts by augmenting the expressiveness of the medium.

In the case of adaptive hypermedia, the current research trend focuses on the Web and more particularly on HTML as the selected medium to present the information. This results on some expressiveness limitations. In HTML things can only be either present or not present (i.e. a link can be exist or not, but a link that *might be there* cannot be easily represented). Additionally, the layout is implicitly organized in a single direction (top-down, left-right). Although there are some mechanisms that allow a persistent user/programmer to work around these limitations, these workarounds are still limited.

In contrast, spatial hypermedia is more expressive. It is capable of representing more subtle nuances and it enables a wider variety of presentations, thus reducing artificial technological limitations that can produce conflicts.

Spatial hypermedia is based in observations of how people use systems such as Aquanet [22] that revealed that often only the relative spatial position between objects is used to imply the relationship between objects [20, 21, 29]. These observations prompted the development of Spatial Hypermedia systems like VIKI [23] and VKB [31]. These systems explore the use of space to represent explicit and implicit links with varying degrees of formality [30, 31]. Spatial Hypermedia supports ambiguities and fluid formalization of the information [26]. This expressiveness makes it desirable to use spatial hypermedia for presentation purposes in adaptive information delivering systems.

Spatial hypermedia research has proved to be a prolific field, as more researchers started to explore these ideas and develop new systems [1, 13, 15, 19, 24, 25, 32, 38]. To our knowledge, no work has been done in regard to the augmentation of this medium with adaptive behavior beyond the access constraints in HyperMap [37]. Thus it is useful to create a framework that aids in the future design and implementation of systems. The result is the creation of the Multi-model Adaptive Spatial Hypermedia (MASH) framework.

3. MASH FRAMEWORK

The MASH framework extends work on adaptive hypermedia by addressing the limitation of single model approaches and augmenting the presentation medium.

The goal of this framework is to guide the design and development of new adaptive spatial hypermedia systems. It consists of three parts: a high-level abstraction of objects and relationships, a generic architectural framework, and a theoretical ontology of spatial adaptations. The high-level abstraction presents a generalization of the spatial hypermedia concepts, which are fundamental for the framework. The generic architecture provides a high level view of MASH functionality that allows classification and comparison of different spatial hypermedia systems. The ontology presents theoretical platform that allows comparison of different adaptation strategies.

3.1 Space, Objects and Relationships

When considering the intrinsic components of spatial hypermedia, Objects and Relationships, it is tempting to draw traditional hypermedia concepts such as nodes and links. While this aids in correlating traditional 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. This results in a discrepancy with the intuitive notion that links mostly connect nodes to nodes.

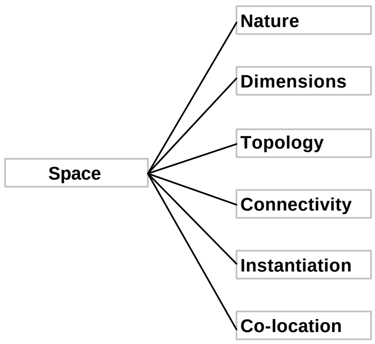

Figure 1. Space

Rather than translating traditional hypermedia concepts to spatial hypermedia, the MASH framework provides an alternative approach that fits better the intrinsic characteristics of spatial hypermedia. In MASH, spatial hypermedia can be considered in terms of Space, Objects and Relationships.

3.1.1 Space

Spatial Hypermedia, as it names suggests, uses space as the basis for establishing relationships between objects. However, as Kolb [18] points out, philosophers discussing about 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 [14, 17, 18]. These studies had an influential role in the present work.

Space can pragmatically be defined in terms of:

- Nature
- Dimensions
- Topology
- Connectivity
- Instantiation
- Co-location
- Rendering

3.1.1.1 Nature

As Kolb [17] 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.

3.1.1.2 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.

3.1.1.3 Topology

Space is not necessarily a homogenous, amorphous entity. A space might have a shape (i.e. 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.

Some times the virtual space (the system's representation of space) can map a real space (such as a building or a city). This is the case of Manufaktur [14] and other augmented reality systems. In these cases, the real space determines the topology of the virtual space.

3.1.1.4 Connectivity

The 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.

3.1.1.5 Instantiation

This refers to how many instances of the same object can exist in different locations at the same time. In the real world *1 thing at 1 place at 1 time*.

3.1.1.6 Co-location

This refers to how many objects can occupy the same location at the same time. In the real world *1 thing at 1 place at 1 time*.

3.1.1.7 Rendering

Within the context of 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.

The conceptual differences between systems 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 many research efforts in spatial hypermedia have focused on exploring the use of 2½-D homogeneous space, there has been relevant experimentation with space deformations [28] and with 3 dimensional spaces [14, 16, 25].

3.1.2 Objects

Objects represent the encoded information. They can be of three kinds: atomic, composite or document.

