Critical understanding of interaction history as a design resource

Moon-Hwan Lee, Tek-Jin Nam

Department of Industrial Design, KAIST, moonhwan@kaist.ac.kr
Department of Industrial Design, KAIST, tjnam@kaist.ac.kr

Abstract: To improve the value of a designed artifact, we investigated *interaction history*, accumulated changes through iterative user-artifact interaction, as a potential design resource. Although various tools such as logging records for digital products have become prevalent in everyday life, there is a lack of both understanding of and design tools for the practical use of interaction history. To provide systematic approaches for using interaction histories as resources for designing interactive artifacts, we analyzed previous design cases that applied interaction history in their systems. Based on the analysis, we discovered impacts of interaction history from utilitarian, emotional, and social perspectives. Then, we obtained design properties of interaction history that should be considered in practice for constructing the impacts: *logging moment*, *logging content*, *target*, *retrieving moment*, and *expressed form*. Finally, we explored potential research and design issues with the consideration of impacts and design properties of interaction history. As an implication, we propose a visual analysis tool that supports design activity when interaction history is used as a resource.

Key words: Interaction history, interaction design, design property, case analysis

1. Introduction

In the realm of human-computer interaction (HCI) and design, there have been studies about improving artifact value. For instance, Chapman explained the notion of *emotional durability* and introduced a framework to provide designers with distinct conceptual for emotional durability and design [5]. In the human-computer interaction (HCI) field, studies on building sustainable relationships between artifacts and users have been conducted [3]. As an example, the concepts of *ensoulment* and *heirloom status* have been discussed [2, 19]. Also Odom et al. [24, 25] explored people's relationships with objects in their homes with an eye toward finding the ways in which artifacts improve rather than deteriorate over time.

In particular, several studies have proposed that it will eventually be possible to design artifacts that become more valuable as time passes by keeping their *interaction histories* which mean changes and effects through repeated user-artifact interaction [19, 21, 24, 26, 31]. As interaction history has been used as a design element in the field of product design and architecture for object conservation or decoration [8, 10], its usage as a design resource is of increasing concern among interaction design professionals.

Currently, neither theoretical background nor design processes in industry are prepared to handle interaction history [35]. Despite previous research efforts, accumulating theoretical knowledge about interaction histories has been stymied by the lack of a unified vocabulary to describe these systems. Consequently, although an

analytical approach to interaction history is needed, investigations of the effects of interaction history, design properties, and strategic methods for applying them in design processes have been rare.

For supporting both design activity that aims to improve artifact values and technology that records interaction histories, we investigate *interaction history,* accumulated changes through repeated user-artifact interaction, as a potential design resource that builds over time and eventually increases the value of an artifact. In the first part of this paper, we examine the literature on interaction history and relevant past studies in traditional design and interaction design areas. Then, we analyze design and research cases that apply interaction history to their systems. By analyzing these cases, we explore several of interaction history's impacts on interactive systems and users. We also introduce salient design properties related to interaction history that should be considered for making the impacts. As a design implication, we suggest a visual analysis tool that consists of design properties for supporting design activity.

We argue that this area would significantly benefit from consensus about the design properties and impacts that characterize interaction history. We expect this research to contribute to a systematic understanding of interaction history that can be applied to the design of interactive artifacts that improve with age.

2. Understanding Interaction History

2.1 What is Interaction History?

Interaction history is created when a user interact with an artifact, causing complex relationships connecting the user, the artifact, and environment. According to design models that introduce how the user and artifact influence each other through repeated interaction [6, 7] , a person acts on an artifact within an environment and receives feedback that prompts further action. The user's perception of the artifact leads to action, which causes the artifact to change in some way. The user then perceives and interprets this change to allow more action. Eventually, through this mutual and repeated interaction process, interaction history can be generated in various ways. For example, a wooden part of a music instrument shows wear and its surface becomes smooth after a user has touched it many times. Histories of using interactive artifacts might be generated in more diverse forms. Likewise, interaction history embraces accumulated effects from physical wear to intangible data. Consequently, in this paper, we define interaction history as changes and effects obtained through iterative user-artifact interaction.

