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Two-Dimensional Spatial Positioning as a Means for Reflection in Design

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ABSTRACT

In the realm of computer support for design, developers have focused primarily on power and expressiveness that are important in framing a design solution. They assume that design is a series of calculated steps that lead to a clearly specified goal. The problem with this focus is that the resulting tools hinder the very process that is critical in early phases of a design task; the reflection-in-action process [15]. In the early phases, what is required as the most important ingredient for a design tool is the ability to interact in ways that require as little commitment as possible. This aspect is most evident in domains where two dimensions play a role, such as sketching in architecture. Surprisingly, it is equally true in linear domains such as writing. In this paper, we present our approach of using two-dimensional positioning of objects as a means for reflection in the early phases of a design task. Taking writing as an example, the ART (Amplifying Representational Talkback) system uses two dimensional positioning to support the early stages of the writing task. An eye-tracking user study illustrates important issues in the domain of computer support for design.

Keywords

Theoretical framework for design support, reflection-in-action, two-dimensional positioning, cognitive models, writing support, an alternative to sketching

1. INTRODUCTION

Our goal is to support the early phases of design with interactive software in such subtle and unobtrusive ways that the designer ceases to interact with the program and instead feels as though the designer is simply interacting with a medium [12]. Our approach to this goal is guided in theory by D. Schoen's [15] analysis of designers and by case studies in supporting writing as a design task [22].

In design activities such as writing and programming, problem analysis (identifying what components should be constructed) and solution synthesis (how these components should be combined) are fundamentally interdependent [14,17]. *Parts* define the *whole* but the roles of parts are defined by the whole – the design process can be viewed as forming a hermeneutic circle [18].

Orthogonal to the hermeneutic circle, a designer is engaged in a cycle of producing representations (such as sketches, mockups and notes), and reflecting on them [15]. The externalized representations "talks back" to the designer. The designer has a conversation with the materials asking questions such as:

- *what parts are missing?*
- *how confident am I that this part fits?*
- *how does this new part complement the rest?*
- *how does this new part affect my view of the other parts?* or
- *is the overall design proceeding according to my intuition and intention?*

Schoen describes design as a reflective conversation with the materials of a situation [15]. The designer interacts with the materials, such as pen and sketch on a sheet of paper, in what is described as *reflection-in-action.* The designer acts and reflects almost simultaneously; acting, interpreting and reacting to the evolving design.

Unfortunately, many of existing computer based design support tools appear to completely ignore the fluidity and tentative exploration a designer does [4]. Instead, they assume that creating an artifact is simply a series of calculated steps, taken in order until they add up to the finished design.

There is no doubt that computer based tools are helpful to designers. The question is when? We believe most of existing design support tools are developed for later phases of a design task with assumptions that prevent their use in early design. The most important reason to this is that they force designers to make explicit certain decisions that must be left unstated and unexamined for the purpose of reflection-in-action. They require unnecessary (or inappropriate) commitments that interfere with the process.

Our goal is to develop computer based tools that mimic and augment the amazing power of simple things like pencil and paper, or post-it notes. What is it about pencil and paper that draws artists to use them [8] when computer based tools are such obvious improvements in power and expressiveness? The answer we have explored is twofold: *directness* and *commitment*. First, working with an existing computer based tool is analogous to using a translator to communicate. For example in architecture one can sketch at infinite levels of abstraction or specificity and in a matter of mere seconds draw doodles without being forced to make explicit what exactly they represent. Contrast this with a computer based tool in which one must go through the tedious steps of choosing brush stroke, color, width, and so on all before being allowed to interact with the sketching surface, which itself is an arbitrarily small size on a screen. One cannot simply act directly - it is always indirectly through palettes or menus. Second, as stated above, sketching can be at any level of abstraction, allowing a designer to overdraw, widen, thicken, or cross out any portions of a drawing in a very subtle manner without forcing them to make any explicitly stated commitment. Subtle aspects of the sketch itself, for instance, the thickness of a line, may indicate how sure a designer feels about the part of the drawing and how much commitment the designer has made with to part. And this "talk-back" from the representation is often meaningful only to the designer him/herself.

In early design, it is not the case that the designer first makes commitment and then produces a representation. This is why opening a menu and choosing a "drawing tool" from a palette does not work naturally for a designer. Rather, the designer first produces a representation and during and after the production the designer may "see" how much commitment the designer has or should make about the representation. It is the designer who assigns meaning to a representation; it is not that the designer has a meaning and produces a representation for the meaning.

Based on these considerations, we argue that to support early phases of a design task with interactive systems, such systems need to provide a designer with a representational means for reflection that is direct, and requires minimum commitment.

Freehand sketching tools are one approach addressing the above problem [8]. But what if we would like to support a design domain where no "sketching" exists? We have studied writing as a "linear" design domain as an object-to-think-with. Other linear design domains include programming or video editing where the final product needs to have its parts ordered in a sequential manner. Our approach is to use two-dimensional positioning as a means for reflection in early design for such domains. In this paper, we argue that two-dimensional positioning is as useful for writing as sketching is for architectural design.

We have developed a system called ART (Amplifying Representational Talkback) that supports the process of writing as design. A two-dimensional space is used to position various objects concerned with a piece of writing.

Positioning objects in a two-dimensional space allows designers to be engaged in reflection *in* and *on* action. During the process of positioning, continuously changing and emerging representations "talk back" to designers allowing them to participate in reflection-*in*-action. Once objects are positioned, then designers can read the two-dimensional spatial representation for understanding the current state and design rationale behind the design allowing them to perform the more detached reflection-*on*-action.