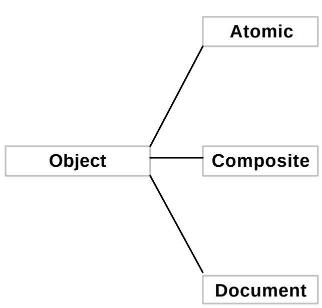

Figure 2. Objects

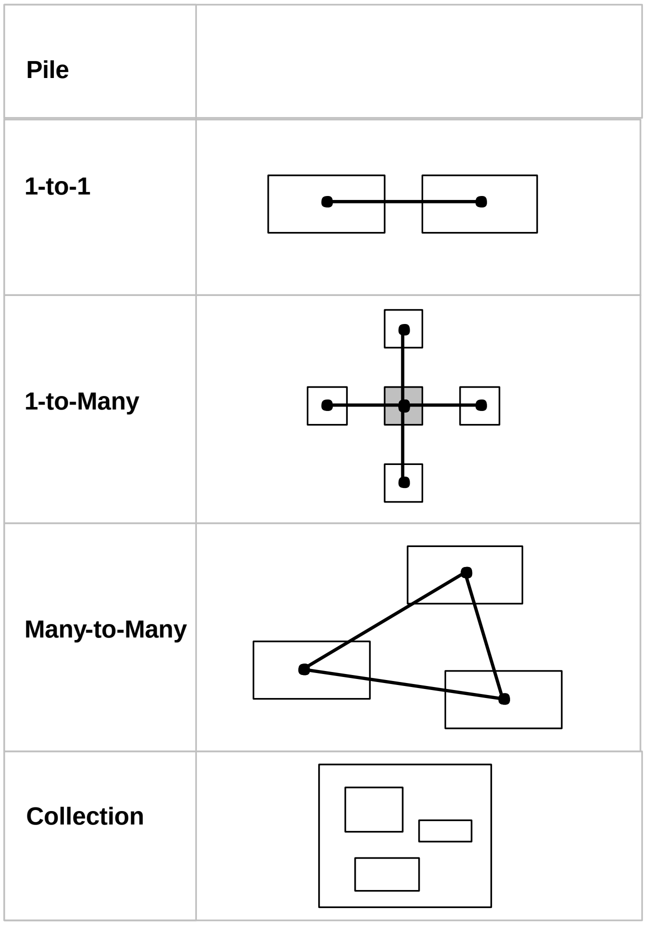

Figure 3. Basic Composites

3.1.2.1 Atomic Objects

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

3.1.2.2 Composite Objects

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

There is a diversity of composite objects that varies accordingly 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 Collection (in 2-D and 2½ D systems) or Construct (in 3-D systems).

The basic composites, shown in Figure 3, provide only a generic composition of objects. Special cases of these composite are often more useful. Some of the special case composites are of special interest and are shown in Figure 4. These special-case composites are Lists and Matrices. List composites are constructed by a objects positioned along a single 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).

The process of selecting which objects should make up a new composite objects often involves not only the relative position but also the type and visual characteristics of the components. For instance, VKB [31] can recognize lists made of visually similar objects. Alternatively, in some applications, it is desirable to distinguish complex composites containing a particular set of objects, each with specific features, which are arranged in a specific configuration. For instance, it is might be desired to recognize labeled lists or Toulmin structures [20]. However, complex 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.

3.1.2.3 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.

3.1.3 Relationships

Relationships in MASH are important. Rather than attempting a fine-grained taxonomy of relationships such as provided by [3, 6, 36], 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.

3.1.3.1 Quality of Relationships

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

3.1.3.2 Association of Relationships

This dimension represents how the relationship emerges. Relative associations are based on the relative position of the related

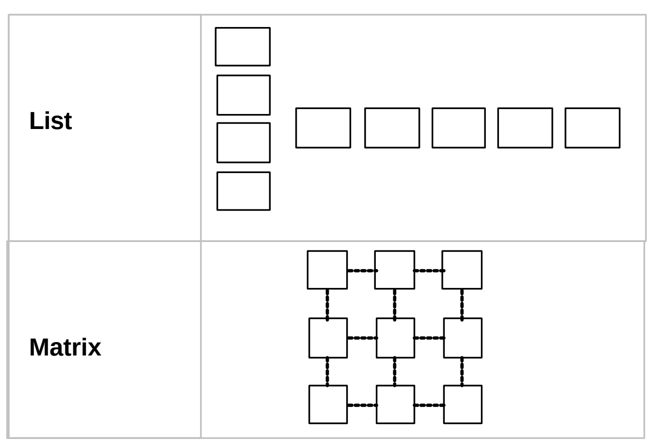

Figure 4. Special Case Composites

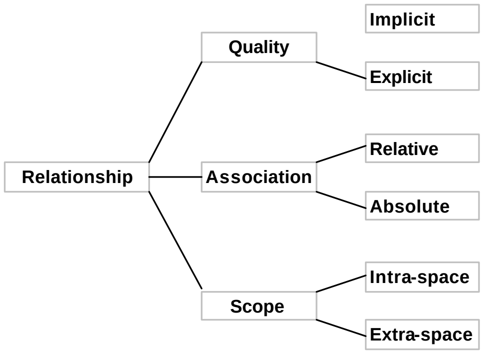

Figure 5. Relationships

entities. Absolute relationships have a visual representation independent of the relative position of the related entities (one example are the navigational and semantic links in VKB [31]).