2.2 Use of Interaction History in Traditional Design

From the 18th century onward, interaction history of a sort has been used for making artifacts more valuable. One such technique that applies interaction history as a design resource, called *patination*, has been broadly used in art and design. Patination originally referred to the time-dependent darkening of paintings [21, 34]. Nowadays, the term is used in a broader sense, denoting techniques for creating the appearance of aging on the surfaces of works of art, specifically the accumulated changes in surface texture and color that would result from normal use of an object over time. Designers intentionally use certain materials and methods on the surface of objects to leave a form of interaction history. The Tyndall Table is one example designed by Thomas Fougere [10]. Its stone top is planed smooth, allowing the material to retain its unique character. Casual wear slowly degrades the stone, exposing fossil fragments and revealing layers of stories embedded within the material. Over

time, the accumulation of puddled water marks may meld into the stone's already varied past, creating a nostalgic condition. In this way, designers have tried to use interaction history as a design resource for constructing aesthetic properties, lending credibility to an object or generating a warm feeling [39]. However, knowledge structure about interaction history has not been settled because most previous trials have been limited to artistic experiments.

2.3 Use of Interaction History in Interaction Design

In interaction design projects, interaction history is usually discussed in relation to “undo” and “back” functionalities, data management, or usability in graphical user interfaces [29]. For instance, Hill and Hollan extended the history of use metaphor to digital objects in document software [15, 16]. This system records how a group of colleagues edit and read a document to support cooperative performance. Similar approaches were restricted, however, to a particular application which relied heavily on graphical interfaces. Nevertheless, they were able to show that their graphical augmentation obtained by using interaction history could be used to help users more effectively navigate changes and engage in distributed collaborative efforts.

On the other hand, several researchers have begun to take an interest in improving the value of physical or digital artifacts via interactive technologies and interaction histories. There are studies that focused primarily on making memory-supporting systems by connecting digital information to physical objects. For example, Living Memory Box [11], MEMENTO [36] and Ubiquitous Memories [20] use technologies such as Radio Frequency Identification (RFID) to trigger the replay of audio commentaries, images, or video associated with a given object, and users are then able to add relevant digital information to it. Although these studies are not exactly contributing to producing more valuable artifacts with accumulated interaction history, they do show the potential for using digital information as a new source of interaction history.

In spite of these emerging strands of research, these researchers do not provide systematic approaches for using interaction histories as resources for designing interactive artifacts, and practical design knowledge for applying such histories is still scarce. This is because interaction history has previously only been considered as a consequence of interaction itself. However, in this research we place interaction history at the center of design as an experiential quality. In the following, we will investigate why interaction history might be considered important within user-artifact interactions and how it can be applied systematically as a design resource.

3. Characterization of Interaction History

There have been some trials to characterize interaction history and relevant systems. As an example, Schütte suggested an agent, an object and trace as three components that make up history rich systems [31]. Wexelblat and Maes presented more detailed properties of proximity, active and passive distinction, rate and form of change, degree of permeation, personal and social distinction, and kind of information [37]. Although these frameworks deliver insightful knowledge about interaction history, since their primary focus was on describing their systems in engineering and computer science fields, it was difficult for general interaction designers to grasp what the properties mean and apply them in practice.

Thus, we tried to reconstruct the design properties of interaction history from previous studies. By investigating impacts of interaction history on interactive systems and key elements that form the impacts, we could obtain several design properties of interaction history. We expected that the design properties would be

design elements to be considered in practice for applying interaction history. These properties also can be thought of as design choices or design questions for interaction designers to answer.

Accordingly, we collected 19 relevant cases that applied interaction history as a key component in their designs. We referred to information from published proceedings and articles, including images and videos of systems in use when available. Using qualitative means (categorizing, grouping, and abstracting the information) [28], we analyzed them according to following criteria: what the positive impacts of interaction history might be for improving certain values, how interaction histories were generated for having positive impacts on designed systems, and for such impacts what the salient properties of interaction history were.

Finally, we figured out various impacts of interaction history and determined salient design properties of interaction history by extending and modifying design properties from the preexisting framework. In the following sections, we explain the findings and present several examples taken from case analysis.

3.1 Positive Impacts of Interaction History

Through our case analysis, the positive aspects of interaction history for increasing the values of artifacts were discovered. The collected cases showed that interaction history has been mainly appreciated for utilitarian reasons such as efficiency or information for users. Meanwhile, other cases have examined interaction history for the emotional and social values of artifacts, beyond pragmatic goals [29]. These impacts of interaction histories were classified into *utilitarian*, *emotional*, and *social* perspectives [4].

1) Utilitarian impact

Utilitarian impacts of interaction history refer to the utilitarian consequences of an artifact and its interaction history, for example the fact that such history might enable a physical or cognitive task to be completed. For instance, Edit Wear and Read Wear are the representative examples showing the utilitarian effects of interaction history, which is used to support co-working performance [16]. These systems record how a group of colleagues edit and read a document. They depict the history by using graphical traces that give a hint about which part of the document is controversial and which part needs further discussion. In case of the research by Hsiao et al. [17], interaction history was visualized in diagrammatic form to encourage students' learning. Their studies confirmed the students could be motivated by watching their own histories related to learning progression. Likewise, interactive systems take advantage of interaction history to provide better experience quality to users and sometimes to deliver useful information about how users have used an artifact or system.