We have previously argued how ART supports the writing process in terms of reflection-*on*-action by reporting on how objects (text chunks) and their positioning help the writer (i.e. designer) [22]. This paper considers how ART also supports reflection-*in*-action. We explore how the writer reflects while taking a certain action (i.e. positioning on a two-dimensional space), and report on a user study using an eye-tracking system to support our claims.

2. REPRESENTATIONS FOR REFLECTION

The design process requires both generating parts and structuring them (solution synthesis) while exploring what to design (problem analysis) [17]. One cannot understand a problem without having started solving it [14]. A partially constructed solution helps uncover problems. In design, problems and solutions co-evolve [4].

While they are inseparable, the types of cognitive activities that designers are engaged in change as phases in such design tasks proceed. In the early phases of design, designers focus more on understanding and identifying problems by iterating the process of reflection in and on action. As the design proceeds, the designer's focus shifts toward synthesizing solutions.

2.1 The Role of Externalization in Design

Designers produce various types of representations for different purposes during both early phases and later phases of a design process. There is a spectrum of types of representations which serve different purposes. At one end of the spectrum, representations serve solutions, while representations at the other end serve reflection and problem analysis.

Externalization is immensely important in design. Bruner [1] comments that externalization "produces a record of our mental

efforts, one that is 'outside us' rather than vaguely 'in memory' ... It relieves us in some measure from the always difficult task of 'thinking about our own thoughts' while often accomplishing the same end. It embodies our thoughts and intentions in a form more accessible to reflective efforts." [1; p23]

Even with this recognition of the importance of externalization, little research has been done on what representations best support designers in their reflection in early phases of a design task. Most existing design support systems that focus on expressiveness provide representations that really just serve synthesis, but not reflection.

2.2 Our Approach: Amplifying Representational Talkback

As reviewed briefly above, in early phases of a design task, designers produce representations that are not necessarily used in a final design artifact. They use such representations not as a direct contribution to a solution but as a means for reflection [8,13]. Such representations may take the form of drawings, textual annotations, memos, coloring, sizing or positioning of objects. One small aspect of a representation, such as the straightness or the thickness of a line, may play an important role in helping them change perspectives on the problem.

The meaning of these representations may be vague and actually change over time. Designers may use such representations simply as reminders. It is impossible to objectively identify the underlying meaning behind the representation since it is not created for this purpose. The representations are processed by a designer perceptually rather than cognitively, exploiting human perceptual abilities [24].

For the last four years, we have studied a concept called Representational Talkback [10]. Representational talkback, based on Schoen's design theory [15], is defined as: "perceptual feedback to the human designer from the externalized design artifact." Representational talkback is an intermediate situation that emerges during a design task. We focus on visual, perceptual representation rather than symbolic representation that are verbally expressible. Perceptual external representations "provide information that can be directly perceived and used without being interpreted and formulated explicitly" [24], and external pictures (representations) can give people access to knowledge and skills that are unavailable from internal representations [13].

A computational medium can support designers in the early phase of their design task by providing representational media that amplify their representational talkback so that the designers can more effectively reflect in and on actions they have taken. The amplification of representational talkback is concerned with two issues:

1. how to make it easier for designers to express what they want to express with directness and minimum commitment,
2. how to make it easier for designers to perceive what has been represented.

Our approach to this problem is the use of two-dimensional spatial positioning of objects. The following section describes the rationale for this approach.

2.3 Reflection *in* and *on* action with Two-Dimensional Spatial Positioning as a Repesentational Means

This paper presents our approach of using two-dimensional spatial positioning of objects as a representation that is useful for reflection in early design. With the direct manipulation, it is easy to grasp and move objects to produce different visual properties. Simply looking at the space will help people identify many visual properties from the space. Thus, the use of positioning as a representation addresses the two concerns mentioned above to amplify representational talkback.

Schoen distinguishes two activities concerning reflection: reflection-*in*-action and reflection-*on*-action [p.278, 15]. The former 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 is the reflective processes that happens when a designer sees a resulting representation. In the latter reflection, the designer is not doing anything constructive in the design space. The designer is simply looking at the representation and reflecting on it.

Although the distinction between the two types of reflection may be a matter of time-span (one can say that a designer is always engaged in reflection-on-action as a matter of milli-second span), Schoen's contribution in design theory resides in this strong claim that reflection-*in*-action is a most important ingredient in early design [p.278, 15]. Sketching, the single most widely used representation over hundreds of years by architectural designers, in fact, allows designers to perform both reflection-in-action and reflection-on-action. A designer may reflect *in* his/her drawing while drawing a circle or moving a pen on a sheet of paper. After he/she finishes drawing, the designer may take a moment to sit back, and examine the just drawn: a time for reflection-*on*-action.

In this paper, we argue that two-dimensional positioning is as powerful a representational medium for reflection as sketching. In fact, there are basically two properties in using a two-dimensional space that correspond to the two types of reflection:

(1) position as a state (a static property), and

(2) positioning as an action(a dynamic property).

Position as a state denotes the result of a certain action taken by the designer. For example, it may be the size of the object placed on the two-dimensional space, or it may be the spatial relation between two objects. When the designer uses this trait, he/she can be said to be reflecting on the action, i.e., reflecting on the results of the previous action.

In contrast, *positioning as an action* denotes what the designer is doing to reach the state of *position as a state*. For example, in

order to have the object at a certain size, the designer must enlarge (or shrink) that object. While the designer is enlarging/shrinking that object, the designer likely is reflecting on how large/small that object should be, i.e. the designer is reflecting while taking the action.

Thus *position as a state* is closely related to reflection-*on*-action while *positioning as an action* is closely related to reflection-*in*-action. Sketching and positioning seem to be equally powerful as a representational means for reflection.

