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ABSTRACT

The proliferation of portable electronic devices in the home creates the opportunity for increasingly complex interactions between household residents and their devices. We present a study of these interactions which focuses on laptop computers in homes with wireless networks, describing the technical infrastructure for the study, and exploring a range of findings about home life. We also present several design implications of this work. Highly accurate position and device usage data has been collected about residents and wireless laptop computers, and visualizations of the data were used to motivate discussion during interviews. This data collection and interviewing method is a novel and promising alternative to other methods such as diaries or self-report surveys.

Author Keywords

Home life, home technology, wireless laptops, mobility.

ACM Classification Keywords

H.5.2. [Information Interfaces and Presentation]: User Interfaces

INTRODUCTION

Portable, wireless devices are rapidly becoming ubiquitous. Wireless networks are being deployed with increasing frequency, both in the home and elsewhere. Similarly, in May 2005, laptop computers outsold desktops for the first time ever [28], and many households now have several laptops, along with an array of other electronic devices. Devices such as wireless laptops provide a broader range of possibilities for interaction with the home environment than do stationary desktop computers. However, little is known about emergent patterns of use for mobile technologies in the home and how they are integrated in daily life. Understanding these patterns would be valuable for the future design of both devices and the architectural spaces that support them.

This paper assumes that objects are unavoidably embedded in activity [15]. In his collection *The Social Life of Things*, Appaduri posits that commodities, like persons, have social lives [1]. To grasp the life of objects, he suggests we need to embrace things-in-motion as disclosing agents in studies of the social-material world. However, it is difficult to capture the full context of objects-in-motion as they circulate in the social-physical environment. We have developed a set of tools to help us move beyond an understanding of objects as mere commodity or instrument as we move to develop new technologies. Specifically, we incorporate other objects, architectural features, and social relationships. Accordingly, we have chosen to study the use of portable computing devices in the context of their location in the architectural layout in the home, as well as in the context of the presence or absence of household members.

In order to study the use of computing devices in these contexts, it is useful to collect a range of detailed information about people's practices in the home and their use of devices. As we discuss further below, many existing methods for studying practices in the home have limitations. For example, contextual inquiry and self-report are challenging because people typically find it difficult to report mundane activities accurately, and video is challenging because many people are understandably reluctant to have cameras deployed throughout their home.

We propose a new method in which we use a sensor-based visual record of the physical movement of people and devices to facilitate more accurate and in-depth discussion during interviews. Previous work has explored the utility of different media in diary studies [4]. Our work offers a rich alternative media (visualization of activity) that does not require participants to capture or record events. Additionally, recently available sensing technology [30] supports accuracy on the scale of centimeters and meters, which is highly appropriate for understanding local movements within and between rooms. This technology has made it technically feasible to track the locations and see the spatial relationships of people and devices in real-world deployments. In addition to providing useful traces for discussion in interviews, this technology offers the ability to automatically collect valuable quantitative data.

In this paper, we report a study in which we gathered precise location data and computer application data, analyzed it, and discussed it with participants in interviews to examine the movement of people and their wireless laptop computers in their homes. We have chosen to focus on homes with wireless networks because these networks afford high mobility in the home and are representative of future trends. Our study makes a range of contributions:

Infrastructure and Method. While many precision location sensing technologies are currently evaluated based on their performance in laboratory environments, this study explores the deployment of location sensing technology in real-world environments. We further report on our novel integration of precise real-world location data in interviews.

Findings about Home Life and the Use of Computing Devices. The novel combination of precise location data, computer application data, and interview data has supported an interesting analysis of activity in the home, particularly with respect to the interactions between occupancy patterns and the use of computing technology. Our findings complement previous studies on the location of information in the home [5,9], and yield novel findings on the contexts in which participants do and do not use computing devices in the home.

Design Implications. Our experiences have prompted several interesting design possibilities. We discuss how our framework of home occupancy is relevant to the design of technology for the home. Further, rather than focusing exclusively on the design of devices, we also leverage our findings on the spatial context of use to motivate improved designs for the architectural frame itself. We discuss how architectural features of the home may be (re-) designed to complement emerging technologies.

The remainder of the paper is organized as follows. In the next section, we discuss related work. We then present our method for studying the movement of people and computing devices in the home, followed by findings. We then turn to learnings on the method and next we discuss design implications. Finally, we present conclusions and discuss directions for future work.

RELATED WORK

Early researchers studying the local movements of people (for example, in public urban spaces [32]) and of communication media in the home [31] were constrained in their collection of long-term observational data primarily to the use of video and direct observation. Various studies on and technical work to support the sensing of human activities have been conducted since then. These have been conducted on the scale of large geographic spaces using GPS sensors [14], proximity sensors [20], or a combination of sensor types [8,19]. They have also been conducted on the scale of buildings, including sensor deployments in built environments [17,18] and in real homes [27,29], using a wide variety of sensing technology including open/close sensors, cameras, motion detectors, and microphones. The technologies used have supported at most multi-meter or room-level accuracy in location measurements, although recent developments in more accurate indoor location technologies are promising [7,30]. Additionally, various researchers have emphasized the importance of studying the social context of computation [10,24,31]. Further, a study by McClard and Somers included device logs as well as self-reports of the locations in which wireless tablets that had been provided to participants were typically used [23]. Crabtree et al. used ethnographic study to examine sites of household coordination [5]. To our knowledge no work has been done to capture highly accurate location information and device usage information simultaneously, nor to use this material as prompts in interviews.