2) Emotional impact

Emotional impacts refer to the affective benefits of interaction history for people interacting with an artifact such as *aesthetics* (pleasure experienced in a sensory capacity), *meaning* (experiences related to one's personality or memory), and *emotion* (provocation of strong feelings) [9]. Especially, we could find that some artifacts are perceived as emotionally more valuable because of accumulated interaction histories that help owners recall past experiences and achievements. Spyn is closely related to this emotional perspective [30]. While people knit a sweater, they can leave behind interaction history by using Spyn system that associates the history of use on fabric. The interaction history, associated with tangible materials such as knit fabrics, enhanced recipients' appreciation of the process and production of crafts. Since the histories symbolize efforts and time, recipients could regard the garment more meaningful. Another example is Memory rich clothing [1]. This

research examined the emotional impacts of garment's interaction histories by recording acts of physical intimacy and indicating the amount of elapsed time with LED light in the garment. Although this interaction history was not useful, it made users arouse interests and evoke autobiographical memories. Such cases show the possibility of creating artifacts that increase in emotional values through accumulated interaction histories.

3) Social impact

Social impacts refer to the social benefits of interaction history for a group of people creating shared memories. Several cases illustrate that people can share past experiences with others or create co-ownership through interaction histories. PatinaMap is an image map in the webpage that tracks and represents its history of use [31]. The map records how people use the map and visualizes interaction histories in diverse ways. The researchers of PatinaMap found that users became interested in knowing how others used this map and comparing those results to themselves. Moreover, the users expressed a sense of belonging by creating interaction histories, finding them within the map, and sharing their experiences. Likewise, especially when an artifact is used by several people, interaction history can reinforce the social values of artifacts.

3.2 Design Properties of Interaction History

Having investigated the positive impacts of interaction history, we turn to the question of how designers can apply interaction history more systemically as design resource by controlling specific properties of the interaction history. By investigating how various impacts of interaction history could be gained and what the key elements were, we extracted five design properties: *logging moment, logging content, target, retrieving moment,* and *expressed form*. It is expected that the properties can be guidance as to what properties should be considered in designing interactive systems using interactive history. In this section, we introduce the design properties that characterize interaction history systems.

1) Logging content

First property that decides interaction history is *logging content.* It is information recorded as a component of interaction history. Infinite kinds of information could be captured as part of interaction history, which can also deliver diverse content. We categorized logging content types as contents about *outcome, process,* and *users* by referring to the former research [37].

Interaction history can contain information about the actual *outcome* of a user's experience using an artifact. Recent call logs and game scores in phone applications correspond to this. It can also deliver information about the *process*—how or when some people use an artifact. With everyday physical artifacts, process information is not delivered clearly, although people may be able to guess how an artifact was handled based on its appearance of physical wear. On the other hand, digital artifacts can deliver more concrete interaction histories that include information about how they have been used. For instance, Footprints builds maps and travel routes based on the interaction histories of previous users browsing the Web [37]. Last, interaction history can contain information about *users* themselves—how they feel, think, or react. Some interactive systems support users leaving feedback about their experiences. The different information and contents that interaction history delivers can improve usability or social and emotional values.

2) Logging moment

Logging moment represents the time interaction history is captured during the entire interactive process. Interaction history is made by recording certain content at specific moments. Since a logging moment is closely related to logging mechanism that decides how to capture and record the history of use, designers need to consider logging moments as one of the design properties in their systems

Logging moments can be either passive or active. When logging moments are passive, interaction histories are generated automatically without users' conscious effort. In most cases, interaction histories are passively generated as a byproduct of lengthy user-artifact interaction. For example, EyePrint creates interaction history from its users' gazes [27]. These histories are presented as highlighted areas on a document to support the browsing of that digital document. In these cases, users do not need to put forth any extra effort in creating interaction history. On the contrary, when logging moments are active, users must actively participate in making the system record information. We found that users sometimes deliberately create a variety of interaction histories. Spyn users apply digital history (audiovisual media, text, and geographic data) to fabric by using a smartphone application that demands their extra efforts and time [30]. That research found that these actively created interaction histories heightened recipients' appreciation for the gifts that resulted and enabled diverse meanings to emerge.