3. SUPPORTING A LINEAR DESIGN DOMAIN: WRITING

To instanciate our approach described above, we have taken writing as an example linear design domain. The rest of this paper focuses on the approach of writing support. Other domains to which we have applied the approach include video analysis tasks [23] (see also 6.3) and component retrieval tasks in object-oriented programming [20].

3.1 Writing as Design

While computer-mediated communication now widely incorporates multimedia, text-based information remains essential. As more and more people have an opportunity to author and publish information, it is important to reconsider writing skill in light of new technologies.

Writing style has changed in recent years as computer tools have come to be widely used in place of pen and paper. Writing often does not proceed as a top-down process where one first identifies a stable structure, then gradually elaborates it from chapter to section to paragraph to sentence [5,6]. It is now easier to produce a collection of disassociated notes and cut-and-paste them to produce a coherent story using a word processor – collage-style writing.

Even with this new writing style (or maybe even more so with this new style), writing remains a complex cognitive task. During a document design process writers often experience problems, for example, dissatisfaction and deadlock. In the beginning writers often do not know: *what to write*; *how to relate information chunks*; or *how to organize the chunks into a coherent document.* As writing proceeds, writers sometimes get stuck. They wonder whether: *the writing is consistent as a unit*; or *one part is in balance with the rest of the document.*

The process should rather be viewed as a process of design where the writer alternately identifies structure and generates content [18]. For example, until one actually starts writing sentences, one cannot pre-plan exactly what words to use. Only when the writer looks at what one has written, can one decide what to write next – the reflection-in-action cycle.

By viewing writing as a design task, design theory tells us that we can take advantage of the power of representations during the writing process. Making a representation of a design situation allows the designer to reflect on an intermediate state, and helps the designer decide how to proceed.

A study by Noda et al. [11] shows that people gain a better understanding when they are allowed to place document chunks in a two-dimensional space. They found that when subjects read a newspaper article with intentionally jumbled paragraphs, they typically used spatial information to make sense of the content. Subjects who were allowed to use visual cues scored better in a post-experiment quiz about the content of the document than subjects who were not allowed to organize sentences spatially on a screen but were only allowed to read the article from the top to bottom. Thus people can use spatial cues as a meta-comment [6] to help understand the content of text.

3.2 Positioning in Writing

We use positioning of objects that are representations for reflection in writing. We provide a way to position a set of text "chunks" that can be freely mapped on a two-dimensional space (see Section 4). While positioning, writers (as designers) can use those properties to represent a variety of situations. For instance, if a writer thinks that a paragraph-A is better than paragraph-B, then the writer can place paragraph-A to the left of paragraph-B. The writer can use the distance between the two objects to reflect the degree of "better-ness." Suppose the writer is moving paragraph-A away from paragraph-B. This act of moving paragraph-A may lead the writer to do reflection-in-action raising awareness of the comparison between the parts. After paragraph-A is positioned, it can later remind the writer that paragraph-A was much better than paragraph-B.

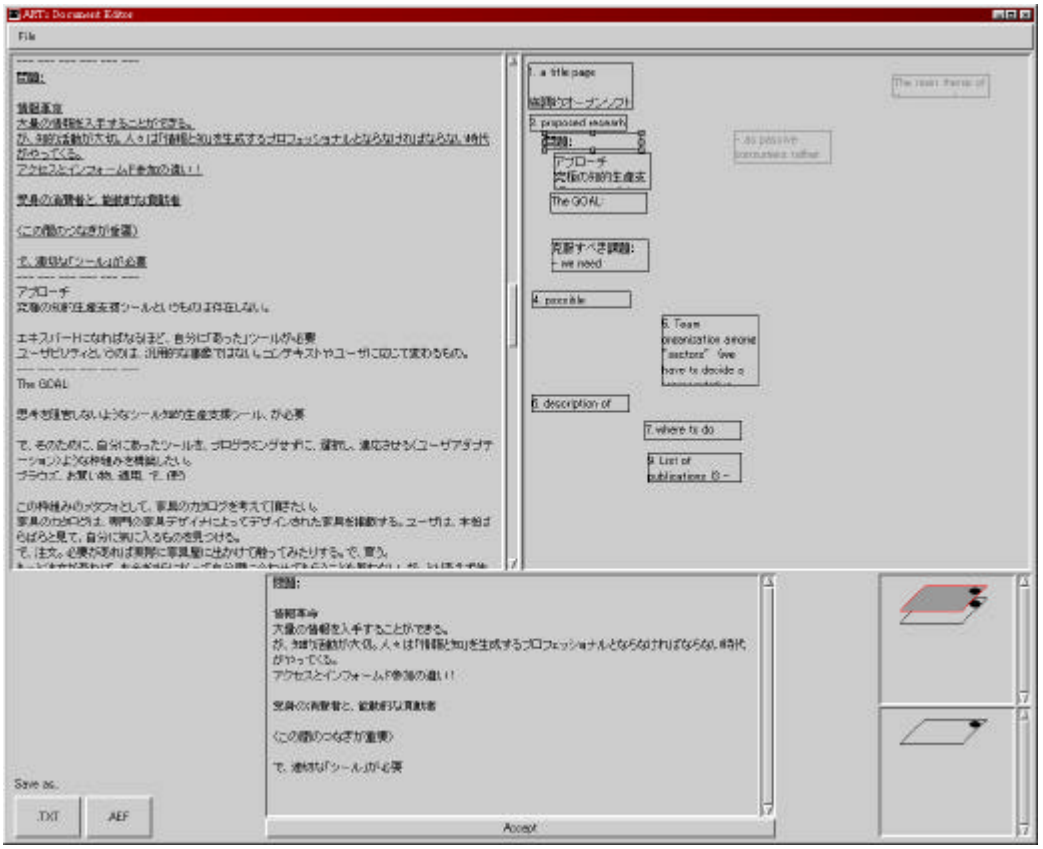


Figure 1. The ART System

Thus, the use of two-dimensional spatial positioning allows writers to represent the current state of mind without verbalizing or formalizing the state. It does not require writers to articulate "paragraph-A is better than paragraph-B by a factor of 5, 50, or 500," no matter what the numbers mean. It is up to the writer to decide on what meanings to extract from the representation. The exact same representation (positioning) may mean very different things to different writers or in different situations.