3.1.3.3 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.

3.2 General Architecture

The MASH framework, shown in Figure 6, proposes a generic block architecture that considers different functional aspects of spatial hypermedia. This architecture allows comparison and classification of systems by reviewing which functional blocks they include. Note that this architecture represents an abstract segmentation of the possible functionality. Different systems, particularly early ones, coalesce blocks into single units.

3.2.1 Generative Spatial Hypermedia

This section refers to the authoring of the spatial hypermedia. The spatial hypermedia generator provides the functionality required to create the documents. Contents might previously exist or they might be created 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 [23]. As a result, many systems blended the generative aspect with the interactive aspect of spatial hypermedia [1, 13, 19, 23, 24, 25, 32, 38]. This is a natural union since often creating a spatial hypermedia document requires interacting with it. In fact it is not until the coming of second-generation systems and the arrival of presentation oriented spatial hypermedia (POSH) that this functional separation starts being observed in the systems' implementation [31]. 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 [15].

3.2.2 Interactive Spatial Hypermedia

Interactive Spatial Hypermedia provides the required platform in which users/readers can interact with and read existing Spatial Hypermedia documents.

As mentioned before, interactive functionality was often blended with the generative aspects and includes functions required to

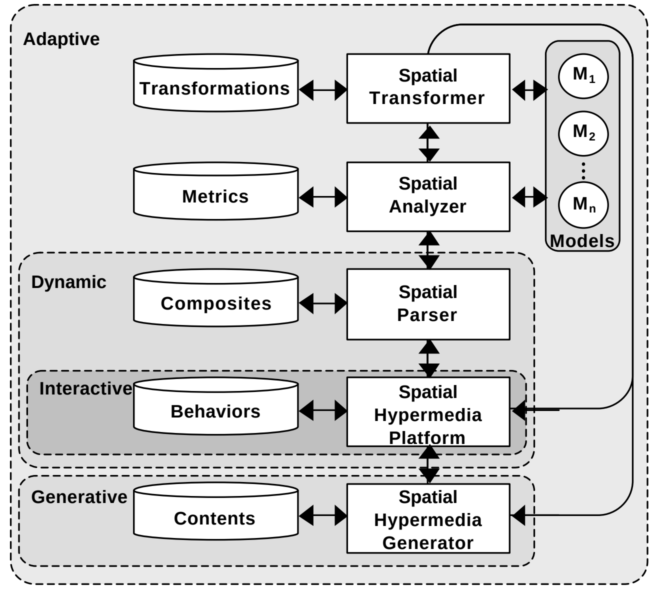

Figure 6. Spatial Hypermedia Framework

author and modify the document. This is in part due to the stand-alone nature of most systems [1, 13, 15, 19, 24, 25, 32, 38]. Also, given the early state of affairs in the field, there has been little work into importing and exporting documents between systems.

However, these generation and interaction functionalities can be easily separated. It is not difficult to visualize schemes where the generation of the spatial hypertext document is handled by a different system than the interaction with the document.

In order to properly use/read spatial hypermedia documents it is often required to support actions or behaviors such as moving or modifying objects. This is why behaviors, and particularly user-triggered behaviors, are also considered part of interactive spatial hypermedia, even though they have a dynamic nature.

3.2.3 Dynamic Spatial Hypermedia

From a broad point of view, all spatial hypermedia systems that support reading and interaction 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 complex behaviors. For instance, dynamic behaviors may make objects to wander around the space or they can make objects fade out as time passes. Dynamic behaviors also distinguish themselves from purely interactive behaviors in that they do not need the users/readers to initiate them.

Behaviors can modify the document's space, objects relationships or composites. Space behaviors modify the underlying space directly. Objects are affected only by how are they positioned in this space. They include panning, scrolling zooming, fish eyes or any other function that acts upon the underlying space. For instance document objects can zoom their content such that the whole document is visible. Another example is collections that pan their space in order to make relevant objects visible.

Object behaviors can be extremely diverse. They might include actions such as making the objects move and wander over the document space. Behaviors can make object follow the mouse or make them attract other objects. Behaviors can mutate objects. For instance images can change their size and/or resolution in response to user actions or they might hide or show depending on arbitrary functions.

Relationship behaviors act upon the relationships between the objects. They modify the relationship quality, association or scope. For instance they can modify the relationship quality making changing it from implicit to explicit.