3) Target

A *target* is the location where interaction history accumulates. It might be the artifact with which users are interacting or a third-party artifact. In case of Live Web Stationery, the system collects histories about the number of people who visit the web page [32]. That history is expressed and reflected with the forms of smudges, rips, stains, and fade marks in the target, the background of the web page. In this case, target is one component of the interactive artifact, so the interaction history is displayed directly on that artifact. In the example of Burning the Candle at Both Ends [31], interaction history is similarly generated when several users log in on a certain Web page. Unlike the previous example, that history instead is transferred to another target object [31]. This instance uses a physical, moving disc as a target that reflects the interaction history. As interaction history is accumulated, hot wax is dropped onto a moving disc in a tangible form of history visualization. As illustrated in the examples, a target can decide the impact and form of interaction history.

4) Retrieving moment

Retrieving moment refers to the moment when the accumulated interaction history will be reflected in the system or artifact. It might also mean the moment when the users encounter past interaction history through a given process.

When the retrieving moment is synchronous, the interaction history is reflected immediately after the interaction history is accumulated. For example, the interaction history in our dirty desktop example is applied directly to modifying the dirty desktop interface [18]. By collecting information about past pointer events (clicks and drags) as interaction history, this system directly develops a pseudo-magnetic dust that creates an attractive field. Some examples show asynchronous retrieval of interaction history, which means that users may encounter interaction history at other points after the history is created. Vibe makes use of the history associated with posts and comments, namely authors, publishing times and dates, tags, text lengths, and commenters, to allow users'

contextual blog explorations [23]. After Vibe's system gathers interaction history associated with a blog, it filters that history and displays it when users select specific functions for locating relevant posts.

As illustrated previously, retrieving moment and retrieving mechanism for it can affect a flow of using systems and experience of users. Designers should consider retrieving moments as one of the design properties for applying interactive history.

5) Expressed form

Expressed form is about how specifically or metaphorically interaction history is described. Depending on the expressed form, interaction history delivers logging contents in abstract or concrete ways. Like recent song lists in music devices, most interactive systems can generate detailed interaction histories. Digital items also have interaction history such as metadata that shows when they were made and modified. In the case of physical wear, the expressed form is relatively abstract and gives very rough information on past experiences. For example, interaction histories of books, like well-thumbed pages, give confused accounts of how the book has been used. People are able to recall past experiences by interpreting the vague forms of interaction histories. Likewise, several cases show interaction history being expressed in abstract ways by designers' intention. History Tablecloth and Intimate Memory examples show an abstract form of interaction history being generated with a halo that grows over a period of time [1, 12]. These works found that the interaction history also serves as a ground for interpretative reflection about technology, an asset for social interaction, and an aesthetic quality beyond evoking reflection on specific events that describe the use of the artifacts.

3.3 Reflection on Past Design Cases

Up to now we have discussed the impacts of interaction history and salient design properties. Through the process of reaching the result, we encountered potential research and design issues. Thus, we explored collected cases again based on our findings, impacts of interaction history and its design properties that were identified (see Table 1). This process made it possible to generate a few insights about what should be considered in design practice and researched more about interaction history.

First of all, in terms of the impacts of using interaction history, the collected cases showed that interaction history could be appreciated for its social and emotional resonance in addition to the pragmatic goals. Some cases focused on increasing utilitarian values such as efficiency for users or giving useful information to users by interaction histories. Meanwhile, other cases examined interaction history for the emotional and social values of artifacts. However, it is still necessary to investigate how to create such diverse values using specific combinations of design properties and which properties are more influential.

About the design properties of interaction history, there are also many issues that should be considered when designing interactive artifacts or systems. In general, we found that interaction history was based mostly on logging contents about outcome and process. Logging contents such as user pathways, frequency, duration, and outcomes were usually captured as components of the interaction history. Using those logging contents as a component of interaction history, most cases created utilitarian values. Conversely, interaction history that reflected information about a given user or a group of users generated emotional and social values among the users. Nevertheless, those cases required user's active participation. This limitation might be caused by the difficulty of automatically collecting a user's cognitive or emotional status. Although they are usually unperceivable without user's participation, they may become a concrete logging contents of interaction history by sensing bio-signal such as pulse rate, breathing pattern, or body heat which partly reflects emotional changes of people.