4. THE ART SYSTEM

The ART system [22] (Figure 1) supports document construction as a design task allowing users to position segmented text as "elements" in a two-dimensional space. An element is any unit that a writer may choose to think of as one, such as a phrase, a sentence, a paragraph, or a longer piece of text.

4.1 System Overview

The ART system consists of the following four components: ElementsMap, ElementEditor, DocumentViewer, and LayerManager.

ElementsMap (Figure 1 top-right) is a two-dimensional space that graphically displays elements that comprise the document. Each element is represented as an icon. An icon does not show the entire content of the element, but only the first ten percent of the text; therefore, the size of the element box initially corresponds to the size of the actual element. A user can freely change the size and position of elements by pointing and dragging icons on the ElementsMap.

Elements can be created and edited using the ElementsMap and the ElementEditor (Figure 1 bottom). Selection of an element in the ElementsMap allows a user to modify the content of the element in the ElementEditor. When nothing is selected in the ElementsMap, a user can type text into the ElementEditor and create a new element by positioning the newly created icon in the ElementsMap. The ElementEditor provides editing functions such as cut, copy, paste, and "spin off" (which divides one element into two). Two or more elements can be merged by selecting multiple elements on the ElementsMap.

The DocumentViewer (Figure 1 top-left) component displays the currently constructed document as a whole. One notable function of the ART system is that the system automatically interprets one aspect of the positioning of elements in the ElementsMap. An element's vertical position in the ElementsMap is interpreted as corresponding to its position in the document sequence, and the DocumentViewer displays the actual content of the document by sequentially scanning the elements displayed in the ElementsMap from top to bottom. Thus, a user can freely change the order of

elements in the whole document by changing the vertical relationship of elements in the ElementsMap. Position changes made in the ElementsMap and content changes made in the ElementEditor are automatically reflected in all of the three components. When a user selects an element in ElementsMap, the corresponding portion of the document in the DocumentViewer is underlined and the window is scrolled to show the portion at the top of the DocumentViewer.

While the ElementsMap serves as a two-dimensional space for a user to position text chunks, the system also provides a third dimension with translucent layer mechanisms. A user can differentiate groups of elements by putting different groups of elements on different layers. The bottom-right two windows of Figure 1 represent the LayerManager of ART. Three layers have been created by the user; two shown in the upper window, and one shown in the lower window. Only the elements that are put on the layers placed in the upper window of the LayerManager are shown in the ElementsMap, the DocumentViewer, and the ElementEditor. In the ElementsMap, elements positioned on the top layer are displayed with the darkest color while those positioned on the second and lower layers are displayed with lighter colors; the closer to the top, the darker it shows. Users can select which layer to put on the top, and which layers to display (i.e. which layers to put in the upper window of the LayerManager) by direct manipulation. These layers serve as the tracing paper that architectural designers regularly use, with which designers make trial-and-error sketches by overlaying the trace paper on existing drawings.

4.2 Representations Used in ART

The ART system provides views to look at both parts and the whole of the document simultaneously. The ElementsMap provides an overview of the whole in terms of the structure of parts, while the ElementEditor provides details of a part. The DocumentViewer displays the context of the part with details of neighborhood elements. The three views are integrated and changes made in one component are dynamically reflected in the other components.

The essential part of the system is the use of the ElementsMap. In our previous user studies of ART reported in [22], we found that subjects used a variety of visual properties of two-dimensional positioning as a representation. Some put elements that need further attention in the bottom right corner of the ElementsMap. Some subjects made a set of completed elements be the same size and carefully aligned them. One user had two elements overlapping each other with a verbal protocol saying that she felt that they should be related to each other but could not describe how they are related (therefore they were overlapped and not aligned). Another user made some elements much larger than others so that it would “call for attention” later in the task.

Interestingly, no subjects complained about the constraint ART imposes on the vertical relationships of elements in the ElementsMap; the contents of the elements are always concatenated in order from top to bottom. Subjects used different distances between two vertically positioned elements to represent different types of relations of the two elements. Some subjects placed two elements that were almost completely horizontally aligned but with a slight height difference so that they “looked” horizontally aligned but are not from the system’s point of view.

5. A USER STUDY

In the previous user study described above, we observed how subjects used two-dimensional positioning in writing and what types of positioning emerged during writing tasks.

Since then, ART has been used by a number of users. The system can be downloaded from the Web and we have identified some people who regularly use the system both within and outside of our institute. So far we have obtained positive feedback from those users but we had no convincing evidence for our claim: that two-dimensional positioning is as useful for writing as sketching for architectural design.

This motivated further user studies and observations. This section presents one of such user observations in depth, which focused on how a user interacts with the two-dimensional positioning in ART and performs reflection-*in*-action and reflection-*on*-action during early phases of a writing task.

Figure 2. The evolution of positioning of elements in ElementsMap

5.1 The Method and the Task

We asked one of the regular ART users to perform a writing task using ART. The subject was a faculty member at our institute. We thought the writing task should be as authentic as possible so that the subject would really be "into" writing, therefore we asked her to do one of her existing writing tasks.

