Design space for navigation in digital media

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Aachen, November 2009
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Abstract

With the development of computer technology, digital media such as e-books, interactive map, digital audio or video is playing a more and more important role in today's life. Because digital media is easily to be delivered, shared, and stored, it is replacing the traditional media types step by step so that is becoming the main medium by which people get information. At the same time, researchers are trying to develop more efficient and natural navigation methods to navigate digital media. Many enhanced designs of the traditional navigation methods have been developed, as well as some novel ones. But meanwhile, designers may feel lost in the large amount of design choices since there is no way to evaluate these navigation methods systematically. And designers do not have a clear picture about the current state-of-the-art and rooms for improvement. To address these problems, this thesis work proposes a systematic way to evaluate the navigation methods in abstraction for digital documents, picture/ interactive map, digital audio and digital video. The work gives a taxonomy which explores the properties of navigation in digital media, based on which a design space is created. Then the work has a comprehensive look at the major existing navigation methods for the four types of digital media by using the design space, analyzes the current design problems, and proposes some future design suggestions. Afterwards, an evaluation tool is proposed to measure the capabilities of the navigation methods for required navigation tasks. With the tool, designers are able to evaluate the suitability of a navigation method for a task, and to compare different navigation methods. A user test is included in the thesis work, which is to verify the correctness of the design rationale of the framework and the results derived from the evaluation tool. It gives the confidence that the design space and evaluation framework is useful for the designers.

Überblick

Durch die Entwicklung der Computer Technologie spielen die digitalen Medien, wie z.B. elektronische Bücher, interaktive Landkarten, oder digitale Musik und Video, eine immer bedeutender werdendere Rolle in unserem heutigen Leben. Da die digitalen Medien sehr schnell und einfach bereitgestellt, getauscht und gespeichert werden können, verdrängen sie nach und nach die traditionellen Medien. Sie werden zu den bedeutendsten Medien für Menschen, um Informationen zu erlangen. Zur gleichen Zeit beschäftigen sich Wissenschaftler damit, die digitalen Medien einfacher und effizienter zu lenken. Jedoch könnten sie sich verloren fühlen in der Fülle der Gestaltungsmöglichkeiten, da es keine Möglichkeit gibt die Lenkungsmethoden systematisch zu erproben. Und die Entwickler haben kein klares Bild über die derzeitigen Verbesserungsmöglichkeiten. Um diesen Problemen zu begegnen, entwickelt diese Abhandlung einen systematischen Weg die Lenkungsmöglichkeiten zu erproben für digitale Dokumente, Bilder und interaktive Landkarten, sowie Musik und Video. Diese Abhandlung gibt eine Systematik der Eigenschaften der Lenkungsmöglichkeiten der digitalen Medien, basieren auf dem jeweiligen Design. Die wichtigsten existierenden Lenkungsmethoden werden beschrieben für die vier Bereiche der digitalen Medien durch die Nutzung des Designs, der Analyse der derzeitigen Designprobleme und durch das Vorschlagen zukünftiger Designs. Zum Schluss wird ein Evaluierungstool vorgestellt, um die Möglichkeiten der Lenkungsmethoden für die gewünschten Aufgaben zu messen. Mit diesem Toll haben Entwickler die Möglichkeit die Brauchbarkeit der Lenkungsmethode für eine Aufgabe zu bestimmen und verschiedene Methoden zu vergleichen. Außerdem enthält die Abhandlung einen Benutzertest, der die Richtigkeit des Designs, der Grundstruktur und der Ergebnisse des Evaluierungstools überprüft. Er gibt die Gewissheit, dass das Design und das Evaluationsstruktur sinnvoll für die Entwickler ist.

Acknowledgements

This thesis would have never been accomplished without the contribution of many people.

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Thanks to my friends, who are alway caring about the progress of my thesis work, talking about the topics with me, and gave me help when I have difficulties. Because of you, my stress from the work is released to a large extent.

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Conventions

Throughout this thesis we use the following conventions.

The whole thesis is written in American English.

"He/she" is used to describe the unidentified third person.

The plural "we" will be used throughout this thesis instead of the singular "I", even when referring to work that was primarily or solely done by the author.

Chapter 1

Introduction

Usage and advantage of digital media

Digital media has been playing an important role in today's life, work, and education, etc. as computer technology develops. It is taking the place of traditional media step by step. People read news and books on computer, in many cases through Internet, using pdf, doc, html files instead of reading newspaper and printed books. They use interactive maps, such as Google map, to locate the desired places all over the world, obtain surrounding information such as hotels, bus stations, ask for the driving route between two cities, and to calculate the distance and estimated time needed to go there, instead of buying printed maps and search on them. Lecture videos are recorded to execute remote education, or to provide to the students for review. Therefore, the ways people read, get information, and even take classes are intrinsically changed. Comparing to traditional media, digital media can be published and distributed faster and more easily; it is more conveniently to be shared, carried and archived for a long time, hence is possible for making a large amount of information; and it is more flexibly to be accessed almost from anywhere computer and Internet are available.

But in the meanwhile media types are changing, the ways people interact with media are also changed. With digital media, the interaction is between human and machine. Input devices such as mouse and keyboard are acting as the mediums instead of human hands to accomplish human-computer interaction tasks. The human actions like flipping a book page and checking a place on the map are replaced by manipulating the slider and typing the place name in the search box, etc. Therefore, the navigations in the digital media are all about using some input devices to manipulate the possible navigation controls provided by the machine for a certain digital media type.

Problem of navigation design

Using mouse or keyboard to linearly navigate through a document or an audio or video clip by manipulating the slider bar or timeline slider has been a major navigation method for human-computer interaction for a long time. But nowadays, researchers are exploring new ways for navigating digital media, aiming at finding faster, more efficient, and more user friendly navigation methods. Some are already widely implemented in the software and accepted by the people, while some are still in the lab stage. But the problem is no matter whether they are popularly used ones or proposed ones, the development of these navigation methods are basically from the researchers' idea which is based on their use experience of the current practices. Researchers do not have a measure to evaluate whether the new proposed navigation method will perform over the existing ones before they implement it into a software; they do not have an idea about which one is better suitable for a certain digital media type than the other ones; and they do not have a clear guidance for them to figure out in which aspects the navigation method should be improved. Furthermore, they may not have had a comprehensive look at the existing navigation methods, so that they may feel confused to decide which navigation methods should be selected to be implemented in their software to achieve the best performance, and to avoid unnecessary redundancy as well. Hence, a design space is needed to give solutions. And these problems are to be addressed in this thesis work with the design space.

Scope of the work

This thesis work will paint a comprehensive picture about navigation in digital media, and propose a framework to systematically describe and analyze navigation methods for different types of digital media. Afterwards, some guidelines and suggestions for future navigation design will be given, and a method for evaluating novel navigation methods will be proposed. Four major kinds of digital media, i.e. digital document, picture/digital map, audio, and video, will be addressed in the work.

The work starts with giving a taxonomy of navigation in digital media based on the several dimensions which describe the properties of the navigation tasks. The design space is then drawn according to the taxonomy, with the notations and analysis methodologies explained. Having the design space, we will have a comprehensive look at the existing major navigation methods for the four media types addressed in the work. The current navigation method practices will be analyzed and summarized, and future design suggestions will be proposed according to the analysis of navigation properties and current designs, which will give us a picture to explore the potential aspects that can be improved. Besides, newly designed navigation methods can also be added to the design space in the future; and the design space can also be used to analyze other novel digital media.

Based on the design space, the work proposes another tool in the framework which is called evaluation block diagram. It is a kind of block diagram which is corresponding to the design space and can be generated from the design space. The evaluation block diagram is used to describe the navigation process of a certain kind of navigation task for a type of digital media, and accordingly, to evaluate whether a navigation method fulfills the requirements of the navigation task; and among a variety of possible navigation methods, which is the most suitable one. It is useful for helping developers to select suitable navigation methods and to evaluate the usefulness of a novel navigation design.

A user test run by a program is included in this work to support the framework proposed. Because of the time and resource restriction, the user test is only designed to validate a part of the framework that is important. More user studies could be done in the future.

Following is a brief summary of each chapter to provide an overall structure of the paper:

2—"Background" has a background look at the digital media, navigation, and design space. It gives an overview of what the navigation in digital media is about and what a design space is.

3—"Related work" lists other related publicized work which is about creating design space, novel navigation and interaction, or evaluation results and user study of navigation methods for digital media.

4—"Navigation of digital media" gives a taxonomy of navigation, explores the current commonly used input devices and navigation controls, and presents all the navigation methods which will be analyzed in this work.

5—"Design space" presents the design space, describes the design rationale, and explains the notations and analysis methodologies. A comprehensive look at the current navigation methods and future design suggestions are stated here.

6—"Evaluation block diagram" presents the generation and evaluation methodologies of using evaluation block diagram.

7—"Validation" describes the user test which is designed to evaluate the validity of the framework, followed by the results and conclusions.

8—"Summary and future work" summarizes the work done in this thesis work, discusses the findings and the work that could be done in the future.

Chapter 2

Background

2.1 Digital media

Concept and examples of digital media

The digital media we are talking about and interested in this work is those media types that are opposed to traditional media types, which are often based on some physical mediums like paper. Digital media is also usually referred as electronic media. That implies the mediums for carrying digital media contents are usually electronic devices, like computer, mobile phone, PDA, etc. Nowadays, the most commonly used types of digital media are digital documents, pictures, interactive maps, digital audio, and digital video, etc. As mentioned earlier, comparing to traditional media, digital media has the advantage that it can be easily distributed, shared, carried, accessed, and archived. A large amount of digital media contents can be obtained for free or at a low rate. Hence, people tend to use digital media contents more and more nowadays; it is even replacing the traditional media. And therefore, digital media has become an important and increasingly interesting research topic these days.

2.2 Navigation designs

Navigation method

The navigation tasks in digital media are usually browsing a digital file, locating a certain part of the content, and searching for some specific information in the content, etc. The way people accomplish these tasks is often using an input device to manipulate a kind of navigation control provided by the software. Therefore, talking about navigation method in this work, it often refers to the combination use of an input device and a kind of software implemented navigation control. Speed, efficiency, natural mapping, and good usability, etc. have been the criteria to evaluate a navigation method. Hence, for the sake of being able to do more efficient and more natural navigation in digital media, a variety of novel input devices and navigation controls are developed.

Input device Input device no longer means only mouse and keyboard. Stylus and touch screen are widely used for electronic devices, especially for handheld devices like smart phone and PDA. Shuttle wheel, joy dial are often used to navigate audio and video clips. The click wheel, which is well known for the use on ipod, acts as another input device which can be used for navigating many digital media types including documents, audio, and video. Joystick is used to adjust real-time camera view by panning and zooming, which is also suitable for interactive map. Besides, some more natural input devices are also being developed by researchers. An example is TWEND ([Herkenrath et al., 2008]), a deformable user interface which uses a block of foam as the input device to navigate by bending it. More details about it will be introduced later in 3—"Related work". Furthermore, besides these input methods which are based on some physical devices, there are some other ones which are based on advanced computer technologies like speech recognition and pattern recognition. They are regarded as the next generation input methods.

Navigation control While creating novel input devices, researchers are also developing more efficient software implemented navigation controls to make navigation tasks easier. Scrollbar is widely used for navigating digital documents. Today, some kinds of enhanced scrolling technologies have been developed, which make scrolling more intelligent so as to speed up the navigation process. Examples include rate-based scrolling, by which user can control the scroll rate; speed-dependent automatic zooming ([Igarashi, 2000]), by which the view zooms out at a higher scroll rate; semantic scrolling, which only jumps to the next semantically meaningful point to the user; thumbnail-enhanced scrollbar, which displays thumbnails of important or visited pages on the scrollbar to enable quick locating; rapid serial visual presentation ([Sun and Guimbretiere, 2005]), which replaces scrolling with page flipping at high scroll rate.

Tool-based navigation controls

Traditional timeline slider is used to navigate audio and video clips. Now, for video navigation, fisheye-style warped timeline is developed by providing screenshots at pre-defined frames to give user an overview of the video clip, and let them have the possibility to jump to the frames in which they may be interested. Zoomable timeline slider gives user the possibility to re-scale the timeline for coarse-grained or fine-grained navigation purposes. Similar approaches which provide overview and pre-defined frames for discrete navigation include thumbnails for digital documents and static or dynamic storyboards for video, etc.

Direct manipulation

Besides indexNavigation control!Direct manipulation these tool-based navigation controls, another navigation class is direct manipulation. While tap-and drag, touch-and-go for navigation documents, pictures, and maps have been more and more familiar to the user, direct manipulation of video is a newly developed approach and still in its early stage. Dragon is such an example ([Karrer et al., 2008]). With Dragon, users can apply dragging actions to any object in scene; they can precisely drag the object to any position on its moving path, which leads to the moving of other objects as well. Similar direct manipulation systems include DIMP ([Dragicevic et al., 2008]) and Goldman's system ([Goldman et al., 2008]), etc. Since direct manipulation makes accurate object positioning much easier, it can well support the tasks like video cutting, scientific footage analysis, detailed sport scene review, and video annotation, etc.

2.3 Design space

Concept of design space

Since a bewildering variety of navigation methods exists for digital media, a way to systematizing them appears to be necessary. A design space is a kind of collection to organize the existing designs in an engineering discipline. As proposed in [Card et al., 1991], with taxonomy, it is possible to organize the designs in terms of abstraction by grounding individual designs into families, which gives an insight into the design space, classifies existing designs, has a comprehensive look at the state of the art, identifies design problems and possible improvements, and suggests future designs.

In this work, the way of creating the design space is from the idea of Card's design space. According to the properties of navigation, several dimensions will be abstracted. And then, taxonomies are made for each dimension. Having the taxonomy, the navigation is classified at an abstract level and the designs can be grounded into families, which lead to a parametrically described design space.

2.4 Evaluation block diagram

Concept of evaluation block diagram

Besides the design space, a new tool, evaluation block diagram, will be proposed in this work as a part of the framework. The evaluation block diagram is a kind of variant of block diagram which describes the navigation process. Through analyzing the navigation path, questions like whether the navigation method is capable of accomplishing the task and whether one navigation method will perform better than the others for a task are able to be answered. With this tool, designers are able to evaluate a new design in an intuitive manner.

Chapter 3

Related work

3.1 Design space

So far, there has not been any dedicated research work on creating a comprehensive design space for navigation in digital media, but there was several earlier publicized work creating the design space for other disciplines such as input device, graphical design, jet engine, etc., from which the idea of this work comes from.

Card's design space

The most important work related to the design space concept in this work is [Card et al., 1991]. The initial idea of creating a design space for navigation in digital media in an abstracted way is also from this work. [Card et al., 1991] developed a framework to systematize input devices. The author gave a taxonomy based on physical properties of input devices, and generated a parametrically described design space using primitive and compositional movement operators. They used a morphological design space analysis method to have an insight into both the properties of the design space and the development of novel designs.

As shown in Figure 3.1, the circles indicate that the input device senses the properties the corresponding areas show, in which the circles are. Different circles, which indicate different properties of the input devices, are connected by three kinds of lines which stand for three composition operators. A black line stands for a merge composition (e.g. mouse X axis movement and Y axis movement); a dashed line stands for a layout composition (e.g. mouse movement and button clicking); and a double line stands for connect composition, which works when the output domain of one input device is mapped onto the input domain of another one (e.g. mouse output is mapped to the cursor on screen). The number in the circle represents the number of identical devices. By putting the circles representing all the existing devices into the design space, it can be easily seen where rooms for improvements are. Besides, the work explored the use of device footprint and Fitts's Law as a test.

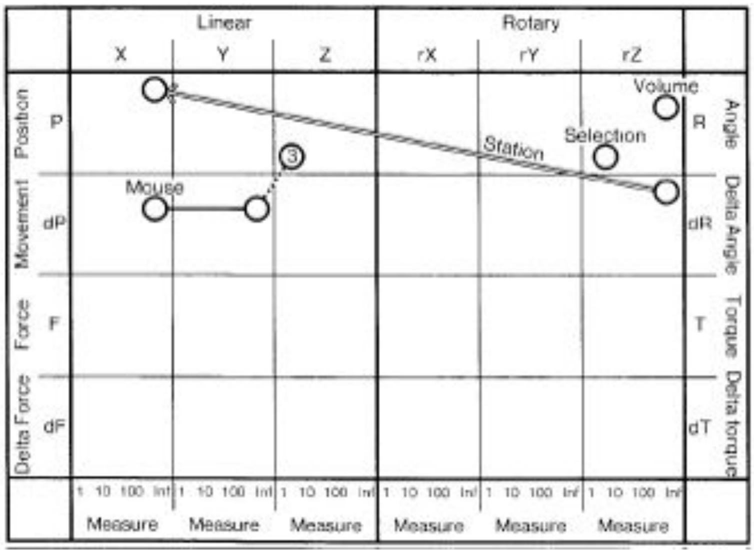

Figure 3.1: Card's design space

Other work on design space

Some other researchers also attempted to classify the input devices for exploring the design space, but did not define a notion of completeness of the design space. [Foley et al., 1984] classified input devices for using in computer graphics subtasks, while [Buxton, 1983] and [Baecker and Buxton, 1987] classified only continuous devices according to their physical properties and the number of spatial dimensions. In [Mackinlay, 1986], the author applied the morphological design space analysis technique to human-computer interface design. He developed an application-independent presentation tool that generates graphic presentation designs.

3.2 Navigation method

There are a variety of research projects proposing ideas for improving the existing navigation methods, as well as some others creating new mechanisms for navigating digital media. By reviewing the existing designs, the classification in this work will be more complete. Some researchers also did user studies to compare their improved or novel navigation methods with the currently commonly used ones, which helps the development of the analysis methodology in this framework with empirical results. The following section will present several improved or novel navigation designs which are interesting and may have big effects on the development of digital media navigation.

Footprints scrollbar

[Alexander et al., 2009] designed a Footprints scrollbar, an enhanced scrollbar, to help people return to the previously visited document regions. As shown in Figure 3.2, the Footprints scrollbar include colored marks to indicate the previously visited areas, with “cold” colors indicate an increasing age than the “hot” ones. A small thumbnail will be shown when the mouse is over a mark, and a bigger thumbnail will be shown when the mouse is over the small thumbnail. Besides, a number can be typed into the “Goto mark” box to directly locate the desired corresponding area. The evaluation results showed that the mean acquisition time decreased when the time of revisiting increased; and the Footprints scrollbar required shorter mean acquisition time than the traditional scrollbar when navigating 40-page documents, although both interfaces performed similarly for 10-page documents.

TWEND

[Herkenrath et al., 2008] proposed a new interaction metaphor by using deformable user interface to deliver gesture inputs. They built a hardware prototype named “TWEND”, which uses twisting and bending as interaction gestures to navigate eBooks, interactive maps, games, etc. (shown in Figure 3.3 and Figure 3.4). Eighteen gestures were defined to naturally map to the different navigation actions, in which some mimics the interaction with physical objects. Bending the prototype into a horizontal wave form, which is like flipping through the pages of a softcover book, is used for scrolling; bending an edge of the

Figure 3.2: Footprint scrollbar

prototype is for a single page flipping; bending completely along its horizontal axis can be used for zooming in and out when navigating interactive maps, etc. The angle of bending may decide the speed of continuous navigation such as the scroll rate. The work also included an experiment to evaluate the efficiency of the gestures.

Furthermore, in a second version of the work shown in an interactive exhibit, TWEND serves as a direct manipulation technique to navigate eBooks. By projecting the images of the eBook pages onto the TWEND surface, it is used as an eBook reader which can be bended to naturally mimic the page flipping action (Figure 3.5).

Figure 3.3: TWEND

Figure 3.4: Flipping with TWEND

Figure 3.5: Reading in TWEND

Halo

[Baudisch and Rosenholtz, 2003] developed “Halo”, a visualization technique that shows users the location of off-screen objects when navigating large space contents such as maps (Figure 3.6). Halo accomplishes this by surrounding off-screen objects with rings which reach into the border region of the display window. Users can infer the off-screen location of an object by estimating the center of the ring. The user study showed that users completed tasks 16-33% faster using “Halo” off-screen indicators than using “Arrow” off-screen indicators.

Figure 3.6: Halo

Dragon

[Karrer et al., 2008] developed DRAGON (DRAGable Object Navigation), a direct manipulation interaction technique for the frame-accurate in-scene video navigation tasks. Unlike the traditional timeline slider navigation, which has a non-linear mapping from movie time to object position that leads to indirect, unnatural, and inconsistent navigation, DRAGON enables user to quickly and precisely drag the interested object in scene to a specific desired position. As shown in Figure 3.7, an object, e.g. a car, a passenger, or even a piece of paper on the ground, can be dragged along its movement trajectory. The evaluation showed that DRAGON significantly reduces the task completion time for in-scene navigation tasks by an average of 19–42% compared to a standard timeline slider. And qualitative feedback showed that users felt more natural when using DRAGON to navigate the videos. Because of the frame locating accuracy of direct manipulation interaction, it can better support the tasks such as video cutting, scientific footage analysis, detailed sport scene review, and video annotation, etc.

Figure 3.7: DRAGON

[Ramos and Balakrishnan, 2003] designed a TLslider (Twist-Lens slider), a variant of fish-eye slider, for use with pressure-sensitive digitizer tablets to navigate video. As illustrated in Figure 3.8, the TLslider is a sequence of thumbnails which provides a visualization of the complete video stream. The thumbnails are mapped to the corresponding video frames. To overcome the thumbnail occlusion problem in regular fish-eye sliders, the TLslider morphs the linear layout to an s-shape layout, and the pen's pressure decides the sinusoidal amplitude of the lens.

TLslider

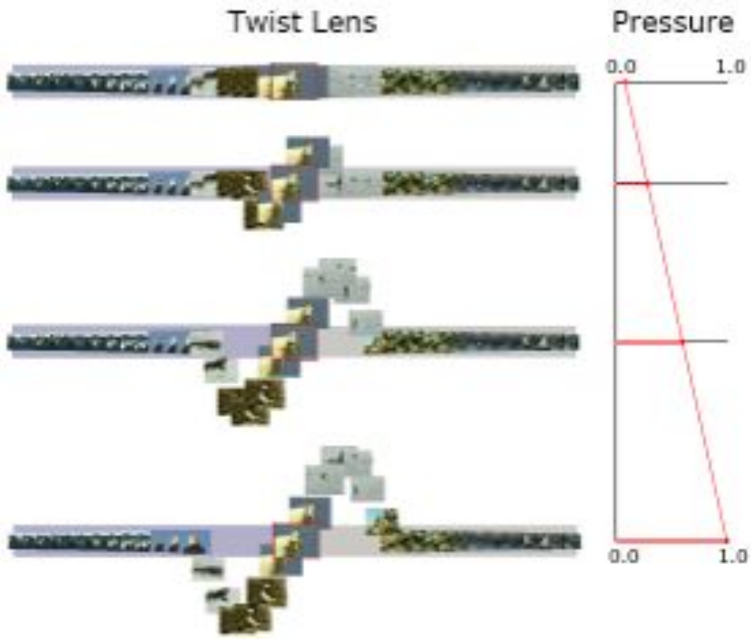

Figure 3.8: TLslider

[Cheng et al., 2009] designed SmartPlayer (Figure 3.9), an adaptive fast-forwarding interaction model adopted by the metaphor of "scenic car driving", which helps people to quickly browse videos with predefined semantic rules. It adjusts the playback speed based on the complexity of the scene and predefined events. The player can also learn user preferences about the predefined event types and adjust adaptively to the suitable playback speed. The most two novel parts in the design are the scented seeker bar and predefined event list. The visual scent on the seeker bar is encoded by the amount of saturation on the red color. The red color saturation value on the seeker bar is higher where

SmartPlayer

Figure 3.9: Smartplayer

the corresponding video segment has a higher amount of motion, which will probably lead to the slowdown of playback. The predefined events are generated based on some predefined rules. For example, in surveillance videos, the events are defined based on the appearance of pedestrians, cars, etc.; while in news reports, the events are categorized into different news types such as financial, political, and sports news.

The user test showed that by using the SmartPlayer, the average manual adjustment time decreased from navigating the first video to the fifth video, since the player learned more about the user's preference along the five navigation tasks. And the average video watching time using SmartPlayer is shorter than that using traditional player, while the comprehension of contents by using SmartPlayer still remained at a high level. The discussion suggested that the predefined events served as good hints to adjust the playback speed. And since SmartPlayer can detect scene complexity and predefined events, the playback speed is adjusted higher in the less important segments; while playback speed can only remains slow when using the traditional player, since the user do not have any information about the video contents.

Navigation designs of digital audio

[Lauer and Hürst, 2007] proposed several designs to facilitate navigation for audio-based educational multimedia contents, some of which are explained below.

Time compression An additional slider was integrated in the player which enables user to adjust the playback speed between 0.5 times and 3.0 times of the original speed. Besides, they integrated an algorithm to detect and remove the speech pauses that are longer than a certain threshold value.

Elastic audio slider In order to allow users to do frequent playback rate changes, the author integrated an elastic audio slider in the progress bar (Figure 3.10). It allows the acceleration or slowdown from the preset audio speed by dragging the slider to the right or left along a "rubber band". The speedup or slowdown factor is determined by the distance between the mouse pointer and the slider thumb, which is called "tension". However, it sacrifices the truly mapping between slider position and audio time. ([Hürst et al., 2004])

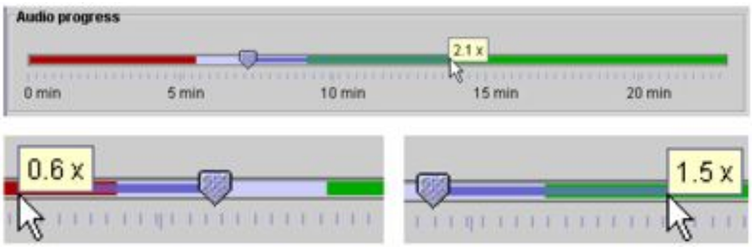

Figure 3.10: Elastic audio slider

Intelligible audio feedback The authors developed a method to provide audio feedback during timeline slider scrolling. A small snippet of audio (1-2 seconds) starting at the current slider position will be played in full before the play of the next snippet, no matter what the user does in between. In addition, the rate at which the snippets are played is determined by the scrolling speed.

3.3 User study and evaluation

Some of the related work described above included user tests to evaluate the proposed designs and to compare with the existing ones. Besides, there is some other previous work which did user studies to evaluate different navigation methods. The results will be presented in the following part and be used to support the proposed design space in the later parts.

User study of rate/position-control scrolling

[Hinckley et al., 2002] did an experiment to compare the performance of IBM ScrollPoint (rate-control scrolling), IntelliMouse Scrolling Wheel (position-control scrolling), and two enhanced scrolling wheels with acceleration algorithms (one at 3 lines/notch and one at 1 line/notch) integrated. The results presented a crossover effect between devices depending on the scrolling distance. At short distances, the rate-control scrolling was significantly slower than the wheel techniques. At about 50 lines, the 1 line/notch accelerated wheel performed best; by 100 lines, both accelerated wheels performed better than the standard wheel and rate-control scrolling. However, by 400 lines, the rate-control scrolling and 3 line/notch accelerated wheel were significantly faster than the standard wheel and 1 line/notch accelerated wheel.

User study of rate/position-based input devices

[Zhai et al., 1997] did an experiment to compare four input devices (standard mouse, mouse with a track wheel, mouse with joystick, and mouse with in-keyboard joystick) for navigating web documents. The results showed that the rate-based devices (mouse with joystick and mouse with in-keyboard joystick) were significantly faster than the position-based devices (standard mouse and mouse with a track wheel), while there was no significant difference found between the two rate-based devices and the two position-based devices.

User study of scrollbars, tap-and-drag and touch-n-go

[MacKay et al., 2005] did a field study to compare three navigation techniques (scrollbars, tap-and-drag and touch-n-go) on mobile devices. The target selection time data showed that the scrollbar technique was significantly slower than both the tap-and-drag and the touch-n-go technique in all of the three conditions (sit, stand, and walk), while there was no significant difference found between the tap-and-drag and touch-n-go. And by the results of participant rankings of ease of use and preference for navigation techniques, scrollbar was also ranked significantly lower than the other two, while no significant difference was found between the tap-and drag and touch-n-go. In addition, although the results for tap-and drag and touch-n-go are comparable, the participants' feedback showed that the touch-n-go technique is the most preferred on small devices, particularly if mobility is important, since it requires less manual effort. In contrast, the two-dimensional scrollbar was the least preferred since the moving horizontally and vertically can only be done separately, and many participants commented it was slow and inconvenient to use.

User study of Zoomable User Interface with Overviews

[Burigat et al., 2008] did a study to compare two Zoomable User Interfaces with Overviews (ZUIOs), a classic ZUIO and a Wireframe ZUIO, against a classic Zoomable User Interface (ZUI) to navigate three types of large information spaces, which are maps, diagrams, and web pages, on a relatively small screen, which is the mobile device screen in the experiment. The results showed that users spent significantly less time to search for targets in maps with Classic ZUIO than with Classic ZUI. Classic ZUIO required significantly fewer zoom actions than Classic ZUI in both MapTasks and DiagramTasks, while it also required significantly fewer pan actions than Classic ZUI in MapTasks. In the SpatialMemoryTask, the results showed that users made significantly less errors with Classic ZUIO than with Classic ZUI for maps. The authors concluded that the overviews bring enough benefits for navigating large information spaces and are worthy of using a part of the view area, if they highlight relevant semantic information that users can exploit during the search, and the structure of the information space does not intrinsically provide appropriate orientation cues.

User study of DimP

[Dragicevic et al., 2008] did user study to compare their interactive video player prototype DimP (Direct manipulation Player), which enables user to navigate the video by directly dragging objects in scene, with a traditional seeker bar. The results showed that the speed of navigating using DimP was at least 250% of that using seeker bar, in case that users were accurate with both techniques although it seemed to be more precise with DimP. The error rate by using DimP was also lower than that by using the seeker bar. Besides, the qualitative results showed that users preferred direct dragging than seeker bar because of the reason that direct dragging was easy to use, had immediate results with a high level of precision, allowed the user to interact with the video elements he/she was interested in, not just video as a whole, etc.

User study of digital audio navigation

[Lee, 2007] did a user study to quantitatively analyze the audio scrolling interfaces to compare rate and position control for navigating audio timeline. The study included three input devices: scroll ring, a rate control consisting of spring-loaded ring; jog dial, a position control using a solid dial; touch wheel, a position control which is touch-sensitive. The users were asked to locate a target between 90 and 100 seconds from the current playback position. The result showed that scroll ring (rate control) is significantly slower than both the jog dial (position control) and the touch wheel (position control), while no significant differences were between the two position control devices. The author concluded that position-based control performs better than rate-based control for closer search targets (90 to 100 seconds in the experiment), and believed that as the search target distance increases, the performance difference will become less significant and there exists a "crossover point", when rate-based control becomes superior. And the author took 100 seconds as a minimum upper boundary for this "crossover point".

Chapter 4

Navigation of digital media

In 2.2—“Navigation designs”, many types of input devices and software implemented navigation controls have been presented. And in 3—“Related work”, some important techniques were described in more details. By exploring the physical properties and navigation features of the existing navigation methods, five dimensions which describe the different aspects of navigation are concluded, which also reflect the different stages in navigation tasks. The five dimensions will be discussed in the following section. After that, a taxonomy according to the five dimensions will be given, which abstracts the navigation of digital media and is able to categorize navigation methods into groups. The proposed design space and evaluation block diagram which will be introduced later are generated based on this taxonomy.

4.1 Dimensions and taxonomy of navigation

Figure 4.1 shows an initial version of the design space which represents the dimensions and the taxonomy to be discussed in this section. It is presented here in order to give an visual and intuitive impression of how the taxonomy discussed below is used in the design space. The complete design space with more notations will be introduced in the next chapter.

1. Input

Absolute input

Relative input

The first dimension-"Input"

This dimension is similar to the one used in the Card's design space of input devices ([Card et al., 1991]). The difference is the "absolute/relative" property here does not mean the physical property of the input devices. Instead, it refers to the input property which is held when combing the use of an input device and a navigation control.

By this dimension, absolute input means the position or time point/ frame of the digital media is uniquely mapped to the position of the input. Locating to a specific input position at any time will definitely lead to the navigation to the same corresponding position or time point/ frame in the digital media. For example, scrollbar is an absolute input for navigating digital documents, since one position of the thumb in the scrollbar is uniquely mapped to a position in a document.

On the other hand, relative input does not have this one-to-one correspondence. Instead, it means the amount of change of the position or time duration in digital media is based on the amount of change of the input, regardless of the exact input position. For example, mouse wheel is a relative input for navigating digital documents, since the amount of document scrolling is based on the amount of mouse wheel scrolling, while there is no relation between the wheel position and document position.

Figure 4.1: The dimensions and the taxonomy in design space

2. Control

Position-based control

Rate-based control

The second dimension-"Control"

Position-based control means the navigation is done by changing the position of the navigation controls or input devices. For example, timeline slider is a kind of position-based control for navigation digital audio or digital video, since the navigating is through changing the thumb position in the timeline slider.

Rate-based control, also called speed-based control, is to use rate-based input devices or navigation controls to adjust the speed of sequential navigation. The navigation action of using rate-based control is only to change and control the navigation speed, while the navigation itself is done automatically. For example, using fast forward/ rewind button to navigate digital audio or digital video is a kind of rate-based control, since the user only needs to click the buttons for setting the playback rate, while the moving of the thumb in the timeline slider is done automatically.

3. Manipulation

Direct manipulation

Tool-based manipulation

The third dimension-"Manipulation"

Direct manipulation is a way to navigate by directly manipulating the digital media object itself. Examples include clicking and dragging the digital documents, maps, or pictures; navigating a piece of video by dragging an in-scene object to the desired position, etc. Currently, there is no navigation method using direct manipulation for audio contents.

Instead of directly manipulating the objects in the digital media content, tool-based navigation is to navigate the media by manipulating some kind of widgets or tools, specific input devices, or special features of input devices, etc. Manipulating scrollbar, thumbnails, timeline slider, etc. are all included in this category.

4. Access

*Continuous Access**

*Discrete Access**

*Random Access***

*Sequential Access***

The fourth dimension-"Access"

There are four kinds of information access properties. They are further classified into two groups (indicated by one-star mark and two-star mark), since they describe the different kinds of properties when accessing digital media contents. Every navigation method holds one property from the first group and one from the second group.

The first group focuses on the continuity of information access. Strictly speaking on technical, the generation and access of digital media is always discrete, since the digital audio and digital video consists of frames, while the picture consists of pixels. But in this work, when talking about continuous access , it refers to always accessing the next possible position or frame which is available to the user, with no accessible information to be skipped. Opposite to the continuous access, the discrete access means the next accessed information is not always the next possible information which is accessible for the user. The access may skip some parts of the information and directly jump to a position or frame. For example, dragging the thumb in the slider to navigate the document is continuous access, while navigating by selecting the thumbnails is discrete access, since it always jumps to the beginning of the selected page.

The second group focuses on the sequence of information access. Sequential access means the access can only be done sequentially along the position or frame of the digital media, either in an increasing sequence or a decreasing sequence. It could be continuous or discrete, but the order of the contents accessed should be the same as the order they exist in the media. On the opposite side, random access is to say that the user can jump to any accessible position or frame as desired, and does not need to follow the sequence the information appears. Furthermore, sequential access is a subset of the random access. Any navigation method which is able to do random access is also be able to do sequential access. For example, using page up/ page down key to navigate document is sequential access, since the user can only access the next page/ previous page by pressing the page down/ page up key; while using thumbnails to navigate can accomplish random access, since the user can click any thumbnail to go to the corresponding page as they wish, regardless the page sequence. And furthermore, using thumbnails can also accomplish sequential access by clicking the thumbnails one by one following the sequence of the pages.

Since a navigation method can hold one property from the first group and one from the second group, the access could be continuous & random, continuous & sequential, discrete & random, and discrete & sequential. An example for each of the four kinds of access is scrollbar, fast forward/ rewind button which increases the playback rate, thumbnails, and page up/ page down key, respectively.

5. Navigation/ Search

Arbitrary browsing

Targeted coordinate/ playback-position search

Targeted object position search

The fifth dimension- ”Navigation/Search”

This dimension addresses the final purpose of the navigation task, which is either browsing the digital media contents or searching for a specific target.

Arbitrary browsing is to browse or review the contents carried by the digital media, have an overview of the information delivered, or find something which may be interested to the user. It is often needed to know about what a document or a video clip is about.

Targeted search is further classified into targeted coordinate/playback-position search and targeted object-position search. Targeted coordinate/playback-position search aims at navigating digital document or picture/ interactive map to a certain coordinate position, or to navigate digital audio or digital video to a certain playback position; while targeted object-position search aims at finding the coordinate/playback position where or when a certain object in the digital media content is at a desired position or in a desired state. In this case, users do not navigate by locating a coordinate/playback position. Instead, they navigate by checking whether the targeted object has reached the desired position or state. For example, navigating to the scene when video time is at 5 minutes is targeted playback-position search, while navigating to the playback position when the first runner crosses the line is targeted object position search.