Table 1. Analysis of cases: Impacts and design properties of interaction history

Case	Design properties of interaction history					Impacts of interaction history
	Logging content	**Logging moment**	**Target**	**Retrieving moment**	**Expressed form**	
Burning the Candle at Both Ends [31]	A group of users' activity in web community	Passive (moments when users log on)	Third-party artifact (physical moving disc)	Synchronous (right after new activity by users is logged)	Tangible form of history (hot wax is dropped)	Emotional value Social value
Deep Diffs [33]	Edited part in documents, editing operations	Passive (moments when document is edited)	Background of documents	Asynchronous (history is retrieved until new document version is created)	Graphical trace (color of background changes according to level of editing)	Utilitarian value (giving attention to passages that are unpolished)
Dirty Desktops [18]	Position where users click on GUI, number of clicks at the position	Passive (moments when users click on GUI)	GUI	Synchronous (interaction history is gradually used)	Graphical trace and pseudo magnetic force	Utilitarian value (improving usability)
Edit Wear [16]	Edited part of documents, duration of editing, ID of users	Passive (moments when a document is edited)	Scrollbar of word processor	Synchronous (interaction history is gradually used)	Graphical trace (expressed like wear)	Utilitarian value (supporting collaborative work)
EyePrint [27]	User's eye gaze trace, keyword when using document	Passive (moments when users log on)	Color behind words in document	Synchronous (while EyePrint software is being used)	Graphical trace (color behind words changes)	Utilitarian value (support the browsing of document)
Footprints [37]	User's path & navigation records while using web	Passive (moments when users navigate in web pages)	Third-party artifact (external software)	Asynchronous (when a user start Footprint software)	Diverse form (map, paths, annotations , signposts)	Utilitarian value (improving navigation)
History Tablecloth [12]	Position of object on tablecloth	Passive (moments when objects are sensed on table)	Lights in tablecloth	Synchronous (right after new activity on table is logged)	Halo at certain position and duration	Emotional value
Intimate Memory [1]	Acts of physical intimacy, time	Passive (moment when activity is sensed by system)	LED in the garment	Synchronous (right after new activity on garment is logged)	Brightness of LED and its duration	Emotional value Social value
Live web stationery [32]	A group of users' activity in webpage	Passive (moment when users access webpage)	Background of webpage	Synchronous (right after new activity on webpage is logged)	Metaphoric forms such as smudges, rips, stains, and fading	Emotional value Social value
Passages through time [14]	User's activity with several texts (when and what they read)	Passive (moments of user behavior at the GUI layer)	Passage software	Asynchronous (when a user starts Passage software)	Detailed explanation with text information	Utilitarian value (information retrieval)
PatinaMap [22]	User's activity in the map (path, mouse event, time, added text)	Passive (moments of mouse event) and active (moment when users leave text)	Icons on map, sound, text	Synchronous (right after new activity on map is logged)	Graphical trace (filtered as color, hue, saturation), sound volume	Emotional value Social value (co-ownership, sharing experience)
Progressor [17]	User's progress records in e-learning web	Passive (moment when user's progress is updated)	Third-party artifact (progressor software)	Asynchronous (when a user starts Progressor software)	Diagram that shows comparison with others	Utilitarian value Social value (giving motivation to students)
Pure Play [1]	User's temperature	Passive (moment when temperature of a user changes)	LED in the garment	Synchronous (every time temperature is sensed)	Brightness of LED and its duration	Emotional value Social value
Read Wear [16]	Read part of documents, duration of reading, ID of users	Passive (moment when a document is read by a group of users	Scrollbar of word processor	Synchronous (interaction history is gradually used)	Graphical trace (expressed like wear)	Utilitarian value (supporting collaborative work)
Spyn [30]	Added media by a user (text, image, location tag)	Active (moment when users participate in adding media)	Third-party artifact (Spyn app) & Position on knit	Asynchronous (when Spyn app is used)	Diverse forms such as text, images, location map.	Emotional value Social value
Touch Memory [1]	Physical touch by others	Passive (moment when garment is being touched)	LED in the garment	Synchronous (right after new activity on garment is logged)	Brightness of LED , its duration, and color	Emotional value Social value
Vibe [23]	Keywords of posts and comments	Passive (moment when new post is added)	Third-party artifact (Vibe software)	Asynchronous (when a user starts Vibe software)	Diagram and extracted keywords	Utilitarian value (effective navigation and exploration)
Visit Wear [34]	User's activity in the digital work space	Passive (moment when there is new activity by users)	Visual interface space	Synchronous (history is applied immediately)	Distortion of a fisheye view	Utilitarian value (supporting special memory)
YeTi [38]	A group of users' activity in YeTi	Passive (moment when there is new activity by users)	YeTi software	Synchronous (new contents are updated right away)	Detailed explanation with text information	Utilitarian value Social value (community building)

Depending on the logging moment type, interactive systems generated diverse effects. While passive logging moments help users create useful or enjoyable histories that are unexpected by them, active logging is sometimes more helpful for generating more sympathetic and subjective results. Regardless, designers should consider creating logging moments and mechanisms that enable natural logging and seamless user experiences. Especially, it is important to critically consider whether the system causes discomfort when the system demand users' active participation. For instance, some people may not like creating interaction histories with extra software or applications, which involve an annoying process. Thus, designers should consider if the process permeates naturally into the whole using process without discomfort. If not, users' active logging might not continue for long.