She brought a task of writing a grant proposal based on three email discussions previously exchanged among her potential co-PIs. The writing was a mixture of English and Japanese. The resulting document needed to be in Japanese.

To observe how her reflection occurs during the writing task, we asked her to use the think-aloud method. However, since writing is such a cognition-intensive task, we did not encourage her to speak up when she unconsciously stopped talking during the task. To complement the think-aloud protocol we transcribed, we asked the subject to wear the eye-tracking device (nac, EMR-NC) that is attachable on a pair of glasses.

The gaze point on the subject screen was displayed with the white cross mark on the experimenter's display. The white mark was not displayed on the subject's display. The screen with the gaze-point cross mark was video-taped, and the whole session was also video-taped in order to transcribe the verbal protocol.

The task lasted fifty-two minutes and ended when the subject claimed that she was done. An informal interview was conducted after the experiment.

5.2 The Result

The subject started her writing task with three elements in ElementsMap (EM), each of which was cut-and-pasted from the pre-existing email messages. During the fifty-two minute writing session, the subject produced twenty elements in EM while three of them were placed in another layer, and one was placed in another layer.

Figure 2 illustrates how positioning in EM changed throughout the writing task. As a result, the subject ended her task with thirteen elements positioned in the active layer. The final document contained 265 lines and approximately 3,000 Japanese characters.

5.3 The Analysis

This subsection reports the result of our analysis focusing on the following topics covering how reflection took place using two-dimensional positioning: positioning patterns, the writing process, and gaze movement patterns.

5.3.1 Positioning Patterns

As Figure 2 illustrates, the subject was observed to use several positioning patterns. Some of them were similar to the previous study. While the subject used rows on the left for positioning elements that "*are important and directly contribute to the final document*" (the original script was in Japanese), she used the right area for positioning elements that "*would either require more attention or were related but not directly useful for my current document.*" See Figure 2-(9) for instance, that smaller elements on the left side were direct components for the final document and

that larger elements on the right were ones that "*require more work*" (originally uttered in Japanese).

This behavior in some sense was found a little confusing because contents of the documents were all concatenated in the order of top to bottom and displayed in DocumentViewer (DV) (as described in 4.1). She carefully positioned elements in the left part of EM in terms of the vertical relationship. At the same time, she could completely ignore the vertical relationship of elements on the right side. In the very end of her writing task, she adjusted the position of the large element on the right side (see Figure 2-(15)) so that the content of this element was incorporated in the appropriate place in DV.

This indicates that the subject was very good at looking at positioning in a context that she mentally projected; in this case the left region and the right region. Although there was no clear boundary displayed in EM, subtle spatial information was enough for her to indicate meaning without confusion. For instance, the large element in window (8) and the elements in window (13) had the almost same coordinates in terms of the two-dimensional space of EM. However, when we asked the subject about the two elements during the post-study interview, she stated that the large element in window (8) was positioned as the second "island" from the right while smaller elements in window (13) were positioned as the third island from the left.

There were other conventions that she used during the study, including making elements much larger than others to indicate that they would need more work, and keeping elements width almost all equal for all the elements in EM.

The consistent use of such positioning patterns corroborate the findings we identified from the previous study. This indicates that two-dimensional positioning is useful for reflection-*on*-action.

5.3.2 The Writing Process

In analyzing the gaze movement data produced by the eye-tracking system during the user study, we have used an encoding schema by which window the subject *looked* at: ElementsMap (EM), DocumentViewer (DV), or ElementEditor (EE).

There are several actions that are possible for a writer to take using ART:

- understanding a piece of text (in EE, in DW),
- understanding the structure of text (in EM, in DV),
- editing a piece of text (in EE), and
- moving a piece of text (in EE, in EM).

With the gaze movement data together with protocols, we observed all of these patterns. Positioning was taking place not only in the process of moving a piece of text, but also in the process of understanding the structure of text.

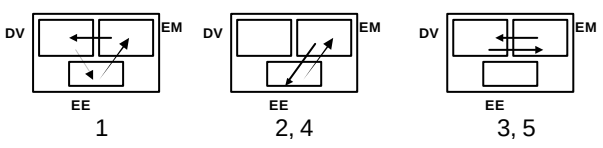


Figure 3. The Five Phases Observed

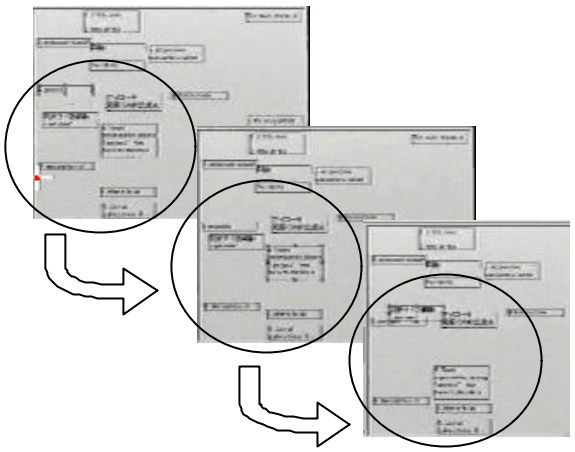


Figure 4. Small changes continuously made to elements in ElementsMap

During the fifty-two minutes of the study session, there were roughly five phases (Figure 3):

1. the EM-DV-EE-EM cycle
2. the EM-EE-EM cycle
3. the EM-DV-EM cycle
4. the EM-EE-EM cycle
5. the EM-DV-EM cycle

The first phase was when the subject was repeating a process of identifying an important portion out of a given document chunk, and cutting and pasting the portion into a new element. In this phase, the subject selected an element in EM, which underlined the corresponding portion of the document in DV and simultaneously showed the content of the element in EE. The subject then read the underlined part in DV deciding an editing strategy – what part to extract to create a new element. The subject then invoked the "spin-off' command in EE, then went back to EM and selected the same element.

