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Supporting Implicit Mobile Communication: Harnessing Ubiquitous Sensors for Context and Content to Support Social Connection /

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Supporting Implicit Mobile Communication: Harnessing Ubiquitous Sensors for Context and Content to Support Social Connection

A dissertation submitted in partial satisfaction of the requirements for the degree of Doctor of Philosophy

in

Computer Science

by

Elizabeth ShanLing Cheng Bales

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2013

The Dissertation of Elizabeth ShanLing Cheng Bales is approved and is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego

2013

DEDICATION

To Nathan Bales the most wonderful and patient husband ever. To my parents who always believed in my abilities even when there was little evidence, and especially to Henry Cheng, my Gung Gung, for being an inspiration in his dedication to his family and his ambition and determination in his career and life.

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Chapter 2, in part, is a reprint of the material as it appears in Supporting a Sense of Connectedness: Meaningful Things in the Lives of New University Students. Bales, E.,

Lindley, S. In Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW 2013), pp. 1137-1146. The dissertation author was the primary investigator and author of this paper.

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Chapter 4, in part, is currently being prepared for submission for publication of the material. Bales, E., Nikzad, N., Quick, N. Ziftci, C., Zappi, P., Krueger, I., Patrick, K. Rosing, T., Griswold, W.G. The dissertation author was the primary investigator and author of this material.

Chapter 5, in part, is a reprint of the material as it appears in Interpersonal informatics: making social influence visible. Bales, E., Griswold, W. In the Proceedings of the ACM Extended Abstracts on Human Factors in Computing (CHI EA' 2011), pp. 2227-2232. The dissertation author was the primary investigator and author of this paper.

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ABSTRACT OF THE DISSERTATION

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by

Elizabeth ShanLing Cheng Bales

Doctor of Philosophy in Computer Science

University of California, San Diego, 2013

William G. Griswold, Chair

Sensors can provide massive amounts of data that can be used to inform individuals of their habits [71], histories [60], and provide insight into their personal behaviors. My research looks at expanding data usage beyond the individual, so that communities and relationships can benefit from these rich datasets. One of the big challenges in this space is to find a way to share automatically collected data in a meaningful way. Sharing automatically generated data is one of the few ways that technology can support true implicit interaction, yet it is easy for generated data to feel "spam-like" to the recipient, leading quickly to frustration and the ignoring of messages. To shed light in

this area I have conducted research in three projects; a qualitative study of how people use traditional physical artifacts to support connection, the design and deployment of CoupleVIBE a hands-free, eyes-free implicit mobile location sharing for couples, and CitiSense a mobile air-quality system for collection and sharing in communities.

Chapter 1

Introduction

A long expected contribution of technology is the promise of connecting across distances and bringing together families and friends for meaningful interaction (Figure 1.1 and 1.2). However as technologies have advanced, a growing concern has is whether new technologies are providing greater connection or are enabling people to disengage with others at a level never before possible. Researchers like Sherry Turkle have presented this case by exploring the ways in which technology adoption has played out in unexpected ways, often leading to less connection, not more:

> *"Technology is seductive when what it offers meets our human vulnerabilities. And as it turns out, we are very vulnerable indeed. We are lonely but fearful of intimacy. Digital connections and the sociable robot may offer the illusion of companionship without the demands of friendship. Our networked life allows us to hide from each other, even as we are tethered to each other. We'd rather text than talk." [118]*

It important to note that no one is arguing that technology should be removed altogether. There are clearly benefits to technology that provide incredible benefits to individuals and society. So the question remains, given that communication technology is too valuable to give up, how can the creators of the technology support connection while minimizing the side effects that these technologies can bring. It is in understanding this darker side of technology that we are able to shine light on the current limitations of communication technology, with the ever present hope of using our newfound knowledge to inform the design of future systems.

One contributing factor to the disillusionment with distance communication stems from a skew in the spectrum of the kinds of communication supported by existing technology. Previous research illuminates that for individuals to feel connected, both implicit and explicit communication must be present. While face-to-face communication support the entire continuum of engagement, from implicit to explicit modes of communication, current communication technologies–like Facebook, Twitter, SMS, email, and telephone calls–are skewed strongly towards the explicit communication end of the spectrum. These technologies do a good job of supporting purposeful interactions, but ignore the kinds of accidental communications that support everyday collocated interactions. Figure 1.4 highlights some common communication technologies showing where they fall in both scale and attention (eg. A typical phone call is between a small number of people but requires high attention because of its synchronous nature, while a typical tweet requires a brief moment of attention and is visible to a large group of people). As visible in figure 1.4, the majority of existing communication technologies focus on explicit and purposeful interactions, while implicit communications remain unsupported.

This gap in support has been noted in the research literature and motivates a collection of work related to calm and ambient awareness technologies. Early work imbued physical actions and objects with ambient cues, such as outfitting a digital photo frame with status information or releasing a lingering scent to the partner to denote presence [88, 111]. More recently, Lottridge et al. proposed sharing music and background sounds with MissU [79]. The Whereabouts Clock introduced a in home peripheral display showing the locations of family members in a glancable format (eg. home, work, school, or elsewhere) [25]. While all of these systems support ambient awareness, the focus has remained primarily in non-mobile settings with small group sizes (Figure 1.5).

In looking at the consumer and research space we see that there remains an unmet need in supporting implicit mobile connection. To better define this gap I introduce four design dimensions which can be used to categorize all communication types:

1. **Attention: Implicit to Explicit:** How attention is allocated, how much effort is required for a successful communication (for both sender and recipient)?

2. **Scale: Intimate to Public:** What is the scale of the interaction, between two people, within a broader community?

3. **Context: Mobile to Situated:** Is the communication location dependent or available in a mobile setting?

4. **Social Structure: Flat to Hierarchical:** What is the social relationship between participants?

For example, we can think of sitting and watching a movie with one's spouse as being implicit, flat, intimate, and situated, while a celebrity twitter account might be explicit, hierarchical, public, and mobile. These four design dimensions impact design choices such as the form factor, whether to make the technology medium synchronous, and how to inform the user of information exchange.

In this dissertation the primary focus is on supporting implicit communication at a distance, and will focus on the implicit end of the awareness spectrum. The remaining three factors of Social Structure, Scale, and Context are varied in the experiments described in this thesis to provide a grounding of how implicit communication at a distance might look in a variety of settings. To complement existing work in the space my work emphasizes the mobile space, although some aspects of situated interaction are also explored.

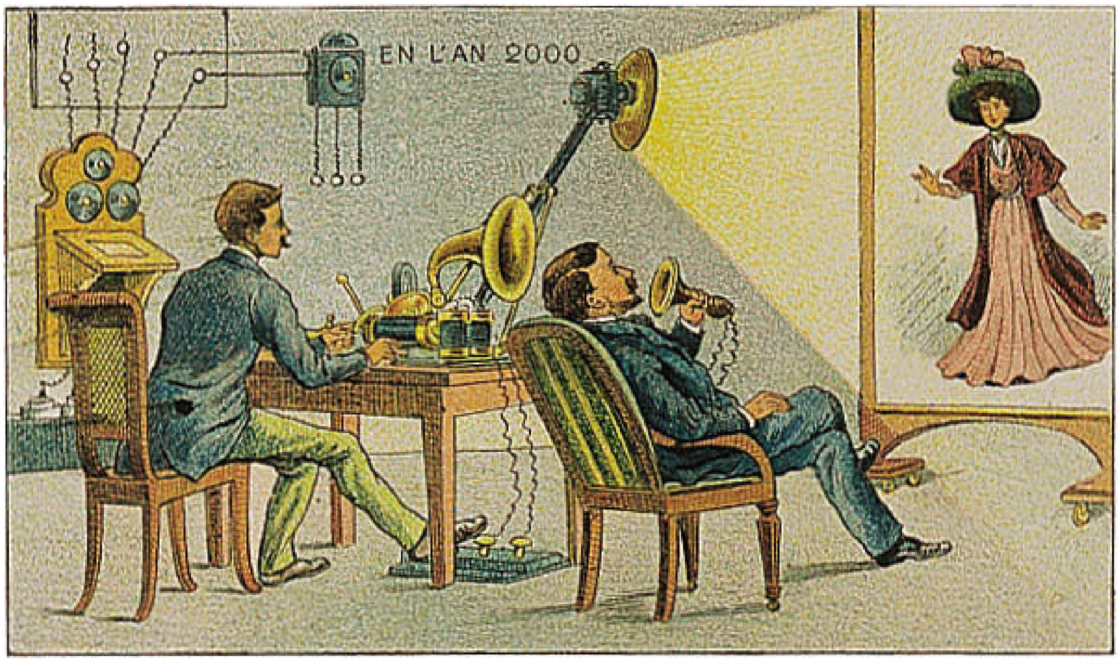

Figure 1.1. The Correspondence Cinema[124]: An early French concept drawing of how live images might influence the distance communication of the future. (Circa 1910)

1.1 Thesis Statement

I claim that to achieve the full potential of long-distance communication, we need to support the fullness of the communication spectrum. The existing tensions felt by Turkle and others are heightened by the existing skew towards the explicit side of the communication spectrum in computer mediated communications. In this dissertation I demonstrate that sharing automatically collected data in a ubiquitous setting can support connection and communication between individuals and communities. In particular, I demonstrate that automatically collected data can support relationships in ways not met by existing technologies.

To support this claim I present three studies that help illuminate this space. The first is an in depth look at the roles of physical, digital and cloud objects in facilitating feelings of connection at a distance. The second includes the design and deployment of a

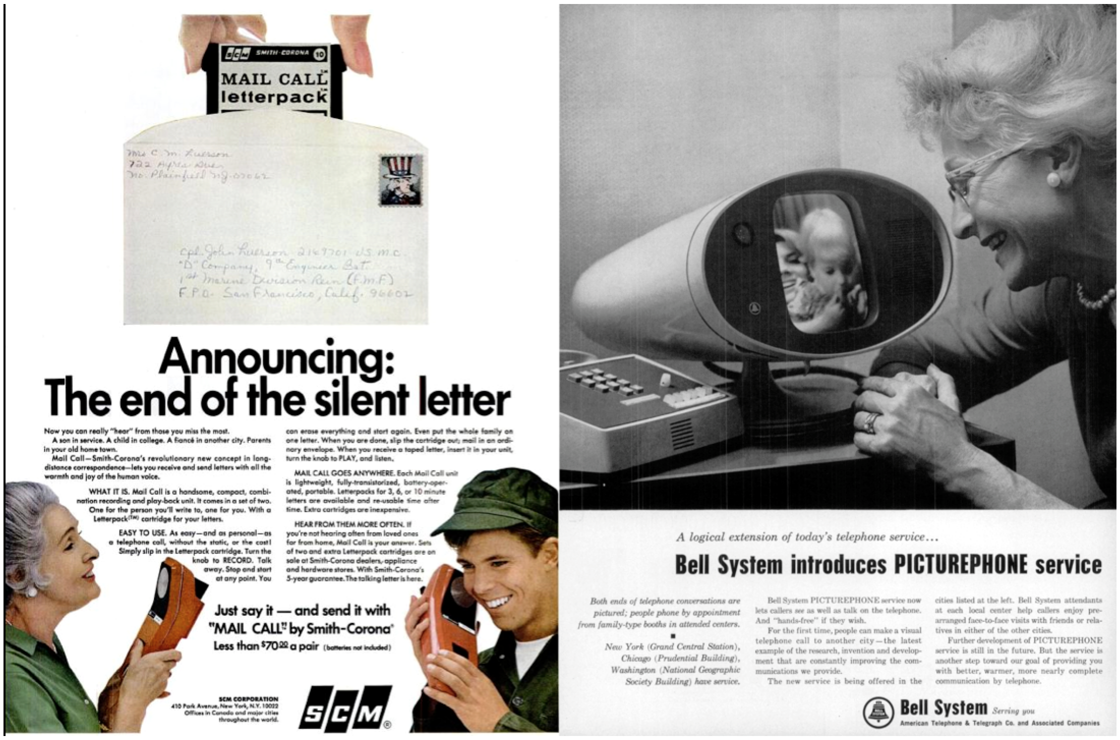

Figure 1.2. Communication technology has long held the promise of connecting loved ones separated by distance. From Mail Call (1970)[108] to the Bell Labs Picturephone (1964)[112], each advance seems to bring us closer together, yet all the while we remain frustratingly distant.

system designed to support awareness between romantic couples separated by distance. Finally, the third explores how this kind of automatically collected and displayed data can be used to support connection in communities. These three studies provide both the theoretical background and present new found evidence for how mobile implicit communication can be supported at a distance, for both intimate (Chapter 3) and public (Chapter 4) scale sharing. Both hierarchical (Chapter 2) and flat (Chapters 3 and 4) relationships are explored with a focus on mobile implementations. My goals in this research were to:

1. Explore existing methods for implicit distance connection, to learn about current practices, limitations, and desires.

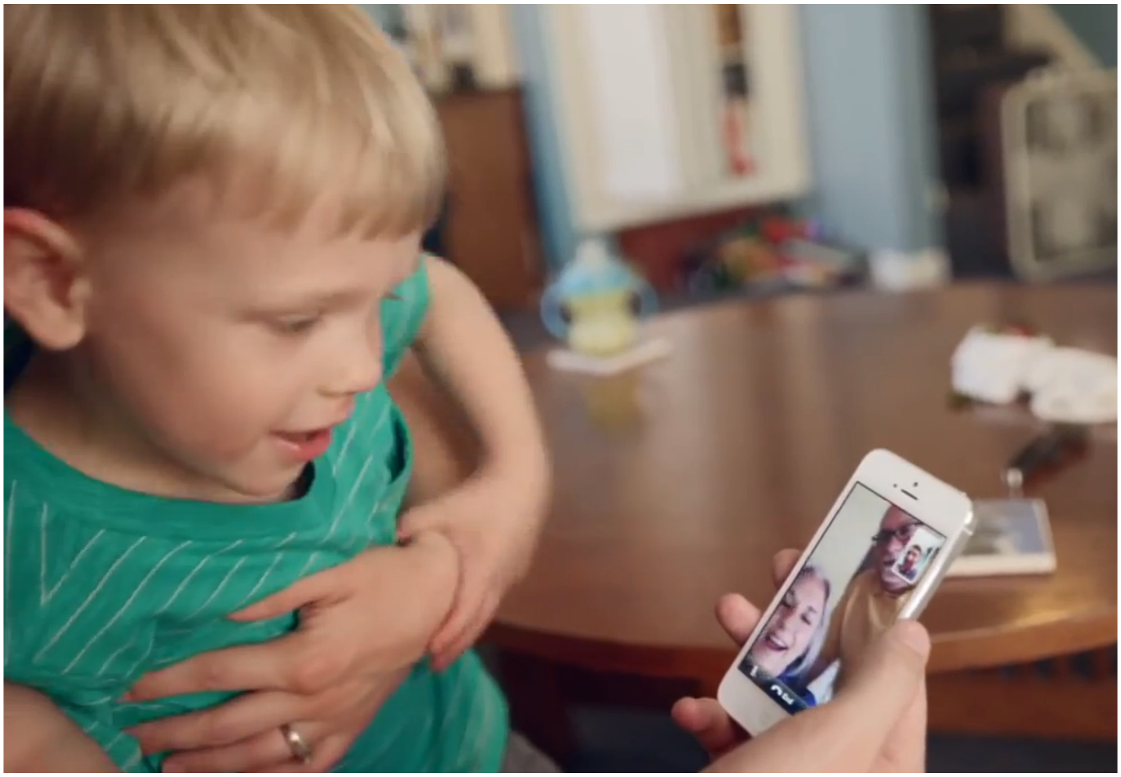

Figure 1.3. This Apple advertisement (2013)[9] presents the same promise made by bell labs in 1964 and the correspondence cinema vision of 1910. Despite a century filled with world-altering technological changes, the leading vision for distance communication looks remarkably the same. While technology has progressed to make the dreams of the past a reality, in practice there still remains a vast gap between collocated communication and communication at a distance.

2. Develop a prototype system as a probe to support truly implicit distance connection through deployment with real users.

3. Explore how meaningful sharing changes within larger user groups through the deployment of a community-scale data collection and sharing system.

The following sections demonstrate the problems introduced by the skew in the existing communication spectrum, and the role that sensors can play in supporting these communication. I close with an overview of the remaining chapters highlighting how they fit together to illuminate the space of mobile implicit computer supported communication.

Figure 1.4. The current landscape of implicit sharing in the consumer space remains sparse for supporting low effort connectedness.

1.2 Awareness Continuum

To better understand why the existing skew in the Awareness Continuum is problematic, it is important to understand the what factors support feelings of connection and intimacy. We can think of all communication falling somewhere along the awareness continuum, with interactions like face-to-face interactions falling towards the explicit end and things like sitting and reading silently together falling towards the implicit end.

Explicit communication - Purposeful interaction with the purpose of communicating. Example explicit communication interactions include: face-to-face conversations, phone calls, text messages, and Facebook status updates.

Implicit communication - Non-purposeful communication that occurs as a byproduct

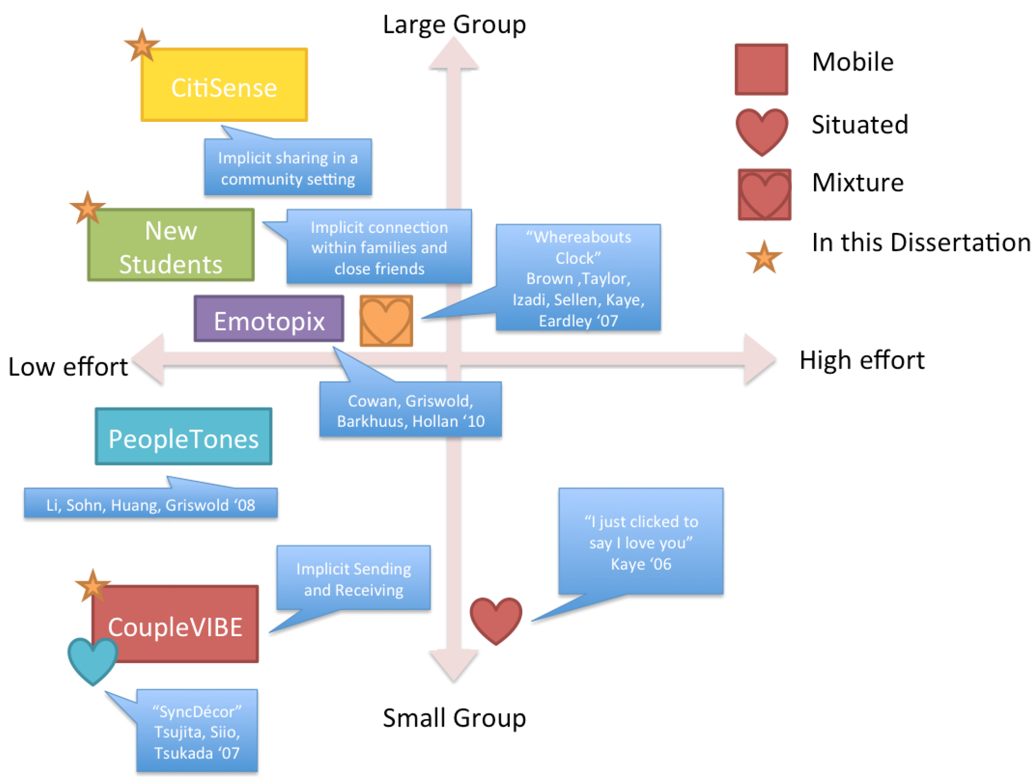

Figure 1.5. Improving remote awareness is a topic that has been addressed in several recent publications. To simplify this graphic only projects that require low to no user effort are displayed.

of actions by yourself or an other. Example implicit communication interactions include: brushing past a loved one in the hallway, hearing the lock turn in the front door, or hearing your spouse laugh while sitting on the couch watching a movie together.

The combination of explicit and implicit communication helps individuals form feelings of connection and intimacy. In their study of proximate and mediated intimacy Kjeldskov et al. define eight aspects of intimacy that together support feelings of human connection between romantic couples [67]. The first four–Physical intimacy, non-verbal communication, self-disclosure, and presence–all represent types of communicative actions, while the remaining four–cognitive intimacy, affective intimacy, commitment,

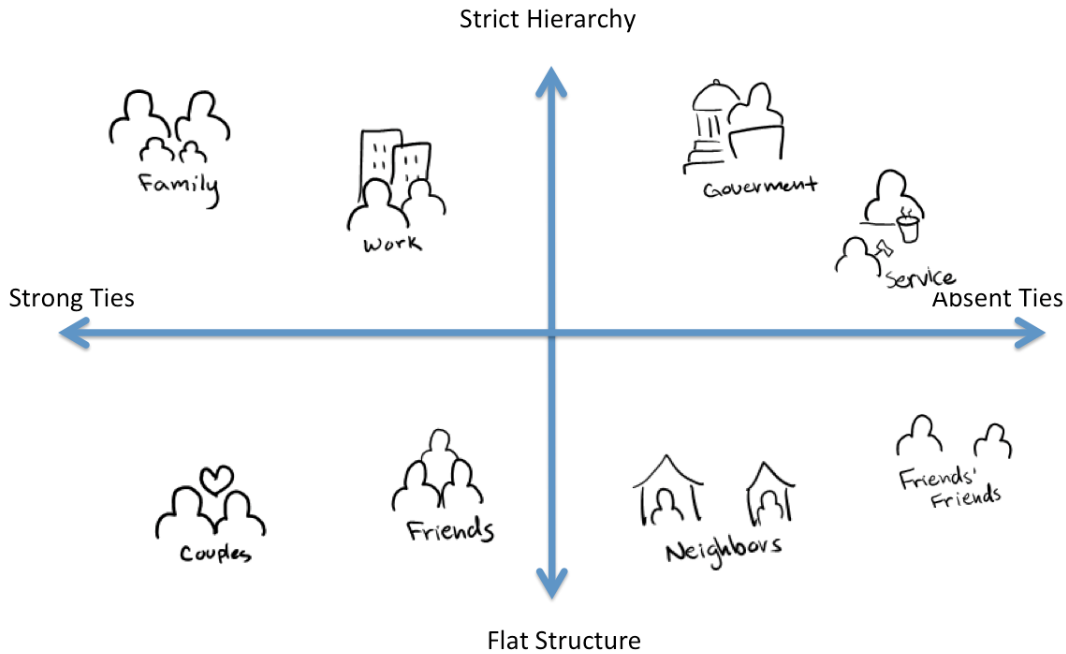

Figure 1.6. The sharing of sensor data can form the foundation for deeper connections between individuals. How this data is shared, and to what outcome, depends both on the strength and hierarchical nature of the relationship.

and mutuality–are four relationship properties that are created and reinforced by the first four (bold denotes primarily supported by implicit communication).

1. **Physical Intimacy**–Feelings of closeness supported by physical touch.
2. **Non-verbal Communication**–Communication that is better supported through a means other than voice (e.g. touch, gesture, facial expression).
3. Self-Disclosure–A deep sense of connection supported by the sharing of close personal feelings.
4. **Presence**–Feelings of closeness supported by non-structured, ambient observation made possible by being proximate to one another.

5. Cognitive Intimacy–"Characterized by the feeling of 'knowing' the other" Understanding their likes and dislikes, their personal preferences and being able to anticipate their reactions to different scenarios

6. Affective Intimacy–A deep sense of affection, caring, and love toward the other individual. Affective Intimacy is often used to differentiate between romantic relationships and close friendships.

7. Commitment–Long-term intent of remaining in the relationship.

8. Mutuality–A communal sense that both parties are striving towards the same goals as a team.

Of the four aspects of intimacy related to communication, only one 'self-disclosure' is primarily an explicit communication mechanism. The rest represent either a combination of implicit and explicit, like physical intimacy, or are primarily implicit by nature (e.g. 'non-verbal communication' and 'presence'). Kjeldskov argues that "it is important to note that these components do not exist or work independently, nor do they individually satisfy the intimate experience. Indeed, the themes overlap greatly and are highly interrelated [67]." Although these traits work together to support feelings of intimacy, existing communication technologies focus on self-disclosure, which is but a single aspect of these pillars of connection. Several, research attempts have been made to understand and support computer-mediated non-verbal communication like textual [125] and haptic emoticons [52], while others have investigated methods for supporting physical intimacy at a distance [42]. In this work I explore computer mediated implicit communication through supporting remote presence and encouraging mutuality in a ubiquitous setting.

1.2.1 Reciprocity as a Marker for Explicit Communication

When differentiating between Explicit and Implicit communication, one useful marker is the presence of reciprocity. In explicit communication there is effort exerted by the producer that is typically reciprocated in kind by the receiver. This reciprocal interaction is a concrete way that both parties acknowledge the exchange of communication. Although Reciprocation may be an obvious property for communications such as synchronous conversation, it is has also been observed in asynchronous communication like text messaging [113]. The threshold for introducing reciprocity in computer-mediated communication lies in the perception of intent and crafting [62]: when the recipient perceives effort was exerted on behalf of the sender feelings of reciprocity are generated by the interaction. A well-known case of low effort reciprocity is the Facebook "poke wars" in which users felt obligation to click the "poke" button in response to their friend "poking" them. Although the "poking" represents a very-low-effort task devoid of message crafting (e.g. simply clicking a button), the need to reply in kind was still widely felt by users.

This reciprocal form of communication and connection is foundational to interpersonal connection and often forms the basis for more complex social structures, from small scale tribal structures [The Gift], to large scale modern interactions, like emails, text messages, and social network interactions. Reciprocity was first defined in the field of Anthropology, where it was observed as a factor in maintaining balance in social orders in pre-currency communities:

Reciprocity (Quote from Sahlins): Economic imbalance is the key to deployment of generosity, or generalized reciprocity, as a starting mechanism of rank and leadership. A gift that is not yet requited in the first place "creates a something between people": it engenders continuity in the relation, solidarity–at least until

> the oblation to reciprocate is discharged. Secondly, falling under "the shadow of indebtedness," the recipient is constrained in his relations with the giver of things. The one who has benefitted is held in a peaceful, circumspect, and responsive position in relation to his benefactor[101].