Among collected cases, it is shown that artifact itself usually becomes the target of interaction history. In those cases, some specific parts of an artifact that people use change according to interaction history. On the contrary, there are few cases when a third-party artifact is designated as the target. To some extent it is expected that people may not be able to understand why a third-party artifact is changing but for sufficient information about the system. Thus, it is necessary to design an interactive system that shows the relevance of that third-party artifact, interaction history, and an artifact that people use.

Retrieving moments can be designed differently depending on the purpose and conditions of specific interactive systems. Designers should explore when interaction history will become more necessary for users. If users need direct and immediate changes of interaction history, designers should consider synchronous retrieval of interaction history. If not, designers may consider other retrieving moments and retrieval mechanisms that satisfy users. Similar to logging moments, designers should consider whether the retrieving moment and mechanism do not disturb the user's experience while using an artifact or systems.

The analyzed cases express interaction history in a various ways from abstract forms using metaphors to detailed forms using diagrams or text. The expressed form of interaction history is closely related to degree of details of information that interaction history shows. The expressed form is determined by how interaction history will be filtered. Just as Gaver et al. [13] discovered that ambiguity acts as a ground for social interaction and an aesthetic quality, users may perceive differently when they encounter diverse degree of details in interaction histories. Since users may perceive diverse forms of interaction histories differently, further research should deal with the relationship between interaction history's expressed form and its impact on the increased value of artifacts.

4. Design implication: Visual analysis of interaction history

In the previous chapters, we studied impacts and design properties that characterize interaction history. In this chapter, we suggest a visual analysis tool for using interaction history in design (Figure 1). The overarching idea is to visualize the design properties of interaction history in a chronological sequence. There are several reasons why we suggest a visual style of description and analysis. Design practitioners already have used sketches, diagrams, and other visual tools in their practices. Interaction designers need to be especially proficient in using informational diagrams to present series of events in chronological order and explain complex relationships among several components. We assume that designers will be able to generate new concepts and analyze interactive systems more efficiently by using a visual analytical approach that shows design properties related to interaction history.

Our visual analysis tool consists of three main parts. First, design properties related to the logging stage are included. The second part includes design properties from the retrieving stage. The third part involves the impacts of interaction history. For applying this tool in design process, it is essential to learn how users and

artifacts interact with each other under their environment. Designers must understand what happens while people use an artifact or how that artifact and its user react. Then, they investigate the design properties of that interaction history in detail. Finally, they can consider the expected impacts of the interaction history.

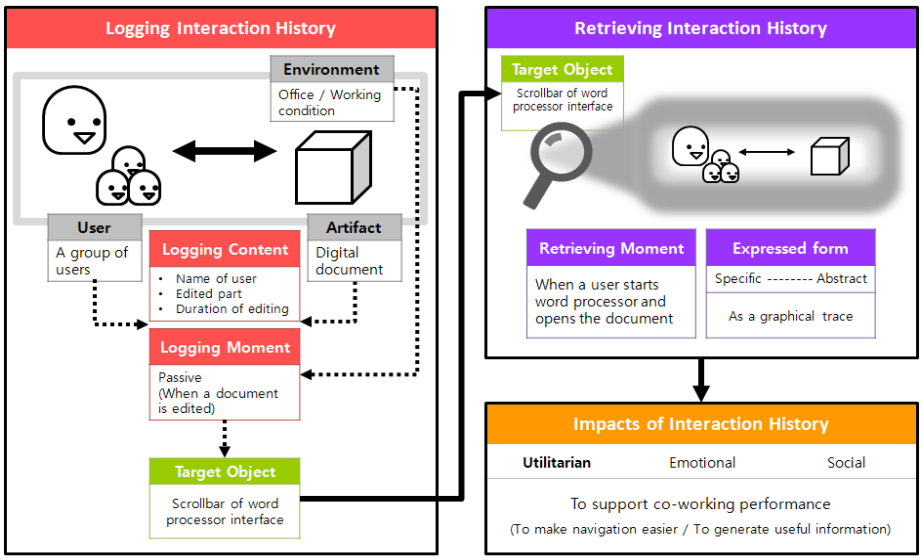

Figure 1. Example of applying visual description tool (Analysis of Edit Wear)

To assess the effect of our tool, we had an expert interview with three design professionals in a doctoral program who had studied interaction design for more than seven years. Specifically, the purpose of this task was to investigate whether our visual analysis tool could support their understanding of interactive systems. Before asking questions, we briefly explained design properties of interaction history and then asked them to analyze existing design case (e.g. Edit Wear [16]) with our tool. After they did so for an hour, we had an interview with participants about their experiences with our tools and analytical approaches to interaction history.