However, recent work has highlighted the need to further explore the role of location in the home and its impact on technology. For example, Elliott et al. found that people used location in extremely nuanced ways in sharing information within the household, often using 13-17 different locations to convey different meanings [9]. O'Brien et al. argue at a more general level that an understanding of domestic patterns can be a good motivator for design [24]. As a specific example, many researchers are now exploring the role of location and other sensor measurements in health and are beginning to propose a range of digital health monitoring technologies (e.g., [27]). A better understanding of domestic space will provide positive feedback to these and other designs.

Additionally, it has been noted that people can be inaccurate at reporting their own use of space [21] but that the use of artifacts such as photos [4], "felt maps" [21,22], and other visual prompts during interviews can help guide discussion and aid recall. Some work has begun to explore the use of "reflected" or "exposed" ubiquitous computing technology to explore the relationship of people to their homes [26]. We build upon these previous methods by using a unique combination of location and activity data as prompts in our in-home interviews.

METHOD

In this initial study of the interaction between the use of mobile computing devices and spatial location, we have focused on the study of households with wireless Internet access and laptops. In each household we collected a mix of quantitative and qualitative data. We describe the type of data we collected, the participants in the study, our procedure, and our methods for analyzing the data.

Data Collection

In order to gain an understanding of patterns of use in the home, we have chosen to track the location of people and computing devices, to log the use of certain devices, and to conduct interviews. For a summary, see Table 1.

Location Data. During preparations for the study, we considered a variety of location tracking technologies,

evaluating each on the following requirements: fidelity, the extent to which objects can be tracked accurately at a high (sub-meter) resolution; suitability for temporary installation; and wearability of tracking badges. Based on these requirements, we chose to use Ubisense [30], a commercially available location tracking system based on Ultra-Wideband (UWB) radio technology. Our setup includes several Ubisensors (each approximately the size of a large brick) as well as a number of Ubitags, small (pager-sized) battery-operated badges that emit UWB pulses and can be worn by residents (typically on lanyards around their neck) or attached to laptop computers. In good conditions, system constraints allow us to cover an entire floor of a small- to medium-sized residence with a typical accuracy of 10-20 centimeters (although readings are sometimes inaccurate or unavailable) or to cover a two-floor residence with a lower degree of accuracy.

We chose to use Ubitags with a peak power of 2.3 mW so that the signals would travel further and more easily go through furniture, walls, and people. However, because UWB devices by definition make use of a broad range of the frequency spectrum, their use is currently quite limited by government regulatory agencies. Despite the fact that this power level is extremely low (e.g., a typical cellular telephone operates at over 100 mW), using it required us to acquire a temporary waiver from the United States Federal Communications Commission (FCC).

To our knowledge, Ubisense provides the most accurate indoor location measurements currently available from a system that can be practically deployed in a temporary, in-home setup. For our purposes, the most significant limitation of Ubisense is that the tags are not quite small enough to attach feasibly to devices such as cellular phones or portable music players; nonetheless, overall we feel it is by far the best alternative currently available. As we discuss later, we may in the future use alternative technologies to track these types of smaller objects.

Device Use Data. In addition to tracking the location of people and laptops, we also tracked the usage of laptop and desktop computers. We have developed software, based on Microsoft Research's VibeLog tool [16], to record in real time which applications are running, which windows are currently active on the screen, and when the keyboard or mouse are in use. Our software also records changes in battery charge level and in power status in order to explore the relationship between availability of power and mobility. Additionally, we logged the on/off status of some of the televisions by measuring the power being drawn by each device. All of the collected data was logged in real time to a central database.

Home Interviews. In each household, we conducted approximately two in-depth interviews. Interview topics included: discussion of the lives and backgrounds of the people who lived in the home; a map exercise in which participants indicated "important places" in the home by annotating floor plans; a tour of the home and the technology in it; and participants' responses to and interpretation of visualizations of data from their home. In all homes, all household members were present at all interviews.

