Designing Reflective User Experience with Social and Ubiquitous Computing Technologies

by

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Abstract

Reflection as a unique human experience has drawn steady attention from researchers in Human-Computer Interaction (HCI). Yet my review of HCI studies involving reflection reveals untapped opportunities to engage social science theories on reflection in HCI research on supporting reflection. In response, I put forth two goals for this dissertation research. First, I wanted to show that it is fruitful to have a deeper engagement with Schön's (1983) theoretical framework, especially those previously underappreciated factors which he suggested can shape reflection, in guiding both the design and evaluation of interactive systems. Second, I wanted to leverage social and ubiquitous computing technologies to create reflective experience as a core technology design outcome in its own right.

I pursued these goals in three studies reported in this dissertation. In the first study, I built a browser extension called Social Overlays to demonstrate *reflective use*, an approach to addressing usability issues by allowing members of a user community to collectively reflect on issues they run into when they use their website. In this study, I called out Social Overlays' power of reframing community members' roles from information consumers to co-designers and co-editors of their website, and I explained how their changed role frame, a construct in Schön's (1983) theory, encouraged participants to reflect on the design and the content of the website.

In the remaining two studies, I investigated using activity traces captured by ubicomp technologies to support reflection. In the second study, I designed a system called Home Trivia to explore how we can use device usage traces in the home to allow household members to

reflect on how they have been using their electronic devices and how they can better manage them. Through a field study of Home Trivia, I showed the effectiveness of using games as a medium for supporting reflection in a family setting. The study contributes a design approach called *reflective play*. Its key idea is that reflection and engagement can reinforce each other in the way that reflection helps the player win the game and the information revealed by the game helps trigger reflection.

In the third study, I explored long-term uses of traces and how traces might allow people in the future to connect with and reflect on the past. To understand what practices can be in the future, I examined a comparable phenomenon in the present: how people today use activity traces (in particular, traces of prior appropriation of their houses) left by their predecessors in the houses where they live. In addition to providing insights about the fabric of their houses, traces also allowed some participants to reflect on local history, aesthetics of an earlier period, and their emotional attachment to their houses. I then proposed three design concepts based on these findings.

To explicate the relationship between my three studies and theories on reflection, I conducted a meta-analysis of the three studies in light of the key concepts in Schön's (1983) theory of reflection-in-action. This meta-analysis shows that it is fruitful to draw on those important yet previously underutilized concepts to inform system design. I concluded this dissertation with several implications to designing reflective user experience.

CHAPTER 1

Introduction

1.1 Background

As a unique and sometimes elusive human experience, reflection has been a subject of influential scholarship. In education, John Dewey (1933) considered reflective thought, often triggered by "perplexity," as the cornerstone of experiential learning. In professional development, Donald Schön (1983) argued that practitioners exercise their expertise through reflection-in-action, a style of reflection that occurs concurrently with action. Both views of reflection have inspired a great amount of scholarly work on the topic of reflection.

Within the field of Human-Computer Interaction (HCI), there is also a long-standing interest in supporting and leveraging users' ability to engage in reflective thinking and practice (Fleck and Fitzpatrick, 2010). Schön's (1983) theory on reflective practice was introduced to the HCI community as early as 1992 by Hill, Hollan, Wroblewski, and McCandless (1992) as the theoretical underpinning of the read wear and edit wear interfaces (described in chapter 2.2.2.4). However, despite the early recognition as an interesting topic in HCI, reflection largely played a supporting role in designing and evaluating interactive systems until it was re-energized recently by the so-called third paradigm of HCI (Harrison, Tatar, & Sengers, 2007).

On the one hand, many HCI researchers designed tools which supposedly involved reflection as a means to helping users achieve particular goals or complete predefined tasks, such as

adopting pro-environmental (e.g., Gustafsson & Gyllenswärd, 2005; Froehlich, Findlater, & Landay, 2010) or pro-health (e.g., Consolvo et al., 2008) behavior, developing computer skills (e.g., Malacria, Scarr, Cockburn, Gutwin, & Grossman, 2013; Bateman, Teevan, & White, 2012), or supporting software development (e.g., DeLine, Khella, Czerwinski, & Robertson, 2005; Eick, Steffen, & Sumner, 1992). However, this body of work usually does not assess reflection *per se*. Instead, it is used to justify the design or explain participants' task performance (Baumer et al., 2014).

On the other hand, the rise of the third paradigm of HCI (Harrison et al., 2007) has made construction of meaning one of its key intellectual commitments. Reflection, as one of the activities through which people grasp the meaning of objects and events (Dewey, 1933), has started to take a more prominent role in the design and evaluation of interactive systems, especially when it comes to non-task oriented computing. Supporting reflection is increasingly seen as a goal worth pursuing in its own right rather than as a means through which a prescribed outcome can be realized. For example, Pousman, Romero, Smith, and Mateas (2008) investigated how to design for the non-task aspects of domestic life in smart homes with Tableau Machine, a sensor-driven ambient display that helps household members reflect on their everyday life. Similarly, Slow Technology, a design agenda introduced by Hallnäs and Redström (2001), aims to design for "reflection and moments of mental rest rather than efficiency in performance."

Joining this burgeoning movement of designing interactive systems for reflection, this dissertation research explores new approaches enabled by social and ubiquitous computing (ubicomp) technologies to designing reflective experiences. In particular, this dissertation is focused on two transformative phenomena driven by the proliferation and maturing of technologies such as Web 2.0, sensors, and the Internet of Things (Holler et al., 2014).

The first phenomenon is that the Web has become highly participatory not only in communication but also in production of information and digital artifacts, as the so-called Web

2.0 continues to develop and mature. More and more users are becoming producers of information and digital artifacts in one way or another. How might this fundamental shift in users' roles allow them to reflect more often on the part of the cyberspace in which they dwell? I address this question in chapter 3 where the Social Overlays project is described.

The second phenomenon is that cheap sensors, the Internet of Things, and cloud computing have started enabling the places we live, work, and play to capture our activity traces. While the dominant narrative around the development and adoption of these technologies is based on their utilitarian value—their ability to help humans get things done through automation and personalization—this dissertation shows that there is enormous potential to use activity traces to create reflective experiences that are emotionally and socially desirable. And this is the design space that the Home Trivia project and the House Memory project described in chapters 4 and 5 respectively set out to explore.

1.2 Research Questions and Overview of Chapters

Below I provide an overview of the chapters in the rest of this dissertation as well as the research questions these chapters address.

In chapter 2, I review two bodies of literature related to designing reflective experience. First, I introduce seminal work on reflection by theorists Dewey (1933) and Schön (1983). In particular, I introduce important factors that can increase or constrict a person's capacity for reflection in Schön's (1983) theory. These factors, such as *role frame* and *interpersonal theory of action*, have received little attention from the HCI community, but they proved to be helpful in guiding the designs of reflective experiences in this dissertation. Second, I provide an overview of prior work in HCI that either seeks to design systems to support reflection or finds reflective thinking or practice as an outcome of system use.

Based on the literature reviewed in chapter 2, I put forth four research questions in response to its shortcomings and untapped opportunities. The first and overarching research question this dissertation seeks to address is:

> ***R1:*** *Can we better understand the design space of computer-supported reflection by having a deeper engagement with theories on reflection, in particular the constants of reflection (e.g., role frame, appreciative system, interpersonal theory of action, etc.) identified by Schön?*

This research question is collectively addressed by all the three studies in this dissertation research. The second research question is:

> ***R2:*** *How can we use ambiguity as a design resource to trigger reflection that goes beyond understanding the meaning of representations?*

This question is intended to address shortcomings identified in existing systems that employ ambiguity as a resource to provoke reflection. The third research question is:

> ***R3:*** *How can we adapt problem-based gaming (PBG) to allow users to reflect on certain aspects of their lives instead of subject knowledge?*

The goal of this question is to explore how well the problem-based gaming approach (Kiili, 2007) can be adapted to support reflection beyond the educational setting where it was developed. The second and third research questions are addressed in the study of the Home Trivia system presented in chapter 4. The last research question is:

> ***R4:*** *How can we use traces, especially traces accumulated over time in a place, to provoke reflection, and what is the character of the reflection provoked by such traces?*

This question is put forth in response to the lack of studies examining the character of reflection provoked by traces of use, especially with regard to the prospect of having traces accumulated over a long period of time in sensor-augmented environments. The subsequent three chapters detail three separate studies that address the above research questions as well as practical problems in their respective domains.

In chapter 3, I describe the Social Overlays project. Motivated by the needs of under-resourced organizations (e.g., charities) to have usable websites, this project explores the idea of

enhancing a website's usability by enabling its user community to reflect on the current design and content of the site and suggest changes to it, instead of paying for professional usability services. Specifically, I created a browser extension called Social Overlays (SO). SO enables users to modify a live web page by creating "overlays," which are DOM modifications applied to webpages and shared among SO users as soon as they are created. The results of a lab-based user study suggest that a group of everyday users of a website can identify more problems than a small team of external usability professionals. Moreover, the user-identified problems had systematic differences from those identified by external experts, which I attributed to reflection enabled by SO. In addition, I employed several constructs in Schön's theory on reflection-in-action to guide the design of SO and explain its evaluation results. This chapter is adapted from a previously published paper (Dong, Ackerman, Newman, & Paruthi, 2013) presented at the INTERACT 2013 conference.

In chapter 4, I turn my attention to supporting reflection with ubicomp technologies in domestic environments and describe the Home Trivia project. In this study, I explored the efficacy of using passively captured activity traces in the home to help families become more aware of and reflective about their technology use. I designed and implemented an interactive system called Home Trivia. It monitors device usage and space usage in the home and then packages those activity traces into a puzzle game the family can play together. The system and its successful field trial show that problem-based gaming (Kiili, 2007) can be adapted to support reflection beyond educational settings and deliver both engaging and reflective experiences when it is combined with traces as the game content. The results of the field study also suggest that allowing users to reduce ambiguity in information representations through active thinking and experimentation can help provoke reflection on the represented events.

In chapter 5, I continue exploring the potential of using traces to create reflective experience but with a focus on traces' long-term uses. In the House Memory study, I set out to explore, on a timescale of decades and centuries, possible future practices of using activity traces (e.g., occupancy and indoor locations) our everyday environments started to capture and amass. To

understand what practices can be in the future, I examined a comparable phenomenon in the present: how people today use activity traces (in particular, traces of prior appropriation of their house) left by their predecessors in the house where they live. The study found that participants received, discovered, and made use of many small traces held by artifacts, people, and building materials. Not only were those traces used to provide practical assistance to participants' appropriation of their house, they also served as resources and triggers for connecting with the past in an evocative manner. This chapter is adapted from a previously published paper (Dong, Ackerman, & Newman, 2014) presented at the ACM DIS 2014 conference.

In chapter 6, I revisit the research questions introduced earlier with findings from the studies presented in chapters 3, 4 and 5. Using Schön's (1983) theoretical framework, I then present a meta-analysis of the three studies in this dissertation research and outline a number of implications for the design of reflective experiences.

1.3 Contributions

The three studies and the dissertation as a whole make a number of contributions to the enterprise of designing reflective experiences. Each of the three studies proposes a new reflection-based approach to addressing a particular domain problem. First, Social Overlays represents the *reflective use* approach that enables users to reflect on ways to improve a website by reframing their roles as co-designers and co-maintainers of the site. Second, Home Trivia takes the *reflective play* approach to align engagement with reflection for the purpose of improving family awareness of technology use. Third, the House Memory study describes *reflective inhabitation*, which means being aware and appreciative of a house's architectural evolution, community identity, and socio-historical context.

As a whole, this dissertation makes two contributions. First, this dissertation shows that it is fruitful to have a deeper engagement with theories on reflection in both system design and

evaluation. In particular, I applied previously underutilized notions in Schön's (1983) theory such as role frame, interpersonal theory of action, and appreciative system in the design of reflective experiences. Secondly, the dissertation demonstrates the enabling powers possessed by social and ubiquitous computing technologies in creating reflective experience. In particular, I called out those technologies' ability to change users' roles from passive consumers to co-creators as well as their ability to capture activity traces as resources for revisitation and reflection.

CHAPTER 2

Literature Review

In this chapter, I review two bodies of literature related to designing reflective experience. To begin with, I provide an overview of the seminal work by Dewey (1933) and Schön (1983) on reflection. In particular, I introduce important factors that can increase or constrict a person's capacity for reflection in Schön's (1983) theory. These factors, such as *role frame* and *interpersonal theory of action*, have received little attention from the HCI community, but they have proved to be helpful in guiding the system design and evaluation in this dissertation. In addition to introducing these classic views on reflection, I also describe frameworks concerning the levels of reflection in order to explain how the character of an instance of reflection can be assessed and articulated. Next, I survey prior work in HCI that either seeks to design systems to support reflection or finds reflective thought or practice as an outcome of system use. I organize my review of those studies by their approaches to supporting reflection. I conclude my review by identifying approaches this dissertation research builds upon as well as intellectual gaps this dissertation aims to bridge.

2.1 Views on Reflection

2.1.1 What is Reflection?

It is hard to define reflection precisely, and some researchers have considered it as a complex and potentially nebulous concept (Baumer et al., 2014). Nevertheless, it is helpful to examine definitions put forward by theorists to understand the concept's essence and variations. Here, I

introduce views on reflection by Moon (2013), Dewey (1933), and Schön (1983), whose work has been most frequently cited by HCI researchers, according to Baumer et al. (2014).

Moon (2013) synthesized what she called a "common-sense" view of reflection by unpacking the meaning of the word in everyday usage. She described reflection as "a form of mental processing with a purpose and/ or an anticipated outcome that is applied to relatively complicated or unstructured ideas for which there is not an obvious solution" (Moon, 2013, p. 4).

There are, of course, more technical definitions of reflection. Primarily concerned about learning, Dewey (1933) suggested, "Active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends, constitutes reflective thought" (p. 5). Dewey (1933) further elaborated on the origin of reflection. He said, "We may recapitulate by saying that the origin of thinking is some perplexity, confusion, or doubt" (p. 10). Building on Dewey's view, Schön (1983) sought to characterize how professionals work with the concept of *reflection-in-action*, which describes a particular type of reflection in which thinking and doing occur in tandem and reinforce each other. Schön (1983) argued:

> *On the other hand, both ordinary people and professional practitioners often think about what they are doing, sometimes even while doing it. Stimulated by surprise, they turn thought back on action and on the knowing which is implicit in action. (p. 50)*

Despite the differences between these definitions of reflection, there are three common elements that are essential to understand the concept. To begin with, reflection is usually triggered by the experience of being surprised, confused, or uncertain. Such an experience destabilizes one's existing beliefs and drives him/her to a new understanding. It thus sets the second element of reflection—mental processing—in motion. Such mental processing includes but is not limited to formulating a hypothesis and testing it, changing perspectives and frames, and connecting dots and establishing relationships. In addition, reflection is usually driven by goals as it is intended to reach "further conclusions" (Dewey, 1933, p. 5). However, it should be

clarified here that a goal usually does not exist before reflection is triggered. In other words, goals are different from triggers of reflection. For example, a person seeing something contradictory to his existing belief might start reflecting on it with the goal of improving his understanding.

Although these views of reflection share some common characteristics, they are still quite different in terms of the situation in which reflection occurs, the object in reflection, and the outcome of reflection. The question is: should we consider these definitions of reflection as different ways of describing inherently different human activities or in fact the same activity? Moon (2013) has taken an inclusive approach to settling this question. She argued, "the apparent differences in reflection are not due to different types of reflection – in other words, to differences in the process itself, but to differences in the way that it is used, applied or guided" (Moon, 2013, p. 5). While an ontologically definitive answer to this question could always be up for debate, an inclusive approach to understanding the concept of reflection is useful in guiding technology design by allowing the designer to draw on constructs and theories developed for different flavors of reflection. Therefore, this dissertation, in general, follows the definition of reflection articulated by Moon (2013), but it also draws heavily on Schön (1983). Below, I describe several additional aspects of reflection, including its major steps, relationship with action, influencing factors, and levels.

2.1.2 The Steps of Reflection

Dewey (1933) elaborated on a canonical process of reflection. There are five steps involved, beginning with "a felt difficulty." Dewey (1933) named three types of difficulty in particular. The first type resides in the conflicts between the means at disposal to the individual and the end he/she wants to reach. The second type involves the difficulty of identifying the character of an object. The third type is related to the challenge of explaining an unexpected event.

The second step is to locate and define the felt difficulty. This step provides the reflective individual with the opportunity to understand the nature of the problem before seeking

solutions. It is closely related to Schön's idea of framing the problem through reflection, which I will introduce in the next section.

The third step is to suggest possible explanations or solutions. This is an inherently divergent process, and all ideas coming up at this stage would be tentative in nature. Dewey (1933) argued, "cultivation of a variety of alternative suggestions is an important factor in good thinking" (p. 69). The third step is followed by the fourth step, rational examination of these tentative suggestions against all conditions and constraints present. At the final step, the reflection process concludes when the prevailing explanation of solution is corroborated by observed facts and in some cases experiment results.

2.1.3 Reflection and Action

Dewey's work had a tremendous influence on Schön, whose theory of reflection-in-action has been widely cited in HCI research seeking to support reflection (Baumer et al., 2014). Not only did Schön inherit Dewey's philosophical orientation that seeks to integrate thought and action, he also directly drew on Dewey's insight into the nature of reflective thought. Schön (1992) summarized this insight as follows: "The inquirer does not stand outside the problematic situation like a spectator; he is in it and in transaction with it" (p. 122).

Based on a series of empirical studies of professional practice, Schön (1983) developed a theoretical framework to further explicate the relationship between reflection and action in a problematic or uncertain situation. In his seminal book entitled *The Reflective Practitioner: How Professionals Think in Action,* Schön's (1983) thoroughly examined and articulated the pivotal role played by action in reflection. He explained and advocated a particular form of reflection called *reflection-in-action* that is common in a variety of professional practices involving design (broadly construed). Distinguishing *reflection-in-action* from *reflection-on-action* which happens after action and is detached from action, Schön (1983) argued that reflection and action could occur in tandem and reinforce each other. This view on reflection is built on a related notion called *knowing-in-action*—practitioners employ and reveal their tacit knowledge in their

actions. Reflection-in-action enables a practitioner to become aware of the knowledge he brings to his action and gain new understandings of the problem he is trying to solve as well as his own behavior by allowing him to listen to the "back-talk" of the situation (e.g., the observable outcome of one's action).

According to Schön (1983), a practitioner can reflect on three things in her action. First, she might reflect on the situation she is dealing with, trying to find the right angle to understand the nature of the problem and perhaps match the situation with cases she has dealt with before. Second, she might reflect on the tacit knowledge manifested in her action, in order to determine if this knowledge applies to the situation. Third, she might reflect on her action by carrying out either thought or actual experiments and examining the results of those experiments.

According to Schön (1983), reflection-in-action bears critical benefits to professional practices. First, it allows the practitioner to reframe the problem to make it more manageable. Second, it allows the practitioner to deal with uncertainty and exceptions. A reflective practitioner constantly evaluates the state of the situation and adjusts his course of action. Third, it enables the practitioner to adapt to new situations and avoid blindly applying past knowledge.

Furthermore, action is linked to triggers of reflection. Like Dewey (1933), Schön (1983) argued that reflection often occurs when the practitioner experiences surprise, puzzlement, or confusion. Schön (1983) suggested that cases of perplexity often resulted from taking certain actions. Reflection then guides the actions the practitioner will take next. Highlighting the dialogic nature of the relationship between thinking and doing, Schön characterized professional work as conversations with the situation.

Reflection-in-action has been recognized by HCI researchers (e.g., Hill et al., 1992) as a useful theory. It is not hard to understand the concept's relevance to HCI, since interactions between humans and computers, HCI's central object of inquiry, are a type of action. On the one hand,

supporting reflection in interaction with technology allows users to develop skills of using the technology (e.g., Matejka, Grossman, & Fitzmaurice, 2013) or discover interesting content through use of the technology (e.g., Hill et al., 1992). On the other hand, interacting with computing systems allows users to receive interesting information that can potentially trigger reflection (e.g., Rogers et al., 2004).

2.1.4 Factors Influencing Reflection

Schön (1983) further suggested that the scale, nature, and effectiveness of reflection-in-action is shaped and bound by a number of factors brought by individuals to a situation. Schön (1983) called those factors the *constants* of reflection-in-action because he considered those factors relatively stable for a particular individual. Since this dissertation uses several of those constants to inform system design and evaluation, I introduce them below.

First, reflection-in-action is supported by the *media, languages, and knowledge repertoires* the practitioner uses to articulate his/her thoughts, carry out experiments, and understand the situation. Taking interaction design as an example, a designer's sketchpad or wire-framing application (media), her mastery of design jargons such as affordance, mental model, and feedback (language), and her knowledge of suitable design patterns (repertoires) are all essential for the designer to think and explore in a design task.

Second, reflection-in-action is conditioned on the practitioner's *appreciative system*. An individual's appreciative system determines what problem is worth solving, what outcome is considered satisfactory, and what means is acceptable. The appreciative system reflects one's value, philosophy, and principles, as well as the norms imposed by the practitioner's professional community. For example, practitioners of user-centered design usually employ an appreciative system that favors the approval and acceptance by users rather than other stakeholders.

Third, reflection-in-action is guided by the *overarching theories* practitioners use to understand the phenomena before them. An overarching theory does not directly explain or address a phenomenon of interest. Rather, it sets a theoretical orientation with which an account or a solution ought to be constructed. In HCI, Lucy Suchman's (2006) theory of situated action would be an example of overarching theories. However, as Schön (1983) pointed out, an overarching theory does not always exist in every instance of reflection-in-action.

Fourth, reflection-in-action is bounded by the way the practitioner frames his role. The practitioner's *role frame* exerts a strong yet often unnoticed influence on how he determines what facts are relevant, what problems belong to him, what knowledge is useful, what actions are appropriate, and what kinds of reflections should be undertaken in action. In other words, a practitioner's role frame, often imposed by his/her institution, creates boundaries within which the practitioner's reflection can operate.

Finally, reflection-in-action is affected by the *interpersonal theory of action*, which is a set of guiding principles for how to behave strategically in a multi-party situation. Because an interpersonal theory of action can affect one's willingness to openly communicate his/her thoughts and calculations with others, it shapes reflection by limiting or enhancing the situation's "back-talk." Schön (1983) used this concept along with role frame to explain why reflection was limited in a town-planning meeting between a planner and a developer. The planner in the meeting adopted a so-called Model I theory of action, which led him to frame the situation as win/lose interactions with the developer. Under this theory, the planner sought to unilaterally control the task, avoid showing signs of weakness, and reserve his evaluation of the situation. The developer responded by adopting a similar theory of action, and eventually he shocked the planner by abandoning the proposed project without revealing his decision process to the planner during the meeting. The concept of interpersonal theory of action is useful in designing reflective experience that involve multiple parties who might have different goals and levels of power. Chapter 4 of this dissertation provides a specific example of applying this concept in the context of designing a system supporting family reflection on home life.

It is one of this dissertation's central arguments that these constants of reflection described above can be useful in systematically exploring the design space of using computing systems to support reflection. The three studies in this dissertation serve as examples to show how we can design technology to change those constants in order to create situations amenable to reflection.

2.1.5 Levels of Reflection

Recognizing that people have different capacity to reflect and reflection can vary greatly from instance to instance, researchers have sought to describe the character of reflection with named levels. In education, Surbeck, Han, and Moyer (1991) derived a three-level framework from assessing student teachers' reflective responses in journals. Their framework categorizes reflection into three levels: *reaction*, *elaboration*, and *contemplation*. First, at the level of reaction, reflection is minimal. It involves factual description of and simple emotional responses to events. Second, at the level of elaboration, reflection takes the form of comparing related experiences and generalizing observations to a principle or a theory. Last, at the level of contemplation, reflection allows an individual to relate an event to his/her personal situation as well as his/her professional context.

Recently, HCI researchers have also made an effort to identify levels of reflection and technologies that help users attain those levels. For example, Fleck and Fitzpatrick (2010) proposed a five-level framework of reflection and applied it to a case study of using a wearable digital camera to support teachers' reflective practice (Fleck, 2012). Fleck and Fitzpatrick (2010) suggested that the higher levels of reflection would occur after the lower levels of reflection in the framework.

Specifically, the framework starts at the level of *R0 Description*, which involves describing an event or experience without further elaboration or explanation. This level does not involve reflection on its own, but Fleck and Fitzpatrick (2010) argued, "any representation of existing

information or knowledge can form the basis for reflection on that information" (p. 218). R0 is then followed by the lowest level of reflection, *R1 Reflective Description*. It occurs when the recalled events need explanation or justification.

At the next level *R2 Dialogic Reflection*, reflection would involve considerations of alternative explanations and perspectives as well as establishment of relationships. An instance of reflection will be elevated to the next level when R2 succeeds, because the level of *R3 Transformative Reflection* is marked by transformation of one's perspective. In my opinion, these two levels of reflection seem to be closest to the reflection construed by Dewey (1933) and Schön (1983). The final level of reflection, *R4 Critical Reflection,* concerns wider societal or moral implications beyond the immediate context.

Fleck and Fitzpatrick (2010) argued that the lower levels are particularly suitable for technological support such as enhancing one's memory, asking reflective questions, and allowing people to see more and see things from different perspectives. Supporting those lower levels of reflection will also make it easier to achieve the higher levels of reflection.

Fleck and Fitzpatrick's framework was used to understand the character of specific instances of reflection in this dissertation research. However, I did not use it to produce quantitative assessment of reflection. As Sumsion and Fleet (1996) pointed out, reflection is not well suited to quantitative measurement because coding reflection involves a high degree of interpretation.

2.1.6 Summary

In this section, I introduced the definitions of reflection, its key elements, and related concepts that are useful in characterizing an instance of reflection. Various theorists, in particular Dewey, Schön, Moon, Fleck and Fitzpatrick, have unpacked the activity people commonly referred to as "reflection" in different ways. Dewey (1933) emphasized the felt perplexity in one's experience as a common trigger of reflection. Building on Dewey's view of reflection as an

activity both triggered by and focused on experience, Schön (1983) developed a theoretical framework of reflection-in-action, a particular type of reflection that takes place in tandem with action, through studying professional practices. He further identified and elaborated on a number of "constants" that can constrain or facilitate reflection-in-action. Focusing on the outcome of reflection, Fleck and Fitzpatrick (2010) identified five levels of reflection a person might be able to achieve and explained how technology can support each of those levels. Finally, Moon (2013) found a common ground between different theoretical views and everyday uses of the term reflection. She called out three essential elements of reflection: a question to which there is no obvious answer, some mental processing, and a purpose or anticipated outcome.

Those theoretical perspectives, frameworks, and constructs are important to computer-supported reflection which I will introduce in the next section, because they relieve technology designers from dealing with reflection as a whole and enable them to focus on certain aspects and conditions of reflection that are amenable to technological enhancements. As described in the next section, technical research on computer-supported reflection has been focused on some of those elements identified by the theorists, e.g., providing interesting and unusual information to trigger reflection, allowing users to explore different perspectives by reflecting with others, and enhancing memory which Fleck and Fitzpatrick (2010) considered a prerequisite for higher levels of reflection. In addition, those theoretical perspectives, frameworks, and constructs are useful in evaluating technologies designed to support reflection. They allow researchers to examine the factors shaping reflection and the steps preceding reflection when reflection itself is hard to observe and measure. In short, those theories allow researchers to employ a divide and conquer strategy in advancing our understanding of computer-supported reflection.

Nonetheless, this intellectual resource has not been fully exploited to support the design of reflective technology. It is the goal of this dissertation to show how we can better understand

the design space of computer-supported reflection by having a deeper engagement with theories, in particular Schön's (1983) constants of reflection described in section 2.1.3.

2.2 Computer-supported Reflection

So far, I have introduced the definitions, styles, processes, conditions, and levels of reflection in the literature. Equipped with this understanding of reflection, I now describe and assess prior work in HCI on supporting reflective practices. I wanted to achieve three goals through reviewing this literature. The first goal was to identify major technical approaches to supporting reflection. The second goal was to learn how those approaches stimulate and/or shape reflection. The third goal was to understand the pros and cons of each approach by critically examining their study results. Reviewing this literature has allowed me to build my research on previously validated approaches, improve techniques that have shown potential, and most importantly address some areas of the design space that have yet to be explored by prior work.

Before presenting my review, I would like to describe what Fleck and Fitzpatrick (2010) and Baumer et al. (2014) have found in their respective reviews of this literature. In addition to proposing the aforementioned five-level framework of reflection, Fleck and Fitzpatrick (2010) also identified a few ways technology has been used to support reflection, in particular at the levels of *R0 Description*, *R1 Reflective Description*, and *R2 Dialogic Reflection*. Those techniques include:

- Recording knowledge and experience
- Reflective questioning
- Facilitating discussion between two people
- Providing multiple perspectives
- Showing things that are not usually available to human perception
- Allowing users to reorganize their knowledge
- Simulating environments that users can explore

My review expands and reorganizes those technical approaches to provide more details, identify opportunities for improvement, and relate them to the studies in this dissertation research.

The review conducted by Baumer et al. (2014), however, was focused on two issues in HCI research on supporting reflection. The first issue was that the term reflection was rarely defined among the 100 papers surveyed by Baumer et al. (2014). Even when reflection was defined, Baumer et al. (2014) found that the definition was usually not grounded in existing theory. The second issue was the studies reviewed by Baumer et al. (2014) rarely assessed reflection *per se*. Baumer et al. (2014) suggested two reasons. First, it was hard to assess reflection without clearly defining it in the first place. Second, reflection was often not an outcome variable that researchers needed to directly measure. Instead, it was used to explain some other outcome (e.g., performance improvement measured by Malacria et al., 2013). My review presented below largely confirms these two problems, but it also highlights recent studies that started to treat reflection as "a core technology design outcome for HCI" (Sengers, Boehner, David, & Kaye, 2005, p. 50).

2.2.1 How Can Technology Support Reflection?

Presented in detail in the rest of this chapter, my review of prior work on supporting reflection has identified several ways computer and information technology can be used to support reflection. First, through capturing, representing, and delivering interesting information, technology has been used to create opportunities for the user to experience perplexity, doubts, and surprises, which are common triggers of reflection as mentioned in section 2.1.1. In particular, interactive systems have been developed to make users aware of information that is usually invisible or hard to notice (e.g., Chetty et al., 2010). Second, researchers have developed systems that transform and display information in novel forms to allow users to see things from a different perspective. For example, the Tableau Machine system intentionally introduces ambiguity into the information presented to users in order to de-familiarize their experience (Pousman et al., 2008). Last, technology has been employed to guide users' reflection by

providing directions, connecting them with others, and embedding triggers of reflection in games. Below, I describe the specific approaches under each of these three categories. I will then discuss how my dissertation builds upon this prior work.