Especially, coordinate position is used for digital document and picture/ interactive map, and playback position is used for digital audio and digital video. The coordinate position also includes the meaning of targeted page numbers. And the object position for audio means a desired note or the start of a desired melody, etc.

4.2 Navigation methods

Having the taxonomy of navigation, the navigation methods can be grounded into families and thus to be analyzed in abstraction according to their properties.

In the following section, all the major existing navigation methods for the four digital media types addressed in this work will be listed. They are the ones which will be put into the design space and analyzed in later chapters. Since a navigation method is usually the combined use of an input device and a software implemented navigation control, as mentioned before, the navigation methods listed in the following section are mostly in the form of an input device plus a navigation control. Besides, the classification will be given for every kind of listed navigation methods according to the taxonomy described above. Since most navigation methods can do all the three kinds of navigation described in Navigation/ Search dimension, only the kinds of navigation which are not able to be done by the navigation method will be mentioned.

In addition, some enhanced techniques will also be listed below the original navigation methods. Although these enhanced navigation methods will not be directly included in the design space, since they are in the same category with the original one, some of them will be used for further analysis. After listing the navigation methods for each kind of digital media, a figure summarizes the properties of the navigation methods for this kind of digital media will be presented.

4.2.1 Digital document

1. Mouse/ Stylus/ Touch screen + Scrollbar

- Absolute input, Position-based control, Tool-based navigation, Continuous & Discrete & Random access

Enhanced:

Mouse/ Stylus/ Touch screen + Semantic scrolling

Mouse/ Stylus/ Touch screen + Speed-dependent automatic zooming

Mouse/ Stylus/ Touch screen + Rapid serial visual presentation

2. Mouse/ Stylus/ Touch screen + Thumbnail enhanced Scrollbar

- Absolute input, Position-based control, Tool-based navigation, Discrete & Random access

3. Mouse/ Stylus/ Touch screen + Thumbnails

- Absolute input, Position-based control, Tool-based navigation, Discrete & Random access

Enhanced:

Mouse/ Stylus/ Touch screen + Space-filling thumbnails

Mouse/ Stylus/ Touch screen + Bookmarks

4. Mouse/ Stylus/ Touch screen + Tap-and-drag

- Relative input, Position-based control, Direct manipulation, Continuous & Sequential access

5. Mouse wheel position-based/ Jog dial/ Click wheel Scrolling

- Relative input, Position-based control, Tool-based navigation, Continuous & Sequential access

Enhanced:

Mouse wheel position-based/ Jog dial/ Click wheel + Semantic scrolling

Mouse wheel position-based/ Jog dial/ Click wheel + Speed-dependent automatic zooming

6. Mouse wheel rate-based Scrolling

- Relative input, Rate-based control, Tool-based navigation, Continuous & Sequential access

Enhanced:

Mouse wheel rate-based Scrolling + Semantic scrolling

Mouse wheel rate-based Scrolling + Speed-dependent automatic zooming

Mouse wheel rate-based Scrolling + Rapid serial visual presentation

7. Keyboard up/down button Scrolling

- Relative input, Position-based control, Tool-based navigation, Continuous & Sequential access

Enhanced:

Keyboard up/down button + Semantic scrolling

8. Keyboard arrow keys + Thumbnails

- Relative input, Position-based control, Tool-based navigation, Discrete & Sequential access

Enhanced:

Keyboard arrow keys + Space-filling thumbnails

Keyboard arrow keys + Bookmarks

9. Keyboard page up/ page down button

- Relative input, Position-based control, Tool-based navigation, Discrete & Sequential access

10. TWEND

- Relative input, Position-based control, Direct manipulation & Tool-based navigation, Continuous & Discrete & Sequential access

11. Search Box ("Find" function)

- Relative input, Position-based control, Tool-based navigation, Discrete & Sequential access, only targeted object-position search is possible

12. "Page number" Input Box

- Absolute input, Position-based control, Tool-based navigation, Discrete & Random access

13. "Page number" increase/ decrease button

- Relative input, Position-based control, Tool-based navigation, Discrete & Sequential access

	Input		Control		Manipulation		Access				Navigation/ Search		
	Absolute	Relative	Position-based	Rate-based	Direct	Tool-based	Continuous	Discrete	Random	Sequential	Arbitrary browsing	Targeted coordinate / playback-position search	Targeted object position search
Mouse + Scrollbar	√		√			√	√	√	√	√	√	√	√
Mouse + Thumbnail enhanced Scrollbar	√		√			√		√	√	√	√	√	√
Mouse + Thumbnails	√		√			√		√	√	√	√	√	√
Mouse +Tap-and-drag		√	√		√		√			√	√	√	√
Mouse wheel position-based Scrolling		√	√			√	√			√	√	√	√
Mouse wheel rate-based Scrolling		√		√		√	√			√	√	√	√
Keyboard up/down button Scrolling		√	√			√	√			√	√	√	√
Keyboard arrow keys + Thumbnails		√	√			√		√		√	√	√	√
Keyboard page up/ page down button		√	√			√		√		√	√	√	√
TWEND		√	√		√	√	√	√		√	√	√	√
Search Box		√	√			√		√		√			√
'Page number' input Box	√		√			√		√	√	√	√	√	√
'Page no.' increase/ decrease button		√	√			√		√		√	√	√	√

Figure 4.2: Summary of navigation methods for digital document

4.2.2 Picture/ Interactive map

1. Mouse/ Stylus/ Touch screen + Scrollbar

- Absolute input, Position-based control, Tool-based navigation, Continuous & Discrete & Random access

2. Mouse/ Stylus/ Touch screen + Tap-and-drag

- Relative input, Position-based control, Direct manipulation, Continuous & Sequential access

3. Mouse/ Stylus/ Touch screen + Touch-and-go

- Relative input, Position-based control, Direct manipulation, Continuous & Sequential access, targeted coordinate-position search not possible

4. Mouse/ Stylus/ Touch screen + Planar

- Relative input, Position-based control, Tool-based navigation, Continuous & Discrete & Sequential access, targeted coordinate-position search not possible

5. Keyboard arrow keys for moving and +/- key for zoom in/out

- Relative input, Position-based control, Tool-based navigation, Continuous & Sequential access

6. Joystick

- Relative input, Rate-based control, Tool-based navigation, Continuous & Sequential access

7. TWEND

- Relative input, Rate-based control, Tool-based navigation, Continuous & Sequential access

8. Search Box

- Relative input, Position-based control, Tool-based navigation, Discrete & Random access, only targeted object-position search possible

	Input		Control		Manipulation		Access				Navigation/ Search		
	Absolute	Relative	Position-based	Rate-based	Direct	Tool-based	Continuous	Discrete	Random	Sequential	Arbitrary browsing	Targeted coordinate / playback-position search	Targeted object position search
Mouse + Scrollbar	√		√			√	√	√	√	√	√	√	√
Mouse +Tap-and-drag		√	√		√		√			√	√	√	√
Mouse +Touch-n-go		√	√		√		√			√	√		√
Mouse + Planar		√	√			√	√	√		√	√		√
Arrow keys for moving +/- for zoom in/out		√	√			√	√			√	√	√	√
Joystick		√		√		√	√			√	√	√	√
TWEND		√		√		√	√			√	√	√	√
Search Box		√	√			√		√	√	√			√

Figure 4.3: Summary of navigation methods for picture/ interactive map

4.2.3 Digital audio

1. Mouse/ Stylus/ Touch Screen + Timeline slider

- Absolute input, Position-based control, Tool-based navigation, Discrete & Random access

Enhanced:

Mouse/ Stylus/ Touch Screen + Zoomable timeline slider

Mouse/ Stylus/ Touch Screen + Position-based navigation with intelligible audio feedback

2. Mouse/ Stylus/ Touch Screen + Fast forward/ Rewind button (increasing playback rate)

- Relative input, Rate-based control, Tool-based navigation, Continuous & Sequential access

3. Mouse/ Stylus/ Touch Screen + Fast forward/ Rewind button (frame skipping)

- Relative input, Rate-based control, Tool-based navigation, Discrete & Sequential access, targeted playback-position search not possible

4. Shuttle wheel (Spring loaded)

- Relative input, Rate-based control, Tool-based navigation, Continuous & Sequential access

5. Jog dial/ Click wheel

- Relative input, Position-based control, Tool-based navigation, Discrete & Sequential access

Enhanced:

Jog dial/ Click wheel + position based navigation with intelligible audio feedback

	Input		Control		Manipulation		Access				Navigation/ Search		
	Absolute	Relative	Position-based	Rate-based	Direct	Tool-based	Continuous	Discrete	Random	Sequential	Arbitrary browsing	Targeted coordinate / playback-position search	Targeted object position search
Mouse + Timeline slider	√		√			√		√	√	√	√	√	√
FF/ RWD button (increasing playback rate)		√		√		√	√			√	√	√	√
FF/ RWD button (frame skipping)		√		√		√		√		√	√		√
Shuttle wheel (Spring loaded)		√		√		√	√			√	√	√	√
Jog dial/ Click wheel		√	√			√		√		√	√	√	√

Figure 4.4: Summary of navigation methods for digital audio

4.2.4 Digital video

1. Mouse/ Stylus/ Touch screen + Timeline slider

- Absolute input, Position-based control, Tool-based navigation, Discrete & Random access

Enhanced:

Mouse/ Stylus/ Touch screen + Zoomable timeline slider

2. Mouse/ Stylus/ Touch screen + Fisheye-style warped timeline

- Absolute input, Position-based control, Tool-based navigation, Discrete & Random access, targeted playback-position search not possible

3. Mouse/ Stylus/ Touch screen + Static or dynamic storyboards

- Absolute input, Position-based control, Tool-based navigation, Discrete & Random access, targeted playback-position search not possible

4. Mouse/ Stylus/ Touch screen + Fast forward/ Rewind button (increasing playback rate)

- Relative input, Rate-based control, Tool-based navigation, Continuous & Sequential access

5. Mouse/ Stylus/ Touch screen + Fast forward/ Rewind button (frame skipping)

- Relative input, Rate-based control, Tool-based navigation, Discrete & Sequential access, targeted playback-position search not possible

6. Shuttle wheel (Spring loaded)

- Relative input, Rate-based control, Tool-based navigation, Continuous & Sequential access

7. Jog dial/ Click wheel

- Relative input, Position-based control, Tool-based navigation, Discrete & Sequential access

8. Dragon

- Absolute input, Position-based control, Direct manipulation, Continuous & Sequential access, targeted playback-position search not possible

	Input		Control		Manipulation		Access				Navigation/ Search		
	Absolute	Relative	Position-based	Rate-based	Direct	Tool-based	Continuous	Discrete	Random	Sequential	Arbitrary browsing	Targeted coordinate / playback-position search	Targeted object position search
Mouse + Timeline slider	√		√			√		√	√	√	√	√	√
Mouse + Fisheye-style warped timeline	√		√			√		√	√	√	√		√
Mouse + Static or dynamic storyboards	√		√			√		√	√	√	√		√
FF/ RWD button (playback rate)		√		√		√	√			√	√	√	√
FF/ RWD button (frame skipping)		√		√		√		√		√	√		√
Shuttle wheel (Spring loaded)		√		√		√	√			√	√	√	√
Jog dial/ Click wheel		√	√			√		√		√	√	√	√
Dragon	√		√		√		√			√	√		√

Figure 4.5: Summary of navigation methods for digital video

Chapter 5

Design space

With the taxonomy of navigation given, the proposed design space will be presented in this chapter. An overview of the design space will be taken at first, with the notation and representation to be explained. Some analysis methodologies and guidelines about how to use the design space are going to be discussed afterward. After that, a comprehensive look at the navigation methods in the four addressed types of digital media will be taken. By using the design space, the current navigation methods and some suggested future designs will be analyzed.

5.1 Design space

5.1.1 Overview

Based on the taxonomy given in the previous chapter, a table-formed six-dimensional design space can be generated (the "Access" dimension is divided into two subdimensions in the design space according to the two groups described before). The classifications of the dimensions which describe the design space are consistent with the given taxonomy of navigation, which classify the properties of navigation. With the structure of the design space, every kind of navigation property discussed in the previous chapter can be presented by a square.

Overview of design space

As shown in Figure 5.1, the three dimensions in the lower part of the design space describe the “Input”, “Control”, and “Manipulation” properties; the upper part describes the first group of the “Access” property, and the right part describes the second group of the “Access” property; the left part describes the “Navigation/ Search” dimension, which represents the target of the navigation task. With the six dimensions, the design space is consisted with 96 squares which represent 96 combinations of navigation properties. Out of the 96 combinations, there are 24 combinations which are not possible. They are represented by “trellis shading” in the design space and are called “blind spot” of navigation in the work. More detailed design rationales will be discussed in the next section.

5.1.2 Design rationale

Shading implication

As can be observed from the design space, the color deepness of the shading for each square slightly increases from the left part to the right part; and from the lower part to the upper part as well. This shading deepness change is introduced to imply that the properties represented by the right upper part of the design space are preferred to the ones represented by the left lower part of the design space. Hence, for every dimension, the more preferred properties are laid out to the right or to the upper part of the less preferred properties. The reason to organize the design space in this way and to use the shading deepness as a visual implication is that it is very easy for the designer to roughly tell how good a design is by looking at in which part of the design space the design lays. And it tells the designers to try to design the navigation methods which have the properties described in the right upper part of the design space.

However, although there exists the implication that the properties in the right upper part are preferred to the ones in the left lower part, it is not necessary to say that a navigation method must outperform another one which lays in the left lower part of it. The reason for this is we can only say the properties in the right upper part are preferred in a

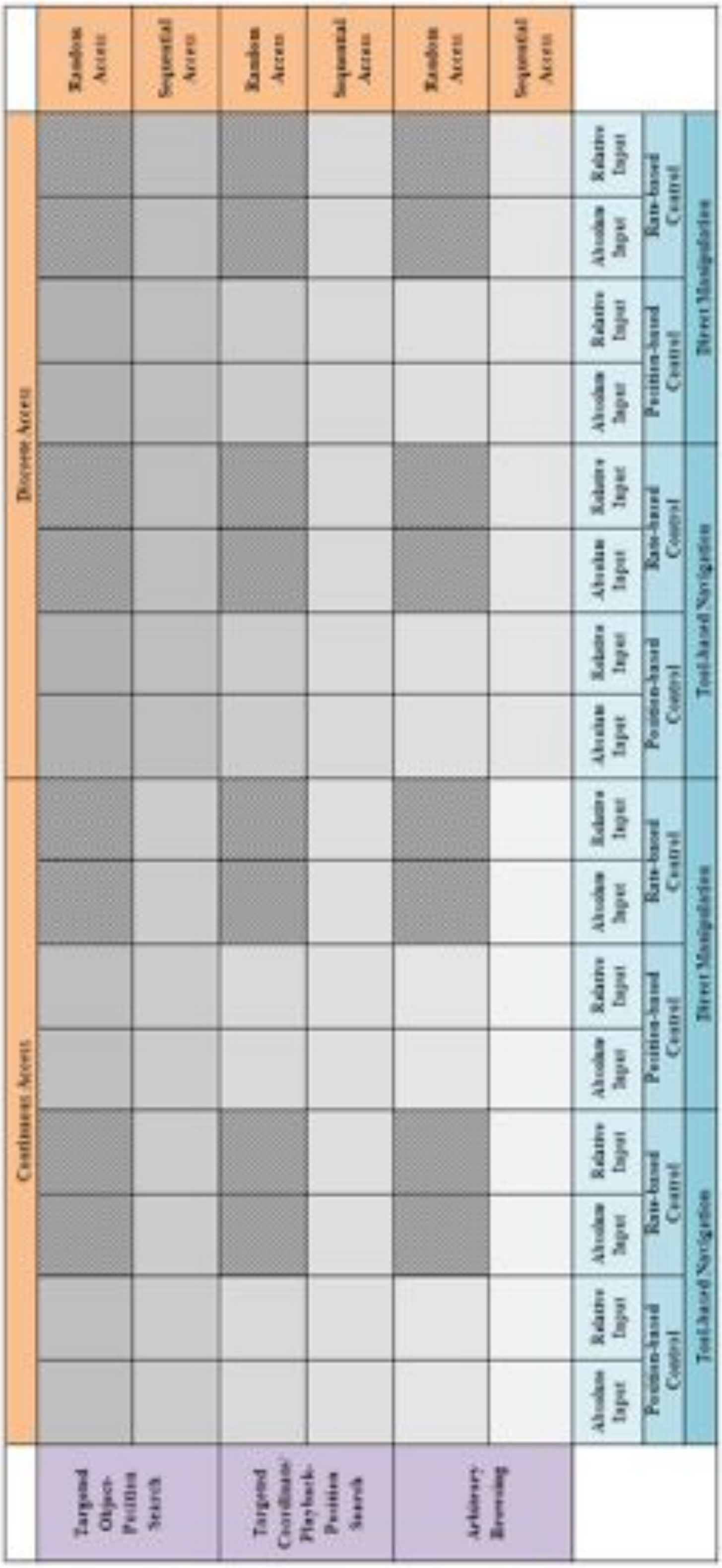

Figure 5.1: Design space overview

large part of the navigation tasks, but not all. The preferred properties for different navigation tasks are different. And for some dimensions, one property is laid to the right or upper side of the other one is just because it has some obvious advantages against the other one, or it is suggested in the future design, but it doesn't necessarily outperform the other one in all navigation tasks. But still, the trend from the left lower part to the right upper part can be very useful to quickly and roughly evaluate the navigation methods.

Design rationale

The following paragraphs are going to discuss about the rationale for the layout of each dimension.

Design rationale of "Input"

Input This is the only dimension in which there is no preferred property. Absolute input and relative input are the physical properties determined by the input devices or input controls. It just describes how the input works when used to navigate. Hence, whether the input is absolute or relative does not have much impact on the navigation performance.

Design rationale of "Control"

Control Since the way of rate-based control decides that it can only access the information sequentially, because users use rate-based control by changing the speed of automatic navigation, which is usually sequential scrolling or playing, we can only compare it with position-based control when the navigation is done by sequential access. As discussed previously, position-based control navigates the digital media by changing the position of the control mechanism. Hence, if the user needs to browse through the whole media content to search for the desired target, rate-based control can increase the navigation speed in less interested places. And if the user has to sequentially navigate to a target far away from the current position, rate-based control can reach the target at a higher speed than position-based control. However, it may be not true if the user needs to navigate a very short document or a very short video clip. In this case, speed does not have advantage any more. Instead, position-based control will be easier to control than rate-based control. And it is also more accurate than rate-based control if the user needs to locate precisely to a specific position. Nevertheless, rate-based control is still laid at the right side of position-based control, since the navigation length is not that short in most cases, and the length of the document, audio, or video nowadays becomes longer and longer. Thus, we believe that in most cases, rate-based control can outperform the position-based control in sequential access. There are some empirical data to support this argument.

The experiment results in [Hinckley et al., 2002] presented a crossover effect to prove that when the document length becomes longer, the rate-based scrolling will outperform the position-based scrolling. The user study in [Zhai et al., 1997] showed that rate-based scrolling is significantly faster than position-based scrolling for navigating web-based documents. The comparison evaluation did in [Lee, 2007] showed that position-based control is better than rate-based control for locating a target between 90s and 100s in audio navigation. But the authors also believed that there exists a crossover where the rate-based control will exceed position-based control. And in real navigation tasks, the target to be searched for will not be in such a short distance like that in the experiment, which is shorter than 2 minutes.

Design rationale of "Manipulation"

Manipulation The most navigation methods today are tool-based. That means the user needs to manipulate some widgets to navigate the digital media. There are few direct manipulation techniques up to now. The well known technique for document and picture/ map navigation is drag-and-drop. And in these years, some direct manipulation techniques have appeared for navigating digital video. For some tasks, tool-based navigation can be more powerful than direct manipulation. For example, if the user needs to browse a video clip, direct navigation is not applicable for doing that. However, the reason why direct manipulation is laid at the right side of tool-based navigation is because it is more accurate and more natural. The advantages of direct manipulation for digital video have been discussed in 2.2—"Navigation designs". For interactive map navigation, it is more flexible than the two-dimensional scrolling bar. Therefore, designing more navigation methods using direct manipulation techniques is suggested.

In [Karrer et al., 2008], the user study showed that DRAGON, a direct manipulation video navigation technique, significantly reduces the task completion time for in-scene navigation tasks by an average of 19–42% compared to a standard timeline slider. In [Dragicevic et al., 2008], the evaluation results showed that navigating using DimP, another direct manipulation video navigation technique, was at least 250% faster than using seeker bar. The error rate by using DimP was also lower than that by using seeker bar. Users' feedback also showed that direct manipulation is easy to use, more natural, and has immediate results with a high level of precision. In [MacKay et al., 2005], the target selection time data showed that the scrollbar technique (tool-based control) was significantly slower than both the tap-and-drag and the touch-n-go technique (both are direct manipulation techniques) in all of the three conditions (sit, stand, and walk).

Design rationale of "Access"

Access Since continuous access needs to go through any available information contained in the digital media, the time for going through the uninterested contents thus cannot be saved. On the contrary, discrete access can jump between some predefined positions or frames. But the problem of discrete access is if visiting the predefined positions or frames cannot make users be able to access all the contents in the media, users may miss the information they want. Therefore, in the case if both access methods can make users be able to access all the information, discrete access then is regarded to be a more efficient way than continuous access to navigate digital media. Thus, discrete access is laid at the right side of continuous access. A user study has been done in this work to prove this hypothesis. The results will be presented and analyzed in the validation part.

Random access is laid at the upper part of sequential access. Navigating by sequential access can only access in the sequence the information contents are organized, even though the user knows where the desired position or frame is. The contents in-between the current position or frame and the desired position or frame cannot be skipped anyway. On the opposite, by random access, the user has full flexibility to locate to any position or frame that is accessible, regardless of the sequence. Furthermore, sequential access is a subset of random access because any navigation method which enables random access can be used to access the information sequentially, since the user has the full flexibility to decide where to go, and thus he/she can access in the sequence of the contents. Also, a user study has been done in this work to prove this hypothesis. The results will be presented and analyzed in the validation part.

Design rationale of "Navigation/Search"

Navigation/ Search From top to bottom, the order of layout are targeted object-position search, targeted coordinate/ playback-position search, and arbitrary browsing. This is consistent with the purpose of navigation. The final goal of a navigation task is to find the object position in the media. It could be a sentence in the document, a place in the map, a certain word in an audio clip, or a certain object in the video being in a desired place. Hence, if the navigation methods can directly find the targeted object position, it is the most preferred. Targeted coordinate/ playback-position is the second preferred, since finding the correct coordinate/ playback position is a way leading to the targeted object position, and coordinate/ playback position is always what the user needs to adjust when doing a navigation task. Arbitrary browsing, although commonly used, is the least preferred, since it never provides a way directly go to a target. Users have to locate the target by manual browsing of the contents.

Blind Spot

Blind Spot As mentioned before, the rate-based control itself determines that it is only possible for sequential access, since the user can only change the navigation rate while the navigation itself is automatic (scrolling, playing, etc.). Therefore, the 24 squares in the design space which combine the properties of rate-based control and random access are not possible for navigation methods. Thus, they are considered as invalid squares called "blind spots" and represented by "trellis shading". Hence, there are totally 72 valid squares in the design space.

Color Metaphor

Color Metaphor To clearly distinguish the dimensions in the design space, different colors are used to indicate different navigation properties. The three dimensions at the lower part of the design space address the control the navigation. They are indicated by blue color, with the color from light to dark to indicate the features along the navigation process. The ”Access” properties, which are at the top and right side of the design space, are indicated by orange color. And the search types which are at the left side are indicated by purple color.

5.1.3 Notations and representation

Effort indicator

Before presenting the notations and representation used in the design space, another navigation property which has a big effect on the navigation performance is going to be introduced. This property measures the amount of efforts a user needs to pay when executing a navigation task using a navigation method. This property is classified into four levels as following.

Direct positioning

Confirmation needed

With the help of predefined frames

Totally manual search

From the first to the fourth measure, the efforts the user needs to pay for finishing the navigation task increases.

“Direct positioning” means there is no manual search effort from the user’s side is needed, after telling the machine what he/she wants to have. In this case, the navigation method will take over all the search responsibilities, and find the unique correct target for the user. For example, if the user type a page number in the “page number” input box and press enter, the navigation method will definitely lead you to the targeted page of the page number given. No extra manual effort is needed.

“Confirmation needed” means the effort needed from the user’s side is to confirm the correctness of the search result given by the navigation method, or to select one from the several possible results the navigation method provides. In this case, the navigation method also does the search work for the user according to his/her requirement, but the user has to confirm whether the given result is the desired one, or to choose one from several candidate results. For example, if the user types some keywords in the search box, the navigation method will lead him/ her to the position where the keywords are included. But since there may be several positions have the keywords included, the user has to confirm whether the first given one is correct. If not, he/she has to choose the desired one from several candidate results.

“With the help of predefined frames” means the user has to search for the target manually, often visually or acoustically. But the navigation method provides some predefined frames to give the user some information about the contents, so that the user can have some clues or hints to find the target more quickly. Using predefined frames is a very helpful technique for accelerating the navigation speed. We will discuss it in more details later in this work. For example, fish-eye style timeline slider is a kind of navigation method with predefined frames. With the small screenshots, the user can get an idea of which part of the video is about which topic. And this information will make user locate to the desired part easier.

“Totally manual search”, which requires the most efforts from the user, means the search task is totally done by the user’s manual search. The navigation method only plays the role for manipulating the digital media, but it does not help to find the target at all. For example, traditional scrollbar and timeline slider both belong to this group, since the only thing the user can do with the navigation methods is dragging the thumb in the scrollbar to scroll the document or dragging the thumb in the timeline slider to browse the video. And users need to read or browse the whole media content to search for the target.

While other navigation properties are represented by the corresponding squares in the design space, the four “effort indicators" will be represented by some extra signs filled in the squares. And they will be presented by different kinds of lines in the "evaluation block diagram". Both will be introduced in the following sections.

Notations and representation

Notations and representation of design space

Figure 5.2, 5.3, 5.4, and 5.5 are the examples of the design spaces for the four types of digital media which include some of the navigation methods. The notations and representation in design space include the following rules.

Properties of navigation methods are circles in the corresponding squares

It has been discussed in 5.1.1—"Overview" that each square (totally 72 valid squares) in the design space represents a combination of some navigation properties. Therefore, when representing a navigation method in the design space, a circle in a square represents that the navigation method has the properties indicated by this square. To completely represent all the properties of a navigation method, the designer can position circles in all the squares which indicate the properties of the navigation method.

Extra signs in the circles are the "effort indicators"

To present the four user's effort levels , which were just discussed, extra signs are added in the circle. No sign is added if it represents "direct positioning"; a "plus" sign is added if it represents "confirmation needed"; a smaller circle is added if it represents "with the help of predefined frames"; a "cross" sign is added if it represents "totally manual search".

Circles belong to the same navigation method are connected by black lines

If the circles belong to the same navigation method, they are connected by black lines. The connected circles and black lines are regarded as a whole to represent a navigation method.

Dashed lines with arrow represent navigation causality

If the work of one navigation method will trigger the work of another one, then a dashed line with an arrow drawn from the first navigation method to the second one, with the arrow pointing to the latter one, is used to represent this navigation causality. Since the circles connected by black lines are regarded as a whole to represent a navigation method, the dashed line can be drawn from any circle of the first navigation method to any circle of the second one.

For example, when the user uses tap-and-drag to navigate the document or map, the thumbs in the scrollbar will also move correspondingly. Thus, there exists causality between the two navigation methods. Drag-and-drop can cause the work of scrollbar. And therefore, a dashed line is drawn from a circle of tap-and-drag to a circle of scrollbar (Figure 5.2).

If the second navigation method is also the cause of the first one, then a dashed line with double arrows should be drawn between them. An example could be scrollbar and "page number" input box.

5.1.4 Analysis methodology and guidelines

Steps to represent navigation methods in design space

When analyzing the navigation methods designed for an application, the designer can firstly make the navigation methods represented in the design space. Following steps can be done to accomplish this easy task.

1. Start with one of the navigation methods. Position circles in the corresponding squares which represent the properties hold by the navigation method.

2. Add "effort indicators" into the circles.

3. Connect the circles which belong to this same navigation method with black lines.

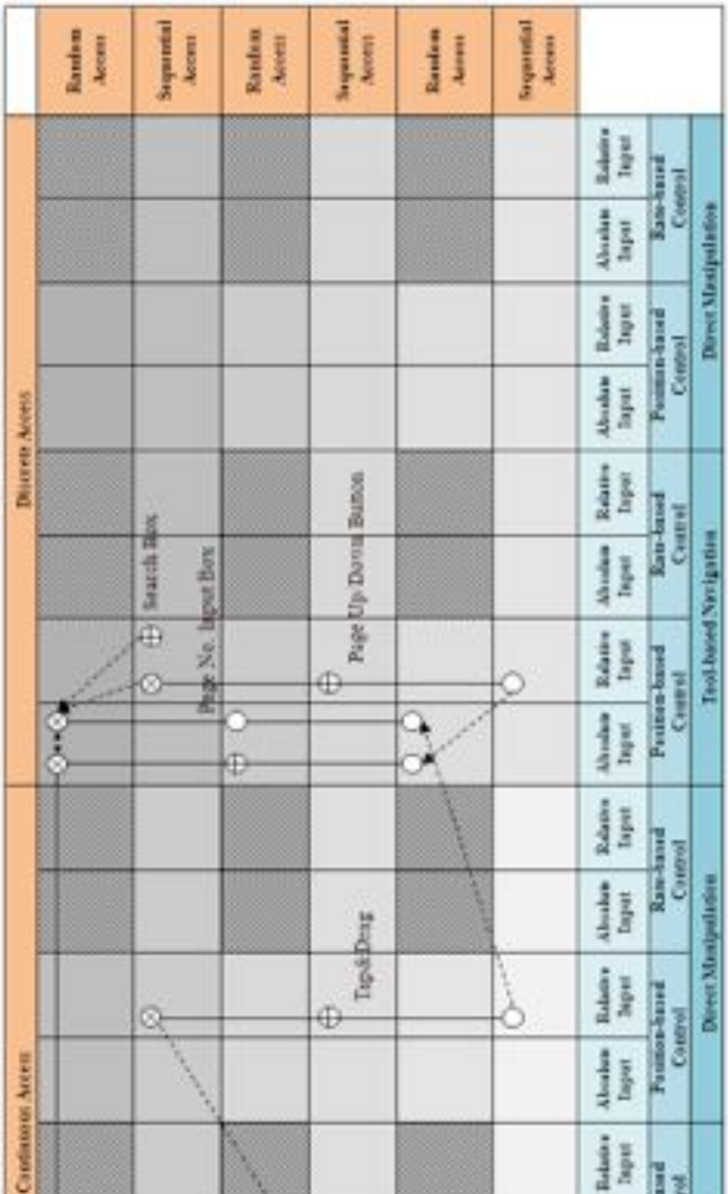

Figure 5.2: Notation of design space for digital document

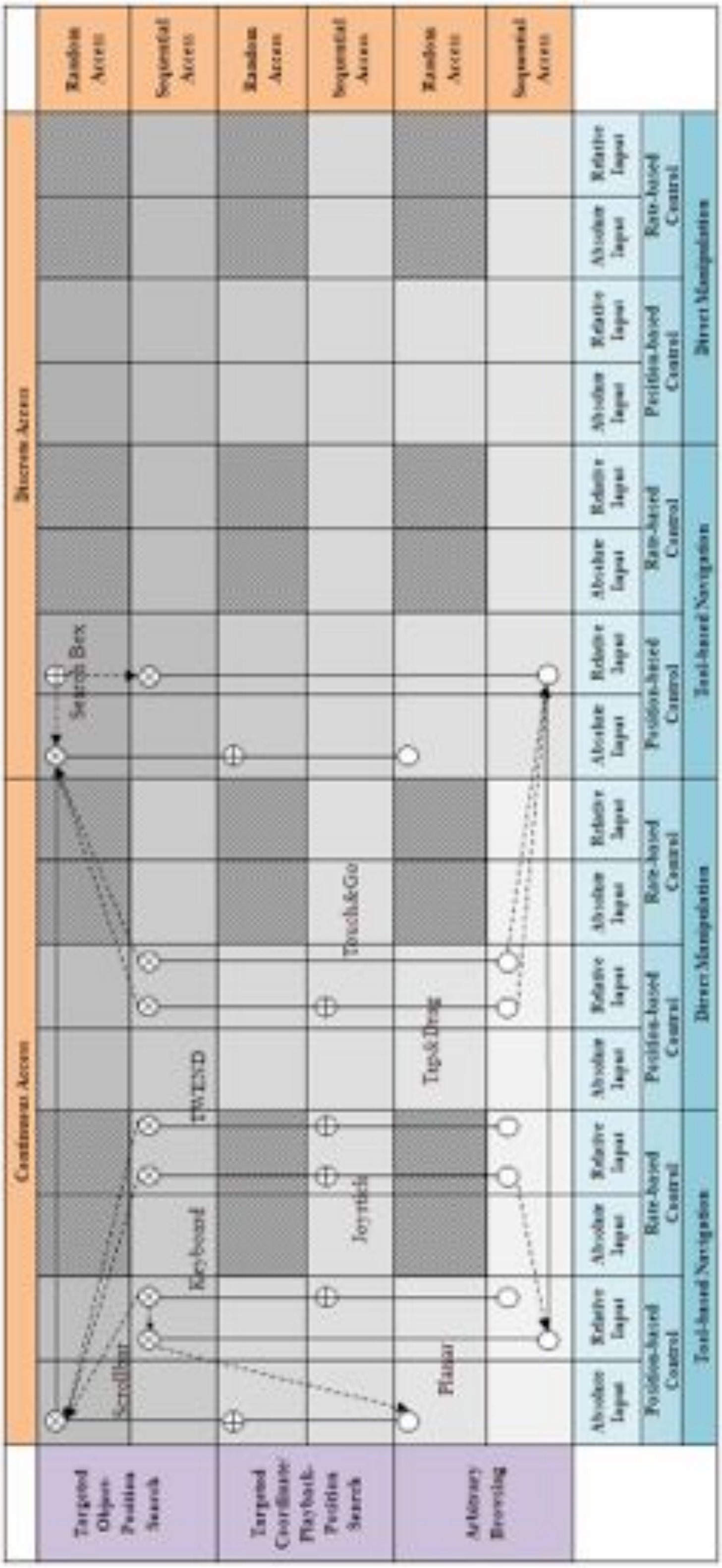

Figure 5.3: Notation of design space for picture / interactive map

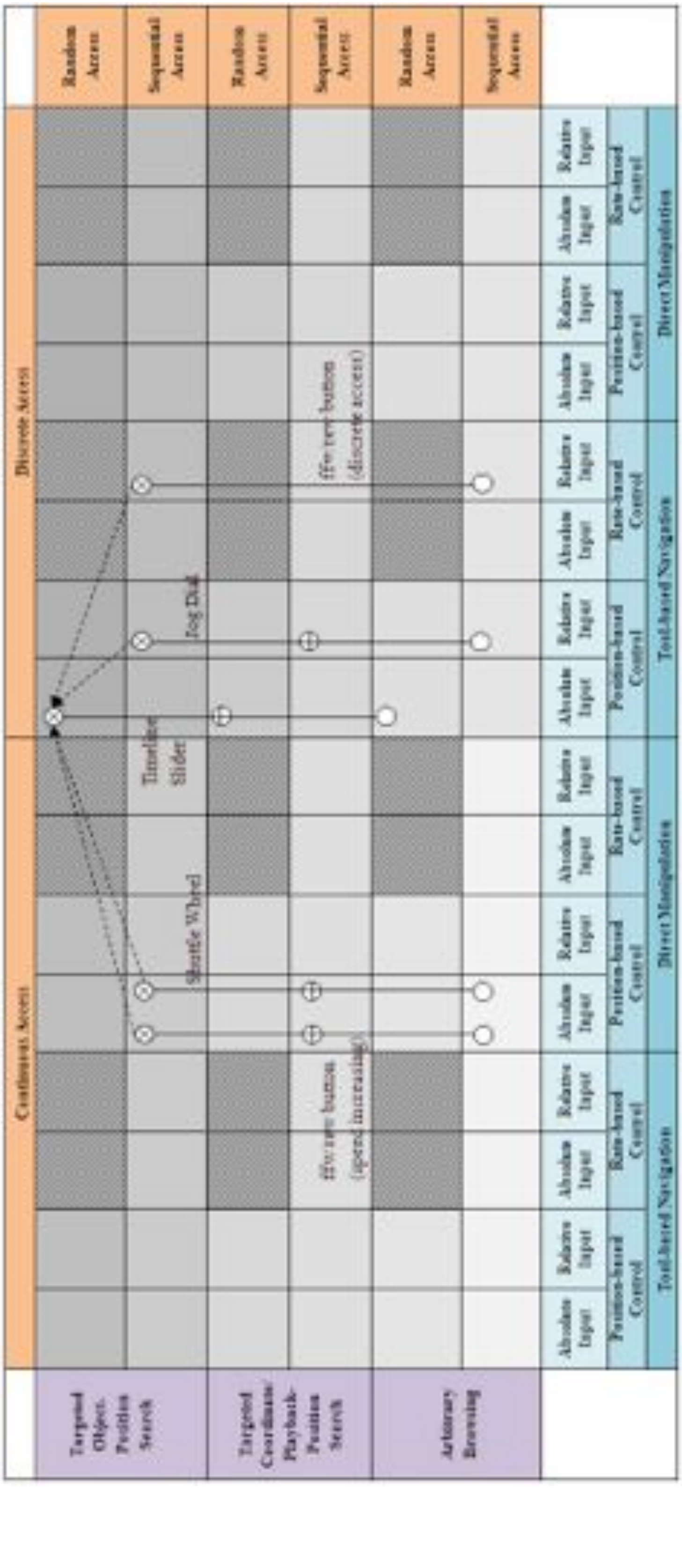

Figure 5.4: Notation of design space for digital audio

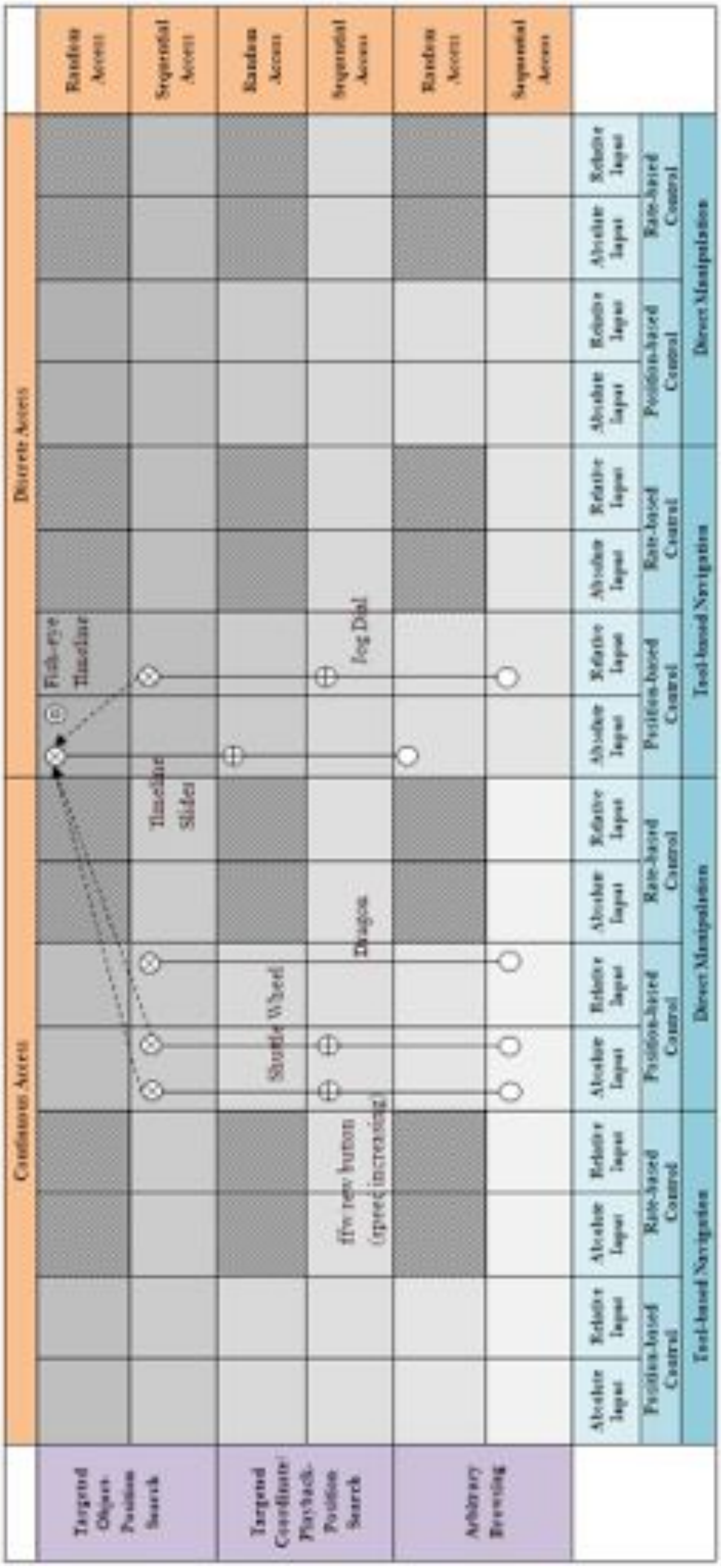

Figure 5.5: Notation of design space for digital video

4. Redo the above 3 steps to represent all the other navigation methods.

5. Check whether there exists causality between every two navigation methods, and add dashed lines with arrow if needed.

By doing the above steps, the total design of navigation methods is represented in the design space, and thus can be evaluated by the methodologies this framework provides.