Precision Location Traces		
Location traces of all household members and laptops	Ubisense [30], Custom logging tool	Animations, spatial queries, thermal maps
Computer Application Logs (Laptops and Desktops)		
Application use, Keyboard/mouse (Boolean), Battery level, Battery/AC	Microsoft VIBELog [16], Logging tool	Animations, usage timelines, application pie charts, radial plots
TV Status (partial data)		
On/Off state	AC current sensors, X10 transmitters, Logging tool	Usage timelines
Interviews		
Interview transcripts, photographs, surveys, annotated floor plans	N/A	Thermal maps, time-slice graphics, application pie charts, radial plots

Table 1. Data Sets in the Study (Type, Base Technology, Visualizations)

Study Participants

Our study included 10 participants in four households in the San Francisco Bay area. The first two households, which consisted of a long-term couple from Australia (Brad and Jacqueline) and a recently married couple from England (Margaret and Jack), were both recruited from the Berkeley graduate student community. This was done to ensure households with an understanding of the nature of research while the technical infrastructure of the study was still being refined and tested. The third and fourth households were recruited from Craig's List, an online classified ad service in the San Francisco area. The third household consisted of a married couple (Mareesa and Carlo) and their one-year-old daughter Jessica (for whom we had a custom badge holder made in the form of a stuffed pig attached to a belt), and the final household consisted of a female couple and a house-mate who rented their extra bedroom (Sierra, Gaby, and Carlota). All participants were provided with monetary thank-you gifts for their participation. Participants were from a wide range of ethnic and cultural backgrounds and had varying occupations such as graduate student, kindergarten teacher, and furniture salesperson, for example. The homes in the study included two one-bedroom apartments and two detached homes, the largest of which was two stories and three bedrooms. The homes were in a range of neighborhoods, including for example an ethnic residential neighborhood and an urban shopping district.

Study Procedure

Our study was conducted in the summer and early fall of 2005. In each household, we began with an initial visit to discuss the study with the participants, and to make an accurate floor plan of the home, which was required by the Ubisense location-tracking software. We subsequently installed the equipment, which involved positioning the Ubisense sensors, connecting the sensors with timing and Ethernet cables, and calibrating the sensors. At the same time, we installed logging software on all of the computers in the home and connected sensors to some of the televisions in the home (issues with X10 made it logistically difficult to monitor all televisions). The installation process took between one and four days, depending on the home.

After installing the sensing equipment, we monitored the data remotely, returning to the households to make adjustments as necessary. In the first two households we also collected timelapse video for one to two days in the public area of the home to allow us to check consistency between the timelapse data and the sensor data. We then analyzed the sensor data and made visual representations of it in preparation for the in-home interviews described above. We collected data for approximately three weeks in each home, with the intent of learning about routines at not only the daily but also at the weekly level. For a two-person household, this amounted to approximately 250,000 location readings over the three week period.

Data Analysis and Visualization

We have conducted data analysis through a triangulation of data sets, making use of location data, computer use data, and data collected from interviews. An important aspect of this analysis was the creation of various data visualizations. These visualizations were designed both to assist in our exploration of the data as researchers and to provoke responses from the study participants through the use of visualizations during interviews. All programmatically generated visualizations were created with Piccolo.NET, a framework for creating graphical applications [2]. The different types of visualizations are described below.

Animations and Snapshots. The most direct way to view the data is through animations showing the location of people and laptops over time. For each participating household, we generated such an animation showing the position of all tagged objects along with activity occurring on the participants' computers. Additionally, we extracted snapshots of particularly interesting points in time which were used in the home interviews.

Thermal Maps (Figure 1). To get a broader overview of the data, we created maps showing the distribution of people and laptops' locations over time, with more intensely colored areas indicating regions where the person or laptop spent the most time. These maps were created by using the open-source geographic information system (GIS) tool Grass [12] to fit a density function to the distribution of readings over time, taking one data point from every minute of the study (using the built-in *v.kernel* command).

Radial Plots (Figure 3). In order to explore patterns of computer activity across time, we created plots showing the periods of computer use, mouse activity and keyboard activity over time. Each plot shows 24-hours of activity from one day, with time progressing clockwise around the plot (e.g., midnight is at the top, and noon is at the bottom). The length of each bar extending from the radius represents amount of activity in that time slice. Additionally, we created pie charts showing aggregate levels of application use throughout the duration of the study in each household.

Dynamic Spatial Queries. To explore the spatial data over time at a more fine-grained level than the thermal maps, we created an interactive tool to execute spatial queries on the data. For each household, the tool displays a floor plan of the home. The user can then select various regions of the home, and a timeline is colored in to show all of the times each object was in the selected region. There are also timelines to show periods of activity on computers and other devices. Conversely, the user can select particular regions on the timeline and view a trace of the movements of a particular object during that period of time.

FINDINGS

In this section, we present findings from our study. We focus on four related points arising from our data sets. First, we discuss the patterns of occupancy in the home. Second, we discuss how people's use of space relates to the movement and use of computing devices. Third, we discuss the impact of social factors on the use of wireless laptops in the home. Fourth, we discuss the strong connection between laptops and people's departure from the home.