2.2.2 Information as Triggers of Reflection

2.2.2.1 Imperceptible Phenomena

Researchers have built systems and tools to make users aware of phenomena that are often difficult, if not impossible, for them to perceive (e.g., Chetty et al., 2010; Gaver et al., 2013; Gustafsson & Gyllenswärd, 2005; Rogers et al., 2004). Studies have shown that enhanced awareness of those background or hidden phenomena allows users to reflect on them.

A phenomenon can be hard to perceive for a number of reasons. First, the event of interest can develop slowly over a long period of time, e.g., the growth of plants. Second, the phenomenon can be hidden. This applies to the invisible work done by various types of infrastructure in our everyday lives (e.g., electricity, water, and networks). Third, the phenomenon might have an effect that is too subtle to be noticed. Researchers have used computing technologies to represent such imperceptible phenomena in *visual, acoustic, or tangible* forms to make them amenable to observation. Examples of each type of representation are described below.

The first and most common technique is visualizing the data measuring certain aspects of the invisible phenomenon. For example, Chetty et al. (2010) designed an information display called Home Watcher to show bandwidth usage by different devices in the home. It provides two views to the members of a household where it is deployed. The current view shows how much bandwidth each device is currently using, while the history view shows how much bandwidth each device used in the recent past. While the field evaluation of Home Watcher was not focused on reflection, several results from the evaluation have shown the approach's potential to support reflection. First, not only did participants learn their network usage from Home Watcher's visualization, they also learned other activities (e.g., waking up, doing homework, staying late, etc.) by combining the bandwidth visualization and their knowledge of the routines

in their homes. Second, some parents who participated in the study envisioned that they could use Home Watcher to validate or invalidate their suspicions about who had been hogging the household bandwidth.

Driven by the goal of fostering sustainable behavior, researchers have also created various styles of visualizations to make the invisible flow of energy in the home visible (Pierce, Odom, & Blevis, 2008). For example, Gustafsson and Gyllenswärd (2005) prototyped the Power Aware Cord, which is an augmented power cord that indicates how much electricity the appliance connected to it consumes in real time by showing glowing patterns on the cord itself. Although the authors cited enabling reflection on energy conception as one of the goals of designing the Power Aware Cord, its evaluation was focused on the intelligibility of the visual representations rather than reflection.

The second technique is representing imperceptible phenomena with sound. For example, Rogers et al. (2004) designed Ambient Wood, a computer-augmented outdoor learning experience in which students could explore the ecology of the woods during field trips. One of the devices in the Ambient Wood is the Ambient Horn, which can play pre-recorded, amplified, and accelerated sounds representing plant or animal processes (e.g., root uptake). Such natural phenomena would otherwise be too slow and too quiet to notice. The authors reported anecdotal evidence that listening to the Ambient Horn prompted students to reflect on the factors contributing to certain ecological processes in the woods.

The third and emerging technique is to make imperceptible phenomena not only visible but also tangible. For instance, Gaver et al. (2013) created the Indoor Weather Station to make subtle changes to the indoor climate, such as wind, temperature, and lighting changes, easier to notice. For example, the Wind Tunnel device, part of the Indoor Weather Station, uses a wind-sensor to detect indoor wind currents, which are usually too minute to make an impression. The Wind Tunnel then amplifies the detected gusts of air with a mini-electronic fan, which blows air through a miniature forest made with paper films. In the field trial of the Indoor

Weather Station, the authors found that those playful devices helped participants reflect on the inter-connectedness between their indoor and outdoor environments as well as the impact of their own movements and activities on the climate in their homes. Furthermore, participants in the field trials showed a remarkable ability to engage in open reflection which borderlines imagination. For example, the authors reported that some participants were entertaining the potential link between the changing indoor climate and "ghosts, secrets and night-time creatures" (Gaver et al., 2013, p. 3459).

To sum up, researchers have used technology to visually, acoustically, and tangibly represent imperceptible phenomena. While those studies are usually focused on raising awareness, some of them (i.e., Chetty et al., 2010; Gaver et al., 2013) also show that being aware of otherwise hidden phenomena might allow the person to relate those phenomena (e.g., bandwidth usage) with other events (e.g., children doing homework). This is an important insight because it suggests that people are willing and able to find meaning in the representations by using their own knowledge and memory. Chapter 4 returns to this insight and shows how it helps lay the foundation for reflective thought.

2.2.2.2 Past Events and Experiences

In addition to making people more aware of imperceptible processes and phenomena, HCI researchers have also proposed systems to allow users to revisit the past. According to Fleck and Fitzpatrick (2010), describing past events and experiences is often the prerequisite of reflecting on them.

Early design and technical studies in HCI have used objects, mostly digital objects, to store information to complement the user's native memory (e.g., Freeman & Fertig, 1995). Motivated by increasingly affordable and pervasive capturing devices and storage space, these so-called lifelogging applications depict a vision of "total recall" through "total capture." However, as Sellen and Whittaker (2010) critiqued, collections of digital data are not memories in themselves, though they can serve as cues to trigger autobiographical memory about past

events. Drawing on theories of autobiographical memory, Hoven and Eggen (2008) also argued that autobiographical memory is often reconstructed in the presence of memory cues rather than retrieved as facts. They explained, “Because of this reconstruction process memories change over time according to current knowledge and beliefs and no two recollections of a specific event are the same” (Hoven and Eggen, 2008, p. 434).

Research has found that the reconstruction process of memory is crucial to triggering reflection (e.g., Harper et al., 2008; Cosley, Sosik, Schultz, Peesapati, & Lee, 2012). One possible reason, according to Sutton (2014), is that when we revisit a past event, we see it from a different perspective. Below, I describe several examples to help illustrate this point.

Harper et al. (2008) conducted a study using SenseCam, a wearable camera that automatically takes pictures for later review. Unlike many other studies using SenseCam, this study was focused on how participants constructed and re-constructed memory when they were viewing the photos captured by SenseCam. As the paper’s title “The Past is a Different Place” suggested, participants re-interpreted past events when they were reviewing photos captured by SenseCam. The meaning of some past experiences was re-constructed from a perspective quite different from the one the participant had at the moment when the event occurred.

Cosley et al. (2012) reported similar findings in their study of Pensieve, a service repurposing a user’s personal social media content as memory cues. Pensieve periodically emails a randomly selected item from the user’s social media accounts to the user as a “memory trigger.” The email will also invite the user to write a response to the memory trigger. Through a 6-month public deployment of the service, the authors found that reminiscing on the events linked by those memory triggers was evaluative. In the authors’ view, evaluative reminiscing was a form of reflection because it required the participant to make sense of the content related to a past event, emotion, or thought.

While Pensieve conveniently repurposes existing content to memory cues, other systems are focused on helping users to create more useful memory cues for their future selves. For example, Kalnikaitė and Whittaker (2011) designed a system called Memory Lane which allows the user to capture digital representations of mementos, and then attach them to different rooms in a digital representation of his/her home, specific places on an electronic map, or pictures of people related to those memories. The purpose of organizing those digital mementos is to make them more accessible and expressive because studies have suggested that when compared to their physical counterparts, digital mementos are often buried and removed from everyday life (Petrelli, Whittaker, & Brockmeier, 2008; Petrelli & Whittaker, 2010). Kalnikaitė and Whittaker (2011) reported that the most evocative reflections triggered by using Memory Lane were related to people. Moreover, reflections triggered by locations and objects often led to further reflections on people.

Researchers have also experimented with rich media and alternative form factors. For example, Petrelli, Villar, Kalnikaite, Dib, and Whittaker (2010) designed Family Memory Radio (FM Radio), a digitally augmented radio that allows families to record "sonic souvenirs" from their vacations and then listen to them at a later time. The authors called FM Radio an embodied digital memento, which could take the advantages of both the physical and digital media. The evaluation of FM Radio brought up two interesting points. First, sound could be more open to reinterpretation than images because it was perceived as being less definitive and sometimes mysterious. This property appeared to allow participants to enjoy the process of reconstructing their memories. Second, FM Radio's form factor helped engender social participation in reminiscence by allowing family members to collectively interpret and reflect on the sonic souvenir they all listened to.

In summary, recent work in augmenting memory has moved away from supporting precise retrieval of facts and instead embraced the constructionist approach. The systems I described above seek to present digital data as memory cues rather than memory itself to users. The evaluations of those systems have shown that it is the cue that can trigger a reconstruction

process of memory where people reflect on past events and find meaning in them. This dissertation research adopts this approach. In particular, chapter 4 and chapter 5 describe two studies examining how activity traces captured in domestic environments might be used as memory cues to support recall and reflection.

2.2.2.3 Trends, Patterns, and Relationships

While allowing users to reminisce and reflect on particular events in the past is valuable, studies in personal informatics and persuasive technology suggest that showing users the long-term patterns of their activities can potentially trigger reflection as well, and there are two main reasons.

First, showing long-term patterns allows users to see the big picture and connect the dots. For example, Ståhl, Höök, Svensson, Taylor, and Combetto (2009) designed a sensor-based system called Affective Diary. It allows the user to see animated representations of his/her bodily movement and emotion (as indicated by the level of arousal) in the past, captured by sensors in an armband the user wears. A field study of the Affective Diary system shows that participants reflected on the patterns they saw in their diary. Even though some of the patterns were not surprising, it occurred to some participants that they never sought to explain why things were the way they were. The authors argued that their long-term engagement with Affective Diary helped them gradually understand the meaning of the representations of their physiological states and allowed them to relate those representations with past situations and events.

Second, seeing one's long-term behavioral patterns can lead to cognitive dissonance which triggers reflection (Consolvo, McDonald, & Landay, 2009). According to the Cognitive Dissonance theory (Festinger, 1962), cognitive dissonance is the discomfort experienced by an individual when he/she finds that reality is in conflict with his/her existing beliefs and ideas. When a person experiences cognitive dissonance, he/she might attempt to reduce this dissonance in order to achieve internal consistency. Consolvo et al. (2009) advocated applying the Cognitive Dissonance theory in the design of persuasive technology. They explained that

providing a user with the historical pattern of her activities is likely to encourage her to become physically more active by highlighting the discrepancy between her past behaviors and her goals.

There is some preliminary evidence showing the potential of this approach in supporting reflection. Klasnja, Consolvo, McDonald, Landay, and Pratt (2009) reported that some participants in the evaluation of UbiFit (Consolvo et al., 2008), a mobile application for promoting physical activities, were surprised when they found that they were quite inactive over the course of the last week, and then they started taking concrete measures to become more active.

The relationship between cognitive dissonance and reflection is further explored in chapter 4. The field study of the Home Trivia system provides several concrete examples illustrating how cognitive dissonance resulted from seeing discrepancies between existing beliefs and the behavioral data captured by the system can trigger reflection.

2.2.2.4 Traces of Use

HCI researchers have also utilized traces of use (Rosner, Ikemiya, Kim, & Koch, 2013), the digital history of people interacting with a shared artifact or a common space, to support a variety of activities that involve some forms of reflection.

This line of research can be traced back to the concept of computational wear proposed by Hill et al. (1992). Drawing on Schön's (1983) view that professionals set problems they need to solve through reflection-in-action, Hill et al. (1992) argued that it would be useful for the user of a document to see how other people have read and edited the document in order to discover the segments that were interesting, contentious, or stable. Specifically, they created edit wear and read wear, two instances of computational wear-based interfaces, to visualize aggregated reading and editing histories of a document on the scroll bar of the document. However, Hill et al. (1992) used reflection as a justification for the design rather than an

outcome from using the system. In fact, no user evaluation of read wear and edit wear was reported in the paper.

Nonetheless, the idea of computational wear initiated considerable interest in the HCI community to use traces of use to support specific types of interactions. This user interface technique has been applied to enhancing code intelligibility (Deline et al., 2005; Eick et al. 1992), supporting indirect collaboration between designers (Fischer, Nakakoji, & Ostwald, 1995), informing decisions in Web browsing (Bateman, Gutwin, & McCalla, 2013; Wexelblat & Maes, 1999), comparing documents (Shannon et al., 2010), and training software users (Malacria et al., 2013; Matejka et al., 2013). In those systems, traces of use often enable the so-called social navigation (Dieberger, Dourish, Höök, Resnick, & Wexelblat, 2000). Contrary to the widespread adoption of the computational wear-based approach, reflection-in-action, the approach's presumed theoretical underpinning became less and less relevant. None of these studies assessed reflection *per se*. Instead, those studies were focused on showing how the proposed systems led to improvements in users' task performance.

Recently, there has been an emerging interest in the HCI community towards using traces for more evocative, less task-centric purposes. This development has led to a handful of studies seeking to assess reflection as one of the outcomes of technology design, though the evidence of actual reflection stimulated by traces of use is still very limited.

One such system is Imprints, a handheld application that allows a museum visitor to leave a digital mark on the artifact he/she has looked at (Boehner, et al., 2005). Though the field evaluation of Imprints shows that imprints can enhance the user's awareness of other visitors' presence and thus transform a usually solitary experience into a social experience, it does not provide direct evidence of reflection, except that traces of others provoked participants' curiosity. The authors argued that this curiosity could be a potential stimulus for reflective thought.

Another system is called History Tablecloth, designed by Gaver et al. (2006) to challenge the then dominant agenda of using ubiquitous computing technologies to support narrowly defined activities in the home. Equipped with electroluminescent material and sensors, History Tablecloth creates a halo beneath any object placed on it, and the halo gradually fades away after the object gets removed. A field trial in a household shows that the History Tablecloth enabled the participants to engage in open-ended and delightful reflection on the flow of objects in the home. Gaver et al. (2006) suggested that patterns of objects on the History Tablecloth sensitized participants to their behavioral repertoire, echoing the findings of Chetty et al. (2010) described earlier.

All things considered, traces of use have shown a great potential for supporting reflection, but this potential has not been fully realized because this approach has largely been applied to task-centric domains where reflection is considered a means to an end, despite the fact that traces of use has been linked to Schön's (1983) theory on reflection from early on (e.g., Hill, et al., 1992). Driven by the third paradigm of HCI (Harrison et al., 2007), this situation is changing, though more work is clearly needed to allow us to better understand how traces of use can support reflection, especially when such traces can be captured more easily than ever thanks to advances in ubicomp technologies. This dissertation, especially the study presented in chapter 5, helps advance that understanding.

2.2.3 Display of Information that Triggers Reflection

While the research reviewed above seeks to provide several types of information that can potentially trigger reflection, a related body of work is concerned about how to effectively present these types of information to users. There are two main goals: 1) making sure the user will have enough exposure to the information that can trigger reflection, and 2) provoking reflective thought when the user is looking at this information. Below I introduce representative systems in this area of research.

2.3.3.1 Ambient Displays

Researchers have taken the "calm computing" approach (Weiser & Brown, 1996) to ensure that potentially useful information will be exposed to users without distracting or annoying them. Glance-able or ambient displays (Pousman & Stasko, 2006) are particularly well suited for this purpose. According to Pousman and Stasko (2006), an ambient display has the following properties. First, it shows information that is useful but not critical or time-sensitive. Second, users can freely choose when and how long they would want to focus their attention on the display. Third, it should be well integrated with the user's environment, both aesthetically and functionally. Fourth, it does not distract the user when the representation of information is being updated.

To support reflection, ambient displays must satisfy two seemingly competing requirements: 1) to ensure that the user will have enough exposure to the information that might trigger reflection; and 2) to not demand users' attention. To strike the best balance between these two requirements, researchers have developed techniques to achieve two general goals: 1) making sure users will routinely see it, and 2) raising users' interest in seeing it.

The make sure the user will see the information regularly, researchers have tried to put the display in a place where a routine activity occurs. There are several ways to do this. First, information can be displayed on the margin of an object. This approach is often applied to visualizing traces of interacting with an object, so users of the object can naturally notice them when the object is being used. For example, the aforementioned edit wear and read wear (Hill et al., 1992) show aggregated reading and editing traces of a document on its scroll bar. Second, information can be shown on the background of a frequently used display. For example, the UbiFit Garden system uses the wallpaper of the user's mobile phone to display its feedback on the user's physical activity (Consolvo et al., 2009). Third, an ambient display can mimic or augment everyday things to make it appropriate for co-locating with an activity the system wants the user to reflect on. For example, Holstius, Kembel, Hurst, Wan, and Forlizzi (2004) augmented a living plant to make it lean towards the recycling bin or the trash bin,

depending on which one was used more frequently. The goal was to prompt users to reflect on their recycling practices at the point of action.

Allowing users to see the display as part of their routine activities is helpful, but what if the display is so attractive that users want to look at it from time to time, and better yet reflect on what they see? Researchers have proposed several techniques to achieve that goal.

The first technique is to make the display aesthetically pleasing. For example, Redström et al. (2000) introduced Informative Art, a type of computer system that identifies itself first as an artwork and then as an information display. The approach of Informative Art goes as far as encouraging designers to take inspirations from real artwork and art styles. For example, Redström et al. (2000) described a system that visualized email traffic in real time by adapting the compositions of the Dutch artist Piet Mondrian. Informative Art seeks to become decorative elements in a space that also provide some useful information that might occasionally trigger reflection.

The second technique is to make those displays playful. This approach is closely related to Ludic Design developed by Gaver et al. (2004). Ludic Design considers users as *homo ludens*—people as playful creatures—and harnesses users' curiosity to motivate their interactions with the system. Sengers et al. (2005) suggested, "ludic design focuses on reflection and engagement through the experience of using the designed object." The aforementioned Indoor Weather Stations (Gaver, et al., 2013) represent a ludic approach to environmental HCI. Being playful provided users with a motivation to occasionally engage with it and a reason to keep it in the home.

The third technique is to intentionally represent information ambiguously to provoke users' curiosity. I describe this technique in detail below, because it is both used and improved by this dissertation research.

2.3.3.2 Ambiguous Representations

Drawing on certain styles and traditions in contemporary arts, Gaver et al. (2003) argued that ambiguity could be a useful resource for designing reflective technology because an ambiguous representation encourages people to explore its meaning and try to make sense out of it. In theory, ambiguity can support reflection, because as Dewey (1933) suggested, reflection is often triggered by perplexity.

There is an increasing number of interactive systems taking this approach, and here I describe two examples that use sensed activity traces to support reflection on home life, a topic addressed in chapter 4. The first example is the Home Health Horoscope (Gaver, Sengers, Kerridge, Kaye, & Bowers, 2007). This system seeks to give feedback to household members on the state of affairs in the home by generating daily horoscopes based on activity traces captured by sensors installed in specific areas in the home. Those sensors capture activities such as accessing the cleaning cupboard, opening the kitchen door, sitting on the love seat, etc. The Home Health Horoscope exploits the ambiguous writing style of horoscopes to allow users to make their own interpretations. The second example is Tableau Machine (Pousman & Stasko, 2006; Romero et al., 2008), an ambient display that characterizes home activity based on analyzing and aggregating overhead video feeds in the home. Tableau Machine presents "the character" of the home activities it captured in the form of abstract animations that are being updated continually.

Field tests of these two systems found that their ambiguous output did stimulate user engagement by tapping into participants' curiosity about the meanings of the output and sometimes their suspicions of the systems' true intentions. However, in both studies, users' reflection was mostly focused on relating representations shown by the systems to events in the home (sometimes mistakenly); they rarely reflected on their home life represented by the two systems. As Pousman et al. (2008) acknowledged, "While there was some evidence of TM providing a resource for reflection (described above), their descriptions of activities, events and rituals around the home were primarily factual reporting" (p. 377).

In brief, the studies described above have shown that ambiguity can be used in system design to stimulate users' interest in seeing information that can potentially trigger reflection. However, the results of those studies also indicate a gulf between reflecting on the representations shown by the system and reflecting on the actual events that are being represented. Chapter 4 in this dissertation further analyzes this issue and demonstrates that allowing users to progressively reduce ambiguity in information representations may help close this gulf.

2.2.4 Guided Reflection

While showing interesting information is one way to trigger reflection, researchers have also designed systems to provide more explicit and active guidance to support reflection. Such guidance can be provided by a system or a coach asking reflective questions, a group of people reflecting on a common topic, or a game embedding triggers for reflection in its narrative or gameplay.

2.2.4.1 Directed Reflection

As mentioned, computing systems can provide directions to guide users' process of reflection in two ways: 1) asking people to respond to reflective questions, and 2) giving guidance from a remote coach.

For example, Family Healthy Living Portal is a web-based application that allows a family to collectively reflect on their lifestyle and post ideas for change (Colineau and Paris, 2011). The application provides a template for users to brainstorm lifestyle ideas and write them down. The template includes three sections: *My lifestyle as it is now*, *What could I change or do differently*, and *Why these changes would result in a healthier lifestyle.* Furthermore, it sets personalized goals for each family in terms of the number of ideas they need to come up based on their responses to a pre-trial survey. Lastly, it allows a family to compare their progress of

reflection (i.e., the number of ideas) with other families. The field trial of the application found that all three aspects of Family Healthy Living Portal encouraged reflection.

To make reflective writing tasks effective, the prompts must be carefully designed. The participants need to perceive the prompts to be relevant and culturally appropriate. Otherwise, those prompts can backfire. For example, Cosley et al. (2012) reported that some participants were upset when they saw a prompt (i.e., a question about one's prom) associated with particular cultures and socio-economic groups they did not belong to. In addition, the authors also noted that the timing of asking the user to respond to those prompts was important and they suggested a context-aware approach to send those prompts when the user was in a mood to reminisce.

Researchers have also tried to provide users with feedback from professionals who are trained to help people reflect on a certain subject via the Internet. One such system is MAHI, a health monitoring application that allowed diabetes patients to post their blood glucose readings along with pictures of their meals and their notes to a web-based message board (Mamykina, Mynatt, Davidson, & Greenblatt, 2008). Diabetes educators can access the information and pictures posted by patients and comment on them. A field evaluation of the system found that diabetes educators coached patients to reflectively analyze their records. Through such guided reflection, some patients changed their perception of their role in diabetes management in a positive way.

2.2.4.2 Group and Peer Reflection

Research has shown that it helps stimulate reflection when there is an audience. Members of the audience can share strong or weak ties, and the relationship between the reflective individual and his/her audience seems to play a role in shaping his/her reflection.

Grimes, Bednar, Bolter, and Grinter (2008) provided an example of letting people who share a weak tie to reflect together. They created EatWell, a voice-based mobile service that aimed to

allow members of low-income African-American communities to share their experiences of trying to eat healthfully. Based on the field trial of the service, they found that EatWell encouraged reflection by providing participants with an audience who cared about the same issue and belonged to the same community. One of the participants in the study mentioned that she felt she was "on a talk show" when she was recording her stories on EatWell. She appreciated the fact that people would care to listen to her thoughts and opinions. EatWell also provided participants with the ability to listen to others' stories, and its voice-based interactions seemed to foster a sense of intimacy among local community members who were part of the trial. Another example of reflecting with strangers who share a common interest is a website called *a journey of reflection* built by Colineau, Paris, and Nepal (2013). It allows users to work in pairs on a set of reflective questions related to employment.

When the audience of reflection is the user's friends instead of strangers, it motivates sharing of thoughts in two different aspects. Procyk and Neustaedter (2014) compared the behaviors of a group of friends and the behaviors of a group of strangers playing GEMS, a location-based storytelling game. The authors reported that the friends group was motivated to share their stories and thoughts about a place when they thought others in the group would appreciate them. Some of them also felt a responsibility to share information and stories about a place because they thought no one else in the group knew that. In contrast, the strangers group had a hard time imagining who would read their stories, though they were instructed to create stories for their future generations.

It also seems important to allow the user to share with other people (even strangers) who are engaged in the same reflective practice, but not just any contacts. In this regard, Cosley et al. (2012) reported a failed attempt to roll out a social version of Pensieve, the social media-based reminiscence triggering service described in section 2.2.2.2. The social version of Pensieve allowed participants to share their responses to memory triggers with their friends via email. However, few people took advantage of this. Compared with EatWell (Grimes et al., 2008) and

GEMS (Procyk & Neustaedter, 2014), the social version of Pensieve lacked a real sense of audience in collective reflection.

Taken all together, reflecting with others is a potentially powerful way of encouraging reflective practice, but more work is needed to understand how different types of audiences and groups might facilitate reflection. To further develop this approach, chapter 4 explores how we might support members of a family to collectively reflect on their home life.

2.2.4.3 Reflection in Games

Games can be an engaging medium for reflection. Prior research has identified several ways computer-based games can stimulate reflection.

First, games can provoke reflection by simulating experiences players cannot otherwise experience in their own lives and allow them to immerse in and learn from those simulated experiences. In her book entitled *Critical Play: Radical Game Design*, Mary Flanagan (2009) described *Darfur Is Dying*, a simulation-based role-playing game, which allows the player to experience the traumatic life of a displaced Darfurian refugee and try to keep the game character alive in a dangerous environment. The game succeeded as a call for awareness and action by intentionally causing discomfort and frustration in the simulated experience. In the same vein, Benford et al. (2004) introduced three games/installations that were designed to allow players to experience and reflect on extraordinary situations such as warfare, seeing a city from the perspective of a runner, and collaborating with strangers on the street.

Second, games can indirectly support reflection by encouraging storytelling. Researchers have found that digital storytelling can help people reflect on their practice in a community setting (Freidus & Hlubinka, 2002). As a location-based storytelling game, GEMS gets players started by sending them directives, which are short prompts or questions that ask players to formulate personal stories related to a place (Procyk & Neustaedter, 2014). For example, a directive could ask: *Is there a place you go with your friends? What draws you there?* Those directives also

serve as short-term game objectives or quests. Each directive has a lifespan of two days to give players a sense of urgency.

Third, games can stimulate reflection by allowing players to evaluate their existing understandings through trial and error. Kiili (2007) called this Problem-based Gaming (PBG). It was developed in the field of education to support Problem-based Learning (PBL), "the learning that results from the process of working towards the understanding and resolution of a problem" (Barrows & Tamblyn, 1980, p. 1). PBG motivates learners to engage in PBL by providing feedback, encouraging reflection, and facilitating collaboration.

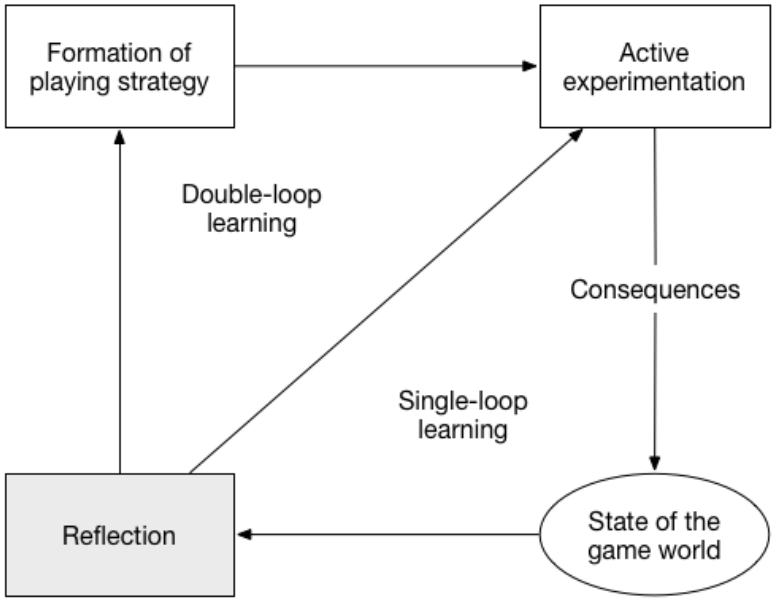

Figure 1: The Model of Problem-based Gaming Developed by Kiili (2007)

Kiili (2007) proposed a model of PBG (see Figure 1). This model describes a cyclic process of solving a meaningful problem presented by the game. The problem-solving cycle usually starts from forming a playing strategy based on the player's prior knowledge. By following this strategy, the player makes decisions and moves to impact the state of the game world. The player will then observe the outcome and reflect on the strategy he/she has been following. Reflection at this stage can lead to three outcomes. First, it can confirm that the player is on the right track and he/she should continue following the current strategy. Second, it could suggest

small adjustments to the player's tactics but not the overall strategy. These two outcomes are classified single-loop learning in the model, while the third outcome, formation of a new strategy, amounts to double-loop learning because it signals a deeper level of understanding obtained through reflection. Kiili (2007) provided preliminary validation of the PBG model by observing and interviewing players of a business simulation game called Realgame (Lainema, 2004).

Though reflection in problem-based gaming may take place either solitarily or collaboratively (Kiili, 2007), collaborative play has two main learning benefits. First, players can share their knowledge and thus facilitate learning (Kiili, 2007; Hummel et al., 2011). Second, teamwork encourages players to verbalize their thought process (van der Meij, Albers, & Leemkuil, 2011).

All in all, the research described above has shown that games can support reflection by immersing users in extraordinary experiences, facilitating users to tell stories, and stimulating users to think about their knowledge and strategies in a problem-solving process. In particular, the Problem-based Gaming approach (Kiili, 2007) has shown a great potential to seamlessly integrate reflection and engagement, but applications of this approach have been mostly confined to educational contexts. To make this approach more useful, it is necessary to investigate how it might be applied to a variety of other settings. As an example, chapter 4 describes a system that combines PBG and activity traces in supporting reflection on home life.

2.3 Situating this Dissertation in the Literature

In this chapter, I introduced theoretical views, conditions, and levels of reflection, described studies that use computer and information technology to support reflection in a variety of domains, and examined the design and technical approaches those studies take. To conclude this chapter, I would like to explain how this dissertation research is situated in the literature reviewed above.

To begin with, this dissertation builds on existing research that uses computer and information technology to support reflection. For example, the design of the Home Trivia system presented in chapter 4 follows and further develops a number of technical insights from prior work:

- Representing usually hard to perceive activity (in this particular case, how much and when an electronic device is used in the home) in an interesting visual format can help users reflect on it.
- Cognitive dissonance can trigger reflection because it confronts the user with discrepancies between their existing beliefs or ideas and the reality.
- Games can be an effective medium to make reflection part of an engaging and fun experience.