Analysis guidelines

Since we want to provide as many as navigation features to the user, and to provide a monotonous navigation environment as well, which means duplicated navigation methods for accomplishing the same navigation effect are not wanted, following analysis guidelines are suggested. (A and B are used to represent two navigation methods here.)

If A points to B and A does not outperform or compensate B in some dimensions, A is considered to be redundant with regard to B.

If one navigation method points to the other one, it tells that the manipulation of it will cause the work of the other one. That means manipulating the navigation method is to indirectly manipulate the other one, and then to have navigation effect on the digital media. Therefore, if the first navigation method does not provide any feature which outperforms the second navigation method, the first one has no meaning to be implemented, since the second one could accomplish anything the first one could, and it can directly have effect on the digital media, with no other navigation methods in-between.

For example, as shown in Figure 5.2, tap-and-drag points to scrollbar. Tap-and drag does not outperform scrollbar in any other dimensions except that it is direct manipulation which compensates the scrollbar. But for navigating digital documents, direct manipulation has no advantage against tool-based navigation in most cases. Therefore, in the application for which direct manipulation does not have advantage against tool-based navigation, tap-and-drag could be considered to be removed from the implementation.

However, if the application is for interactive map, for which direct manipulation could be more efficient than tool-based navigation, then tap-and-drag should be retained.

If A and B fit into same squares and have same "effort indicators", only the one with better usability need to be considered to be implemented.

If the representations of two navigation methods in the design space are totally the same, it implies that the two navigation methods hold the same navigation properties, which means the performance of them should be similar. In this case, the designer could consider choosing only one of them with better usability to implement in the application.

If A is a subset of B, A may not need to be implemented.

If one navigation method is a subset of the other one, it means that the second one holds all the properties the first one holds. In this case, what could be accomplished by the first one could also probably be accomplished by the second one. Therefore, the first navigation method could be considered to be removed from the implementation.

If B outperforms A in some dimensions and A does not outperform B in any dimension, A may not need to be implemented.

In this case, A does not have any feature which can outperform B from the observation by the design space. Therefore, if the ways of A and B to navigate digital media are similar, A could be considered to be removed from the implementation.

By the above four guidelines, the designer can eliminate the redundant and unnecessary implementation of navigation methods, thus to accomplish the goal of providing users a monotonous navigation environment. Besides, by representing all the navigation methods in the design space, the designer can also easily figure out which properties have not been included in the current design, and thus to

Implement other navigation methods to compensate the capabilities which the current ones do not have.

The designer can figure out the squares which represent the properties that are not included in the current design but are needed by the application, and then to find suitable navigation methods which fit into these squares, or to design new navigation methods to compensate these properties.

5.2 A comprehensive look at the navigation methods in digital media

In this chapter, all the major existing navigation methods for the four types of digital media will be represented in the design space. By doing this, a comprehensive look will be taken at the state of the art of current navigation method designs. Also, the shortages of the current designs and rooms for improvement will be explored. And afterwards, some future design suggestions will be proposed.

Notations of effort indicator

For including all the navigation methods for a digital media type in a design space and having a comprehensive look at them, the navigation methods are represented by numbers in the design space. Similar with the representation of "effort indicators" added in the circles, which is introduced in 5.1.3—"Notations and representation", no extra sign means "direct positioning"; "plus" sign represents "confirmation needed"; "small circle" sign represents "with the help of predefined frames"; and "cross" sign represents "totally manual search". The difference is the signs are added after the numbers here.

5.2.1 Digital document

Current design overview

By examining the design space for digital document (Figure 5.6), findings obtained from observing the current navigation method designs include:

Current design situation of navigation in digital document

Most navigation methods are tool-based and position-based control.

For sequential access, there are fewer navigation methods with rate-based control than that with position-based control.

There are very few navigation methods which use direct manipulation techniques.

Most navigation methods with continuous access can do sequential access only.

Almost all targeted object-position search methods require user's manual visual search effort.

Future design suggestions

For any digital media, the goal of a good navigation method is to correctly locate the desired information in the digital media as fast as possible. For digital documents, the most navigation tasks executed by the user are browsing the content of a new document, searching for the interested or targeted information in the document, or locating the interested parts of information in a document which was read before. Hence, what a good navigation method should do is to help users finish these tasks as fast as possible. Combining these goals and the finding of current designs concluded above, the following design suggestions are proposed.

Future design suggestions for navigation in digital document

Design more navigation methods with rate-based control for sequential access.

As has been discussed in 5.1.2—"Design rationale", rate-based control can make the navigation time for longer documents shorter than position-based control if the access is sequential. Since the length of today's digital documents becomes longer and longer, especially for e-books, implementing the feature of rate-based control can speed up user's browsing speed to some extent.

Design semantic direct manipulation techniques for digital documents.

Previously, the most known direct manipulation technique for digital document is tap-and-drag. But actually this direct manipulation technique does not help a lot for navigating digital documents. The reason for this is unlike interactive map or video, in which the direct manipulation can give user more flexible control, make user get rid of the two-dimensional navigation, or enables a more accurate control, the tap-and-drag technique for navigating digital documents does not have these advantages. Furthermore, it makes the navigation very slow, which requires continuous user actions to drag the document. Recently, TWEND improves this disadvantage by mimicking the page flipping as it enables discrete access page by page.

However, direct manipulation can be more helpful if it is semantic. Since direct manipulation may enable users to interact directly with the contents, the user may be able to use the contents of the current selection or current focus as the information to navigate to the desired parts. For example, selecting a word may give user the option to locate to its definition in the same document if any; selecting a paragraph may give user the information about the locations of the paragraphs about the same topic; or pointing to a picture in the document may give user the option to lead to the related discussion in the document, etc.

Provide user the possibility to access randomly together with continuous access.

Since most of the current navigation methods with continuous access can only do sequential access, it is suggested that the feature of random access should also be implemented. Continuous access is a natural way for reading the document, but with random access provided, users will have more flexibility to locate among different parts of the document. An example is scrollbar, it enables users to access continuously, but user can also randomly locate to any position they want by clicking the corresponding position in the scrollbar, if the setting of "click" on the scrollbar is "jump here" instead of "jump to the next page". However, this setting of the scrollbar introduces modes.

Reduce user's manual effort for targeted search.

It can be observed from the design space that all but one targeted object-position search method require totally manual search of the content by the user. It means that the navigation methods do not give any help to the user for finding the desired target. To improve this, the technique of "predefined frames" can be used. The navigation methods could provide user some information about the content, e.g. using bookmarks, indicating positions of chapter change, etc., to help users navigate more quickly, instead of searching for everything visually. Besides, the navigation methods could log user's navigation history, indicate those places where the user visited most often or most recently. A good example is the footprint scrollbar introduced in [Alexander et al., 2009], it remembers the important places for the user, so that it can help users locate to the possible interested positions more quickly. And the small thumbnails can enable users to have a concept of what the page is about without having to navigate to this page first.

	Continuous Access								Discrete Access								
	Tool-based Navigation				Direct Manipulation				Tool-based Navigation				Direct Manipulation				
	Position-based Control		Rate-based Control		Position-based Control		Rate-based Control		Position-based Control		Rate-based Control		Position-based Control		Rate-based Control		
	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	
Targeted Object-Position Search	1o								1o, 2o 3o, 12o								Random Access
		5o, 7o		6o, 10o		4o				8o, 9o, 10o, 11+ 13o				10o			Sequential Access
Targeted Coordinate/Playback-Position Search	1+								1+, 2+ 3+, 12								Random Access
		5+, 7+		6+, 10+		4+				8+, 9+ 10+ 13+				10+			Sequential Access
Arbitrary Browsing	1								1, 2 3, 12								Random Access
		5, 7		6, 10		4				8, 9 10 13				10			Sequential Access

Figure 5.6: Design space for digital document

Notations:

1. Mouse/ Stylus/ Touch screen + Scrollbar

2. Mouse/ Stylus/ Touch screen + Thumbnail enhanced Scrollbar

3. Mouse/ Stylus/ Touch screen + Thumbnails

4. Mouse/ Stylus/ Touch screen + Tap-and-drag

5. Mouse wheel position-based/ Jog dial/ Click wheel Scrolling

6. Mouse wheel rate-based Scrolling

7. Keyboard up/down button Scrolling

8. Keyboard arrow keys + Thumbnails

9. Keyboard page up/ page down button

10. TWEND

11. Search Box ("Find" function)

12. "Page number" Input Box

13. "Page number" increase/ decrease button

5.2.2 Picture/ Interactive map

Current design overview

Current design situation of navigation in picture/interactive map

By examining the design space for picture/ interactive map (Figure 5.7), findings obtained from observing the current navigation method designs include:

Most navigation methods are tool-based; few are with direct manipulation.

Most navigation methods are continuous access; few are discrete access.

Almost all targeted object-position search methods require user's manual visual search effort.

Future design suggestions

Future design suggestions for navigation in picture/interactive map

The biggest problem for navigating a large scale and high information density picture or an interactive map is that the user has no information about the position, distance, and direction of the desired target in most cases. Thus, searching for the target in such a complex environment will be exhausted, and always depends on luck. Therefore, providing helpful information or cues is very important when implementing navigation methods. Some proposed suggestions are given below.

Use color metaphor or shape metaphor, etc. to classify areas.

Color metaphor or shape metaphor can limit the areas user needs to check, thus to reduce user's visual effort and to make the search faster. For example, Google map uses red color to indicate hospitals and green color to indicate parks, etc.

Highlight important information or provide quick access to the important targets.

When having a search task, the user often has some information about some nearby places, e.g. the target is near the central railway station, or the place can be reached by taking a certain bus to a given stop, etc. Hence, highlighting some important information or providing quick access to some important targets may give user semantic information about the possible target position, if the highlighted targets are related to the information the user has.

Dynamically indicate related information.

Sometimes, highlighting too many important positions in the picture or interactive map will make the original view look like a mess, which is also not good for searching for the targets. And it is always not possible to highlight all kinds of information in the view. In this case, designers can implement some intelligent dynamic indicating methods, by which the information related to the current selection or focus will be dynamically shown in the view. For example, when clicking a railway station in a map, the map could show all the railway stations in this city; or when clicking a station of a bus, all the stations of this bus and the route of the bus will be shown.

Use overview to provide semantic information.

In many cases, the small display can only show a small part of a big scale picture or map. The user does not have any information about the contents outside of the screen. Therefore, providing an overview with enough semantic information is a good way to help user have an idea about what exist outside of the current view. [Burigat et al., 2008] did some user studies and found that the overview with semantic information does bring benefit for navigating large information spaces.

Provide orientation cues.

Unlike digital document, digital audio and digital video, in which the browsing is always from the beginning to the end, the user has to choose a direction to browse the information in a picture or in a map. Hence, no orientation information will make the searching be in a hopeless tangle. Therefore, orientation cues such as off-screen indicators are good information to tell the user where to go.

Besides the above proposed techniques for providing searching cues, designers could also

Design navigation methods with direct manipulation technique

Since direct manipulation technique can provide users with the flexibility the two-dimensional scrollbars cannot, and it is more natural, direct manipulation is a meaningful technique to be implemented for navigating picture/ interactive map.

Enable discrete access for navigating large scale pictures/ interactive maps

Although discrete access is not that important for navigating picture/ interactive map, it will also benefit if the information space is really large and the user needs to locate a place far away from the current position.

		Continuous Access								Discrete Access								
Targeted Object-Position Search	Random Access	1a								1a	8+							
	Sequential Access		4a, 5a		6a, 7a		2a, 3a				4a							
Targeted Coordinate/ Playback-Position Search	Random Access	1+								1+								
	Sequential Access		5+		6+, 7+		2+											
Arbitrary Browsing	Random Access	1								1								
	Sequential Access		4, 5		6, 7		2, 3				4							
		Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	Absolute Input	Relative Input	
		Position-based Control		Rate-based Control		Position-based Control		Rate-based Control		Position-based Control		Rate-based Control		Position-based Control		Rate-based Control		
		Tool-based Navigation				Direct Manipulation				Tool-based Navigation				Direct Manipulation				

Figure 5.7: Design space for picture/ interactive map

Notations:

1. Mouse/ Stylus/ Touch screen + Scrollbar

2. Mouse/ Stylus/ Touch screen + Tap-and-drag

3. Mouse/ Stylus/ Touch screen + Touch-and-go

4. Mouse/ Stylus/ Touch screen + Planar

5. Keyboard arrow keys for moving and +/- key for zoom in/out

6. Joystick

7. TWEND

8. Search Box

5.2.3 Digital audio

Current design overview

Current design situation of navigation in digital audio

By examining the design space for digital audio (Figure 5.8), findings obtained from observing the current navigation method designs include:

There are few existing navigation methods available for digital audio overall.

No navigation method is direct manipulation.

All targeted object-position search methods require user's manual acoustic search effort.

There are very few navigation methods which can do random access.

Future design suggestions

Future design suggestions for navigation in digital audio

Currently, there are few navigation methods for navigating digital audio contents. And especially, these navigation methods cannot give user any help for searching for some targets in an audio clip. Thus, the biggest problem for digital audio navigation is the user does not have any information about the audio content without listening. The user has to listen carefully to search for desired targets. Therefore, some suggested possible improvements for providing user valuable information about the audio content are proposed.

"Search" in digital audio

It sounds that "search" is not applicable for digital audio since unlike digital document or interactive map, there is no words in the audio content. But with the development and improvement of speech recognition, computer may be able to recognize the audio content with high accuracy. Therefore, using typed keywords or keywords by speech input may be possible to accomplish "search" in the digital audio by matching the keywords with the corresponding audio content in the future. Besides, for music files, it may be possible to design some novel musical keyboard based input devices to match the notes in the audio file.

Design navigation methods with "predefined frames" technique.

With the audio analysis and speech recognition techniques, the navigation methods may provide some predefined frames for the user. For example, indicating the positions where there are speech changes; indicating the different types of contents in the audio; or indicating the repeated part of the current selection, etc.

Visualization of audio

A reason why users have difficulty to know the audio contents is the audio is not visual to the user. With the audio analysis technique, it may possible to recognize the audio contents and to automatically generate scripts, which can serve as the visual representation to users. For example, when pointing to a position in the timeline slider, the system can provide a certain amount of scripts. Thus, the user is able to know what the following part of the audio is about without navigating to that position and listen to the audio content.

Direct manipulation

There is no navigation method which enables direct manipulation at the moment, since audio is not something like an entity which can be manipulated. But by providing novel representation formats of digital audio may also make direct manipulation possible. For example, digital audio can be represented by a sequence of notes, or a sequence of waves. In this format, it may be able to be manipulated directly for some professional purposes.

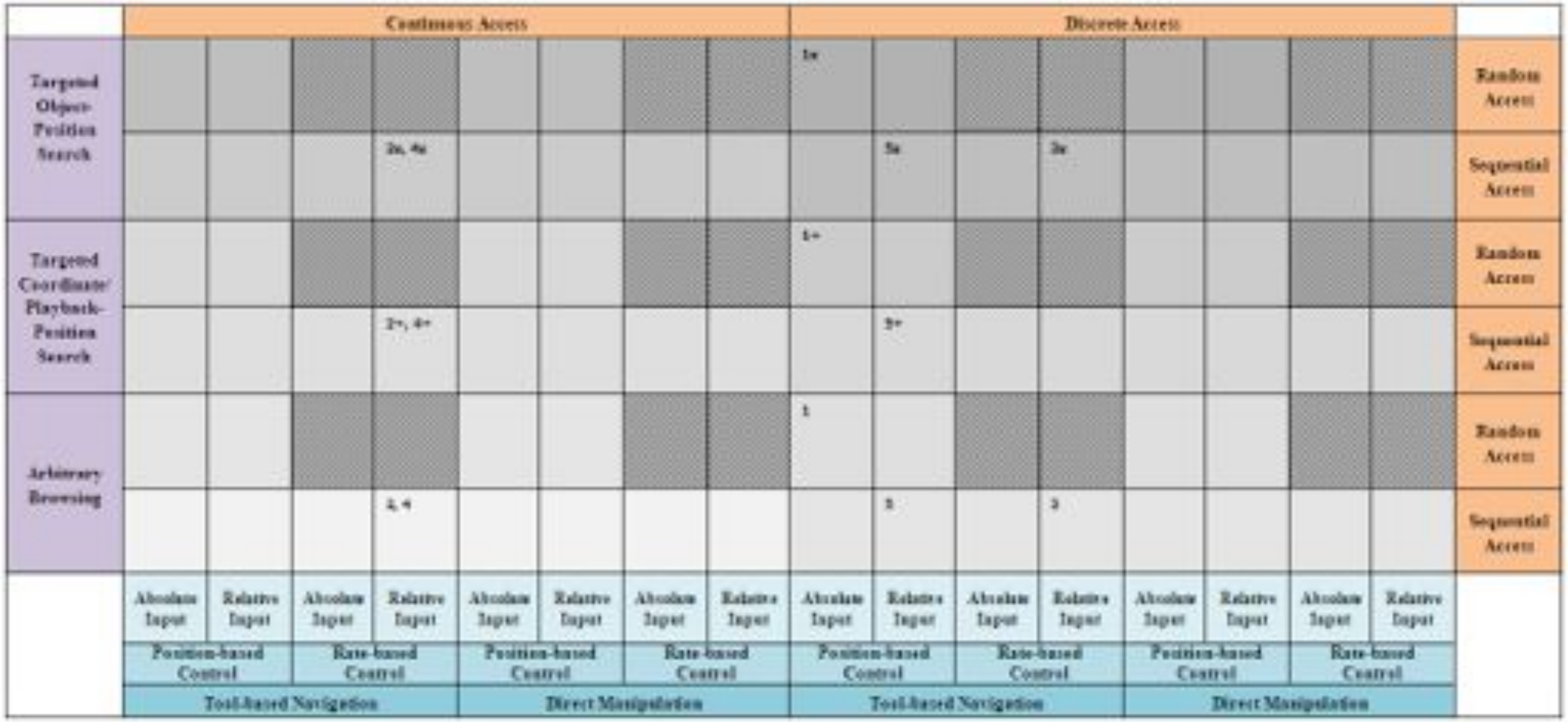

Figure 5.8: Design space for digital audio

Notations:

1. Mouse/ Stylus/ Touch Screen + Timeline slider

2. Mouse/ Stylus/ Touch Screen + Fast forward/ Rewind button (increasing playback rate)

3. Mouse/ Stylus/ Touch Screen + Fast forward/ Rewind button (frame skipping)

4. Shuttle wheel (Spring loaded)

5. Jog dial/ Click wheel

5.2.4 Digital video

Current design overview

Current design situation of navigation in digital video

By examining the design space for digital audio (Figure 5.9), findings obtained from observing the current navigation method designs include:

There are a variety of navigation methods which is tool-based.

There are some navigation methods which provide predefined frames.

There are few navigation methods with direct manipulation technique.

Future design suggestions

Future design suggestions for navigation in digital video

There are already a variety of tool-based navigation methods for digital video nowadays. Therefore, a main task for designing new navigation methods is to design and improve direct manipulation techniques. Direct manipulation is especially useful and important for accurate video navigation for professional video processing like analysis, cutting and annotation, etc. Therefore, exploring the design in this area is worthy to be done by designers. Besides, making the current navigation methods more efficient could also be tried. Some suggestions are proposed below.

Improve direct manipulation technique.

Although there have been several direct manipulation techniques developed, they are still not so efficient and flexible. Some require preprocessing, which do not support real-time interaction; some can only manipulate the predefined objects. Therefore, improving the techniques to make direct manipulation as flexible and easily to be integrated as tool-based navigation methods is essential.

Implement random access and "predefined frames" into direct manipulation.

Today's direct manipulation techniques are still simple sequential access by dragging the objects in scene. Hence, it is suggested that the feature of random access can also be introduced to direct manipulation. And the system can also provide some "predefined frames" which can be accessed by direct manipulation techniques.

Design dynamic "predefined frames".

Navigation methods with "predefined frames" such as fisheye style timeline and storyboards provide users with useful information about the contents of different parts. If the "predefined frames" is dynamic and can be adjusted by logging the user's navigation experience and preference, the navigation methods will be more intelligent.

Design accurate playback-position search.

Some professional video processing may need accurate playback-position search. For example, directly typing the time value to locate is a kind of targeted playback-position search without any user's manual visual effort.

Make navigation methods more intelligent.

By implementing some intelligent algorithms, the navigation methods may become more efficient. For example, the SmartPlayer introduced in [Cheng et al., 2009] which uses adaptive fast forwarding is an improved variant of traditional fast forwarding technique. It increases the navigation efficiency.

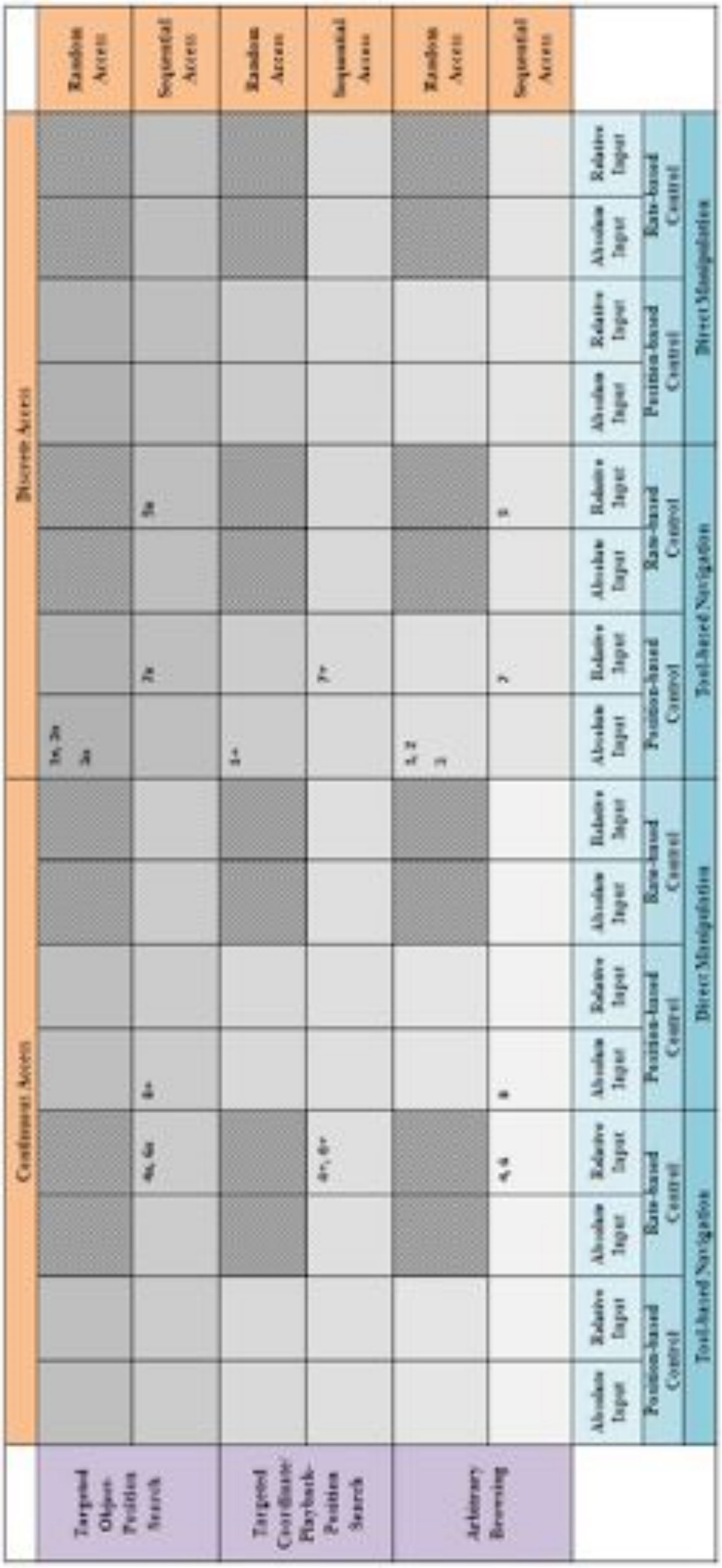

Figure 5.9: Design space for digital video

Notations:

1. Mouse/ Stylus/ Touch screen + Timeline slider

2. Mouse/ Stylus/ Touch screen + Fisheye-style warped timeline

3. Mouse/ Stylus/ Touch screen + Static or dynamic storyboards

4. Mouse/ Stylus/ Touch screen + Fast forward/ Rewind button (increasing playback rate)

5. Mouse/ Stylus/ Touch screen + Fast forward/ Rewind button (frame skipping)

6. Shuttle wheel (Spring loaded)

7. Jog dial/ Click wheel

8. Dragon

Chapter 6

Evaluation block diagram

So far, the work has analyzed the navigation in digital media, introduced the design space, and had a comprehensive look at the current navigation designs for the four types of digital media. In this chapter, another useful tool in the framework, evaluation block diagram, is going to be explained.

What is evaluation block diagram?

Evaluation block diagram is a kind of navigation flow diagram which is used by adding connections between predefined states to examine the navigation capabilities by paths formed in the diagram. The states in the evaluation block diagram are the navigation properties in the design space, and having a certain property is represented by having a connection to the corresponding state. The purpose of introducing the evaluation block diagram is that instead of examining the navigation capabilities by checking the squares in the design space, it can be more easily and intuitively observed in the block diagram by looking at which states are reachable and what the possible paths are. Given the information of required states or optimal path, it can be easily used to measure whether a navigation method is able to accomplish a navigation task. And it is very easy to compare the different navigation methods and measure the suitability by comparing with the given optimal path.

6.1 Structure

Structure of evaluation block diagram

The structure of the evaluation block diagram is shown in Figure 6.1. The block diagram is generated from the design space. The circles in the block diagram are called "states", which correspond to the properties in the design space. Therefore, the evaluation block diagram and the design space are fully consistent with regard to the structure and the evaluation results as well.

The states in the evaluation block diagram, which are the properties of navigation methods, are arranged from left to right according to the navigation process, with the right most state represents the final purpose of navigation. Therefore, the states are divided into four stages along the navigation process, which are indicated by four dash-line frames in Figure 6.1.

Three stages in the evaluation block diagram

The first stage is the start stage of the navigation, which is the input and manipulation. One of the first two circles and one of the second two circles are connected to represent the combination of the input and manipulation properties. There is no consequential relationship between the first two groups of states.

The second stage indicates the access properties of the navigation. As discussed in 5.1.2—"Design rationale", sequential access is the subset of random access, since any navigation method which can do random access can also accomplish sequential access. Therefore, sequential access is represented as an inner circle within the big circle which represents random access, both for discrete access and continuous access. And if the navigation method is able to accomplish random access, the connection line will stop at the edge of the big circle; while the line will go to the inner circle if the navigation method can only accomplish sequential access.

The third stage represents the navigation effect the access brings. It either enables the user to do arbitrary browsing or locate to a targeted coordinate/ playback position. Although the targeted object-position search is also one of the navigation effects, it is separated as the fourth stage, which

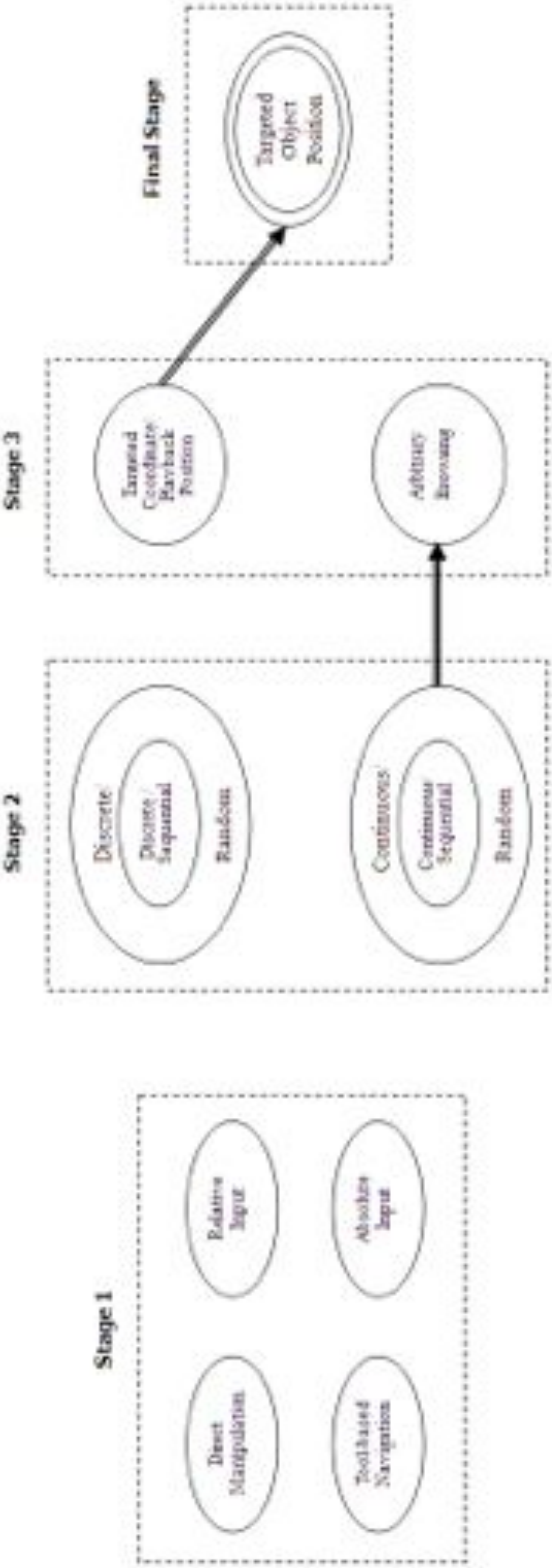

Figure 6.1: Evaluation block diagram structure

is also the final stage, since locating the targeted object position is always the final purpose of a navigation/ search task. (Strictly speaking, arbitrary browsing could not be regarded as a goal of navigation.) This final state is distinguished from the other states by using a double circle.

6.2 Notations and representation

Notations and representation of evaluation block diagram

Figure 6.2 shows the notations used in the evaluation block diagram. As mentioned in the previous section, the circles represent the navigation states, and the double circle in the final stage represents the final state of the navigation methods. Besides, several different kinds of lines are used to connect the states, and thus to form the navigation paths.

"Connecting line" is used to connect the states in the first two groups in the first stage. Since there is no consequential relationship between the first two groups of properties, the line is a normal black line without an arrow. By using this line, the connection of a manipulation method and an input property is regarded as a combination of the physical properties.

The two types of lines with arrow which represent "position-based control" and "rate-based control" are to connect the states in the first stage and second stage. They describe whether the control is position based or rate based, which can also be told from the design space. As mentioned before, if the access is random, the line stops at the edge of the big circle; while if the access is only sequential, the line goes into the big circle and stops at the edge of the inner circle.