Anthropologist Malinowski introduced the idea of a continuum of reciprocities with barter at one end and "the true gift" at the other. This suggests that different actions can incorporate differing amounts of reciprocity.

Continuum of Reciprocities (Quote from Malonowski): It seems possible to place reciprocities based on the "vice-versa" nature of exchanges, along which empirical instances encountered in the particular ethnographic case can be placed[80].

Taylor and Harper extended the idea of reciprocity to include digital exchanges, and the sharing of digital objects. In their study of the digital exchanges in teenage social structures they found evidence of different social value attributed to different artifacts, often linked either to effort, monitory cost (such as free vs. paid for text messages), and sharing digital objects to show trust[113]. The exchange of virtual commodities such as text messages, Facebook pokes, and "likes" generated imbalances in feelings of reciprocity, which propagated similarly to those generated from the exchange of physical objects.

For the purposes of this dissertation I focus on interaction in that thin slice of interactions where feelings of reciprocity are not generated. This kind of interaction must lack intent and crafting by the sender, while artfully avoiding the generation of feelings of resentment in the recipient by being bombarded with unwanted messages. It is in this thin slice of implicit communication that I believe that automated sensing and data communications can help support feelings of connection and begin to fill in some of the gaps which have left technology users feeling connected yet lonely.

1.2.2 Mismatched Mode of Attention

One of the major problems in ignoring the implicit side of the continuum is that social interactions that are better supported by low attention methods are forced to escalate to higher attention levels. This has two drawbacks that are readily seen in existing technologies:

1. **Violates Respect and Privacy Expectations**: When technologies force users to give more attention to an interaction, naturally implicit interactions are escalated to explicit forms. This often requires users to pay more attention than is socially appropriate, even if that is not their intent. This is evident in many existing location-sharing systems where the intent of the user is often mismatched with how that goal can be accomplished with the technology. For example, two of the most common uses of location sharing applications are for users wondering when another person will arrive (time information) or using location as a proxy for well-being (is in a safe place). However the default location sharing system is sharing a map containing the exact locations of others. This can be uncomfortable for both parties and often leads to the choice to avoid the technology altogether, despite its obvious benefits.

2. **Increases User Burden**: By forcing individuals to transpose a passive to an active technology we require their attention, often interrupting existing tasks and increasing user burden.

Attention is a way of showing respect in relationships, but when technologies enforce various amounts of attention due to lack of support in less explicit features the result can be uncomfortable for the users. By supporting more interaction at the implicit end of the continuum we can allow people to engage at the level that is appropriate for the task. Implicit support can empower people to maintain their privacy while also showing respect for others by only requesting relationally appropriate amounts of data sharing. Finally, implicit methods can allow for people to share “nice-to-know” data by lowering the barrier for the sharing of ‘nice-to-know’ information.

1.3 Sensors for Supporting Implicit Communication at a Distance

With our understanding of implicit communication and reciprocity, the question remains of how these communication goals can be met through design and technology. It is here that the role of sensors becomes apparent. Nearly every interaction we have in modern life creates data streams, from using GPS to navigate to the store, buying products on our credit cards, to communicating with old friends online. Passive actions like carrying a phone in your pocket can produce a full location history, even though the technology is not actively being engaged with. What we search for, where we go, how much power we consume, the money we spend, the miles we drive; all of these pieces of data tell stories of our lives and interactions. Corporations have been acting on this for some time, and have harnessed the data stream available to them to target sales, and maximize profits [56]. More recently an increasingly large number of individuals have started tracking their own data for a variety of reasons, from health [54], to curiosity [44].

My goal is to harness these data streams and instead of using them to support personal or commercial knowledge, use them to facilitate implicit communication. As noted in the previous section, to be truly implicit an interaction must not generate feelings of reciprocity. However, we know from Kaye’s [62] work that even the slightest amount of effort or crating can generate reciprocal feelings. Given these constraints, sensors become the obvious choice for collecting data. In collocated situations humans use their built in sensors (eg. eyes, ears, mouth, nose, skin) to be able to passively take in their context, choosing to escalate engagement when needed. In a similar way sensors can provide this same capability across distances, and can support users in choosing when they would like to escalate to more active forms of engagement with a remote other.

Any device that can be used to collect this automatically generated data can be thought of as a sensor. In particular, in this dissertation I will focus primarily on mobile sensors as they have the capability to cover a broad portion of a user's daily activity.

Through the sharing of automatically collected data we can support true implicit communication because no information needs to be thoughtfully crafted by the sending party. Likewise, through situationally customized delivery (such as tactile messages or ambient displays) we can relieve receiver burden, allowing them to easily attend to or ignore data as it come to them, in a similar fashion to how recipients of collocated implicit interactions can modulate their engagement in respect to their interest in the activity of their cohabitants.

1.4 The Benefits of Mobility

By designing a mobile form factor for implicit technologies we get two important attributes for free:

1. **Continuous sensing**–To get the full benefit of sensing one of two things must be true to avoid problematic gaps in the data. Either the space in which you are interested in must be fully instrumented with sensors, or the object you are interested in must be instrumented with sensors. In our case, where we are interested in the sharing between humans, introducing mobile wearable sensors is much more feasible than outfitting all of the possible spaces in which those humans might travel.

2. **Real-time connection**–Data that is a good candidate for implicit communication

generally falls into the 'nice-to-know' category. This information, while valuable to the recipient if received temporally proximate to the trigger event, looses value quickly after the moment passes. An concrete example of time-based value can be observed in location sharing technologies. While receiving a real-time notification that your partner has left the office and is on his way home has utility, receiving that same information hours later when you are already home together is both useless and annoying.

These attributes are made possible by using a mobile platform and allow for continuous sharing between remote individuals.

1.5 Overview of Dissertation

The following sections outline the studies presented in this dissertation to highlight how they fit together to illuminate the space of implicit communication through data capture.

1.5.1 Chapter 2: The Communicative Properties of Everyday Objects

Chapter 2 Introduces a study conducted to find the background information necessary to learn how people use existing physical and digital objects to maintain a sense of connectedness with distant loved ones. By observing the use of these objects we were able to learn both what kinds of interactions are currently supported and where there might be room for support. On the design spectrum this study focussed primarily on implicit, intimate, situated, hierarchical space. The primary goal of this work was to learn how implicit connection is currently supported through the interaction with and placement of physical, digital and cloud objects.

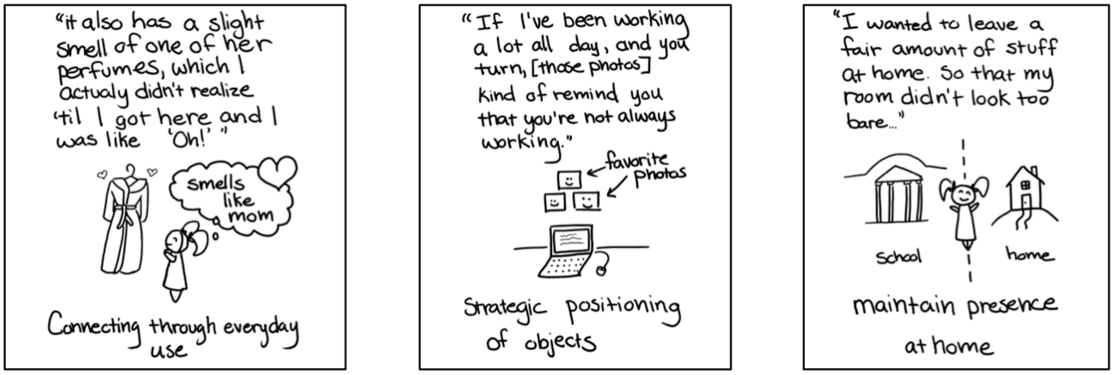

Figure 1.7. For many objects we found that a sense of connection was experience through their usage, such as with wearing a hand-me-down bathrobe that retained the scent of a mother's perfume, or making tea with the old family kettle. In other cases strategic positioning of objects played a key role in connection with important photos place above a workspace or next to one's pillow. Placement on the large scale also mattered, with some objects purposefully left at home allowing students to maintain a presence there as well. We explored how the properties we observed in these physical objects might be used to inform technical designs, and how the designs of existing digital artifacts helped or hindered their usage.

Maintaining connection at a distance is a familiar challenge in modern life, as education and employment needs frequently require families and friends to live at a distance. We set out to study how people in this position worked to maintain feelings of connection. I conducted a qualitative study in conjunction with researcher Siân Lindley of Microsoft Research Cambridge at Cambridge University with first-year university students within two months of their moving away from home [18]. We felt this environment would be especially fruitful because the students had just moved away from their homes and families for the first time and were particularly aware of the trade-offs and choices they were making to stay connected. Our study focused chiefly on ambient forms of connection, looking at meaningful objects and their arrangement in the physical, digital, and cloud spaces. We explored what students chose to bring, what they chose to leave behind, and how their interactions provided a sense of connection with their loved ones. We identified 3 ways in which the artifacts underpinned a sense of connection: conveying the character of home, supporting a sense of continuity, and enabling the maintenance of a remote physical presence at home. We also considered how the affordances of objects, such as function and the ability to place, provided opportunities for connection. We then suggested opportunities for the design of digital objects that are informed by our findings, such as supporting the curation of collections that are collectively owned, and creating digital displays that acknowledge provenance.

1.5.2 Chapter 3: Implicit Connection for Couples

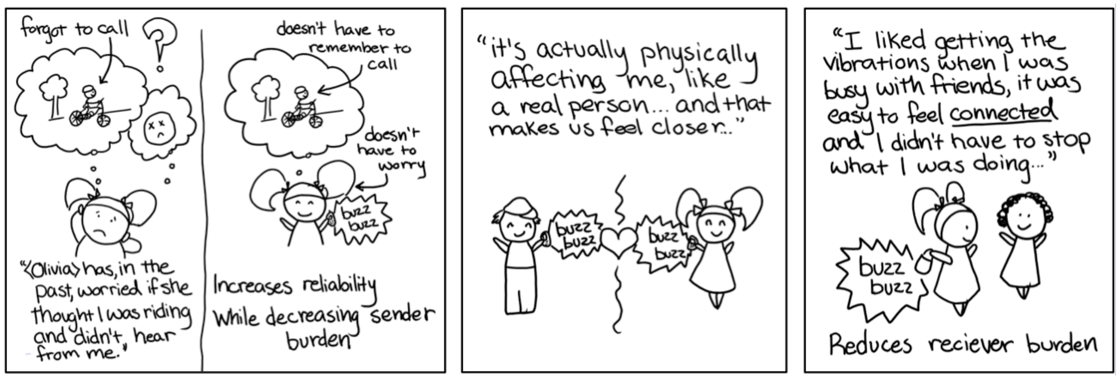

Figure 1.8. CoupleVIBE: Automatic ambient cues allowed for participants to stay connected without interrupting their daily activities. The end-to-end automation proved to provide an extremely lightweight communication channel, and supported feelings of connection without generating feelings of reciprocity (a requisite for true implicit communication

Chapter 3 gives an in depth look into a system we developed to support feelings of connectedness for long distance couples. CoupleVIBE provides a eyes-free, hands-free backchannel that couples can use to stay in sync with one another despite distance. On the design spectrum this study focussed primarily on implicit, intimate, mobile, flat space. The primary goal of this work was to learn how ubiquitous implicit communication fit into the communication habits of romantic couples.

As the new student study confirmed, both explicit and implicit connections support the needs of people living at a distance. These two types of interactions are complimentary to one another providing a more complete feeling of connection in human relationships [12]. However, as most modern communication technologies focus on explicit communication, less is known of how technology can support implicit interactions. I therefore designed, built, and deployed the CoupleVIBE system to explore how mobile technology could be used to support implicit connection at a distance. CoupleVIBE is designed for romantic couples and is a system that supports eyes-free, hands-free location sharing. Through the study of CoupleVIBE we found that implicit messaging channels have unique properties that can better address some communication needs of long-distance couples.

One leading design guideline was to avoid generating feelings of reciprocity, which would cause users to feel the need to respond to messages received from their partner. To accomplish this I designed the CoupleVIBE system automatically recognizes and pushes a user's location-information to her partner's mobile phone, and delivers the message via vibrotactile cues. This end-to-end automation allowed for partners to learn about one another without engaging in purposeful communication actions and was found to nicely supplement other forms of communication. Privacy is a key concern raised by this kind of automation, and in the design and deployment of the devices I was careful to include and explain mechanisms that allowed for users to control, and if desired, turn off sharing. One of the most interesting outcomes of the study was that although the privacy features were not used to hide activity, they were used as a mechanism for showing respect to remote partners. For example, participants in different time zones would turn off sharing when they knew their partner to be asleep so that they wouldn't buzz their phone and wake them up. Although I did not initially set out to design a respect-centered interface, through the observations of usage I realized that designing mechanisms for showing respect are an important and overlooked aspect of technical communication. This finding has many applications most notably in the social network space where very little has been done to explore how interfaces can support respectful actions.

1.5.3 Chapter 4: Sensor Sharing for Communities

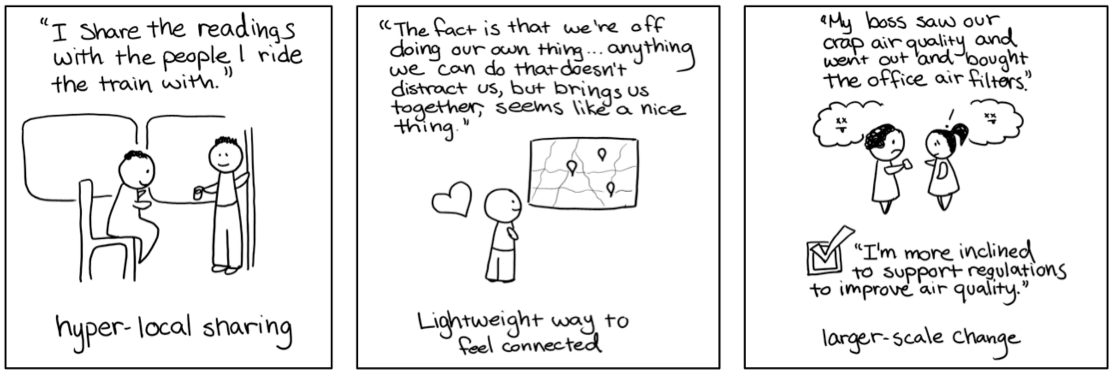

Figure 1.9. CitiSense supported connection both with those who were physically close, and was a lightweight way to connect with their local community. CitiSense provided users with new information that users stated helped to inform them for changing behavior at individual, local and government levels

Chapter 4 introduces CitiSense, a real-time mobile air-quality sensor for novice users. In this chapter we explore how access to sensor data can empower users in their individual choices and encourage feelings of connectedness with their communities. Although our deployment was only one month long, our interviews suggest increase in interest in political activism and engagement with their local communities based on the sensor data collected. On the design spectrum this study focussed primarily on implicit, public, mobile/situated, flat space. The primary goal of this work was to learn how automatically collected data could improve personal and community awareness.

Sharing and connecting becomes increasingly complicated as we start to include larger groups of people. Despite this challenge, it is still very important to look at supporting connection in larger groups because feeling connected to one's community is an important aspect of well-being. To look at supporting communities, I worked with an interdisciplinary team to help design, build, and deploy the CitiSense mobile air quality system [16][89]. This work is motivated on numerous levels, as in addition to supporting connection in communities, poor air quality is a growing global concern that impacts millions of people worldwide. Air pollution is linked with increases in heart attacks, asthma, dementia, and cancer, as well as reduced quality of life for people who live in highly polluted areas. Although we are beginning to understand the health impacts of air pollution, it remains a challenge to provide people with the information they need to make health-conscious choices, both at the personal and community. We designed CitiSense to provide individuals the real-time tools they need to be able to identify when and where they are exposed to poor air.

In the course of the CitiSense Study I have deployed the system with a total of 40 participants, all using the system within the context of their everyday lives. Through these deployments I learned how people reasoned about air quality data and how having access to the system influenced their interactions with others. One major finding was the interest our users had in sharing their readings, saying that this was the first time they had used technology that made them want to engage with others, in contrast to other mobile technologies that they often used as a social retreat.

> *"previously I would sit on the bus and I wouldn't talk to anybody, I would be on my cell phone [...] whereas actually this, because I was becoming aware of my environment, and I was aware that people were sharing the environment, it then helped me to talk to people." -participant (public transport user)*

1.5.4 Chapter 5: Future Work: Interpersonal Informatics

Chapter 5 builds on the ideas from these previous projects, and explores future research goals that expand upon the space of meaningful data sharing to include very large networks. In this chapter I propose the idea of Interpersonal Informatics [13], an area that builds on my previous work and on Ian Li's Personal Informatics [71] to include

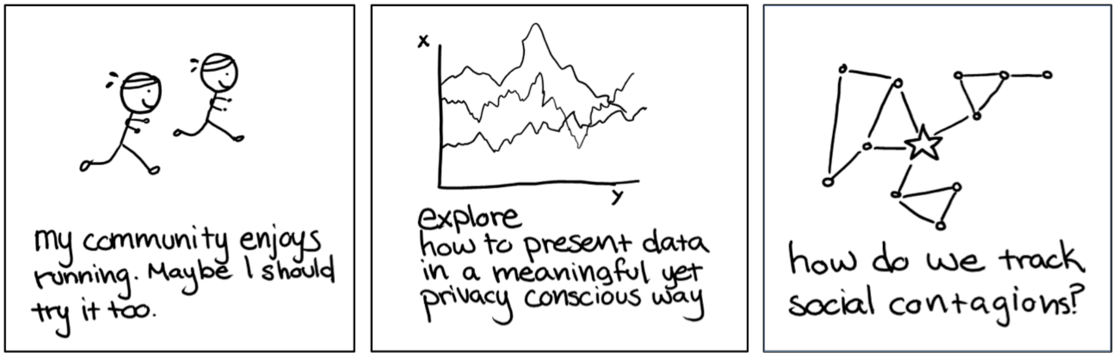

Figure 1.10. Interpersonal Informatics (IPI) can be used to show people the positive and negative influences they are exposed to through their community. This knowledge can help people find way to connect by making shared interests visible, and could also help users become aware of possible negative influences. There are many open challenges, such as how to visualize data, how to respect privacy, and how to track contagions as they spread through networks.

larger social groups to gain insight on one's self and community.

1.5.5 Chapter 6: Final Thoughts and Contributions

Chapter 6 completes this thesis summarizing the methods and highlighting the major contributions.

Chapter 2

The Communicative Properties of Everyday Objects

Figure 2.1. Meaningful physical, digital, and cloud objects can help support feelings of connection when loved ones are at a distance.

As a first step to understanding how technology can support connection at a distance we conducted a study to learn how individuals harness existing objects and technologies for this task. In this chapter we report findings from interviews with new undergraduate students, in which they identified particular items as supporting a sense of connectedness with home. We characterize ways in which artifacts underpinned a sense of connection, including by conveying the character of the parental home, supporting a sense of continuity with it, and enabling a physical presence to be maintained there. We then consider how simple affordances offered by these artifacts, such as being able to move, position and sort them, enabled participants to reinforce the meanings that were associated with them. Such actions are normally taken for granted, but we describe how they are compromised for social media especially, due to functional limitations and questions of ownership. We highlight design opportunities for making the transition from home more gradual, and supporting the archiving and display of social media.

2.1 Motivation

The importance of cherished objects is well recognized in HCI. Researchers have tried to understand how it is that objects come to be cherished, the roles they play within family life [65], and why it is that participants rarely highlight the digital when talking about their cherished possessions, despite an increasing abundance of digital mementos, including video, photos, and emails [97]. These studies tend to explore established "family archives" [65][97][98], but less is known about how these archives are formed and curated over time, or the events that prompt people to consciously shape them, discarding things once considered precious, and keeping others, in a reaffirmation of their status as important.

Yet there are clear trigger points that cause people to take stock of their belongings and consciously engage with them. Transition points, such as moving, are an excellent example of this. These periods of transition create moments when people are forced to make decisions about what to bring with them, decisions that will shape the way that they can connect with the past, and continue to reminisce in the future. In this paper, we focus on a specific type of transition: that of moving away from home for the first time to go to university. The move to university is especially interesting because students often simultaneously maintain a space at home whilst creating a new space for themselves at university. This echoes social changes that also occur in the lives of students at this time. They may wish to balance the maintenance of ties with their childhood friends and family with the forging of a new identity for themselves in their new environment.

New university students are also an interesting group because they, generally speaking, belong to a generation of so-called “digital natives”. While HCI researchers have struggled to get participants to identify the digital when pointing to things that are cherished, work with teenagers has revealed a more complex set of practices surrounding what Odom et al. [93] describe as “virtual possessions”. These practices include making virtual possessions physical, for example by printing them, and combining media to create new, personalized digital artifacts. We might expect digital things to also fall under the rubric of cherished possessions for university students and, while virtual possessions are not subject to the same sort of constraints as physical things, the psychological and social nature of the transition to university may nevertheless prompt their curation. This may especially so for content on social network sites, which play an inherent role in interactions with (new) others.

In this paper, we report findings from interviews with ten new university students about their meaningful things after moving to a new hall of residence, placing particular emphasis on how these items support a sense of connectedness to home. We show how this was underpinned by a variety of artifacts, and consider how the affordances that they offered enabled participants to reinforce the meanings associated with them. We note that this was compromised with social media especially, which nevertheless served as a key source of content for our participants. We suggest opportunities for design that relate to supporting the personal archiving and display of social media content, and a transition from home that is gradual.

2.2 Related Work

Research on transitioning to university has explored how technologies play a role in supporting communication between college students and their parents as well as how new technologies might be designed to support a sense of connectedness to home. Chen and Katz[78] focus on the fundamental role that the mobile phone plays in supporting communication between college students and their parents, and Dey and de Guzman[41] highlight the importance of objects such as photographs and gifts, that can be peripherally displayed and that cue memories associated with friends and family. Smith et al. [107] illustrate a more complex relationship with home: in their research, the use of technologies by college freshmen was seen as mediating both closeness with, and independence from, parents. Smith et al.'s work in particular underlines how the nature of going to university entails something of a balance between staying connected and moving on. Yet, this circumstance is not unique to students. Shklovski et al.'s [105] research on residential mobility more generally suggests the need, initially at least, to keep in touch with a prior location, be this through following local news or checking the weather. Such practices not only support a sense of connectedness, but also serve as a social vehicle for conversations with friends who still live there. Shklovski et al.'s later work [104] examines in more detail how technology is implicated in keeping in touch following a residential move. They highlight the role of communications such as emails, which can be understood as both communication act and tangible good, and which serve as an unobtrusive reminder of a relationship as they persist in the inbox.

However, and as Shklovski et al. Shklovski2005 notes, an essential part of settling into a new home is overcoming the tension between the old and the new by leaving aspects of the old behind. Marcoux [81] has demonstrated how this tension is sometimes tackled head-on; the act of sorting through one's possessions can serve as a means to re-evaluate relationships and “reshuffle memories”, enabling the opportunity to leave things behind. On the flip side of this, of course, possessions that survive a move and become integrated into new living spaces and practices can serve as a point of continuity with the past. Petrelli and Whittaker [97] argue that homes are designed to express and reinforce memories, with mementos being integrated into familiar spaces and everyday practices. Kirk and Sellen[65] build on this point, noting that the “archiving” of cherished objects entails their being enmeshed in and constitutive of the material fabric of the home. They note that artifacts on display support a form of “ready reminiscence” by dint of their being continually present. In other cases, sentimental objects (such as a grandmother’s ladle) are stored in such a way as to support functional use, while a third category of artifacts are placed in “deep storage”, where they might be encountered serendipitously but otherwise need to be consciously sought out. Kirk and Sellen suggest that through being embedded in the home, objects play a role in defining the self, honoring those that are cared about, connecting with the past, framing the family, fulfilling duty, and enabling forgetting. Durrant et al.[43] also observe how the display of photos at home is curated to present a unifying image of family.

This integration of material objects in home life offers a contrast to the ways in which virtual possessions are stored and used. While family members in the studies described above could readily identify physical objects as sentimental or cherished, they found it difficult to do the same for their virtual possessions. Petrelli and Whittaker [97] suggest that the digital mementos that their participants did eventually identify, such as photos and communications, did not initially spring to mind because of the ways in which they are stored; they are simply not located in places where they are persistently encountered. Related to this, Petrelli et al. [98] note that the periodic sorting and distilling of personal belongings is important in sustaining a compact collection that one can meaningfully engage with, a process that is atypical with digital content [e.g.

[82]]. Additional reasons highlighted in various studies include that digital media is not really experienced as an "object" [46], that it is perceived as transient and inexpressive [97], and that it conveys simple and representative meanings, rather than these being abstract and esoteric citePetrelli2008. In an exploration of the attributes of physical and digital things, Banks [2] also notes that the former offer qualities such as uniqueness and the acquisition of patina, which are difficult to meaningfully replicate with digital materials.

Nevertheless, other researchers have argued that virtual possessions are valued artifacts. Indeed, Banks [19] also notes that digital artifacts have their own set of attributes, such as the ability to underpin serendipitous encounters, which offer opportunities for design, and Golsteijn et al. [46] highlight how the crafting of digital artifacts such as websites can add to their perceived value. Furthermore, work with teenagers has highlighted text messages as gifts that can embody memories, and has shown how practices develop around preserving those that are deemed particularly special[114]. In a more recent study, Odom et al.[93] demonstrate how some of the unique qualities of digital media, such as the accrual of metadata and the placelessness of data stored online, support a unique set of meanings and uses. Metadata was found to provide a platform for users to collaboratively and individually personalize digital media, as well as to link different types of content together. The collaborative tagging of and commenting upon Facebook photos was felt to create a more authentic representation of an event and to reinforce affiliations amongst friends, whilst the giving and receiving of musical playlists often incorporated modified metadata, such as photos instead of album artwork. The placelessness of content in the cloud also enabled teenagers to draw on their virtual possessions across contexts. Interestingly though, they also amplified the material presence of their digital things, by keeping their computers, mobile phones and media devices always on and connected to their virtual collections, and in some cases by printing them out to create physical collages.