Moreover, this dissertation also addresses several gaps and shortcomings I identified in this literature. First, ambiguous representations seem to be effective in provoking curiosity, but reflection is often limited to understanding how representations are related to events as prior studies have shown (Gaver et al., 2007; Pousman et al., 2008). Second, Problem-based Gaming (Kiili, 2007) has shown great potential in educational contexts, but it has not been adapted to support reflection in everyday settings. Third, the character of reflection provoked by traces of use is understudied. There is also no study examining how the age of traces might impact reflection they provoke. Research questions 2, 3, and 4 described in chapter 1.2 are motivated by those gaps, respectively. In the rest of this dissertation, the first two issues are addressed in chapter 4, which describes the design and evaluation of the Home Trivia system, and the remaining issue is addressed in chapter 5, which looks into potential long-term uses of activity traces captured in places.

Last, I believe there is an untapped opportunity to guide technology design with the constants of reflection in Schön's (1983) theoretical framework. This opportunity provides motivation for the overarching research question I put forth in chapter 1.2. All the following three chapters answer this question from different aspects. For example, chapter 3 describes Social Overlays, a browser extension that enables users to reflect on a website's usability problems as they use it.

The design of the extension addresses a number of constants in Schön's (1983) theory including the *media* on which reflection is worked out, the *role frame* the individual sets for him/herself in the situation, and the *appreciative system* the individual adopts to evaluate the outcome of his/her reflection. While the majority of prior work is focused on triggering reflection, engaging those theoretical constructs allows this dissertation to put an equal weight on shaping reflection, which is important to foster rich reflective experiences.

CHAPTER 3

Reflective Use: Collectively Making Websites More Usable with Social Overlays[1]

3.1 Introduction

Many small organizations' websites need usability improvement. For organizations like charities, museums, and schools, their constraints on technical resources and usability expertise keep them from sufficiently making their websites easy to use. For example:

- TriCounty GoodDeeds is rolling out its website. But its web designer and Webmaster are volunteers, and there are no spare resources for usability tests. How can they create a web site that is usable and helpful for the charity's constituents?
- The Tree City municipal government's financial services group created a new website for travel reimbursement. It is unusable, since it is full of jargon and appears to be meant for accounting professionals. How can staff in departments help the financial group with their usability?
- The History Department at the University of the Midwest recently created a new website using a content management system. The department has a well-meaning web

[1] The work presented in this chapter was principally conducted by me, but benefited by contributions from Mark S. Ackerman, Mark W. Newman, and Gaurav Paruthi. An earlier version of this chapter (Dong et al., 2013) was published at the INTERACT 2013 conference.

developer, who is an ex–computer science major. The students have to use the website to get information for courses, requirements, and school events, though they often feel the developer doesn't know how they actually use the website. How can the department create a usable, useful website?

The common problem faced by those organizations is that they cannot afford professional usability services. At a high level, there are two standard approaches to evaluating usability on websites: usability testing and expert evaluation (Nielsen, 1993). While these approaches have many variants, they all share the characteristic that usability experts play a critical role in determining the existence and nature of usability problems. An alternative approach is to solicit problem reports from users. Post–deployment usability approaches focus on collecting feedback from users in the field at the time the problem is encountered (Hartson & Castillo, 1998; Nichols, McKay, & Twidale, 2003). However Chilana, Ko, Wobbrock, Grossman, and Fitzmaurice (2011) found that few usability practitioners analyze or respond to such feedback. Participatory techniques have been proposed for involving users in usability evaluation during the formative stages of system development as well (Bias, 1994; Muller, Matheson, Page, & Gallup, 1998), though these techniques still depend on the participation of usability experts and product developers. In this chapter, we investigate a novel approach to creating usable interactive systems: enabling community members themselves to collectively improve the system as part of their everyday interactions with it. Our approach is aimed primarily at websites built to serve small–to–medium sized organizations or communities—precisely the sites that often do not have the resources to hire usability professionals or implement frequent changes to a site. Our question, then, is how can we leverage the user community of a website to uncover and service usability problems?

We have designed and built a system called Social Overlays (SO). By harnessing the "wisdom of the crowd," SO allows members of a website's community to reflect on the issues they encounter and collectively address those issues, without the need for formal usability methods or professional usability expertise. Using SO, community members can create "overlays," which

effectively rewrite particular page elements (e.g., text, links, and tooltips), thereby improving the site's usability for subsequent visitors. SO also provides lightweight mechanisms for different community members to nominate potential problems, propose alternate fixes for the identified problems, and vote for the best solution. In short, SO harnesses the diversity of experience and ideas within a community to "crowd source" usability.

While, at a technical level, SO could be deployed on a wide range of sites, our initial focus is on a type of site that is particularly in need of and well-suited to the SO approach. Those are the sites that serve communities or organizations with a few dozen to several hundred members. While such communities are the ones most in need of a low-cost approach to usability improvement, we also expect them to be relatively cohesive and possessing members who have sufficient common ground in vocabulary, practices, and expectations (McGrath & Spear, 1991). In these communities, members often know one another, creating the grounds for altruism and self–policing (Sproull, Kiesler, & Kiesler, 1992). In a word, those communities possess the desirable social properties that would allow the SO approach to be adopted most effectively.

To examine the viability of the SO approach, we conducted a study with thirteen members of a medium–sized academic community. We found that they were able to find and repair a large number of usability problems on the community's website. Moreover, compared with usability experts whom we asked to evaluate the same site and an external usability team who conducted a conventional usability test, the community members reported more problems. The problems they found differed in systematic but useful ways from those found using standard usability methods. Thus, our study results argue for the feasibility of the SO approach, at least for small-to-medium sized communities and organizations.

The contribution of this chapter, then, is twofold. First, we present a novel approach to collectively improving website usability by members of the site's community through *reflective use*, a process of identifying problems and suggesting solutions as part of normal use. Second,

we provide evidence that our approach leads to usability improvements for important types of communities that are comparable to standard but more costly methods such as expert inspection and usability testing. In addition, we discuss how this approach can be extended for larger or less socially cohesive communities and how this approach is situated in the literature.

3.2 System Design and Implementation

3.2.1 Fostering Reflective Use

The goal of Social Overlays (SO) is to allow users of a website to identify and repair usability problems during the course of their regular use of the site. To achieve this goal, SO must foster a manner of use we named *reflective use*. The basic idea is that when an individual experiences difficulty in using a computing system, he/she reflects on the difficulty with a purpose of understanding the cause of the problem and suggesting remedies. Reflective use can also be viewed as a kind of reflection-in-action (Schön, 1983), the action here being interactions with the system. While reflective use bears some similarity to the principles of Meta-design (Fischer & Giaccardi, 2006), it explicitly supports reflection-in-action as the mechanism to involve users in the evolution of a deployed interactive system.

One of our strategies to foster reflective use is to change the way users of a website frame their roles. As Schön (1983) suggested, a person's role frame can have a considerable influence over how he/she frames the problem, whether and how he/she reflects on it, and what knowledge he/she considers relevant. In our case, we wanted SO to help users reframe their usually passive role of "users" to more active roles such as co-maintainers, co-designers, and co-editors of the site they use. We hypothesized that when users switched to those roles, they would perceive a bigger responsibility as well as bigger influence over the website's usability and content.

What would an ideal instance of reflective use be like? Based on Dewey's classic five-step model of reflective thinking (Dewey, 1933), we expect these steps: 1) encountering a difficulty

or discrepancy in accomplishing a task; 2) examining the relevant webpages and identifying the cause of the difficulty; 3) suggesting explanations or possible solutions; 4) describing or illustrating the idea to address the problem; 5) verifying the suggested solution.

To reframe the user's role and support the above steps in reflective use, we identified, through pre-studies, an initial set of requirements:

- To support Step 1 and 2, SO must be readily available at the time when the user experiences a difficulty and on the page where the user looks for the source of the problem. That is the reason we built SO as a browser extension.
- To support Step 4, SO must provide easy-to-use tools to allow a non-technical user to experiment and express his ideas in a concrete way. That is what overlays do. We describe them later in this section.
- To support Step 5, SO must allow the user to see and try out the improvement she suggested immediately.
- In addition to the previous requirement, members of the user community should be able to verify tentative solutions proposed by other members.
- SO should allow flexibility in role framing; therefore when a user does not know how to repair a problem with SO, he can fall back to a less involved role and report the issue instead.

In the rest of this section, we first walk through a scenario that illustrates reflective use enabled by SO, and then describe SO's main features.

3.2.2 A Scenario of Reflective Use

A) Select the Text tool B) Select a target element C) Edit the label

Figure 2: Social Overlays has a three-step process of making modifications to an existing web page: a) select a modification type, b) select a page element, and c) specify the modification. For example, the user in this scenario renames a mislabeled button from “Apply” to “Search.”

Chelsea, a master’s student in the aforementioned history department, is looking up a class she is considering for next semester. On the page that allows her to search for courses, she finds herself annoyed by the weirdly labeled “Apply” button next to the course search field. She wonders, “Why couldn’t they just put the word ‘Search’ on that search button?” Coming from a literature background, Chelsea often jokes that she is a “language snob.”

Fortunately, Chelsea has a new browser extension called Social Overlays that allows her to revise the button’s label. She does so, and sees the change immediately. In more detail, Chelsea chooses the Text tool in the SO panel (see Figure 2a). Now when her mouse hovers over a page element, it is highlighted with an orange dashed outline (see Figure 2b). She clicks the “Apply” button that annoyed her on the page to invoke SO’s element editing dialog box, where she enters the text string “Search” to change the button’s label (see Figure 2c). Clicking the “Save” button instantly applies the change for her.

Within an hour, Chelsea finds that her overlay (the alternate label for the button) has received thumbs-up from 5 other SO users in her department. After several days, her department’s IT person notified her that the website has implemented her change permanently, because of strong user preference shown on SO.

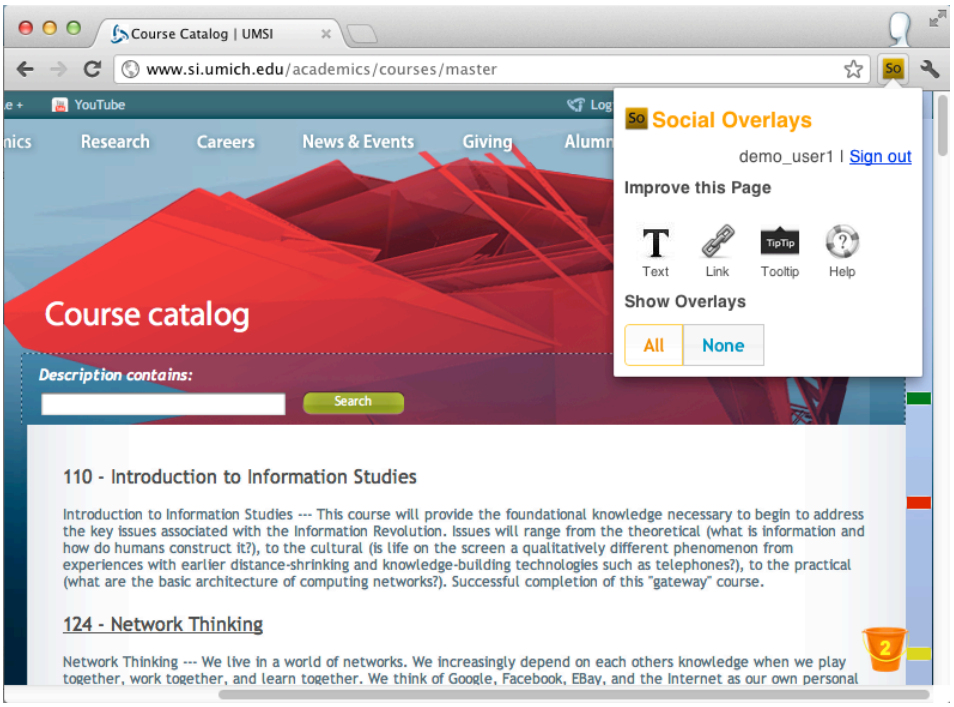

Figure 3: A user can access the Social Overlays browser extension by clicking its icon on the browser's toolbar. The icons from left to right represent the Text tool, the Link tool, Tooltip tool, and the Help button. The green, red, and yellow indicators on the right margin are used to indicate overlays, help requests, and both overlays and requests, respectively, made on a page element on the same horizontal line. The bucket at the right–bottom corner is a repository for page–wide issues.

3.2.3 Overlays

In the above scenario, Chelsea repairs an unconventionally labeled button by creating an overlay using the Text tool provided by SO. Overlays are user–generated in–place modifications to existing web page elements. There are three types of overlays supported in the current version of SO: *Text*, *Links*, and *Tooltips*. Each type of overlay can be created and edited using tools provided by the SO extension panel (see Figure 3).

As the scenario above has shown, the *Text* tool allows the user to revise inaccurate or unintuitive terms or language used on buttons, links, or headers. The *Link* tool allows the user to add a link to any element of a web page by entering a target URL. This can be useful for creating navigation shortcuts or pointing to additional information that might be helpful for a

given task. In addition, the *Link* tool allows the user to edit the URL of a broken or outdated hyperlink. The *Tooltip* tool allows users to create or rewrite tooltips (i.e., short messages that appear when an element is hovered over) that are attached to any page element. This tool allows a user to explain or clarify what an element does (or does not do) and how to make use of a feature on the site to his/her fellow users.

The *Link* tool and the *Tooltip* tool follow the same workflow as the Text tool to make overlays. A user can combine different types of overlays if needed. For example, the user can modify the text of a hyperlink, and also install a tooltip for it.

3.2.4 Help Requests

Although the changes that SO currently supports are relatively simple, some users might not feel confident enough to make a change. Additionally, some users might want a more sophisticated change that SO does not yet support. In such situations, a user can request help from the community or the Webmaster using the Help button (see Figure 3). The Help button allows the user to attach a message to the element that needs to be fixed or improved through a process similar to editing a button's label. If the request is not related to a particular element, the user has the option to submit a general request for the page by selecting the "bucket" at the bottom–right corner.

3.2.5 Indicators

When a page loads, SO shows page modifications made by the user community on the current page. A modified element will flash for half a second to help a user distinguish it from the original element, unless a particular overlay has been previously approved by the current user or by a certain number of other community members. Inspired by Edit Wear (Hill et al., 1992), SO uses the side margin of the web browser to provide lightweight visual indicators of prior community activity on the current page (see Figure 3). Each indicator corresponds to an element that has community–generated overlays or requests, and they are visually aligned on

the same line. When the user hovers over an indicator, its associated element will be highlighted. The color of the indicator shows the status of the element. A green indicator signals that there are existing overlays for the element, while a red indicator signals that there are active requests to fix this element. If an element has both overlays and unresolved requests, a yellow indicator is displayed.

If the user wants to see the original version of the element, clicking on the indicator will toggle between the original version and the community–enhanced version. He can also toggle between the original page and the community–enhanced page using the "Show Overlays" switch on the SO panel.

3.2.6 Selection Rules

When multiple users have defined overlays for an element, one of them must be chosen to display. We implemented a voting mechanism that allows each user to indicate whether an overlay works for him or not. The most approved overlay for an element is automatically displayed unless the current user has approved a different one. In addition, if an overlay's number of votes reaches a community–specific threshold, it will no longer flash to draw the user's attention when the page loads, since it is likely to be working for her as well.

3.2.7 Implementation Details

We implemented SO as an extension for the Chrome web browser[2] that is coupled to a server–side application. Every time the user visits a new web page, the SO extension injects a set of JavaScript files into the current page to access and manipulate the page's HTML Document Object Model (DOM). With the full control of the target page's DOM, the SO extension enables a set of augmented capabilities within the browser, allowing the user to identify usability problems, suggest localized changes, or make quick modifications to the current page. The SO

[2] What are extensions? http://developer.chrome.com/extensions/

extension sends the changes made by the user to the SO server's repository of overlays. Upon a subsequent page load, the SO extension retrieves the overlays and requests made by all the community members associated with the current page from the server and applies these changes by modifying the DOM of the rendered web page.

This implementation allows us to gain complete control over the rendering of each web page. It also allows easy porting to extensions for other browsers or a bookmarklet-based application.

3.3 Study Design, Site, and Data Collection

After creating Social Overlays, we wanted to know whether it was a feasible approach. To evaluate the feasibility of Social Overlays, we conducted a three-phase study. In the first phase, we determined whether community members could use SO to identify and repair usability problems. We learned that people could use SO effectively, but we could not tell how good SO's results were compared to those generated by standard usability methods. Thus, in the next two phases we compared SO to two standard usability methods: expert inspection and usability testing. The results of all three phases show that SO is a feasible approach to website usability.

3.3.1 SO Evaluation

First, we needed to know whether community members without training in usability could identify and repair usability deficiencies on their website using SO. Therefore, in the initial phase of our study (which we will call the "SO evaluation"), we asked 13 information science students, none of whom had any formal usability education or experience, to use SO in the process of completing four tasks on the website of their school (and ours), the University of Michigan School of Information (UMSI).

We did not choose the website and users as a matter of convenience. UMSI's website had been recently overhauled and had many flaws and problems, thus providing a good testbed. In

addition, by using UMSI and its users, we could emulate website users coming to the webpages they use everyday and finding problems based on their normal tasks. Moreover, UMSI is an organization similar to those foreseen as our target communities. It consists of approximately 400 people, including students, staff, and faculty, and is reasonably cohesive socially.

We selected four common information–seeking tasks (see Appendix A) and asked participants to carry out the tasks, using SO to identify and, if possible, repair any issues they encountered as they went along. Each task had known usability issues associated with the website. While the four tasks selected covered only a small subset of the site's possible interactions, they were enough to observe the community process of discovering, noting, fixing and voting on changes to usability problems within a tractable timeframe. We anticipate that, if SO were deployed over a longer time period, a larger number of community members would visit many more pages, ultimately covering all of the most common interaction paths.

To emulate people coming to a web site over time, we ran our participants consecutively. Thus, the overlays (UI modifications) and requests made by a participant were available to all participants after him/her. Participants were first given a demonstration of using SO to fix four example usability problems, and then they were instructed to identify usability problems while solving the four tasks. The participants were asked to state their ideal solution to a problem, and then solve the issue using SO. If a problem could not be repaired by SO's Text, Link, and Tooltip tools, the participant had the option of submitting a request in SO or not doing anything. Each session lasted about an hour, and each participant received a $10 coffee shop gift card.

3.3.2 Expert Inspection and Usability Test

As mentioned, to address whether SO worked as well as standard usability methods, we conducted two additional evaluations. In the second phase (which we will term the "expert inspection"), we asked four usability specialists with at least four years of professional experience to conduct an expert walkthrough (as described in Oppermann & Reiterer, 1997) of

the same four tasks that were used in the SO evaluation. The experts were given the same demonstration of SO in the beginning of each session. They were asked to identify as many problems as they could while walking through the four tasks, and envision how SO could be used for implementing their suggested solutions. Each expert was compensated $50 for participating an hour-long session.

In the third and final phase (the usability test), we commissioned a team of external usability evaluators to conduct a conventional lab-based usability test on the UMSI site, and asked them to report the problems they found along with recommendations to address those problems. The usability team consisted of two graduate students with formal training in usability testing and one usability professional with formal training and three years of professional experience.

The usability test followed the standard protocol described in Rubin and Chisnell's widely-used textbook (Rubin & Chisnell, 2008), which consists of pre–test and post–test questionnaires, task observation, and debriefing. Eight additional UMSI students participated in the test and tackled the same four tasks used in the SO evaluation and expert inspection. Each session in the usability test lasted about an hour and each participant received $20.

3.4 Evaluation Results

In this section, we answer the following questions:

- Within our evaluation study, could community members use SO to report a substantial number of usability problems on their website?
- In addition to identifying problems, were community members able to use SO to repair at least some of them in a helpful way?
- How well did the SO approach work, in comparison with expert inspection and usability testing?
- How did community members reflect on problems they encountered when they were trying to accomplish the tasks?

- How did community members collaborate informally in using SO to improve their site and benefit from one another's efforts?

In short, is the SO approach likely to be viable?

3.4.1 Community–based Usability Improvements

The results of our evaluation show that community members without training in usability can identify a large quantity of usability deficiencies on their website, at least in this community.

In our data analysis, we tallied all problems for which the SO evaluation participants either made an overlay or submitted a help request. We then manually verified these issues on the UMSI website, confirming the existence of identified problems and eliminating duplicates. As a group, they documented 47 unique problems in the process of solving the 4 evaluation tasks. These included issues that could and could not be fixed with SO, but excluded issues that were verbally reported only as well as issues that were similar to those used as examples in the SO demo. In the rest of this subsection, we describe the problems identified by community members in the SO evaluation, and how they as a collective addressed those problems.

3.4.1.1 Types and Characteristics of Overlays

Using the Text, Link, and Tooltip tools provided by SO, the participants in the SO evaluation made 50 overlays (i.e. page modifications) to address 27 (57.4%) of the total 47 problems they documented. Among the 50 overlays, 10 were alternative text or labels, 11 were hyperlinks attached to existing elements, and 29 were tooltips.

As expected, the Text tool was often used to correct or clarify a link's label. For example, P3 changed a link's label from "Course schedule" to "Course schedule by term," as she thought people might expect the linked schedule to be organized by week. Other uses of the Text tool included replacing an unfamiliar term, correcting typos, and appending a commonly-used acronym.

The Link tool was generally used to shorten navigational paths. For example, five different participants linked 5 static course titles on a degree requirement page to their respective course information pages after they found it took too many clicks to check course information from the requirement page.

Usage of the Tooltip tool was more varied and interesting. Most of the tooltips were added to links in order to help users decide whether or not to click on them. First, tooltips were created for a link to hint what information could be expected in the linked page. For example, P7 attached the following tooltip to the "guest speakers" link on the Media page: "job candidate talks are accessible through this link." Second, tooltips were used to clarify community-specific jargon. For example, P3 added the following tooltip to explain "faculty guest lectures" as "another way of saying 'job talks'." Lastly, P1 and P10 used tooltips to give specific directions to aid navigation. Figure 4 shows a tooltip P10 created to direct users to other course schedule viewing options that were hard to find due to the poor information architecture.

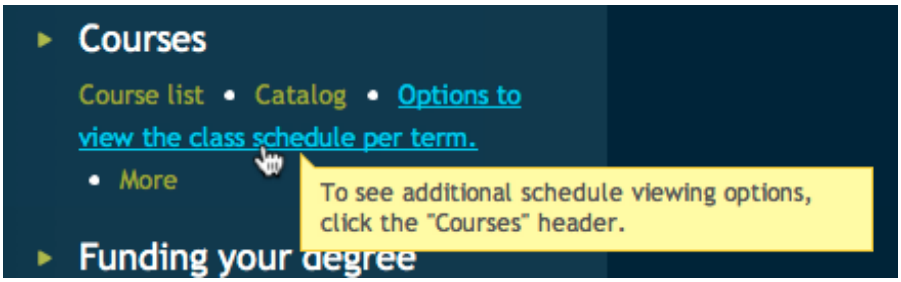

Figure 4: P10 added a tooltip to indicate that there are other options to view the class schedule (e.g. by week) on the page linked to the "Courses" header.

3.4.1.2 Help Requests

Though the remaining 20 problems were not "overlaid" with page modifications, they were identified via 33 help requests from the SO evaluation participants. When did participants choose to submit a request rather than create an overlay? First, requests were submitted when the issue fell out of the scope of tools like SO. There were 10 issues related to backend

capability, missing content, or missing features. Second, among the remaining 10 problems, 3 of them could possibly be repaired with the current version of SO, while the other 7 issues could potentially become repairable using an improved version of SO outlined in the Discussion section.

We also examined those requests concerning quality, placements on the page, and intended audiences. First, close to 90% of help requests included specific recommendations for improving the website, which suggests that participants generally had pretty clear ideas about how the problems they identified could be resolved.

Second, participants appear to be able to find an appropriate element to associate their requests to. Among the 33 requests submitted, 21 requests were attached to a specific page element, while 12 went into the "bucket" as page–wide issues or general comments. Most requests were attached to an appropriate element that helped us understand what the issues were.

Finally, many requests appeared to be added in the hope that the webmaster would fix them. However, there were also 4 requests intended to go to other community members, asking whether a change was accurate or dividing up the work of making a series of similar changes.

3.4.1.3 Quality of Community–Generated Usability Enhancements

Did the participants in the SO evaluation make helpful changes? Our analysis suggests that at least some user-generated overlays made subsequent participants more efficient in solving tasks. For example, one of these helpful overlays was P1's tooltip added to the "Guest speaker series" link on the "Events and News" page, as Figure 5 shows. The tooltip explained what was in the linked page, which was linked to the faculty candidate talks that participants were asked to find in Task 1. The mouse click counts in Figure 6 shows that Task 1 became substantially easier after P1 created that tooltip.

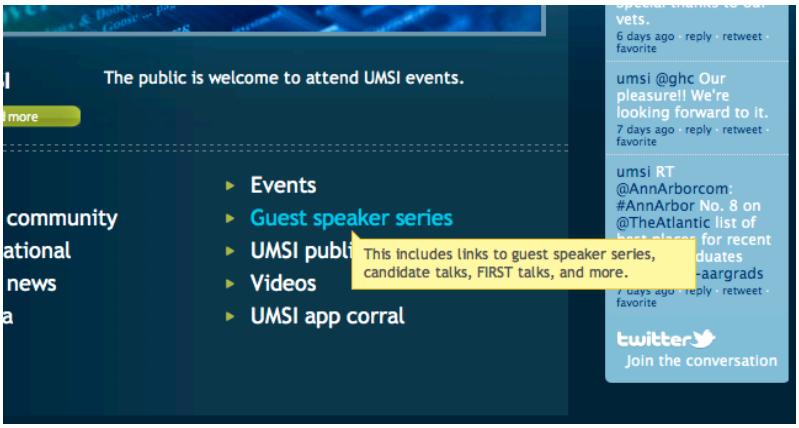

Figure 5: P1 added a tooltip to the "Guest speaker series" link to indicate that users can find faculty candidate talks on the linked page. This tooltip significantly reduced the number of clicks taken by subsequent participants once they reached this page.

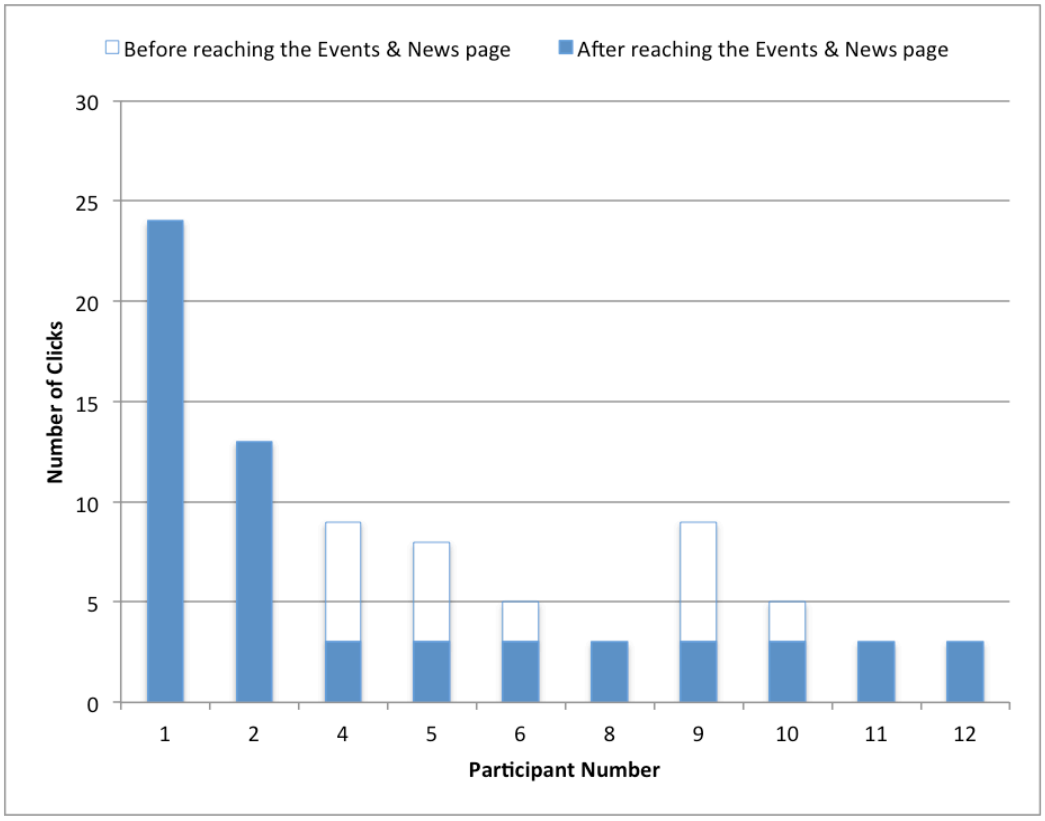

Figure 6: The number of mouse clicks users made decreased dramatically after P1 added a tooltip to clarify a critical link on the Events & News page. Participants who did not take this route were omitted from the figure.

The participants made helpful overlays to simplify other tasks as well. For example, after completing task 3, P7 linked a course title to a page that provided additional information about the course, and then P12 came across it and said, “So someone added a link. Oh man, it doesn’t tell me if it has PEP credits or not. So someone helpfully probably put this link in. [Clicking the link]. That was helpful, that was totally helpful.”

However, not all overlays were well crafted. For example, there were tooltips added to clarify the difference between the course list and the course catalog, but apparently these tooltips still lacked detail that would help P12 pick one course page over another. Although the quality of the user–generated usability enhancements varied, they rarely made the website harder to use. In summary, we found that Social Overlays could lead to a substantially improved website. However, this improvement was not uniform, and much of the improvement showed satisficing behavior.

3.4.2 Differences between Social Overlays and Standard Usability Methods

To assess and contextualize the problems identified by participants in the SO evaluation, we first compare them with the results of the expert inspection and then with those of the usability test. Specifically, we went through the list of issues reported in the SO evaluation and checked whether each of them was covered by either the expert inspection or the usability test.

To our surprise, participants in the SO evaluation documented 52% more problems than the 31 problems reported by the expert inspectors. Only 12 out of the 47 problems documented in the SO evaluation were also identified by the experts (see Figure 7). How could the participants in the SO evaluation find these 35 additional problems? As members of the community, they appear to have advantages in three aspects, based on our analysis.