Tendency to Dwell in Favored Places in the Home

In the households we studied, each household member typically had one to three *favored places* that they used during waking hours. Favored places are places in which people spend extended periods of (often unstructured) time. Common physical characteristics of favored places included physical or ergonomic comfort, view, lighting, proximity to social activity in the home, and proximity to media such as the television or stereo. Behaviorally, favored places tended to be visited multiple times during the day and to have multi-functional use. Notably, the use of favored places can be quite complex, encompassing multiple seating positions and minor variations in location, e.g., different physical positions such as reclining or sitting on the couch. Example favored places might include a spot on a sofa where a person sits to read, watch TV, play video games, work on their laptop, or speak on the phone (this is an example of a *comfortable* favored place); or a chair at a desk where a person often sits to work on their desktop computer, talk on the phone, or pay bills (this is an example of an *ergonomic* favored place). These favored

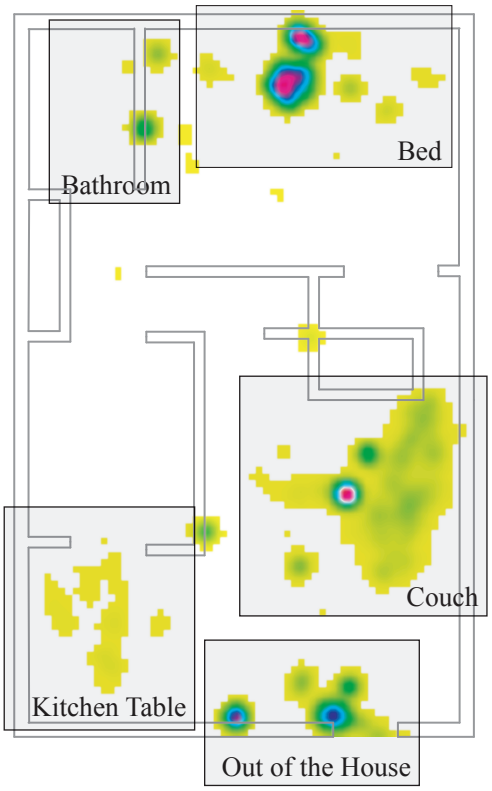

Figure 1. Thermal map showing Jacqueline's use of space across the duration of the study (20 days). More intensely colored regions indicate more heavily used spaces. Most daytime use centers around the couch, with a very small amount of time spent at the kitchen table. The unlabelled spot along the wall between the kitchen table and the couch is an example of an artifact of noisy data, probably a result of multi-path reflection from a spot near the door. Note that the labels and boxes have been added for the purpose of presentation; such annotations were not presented to participants.

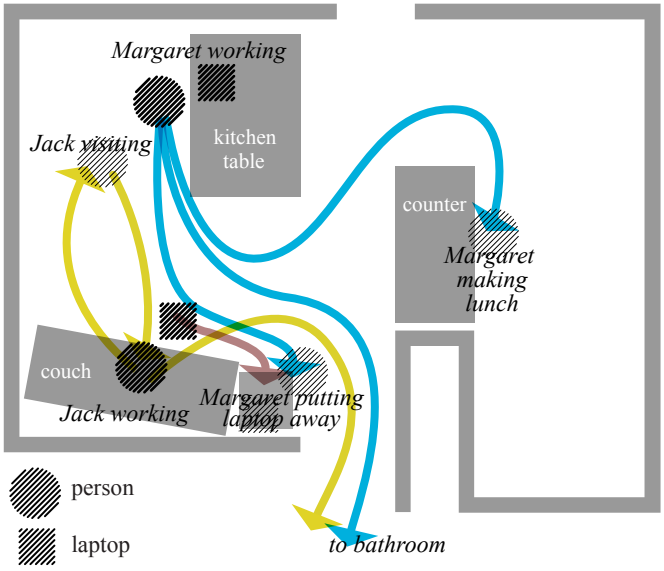

Figure 2. Sunday evening at Margaret and Jack's home (10pm to 11pm). This diagram shows the range of favored places and activity place used by Margaret and Jack during a typical evening. For most of the evening, they were in a configuration that was typical for them: Jack was in a comfortable place on the couch, using their "old laptop," and Margaret was at an ergonomic place at the table, working on their "new laptop." However, they had occasional activities in other places in the home. At the end of the evening, Margaret put away the "old laptop." Again, note that annotations are for the purpose of presentation.

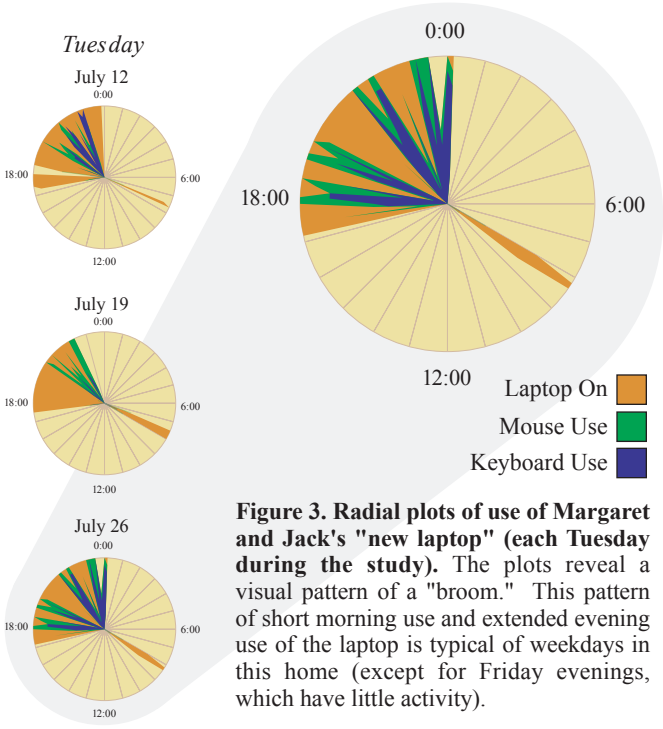

Figure 3. Radial plots of use of Margaret and Jack's "new laptop" (each Tuesday during the study). The plots reveal a visual pattern of a "broom." This pattern of short morning use and extended evening use of the laptop is typical of weekdays in this home (except for Friday evenings, which have little activity).

