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Interaction design for scholarly writing: Hypertext representations as a means for creative knowledge work

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This paper presents our approach of using hypertext representations to support a scholar in the early stages of a scholarly writing process. We take D. A. Schoen's model of design as a theoretical framework. Schoen views design as a reflective conversation with the materials of a situation, where the designer interacts with the materials, such as pen and sketch on a sheet of paper, in the reflection-in-action process. The designer acts and reflects almost simultaneously; acting on external representations, interpreting emerging representations, and reacting to them. We argue that a scholar needs to engage in two different types of representations in the reflection-in-action process: external representations for thinking about the problem, and representations for expressing a solution in a publishable form. The former does not necessarily precede the latter; rather, the two representations coevolve through the reflection-in-action process. Our approach uses hypertext representations as a means to interact with in the early stages of scholarly writing both for thinking about the problem and for expressing a solution. Hypertext representations have long been studied in their relation to supporting human intellectual work; our approach, however, is unique in providing the two representations with a specific concern for supporting reflection-in-action by applying the concept called ART (Amplifying Representational Talkback) as an interaction design principle. Based on this framework, we have developed ART014, a tool for scholarly writing. ART014 simultaneously supports two types of hypertext representations: a column-based network hypertext representation and a spatial hypertext representation. The two representations are located side by side, and integrated when an interaction with one representation is reflected in the visual presentation of the other. Although a user operates on the same set of objects through the two representations, the user expresses relationships among the objects independently in the two representations. We present a scenario to illustrate in detail how the design concepts underpinning ART014 supports scholarly writing. This paper then discusses our approach from three viewpoints by using the scenario: use of the two representations, engagement in reflection-in-action, and modes of authoring. The paper concludes with a description of future directions.

1. Introduction

This paper presents a theoretical framework and a tool based on that framework to support the early stages of scholarly writing using hypertext

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representations. The type of scholarly writing our tool supports consists of the following intertwining processes: (1) collecting pieces of text and data from source documents according to the theme that the scholar chooses, such as previously written papers, notes, e-mail communications with peers, or papers published by others; (2) understanding them by posing questions, making hypotheses, estimating values, and expressing opinions on what the collected pieces are and how they are related to one another; (3) revising and/or adding new statements as the understanding emerges; (4) constructing a coherent story incorporating these statements; and (5) producing a structure using those pieces toward a publishable form (possibly leaving some of them for future reflections or for other themes). A good example of a user would be a student writing a doctoral dissertation: the student would gather what he/she has written during the study as well as quotations from other papers, and identify what should be included in the dissertation and the structure of the dissertation.

Scholarly hypertexts have recently been studied as a way to represent scholarly arguments and inquiry, such as asking questions, making assertions, and presenting argumentation (Kolb 1997). Scholarly hypertexts enable "new modes of reflection, new ways of organizing inquiry, and new intellectual objects" (Kolb 1997, p. 31); they differ from information hypertext or narrative hypertext (Kolb 1997).

The interesting aspect of scholarly writing is where scholars are not only engaged in scholarly inquiry and argumentation but are also producing a representation; it involves not only the aspect of knowledge structuring and argumentation but also that of a design task.

Questions a scholar would ask during a scholarly writing process in the beginning include:

- Which concept is implied by this concept?
- Which concept cannot be implied by this?
- How are those two claims related to each other?
- Should I treat these claims as independent factors?
- What argument would I need to develop in order to draw this conclusion from the theory?
- Which story would make a better sense for readers?
- What supporting arguments would we need to argue for this perspective?

Our approach to support such a process is to take D. A. Schoen's model of design as a theoretical framework to guide us in the interaction design of a tool for scholarly writing. This paper uses the term "interaction design" to mean determining "the representations and operations of an application system by considering what representations the user needs to interact with, through what operations" (Yamamoto and Nakakoji in press).

Schoen views design as a reflective conversation with the materials of a situation (Schoen 1983), where the designer interacts with the materials, such as pen and sketch on a sheet of paper, in the reflection-*in*-action process being distinguished from reflection-*on*-action (Schoen 1983, p. 278). Reflection-*in*-

action denotes the reflective processes that take place while drawing or externalizing representations. The emerging and changing shape "talks back" to a designer, who simultaneously talks back to the material by changing representations, such as adding a circle or thickening a line. Reflection-*on*-action, in contrast, is the reflective process that happens when a designer sees a resulting representation. The distinction between the two notions is not very definitive but worthy of some attention. User interfaces of traditional systems presuppose command-based, turn-taking-style interactions, which support only reflection-on-action. The interaction design of a system, however, has as a central concern realizing reflection-in-action.

This paper argues that a scholar needs to be able to interact with two different types of representations when engaged in the reflection-in-action process: external representations for thinking about the problem, and representations for expressing a solution in a publishable form. The former does not necessarily precede the latter; rather, the two representations coevolve through the reflection-in-action process.

Our approach uses separate hypertext representations as means for a scholar to interact with in the early stages of scholarly writing: one for thinking about the problem, and one for expressing a solution. Hypertext representations have long been studied to support human intellectual work; our approach is unique, however, in providing the two representations with a specific concern for supporting reflection-in-action by applying the concept called Amplifying Representational Talkback (ART) as an interaction design principle (Nakakoji *et al.* 1998, Nakakoji and Yamamoto 2001). Representational talkback is defined as "perceptual feedback to a user from the externalized representation" (Nakakoji *et al.* 1998).

Based on this framework, we have developed ART014, a tool for scholarly writing designed around the ART design principle. ART014 simultaneously supports two types of hypertext representations: a column-based network hypertext representation and a spatial hypertext representation. The two representations are located adjacent to each other, and integrated when an interaction with one representation is dynamically reflected in the visual presentation of the other. The spatial hypertext representation allows a user to interact with emerging relationships among objects freely positioned in a two-dimensional (2D) space relieving the user from making unnecessary formalizations (Marshall and Shipman 1995). The column-based network hypertext representation allows a user to explicitly specify which object should or should not have an inbound or outbound link to each node. Although the user operates on the same set of objects through the two representations, relationships among the objects are expressed independently in the two representations. Such interactions help scholars to engage in the reflection-in-action process.

We present a scenario to demonstrate in detail how the design concept underpinning ART014 supports scholarly writing. Using materials of writing from an actual paper-writing project, the scenario is intended to illustrate how the tight visual integration of the two representations of ART014 helps a

scholar to engage in the reflection-in-action process. We then use the scenario in discussing our approach from the following three aspects: use of the two representations, engagement in reflection-in-action, and modes of authoring.

In what follows, Section 2 presents a theoretical framework for the approach. We describe how we model scholarly writing by viewing it as a design task, and examine existing hypertext approaches and concepts in the light of the framework. Section 3 gives an overview of ART014 followed by a description of the scenario. The paper discusses our approach and concludes with future directions.

2. Theoretical framework

In scholarly writing, we use a variety of externalizations: producing a number of notes, retrieving previously written passages, or referring to related articles at hand, even when they may not be used in our writing (figure 1). Looking at intermediate stages of writing, comments about the writing, or texts potentially relevant to the current writing task helps a scholar not only reduce the cognitive load of remembering, but, more importantly, also allows the scholar to "have a conversation with the material" (Schoen 1983). Many of those representations are produced not necessarily for the sake of being used as a part of a final document; rather, they are produced for reflection. Externalization "relieves us in some measure from the always difficult task of thinking about our own thoughts" (Bruner 1996, p. 23).

The goal of our research is to design and develop application systems to serve as such media for externalization for scholars. Our approach takes the

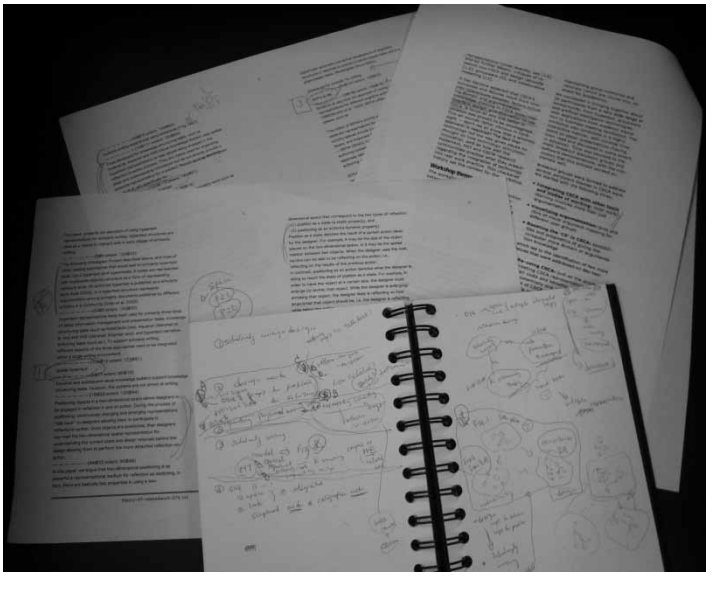


Figure 1. Varieties of externalizations used in the early stages of scholarly writing.

notion of cognitive load as a central concern (Yamamoto and Nakakoji in press). Creative knowledge work, including scholarly writing, is a cognitively intensive human activity, and yet cognitive resources have limitations. Scholars need tools to generate representations and interact with them, but using tools consumes some of the cognitive resources, which then becomes a cognitive overhead. The more cognitive resources demanded by the tools, the fewer cognitive resources designers can spend on their own creative thinking (Streitz *et al.* 1989). Our approach toward the design of computer tools for supporting scholarly writing as a design task is to decrease the cognitive overhead in using tools so that scholars "can spend more cognitive resources for their creative thinking, such as listening to the situation talking back and projecting a design context" (Yamamoto and Nakakoji in press).