First, the community members in the SO evaluation leveraged their lived experiences in the organization during problem identification. For example, P3 pointed out that the Tracking and Planning Sheet, a useful PDF file that she could print out and use as a resource in completing task 4, was buried too deep in the site. She was aware of this problem because of her prior experience in planning courses as a master's student at UMSI.

Second, community members uncovered similar problems that occurred in different places in the website, since as a whole, they were exposed to more pages and explored different paths than the group of experts.

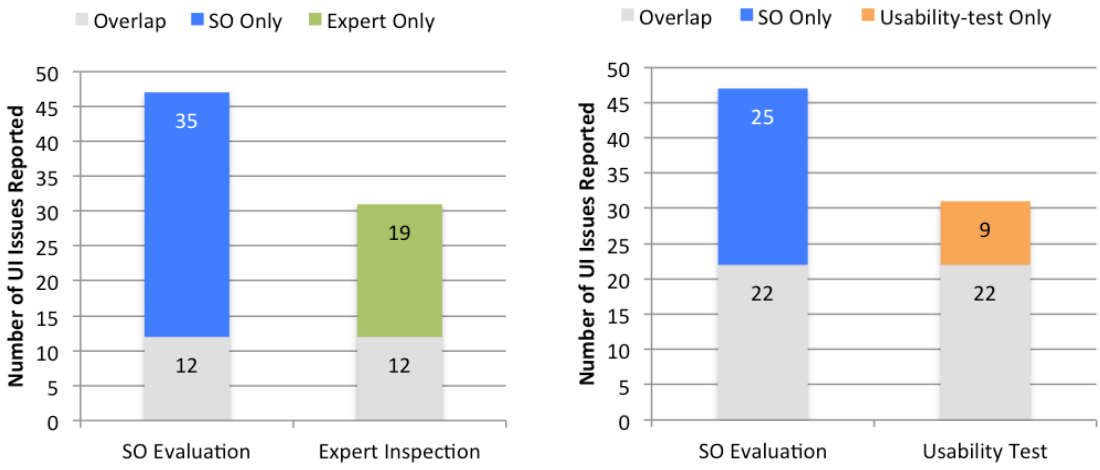

Figure 7: The above bar charts show that community members using Social Overlays reported not only more but also different usability issues than the expert inspectors and the usability testing team. We describe those differences in section 4.2.

Third, the community members were able to project the needs and preferences of their sub–communities. For example, two masters' students, P4 and P11, believed that other students would want to find student club events in the school's official Events page.

Nevertheless, the SO evaluation participants did not identify 19 problems that were found in the expert inspection. It appears that the experts were able to spot these additional issues by following general principles and heuristics. For example, the experts were sensitive to inconsistencies on the website such as showing Prof. A's profile on the same page of a course

taught by Prof. B. The experts also seemed to evaluate the site following best practices in usability. For example, E1, E2, and E3 mentioned that the website failed to visually separate groups of content on several pages.

Next, we compare the results of the SO evaluation with those of the usability test. The usability testing team reported 31 problems, some of which were broad statements and covered multiple narrower problems documented by the participants in the SO evaluation. In total, the usability test covered 22 of the 47 problems documented by the participants in the SO evaluation (see Figure 7), representing a larger overlap than that between the SO evaluation and the expert inspection. This increased similarity is not surprising, since usability testing could also access community members' lived experience and local knowledge about the site.

But how did the participants in the SO evaluation report 25 problems that were not found by the usability testing team? First, participants showed empathy with their peers in the UMSI community, pointing out 12 issues that did not prevent themselves from solving tasks but that they believed could be frustrating or confusing to less experienced peers. For example, P3 found it a potential problem that the acronym "PEP" was not linked to its full description page, though she already knew what PEP stood for ("Practical Engagement Program"). Second, participants in the SO evaluation pointed out 7 more issues related to missing information or features that they expected to see on the site.

In short, we found that community members reported more problems compared with usability experts and the external usability testing team, and that their reported problems differed in systematic but useful ways from the results generated by the expert inspection and the usability test.

3.4.3 Community Processes in SO

We also wanted to assess whether SO would show preliminary evidence of community activity. The most important community activity, as mentioned in section 3.4.1, was getting assistance

from the webpage improvements made by other users. We also observed community members giving feedback on the overlays made by others. Six of our participants used the voting feature of SO, and they gave 15 thumbs–up and 6 thumbs–down to overlays made by prior participants.

We did not observe conflicting votes on any of these changes. Other users verbally commented on the helpfulness of other users' overlays, but they did not click the voting button in SO. Four of the 6 thumbs–down were given to point out errors made by P8 and P9, while the other 2 thumbs–down were cast by P7 and P9 when they disliked existing overlays and sought to replace them with one of their own.

We also observed some evidence of social dysfunctionalities that might become more critical in larger communities or with more use. P4 showed self-serving tendencies, declaring, "I would make that a link, but it would be motivated by my convenience and not out of altruism for other users." Another participant did not like all of the changes, but did not revert or modify those changes. (This might also be tacit approval of the change's sufficiency, however.) Additionally, participants did not vote as much as we hoped. We will return to these issues in the Discussion section.

3.4.4 Subjective Perception of the Utility of SO

Participants in the SO evaluation commented on what aspects of SO they found particularly helpful. First of all, participants liked the ability to immediately see the change they made using SO. Many of them were delightedly surprised when they saw problems repaired instantly. Second, participants liked that SO provides peripheral awareness of community activities through the indicators on the side margin (see Figure 3), as P5 mentioned, "I really like the scroll bar [indicators] that change colors. That's the first thing I looked to, besides the blinking." Third, participants appreciated that the changes they made were shared with other community members. P3 enthusiastically commented, "It can only be in the long term a very big asset to the community, especially the social element ... where people vote up and down changes."

In summary, the above results of the SO evaluation and our comparisons with expert inspection and usability test show that:

1. With Social Overlays, community users identified a substantial number of problems as they interacted with the site. They were able to repair many of them by creating overlays helpful to others and address the rest by submitting constructive requests.
2. With Social Overlays, community users uncovered problems that existed along multiple paths of browsing and brought to the problem identification and solving process their lived experience and ideas that only members of the community would have.
3. With Social Overlays, community users seemed to take on a more active role in reporting UI problems than the participants in the usability test.

Our findings argue that Social Overlays is useful and feasible for communities, as least those similar to UMSI in size and cohesiveness, to collectively identify and address usability problems on their website. Moreover, the results of using SO were comparable to standard methods that are more expensive, such as expert inspection and usability testing, though each of the three approaches showed different strengths and priorities in our study.

3.5 Discussion

To summarize, this chapter:

- Presented a new system called Social Overlays that embodies the approach of *reflective use* and demonstrated its technical feasibility.
- Demonstrated the usefulness of drawing on the idea of role frame, a construct in Schön's frame, in developing and evaluating the reflective use approach.
- Provided an evaluation that showed that Social Overlays and the approach it enables are useful and feasible for an important set of communities and websites.

3.5.1 Reflective Use with Social Overlays

As described in the previous section, we found that ordinary members of a website's user community could engage in reflective use with the tools provided by SO. Most of the time, participants were able to characterize and explain the nature of the problems they experienced, suggest ways to make improvements, and create useful overlays for themselves and participants who came later.

Reflection was, in our opinion, the main reason that participants in the SO evaluation identified problems that were not found in the expert inspection or usability tests. We have mentioned some of those instances of reflection in section 3.4. In those instances, the reflective user considered the issues he/she ran into or noticed in the larger social and institutional context of the site in several ways. First, some participants tapped into their lived experiences to formulate constructive suggestions. Second, some participants showed empathy towards less experienced users of the site. Last, some participants spoke out for the interest and needs of the sub-groups they belonged to.

Why were participants able to reflect in those particular fashions? The design of SO facilitated their reflection in at least three ways. First, SO supported reflection-in-action by embedding its user interfaces into the webpage where the participant might run into problems. This allowed participants to consider the nature of the issue and, more importantly, to identify it when the full context of the issue is still available to them. Second, SO augmented live webpages and turned them into a medium for reflection. According to Schön (1983), the medium (e.g., a sketchpad) at the disposal of an individual helps shape his/her reflection by affecting his/her ability to examine, explore, and conduct experiments on the situation. With SO, participants could create overlays to quickly explore different ways of fixing a usability issue on the page. Third and most importantly, SO potentially changed participants' role frames by providing them with the ability to modify a live webpage. Schön (1983) suggested that reflection is bounded by the way an individual framed his role. SO effectively made participants co-designers and co-

editors of the site, which gave them a legitimate reason and responsibility to address issues they noticed on the site.

3.5.2 Limitations and Future Work

Despite SO's success, we found five issues with it and the approach in our evaluation. First, we saw that users using SO might need help formulating holistic and broad redesign recommendations. An interesting question we would like to explore in future work is how SO can be used with some lightweight expert involvement, e.g. with an expert synthesizing or gatekeeping modifications proposed by users.

Second, although our evaluation argued that SO was likely to be helpful for communities with a few dozen to several hundred members, there are many other types of communities with many more members, less social cohesion, and potentially less trust. Addressing these communities will require additional functionality. Some public-facing websites are subject to spam, problematic content, and attacks, requiring more security mechanisms. Larger or more public websites and communities may suffer more motivation issues, although they also potentially have more users for SO. All of these issues remain to be addressed in future work, and we plan to do so in subsequent efforts. Nonetheless, we were pleased that SO appears to be able to work in at least an important subset of small-to-medium communities. The same type of community exists in many educational settings, community organizations, charities, and the like. Nonetheless, we will not know all the issues until this tool is released into the wild and used by other sites and communities.

Third, the current version of SO provided only three simple modification tools. Even with these limited capabilities, our participants were able to address common and important usability problems with ease: confusing labels and vocabulary issues, broken and cumbersome navigational paths, and unclear site functionality. We believe, based on our evaluation, that additional tools would make SO even more helpful. We are currently investigating capabilities to insert new links into a page, convert the highlighted part of text into a hyperlink, support the

navigational use of tooltips with better hyperlinking, and address higher-level issues of page and site organization. We are also examining how to address potential information overload problems that would arise if SO were to scale, including new awareness visualizations and mechanisms for issue consolidation.

While it is technically possible to include more powerful and sophisticated tools such as a full-fledged style editor, we believe this would run the risk of having naïve users freeze or make too many mistakes. We also plan to examine this risk in future studies.

Fourth, based on even our limited study, we suspect there will be resulting problems as SO use grows in a site. As the number of users grows, it will increasingly be a concern that different subcommunities inhabit different language worlds, and individuals may wish to place markers for themselves that would be inappropriate for the entire community. We are currently investigating mechanisms to allow both subcommunity and individual personalization.

Finally, as mentioned, we had less usage of the voting feature than we had hoped. In our observations, non-voting behavior often implied agreement, and there were very few overlays or requests that were perceived negatively by participants. We expect both the use and the utility of the voting feature to increase as more users participate in an SO deployment; however, we are investigating new user interface designs to make voting easier and more meaningful.

We must also acknowledge the many limitations in the current study. Our tasks were artificial and scoped, as with any lab–based study. In addition, the study was short–term and used selected pages. As mentioned, we will not know all the issues until SO is released into the wild and used by other communities—work that is presently ongoing. The current system and evaluation reported here, however, have led us to believe the usefulness and stability of SO are such that such explorations can fruitfully occur.

3.6 Related Work

The SO system and the approach it enables, as presented above, aim to tackle the challenge of post-deployment usability which is important but has been undervalued in the user-centered design practice (Chilana et al., 2011; Wagner & Piccoli, 2007). A number of commercial offerings have sprung up that facilitate the collection of user feedback on deployed websites, either through web forms (e.g., Feedback Army[3] and UserVoice[4]) or message boards (e.g., SuggestionBox[5]). Additionally, web annotation systems (e.g., Diigo[6] and AnnotateIt[7]) could potentially be employed to obtain user feedback, though most of them are focused on learning and information management. It is evident that, while being reasonable solutions for collecting user feedback, all of these tools require users to depend on website supporting staff to assess the severity of the problem, design a solution, and implement the change. In contrast, SO addresses usability by enabling a website's user community to not only identify problems but also repair many of them immediately.

To design a system like SO, we draw on three bodies of technical work: web-rewriting systems, collaborative web accessibility tools, and community-based help systems. We will describe each of them in turn.

First, we build upon web-rewriting systems that allow users to alter the design or behavior of a webpage at runtime. General-purpose web-rewriting systems like Chickenfoot (Bolin, Webber, Rha, Wilson, & Miller, 2005) and GreaseMonkey (McFarlane, 2005) support such rewriting, and they have online repositories whereby users can share, discover, and make use of scripts created by others. However, the versatile capability of these systems creates difficulties for most users, since many users do not know how or want to inspect, edit, and debug scripts. SO

[3] http://www.feedbackarmy.com
[4] http://www.uservoice.com/
[5] http://www.suggestionbox.com/
[6] http://www.diigo.com/
[7] http://annotateit.org/

leverages some of the same technologies used in Web rewriting systems (e.g., JavaScript injection), but SO nonetheless has been designed specially to allow naive users to contribute.

Second, collaborative web accessibility tools (e.g. AccessMonkey [Bigham, 2007] and Social Accessibility [Takagi, Kawanaka, Kobayashi, Itoh, & Asakawa, 2008]) represent a specialized class of web-rewriting systems—one that shares SO's high-level goal to make websites easier to navigate and use. Accessibility systems, though, are focused on helping particular subsets of users who share particular disabilities. For example, the Social Accessibility system allows volunteers to enter missing metadata that can then be consumed by visually impaired users who subsequently visit the augmented sites using screen readers. Though the underlying technologies that enable SO and Social Accessibility are similar, the sociality afforded by the SO approach is fundamentally different because in SO both producers and consumers of collaborative usability enhancements belong to the same group. Our study has shown that many usability problems can best be identified and addressed by users who share lived experience relevant to the community of the site.

Therefore, the sociality supported by SO is closer to that studied in the third body of work we draw upon: community-based help systems. These systems assist users by providing information generated by other members of the community. Community-based help systems, such as Answer Garden (Ackerman, 1994), QuME (Zhang, Ackerman, Adamic, & Nam, 2007), IP–QAT (Matejka, Grossman, & Fitzmaurice, 2011), and LemonAid (Chilana, Ko, & Wobbrock, 2012), have focused on making it easier for users to ask questions and find answers, and these systems have shown resoundingly that users can collectively create useful information. Answer Garden builds a store of questions and answers, but accessing it requires using a separate system, resulting in a potential distraction from the core tasks users are trying to accomplish. IP-QAT and LemonAid associate questions with related UI elements and display answers as part of the system for which help is sought. IP-QAT and LemonAid, however, do not seek to actually improve the user experience of the system by effecting design changes, as SO does, which has the additional benefit of reducing the need for seeking help in the future.

In short, none of the above systems are focused on post-deployment usability assessment and correction, though we draw inspirations and learn lessons from them to inform different aspects of SO design. By specifically designing for the collaborative work around post-deployment usability, Social Overlays provides new capabilities of community interaction and assistance.

3.7 Conclusions

In this chapter, we presented the Social Overlays (SO) system and its evaluation. SO enables end–users to identify and repair common user interface problems on a website by making "overlays" that rewrite specific page elements. Moreover, SO displays page modifications to others who also have this extension installed.

We characterized the particular type of use that SO intends to enable as *reflective use*, a manner of engaging with a computing system in which the user reflects on breakdowns and suggests remedies as part of normal use. Drawing on Schön's (1983) theory, SO supports reflection-in-action by making itself available as the user surfs the Web, turning live webpages into media for experimenting ideas, and reframing users' roles to co-designers and co-editors of the site.

In the evaluation of SO, we found preliminary evidence that the community members participated in our study were capable of engaging in reflective use of their website. In particular, participants reflected on site issues by drawing on their lived experiences, showing empathy towards less experienced users, and speaking out on behalf of the sub-communities they belonged to. Through reflective use, participants identified many issues not found by outside experts.

Taken all together, our experience with designing and evaluating Social Overlays allows us to start addressing the overarching research question of this dissertation: *Can we better understand the design space of computer-supported reflection by having a deeper engagement with theories on reflection, in particular the constants of reflection (e.g., role frame, appreciative system, interpersonal theory of action, etc.) identified by Schön?* SO has shown that it is fruitful to draw on Schön's (1983) constants of reflection. Chapters 4 and 5 will further elaborate how those constants can be used to guide the design of interactive systems supporting reflection.

CHAPTER 4

Reflective Play: Enhancing Awareness of Technology Use with Home Trivia[8]

4.1 Introduction

On August 22, 2013, a discomforting video entitled *I Forgot My Phone*[9] appeared in many people's social media feeds. It was discomforting because many people saw themselves and their technology-addicted lifestyle depicted and mocked in the video. The video was viewed over 15 million times within 10 days after its release (Bilton, 2013). The viral response to this video was one of the signs that we as a society were becoming increasingly anxious about our overly intimate relationship with our gadgets and online lives. This anxiety was not unfounded. MIT psychologist and sociologist Sherry Turkle (2013) recently published a high-profile book entitled *Alone Together*, in which she described the phenomenon that many people's increasing dependence on technology and tendency to seek sanctuary in cyberspace has started to make them mentally absent when they are physically together with their loved ones, including their families.

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[8] I primarily conducted the work in this chapter, with guidance from Mark W. Newman, Mark S. Ackerman, and Sarita Yardi Schoenebeck. This work has not been previously published.

[9] I Forgot My Phone. https://www.youtube.com/watch?v=OINa46HeWg8

What was more worrisome was that for many people the video came as a sudden awakening to their smartphone obsession. After all, how shocking could it have been if they were already well aware of this issue and talking about it regularly? This lack of awareness is likely to drive people to more socially inappropriate use of technology that they will eventually regret when they realize how others might have perceived their behaviors.

So how can we help people become more aware of their technology use and begin thinking about changes? In this work, we are particularly interested in helping families better manage technology use at home because the existing strategies taken by parents to regulate their children's technology use, such as monitoring usage, cutting off access, and stigmatizing overuse, are not only insufficient but also counterproductive, not to mention that parents often fail to be mindful of their own technology use.

To that end, we propose a novel system called Home Trivia which harnesses the emerging ability of people's homes to capture activity traces to inform them of how and when they use technology. Home Trivia mainly consists of a router-based device activity tracker capturing usage of devices connected to the home Wi-Fi, several space usage trackers providing additional contexts of home activities, and an interactive puzzle game which uses the captured activity traces as its main content.

We deployed Home Trivia into 5 households in Southeast Michigan, United States. We specifically targeted families with at least one child aged from 7 to 13 because children in this age range start to have their own mobile devices and laptop computers (Lenhart, 2010). We believe it is beneficial for parents and children to engage in conversations about technology use at this formative stage when children start to develop habits about using technology.

Each field trial consisted of three steps. It started with an initial interview during which we learned the family's routines and technology use. Then, we deployed trackers of device usage

and space usage in the participants' homes for one to two weeks to collect activity data. Finally, we conducted a gameplay session where the family played the game together in their home.

The main findings of our field study include the following:

- The Home Trivia game engaged both child and adult participants by serving personalized puzzles based on activity traces, encouraging teamwork, and putting children and parents on an equal footing.
- The Home Trivia game created opportunities for family members to revisit and rediscover their past experience by turning simple, aggregated activity traces into puzzles.
- The Home Trivia game provoked perspective-shifting reflections on technology use by highlighting discrepancies between one's impressions and the activity data captured by the system.

This chapter then offers three contributions. First, Home Trivia represents and instantiates a new design approach called *Reflective Play.* We applied this approach to helping families manage technology use through raising awareness, supporting reflection, and enhancing communication. Second, Home Trivia expands the nascent design space of using sensor data for non-utilitarian purposes (c.f. Gaver et al., 2007; Pousman et al. 2008, Dong et al. 2014). The goal of this line of research is to understand how digital traces captured in the home can be retained, transformed, and presented in an emotionally or socially useful way. Third, designing for reflection has received a growing interest since Senger et al. (2005) advocated the Reflective Design approach and since the third paradigm of HCI (Harrison et al., 2007) called for supporting reflection in its own right rather than as a means to an end. Our study results help designers better understand how to leverage games or game-like activities to create reflective experience.

The rest of the chapter is organized as follows. We first provide an overview of prior work related to the main goals of this work, and then we describe the design and implementation of

the Home Trivia system. Following that, we detail our field study and its results. We then offer a discussion of the design approach we took, the limitations of our work, and the future work that needs to be done.

4.2 Design Goals and Related Work

In this section, we describe prior work related to four primary goals of Home Trivia: facilitating family communication, enhancing awareness, fostering reflection on technology use, and engaging family members to achieve the previous three goals together. We also derive a set of design requirements by reviewing this related work.

4.2.1 Facilitating Family Communication about Technology Use

There are many tools on the market that allow parents to mediate their children's Internet and device usage. They usually allow parents to implement two mediation strategies: technical restrictions (e.g., filtering content and blocking access) and monitoring. However, they are inadequate as we will discuss below and prior research has called for tools to support better family communication about technology use.

4.2.1.1 Technical Restrictions

Some parents seek to proactively control their children's technology usage. To satisfy such needs, many computers and mobile devices feature built-in tools to allow parents to specify when the device can be used and what websites or applications can be opened. Some well-known examples include the FreeTime application on Amazon Kindle tablets and the Parental Controls panel on Mac OS X (see Figure 8). Those device-specific tools provide parents powerful control over usage, but it can be inconvenient to manage these settings on multiple devices. Thus, some households take advantages of the parental control feature provided by the router in the home. For example, NETGEAR, a major maker of routers, boasts, "With NETGEAR

Parental Controls[10], control happens at the router level, so the rules you make are applied on all your connected devices—Laptops, tablets, smartphones, even game consoles."

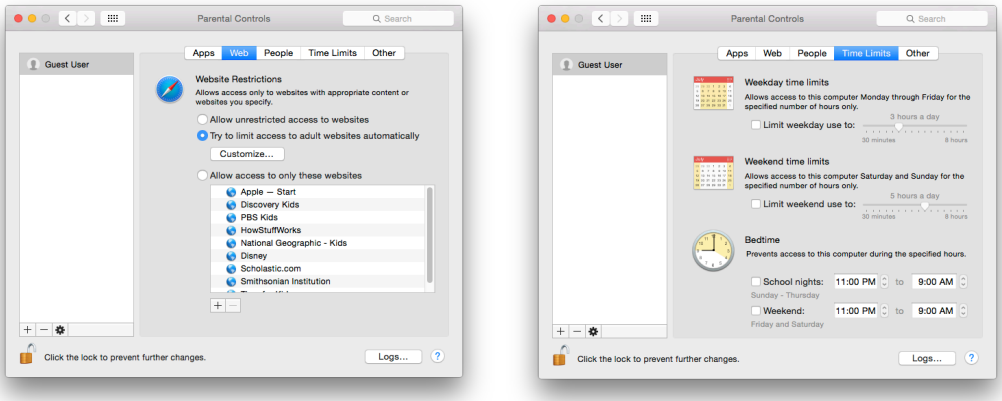

Figure 8: The Parental Controls Feature in Mac OS X.

Despite the abundance of content filtering and access blocking tools on the market, their adoption and effectiveness is undermined by two critical shortcomings. First, it is well-known in the HCI literature that access control rules are hard to create and maintain, even for trained security professionals (Stevens & Wulf, 2009). Second, parents unilaterally imposing and inflexibly enforcing preset rules can lead to children's psychological reactance (Brehm & Brehm, 1981) and undermine the family's ability to trust one another and communicate openly (Byrne & Lee, 2011).

4.2.1.2 Monitoring

Some families turn to other mediation tools that emphasize monitoring rather than limiting access. As technical solutions, these tools can also be installed on individual devices or on a router. For example, the Verity child monitoring software[11] not only logs which websites the computer has visited but also takes screenshots periodically as part of the usage report parents

[10] NETGEAR Parental Controls. http://www.netgear.com/lpc
[11] Verity child monitoring software. http://www.nchsoftware.com/childmonitoring/screenshots.html

can later examine. Some router administration software has the ability to monitor Internet usage as well, such as the Web Monitor featured in the third-party firmware Tomato[12].

Although these usage monitoring tools might help parents adopt a less restrictive and stringent approach towards managing their children's technology use, those tools are often designed and deployed with the assumption that children, the users of those devices being monitored, have neither a need nor a right to see their own usage records, and hence enact a questionable asymmetrical relationship whereby the parents get to know everything their children do on their devices, while the children receive no information about their own or their parents' technology usage.

4.2.1.3 Lack of Tools Supporting Communication

Few tools have been created to support families to discuss technology use, despite its importance. In a survey, Bryne and Lee (2011) found that lack of open communication about the risk of Internet usage between parents and children can potentially lead to their disagreement over the strategies parents adopted to regulate children's Internet usage. The authors further argued that mutual respect resulting from open communication could make children less likely to perceive that implementing mediation strategies was intended to take away their freedoms.

What makes it urgent to support communication is that natural opportunities to talk about technology use are likely to dwindle in the home. A 2008 survey in the UK indicates that active co-use, where parents talk to children about Internet use when they are online, is one of the preferred mediation strategies (Livingstone & Helsper, 2008). However, devices with smaller screens (e.g., tablets, smart phones, and mobile media players) have started to take over the domestic computing market since the launch of the iPod Touch in 2008 and the iPad in 2010.

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[12] Tomato (firmware). http://en.wikipedia.org/wiki/Tomato_(firmware)

One of the likely consequences is that it would be difficult for parents and children to actively co-use these devices because of their small form factors and their mobility even inside the home.

Given the above reasons, we arrived at the first design requirement of Home Trivia:

> *Requirement #1: Create opportunities in the home to talk about technology use casually and regularly among family members.*

4.2.2 Enhancing Awareness of Technology Use

Becoming more aware of technology use seems to be an important first step towards more communication about it, but keeping track of one's own behavior can be difficult because "we often have incomplete knowledge of ourselves, we cannot monitor our behaviors all the time, and we cannot easily find patterns in our behaviors" (Li, Dey, & Forlizzi, 2010, p. 4490). Staying aware of mobile device usage can be particularly challenging because the use is often unplanned and fragmented. Studies have shown that people can develop habits of using mobile devices. Oulasvirta et al. (2012) noted a particular usage habit that involves brief and frequent interactions with one's mobile device (e.g., checking emails or social media update). Lee et al. (2014) reported that some participants lost sense of time when they were engaged in habit-driven usage of their mobile phones. Furthermore, though such habitual usage often occurs unnoticed by the user herself, people who are around her can experience an "invisible shield" blocking social interactions (Kawsar & Brush, 2013).

In response to the difficulty of keeping track of one's device usage, a few commercial tools have emerged to provide users with information about when, how long, and for what they used their devices. These tools are often marketed as productivity boosters and distraction killers. For example, RescueTime[13] is a program that tracks what the user does on his/her computer in the

[13] RescueTime : Time management software for staying productive and happy in the modern workplace. https://www.rescuetime.com/

background. It allows the user to see statistics about how he/she spends his/her time on different types of activities. On mobile devices, Moments[14] is an iOS application that tracks how much the user uses his/her phone each day. It also allows the user to set a self-imposed time limit for phone usage. Researchers also developed tools such as SmartLogger (Lee et al., 2014) to log different types of usage on smart phones, but the data was meant for analyzing user behaviors instead of informing the user of his/her own usage patterns.

Tools for a household instead of an individual to stay aware of their technology use are relatively rare. One of the few exceptions is Home Watcher, a system that monitors and displays bandwidth usage by device in the home (Chetty et al., 2010). Home Watcher provides two views to the members of a household where it is deployed. The current view shows how much bandwidth each device is currently using, while the history view shows how much bandwidth each device used in the recent past.

Chetty et al. (2010) conducted a field evaluation of Home Watcher and the results of the study show that making household members' bandwidth usage visible in the home had interesting social consequences. First, not only did Home Watcher provide participants an interpersonal awareness of Internet uses at home but also an awareness of domestic activities indicated by those uses (e.g., waking up, doing homework, staying up late, etc.). Second, the information about bandwidth usage shown by Home Watcher allowed participants to better negotiate the distribution of this shared resource with other household members. Third, some participants were concerned about personal representation in the home as others could "read" their activities from their usage of bandwidth. While the field evaluation of Home Watcher was not focused on reflection, the new awareness of bandwidth usage can potentially support reflection. For example, some parents who participated in the study envisioned that they could

[14] Moment – Automatically track your daily iPhone use. http://inthemoment.io/

use Home Watcher to validate or invalidate their suspicions about who had been hogging the household bandwidth.

Chetty et al.'s (2010) work clearly shows that technology use at home is not an individual but a social activity. While the social nature of technology use in their study was rooted in the fact that household members shared bandwidth, in our study technology use was also social due to its potential impact on the quality of family time and the perception of family togetherness. Since technology use in the home is not an individual activity, previously mentioned tools for tracking personal device usage are unlikely to be sufficient to support awareness and management of technology use at home.

Like Chetty et al. (2010), we wanted to explore social consequences of revealing household members' traces of technology use by having them interact with Home Trivia. Thus, we made the second design requirement of Home Trivia as follows:

> *Requirement #2: Enhance family awareness instead of personal awareness of domestic activities with an emphasis on technology use.*

Our study nonetheless differed from this prior work in several important ways. First, our primary concern over technology use in the home was about its impact on family togetherness rather than resource management. Second, we wanted Home Trivia to support not only awareness but also reflection. Third, we employed games rather than information displays as a medium to deliver the information to users, and we found our game design helped stimulate reflection.

4.2.3 Supporting Reflection on Technology Use

4.2.3.1 Elevating Awareness to Reflection

Enhanced awareness of technology use can lay the foundation for reflecting on it (Fleck & Fitzpatrick, 2010), and reflection on technology use can potentially lead to changes in knowledge (Dewey, 1933), attitudes, and lifestyles.

Fleck and Fitzpatrick (2010) proposed a 5-level framework for assessing reflection. At the bottom of the framework is simple revisitation of past events and experience. Building on top of the awareness gained from revisiting the past was *Reflective Description*, where simple explanations or justifications were provided for an event. Going deeper, *Dialogic Reflection* allows for seeing things from a different perspective and *Transformative Reflection* leads to changes of understandings and actions. In the context of this work, it is important to help family members reflect on their technology use to better understand how it integrates with and affects other parts of their home lives.

Moreover, reflecting on technology use is likely to benefit both adults and children in the family. Research has shown that children over the age of five have self-awareness and the ability to reflect on their own behavior (Beaman et al., 1979). In addition, encouraging children to become more self-aware about their own technology use behaviors at an early formative stage will help them establish these behaviors in the long run (Robinson et al., 2009; Roggman et al., 2009).