As a result, we could confirm several potential benefits for interaction design. Firstly, participants mentioned that they were able to explain the flow of interactive systems clearly. When they were asked to describe these systems, most of their descriptions were similar and understandable. We therefore expected that this tool would help designers to describe interactive service or systems in an understandable way. Secondly, our visual analysis tool would help designers evaluate quality of interactive systems. Participants said they could judge the quality of designed cases with precise criteria using our tool. When the whole interaction flow seemed unnatural or design properties seemed inappropriate, they could ask themselves what needed to change. Participants also mentioned that our tool was helpful for generating alternative solutions. After evaluating each design property, participants suggested better design solutions for improving their systems.

5. Conclusion

As an early attempt to explore ways of using interaction histories to make more valuable artifacts, our research drew upon previous investigations of how those histories affect user-artifact interactions and the design properties that matter. Through our analysis of field study results, we extracted properties of interaction history that could serve as a foundation for developing more practical design knowledge. Finally, we proposed a visual analysis tool for using interaction history.

Since current design properties may not be comprehensive enough, further research should verify whether design properties are sufficient to explain how interaction history works and apply interaction history more systematically. In addition, we will need to prove the potential value of our visual analysis tool by applying it to actual design processes.

Nevertheless, considering the paucity of work in this area, we wanted to start with a small cases to gain a basic understanding that can drive future research. Our research makes a special contribution by offering an analytical perspective on interaction histories as a resource for interaction design. Our investigation of interaction history described a space for possible history-rich artifacts and identified dimensions that can be used to analyze existing systems or to design new interactive artifacts. We hope this research inspires future studies into how interaction history might be used to increase the values of digital artifacts and services.

6. Acknowledgement

This research was supported by the SW Computing R&D Program of MOTIE/KEIT (2011-10041313, UX-oriented Mobile SW Platform).

7. Reference

[1] Berzowska, J. (2005) *Memory rich clothing: second skins that communicate physical memory.* In Proceedings of the 5th conference on Creativity & cognition.

[2] Blevis[1], E., & Stolterman[1], E. (2007) *Ensoulment and sustainable interaction design.* In Proceedings of IASDR, Hongkong.

[3] Blevis, E. (2007) *Sustainable interaction design: invention & disposal, renewal & reuse.* In Proceedings of the SIGCHI conference on Human factors in computing systems.

[4] Boztepe, S. (2007) *User value: Competing theories and models*. International journal of design, 1(2), 55-63.

[5] Chapman, J. (2009) *Design for (emotional) durability. Design Issues*, *25*(4), 29-35.

[6] Crilly, N., Maier, A., & Clarkson, P. J. (2008) *Representing artefacts as media: Modelling the relationship between designer intent and consumer experience*. International Journal of Design, 2(3), 15-27.

[7] De Souza, C. S. (2005) *The semiotic engineering of human-computer interaction*: MIT press.

[8] DeSilvey, C. (2006) *Observed decay: telling stories with mutable things*. Journal of Material Culture, 11(3), 318-338.

[9] Desmet, P. M., & Hekkert, P. (2007) *Framework of product experience*. International Journal of Design, 1(1), 57-66.

[10] Fougere, T. (2012) *Tyndall Table*. from http://thomfougere.com/thomfougere-TyndallTable

[11] Frohlich, D., & Murphy, R. (2000) *The memory box*. Personal Technologies, 4(4), 238-240.

[12] Gaver, W., Bowers, J., Boucher, A., Law, A., Pennington, S., & Villar, N. (2006) *The history tablecloth: illuminating domestic activity.* In Proceedings of the 6 th conference on Designing Interactive systems.

[13] Gaver, W. W., Beaver, J., & Benford, S. (2003) *Ambiguity as a resource for design.* In Proceedings of the SIGCHI conference on Human factors in computing systems.

[14] Gyllstrom, K. (2009) *Passages through time: chronicling users' information interaction history by recording when and what they read.* In Proceedings of the 14th international conference on Intelligent user interfaces.

[15] Hill, W. C., & Hollan, J. D. (1994) *History-enriched digital objects: Prototypes and policy issues*. The Information Society, 10(2), 139-145.