Odom et al.'s[93] findings illustrate how teenagers find ways to integrate their virtual possessions into their environments, whilst also highlighting the collaborative and essentially placeless nature of these artifacts. These qualities are of interest in the context of transitioning to university and maintaining a connection to home. Text messages, emails and social media might all be understood as virtual possessions that, as Shklovski et al.[104] note, serve as reminders of relationships but, more than that, might be consciously integrated into student bedrooms to underpin a sense of connectedness.

Yet the nature of content stored in the cloud has been found to have other implications for how virtual possessions are understood. Odom et al.[91] have argued that simple concepts such as that of "possession" become weakened when one does not really know where one's content is. We might wonder if this sense of ownership might be compromised further by the collective quality of social media, yet Marshall and Shipman have demonstrated through surveys that people do feel they have the right to save and reuse photos [84] and tweets[83] that are shared online. Thus it seems that the ways in which people conceptualize these new types of "virtual possession" are complex and perhaps even contradictory: a sense of ownership over one's own content is diluted, but also extended to embrace that which is generated by others.

2.3 Research Aims

Given this mix of physical objects, virtual possessions stored on one's own devices, digital content in the cloud, and digital content posted online by others, we sought to explore how new university students would conceptualize their meaningful "things" and, further, the ways in which these would support a sense of connectedness with home. We expected that, due to their recent transition to university, it would be important to new students to retain a sense of connectedness to home[32][107], and that they would be sensitized to the notion of selecting and curating their belongings to support this. Indeed, if homes are understood to be curated[43], or even designed to reinforce memories[97], then we might expect new students to do something similar with the bedrooms that represent the first step in their transition from the parental home.

During our interviews, we focused especially on what attributes of these objects (both physical and digital) facilitated feelings of connection, and whether this was with the notion of home as a place, or with the people who live there. Our aim was to draw on these observations to underpin recommendations for design.

We also aimed to unpack the potential value of social metadata such as comments and tags, and to explore how issues of ownership come into play when considering cherished possessions. In particular, we wondered whether digital artifacts that have a collaborative quality (such as the Facebook photos described by Odom et al. [93]) would be valued differently to personal archives that are hosted online (such as webmail archives), and whether these in turn would take on different meanings to digital content that is stored on one's own personal devices and, perhaps, associated with a stronger sense of "possession". We anticipated that, like the teenagers that Odom et al.[93] described, university students would have a range of meaningful virtual possessions, and that these might be stored or hosted in a number of places including the cloud and on social network sites. Indeed, we wondered whether the small amount of space allocated to students in halls of residence might lead to a greater emphasis on digital content when discussing their possessions.

In the following sections we describe how items identified by the participants supported a sense of connectedness, and how the different qualities of these things, being physical, digital, stored in the cloud, or hosted in shared spaces such as social network sites, affected the ways in which participants viewed them as meaningful. We begin by describing our approach in more detail.

2.4 Methodology

2.4.1 Participants

Figure 2.2. We recruited 10 students for our in-depth interview study. Each student was in their first 3 months of moving away from home for the first time and had relocated at least 40 miles (64km). Cambridge first year students are not allowed to bring a car, a limitation that reduced the likelihood for trips home mid-term.

We recruited and interviewed ten first-year university students (five female, five male) within the first two months of their moving away from home for the first time (October of 2011). Participants were all between 18 and 21 years old. We selected for students who came from homes located at least 40 miles (64 km) distant, and who did not personally own a vehicle. Due to the practicalities of the move, each participant had only been able to take a single carload of possessions with them to university, and therefore had to be selective about what they chose to bring. Participants were recruited through a combination of fliers and advertising in a weekly university email bulletin, and were compensated with a gift voucher to an online retailer for participation in the study. Each participant had a personal computer, and half of those computers had been purchased recently, specifically for university. All ten also had cell phones; three had two cell phones. Two had cameras, seven had iPods, and other digital devices that participants had brought with them to university included an iPad, a digital photo frame, a digivice, a Gameboy, and a Kindle. Additionally all participants regularly accessed their personal webmail and Facebook accounts.

2.4.2 Interviews

We conducted semi-structured interviews situated in the participants' personal bedrooms. The university where we conducted the interviews provides each first-year student with their own private room, so the bedroom spaces consisted only of items the participants had brought, along with some university provided furniture.

The interview began with general questions about what participants had brought with them to university that was important to them and made them feel connected to home. Often this question prompted descriptions of physical objects, and so we also explicitly asked questions about digital items, both stored on computers and hosted in the cloud, to allow us to understand if, and if so, why (or why not) these other types of content were also seen as meaningful. We designed several of our questions based on those asked by Csikszentmihalyi and Rochberg-Halton[39] in their work on meaningful things, adapting them as needed to include digital objects. We were concerned that asking unaltered questions such as, "If the building were on fire what three items would you save?" might skew students towards considering only physical items, so we added additional questions that focused on purely digital content, such as, "If you could save only three digital things what would you save?" We also asked questions relating specifically to identifying objects both digital and physical which supported feelings of connectedness with home, such as "can you show me something on your computer that reminds you of home, family, or friends?" The interviews were audio recorded and transcribed. All objects were photographed at the end of each interview.

2.4.3 Analysis

Transcripts of the interviews were analyzed using grounded theory techniques[37], so as to allow themes to emerge from the data in a bottom-up manner. This approach was adopted because of the broad nature of the research questions. Initial data analyses comprised of ascribing open codes before undertaking axial coding and developing higher-level categories. We did a first pass at this after conducting five interviews in order to inform the focus of the remaining data collection. After a further five interviews we undertook a second pass of coding, iterating the development of categories until we the judged that the major categories showed sufficient depth and breadth and we considered sufficient sampling to have occurred.

2.5 Findings

In this section we first discuss the different ways in which the objects that participants identified underpinned a sense of connectedness with home. We then consider how the attributes of these things supported this sense of connection.

2.5.1 Supporting a Sense of Connectedness

The artifacts that participants pointed to supported a sense of connectedness with home for numerous reasons that resonate with prior work. They were, for example, previously owned by, created by, or received as gifts from, family and friends. We will not re-articulate these values here, focusing instead on the transition to university and how connectedness is supported in this context. We focus on five non-mutually exclusive themes: integrating representations of friends and family; conveying the unique character of home-life; supporting continuity with home; maintaining a sense of home at home; and visiting digital spaces to connect with home.

Integrating representations of friends and family

Our participants' bedrooms featured content that was carefully curated, and in some cases especially created, in order to integrate representations of friends and family from home into this new space. This was done by placing framed photos around the room to highlight particular individuals such as boyfriends and girlfriends, as well as by building larger collages to represent groups of friends and family. Where montages of printed photos were assembled, care was taken to include everyone, even if this meant including pictures that were less favored, as 7M describes:

> *"I was trying to kind of go through and work out which friends I wanted to be reminded of in particular. Went roughly on that and then I found there's some people like there just aren't any photos of them that I have, so I kind of, that's why some of the photos are just massive group ones."*

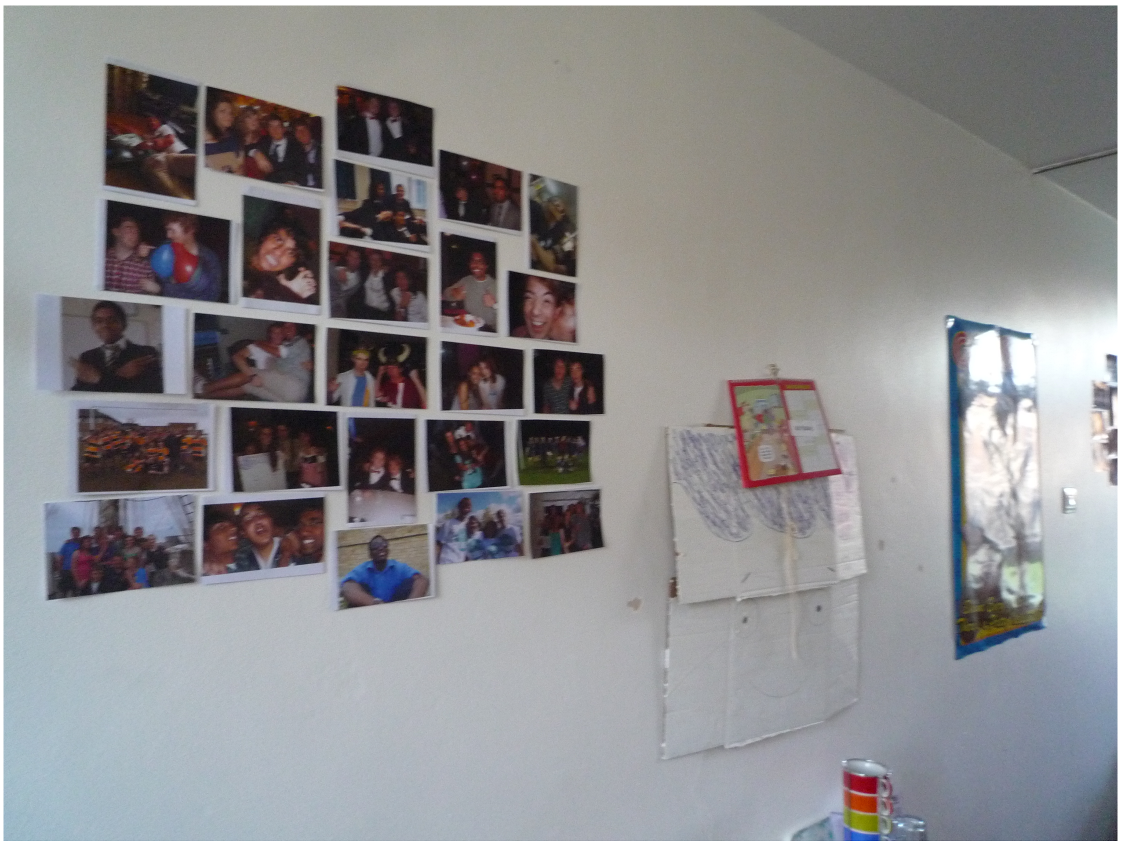

Figure 2.3. Wall photo collage representing people and events that our participant wanted to remember. For this particular participant inclusion was more important that asthetics.

Similarly, where participants had brought with them a selection of their belongings, such as only a fraction of their books, they had been careful to include those that represented friends and family. For example, 2F kept a book that had been written by a friend with a small collection of others that she had brought with her:

> *"... it's a novel that a friend of mine wrote, and I love the friend dearly, but it's a terrible novel, it's really awful, but I love the person so it's there."*

Although 2F did not enjoy reading the book, she kept it with others that were important to her, a collection that also included a copy of Shakespeare that had been owned by her mother and grandfather, and a first edition copy of an Oscar Wilde book gifted from a boyfriend. Through grouping these together, she was able to emphasize their significance. This type of enmeshing is easier with physical objects, although participants did do something similar with digital content when creating collages. Here photos printed from friends' Facebook pages were combined with those printed from the participants' own collections, and with older photos from the family film camera.

In rare cases, content was displayed in its digital format. This was mainly achieved by setting computer desktop wallpaper to display a particular photo. Like the framed photos we saw, these were often of a significant other rather than representing a scrolling collection or a randomly generated slideshow. In contrast, the only digital photo frame that we encountered in the study, which would have offered a slideshow experience, was switched off.

In summary, the ways in which artifacts were integrated into participants' bedrooms was undertaken to highlight relationships with boyfriends and girlfriends, to group together friends and family and to encompass objects that connected the participants with others into more general collections of meaningful objects. This integration supported a sense of connectedness with home.

Conveying the unique character of home-life

While artifacts identified in the previous section were notable for their associations with people, be these particular individuals or entire groups of friends, other objects were notable for the ways in which they highlighted the qualities of home-life more generally, and its idiosyncrasies in particular. These often reflected in-jokes that were associated with family or particular groups of close friends, meanings that could not be understood by others. Nevertheless, these objects were often prominently displayed. As an example, 4F described how a pipe (see Figure 1) that was positioned by her window represented *"a running joke I had with my dad about how I'd like to be a gent"* (4F). The pipe supports the telling of a humorous tale that highlights something of the character of 4F and ties this to her relationship with her family (4F being a woman who wishes to be a pipe-smoking English gentleman). Other items on display also had the potential to support this type of storytelling, for example 3F described how a printed copy of a digitally-drawn picture of herself and her closest friends, which was pinned to her notice board, incorporated various in-jokes that only made sense to them, and M8 pointed out a glass vase that made him feel connected to his parents:

> *"Um, you see that glass thing there? That's sort of what I suppose that's um an example of a habit my parents have. I really like going and looking around charity shops and car boot sales and stuff, um and that's sort of a habit they have. I actually unashamedly enjoy doing that with them so that was something I got here."*

Such objects enable participants to reveal (or choose not to reveal) aspects of their character to new-found friends. In this way they can serve as social vehicles for conveying how identity is bound up with home.

Supporting continuity with home

Another value associated with objects that supported a sense of connectedness with home was bound up with continuity. These artifacts had either been part of the home environment, or somehow echoed aspects of that space. These objects might be practical or precious, and cherished for themselves or appreciated for the practices they enabled. For example, 4F described how she had had the opportunity to buy new items for her

Figure 2.4. Computer drawn image created by a close friend that incorporates inside jokes from shared interests. 3F displayed this printed image prominently on her bulletin board despite it's cryptic content.

room at university but had decided to bring her existing storage baskets instead:

> *".. originally I was thinking maybe I should just leave them at home, and then just get new stuff, but then I thought it was quite nice just to have a little bit of continuity, and I knew they'd look good. It's quite nice as well just to have some bits from your old room, sort of scattered about so it's not a completely separate place."*

Practical objects of this type had not been brought primarily for reasons of nostalgia or sentiment, but nonetheless were noted for supporting connectedness through their use. 4F also described how a dressing gown she had brought to university simply because did not have one of her own, and chiefly appreciated because she now found herself using a communal bathroom, also had more subtle qualities that reminded her of home:

> *".. she [my mother] was sort of saying before I left you know you have to*

Figure 2.5. 4F displayed a pipe her father gave her as a gag gift.

> *have a proper dressing gown and I was like naw don't worry I'll just sort of put on a jumper, but she was like no have a dressing gown [...] it also has a slight smell of one of her perfumes which actually I didn't realize 'til I got here and I was like, Oh!"*

Such everyday items often supported feelings of connectedness in addition to fulfilling immediate needs. In other cases, objects were brought to university purely out of sentiment. 3F commented upon a stuffed toy seal that provided a sense of connection with her life at home:

> *"[seal is] a constant factor that has been there for my whole life. And that's quite nice when you've like moved somewhere completely new with completely new people, and then it's just like one thing constant, that I can always like hug and pretend like I'm at home still, which is nice occasionally."*

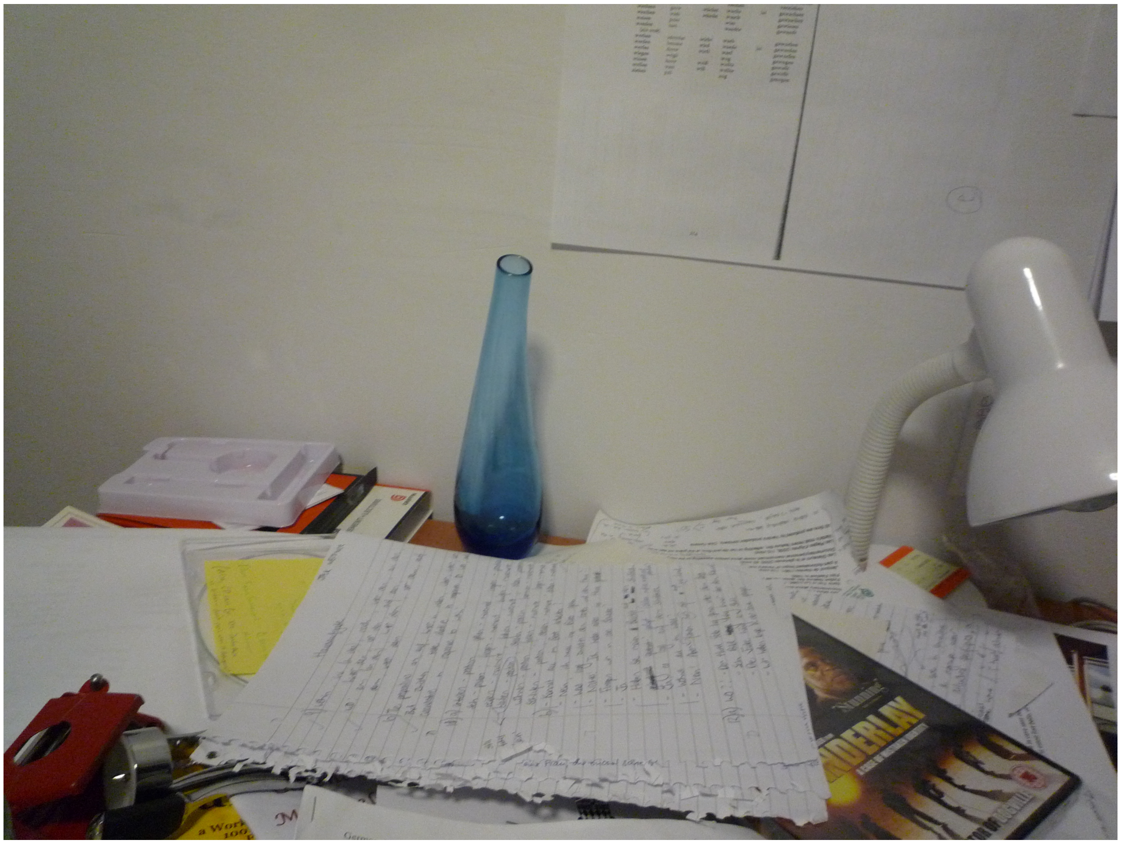

Figure 2.6. While this vase wasn't brought from home, it still reminds the participant of his family because of how it was procured. M8's parents are frequent charity shop perusers. When M8 went on his own to a charity shop in Cambridge he was reminded of his family through engagement in a shared interest.

In 3F's case her stuffed seal represented a bridge between her new life and her old. The continuity with home that seal provided was a welcome comfort as she adjusted to living away from her family for the first time.

Finally, a sense of continuity with home was underpinned by objects that were duplicates of, or otherwise mirrored, those at home. When 1F described a wedding portrait of her parents that was positioned in her room, she also noted that *"we have a larger one at home on the shelf"*. Similarly, 2F had a decorative bird shaped candleholder that was twinned with another *"at home hanging in the window"*.

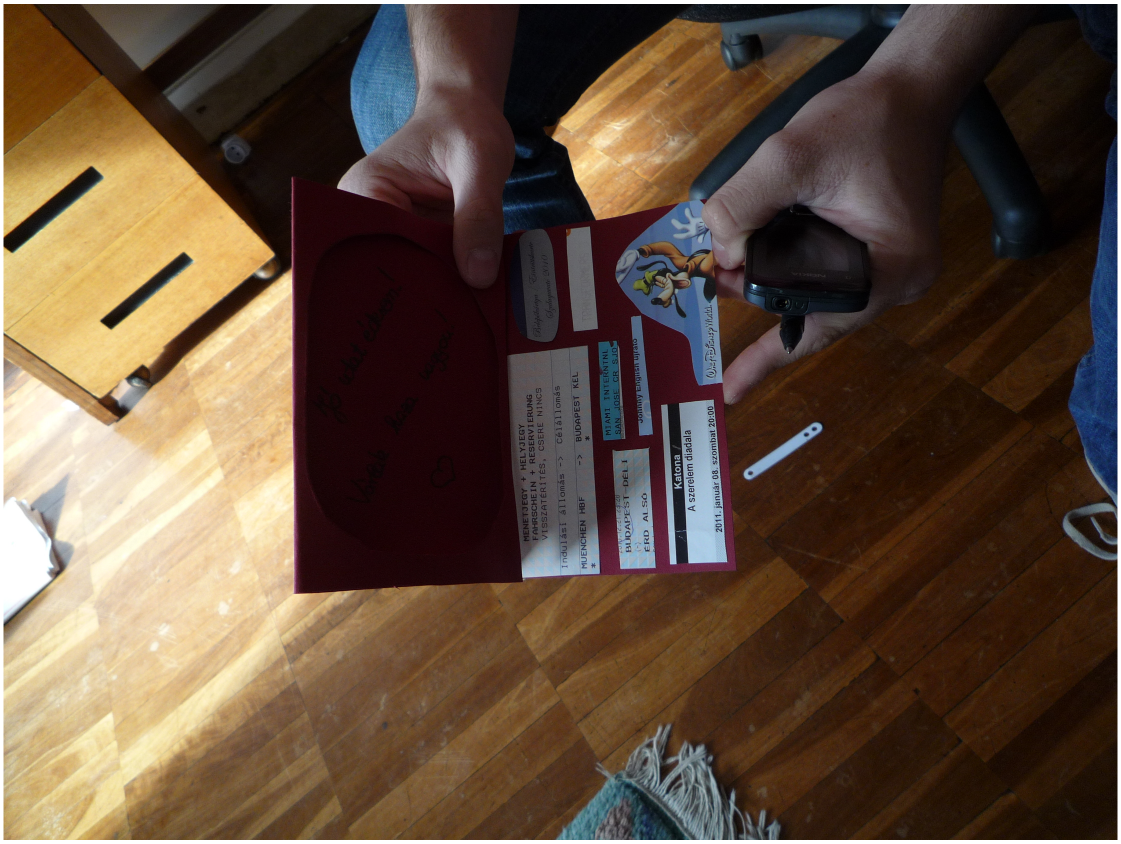

Figure 2.7. Special mementos hidden inside a picture frame by a distant girlfriend.

2.5.2 Maintaining a sense of home at home

A fourth value that emerged relates not so much to the bringing of belongings to university, but the leaving of them behind. By not bringing every meaningful item with them, students were able to maintain a sense that their space at home was intact, to be returned to. Most participants still retained their childhood bedroom, and did not want to empty this of their possessions, as stated by 4F:

> *"I wanted to leave like a fair amount of stuff at home just to um so that my room didn't look too bare when I got back."*

Home was also seen as a safe place for precious possessions. Several participants described items that they chose to leave behind out of fear of loss or damage to them:

Figure 2.8. From the display shelf in the room the mementos inside the frame are hidden from view.

> *".. for my 18th I got like a photo album of my last kind of 18 years that I left at home purposely [...] cos it's valuable to me and it would probably be safer at home" (10M).*

By keeping these meaningful items at home students were able to protect them, whilst also retaining a presence in their home space while they were away.

Visiting digital spaces to connect with home

As a final point, some participants spoke about practices that involved visiting websites and social network sites or perusing digital archives in order to feel connected with home, friends and family.

The visiting of websites associated with home was often a newly developed practice, which centered around previous schools, sports teams and other groups participants had belonged to. 3F described how she visited various websites that reminded her of home:

Figure 2.9. Two bulletin boards display photos and moments from family and friends. The small board on the right is located centrally in the room and features photos of immediate family, while the larger board represents a wider range of relationships.

> *"I sort of go on my old school and sixth form website and see what's happening there sometimes. Which is quite nice, sort of stalk them a little bit."*

In other cases, participants described how they revisited old text messages or reminisced by visiting Facebook:

> *"I do go back [on Facebook] and look at old photos and yeah sometimes, I don't know just for no particular reason really" (1F).*

Unlike visits to the websites, this type of activity tended to be something that participants would get sidetracked into after going to Facebook to chat with friends, check for notifications and read recent news feeds. Similarly, the perusal of old text messages was something that participants engaged in while killing time or got sucked into during the larger activity of sorting out their inboxes. For our sample, reminiscing through Facebook seemed to be encouraged by a now retired Facebook feature, which highlighted old photos and conversations in the side bar, increasing the likelihood that users would encounter older content.

In discussing the advantages of socially networked content, participants noted that the comments attributed to photos posted on Facebook could enhance their meaningfulness:

> *"I think it's more just like people's character coming through, so you, cos they're quite chatty, so, it gives the photos a bit more life I suppose" (6F).*

Further, this type of content was also noted for supporting a very strong sense of connection by providing a platform for joint action. 1F described how she and her friends from home would comment on the same Facebook photos:

> *"I like it, and then, I mean I know I'm not the only person that does this, you get notifications from friends on photos from like three years ago leaving some soppy comment, and that's cool and then everyone goes back, and everyone is looking at all their old photos at the same time, and that's nice, it's like you're having a mass reunion even though you're all really far away from each other."*

The experience of interacting around an old photo enabled joint reminiscing, offering the experience of being in the same place, at the same time, together.

Nevertheless, comments and metadata were not always perceived as a reliable way of identifying meaningful content online. 3F noted that no metadata could *"reference the enjoyment I got out of it"*, and 1F noted how online content often failed to depict her own *"emotional"* reactions to content. Thus, while commenting provided a vehicle for social interaction and thus could convey the character of others, it was not seen as accurately capturing one's own feelings towards digital content.

In summary, digital spaces were implicated in new practices that enabled participants to feel connected to home. Unlike in the prior themes, the artifacts highlighted by our participants here were valued for the exploration they supported; participants became immersed in reading text messages, or got sidetracked into looking at Facebook photos and, occasionally, into conversing around them.

2.5.3 Reinforcing the Meaning of Things

Having described how artifacts, both digital and physical, were found to support a sense of connectedness with home, we now analyze in more detail how the meanings associated with them were reinforced through their material qualities and the actions that they consequently permitted.

We focus in particular on how participants were able to interact with these artifacts because, while it is true to say that some of the objects identified were highlighted because of some inherent quality, such as the lingering scent of a mother's perfume on a dressing gown, in most cases their meanings were intrinsically linked to the choices that participants made and the actions they took in relation to them. This difference was perhaps most evident when we looked at participants' descriptions of photos, a medium that existed prominently in both the physical and digital realm. In many cases, printed photos identified by participants as important were also available in digital format, either stored locally or on social network sites. However, when asked about meaningful content stored digitally, these same photos were never highlighted (indeed, participants found it difficult to pinpoint any photos that they particularly valued within their digital archives). We use this example to highlight how, while the image is the same, the affordances that these digital and physical photos offer clearly had implications for how they were able to underpin a sense of connectedness to home. In what follows, we highlight three themes that relate to attributes of artifacts identified by participants, and consider how these were important in reinforcing the meanings they were associated with.