4.2.3.2 Triggering Reflection

Reflection does not happen randomly. According to Dewey (1933), it is the experience of uncertainty that usually triggers reflection because moments of uncertainty can defamiliarize one's everyday environments, suspend beliefs used to be taken for granted, and create a shock or an interruption that calls for explanations.

Based on this view on how reflection is triggered, HCI researchers have attempted to create experiences of uncertainty by intentionally introducing ambiguity into information displays (Gaver et al., 2003). In the particular domain of supporting reflection on home life, the Home Health Horoscope seeks to give feedback to household members on the state of affairs in the home by generating daily horoscopes based on activity traces captured by sensors installed in specific areas in the home (Gaver, et al., 2007). Those sensors capture activities such as

accessing the cleaning cupboard, opening the kitchen door, and sitting on the loveseat. The Home Health Horoscope exploits the obscure writing style of horoscopes to allow users to make their own interpretations. Pousman et al. (2008) took a similar approach. They designed Tableau Machine, an ambient display that seeks to characterize activity based on analyzing and aggregating overhead video feeds in the home. Tableau Machine presents "the character" of the activities it captured in the form of continually updating abstract animations.

Field tests of the Home Health Horoscope in 1 household and Tableau Machine in 3 households found that the output of these two systems made users think by tapping into their curiosity about the meanings of the system output and sometimes their suspicions of the systems' true intentions. However, as Pousman et al. (2008) acknowledged, actual reflections on home life rarely occurred. We learned two important lessons from the limited successes these two systems had in their field tests.

First, it appeared that the participants' goal of reflection in both systems' field tests was mostly about understanding the meanings of the system output but not the home life the output represented. This limitation might be attributed to the two systems' lack of feedback on users' understanding of their outputs. Therefore, users' existing understandings (or lack thereof) of their home lives remained unchallenged. While it might be reasonable for a system prioritizing playfulness to stay enigmatic, we believe for systems that intend to serve more specific goals such as facilitating reflection on technology use, the ambiguity in the representations needs to be resolvable or at least reduced to allow users to check if there is any difference between their existing understandings and the reality, because as Consolvo et al. (2009) advocated, cognitive dissonance can provoke reflection. Thus, our third design requirement for Home Trivia was generated:

> *Requirement #3: Trigger reflection by showing discrepancies between existing beliefs and the reality, as indicated by captured traces, and allow users to resolve this cognitive dissonance through reflection.*

Second, being ambient and peripheral, both the Home Health Horoscope and Tableau Machine lack the affordance of gathering family members and allowing them to interact with the system at the same time. Prior research in HCI has shown that both recounting past events with peers (Grimes, et al., 2008) and seeing the past from a different perspective (Harper et al., 2008), which a different person may provide, can help trigger reflection. Thus, we wanted to explore an alternative way, namely, using games to display activity traces in the home in order to address these limitations. This has led to the fourth design requirement of Home Trivia:

> *Requirement #4: Motivate family members to collectively reflect on technology use in the same place at the same time so they can share their thoughts and experience.*

4.2.3.3 Framing Roles

How likely reflection is to occur and what reflection will lead to further depend on the person's role frame, the way he/she perceives his/her role in a situation (Schön, 1983). According to Schön (1983), a person's role frame exerts a strong yet often unnoticed influence on how she determines what facts are relevant, what problems belong to her, what knowledge is useful, what actions are appropriate, and what kinds of reflections should be undertaken in action.

In a family, there are often presumed roles played by different family members. Though parenting styles vary from family to family, an asymmetry of power between parents and children often exists. Children are often in a passive role of adhering to rules but not enacting them; they are often asked to listen but not always heard (Byrne & Lee, 2011). In contrast, parents might believe they are mature and do not need to regulate their own technology use behavior. These role frames hold both children and parents back from reflecting on how they use technology as part of their home life. Therefore, we wanted Home Trivia to put children and parents on an equal footing, though temporarily, so they would examine their own and their family's technology use behaviors with an open mindset. This is the fifth design requirement of Home Trivia.

> *Requirement #5: Change family members' role frames when they reflect on their technology use by putting children and parents on an equal footing.*

4.2.3.4 Adopting a Cooperative Interpersonal Theory of Action

Reflection can also be affected by one's interpersonal theory of action, a set of guiding principles for how to behave in a multi-party conversation (Schön, 1983). It affects reflection by changing the willingness of different parties to openly communicate their thoughts and calculations.

According to Schön (1983), when an individual conforms to Model I, a competitive interpersonal theory of action, he would be likely to reserve his information about and understanding of the situation to himself. As a result, it is difficult to detect potential misunderstandings, which can help provoke reflection on one's behaviors and allow the person to make adjustments on the spot. In contrast, Model II, a cooperative interpersonal theory of action, would lead to a more open and transparent conversation. Choices will be made based on valid information rather than assumptions and guesses. Therefore, it is important to encourage users to share instead of withhold their knowledge and thought process with others, and this constitutes our sixth design requirement for Home Trivia.

> *Requirement #6: Encourage family members to share their thoughts and experience by fostering a cooperative interpersonal theory of action.*

4.2.4 Aligning Engagement with Communication, Awareness and Reflection

As we have described above, we set several interlinked goals for the design of Home Trivia. First, it needs to facilitate family *communication* about technology use. Not only can such communication raise a person's awareness of others' home activities, it also allows the person to know how others have perceived his/her behaviors. Second, it needs to enhance a household member's *awareness* of how he/she as well as other members were using technology at home. This awareness can potentially become a resource to facilitate both communication and reflection. Third, Home Trivia needs to provoke and positively shape family members' *reflection* on their technology use at home through inducing cognitive dissonance, reframing family members' roles, and fostering a cooperative interpersonal theory of action. To

achieve these goals, Home Trivia must engage users, both adult and child members of a family, in the first place. To this end, we drew on the Problem-based Gaming (PBG) approach (Kiili, 2007) originally developed in education to align engagement with these goals.

As its name suggests, Problem-based Gaming (PBG) is rooted in Problem-based Learning (PBL), an approach used extensively in educational settings. According to Barrows and Tamblyn (1980), PBL is "the learning that results from the process of working towards the understanding and resolution of a problem" (p. 1). PBG motivates learners to engage in PBL by providing feedback, encouraging reflection, and facilitating collaboration.

Kiili (2007) proposed and validated a model of PBG (see Figure 1), which provides a basis for us to explain how PBG is well-aligned with the goals we wanted Home Trivia users to achieve, on the aspects of awareness, reflection, and communication. This model describes a cyclic process of solving a meaningful problem presented in the game. The problem-solving cycle usually starts from *formation of playing strategy* based on the player's prior knowledge. In the context of Home Trivia, players' prior knowledge would be their memory of what was happening and what everyone was doing in the home on a particular day.

Next, players need to test their prior knowledge by engaging in *active experimentation* in the game world, and they receive feedback from the game. In the context of Home Trivia, the game world represents the device and space usage in the home, and active experimentation entails making an informed guess about the source of an activity stream. By observing the *consequences* of experimentation on the *state of the game world*, players can confirm their prior knowledge, gain new insights, or notice discrepancies between what they believe to be and the reality revealed by the game. This experimentation process helps players' *reflection* on technology use.

What is not explicitly illustrated in this model is that reflection may take place either as a solitary activity or a collaboration one (Kiili, 2007). Studies have shown that collaborative

gameplay has two main learning benefits. First, players can share their knowledge and thus facilitate learning (Kiili, 2007; Hummel et al., 2011). Second, teamwork encourages players to verbalize their thought process (van der Meij, Albers, & Leemkuil, 2011). Thus collaborative play is an important design choice we made for Home Trivia. Not only do we expect collaborative play to lead to more conversations in the family about technology and space usage but also to encourage family members to share what they remember and what they believe to be to gain a better understanding of their home lives.

As made clear in this model, PBG aligns reflection with the essential elements that make games engaging. Those elements include clear goals and rules, immediate feedback, and a sense of getting better at something meaningful (McGonigal, 2011). By adapting PBG, we wanted to satisfy our last design requirement for Home Trivia, stated as follows:

> *Requirement #7: Encourage thinking about as well as talking about technology use in the recent past by making it necessary to win the game.*

4.2.5 Design Requirements

Below, we reiterate the design requirements derived from our critical analysis of prior work related to the goals of Home Trivia:

- Create opportunities in the home to talk about technology use casually and regularly among family members.
- Enhance family awareness instead of personal awareness of domestic activities with an emphasis on technology use.
- Trigger reflection by showing discrepancies between existing beliefs and the reality, as indicated by captured traces, and allow users to resolve this cognitive dissonance through reflection.
- Motivate family members to collectively reflect on technology use in the same place at the same time so they can share their thoughts and experience.
- Change family members' role frames when they reflect on their technology use by putting children and parents on an equal footing.

- Encourage family members to share their thoughts and experience by fostering a cooperative interpersonal theory of action.
- Encourage thinking about as well as talking about technology use in the recent past by making it necessary to win the game.

We describe how these requirements are satisfied by the design of Home Trivia in the next section.

4.3 System Design and Implementation

4.3.1 System Overview

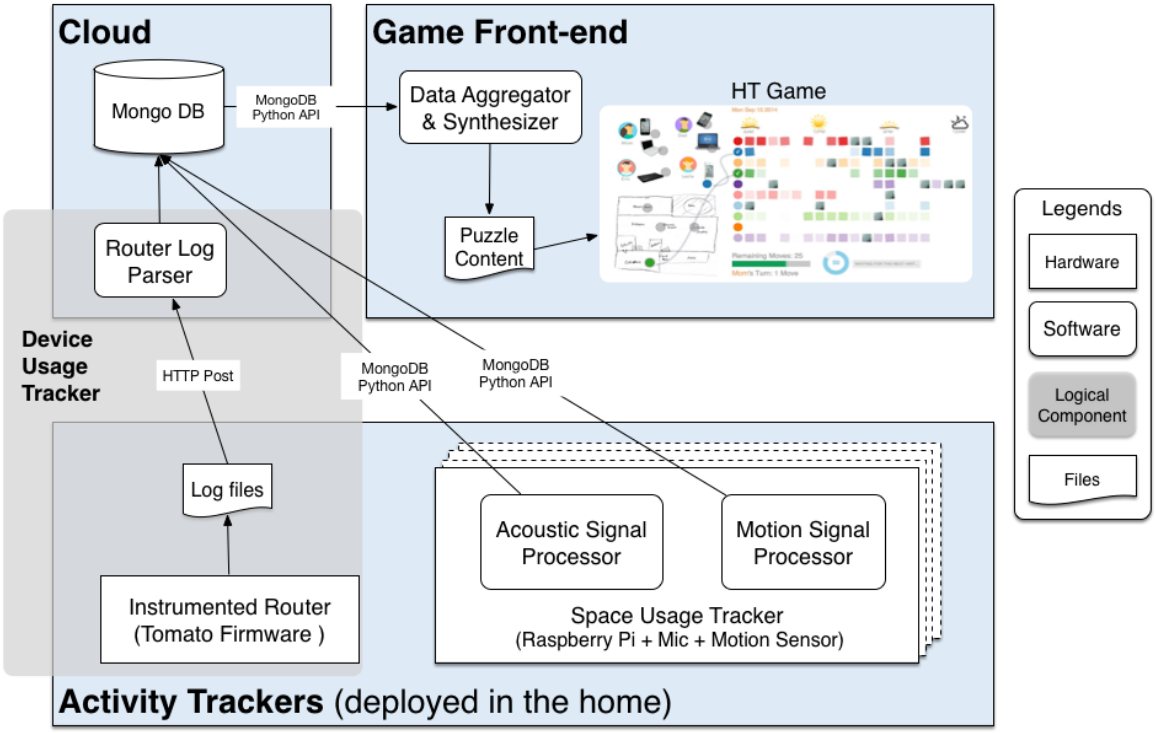

Figure 9: The System Architecture of Home Trivia.

In this section, we describe how we designed and implemented Home Trivia to support the goals we have outlined in the previous section. Home Trivia is a computing system that allows users to better understand their technology use at home. It mainly consists of a device activity

tracker capturing usage of devices connected to the home WiFi network, several space usage trackers capturing acoustic and motion signals in the home, and a computer/tablet game which displays the captured activity traces as its main content. The diagram below (see Figure 9) provides an overview of the system architecture. In the rest of this section, we describe each of these components as well as how they work together.

4.3.2 Sensing Activity

4.3.2.1 Device Usage Tracker

The device usage tracker in Home Trivia consists of an instrumented wireless router and a server-side log-parsing program running in a cloud-based application server. It uses a device's Internet access records kept by the router to approximate when it was used in the home. Granted, the device usage tracker is not capable of tracking usage of devices with no Internet connectivity or usage instances that do not use the Internet, but such untraceable usage is rare these days.

Device usage traces are captured in three steps: usage logging, log transmission, and log parsing and storage. Usage logging is enabled by replacing the stock firmware on the Linksys E2500 wireless router we used for this study with the Tomato firmware (in particular a mod maintained by Shibby[15]). Tomato is a feature-rich Linux-based open-source router firmware. Tomato's Web monitoring feature generates a log file that contains Internet access records of each device connected to the router. Each record in the log file includes a timestamp, the LAN IP address of the device, and the name of the domain from which the device requested data.

A Linux shell script will then periodically transmit the latest version of the log file to the server-side log-parsing program by making an HTTP POST using CURL, a command line utility for transmitting data in a network. Every 30 minutes, another shell script will send the latest device

[15] Tomato by Shibby. http://tomato.groov.pl/

list, a file containing a table of host names and IP addresses of the devices currently connected to the router, to the same log parser. Every time the router sends data to the log parser, a home ID will be included in the HTTP request.

Upon receiving the log file, the parser will scan the file line by line, look up each device's name in the latest device list based on its IP address, and then create a device usage record in the database which contains only three fields: home ID, device name, and access time. The log parser does not keep the domains devices accessed in order to mitigate potential privacy concerns. The parser deletes original log files as soon as the relevant information has been extracted and stored in the database.

4.3.2.2 Space Usage Trackers

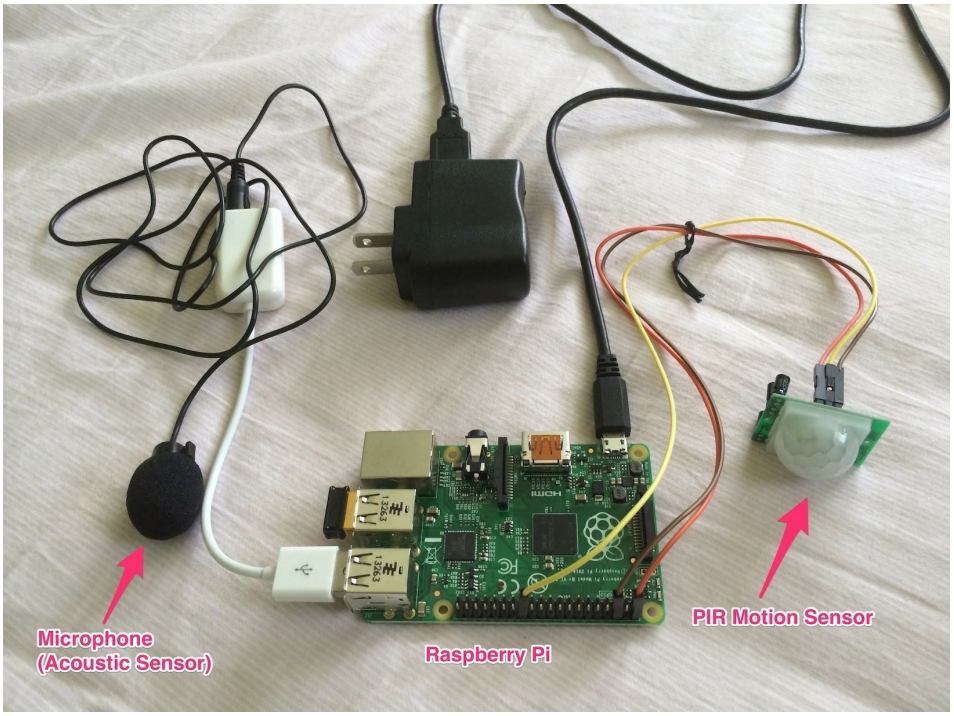

Figure 10: The hardware components of a space usage tracker

Each space usage tracker includes a PIR motion sensor, a microphone, and a Raspberry Pi, a $35 Linux-based mini-controller (see Figure 10). Home Trivia combines acoustic and motion signals

in a space to characterize its activeness. Our assumption is that when a space in the home is active, there are usually people talking or having physical movements. Those space usage trackers are mainly installed in family spaces identified by participants.

The motion signals are binary. Every time the PIR sensor detects motion, the Motion Signal Processor logs a timestamp. Every minute, acoustic signals are first recorded in a wave file, and then the Acoustic Signal Processor will extract a time-series of amplitudes from the file and aggregate the amplitudes at the second level. The recorded audio will be discarded as soon as amplitudes have been extracted. Every minute, new observations of a space's motion and acoustic signals will be written to Home Trivia's database powered by MongoDB.

4.3.3 Characterizing Activeness

4.3.3.1 Defining Activeness

To generate puzzles in Home Trivia, raw activity traces need to be aggregated and transformed to characterize how active a device was during the hours when it was tracked. We created a normalized measure called *Activeness* for this purpose. In a nutshell, Activeness is the percentile rank of the amount of activity a device or a space had during a particular hour based on its entire activity history. Therefore, a device or a space's Activeness is always relative to its own activity history, and the value of Activeness ranges from 0% to 100%.

Defining Activeness this way has pros and cons. One of the main advantages of making Activeness relative to the activity source's own activity history is that it can make usage spikes of generally lightly-used devices or spaces stand out, which could indicate unusual events or behavior. It also helps mitigate the bias introduced by background networking processes on some devices (especially PCs) that frequently check updates and send status reports. The downside is that Activeness cannot be easily compared between two devices or two spaces on absolute terms.

The procedure of computing Activeness for a device is different from the procedure for a space. Below I describe their respective procedures.

4.3.3.2 Computing the Activeness of a Device

It is relatively simple to compute the Activeness of a device during a particular hour. The process starts with retrieving all the Internet access records of the device during the hour from the database. The second step is to count the number of records. The third and final step is to determine the percentile rank of the hour's record count in the device's activity history. The resulting percentile is then treated as the Activeness of this device during that hour.

4.3.3.3 Computing the Activeness of a Space

The process of computing the Activeness of a space involves more steps. The input would be a list of activity measurements taken at each second. For acoustic signals, each observation is the average amplitude for a particular second. For motion signals, each observation is a binary value indicating whether motion was detected this second. A space's overall activeness is a combination of its acoustic activeness and its motion activeness, which is described below.

For either motion data or acoustic data, the first step is to aggregate the second-level observations by minute, and then determine whether the space is active during that minute by checking a preset threshold. For acoustic data, the threshold is the minimum average amplitude, while for motion data, the threshold is the minimum number of motions detected during a minute. This threshold can be customized to each space to account for the background noise and pet movement. After the system determines the number of minutes that were acoustically active during the hour, the system will calculate its percentile rank. A similar process is applied to the motion data.

The last step is to calculate the weighted average of the percentile ranks of the spaces' acoustic Activeness and motion Activeness. In most situations, motion activeness and acoustic activeness are equally weighted to account for both types of activities (e.g., talking, watching

TV, and walking around). But for houses with pets, we set the weight of acoustic activeness greater than the weight of the motion activeness to mitigate the noise introduced by pet movements. However, in areas affected by external noise (e.g., a garage with its door left open during the day), the motion activeness would be prioritized.

4.3.4 Gamifying Activity Traces

The activity data captured by the system will then be used to generate puzzles in the Home Trivia game, which family members can play together to learn how they spent time at home. Designed as an electronic board game, Home Trivia allows conversations about technology use to happen in a relaxed atmosphere, which addresses Design Requirement #1. In addition, like a board game, Home Trivia also requires family members to play in the same place at the same time, and this addresses Design Requirement #4, which concerns about sharing thoughts and experience in a face-to-face activity.

The game is implemented with Web technologies (i.e. JavaScript and HTML), so it can be played on either a laptop computer or a tablet. When a family plays the game, the game screen will be projected to the Television Set via a device called Chromecast[16] so that everyone in the room will be able to see all the information about home activities and all the moves made by other players. This addresses Design Requirement #2: enhancing family awareness instead of personal awareness.

4.3.4.1 Visual Representation of Activity Data

Each puzzle in the game includes a 24 by N grid, which visually represents the device and space usage traces captured in the participants' home on a particular day (see Figure 11). N equals the total number of *activity sources*—the devices and spaces tracked by the system in the home. Each row in the grid depicts the changing Activeness (as defined previously) of a device

[16] Chromecast. http://www.chromecast.com

or a space throughout a day, and each row is assigned to a unique color. Each square in the grid corresponds to a particular activity source's activity during a particular hour. The more the device or space was used, the darker the color of the square would become.

On the left-hand side of the puzzle, the devices and spaces where those activity traces originated are represented with icons and dots on a floor plan. The floor plan is hand-drawn by one of the family members during the initial interview.

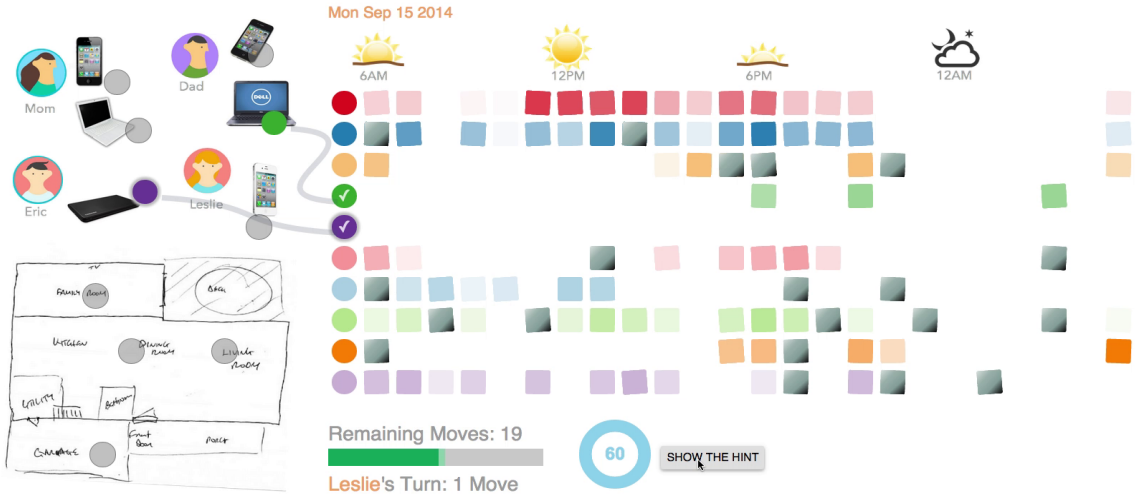

Figure 11: A Screenshot of the Home Trivia Game. The names in the screenshots are pseudonyms.

4.3.4.2 Objective: Identifying Activity Sources

The objective of the game is to match each color in the grid to an activity source, a device or a space that was responsible for generating activities represented in that color. To identify an activity source for a particular color, the player is expected to examine all the squares in various shades of the color, think about and possibly discuss with others what device or space's activity might be responsible for generating those activities represented in those squares, and then make an informed guess. This process addresses Design Requirement #7, which ties recalling technology use in the recent past to the progress the player can make in the game.

To link up a color and an activity source, the player can “grab” the dot in that color located in front of the squares and then “drop” it onto the gray slot near the target activity source on the left-hand side. The player will receive immediate feedback on whether or not he/she made a successful move. This feedback is crucial to provoke reflection because it allows the player to compare his/her existing beliefs and the reality observed by the system. Thus, it helps satisfy Design Requirement #3.

4.3.4.3 Challenges: Limiting Moves and Showing “Mystery Boxes”

In order to stimulate thinking, the game comes with two ways to discourage mindless trial and error. First, family members are required to identify all the activity sources within a limited number of moves. This constraint is expected to motivate players to think about events in the home that day before they make a match. Second, not all activity squares are made visible in a puzzle. Some of them can be hidden in those gray “mystery boxes.” The player can click on one of those boxes to reveal the Activeness of the hour it represents. However, doing so will cost the player a move. Thus, it is important to be strategic when deciding whether opening a mystery box will be helpful.

4.3.4.4 Collaborative Play

Family members play this game collaboratively instead of competitively in order to encourage exchanges of their thoughts and perspectives. This choice reflects Design Requirement #6.

In order to put children and parents on an equal footing as specified in Design Requirement #5, family members take turns in the game, thus each of them can have equal opportunities to help understand how they use technology and spend time at home. Each player can make the same number of moves when it is his/her turn. Every matching attempt will cost a move, and opening a “mystery box” will cost a move as well.

4.3.4.5 Hints: Identifying the Type of Activity

It is important to maintain players' confidence that they can eventually solve the puzzle. Therefore, each puzzle provides hints that identify the type of activity source (i.e. device or space) represented by a randomly selected color. A new hint will become available every minute until the type of every color has been revealed.

4.3.4.6 Reward: Playing Back the Rhythm of the Day

When a puzzle is solved, meaning all the colors have been matched to correct activity sources, the game will reward the players with a "victory" animation called *The Rhythm of The Day* (see Figure 12). The animation plays back the changing activeness of tracked devices and spaces in the home hour by hour over 48 seconds. The players will get a fast-forwarded recap of their activities that day and have another chance to think and talk about it.

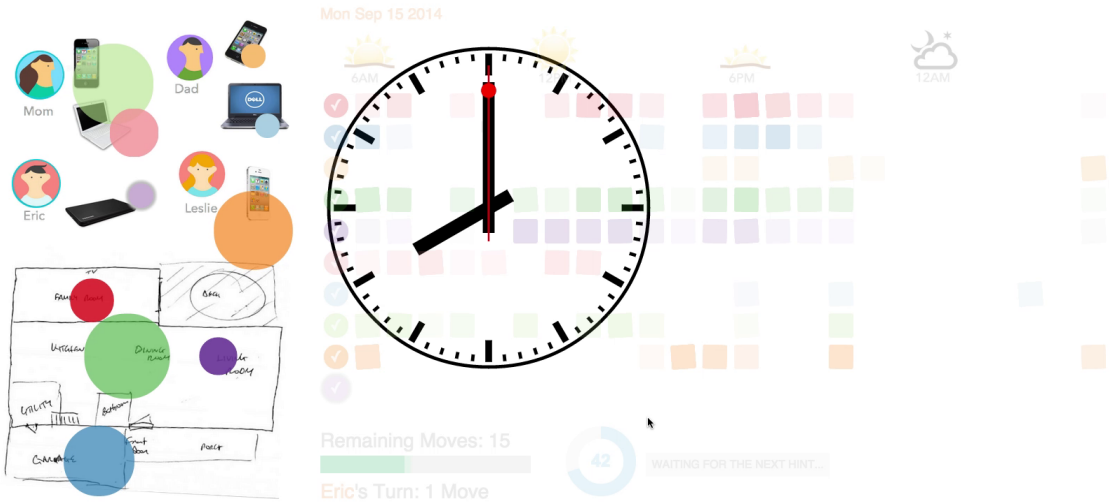

Figure 12: The Rhythm of the Day animation played when a puzzle is solved.

4.4 Field Study

4.4.1 Study Sites and Participants

To understand how Home Trivia might help families understand, talk about, and change perspectives on technology use in the home, we conducted a field study of Home Trivia with

five local families, after a pilot deployment in my own home. We recruited families that met the following criteria:

- use smart phones, tablets, or other kinds of technology at home
- have at least one child aged from 7 to 13
- have at least one device primarily used by a child
- live in or near Ann Arbor, MI

We recruited participants by posting ads to relevant mailing lists, public libraries, grocery stores, and schools. We also used snowball sampling in our recruiting process. Potential participants signed up for the study via a web form, where we asked a few questions to confirm their eligibility.

We specifically targeted families with at least a child aged from 7 to 13 because children in this age range start to have their own mobile devices and laptop computers (Lenhart, 2010). We believe it is beneficial for parents and children to engage in conversations about technology use at this formative stage when children start to develop habits of using technology.

Five families participated in our field study. We summarize the background, composition, and device ownerships of those families in Table 1. In the rest of the chapter, we also use abbreviations such as H01 (Household 01), F (Father), M (Mother), S (Son), D (Daughter), G (Grandmother) and H01-F (the father in Household 01) to refer to those households and their members. All names appear in direct quotes are pseudonyms.

	Household 01	Household 02	Household 03	Household 04	Household 05
Parents	Father, 40s (software developer) Mother, 30s (assistant to a psychiatrist, work from home)	Father, 30s (geographer) Mother, 30s (genetic counselor, part-time)	Father, 40s (grant officer in a foundation) Mother, 40s (research support staff) Grandma, 70s	Father, 40s (corporate tax specialist) Mother, 40s (stay-at-home mom)	Father, 30s (therapist) Mother, 30s (children's pastor)

			(retired)		
Children	Daughter, 9 Son, 7	Son-1, 9 Son-2, 7 *Daughter, 3	Daughter-1, 12 Daughter-2, 8	Daughter, 13 Son, 10 Non-participants: 2 older daughters aged 16 and 18 respectively.	Daughter, 12
Pets	Two cats	None	Two cats	Two dogs	One dog
Devices and Users	Father {Android phone, laptop} Mother {iPad, iPhone} Daughter {iPad} Son {iPad} Shared {Desktop PC, Smart TV, X-Box}	Father {iPhone, Laptop} Mother {iPhone} Son 1 {Kindle Fire} Son 2 {iPad} Shared {Roku, Desktop Mac}	Father & Daughter 2 {Black tablet} Mother {Android phone} Mother & Grandma {Nook 1} Daughter-1 {Nook 2} Daughter-1 & Daughter-2 {Brown tablet} Shared {Smart TV}	Father {Laptop, iPhone} Mother {iPhone, iPad, Laptop} Daughter-3 {iPhone} Son {Laptop}	Father {Android phone, Laptop} Mother {Android phone, Laptop} Daughter {iPod, Laptop} Shared {Smart TV}
User Test Time	Tuesday Evening	Sunday Morning	Friday Evening	Sunday Morning	Tuesday Evening

Table 1: Households participated in the field study of Home Trivia. * The 3-year-old daughter in H03 was technically not eligible to participate, but we added her to the game after she expressed extreme frustration when she was left out of the game.