[16] Hill, W. C., Hollan, J. D., Wroblewski, D., & McCandless, T. (1992) *Edit wear and read wear.* In Proceedings of the SIGCHI conference on Human factors in computing systems.

[17] Hsiao, I.-H., Guerra, J., Parra, D., Bakalov, F., König-Ries, B., & Brusilovsky, P. (2012) *Comparative social visualization for personalized e-learning.* In Proceedings of the International Working Conference on Advanced Visual Interfaces.

[18] Hurst, A., Mankoff, J., Dey, A. K., & Hudson, S. E. (2007) *Dirty desktops: using a patina of magnetic mouse dust to make common interactor targets easier to select.* In Proceedings of the 20 th annual ACM symposium on User interface software and technology.

[19] Jung, H., Bardzell, S., Blevis, E., Pierce, J., & Stolterman, E. (2011) *How deep is your love: Deep narratives of ensoulment and heirloom status*. International Journal of Design, *5*(1), 59-71.

[20] Kawamura, T., Fukuhara, T., Takeda, H., Kono, Y., & Kidode, M. (2003) *Ubiquitous memories: wearable interface for computational augmentation of human memory based on real world objects.* In Proc. 4th International Conference on Cognitive Science (ICCS2003).

[21] Kirk, D., & Banks, R. (2008) On the design of technology heirlooms. *SIMTech'08*.

[22] Krumbein, W. E. (2002) *Patina and cultural heritage-a geomicrobiologist's perspective.* In Proceedings of the 5th European Commission Conference "Cultural Heritage Research: a Pan European Challenge", Crakow.

[23] Marques, N., Dias, R., & Fonseca, M. J. (2012) *Improving blog exploration through interactive visualization.* In Proceedings of the International Working Conference on Advanced Visual Interfaces.

[24] Odom, W., & Pierce, J. (2009) *Improving with age: designing enduring interactive products.* In Proceedings of the 27th international conference extended abstracts on Human factors in computing systems.

[25] Odom, W., Pierce, J., Stolterman, E., & Blevis, E. (2009) *Understanding why we preserve some things and discard others in the context of interaction design.* In Proceedings of the 27th international conference on Human factors in computing systems.

[26] Odom, W., Zimmerman, J., & Forlizzi, J. (2010) *Virtual possessions.* In Proceedings of the 8th ACM Conference on Designing Interactive Systems.

[27] Ohno, T. (2004) *EyePrint: support of document browsing with eye gaze trace.* In Proceedings of the 6th international conference on Multimodal interfaces.

[28] Rogers, Y., Sharp, H., & Preece, J. (2011) *Interaction Design: Beyond Human Computer Interaction* (3rd ed.): John Wiley & Sons.

[29] Rosner, D. K. (2011) *Tracing provenance*. interactions, 18(5), 32-37.

[30] Rosner, D. K., & Ryokai, K. (2010) *Spyn: augmenting the creative and communicative potential of craft.* In Proceedings of the 28th international conference on Human factors in computing systems.

[31] Schütte, A. A. (1998) *Patina: layering a history-of-use on digital objects*. Master thesis, Massachusetts Institute of Technology. Cambridge, MA.

[32] Seligmann, D. D., & Bugaj, S. V. (1997) *Live Web stationery: virtual paper aging.* SIGGRAPH 97 Visual Proceedings: The art and interdisciplinary programs of SIGGRAPH'97.

[33] Shannon, R., Quigley, A., & Nixon, P. (2010) *Deep Diffs: visually exploring the history of a document.* In Proceedings of the International Conference on Advanced Visual Interfaces.

[34] Skopik, A., & Gutwin, C. (2005) *Improving revisitation in fisheye views with visit wear.* In Proceedings of the SIGCHI conference on Human factors in computing systems.

[35] Speed, C. (2011) *An internet of things that do not exist. interactions, 18*(3), 18-21.

[36] West, D., Quigley, A., & Kay, J. (2007) *MEMENTO: a digital-physical scrapbook for memory sharing*. Personal and Ubiquitous Computing, 11(4), 313-328.

[37] Wexelblat, A., & Maes, P. (1999) *Footprints: history-rich tools for information foraging.* In Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit.

[38] Yamada, T., Shingu, J., Churchill, E., Nelson, L., Helfman, J., & Murphy, P. (2004) *Who cares?: reflecting who is reading what on distributed community bulletin boards.* In Proceedings of the 17th annual ACM symposium on User interface software and technology.

[39] Zancheti, S. M., de Figueirôa Silva, A., Braga, A. C., Gameiro, F. G., Lira, F. B., & Costa, L. S. (2006) *The patina of the city*. *City & Time, 2*(2).