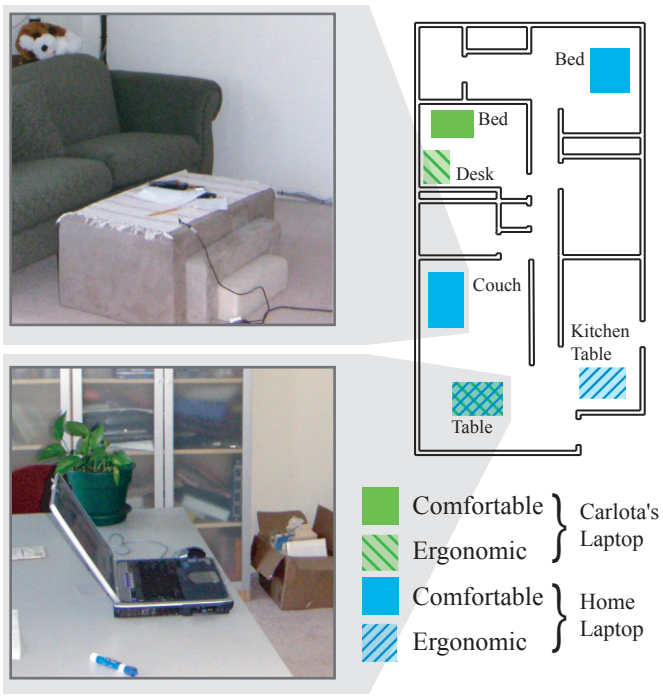

Figure 4. Comfortable and ergonomic favored places for laptops in the home of Sierra, Gaby, and Carlota. Sierra's and Gaby's laptop had more places than was typical, primarily in the public space of the house. Renter Carlota's laptop use centered in her bedroom. Note the power cord draped on the ottoman on the right side of the picture of the comfortable spot on the couch.

places have similar characteristics to those reported for elders (particularly elders with low mobility) [25] but it is interesting to observe this similar pattern of spatial occupation in a younger population and to illustrate it through precise location data.

While there is naturally some variation in the number and use of favored places due to individual characteristics as well as differing properties of the home, the precise location data from the current set of households and occupants suggests that the number of favored places is quite low. Even in a home with a young child in which the mother understandably had less time to spend in favored places, she still had approximately two favored places in the home; in another home, one participant had only one favored place in which she spent most waking time in the home (see Figure 1). One might imagine that people living in larger houses would have a significantly larger number of favored places, but our preliminary findings suggest that the number of favored places per person remains relatively stable (this is consistent with findings from a study of large homes, often with a small number of occupants, in which participants were asked to indicate their places in the home on a felt map [21]). While it may be true that larger houses afford more *choices* of locations for favored places, apparently people still choose to have a relatively low number, perhaps because favored places require work in developing and maintaining (e.g., keeping books or a drink at hand) and/or because people prefer to be in a familiar place.

In addition to favored places, participants of course had other places they used in the home. Such places were often for focused and/or routinized activities of shorter duration, e.g., a mirror for getting ready in the morning, a particular place in the bedroom that was used for doing sit-ups, a kitchen counter that was used to make sandwiches and prepare the evening meal, or a refrigerator that was visited multiple times during the day to get drinks. Due to space constraints and the predominant use of computing devices in favored places which we discuss below, we have chosen to focus on discussion of favored places rather than a detailed framework of these other locations in the home.

Wireless Laptops are Portable, Not Mobile

We have examined the relationship of patterns of occupancy to the use of computing devices. Laptops are typically used in three kinds of locations in the home: *ergonomic favored places*, *comfortable favored places*, and *activity places*. The first two are by far the most common use, while situated use in activity places is more uncommon and marked, and people were often excited to report it to us. We discuss these places in turn.

Ergonomic favored places: Participants often had one or occasionally two ergonomic places for using computing devices (and in fact all ergonomic places were associated with either a laptop or a desktop). An ergonomic place was typically characterized by a hard surface such as a dining table or desk and an upright chair such as a dining room chair or an office chair. Ergonomic places enabled participants to use peripherals like mice; further, participants spread out materials such as books or paper to be both at hand and sometimes to remain in those positions. In many cases, the ergonomic place would have a desktop computer (and all the desktop computers we saw were in ergonomic places). In other cases, this would be a place to which people sometimes brought their laptop, such as a place at the dining room table or a project table.