Composite behaviors support a complex and expressive dynamic behavior. A key component required to support composite relationships 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.

3.2.4 Adaptive Spatial Hypermedia

Adaptive Spatial hypermedia systems adapt the presentation of the document automatically. This includes transforming objects, composites and the 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 framework encapsulates the evaluation functionality within the Spatial Analyzer and the functionality of generating an improved version in the Spatial Transformer.

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 or absolute (the screen real estate for a list can be computed at run-time or the ambiguity value of a matrix may be an absolute value of "*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.

One advantage of interacting with the models at this high-level is that it can simplify the issue of conflict resolution and conflict avoidance. First, the Spatial Transformer can adjust the level of ambiguity in the presentation in order to represent the tension between the models to the reader/user. And second, the Spatial Transformer can implement different conflict resolution techniques in order to solve more radical discords between the models as they are identified.

3.2.5 Multi-model Approach

Having multiple adaptation models is a key component of the framework. It augments previous approaches to adaptivity [2, 5] by enabling the fine-tuning and support of multiple factors that modify the presentation. The MASH framework allows these to be independent models. It also does not make any assumptions about the nature of the models, allowing the system designer to design freely the models inner-workings and possible model interactions. This creates a more flexible, even adaptable, adaptation mechanism, which facilitates migration across domains, applications and time.

This framework does not exclude the use of a single model whenever is appropriate. Systems that employ a single model are just a sub-case of MASH. While work on multi-model adaptation is still in an early stage, it is a promising approach that complements the highly expressive nature of spatial hypermedia while also facilitating a variety of adaptations.

3.3 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 [2] and De Bra [5].

Just like Spatial Hypermedia is best comprehended using objects, relationships and space, the classification of the kinds of adaptation of spatial hypermedia is best accomplished using these dimensions. These three dimensions address the intrinsic nature of spatial hypermedia, but it is also necessary to address the *adaptive* component itself. This results in the four kinds of adaptations shown in Table 1.

Table 1. Kinds of adaptations in Spatial Hypermedia

Semantic	Refers to *what information* is shown. Brusilovsky refers to this kind of adaptation as adaptive presentation [2] and De Bra as content-adaptation [5].
Relational	Refers to *what interconnections* (links in traditional hypermedia, relationships in spatial hypermedia) exist between the different parts of the presentation. Brusilovsky calls this adaptive navigation [2] and De Bra link-adaptation [5].
Spatial	Refers to *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	Refers to *what adaptations* can applied to the adaptation mechanism itself. This is an emergent characteristic of the multi-modal approach.

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

3.3.1 Methods and Techniques

Similarly to Brusilovsky's [2] and De Bra's [5] frameworks, the MASH ontology for spatial adaptations abstracts the different adaptation approaches into high-level methods and low-level techniques. Tables 3, 4, and 5 show the methods and techniques for the semantic, relational and formal dimensions.

Table 2. Semantic Adaptation

Methods	Techniques
Explanations (Additional, prerequisite and comparative)	• Show/Hide objects • Show/Hide composites • Transform objects • Transform composites • Layer objects and composites
Explanation variants	• Instantiate objects • Instantiate composites • Show/Hide objects • Show/Hide composites
Grouping	• 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
Sorting	• Instantiate explicit composites • Adjust the features of the objects in the group to match a given order • Transform composites
Highlighting	Increase object's relative weight
Softening	Decrease object's relative weight

Reviewing the adaptation methods and techniques shown in Table 3 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.

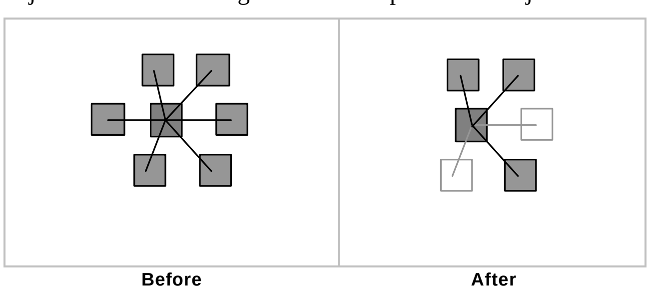

Figure 7. Example of a Semantic Adaptation

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

Table 3. Relational Adaptation

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

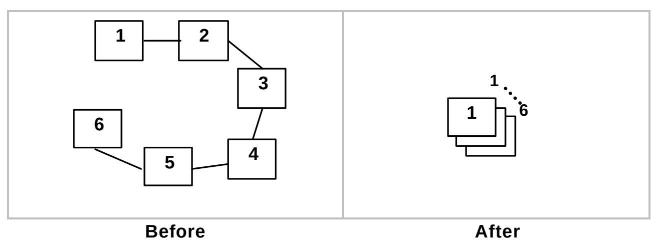

Figure 8. Example of a Relational Adaptation

Figure 8 shows how an explicit list is transformed into a pile. This is an example of a local navigation method using a composite transformation technique.