2.1 Scholarly writing as design

While drawing a sketch, an architectural designer keeps making hypotheses and verifying them, gradually uncovering design ideas through a trial-and-error process (Lawson 1994, 1997). For instance, while drawing sketches when designing a floor plan, an architectural designer may keep asking him/herself questions such as "What if I put a refrigerator here?", "What interaction would happen with the door?", or "How does the sunlight come in?" while repeatedly drawing lines and circles on the sketches.

Similar to this process—especially in the early stages of scholarly writing—a scholar is engaged in a cycle of producing representations and reflecting on them (Schoen 1983). The externalized representations serve as "situations" that talk back to the designer. During the process, the designer has a conversation with the material, asking questions such as those listed in the previous section, making assertions, projecting the meaning onto the externalization, and revising the meaning by having a better understanding of the situation. Snodgrass and Coyne view the process as a hermeneutic circle, where projection, anticipation, and expectation of the meaning play crucial roles (Snodgrass and Coyne 1997):

> This preliminary projection is continually revised as the reader or listener penetrates deeper into the meaning of the parts. The projection, at first unclear and only existing in outline, plays back into the interpretations of the parts, requiring their revision even as the projected meaning itself is continually revised in the light of the interpretation and increasing understanding of the parts. By this process of to-and-fro reflection the understanding of the whole gradually emerges. (Snodgrass and Coyne 1997, p. 76).

In designing representations for the early stages of scholarly writing, we have identified a need for two separate representations: those serving problems, and those serving solutions.

As illustrated in figure 2, a scholar works on a large number of external representations, by collecting pieces of text and data relevant to the current theme from previously written papers, notes, e-mail communications with peers, or papers published by others, and by producing a number of notes,

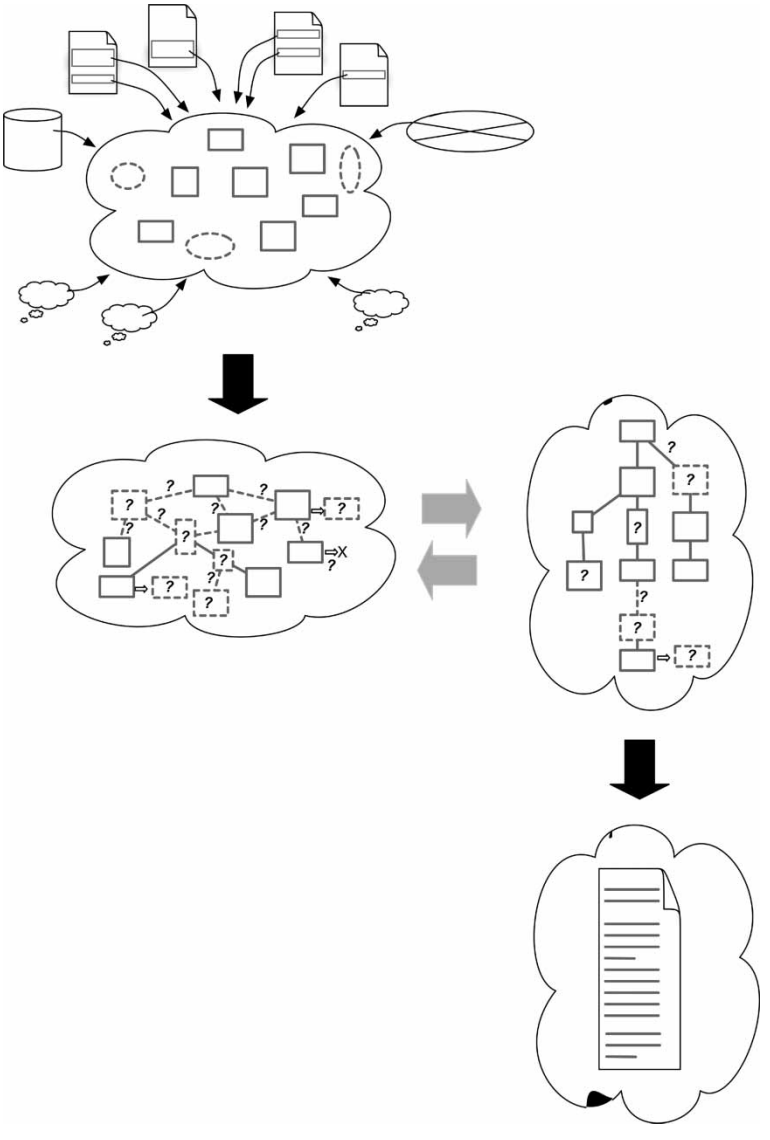


Figure 2. Model for scholarly writing.

doodles, sketches, and annotations for the collected and produced externalizations. A scholar interacts with the externalized representations to understand how concepts are related to each other, which evidence supports his/her claims, and what arguments would strengthen his/her claims, all part of knowledge structuring tasks (Marshall *et al.* 1991).

At the same time, the end product of scholarly writing cannot be of any arbitrary form. As a member of a scholarly community, a scholar needs to produce written forms in a structure that is communicable with peers in the

community. To publish a scholarly work means to produce a knowledge product conforming with a certain form so that other members of the community can easily compare, debate, and argue about it with existing knowledge products represented in the same form. For instance, traditional linearly written scientific papers often have a structure consisting of introduction, approach, hypotheses, experiments, results, and discussions, followed by conclusion. Thus, one could easily compare the conclusions of two scientific papers by looking at the final section of each paper.

As figure 2 implies, although the problem representation is not transformed into the solution representation, the structure of the resulting form depends on understanding the problem space. Issues and aspects to be explored are identified as the writing task proceeds. Different ways of writing might be possible for the same problem space. Scholars need to have both types of representations to be better engaged in the reflection-in-action process.

As described in the previous section, Schoen distinguishes the notion of reflection-*in*-action and reflection-*on*-action, and argues for the importance of the former. A tool for scholarly writing providing two representations for the problem and the solution needs to allow a user to reflect while interacting with the representations. In pursuing this, we have studied the concept called Amplifying Representational Talkback (Nakakoji *et al.* 1998, Nakakoji and Yamamoto 2001). The ART design principle uses perceptual visual feedback as a primary method of supporting users. Perceptual external representations "provide information that can be directly perceived and used without being interpreted and formulated explicitly" (Zhang 1997). External pictures can give people access to knowledge and skills that are unavailable from internal representations (Reisberg 1987).

Our approach is to use hypertext representations and apply visual interaction design based on the ART design principle to develop a tool for scholarly writing. The following subsection examines existing studies on different kinds of hypertext representations in the light of the framework outlined above.

2.2 Existing hypertext approaches and concepts for scholarly writing

This subsection discusses existing approaches in (1) spatial hypertext representations, (2) hypertext argumentation, (3) hypertext tools for writing, and (4) literary hypertexts and sculptural hypertexts, in terms of our theoretical framework.

2.2.1. Spatial hypertext representations. Tools developed for knowledge structuring and information triaging tasks, such as Aquanet (Marshall *et al.* 1991) and VKB (Visual Knowledge Builder) (Marshall and Shipman 1995, Shipman *et al.* 2002), use spatial layouts, or spatial hypertext representations. The representations have also been explored in literary hypertext (Rosenberg 2001, Tinderbox). Spatial hypertext representations help users gradually define and fix relationships among objects by using emerging structures (Marshall and

Shipman 1995, Rosenberg 2001). The spatial hypertext technique allows a user to incrementally generate, organize, and structure elements and their relationships (Marshall and Shipman 1995).

Positioning objects in a two-dimensional space allows designers to be engaged in both the reflection-in-action and reflection-on-action processes by viewing *positioning* as an action (a static property), and *positions* as a state (a dynamic property) (Nakakoji *et al.* 2000). During the process of positioning objects through direct manipulation, continuously changing and emerging representations "talk back" to designers, allowing them to participate in reflection-in-action. Once objects are positioned, designers can then read the two-dimensional spatial representation for understanding the current state allowing them to perform the more detached reflection-on-action.