Comfortable favored places: Laptops are frequently used in comfortable favored places in the home. These are typically places such as a couch or a "cozy" chair, often within viewing distance of the TV. The laptop is unlikely to be used continuously in these places, but is often kept at hand (almost all comfortable favored places were associated with laptop use). Power cords are often left in these places, e.g., a power cord snaking to a sofa (see Figure 4). Variation in physical position supports different types of laptop use in a favored place, e.g., a given person may use their laptop on the coffee table or put it on their lap, depending on the activity s/he is engaged in or whether s/he is tired. The important shift in behavior among our participants is the emergence of the use of the comfortable place in addition to the ergonomic one for laptop use. Though this is not an overly surprising trend, it demonstrates how portability enables use of the laptop in the home environment.

Activity places: Activity places were areas often defined and delineated by certain routine activities. Laptops were occasionally situated in these sites of ongoing activity in the home. For example, laptops were occasionally brought into the kitchen to be consulted for recipes during the "cooking activity." As another example, we saw an interesting use of computing technology during the "napping activity." In Mareesa and Carlo's home, if the baby girl had fallen asleep in the car on the way home, Carlo sometimes brought the laptop to the car to allow Mareesa to use the Internet while supervising the child's nap. In a similar integration of technology into the "napping activity," Mareesa sometimes also brought the laptop to the child's bedroom during naps so she could be with her while she napped. As a final example, we also saw technology incorporated into the "eating activity." In Margaret and Jack's home, the dining table doubles as the desk on which the primary laptop resides, and this laptop is sometimes incorporated in their evening meal, showing either a slide show of photographs or serving as a resource for answering conversational questions. Figure 2 shows a time after dinner one evening in Margaret and Jack's home, in which they are dwelling in favored places with occasional use of activity places.

Such examples of laptop use situated in activity were interesting and compelling to the participants, but our precise location and computer logging data revealed they

were surprisingly rare. Simply listening to the participants talk about the events would have led us to assume they were a frequent practice. Indeed they were not. Their infrequency, however, also made them stand out in the data, so we could directly inquire about them. As part of this inquiry, we learned that despite the fact that all the houses we studied had wireless networks, there were a number of obstacles to laptops moving fluidly through the home (e.g., ergonomic considerations, power, or concerns about laptops getting broken).

Overall, people had a small number of favored places they dwelled in the home. Wireless laptops were typically used in this set of favored places (both comfortable and ergonomic). Laptops could be used in different positions in a given favored place, and they were portable between these places, as well as to outside locations such as work. They also made occasional visits to other places in the home such as the kitchen, bedroom, or cars according to the activities the participants were engaged in. Interestingly, wireless laptops in our participants' homes, though offering the opportunity/affordances to go "anywhere in the home" [23], tended to have relatively limited mobility. They were portable but not mobile per se; they did not move fluidly through the home.

Social Laptop Use: Sharing, Competing, and Following

We saw three primary behaviors related to social use of laptops: sharing, competition, and following. We discuss these in turn. First, not surprisingly, laptops are sometimes used collaboratively. For example, a couple may view a laptop screen together when developing a website. As another example, music or other media may be played on the laptop. Such use is often coordinated, e.g., Jack has a practice of turning on a radio news feed on the laptop in the morning for his wife Margaret, who likes to listen to it as part of her morning routine.

Additionally, similar to findings in previous research [10], we observed occasional competition over the use of computing resources. This was most pronounced with Jack and Margaret, who shared two laptops which they referred to as the "new laptop" and the "old laptop." The new laptop was preferred by both because it was faster and could run more applications. While they took turns using the laptops, as we could see in our data, Margaret was the primary user of the new laptop, deferred to by Jack because Margaret had less access to computing resources at work.

Finally, we observed laptops and their users following other people in the home. For example, Jacqueline does not like to be alone in the bed when sleeping, so her boyfriend Brad would occasionally bring the laptop to bed so he could be near her for company. Wireless networks and laptops have strong affordances for this type of behavior, and we have not seen it reported previously. An interesting counterpoint in this household was customization of the non-portable desktop computing space to accommodate the child; the parents had a special chair that could attach to either of their desks so their daughter could be near them while they were working. In this case, because the desktops are not portable, the child followed the technology.

Connection Between Laptops and Departure

The combined portability and computing capabilities of laptops seem to give them a special status during departure from the home. During the departure routine, people interact with laptops much more than with other appliances or devices such as televisions or desktop computers. Some interaction is fairly mundane, relating to maintenance, security, or packing up. For example, we saw patterns of people putting down the laptop in a charging place and connecting it to an adapter, closing blinds so that laptops would not be visible and tempt a burglar (laptops are of course particularly vulnerable to theft due to portable, expensive, commodity items), and packing laptops into bags to be taken outside the home.