The different strategies available in spatial hypermedia for modifying the underlying space are shown in Table 5. These methods and techniques affect space characteristics such as continuousness, linearity, uniformity, rendering and affordances and constraints supported by the space.

Continuousness 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 it's characteristics are similar everywhere. The space rendering affects how the space is represented on screen.

Table 4. Spatial Adaptation

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

Finally, Table 5 shows the adaptation methods for the meta-adaptation dimension.

Table 5. 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 about changing computational procedures, there are plentiful meta-adaptation strategies. Therefore, rather imposing artificial limits, MASH does not include a technique level, only providing high-level methods.

3.3.2 Adaptation Genres

When talking about adaptation, there are two aspects to consider: *what* and *how*. The question of how to manage the contents, relationships and space can have multiple meanings. It can mean "how formal should be the presentation?" or how should content be emphasized compared to the structure of the information?" In fact the question of how implies an adjective such as formal, detailed, visible, etc. These adjectives can theoretically be applied to each adaptation type. MASH refers to these adjectives as Adaptation Genres. Some possible genres are shown in Table 6.

Table 6. Adaptation Kinds and Genres

	Semantic	Relational	Spatial
Formal			
Ambiguous			
Accessible			
Detailed			
Condensed			
Emphasized			

Table 6 illustrates how adaptation genres can affect every adaptation kind. Which specific genres are used depend on the particular needs and adaptation goals of the system. An adaptive system does not need to support adaptation to all kind-genre pairs.

Two genres worth noticing, although they are not strictly mandatory, refer to the *formality* and *ambiguity*. These are important because Spatial Hypertext have often dealt with issues of incremental formalization of the information [30].

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

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

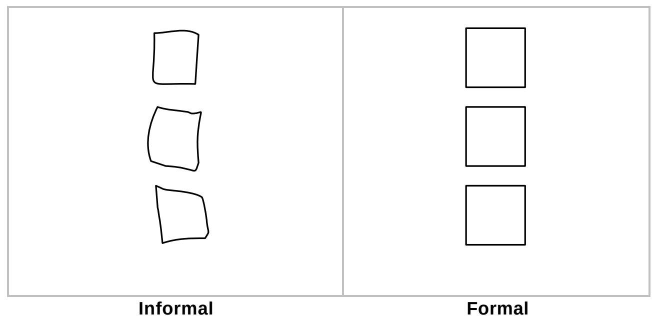

Figure 9. Informal vs. Formal Spatial Presentations

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 positions.

Ambiguity refers to the clarity. 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

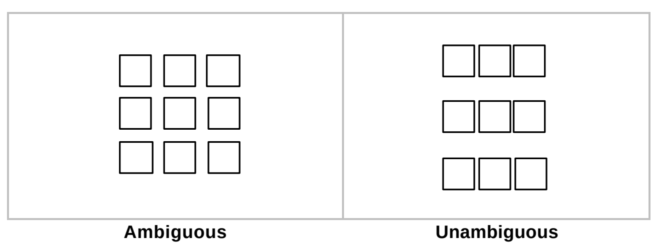

Figure 10. Ambiguous vs. Unambiguous Spatial

In the ambiguous case it is impossible to know if there are three rows of objects or three columns or a 1-to-many relationship. However on the unambiguous case, the relative position clearly shows that there are three rows of objects, each with three objects.

Table 7 shows the different methods and techniques that can be used in order to make the presentation more formal or informal.

Table 7. 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 8 shows the different methods and techniques used for modifying the ambiguity of the presentation.

Table 8. 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

In summary, the MASH framework provides useful guidelines for the design of the next generation of spatial hypermedia systems. It provides the theoretical abstraction necessary for classifying and analyzing existing systems. In addition the MASH framework is intended to guide the design of the next generation of spatial hypermedia systems. The guidelines provided by MASH were the basis for the creation of WARP, which is briefly discussed in section 4.

4. WARP System

WARP (Web bAsed Research Project) is a first implementation of MASH. It is created to validate the framework and to explore the use of Dynamic and Adaptive Spatial Hypermedia.

4.1 Browser-based implementation

WARP is a Web-based dynamic hypermedia application written almost completely in Javascript (the main system can use complementary Java-based Servlets as a way to augment the performance of some objects). The system executes inside the Web-browsers. This helps to avoid dependencies on operating systems and hardware platforms. At the current moment it runs on Netscape 6 and higher and IE 6 and higher (Opera 7 can also execute it with some limitations). Figure 11 shows a screen shot of the MASH interface running on Internet Explorer.

4.2 Interactive Support

Visible in Figure 11 are some text objects, image objects, collections and document objects. The left document object in Figure 11 (titled "Authoring Prototype") shows another POSH document located somewhere else on the Web. This is an actual space included in the parent space by reference. The user/reader can interact with it and can move objects between them. Document objects are key for Collaborative Spatial Hypermedia.