2.5.4 Moving and choosing

The first set of actions we wish to highlight in this paper relate to being able to move artifacts from one place to another. For example, as we have already seen, participants left objects at home as a means of maintaining a physical presence there, selected items that represented their friends and family for their new bedrooms, and included artifacts that echoed or otherwise represented continuity with home.

This sense of moving things from one space to another was largely lacking for digital things, and only in cases where digital media had been carefully embodied was there a sense that it had been deliberately placed in a particular location. For example, 1F described how she left her USB sticks containing precious digital media at home, encased in a cardboard box that was taped shut. However, this type of example was very rare in our data. In general participants brought all of their digital content with them, copying indiscriminately from the family computer if they had recently acquired a new laptop (half of our sample owned new computers). Further, this duplication of digital content was not seen as echoing other spaces in the same way that duplicates of physical things were, and while maintaining a physical space at home was important, maintaining a digital presence at home was simply not reflected upon. Indeed, participants often had very little idea of what digital content they had stored in different places, either locally or remote, or how content was duplicated across these locations.

Rather, going to university was found to encourage participants to create new artifacts, such as collages, out of digital media. For example, the printed photo montages that participants pointed out had often been downloaded from Facebook or copied from the family computer. Instead of necessitating the choosing of which digital artifacts to bring to university, the transition seemed to trigger the crafting of virtual-made-material displays.

Positioning and grouping

Of course, moving things from one location to another was only one aspect of how objects were acted upon. Their specific positioning within the participants' bedrooms, be that apart from others, or as part of an important collection (such as in the case of the "terrible" novel), was also essential in reinforcing the meanings associated with them. For example, 5M described a framed photo that his long-distance girlfriend had given to him before he left for university (see Figure 1):

> *"It's a picture of us and inside there are some um, things that remind me of the things that we have done together. Disney World, airplane ticket to Miami, things like that."*

The frame was designed so that only the photo was visible to an observer, whilst hidden inside was a selection of mementos. The singular status of this photo frame was made evident through it being set apart from other things, an emphasis that was also lent to desktop wallpapers that featured images of significant others or depicted special occasions, such as a picture of a picnic with a boyfriend:

> *"That (current desktop photo) was the night before I left, we went out and had a night-time picnic on the cliffs." (2F)*

The positioning of collages was also done mindfully, in order to separate out different types of relationship and to support encounters with them. For example, 6F had two notice boards in her room featuring photos printed from her digital collection, one focusing on family and one on friends. The family board was prioritized in terms of its location *"cos you know, I probably miss them more"* (See Figure 2.9). 7M also described how he positioned his photos above his desk in order to support encounters with them:

> *"I put them there so it was like the ones that I really wanted up. [...] I just look at them and kind of smile [...] If I've been working a lot all day and you just turn, it kind of reminds you that you're not always working."*

(7M)

When asked about meaningful content on their laptops or on Facebook, neither of these participants mentioned these same images. In contrast, the printed versions had had their meaningfulness reinforced from the context of the room, where they had been organized into collections and made glanceable from specific viewpoints.

Sorting, gathering and deleting

In contrast to artifacts that were brought to university from home, participants also had to manage assemblies of digital content that continued to grow and require managing after the move. These included inboxes of emails and text messages, and content hosted on social network sites. These archives were spaces that participants could visit, explore and get sucked into as a way of feeling connected to home.

That these archives underpinned this type of exploration was related to the ways in which they were managed. For example, 1F told us, *"I don't save all my old texts, just the ones I like"*, and 9M put every email from his parents in the same webmail folder:

> *"I'm kind of making a family archive, sort of every email I get from my parents or whatever so I can remember it. So that sort of reminds me of home."*

These approaches are very different: while 1F maintains a small, selective collection of text messages that she wants to keep, 9M archives the email he receives from his family. Indeed, he noted how he adopts a similar strategy with his new phone:

> *"on my old phone I did delete every text after, pretty much after I'd read it, [...] whereas my new phone I've kept all my texts cos it does it in sort of a conversationy thing, with bubbles and stuff. I don't think I'd want to delete them cos it's sort of memories and stuff."*

Here the structure of the data affects the perceived value of the messages. 9M's webmail allowed him to create structure, while his old phone neither provided by default, nor supported the creation of, a structure for his texts.

In addition to these personal archives, content hosted on social network sites was also noted for supporting a sense of connectedness. However, websites like Facebook were not generally seen as hosting content that could be managed and curated, and this was the case even when that content was one's own. Put simply, participants did not feel fully in control of the content that they and their friends posted online. Some of the reasons for this were straightforward; for example, participants noted the difficulty of being able to "keep" content that is not really their own:

> *"I guess it makes it, you know, more difficult for me to keep them cause since they are not my pictures they can always get deleted from one day to the other." (5M)*

But in other cases the reasoning was more subtle. Participants described how what they posted and what they removed was done with a wider view to the social nature of Facebook. They described how they would post content to *"elicit a conversation"* (2M), and then *"just delete it .. if it doesn't have very many 'likes'."* (1F) Further, they were sometimes explicitly asked to remove content because it was, for example, deemed unflattering: *"they'll be like oh please take it down it's not nice."* (4F)

The social quality of Facebook meant that photos were posted for social ends and edited with regard to the views of others, rather than to emphasize one's own set of meanings. Consequently and, as noted earlier, participants felt that there was little on the site in terms of comments or metadata to illustrate which images were most enjoyable *to them*, or had triggered emotional reactions *for themselves*. Instead the collection was seen as *"pretty generic"* and *"nice to have"* (4F) rather than essential to keep. This is particularly striking, given that only two of our participants owned their own cameras, and only a further two knew how to download photos off their camera phones. Thus despite this ambivalence, Facebook represented a primary source of photos. As 7M commented about his printed photos:

> *"they're virtually all from Facebook, um there's a couple that are actually from like my [family's] camera or someone else's camera where I got an email and I copied, but at least three quarters are from Facebook."*

2.6 Discussion

In this paper we have considered how physical and digital artifacts support a sense of connectedness with home for new university students, and have reflected on how the affordances they offer enable the meanings associated with them to be reinforced through action. In the discussion, we consider opportunities for the design of technologies to support connectedness for new students, before considering whether our findings can generalize beyond this group.

2.6.1 Opportunities for Design

Our findings suggest a number of opportunities for design, including creating archives that can be browsed and explored[97], designing digital materials that can be persistently encountered[98] and kept in "functional" storage [65] rather than hidden away in computers, enabling digital "gifts"[46] and supporting happy coincidences [10] through interactions around content. Some of our observations suggest ways in which these might be realized, for example, the now-retired Facebook feature that enabled "mass reunions" around old photos was a good example of how digital media can be more persistently encountered, and in doing so, support interactions with old friends. In general though, these findings resonate with prior work. Therefore, in this section we focus on three opportunities that relate to supporting connectedness in the circumstance of transitioning to university, and where the predominance of social media means that virtual possessions are often collectively, rather than personally, owned.

Integrating the digital into physical space

Physical artifacts were an important part of making the transition to university; they supported the notion that participants still had a place at the parental home, allowed this presence to be gradually withdrawn, reinforced the idea of home as a safe place, and allowed for a sense of continuity with it. Opportunities for the design of technology include supporting ways of storing digital content that can be prominently displayed (a good example here is George Guo's hard disk robot[50]), so that it can be integrated into the fabric of both old and new locations. Content stored on such devices would, of course, need to be deeply secure, and this could be reinforced if it could only be accessed from certain locations, for example one's bedroom at home and one's bedroom at university. The notion of twinning locations also suggests a second possibility. Location-sensitive desktop wallpapers might be displayed only in one's bedroom, be this either at university or at home. Both suggestions could underpin a sense of continuity, emphasizing a connection across the two spaces.

Curation of archives that are collectively owned

Curation was a way of reinforcing the meanings of digital materials, be this by maintaining small selective archives of text messages, or by developing webmail folders to emphasize the importance of certain relationships. Yet the curation of digital materials is notoriously difficult[82], and we found it to be especially complex when it comes to content hosted on social network sites. This complexity has both technical and social elements. Firstly, content hosted on social network sites spans users. Thus the collection of photos that one is tagged in, or that one can browse, is unlikely to be the same as that which one has rights to edit. Secondly and importantly, even if the technical means were available for users to edit photos within this collection, the social nature of the site makes it difficult for them to do so. Indeed, we found that participants did not feel in control of their *own* content because of the implications that editing it had for others. This extends prior work on the concept of ownership, suggesting that while users do feel able to *download* and reuse social media[84], they do not feel a real sense that they can do with it as they will while it is hosted *online*. Further, their sense of control is not only compromised by a lack of certainty regarding *where* content is[91], but more strongly by the simple fact that it is hosted in a space where their actions have implications for others.

This suggests an opportunity for social network sites to provide a means for users to privately "archive" this collective content. Enabling a way of doing this that is not disclosed to the wider network is essential if such an archive is not to become compromised by concerns over self-presentation and the management of social relationships. Further, users would only be likely to invest in such a feature if there was no risk that content would then be withdrawn; such a feature would only be compelling if it enabled one to "keep" content through the process of "archiving" it. Implicated here is the management of digital rights to images posted online, and who can do what with them. Actions such as tagging may offer a natural way for users to extend permissions to specific others, enabling them to copy or even "keep" content.

Creating digital displays that acknowledge provenance

Golsteijn et al.[46] suggest craft as a means of making digital objects more cherishable, and here we found that the move to university was a significant motivator for the creation of new artifacts out of digital materials. Furthermore, these materials were often owned by others, many having been printed off from Facebook. Making the provenance of these materials visible could be one way of supporting connectedness, in the same way that physical artifacts previously owned by others, such as the dressing gown and copy of Shakespeare, underpinned this. This suggests an opportunity for

Figure 2.10. In a practice dating back to the Tang Dynasty (C.E. 750) Starting in the Tang Dynasty, art collectors in Chine It was common in the Tang and Song Dynasties (and continues in some cases until present day) for art collectors to make additions to the work, either by stamping their insignia on the painting, or by adding their thoughts in appended colophons (as is visible on the right of this painting where the color changes)[45]. Through this practice a rich history is know for each work, as well at the historical perceptions of the piece. In this example "X Night" a rich history has been preserved along with the painting. For example in the middle of this painting we see a standard seal of ownership while on the left there is a black seal which indicates the recipient was in mourning when they received the painting.

the creation of dynamic photo displays that acknowledge origin whilst also supporting personalization.

In designing for such displays we could draw inspiration from ancient Chinese art, where in addition to the artist leaving his seal on the painting, prominent owners would leave their own seal and add additional colophons, recording their thoughts about the piece in beautiful calligraphy[70]. Similarly, digital materials could be designed to become more unique through making their provenance visible whilst also allowing them to be tailored by the person who crafts their display. Such displays could be created using e-paper, and could show favorite photos along with visual indicators that show the heritage of the photo, such as an image of who the photo was taken by. This kind of digital patina can complement other existing sources of digital personalization, such as photo comments on a social network, and digital photo filters such as those provided by services like Instagram[5], allowing for the creation of unique digital objects that hold their own value.

2.6.2 Limitations and Future Work

Our decision to interview first year university students for this study was taken because we expected them to be sensitive to the process of choosing which items to bring to university to help them feel connected to home. Additionally, we expected them to have a wealth of virtual possessions, thus supporting a discussion about valued digital things. The advantages of using such a sample can be balanced against the limitations, as follows.

Firstly, our findings offered insights into the importance of maintaining a space at the parental home when transitioning to university. This is a unique circumstance that does not typically generalize to residential mobility, where people leave a location behind. Nevertheless, it does suggest possibilities for future work. One group worth exploring further may be children of divorced parents. Prior research[92] has indicated how the shift from living in one parental home to residing across two might be eased by the integration of personal things into new spaces. Our own findings raise questions regarding whether supporting presence in absence could also be valued, and how this can be achieved through virtual possessions, which are known to be meaningful for teenagers in particular[93].

Secondly, our participants were interesting because of the type of digital content that they owned or had access to. Only two owned cameras and, while all ten had a camera phone, only two could easily extract photos from them. Instead photos were taken from social network sites and family computers. The fact that many of our participants did not own their own cameras, or relied on photos posted online by others, is not out of kilter with other work (see e.g.[43][120]), and offers an interesting contrast to prior work on cherished objects that has largely focused on parents and their own content [65][97][98]. We believe our findings point to the importance of an emerging issue, that of being able to archive content that is "collectively" owned and hosted on social network sites.

2.7 Design Lessons and Overview

We have reported findings from an in-bedroom interview study conducted with first year undergraduate students within two months of moving away from home for the first time. Participants derived a sense of connectedness with home through displaying and interacting with a variety of artifacts, including those that represented others, conveyed the character of home-life, and supported a sense of continuity with home. Further, while physical items allowed participants to maintain a presence at their parental home, digital spaces became the focus of new practices. We consider how the affordances offered by these artifacts enabled participants to reinforce the meanings associated with them, and note that this was compromised for social media especially. A first set of reasons for this were technical, in that there is a lack of functionality for storing and organizing social media, especially when this has been uploaded by someone else. A second set of reasons were social, because any actions taken in relation to social media are performed in a public space, and thus have ramifications for others, as well as possibly triggering or influencing interactions with them. Opportunities for design include providing a means for the personal archiving and display of social media content. We believe that the current requirement to download and print off social media content in order to make it one's "own" could be improved upon by providing new possibilities for interacting with it both online and through the creation of new digital displays. Doing so could result in artifacts that encompass values currently associated with either digital or physical media, but not with both.

2.8 Acknowledgments

This chapter, in part, is a reprint of the material as it appears in Supporting a Sense of Connectedness: Meaningful Things in the Lives of New University Students. Bales, E., Lindley, S. In Proceedings of the ACM Conference on Computer Supported Cooperative Work (CSCW 2013), pp. 1137-1146. The dissertation author was the primary investigator and author of this paper.

Chapter 3

Implicit Connection for Couples

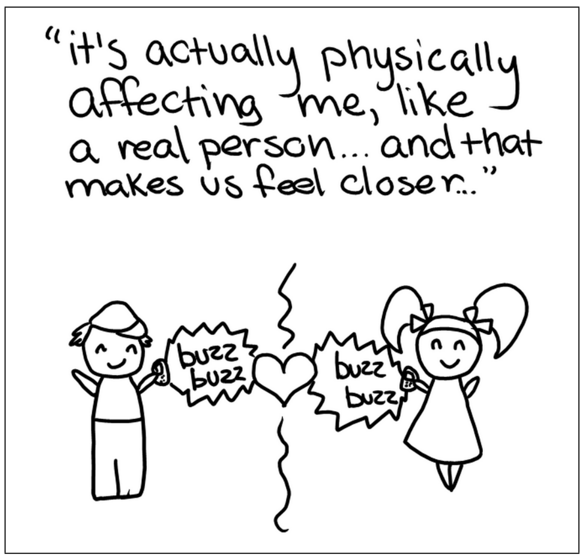

Figure 3.1. Maintaining feelings of connection while apart can be difficult. Designing mobile technologies that support awareness at a distance can help.

Long-distance couples face considerable communication challenges in their relationships. Unlike collocated couples, long-distance couples lack awareness cues associated with physical proximity and must use technologies such as SMS or telephony to stay in sync. We posit that long-distance couples have needs that are not met by prevailing communication technologies, which require explicit action from the sender as well as the receiver. We built CoupleVIBE to explore the properties of an implicit messaging channel and observe how couples would use such a technology.

CoupleVIBE is a mobile application that automatically pushes a user's location-information to her partner's mobile phone via vibrotactile cues. We present qualitative results of a four-week user study, studying how seven couples used CoupleVIBE. A key result is that CoupleVIBE's implicit communication modality operated as a foundation that helps keep couples in sync, with other modalities being brought into play when further interaction was needed.

3.1 Motivation

Implicit cues are an important means of communication between the partners of a couple. When a partner gets up in the morning, the other feels and hears the change in her partner's life because it intersects in time and space with her own. Such cues help partners stay effortlessly in sync [48]. Long-distance couples lack these cues, causing substantial challenges in their relationships [67]. Consider the following scenario, inspired by interviews we conducted.

> *Krista and Jason are long-distance partners who both work outside the home. Krista commutes by bicycle to reduce save money. Jason is proud of her, but worries for her safety because she bikes on busy roads during her commute.*

The increasing adoption of mobile computers and smart phones is allowing couples like Krista and Jason to email, call, or message each other via instant messaging (IM), text messaging (SMS), or a social network like Twitter or Facebook. Harper and Hodges have noted that each such communication channel has unique affordances, explaining why new technologies coexist with old ones, rather than supplant them [53].

> *Krista and Jason have agreed that Krista will send an SMS message or call when she arrives home. Only a few days into their new routine, Krista is preoccupied with a deadline and forgets to send a message upon arriving home. Jason doesn't want to call her for fear of distracting her while on a busy stretch of road. Jason finally calls her, anxious and*

distraught. Krista is sorry and redoubles her efforts, but only a week later Krista forgets again.

We all know the feeling of dread when a loved one doesn't arrive home or contact us when expected. SMS and telephony allow Krista to share status information provided she remembers to send the message or place the call. Indeed, all of the prevailing technologies, even new ones like Loopt[6], require some form of explicit action by one or both partners to successfully convey status information, a barrier for busy couples.

We posit that an implicit messaging channel has unique properties that could better address some communication needs of long-distance couples. To explore these properties and the usage habits that result from them, we built an implicit mobile messaging application called CoupleVIBE.

CoupleVIBE automatically sends touch cues between partners' mobile phones to share location information. Specifically, as a user moves between locations in her day, her partner receives specialized vibrations, allowing both to keep updated without either party ever having to take their phone out. The combination of coarse location sharing and vibrotactile cues results in a privacy-friendly, unobtrusive communication channel with unique properties.

In this paper we make three contributions:

1. We present the design of CoupleVIBE, a mobile implicit messaging application that automatically pushes awareness information to couples.

2. We report qualitative results of a 4-week study of how couples used this type of awareness application.

3. We discuss the properties of an implicit messaging channel that make it both unique and powerful for couples, examine how it meshes with existing communication practices, and propose design guidelines for future implicit communication

applications.

A key finding is that CoupleVIBE operated as a foundation that helped participants stay in sync with their partner's daily activities, supplanting some explicit communications while better coordinating others. Surprisingly, collocated couples also found CoupleVIBE to be useful. Importantly, a combination of application design and user practices sidestepped the potential annoyances of end-to-end automated push communication. Also, automated push eliminated the impulse for reciprocation, keeping communications lightweight.

3.2 Related Work

As an example of the prevalence of long-distance couples, Stafford and Reske hypothesize that a third of college relationships are long distance [110]. These couples face significant challenges because they lack traditional intimacy-building interactions, such as touching, non-verbal communications, and presence [67]. Long-distance couples are creative in using existing technologies to facilitate communication, but they often fall short of expectations. Bhandari and Bardzell found this in their interviews with long distance partners, being told by one participant *"the use of cell phone in long distance relationship [sic] is akin to talking to the electric waves as opposed to his girlfriend"* and saying about another *"that talking on the phone makes him feel he is talking to a slightly different person... certain personality of his partner and not her in totality"* [23]. Time zone differences exacerbate the problem [28].

One line of research has focused on increasing intimacy between partners with small 'thinking of you' actions. Early work used interaction with a tangible object like a picture frame, releasing a lingering scent to the partner [88, 111]. Other designs have supported two-way interaction through computer-linked haptic shakers or rollers

[24, 111]. More recently, Lottridge et al. proposed sharing music and background sounds with MissU [79]. Kaye employed a virtual approach, whereby separated partners click a small dot on their computer screen to cause the dot on their partner's computer to change from blue to red, thus conveying 'just thinking of you' [63, 62]. Similar to reciprocity effects observed with SMS [113], Kaye observed that even when a tiny amount of effort is expended by the sender, the receiver often feels an obligation to reciprocate.

Another line of research has involved helping distant couples by digitally linking everyday objects that they use, typified by Lover's Cups [35], LumiTouch [30], and SyncDecor [116, 117, **?**]. For example, when a person turns on a lamp, a lamp in the partner's home turns on as well, providing lightweight non-verbal communication and presence.

The Whereabouts Clock is a peripheral display placed in the home that family members can casually glance at to learn about the locations of fellow family members who are outside the home (tracked by carrying location-aware phones) by displaying their pictures in one of four zones – home, work, school, or elsewhere [25]. The Whereabouts Clock evinces both affective qualities (through pictures) and practical aspects (through location status).

The above object-based systems are incomplete solutions for busy couples, who are out of their homes and on the go much of the day, often at the same time. Such couples would benefit from a mobile design so that each could be aware of the other's status anywhere.

3.3 Design

We are attracted by the tangible qualities of many of the above implicit communication designs, yet their embodiment in common objects (lamps and clocks) that are bound to fixed locations (home or work) works against the ubiquity that long-distance couples need to stay in sync through-out their day. We considered using auditory cues, but their intrusiveness in public settings was a concern. Instead, we focused on the concept of person-to-person touch, without reference to a mediating object that would have to be carried around. Consequently, many of the day's most significant events could be communicated anywhere, at any time.

In CoupleVIBE, when a user arrives at or departs from a frequented location, her partner automatically receives a vibrotactile message on his mobile phone, communicating the specific change of status. This design is akin to location-based social-mobile media [4][6][20][106], but with proactive detection, sending, delivery, and 'playing' of the status (i.e. vibration of the phone, not just passive visual display). By using tactile cues, we hoped to achieve an unobtrusive solution, freeing the user from having to explicitly interact with their phone to send and receive status updates. Mobile phones were chosen as the sensing and delivery platform for their ubiquity. Within these constraints, past work has shown a considerable number of distinguishable vibrotactile patterns can be generated [26].

We expected that CoupleVIBE's design would minimize feelings of reciprocal obligation – an urge to respond to status messages – as there is no intentful action to acknowledge. Reciprocal obligation can be a positive force in communication. For our anticipated scenarios, however, response actions would increase effort and be a step away from implicit communication. Thus, we hoped both that there would be no feelings of reciprocity and that active reciprocation would not be required to sustain use, as seen with some lightweight messaging systems [38]. In this spirit, to further avoid incurring feelings of reciprocity, CoupleVIBE vibrates just the receiver's phone on a location change, not the sender's. Thus, a user learns through experience that her partner is not consciously aware that a message was sent, and hence a reply could not be expected.

CoupleVIBE's visual interface is basic, consisting of just two screens, the status screen and the vibration assignment screen (Figure 1). A user tags a location by selecting the ‘new location’ option when he is physically at the location. The user is asked to give a name to the location, which is stored with the phone’s current location fingerprint (See Implementation). Separately, the user’s partner selects a vibrotactile message to identify the location.

3.3.1 Balancing Proactivity with Other Considerations

The intent with CoupleVIBE is that a user can go about his day and stay updated on how his partner’s day is going, without ever having to take the phone out to interact with it. The design decisions that support this goal strike a balance among four variables with respect to proactive implicit communication: meaningfulness, control, unobtrusiveness, and reliable delivery. When faced with a tradeoff, we favored the choice that was most consistent with implicit communication, with the goal of learning more about it during the user study.

Figure 3.2. Left: CoupleVIBE’s main screen. Right: Prompt for tagging a location with a vibrotactile cue.

3.3.2 Meaningfulness

To automatically capture status, the status must be inferable from ubiquitously available context. Past work in location-based reminders had found that for a single user, location can act as a proxy for availability [109]. We expected a similar result; a knowledgeable partner should be able to infer detailed status information from a partner's location.

However, not every location holds meaning for a partner, In CoupleVIBE, only predefined locations signal status changes. The intent is that the user will select locations that are meaningful to her partner – for example, frequented places that convey key aspects of her daily routine, such as home, work, gym, and grocery store. With this design choice, there is a chance that an important change in status will occur outside normal routine and will not be signaled – something to look for in the study.

3.3.3 Control

Although partners are generally open with each other, services that support monitoring can enable abusive or controlling behaviors. For the purposes of this study, then, we felt it was important to give users control over the information communicated to see how such a feature might be used (e.g., for privacy). Users can disable the sending of status messages from CoupleVIBE's main screen in a way that is invisible to their partner. On the other hand, we made an explicit decision to make it hard for people to turn off the receipt of messages. Both decisions are consistent with the way physical implicit communication works: one can make a point of being quiet, but it's harder to avoid hearing noises in your vicinity. Finally, we note that allowing each user to choose and name her locations provides an additional control for personal expression or privacy.

3.3.4 Unobtrusiveness

Vibrotactile messaging is designed to be relatively unobtrusive, but frequent status messages could still be distracting to the receiver. We expected that CoupleVIBE's use of predefined locations would limit the number of status messages. There is also a chance that vibrotactile messages could be insufficiently 'obtrusive' to gain one's attention when desired, something we looked for in the user study.

3.3.5 Reliable Delivery

The reliability of delivery can be divided into three successive questions: did the sender's phone detect that it changed location, did the receiver detect the delivery of a message, and did the receiver understand the specific message?

Previous work reported that users frequently do not carry their phones on their person[94]. This could compromise both sensing and delivery. However, this study also reports that people do tend to keep their phones in an accessible location (e.g., in the house, when at home). Since our design presumes that locations can be detected through coarse positioning (See Implementation below for details), such separation is acceptable. Regarding delivery, we expected partners had already developed practices for the reliable receipt of explicit communications via mobile phones; we hoped to learn how those practices are carried over or ex-tended for implicit communication.