Other interaction around the departure routine is related to the core computing functionality of the laptop; application use is sometimes integrated in the departure routine. For example, some participants checked their email before leaving home. Figure 3 illustrates Margaret and Jack's use of the laptop on Tuesday mornings. As another example, when they were leaving the home, Mareesa and Carlo often used the laptop to look up and print directions from MapQuest (an Internet mapping service). Coincidentally, their destination itself was often determined by another Internet service – Mareesa was a frequent users of Craig's List, and they would often be going to purchase or trade something from another user of that list.

Interestingly, laptops may not be as strongly integrated in the coming home routine. For example, one participant was articulate about the need to "unwind" before getting out his laptop upon returning home.

LEARNINGS ON THE METHOD

In conducting this study, we gained experience collecting and analyzing sensor data, and presenting it as prompting material during interviews. Overall, we have been very happy with the method. While collecting such data still presents technical challenges and the data is far from perfectly accurate, it is still highly revealing about real-world behaviors. Additionally, combined with computer application data, this data has provided very effective prompting materials for interviews. We believe these materials led to significant discussion with the participants, much of which would have been unlikely to occur with other methods such as contextual inquiry or self-report. Below, we reflect further on this method from the participants' perspective, considering participant responses to the data, and to the badges and sensors themselves.

Participant Responses to Sensor Data

Using sensor data as a prompt during interviews proved to be a highly useful technique. Presented with visual

prompts about particular spots or paths through the home, participants easily volunteered routines and activities associated with those locations. In some cases, as we had hoped, the visual artifacts clearly reminded them of activities they had forgotten to tell us about when questioned in general about their activities. For example, when a thermal map revealed that Carlo occasionally went to "mom's" guest bedroom, he and his wife were initially mystified because he had reported he almost never went in there but upon reflection he remembered that "one of the things I do every day is I put the mail in her room."

Similarly, we also observed that some prompts aid participants in reconstructing what actually happened during a particular period of time, especially when groups of participants can work together with the specific artifact to jointly reconstruct the activity. We observed that in cases of disagreement the artifact is a resource that allows participants to press each other to reach consensus. For example, one household disagreed as to whether they had had dinner together on a particular evening and the visual record allowed Sierra to pursue the topic more insistently than she might have otherwise. This ultimately resulted in a satisfying epiphany by Carlota that she had in fact been present for dinner and had had tomato soup.

The visual artifacts we chose to present tended to be concrete (e.g., showing specific locations) but also ambiguous (e.g., not contain speculative labels about activity), thereby allowing many possible interpretations. We observed that the visualizations (both static and animated) tended to lack much of the context such as a sense of "mood" that is present in media such as time-lapse video. Additionally, in some cases, the data was also likely incorrect. However, the ambiguity resulting from the lack of context and from the potential for inaccurate data was an excellent resource for the participants [11], who proved extremely facile at generating rich stories around these relatively impoverished visual artifacts. Although participants often took the visual record at face value, note they did not seem to feel bound by it; they were willing to generate stories that contradicted it, speculating that the location must have been measured incorrectly in that case.

Whether or not people's stories correspond to the particular instance reflected in the prompt, they reveal interesting insights into household residents' construction of what goes on in their lives and how they use the space in their homes. Sometimes these observations were related to personal daily routines, and at other times they revealed (and could be used as leverage in) more complex household dynamics. For example, when we presented one household with their thermal maps, Sierra immediately observed that she had activity near the kitchen sink and exclaimed to her partner, "You see! I wash dishes!"

In working with the data presentation, we found paper artifacts to be more engaging during interviews than computer-based animations. Paper gave participants the ability to control the flow of the interview. When we provided participants with paper artifacts, they tended to move between them and compare several visualizations with each other. However, when we presented participants with an animation on a computer screen, they tended to sit back and allow the interviewer to manipulate the data and choose the next direction.

Participant Responses to Badges and Sensors

Participants were highly accommodating of the physical infrastructure of the study. Participants readily established routines for wearing the tags. They typically put their badges on early in their morning routine, taking them off only to leave the house or to go to sleep. None of the households complained about having to wear the badges during the entire study. In fact, most participants reported forgetting that they were wearing their badges at least some of the time, occasionally walking out the door without taking the badge off. Some participants expressed minor embarrassment about wearing the tag in front of outsiders (e.g., when answering the door), but they also often excitedly described the study and the sensors to friends and neighbors.

Somewhat to our surprise, no one expressed significant concerns about wearing the badges, either with respect to safety or with respect to privacy. Participants did however seem to have a clear sense that they were being monitored, often making comments that began with, "You'll see…". For example, Margaret told us, "You'll see, I always turn on a computer and then I walk away." At the same time, participants seemed to interpret the ambiguity of the data as affording them some privacy. For example, Jack told us: "I was thinking… you know where we are, but you don't know at all why we're there… if you take a specific situation, you know, we might both be asleep, or I don't know…"

This was in stark contrast to participant responses to time-lapse video data, which we recorded in two of the households (without audio) for one to two days. These households told us how glad they were when the camera was removed. As Jacqueline said, "I don't like that a lot [having a camera in the public part of the house]. I wouldn't do it for any more than that [one day]."

DESIGN IMPLICATIONS

We now explore several implications for the design of technology and domestic spaces, ranging from a set of design principles to proposed redesigns of the domestic space itself.