The four types of lines with arrow which represent "direct positioning" (the same line with that represents "position-based control"), "confirmation needed", "with the help of predefined frames", and "totally manual search" correspond to the four "effort indicators" described in 5.1.3—"Notations and representation". They are used to connect the states in the second stage to the states in the third stage or in the final stage. They describe that with which level of

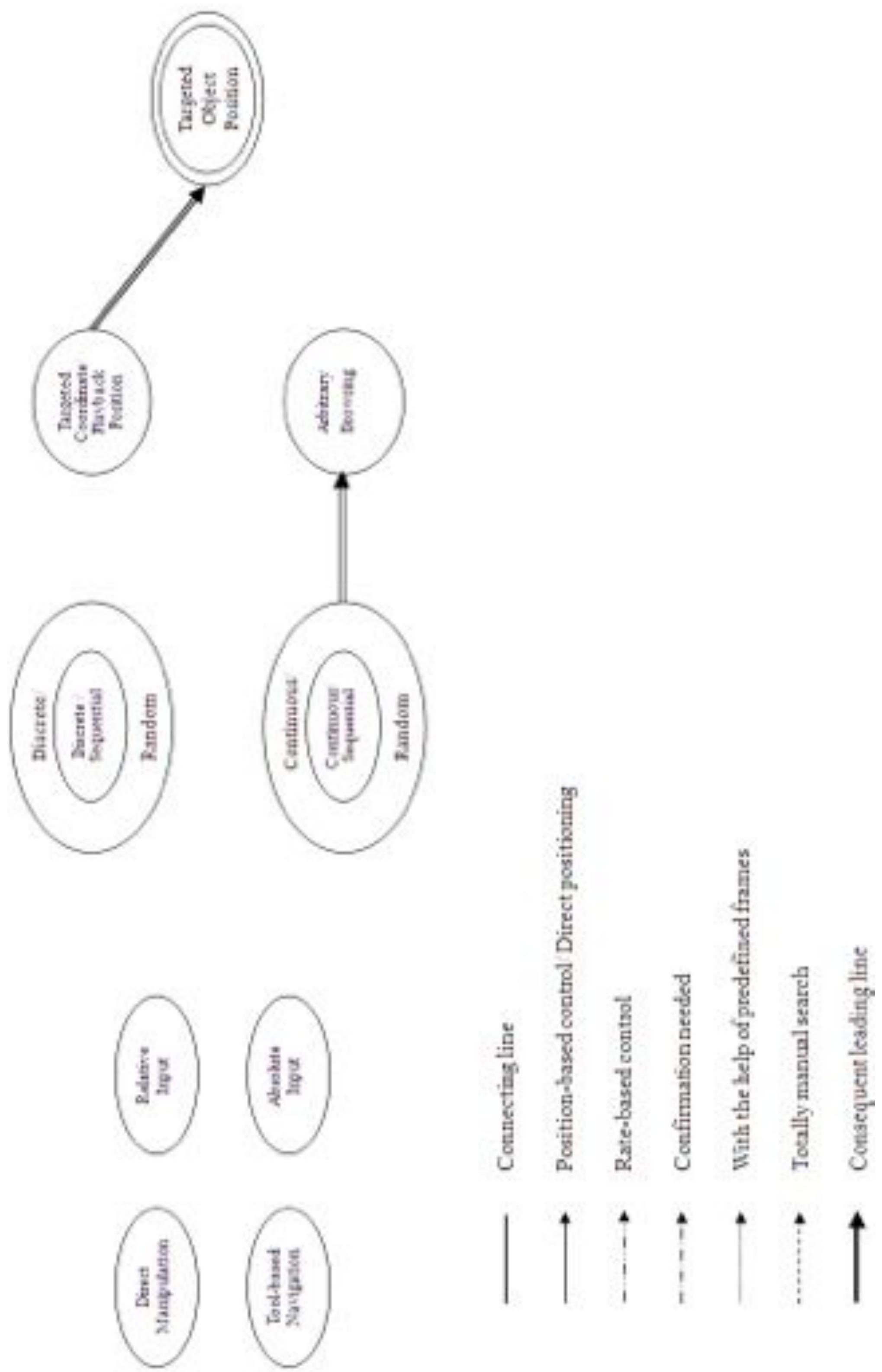

Figure 6.2: Notations of evaluation block diagram

effort the user is able to accomplish which kinds of navigation purposes.

In addition, the last type of line is a double line with an arrow, which is there in the initial representation of the evaluation block diagram. This type of line is called "consequent leading line", and it represents the necessary result. In the block diagram, the line connecting "targeted coordinate/ playback position" and "targeted object position" indicates that if the navigation is able to reach targeted coordinate/ playback position, it must be able to reach targeted object position, since every object position corresponds to a coordinate or playback position. Therefore, locating the corresponding coordinate or playback position is locating the object position. Similarly, the line connecting "continuous" and "arbitrary browsing" indicates that if the navigation is able to accomplish continuous access, it must be able to enable the user to do arbitrary browsing, since continuous accessing means that the user can access any information in the digital media.

In conclusion, with these notations, all the properties which can be told from the design space can also be described by the evaluation block diagram. And the two mechanisms keep consistent.

6.3 Generation from design space

Steps to generate evaluation block diagram from design space

Generating the evaluation block diagram for a navigation method from the design space is simple. Generally speaking, it is to add connections among the states where necessary by checking the properties in the design space. It can be done by following the below steps, which address the connections from left to right along the navigation process.

1. Check whether the navigation method is "direct manipulation" or "tool-based navigation"; and check which kind of input it is. Connect the reachable states by "connecting line".

2. Check which kind of access the navigation method is able to accomplish; and check whether it is position based or rate based. Use the corresponding line to connect to the reachable access state from the reachable input state.

3. Check which kinds of search the navigation method is able to accomplish; and check the “effort indicators”. Use the corresponding lines to connect to the reachable search states from the reachable access state.

Following the above three steps, the possible navigation paths for a navigation method are easily represented in the evaluation block diagram.

6.4 Evaluation methodology

Standard block diagram for evaluation

Having generated the evaluation block diagrams for the navigation methods from the design space, it is possible to evaluate these navigation methods. Generally speaking, the evaluation methodology is comparing the block diagrams of the navigation methods to the “standard block diagram” for a navigation task to have a ranking of the navigation methods by the suitability for the task.

Required states

There are two important notions in the standard block diagram: “required state” and “optimal path”. A “standard block diagram” is used to describe the requirement of a navigation task. Therefore, in a standard block diagram, one or more “required states” are indicated to tell the states which must be reached through a navigation path by using a navigation method if it is able to finish the task. If there exists a navigation path in the evaluation block diagram of the navigation method which leads to the required state, the navigation method is regarded to be capable of accomplishing this task. Otherwise, it is regarded not being able to finish the navigation task.

Optimal path

Besides the required state, “optimal path” is another measure to evaluate the suitability of a navigation method for a navigation task. As long as there is a path reaching the required state, the navigated method is regarded to be capable for a task. But for some tasks, there may be some optimal paths, by going through which the navigation will be more efficient. This is defined by the optimal path in the standard block diagram. The navigation methods which have the paths that are the same as the optimal path are regarded more suitable for the navigation task than the navigation methods which do not have such paths.

Evaluation preferences

Furthermore, for evaluating the suitability within the navigation methods which have the optimal path and within those which do not, the following preferences of navigation properties, which are listed from high preference to low preference, are referenced. The listed properties correspond to the notations in the evaluation block diagram, thus can be easily told from the different types of lines and the states reached.

Direct positioning

Confirmation needed

With the help of predefined frames

Totally manual search

Discrete/ Random

Continuous/ Random

Discrete/ Sequential

Continuous/ Sequential

Rate-based control

Position-based control

Since different navigation tasks have different requirements, the required state and optimal path for every kind of task are different. Therefore, the suitability ranking of navigation methods is only meaningful with regard to a specific kind of navigation task. In the following part, an example will be showed to explain how the evaluation block diagram is used.

Example: Evaluate the suitability for navigation task "go to Chapter 5.1" in a document

An example evaluation task

For this navigation task, the required state is the final state "targeted object position", since it is to find some information in the document. The optimal path is from the second stage (access) directly to the final state without going through the third stage, since it is preferred if the navigation method can directly lead users to the desired object position than if the object position can only be reached by changing the coordinate position. The standard block diagram is as shown in Figure 6.3. The required state is highlighted, and the optimal path is represented by a red line pointing from the second stage to the required state. By comparing the evaluation block diagrams of navigation methods for digital document, which can be found in A—"Evaluation block diagrams for digital document", with the standard block diagram, and by applying the property reference, the suitability ranking (from high suitability to low suitability) of the navigation methods for this task is shown as below.

Level 1: Search Box

Level 2: Mouse + Scrollbar, Mouse + Thumbnail enhanced scrollbar, Mouse + Thumbnails, "Page number" Input Box

Level 3: Keyboard + Thumbnails, Keyboard page up/ page down button, TWEND, "Page number" increase/ decrease button

Level 4: Mouse wheel rate-based Scrolling

Level 5: Tap-and-drag, Mouse wheel position-based/ Jog dial/ Click wheel Scrolling, Keyboard up/down button Scrolling

The levels are classified by the preferences. The navigation methods in the different levels have different navigation properties, while those in the same level have the same properties according to the evaluation criteria of this work. Therefore, the navigation methods in the same level are believed not to have significant performance differences, although there may exist some minor differences.

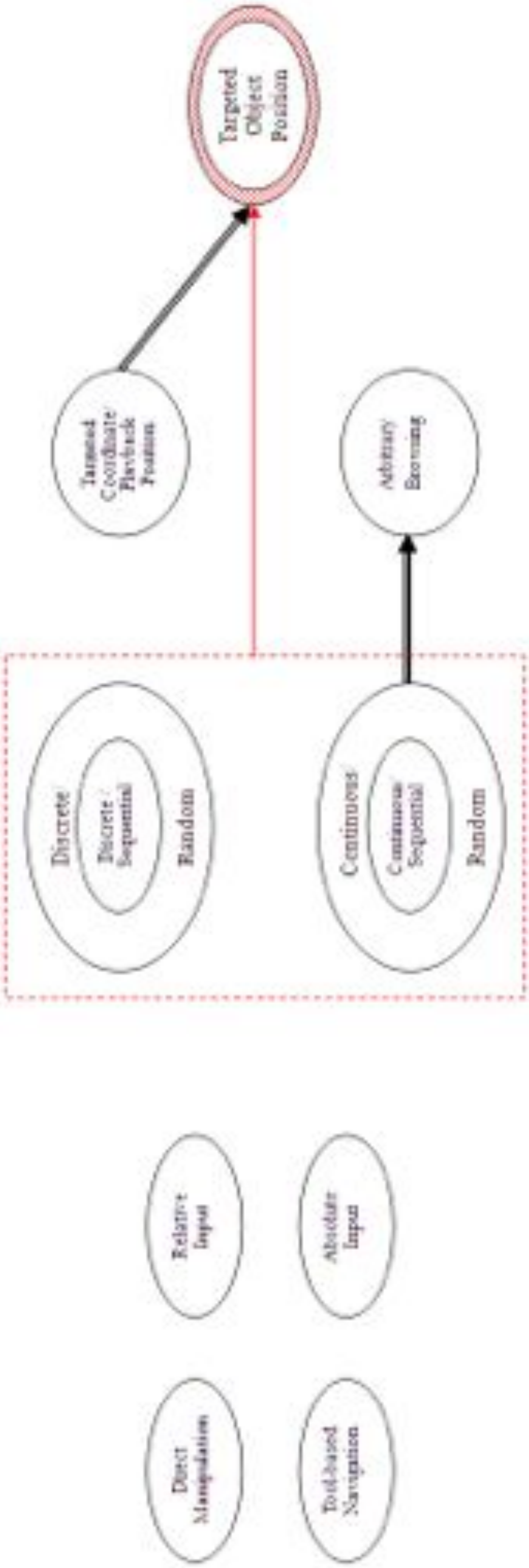

Figure 6.3: An example standard block diagram

Chapter 7

Validation

A user test is done in this thesis work. The purpose of the user test is to get empirical data to verify the correctness of the hypothesis for designing the layout of the design space, the preference proposed when using the evaluation block diagram to measure the navigation methods, and thus to verify the correctness of the results derived from the evaluation block diagram analysis. However, because of the time and resource limitation, the user test done in the work can only verify parts of the framework which are regarded as the most important aspects. More validation work will be done in the future work.

7.1 Task & Setup

The user test is a quantitative experiment which is run by a program to measure the task completion time. The test addresses three types of digital media which are digital document, interactive map, and digital video. For each of the three media types, several selected navigation methods are tested. Each user is asked to do all the tests for the three media types.

Task & Setup for digital document

Part 1 Digital document

Task: Find a required paragraph, figure, theorem, or definition, etc. in a pdf document.

Selected navigation methods:

1) Search Box ("Find" function) –*targeted object search with manual confirmation*

2) Mouse + Thumbnails –*discrete/random*

3) "Page number" increase/decrease button –*discrete/sequential*

4) Mouse + Scrollbar (Scrolling to the next page by "click") –*continuous/sequential*

Hypothesis:

The task completion time gets longer from the navigation method 1) to 4).

Documents for test:

1 document is selected for the practice test and 3 documents are for the formal tests. In order to analyze the performance for navigating documents of different length and to average the task completion time, the length of the three documents selected for the formal tests are 10 pages, 44 pages, and 106 pages. And the target is on the 5th, 23rd, and 66th page respectively.

Procedure:

For each of the four navigation methods, the users is asked to do navigation tasks on the three selected documents. The order of the four navigation methods and the order of the three documents for each navigation method will be pseudo-randomized so as to counter-balance the learning effect of the user.

Before the formal tests of each navigation method, the user will have the chance to practice with the coming navigation method on the practice document. After finishing the practice test, the user can start to do the formal tests. The user is asked to press F1 to load the document and start the time recording, and to press F2 to confirm the target is found which stops the time recording as well. The program will check the correctness of the found target by checking the current page. Only if the target is correct is the user able to proceed to the next task. Otherwise, the user is asked to continue with the current task and the time recording will not stop.

Special requirements:

Search Box ("Find" function)

The task description will not give the exact complete keywords which are used for searching by the user. Instead, the tasks are described in a more natural way which is more like the tasks in the user's idea in practical use. For example, "find the second figure in the paper" or "find the paragraph which describes a prototype named 'Flex Spreadsheet' in Chapter 5" will be given as a task.

Thumbnails

The thumbnails are laid out in multiple columns instead of one column, and most thumbnails are displayed in the initial view after the document is loaded. This gives the user more freedom to jump between thumbnails and thus to provide a totally discrete/random access of the document.

Scrollbar

In 4.2.1—"Digital document", scrollbar was defined as a kind of continuous & discrete & random access. This is because beside the continuous/sequential access which can be accomplished by dragging the thumb in the scrollbar, it can also be set to "jump here" when clicking somewhere on the scrollbar. The latter one can achieve discrete and random access. But in the user test, what is expected from the scrollbar is only the property of continuous/sequential access. Therefore, in the experiment setup, the system is set to "smoothly scroll to the next page" when clicking somewhere on the scrollbar. By this setting, the user can only jump to anywhere he/she wants, and thus it mimics the continuous/sequential access.

Document display

One page of the document will fill the size of the screen so that user can read all the things on one page without scrolling. This makes it possible to forbid the use of other navigation methods when using thumbnails and "page number" increase/decrease button to perform the tasks.

Test environment consistency

The program window will be displayed at the same position on the screen and of the same size without the possibility of change so that the test environment for all users will be the same.

Task & Setup for interactive map

Part 2 Interactive Map

Task: Find a required place (e.g. Ardwick Green Park) in a city map

Selected navigation methods:

1) Search Box –*targeted object search with manual confirmation*

2) Tap-and-drag with some cues provided –*manual search with the help of predefined frames*

3) Tap-and-drag –*totally manual search*

Hypothesis:

The task completion time gets longer from the navigation method 1) to 3).

Maps for test:

1 city map is selected for the practice test and 3 city maps are for the formal tests. The cities for formal tests are nei-

ther from the countries of the participants nor top tourist cities. Therefore, the participants do not have enough knowledge of the city so as to be able to avoid the impact on the performance. The targets are selected to be 1.2km, 3km, and 5km from the city center respectively.

Procedure:

For each of the three navigation methods, the user is asked to do navigation tasks on the three selected city maps. The order of the three navigation methods and the order of the three city maps for each navigation method will be pseudo-randomized so as to counter-balance the learning effect of the user.

Before the formal tests of each navigation method, the user will have the chance to practice with the coming navigation method on the practice city map. After finishing the practice test, the user can start to do the formal tests. The user is asked to press F1 to load the city map and start the time recording, and to double click the found target to locate it to the screen center and press F2 to confirm which stops the time recording as well. The program will check the correctness of the found target by checking the latitude/longitude of the found target. Only if the target is correct is the user able to proceed to the next task. Otherwise, the user is asked to continue with the current task and the time recording will not stop.

Special requirements:

Tap-and-drag with some cues provided

The cues are provided in the form of some bubbles indicating some places or a highlighted line indicating a metro route. The information about the distance from the target to one of the predefined frames is provided. Examples are "10 minutes walk to the 'Ardwick' railway station" and "6 minutes walk to Metro Line A 'Arenes' station".

Test environment consistency

The program window will be displayed at the same position on the screen and of the same size without the possibility of change so that the test environment for all users will be the same.

Task & Setup for digital video

Part 3 Digital video (Lecture video)

Task: Find the time point where a required slide is shown

Selected navigation methods:

1) Mouse + Timeline slider –*discrete/random*

2) Fast forward/ Rewind button (increasing playback rate)–*continuous/sequential*

Hypothesis:

The task completion time using timeline slider is shorter than that using fast forward/rewind button.

Video for test:

1 piece of video is selected for the practice test and 3 pieces of video are for the formal tests. In order to analyze the performance for navigating video of different length and to average the task completion time, the length of the three pieces of video selected for the formal tests are 20 minutes, 20 minutes, and 50 minutes. And the targets are at around 5 minutes, 15 minutes, and 25 minutes respectively.

Procedure:

For each of the two navigation methods, the user is asked to do navigation tasks on the three selected pieces of video. The order of the two navigation methods and the order of the three pieces of video for each navigation method will be pseudo-randomized so as to counter-balance the learning effect of the user.

Before the formal tests of each navigation method, the user will have the chance to practice with the coming navigation method on the practice video. After finishing the practice test, the user can start to do the formal tests. The user is asked to press F1 to load the video and start playing and time recording, and to press F2 to confirm the target is found which stops the time recording as well. The program will check the correctness of the found target by checking the current time. Only if the target is correct is the user able to proceed to the next task. Otherwise, the user is asked to continue with the current task and the time recording will not stop.

Special requirements:

Confirmation of finding the target

User will be required to confirm finding the targeted time point as soon as he/she sees the required slide, either from forward or backward. He/she does not need to locate the exact time point where it changes to this required slide from the previous one.

Test environment consistency

The program window will be displayed at the same position on the screen and of the same size without the possibility of change so that the test environment for all users will be the same.

7.2 Participants

Participants

Since four navigation methods for digital document need to be tested, there are totally 24 permutations for the order of the four navigation methods. Therefore, to fully balance the learning effect, 24 versions of the test programs are developed. For each version, 3 participants are expected for obtaining an average data.

72 participants took part in the experiment, with every 3 participants did the same version of the test program. The participants are all students in the university. 52 of them are male and 20 of them are female. The average age of the participants is around 20. They are from Europe, Asia, and America; and study computer science, communication engineering, and economic engineering, etc. Most of

them had previous experience to use the required navigation methods in the user test.

7.3 User test program

24 versions of the test program

The user test is run by the test program. As mentioned before, since there are totally 24 permutations for the four navigation methods for digital document, 24 versions of the test program were developed. The permutation of the navigation methods for interactive map and digital video just repeats for 4 times and 12 times respectively.

Benefits of the test program

Figure 7.1 - 7.9 show the screenshots of the test program for every navigation method. The benefits of running the user test by the test program include the following points.

Navigation method limitation

The program only provides one navigation method for a task. Therefore, the user is restricted to use the required navigation method to perform the task, and thus the results will not be impacted by using the undesired navigation methods.

Automatic target checking

The correctness of the target found is checked by the program. The check for digital document is done by checking the current page; the check for interactive map is done by checking the latitude/longitude value of the found target; and the check for digital video is done by checking the current time. If the target found is incorrect, the program will give feedback to ask the user to continue and the time recording will not stop. Only if the target found is correct will the "continue" button be shown in the program window and can the user proceed to the next task.

Precise time recording

The time is recorded by the program instead of by using a stopwatch. Hence, the time recorded is more precise.

Unsupervised test process

Because the user test can be processed in an unsupervised way, it is possible to do several tests simultaneously with several users. Therefore, a large number of participants are possible to be involved in the user test.

Figure 7.1: Test program screenshot - "page number" increase/decrease button in digital document