WARP provides full interactive functionality including behavior support. Different behaviors have been implemented that act upon space, objects or composites. Some of the behaviors implemented allow objects to mutate (changing the images), or to wander around the screen in random directions. They can also modify the zoom level of the space.

Almost at the top of the POSH document in Figure 11 there are four images spelling "Multi-model", "Adaptive", "Spatial", and "Hypermedia". These images have been defined as part of an explicit list. Moving any of the objects causes the other objects to follow the dragged object. Figure 12 exemplifies this. The user has moved the two objects on the left into the collection on the right. Afterwards, the user/reader moved the "Multi-model" image object towards the middle of the space, which in turn dragged all the other image objects in the list as if they were tethered. This is just one example of the dynamic behaviors included in WARP.

4.3 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. However, it also requires dealing with browsers' affordances and constraints. An interesting issue arising from publishing POSH documents on the Web relates to how to publish and access the documents.

As mentioned before, reading a spatial hypermedia document often requires interacting 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 a *personal access* to the document, 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.

In WARP, the first time that a user/reader accesses a document, s/he gets a copy of the original POSH document. The author is allowed to specify if the user can or cannot modify properties of the objects (such as their position). In addition WARP supports the creation of user/reader annotations on the document by creating new objects. These are personal annotations and at the moment cannot be shared. After the user/reader finishes his/her session, WARP is capable of recording the document's state. This allows the user/reader to return to their personal version of the document the next time s/he access it.

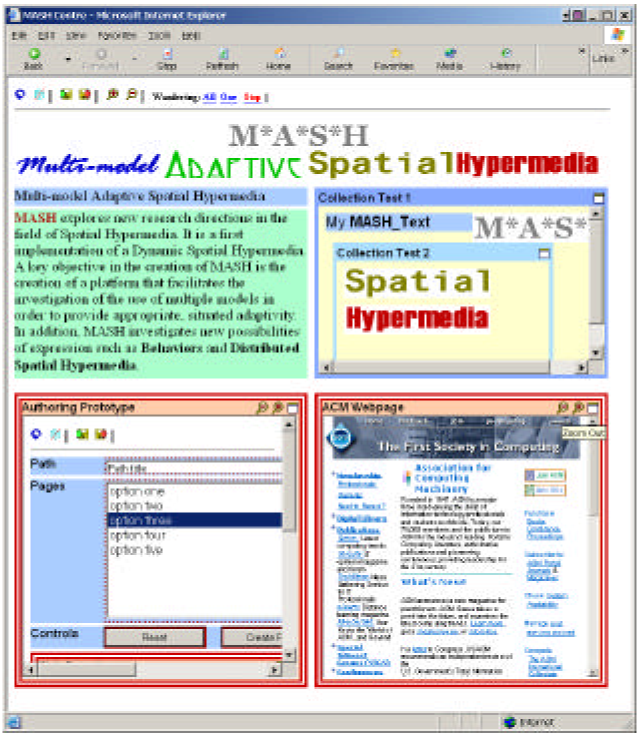

Figure 11. WARP

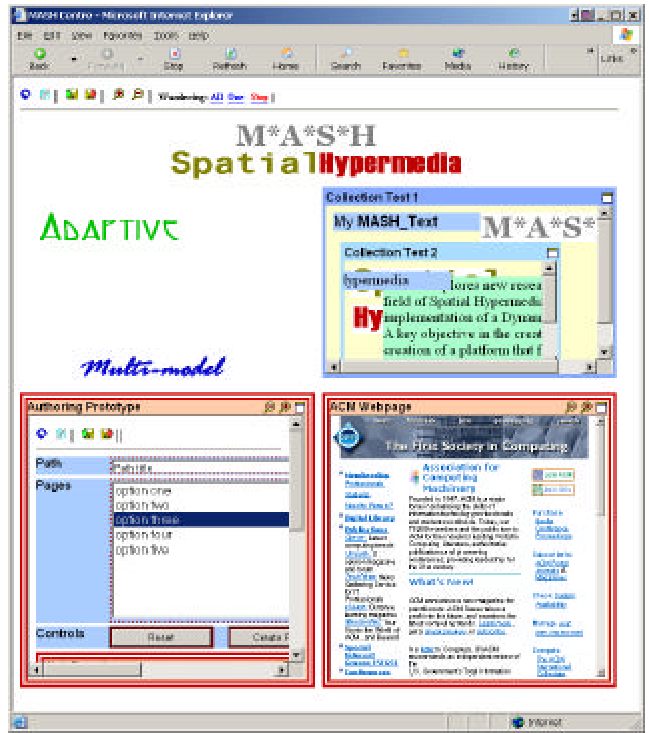

Figure 12. Interaction in WARP

4.4 Dynamic and Adaptive Support

As such special emphasis is set upon the dynamic and adaptive components of the framework. The approach assumes an existing POSH document and adapts it according to the models. In the current implementation, authoring of documents is being delegated to VKB [31]. This decision has two advantages. First, it releases the system developing of the time-consuming implementation of a complete authoring environment. But more importantly, this allows testing of new system interoperability concepts. WARP and VKB are not one-to-one equivalent. Thus it is necessary to deal with the differences when supporting import/export operations.