4.4.2 Study Procedure

Each field trial involved three steps. The first step was a semi-structured interview conducted in the participating family's home. At the second step, we deployed the activity trackers to the participants' home. The final step was a gameplay session with the participating family.

4.4.2.1 Initial Interview

The initial interview was conducted with the parents, except that we interviewed both parents and a grandparent in H03. The initial interview served several purposes, including:

- Explaining the Home Trivia system and the field trial to participants.
- Understanding how the family uses and manages technology.
- Identifying the main family spaces and assessing the technical feasibility of deploying the space usage trackers in those locations.
- Learning about the families' routines and schedules, which we used to verify the data captured by activity trackers after they were deployed.

During the interview, the researcher employed techniques such as floor plan drawing, timeline exercise, and artifact walkthrough to elicit grounded responses from participants. In particular, the researcher asked the participants to draw a floor plan of their home and circle main activity spaces, annotate a week-view calendar with main family times, and show and tell devices in the home. Each interview lasted approximately for an hour, and it was audiotaped and partially transcribed. Please see Appendix B for the interview protocol.

4.4.2.2 Activity Tracker Deployment

Following the initial interview, we deployed the activity trackers on a subsequent visit. During the deployment, the researcher swapped the participants' WiFi router with the instrumented router with the logging capability. Usually, the researcher installed the space usage trackers at 3 to 4 locations in the house, mainly the family spaces identified by participants in the interview. Those activity trackers stayed in the participants' home for at least a week to capture activity traces.

4.4.2.3 Gameplay Session

In the gameplay session, the researcher asked household members (including children within the target age range) to solve several puzzles Home Trivia generated based on the device and space usage data captured in their home during the previous week. The researcher started this

session with a short introduction to the game including its controls, rules, and objectives. Then the researcher asked participants to practice, and the researcher provided necessary guidance. As soon as participants appeared to be familiar with the game, the researcher asked the parents to take over and run the game session as if it was one of their family game nights.

The researcher then retreated into the background and observed how participants went about solving the puzzles and reacted to the activity data revealed to them. When participants were done with 2 or 3 puzzles, the researcher asked whether they wanted to play one more puzzle or stop there. This question was intentionally directed to the child participants with the purpose to allow us understand whether the game was engaging to the participants. We call this question the play-one-more test.

When participants finished playing, the researcher conducted a quick debriefing with all the participants, including children. The researcher then asked the adult participants to fill out a short questionnaire and explain their responses. The gameplay session usually lasted about 70 minutes. The game screens were recorded, and the debriefing was audiotaped. Please see Appendix C for more details about the gameplay procedure.

4.4.3 Data Analysis

We analyzed the data collected from initial interviews and user tests to understand how participants interacted with the game and with one another in their families. We started with an initial analytical framework derived from the goals we set for Home Trivia, including facilitating communication, enhancing awareness, supporting reflection, and engaging family, as well as relevant prior work (e.g., Fleck & Fitzpatrick, 2010; Kiili, 2007). The initial framework included high-level themes such as Engagement, Remembering, Reflection, Learning, and Family Communication. This framework evolved as we analyzed each new case.

For each case, we conducted a three-step analysis guided by the latest version of the analytical framework. First, we reviewed and annotated the screen recordings of the user test. Each move

in the game session was tagged with a number of attributes and critical incidents listed in Table 2. Second, we coded transcriptions of the initial interviews and the post-test debriefings with the themes in the framework. Third, we wrote an analytical memo for the case to organize evidence and develop arguments. The memoing process also helped us update and refine our framework by developing categories and subcategories, refining definitions of concepts, and considering edge instances. The refined framework was then used to analyze the next case. After we finished analyzing all the cases, we applied the framework developed from this process to all the cases again to make sure our analyses were done consistently and thoroughly.

Attribute	Explanation
ST	The starting time of this turn.
ET	The ending time of this turn.
Player	The PID of the active player of this turn.
Speakers	Participants who said something related to the game during this turn.
Giving suggestions	Whether or not any inactive player gave suggestions to the active player
Taking suggestions	Whether or not the active player followed suggestions given by others
Outcome	Outcome of this move, e.g., success, failure, or opened a mystery box
Clicked Hint	Whether or not the Hint button was clicked during this move.
Revisiting	Whether or not players talked about past events, both in general or in specific
Reflection	Whether or not players reflected on their home life or device usage
Talk Tech	Whether or not players talked about technology use

Table 2: The attributes used to annotate each move in a game session

4.5 Findings

In this section, we report the results of our data analysis with a focus on Home Trivia's goals such as facilitating family communication, enhancing awareness, supporting reflection, and engaging families. Here we highlight some of the most important findings from our analysis:

- Having game content tailored to individual families and reflecting their home activities helped engage participants.
- Presenting activity traces in a way that required participants to act stimulated thinking, activated memory, and laid a foundation for reflection.
- Revisiting ordinary experience with one's family can be pleasant even though the experience itself might not be.

- Discrepancies between one's prior knowledge and the activity data could trigger reflection and foster changes of attitudes.

4.5.1 Engagement

Achieving Home Trivia's goal of enhancing awareness, reflection, and communication depends on how well it can engage users. To our relief, the field tests show that almost all of our participants enjoyed playing the game with their family members. Below, we describe evidence of engagement and identify elements in Home Trivia's design that fostered engagement.

4.5.1.1 Evidence of Engagement

We have a variety of evidence showing participant engagement, including the results of the play-one-more tests described in section 4.4, statistics of non-active players' participation, responses to the post-test questionnaires, and participants' remarks made during the game as well as in the debriefing.

First, when asked whether they wanted to play one more puzzle or stop, 17 out of 18 participants wanted to start a new puzzle. Some child participants even showed disappointment when they realized there was only one puzzle left. Consider the following dialog in H01:

> *H01-S: Play one more then we're done?*
> *H01-M: Yep. It's late, guys. Sit down.*
> *H01-D: Aw…. It's a fun game.*

Second, we found that non-active players, people who were waiting for their turn, continued paying attention to the game and continued participating by offering help to the active player. For example, in H04 there were about 2 non-active players (out of 3 in total) on average talking about the game (e.g., making suggestions, recounting events, or going through remaining options) during each turn.

Third, 10 out of the 11 adult participants strongly agreed with the statement "I found the game engaging" in the post-test questionnaire, and the remaining one somewhat agreed with the statement. Asked to choose up to five words to describe their experience with the game, five participants circled "Fun," making it the most popular word.

Finally, some participants told us about how the game engaged their family in an unexpected way during the debriefing. For example, the parents in H04 told us that playing the game reversed their children's initial negative attitudes towards the study as yet another thing their parents made them do. The father said:

> *What was neat about it was that kids were also [enjoying it]. [At first,] They were quite negative and didn't want to do it. They didn't want you here, didn't want your monitoring equipment, and didn't want to play your game. So it's nice to see [they liked it]...It was neat to see how much fun they had. (H04-F)*

4.5.1.2 Elements of Engagement

Participants found the game fun for reasons that were directly linked to the activity data captured by the system, the cooperative interpersonal theory of action the game supported, and the role frame family members adopted in the game.

First, participants were pleased to find that each puzzle in the game was uniquely created based on their activity data. As the mother in H04 said:

> *I've never seen a board game talking specifically about things that you do. It's tailored to us. (H04-M)*

What made household-specific content so interesting? Our participants suggested three reasons. The first reason was that the tailored game content provided information participants were interested in learning about, and as the grandmother in H03 said, "I think it was entertaining in the fact that it told us about us." The second reason was that game content generated from a family's activity data helped connect family members. The mother in H04 told us, "I thought you got yourself involved in talking with each other about something that we all

have in common, yet it's different from any of the board games you play. I think that's why it's engaging." The last reason was that making the puzzles tailored to the family seemed to elevate the meaning of making a correct move in the game; as the mother in H04 added, "It made it more personal and we were more interested in getting it right, because it showed how much you know the people in the family."

Second, the game's collaborative play mode helped foster and maintain engagement. The daughter in H04 told us that "the teamwork and thought you have to put into it" was the most interesting part of the game. Her father agreed with the sentiment, and he particularly appreciated that the game mobilized everyone in the family:

> *It was neat to use everybody's experiences and thoughts. Even Tim (H04-Son) became quite perceptive. That was good. (H04-F)*

The game statistics supported his perception. In H04, the active player received suggestions from other family members 6 out of 10 turns. The active player usually followed those suggestions.

Furthermore, the father in H03 thought collaborative play helped sustain the engagement. He compared Home Trivia with the board games they had played before, in which they competed with one another:

> *Board games usually are [played together], but then someone gets upset 'cause they're losing or... Then people quit and walk away, and so we sometimes have a hard time with games. But there's no winners and losers in this, so that kept everyone going. (H03-F)*

Last, some child participants appreciated the fact that the game put them and their parents on an equal footing by giving them equal access to the game as their parents and allowing them to see everyone else's device usage patterns in addition to their own. Across all the households, children were active contributors to the resolution of the puzzles by either making thoughtful moves when they were playing or helping others recall and recognize activity patterns while

they were waiting for their turns. Most parents gave their children credit when they did something right or helpful, and that further motivated them to keep participating in the game.

Doing well in the puzzles gave children more than bragging rights. Some of them felt empowered. For example, when asked what the most interesting part of the game was, the son in H04 told us:

> *It makes those (his parents and sister) understand that I know best, so they should always listen to me. But still they don't. (H04-S)*

His remark made his family chuckle. His mother then asked whether he would want to play the game again. He responded by nodding his head.

4.5.2 Revisitation

Soon after they started playing, participants realized that they needed to think about what they did on the particular day represented by the puzzle in order to win the game, just as we anticipated. This is important, because participants' enhanced awareness of their recent behaviors and the state of affairs in their homes was a necessary condition for them to reflect on how they spent time at home, according to the five-level framework of reflection by Fleck and Fitzpatrick (2010). In the rest of this subsection, we would like to characterize the content, conditions, and experience of our participants' revisitation of past events based on our field observations.

4.5.2.1 Revisiting the Past, General and Specific

Most instances of revisiting the past involved thinking about the general patterns of recent activities in the home. It was usually a good starting point to determine an activity stream's source because as the father in H04 said, "We are such creatures of habits." Based on our observations, participants would often start thinking about their activities by identifying the type of day (e.g., weekend vs. workday/school day, or a mom-stays-at-home day vs. a mom-goes-to-work day), and then they would consider their usual schedules and usage of their

devices on days of that type. When participants were talking about their schedules, they paid special attention to the events that could carry the most information about their activeness or presence in the home, such as leaving for work, coming back home, going to bed, etc.

Although this type of knowledge was relatively general, it often helped participants narrow down the choices they were facing. Nonetheless, participants did sometimes mention or recount specific events and experiences. That usually happened in situations such as: the general knowledge was not adequate in narrowing down choices; the outcome of a matching attempt ran contrary to the participants' belief and they needed to make sense of it with an alternative explanation; or the participants found reminiscing about a past event interesting in its own right. Below, we further explicate the situations and manners in which participants revisited the past.

4.5.2.2 Recognizing, Reminding, and Reminiscing

According to Casey (2000), "memory shows itself" in 3 forms (or mnemonic modes) that carry different experiences from one another. Our analysis revealed that all three modes, including *recognizing*, *reminding*, and *reminiscing*, were present when our participants were playing the Home Trivia game.

It is not surprising that *recognizing* was the most common mnemonic mode observed in our field tests, since the central task in the game could be considered as recognizing devices and spaces from the visualization of their activity traces. However, identifying a recognition process could be a challenge sometimes because participants could identify a device very quickly without fully verbalizing their thought process. Consider the following dialog:

> *H01-D: It's after 2 [pm]…*
> *H01-M: Hang on. Let's see what it goes to.*
> *H01-D: It's probably an iPad…*
> *H01-M: 6, 7, 8.. till 8. I'm guess that's probably Owen's iPad.*

Did the mother consult her memory or did she just know it? We believe she implicitly drew on her memory, because as Casey (2000) argued, "we cannot recognize something we have not encountered before at some point and in some way" (p. 126). In his view, the act of recognizing involves trying to *merge* what we experienced in the past with what we just perceived in the present in a covert manner. Recognition depends on one's ability to summon his/her past experience, albeit at a varying level of specificity.

When a device or a space was recognized correctly, participants felt that their memory or knowledge was validated by the data captured by the system. In other words, it was a sense of "making it official," according to the mother in H02.

Next**,** activity traces displayed in the game could serve as reminders of past events when their sources were not immediately recognizable. In that kind of situation, the participant often felt an urge to search her particular memories beyond the big picture, in order to account for the existence or absence of activity during a particular period of time. The outcome of this process could *remind* the participant about an event that did not make a strong impression on her and was being forgotten. For instance, the following dialog shows how the seemingly odd activities in an early morning reminded the parents in H04 that their eldest daughter left home at dawn for a hockey game:

> *H04-F: So purple was one of the rooms, and there was a slight bit of activity in the late.*
> *H04-M: [I was] checking on the dogs.*
> *H04-F: So who was up 5 to 6, doing stuff?*
> *H04-D: Biscuit (one of the family dogs).*
> *H04-M: 5 to 6. Hmm...*
> *H04-F: Kelly (the eldest daughter who did not participate in the study) was up.*
> *H04-M: Yeah, you're right.*

Finally, because of the collaborative nature of the game, family members recounted past events together, with one correcting or complementing another's story. According to Casey (2000), "remembering with others" (p. 105) is the essence of reminiscing. Participants often started reminiscing when they were bewildered by the activity traces displayed by the game:

H01-F: We went to your parents' house on Saturday, didn't we?
H01-M: We did.
H01-F: Interesting.
H01-M: But we have cats. So I'm guessing the orange is some place the cats would have been.

Participants also engaged in reminiscing in a more deliberate manner. For example, the mother in H04 proposed it as a new strategy after reflecting on how they had been playing the game:

H04-M: Maybe we should go by person rather than looking at the screen so much.
H04-F: Yeah.
H04-F: So, Friday I got up early.
H04-M: That's right, before 6 AM.
H04-F: Is that right?
H04-M: Seems like it.
H04-F: No, Thursday I got up real early. Thursday I got up like 5.
H04-F: So Friday… In fact, your alarm woke me up at 6:40.
H04-M: Okay. Oh, Wow.
H04-F: So I think [my phone is] not red, the first one.

Recounting those mundane bits of everyday life might look uninspiring on paper, but it appeared to be delightful to the participants involved according to our observation in the field. In addition to the above example, the father in H04 was amused when he found that the activity trackers captured his foray into the dining room at 2 AM to finish some overdue paperwork on his laptop. He was eager to tell his family about it, and everyone laughed when they saw that event showing up again in the Rhythm of the Day animation played after they solved the puzzle:

H04-F: Boom! Daddy wakes up.
[Everybody laughs]

To sum up, displaying activity traces as the content of puzzles seemed to be effective in encouraging participants to call upon their memory, which was a precursor for reflection.

4.5.3 Reflection

Though Fleck and Fitzpatrick (2000) provided a framework to assess reflection, there is still considerable amount of gray space between recognizable reflection and simple recollection of past events. For example, the mother in H02 thought the information displayed in the puzzles

made what she knew official. This statement could be interpreted as a simple acknowledgement of the perceived accuracy of the activity representation in the game. However, it can also be seen as reflective because her statement implied an evaluative process she undertook in the game which resulted in the conclusion that she did in fact know what was happening in her home. There were many instances of this kind of reflection in our field tests. They were brief, non-dramatic, and sometimes not fully articulated, but they led participants to a better understanding of their behaviors, attitudes, and the state of affairs in their homes.

We also observed more clear instances of reflection that often involved articulating a changed perspective. According to Fleck & Fitzpatrick (2000), the second level of reflection—Dialogic Reflection—is characterized as "consideration of different explanations, hypothesis and other points of view" (p. 218). Our participants adopted new perspectives because Home Trivia allowed them to rediscover the meaning of a past experience, to check their presumptions against reality (as indicated by the activity data), or to receive feedback from the game or other family members.

4.5.3.1 Rediscovering Past Experience

Let us first return to the example we described earlier about the father in H04 who got up at 2 AM to finish some overdue paperwork. He probably felt frustrated when he realized that he had to do that. Yet, when he was reminded about the event a few days later by the traces displayed in the Home Trivia game, he made fun of this experience. He considered it such an interesting moment in his predictable everyday life that he wanted to share his "suffering" with other family members and the researcher.

What changed his attitude towards this event? Goldie (2012) suggested that people can take a different emotional or evaluative perspective on a past event when they look at it again (as cited in Sutton, 2014, p. 2). Harper et al. (2008) also supported this view. They conducted a study in which they asked participants to view old photos taken by SenseCam, a wearable camera that automatically takes pictures to record your life. The study found that participants

were able to shed a more positive light on events they initially reacted to with negative emotions.

4.5.3.2 Checking Reality

Participants also learned something contrary to what they believed to be from the activity traces presented in the game, and that often provoked reflection.

In the initial interview with the parents in H04, the mother said she was worried that they used electronic devices too much. She specifically mentioned that her son liked playing games on his laptop. However, that perception turned out to be inaccurate, at least on warm days. During the debriefing, she told us:

> *When you asked me last week, I would say he was on the computer all the time. [Laugh] But actually that showed his computer had the least usage. (H04-M)*

This discrepancy between her impression and the reality triggered reflection. Seeing that her son was not on his computer as much as she believed, the mother reported that it made sense after thinking about it:

> *Because when I thought about it he was outside awful a lot. He would come home from school doing his homework and he was gone until it was dark. And then he would get on it a little bit, but [not very long]. (H04-M)*

She further reflected that she probably has "nagged" her son too much about computer usage.

4.5.3.3 Receiving Feedback

Another situation where participants reflected on their behavior was when they switched from a first-person view of their experience to an observer view when they received feedback either from the system or from other family members.

The mother in H01 realized that she probably should get off her phone more often after her daughter showed surprisingly good knowledge of her technology-use habits and would

attribute any device usage late in the night to her. The mother then said the following during debriefing:

> *You can tell my patterns because I'm the night owl… So if it's between the hours, like she (her daughter) even said, if it's between the hours of 10 and midnight, it's me. (H01-M)*

> *It did [inaudible] me to put down my phone a little bit more. (H01-M)*

Similarly, seeing one's own device usage pattern mirrored in the game could also prompt reconsideration of one's lifestyle. For example:

> *I am on my phone quite a bit, and I kind of already know that. But visually seeing it is... That makes me feel a little bit like I should probably not be on my phone as much as I am (H02-M).*

4.5.4 Communication

One of our goals of designing Home Trivia was to improve how parents and children talk about technology use. We have seen that potential in our field study. Here, we would like to describe the existing mediation strategies used by our participants, and then characterize the parent-child communication that occurred when participants played Home Trivia. This comparison will show the unique value of incorporating Home Trivia into a family's toolbox for managing technology use.

The parents among our participants were no doubt self-selected towards being conscious of technology use. Therefore, they had adopted several common strategies to mediate children's technology use at home. The first strategy was imposing rules and protocols that parents expected their children to follow. Those rules and protocols could limit where children can use devices (e.g., no electronics in the bedroom), what websites they could visit (e.g., permission required to open a webpage), and who they could talk to online (e.g., approval needed to add a friend on social media). The second strategy was monitoring children's device usage and stopping them when it was deemed excessive. The mother in H02 would ask her sons to estimate the amount of time they needed. If she agreed, she would set a timer. Lastly, one of the households actively practiced co-use of technology. However, co-use was largely limited to the shared desktop computer located in the kitchen.

Though it seems that those parents had several methods at their disposal to mediate their children's technology use, regular and open communication was lacking. It was revealing to hear that from the mother and grandmother in H03:

> *Researcher: Did you talk about this (technology use) with anyone in your family before?*
> *H03-M: Other than saying, "Would you get off the tablet? Would you get off the tablet? Would you get off the tablet? Would you get off the tablet now?" [chuckle]*
> *H03-M: No, not really [talked about it]. [laughter]*
> *H03-G: Literally take it out of their hands and pull it out of their ears.*

This kind of knee-jerk reaction was in contrast to the dialogs families had when they played Home Trivia. First, Home Trivia allowed participants to notice and talk about positive behaviors of technology use, instead of focusing on correcting problems. For example, the mother in H02 was pleased to learn that she did not watch TV (via a media streaming device called Roku) as much as she thought, "Wow, I was pretty good with the Roku that day!" Second, the conversations around technology use tended to be evaluative rather than reactive, since the event in question was in the past rather than ongoing. Participants would seek explanations and clarify expectations of future behavior. Consider this dialog:

> *H04-M: What time was that? Was it midnight? 11 O'clock. You need to stop that.*
> *H04-D: That's because I didn't set the alarm. I forgot to. Then I woke up at 11, and then [I set the alarm].*

4.6 Discussion

4.6.1 Reflective Play: A Design Approach

Our analysis has shown that the Home Trivia game was engaging to both the adults and children who participated in our field study. Moreover, our data indicate that their engagement with the game led to increased awareness of their past experience, new opportunities to talk about technology use, and reflections on how they used technology as well as how they spent time at home.

We were especially pleased to find that the reflective aspect and the playful aspect of the system seemed to support one another in the field trial. In other words, our participants were able to engage in *reflective play*, which was enabled by two specific design choices in Home Trivia.

4.6.1.1 Reducing Ambiguity through Play

First, we intentionally chose to provide activity tracking results with "missing information" (i.e., the links between activity patterns and their sources), in order to leverage participants' curiosity about their own behaviors in the past. Home Trivia then allowed those participants to take actions in the game to satisfy their curiosity. The mother in H02 agreed with us on the effectiveness of this strategy:

> *Playing it in a game really makes you think more about devices and how much family members use it. It's a different way of using your brain to think about it. Other than, let's say, if you did it in like wrote us a report, [chuckle] I think that's not gonna be... It's not as interesting or fun to learn about it in that way than playing it with the game. (H02-M)*

Our approach bears some similarity to Gaver's idea of using ambiguity as a resource for design (Gaver et al., 2003), but our design has a key difference. Not only does the Home Trivia game introduce ambiguity into the representation of activity data by withholding the links between activity patterns and their sources, it also makes it very clear that players can reduce this ambiguity by using their memories, exchanging ideas with one another, and experimenting in the game.

The behaviors we observed in our field tests suggest that it is engaging to work on a meaningful problem that is solvable. Moreover, as the user tries to resolve the ambiguity in the relationship between an activity stream and its source, the user has many opportunities to check whether his/her existing beliefs match the reality revealed in the data captured by the activity trackers based on the feedback he/she receives from the game. In section 4.5.3, we have shown that this allowed some participants to experience cognitive dissonance, which then triggered

reflection. Thus, this technique of reducing ambiguity through play addresses both the second and the third research questions of this dissertation:

> *R2: How can we use ambiguity as a design resource to trigger reflection that goes beyond understanding the meaning of representations?*
>
> *R3: How can we adapt problem-based gaming (PBG) to allow users to reflect on certain aspects of their lives instead of subject knowledge?*

4.6.1.2 Social and Directed Co-interpretation

Second, we made specific design decisions to make sure that the gameplay would facilitate the kinds of family interactions we wanted to support. For one thing, the turn-taking aspect of the game put children and parents on an equal footing and thus encouraged all family members to contribute their knowledge. For another, the collaborative play mode encouraged information sharing among family members and helped create opportunities for conversations.

Our work extends the co-interpretation approach advocated by Pousman et al. (2008) in the Tableau Machine project. The idea of co-interpretation is to leverage users' curiosity and ability to find meaning to complement a computing system's understanding of sensed data. Home Trivia broadens the notion of co-interpretation in two ways. First, co-interpretation in Home Trivia is social. It is not only a process between the system and users but also between family members. Home Trivia enables them to consolidate and compare knowledge, which used to be private. Our field study also shows that our participants regarded such teamwork as one of the fun factors of the game. Second, co-interpretation in Home Trivia is directed by the objective and structure of the game. Home Trivia helps users to focus their co-interpretation on identifying each activity stream's source. Combining these two aspects, we call this approach *social and directed co-interpretation*.

Characterized by the above two aspects, *Reflective Play* is a design approach we would like to advocate for creating integrated experiences for people who are both by nature playful creatures and reflective learners.

4.6.2 Limitations

We would like to acknowledge the study's limitations related to the sample, the duration of each trial, the way reflection is assessed, and the design of the system.

First of all, the number of homes in which we tested Home Trivia was small, though it was on par with prior work in this space (e.g., Gaver et al., 2007; Pousman et al., 2008; Chetty et al., 2010). Furthermore, the families who participated in the study did not have enough diversity in terms of their socio-economic status, education, and ethnicity, due to the geographical constraints of our field study and potential selection bias.

Second, each field trial lasted less than two weeks and the game was tested only once for about an hour in each trial. While we believe getting quick feedback from participants is valuable, especially for the first study of this kind of system, the limited duration of the trials prevented us from fully understand the novelty effect, learning effect, and potential ways to incorporate the game into the routines of busy families.

The learning effect we observed in our study was that some participants started to remember the visual pattern of a device or a space's activity and use that pattern to recognize the same device or space in a new puzzle. In other words, the recognition of activity patterns might be able to persist, making revisiting the past less necessary or explicit over time. Therefore, future versions of Home Trivia should probably identify deviations from users' normal routines and prioritize special days (or weeks) to keep users interested in the long run.

Third, constrained by the short duration of each deployment, each puzzle in the field trial of Home Trivia only showed data from a particular day, as opposed to, say, a week or month in aggregate. We do not know if representations at other levels of granularity might have been more or less engaging and thought provoking when used as game content, though the results of our study show that representing a day's worth of data in a puzzle can engage family members and provoke reflective thought.

Last, assessing reflection directly proved difficult, though we handled that with extra care in both the system design and our study protocol. The challenge was on several levels. First of all, reflection is often an unarticulated mental process. Secondly, Think-aloud Protocol (Ericsson & Simon, 1980), a common technique researchers use to ask participants to verbalize their thoughts, was inappropriate in our study because verbalizing one's thoughts can help and even trigger reflection. Instead, we wanted to observe what families would naturally talk about during the game. We mitigated this problem by making the game turn-based and collaborative. This arrangement gave participants a genuine motivation to share their thoughts with one another in order to coordinate their puzzle-solving efforts. Nonetheless, participants obviously did not verbalize every thought they had, and some participants were more articulate than others.

4.6.3 Future Work

The promising results of our field study as well as its limitations warrant further investigations in several aspects. First, a longitudinal study is needed to understand how families might integrate Home Trivia to their home lives and how the opportunity of seeing their activity traces in the game might impact their technology use behavior in the long run. It would be especially interesting to see how children might change the way they think about the game as they grow up.

Second, the sensing infrastructure of Home Trivia can be improved to capture more types of data. For example, low-powered Bluetooth beacons can be deployed in the home to enable localization of devices. This data can provide additional context to device usage. However, to introduce new types of data to the game would require creative redesign of the game interfaces and game mechanics in order to take advantage of the additional information.

Last, we should expand our design effort from designing a system to designing a family activity, which includes components that are supported by technology and components that are not.

For example, it would be useful to design and experiment a form of post-game reflection session that can be run by the family instead of the researcher. One idea is to include personalized questions and the ability to pause during the Rhythm of the Day animation that played after each puzzle is solved.

4.7 Conclusion

In this chapter, we have presented the design and a field study of the Home Trivia system. Home Trivia captures device usage and space usage in the home through an instrumented router, acoustic sensors, and motion sensors. Home Trivia then uses the captured activity traces as the content of a puzzle game family members can play together for the purpose of raising their awareness of how they spend time at home and triggering their reflections on technology use. The participants in our study found the game engaging and thought provoking. Home Trivia expands the emerging design space of using domestic sensing to support reflection. Home Trivia also represents a new design approach in this space called *Reflective Play*. Adapted from Problem-based Gaming in education, Reflective Play makes engagement and reflection reinforce each other in the home context.

CHAPTER 5

Reflective Inhabitation: Designing with Traces of Places[17]

5.1 Introduction

With advances in sensor technologies and the Internet of Things, many everyday places seem to be gaining some capability of capturing our activity traces. Some sensors are already widely deployed. For example, many buildings have occupancy sensors installed to control lights. Soon, not only our occupancy but also our movement in a space will be captured through the latest generation of commercially available indoor localization technologies such as iBeacon[18]. There are many exciting developments in both academic and industry laboratories that allow everyday environments to track, understand, and augment our activities in them (e.g., the assorted sensors described in Hnat et al., 2011). It has been widely acknowledged that those technologies have the potential to change our relationship with the places where we live, work, and play by making them more responsive to our needs and habits. However, how should we deal with the enormous amount of activity traces those instrumented environments will be amassing in the long run? Should we allow them to keep our traces and for how long?

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[17] I primarily conducted this study with some guidance from my advisors Mark S. Ackerman and Mark W. Newman. An earlier version of this chapter has been published at the ACM Conference on Designing Interactive Systems (Dong, et al., 2014).

[18] iBeacon. http://en.wikipedia.org/wiki/IBeacon

In this work, we explore potential uses of activity traces captured by an instrumented space on a timescale of decades with a focus on how such traces might be used to support reflection. We fear that without understanding the long-term value of activity traces bound to a place, people will make an immature decision to discard those traces after they fulfill their immediate purposes, such as automation and personalization, because the perceived risk of privacy breach will easily outweigh the perceived benefits.

We would like to argue, through the study and design concepts presented in this chapter, that human activity traces left in a place constitute an important part of our collective memory about and beyond the place, and a critical function of such a memory is to allow us to look back and reflect on the transformation the place has undergone. Therefore, in this study we sought to answer the fourth research question I proposed in chapter 1.2:

> *How can we use traces, especially traces accumulated over time in a place, to provoke reflection, and what is the character of the reflection provoked by such traces?*

To answer this question requires us to put ourselves in the shoes of people in the future and anticipate how they might interpret, use, and act on the traces their predecessors left. Would they even care? Indeed, it is difficult, if not impossible, to predict the future, but we might be able to provide some hints by studying people's practice in the present, which could be considered as the future of the past. Therefore we explore our research question indirectly by examining how people of the present make sense of and make use of the traces left by their predecessors in the place they live.

To ground our inquiry, we studied how previous occupants' traces of inhabiting and appropriating a house were interpreted and used by current homeowners. We chose the house over other types of places for several reasons. First, the home is becoming one of the most instrumented places with which we all interact regularly, as numerous commercial products and research systems have sought to put sensors in domestic environments. Second, every owner of a house leaves long-lasting personal and family marks on the house through

remodeling and reconfiguring the space, and these marks often carry significant meaning. Lastly, the house, usually considered private, helps us consider privacy and ethical implications when we design systems that enable potential social uses of traces in it.