To maximize the distinctiveness of CoupleVIBE's messages, we used an approach similar to Li et al. to vary vibration intensity[76]. We then constructed 7 user-differentiable vibration patterns (each about 2 seconds long) by varying rhythm and roughness, similar to Brown et. al [26]. Supporting more vibrations would have reduced their distinctiveness and increased the cognitive load of matching a message to its corresponding location.

In use, these location messages are paired with a transition message, with some

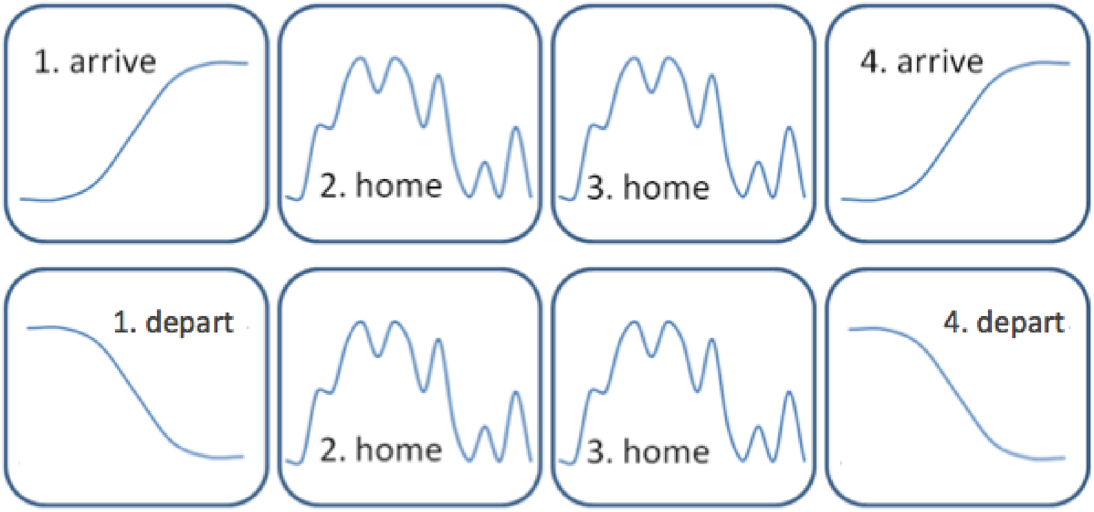

Figure 3.3. Four-part vibrotactile message for ‘arriving at home.’ The message for ‘leaving home’ would look similar, with ‘departure’ cue segments at the beginning and end.

repetition to increase comprehension. When a user arrives at home, for example, her partner receives a 4-part message: arrival cue, home message, home message, arrival cue. The arrival cue is a 1.2s vibration with increasing intensity, whereas the departure cue is a 1.2s vibration with decreasing intensity. There is a 1.0s pause between the arrival and home cues and a 3.0s pause between the two location cues.

We initially tried using a single arrival/departure cue at the beginning of the sequence followed by a single location cue. However, in our pilot studies, we found that participants would sometimes miss the first part of the cue. As a result, users could recognize the location information but did not know whether it was an arrival or departure cue. Pilot users also reported that they would sometimes miss part of the location cue. Repeating both the arrival/departure qualifier as well as the location pattern solved this issue, albeit at the expense of a concise cue.

With implicit communication in mind, our goal was for the vibrotactile interface to fully convey all messages, achieving an unobtrusive interaction. However, if the user misses a status message – say, because the user was otherwise occupied when it played – CoupleVIBE's main screen displays the most recent status change.

3.4 Implementation

We implemented CoupleVIBE in C # and C++ on Windows Mobile Smartphone 5.0. Location updates are sent between phones using specially formatted SMS messages. CoupleVIBE runs in the background, intercepting these messages. When a CoupleVIBE message is received, the vibrotactile message for the corresponding location plays.

3.4.1 Fingerprint-based GSM location algorithm

We chose to employ GSM-based positioning over GPS, given that it works indoors, is widely available, and generally has lower energy consumption. To determine location we use a tower fingerprinting method[20][69]. Our algorithm reads the cell tower IDs visible to the phone every ten seconds. To filter noise, we introduced voting into our finger-printing algorithm. A vote is cast for a location when the observed fingerprint is at least 65% similar to a known location fingerprint; otherwise, a vote is cast for 'unknown'. A user's location is updated when one location wins a majority of the votes over a 5 minute period and it is different from the current location stored in the phone. This five-minute voting method minimizes location 'jumping' when users are moving through boundary areas.

In practice, the algorithm works extremely well. We discuss real-world anomalies and their handling by users in the Discussion. To formally evaluate our algorithm, we ran a simulation on GPS-tagged GSM data collected by Chen et al. from their wardriving of the Seattle area [31].

Our algorithm recognizes a location by comparing multiple samples over time from fixed locations. Since it would be unrealistic to collect long traces at each of

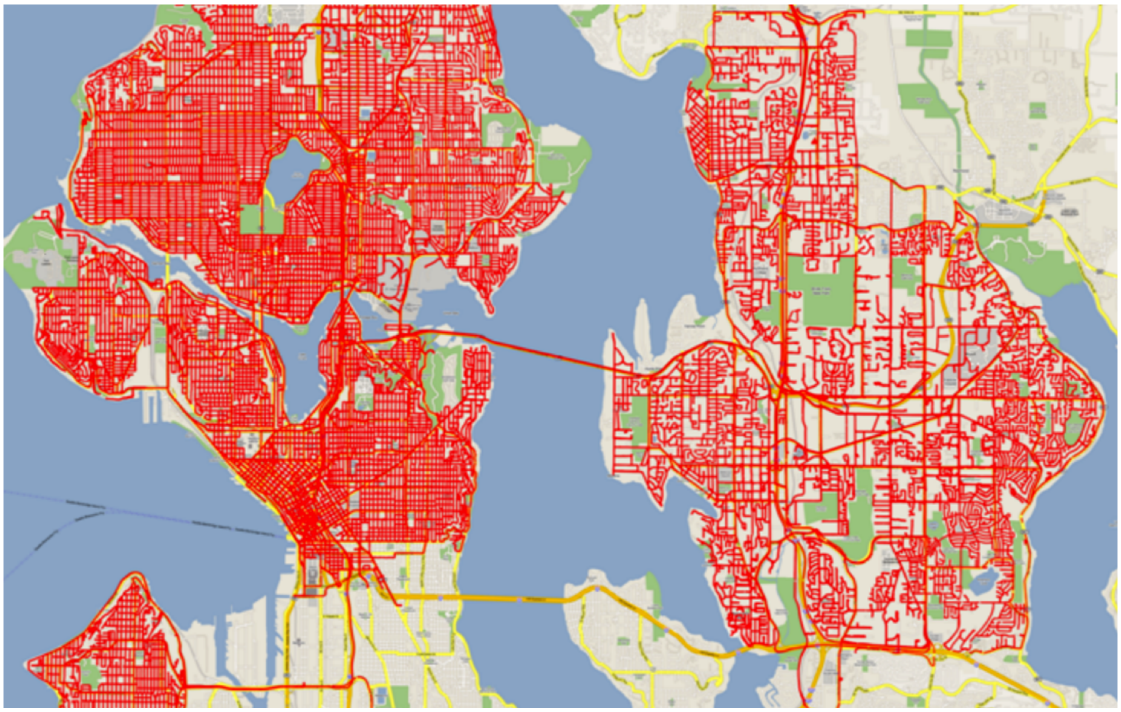

Figure 3.4. Coverage included in the Seattle area war drive data provided by Intel Labs. Both dense city and suburban locations were sampled to supply realistic conditions for both types of locations.

hundreds of locations, we simulated fixed locations using the wardrive datas and a bucketing technique. To simulate multiple samples per location, we modeled a 'location' by choosing one (GPS, GSM) reading pair as a location fingerprint, and treating all the sample points that fell within a 0.05km radius of the fingerprint as a trace gathered from that location. This approach is conservative, as the readings for each location (1 city block) are distributed over a larger area than one would expect from a home, or other typical location.

We performed four measurements. Figure 3a shows how voting amplifies the accuracy of basic fingerprinting, for every given fingerprinted location in the dataset. The question, however, is how this maps to user experience – how quick is the algorithm at recognizing arrival at a location, and how unlikely is it to falsely report a departure once there. Arrival was detected within 5min for 66% of locations, and within 10min for 92%

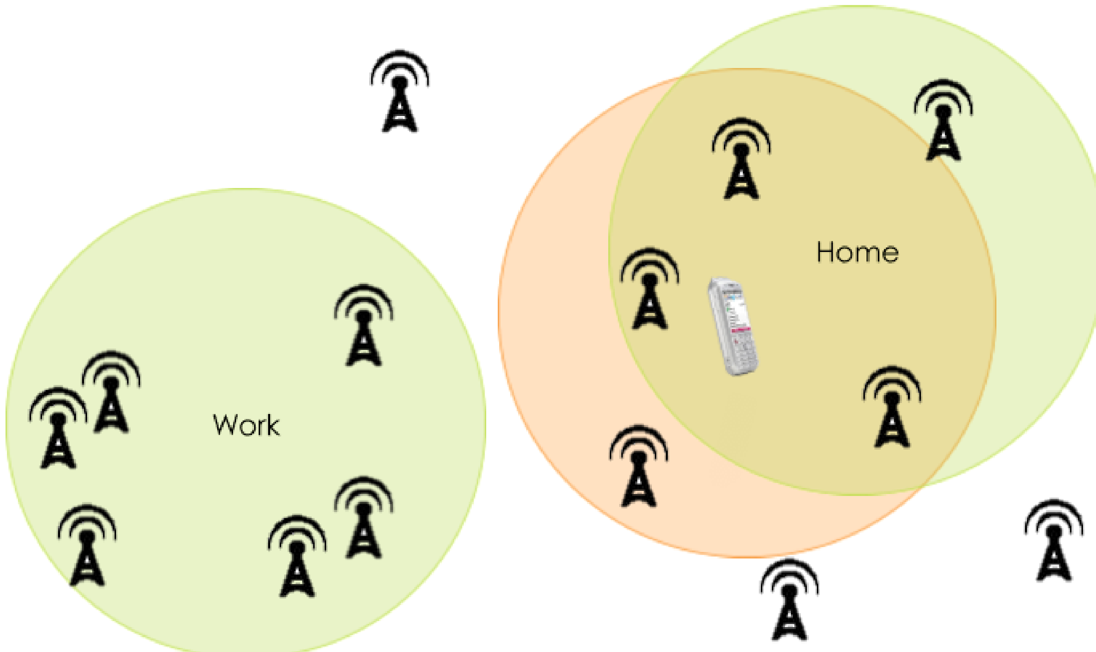

Figure 3.5. Cell tower fingerprinting allows participants to mark locations without requiring the participants to share the exact GPS location of tagged places. When the user marks a place a snapshot of the visible cell towers is stored in the phone, later that fingerprint can be compared to currently visible cell towers to determine if there is a location match.

of locations. On average, 83% of locations would not send a false departure cue for at least 36 hours. Lastly, if two tagged locations are close to each other, the algorithm might falsely report an arrival at one location when at the other. Figure 3b shows the rate of false positives at various distances from a given location. Locations at least 0.3km apart were less than a 0.4% likely to falsely report an arrival.

These levels of (conservatively measured) accuracy are compatible with our intended usage scenarios, where the information is nice to know, and the tagged locations are likely few and far apart.

3.5 Methodology

We ran a 4-week exploratory, qualitative field study to learn how couples would incorporate CoupleVIBE's implicit communications into their lives, as well as identify salient design issues for implicit mobile communication. We studied 3 long-distance couples and 4 couples who lived together. We used Facebook advertisements as our primary recruiting tool, but not from our own networks.

3.5.1 Study Overview

The CoupleVIBE system was used for weeks 2-3 of the study, with one week of data collection both before and after the deployment to capture existing practices and observe the transition back. During the study several different methods of information gathering techniques were used. Nightly online-journal entries were used for the entire length of the study. Communication logging was also used every week of the study, except for the second week when logging was suspended to reduce participant fatigue. Figure 4 illustrates how long each method was deployed, as well as when the CoupleVIBE technology was used by the participants. The two-week deployment of the technology, though brief, helped us identify and address important issues, which can be integrated into later experiments.

At the end of the study, participants were interviewed both together as a couple and individually in private. Collocated couples were interviewed in-person, while long-distance interviews were conducted using video chat.

We considered using the experience sampling method (ESM) to gain in-the-moment insight on usage [36]. However, interrupting users would have been counter to our unobtrusive design goal, so we decided against it. Consequently, we focused on gathering data in the form of message event counts, end-of-day journals, and interviews.

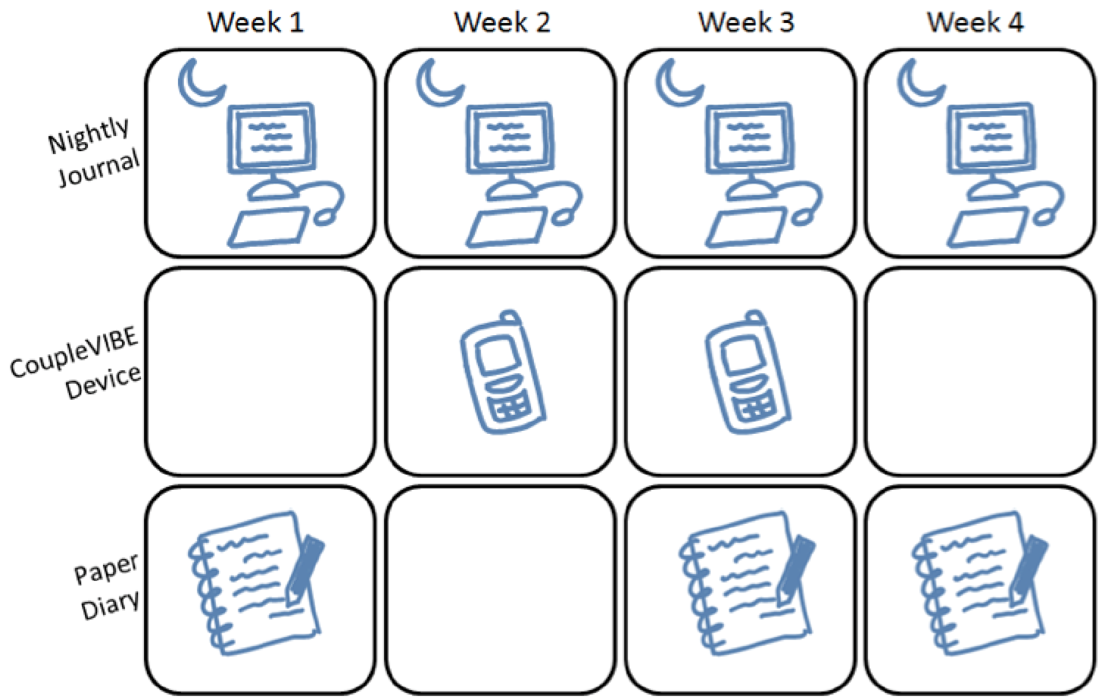

Figure 3.6. Visualization of introduction of technology and data collection methods over the 4 week study. We collected data before and after CoupleVIBE usage to observe changes in behavior.

3.5.2 Participants

We recruited 7 couples, four living together in shared households and three living apart. The latter three had been apart for six months or more and were separated by at least 400 miles. We originally recruited four long-distance couples but one dropped from the study due to time commitments. The couples recruited were between 21–32, and did not have children. The study therefore reflects CoupleVIBE usage for this typical demographic, which comprises the majority of, but not all, long-distance couples. All couples had been together for at least 2 years.

1. Close 23 year old Abigail and 28 year old Adam have been together for over two years. They live in the same house located near Abigail's barista job and the bus route that Adam takes to school. When Abigail is at home, they communicate

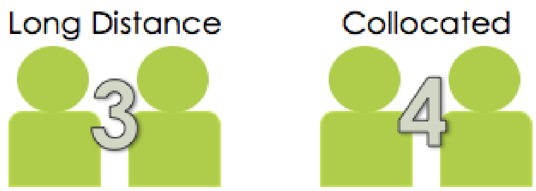

Figure 3.7. Seven couples, a total of 14 people, participated in our study, 3 in long-distance relationships, and 4 in collocated relationships.

frequently over IM. Her employer does not allow her to use any communication devices while she is at work. Recently, Abigail got upset with Adam when he went to a friend's house for the evening without notifying her or answering his phone. She worried about his safety for several hours.

2. Close Brenda and Bob are 28 and 32 and have been together for over 4 years. Brenda is looking for work while Bob supports them with his postdoc position. To coordinate their days, Brenda and Bob use shared online calendars. Bob is a bicycle commuter and Brenda worries when he forgets to call before he sets out on the road.

3. Close Cheryl and Chris are a 28 and 30 year old secretary and student, together for 8 years. Often at their computers, they use IM as a primary means of communication. Chris is a bicycle commuter and has flexible hours. This often causes Cheryl to worry when Chris doesn't call or IM to let her know when he is heading home.

4. Close Deborah and Dale are 25 and 30 year old graduate students at the same school, together for 3 years. They work about a mile apart on campus. They primarily call to coordinate things like when to eat or go home. They are also avid IM users since they are often at their computers.

5. Long Distance Martha and Mark are 21 year old undergraduate students who attend schools 2,400 miles and three time zones apart. They are high school

sweethearts and have been together for over 4 years. Throughout the day they communicate through text messaging, which they use to keep up to date with each other's activities and to coordinate their evening phone call.

6. Long Distance Nancy, 24 and Nick, 26 have been together for 6 and a half years. Nick has a software job but Nancy is still a student and lives three time zones and 1,900 miles away. They chat on the phone during Nick's commutes, and while at work they often keep a chat window open to communicate throughout the day. Sometimes they leave a video chat window open with the sound turned off so that they can see each other as they work.

7. Long Distance Olivia, 30 and Orlando, 31 have been together for 9 years and living apart for 8 years. Olivia is an engineer and Orlando works as a researcher for a company located 400 miles away. Olivia's work prohibits the use of phone and instant messaging, so most of their communication occurs on the phone when Olivia is commuting, and in the evening when they have their nightly phone call. Orlando is also an occasional bicycle commuter and Olivia appreciates when he lets her know when he chooses to bike.

3.6 Data on Location Selection and Messaging

All participants tagged their home, as well as work or school, as appropriate (Figure 5). Other popular places to tag included the gym, restaurants, shops, and friends' houses. All 14 participants said that they selected places that are part of their regular routine. Three participants also volunteered that they chose places that they thought would be of interest to their partners. Olivia volunteered that, *"There were the ones that were, you know, standard, home and work"* and Chris said, *"I just chose the most frequent locations I'm at and the ones I thought Cheryl would care about."* A few locations were selected to elicit a particular response from the partner, notably places that are favorites of the remote partner from previous visits.

Overall, the number of locations tagged per user ranged from 2 to 9 with an average of 4.6. Users were limited to 7 unique vibrations, but they could define more locations, mapping some to the same vibration. Two users defined more than 7 locations because they spent time in multiple cities during the study. They knew that their partners would be aware of which city they were in, so they could unambiguously assign locations like home and work in one city to the same vibrations as chosen in the other.

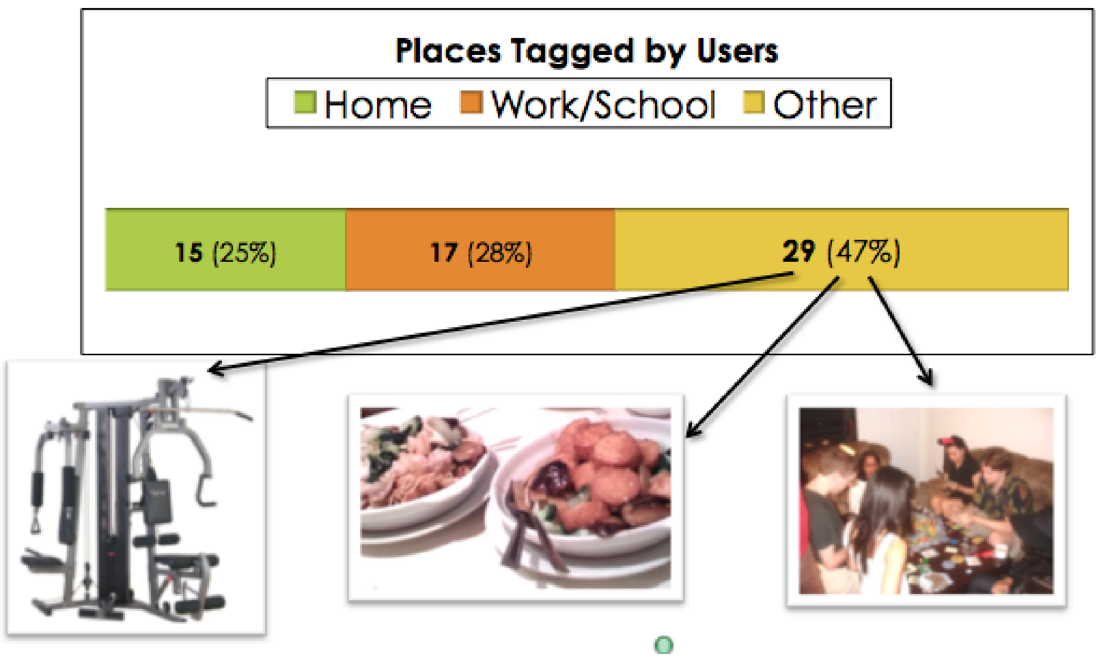

Figure 3.8. Number of places tagged by users, aggregated across all users. Tagged places are categorized by type.

Thirty-seven out of the 65 (58%) were tagged within the first two days. By the end of the first week 57 (88%) locations had been tagged. On average, 3.0 messages were sent per user per day (std. dev. 2.4). Users reported not using the application when spending the day together, such as weekends. This and related factors moderated the average.

3.7 Uses of CoupleVIBE

Past work has found that when introducing new technologies to improve awareness in families [25] or between couples [79], coordination, connectedness, and reassurance are common uses. CoupleVIBE compliments the findings of these studies by reporting the unique properties of mobile- symmetric-implicit communication.

3.7.1 Coordination: Location as a Proxy of Availability

Participants frequently used the information they gleaned from CoupleVIBE to help them coordinate a future activity with their partner. Eleven out of 14 participants volunteered examples of using CoupleVIBE for coordination activities.

Not surprisingly, coordination between long-distance partners centered on determining when to call or text the other person. As Abigail noted in her journal, *"I needed to ask Adam a question today and knew that he was at lunch because I had received a vibration. I was alerted that he had returned to his office and could then call him to ask him the question without interrupting his lunch."* Her partner Adam related a similar experience in his journal saying that the *"application was useful for knowing when to call...I knew when she left work and was able to call then."* Thus, like users in the Place-its [109], and Connecto studies [20], location was used as a proxy for availability. In a couple-based application, this extends to communication coordination. Sometimes coordination extended to making a more informed safety decision. Mark recorded in his journal, *"I knew Martha left her house to work out at the gym. This was helpful, I knew I shouldn't text her if she is driving."*

Collocated couples used CoupleVIBE for coordinating face-to-face interactions, such as unlocking doors, tidying the apartment, or putting away the PlayStation when one feels his partner arriving home. They also coordinated communications, like the long-distance couples.

3.7.2 Increased Feeling of Connectedness Between Partners

Eleven participants noted that vibrations often elicited feelings of connectedness. Martha was typical, saying, *"It put a smile on my face, just knowing something about him."* Participant Olivia reflected on how she enjoyed receiving her partner's location changes, saying *"I was able to follow Orlando through his day, activities like ultimate frisbee and going to Jamba Juice."* Interestingly, feelings of connectedness were not only generated by receiving location updates, but also by sharing one's own location status. Olivia continued, *"It was nice to go to local places and have him know where I was without having to tell him."*

Three participants also volunteered that they appreciated how CoupleVIBE's lightweight messaging helped them stay connected without detracting from other social experiences. Martha observed, *"I liked getting the vibrations when I was busy with friends, it was easy to feel connected and I didn't have to stop what I was doing to talk to him."* As mentioned in Location Selection, some locations were tagged in order to evoke a memory. Olivia wrote in her journal *"I put in that I was at <restaurant> and I received a text msg that he was jealous that he wasn't there. =) "*

The CoupleVIBE cues were visceral for some. Mark told us *"I can't remember how many times I've told Martha she's 'the voice in the phone, like that's who you are to me right now, you're the voice on the phone, how depressing.' And it's not until she comes and visits that she becomes physical and more real in a way. And the vibrations sort of take those abstract concepts and make it real, like it's actually physically affecting me like a real person, so maybe it sort of attaches the emotions to a more physical And that makes us feel closer, or at least makes me feel closer."* This attachment extended beyond the end of the study for some such as Nancy: *"It became like a habit and when I* *had to switch back to my iPhone I kind of missed the vibrations and I expected them but I didn't [receive any]."*

3.7.3 Peace of Mind: Knowing Your Partner is OK

Three of the couples had pre-existing conflicts over bicycle commuting, as prefaced by the scenario in the Introduction. These couples all commented on how using CoupleVIBE allowed for greater peace of mind since the cyclists no longer had to remember to call. Abigail wrote, *"Adam biked home from work today and I liked that I was able to know when he left work and when he got home. I worry when he rides his bike on busy streets."* Additionally, if the cyclist stopped by any other shared location on the way home, the partner was notified and knew to expect a delay. As Brenda noted in her journal, *"It was nice knowing he stopped off in another building on campus rather than coming straight home, so I didn't worry that he was hit by a car."*

Another example of comfort with the CoupleVIBE system was documented by Nick when he was concerned that his partner might have trouble using public transportation: *"I was worried about her ability to find the <local landmark>, where her car was parked. The vibrations showed that she left <city> safely and arrived <at landmark> 45 minutes later. I knew all this without calling or texting."* It was beneficial to both that Nick was able to observe his partner's successful journey without having to explicitly contact his partner while she engaged in an unfamiliar task.