Thus, sketches and spatial hypertext seem to be equally powerful as a representational means for reflection for early stages of design (Yamamoto *et al.* 2000). We have developed the three design principles for tools to serve as externalization media for the early stages of information design (Yamamoto and Nakakoji in press). They are: (1) interpretation-rich representations, (2) representations with constant grounding, and (3) interaction methods for hands-on generation and manipulation of the representations. Representations for the early stages of design should not narrow a possible design space but rather help people discover new aspects of the situation and explore them through interacting with the representation. At the same time, such representations need to be easily mapped to a projected meaning by providing a method of constant grounding. Finally, such representations should not demand additional cognitive load; people need to feel as if they interact with the representations rather than with the computer system. As with hand-drawing sketches, spatial positioning of objects as a representation conforms to these three principles (Yamamoto and Nakakoji in press).

In further supporting a user's reflection process by listening to a "back-talk" of a situation, VKB offers spatial parsers and suggestion managers to help people formalize "knowledge" underpinned in spatial representations (Shipman *et al.* 2002). Because they are geared toward organizing ideas and understanding information, those tools do not directly provide a separate representation for a solution. In fact, people used external word-processing tools to write the final document when using NoteCards, a predecessor of VKB and Aquanet (Trigg and Irish 1987). While people may use a different "space" for expressing a solution, such a representation would not necessarily be integrated with representations in other spaces.

Our recent project (reported in Yamamoto *et al.* 2002) uses spatial hypertext representation as a means to produce a linear structure. With ART001, a user first generates an element (i.e. a chunk of text) and then specifies where to put it in the currently composed linear information by spatially positioning the element in a two-dimensional space, where positioned parts are serialized in order from top to bottom. Additionally, ART001 uses a space to provide a way to view the entirety, giving a global view of the space of information chunks being constructed.

Although the space of ART001 can be viewed as a representation for the problem and its serialized text view as that for the solution, the space is used more for manipulating objects composing a linear document (Nakakoji *et al.* 2000, Yamamoto *et al.* 2002).

2.2.2. Hypertext argumentation. Hypertext representations have long been explored to represent argumentation as "something of an experimental white rat" (Buckingham Shum 2000, p. 27), motivated by the visions of Bush and Engelbart on the technological support for complex knowledge work.

While this paper focuses on the approaches that use hypertext representations as a means for reflection-in-action in producing scholarly writing, many existing hypertext argumentation approaches (Buckingham Shum and Hammond 1994) have evolved to use a hypertext (and hypermedia, if nodes are represented with multimedia objects) representation as a form for representing scholarly work. Kolb, for instance, has recently reported his experience of publishing his scholarly work in the form of a hypertext representation in comparison with a more traditional linear text representation (Kolb 2004).

The Scholarly Ontologies Project is investigating the representational and interaction design challenges of a tool for publishing and debating research claims among scholars in a research community (Buckingham Shum *et al.* 2003, Buckingham Shum *et al.* in press). The approach has focused on the development of the ontology of discipline-independent relationships among scholarly concepts, such as *proves*, *refutes*, or *isEvidenceFor*, "to represent the rhetorical moves researchers make when they present their arguments" (Uren *et al.* 2003). A suite of annotation and analysis tools have been developed by using such typed directed links among scholarly articles and short texts representing concepts, including ClaiMapper, to construct a ClaiMaker argumentation space, ClaimFinder to generate interactive visualizations of argument structures in response to queries in column-based views and in graph-based views, and ClaimSpotter to visually suggest concepts and identify potentially relevant areas in the source text (Buckingham Shum *et al.* in press, Sereno *et al.* 2005).

The ClaiMaker approach helps users in the reflection-in-action process from the semantic point of view by analysing available documents and scholars' data at the hand. Our approach, in contrast, is geared toward individual scholarly writing, with more emphasis on perceptual feedback generated, while a scholar interacts with representations. We view our approach to be complementary to those existing hypertext argumentation approaches rather than replacing them.

2.2.3. Hypertext tools for writing in early days. Having different representations in support of writing has long been explored, especially around the late 1980s and early 1990s by systems such as WE (Writing Environment) (Smith *et al.* 1987) and SEPIA (Structured Elicitation and Processing of Ideas and for Authoring) (Streitz *et al.* 1989).

The WE system provides multiple representations according to a cognitive process of writing a linear text, in which objects to write are transformed among spatial, network, and linear representations.

SEPIA provides spaces for different representations, called activity spaces, which include Content Space, Rhetoric Space, Planning Space, and Argument Space (Streitz *et al.* 1989). The activity spaces are tailored to support the cognitive processes of authoring (Thuering *et al.* 1991).

Both approaches assume that different representations are necessary to support different cognitive activities. In this regard, they assume that objects are transformed from one representation to another. In support of a user's reflection in this framework, SEPIA provides automatic transferring design objects between specified spaces and indication and control of references between activity spaces (Streitz *et al.* 1993).

In contrast, we argued in the previous section that two representations are necessary for a scholar engaged in the reflection-in-action process as a whole. These two representations are not for transforming objects between them but for informing each other. How they are related to each other is at the hand of a creative mind, and beyond the machine's understanding (Winograd and Flores 1986). As a result, our approach does not focus on machine-processable semantics but instead focuses on providing tighter representational coupling between the separate representations.

2.2.4. Literary hypertexts and sculptural hypertexts. Literary hypertexts aim to "offer adventuresome models of encounter and ongoing textual redefinition" (Kolb 1997). Whereas our goal is to support scholarly writers engaged in the reflection-in-action process, the goal of literary hypertexts can be stated as to support *readers* engaged in reflection-in-action. Many literary hypertext tools are concerned with emerging meaning through a reading experience, and explored concepts such as contours (Bernstein *et al.* 1992), regions (Kolb 1997), and episodes (Rosenberg 1996).

Our approach could be viewed as a way to provide tools for a writer-as-reader activity. Rosenberg argues that readers of narrative hypertexts create their own hypertext reading experience as an episode (Rosenberg 1996). With scholarly writing viewed as a design task, a writer constantly needs to read his/her partially written documents, listening to the situation's backtalk (Schoen 1983). Their interaction design concerns overlap with our approach, such as how to design visual feedback and annotation using adornments.

Sculptural hypertext was originally introduced as "exotic tools for hypertext narratives" (Bernstein 2001). Sculptural hypertext refers to a type of hypertext by which one "creates a structure by removing unwanted connections, much as a sculptor may create objects by removing unwanted material" (Bernstein 2001).

Although this notion was concerned with dynamically adding or removing links when reading (Bernstein *et al.* 2002), it motivated us to ask an interesting question in support of scholarly writing. A conventional authoring tool asks the user to specify a relation to connect two nodes. This leaves

ambiguties as to whether other connections are not made because there is no relation, or whether they are simply not yet specified. What if we reverse the default situation, so that the user now faces the opposite question: is this link important to preserve? We propose that there are situations, especially in complex intellectual tasks, when this way of looking at the problem and solution spaces might better serve the scholar's reflection.

3. ART014: A hypertext tool for scholarly writing

This section describes ART014, a tool we have developed as an instantiation of the theoretical framework described above. ART014 simultaneously supports two types of hypertext representations: a column-based network hypertext representation and a spatial hypertext representation. The two representations are located side by side, and integrated when an interaction with one representation is reflected in the visual presentation of the other. Although a user operates on the same set of objects through the two representations, the user expresses relationships among the objects independently in the two representations.

3.1 Overview

ART014 is designed to support a user in creating, modifying, or removing elements (i.e. nodes) and their directed links (inbound and outbound). Each element consists of (1) a title, (2) a text content, (3) a list of inbound links, and (4) a list of outbound links. Currently, the system can deal only with textual content for each element.

The ART014 system (figure 3) consists of two parts: ElementSpace and StructureColumn. ElementSpace, located in the upper half of the system, is a two-dimensional space for hypertext where a user can freely position elements. StructureColumn, located in the lower half of the system, consists of three columns: ElementEditor in the centre, the InboundLinkList on the left, and the OutboundLinkList on the right.

Each element in ElementSpace is represented as a box with its title as the label, which is created through ElementEditor. A user drags an element in ElementSpace and moves its position through direct manipulation. All elements are always visible in ElementSpace; to keep dragging an element toward an edge of the space expands the space by zooming out. Straight lines connecting boxes are links, which are specified through StructureColumn. Each element box has two triangles on each side. Straight lines representing inbound (outbound) links of an element have their heads (tails) attached to the triangle on the left (right) side of the box. As a user drags an element in ElementSpace, straight lines representing links follow in a real-time manner.