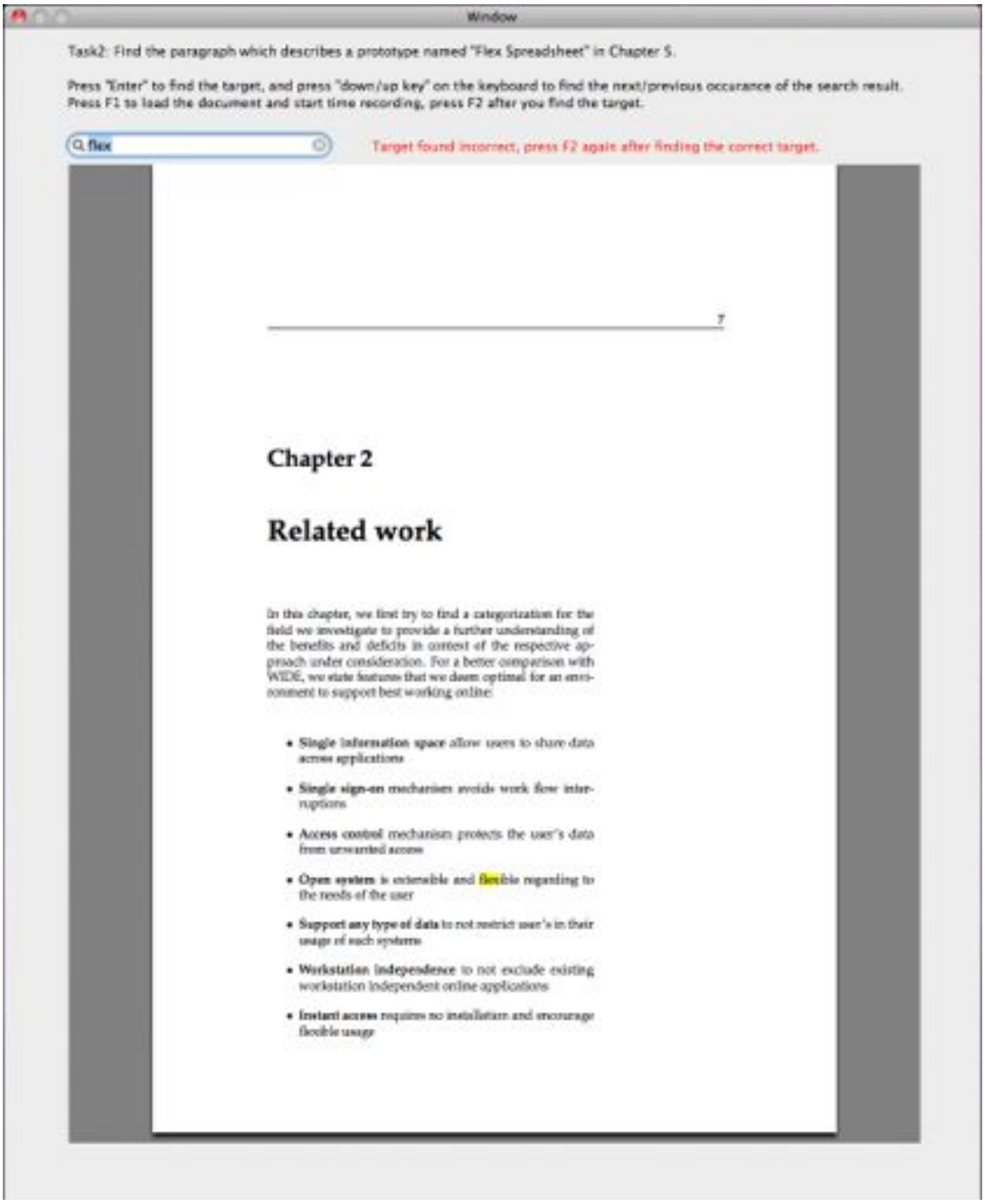

Figure 7.2: Test program screenshot - search box in digital document

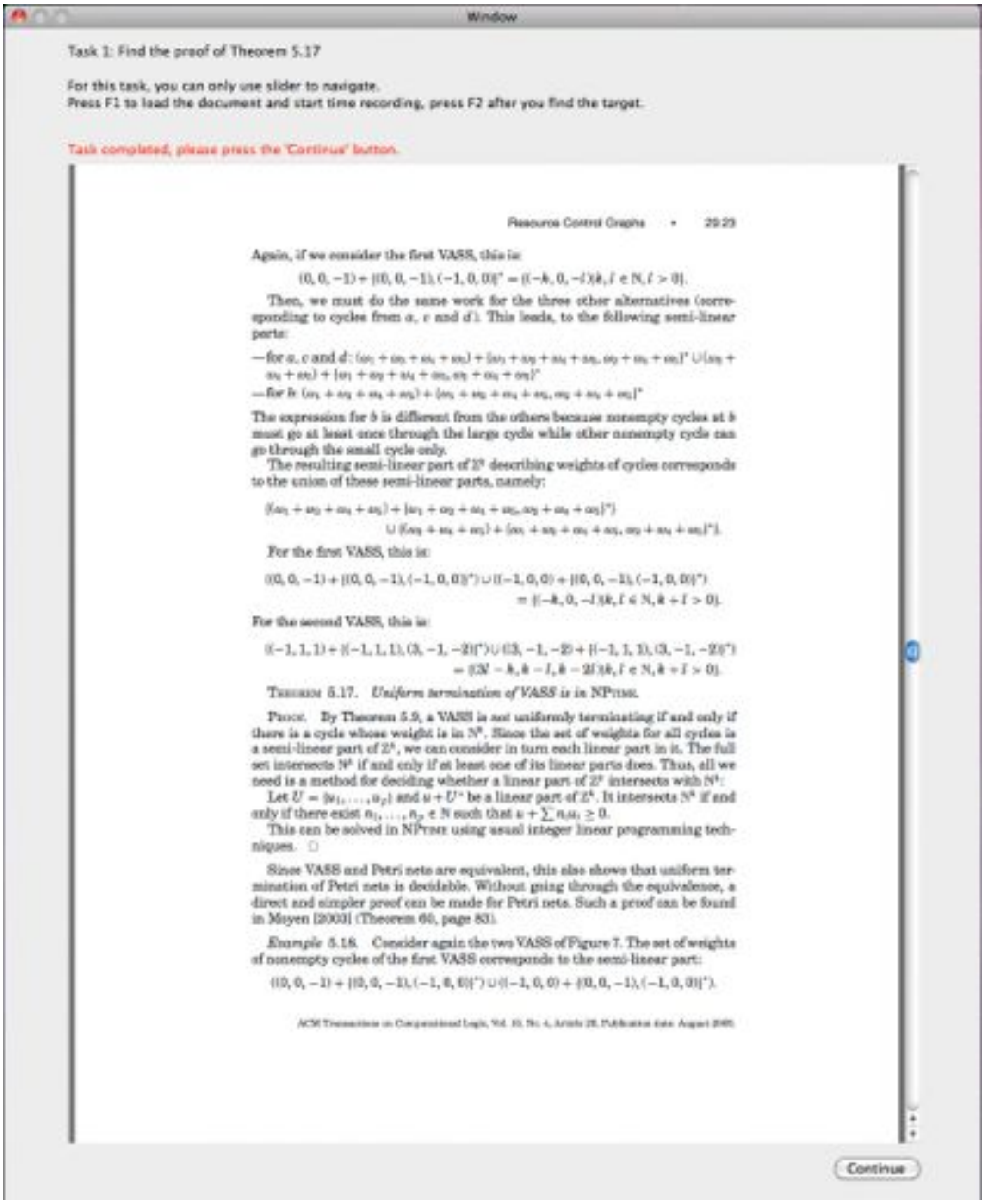

Figure 7.3: Test program screenshot - scrollbar in digital document

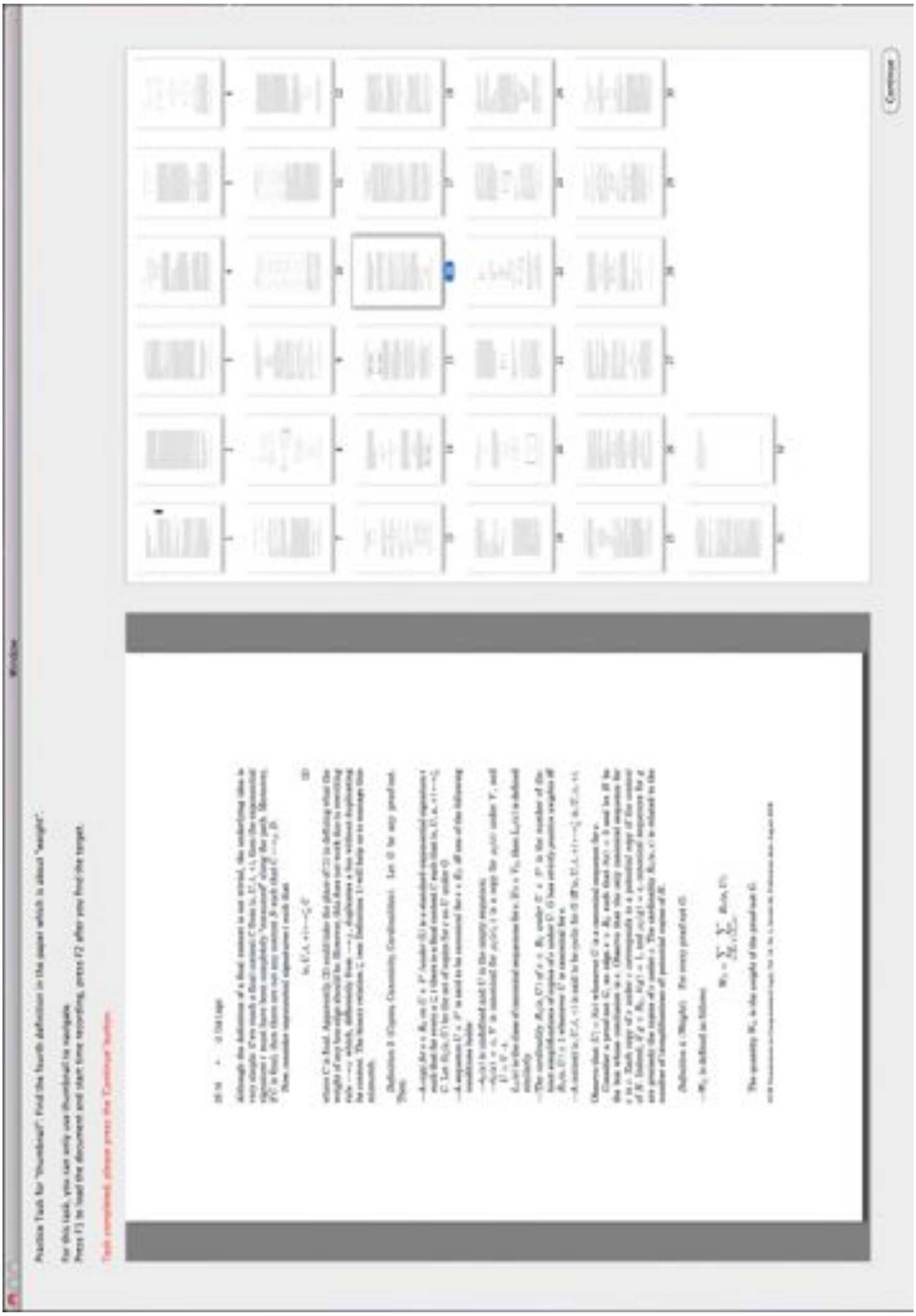

Figure 7.4: Test program screenshot - thumbnails in digital document

Figure 7.5: Test program screenshot - search box in interactive map

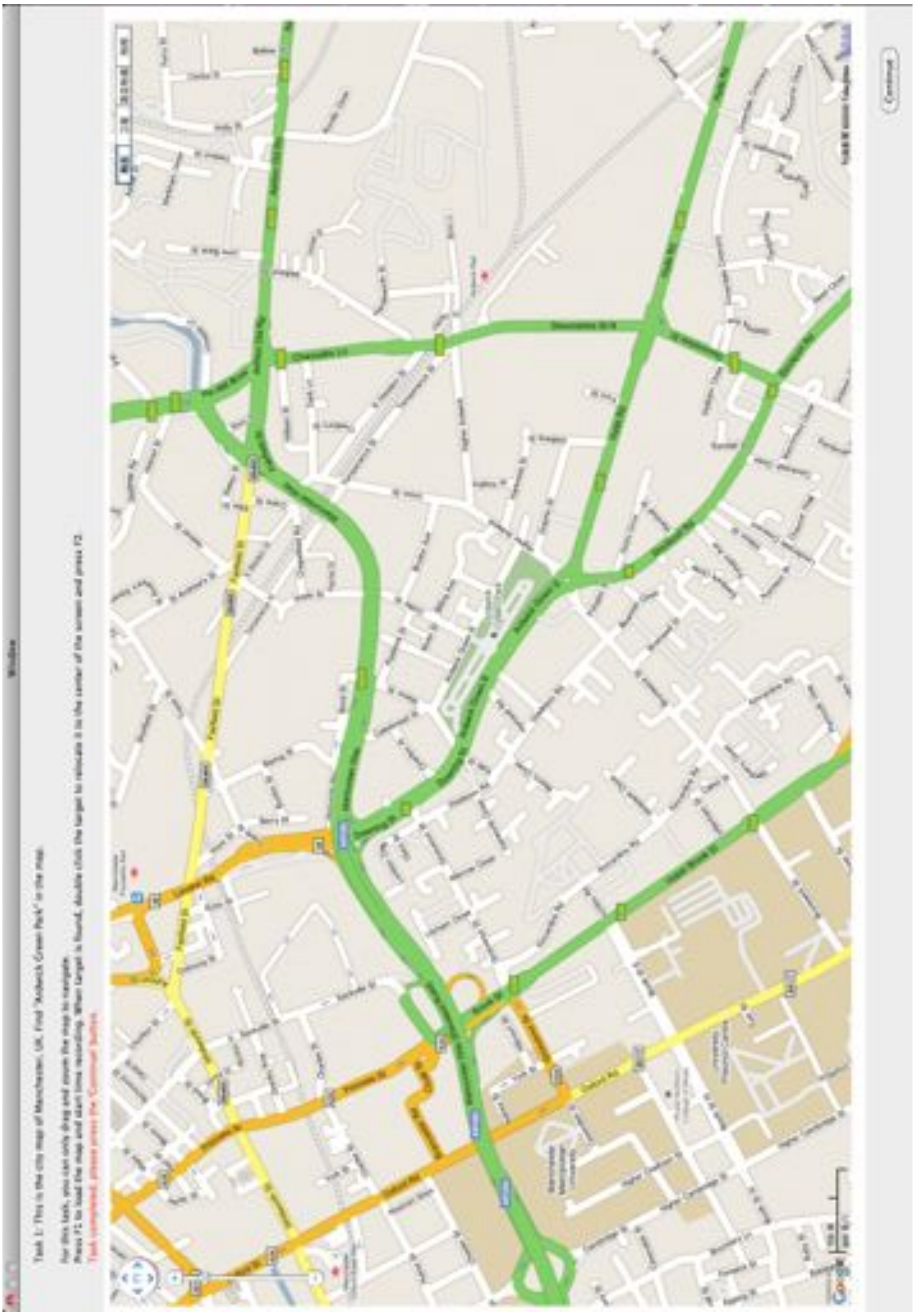

Figure 7.6: Test program screenshot - tap-and-drag in interactive map

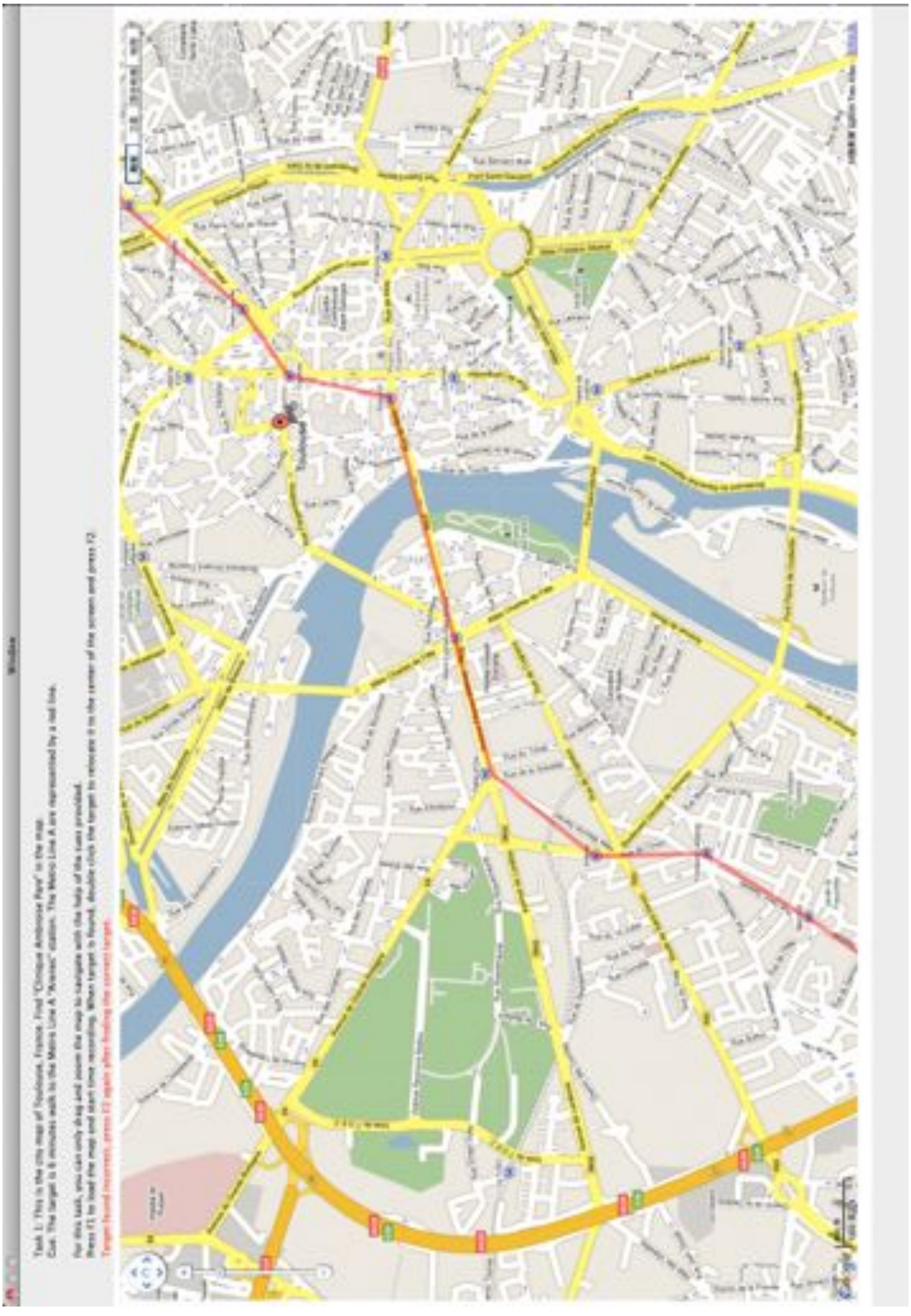

Figure 7.7: Test program screenshot - tap-and-drag with cue in interactive map

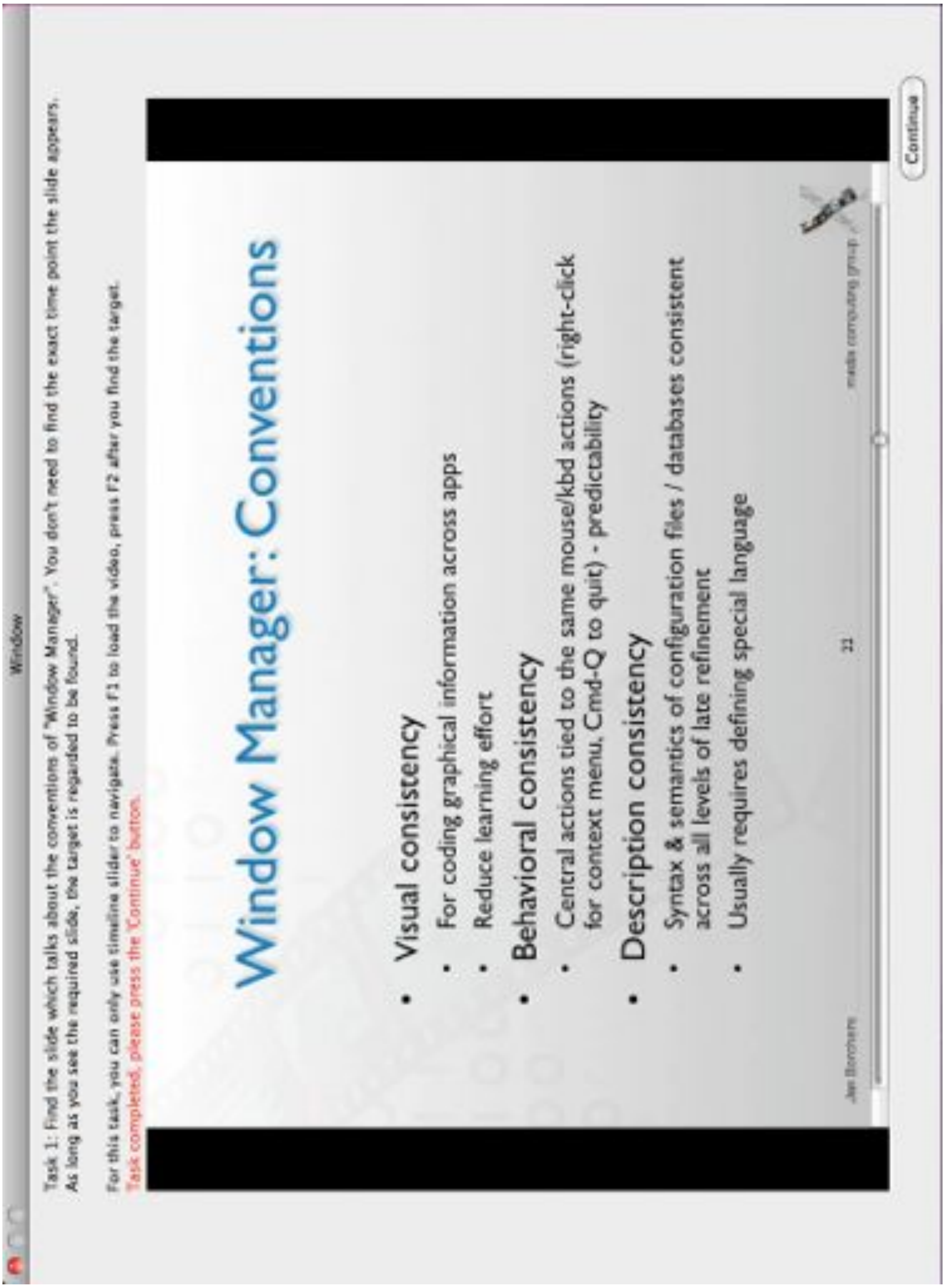

Figure 7.8: Test program screenshot - timeline slider in digital video

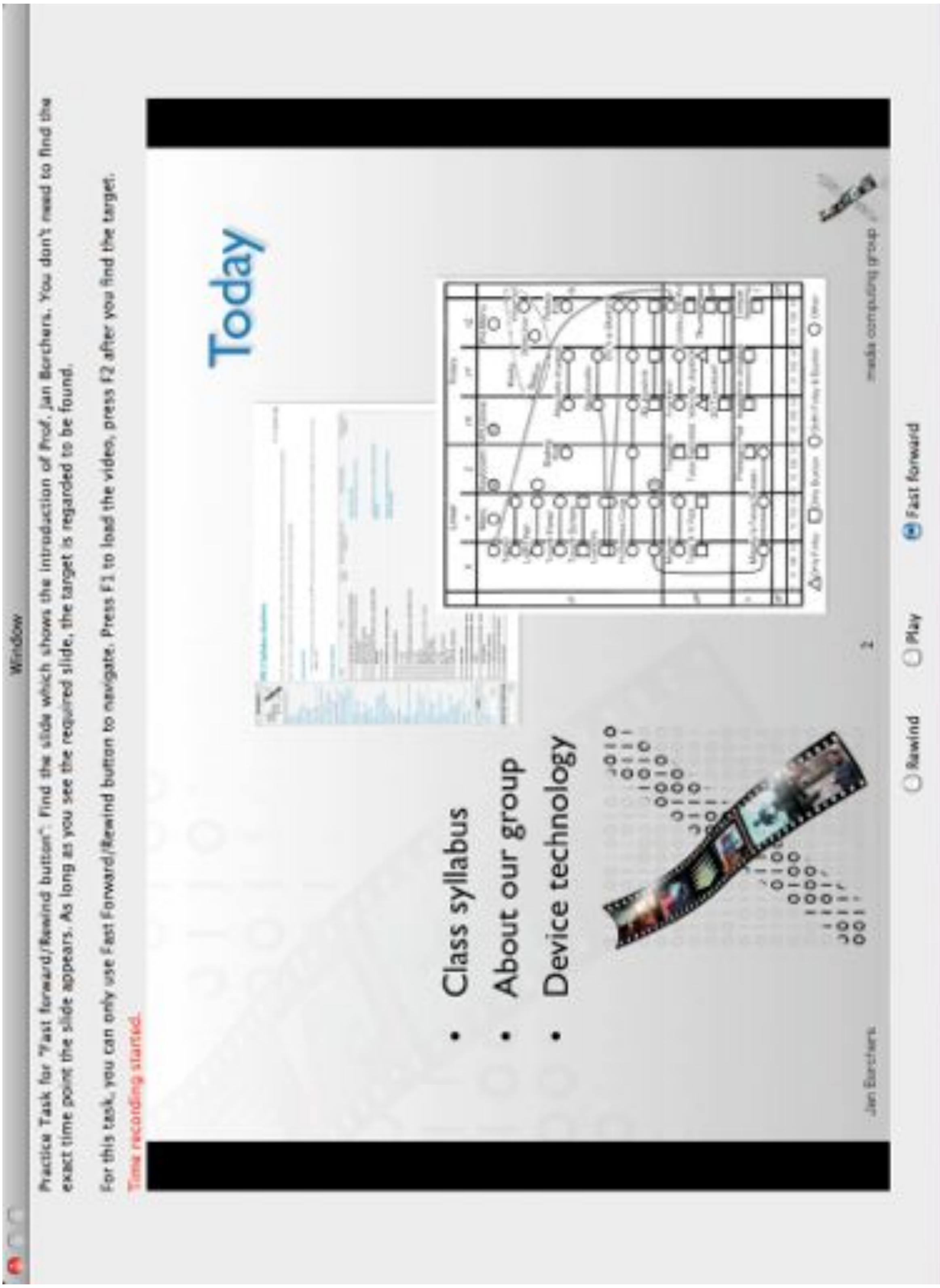

Figure 7.9: Test program screenshot - fast forward/rewind button rate-based control in digital video

7.4 Results

User test results

The results of the user test can be found in the following tables for digital document, interactive map, and digital video respectively. Overall speaking, the average task completion time proved the hypothesis in 7.1—"Task & Setup".

For digital document, the average task completion time of using scrollbar is 34.658262s, which is the slowest. "Page number" increase/decrease button and thumbnails follow by the average completion time of 28.991567s and 25.495950s respectively. The fastest navigation method is search box, by using which the average task completion time is 15.308935s.

For interactive map, the average task completion time of using tap-and-drag, which depends totally on the user's manual search, is very long (223.033219s). By using tap-and-drag with cues, the average completion time becomes much shorter which is 95.765255s. Similar with the results of digital document, search box proves to be the fastest way by using which the average task completion time is 23.057424s.

For digital video, the result of using fast forward/ rewind button (increasing speed) and that of using timeline slider differs a lot. While the average task completion time of using fast forward/ rewind button is 242.677879s, which takes a lot time, the average completion time of using timeline slider is only 25.032224s.

	Doc 1(s)	Doc 2(s)	Doc 3(s)	Average (s)
Mouse + Scrollbar	10.798084	35.930096	57.246605	34.658262
up/down button	7.094392	27.131941	52.748366	28.991567
Mouse+ Thumbnails	6.823859	24.277129	45.386862	25.495950
Search Box	14.744578	16.510329	14.671899	15.308935

Table 7.1: User test results for digital document

	Map 1(s)	Map 2(s)	Map 3(s)	Average (s)
Tap-and-drag	181.197867	282.636374	205.265415	223.033219
Tap-and-drag with cue	49.185602	110.415503	127.694658	95.765255
Search Box	20.195422	28.274294	20.702556	23.057424

Table 7.2: User test results for interactive map

	Video 1(s)	Video 2(s)	Video 3(s)	Average (s)
FFW/RWD rate control	247.523647	389.070588	91.439403	242.677879
Timeline Slider	30.513441	18.851420	25.683491	25.032224

Table 7.3: User test results for digital video

7.5 Analysis and conclusions

7.5.1 Digital document

Analysis of the user test results for digital document

As shown in Figure 7.10, for document 2 and 3, the middle-length and long-length documents, the task completion time decreases along the four navigation methods. For document 1, which is the short-length document, the task completion time also decreases along the first three navigation methods. But the time for search box is longer than those of the other three, which is different from the results of document 2 and 3. From the results, we can see that while search box is the fastest navigation method for middle-length and long-length documents, it does not have advantage against the other navigation methods, and even performs worse than the others. The reason for this is although using search box requires a short navigation time, it does require a minimum time for the user to input the keywords. But with the length of the document increases, the time required using search box does not increase. We can see from the figure that unlike the other three navigation methods, the task completion time for the three documents with different length using search box does not vary a lot.

For document 1, scrollbar is significantly slower than "page number" increase/decrease button ($p<0.01$) and thumbnails ($p<0.01$). Search box is significantly slower than the other three navigation methods ($p<0.01$ for all). Although the number shows "page number" increase/decrease is

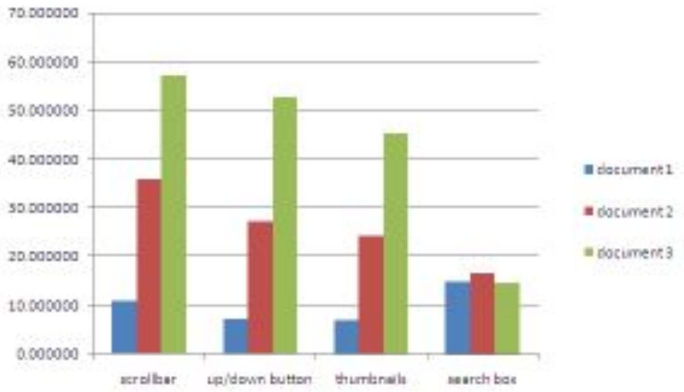

Figure 7.10: Performance of navigation methods for the three documents

slower than thumbnails, there is no significant difference between them.

For document 2, scrollbar is significantly slower than "page number" increase/decrease button ($p<0.05$), thumbnails ($p<0.01$), and search box ($p<0.01$). Search box is significantly faster than the other three ($p<0.01$ for all). Although the number shows "page number" increase/decrease is slower than thumbnails, there is no significant difference between them.

For document 3, search box is significantly faster than the other three navigation methods ($p<0.01$ for all). Although the number shows scrollbar is slower than "page number" increase/decrease button and "page number" increase/decrease button is slower than thumbnails, there is no significant difference shown between any two of them. This result may be related to the navigation task setup. The task for document 3 is "Find the paragraph which describes a prototype named 'Flex Spreadsheet' in Chapter 5". As long as the user knows the target is in chapter 5, he/she can quickly skip a large part of the document by using any of the first three navigation method. Thus, the time difference is reduced.

Figure 7.11 shows the average task completion time by using the four navigation methods. The figure also shows the decreasing trend along the four navigation methods. Significant difference is found between scrollbar and thumbnails ($p<0.05$), and between search box and any of the other three navigation methods ($p<0.01$ for all).

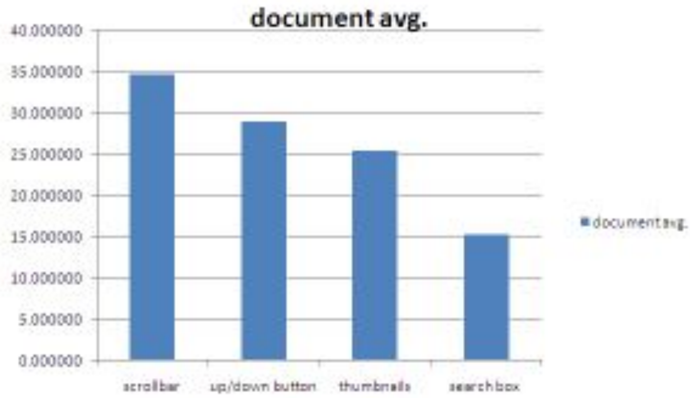

Figure 7.11: Average performance of navigation methods for digital document

Figure 7.12 shows that while there is an approximate linear relationship between the task completion time using any of the first three navigation methods and the target page number, there is no linear relationship shown between the task completion task using search box and the target page number. Significant difference is found for all of the first three navigation methods to show that navigating document 3 is significantly slower than navigating document 2, and navigating document 2 is significantly slower than navigating document 1 ($p<0.01$ for all).

It is found that there are several very large numbers in the row data which are weird. Per observation during the user test, the reason may be misunderstanding the task requirements. Especially, some participants misunderstood the task description because of the language, since many participants are not English native speaker, and some of the participants are from Asia, whose native language structure is different from that of English. Therefore, an extra

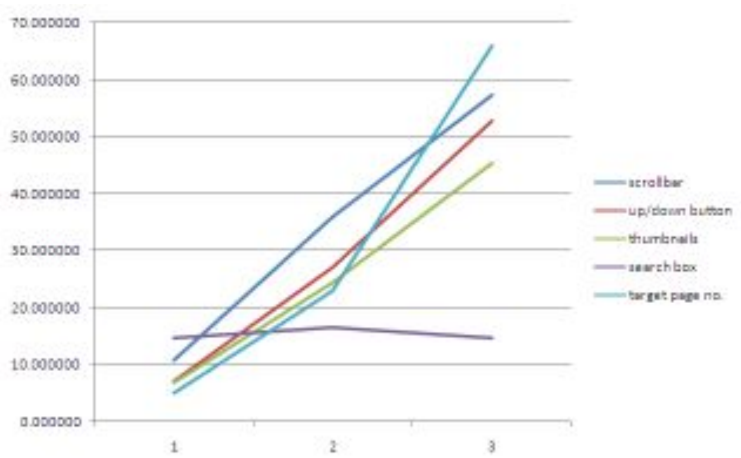

Figure 7.12: Relationship between task completion time and target page number

analysis was done by using the numbers that are in the range of average +/- 2*standard derivation, which waives the weird data and uses the remaining 95% of the original data set according to the normal distribution. The analysis result shows that by waiving the weird data, significant difference is shown between the average task completion time by using scrollbar and that by using "page number" increase/decrease button. This result better supports the hypothesis.

In conclusion, although significant difference is not found between all the two pairs of the four navigation methods, each of the three documents separately and the average data show the decreasing trend along the four navigation methods, except for the search box in document 1. And from the analysis result by waiving the weird data, it can be believed that the original results can be improved by involving a larger number of participants to reduce the effect of the weird data. Hence, it is concluded that the hypothesis is proved. Therefore, we can say that for digital document, targeted object search with manual confirmation performs better than the navigation methods which require manual search; random access has advantage against sequential access, and discrete access has advantage against continuous access.

7.5.2 Interactive map

Analysis of the user test results for interactive map

As shown in Figure 7.13, for all the three city maps, search box is faster than tap-and-drag with cues, and tap-and-drag with cues is faster than tap-and-drag. For map 1 and map 2, which are the maps of Manchester, UK and Toulouse, France, and for the average data (shown in Figure 7.14), significant difference is found between every two of the three navigation methods ($p<0.01$ for all). And for map 3, which is the map of Washington D.C., U.S., significant difference is also found between tap-and-drag and tap-and-drag with cues ($p<0.05$) and between any other pairs of the navigation methods ($p<0.01$).

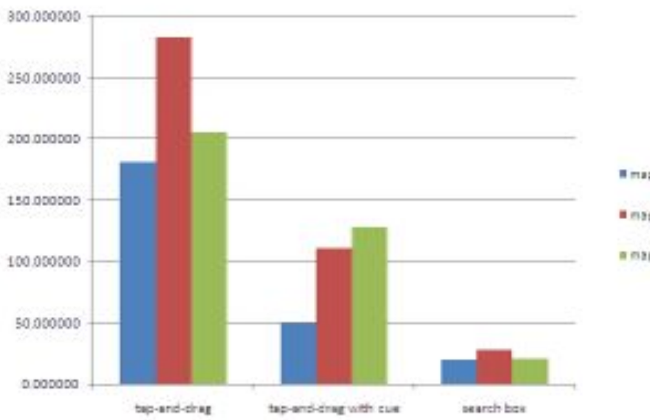

Figure 7.13: Performance of navigation methods for the three maps

It is observed that while map 2 requires the most navigation time when using tap-and-drag and search box, map 3 requires the most time when using tap-and-drag with cues. The reason may be most of the cues provided in map 3 are off-screen, while almost all the cues provided in map 1 and map 2 are displayed in the initial view when the map is loaded. Hence, users spent more time to search for the off-screen cues when navigating map 3.

Furthermore, Figure 7.15 shows that when the cues are in the current display, the task completion time using tap-and-

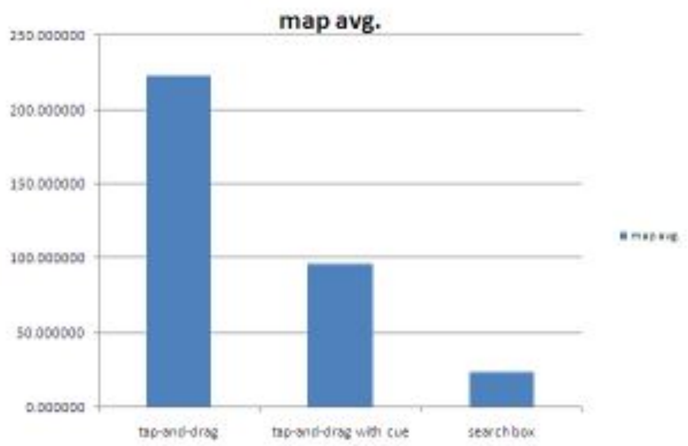

Figure 7.14: Average performance of navigation methods for interactive map

drag with cues has an approximate linear relationship with the number of cues provided. (The difference between the task completion time using tap-and-drag with cues in map 1 and in map 2 is significant ($p<0.01$).) This suggests that the task completion time is decided by the number of cues the user needs to check. Therefore, it implies that the system should only provide the important cues for the user. If too many cues are provided, the task completion time will also increase.

In conclusion, the results show significantly that search box is faster than tap-and-drag with cues, and tap-and-drag with cues is faster than tap-and-drag. Therefore, the hypothesis is proved. For interactive map, targeted object search with manual confirmation performs better than manual search with the help of predefined frames, and the latter performs better than totally manual search. This is also the preference given for the "effort indicators".

Furthermore, the deviation analysis also shows that targeted object search with manual confirmation has much less deviation than the other two methods, and the deviation using totally manual search is even bigger than that using manual search with the help of predefined frames.

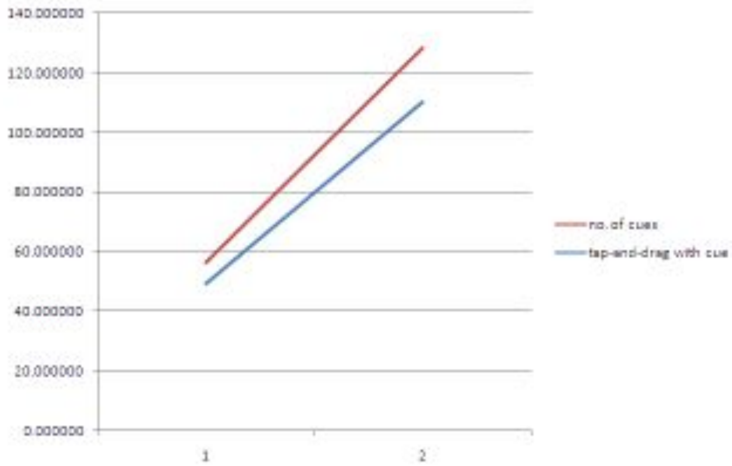

Figure 7.15: Relationship between task completion time and number of cues

7.5.3 Digital video

Analysis of the user test results for digital video

As shown in Figure 7.16, for all the three pieces of video, timeline slider is significantly faster than fast forward/rewind button rate control ($p<0.01$ for all). The time difference between the two navigation methods increases when the target length increases. But although video 2 requires the most time to navigate when using fast forward/rewind button rate control, it does not require the most time when using timeline slider. The average data illustrated in Figure 7.17 also shows that timeline slider is significantly faster than fast forward/rewind button rate control in average ($p<0.01$).

Besides, for fast forward/rewind button rate control, it shows to be an approximate linear relationship between the task completion time and target length (shown in Figure 7.18). The difference between the task completion time for all the three pieces of video is significant ($p<0.01$ for all). And deviation analysis shows that when using fast forward/rewind button rate control to navigate, there is very little deviation of the task completion time. This implies that the navigation depends on the system itself to a large extent. Since it requires very little user's interaction with

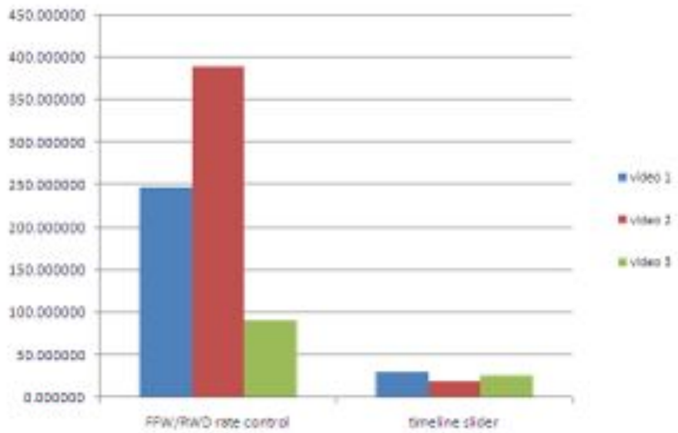

Figure 7.16: Performance of navigation methods for the three pieces of video

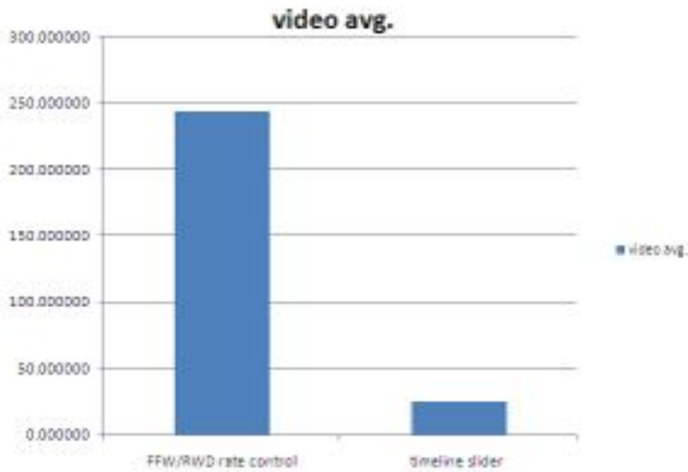

Figure 7.17: Average performance of navigation methods for digital video

the computer, the task completion time does not vary a lot among the users.

In conclusion, the results show that timeline slider is significantly faster than fast forward/rewind button rate control,

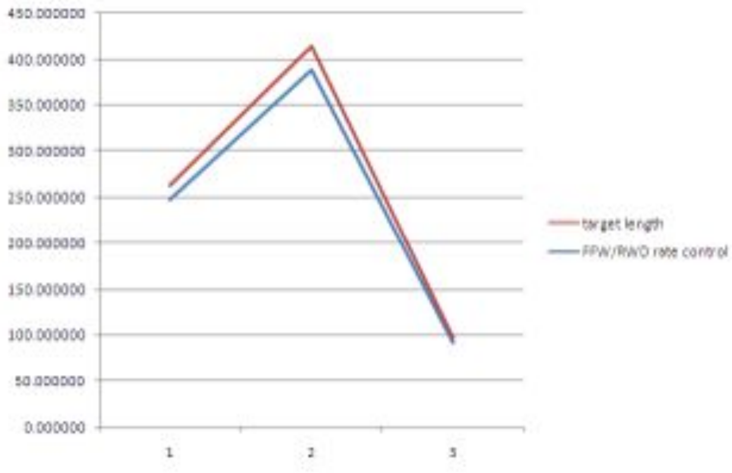

Figure 7.18: Relationship between task completion time and target length

which proves the hypothesis. Therefore, it is concluded that for digital video, discrete/random access has advantage against continuous/sequential access.

Chapter 8

Summary and future work

This chapter provides a retrospection of what have been done in the work, summarizes the problems addressed in the work and contributions for the field of human computer interaction. After that, some future work idea is proposed for going deeper into the theoretical research of navigation and design space.

8.1 Summary and contributions

Summary of the work

Overall speaking, the work is a theoretical analysis of the navigation in digital media in the form of creating a design space. By introducing the background of navigation in digital media and design space in 2—"Background", and by reviewing the related work of navigation design, analysis and design space in 3—"Related work", we know that there had been no previous work to create a design space for the navigation in digital media, and to have a comprehensive look at the navigation methods used in different types of digital media up to now. Thus, this work systemized the analysis of navigation in digital media by creating a design space to describe the navigation in an abstract way, which classifies navigation methods according to the navigation properties. Furthermore, the work provided a series of analysis methodologies to systematically analyze navigation methods, both by the design space and by the evaluation block diagram.

4—"Navigation of digital media" abstracted the navigation in digital media by providing a taxonomy which addresses the five dimensions of the navigation- input, control, manipulation, access, and navigation/ search. Then, the major existing navigation methods for the four types of digital media, digital document, picture/ interactive map, digital audio and digital video, are classified using this taxonomy.

5—"Design space" then presented the design space created based on the five dimensions and the taxonomy proposed. With the notations, the navigation methods were represented in the design space. And a series of analysis methodologies and guidelines for systematically analyze the navigation methods with the design space were introduced. Afterwards, by representing all the major existing navigation methods for the four types of digital media in the design space, the work had a comprehensive look at the state-of-the-art of navigation in digital media, discussed the current design problems, and proposed future design suggestions.

6—"Evaluation block diagram" proposed another evaluation tool- evaluation block diagram. It is a kind of block diagram based flow diagram generated from the design space but describes the navigation by states and paths. The evaluation block diagram is a useful tool to evaluate the capabilities of the navigation methods by comparing with standard block diagram for a navigation task. The generation method was explained in the chapter, followed by the evaluation methodology. An example was also given to explain how to use the evaluation tool.

7—"Validation" described a user test, which aimed to verify the correctness of the analysis methodologies and framework proposed in the work. A test program was developed to run the user test in a system controlled way. As expected, the test results proved the hypothesis. For digital document, it proved that targeted object search with manual confirmation performs better than the navigation methods which require manual search; random access has advantage against sequential access, and discrete access has advantage against continuous access. For interactive map, it proved that targeted object search with manual confirmation performs better than manual search with the help of predefined frames, and the latter performs better than totally manual search. And for digital video, it proved that discrete/random access has advantage against continuous/sequential access. These results are consistent with the analysis methodologies provided in the work, and are the same as the results derived from the evaluation block diagram.

Because of the time and resource limitation, the user test was only able to verify the correctness of a part of the work. However, the results gave us confidence that the evaluation tools and methodologies proposed in the work are useful. And we believe that the other parts of the work are also rational. But the validation work will be done in the future.

Contribution of the work

The main contribution of the work is that this work is the first to create a design space for navigation in digital media, provide a systematic way to analyze the navigation methods, and to have a comprehensive look at the current navigation designs. It described the navigation in an abstract way by exploring a taxonomy. Besides, the work also proposed a useful evaluation tool to measure the capabilities of navigation methods for different navigation tasks. And so far, the user test proved its correctness.

8.2 Future work

Future work

Since this work is just a start to explore the navigation in digital media and the technologies of digital media are rapidly developing, there is still much work can be done in the future.

First, for getting more convincing data, we should redo the user tests for those where weird data appeared. Besides, there is room for the test program to be improved. Timeout could be set for those really touch tasks, e.g. tap-and-drag with totally manual search for the interactive map, to make the user test more humane. Some action logs could be recorded for the analysis of the data. For example, the logs of user finding the incorrect targets can be recorded so that we may be able to know the reason of the existence of those weird data. And since the user test in this work only proved a part of the framework, more complete user test should be done in the future to validate the whole work.

In this work, the design space only addressed four types of digital media which are commonly used. But in fact, there are more types of digital media and some may become the major ones in the future, e.g. website with links, 3D environment, virtual reality environment, etc. Hence, extending the design space to include more types of digital media and explore more properties of navigating digital media should be addressed in the future. Besides, in different use environments, the performance of navigation methods would vary somewhat. Therefore, analyzing the navigation in different use environment, e.g. for mobile use, in shared environment, etc. could also be done in the future. In addition, future work may also address the novel navigation methods such as speech recognition, which is not of the form as today's navigation methods.