A Domestic Design Framework

In exploring the implications of our findings for the design of domestic technologies, we were struck by the differences between the places in the home, particularly between the places where laptop computers are and are not used. It is our hope that consideration of these issues is useful for design.

For example, as discussed previously, favored places tend to support the use of laptop computers while activity places do not. Perhaps activity places are well-suited for built-in technology like embedded displays that support localized activity associated with that place. And perhaps favored places are well-suited for portable devices like laptops that are used for multi-purpose, free-form use. As another example, perhaps sensors to support context-aware computing need only be installed in particular types of places within the home based on the characteristics of those places and the requirements of the desired applications.

It is our hope that an understanding of the different places in the home will provide a useful framework for designs for domestic technologies.

Electronic Foyer

The foyer encapsulates many interesting issues, partially because laptop computers are bound up in the process of entering and departing from the home. As a result, we consider a principled redesign of the foyer. In existing homes, the foyer (or often a hallway table or a hook in homes without a distinct foyer) becomes a receptacle for information [5] and artifacts such as packages, clothing, keys and notes as people enter and leave the home. In the same way, the laptop becomes a passageway for information that is needed as people enter and leave the home, such as when Mareesa and Carlo used theirs to print maps on the way out the door or took it to the car when Jessica was napping.

The relationship between technology and the foyer as an activity space has implications for varying levels of more or less permanent artifacts in the space, ranging from furniture to technology built into the structure of the space [3]. We explore examples at several of these levels:

Furniture. When study participants returned home, they sometimes left their laptops in their bags because they did not want to deal with them as they began to relax at the end of the day. However, there is a certain level of maintenance that one would like to carry out (such as charging batteries) to prepare the laptop for its next use. A electronic foyer could include a "magazine rack"-like piece of furniture that would interface with the laptop, perhaps while still in its bag, charging the batteries as well as providing a place for the laptop to rest until it was needed.

Fixture. Fixtures, such as light switches, thermostats, and coat racks are more permanent than furniture but are still not completely built into the environment. One example of a fixture for a redesigned foyer is a compact, wall-mounted printer, perhaps placed next to the door. The printer could output documents on a till-receipt-like paper roll or on small index cards. For example, the printer could serve as a "map printer" that would receive map documents from the laptop and have them ready (serving as a visual reminder) as residents walked out the door rather than requiring them to be printed to other less conveniently located printers (e.g., the one in the basement of Mareesa and Carlo's home).

Built-in. A redesigned foyer could include a range of devices built directly into the floor, door, walls or ceiling. Such devices would enable a "cleaner looking" foyer, a natural fit for a front-stage area in the home. Built-in devices might display ambient data typical to domestic displays (e.g., [26,27]).

Reconfigurable Space

An understanding of how people make use of space, particularly the division between ergonomic and comfortable favored places, has led us to explore various ways of partitioning domestic space (similar to work by [18]). In particular, we observed that while participants had only a few favored places, almost all participants had more than one, most frequently having one ergonomic and one comfortable place. These places tended to be in more open areas of the home. Additionally, residents moved between their favored places several times a day, but rarely alternated rapidly between them. In light of this observation, we propose a moveable wall that makes possible the allocation of more space to one or the other of these places and that facilitates the transition between the two. From a technological perspective, this wall could also include shared technology to support each space, perhaps taking a different form on either side of the wall.

Work in this vein fits closely with existing characterizations of the connectivity and configuration of space [13] and explorations of the "fractal nature" of complex spaces [6]. We propose an exploration of dynamically changing these characteristics of the environment and of exploring the impact that different types of technology can have in such measures.

CONCLUSIONS AND FUTURE WORK

We have presented the results of a study of people living in homes and their use of wireless laptop computers. Our study included the collection of precise location data about household members and these devices, as well as the collection of computer application data. These data sets were analyzed and incorporated in interviews in a novel way to explore home life and emergent patterns of use for wireless and stationary computing devices in the home. We have presented findings regarding patterns of occupancy and computing use in the home. Participants had a limited number of favored places in the home where they dwelled, and wireless laptops were used in almost all of those places. Wireless laptops were used much less frequently in activity places in the home. Wireless laptops appear to be portable but not mobile within the home; they do move among places, but not fluidly. We have discussed learnings on the method and design implications of our findings.

We are excited about pursuing a number of directions in the future. First, we are continuing with similar methodology in a broader sample of homes: more

households, more households with children, and households in a variety of geographic regions so we can study multi-cultural issues in the use of space and technology. Second, we are investigating alternative sensing methods which would allow us to track (albeit probably with less accuracy) a wider range of objects such as cellphones, portable music players, paper documents, and wallets both in the home and ideally in daily life outside the home as well. Third, we are conducting a more detailed quantitative analysis of the data, for example to classify different types of movements. Fourth, we continue to refine the method; here we have explored particular levels of abstraction in the data presented to participants, and we intend to explore other options in the future. Fifth, we are interested in correlating people's movements and computer use with other data such as weather or status of personal relationships.

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