By clicking on an element in ElementSpace, a user focuses on the element. A focused element is shown with a dark background with white type in ElementSpace. Links going into or going out from the focused element become emphasized in black (the rest of the links remain grey).

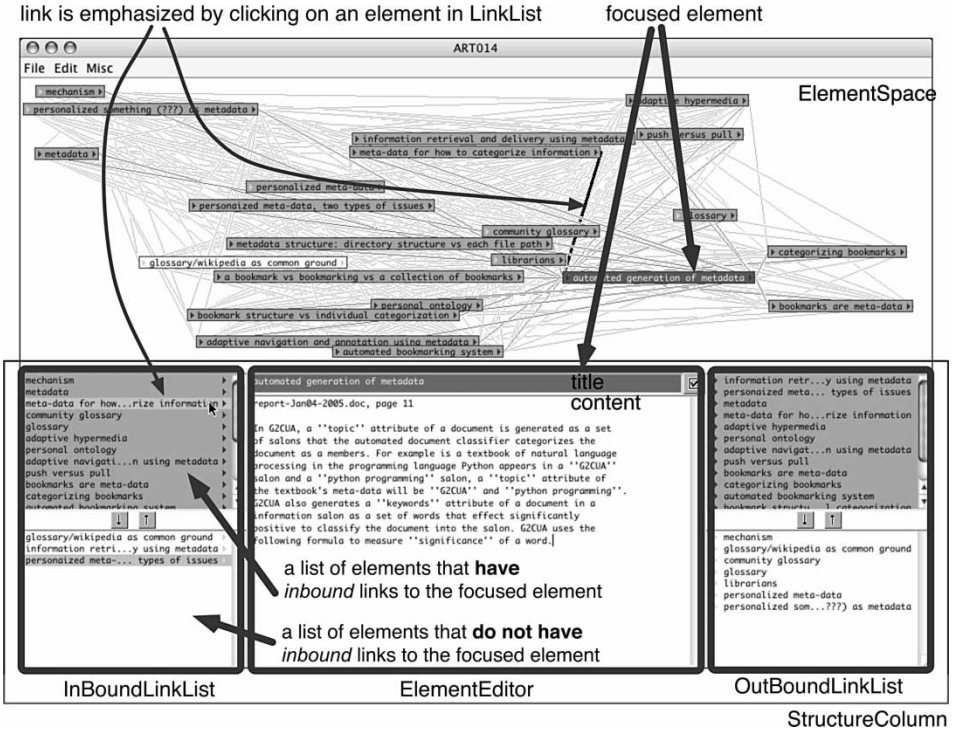


Figure 3. ART014 system.

When focused, the element is presented in the central column of StructureColumn, called ElementEditor, with which a user can create or modify its title (a small pane on the top) and its content (the larger pane in the bottom).

Each of the left (InboundLinkList) and right (OutboundLinkList) columns allows a user to create or remove links of the focused element. The left (right) column consists of two panes. The upper pane shows a list of titles of elements with which the focused link has inbound (outbound) links. The lower pane shows a list of titles of elements with which the focused link has no inbound (outbound) links. The upper and lower panes together always list all the other existing elements in each of the two columns.

The user can specify to which elements the focused element has inbound (outbound) links by moving elements between the two panes; by selecting an element from one pane and pushing the upward or downward arrow located between the two panes. Selecting an element in InboundLinkList or OutboundLinkList highlights the corresponding element in ElementSpace (see figure 3). A user may shift the focus by clicking on an arrowhead attached to the selected element in InboundLinkList or OutboundLinkList.

Basic authoring activities using ART014 include creating a new element or focusing on an element and editing the element's title, content and/or links. When creating a new element, a user clicks on an empty space in Element-

Space. Then, the system releases the focus, making ElementEditor blank, and is ready for the user to create a new element. When this happens, all existing elements are listed in the upper panes of InboundLinkList and OutboundLinkList, ready to be designated as links. Thus, by default, a new element is set to have inbound and outbound links to all the other existing elements. When pressing the check-box (located to the right of the title pane), a new element appears in ElementSpace with lines connected to all the other elements created in what we call a *sculptural* mode, which as explained is a term adapted from the notion of sculptural hypertext (Bernstein 2001). In contrast, if the user presses the shift key and the check-box simultaneously, all the links are taken away, and elements listed in the upper panes all move to the lower panes. A newly created element is now not connected to any other elements created in what we call a *calligraphic* mode; the term was also adapted from the notion by (Bernstein 2001). A user can thus switch between the sculptural and calligraphic modes by simply holding or releasing the shift key when pressing the check-box.

Once created, any element can be selected as a focused element and brought into StructureColumn by clicking on an element in ElementSpace or by clicking on the arrowhead of a selected element in the link lists. Thus, dragging an element in ElementSpace always focuses on the element. A user may add or remove any inbound and outbound links of the focused element by transferring elements between the upper pane and lower pane by using the upward or downward arrow.

3.2 Scenario of scholarly writing using ART014

The intent of the scenario presented in this subsection is to demonstrate how the design concepts underpinning ART014 support scholarly writing, rather than to argue specifically for the validity or usability of the current version of the system.

Joe is writing a conference paper based on his dissertation project.[1] He has written five documents, which he handed in to his advisor as progress reports over the last 3 years. All of the five documents are about the system he has developed as a part of his dissertation work, but each document focuses on a different aspect of the system. Joe has used differing terms and expressions to describe certain aspects of the system in each of the documents.

Prior to the writing task, Joe had a vague goal for this conference paper. He wanted his paper to focus on the technical aspect. He is aware that he needs to construct sound arguments for why the system is important in a particular context.

[1] The writing material we use in the scenario was collected from one of our previous paper writing projects, which did not use any computational media in its early phases. The project identified key concepts/mechanisms from five previously written documents and put each of them on a post-it like card. The members of the project then spatially arranged the cards on a table in collaboration while exploring the theme of the paper.

As a user of ART014, Joe went back to each of the five documents and identified key concepts and/or mechanisms within the document. He then extracted text from the original document that he thought best illustrated each of those key concepts/mechanisms.

Joe's task using ART014 has proceeded roughly in three phases. Figure 4 illustrates snapshots of each of the three phases. Note that those elements that have either inbound or outbound links to the focused element are displayed with a grey background in ElementSpace; the other elements are displayed with a white background.

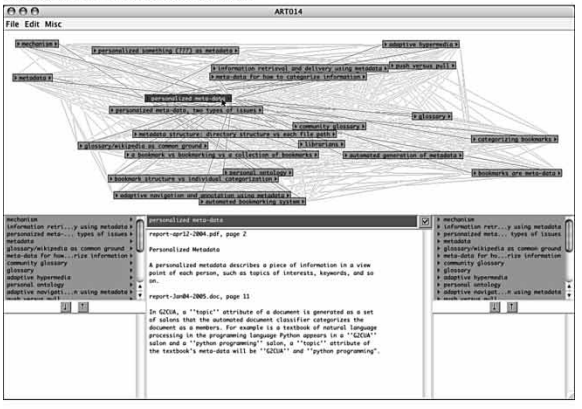
In the first phase, Joe created elements for the concepts/mechanisms extracted from the existing documents by using the sculptural mode; thus, every element was initially linked with every other element. Joe placed each element in ElementSpace close to those with similar keywords, but not very carefully (e.g. when he was not sure where to put it, he just put it where more room was available). He randomly visited an element by clicking on ElementSpace and gradually removed some links during the process. His main concern in this phase was which elements were related and not related to other ones. In the second phase, new elements were gradually added as Joe moved elements around. Such newly added elements were created by using the calligraphic mode. Joe gradually added links to and from the newly added elements during the process. His main concern in the second phase was to design a coherent story among the elements. In the third phase, Joe stopped creating new elements and started spatially clustering elements in Element-Space based on his emerging understanding of what the structure of the paper should be (e.g. a cluster of elements belonging to the Introduction section). He decided on the central theme for this conference paper. Joe further edited links in terms of the central theme element. His main concern in this last phase was to make sure that each section was related to the central theme.

3.2.1. Phase 1. Joe creates elements for the identified key concepts/mechanisms in ART014. He copies and pastes extracted associated texts from the original documents as the content of each element. ART014 now shows each key concept/mechanism represented as an element title placed in the Element-Space. Joe uses the space to put similar elements (i.e. concepts/mechanisms) closer to each other, but Joe is not yet particularly sure about how to categorize or structure those elements.