The second and forth phases were when the subject was in the process of actually adding and modifying text in EE. Typically, the subject selected an element in EM and edited the content in the EE. In this phase, the subject sometimes "split" off a portion out of the element, and positioned the separate part in EM and then went back to EE.

The third and fifth phases were when the subject was mainly trying to understand the current state of what had been written. The subject selected an element in EM which automatically underlined the corresponding text portion in DV. The subject read the underlined portion, went back to EM, and selected one of neighboring items.

As mentioned above, the subject was engaged in two-dimensional positioning in two different types of tasks:

- in moving a piece of text, and
- in understanding a structure of text, or the flow of the text.

With *positioning for moving*, it was a pretty straightforward movement of objects when moving an existing element to another part of the EM. This includes changing the order of elements, making room for another elements, or putting an element far away to the right indicating "this is done."

An interesting point was observed when creating a new element. When positioning a new element in the first, second and fourth phases, the subject was observed conducting reflection-*in*-action while positioning the element. The subject often slowly moved the element within the left-side area of EM without releasing a mouse button, carefully comparing with neighborhood elements (as indicated with the gaze movement). It was also often observed that the subject moved an element back and forth slightly above or below another element. Verbal protocol transcribed during this process illustrates that the subject tried to understand what was already there – by examining contents of neighborhood elements. Interestingly, this examination was seldom done while actually looking at the contents either in DV or in EE. A little portion of the document displayed on an icon surface in EM was enough for the subject to remember the content of each element.

With *positioning for understanding*, Figure 4 shows how a subject was trying to reach a state where an element appropriately shows the relationship between it and other elements. The subject was continuously moving an element. The upper left EM was the starting point and the lower right EM was the end point. While the subject was moving she could be said to be doing reflection-*in*-action, i.e., she was considering the relationships of the element with other elements. She may stop moving at a certain point, such as was the case with the middle EM, and reflect at that time. This can be considered to be reflection-*on*-action. This is an example showing that the difference between reflection-*in*-action and reflection-*on*-action is in some cases a difference in granularity. If we just take the middle EM, then the subject was doing reflection-*on*-action, but if we consider the process between the upper left EM to the lower right EM, then the subject was engaged in reflection-*in*-action.

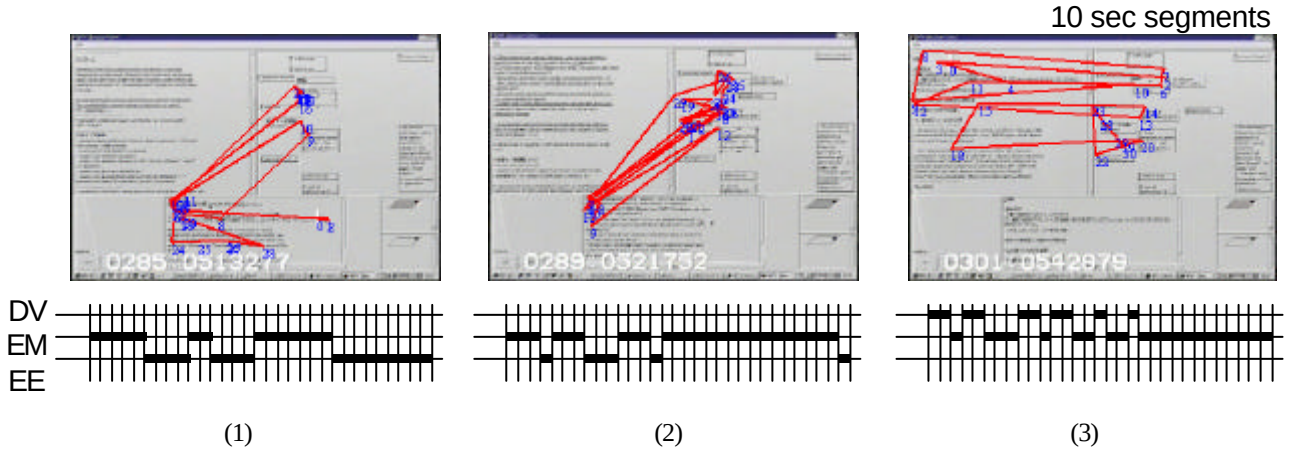
5.3.3 Gaze Movement Analysis

Figure 5 illustrates three typical gaze movement observed in the study. Each gaze movement is a ten-second-long portion of the eye-tracking data. The bar chart below indicates how long each gaze position stayed within the same window: DV, EM or EE. In each case, there are quite a number of gaze movements across different windows considering that the total length is just ten seconds. For instance, in Figure 5-(3), the subject changed the window to look at more than once per second.

Figure 5-(1) indicates a typical gaze movement during the time when the subject was editing text in EE. As the figure shows, although the subject mainly looked at the EE, she also looked at the EM. It seems that the subject looked at EM to confirm the context within which she was writing in. In addition, as can be seen from this figure, she looked at two elements that were in some way related with the piece of text she was currently editing. Thus, we could conclude that she was reflecting while she was editing (reflection-*in*-action) by using the results of some previous action (reflection-*on*-action).

ART allowed the subject to go back and forth between EM and EE to keep in mind the context within which a certain editing task was taking place. Without the EM she would have needed to scroll DV and hence possibly might have lost where she had been, and not be able to keep in mind how a certain part of the text was related with other parts.