Appendix A

Evaluation block diagrams for digital document

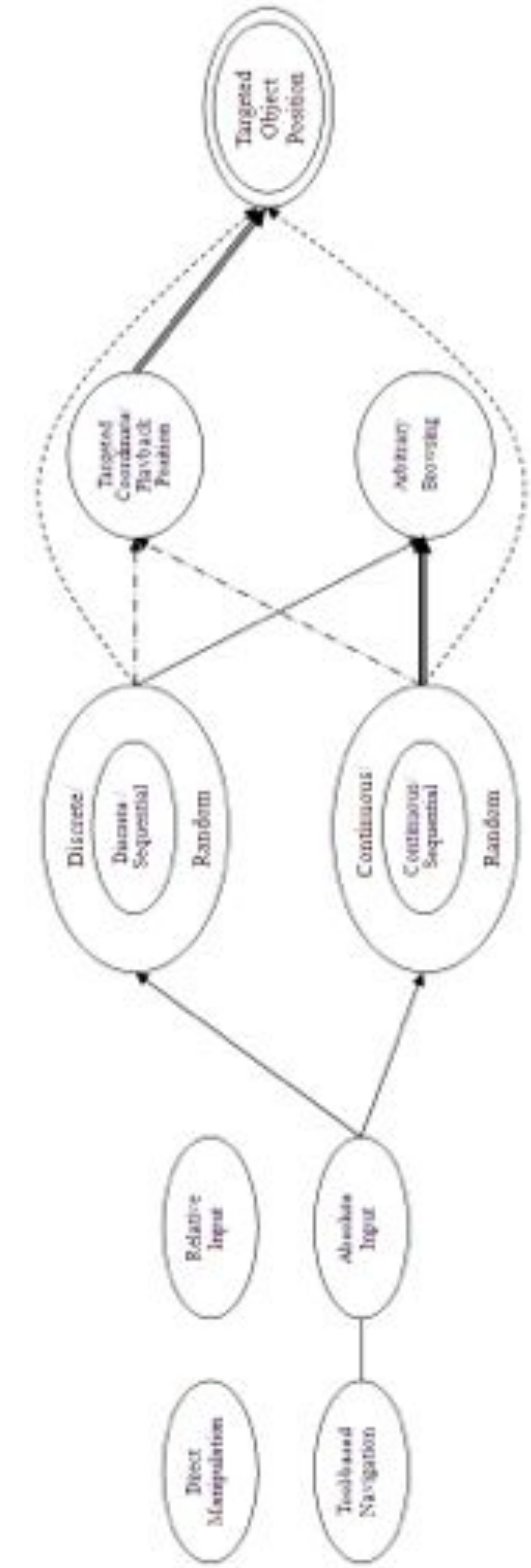

Figure A.1: Evaluation block diagram of mouse/ stylus/ touch screen + scrollbar for digital document

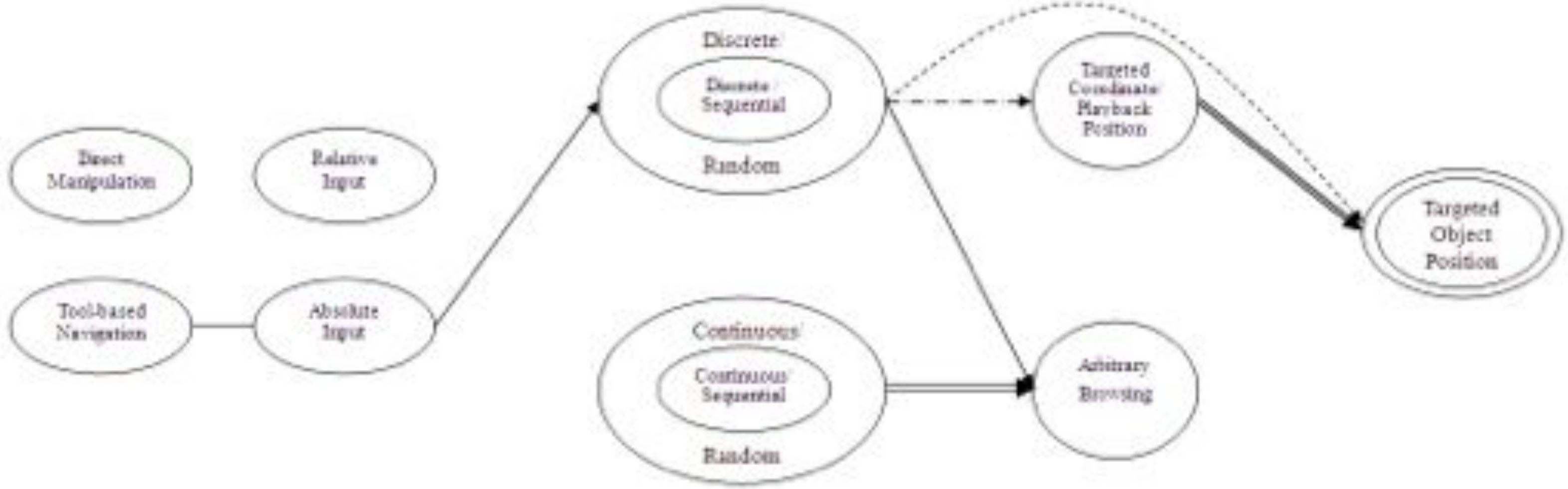

Figure A.2: Evaluation block diagram of mouse/ stylus/ touch screen + thumbnail enhanced scrollbar for digital document

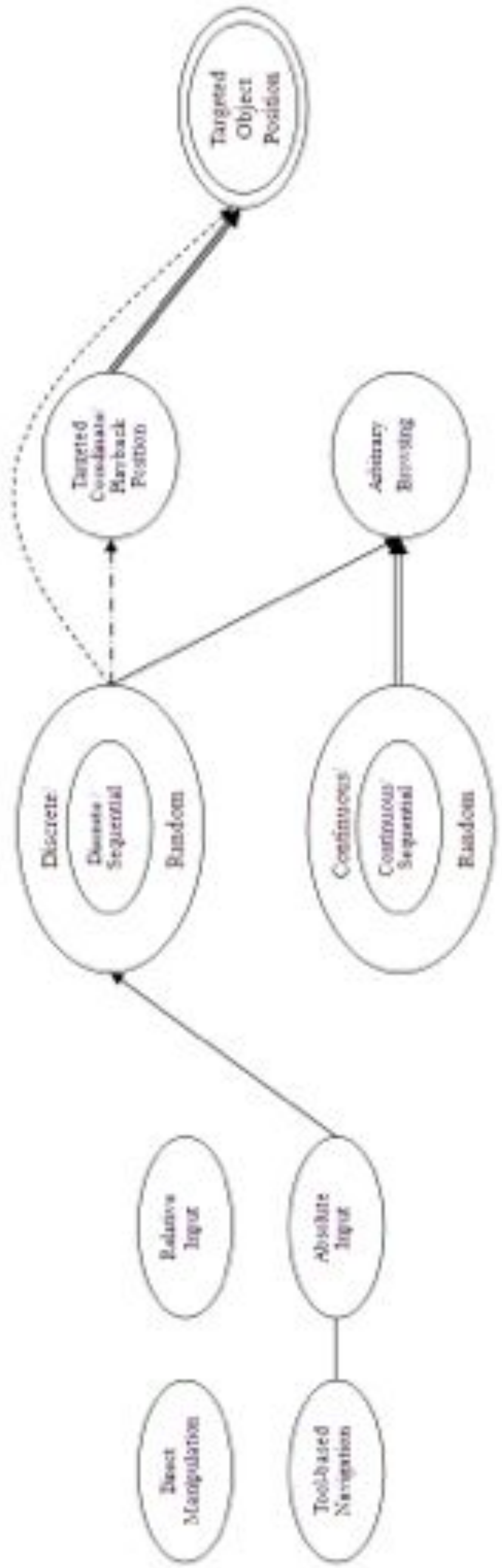

Figure A.3: Evaluation block diagram of mouse/ stylus/ touch screen + thumbnails for digital document

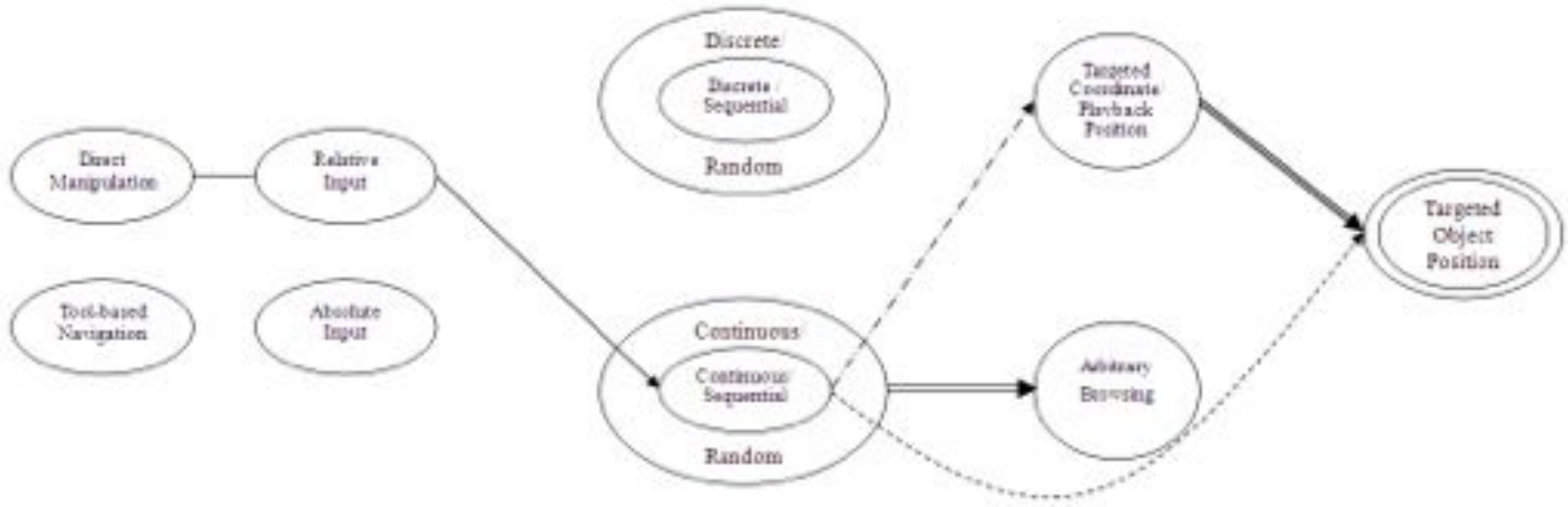

Figure A.4: Evaluation block diagram of mouse/ stylus/ touch screen + tap-and-drag for digital document

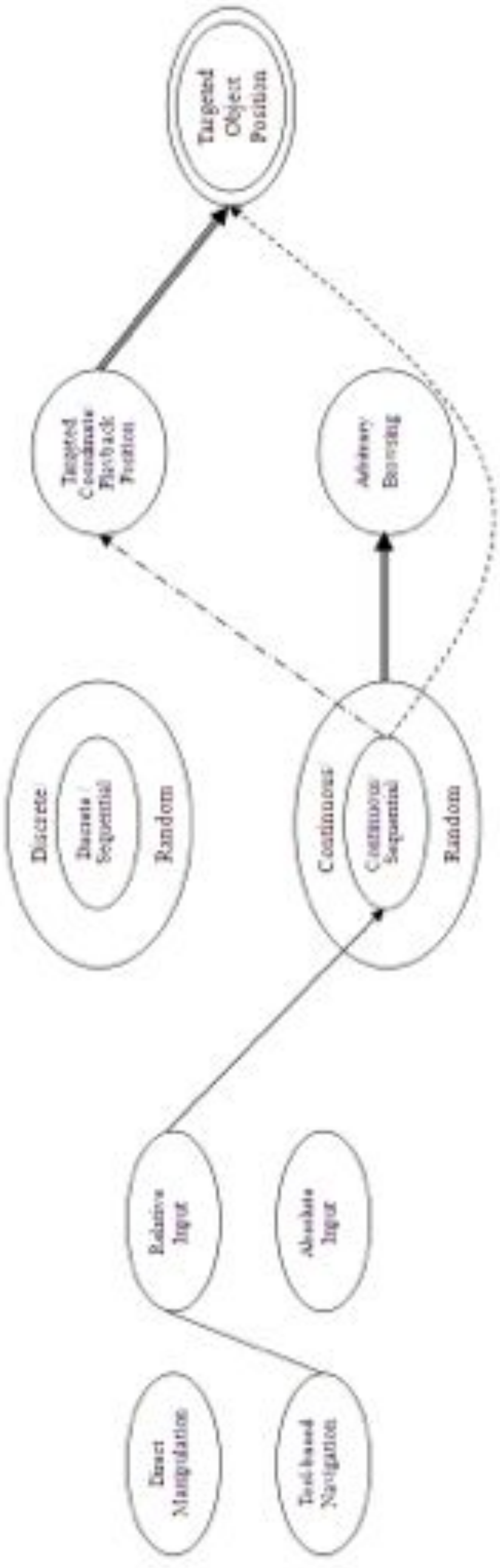

Figure A.5: Evaluation block diagram of mouse wheel position-based/ joy dial/ click wheel scrolling for digital document

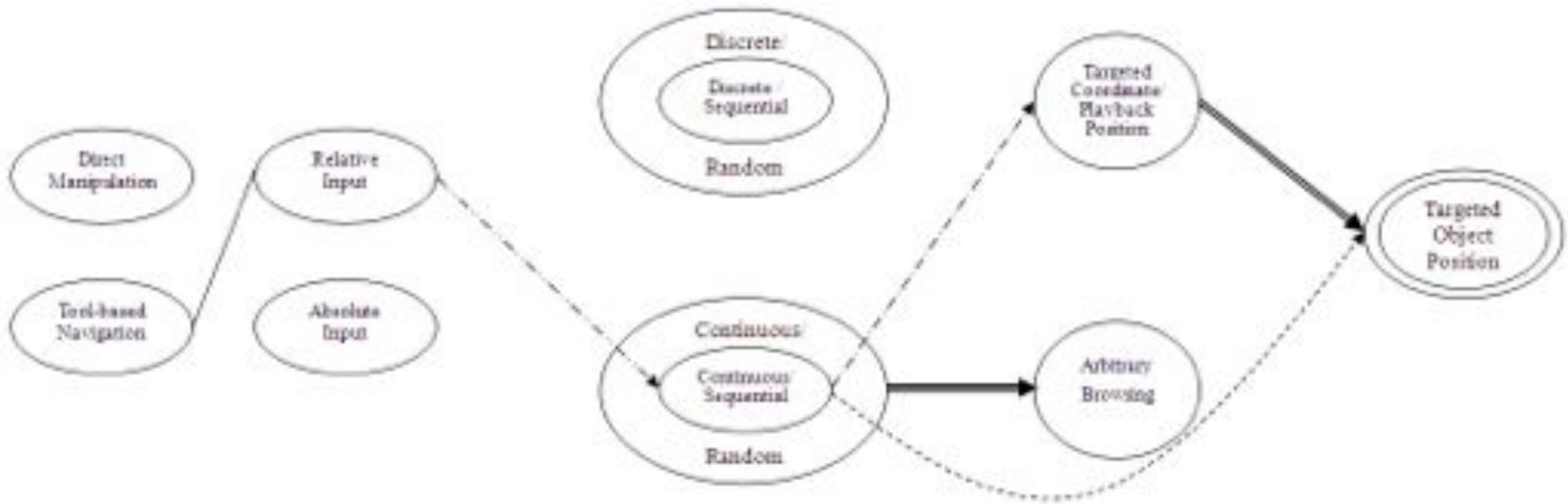

Figure A.6: Evaluation block diagram of mouse wheel rate-based scrolling for digital document

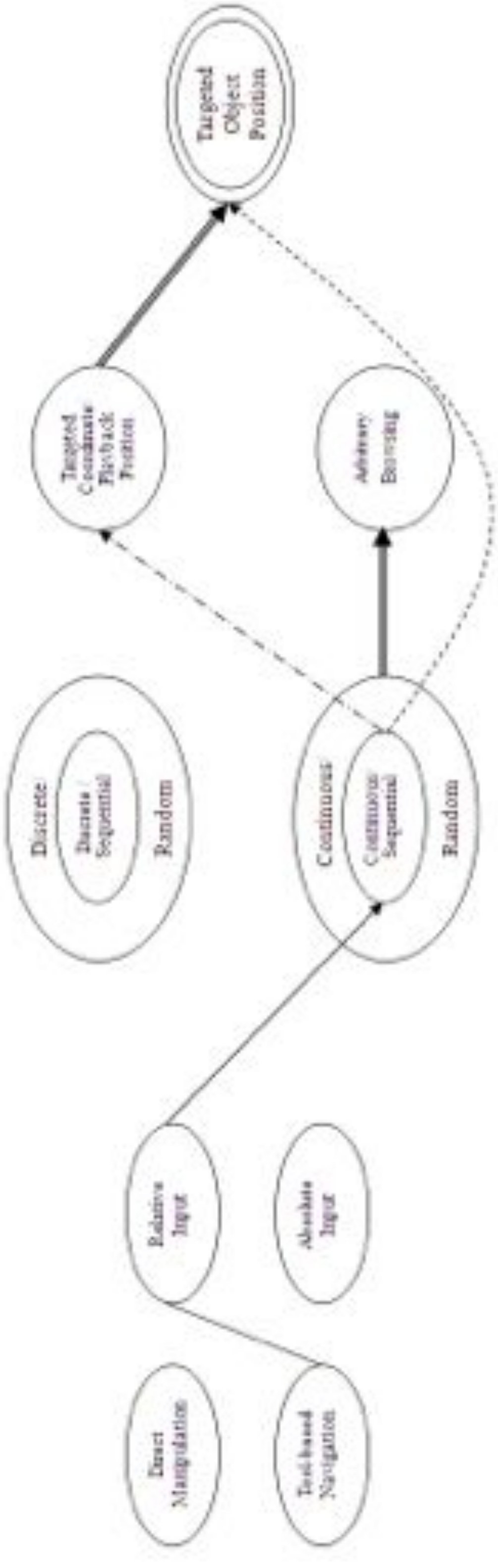

Figure A.7: Evaluation block diagram of keyboard up/down button scrolling for digital document

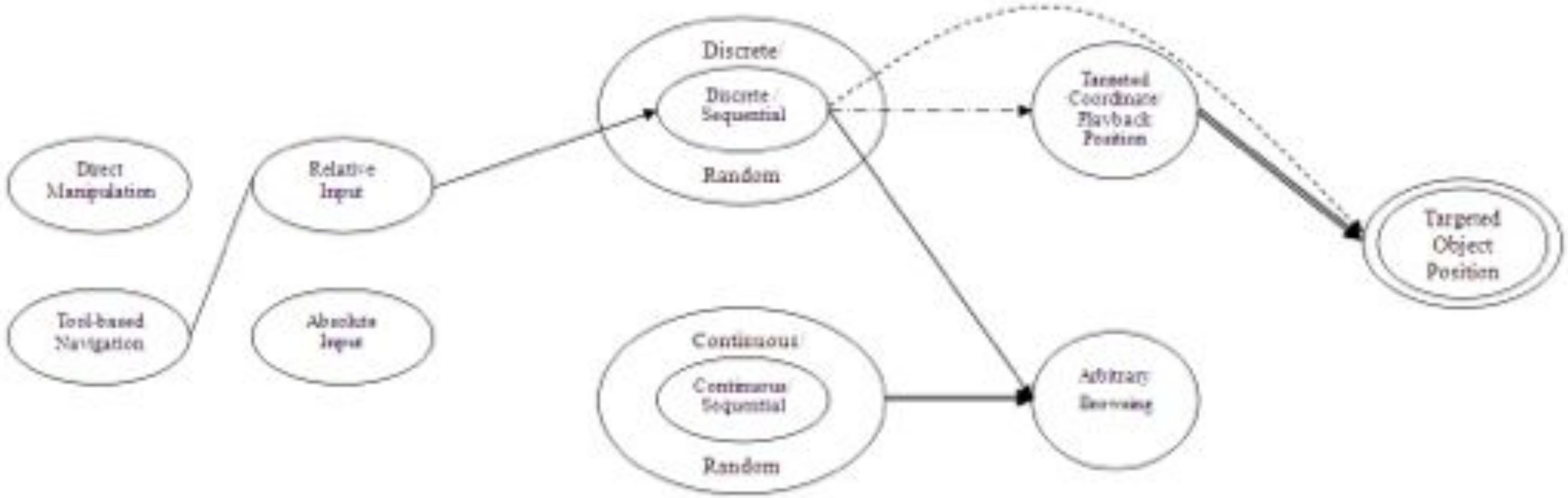

Figure A.8: Evaluation block diagram of keyboard arrow keys + thumbnails for digital document

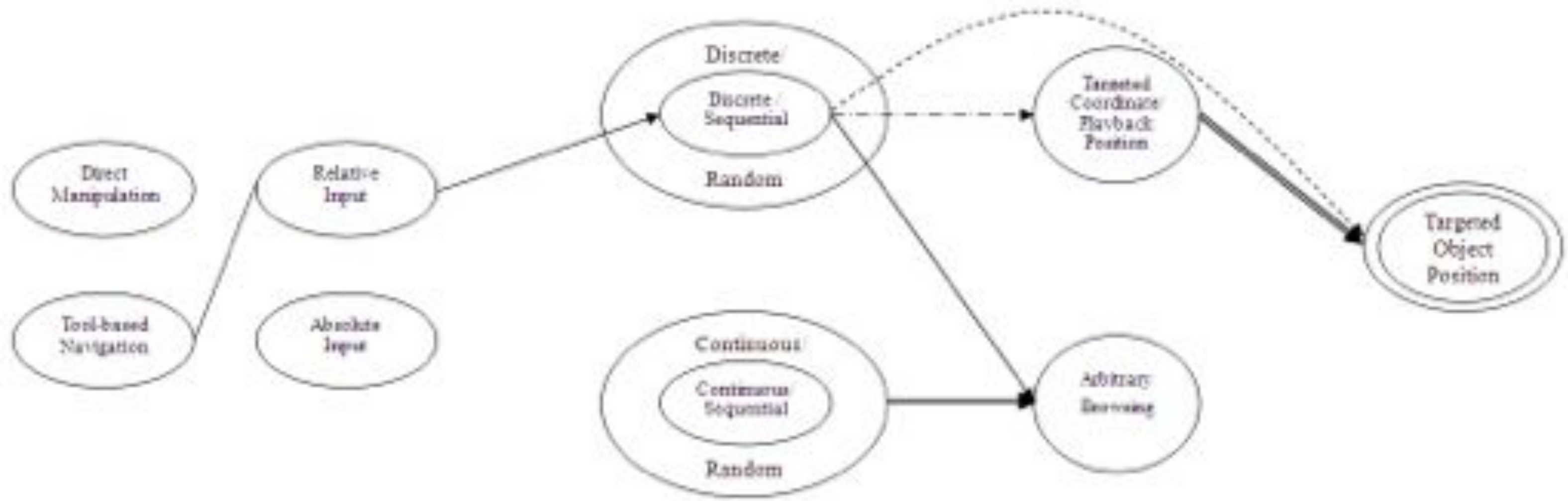

Figure A.9: Evaluation block diagram of keyboard page up/ page down button for digital document

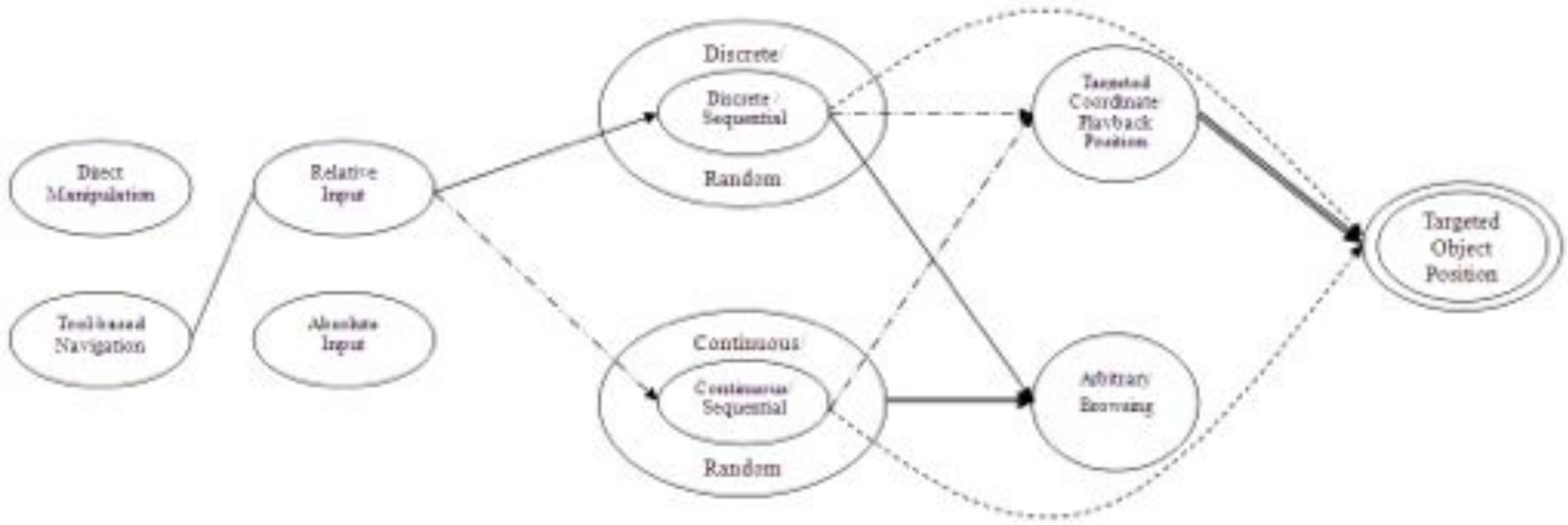

Figure A.10: Evaluation block diagram of TWEND for digital document

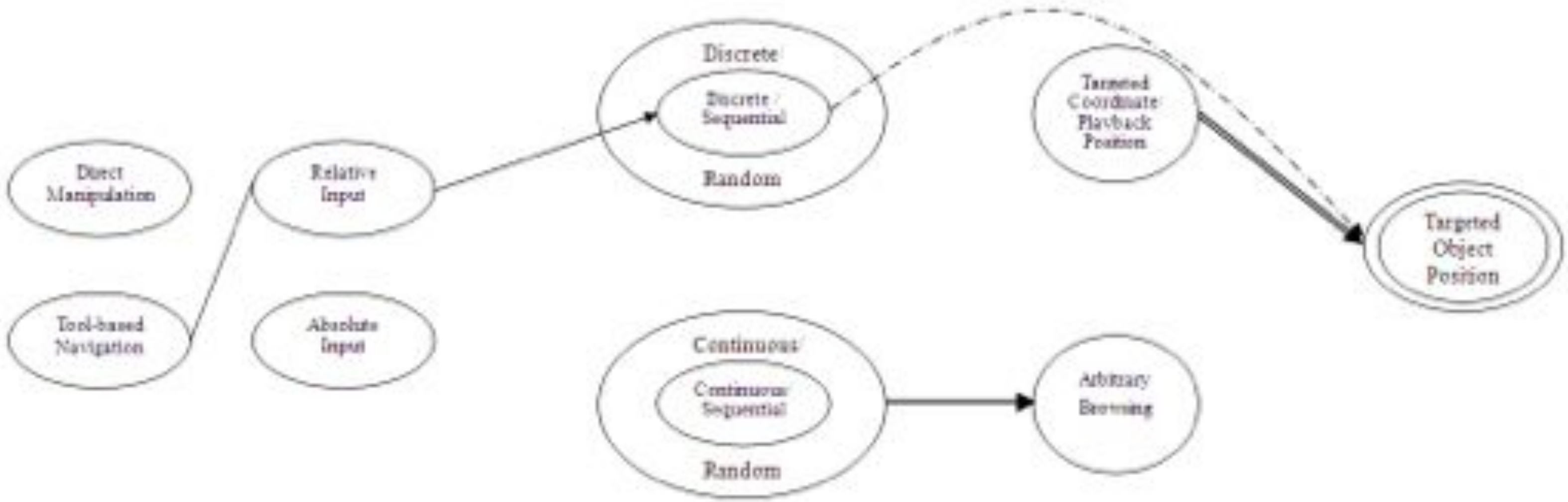

Figure A.11: Evaluation block diagram of search box ("find" function) for digital document

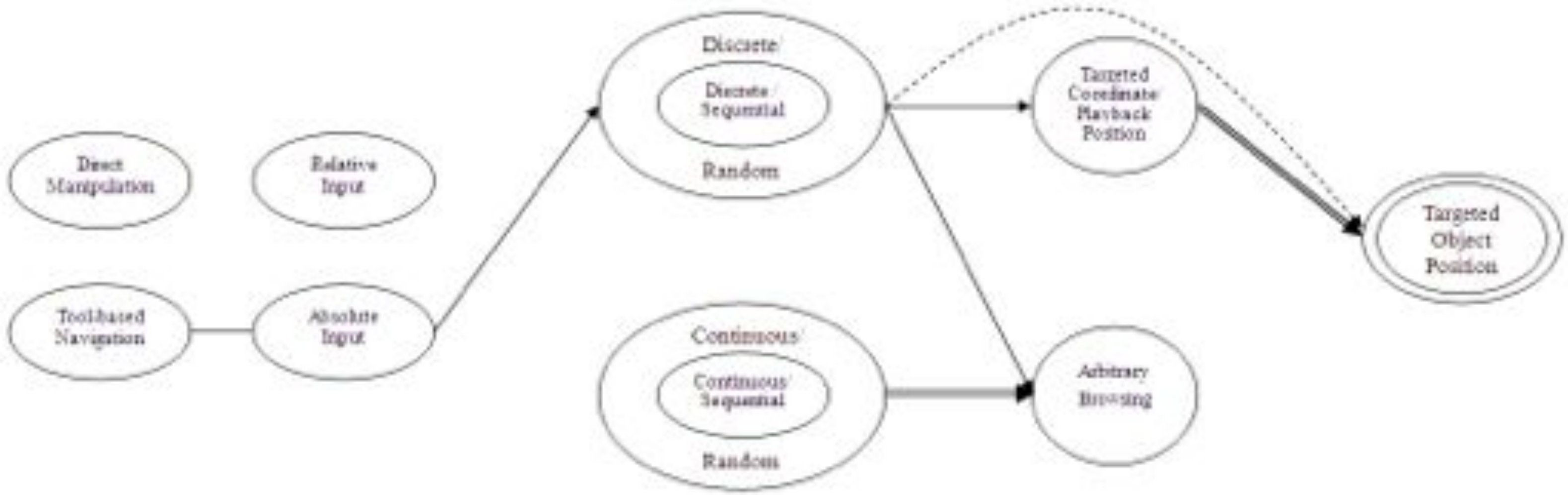

Figure A.12: Evaluation block diagram of "page number" input box for digital document

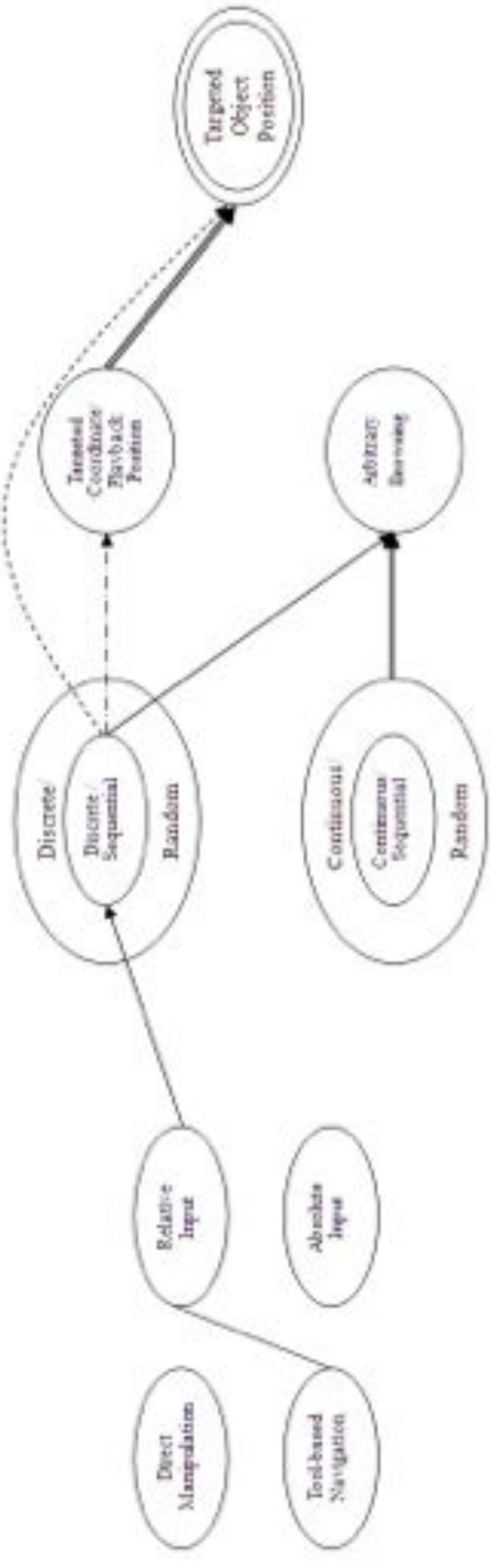

Figure A.13: Evaluation block diagram of "page number" increase / decrease button for digital document

Appendix B

Evaluation block diagrams for picture/ interactive map

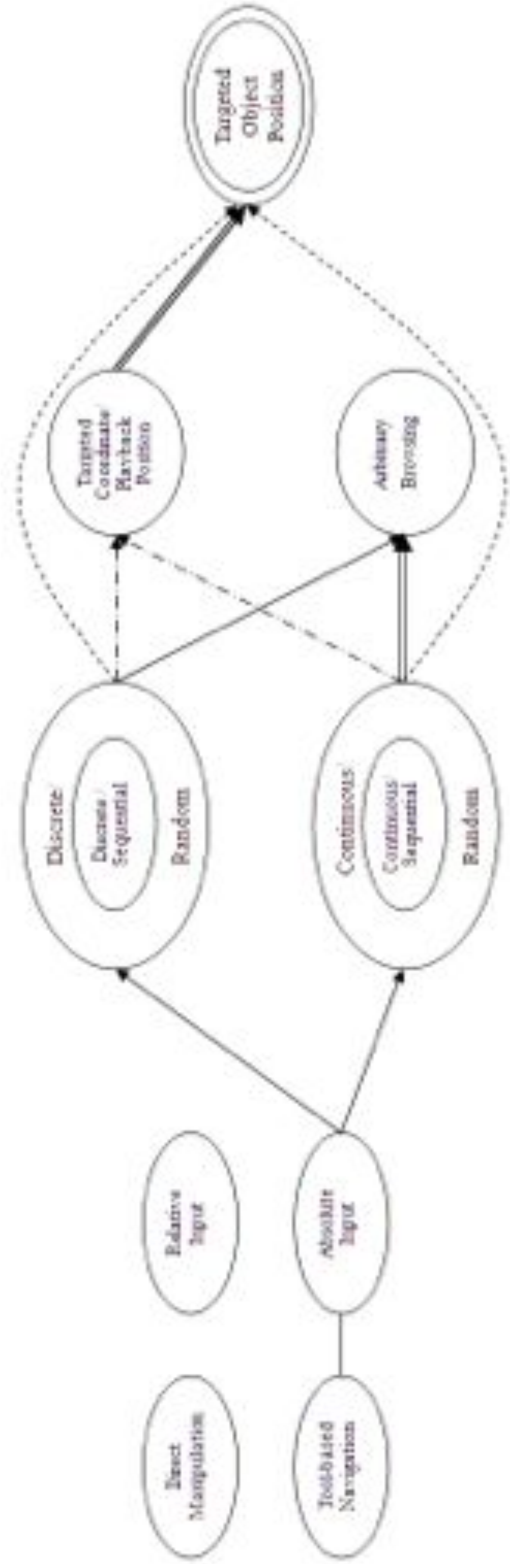

Figure B.1: Evaluation block diagram of mouse/ stylus/ touch screen + scrollbar for picture/ interactive map

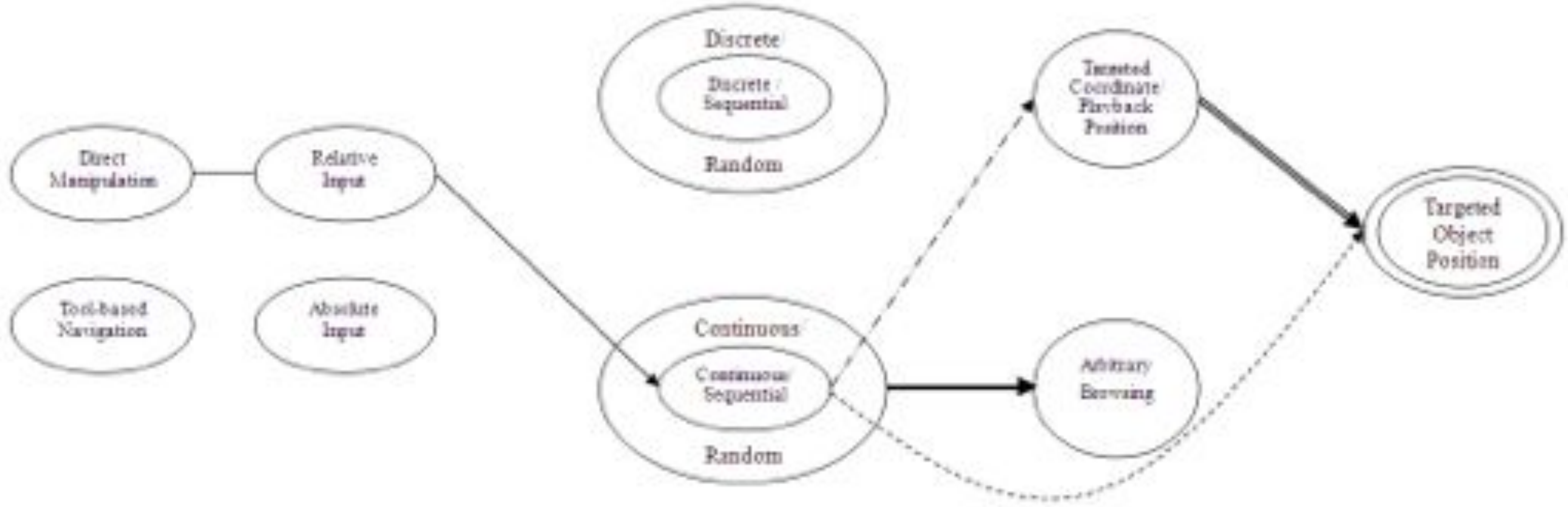

Figure B.2: Evaluation block diagram of mouse/ stylus/ touch screen + tap-and-drag for picture/ interactive map

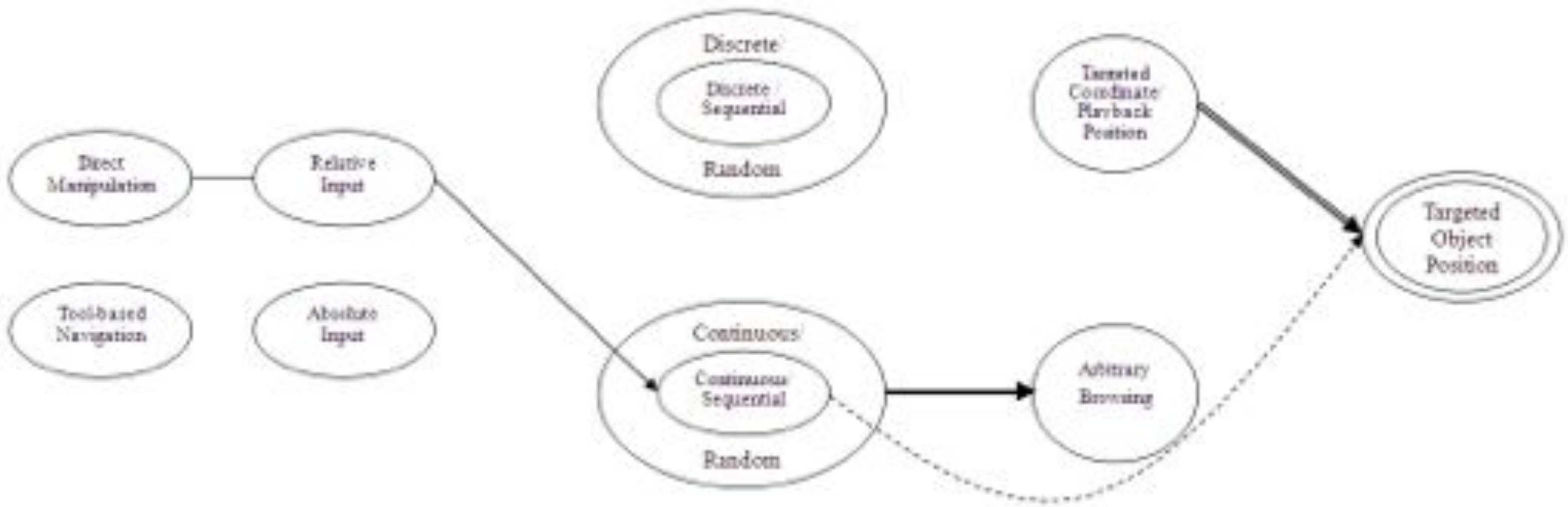

Figure B.3: Evaluation block diagram of mouse/ stylus/ touch screen + touch-and-go for picture/ interactive map