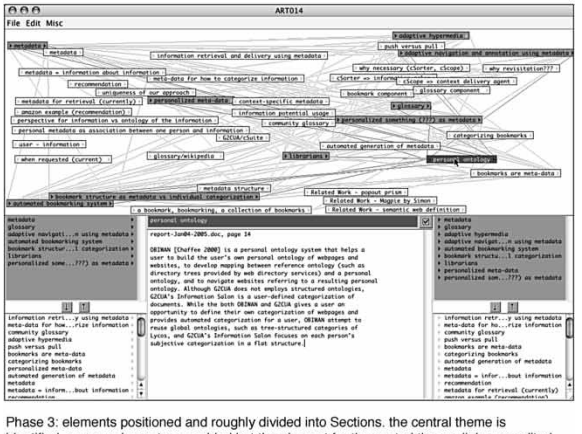
Now, Joe starts focusing on an element by clicking on an element box displayed in ElementSpace. Figure 5 shows a screen image of when Joe focuses on the "glossary" element in Phase 1. Note that the element initially has in- and outbound links with all the other elements because the element was created with the sculptural mode; that is, all the other elements are listed in the upper panes of the InBoundLinkList and OutBoundLinkList.

Joe scans the list of elements in the upper pane, trying to decide which elements should not have links to the focused element. Having looked around several elements in both InBoundLinkList and OutBoundLikList, Joe has decided to use inbound links to represent "necessary" concepts and

Phase 1: elements extracted from existing documents. elements placed in ElementSpace close to those with similar keywords. elements created with the sculptural mode, and links gradually removed in the process. Joe's main concern in this phase is which elements are related and not related to which ones.



Phase 2: new elements added as moving elements around in ElementSpace while several aspects emerged. elements created with the calligraphic mode, and links gradually added in the process. Joe's main concern in this phase is to design a coherent story among the elements.



Phase 3: elements positioned and roughly divided into Sections. the central theme is identified. no new elements are added but the element for the central theme. links are edited in terms of the central theme element. Joe's main concern in this phase is to make sure how each sectionized elements are related to the central theme.

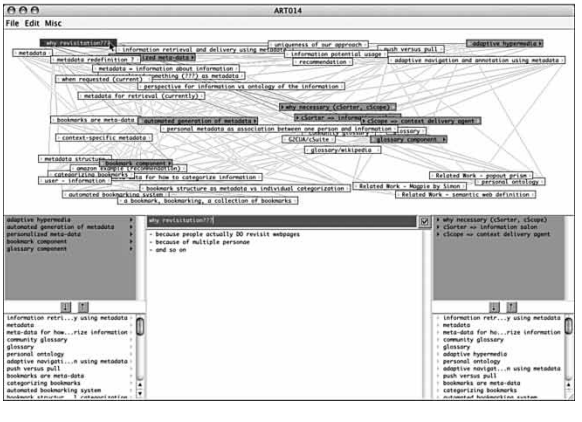


Figure 4. Three scholarly writing phases in the scenario.

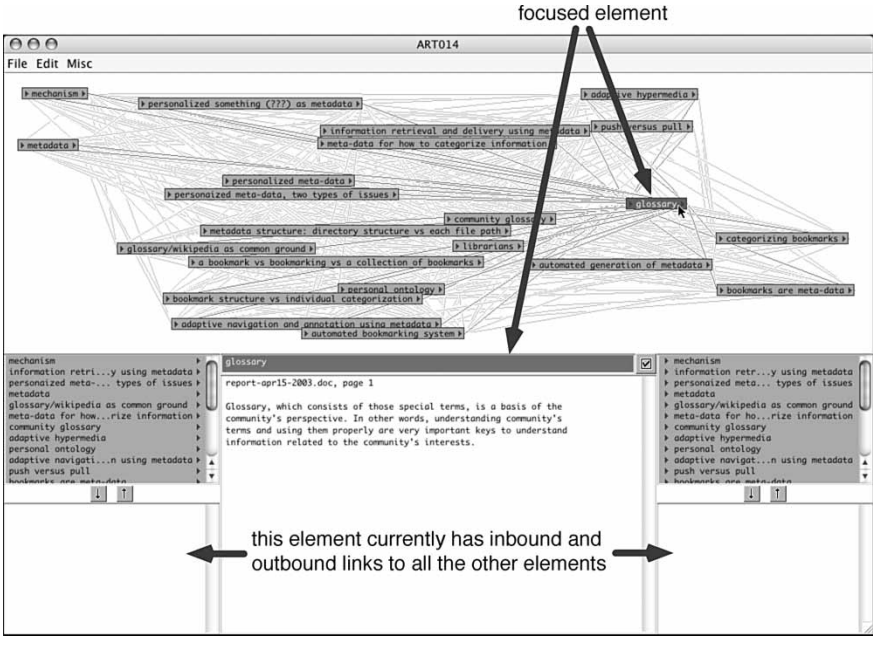


Figure 5. Screen shot in Phase1.

mechanisms for the focused concept/mechanism and outbound links for listing concepts/mechanisms that are "enabled by" the focused one. Once Joe has decided on this scheme, his link editing activity has become smoother.

Figure 6 shows the situation when Joe focuses on the "personalized metadata" element, and considers how the "automated bookmarking system" element is related to the focused element. The link between the two elements is visually emphasized with a thick bold line in ElementSpace when Joe clicks on the automated bookmarking system element in Out-BoundLinkList (figure 6; top). Joe thinks that the automated bookmarking system is not necessarily enabled by personalized metadata, so he decides to remove the link by clicking on the downward button (figure 6; middle). Now, the automated bookmarking system element is moved to the lower pane, and the link has changed from a thick bold line to a thinner dotted line, indicating that there is no link from this element to the focused element (figure 6; bottom).

When Joe asks to which elements the focused element does not have inbound/outbound links, he clicks on each element one by one from top to bottom in In/OutBoundLinkList at a relatively quick pace. Figure 7 illustrates the situation when Joe focuses on the "automated generation of metadata" element. As he clicks on each element one by one in InBoundLinkList, a link from the element is visually emphasized in ElementSpace with a thick bold line. Because those currently linked elements are placed in different positions in ElementSpace, this creates a flipping visual effect in which the bold line is displayed heading here and there from the currently focused element (figure 7).

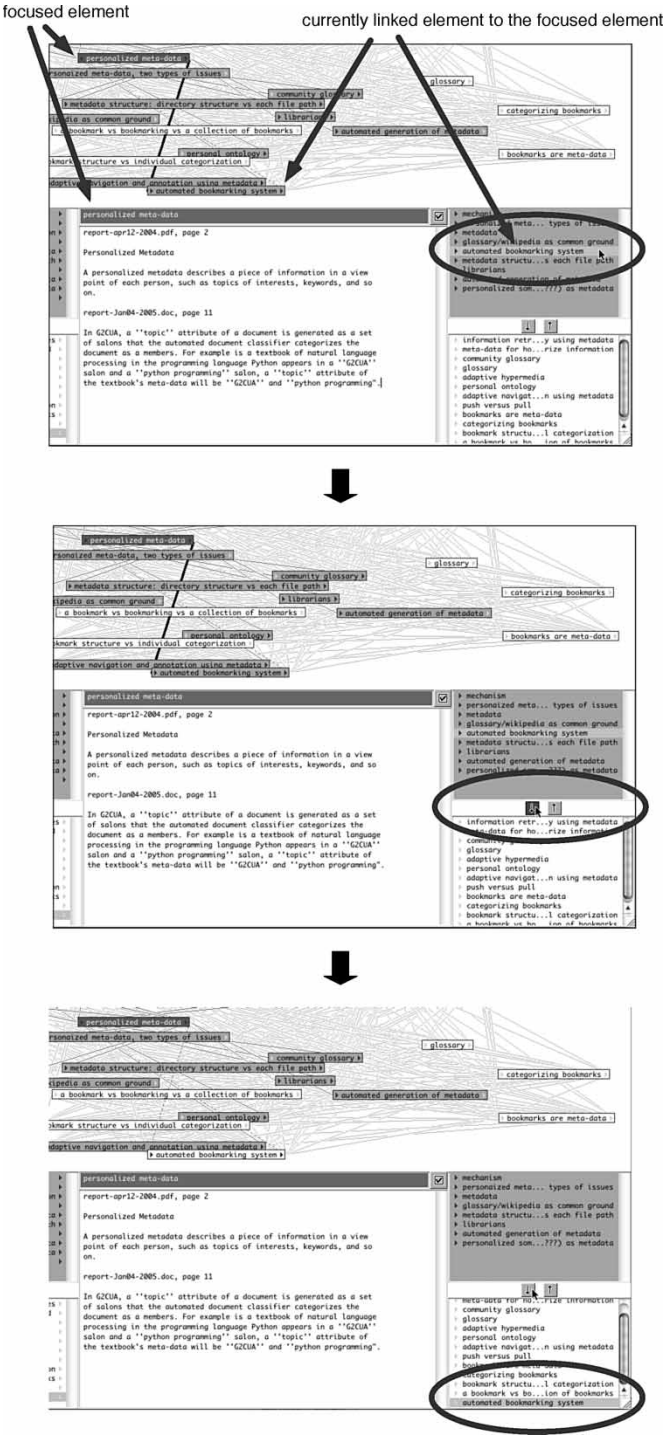


Figure 6. How links are added and removed by using the link list.