In Figure 5-(2), the subject was trying to find a certain element to edit. She was going back and forth between the EM and EE as EM only shows a part of the text. The subject looked at EM, clicked one of the elements, examined the content of the element in EE, then went back to EM to select another element. Interestingly, the subject repeatedly examined the same set of elements all of which were positioned within a relatively small area. It seems that the



(1) (2) (3)

Figure 5. Types of Typical Gaze Movement

positioning of elements in a certain area (usually the top left quarter of the EM area with the case of this subject) indicated the elements of interest during the task.

Figure 5-(3) indicates a typical gaze movement when the subject was trying to understand the current state of the document. The subject went back and forth between EM and DV. As described above, the selection of an element in EM brings the corresponding portion of the document to be displayed in DV. The subject was using the elements in EM as if they were bookmarks. As mentioned in the previous paragraph, the elements that the subject looked at belonged to a small area of the EM space. With the verbal protocol recorded, we have observed that the subject used the spatial relationships among the elements in the small area to understand the roles of each element, examining and confirming what the current state of the document was.

6. DISCUSSION

This section first discusses related work from two perspectives: research that focuses on representations serving for reflection in early phases of a design task, and research that uses two-dimensional positioning as a representational medium. Finally, we briefly present our recent effort in applying the approach to a video analysis task.

6.1 Representations for Early Stages of Design

Tools that allow free-hand drawing, such as the CocktailNapkin system [2], share our goals. While our approach uses two-dimensional positioning as a representation for a designer's state-of-mind, they use free-hand drawing as a representation. A sketch-based interface can be viewed as amplifying representational talkback for design domains that are dependent on two-dimensional representations. With a sketch-based interface, users can externalize various situations without having to verbalize or formulate sentences to express such situations. The meaning associated with the representation is "obvious" to the user who made the sketches – the representation talks back to the user.

A line of research in design rationale [9] has also focused on representation that is useful for reflection. Design rationale is typically a textual description of what alternatives should be taken and arguments that support or negate each alternative. Although such design rationale mechanisms provide powerful cognitive representations for designers to understand the history of design evolution and how to proceed with the design task, they aim at a larger scale in terms of time. Most design rationale system allows users to record (externalize) rationale after the design session finishes. It is also limited to textual representation.

Our focus is more on on-time help for reflection. We use perceptual representations that help designers. We view our approach to be complementary to the design rationale research rather than as a replacement.

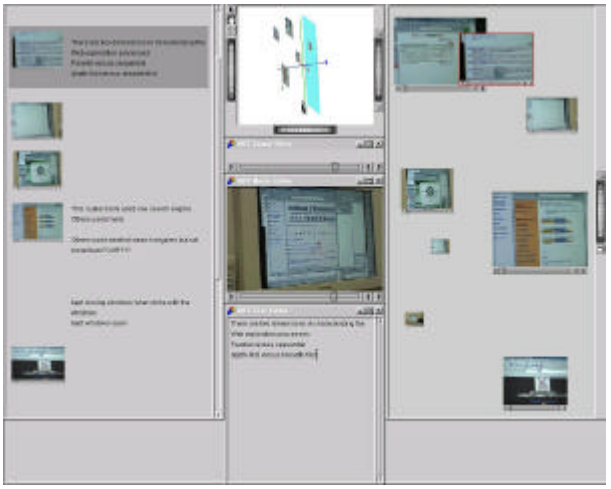


Figure 6. Time-ART System

6.2 The Use of Two-Dimensional Space as a Representational Medium

Various research on using space for representation has been done. Shipman et al. [16] found that people use the visual and spatial characteristics of graphical layouts to express relationships between icons and other visual symbols. Fentem et al. [3] argues that spatial positioning serves as a shared language among a group of people working together. Other work has focused on inferring the user's underlying intent of a positioning based on methods such as statistical analysis [19] and genetic algorithms [7].

We focus on the use of a representation produced by a user using space. The representation can be considered as an intermediate status of some task. The representation helps the user in their task, while using it does not disturb their cognitive processes, i.e. it does not detract from what they want to do.

Some research offers a two-dimensional space to represent a user's intention but the meaning of axes are pre-assigned by the system. The SearchSpace system [21], for instance, uses a two dimensional space to represent a query for document search. The vertical axis of the space is used to represent the degree of importance of positioned keywords and the horizontal axis is used to represent the degree of spelling ambiguity of positioned keywords. A user can position multiple keywords in the space with positioning as the representation of the properties of the keywords.

6.3 Application of the Approach to Experimental Video Analysis

Having encouraging effects of two-dimensional spatial positioning of objects in supporting early stages of a writing task, we have started applying the same framework for other types of design domains. One of such domains is a video analysis task in empirical studies.

Figure 6 illustrates our prototype system called Time-ART [23]. In empirical studies, experimenters collect various types of data.

Understanding such data requires cognitively intensive qualitative analysis based on the cycle of discovery and validation processes. Time-ART is an interactive computational tool that is suitable for supporting experimenters to discover important aspects of the data, to collect them, to store them and to share them with peers. Using Time-ART, a user browses time-stamped multimedia data (video, sound, or gaze tracking), identifies an interesting portion of them (in the middle windows), and position it in a two-dimensional space in the right window. Each element in this space is in fact located in the three-dimensional space (see top-center) where the depth represents the time sequence. The user may textually annotate the portion using the text editor in the bottom-center, and the left window displays a result of synthesizing such annotations.

Although the system is still at a primitive stage, we are starting user studies using Time-ART.