Orlando sometimes commuted to work via a combination of bicycle and light rail train. He tagged the light rail station so Olivia would know how he was commuting to work that day – and that he had arrived safely. *"I thought the tagging of the train stations was particularly nice just for the whole bike ride thing, cause Olivia has in the past worried, if she thought I was riding and didn't hear from me."* Olivia reflected in her nightly journal, *"I was able to get a CoupleVIBE message when Orlando arrived at the*

Light Rail Station. That was nice to know – I could infer from that [that] he was biking to work today instead of driving."

3.8 Discussion

With this background on how CoupleVIBE was used, we now reflect on some of the properties of implicit mobile communication that were observed during our study.

3.8.1 Long-distance versus Collocated Couples

Both long-distance and collocated couples benefited from CoupleVIBE's affordances, although in somewhat different ways. The long-distance couples experienced more 'discovery' events, learning of a partner's activity that she otherwise would not have known about, which enhances connectedness. The collocated couples were able to use CoupleVIBE for coordinating face-to-face interactions.

Both groups used the information provided by CoupleVIBE for communication and coordination, with 9 subjects reporting they used it to determine a good time to contact their partner. Both groups also indicated that they used the location information shared to infer greater context, such as likely activity and interruptability.

As expected, there were times for collocated couples when CoupleVIBE's cues were unnecessary, especially week-ends, when a lot of time was spent together. A simple fix would be to use CoupleVIBE's location detection to detect the proximity of partners to turn off message delivery.

3.8.2 Benefits of End-to-End Automation of Communication

Automation in social communication is often dismissed for being impersonal, intrusive, and error-prone. However, results from the study lead us to believe that well-designed automation can avoid these pitfalls and provide benefits missed by traditional user-initiated communications.

No (Need for) Reciprocation

In our one-on-one interviews we asked each participant whether he or she felt any obligation to reciprocate when a CoupleVIBE message was received. All of the participants reported that they felt no obligation to respond to the vibration messages. When asked to compare their experiences with CoupleVIBE to other communication technologies they used regularly, participants made observations like:

> *"It wasn't like if I received a text message or an IM, that's when I feel guilty like oh I gotta write back, but no, this wasn't like that at all, completely opposite." -Abigail*

> *"You're never really aware that you're buzzing the other person [...] cause you're never aware of it you're never expecting a call back." - Dale*

These reports and others also convey that participants didn't want or expect their partners to actively reciprocate either, indicating overall that reciprocity was not an important dynamic. This helped maintain the effortless properties of implicit communication.

'Real' Real-time Updates

With explicit communication of status, sharing is often initiated in anticipation of an event or postponed until after the event. We found several cases of event disclosure in anticipation of an event, such as when a participant told his partner over IM that he was leaving work to come home when in actuality he didn't leave for another ten to twenty minutes. This time shifting can cause a disconnect in how partners understand each other's schedules. All of the participants reported that they share their schedules with their partners. In interviews several remarked on the differences they noticed with CoupleVIBE because now they knew in real-time when an event occurred instead of just knowing *'she visits the gym around 5:00ish.'* The two couples separated by time-zones mentioned that these real-time updates helped them understand the time difference in a richer way.

3.8.3 Privacy Concerns with Sharing Location

In our one-on-one post-study interviews, we asked about concerns over one's partner knowing his or her whereabouts. Twelve of the 14 participants reported comfort with the level of sharing. CoupleVIBE was considered noninvasive not because of its privacy controls – no one employed them for privacy – but because of who the user was sharing with and what they already knew. Brenda was typical, saying, *"I usually tell Bob when I am going places anyway and we do have this shared calendar."* Even the two users citing discomfort said their partners had in-depth awareness of their whereabouts; the issue was about feeling in direct control of when and how that information was shared.

When asked about using CoupleVIBE with people other than their partners, users said they would exercise more control over the location information. Orlando commented, *"I can imagine doing this publicly, but at a coarser grain than this."* Nancy commented that she would *" turn off the application at certain times"* because she would not want friends and family knowing what she was doing at 1 a.m.

Three users volunteered that their levels of comfort with the system were inversely proportional to the level of detail in sharing. Location information was viewed as minimally invasive and not uncomfortable to share, while detailed task information such as whether a participant was working or playing a computer game was deemed too fine-grained, with Cheryl stating *"if it was that granularity I would feel very, very uncomfortable, even with Chris."*

3.8.4 Unobtrusiveness versus Reliability of Message Cues

When we asked participants if they felt that the vibrations were sufficiently subtle, they said that the level of subtlety depended on the placement of the phone. For participants who carried their phone in a pocket, there were no reports of others noticing the vibrations. However, two participants said they placed their phones on their desks, which amplified the vibration noise enough that their office mates could hear it. They said that even when others did notice the vibrations that they did not seem bothered. This may be due to the relative infrequency of the messages, as well as the fact that people are generally accustomed to mobile phones making occasional noises in public settings.

Interestingly, several participants actively managed the placement of their phones in order to decrease obtrusiveness or, conversely, increase reliability of delivery. For example, one participant, who didn't carry her phone at home, used noise amplification to her advantage by placing her phone on a glass coffee table in the living room. On the flip side, two participants reported not bringing the phone to functions where they felt that overheard vibrations would be inappropriate, such as a job interview.

From these stories we observe that vibration can be a powerful tangible affordance, as simply moving the phone – as opposed to navigating its interface – can dramatically change the characteristics of the application to manage an important tradeoff. The fact that users often don't carry their phones[94] can sometimes be seen as a positive feature of mobile phones as a ubiquitous computing platform.

3.8.5 Role of Context in Recognizing Vibrotactile Messages

Several users said they could discern the different vibration patterns after a few days, but six users reported that they never got the hang of it, beyond recognizing their partner's most frequented locations, such as home and work. Five of the six, all women, tended to keep their phones in a hand bag. Indeed, women's clothing rarely allows for carrying a mobile phone on the person. Interestingly, three of the six women reported using time as a disambiguating cue for determining their partner's status when they received a vibration. As Olivia noted, *"The vibrations distinguishing one location from another [are] difficult to recognize. It might be possible that I will 'learn' them. But [I] can guess from the timing."* Participants reported using CoupleVIBE's status screen when they couldn't identify the location from context. A few users also reported using the status screen as something to look at when they were thinking of their partner.

We attempted to design a laboratory study to learn more about the effects of placement and context issues on recognition, but found it difficult to reproduce the relevant contextual factors, such as time of day, phone placement, and sources of external vibration. Also, there were important variables that we could not control across our 14 participants, such as the number of vibrations they used during the study and the amount of experience they had with them.

3.8.6 Handling of Anomalies

We know from previous sections that location recognition worked well, except for a few locations that were close together. Participants adapted to these difficulties in a couple of ways. Deborah and Dale, who worked close to their home, enabled the privacy feature when home together at night, when false cues tended to occur. When Nancy incidentally drove past her gym, Nick would sometimes receive an arrival cue. However, he used situational context to disregard those cues. Thus, as we've seen throughout the Discussion, users were adept at adapting CoupleVIBE and their own practices to make the most of CoupleVIBE.

3.8.7 Integrating CoupleVIBE with Existing Practices

All of the couples in our study used a combination of IM, phone, or email to stay in touch prior to the study. CoupleVIBE filled an important niche in their communication needs. As one example, several partners used CoupleVIBE's cues to determine which type of communication to use. A typical example is that a user would use IM when she knew her partner was at the office, but called the house phone when she felt her partner arrive home. As another example, couples would use different technologies for different purposes, according to what best suited the situation. Two couples' stories highlight this practice.

One couple would chat via IM throughout the day, messaging each other when one was about to go somewhere. During the study, they still used IM to stay in touch. However, for tracking and conveying location, they used CoupleVIBE instead. As Cheryl commented, *"[CoupleVIBE] is nice because you don't have to check the IMs, you just hear the vibrating and you're like 'oh, okay'."* T he other couple would call each other whenever either left one place to go to another. Nancy commented *"Say Nick left his gym or workout place and the phone vibrated to let me know. I know that's a cue that he's going to call me soon because we do have that habit of calling each other when we drive. So when the vibration would go off and he wouldn't call me for a while, I would call him and be like what are you doing. Oh I'm on the phone with my parents or something had come up. It was like a cue for me for why isn't he calling me. It's unusual for him."*

In short, the couples adopted CoupleVIBE for status that used to be exchanged over IM and phone, achieving high awareness. In essence, CoupleVIBE provided a baseline awareness for helping couples stay in sync. IM and phone calls were used for more interactive and detailed communication, often coordinated or prompted by status changes signaled by CoupleVIBE.

3.8.8 Improving Upon, Not Just Imitating, the Physical World

One of the design goals of CoupleVIBE was to recreate the awareness couples get through physical proximity. By mapping a user's physical location at a particular time across space, we had hoped to increase a user's awareness of her partner. This awareness is usually nice to know, but it can be disruptive if it interrupts a user's activity.

Two of the couples in our study lived in different time zones. In both cases, the partner living in the later time zone complained of being woken up when the other partner left home in the morning. Mark complained, 'I was asleep and she's three hours ahead and she left for the gym and it woke me up.' As a workaround, one of the participants developed a strategy of placing his phone on the carpet before going to sleep.

It is encouraging that the couples were able to invent practices that avoided these problems. Still, being awoken by these 'disruptive' cues is similar to being woken up by a collocated partner's actions. However, some argue that a new communication mechanism should improve upon, not simply imitate, real world communication[57].

3.8.9 Comparison to Previous Studies

Some of our results parallel those of previous studies, such as the Whereabouts Clock[25] and MissU[79], mentioned in Related Work. The CoupleVIBE study highlights many insights unique to (long-distance) couples, while providing insight on mobile, two-way, touch-based design.

It was important for couples to receive cues regardless of where they were, not just at home. The touch-based design proved similarly important, because it proactively played the status messages so partners were more in sync with the timing of each other's day.

As professional couples can have active lives outside home and work, we chose to support a larger number of locations than the Whereabouts Clock. We hadn't even supposed that some partners' travel for work would result in multiple 'homes'. With an average of 4.6 tagged locations, 9 max, and 47% of locations falling into the 'other' category, this design decision bears out.

CoupleVIBE's mobile design led us to design for unobtrusiveness, which proved successful with a touch-based design. The small number of messages per day – even with the larger number of tagged locations – also aided unobtrusiveness. Further, we were able to observe how the couples devised practices of phone placement and use of the privacy feature to achieve the level of (un)obtrusiveness desired.

Finally, CoupleVIBE's focus on lightweight two-way communication encouraged us to design to avoid reciprocity and reflect up on its consequences.

3.9 Design Lessons and Overview

Long-distance couples have unique communication needs that are not adequately met by explicit communication modalities. In creating future technologies to support these couples the following design guidelines should be kept in mind.

3.9.1 Design for inattention, not just distance.

Despite their frequent proximity, collocated couples found ample uses for CoupleVIBE – some involving coordination that are unavailable to long-distance couples. Seemingly, the busy life of a modern couple can create breakdowns in communication that are tantamount to physical distance. On the other hand, when a couple is truly together, a tool like CoupleVIBE needs to go into silent mode to allow proximal implicit communication to do its work.

3.9.2 Design for respect, not just privacy.

In our couple scenarios, consideration of others played a bigger role than one's own privacy. Participants only used CoupleVIBE's privacy control as a courtesy, such as when their partner was likely sleeping, not to actually control privacy. Additionally, four participants expressed interest in being able to turn off the receiving of cues, such as during job interviews or when partners were together. In future designs, we would recommend including an 'opt out' feature for incoming messages in addition to optional sharing. However, to support the inevitable conversations about the cues one was sent, mechanisms should be available to review suppressed cues.

3.9.3 Design to complement, not replace existing technologies.

Harper and Hodge's observations about how a new communication modality ends up living besides old ones [53] suggests that a new modality should be designed to mesh with current ones rather than presume to replace them. By focusing on filling the existing gap in implicit communication for long-distance couples, CoupleVIBE did just that. For one, CoupleVIBE was easy to use, beneficial when already 'juggling' other tools. Two, because CoupleVIBE was hosted on mobile phones, today's go-to communication device, it was a small step for couples to fashion a new practice of staying in sync – at no extra weight or cost. Recall that users often used CoupleVIBE messages to choose when (not) to call or text their partner: a CoupleVIBE vibration could cue a user to call their partner, while also confirming the phone's location. Conversely, when getting out the phone to place a call, a glance at the CoupleVIBE screen could confirm the aptness of the timing.

3.9.4 Take advantage of context.

We had anticipated that location would be a rich proxy for determining a partner's status. More surprisingly, context played a key role in disambiguating vibrotactile location messages. A user frequently combined an ambiguous cue, the time of day, and a general knowledge of her partner's habits to first disambiguate the cue into a location status, and then infer what her partner was doing. The take-away is that implicit communication cues need not be literal or complete to be useful, which allows for a larger design space in future applications. This is valuable, as taking advantage of context enables achieving more with less, as advocated in the previous lesson.

3.9.5 Final Thoughts

The design and deployment of CoupleVIBE, a mobile application that automatically shares location information between partners with cues of touch, shows that technology-mediated implicit communication can meet some of those needs. We highlight two takeaways:

1. For couples, CoupleVIBE operated as a foundation for staying in sync with a partner's daily activities, supplanting some explicit communications and better coordinating others, while also contributing to connectedness and peace of mind for their partner's safety. Collocated couples also used CoupleVIBE for physical coordination, such as tidying the house prior to a partner's arrival.

2. A combination of application design and user practices can sidestep the annoyances of end-to-end automated push communication. Vibrotactile cues signaling a partners' movements between frequented locations provided the desired awareness information while still providing unobtrusiveness. Simple practices of phone placement balanced unobtrusiveness and reliability, as did inventive use of CoupleVIBE's privacy feature. Additionally, users were adept at using context to disambiguate partially sensed cues and ignore erroneous ones. Finally, automated communication eliminated the impulse for reciprocation, keeping communications lightweight.

With these observations in mind, it is possible to envision a world with a broad set of implicit communication tools that quietly keep us apprised of goings-on beyond our immediate attention, helping us to feel more connected, better coordinate activities, and increase peace of mind. Based on our results with couples, we postulate four design lessons that can apply to future mobile implicit communication systems designed for other social groupings.

3.10 Acknowledgements

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Chapter 4

Sensor Sharing for Communities

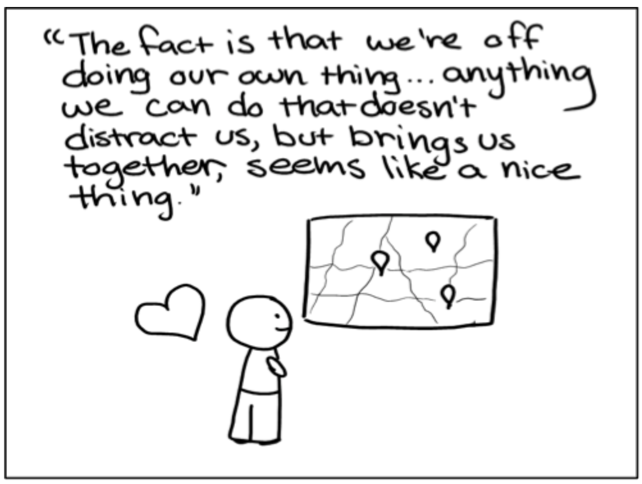

Figure 4.1. Contributing to a community you care about can be hard. Sensors combined with well designed sharing mechanisms can provide low-effort ways for people to feel connected in larger groups.

Poor air quality is a growing global health concern that impacts millions of people worldwide. Although we are beginning to understand the health impacts of air pollution, it remains a challenge to provide people with the information needed to support health-conscious choices. The CitiSense system gives individuals the real-time tools they need to be able to identify when and where they are exposed to poor air. We present the results of a qualitative study regarding a 4-week "in the wild" deployment of the CitiSense air-quality sensor and system. We focus on how the 16 participants responded to their new-found information about their environment, how they shared information, and what kinds of actions were enabled by having access to real-time air-quality data. We then ran a follow on study with 14 participants who belonged to a shared community. In addition to providing them with their own data, their collective pollution readings were displayed on four large-scale displays installed in central locations in their work building. Quantitative data gathered through the course of the studies frames participant responses by showing what levels of pollution were experienced and what activities heightened exposure. We found that CitiSense's real-time graphical displays and everywhere monitoring provided a critical bridge between data and experience, enabling sophisticated in-the-world sensemaking and sharing with those nearby. Additionally, in the community scenario, we found evidence that the automated sharing of air quality data allowed people to feel like they were contributing to their community in a non-invasive, low-effort way. Ultimately, in both studies we found that using the CitiSense system affected behaviors and attitudes leading to shifts in how users reasoned about their world, how they assessed their personal choices and impact, and how they connected with their communities.

4.1 Motivation

Indoor and outdoor air pollution is responsible for an estimated 3.2 million deaths worldwide each year [128] and is linked with increases in heart attacks, asthma, dementia, and cancer[3][127][129]. These impacts are felt most severely in developing nations where there is little regulation of emissions. However, even in the United States, where clean air regulation has been in effect for over four decades, an estimated 50,000 premature deaths each year are attributed to poor air, with additional costs of pollution-related illness estimated to be $150 billion a year[90]. Loss of quality of life due to restricted behavior, more hospital visits, and an unpleasant outdoor environment are

Figure 4.2. The CitiSense project provided novice users with real-time access to personal pollution exposure anytime, anywhere.

additional costs borne by communities with poor air quality.

Surprisingly, even in regions where air pollution is the exception rather than the norm there is still cause for concern. While scientists have known for some time that prolonged exposure to pollutants has negative health effects, new research suggests that even short-term exposure to poor air quality can have life-changing health effects for sensitive groups such as the very young, or those with underlying cardiovascular disease or asthma[59][68][127].

The sampling currently used by governments employs stationary air monitoring stations to estimate regional air quality. This is an important starting point, but unfortunately conveys little detail about actual individual-level exposure. Regional air quality assessment is conducted by widely dispersed sensors, with many large cities being covered by only a handful of stations. Air quality can be highly variable across neighboring locales due to regional geography, industrial areas, weather, and traffic patterns. Also, for pragmatic reasons, regional air quality monitors are often placed in locations removed from where people actually spend their time, such as on top of buildings, away from major roads and freeways, and of course not in people's homes. As a result, current monitoring methods may do little to inform individuals of the elevated exposures they encounter in their daily lives while sitting in traffic, sleeping in their homes, or walking along a busy road.

This lack of awareness can make it hard for individuals to act in informed ways regarding their pollution exposure. Many harmful pollutants are invisible to the human senses, and without the ability to see or smell contaminants it is hard to devise ways to avoid them.

The goal of the CitiSense project is to provide individuals with a system that makes the invisible visible: providing people, for the first time, a way to see what their pollution exposure is in real-time. To our knowledge, our 4-week deployment is the first "in the wild" study of a mobile air sensing system designed for novice users.

In this paper, we present three contributions that help inform research in the space of mobile environmental sensing:

1. Results from the first month-long "in-the-wild" deployment with non-experts users for a real-time mobile air quality system.

2. An in-depth look at user perspectives on, and responses to, viewing their own air quality data.

3. Insight for what properties supported synthesis by users, with a particular focus on how design decisions impacted usage, adoption, and integration.

These contributions help us expand our understanding of individuals might engage with mobile sensing systems to collect, reason about, and apply sensed information in everyday life. In this paper we also look at how and when individuals chose to share their data with others, both in person and online. Finally we present design guidelines for future systems, and ideas for deployments with more diverse groups.

4.2 Related Work

Sampling air quality is an important but difficult task that researchers have explored using a variety of techniques.

4.2.1 Making Existing Data Accessible

Environmental data is often publicly provided by government agencies that collect it for public health purposes. However, there is often a significant gap between how agencies report data and the people who would benefit from access to that knowledge. Several systems have explored designs that bridge the gap to provide publicly collected data in an easy-to-digest format for everyday users. The Ergo SMS-based system was the first to provide individuals with access to localized data in real-time. While the data reported was limited in precision (reported at the zip code level), and only consisted of outdoor readings, participants still reported using the system to support their decision making processes, a feature that was especially useful for individuals with respiratory problems. From these positive results we postulate that personalizing the data further to include finer-grained exposure data and including indoor air quality will empower users in their decision to an even greater degree[95]. Systems such as iMAP and PIER have taken this approach a step further by creating pollution models from multiple data sources such as traffic patterns, weather, and regional air quality sensors[40][87]. They then provide exposure predictions based on location data collected from an individual's mobile phone.

4.2.2 Going Indoors

The InAir[64] and MAQS[58] systems target the significant challenge of indoor air quality sensing, an important area since, as reported by Jiang et al., on average over 90% of modern life is lived indoors[58]. InAir provided participants with a stationary indoor air quality sensor for particulate matter. Participants used the system for 2 weeks and were allowed to install the system in any easily observable space in their home (e.g., next to the bed, on the kitchen counter). Real-time visualizations were provided by a paired iPod touch that displayed daily graphs of the observed particulate readings at the installed location. Similar to the Ergo study, participants reported building the checking of air quality into their daily routines, again suggesting that there is general interest in this type of environmental sensing.

The MAQS[58] air quality system also explored improving indoor air tracking through mobile sensors that sampled CO2 and interpolated VOCs (volatile organic compounds) using air exchange rates. The focus was to give personalized, room-level data to individuals that used the system. Participants in the MAQS study spent 12 weeks training a location algorithm on Android phones to get accurate room-level data with weekly meetings with the sensor carriers to verify accuracy. Participants then carried the MAQS mobile air sensor for an additional 3 weeks to collect air samples of their daily exposure patterns. Sampled data was made available to sensor carriers and other collocated individuals, although the nature of the data format and interface is not reported. Jiang et al. found that participants frequently experienced poor indoor air quality during the course of the study in a variety of indoor locations, suggesting that further research in indoor air quality sensing could benefit users.

4.2.3 Taking it Outside

Wearable sensors have also been used to sample outdoor air quality. The GasMobile System explored a bicycle-mounted Ozone sensor to discover urban pollution distribution. In the data collection phase, researchers rode the bicycles to collect air samples and discovered high variance between different outdoor locations, including those with close proximity to one another. This supports the findings of Vardoulakis et al. who reported that “urban street canyons” support microclimates that can vary widely from one another[121]. The AIR project extended this research by building a mobile air quality sensor for nitrogen oxides, carbon monoxide, and ozone[1]. Participants were asked to carry the device for no longer 24-hours and then pass the sensor on to a new individual. Data was collected to artistic visualizations intended to help communities think about their air quality.

Aoki and Willett et al.’s CommonSense[8][130] system explored outdoor sensors in a variety of contexts including sensors mounted on street sweepers, and hand held sensors that could be used by individuals to sample interesting outdoor locations. The street sweeper deployment strove to augment a city’s existing sensor infrastructure with vehicle-mounted sensors. Aoki also explored the tradeoffs in air quality management, and the requirements for collecting data to support social and political change[8].

In the CommonSense handheld deployment participants took part in a one-day workshop where they were encouraged explore their local environment with a hand-held particulate sensor. Participants were then asked to give feedback to various data visualization techniques for exploring their data[130]. We drew from these visualizations such as the “tracks” map-based visualization for our system. The CitiSense system extends the findings of the CommonSense system by exploring “in-the-moment” visualizations that support real-time analysis, in addition to providing desktop based, reflection supporting visualizations.

4.2.4 Opportunity for Impact

Through exploring the existing research space we found an unmet need for a wearable indoor/outdoor air quality sensor. Such a sensor could support a holistic view of personal air quality sensing, representing the indoor air readings that make up the majority of the day with the peak exposures experienced during outdoor activities. We also found opportunity for learning how such a sensor might be accepted and adopted into daily tasks through a longer term deployment. Prior work on CitiSense defined the system design, described a collection study looking at the distribution of air pollutants in an urban area and reported on how a small group of users responded to the system design and interface [16][89]. To our knowledge the study presented in this paper is the first month-long “in the wild” deployment of a mobile air quality system with novice users.

4.3 CitiSense Design

The CitiSense system is comprised of four main components: a wearable sensor board that pairs with an Android phone, a server-supported, web-based personalized daily pollution map, and a social component supported through Facebook and Twitter integration.

4.3.1 Sensor and Phone

The mobile component of the CitiSense system consists of an Android mobile phone running custom application and a mobile air-quality monitoring unit (Figure 4.6 and 4.7) that sends sensor data to the phone via Bluetooth. The air-quality monitoring unit contains the following 6 sensors attached to a custom board; Carbon Monoxide (CO ppm), Nitrogen Dioxide (NO2 ppb), Ozone (O3 ppb), Temperature (F), Barometric

Pressure (MBAR), Humidity (reported as percentage).

As we recruited individuals with no prior air-quality sampling experience we wanted to focus on presenting the data in an easy-to-understand way. We developed a modified version of the Environmental Protection Agency's (EPA) Air Quality Index (AQI) number and color mapping (See Figure 4.5) to help our users easily and quickly interpret sensor data. While the EPA's AQI values represent an average pollutant level at a location over time, CitiSense provides an instantaneous report of the same value. Since the CitiSense sensor is mobile and we expected users to be interested in locating times of peak exposure, an instantaneous report was deemed more appropriate. We call this number My Instantaneous Air Quality Index (miAQI).

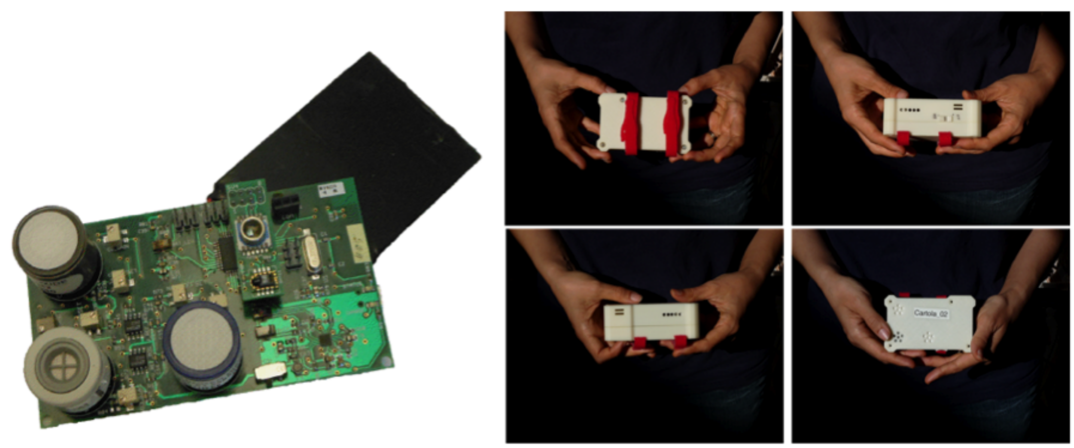

Figure 4.3. (a) sensorboard. (b) Sensorboard in printed plastic case. Velcro straps are attached to the case so users can easily attach the sensor board to backpack straps and bike frames.