The current WARP implementation uses Behaviors, Composites and the Spatial Parser in order to provide the required functionality for Dynamic Spatial Hypermedia. However, while much of the theoretical work required for the Metrics and Transformations is already completed at the present moment, work on the Spatial Analyzer and Spatial Transformer is still underway.

5. NEXT STEPS

The first objective is to complete the implementation of WARP and gain experience with a full-fledged multi-model adaptive spatial hypermedia. This requires a deeper investigation into the use of multiple models, conflict resolution mechanisms, and the use of ambiguity as a way to avoid conflict.

The implementation of the Spatial Transformer requires creating a Transformation Algebra or Transformation Grammar that controls how different transformations are used and combined.

Once a complete implementation is achieved, studies will be conducted to evaluate the usability and effectiveness of the system, particularly of the adaptive aspects of the system.

MASH and WARP raise a number of other interesting issues for study in the areas of Computer Supported Collaborative Work with Spatial Hypermedia and POSH Document Shared Access.

6. CONCLUSIONS

The MASH framework provides a solid theoretical grounding for the study of Dynamic and Adaptive Spatial Hypermedia. Although MASH is influenced by research into traditional adaptive hypermedia, it deviates from previous taxonomies and models in order to address the different expressiveness of spatial hypermedia.

The framework is composed of three parts: basic spatial hypermedia concepts, a general architecture and an ontology of the possible adaptation strategies in spatial hypermedia. The basic spatial hypermedia concepts set the common ground required for the analysis of different systems and approaches. The general architecture provides a way to classify current and future spatial hypermedia systems based on their generative, interactive, dynamic and adaptive functionality. 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.

In addition to the classification of current systems, the MASH framework provides useful guidelines for augmenting and developing new spatial hypermedia systems. The desire to validate these guidelines and explore the augmented functionality supported by the framework resulted in the implementation of a prototype system: WARP.

WARP is a Web-based system designed in accordance to the MASH framework. WARP's novel functionality includes the containment of spatial hypertext documents as an alternative to navigational linking, behaviors supporting dynamic spatial hypermedia, and personal annotations to spatial hypermedia. It also provides the required platform for the study of several extensions to spatial hypermedia such as Web-based spatial hypermedia, document publication and document access, and interoperability issues between different systems.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] Bernstein, M. Notes on the Vitality of Hypertext Systems. http://www.well.com/user/jer/SH1/papers.html.

[2] Brusilovsky, P. Methods and techniques of adaptive hypermedia. User Modeling and User-Adapted Interaction, 6 (2-3) Kluwer academic publishers, 1996, pp. 87-129

[3] Conklin, J. Hypertext: An Introduction and Survey. In IEEE Computer, 20(9) (September 1987), pp. 17-41.

[4] Conry, S., Meyer, R. A. and Lesser, V. Multistage Negotiation in Distributed Artificial Intelligence. In Bond, A. and Gasser, L. (Ed.) Readings in Distributed Artificial Intelligence. Morgan Kaufman, 1988.

[5] De Bra, P., Houben, G-J., and Wu, H. 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, 1999) ACM Press, pp. 147-156.

[6] DeRose, S. J. Expanding the Notion of Links. In Proceedings of Hypertext '89 (Pittsburgh PA, November 1989), ACM Press, pp. 249-257.

[7] Durfee, E. H., Lesser, V. R., and Corkill, D. D. 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.

[8] Encarnação, L. M. 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 1997) ACM Press, pp. 187-194

[9] Ferber, J. Multi–Agent Systems. An Introduction to Distributed Artificial Intelligence. Addison-Wesley, Harlow, U.K. 1999.

[10] Francisco-Revilla L. User & Situation Models for Medical Information Delivery. Masters Thesis. Dept. of Computer Science. Texas A&M University, College Station, TX, USA, 1998.

[11] Francisco-Revilla L., and Shipman, F.M. Adaptive Medical Information Delivery: Combining User, Task and Situation Models, in Proceeding of IUI 2000 (New Orleans, USA, Jan 9-12, 2000) ACM Press, pp. 94-97.

[12] Francisco-Revilla L., and Shipman, F.M. Adaptive Medical Information Delivery: Combining User, Task and Situation Models, in SIGWEB Newsletter 8, 1 (February 1999) ACM Press, pp. 18-20.