7. CONCLUSION

This paper presents our approach to support early phases of design by providing a representational medium that allows designers to directly externalize thoughts and ideas without forcing any commitment; therefore interaction with the medium does not interfere with the designer's cognitive processes. Our focus is not on representations that serve final artifacts but on ones that serve for reflection, especially in early design. We use two-dimensional spatial positioning of design objects as a perceptual representation that allows designers to express their state of mind. The case study was presented to illustrate how two-dimensional positioning as an action helps designers be engaged in reflection-*in*-action, and how the resulting two-dimensional positioning of objects allows designers to perform reflection-*on*-action.

While passive materials and artifacts cannot speak for themselves, computational materials can. Although this fundamental difference provides great leverage in improving the way designers work and learn, it can also be a pitfall by imposing representations that may not necessarily be right for the task. What is important is to give designers representational media that allow them to externalize what they want to externalize in ways they like. While doing so, the computational media need to stay as invisible as possible to designers requiring minimum commitment. Our approach is a step forward to let designers deal with tacit knowledge on an interactive computer system. Meanings can be extracted from a representation only by the designer; the system remains as a medium – but a useful one.

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9. REFERENCES

[1] Bruner, J., "The Culture of Education," Harvard University Press, Cambridge, MA (1996).

[2] Do, E. Y.-L., & Gross, M. D., "Inferring Design Intentions from Sketches: An Investigation of Freehand Drawing Conventions in Design." Proc. of the 2nd Conf. on Computer Aided Architectural Design Research in Asia (CAADRIA'97), Taipei, Taiwan (1997).

[3] Fentem, A., Dumas, C., & McDonnell, J., "Evolving Spatial Representations to Support Innovation and the Communication of Strategic Knowledge," Knowledge-Based Systems Journal, 11(7-8), 417-428 (1998).

[4] Fischer, G., Nakakoji, K., "Beyond the Macho Approach of Artificial Intelligence: Empower Human Designers – Do Not Replace Them," Knowledge-Based Systems Journal, Vol.5, No.1, pp.15-30 (1992).

[5] Hayes, J.R. Flower, L.S., "Writing research and the writer," American Psychologist, Vol.41, No.10, pp.1106-1113 (1980).

[6] Hunter, W.J., Begoray, J., "A framework for the activities involved in the writing process," The Writing Notebook, Vol.8, No.1 (1990).

[7] Igarashi, T., Matsuoka, S., & Masui, T., "Adaptive Recognition of Implicit Structures in Human-Organized Layouts," Proc. of the 11th IEEE Symposium on Visual Languages, 258-266 (1995).

[8] Lawson, B., "Design in Mind," Architectural Press, MA (1994).

[9] Moran, T. P., & Carroll, J. M. (Ed.), "Design Rationale: Concepts, Techniques, and Use," Lawrence Erlbaum Associates, Inc, Hillsdale, NJ (1996).

[10] Nakakoji, K., Yamamoto, Y., Suzuki, T., Takada, S., & Gross, M., "Beyond Critiquing: Using Representational Talkback to Elicit Design Intention," Knowledge-Based Systems Journal, 11(7-8), 457-468 (1998).

[11] Noda, K., Furuta, K., Aoki A., Masukawa, K., Yagi, H., Miyake, N., "Toward the facilitation of collaborative learning by externalization and record-keeping of understanding processes," Workshop on Creativity Support System, 17-24, (1997) (in Japanese).

[12] Norman, D. A., "The Invisible Computer," MIT Press, Cambridge, MA (1998).

[13] Reisberg, D., "External Representations and the Advantages of Externalizing One's Thoughts," Proc. of the 8th Annual Conference of the Cognitive Science Society. Cognitive Science Society (1987).

[14] Rittel, H., & Webber, M. M., "Planning Problems are Wicked Problems," In N. Cross (Eds.), Developments in Design Methodology. 135-144. John Wiley & Sons, New York (1984).

[15] Schoen, D. A., "The Reflective Practitioner: How Professionals Think in Action," Basic Books, NY (1983).

[16] Shipman, F. M., Marshall, C. C., & Moran, T. P., "Finding and Using Implicit Structure in Human-Organized Spatial

Layouts of Information," Human Factors in Computing Systems (CHI '95) Denver, CO. 346-353 (1995).

[17] Simon, H. A., "The Sciences of the Artificial (Third ed.)," The MIT Press, Cambridge, MA (1996).

[18] Snodgrass, A., & Coyne, R., "Is Designing Hermeneutical?" Dept of Architectural and Design Science, University of Sydney (1990).

[19] Sugimoto, M., Hori, K., & Ohsuga, S., "A System for Visualizing Viewpoints and its Application to Intelligent Activity Support," IEEE Trans. on Systems, Man, and Cybernetics, 28C(1), 124-136 (1998).

[20] Takada, S., Yamamoto, Y., & Nakakoji, K., "Two-Dimensional Positioning as Visual Thinking," Diagrams2000, Edinburgh, UK., (September, 2000) (in print).

[21] Tsutsumi, F., & Shinohara, Y., "Search Space: Document Retrieval by 2-D Positioning Keyword Query," Computer Software, 15(4), 2-15 (1998) (in Japanese).

[22] Yamamoto, Y., Takada, S., & Nakakoji, K., "Representational Talkback: An Approach to Support Writing as Design," Proc. of 3rd Asia Pacific Computer Human Interaction Conference, 125-131, Kanagawa, Japan. IEEE Computer Society (1998).

[23] Yamamoto, Y., Nakakoji, K, & Aoki, A., "An Interaction Model for Experimental Data Analysis Using Spatial Positioning," Proceedings of the International Symposium on Future Software Technology (ISFST-00), Guiyang, China, Software Engineers Associates, (August, 2000) (to appear).

[24] Zhang, J., "The Nature of External Representations in Problem Solving," Cognitive Science, 21(2), 179-217 (1997).