The miAQI number and color is displayed prominently on the mobile application home screen (Figure 4.4) and is also used to populate and color the balloons on each participant's personalized map page (Figure 4.7).

Figure 4.4. (a) CitiSense application home screen. The cloud's color and number changes based on the sensor readings. The color bar underneath indicates where on the scale the reading lies. Tapping the "?" button displays the official EPA color chart (Figure 4.5) along with a link to details on each pollutant and its health implications. (b) Pollutant details screen. This screen displays the exact readings for each sensor and a graph indicating the maximum miAQI recorded each hour.

4.3.2 Web and Social

A personal map page was maintained for each participant throughout the course of the study. These pages were generated in real-time, and feature a daily exposure map, and a chart displaying pollution exposure by time of day. This webpage was designed to allow users to dig deeper into their data and see trends in their exposure (Figure 4.7). The visual nature of the time chart and map allow users to quickly locate the time and place of peak exposures. These web pages were also designed to give drivers and cyclists, who can't look at the phone display while they commute, a way to see their commute data in

	Good	Moderate	Unhealthy for Sensitive Groups	Unhealthy	Very Unhealthy
O3 (ppm)	0-.059	.060-.075	.076-.095	.096-.115	.116-.135
CO (ppm)	0.0-4.4	4.5-9.4	9.5-12.4	12.5-15.4	15.5-30.4
NO2 (ppm)	-	-	-	-	.65-1.24

Figure 4.5. Color-coded air quality safety chart created by the Environmental Protection Agency (EPA)[119]. The CitiSense system uses the EPA's colors and numbers to generate easy-to-reference values for the main screen.

a safe way.

The webpage and Android application both support sharing through the Facebook and Twitter social networks. This integration allowed users to post air quality data directly to their social networks with a single click.

4.3.3 Public Displays

In the second study large scale public displays were utilized to collectively share the data collected by the participants. The screens were installed in a 4 floor building and were centrally located in common areas near the elevators and staircases. The screens ranged in size from sidle 46" inch displays on the first and second floors to 2x2 grids of 46" displays on the third and fourth floors (Figures 4.8 and 4.9).

4.4 Methodology

We recruited 16 participants (8 men, 8 women) to carry the sensors for one month. The age of participants ranged from 20 to 56 years (mean age 38.5 years) and their

Figure 4.6. These prototype boards could be carried attached to a backpack strap, secured to a bicycle frame, or carried in hand.

commute distance ranged from 4 miles (6.4 km) round trip to 65 miles (104.6 km) round trip (mean of 36.4 miles or 58.5 km). Our recruitment criteria were that participants commute at least five days a week and that they be regular users of online social networks (defined as posting content multiple times per week). We recruited participants through an on-campus mailing list for commuters. As this was an exploratory study we tried to select a range of commute types so that we could observe a wider variety of exposure profiles as shown in Table 4.1.

Our participants came from a variety of backgrounds, including a librarian, a science writer, a programmer analyst, a public information officer, a fund manager, a student advisor, a maintenance painter, a professor, a postdoc, an administrative assistant, a pulmonologist, a senior budget analyst, a graduate program advisor, a faculty assistant, and two students. Participation in the study consisted of carrying the sensor and phone

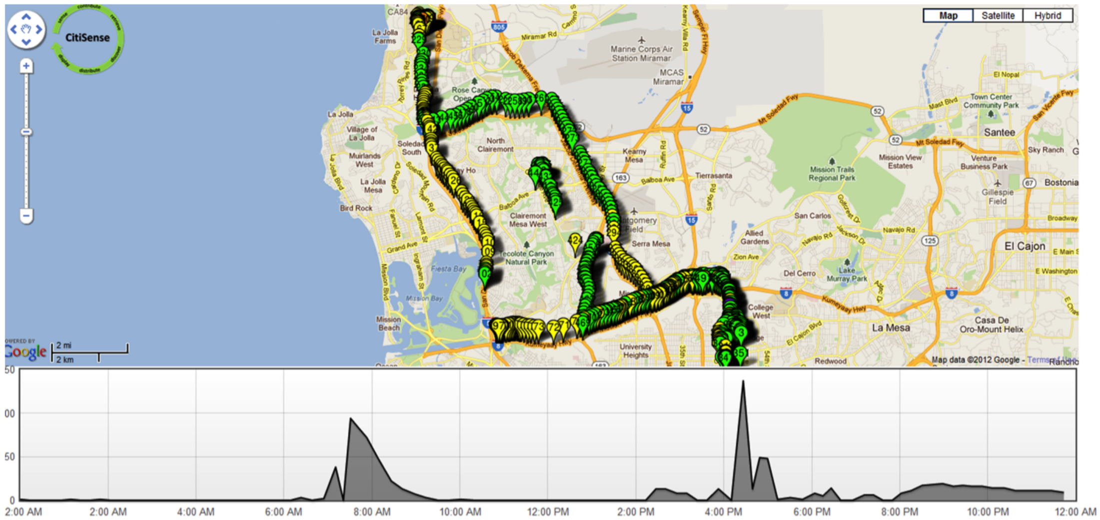

Figure 4.7. Personalized map page with miAQI plotted by location. Users can click a balloon to learn more detailed information. The graph displays samples plotted by time of day. In this case you can see the user's commute to and from work as the two peak exposure times. Our maps are implemented as an overlay on the publicly available Google Maps framework[47].

during commuting activity, attend a 30 minute training session, responding in 4 weekly diary entries, a pre- and post-study survey, and participating in an hour long in-person, open-ended interview at the end of the study. While participants were primarily asked to carry the sensor while commuting, we invited them to take the sensor anywhere they wanted over the course of the study. Participants were compensated $75 for their time and travel costs.

To analyze our data we used an iterative approach to code the interviews and open-ended survey questions. We also conducted a focused textual analysis looking at our participants' word choices when discussing their relationship to system and to the pollution readings they encountered.

Figure 4.8. Large scale displays installed in communal areas on each floor of the building provided natural opportunities for sensor carriers and others to view the air quality data collected by our participants.

4.5 Results

Our main goal was to learn how access to air quality data might affect the participant's behavior throughout the study. In this section we look at data from the surveys and interviews to learn how the sensors integrated into their daily activity and how the participants' perception of the world was shaped by access to real-time air quality readings.

Figure 4.9. The large scale displays included both a live map showing all sensor readings in the past hour as well a transparent interpolated color layer generated from machine learning algorithms developed by Verma []. In addition to the map a short explanation of the project was included to help non-sensor wearers understand the data readings they were seeing.

4.5.1 Mining Sensor data for Quantitative Context

To help frame the responses from our participants we also collected location and air quality data in a central server throughout the study. This data helps give context for what the participants actually experienced during the one month deployment. In total, we computed and collected $4,824,265$ miAQI readings (representing a total of 335 days worth of sensor readings). To participate in the study, participants were required to carry the sensor only while commuting or a total of about 40 hours each. However, our data reveals that the participants voluntarily carried the sensor an additional 502.5 hours on

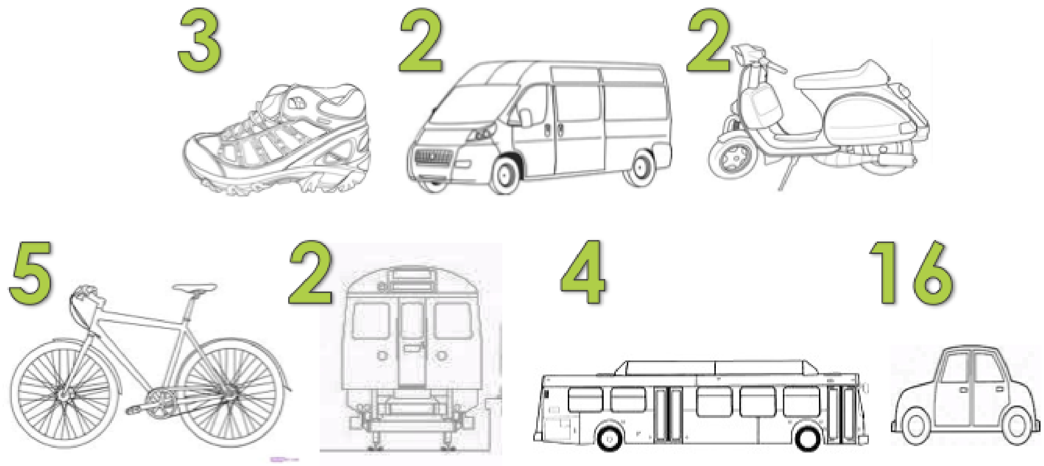

Figure 4.10. Combined commute types represented in the deployment studies. Some participants used a combination of commute methods (e.g. carpooling to the bus stop, and taking the train and then the bus).

average, over 12 times the required amount. This suggests that the participants were receiving value from carrying the sensor.

In taking a closer look at the data we observe that by EPA standards, most of the air samples were well within the safe range, with $4,618,706$ readings in the *"good"* category, $118,806$ readings in the *"moderate"* category, and $31,227$ readings in the *"unhealthy for sensitive groups"* category. This finding is in line with what we expected as most modern office buildings have advanced air filtration systems, and homes generally have low readings for CO, NO2, and Ozone. Emissions from gas stoves and burning incense are two exceptions in the home that were noted by our participants. Yet, all of our participants also experienced periods of exposure to unhealthy air. Over the course of the study a total of $55,526$ readings were observed in the unhealthy range (miAQI greater than 150). Delving deeper into the poor air readings collected, we compared stationary to mobile readings (See Table 4.2).

The readings collected by our participants conform with our expectations that the air quality experienced while in transit has higher pollution levels than in homes

Table 4.1. Participants self-reported commute data. ID encodes age, transport method, and gender

Participant ID	Method	Miles/km
43BkF	Bike	27/43.5
32CrBsF	Halfway car, halfway bus	40/64
33TnBsM	Train and Bus	60/96.6
45CrM	Car	65/104.6
41BsTrM	Bus and Trolley	54/86.9
28BkM	Bike	20/32.2
41CrF	Car	58/93.3
20ScM	Motorized Scooter	14/22.5
48CrM	Car	50/80.5
20CrM	Car	4/6.4
56VpF	Vanpool	34/54.7
47BkM	Bike	4/6.4
48CpF	Carpool (with spouse)	50/80.5
32CrF	Car	42/67.6
44BkF	Bike	30/48.3
34CrBsF	Car and Bus	30/48.3

Table 4.2. miAQI readings by transportation type

	Biking	Car	Other	Stationary
Average AQI	98.58	35.55	29.26	14.9

and workplaces. The method of travel also played a significant role in the air quality experienced, with the average miAQI for bicycle commuters being over twice of that experienced by car commuters and over 6 times the average reading when stationary. This disparity between the data collected by cyclists and car drivers is addressed in the Discussion.

4.5.2 Discovery and experimentation

CitiSense provided what some users called a *"sixth sense"*, the ability to see what had previously been invisible to them and the people around them. This new ability was described by participants as *"fun"* and *"informative."* As the study progressed, participants reported settling into a more sustained pattern, shifting from checking their phone at regular intervals, to only when they were prompted by an anomalous observation, such as walking past a new construction site, or driving behind a particularly smelly truck. 32CrF summed up her experience with the system saying

> *"[It was] very cool that you can quantify the hunches that you may have [...] I mostly just did my everyday thing, and then checked it in particular places that I thought were interesting." –32CrF*

This ability to verify pollution expectations allowed participants to develop a better sense of real pollution source, an ability that, as is described in the next section, often challenged their prior belief about air and pollution distribution.

4.5.3 Reconciling readings with previous beliefs

Prior to the study, 15 of our 16 participants had mental models that were inconsistent with actual air distribution, believing instead that pollution was distributed evenly, or not professing any beliefs at all. These 15 also reported that air quality was something they rarely thought about; a reasonable omission given they possessed no means to measure or view their exposure.. The main information source for local air pollution was print and broadcast news, formats that generally focus on broad regional readings, and often only at times of abnormally high pollution levels. Thus, this new window into air quality generated surprise for many of our participants when the readings they observed didn't match their pre-existing beliefs of where bad and good air should be. One major source of surprise was how variable air quality was over short distances. 47BkM's response was representative:

> *"The very localized spikes in pollutants near major roads was a bit of a surprise. I expected overall air quality to not be as variable over short distances." –47BkM*

As participants began to attribute these variations to sources such as roads and intersections, they began to shift their mental model to incorporate their findings.

> *"I've become more aware of how things like freeways, power plants, etc. affect the surrounding area. I guess I always just thought of the atmosphere as being evenly mixed but it is not." –33TnBM*

Discovery of air pollution in unexpected places was another source of surprise for participants. 20CrM shared his surprise over learning that his lab, where he solders electrical equipment, often had unsafe pollution levels that he couldn't otherwise sense:

> *"The places I thought would be good, like inside buildings for the most part are clean but then anywhere where you're working with electrical equipment or chemicals, like the air quality seems fine, but the readings say otherwise." –20CrM*

Another misconception that was challenged through data observation was that faster roads would have worse quality air than slower roads. In reality, there are many factors that contribute to poor air. For example a slow road that climbs a steep grade may have much worse air quality than a fast but flat freeway. 44BkF noted, for example:

> *"I would expect it to be bad on the freeway, but I wouldn't expect it to be bad on single lane roads that goes 30 [miles per hour], but that just doesn't make any sense I guess. So I was surprised at how bad the air quality was all around." –44BkF*

These reflections are evidence of the intellectual work that participants undertook to process the readings they observed. Carrying the sensor with them and having access to real-time data allowed the participants to observe, reason about, integrate, and adapt their mental model of air pollution to be consistent with the new data they were observing. These observations helped form and shift our participant's understanding of when and where they experienced bad air quality. The data challenged previously-held beliefs of safe and unsafe places, and also helped solidify understanding that had been based previously on guesses.

4.5.4 Sensemaking: correlating data within environmental context

Another aspect of interest was whether participants would be able to correlate the readings they observed with the environment around them. This issue is important because, as Kim and Paulos discuss in their work, the ability to identify the source of a high pollution reading is key in designing systems that enable change and avoid triggering feelings of powerlessness[64]. To investigate this, we focused on how our participants spoke about their readings and the way they attributed causation for the readings they observed. We particularly looked for occasions where participants spoke about bad air and gave attribution to objects in their environment that they perceived to be the source. An example of such an attribution is "I could see that idling my car resulted in bad air quality" as compared with "I saw that I frequently experienced bad air", where the formulation of the sentence implies causation to the action of idling the car rather than just observations about the readings.

In our analysis we found that 13 of the 16 participants used language that attributed cause to objects in their environment, saying things like:

> *"I always see a spike in the air quality values when I arrive at <local college> - I think it's when I walk through an area where several city buses are stopped and running. I think it's very interesting!!!" –32CrF*

> *"Burning incense is terrible for my health"–43BkF*

> *"It seems like my gas stove kicks out carbon monoxide and it isn't vented." –33TnBsM*

The remaining 3 subjects did notice differences in their readings, but instead of associating higher readings with particular objects or environments, referred to them as "*sporadic.*" There were also several cases where participants noticed a consistent pattern in their data but struggled to attribute cause:

> *"It's fascinating... walking up to the <local monument> the pollutants*

were at 250ish for quite a few days...what's over there?"–56VpF

These unidentifiable spikes seemed to generate feelings of curiosity rather than helplessness, likely because the locations of the readings were outside their routine, in easily avoidable places. In addition to linking sensor readings with environmental context, our participants were also able to use the sensors to help understand physical reactions they were having to their environment, as in 32CrBsF's experience of an air-quality-related health event.

> *"I liked being able to see what the air around me was like. Especially when I was having a hard time breathing and then found out that ozone was in the purple range." –32CrBsF*

Perhaps the largest factor for participants in make these linkages between the sensor readings and their environment was the real-time nature of the device.

> *"I really liked that the readings were real time [...] so then I could be like at this specific moment the spike happened, because if there was a delay, I wouldn't, you wouldn't, you forget." –34CrBsF*

On the extreme end of sensemakeing were reports like 38BsF's, who conducted her own mini-experiments with the sensor while riding in her friend's car. *"I am experimenting, [...] trying windows down or up, air conditioning on or off, with or without recirculated air."* The real-time nature of the system allowed her to purposefully manipulate her environment and observe how her actions impacted the readings on the screen, allowing her to make assessments of how her actions impacted her air quality

4.5.5 From Awareness to Empowerment

Air quality provides a different challenge when compared with many other health concerns, because unlike things like calorie counting or exercise, it is difficult to change air quality or exposure at the individual level. We had been concerned that exposing individuals to pollution readings may inspire feelings of powerlessness due to inability to change their circumstances. In looking at our data we were careful to watch for language that suggested feelings of helplessness, and also watched for language that indicated feelings of empowerment. While we did see some language relating to feelings of limited ability to alter daily commute routes, our participants did not express much concern over this lack of flexibility. We do not take this as an indication that lack of control over pollution exposure is not an issue, but rather that in this study its importance was lessened due to pollution exposures being generally low, even during commutes, with occasional spikes into unhealthy ranges. Ridesharer 48CpF summed up her experience, saying *"there wasn't any data that concerned me to the point where I thought, 'Oh, I'm not going to go over there."'* Instead, what we observed was empowerment through a collection of smaller-scale changes. Some of these changes happened at the individual level, and some were broader, positively affecting the communities of people who lived and worked with the participant.

Small-scale changes at the individual level were some of the simplest ways that participants acted on the readings they observed through using the CitiSense system. While these modifications did not change the overall commute structure – carpoolers still carpooled, bus commuters still bussed – these small modifications allowed users to lessen their overall exposure by identifying and avoiding behaviors that they correlated with high readings:

> *"My husband drops me off at the bus stop, and it's a minor thing, but he drops me off in front of the bus so that I don't get out near the fumes." –34CrBsF*

> *"I'm more conscious of leaving my car idling and keeping the windows closed on the freeway. I am also more careful to walk on side-streets instead of busier roads" –33TnBsM*

Participants also related stories of how the data they collected with their sensors resulted in positive for those around them. For example, 43BkF related that *"My boss*

[?] saw so many red and orange and yellow data points on my sensor [...] and went out and bought the office air filters." Because 43BkF was able to easily sample and share her real-time readings with others who worked with her, people who had the power to make positive changes did so. Similarly, by sharing his sensor readings with his fellow electrical engineering students, 20CrM encouraged them to avoid bad air in the lab while they were soldering.

> *"The only ventilation would be like going out this small door in front, but the lab is like long and narrow, so like if you're at the end the ventilation wouldn't go out as much [...] we try to do everything outside now that releases fumes." –20CrM*

Perhaps one of the most interesting changes we saw in the study was a change in attitude and concern towards local air quality. As 48CpF noted, it is hard to care about something you can't see:

> *"If they know how it's impacting them, and their children, then that's when they start to take action on it." –48CpF*

Over the course of the study, participants gained a better understanding of the pollution in their communities and their interest in making positive changes increased. 41BsTrM described how carrying the system increased his interest in local pollution levels.

> *"I am enjoying collecting data at home, work and in my public transportation commute using the CitiSense system. Despite my initial lack of interest in commonplace city airborne pollutants, I am now fostering an enthusiasm about its relevance!" –41BsTrM*

This sentiment was echoed by other participants like 33TnBsM, who felt that his new understanding of air pollution made him more receptive to political measures related to clean air.

> *"I'm more inclined to support regulations to improve air quality. It's made me aware that polluting our air is like fish pooping in their tank."*

–33TnBsM

Even in cases where participants didn't alter their behavior, participants related that using CitiSense had changed the way they thought about the choices they made:

> *"It might not have a big effect on how many times I ride on the road verses the canyon, but it affects how I think about it." –44BkF*

Having access to the sensor data meant that participants were able to quantify their exposure and make more informed choices based on real data, rather than guesses. These types of responses suggest that there may be opportunities for these systems to motivate people to advocate for change both at the behavioral level and at the policy level. The CitiSense system makes the previously invisible problem of poor air quality both visible and quantifiable, which may help people feel informed enough to make informed personal choices and to get involved to help improve their communities.

4.6 Sharing within communities

In our study we included functionality in both the mobile app and webpage to facilitate online sharing through social networks. In addition to this online sharing, participants also frequently shared with the people around them.

4.6.1 Sharing Online

Online sharing was a one way that participants shared their air quality data with their friends and family. The response from friends was mixed, with some friends engaging and asking questions, while others were confused about their friend's sudden interest in air quality (See Figure 4.11 for a typical conversation on Facebook). One participant in particular received very positive feedback from his online friends, which may be due to him officially introducing the study on Facebook through the sharing of an annotated photograph (See Figure 4.12). This introduction set the stage for his subsequent air quality posts.

While some participants received responses from friends on their online posts, others did not. However, even in the cases where participants did not receive online responses, it was common for local friends to ask about the posts in face-to-face conversation:

> *"The Facebook posts, to me, were a jumping off point, when I would see someone in real life they would bring it up, whereas I probably wouldn't just bring it up in conversation with anybody, unless they saw on Facebook that I was doing it. [...] Starting the conversation usually happened because of a Facebook posting." –48CpF*

In this way the online posts acted as a catalyst for face-to-face conversation, where participants could share their current miAQI reading, and also explain the study.

4.6.2 Sharing In Person

In addition to the local sharing inspired by the online posts, participants found other opportunities to engage with proximate others to share their readings. The hyper-local nature of the data often prompted our participants to share with others nearby, even strangers. Four of the 16 participants reported occasions where they had shared their sensor data with strangers who were sharing their commute:

> *"I share the readings with the people I ride the train with and anyone else I interact with and they are usually interested. They seem pleased to see that it is pretty good and like me, surprised at the difference near the freeways." –33TnBsM*

For 33TnBsM, who shared his commute – and thus his air – with his fellow passengers, it was natural to share with them the data he was collecting. Together they were able to reason about the readings they observed, drawing correlations between spans of bad readings and the possible bad air sources near the train.

Figure 4.11. Example of a CitiSense post shared on Facebook. The URL links to the live map page showing the points from the time window that the participant decided to share.

4.6.3 Impact of Display

In the collocated deployment the large scale displays offered yet another opportunity for social engagement. Participants reported feeling that the combination of carrying the sensor and the shared large scale displays felt like they were able to contribute to the community in a meaningful but low effort way.

> *"The fact is that we're off doing our own thing[...] and anything we can do that doesn't distract us, but brings us together seems like a nice thing."*
> *–55ScM*

Being part of a community often desirable, but can be difficult to maintain when work and other obligations make demands on one's time. The CitiSense display provided a way for individuals to contribute to the community in a low effort way. As the display updated with a rolling one hour window, it also allowed people to visualize movement within the department as markers would appear as people commuted to work, wanders campus on their breaks, and finally left in the evening.

Figure 4.12. Unprompted introductory post created by one participant. By introducing his online community to the CitiSense project, he better prepared them for understanding and responding to his subsequent air quality posts.

4.7 Discussion

The deployment of the CitiSense system provided an opportunity to observe how people used and integrated our mobile sensing system into their everyday lives. In this section we take a high-level view of both the positive outcomes and the challenges faced in this deployment, highlighting what design decisions provided significant benefit to the users and what changes might be considered for future systems of this type.

4.7.1 Same place, different realities

Our participants represented a range of commuting methods, which brought to light an unexpected dichotomy. Although some of our participants traveled the same paths, their experience and exposure to pollutants could be vastly different depending on their choice of transportation. For example car commuter 48CrM shared his surprise at how much better the air was than he expected. *"I'm just surprised of generally, how clean the air is in the freeway areas... :)"* Conversely, 32CrBsF, left the study realizing that she was being exposed to much higher levels of pollution than she had expected:*"I really had no idea how frequently I am exposed to pollutants."* This discrepancy stems from the fact that even though our participants were in the same space geographically, the exposure of ones riding in modern cars were often mitigated by air filters and vehicle bodies. Being aware of only their own readings, participants generally couldn't observe this discrepancy, and expected that the readings they were observing generalized to the general population. 44BkF was one of the few who observed how her choice of transport influenced her exposure, and only because she commuted in two substantially different ways:

> *"[What] stood out the most to me is how I drove to work, and then I rode my bike back the same way. And on the way there the air was perfect, green, the whole way, and on the way back it was terrible the whole way. So, like the car protected me from the bad air and that was shocking to me, [...] Like here I am riding my bike and I'm, it's probably worse for me." – 44BkF*

This finding is important as we consider additional opportunities for citizen sensing. All community members do not have the same experience and exposure, even when traveling to, and living in, the same places. Without ways to allow users to compare and learn from each other's readings it is very possible for individual users to adopt a skewed view of reality. In this deployment of CitiSense, we did not provide a way for users to share their readings with each other, which resulted in our participants leaving the study with quite different views on the state of the air in their shared community. In future systems, finding ways to help participants see how their personal data fits within a greater corpus of collected data may help clear up some of these discrepancies.

4.7.2 Bridging Data and Real Life

Three features of the CitiSense system played a key role in our participants being able to reason about and link the data they were collecting with their real-world experiences.

The first, real-time readings, provided insight about the sources of pollution. When participants saw a bad reading, their first instinct was to look around and try to identify the source. Conversely, when participants observed something in their environment that they expected would have an impact on their air quality, they could check immediately to see if they were correct in their assumption. This ability to quickly verify assumptions allowed users to easily test their beliefs and revise their understanding.