Joe repeats this process several times and looks at the changing visual appearance. After repeating the process for some time, he gradually starts to remove the link or move the element in ElementSpace.

In Phase 1, Joe sometimes drags an element and moves it around in a small area in ElementSpace (figure 8). As he drags the focused element, all the links follow in ElementSpace. When this happens, Joe often puts the element back almost in the original position. Joe's action therefore does not cause any changes in state of the artefacts he is working on, but this process seems to be important to Joe.

3.2.2. Phase 2. Now that Joe thinks he has worked enough with the current set of elements, he has decided to add more new concepts as elements. This time Joe uses the calligraphic mode of ART014; when he adds a new concept in ElementSpace, the node is created with no link to any other elements. Joe now examines elements listed in the lower pane of In/OutBoundLinkList; different from the previous phase, Joe now has to consider which links should be added instead of which links to remove. Joe takes the same action he had taken in Phase 1; that is, clicking on each element one by one in In/OutBoundLink-List. However, in this phase, Joe interacts more actively with elements in ElementSpace than merely adding or removing links.

Joe repeats the process of adding an element (both title and content), editing links and moving elements in ElementSpace.

Toward the end of Phase 2, Joe spends a long time interacting with the elements in ElementSpace, making changes to the spatial layout of the elements in ElementSpace to further identify and refine relationships among

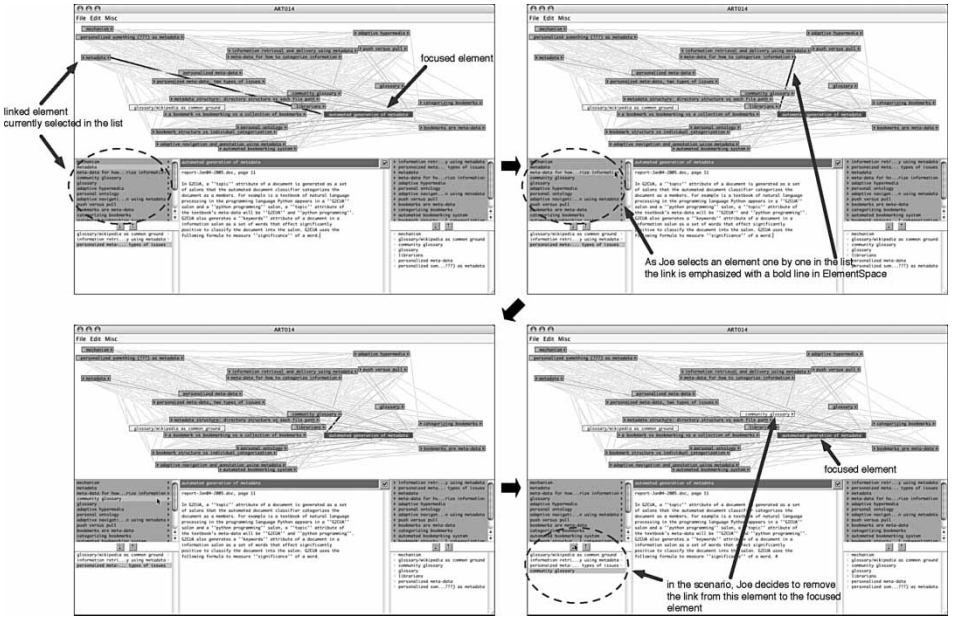


Figure 7. Flipping through different linked elements to the focused element.

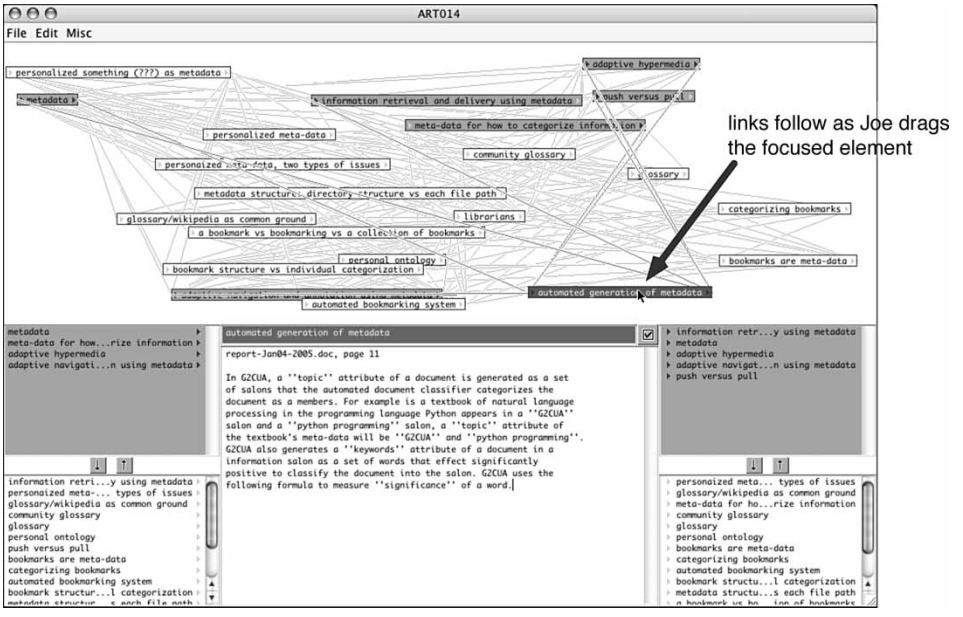


Figure 8. Moving the focused element in ElementSpace supporting reflection-in-action.

the elements. At the end of Phase 2, Joe gradually sees what would be an appropriate story to tell in his paper.

Figure 9 illustrates the situation. As Joe adds new concepts, he has gradually decided that the notion of "revisitation" (of information) should play a central role in his paper. Joe focuses on the revisitation element and keeps clicking on each element one by one from top to bottom in the upper pane of InBoundLinkList to identify which element is the most important necessary element for the revisitation concept. After wandering around in the list for a while, he decides on the "adaptive hypermedia" concept to be the most important one, and clicks on the element in InBoundLinkList and stops wandering around (figure 9; top left). Now, he sees that the link between the revisitation and adaptive hypermedia elements is visually emphasized with a thick bold line in ElementSpace.

Joe then clicks on the triangle marker of the adaptive hypermedia element in InBoundLinkList. Now, the focus is shifted from revisitation to adaptive hypermedia. Joe then starts looking for the most necessary element for the adaptive hypermedia element by clicking on each element from top to bottom in its InBoundLinkList. He decides that the "metadata" element is the most necessary one. He then shifts the focus from adaptive hypermedia to metadata again by clicking on the triangular marker of the metadata element in InBoundLinkList (figure 9; top right).

As figure 9 shows, Joe continues this process for several steps, hopping from the most important element to its most necessary element, and then focusing on the most necessary element, and so on, reflecting on the story he is gradually identifying.

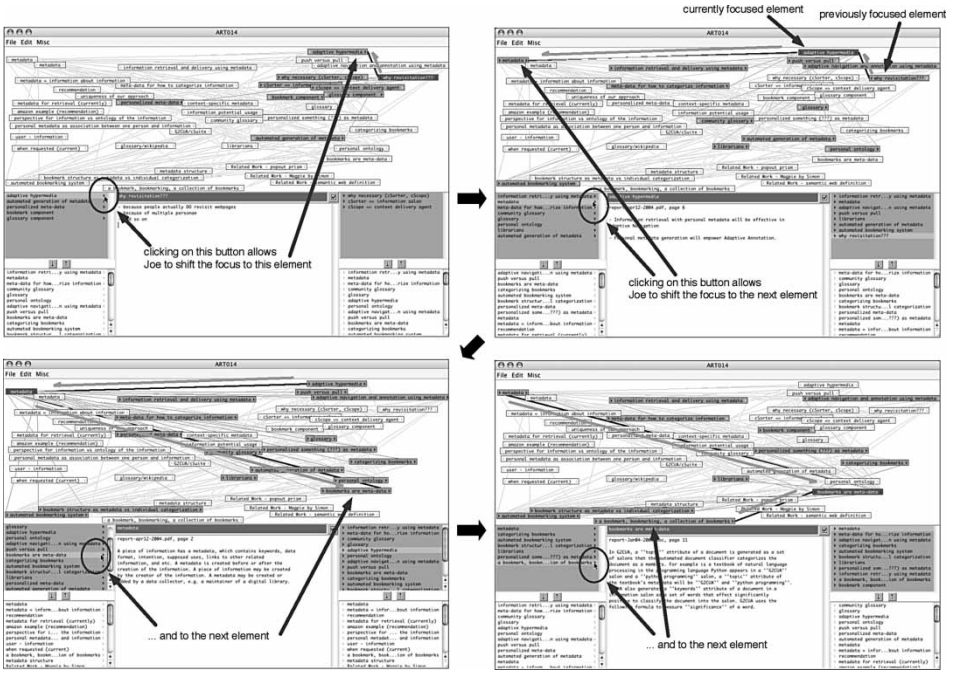


Figure 9. Traversing links in ElementSpace by using the LinkList in Phase2 examining a possible coherent story among elements.