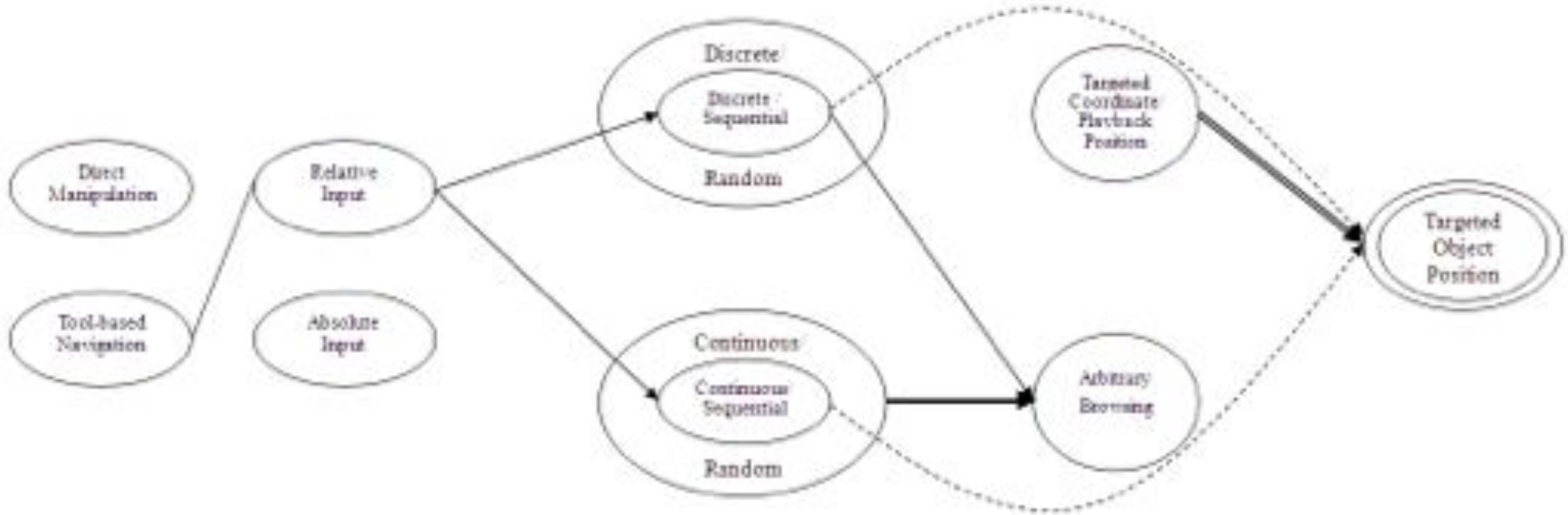

Figure B.4: Evaluation block diagram of mouse/ stylus/ touch screen + planar for picture/ interactive map

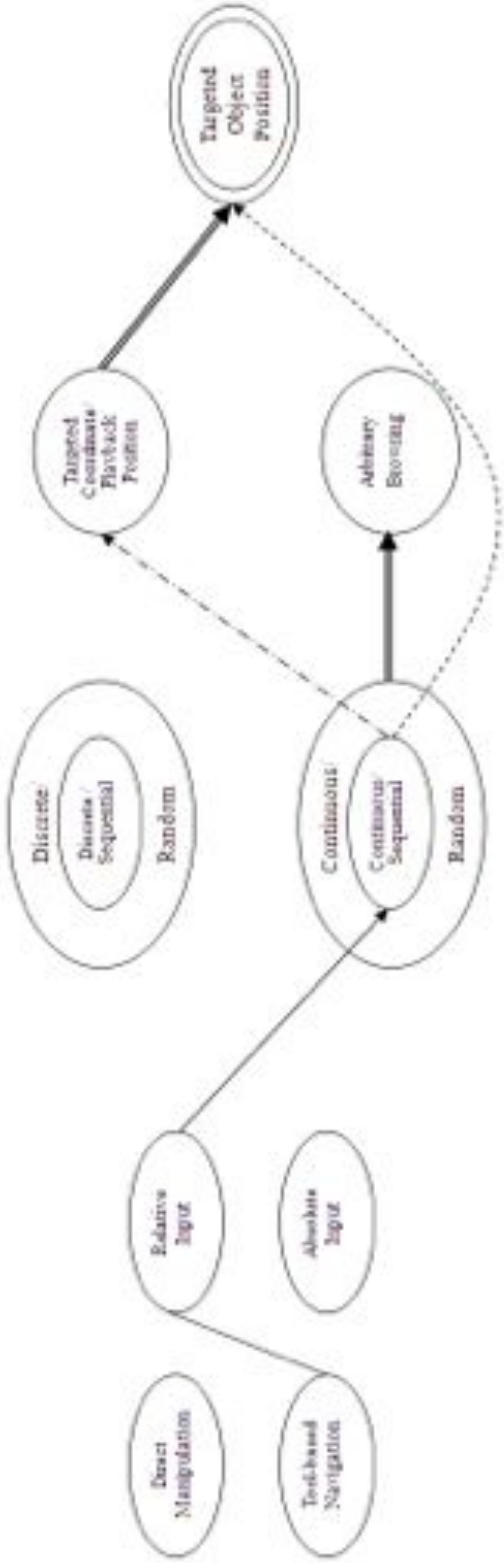

Figure B.5: Evaluation block diagram of keyboard arrow keys for moving and +/- key for zoom in/out for picture/ interactive map

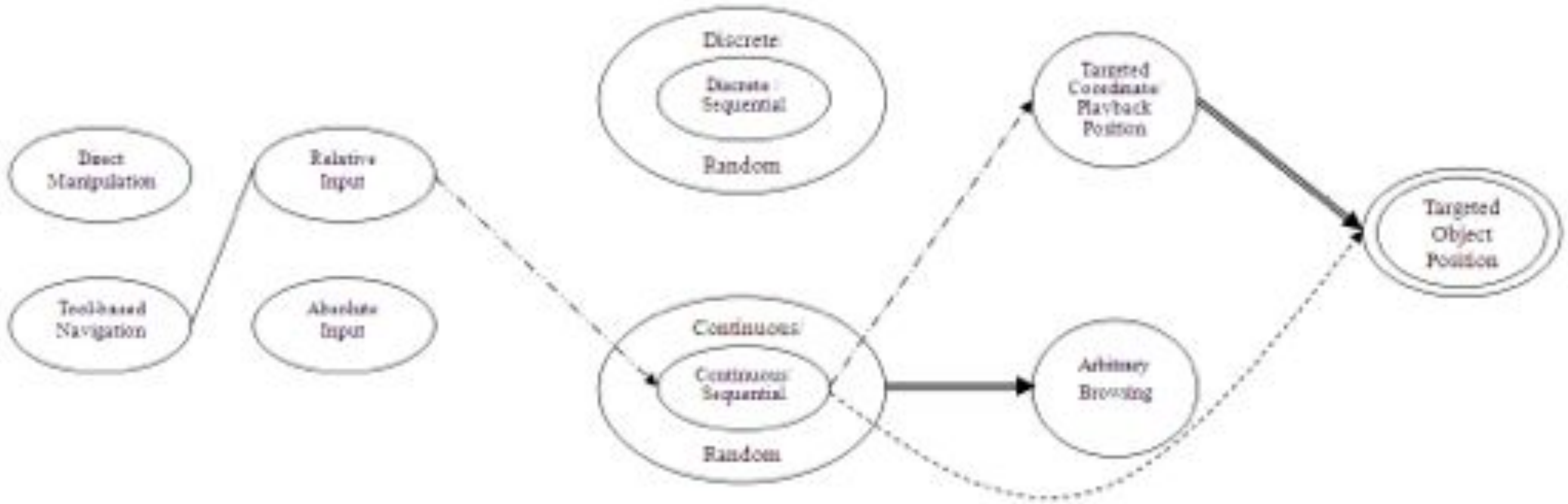

Figure B.6: Evaluation block diagram of joystick for picture/ interactive map

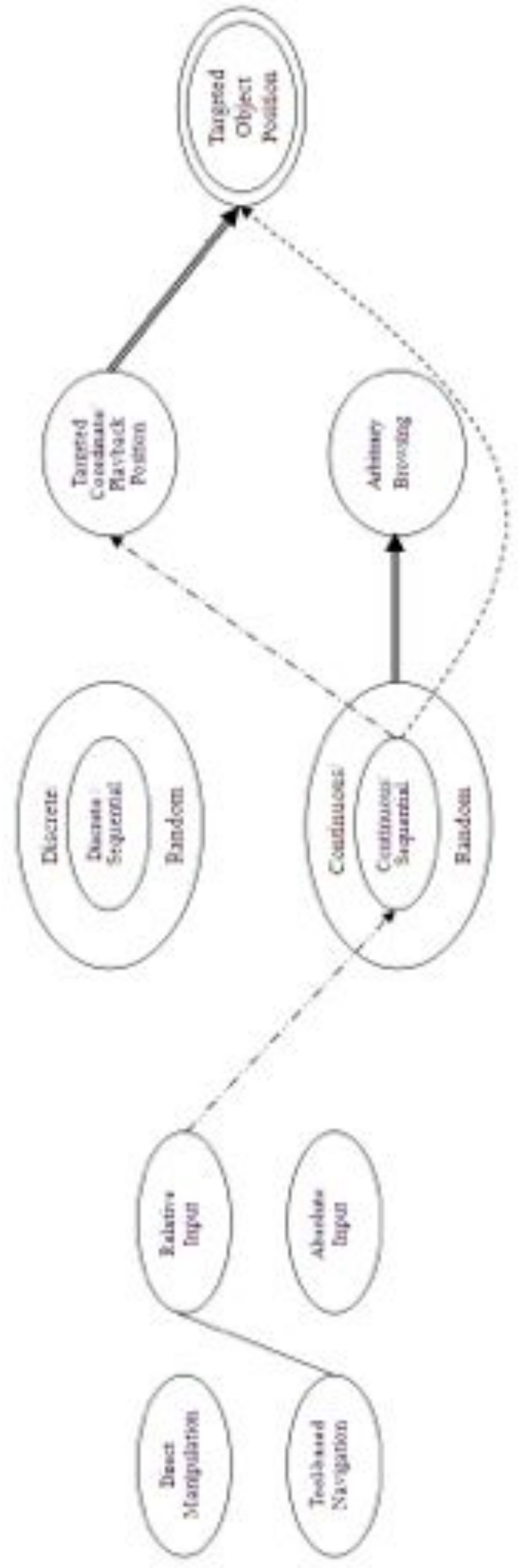

Figure B.7: Evaluation block diagram of TWEND for picture/ interactive map

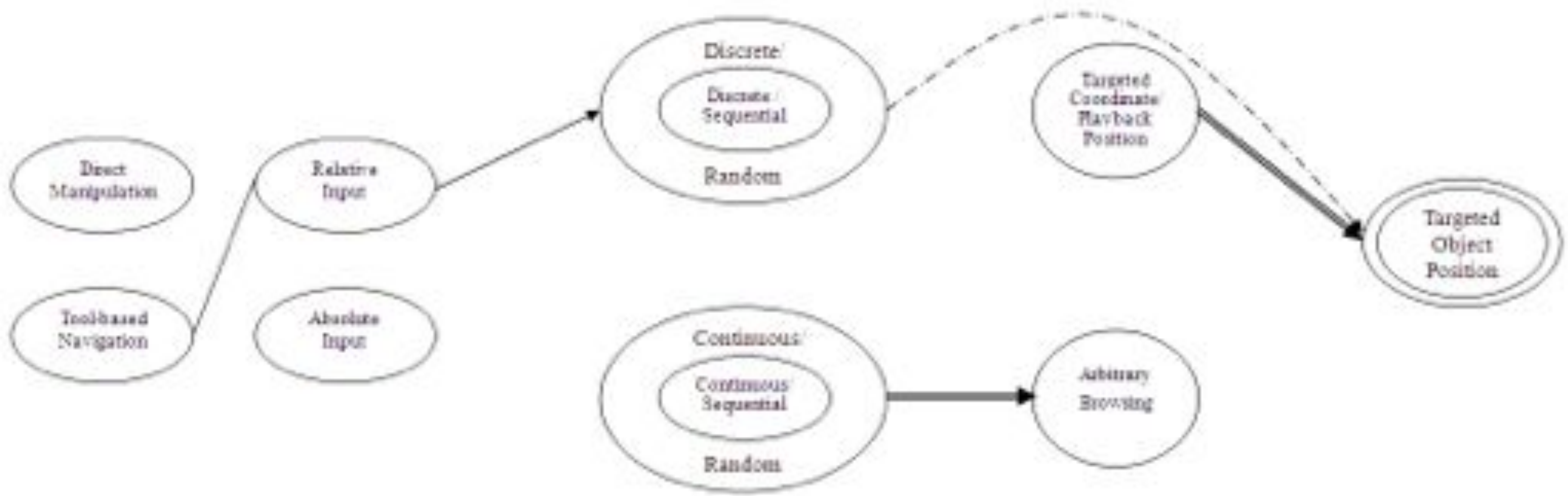

Figure B.8: Evaluation block diagram of search box for picture/ interactive map

Appendix C

Evaluation block diagrams for digital audio

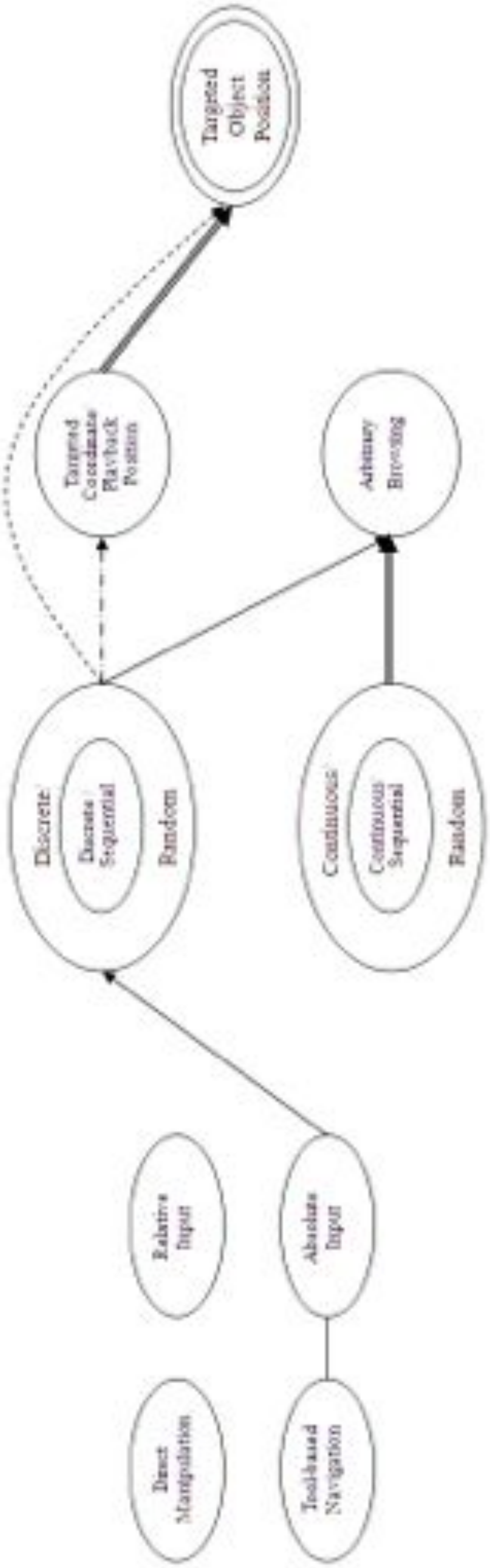

Figure C.1: Evaluation block diagram of mouse/ stylus/ touch screen + timeline slider for digital audio

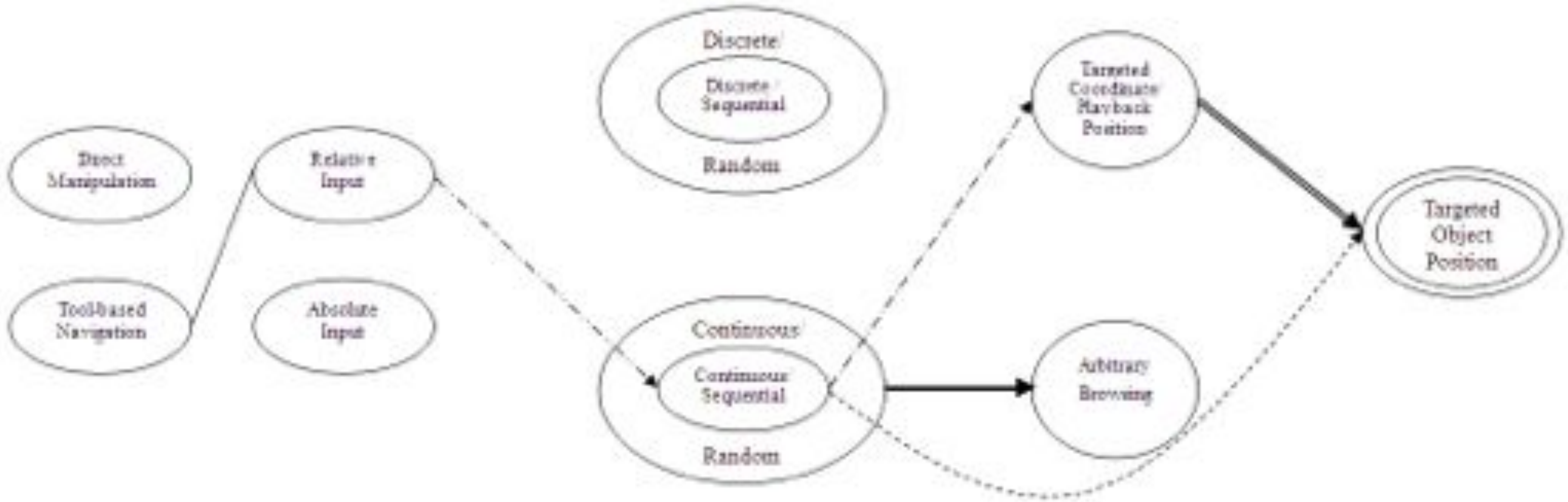

Figure C.2: Evaluation block diagram of mouse/ stylus/ touch screen + fast forward/ rewind button (increasing playback rate) for digital audio

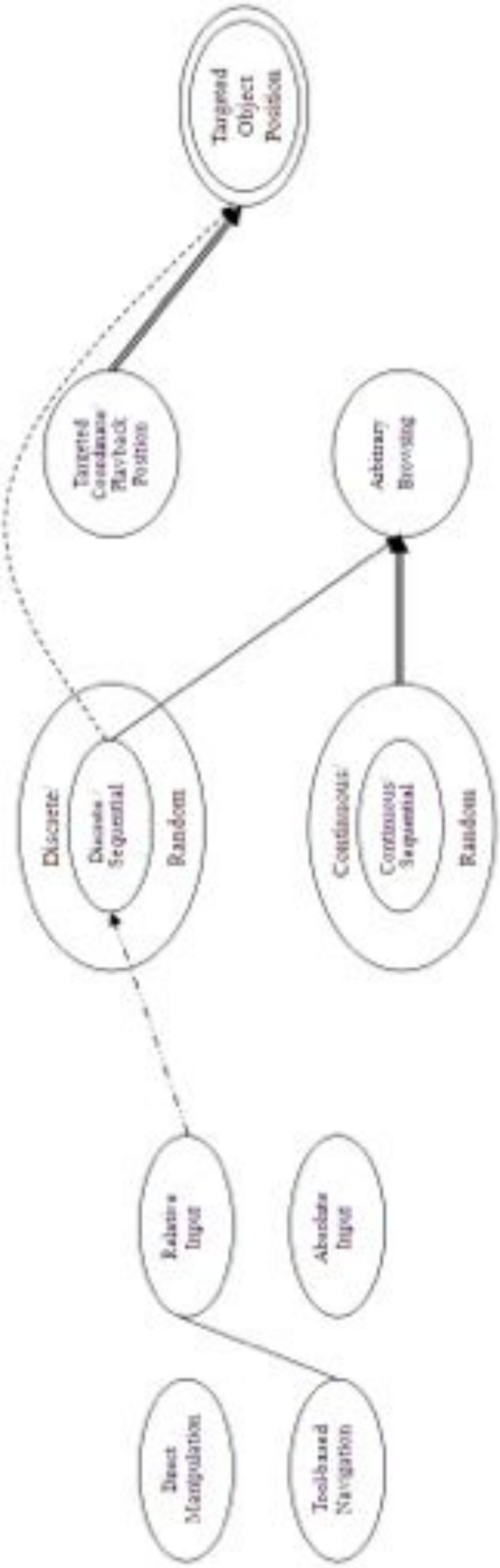

Figure C.3: Evaluation block diagram of mouse/ stylus/ touch screen + fast forward/ rewind button (frame skipping) for digital audio

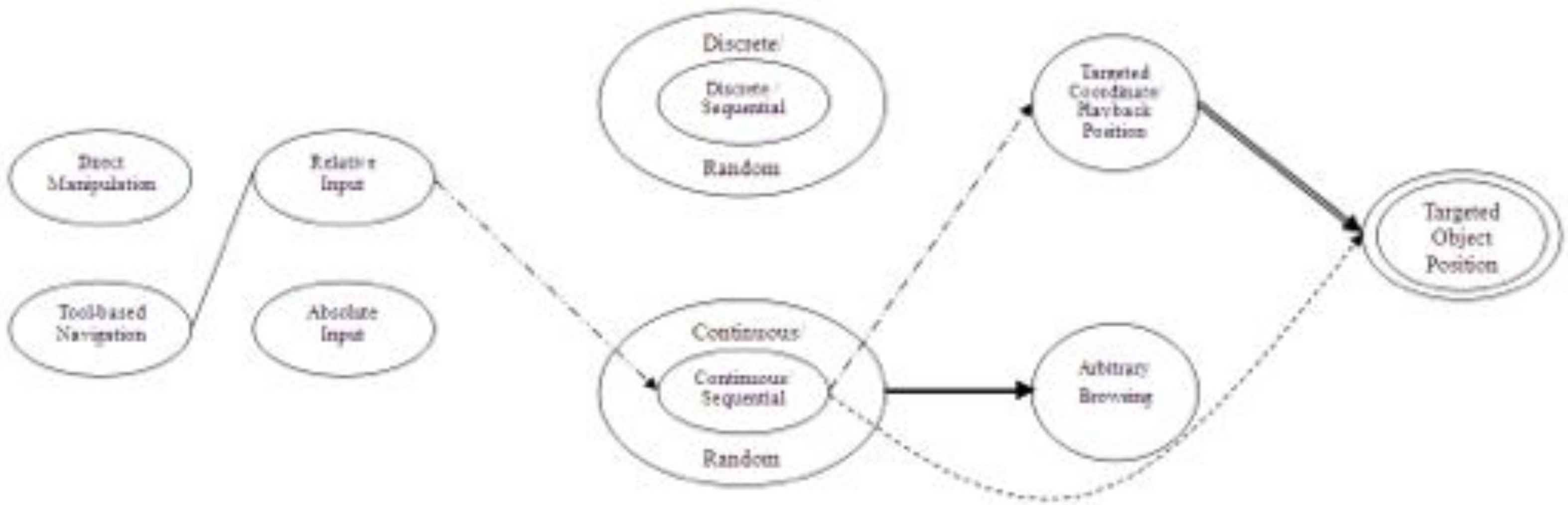

Figure C.4: Evaluation block diagram of shuttle wheel (spring loaded) for digital audio

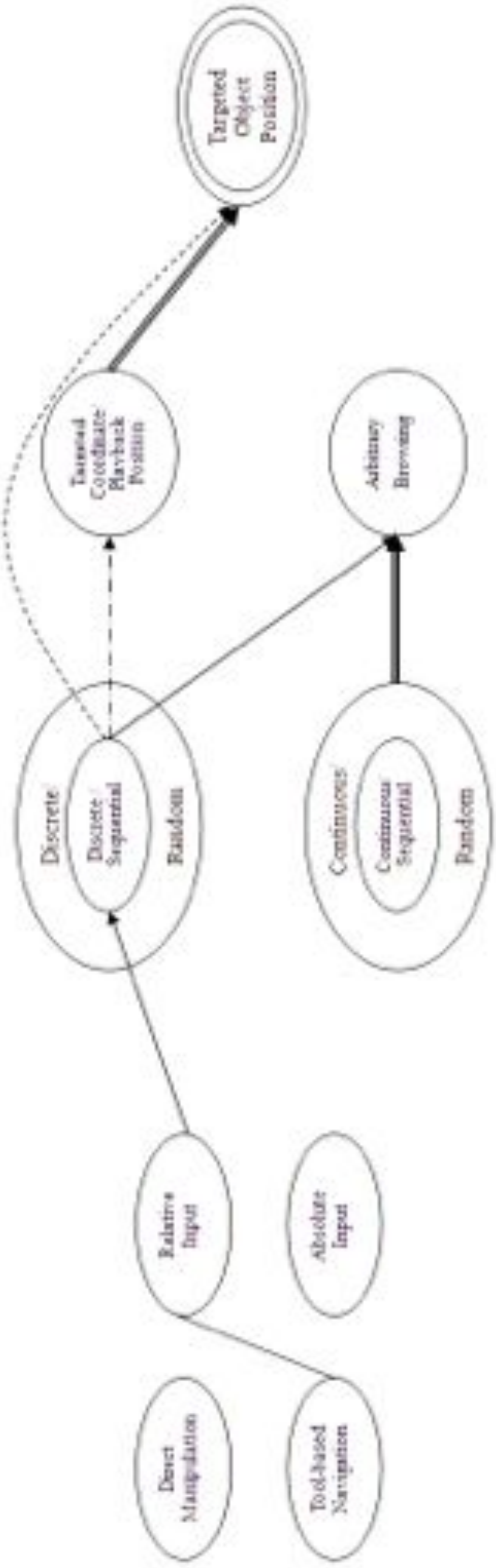

Figure C.5: Evaluation block diagram of jog dial/ click wheel for digital audio

Appendix D

Evaluation block diagrams for digital video

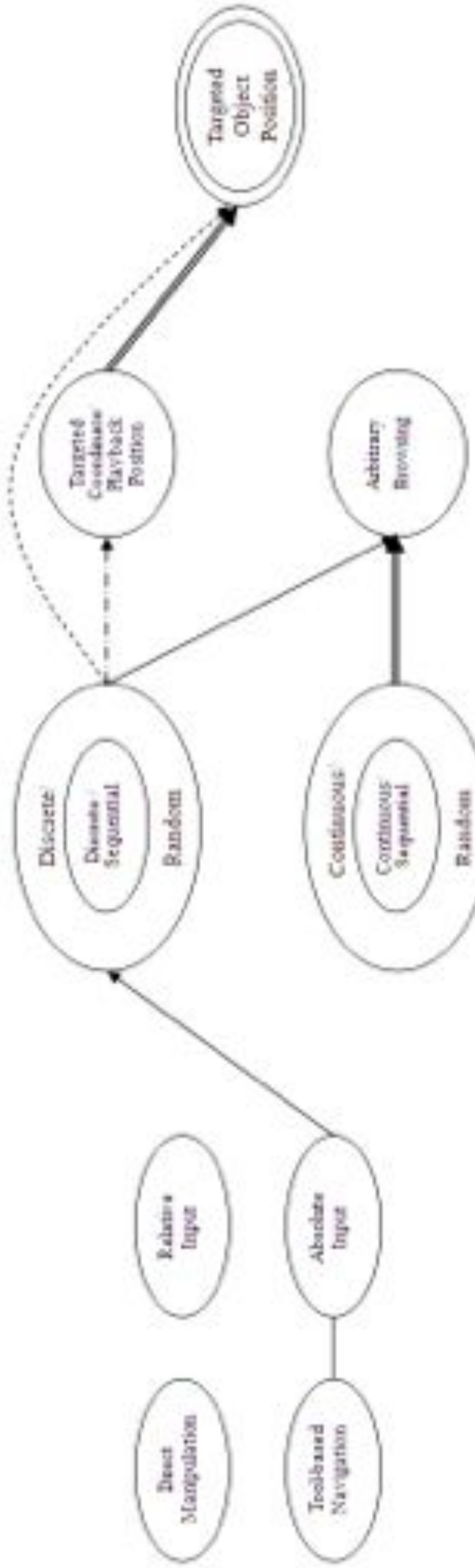

Figure D.1: Evaluation block diagram of mouse/ stylus/ touch screen + timeline slider for digital video

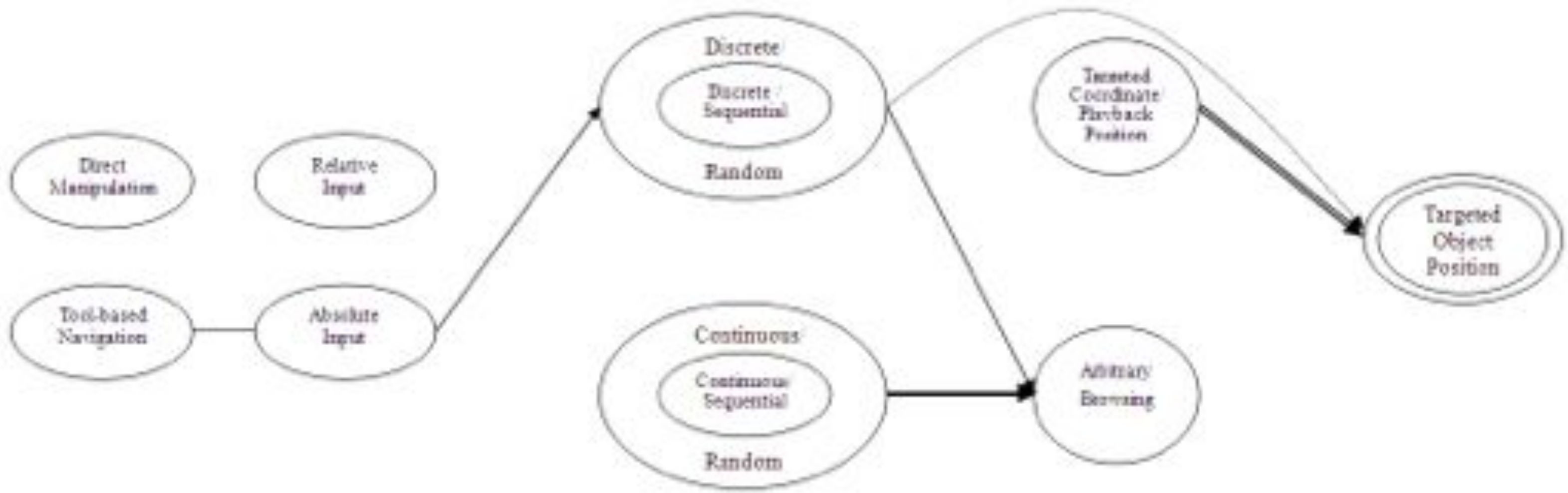

Figure D.2: Evaluation block diagram of mouse/ stylus/ touch screen + fisheye-style warped timeline for digital video

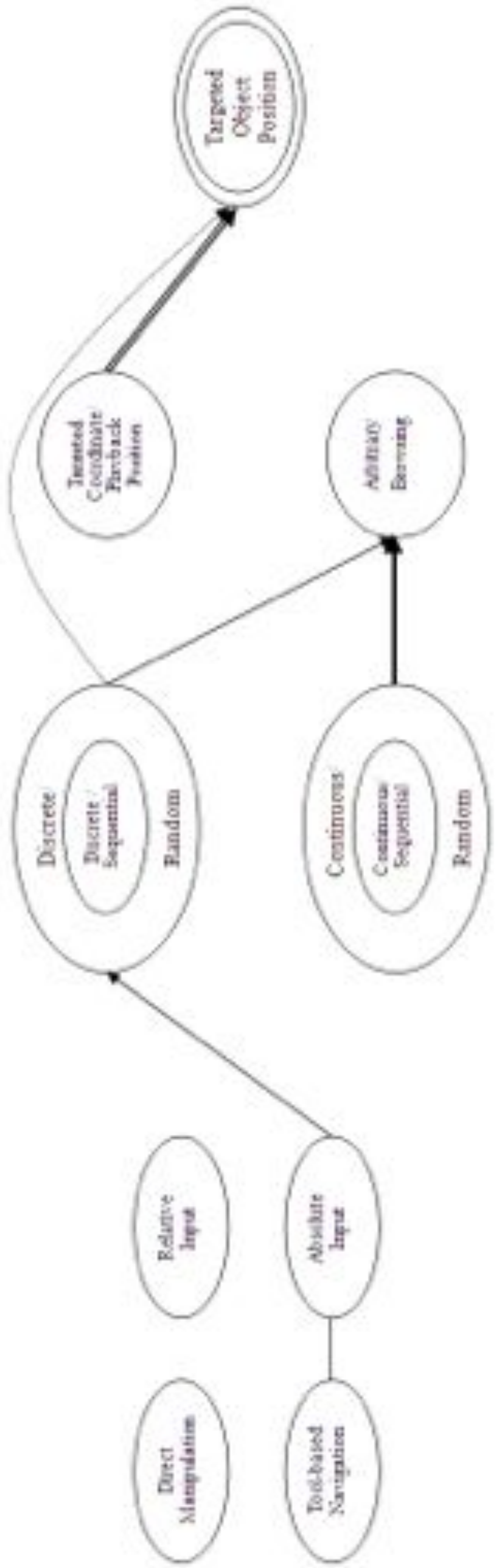

Figure D.3: Evaluation block diagram of mouse/ stylus/ touch screen + static or dynamic storyboards for digital video

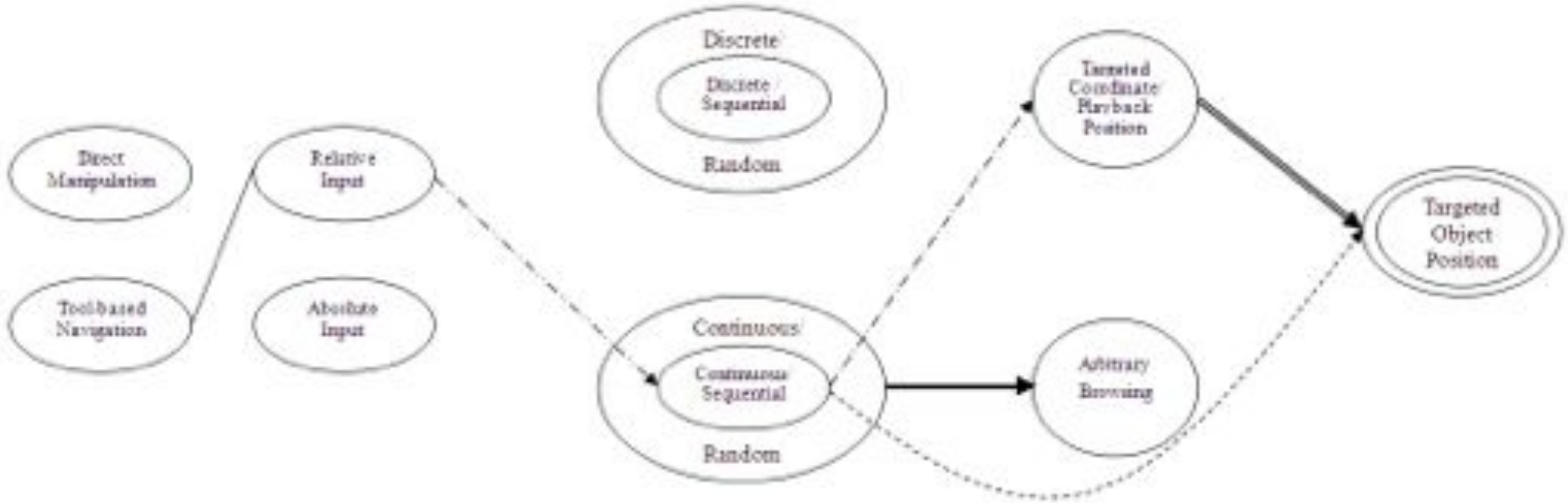

Figure D.4: Evaluation block diagram of mouse/ stylus/ touch screen + fast forward/ rewind button (increasing playback rate) for digital video

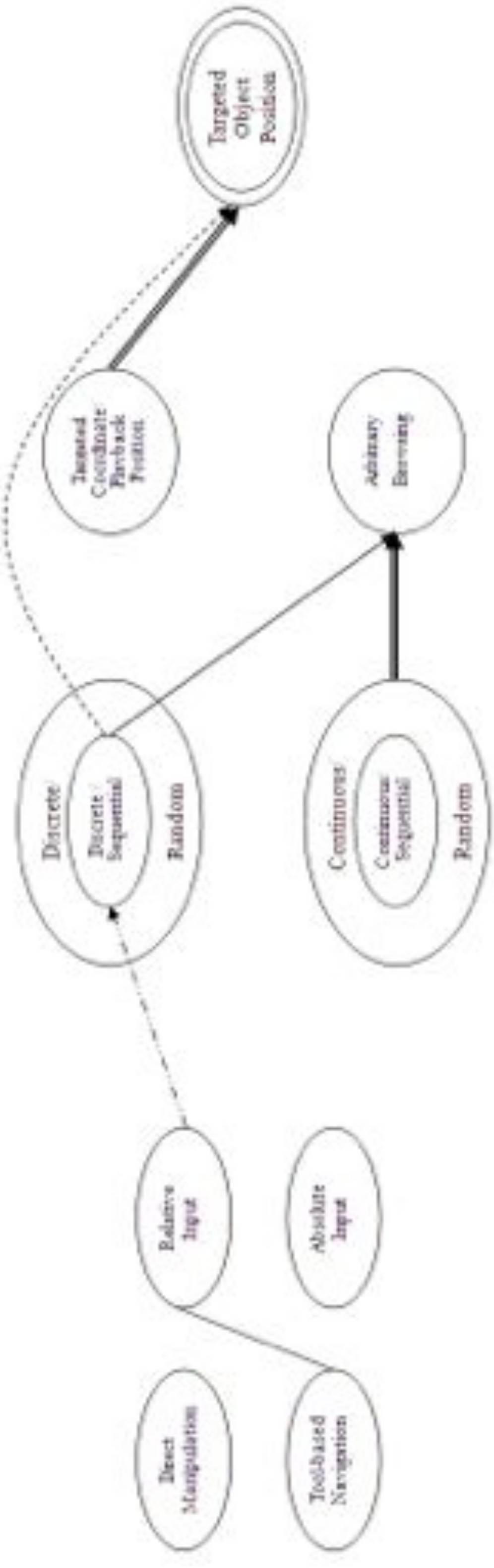

Figure D.5: Evaluation block diagram of mouse/ stylus/ touch screen + fast forward/ rewind button (frame skipping) for digital video