The second feature, personal pollution maps, supported users' ability to connect data collection with their real world experiences by providing a visual link between the data points and familiar locations. When participants reviewed their maps they had an easy time locating places where they had been stuck in traffic, or walking past construction sites. By seeing all the data in one place, rather than seeing just one or two readings, they had an easier time reasoning about larger-scale sources of pollution.

The third and possibly most important feature of CitiSense was the conversion of raw sensor readings into a cohesive color-coded and numbered reading. Although there were three pollutant sensors on the board, only the miAQI value was reported on the main screen, a value generated from an equation that takes the raw sensor readings into consideration. This simplification allowed participants to quickly distinguish *"good"* and *"bad"* air without having to memorize numbers or ranges. When participants discussed their readings in interviews and surveys, not a single user referred to the raw sensor readings we provided on the details screen. Instead, they would refer to the color or miAQI value, like 20CrM, who stated *"For the most part I looked at it and it was in the green, so it wasn't too bad."* We expect that by decreasing the burden of data interpretation, participants were freer to think about *"why am I getting this reading?"* rather than focusing on *"what does this reading mean?"*

4.7.3 Mobile can go where public services stop

Another benefit of the CitiSense system was that participants were able to gain a full picture of their individual pollution exposure, both indoors and out. Because of the high variability of pollution over even short distances, the cost and complexity of pervasively instrumenting the environment is not, at least today, a practical alternative. Even if appropriate densities could be achieved, stitching together a holistic picture across the different administrative domains (government, work, personal spaces, every storefront business, homes of friends, etc.) would be complex and expensive. Mobile sensors that move with individuals are the easiest way to begin collecting this kind of *"whole picture"* data to learn what pollution levels are actually being experienced by individuals on a daily basis.

As we begin to use this type of mobile sensor data, there are new concerns regarding privacy and validity that must be addressed. As with all services that collect personally identifiable data, it is critical to obfuscate data collectors to reduce the possibility of harm coming through the use of the service. Perhaps even more importantly, it will be important as we consider systems that share this data between individuals, to remove data points that have been collected in private residences and businesses. When interpolating a model of the outdoor air, sporadic data points collected from indoor sources will falsely influence the model.

One possible solution to maintain data quality for both individual and community users might be using the phone's GPS capability to segregate indoor and outdoor data. The structure of most buildings blocks GPS signals, which can be a good indicator for when an individual is indoors. GPS could be used to label data as being collected in a car (whose filtration system and body reduce readings), by using the GPS readings to infer speed. Then, data points collected while driving could be treated differently in inferring pollution outdoor levels versus individual exposure.

4.7.4 Technologies that engage the physical world

Mobile communications and computing technologies are typically seen as distracting people from their immediate surroundings, altering interpersonal interactions and creating dangerous situations. In contrast, the hyper-local nature of CitiSense's design encouraged engagement with physically proximate people:

> *"It was nice, technology as a conversation starter [...] previously I would sit on the bus and I wouldn't talk to anybody, I would be on my cell phone. And so that was a use of technology that basically cuts me off from my environment and my community, whereas actually this, because I was becoming aware of my environment, and I was aware that people were sharing the environment, it then helped me to talk to people." –34CrBsF*

There are likely more opportunities in this space for creating technologies that connect individuals with the people around them. We hypothesize that exposing *"common ground"* to proximate individuals, as CitiSense does with air pollution, is key to achieving this goal.

4.7.5 Future Directions

This study focused on healthy adults from middle-class backgrounds. By choosing this set of participants we were able to learn about how a real-time mobile air quality system might be used in everyday life. In future studies we plan to explore more diverse populations to gain a broader view of how these systems may be used in situations where poor air quality is more typical at home and work. With road workers on a highway, for example, it may be very difficult to institute changes to avoid unhealthy air. It is important that we look towards empowering communities rather than creating a sense of helplessness.

In another dimension, we plan to run studies with families of asthmatic children. We believe that a technology like CitiSense can be useful for parents who want to pinpoint areas of high exposure so that they can help their children avoid unnecessary hospitalizations.

4.8 Design Lessons and Overview

In this paper we introduced the CitiSense mobile air-quality system and presented results of a 4-week *"in the wild"* study with 16 participants, and a sister study with 14 collocated participants. We provided in depth discussion regarding the usage and adoption of the system using quantitative and qualitative methods. The observations and lessons we learned from this study of the CitiSense system can be of benefit to researchers and practitioners building similar systems, helping to avoid pitfalls and to think about what design decisions may best serve their target populations.

4.9 Acknowledgments

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Chapter 5

Future Directions

Figure 5.1. Can sharing automatically collected data with our communities help support connection and encourage positive change?

Building on the ideas from these previous projects, my future research goals expand the space of meaningful data sharing to include very large networks. I propose the idea of Interpersonal Informatics [13], an area that builds on Ian Li's Personal Informatics[71] to include larger social groups to gain insight. Humans are social creatures, and the decisions they make are often consciously and subconsciously influenced by the "tribe" to which they belong. Recent research in social networks has found that everything from the likelihood that a person will smoke cigarettes, to the likelihood that a person will be happy is significantly influenced by their social network. Even more surprisingly, due to hyperdyadic spread, the phenomenon of social influences spreading beyond our immediate social network, it is possible that many of the influences exerted on an individual come from people they don't even know. Ultimately, as stated by Christakis and Fowler, "to truly know ourselves, we must first understand how and why we are connected"[34].

Although we are beginning to understand the strength and influence of these connections on people's lives, it turns out these influences are rather opaque to any particular person in the network. In short, although we now know that our social network affects us, it is very hard for any individual to look at their own network and discern what influences they are being subjected to, both positive and negative. Interpersonal informatics strives to do this by allowing people to share and analyze data within their social networks. The ubiquity of technologies such as mobile smart phones, commodity sensing products and online social networks such as Facebook will serve as the foundation on which interpersonal informatics tools are based. There are many open challenges in this area, such as data quality, scale, privacy, and concisely presenting the mass of information being shared. Applications of IPI in areas such as health, happiness, safety, social support, and cultural identity are expected contributions of this work

Recent research in social network science has found that that what we do and say flows through our social network, impacting our friends, our friends' friends, and beyond. Likewise, our own personal choices are also the influenced by the social networks we participate in. We introduce the area of interpersonal informatics, a class of tools that allows groups of people to collect, aggregate, analyze, and share personally relevant information. The goal of interpersonal informatics is to help people gain awareness of how those around them affect their habits, beliefs, and health.

5.1 Motivation

Although we now recognize that the choices of others in our communities subconsciously influence our own behaviors, it is still very hard for an individual to detect those influences, as they are the result of thousands of small impressions left by our friends, family, colleagues, and neighbors. This kind of paradoxical invisibility is a motivation for personal informatics as well. People know that what they eat affects their weight. However, it's not until people are provided a way to track and analyze their eating habits and weight that people realize the exact impact of eating a slice of chocolate cheesecake. As awareness is often the first step to wellbeing, it follows that an understanding our social networks is an important step to understanding ourselves, and ultimately in making changes. With such knowledge, we can proactively respond to influences that were previously invisible to us.

Taking a page from the Personal Informatics community [73][72][75], Interpersonal Informatics (IPI) propose the study of how to make personal data collection valuable beyond the individual. Whereas personal informatics aims to help individuals learn about themselves by collecting and analyzing data about their daily activity, IPI aims to extend this vision to include helping people make sense of the social networks they are in and enabling people to make informed choices about how those networks influence them. Interpersonal informatics strives to do this by allowing people to share data and analyze data within their social networks. If we think of personal informatics as a timeline of a single individual, interpersonal informatics is the combined timelines of many individuals. In some sense, IPI combines personal informatics with traditional social-mobile ubiquitous computing so that you can understand yourself better by understanding your social network. The ubiquity of technologies such as mobile smart phones, commodity sensing products and online social networks such as Facebook will serve as the foundation on which interpersonal informatics tools are based.

This chapter introduces interpersonal informatics, and discusses issues such as data quality, privacy, and concisely presenting the mass of information being shared. Applications of IPI in areas such as health, happiness, safety, social support, art and cultural identity are likely outcomes.

5.2 Examples and challenges

5.2.1 IPI Example

Julie has always considered herself a healthy individual, so she is surprised to learn that she has gained several pounds since her last doctor's visit, and now her weight-to-height ratio is considered unhealthy. Julie talks with her sister Amy about her results and Amy introduces her to healthyFriends, a new Facebook application that enables weight tracking and sharing. Julie is apprehensive about sharing her weight with her whole social network. However, when Amy shows her the interface, Julie realizes that individual weights are not shared, just the average Body Mass Index (BMI) of subgroups of her social network. Julie notices right away that the average BMI for people at her office is several points higher than what is considered healthy. Amy suggests that this might be a factor in Julie's most recent weight gain, since when she is at work her coworkers influence her eating habits.

With this new information, Julie is more aware of what kinds of influences she is exposed to at work and is more aware of the choices she makes there. She begins taking the stairs instead of the elevator with her coworkers, and makes more healthful decisions about what she eats. After a couple weeks Julie is so motivated by her initial weight loss that she invests in a wireless scale that automatically syncs with her computer and healthyFriends. After Julie reaches her ideal weight, she continues to use the scale in her weekly routine in hopes that others in her social network will benefit from the data.

This scenario represents one example of how IPI can allow individuals to see invisible influences in their lives. Promoting health is one example use of IPI, and there are many other possible areas of application, such as time management, fuel consumption, debt, happiness (mood), and many others. These applications would allow users to contrast their habits with their friends' (and friends' friends') habits, thereby exposing influences, helping users understand what is going on around them, and supporting change by enabling the conscious counteraction of adverse influences. To better expose "localized" influences, the applications would enable disaggregating and comparing different segments of your network, such as friends, colleagues, and family. They might also provide averaged data from the general population as well as ideals defined by professionals ; doctors, psychologists, financial advisors, etc.

5.2.2 Unique Characteristics and Challenges

The preceding scenario and discussion have significant implications for IPI systems design, presenting several research challenges beyond those presented by personal informatics.

Large aggregate data sources

Although much of the data collected for IPI applications is similar to those for personal informatics, the data now must be aggregated for efficient personalized presentation. As influences have been found to persist to three degrees into the network, the inference of a person's influence map for a given quality can involve millions of people. Managing the data and computing the result of such a quantity for millions of people can be an enormous undertaking.

End-User Openness

Whereas an individual can – with effort – collect and analyze new kinds of data about herself through sheer discipline and an excel spreadsheet, for IPI, networked computing support is essential to collecting data from one's social network. This presents unique challenges for enabling users to pursue their own interests. However, specialized service could be build in to social platforms like Facebook to allow allow end-users to define new data collectors ; basically simple, end-user-defined applications. Such a collector might just be a multiple-choice question that a person and her friends answer every morning. Or, it might search Facebook posts for relevant data , data that might be automatically generated by hardware devices like those being marketed now for personal informatics (weight scales, blood pressure monitors, etc.[7]). Such grassroots data gathering would also require declarative tools for specifying new data comparisons and visualizations, and perhaps even real-time notifications of interesting correlated events in one's social network.

Critical Mass

Few individuals will have their complete social network logging and sharing data. However, to gain statistical confidence from the data collected from one's social network, there will need to be a certain level of adoption in each unique cluster of one's network. In cases of low adoption, it may be possible for users to provide estimates of the missing data based on what they know about their friends. Population-level data harvested from other sources may also be used; though one's friends may be atypical, their age, education level, etc. can be used to identify a representative demographic with known characteristics.

In-the-moment sharing

Personal informatics applications relating to health and safety can support real-time notification, for example an alert to a diabetic of low blood sugar. IPI expands on this requirement to include detecting interesting or important real-time events in your social network, such as the moment when more than half your local network has gone to bed for the night, signaling perhaps that you might benefit from going to bed as well. Due to the scale characteristics of IPI, this presents unique computational challenges. Also, such alerts could become too disruptive if there are many of them and the alerts are overt.

Privacy and Safety

Now that we are involving multiple users it is important that each user be able to easily select both what types of information they would like to share. With IPI extending many personal informatics pursuits, such as health management, people may desire to track more information about themselves than they might be comfortable sharing. For example, a user may want to track both her weight and daily activity, but may only be comfortable sharing their activity. Others may be willing to go farther and share changes in weight. It will be important to design applications that (a) clearly distinguish and label private and shared data, and (b) depend on data that people are generally willing to share (e.g., changes in weight rather than total weight).

Additionally, with large-scale social applications it is important to consider how malicious individuals could misuse such a system. It is possible that with large amounts of personal information being shared, the data could be used by one user to exert control over another, especially in existing unhealthy relationships. Thus, it will be important to keep these possibilities in mind when designing IPI systems to minimize possible negative consequences.

(un)willingness to share

The level to which an online representation of self is an accurate portrayal of reality is debated[11][103]. However, it is likely that people will feel varying levels of comfort when it comes to sharing different kinds of data online. Therefore, there will be some level of self-censorship of data that could be viewed by others as negative. Such self-censorship could have unfortunate consequences for individuals who wish to learn what kinds of negative influence they may be exposed to through their social network. For example, it may be hard for a user to find out how many of her friends drink a lot of alcohol because sharing such information could be seen as negative. Some of these issues may be solved by something as simple anonymous sharing, while others may require more creative solutions.

5.3 Related Work

Beyond the obvious relationship to personal informatics there are a couple of areas with some complementary connections to interpersonal informatics. In contrast to how interpersonal informatics is concerned with understanding how your social network influences you, Community Informatics is "the application of information and communications technology to enable and empower community process"[51]. Participatory Sensing is the idea that private and professional individuals can share and analyze data that they collect about their environment using every-day mobile devices[27]. Although the focus of participatory sensing contrasts with IPI's, the underlying technologies can be quite similar.

Many research groups are exploring how to use online social networks to effect health behavior changes[61]. These projects are in essence trying to enhance the social network effects that IPI is aiming to make visible and understand, often by providing new mechanisms for social support, competition, etc.

The online web community PatientsLikeMe[54] has features of interpersonal informatics. Patients with various diseases track their health and treatments while sharing their progress with the rest of the community. Members of the community can then compare their progress with others who have been diagnosed with the same illness, which can help them decide which treatments they would like to pursue. There are a few ways that PatientsLikeMe differs from the goals of IPI, the most important being that the social network is emergent around a patient's illness, rather than defined by preexisting social bonds.

5.4 Final Thoughts

Interpersonal informatics is the next step in personal informatics: whereas personal informatics can reveal who we are, IPI can reveal why we are who we are. By creating systems that aggregate, distill, and display the data that friends gather about themselves, a person will be able to learn more about the influences they are exposed to, and in turn, make more informed choices about how they choose to live their lives.

5.5 Acknowledgements

This chapter, in part, is a reprint of the material as it appears in Interpersonal informatics: making social influence visible. Bales, E., Griswold, W. In the Proceedings of the ACM Extended Abstracts on Human Factors in Computing (CHI EA' 2011), pp. 2227-2232. The dissertation author was the primary investigator and author of this paper.

Chapter 6

Conclusion

The disillusionment with modern communication technology stems from a variety of sources, but one of the significant contributor is the underrepresentation of implicit communication in distance communication technologies. This gap in the existing technology space is the focus of this dissertation. I focused primarily on mobile and semi-mobile technologies as they remain mostly unexplored in the research literature and also because have the capability to capture the kinds of 'real-time' contextual data that can support implicit communication.

6.1 Primary Contributions

In this dissertation I presented three projects designed to explore the interpersonal opportunities in sensor supported mobile data collection. The Cambridge study explored the existing methods students used both actively and passively to support feelings of connection with distant others. The design, development, and deployment of the CoupleVibe system with real long distance and collocated couples provided insight into how lambently captured and delivered location data could be leveraged to support feelings of connectedness and provide a better foundation for initiating additional interactions. Finally, CitiSense explored how automatically collected sensor data could be leveraged to allow individuals to both learn more about their own exposure and connect with their broader communities. My contributions to the research community through this research are detailed in the following two sections: "The Importance of Ubiquitous Design in Implicit Communication Technology" and "Mobile Implicit Communication is Used and Valued."

6.1.1 The Importance of Ubiquitous Design in Implicit Communication Technology

In the area of ambient awareness in the mobile space is incredibly important because so much of what happens in a user's day occurs in spaces where they have little control to control their surroundings (e.g. you can't install a personal display at the grocery store or gym, and even many workplaces limit what employees can do with their space). For example in CoupleVIBE we found that 47% of the locations shared were outside of work and home.

1. **support whole-of-day capture**: The value of knowing about your partner often increases when they are in transit (e.g. concerns about wellbeing, logistical questions about when to call). Unfortunately this is often the time when people are least connected with each other, with the likely hood of no-phone driving laws only making that more prevalent. By providing mobile capture meaningful events can be shared regardless of wether a user is sitting at her desk, is stuck in traffic on the highway, or is traveling to a new city for work.

2. **support real-time receipt**: Mobile on the receiver side is also critical because it supports real-time awareness regardless of where the user might be. This real time awareness supports a range of functions that are difficult for humans to recreate with logged data, as is discussed in section 6.1.3.

This work extends existing work in ambient awareness by supporting ubiquitous capture, sharing and receipt. By supporting "everywhere sharing" we allow for a greater range of types of data that can be shared. In this dissertation I explored sharing location data, and air-quality data, two data sources that represent particularly meaningful data-sets outside of the traditional home/office setting.

6.1.2 Mobile Implicit Communication is Used and Valued

This dissertation also illustrates how implicit communication was able support new kinds of remote communication that was valued by users. This information was often things they had no way of knowing in the past such as when calling or texting a partner might diminish their partner's safety:

> *"I knew Martha left her house to work out at the gym. This was helpful, I knew I shouldn't text her if she is driving." - CoupleVIBE user*

To providing peace of mind to a partner who was able to observe his partner's successful journey without having to explicitly contact his partner while she engaged in an unfamiliar task.

> "I was worried about her ability to find the <local landmark>, where her car was parked. The vibrations showed that she left <city> safely and arrived <at landmark> 45 minutes later. I knew all this without calling or texting." -CoupleVIBE user

The introduction of this dissertation proposed that because existing technologies do not support implicit communication at a distance, users are forced to escalate naturally implicit interactions to explicit interactions. In CoupleVIBE we saw users replacing some of their existing behaviors with the implicit cues from CoupleVIBE (e.g. CoupleVIBE's implicit messages replaced existing practices of texting one another when partners moved between locations). Implicit messages also supported interactions that were not possible in the past, such as sending messages while engaged in dangerous tasks like driving. For example, one reported use of CoupleVIBE was to learn when a partner was getting close to home. In this case the partner who was already home was able to unlock and open the door for their partner, an act that wouldn't have been possible without implicit sending as interacting with a phone while driving is illegal in many places.

The implicit interactions supported by CoupleVIBE and CitiSense easily fit within the existing practices of the users. These systems worked in harmony with existing communication technologies, supporting a genre of communication that had previously been ignored, or awkwardly adapted to explicit methods. Although CoupleVIBE and CitiSense in no way represent the complete spectrum of what's possibly for implicit communication, the patterns of adoption suggest that future communication technologies supporting implicit sharing would be a welcome addition.

6.1.3 Additional Contributions

While the main contributions of this work are to defining the importance of mobile implicit communication, there are also other contributions which may be valuable to future researchers.

Design guidelines for supporting provenance in digital and cloud artifacts

One finding from the Cambridge study was that technology objects don't support the same kind of provenance as physical one. For example, a printed family photo may get dog-eared, and collect the handwriting of cherished relatives on it's back, while the metadata on a digital photo contains time, date, and size information but encapsulates none of the personal meaning of the image. Supporting this kind of digital provenance by providing digital ways to encapsulate meaning with a digital object is a finding from this work.

Design considerations for automated "non-spamy" messages

The Cambridge study and the CoupleVIBE study both provide insight into how awareness can be supported in ways that avoid feelings of annoyance. By studying how objects (physical, digital and cloud) support connection while remaining ‘calm’ for the user can help inform the design of other more instrumented designs.

CoupleVIBE supported this by choosing to represent ‘nice-to-know’ messages and sending them without intervention. This design choice allowed for an environment where ignoring or not ignoring the message were equally socially valid (dissimilar to how users experienced text messages).

> *“It wasn’t like if I received a text message or an IM, that’s when I feel guilty like oh I gotta write back, but no, this wasn’t like that at all, completely opposite.” -CoupleVIBE user*

> *“You’re never really aware that you’re buzzing the other person [...] cause you’re never aware of it you’re never expecting a call back.” -CoupleVIBE user*

The alerts in CoupleVIBE were also transitory, leaving no long term trace and requiring no maintenance for the receiver.

Methods and Limitations for eyes-free hands-free messages

To make CoupleVIBE implicit yet mobile required an eyes-free hands-free design. Lessons learned included that while having the service embedded in the phone was convenient because users didn’t have to carry and charge another device, it did mean that they the vibrations were sometimes not perceived by the users due to distance from their devices. Modern wearables like bluetooth wristbands might solve this problem because they are discreet and can always be in contact with the body.

Respect as a Design Consideration

In recent years, privacy has become a mainstay in discussions surrounding the sharing of data. However, respect is an often overlooked parallel concern that also deserves thought and engagement in the design process. How people perceive others will encounter their shared data impacts how much they are willing to share.

1. **Privacy**: Controlling who is capable of viewing data. Privacy protects the person who is engaging in sharing.

2. **Respect**: The individual who is sharing is mindful to avoid overloading recipients with too much data and self-limits. Respect protects recipients.

Respect is an especially important consideration in push environments, where data is proactively presented to recipients (eg. as in the Facebook newsfeed). The CoupleVIBE user deployment shed light on this concept through the appropriation of the 'privacy' feature to avoid sending messages at times that would disturb their partner. While the privacy feature was not originally designed to support respect, the adoption of it during the study to support acts of respect suggest that bringing respect in as a design consideration could help inform the design of future technologies.

Design for technologies that engage in context rather than detract from context

A common complaint is that while technologies allow us to connect with people all over the world, they often come at the cost of disengaging us from the people and places we are physically near. There are countless news stories of teenagers texting at the dinner table, and parents engrossed in Facebook at the playground. A major challenge is to create technologies support people in engaging with the context around them.

In the new students study we saw that physical objects support connection passively, allowing individuals to engage or ignore them as necessary. A photo board or a nostalgic mug don't beep of cry for attention, but they are readily available for moments when feeling a connection to home and friends is important. CoupleVIBE also engaged with this idea by allowing people to engage or ignore technology as was appropriate for their situation, such as was expressed in the following quote where CoupleVIBE provided one participant peace-of-mind about her partner while she was spending time with her friend without interrupting her.

> *"I liked getting the vibrations when I was busy with friends, it was easy to feel connected and I didn't have to stop what I was doing to talk to him."-CoupleVIBE user*

CitiSense allowed participants to take this idea of technologies that support contextual engagement by supplying users with locally interesting data. Participants recognized that the air readings they were seeing were also important to the people around them and often served as a conversation starter with both friends and familiar strangers.

> *"It was nice, technology as a conversation starter [...] previously I would sit on the bus and I wouldn't talk to anybody, I would be on my cell phone. And so that was a use of technology that basically cuts me off from my environment and my community, whereas actually this, because I was becoming aware of my environment, and I was aware that people were sharing the environment, it then helped me to talk to people." -Citisense user*

The role of real-time for sense making

In both CitiSense and CoupleVIBE the real time nature of the readings was critical to the interpretation. Participants in CitiSense, despite not having previous training, reported that the real-time nature of the data allowed them to make reasonably good inferences about pollution sources. For example, when participants noticed a particularly high reading on their phone they would look around and try to find the most likely source to attribute the reading to (such as an idling truck or a busy intersection). This ability to attribute was important because it supported a sense of control over their personal air exposure, basically that if they wanted to avoid readings like that in the future they could travel at less busy times, run their car's air conditioner, or walk on a less busy street. Participants reported that these kinds of inferences were harder to do after the fact because even with a detailed map it is hard to remember exactly what vehicles or other pollution sources were present when the reading was taken.

> *"I really liked that the readings were real time [...] so then I could be like at this specific moment the spike happened, because if there was a delay, I wouldn't, you wouldn't, you forget." –CitiSense user*

CoupleVIBE benefitted similarly from real-time aspects because time played a large role in vibration recognition. While several users said they could discern the different vibration patterns after a few days, six users reported that they never mastered the recognition and instead used other cues such as time context to infer meaning.

> *"The vibrations distinguishing one location from another [are] difficult to recognize. It might be possible that I will 'learn' them. But [I] can guess from the timing."*

Additionally, in interviews several participants remarked on how real-time communication supported a better understanding of their partners context because now they knew in real-time when an event occurred instead of just knowing *'she visits the gym around 5:00ish.'* The two couples separated by time-zones also mentioned that these real-time updates helped them understand the time difference in a richer way. This increased contextual awareness helped partners better discern when would be a good time to engage in richer forms of communication such and phone and video calls and text messages.

> *'I needed to ask Adam a question today and knew that he was at lunch because I had received a vibration. I was alerted that he had returned to his office and could then call him to ask him the question without interrupting his lunch."*

Supporting implicit communication in a mobile context has the potential to provide benefit, however there still remain many technological challenges. Additionally, these challenges change as we move along the design dimensions of scale, context, and social structure. For example, CoupleVIBE functioned to link two close individuals, in this case using vibrotactile messages allowed for meaningful sharing that was appropriate for a variety of contexts. However, in scenarios like CitiSense where a large group of loosely linked individuals are using a system collaboratively sharing data via a visualization allowed for large amounts of data to be shared without constantly alerting the user.

6.2 Closing Remarks

While distance communication technologies have advanced exponentially in supporting explicit communication (eg. from phone calls to Facebook), equal gains have not occurred in implicit distance communication. This disconnect means that important aspects of intimacy are not supported at a distance. The work presented in this dissertation demonstrates a first step in understanding how to support mobile implicit distance communication. The adoption of these deign methods and techniques serve as a grounding for how mobile implicit communication can broaden the communication space and support individuals and communities in communicating in ways that fill the gaps left by existing explicit communication tools.

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