[13] Golovchinsky, G. Bridging paradigms: Spatial hypertext in the document world. In the First Workshop on Spatial Hypertext (Århus, Denmark, August 14, 2001). http://www.well.com/user/jer/SH1/papers.html

[14] Grønbæck, K, Vestergaard, P., P., and Ørbæck, P. Towards Geo-Spatial hypermedia: Concepts and Prototype Implementation. In Proceedings of the 13th ACM Conference on Hypertext and Hypermedia (Maryland, USA, June 11-15, 2002) ACM Press, pp. 117-126.

[15] Hsieh, H. and Shipman, F., 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, pp. 141-148.

[16] HotSauce: http://www.xspace.net/hotsauce/

[17] Kolb, D. Aristotelian Spatial Hypertext. In the Second Workshop on Spatial Hypertext (College Park, Maryland, USA, June 12, 2002). http://www.well.com/user/jer/SH1/papers.html.

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

[19] Manccini, C., and Shum, S. B. 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, 2001) ACM Press, pp. 165-174.

[20] Marshall C.C. and Rogers R.A. Two Years before the Mist: Experiences with Aquanet, In Proceedings for the Fourth ACM Conference on Hypertext (Milano, Italy, November 30-December 4, 1992) ACM Press, pp. 53-62.

[21] Marshall C.C., and Shipman, F. M. III. Searching for the Missing Link: Discovering Implicit Structure in Spatial Hypertext. In Proceedings of 5th ACM Conference on Hypertext (Seattle, Washington, USA, November 14-18, 1993) ACM Press, pp. 217-230.

[22] Marshall C.C., Halasz, F.G., Rogers, R.A., and Janssen W. C. Jr. Aquanet: A Hypertext Tool to Hold Your Knowledge in Place. In proceedings of the Third ACM Conference on Hypertext (San Antonio, Texas, USA, December 15-18, 1991) ACM Press, pp. 261-275.

[23] Marshall C.C., Shipman, F. M., and Coombs, J. H. VIKI: Spatial Hypertext Supporting Emergent Structure. In Proceedings of the 6th ACM European Conference on Hypermedia Technology (Edinburgh, Scotland, September 18-23, 1994) ACM Press, pp. 13-23.

[24] Nakakoji, K. and Yamamoto, Y. Spatial Positioning as a Representation that Helps us Think. In the First Workshop on Spatial Hypertext (Århus, Denmark, August 14, 2001). http://www.well.com/user/jer/SH1/papers.html.

[25] Nielsen M. B. and Ørbæk, P. Spatial Parsing within the Topos 3D Environment. In the First Workshop on Spatial Hypertext (Århus, Denmark, August 14, 2001). http://www.well.com/user/jer/SH1/papers.html.

[26] Rosenberg, J. 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, 2001) ACM Press, pp. 51-60.

[27] Sandholm, T. W. Distributed Rational Decision Making. In Weiss, G. Multi-Agent Systems. Pp. 201-258. MIT Press, Cambridge, MA, 1999.

[28] Shipman, F. M., Marshall, C. C., and LeMere, M. Beyond Location: Hypertext Workspaces and Non-Linear Views. In Proceedings of the 10th ACM Conference on Hypertext and Hypermedia (Darmstadt, Germany, February 21-25, 1999) ACM Press, pp. 121-130.

[29] Shipman, F. M., Marshall, C. C., and Moran, T. P. Finding and Using Implicit Structure in Human Organized Spatial Layouts of Information. In Proceedings of CHI'95 (Denver, Colorado, USA, May 7-11, 1995) ACM Press, pp. 346-353.

[30] Shipman, F. M., and McCall, R. Supporting Knowledge-Base Evolution with Incremental Formalization. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: Celebrating independence (Boston, Massachussetts, USA, April 24-28, 1994) ACM Press, pp. 285-291.

[31] Shipman, F., Hsieh, H., and Airhart, R., Maloor, P., and Moore, J.M. 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, 2001) ACM Press, pp. 113-122.

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

[33] Stephanidis, C., Karagiannidis, C., and Koumpis, A. Decision Making in Intelligent User Interfaces. In Proceedings of Intelligent User Interfaces '97 (Orlando, Florida - January 6-9 1997) ACM Press, pp. 195-202

[34] Suchman, L. A. Plans and Situated Actions. Cambridge University Press, New York, USA, 1987.

[35] Sycara, K. Multiagent Compromise via Negotiation. In Gasser, L. and Huhns, M. Distributed Artificial intelligence. Pitman, 1989.

[36] TaskGallery: http://research.microsoft.com/adapt/TaskGallery/

[37] Trigg R.H., and Weiser, M. TEXTNET: A Networking-Based Approach to Text Handling. In ACM Transactions on Office Information Systems, 4(1) (January 1986), ACM Press, pp. 1-23.

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

[39] Web Squirrel: http://www.eastgate.com/squirrel/FAQ.html.