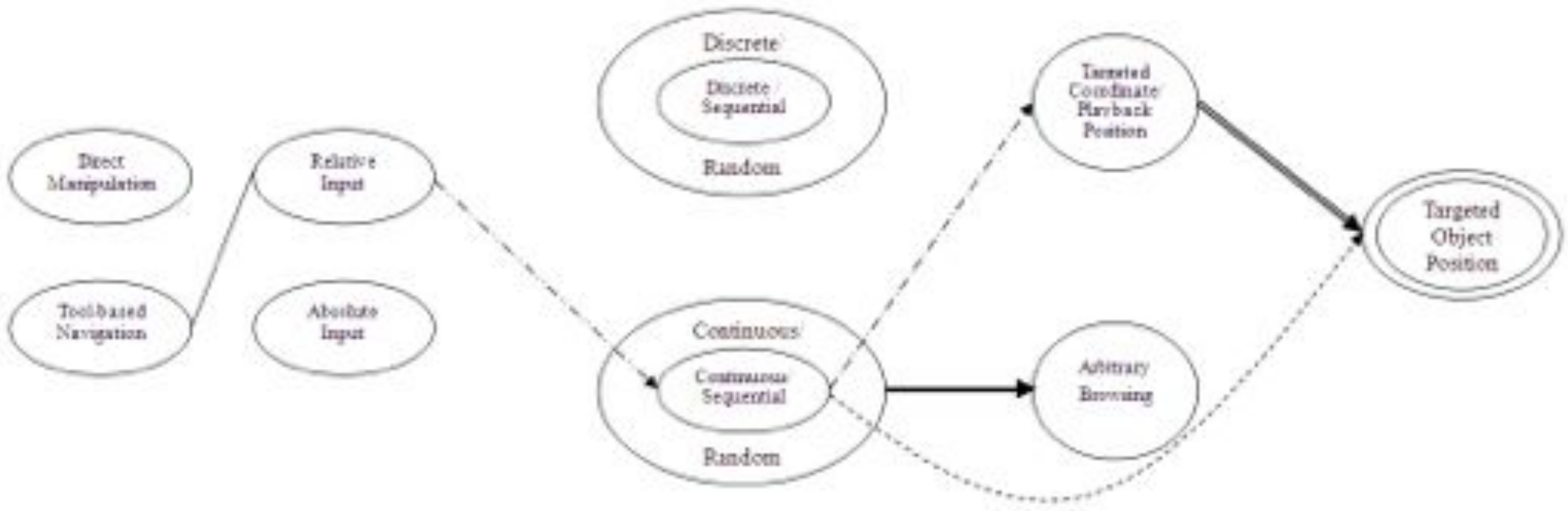

Figure D.6: Evaluation block diagram of shuttle wheel (spring loaded) for digital video

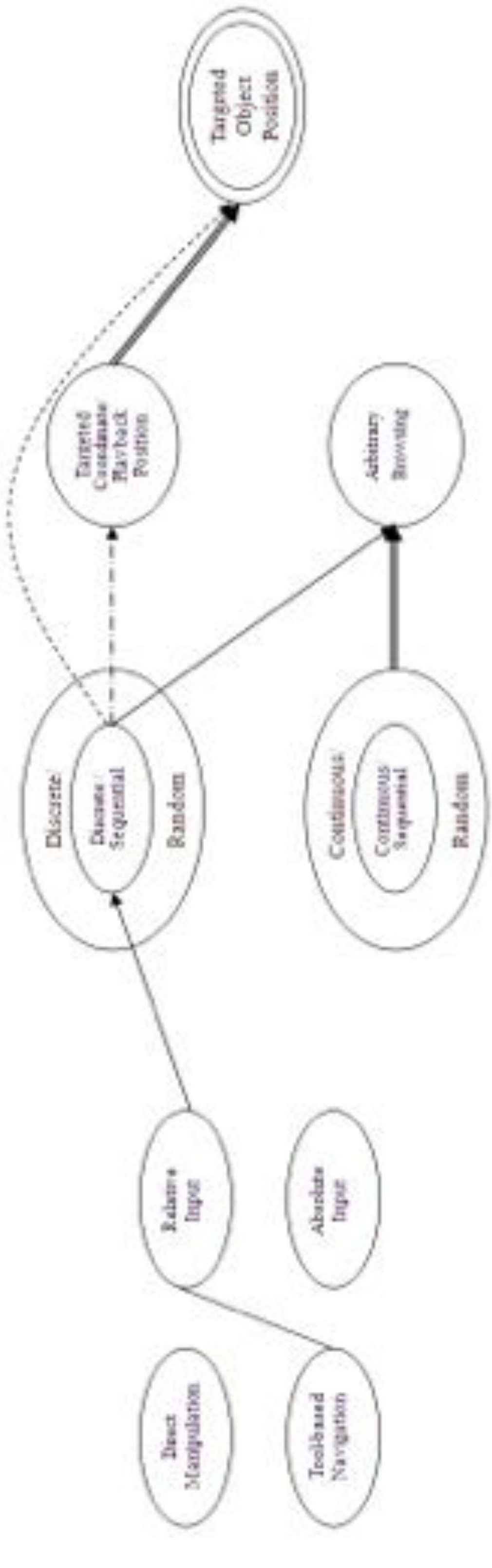

Figure D.7: Evaluation block diagram of jog dial/ click wheel for digital video

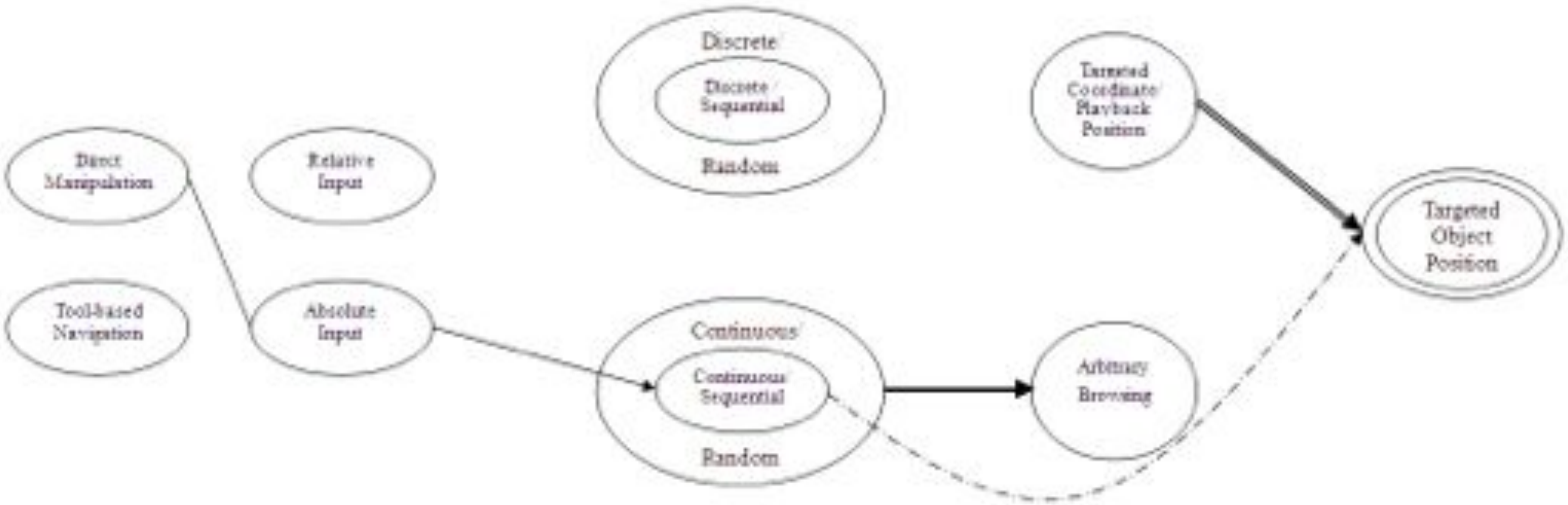

Figure D.8: Evaluation block diagram of Dragon for digital video

Appendix E

Raw test data

	document 1				document 2				document 3			
	scrollbar	up/down button	thumbnails	search box	scrollbar	up/down button	thumbnails	search box	scrollbar	up/down button	thumbnails	search box
	C1	A1	D1	B1	C2	A2	D2	B2	C3	A3	D3	B3
1-1	7.828489	10.343741	4.878454	9.461450	13.610793	23.831575	11.748052	6.190913	15.927023	60.513500	21.330353	12.575802
1-2	5.850001	7.977798	2.129074	10.330487	9.386296	19.373516	5.266953	8.327389	27.007318	40.496044	21.078487	6.655559
1-3	4.778304	5.161993	1.977027	6.458419	9.839728	21.249607	12.820584	6.075986	21.175564	47.011803	31.172007	8.804986
2-1	5.800441	6.347537	2.84987	10.957605	33.561928	25.039404	17.807026	15.696579	22.666195	75.687508	57.532509	13.451102
2-2	5.218892	19.057743	3.567248	3.452604	18.065054	42.336254	15.498444	2.58498	18.14378	69.905083	22.241634	3.58025
2-3	5.450228	8.487641	2.100127	5.550981	18.915619	38.326107	17.532829	13.620762	10.760893	10.760893	18.626186	25.195395
3-1	11.952688	8.293553	4.365886	14.807212	19.061634	73.432365	21.248936	12.059014	16.060377	62.505318	43.522858	22.68574
3-2	6.873468	9.25273	3.135108	18.032661	31.59853	50.216461	20.783489	12.901339	39.68111	40.172298	20.693642	11.352461
3-3	9.139861	10.476322	2.682716	4.949403	49.829376	86.663132	30.137959	18.472582	31.138521	84.378555	20.190538	10.6647
4-1	7.178938	5.804776	2.379846	5.610698	12.919325	56.93795	9.31577	2.872651	22.150215	60.014748	28.233692	2.252318
4-2	5.598271	7.224875	2.665654	15.29407	22.262386	41.667484	23.275372	10.214008	17.955526	139.878357	14.961264	16.110912
4-3	6.335803	8.932352	2.66478	12.983526	22.798759	57.289558	15.435466	8.50941	18.758762	56.918842	17.75876	3.553623
5-1	7.174658	9.030457	9.191775	15.108121	25.011929	67.616669	12.519205	7.671767	28.08103	57.778603	58.687668	19.580984
5-2	5.146806	7.959884	5.477712	2.979303	16.327065	47.454075	27.337124	7.182556	9.858203	104.424202	63.373539	4.127843
5-3	7.34194	6.436728	3.319336	9.023781	13.896598	56.893303	18.9389	8.063222	19.798922	106.888741	20.412502	12.30631
6-1	6.638334	18.337849	3.956359	29.10103	71.164162	33.300884	18.754362	7.937556	69.588921	108.519569	91.762199	17.685623
6-2	5.02908	9.167356	3.537554	10.314856	12.236812	96.06266	11.730455	15.830589	36.931175	293.034607	33.266838	5.196678
6-3	7.89448	14.400747	4.878538	8.144938	16.37974	64.520378	25.242989	8.783917	95.523949	195.224899	81.027603	17.999525
7-1	4.15802	5.458792	2.883789	13.61654	11.583012	17.847116	7.740644	14.869101	23.587011	57.672249	23.509459	13.23302
7-2	11.164187	6.370637	5.129771	18.595678	14.130863	14.814397	7.890439	15.610071	19.145193	74.404221	5.129771	15.091558
7-3	6.923334	8.278675	3.370848	20.008938	24.793413	23.91559	19.258015	43.781742	34.819416	37.83094	14.004335	8.342223
8-1	14.684916	9.676224	7.484425	28.492355	25.748989	35.786232	21.537874	36.86245	40.803665	55.025314	60.122993	19.156511
8-2	7.879063	7.657088	3.184621	48.913067	18.874886	27.016876	20.165609	7.41726	20.535114	108.654709	23.962147	52.825626
8-3	3.352705	3.599621	2.230192	10.532153	9.839397	12.633036	18.192495	18.836733	13.210627	38.328125	30.776047	18.497396
9-1	10.209527	4.87043	3.906123	27.027832	41.371548	16.123236	14.506549	25.515558	81.675995	28.604118	47.256119	16.164997
9-2	9.62218	7.905747	3.890533	23.343355	43.905037	27.638691	18.536428	30.140915	48.096146	35.711769	24.833096	9.932098
9-3	5.851016	5.743238	4.610146	13.757078	20.100107	21.485556	24.640224	9.282306	64.493927	52.110336	40.522373	15.149613
10-1	25.564775	5.678409	27.342514	50.46627	75.906685	17.865292	21.705381	9.221023	75.320511	44.399448	34.473236	10.243149

Figure E.1: Raw test data for digital document 1

	document 1				document 2				document 3			
	scrollbar	up/down button	thumbnails	search box	scrollbar	up/down button	thumbnails	search box	scrollbar	up/down button	thumbnails	search box
	C1	A1	D1	B1	C2	A2	D2	B2	C3	A3	D3	B3
10-2	19.814819	15.133644	20.234159	24.28727	84.524475	14.445617	20.36433	46.896835	104.911194	35.00465	58.195602	8.569406
10-3	11.069712	6.114071	3.033071	31.443411	52.337242	10.103896	19.542297	36.04834	100.530861	41.747311	14.560714	14.439018
11-1	4.173647	7.823582	3.335423	8.631847	10.074632	14.009694	53.74826	70.883675	16.294224	39.184837	77.581406	15.354854
11-2	6.839704	7.318433	8.360832	21.101555	41.775887	24.895098	16.231659	47.077736	15.658171	36.699909	39.912441	37.875328
11-3	5.395475	22.006643	5.984005	12.387146	19.310476	17.579708	76.246986	31.507818	16.413349	44.64719	48.121765	46.253056
12-1	6.435939	3.916424	5.767888	15.82895	15.992573	24.101692	13.778184	16.83283	67.039909	29.341583	33.628845	35.309792
12-2	2.764283	3.111748	4.676945	12.945743	26.470472	8.492336	20.297169	13.109398	23.65431	17.238234	19.14904	8.155216
12-3	8.902259	7.320985	7.141167	9.363526	26.218439	22.643299	45.644897	34.640541	24.694481	29.140087	43.39249	16.83267
13-1	20.304207	5.024289	3.25211	8.653708	39.763634	11.711251	27.446297	5.420806	56.134804	34.908184	27.649887	3.201248
13-2	27.447197	9.670103	3.235834	38.182495	36.025417	20.062601	21.319443	19.718775	67.627235	99.300293	14.708355	14.11521
13-3	8.264389	5.223296	2.397097	7.743734	40.119408	25.974945	10.456837	5.460617	46.409092	62.871906	32.678608	6.286923
14-1	7.054394	4.481551	2.588576	6.858248	31.957829	20.184933	7.035059	4.356347	27.826876	27.582903	10.483216	7.23538
14-2	33.096912	5.70983	6.185359	15.125122	18.925917	18.925917	19.898209	8.497826	273.097015	40.456226	25.000513	17.487038
14-3	15.762789	5.006162	3.217625	7.532803	18.372599	20.497416	19.751663	5.068161	188.136292	27.330002	24.389641	6.960405
15-1	6.824949	3.363063	2.998634	12.35076	19.846786	18.787554	18.101458	12.263734	39.350925	26.742485	21.263176	13.363964
15-2	15.125659	3.965338	3.540728	16.724686	154.783401	29.685196	19.324244	11.177004	130.057144	48.537411	43.441235	18.087973
15-3	33.91716	4.485606	5.097415	17.305504	62.86311	15.297135	31.546261	15.484457	136.48819	59.361645	30.953653	27.060833
16-1	11.155691	3.547053	2.76622	15.301554	18.413015	14.661769	11.228796	7.392283	58.698868	26.306948	26.829128	6.085615
16-2	17.706713	5.859695	5.14797	11.496677	225.358627	14.57715	16.5406	7.794258	663.679016	36.633671	42.385239	8.531537
16-3	12.124366	17.021811	4.084919	14.697931	66.822189	24.623262	16.609444	9.956647	69.964203	47.700352	29.953762	12.908765
17-1	9.530452	2.337205	2.307549	5.393724	90.373566	15.709636	26.422434	35.136658	44.163975	27.083147	22.478689	3.010325
17-2	14.7056	5.359174	3.905563	7.824401	75.45446	15.552684	15.30203	6.251774	13.025549	26.306911	17.760105	10.69563
17-3	38.931099	9.853318	7.108203	4.214388	75.333534	14.5634	29.685102	5.922018	30.868362	46.104652	27.801683	5.364413
18-1	21.410046	4.019159	5.690231	27.640642	34.255211	24.350819	10.540725	6.543171	167.391144	47.732841	39.689125	13.43163
18-2	6.089997	4.304018	5.062481	11.801629	35.119122	12.331045	18.478081	7.81696	36.179806	21.144318	28.563803	7.727388
18-3	50.211189	4.234871	10.238294	12.798824	35.582691	29.550306	15.234822	10.096646	69.696457	25.955452	49.761158	5.772913
19-1	8.230975	7.220507	7.549818	11.161051	34.080006	14.695174	34.523891	17.985207	23.369419	66.725037	105.33358	3.219169
19-2	5.481865	4.116893	5.217879	15.435272	22.765104	13.169361	13.199859	5.884102	35.975632	23.811684	54.351086	7.810862

Figure E.2: Raw test data for digital document 2

	document 1				document 2				document 3			
	scrollbar	up/down button	thumbnails	search box	scrollbar	up/down button	thumbnails	search box	scrollbar	up/down button	thumbnails	search box
	C1	A1	D1	B1	C2	A2	D2	B2	C3	A3	D3	B3
19-3	7.259441	5.745397	12.831347	5.99536	21.691824	36.559208	23.532642	29.319889	40.804291	27.464596	107.415787	13.109278
20-1	5.716484	4.519779	3.781484	11.302991	52.521667	20.45105	73.079773	10.523142	60.586899	67.94989	81.448318	27.644779
20-2	8.125831	5.442812	6.491777	11.238809	17.366249	28.18947	28.569384	4.085961	19.782017	36.167984	66.92981	11.272371
20-3	5.197537	3.617252	4.651421	11.338715	16.302488	23.253387	50.534966	7.369453	14.451402	37.449932	56.047134	14.736582
21-1	6.015856	6.063943	7.206143	14.741198	44.994534	16.575296	53.279667	21.155354	31.600428	25.671465	77.885231	9.927473
21-2	10.426169	3.328633	5.870392	10.671963	7.890633	7.619865	13.364378	5.833059	12.354193	24.897369	86.435135	9.507586
21-3	5.348102	3.934302	8.09954	16.325453	14.869602	15.012369	41.414257	23.256687	8.365609	37.086742	75.256454	35.625683
22-1	5.615864	5.3775	6.156703	5.377207	44.30666	25.256336	67.695343	7.901265	21.943939	36.902264	55.622154	24.492407
22-2	6.369797	2.960349	3.359084	12.208003	41.976753	13.573478	16.981945	52.990952	31.919323	21.010389	47.126461	9.189225
22-3	5.732897	4.679	9.627213	11.555851	27.420618	18.376162	33.270905	50.441727	41.693298	25.476135	77.243828	11.919221
23-1	11.399808	6.530531	34.034576	14.882561	57.668236	21.886593	30.981188	20.352776	135.15123	40.592373	67.202629	10.106918
23-2	6.363624	4.018091	5.301923	9.106168	29.287523	10.487521	23.693405	5.900141	12.270879	27.194925	87.713486	8.833351
23-3	13.361709	8.978066	11.252835	15.737956	29.235439	46.93399	32.695751	17.132521	53.963203	37.355614	108.306122	22.16514
24-1	8.266197	4.87396	8.354582	14.923845	8.013063	13.155124	42.089661	7.566714	62.765881	26.256552	113.16246	14.484446
24-2	11.551874	5.493218	33.045612	25.904739	16.126261	16.708136	48.908611	21.884163	40.116425	31.960741	96.331085	28.799555
24-3	11.298974	9.752007	51.337227	18.75176	41.255859	10.941493	29.794798	13.27285	43.754974	51.990726	83.248169	31.000162

Figure E.3: Raw test data for digital document 3

	map 1			map 2			map 3		
	tap-and-drag	tap-and-drag with cue	search box	tap-and-drag	tap-and-drag with cue	search box	tap-and-drag	tap-and-drag with cue	search box
	B1	C1	A1	B2	C2	A2	B3	C3	A3
1-1	33.492004	19.220930	17.390249	700.133972	124.645485	16.114428	22.224455	26.877041	9.393942
1-2	26.293484	10.640059	14.225342	53.115639	35.240944	24.466049	17.589079	9.624372	22.049269
1-3	473.112488	20.705084	7.905945	496.893036	25.565126	8.937757	223.734207	28.481152	11.010007
2-1	33.255733	27.192213	15.899711	101.981987	50.784203	21.201363	7.608566	190.356842	14.033691
2-2	17.598425	39.128704	30.146416	47.877884	39.129211	25.73074	31.796944	70.909615	23.114021
2-3	20.814602	83.789375	35.117779	12.881642	34.162628	24.596605	283.938324	2.231296	18.231579
3-1	437.938934	3.970137	10.376778	1465.884277	43.871861	24.002638	73.005615	10.368725	24.056683
3-2	0.575017	92.486679	16.642969	214.73877	35.392204	22.546968	136.340729	12.064654	11.978482
3-3	585.976501	143.815292	20.425571	65.378094	38.439407	18.184731	318.107422	22.40769	20.448627
4-1	663.13269	14.272876	12.591488	423.173492	281.305267	16.385582	528.216309	24.481419	9.395258
4-2	469.661957	9.089083	14.308621	395.382355	28.49618	21.122149	258.480133	14.024861	15.610715
4-3	87.155251	19.975981	11.137732	221.816101	40.935135	16.973513	242.642471	53.492367	10.000653
5-1	118.545921	42.646881	22.400724	218.537537	103.50135	21.163544	25.799822	63.434689	20.841101
5-2	21.30397	92.316628	18.88862	56.014931	197.168137	23.160822	175.825851	366.085785	23.736996
5-3	28.399727	125.637619	19.722029	386.32428	105.589729	213.179581	20.509327	143.845367	39.775585
6-1	9.824256	65.594215	22.698353	797.79187	636.119141	23.896008	92.613495	174.767563	21.083099
6-2	199.262054	141.71701	14.32145	22.632401	122.551224	22.115896	28.454849	93.62661	12.146601
6-3	331.727325	70.166008	26.81694	339.435791	246.466995	27.976532	252.478363	131.763519	23.032652
7-1	814.610352	35.29628	13.29782	196.873749	39.520012	13.137724	29.623611	9.524945	9.186114
7-2	638.608398	24.382908	10.174314	511.809387	38.957737	12.865426	452.654877	23.552853	9.94602
7-3	15.338257	41.50386	20.485172	264.725159	18.016546	23.352821	32.328148	12.105121	19.809635
8-1	57.142471	40.856056	23.240948	51.397713	960.221008	21.505449	19.807909	256.946594	25.83252
8-2	43.126987	81.023033	27.809235	86.341377	319.772125	34.433376	67.36618	323.430298	33.345131
8-3	11.035287	56.648624	12.825602	27.590731	31.921976	13.825871	7.290532	66.276398	9.713623
9-1	352.332367	39.888519	16.673296	1263.261353	67.454628	24.961329	344.896454	20.216204	33.457161
9-2	580.868042	28.744062	23.720821	484.32901	106.157196	14.421966	545.708313	24.464476	21.817272
9-3	352.636444	28.557383	14.251637	351.079956	42.240177	23.627201	317.919525	17.865276	11.898041
10-1	254.237991	28.567944	25.825806	359.283936	42.279327	70.319832	676.210266	19.592415	41.44059

Figure E.4: Raw test data for interactive map 1

	map 1			map 2			map 3		
	tap-and-drag	tap-and-drag with cue	search box	tap-and-drag	tap-and-drag with cue	search box	tap-and-drag	tap-and-drag with cue	search box
	B1	C1	A1	B2	C2	A2	B3	C3	A3
10-2	31.800119	20.032841	23.397564	440.333313	171.209702	22.701508	428.461548	94.198273	15.83357
10-3	82.509186	107.804665	11.46533	474.821381	35.639584	19.352804	46.667301	13.328263	9.056556
11-1	69.408188	38.663254	34.928627	34.9837	68.126648	38.872391	71.4431	234.676651	17.16851
11-2	24.079546	63.350422	16.835684	414.906067	66.63916	21.275991	169.193817	179.05899	22.160227
11-3	8.246265	86.835526	17.24964	175.977646	159.52652	29.654604	12.923911	360.645844	15.254761
12-1	14.64033	32.89257	8.065247	20.016373	49.412125	22.699898	285.442627	241.920151	12.395653
12-2	15.367405	20.885462	22.849644	217.616913	34.358406	23.348249	13.928317	695.014893	10.442567
12-3	44.216843	35.831966	28.234852	72.271202	62.924423	18.498339	16.729521	304.594299	13.833623
13-1	286.186646	27.856028	31.612732	802.701599	20.160137	18.201241	223.67099	35.015724	24.025049
13-2	196.241776	94.965919	22.873461	72.813858	64.51519	25.569494	32.547981	38.359959	22.83338
13-3	74.930168	30.843313	13.705894	407.449402	27.912746	25.593746	14.511828	27.460382	33.505226
14-1	24.669687	52.068878	13.305328	53.274948	45.919128	23.867718	7.270976	23.506905	8.816184
14-2	27.057787	104.772858	22.028824	214.237808	52.59457	18.176744	46.590546	168.557129	22.646492
14-3	235.816574	32.968388	11.326012	438.785645	36.460308	15.329622	188.337433	97.525665	18.843923
15-1	138.194229	13.77606	21.466696	312.807404	23.539082	14.714219	318.651245	35.350674	29.242155
15-2	165.674652	45.798992	17.049458	622.03363	67.066154	21.404924	450.170197	437.144806	17.449184
15-3	42.041843	22.367392	24.248962	79.097733	76.150192	25.913769	183.926895	25.056265	18.032953
16-1	110.073235	18.953028	11.943599	389.41806	32.204151	19.154875	117.78299	23.46439	13.138355
16-2	162.442322	16.4723	17.212053	621.149048	18.737137	50.348713	718.110657	16.344461	30.658573
16-3	221.089218	27.040222	11.818304	487.589447	32.412292	16.049419	146.282837	103.565285	12.385684
17-1	13.619762	13.152976	12.601797	20.25181	40.557652	21.28862	7.764654	65.808121	22.425169
17-2	15.144079	31.120493	37.202557	50.374809	557.378174	33.625072	42.678318	51.246078	30.521408
17-3	30.80015	69.379669	69.18222	19.479397	305.927277	113.211983	31.92005	137.090424	121.484894
18-1	8.568076	33.21072	13.320855	225.463547	1.970483	41.748428	89.259651	80.315552	10.880809
18-2	16.744076	107.093323	27.96051	41.277355	96.513786	37.545425	14.308738	667.546204	15.52047
18-3	6.745085	9.747192	36.13179	35.701557	146.076248	22.714731	57.091434	255.362885	20.817444
19-1	657.742004	32.192226	13.001157	183.50531	24.024183	12.370196	623.390076	8.790661	16.089392
19-2	278.039459	17.768724	11.441246	36.760075	31.136284	10.907847	459.545074	25.292719	11.280211

Figure E.5: Raw test data for interactive map 2

	map 1			map 2			map 3		
	tap-and-drag	tap-and-drag with cue	search box	tap-and-drag	tap-and-drag with cue	search box	tap-and-drag	tap-and-drag with cue	search box
	B1	C1	A1	B2	C2	A2	B3	C3	A3
19-3	27.00246	29.42449	15.912876	30.233725	66.390526	18.3382	191.462204	316.623505	19.009777
20-1	13.090539	227.380615	31.579082	92.326111	107.30825	57.580963	8.008275	296.253204	13.273841
20-2	87.928551	46.767807	24.643946	39.966812	157.666977	35.408901	57.023911	181.883133	19.220539
20-3	20.63261	62.063221	19.265429	238.867767	61.079838	16.906483	10.256109	306.291412	16.393676
21-1	796.335266	28.231628	14.529512	749.095642	469.772552	32.369877	199.95845	204.767044	16.649809
21-2	607.300842	14.765514	10.713114	579.200378	26.61342	17.466543	483.134664	55.93409	23.257433
21-3	760.617371	86.615334	29.477674	426.768188	42.255581	37.202072	421.449188	37.739426	22.049059
22-1	204.082764	16.552948	15.195266	170.476715	36.172943	21.650253	1362.317383	19.385056	17.730246
22-2	75.205818	5.6408	12.891393	88.502708	9.17374	23.034407	834.322815	8.470324	10.018646
22-3	106.45118	33.88522	21.353764	121.739926	44.06424	25.377409	581.289673	25.489023	18.728952
23-1	27.119678	35.9641	33.489559	67.933899	101.363617	37.258347	137.458221	191.788239	28.489019
23-2	25.387564	102.926796	15.786008	18.68495	37.467724	42.956581	53.272362	37.631199	13.665532
23-3	347.073914	51.928101	26.977022	678.315857	178.739349	23.881475	257.117462	368.261108	23.608906
24-1	228.827286	56.368687	21.441929	157.315598	92.94413	18.609911	82.21006	296.620239	14.273976
24-2	12.063902	30.40416	20.323475	205.972244	190.385281	19.702137	13.842634	65.498871	17.635778
24-3	26.831039	54.765102	18.508934	22.41292	123.32135	19.45916	34.211964	122.099709	53.051388

Figure E.6: Raw test data for interactive map 3

	video 1		video 2		video 3	
	FFW/RWD rate control	timeline slider	FFW/RWD rate control	timeline slider	FFW/RWD rate control	timeline slider
	B1	A1	B2	A2	B3	A3
1-1	250.580032	22.560389	375.711456	4.346495	78.726913	20.124914
1-2	229.410629	35.715996	377.785309	22.305012	82.681038	20.598324
1-3	223.038696	14.590585	376.836090	10.048069	79.043655	7.982382
2-1	329.487244	6.616038	376.996613	11.478761	81.071976	5.785348
2-2	222.771439	16.845926	377.395386	5.059516	78.693431	6.097743
2-3	229.757751	16.388281	376.465759	5.701487	77.799347	2.096472
3-1	229.674469	49.872482	377.944336	18.331388	79.282455	17.7819
3-2	232.871994	34.947044	380.967407	22.590517	79.587639	10.59209
3-3	223.305664	46.839016	377.996918	129.942917	78.318428	24.772032
4-1	233.278671	4.079925	379.366241	5.907041	81.499985	11.216089
4-2	235.354462	20.508522	376.425201	5.356523	94.243637	54.081978
4-3	287.841064	14.544296	410.142426	18.784492	92.025894	12.045669
5-1	223.419418	35.768406	377.689728	16.269312	80.627472	52.050392
5-2	224.572495	28.061298	377.571228	19.127134	80.482529	29.952494
5-3	241.082291	25.617069	380.462677	14.674648	78.603455	80.67627
6-1	228.818192	15.15501	378.873077	43.186497	94.883224	13.629045
6-2	248.791809	10.669009	378.957672	5.201222	78.652847	5.337884
6-3	227.601135	70.627724	377.63147	9.019449	83.381531	30.040285
7-1	223.56749	95.93763	377.59906	15.377327	78.690247	8.415084
7-2	233.387589	64.442673	378.138153	27.955616	77.152878	12.553497
7-3	244.420578	13.792879	398.599426	15.168387	81.48317	8.500718
8-1	422.999298	28.609709	381.216553	7.393475	96.455437	41.984123
8-2	300.523773	16.118788	497.3479	6.930283	80.94709	7.206478
8-3	237.842957	6.500067	376.245178	5.223886	78.113747	9.990074
9-1	224.519211	37.149323	377.958832	44.052158	79.676697	12.772477
9-2	222.789062	64.850319	376.690125	104.090492	77.601379	19.977737
9-3	226.500092	23.545797	378.947968	9.41949	98.792984	9.166361
10-1	229.649563	29.986975	376.36792	19.126659	76.29612	7.496181

Figure E.7: Raw test data for digital video 1

	video 1		video 2		video 3	
	FFW/RWD rate control	timeline slider	FFW/RWD rate control	timeline slider	FFW/RWD rate control	timeline slider
	B1	A1	B2	A2	B3	A3
10-2	223.489151	49.48156	378.270233	12.712651	78.536903	30.928432
10-3	228.850052	3.573059	379.462738	12.665554	82.44635	13.81314
11-1	227.729385	46.896294	379.460449	21.673489	78.789619	22.81955
11-2	224.747513	35.541702	377.316864	12.779098	78.450386	21.460449
11-3	222.656982	42.531521	377.982178	23.503481	128.877777	44.563473
12-1	369.985535	8.199023	377.242828	15.99494	85.826447	11.153039
12-2	232.372223	9.547625	380.363464	6.514745	77.936066	9.226222
12-3	238.420853	9.954631	381.951172	9.484839	77.803955	31.803778
13-1	258.0961	77.833527	378.884338	46.441277	81.296928	39.604897
13-2	228.979691	41.00317	376.990906	19.937195	128.278992	12.210819
13-3	222.835083	23.184452	376.025787	9.751804	77.462997	15.39494
14-1	225.14769	6.806225	381.835968	6.036398	83.66436	21.498291
14-2	226.259827	1.257773	379.303223	4.221502	85.438705	11.673141
14-3	249.727722	10.060672	390.63678	6.43855	82.10408	9.181697
15-1	236.924576	15.368492	379.497284	8.300226	404.660706	8.581778
15-2	225.092896	52.874706	377.914856	59.289429	91.649269	49.348064
15-3	221.909561	81.578506	378.949097	48.61562	89.048256	21.804291
16-1	227.642761	5.793877	379.997894	6.845484	108.593781	13.477803
16-2	229.791489	39.057758	409.611115	24.450703	90.138847	20.431234
16-3	223.651276	17.348433	752.750916	7.951586	77.873184	16.343086
17-1	663.058228	10.683849	396.712708	9.524494	79.043793	13.083966
17-2	224.037064	53.709648	376.764374	19.764734	77.994041	24.608603
17-3	224.676437	62.776981	378.207184	21.378059	90.253731	20.648893
18-1	222.883728	21.099243	377.297058	7.732182	83.142052	9.310611
18-2	225.666351	13.743311	380.636383	6.162635	101.55751	5.384328
18-3	299.853119	41.262943	383.478729	9.802681	156.272949	145.442947
19-1	227.855469	39.621292	383.228577	7.546536	80.798378	62.834541
19-2	222.876831	31.181433	385.94751	15.895793	80.245277	23.952654

Figure E.8: Raw test data for digital video 2

	video 1		video 2		video 3	
	FFW/RWD rate control	timeline slider	FFW/RWD rate control	timeline slider	FFW/RWD rate control	timeline slider
	B1	A1	B2	A2	B3	A3
19-3	224.352631	52.031693	379.230713	20.209869	79.664574	50.985168
20-1	240.935638	12.505745	378.589172	7.652126	86.815125	8.327357
20-2	239.656891	19.412971	382.043884	20.995796	82.498177	7.243198
20-3	317.441956	11.245672	378.071777	10.773833	79.338364	7.220784
21-1	223.726517	40.83049	378.147949	32.025116	78.273483	132.192444
21-2	224.972638	21.582006	470.8797	15.710545	163.493164	11.363165
21-3	234.450363	78.357994	381.873047	46.892311	116.507759	56.519634
22-1	231.501038	10.331546	378.214417	5.454381	83.492561	62.53035
22-2	244.03717	7.826705	375.876862	8.427612	77.286911	5.828831
22-3	224.858521	27.458574	377.178314	12.213368	93.217148	14.597469
23-1	340.724548	39.410572	391.824829	23.010826	82.008362	26.131651
23-2	225.076843	34.738991	378.652405	18.898689	78.116989	103.851959
23-3	223.255875	59.66888	417.683197	14.83028	100.667686	46.814259
24-1	225.884216	10.307269	377.579041	6.312618	79.892075	11.04314
24-2	234.086655	34.360664	379.556783	7.759402	81.326607	10.218164
24-3	223.666443	14.40322	376.629517	22.651358	80.037437	20.828691

Figure E.9: Raw test data for digital video 3

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