3.2.3. Phase 3. Having decided on the story, Joe decides to start constructing a structure for the paper. He starts moving the elements in ElementSpace resulting in six clusters, which he thinks can correspond to six sections of his paper. Figure 10 illustrates the clustered result.

After having clustered the elements, Joe focuses on the revisitation element, which should be the central theme for his paper. Joe then becomes aware that one cluster in the bottom right corner of ElementSpace does not have any elements with a grey background colour, whereas all the other clustered areas have at least one grey element (figure 10). This implies that no elements in the bottom right corner have any inbound or outbound links to the revisitation element. The bottom-right corner cluster has elements that would constitute a related work section. Joe then remembers that he has recently read a paper on the study of observing how people revisit information. Joe adds an element with the label "related work—revisitation" and provides a reference pointer to the paper as the content for the element (figure 11; right).

Joe now feels comfortable using the story and the structure represented in ART014 for his conference paper and finishes his task by using ART014.

How Joe proceeds with his paper-writing project by actually editing text is not the main scope of this paper. However, a text editing tool, such as ART001, which uses a spatial hypertext representation to produce a linear structure (Yamamoto *et al*. 2002), could be used to continue the work by

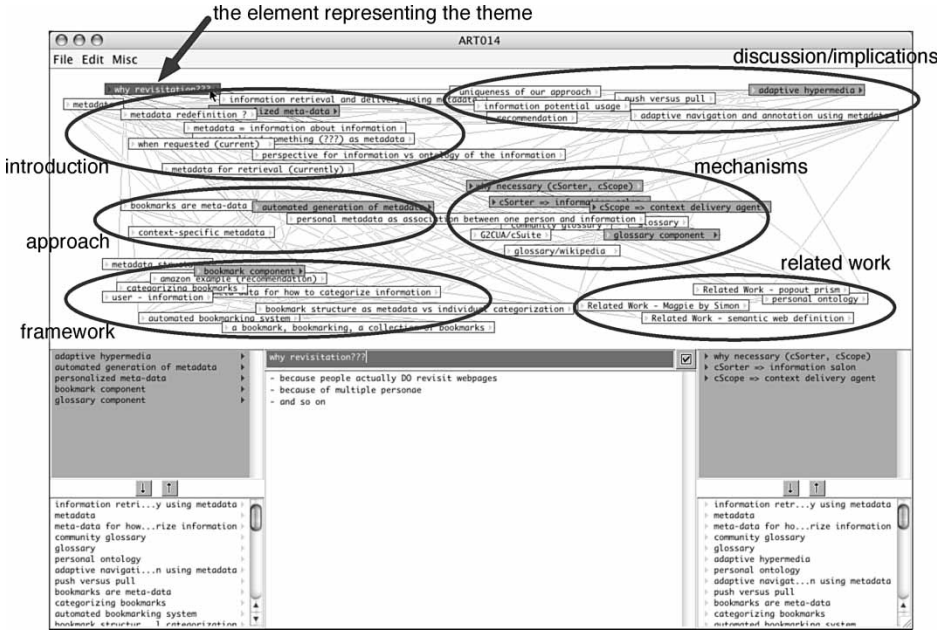


Figure 10. Emerged section groupings by using ElementSpace in Phase3.

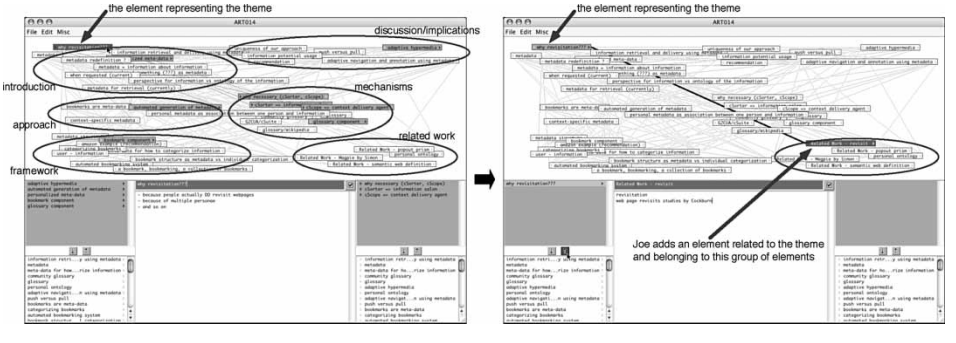


Figure 11. Reflecting on the space and links simultaneously.

copying and pasting the clustered elements into the text-editing tools (figure 12).

4. Discussions

The above scenario is presented to demonstrate idiosyncratic ways a user would engage in the early stages of scholarly writing using ART014. This section focuses on the following three aspects of the approach depicted in the scenario: use of the two representations, engagement in reflection-in-action, and modes of authoring. We then discuss future directions.

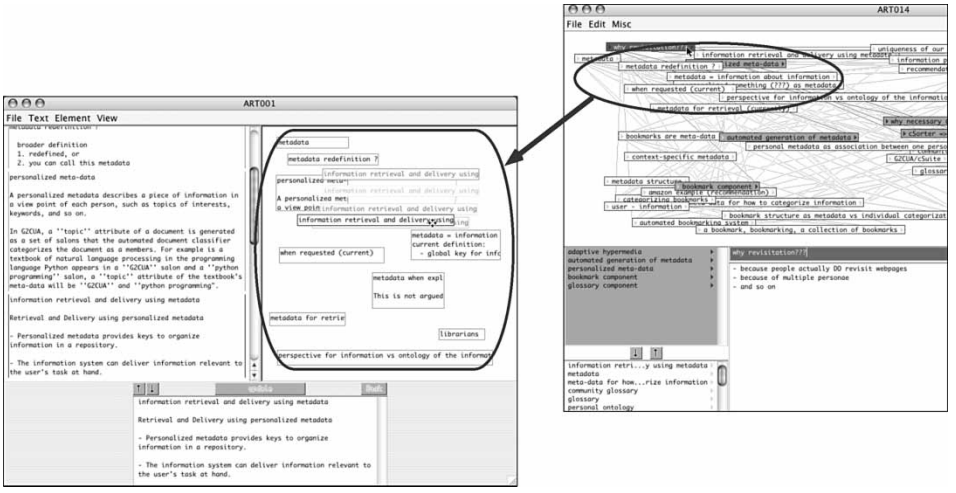


Figure 12. Subsequent writing supported with ART001.

4.1 Three aspects of the approach

4.1.1. Use of the two representations. Arguing for two separate hypertext representations for the problem and the solution, we have designed ART014 to provide a spatial hypertext representation and a column-based network representation. The scenario illustrated how the two representations can be used in terms of the model depicted in figure 2.

The scenario shows that the two hypertext representations of ART014 should not be necessarily used in a manner of one-to-one mapping, where one representation is for a problem, and one is for a solution. Rather, the user could switch how he/she uses each of the representations as the situation evolved. In the scenario, such switches or changes in use of the representations corresponded to phases in the process.

In the scenario, Joe first used the space to organize concepts, and the network for understanding how each concept should be related to the others. At this point, the space is used more for a problem and the network more for a solution. However, in the second and third phases, Joe used the space to design a structure for his paper while using the network to represent his understanding of the problem space. We also tried with the scenario to illustrate the point that Joe can decide how to use inbound and outbound links to organize ideas (such as elements with inbound links are ''enablers'' and those with outbound links are ''enablees'') as the task proceeds, during the time of deciding which elements have links to the focused element.

''How'' to use a representation for what purposes, thus, can evolve as the scholarly writing task proceeds. The use of the tool itself seems to demonstrate the nature of design.

4.1.2. Engagement in reflection-in-action. The scenario also illustrates the way in which Joe used ElementSpace of ART014 corresponding to the findings

reported in previous studies in spatial hypertext (Marshall *et al.* 1991, Marshall and Shipman 1995). In Phase 3, Joe did not know how many clusters he would have in the beginning of clustering elements. As he placed elements according to the unit of "sections" of his paper in ElementSpace, his understanding of the information evolved, and six clusters emerged as he interacted with the spatially arranged elements in ElementSpace being engaged in the reflection-in-action process.