To do this, we conducted a field-based study in the US Midwest by interviewing 24 homeowners in their houses. Our study was focused on the current practices, motivations, and consequences of seeking, reusing, and documenting the past of their residences. To obtain grounded data, we situated our interviews in a show-and-tell-style exercise in which the participant presented traces of previous use and appropriation of the space, including old architectural and decorative elements, results and records of home improvement projects, and artifacts and stories related to the house's history.

We found that our participants obtained access to a variety of traces indicating their predecessors' appropriation of their houses in building plans, photos, oral histories, and material remnants. Though those traces were often highly fragmented, they helped our participants engage in reflection for both practical and evocative purposes. Specifically, our participants used those traces to guide their own appropriation of the house, to reflect on the changing lifestyle, fashion, and community dynamics, and to identify and connect with their local community by understanding their houses' historical background. Furthermore, we found that many traces were socially preserved and passed on. This social aspect of keeping and evoking memories of a house constituted an important part of many participants' experience of connecting with the past through their houses. Lastly, we note the role of the mutability of the house in shaping participants' attitudes towards creating and passing on traces.

How might those findings from studying "the future of the past" shed light on potential ways of using our digital traces left in a place decades later? Returning to this research question we originally set out to answer, we illustrate the design implications of our study with three design concepts. The first two concepts, Footprints and Phantoms, consider potential uses of accumulated occupancy and indoor location traces for practical and reflective purposes

respectively. The third concept, Stewards, explores potential ways to honor the social nature of remembering a place. We then discuss privacy and ethical implications of long-term social use of such traces.

This study then offers two contributions:

- We identified and characterized potential long-term uses (including supporting reflection) of activity traces captured in places.
- We offered three design concepts to illustrate how the findings of our study can inform the design of systems that use digital traces captured by smart environments in the future.

5.2 Related Work

Our exploration of the long-term value of preserving and reusing activity traces left in a place can be considered from two dialectic perspectives: using objects and places to augment memories (broadly construed as explained later), and vice versa. Below, we provide an overview of the research on these two topics to contextualize our study.

5.2.1 Using Objects and Places to Augment Memories

How can we use objects and places to augment memories? The shifting focus of research on this topic suggests that the answer to that question depends on what we think memories are and do in the first place. Numerous design and technical studies in HCI have used objects, mostly digital, to store information to complement the user's native but unreliable memory (e.g., Freeman & Fertig, 1995). Motivated by increasingly affordable and pervasive capturing devices and storage space, these so-called lifelogging applications, depict a vision of "total recall" through "total capture."

The overall uptake of those lifelogging systems has been disappointing, and researchers (Sellen & Whittaker, 2010; Whittaker et al., 2012) have pointed out some of their most critical

shortcomings, especially viewing memory as a repository of factual knowledge. Sellen and Whittaker (2010) argued that there are five different ways technology can help us connect with the past, including recollecting, reminiscing, retrieving, reflecting, and remembering intentions. In contrast, early lifelogging systems rarely supported anything beyond recollecting and retrieving.

The versatility of objects in their ability to connect us with the past was further uncovered in a field-based study of home archiving practices conducted by Kirk and Sellen (2010). What was particularly interesting in that study was that an object could connect people to a past that they had never experienced firsthand, e.g., their parents' childhood. Nonetheless, this past was a part of the family memory. In that sense, objects appear to help move memories from an individual to the family, and potentially to a larger community.

In addition to the manifold ways objects can bring the past closer, researchers have also noted a distinct advantage of physical objects over digital objects. Whittaker et al. (2012) argued against early lifelogging systems with the notion of "digital invisibility." Citing findings of an ethnographic study which contrasted physical and digital mementos in the home (Petrelli & Whittaker, 2010), the authors argued that digital mementos were less salient than their physical counterparts, partly because it was much more difficult to integrate digital mementos into everyday life than it was physical ones. Based on this study, Whittaker et al. (2012) included Embodiment as one of the four design principles for what they called socio-technical lifelogging. In particular, they suggested embedding digital information about the past in physical objects that users can use or encounter in their everyday lives. Family Memory Radio (aka. FM Radio) is a fine example designed based on this principle (Petrelli et al., 2010).

What is more relevant to our inquiry is phenomenologist Edward Casey's notion of Place Memory, a particular type of memory mediated by and attached to places (Casey, 2000). Casey's analysis suggests that a place with its stable peculiarities provides natural points of attachment for memories congruous with it, while making other memories seem out of place.

Morton's fieldwork with a southern African tribe further shows that houses and things therein bring about memories of past events or other places (Morton, 2007).

In a bizarrely interesting case related to remembering through places, DeSilvey (2006) examined an abandoned house in the process of decay and described how her engagement with the house's material remnants sparked reflections on the area's once robust economies and particular ways of life. She stated, "Memory, in this sense, is based on chance and imagination as much as evidence and explanation; the forgetting brought on by decay allows for a different form of recollection." This view further problematizes and expands the view of memory as a data repository, manifested in the design of early lifelogging systems.

5.2.2 Using "Memories" to Augment Objects and Places

As the earlier work described above has shown, objects and places play an important role in connecting us with the past in many different ways. However, research has also shown that objects and places can become more interesting, useful, and evocative when they carry "memories," including data, narratives, or traces that show their historical existence.

In the context of the Internet of Things, researchers have explored embedding information in physical objects. Early work in this area was focused on embedding factual information (usually the provenance of an item) to facilitate product lifecycle management (e.g., Schneider & Kroner, 2008), and most of this work has been technical. However, recent work has started integrating stories with everyday things. For example, de Jode et al. (2012) reported a particularly interesting case in which celebrities donated clothing to a charity shop and attached stories about where they had worn each item using a system called Tales of Things (Barthel et al., 2013). This case study demonstrates how mundane items can be instilled with meaning given the right memory narratives.

Another way of augmenting an object with memories is preserving and presenting the traces of earlier interactions with the object. Examining traces from materialistic perspectives, Rosner et

al. (2013) identified three different kinds of material traces. First, traces of use indicate activities involving the object. Second, traces of skill reveal object users' techniques and expertise. Lastly, traces of time stress the temporal attributes of those activities such as starting time and duration.

An early example of using traces to augment objects in HCI was the read wear and edit wear interfaces created by Hill et al. (1992). These interfaces allow digital documents, mimicking their physical counterparts, to accrue and show "histories" of interacting with them over time. The authors argued that such "computational wear" could support "reflective conversation with work materials," central to Schön's analysis of professional work (Schön, 1983). The idea of computational wear has been applied in a variety of domains, including software development (DeLine et al., 2005), web browsing (Wexelblat & Maes, 1999), software training (Matejka et al., 2013), etc. However, these systems were focused on augmenting digital objects instead of physical ones.

With the growing interest in ubiquitous computing, HCI researchers have started using digital traces to augment physical spaces and objects. For example, Boehner et al. (2005) designed Imprints, a handheld system that allows museum visitors to leave personal marks on artifacts they looked at. It also allows the visitor to see other visitors' digital marks to get a sense of collective presence. Gaver et al. (2006) created History Tablecloth, where an electroluminescent layer displays a glowing mark when an object is placed on it. Those marks, gradually fading away after objects were removed, visualize the flow of objects in the home. Nonetheless, both studies were focused on augmenting a space with relatively recent traces of people's activities in it.

Our analysis and design, though with a distinct focus on the appropriation of domestic spaces and the traces accumulated over a very long period of time, builds upon this earlier work in the following aspects: 1) taking a constructionist view of memories and recognizing many ways of remembering beyond recollection and retrieving, 2) highlighting the role played by objects and

places, especially physical ones, in mediating not only personal memories but also collective and social memories, and 3) showing that abstract traces can be as powerful as narratives in augmenting objects and spaces.

5.3 Study Design

To understand how current homeowners might interpret and use activity traces left by their predecessors in their houses a long time ago, we interviewed 24 homeowners from 20 different households in their homes. We recruited them through an open mailing list, word of mouth, and snowballing. Among them, 15 were males and 9 were females. These householders had all done substantial home repairs or improvements to their houses, and 17 of them were involved in at least some amount of home do-it-yourself (DIY) work, though the types of projects and sophistication varied greatly from household to household.

Our participants' houses were all located in the Midwest US, and the houses, on average, were built 94 years ago at the time of the study. We targeted older homes in our study because they were more likely to contain traces from prior inhabitation and appropriation.

We conducted semi-structured interviews with participants in their homes for approximately an hour each. We started with several factual questions such as: *When was your house built? How long have you been living here? Who does home repairs in your house?* We then asked each participant what they knew about the house's history, who had lived there before them, and how they learned about the past of the house.

With this general understanding of the house and the participant's awareness of its past, we then asked each participant to show us a few home repair or improvement projects done in the past either by them or their predecessors. During this tour of projects, we probed how they dealt with traces of prior work (or lack thereof) when they were trying to modify or appropriate the place to fit their own needs and tastes. We asked questions such as: *Was there anything*

surprising or unexpected in this project? What guesswork did you have to do? What did you learn about the house from this project? If the participant had records about the house, we asked about whether those records were useful in these projects. The home tour and walkthrough of artifacts and records also occasionally took us back to discussing the broader historical background of the house and the neighborhood.

During the tour, we also asked about the participant's practice of documenting his/her home improvement projects, and asked the participant to show us records or photos they had. Lastly, we asked the participant to consider a hypothetical question: What would you pass on to the next owner when you move? Throughout, the participants were probed with general questions, such as *In general, what are you interested in doing with your house? Why?* We found the participants' rationales perhaps the most significant data.

All interviews were audio recorded and later transcribed. We also took pictures in the participant's home during the projects tour. We coded the transcripts to develop categories under several high-level themes such as forms of traces, origins of traces, uses of traces, etc. We also frequently used the memoing technique to synthesize our understanding of the data and consolidate findings across cases.

5.4 Findings

Our fieldwork has led us to a holistic understanding of origins, forms, and uses of traces in the house. In this section, we first describe what and where those traces were through two case studies, and then we detail two main ways our participants used those traces: providing information and evoking reflection or emotion. Furthermore, we highlight the mutual constitution of memory and its social context. Lastly, we touch on the perceived mutability of the house and how that influenced the practice of keeping traces for the house.

5.4.1 Origins and Forms of Traces

We identified three major forms in which traces of previous appropriation of a house existed. They are records, people, and building materials. We present two cases below to illustrate what those traces were and how they were discovered and used. These two cases also provide a necessary context for understanding the rest of this section.

Case P05: Traces in records and people

P05 has lived in her 1900s home for 12 years in a village where she grew up. When she bought the house, a family who previously lived there had converted it into three apartments. Immediately after buying the house, P05 and her husband started their quest to bring it back to a single-family house, though she admitted that at that time, they had little idea of how they would do it.

Luckily, the guide to rehabilitating the house presented itself. During the closing, the seller handed P05 a scroll of smeared paper, which turned out to be the original architectural drawings from when the house was built.

Those plans turned out to be quite helpful in guiding her through the renovation process, for both suggesting ideas and avoiding mistakes. For example, she found an old pocket door in the basement used as a wall divider but she could not figure out where that door used to be. By reading the plans, she noticed that the plan for the first floor indicated spaces inside several walls that had apparently accommodated pocket doors in the past (see Figure 13). Not only did these plans help her understand the original single-family house's reference design, it also saved her time and risk from demolishing opportunistically and running into unexpected problems.

Figure 13: On this original plan P05 received from the previous owner of her house, she noticed that a wall in her house used to be a pocket door. She was able to reopen the wall to restore the doorway.

In addition to those original architectural plans passed on to P05 through the line of all the previous owners across a century, she found many people in her village had stories to tell about her house. They were the children of previous owners, long-time neighbors, and people who previously helped remodel the house.

One aspect of the house P05 wanted to find out about was its original detailing, which was not included in the architectural drawings she got. She managed to find a bit of information on that through a chain of people and artifacts. It started with a 1905 postcard featuring her house that a friend gave her (see figure 14). The family name written on the back of the postcard led P05 to meet an older woman who was a previous owner's daughter and who lived in her town. The woman later sent her a wedding photo taken inside the house during the 1940s, and that photo showed the detailing of the original staircase.

Figure 14: P05 obtained this antique postcard from one of her friends. The picture on the postcard shows the exterior detailing of her house in 1905.

As we have shown in this case, the traces about a house's past could exist in formal records but also in artifacts not necessarily created to document the place. Furthermore, these records and artifacts were held by individuals with different kinds of ties to the house. In this case, they were previous owners and occupants as well as other locals.

Before going into our further analysis, we would like to present another case, which shows that traces from a house's past could also exist in its material.

Case P10&P11: Learning from the "shadows" of the past

P10 and P11 lived in a farmhouse originally built in the 1850s, which as they told us "was never well taken care of" by previous owners. Self-identifying as "old houses enthusiasts," they wanted to rehabilitate the house and restore its original architectural character, but how would they know the character that had been lost?

During the process of tearing down materials, they found that the house carried its own memory in covered flooring, overlaid wallpaper, and remnants of old materials. P10 and P11

called those “shadows of what had been there before.” They were able to exploit those shadows to recreate what they believed to be much of their home’s original character.

For example, they discovered that the house used to have taller moldings, as implied by the height of the unpainted area of the old drywall that got exposed after they removed newer drywall (see Figure 15). As P11 recalled:

> *When we pulled off the drywall, you could see that, okay, the molding used to reach up this far. The molding doesn’t reach up that far anymore, right?*

Fortunately, they found some tall, beautiful moldings in a closet, which matched the height of the unpainted area. P11 replicated those moldings and replaced the cheap moldings in the house with them. That was not the only shadow they encountered and utilized as they restored the house, e.g., they found an original door hidden inside a wall as well as evidence of a double door to their parlor.

As this case has shown, traces indicating what has been there and what has been done can also take the form of material remnants, or “shadows” as these two participants called them. However, successfully “reading” those traces would require background knowledge about how houses were built and decorated in an earlier period as well as a deep engagement with the fabric of the house.

Although our participants appeared to be able to retain and recover at least some information about how their houses had evolved and been treated over the years, all of them wished that they had more knowledge about the past of their houses. It was not surprising that only a small fraction of traces survived over the course of ownership changes, renovations, and natural decay of records and personal memories. It was an even smaller fraction of traces that were eventually accessed, interpreted correctly, and made use of. Nonetheless, those bits and pieces of evidence of something that had happened and been there had profound impacts on our participants and the way they appropriated their houses. We describe those uses of traces below.

Figure 15: P11 determined that the house used to have taller molding after carefully examining the unpainted area after he removed the first layer of the drywall.

5.4.2 Traces as the Missing Manual of the House

It was a challenging task to many participants, even those skilled in home repair, to understand the fabric of their houses. To this end, traces served as the missing manual of the house. Though those traces would not provide all the information needed, they provided guidance to our participants in two ways.

First, traces helped some participants take a deep view of their houses. For example, P05 did not see her house as a deep object with hidden structures until she carefully examined the original building plan given by the previous owner. From the original plan, she noticed the

locations of several pocket door openings and then verified their existence inside several walls that were apparently built later.

That was a moment of enlightenment to her because she realized that though the house appeared to have been completely gutted and its character ruined when it was converted into apartments, deep under the surface of walls, floors, and ceilings, some elements of the original house might still have survived.

Realizing the importance of understanding what was inside and what was beneath, some participants took the effort to document their houses. For example, P18, an automobile engineer, described his practice as follows:

> *Before I put the drywall on, I took photographs where all the wiring was, so if ever you've got a problem or you want to put something, you know there are some wires running down because you know where they are.*

Such practice was also adopted by P09, a "naïve" homeowner who neither had a technical background nor experience in home repair. After her contractors asked her what was inside walls several times, she started taking pictures when walls were opened during repair and remodeling projects.

5.4.3 Traces as the Missing Diary of the House

If the purpose of a manual is to provide information and guidance as described above, then the reason for reading a diary is often to reminisce and reflect. We found that some traces had this kind of evocative effect on participants.

First, some traces helped participants take a historical view of their houses. Our participants' initial knowledge about their houses was often limited to what they could immediately see. Traces of previous owners' appropriation of the place helped them extend their knowledge about their houses beyond here and now. For instance, few experiences would make an

individual feel closer to the life of an earlier period than discovering different styles of old wallpapers and floors one layer under another.

P10 and P11 had this kind of experience in the process of renovating their house, which made them reflect on the changing aesthetics:

> *We like the older style. It tends to be a little bit more detailed than what you will find in modern construction, especially in the modern construction from the era when the last remodel had been done here, because that was all like little round moldings... and aluminum everything.*

P16 was surprised when he found a nice hardwood floor covered under linoleum, which he considered ugly, in his kitchen (see Figure 16). That discovery made him wonder about the changing taste over the years:

> *I know, it's because, in the 70s, everybody wanted it to look a certain way. Every few decades, we have a different style [that's] considered appropriate. I guess they must have thought that hardwood looked country or rural or something.*

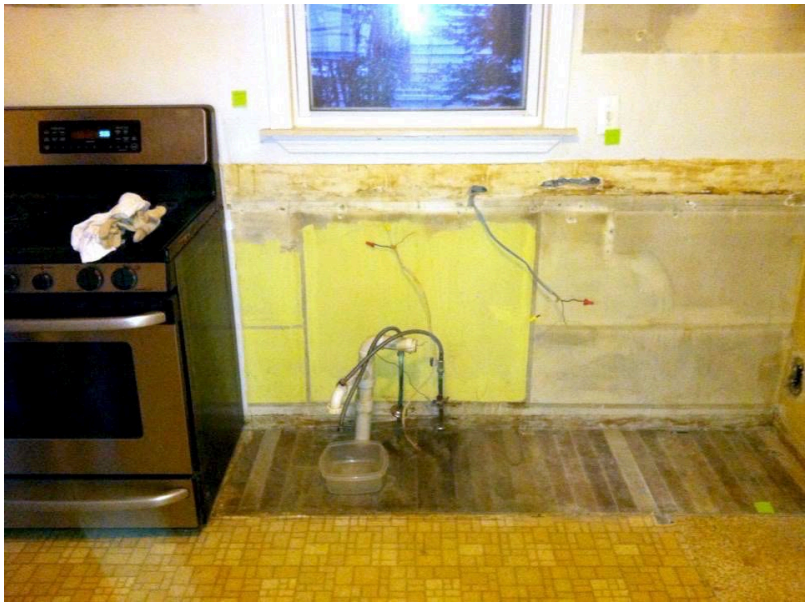

Figure 16: P16 discovered a nice hardwood floor covered under linoleum.

Learning the history of one's house might also help develop one's attachment to it. For example, P10 made a sentimental comment along these lines:

> *The house was there before you were born; the house is going to be there after you die, the concept being that it's your job to sort of take care of it while you're there. I think that that kind of fits with our gestalt.*

Second, some traces prompted participants to do something special to honor and remember the past of their houses in place. For example, P10 and P11 planted apple trees behind their house, because a neighbor told them the house used to have an orchard and the previous owner gave them free apples. In the same spirit, P11 built an outbuilding to use as his workshop that looked like a mini-barn after they found the house used to have a barn. What they did seemed to be driven, in part, by nostalgia for an earlier era and a desire to restore the house's original character. We probably can characterize this type of practice in P13's words:

> *As an archivist, I am kind of into the idea of history and kind of reproducing that. We are not trying to live in the past, but we are just trying to accentuate that time, you know, with a modern spin.*

Another way traces helped the current occupant connect with the past, especially local history, was through revealing the identities of previous owners. P17 was delighted when she learned that the first owner of her house was the founder of the village. She learned this from 19th century tax records in the archive of the local historical society, but she told me that the original purpose of her visit was to find out if there were ghosts in her house because her house stood through the Civil War.

5.4.4 Mutual Constitution of Social Context and Traces

We found there is a mutual constitutive relationship between a house's traces and its social context. This relationship is manifested in three aspects.

First, some traces are kept by community members and passed on during social interactions. This aspect is evident in the case of P05 described earlier in the chapter. She obtained the original building plan, the antique postcard featuring her house from 1905, and the wedding photo showing the detailing of the staircase in the 1940s from members of her local community.

Second, stories of an old house are resources for community members to socialize and build relationships. It seems that talking about an old house is a convenient way to start a conversation with the new owner of the house as well as to present oneself as an old-timer. For example, P05 had multiple experiences of other locals telling her stories about her house, and she felt proud about this:

> *It's kind of cool, because you live in a town long enough, people have stories about your house.*

Lastly, choosing what artifacts to pass on and what stories to tell is often a collective decision by multiple generations of homeowners. We found that participants' attitudes towards passing on records and artifacts were influenced by how their predecessor handled that decision. For example, at closing, the previous owner gave P22 a letter Albert Einstein wrote to the original owner of the house. When we asked what he would do with the letter, he firmly answered that he would definitely give the letter to the next owner. He explained the reason by vividly recalling the moment the previous owner handed over the letter:

> *It's given to us in trust, you know. The previous owner said, 'this has been with the house ever since the first owner. Each owner has passed it onto the next. We're passing it on to you. We encourage you to do that.' So it's a sense of promise that we will do that, that it will stay with the house rather than go with us. So I just feel that's appropriate.*

As these examples suggest, the survival of traces often depends on social norms, ties, and interactions in the local community, but traces from the past of locally prominent houses also help to hold a community together.

5.4.5 Remembering the House as a Mutable Thing

Some participants recognized the house as a mutable thing that had been different and would be changed. As mentioned earlier, seeing architectural features that belonged to an earlier period was an evocative experience for many participants. Furthermore, our analysis indicates that the mutability of the house might play a role in shaping some participants' practice of documenting what they have done and their attitudes towards passing on those traces.

First of all, many of our participants took pride in the positive changes they made to the house since they lived there, and they showed us numerous before-and-after pictures of their home repair and improvement projects. When we asked P10 and P11 about the reason they took a whole album of before-and-after pictures, they said,

> *We knew the after was going to be substantially different. (P10)*
> *Yes, it was so scary. (P11)*

As such, the changes captured by those pictures could be viewed as proof of their accomplishment. Those photos were used beyond personal reminiscence. Almost every participant who had such photos showed them to family, friends, and guests.

Second, the fear that the house will fall into disrepair or will be mistreated by future occupants sometimes motivates the current owner to pass on the traces he/she has obtained and produced. For this reason, P21 said she would pass on the records and photos of the house. She further elaborated:

> *[I'll] keep its history with it so that people value it as an old house and it doesn't get torn down to be weird apartments like across the street.*

Although P21 had lived in the house for only about a year, she had developed an attachment to it, as we could feel from her passionate description of her vision for the house.

5.4.6 Summary of Findings

Before we consider the design implications of our study, we would like to summarize and discuss our main findings.

First, traces that indicate what has happened in a house could take the form of formal records, everyday artifacts, and oral histories, as well as material remnants. Our data also shows that it is critical to preserve traces' original social and physical contexts in order to allow people in the future to find and understand them.

Second, our participants largely used those traces for two purposes, and both of them involved reflective thought. The first purpose was to learn the fabric of the house and the changes made by previous owners to guide their own appropriation of the space. The experience could be characterized as reading a manual (albeit often incomplete) of the house. The second purpose is more complex and it could be generally characterized as connecting with the past in a sentimental manner. Our participants, who chose to buy and live in old houses, might be fonder of this than the general population.

Third, we found that traces of a house and its social context shape each other. To recognize this mutually constitutive relationship, we need to understand that traces, no matter what form they take, are controlled, used, and shared by human agents, whose behaviors are often influenced by norms, customs, and social structures in a community.

Lastly, we note the mutability of the house (and any building in general) plays an important role in shaping the practice of producing and sharing traces. In addition, changes made to a house, especially those that carry marks of a prior era, enrich the occupant's experience of time.

5.5 Designing with the Memory of Place

How could these findings inform the design of systems in a future where a large amount of digital traces have been amassed in domestic environments? We think the best way to consider the design implications of our study is to illustrate them through three concrete design concepts.

The first two concepts address the potential of preserving and reusing a particular type of activity trace, which is increasingly feasible to capture in everyday environments: people's indoor location and their movement through the space. A question for an interaction designer in the future (e.g, in year 2046) would be:

How could you make use of decades' worth of activity traces captured by a place in a way that would be both useful to your contemporaries and respectful to those traces' originators?

The first concept, Footprints, approaches this question from a practical perspective, while the second concept, Phantoms, aims to create an evocative experience using the same data. Both concepts attempt to highlight the mutability of the space.

5.5.1 Design Concept 1: Footprints

Footprints overlays historical patterns of previous occupants' indoor movements on top of the current floor plan of the house, presumably using electronic paper.

As we have learned from P05's case, the knowledge about a space's previous configuration could provide tremendous help in remodeling the space, including saving time, money, and materials. However, it was extremely rare among our participants to obtain the original building plans of their houses, not to mention as-built plans that reflect the actual layout of the house in the past. By aggregating and presenting traces of previous occupants' indoor movement, Footprints gives the user a sense of the space's prior layout and flow. For example, the sketch in Figure 17 shows a trail of footprints through the window of the dining room. What does that suggest? It is possible that that window was modified from a doorway to a deck the house used to have. Additionally, trails of footprints that do not show up in a room until a certain point in time might indicate that that part of the house was added later than the original building.

The design of Footprints takes inspiration from the concept of "computational wear" (Hill et al., 1992), but Footprints helps the user better understand the changing spatiality and topography of the place over time. Thus, Footprints represents one of the practical uses of activity traces accumulated over a long time scale. By aggregating indoor location traces in a useful way, this design concept also provides a simple mechanism to preserve privacy.

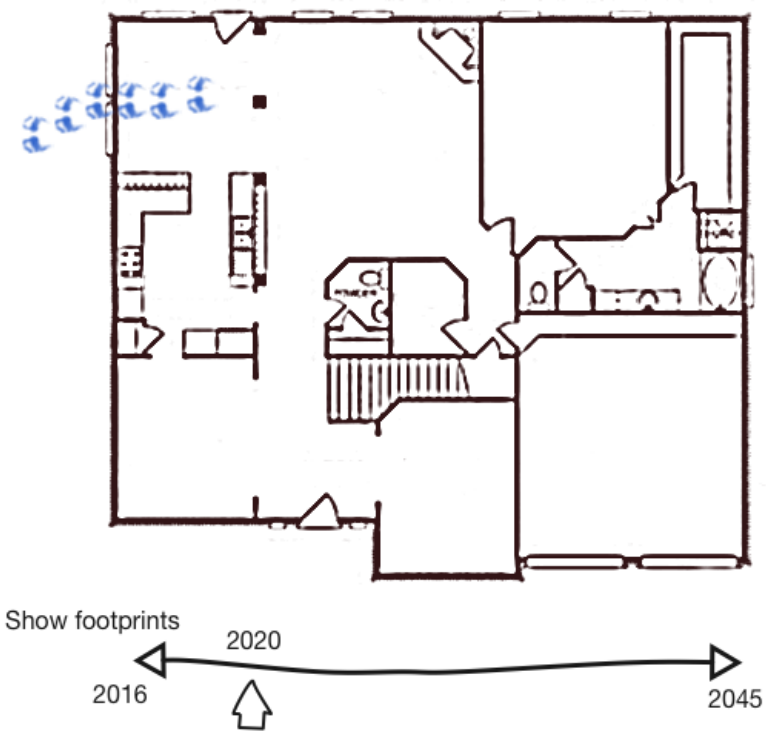

Figure 17: A sketch of the Footprints design concept.

5.5.2 Design Concept 2: Phantoms

While Footprints mostly serves a practical purpose, Phantoms is designed to evoke users' reflection and imagination by presenting snapshots of previous occupants' locations. Phantoms has neither controls nor mechanisms to take user input. It plays back snapshots of indoor location traces in a mysterious if not random order (see Figure 18). The purpose is not to inform but to evoke the viewer's own memory of the past. Those traces could either be from the viewer herself or from an anonymous occupant in the past.

To understand its user experience, let us consider the following scenario:

> *Repetitively seeing Phantoms displaying images like the one in Figure 18, Harry, a middle-aged man from the 2040s, speculates that the family who previously lived here must have a routine of watching TV together after dinner, as those blue footprints in the family room suggests. It reminds him of his childhood, when there was still a TV in his parents' house. He cannot help but readjust his glasses, with which he and everyone else watch "TV" nowadays. A fleeting thought goes through his mind, "good old days… but at least we no longer need to compete for the remote control now."*

Phantoms, as its name suggests, allows the user to engage in co-reminiscing with the "phantom" of a previous occupant or a past self. While we do not expect Phantoms to induce this kind of sentiment frequently, we believe it can enrich the experience of inhabiting a place by occasionally making the user pause and reflect.

Figure 18: A sketch of the Phantoms design concept.

5.5.3 Design Concept 3: Stewards

The third design concept, Stewards, speaks to our finding that traces about the past of a house are often socially curated through various ties formed between the house and individuals who have lived in, visited, or simply appreciated it. Our study has shown that memories of a locally prominent house could be a valuable resource that can help the current occupant identify and connect with her community. Furthermore, we think it is important to support the interpersonal process of passing on traces of previous uses and appropriations of a house.

One problem is that homeowners' interactions with locals who know their houses, as in P05's case, are becoming increasingly rare. To facilitate collective remembering of a house in this

context, Stewards creates a closed online community for people who are associated with a house. Previous occupants, guests, contractors, and neighbors can join the community anonymously or under pseudonyms.

While we expect infrequent activities in a house's small online community, it serves at least three unique purposes. First, it is a Q&A platform where the current owner can learn the house's history, obtain contact information for previous contractors, or get a puzzle about a hidden room in the basement solved, for example. Second, the online community provides an audience with whom a member can reminisce about her days living in or near the house. This audience is likely to be interested in hearing those stories, as we have seen in our study. Lastly, the members could request and share traces from other members through this platform.

As P10 said, "The house was there before you were born, the house is going to be there after you die." In this spirit, Stewards connects multiple generations of people through their collective memories of the common houses they lived.

5.6 Discussion

The three design concepts presented above illustrate several ways our successors may find value and meaning in our digital activity traces captured by today and tomorrow's ubicomp environments. We hope those potential benefits could help us make a well-rounded decision on whether and for how long we should preserve those traces.

Still, there are important privacy and ethical questions to be answered. One of those questions is: who owns and controls the data? We have considered several possibilities. In the first arrangement, the trace originator owns and controls the access to her traces, and she can grant others access to her traces upon request either for free or for a fee. Alternatively, the place or the owner of the place can own these traces, but a user needs to be able to opt out of sensing along with all the benefits with which it comes. The third possibility is that the local historical

society would archive those traces and then make them available after a certain amount of time has passed. While none of these options is likely to work for everyone or everywhere, we would like to argue, by considering those options, that the resolution of the privacy issue related to traces needs to be more nuanced than simply getting rid of them or, as popular book writer Mayer-Schönberger (2011) has suggested, making digital traces expire after a certain period of time. In contrast, our findings suggest an opportunity, if not a responsibility, to maintain or revive traces from the distant past.

Drawing on Schön's (1983) notion of role frame and how it helps shape reflection, we also began to notice the potential interplay between traces in the house and homeowners' role frames. On the one hand, traces of an old house, including its history in official records, stories told by locals, and peculiar features that hint at the house's previous uses and aesthetics, seem helpful in cultivating a sense of attachment to one's house. To some participants, such as P05, P10 and P11, connecting with the past via traces in their houses might have transformed how they see their relationship with their houses from simple ownership to stewardship. On the other hand, when a homeowner sees herself as the current steward of her house, she might be more likely to reflect on traces she sees, pass on traces to future occupants of the house, and act on the information provided by traces, e.g., restoring some features the house has lost.

5.7 Conclusion

In this work, we explored the long-term value of using activity traces captured in ubicomp environments to support reflection. To shed light on this question, we conducted a field-based study to examine how today's people use traces left by their predecessors in the houses in which they live. Our data indicates that traces can be used to provoke reflection for both practical and evocative purposes. Our analysis also suggests that traces are curated and passed on within a house's social context. Furthermore, we note the role of a place's mutability in shaping the attitudes toward making and sharing those traces. To illustrate the design implications of those findings, we offer three design concepts to characterize potential ways of

using traces captured by ubicomp environments as memories of places as well as resources for reflection.

CHAPTER 6

Conclusion

In this concluding chapter, I will accomplish five main goals. First, I will revisit the research questions described in chapter 1 and explain how they have been addressed by this dissertation. Second, I will summarize the findings and contributions of the three studies presented in this dissertation. Third, I will provide a meta-analysis of these three studies in light of Schön's (1983) theory of reflection in order to further address the overarching research question. Fourth, I will discuss the caveats of applying Schön's (1983) theory beyond professional settings. Finally, I will outline implications of this work on reflective design. Since I have discussed the limitations and the future work related to each of the three studies in their respective chapters, I will not reiterate them below.

6.1 Research Questions, Revisited

R1: Can we better understand the design space of computer-supported reflection by having a deeper engagement with theories on reflection, in particular Schön's (1983) constants of reflection (e.g., role frame, appreciative system, interpersonal theory of action, etc.)?

I have answered this question affirmatively by demonstrating the usefulness of employing Schön's (1983) constants of reflection in all the three studies in this dissertation research. In chapter 3, Social Overlays augments live web pages as *media* for reflecting on usability issues. It also supports reflection by changing users' *role frames* from information consumers to co-

designers of a website. In chapter 4, Home Trivia changes family members' role frames in conversations about technology use by putting children and parents on an equal footing. Home Trivia also fosters a cooperative *interpersonal theory of action* among players by favoring collaborative play over competitive play. In chapter 5, the concept of *role frame* allows me to understand how traces might help some people develop an attachment to their houses beyond seeing it as a property. The implications of using Schön's (1983) theoretical framework in design are further discussed in section 6.3.

R2: How can we use ambiguity as a design resource to trigger reflection that goes beyond understanding the meaning of representations?

In chapter 4, the evaluation results of Home Trivia have shown that gradually reducing the amount of ambiguity in the representations can help users cross the gulf between understanding the representations and reflecting on the represented events. Specifically, this technique involves three steps:

1. Use ambiguity to stimulate thinking and exploration.
2. Reduce ambiguity gradually as the user interacts with the system.
3. Provoke reflection by making the user aware of the discrepancies between his/her existing beliefs and the reality represented by the system.

R3: How can we adapt problem-based gaming (PBG) to allow users to reflect on certain aspects of their lives instead of subject knowledge?

Again, in chapter 4, the successful field trial of Home Trivia suggests that problem-based gaming can be married with data about the user's everyday life to support reflection. I also found that gaming and reflection reinforced each other in the field study of Home Trivia.

R4: How can we use traces, especially traces accumulated over time in a place, to provoke reflection, and what is the character of the reflection provoked by such traces?

In chapter 5, I have shown that activity traces left in a place can provoke reflection when their original social and physical contexts are preserved. In addition, not only can traces provoke reflection on a practical problem related to the place, they can also support reflection on emotional aspects of the place's past, such as its culture, aesthetics, and community.

6.2 Summary of Studies

In this dissertation research, I conducted three studies where I sought to develop reflection-based approaches to address important problems in three distinct domains: Web usability, family technology use, and local heritage and historic preservation. Below, I summarize these studies from the perspective of the domain problem each of them addressed.

In chapter 3, I described the design of Social Overlays (SO) and its lab-based evaluation. Motivated by the needs of under-resourced organizations (e.g., charities) to have usable websites, this study explores the idea of enhancing a website's usability by enabling its user community to reflect on the current design and content of the site and suggest potential improvements, since those organizations often cannot afford professional usability services. Specifically, SO enables users to modify a live web page by creating "overlays," which are DOM modifications applied to a live webpage and shared among SO users as soon as they are created. The results of a lab-based user study suggest that a group of ordinary users can identify more problems than a small team of external usability professionals. Furthermore, the user-identified problems had systematic differences from those identified by external experts, and those differences showed that at least some participants were able to engage in *reflective use* with the support of SO.

In chapter 4, I turned my attention to supporting reflection with ubicomp technologies in domestic environments and described the Home Trivia project. In this study, I explored the efficacy of using passively captured activity traces in the home to help families become more

aware of their technology use and help them reflect on how well they have been managing it. I designed and implemented an interactive system called Home Trivia, which monitors device usage and space usage in the home and then packages those activity traces into a puzzle game family members can play together. A field study of the system has led to a number of interesting findings. First, Home Trivia stimulated reflection by helping participants discover the discrepancies between their prior knowledge about home activities and the behaviors revealed by the traces. Second, Home Trivia encouraged participation of children by putting them and their parents on an equal footing. Last, Home Trivia engaged family members by using their own activity traces as game content.

In chapter 5, I reported the House Memory study, where I continued exploring the potential of using traces to create reflective experience but with a focus on long-term uses. Augmented by sensors and the Internet of Things, our everyday environments have started to capture and amass the traces of our activities (e.g., occupancy and indoor locations) in them. My goal was to explore how we can use those traces to provoke reflection and understand what the character of the reflection provoked by such traces is. To understand what practices can be in the future, I examined a comparable phenomenon in the present: how today's people use and make sense of activity traces (in particular, traces of prior appropriation of their house) left by their predecessors in the house where they live. The study found that participants received, discovered, and made use of many small traces held by artifacts, people, and building materials. Not only were those traces used to provide practical assistance to participants' appropriation of their house, they also served as resources and triggers for reflecting on events, people, and aesthetic styles that belonged to an earlier period.

6.3 Meta-analysis

The individual studies, summarized above, were reported with a focus on their respective domain problems. To explicate these studies' contributions to the literature on supporting reflection and more comprehensively answer the overarching research question I set forth, I

conducted a meta-analysis of these three studies based on Schön's (1983) theoretical framework. In particular, I wanted to accomplish two tasks though this meta-analysis:

1. Mapping the design of systems and findings of the three studies to the key aspects of Schön's (1983) theory.
2. Explaining how computer and information technology can support different aspects of reflection in Schön's (1983) theory.

6.3.1 The Role of Action in Reflection

At the center of Schön's (1983) view on reflection is the role played by action. He related action to reflection in professional practice in three ways. First, practitioners encounter uncertainty and surprises in action, and according to Dewey (1933) uncertainty triggers reflection. As Schön (1983) claimed, "… when intuitive performance leads to surprises, pleasing and promising or unwanted, we may respond by reflecting-in-action" (p, 56). Second, practitioners reflect on their actions and the tacit knowledge revealed by their actions during the so-called "action-present," the period of time in which action is still making an impact on the situation. Third, a practitioner's reflection is shaped by his/her system of knowing-in-action, which governs how he/she formulates hypotheses, conducts experiments, and evaluates the "back-talk" of the situation. In short, action provides triggers, targets, and conditions for reflection.

Given this intimate relationship between action and reflection, I put action in a prominent place in all of my three studies in this dissertation. The three studies deal with three types of actions respectively: browsing websites, playing the Home Trivia game, and repairing or renovating old homes.

To begin with, Social Overlays is designed to be used opportunistically by a user when she is browsing a website to fulfill her normal information needs, rather than used as a separate, dedicated usability tool. Embedding SO in everyday Web browsing has a number of advantages in terms of supporting reflection. First, it allows interactions with SO to occur when the user encounters difficulties in finding information or completing a transaction on the site. Second,

SO is readily available for users to explore potential improvements after these concrete problems triggered their reflection on the website's design and content. Last, since the user is carrying out a real task, she is likely to bring her knowledge about the website, the organization, and the community to her reflection. This knowledge can help the user understand the nature of the issue and evaluate potential solutions.

While SO augments an existing action (i.e. browsing a website), Home Trivia creates a new action: solving puzzles that contain information about users' technology use and movements in the home. In particular, the action enabled by Home Trivia is to recognize the source of the activities represented in color-coded squares. My field study of Home Trivia shows that reflection is triggered when a device or a space's activity traces do not completely match the user's memory or assumptions, which the user has to call upon in order to make successful moves in the game.

It is theoretically interesting to note that the reflection provoked by Home Trivia is both reflection-in-action and reflection-on-action. For example, participants reflected on their past usage of devices in the present action of trying to identify the source of activities represented in the game. Therefore, reflection-in-action and reflection-on-action seem to reinforce each other in Home Trivia. Put in another way, it is possible to enable reflection-in-action on another action.

6.2.2 Media of Reflection

According to Schön (1983), a practitioner examines, explores, and experiments on the situation by using some media for reflection. Such media can be as tangible as the architect's sketchpad or as intangible as the dialog or the relation between two parties. It is the manipulation of media that allows an individual to carry out a conversation with his/her situation, which is considered a distinct characteristic of reflection-in-action.

In this dissertation, I explored three ways in which technology can help augment media of reflection. First, technology can improve the manipulability of an existing medium. For example, the ability to manipulate elements on a live website is usually very limited to an end-user. SO allows users to create certain types of user interface improvements and apply them to a live webpage instantly. This improved manipulability of the webpage allows users to test and illustrate ideas in place.

Second, technology can create a new medium where users can examine and explore the information they want to reflect on. Serving as such a medium, the Home Trivia game supports reflection in three aspects. Firstly, the Home Trivia game provides visual representations of device and space usage information that can be seen by all the family members at the same time. The visualization of information helps users to understand the patterns of their activities. Secondly, the Home Trivia game provides a virtual space for family members to explore the relationship between activity patterns and activity sources. The instant feedback provided by the game on players' matching attempts provides "back-talks" of the situation. Lastly, the Rhythm of the Day animation shown when a puzzle is solved provides an alternative view of the device and space usage in the home from which players might gain additional insights.

Third, technology can augment a medium by attaching traces of prior interactions with the medium to it. For participants in the House Memory study, their media of reflection included various architectural drawings, pictures of prior renovations and repairs, and the house itself. Traces of prior uses of those media helped them understand what would be possible, what would be aesthetically appropriate, and what would be historically authentic.

6.2.3 Appreciative System

According to Schön (1983), reflection-in-action is conditioned on the practitioner's appreciative system as well as a handful of other factors. An individual's appreciative system determines what problem is worth solving, what outcome is considered satisfactory, and what means is

acceptable. It reflects one's value, philosophy, and principles. In a professional setting, it is often influenced by the norms in the practitioner's professional community as well.

When we employ technology to support reflection, the following two questions become immediately relevant:

1. Can technology shape one's appreciative system?
2. Is it possible for technology to be neutral in terms of shaping one's appreciative system?

The answer to the first question is likely to be "Yes," based on the study results of SO reported in chapter 3. Since SO makes the page modifications a user created visible to other users, the user needs to evaluate his proposed modification against community needs and norms, in addition to the utility it can potentially provide to the user himself. In other words, the sharing mechanism in SO transforms a private act of personalization to a public performance. This is evident in some examples I observed in SO's evaluation. For example, one of the participants linked "PEP" to the page that has the acronym's description, because she believed a new user of the site could have trouble understanding it.

Sometimes technology shapes users' appreciative systems in a more implicit manner. For example, in chapter 5.5, I envisioned how we could make traces of prior activities in a house available to its current occupants. While the designs I proposed neither convey persuasive messages nor promote any particular values, the mere presence of such traces about a house is likely to make the current occupants more concerned about preservation of its character and more keen on pursuing cultural continuity in repairing and renovating the house.

So is it possible for technology to be neutral in terms of shaping one's appreciative system? I think it is hard for any technology to be value-free, but designers can and should control where technology exerts its influence on users' appreciative systems. For example, the Home Trivia game's objectives and rules implicitly impose the value that the more one knows about what has happened in the home, the better family member that person is. However, the game avoids

passing any judgment on how much and when technology use is appropriate. Prescribing the appreciative system at this level of detail is likely to constrict users' capacity to reflect and lead to rejection of the system.

6.2.4 Role Frame

Reflection-in-action is also bounded by the way the practitioner frames his role. The practitioner's role frame exerts a strong yet often unnoticed influence on how he determines what facts are relevant, what problems belong to him, what knowledge is useful, what behaviors are appropriate, and what kinds of reflections should be undertaken in action.

This dissertation has shown that technology can help reframe a user's role in a number of ways: 1) providing tools and granting capabilities, 2) reframing the nature of interactions, and 3) fostering attachment.

First, technology can change how a person sees her role in a situation by changing what she can do, what she is allowed to do, and what she is asked to do. For example, not only does SO make it possible for an ordinary user to edit a live webpage, it also makes it seem appropriate and even welcomed to make a few edits or comments on the site, since SO shows up right on the page where a few other users might have already left their overlays. Thus, SO helps at least some users see themselves as co-editors, co-designers, or co-managers of the site, and these role frames allow them to more actively and critically reflect on issues they run into while using the site.

Second, technology can temporarily change role frames by reframing the nature of interactions. For example, in order to encourage children to reflect on their own and their family's behaviors of using technology at home, Home Trivia reframes the situation of talking about technology use to playing games with one's family, since children are naturally enthusiastic about games. This reframing of the situation is intended to make children feel that they and their parents are

equal players, and they should make play an active role in sharing their knowledge and understanding about using their devices at home.

Third, technology may help reframe roles by fostering emotional attachment to an object or a place. In the House Memory study, I have shown that some participants assumed a larger role than homeowner when they learned about their houses' history and significance in the community. For example, though P10 and P11 bought their home because they were looking for a "project;" later they gained a sense of being the steward of the house after they learned about the house's original character.

6.2.5 Interpersonal Theory of Action

Finally, reflection-in-action is affected by the interpersonal theory of action, which is a set of guiding principles one follows in a multi-party situation. It affects reflection by changing the willingness of different parties to openly communicate their thoughts and calculations. According to Schön (1983), when parties in a situation act cooperatively and communicate openly, there will be more opportunities for reflection-in-action because a person's awareness of other parties' intentions and misunderstandings can provoke his/her reflection. While this dissertation shows that technology can shape users' interpersonal theory of action, it often comes with tradeoffs as explained below.

In the Home Trivia study, the design choice was whether family members would compete against or collaborate with one another in the game. Competition is one of the well-known factors that make games engaging (Caillois, 1961), but encouraging competition between family members is likely to create incentives for withholding information in order to gain a competitive edge in the game. Since this kind of behavior would defeat the purpose of the game, I decided to implement the collaborative play mode. It turned out that collaboration in a family setting brought a different kind of fun that compensated the potential loss of engagement from lacking competitiveness.

In the design of Social Overlays, the trade-off was between control and participation. The implementation I tested in the lab study favored participation over control: everyone who had access to Social Overlays was able to create overlays and instantly make them available to other users. In a close-knit community, it is beneficial to allow every member to reflect on the shortcomings of the website and the improvements suggested by others. However, this type of laissez-faire policy can create tension and "editing wars" in larger, looser communities (Suh, Chi, Pendleton, & Kittur, 2007). Thus, a different interpersonal theory of action should be fostered as the community composition changes.

In the context of the House Memory study, a house's previous, current, and future owners can "communicate" through the house over a very long period of time. For example, a future homeowner's ability to understand his/her house often depends on how much information the current homeowner is willing to pass on. However, privacy, financial, and legal concerns can complicate this passage of information. The hope, revealed by my fieldwork, is that a previous owner's good will often creates an expectation in subsequent owners that certain information and artifacts should belong to the house, and it is the right thing to do to pass them on.

6.4 Caveats and Suggestions for Future Work

Applying Schön's (1983) theory to the problems examined by this dissertation comes with an obvious caveat: his theory was developed to account for reflection in professional practices. So how applicable is his theory to everyday settings? To shed light on this question, we need to first understand how a practitioner's professional expertise and institutional context impacts the way he/she performs reflection-in-action. There are several aspects, according to Schön (1983).

The first aspect is that professionals have superior skills in the manipulation of media, languages and repertoires in their practice. Their skills come from their formal training and work experience. Schön (1983) argued that those skills are crucial for a practitioner to hear the

"back-talk" of the situation. In contrast, we cannot expect to consistently find such skills in lay people. For example, among the participants in the SO evaluation, some were more familiar with the website used for evaluation than others. Similarly, in the House Memory study, some homeowners had more experience repairing their homes than others. Those more skilled amateurs seemed to have an advantage in seeing subtle things through the media they dealt with. For example, H11, who had years of experience renovating homes, was able to notice the "shadow" of the original molding upon removing the drywall.

Given the difference in those key skills between the general population and professionals, I would like to offer two suggestions for future research on technological support of reflection. First, it would be important to measure the individual differences with respect to their skills in the manipulation of media, languages and repertoires, so researchers can uncover the relationship between their skills and their capacity to engage in reflection-in-action. Second, it would be interesting to track users' skill development and measure how better skills in manipulation of media might improve their capacity to reflect. It would be particularly relevant to understand the long-term trajectory of tools such as Home Trivia, since it provides a new medium for reflection that requires learning.

The second aspect is that professionals might follow certain overarching theories in their fields when they reflect on a problem. As stated in chapter 2.1.3, an overarching theory does not directly explain or address a phenomenon of interest. Rather, it sets a theoretical orientation with which an account or a solution ought to be constructed.

While Schön (1983) acknowledged that not all practitioners follow an overarching theory, laypersons are more likely to not have that when they reflect. However, lacking the guidance of a formal overarching theory does not preclude them from following informal theories that might be part of their worldviews and values. For examples, some of my participants in the House Memory study were close to a hobbyist community of rehabilitating old homes. They read their magazines and approved their values. Therefore, it would be helpful in future

research to uncover the informal overarching theories individuals might have employed in their reflection.

The third aspect is that a practitioner's institution and community can have considerable influence on his/her role frame and appreciative system. It is not hard to understand that a professional must live up to the expectations of his peers and conform to the norms and rules in his/her professional communities. Therefore, it is critical to examine the practitioner's institutional and social contexts in order to understand his/her appreciative system and role frame.

In contrast, an ordinary person might have a flexible role frame and a loosely constructed appreciative system. This might, in fact, allow more room for technological intervention. In addition, an ordinary person might have a role frame and an appreciative system shaped by a broader socio-cultural context than that of a professional. One of the limitations in this dissertation was that my understanding about the background of each individual participant was often not sufficient, and that precluded me from providing a more thorough account of their role frames and appreciative systems. Therefore, I suggest that future research needs to take special care in understanding the contexts in which participants frame their roles and develop their appreciate systems.

6.5 Implications For Reflective Design

Sengers et al. (2005) contended, "We believe that, for those concerned about the social implications of the technologies we build, **reflection itself should be a core technology design outcome for HCI.**" While I find myself in agreement with this statement, my dissertation research has suggested a number of additional benefits of moving reflection to the center and front of technology design.

First, focusing on reflection allows designers to better understand the design spaces they are dealing with by drawing on the theories on reflection. As I have highlighted in the meta-analysis presented in this chapter, the factors shaping reflection identified by Schön (1983) can serve as a number of "levers" which can be manipulated by a technology designer to support reflection in specific domains.

Second, focusing on reflection allows designers to better understand how the goal of the system is achieved even if reflection is only used as a means to an end. For example, SO was developed to serve a practical purpose: helping non-profit organizations to enlist volunteers to fix their websites. But it would have been hard to explain why a group of ordinary users found more and different issues than a team of usability professionals, without drawing on Schön's theoretical framework, especially the concepts of media and role frame.

Lastly, focusing on reflection allows designers to cherish rather than overlook unanticipated benefits of reflection. All of my three studies were initially motivated by practical goals. SO was developed to allow user communities to help fix their websites; Home Trivia was designed to help families better manage technology use; and the House Memory study was originally intended to provide useful information to puzzled owners of old homes. Yet, these studies all identified valuable "byproducts" from participants' reflection. There were many examples. First, participants in the SO evaluation showed empathy towards their fellow students. Second, families that played the Home Trivia game found it fun to recollect past events together. Last, homeowners I interviewed in the House Memory study developed emotional attachment to their houses. As those examples have shown, reflection is a process through which people construct meaning. That is why adopting the third paradigm of HCI is beneficial, if not necessary, for holistically designing and evaluating technologies supporting reflection.

APPENDICES

APPENDIX A:

Evaluation Tasks of Social Overlays

The evaluation of Social Overlays described in chapter 3.3 used the following tasks:

1. Imagine you're a UMSI faculty member who has traveled a lot recently. As a result, you missed several faculty candidate talks. Now you want to find the video recordings of the following candidates' talks on the UMSI website: Jiang Chen, John Smyth, and Amit Gupta [names changed for publications]
2. Imagine you're a master's student at UMSI who stays in town this summer. You'd like to find out what's happening at UMSI during the summer.
3. Imagine that you're a new master's student. As part of the program requirements, you need to earn a certain number of PEP (Practical Engagement Program) credits. You're thinking about taking SX 622, so you'd like to find out how many PEP credits SX 622 offers.
4. Imagine you're a second–year master's student in the Human Computer Interaction (HCI) specialization. You're in the process of planning coursework for next semester. You'd like to find three HCI elective courses you're interested in and find out who is teaching each of these classes.

APPENDIX B:

Initial Interview Protocol in the Home Trivia Study

Introduction and Informed Consent (10 minutes)

Upon arrival the participants' home, the researcher will introduce the Home Trivia system to the participants, including presenting a screenshot of the game and a picture of the space usage tracker. The researcher will then describe the three steps of the study to the participants. If the participants agree to move forward, the researcher will ask each of the adult participants to sign an informed consent, get parental permissions for minor participants, and obtain oral assent from child participants.

Background Questions (5 minutes)

The interview will start with several basic questions about the family, for example:

- Could you tell me who lives in the home?
- How old are your children?
- Are there any regular visitors like a nanny or grandparents?
- Who has a full-time or part-time job in your home?
- What is a typical weekday like in your house?
- How did you spend your last weekend?

Timeline Exercise (10 minutes)

The researcher will then ask the interviewees to collaboratively mark family activities on a week-view calendar on paper (see figure x). They will be encouraged to define their own notion

of family times. After all the interviewees finish annotating their calendars, the researcher will ask them to describe the events they put on the calendar.

Figure x: The week-view calendar participants annotate in the initial interview.

Floor Plan Exercise (15 minutes)

After understanding the family's routines and schedules, the researcher will seek to understand where family activities occur in the home with a floor plan exercise. The researcher will ask interviewees to draw a floor plan together and identify areas they spend time as a family.

After participants finished drawing floor plans, the researcher will ask the following questions:

- What do you usually do in this area?
- Who are usually involved in <an activity mentioned by the participant>?
- When do you usually do that <activity>?
- How often do you do that?

- Did you do this <the activity> recently? Please tell me more about that.
- How long does it <the activity> usually last?
- Who is usually the person starting <the activity>?
- Is this room used for any other purposes?
- Is there any other family activity you haven't mentioned?

Device Walkthrough (15-20 minutes)

The researcher will ask participants to talk about, and if possible, show all the Internet-connected devices used by household members. Take photographs of those devices.

Starter Questions

"Can you write down a list of electronic devices you use at home? For example, cell phones, computers, TV, gaming console, etc. We'll talk about how these devices are used."

Additional questions

- When participants are done, go through each person's list of devices and ask the following questions:
- Who is the primary user?
- Who else uses this device?
- When is this device usually used? — Use the timeline to cue memory when asking this question.
- Where is this device usually used (if it's mobile)? — Use the floor plan to cue memory when asking this question
- Do you have house rules about when and how this device should be used?
- Could you comment on the pros and cons of having it in your household?
- Is there any device your children want to get but you don't think it a good idea or haven't decided?
- Have you heard other parents talking about how to deal with children's device use?

APPENDIX C:

Gameplay Session Protocol in the Home Trivia Study

Study Setting

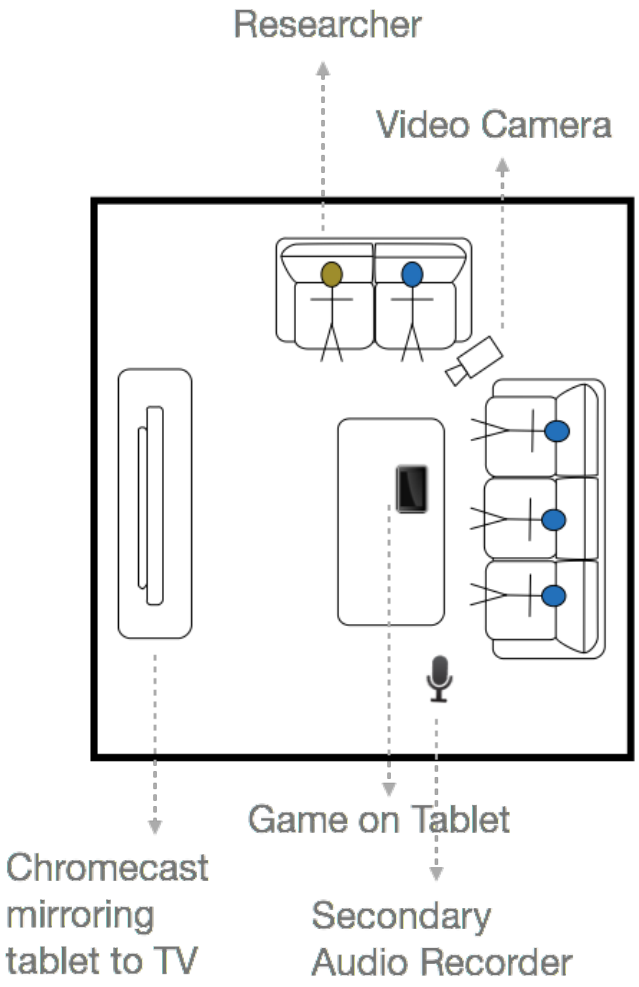

Figure 19: A schematic setup for the gameplay session in the Home Trivia study.

The gameplay session is usually conducted in participants' family room. Participants will be comfortably sitting in their couch as they normally would. The game will be loaded to a 10" Android tablet, which participants will pass around to take their turns. The tablet screen will be synchronously mirrored to the TV in the room by using Google Chromecast, a media stick attached to the TV's HDMI port. This setup allows people who are not currently playing to keep track of what is going on in the game.

Group Debriefing Questions

When participants are done with at least 3 puzzles, the researcher will ask them the following questions:

- What was the most interesting part of playing this game?
- Did anything surprise you in the game?
- Could you tell me how you solved the puzzle? What's the best way of doing this?
- What aspects of the game would you like to change?
- If you were to play this game again next week, what you might do differently?

Post-test Questionnaire

The post-test questionnaire consists a series of likert-scale questions and a word choice question adapted from Microsoft Product Reaction Cards (Benedek & Miner, 2002). After the adult participants fill out the questionnaire, the researcher will ask each of them to explain their responses.

1. For each statement, please put circle the box that best matches how you feel about the statement.

Statements	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree

Overall, I found the game accurately represent the activities in my home.					
I became more aware of how I spent my time last week after playing the game.					
I became more aware of how my family spent time last week after playing the game					
The information I received from playing the game resonated what I feel about my home life.					
The information I received from playing the game surprised me.					
I found the game engaging.					
I found the game difficult.					
I found the game thought provoking.					

2. From the set of words below, circle 2-5 of them that best describe your experience of playing the game. You may also write in additional words in the blank box provided below. (The list of words might be changed to better suit the application being evaluated.)

Accessible	Creative	Fast	Meaningful	Slow
Advanced	Customizable	Flexible	Motivating	Sophisticated
Annoying	Cutting edge	Fragile	Not Secure	Stable
Appealing	Dated	Fresh	Not Valuable	Sterile
Approachable	Desirable	Friendly	Novel	Stimulating
Attractive	Difficult	Frustrating	Old	Straight Forward
Boring	Disconnected	Fun	Optimistic	Stressful

Business-like	Disruptive	Gets in the way	Ordinary	Time-consuming
Busy	Distracting	Hard to Use	Organized	Time-Saving
Calm	Dull	Helpful	Overbearing	Too Technical
Clean	Easy to use	High quality	Overwhelming	Trustworthy
Clear	Effective	Impersonal	Patronizing	Unapproachable
Collaborative	Efficient	Impressive	Personal	Unattractive
Comfortable	Effortless	Incomprehensible	Poor quality	Uncontrollable
Compatible	Empowering	Inconsistent	Powerful	Unconventional
Compelling	Energetic	Ineffective	Predictable	Understandable
Complex	Engaging	Innovative	Professional	Undesirable
Comprehensive	Entertaining	Inspiring	Relevant	Unpredictable
Confident	Enthusiastic	Integrated	Reliable	Unrefined
Confusing	Essential	Intimidating	Responsive	Usable
Connected	Exceptional	Intuitive	Rigid	Useful
Consistent	Exciting	Inviting	Satisfying	Valuable
Controllable	Expected	Irrelevant	Secure	
Convenient	Familiar	Low Maintenance	Simplistic	

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