Although not expressed in the scenario, from our own experience of using ART014, we have often felt a need for an "in-between" representation for specifying links. In using StructureColumn of ART014, there is no way to distinguish elements that a user was sure about having a link from those he/she thought might have a link to a focused element. The current implementation of ART014 does not allow a user to control where to put an element in the sequentially ordered link list. He/she had no way to represent the degree of necessity or unnecessity of a link in a semi-formal manner, inhibiting the participant from being engaged in the reflection-in-action process. This aspect is the most valuable representational affordance that a spatial hypertext representation provides (Marshall *et al.* 1991). The question of how to incorporate a semi-formal representation to a column-based network representation remains a challenging issue for us.

The scenario has put an emphasis on Joe's differing engagements in the reflection-in-action processes by interacting with visual feedback. Situations depicted by figures 7–9 all show that Joe played with a representation, and the tool generates representational backtalk to Joe. In figure 7, for instance, Joe flipped over a list of elements in InBoundLinkList, and saw how a thick bold line heading into the focused element appeared in different places in ElementSpace. Joe gradually saw meanings emerging in the space through how he placed elements in the space, and this allowed him to reflect on the links with richer contexts. In figure 8, Joe interacted with an element in ElementSpace, which was similar to the interaction with a spatial hypertext system as described above. However, Joe not only experienced emerging structures in the space by dragging an element but also saw consequences and relations to others in another context by looking at links following the dragged element. Figure 9 shows a situation in which Joe hopped over the elements in ElementSpace by traversing links by using the network structure. Although the same consequence (i.e. to focus on an element) could be achieved by directly clicking on the element in ElementSpace, the experience of interacting with the representation seems to feel quite different.

It is interesting to note that none of the three actions depicted above would result in the change in the state of artefacts that Joe is producing. These activities do not necessarily change the links among a network of elements or spatial layouts of elements in the space. They result only in changes of visual appearances.

It is not our aim here to make any assumptions on how interacting with those changing visual appearances leads to a better paper as a scholarly writing product. However, as illustrated in the scenario, our own experience

tells us that projection, negotiation, and revisions of the meaning are likely to be happening during the engagement in reflection-in-action.

4.1.3. Modes of authoring. Adapting the terms from the notion of sculptural hypertext, ART014 provides ways to switch between the sculptural mode and calligraphic mode when creating a new element. In a well-defined problem domain, it is a matter of economy whether to start with an orphan node and then define its links (i.e. calligraphic mode) or to start with a node linked to any others then remove some (or all) of its links (i.e. sculptural mode); both would have the same result except for the different numbers of procedural steps needed to reach that result. We argue that, in contrast, in an ill-defined design domain such as scholarly writing, the difference would not merely be a matter of economy. Our approach is to give users options for both modes by simple space-click toggling.

In the scenario, choosing which modes to use depended on the phase of the process, and not on the element to be created. In Phase 1, where Joe has a fixed set of elements to start with, he used the sculptural mode. In Phase 2, in contrast, when he gradually adds new concepts, Joe uses the calligraphic mode throughout the phase.

We set up the scenario this way because of the nature of the procedural steps and that of links ART014 provides. An outbound link of element-A to element-B is an inbound link of element-B from element-A in ART014. ART014 allows a user to create an element at any time, and adding or removing one link overwrites the other. Thus, if a user first creates an element-A with a sculptural mode hoping to have element-A linked to all the others, and the user later creates an element-B with a calligraphic mode, hoping to have element-B linked to nothing, the latter operation overwrites the former intention, and therefore links between element-A and element-B will be lost.

If the user does not switch the mode and does not edit the links before adding new elements, the sculptural mode would work; otherwise, the mechanisms to specify future behaviours of an element would be necessary; for instance, to specify that this particular element will not have any links with any elements that are created in the future even if the elements are created in a calligraphic mode. Such mechanisms would need to specify complex conditions solving conflicting constraints for possible behaviours similar to those explored in sculptural hypertext authoring tools (Millard *et al.* 2003). We do not think that such a cognitively demanding task should be introduced in the early stages of scholarly writing. The current mode-switching option in ART014 therefore needs to be reconsidered.

4.2 Future directions

4.2.1. Integrating multiple views. This paper argued that tools for scholarly writing require multiple representations for the problem and the solution

supporting reflection-in-action. ART014 integrated a network hypertext representation and a spatial hypertext representation.

Our interaction design decision is to use the notion of "focus" to integrate the two representations of ART014. A user can focus on an element either in ElementSpace or in StructureColumn (figure 3). The focused element is visually emphasized in both representations.

While this design approach work to some extent is illustrated in the scenario, there is also a limitation. The greatest problem is when a user wants to focus on multiple elements. It is quite straightforward to allow a user to focus on multiple elements in the spatial hypertext representation. However, the current column-based network representation does not afford a multiple selection of elements. Thus, allowing users to focus on multiple elements would diminish the representational integrity.

Integrating multiple views without losing consistency and coherence has been found to be a challenging issue in the field of interaction design (Robertson *et al.* 2005). This will need further studies.

4.2.2. Combining other types of representations. ART014 integrated a column-based network hypertext representation and a spatial hypertext representation. A spatial hypertext representation was considered to serve for representing a problem by allowing users to interact with emerging structures, while a network hypertext representation was considered to serve for representing a solution by allowing users to express a more formal structure.

As illustrated in the previous subsection, however, the roles of the two representations could change over time, and a user could use the representations in a flexible manner. As also mentioned above, we have identified a need for a semi-formal way of representing links for a network representation.

Based on these findings, we need to explore different ways of combining other types of representations, including the integration of two spatial hypertext representations being an option.

4.2.3. Expanding the scope. The interaction design of ART014 is based on the scholarly writing process model, as illustrated in figure 2. Our approach presumes that scholarly writing largely consists of producing elements and determining relationships among them. The style of scholarly writing our approach supports depends on how one collects relevant information and knowledge pieces with which a scholar interacts in the early stages of scholarly writing. Scholarly writing can be viewed as a process of articulation. To articulate means "to fit together into a coherent whole". Scholars find, modify, or produce elements of knowledge that are to be joined together to form a coherent structure.

In this regard, the style of scholarly writing can be situated in a larger context of creative knowledge work. The Knowledge Liquidization and Crystallization (KLC) cycle is a process framework of our ongoing Knowledge-Creation and -Communication Cycle (KCCC) project (Hori *et al.* 2004). By acknowledging that knowledge generalized and instantiated in traditional

knowledge management approaches cannot afford dealing with emerging contexts (Fischer and Ostwald 2001), our KLC cycle consists of two processes (Hori *et al.* 2004): (1) dividing a cohesive structure into coherent knowledge units by adding links among them to achieve more flexible, "softer," malleable structure (liquidization); and (2) discovering a new cohesive structure among the coherent units (crystallization). By knowledge, we mean external representations of knowledge. In order to drive the cyclic process, the framework demands the involvement of human interaction in the process (Hori 1994, Nakakoji *et al.* 1998).

ART014 can be viewed as supporting such crystallization processes in this framework. Several tools have been developed to semi-automatically support the liquidization process in the KCCC project; some of the tools can be integrated with ART014.

For instance, the KCCC001 system, which is currently under development, aims at supporting a user in segmenting his/her previously written documents into knowledge units, annotating each unit with typed attributes so that the system discovers possible paths among knowledge units, which is similar to the lineage service of ClaiMaker (Uren *et al.* 2003). The scenario presented in Section 3.2 depicted the situation when the user of ART014 identified concepts from previously written documents and manually extracted corresponding text from the documents. KCCC001 would provide semi-automatic support for this part of the process.

Another example is the Word Colony mechanism, which identifies possible segmentations of a document using the notion of the dependency of term co-occurrence of a document, and visually presents possible associations among the segmented knowledge units (Akaishi *et al.* 2004). In our preliminary user observations using the mechanism, people have started generating hypotheses and stories implied by the automatically generated segmentations, which promoted their creative thinking (Fischer and Nakakoji 1994). Incorporating this type of mechanism would provide ART014 with a proactive support for scholars engaged in scholarly writing as a design task (Nakakoji and Fischer 1995).

5. Concluding remarks

Means of externalizations and available operations are essential elements in people's creative knowledge work. Being a cognitive tool, an application system affects how a user understands and solves a problem. The interaction design of an application system guides or distracts, encourages or discourages, and permits or prohibits a user from taking certain courses of actions and states of mind. Since scholarly work is one of *the* most cognitively intensive intellectual tasks, tools for scholarly work need to be very carefully designed; a scholar concomitantly needs to be very careful in choosing which tool to use for their scholarly work.

It is not our intention here to argue that ART014 is the solution for a wide variety of scholarly writing. The paper presented ART014 as an instantiation

of our theoretical approach by applying the ART design principle. The theoretical framework presented in this paper is grounded in theories of human cognition and theories of design. As a long-term goal, we hope to further instantiate the theoretical framework and test it under different design principles.

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