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Lightweight social communication using visual media and mobile phones

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Lightweight Social Communication using Visual Media and Mobile Phones

A dissertation submitted in partial satisfaction of the
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in

Computer Science

by

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The dissertation of Lisa G. Cowan is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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ABSTRACT OF THE DISSERTATION

Lightweight Social Communication using Visual Media and Mobile Phones

by

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Doctor of Philosophy in Computer Science

University of California, San Diego, 2011

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When traditional social media are brought off the desktop into the mobile milieu, the resulting interactions may become cumbersome. Yet, the mobile milieu demands even lighter-weight interactions than those on the desktop. We posit that mobile tools can support expressive, lightweight communication by leveraging users' existing tools and practices, streamlining essential interactions, and exploiting the affordances of visual media.

To evaluate our ideas, we explore the design space of tools for supporting lightweight social communication using visual media and mobile phones. We present four projects representing points in this space, covering it in the dimensions of proximity (proximate or remote) and interaction focus (input or output).

In our analysis, we consider why and how people communicate using these tools, the social consequences of using them, and the implications for design.

In the remote-output part of the design space, the Emotipix project aims to reduce demands on attention by embedding an ambient display of friends' photos in the background of the mobile workflow. In the remote-input part of the space, the UbiSketch project aims to enrich communication by supporting ubiquitous sketching, enabling users to easily publish paper-based information to social media channels in real time. In the proximate-output part of the space, the projector phone project explores the use of personal, mobile projection to transcend the limitations of phones' small screens, enabling the use of arbitrary elements of the physical world as (potentially large) display surfaces. In the proximate-input part of the space, the ShadowPuppets project looks at employing hand shadows as input to support collocated interaction with projector phones.

We implemented functional prototype systems and conducted user studies, with quantitative and qualitative measures, which validated our techniques. Our design devices were largely successful in supporting expressive, lightweight mobile communication, and some surprising results point to areas for future work.

Chapter 1

Introduction

1.1 Motivation

1.1.1 The need for social communication anytime and anywhere

People are inherently social, having a fundamental need to communicate to carry out the activities of life. Digital communication tools can support our social interactions, and social media tools, such as Facebook and Twitter, are transforming how we communicate with family, friends, and colleagues. These tools provide options for lightweight communication, enabling users to quickly and efficiently broadcast short messages (i.e., *microblog*), making information available to their friends without obliging them to respond. Messages are displayed in *news feeds* or *streams* that friends can browse when they have time or ignore when they don't, and older messages simply disappear as newer ones replace them. Facebook alone facilitates the sharing of more than 30 billion pieces of information, including text, photos, and videos, each month[1], highlighting our deep need to communicate.

Communication needs can emerge from all of our activities, and therefore mobile tools are required to meet them anytime and anywhere. The need for ubiquitous digital communication is evidenced by mobile social media use. Over 200 million mobile users access Facebook, and they are twice as active as non-

[1] http://www.facebook.com/press/info.php?statistics

mobile users[1].

Mobile social media tools can leverage the fact that people carry their phones with them nearly everywhere [97], yet these tools must be specifically designed for the mobile milieu to preserve the lightweight characteristics of interactions. Interaction with mobile devices is often embedded in other activities, such as walking, shopping, or proximate conversation, so users' attention may be divided and their physical bodies may be performing multiple tasks. Therefore, mobile tools must be even lighter weight than those designed for the desktop.

Interaction with social media on mobile phones may be cumbersome, since mobile applications are often simply stripped down versions of desktop applications. Consider the mobile Facebook application. Browsing the *news feed* requires scrolling and/or zooming to read information that extends beyond the phones' small screen, and posting textual status updates via the small keypad or touchscreen is slow and error-prone [37]. Posting photos and videos can be similarly inconvenient, requiring multiple steps.

Supporting lightweight interaction is key to enabling social communication anytime and anywhere. Timeliness is particularly important in digital social media, and if sending a message is too cumbersome, then a user may defer sending it for a later time or simply never send it. In many cases users do not perform deferred communication activities, even if they originally intend to do so, because they forget or because the information is no longer relevant [114, 130].

Lightweight interactions can also lower social barriers to communication. The effort required to send and receive a message affects people's perceptions of what kind of information is worth sharing [93]. Lightweight tools can enable people to share information that they might otherwise consider unworthy of sharing.

Lightweight tools for social communication can also enable users to receive information without become distracted from their other ongoing activities. Although mobile phones can support communication, they can also draw users' attention into private digital worlds, away from the physical world around them [97]. Lighter weight tools can reduce the risk of drawing users out of the local experience, and can even provide opportunities for augmenting the local experience.

1.1.2 Exploiting the power of human vision and the affordances of visual media

If communication tools are designed properly, they can leverage the power of the human visual system, including the eyes and brain. By exploiting this system's high speed and bandwidth, we can reduce the time and attention required to communicate. Visual media leverages the power of the human visual system and also provides unique affordances for communication.

The human visual system can process information at high speed. Thorpe et al. [124] observed that visual processing to classify previously unseen photographs can be achieved in under 150 ms. The researchers flashed each photo for 20 ms, asked subjects to determine whether the photo contained an animal or not, and detected signs of processing by measuring event-related potentials. In a later study, Thorpe et al. [125] measured the speed of categorization in the human visual system, determining from intracerebral recordings that visual processing was underway in as little as 100 ms. The task presented to subjects in this study was to determine whether an object was a face, an animal, a chair, a fruit, or a vehicle.

Researchers have estimated that the bandwidth of the human visual system is on the order of a fast Ethernet connection. Koch et al. [69] displayed videos of motion in natural scenes to retinal ganglion cells on electrode arrays, and found that mean information rates across cell types were (613 bits/s). They determined that, given the proportions of each cell type and the roughly 1 million ganglion cells in the retina, the human visual system can transmit data at around 10 Mb/s.

Visual media can be viewed quickly, especially when compared with text-only channels. High definition video conveys information at a bandwidth of up to 6 Mb/s, although there is significant visual continuity from frame to frame, and a seemingly instantaneous glance at a still image may be sufficient to grasp the information or determine whether a closer look is warranted. In contrast, the rate at which humans read text is much slower. The average American adult reads for comprehension at 200 to 400 words per minute and skims (at a lower level of comprehension) at 400 to 700 words per minute [19].

Visual media also has unique affordances for communication, enabling rich forms of expression. For example, it is easier to explain some thoughts and ideas visually by sketching them than by attempting to verbally describe them, because sketches can convey visuo-spatial ideas directly [127]. Tufte [126] has articulated the expressive power of visually representing information. Visual information can also have benefits for learning and remembering. Educational psychologist Jerome Bruner reported that people remember about 30 percent of what they read and about 80 percent of what they see [73]. Perceiving visual information can also stimulate visceral and emotional responses.

Daft and Lengel [34] have theorized that visual channels are richer than text-only channels because they convey a greater variety of communicative cues. For example, email messages can easily be misinterpreted due to their brevity and the lack of communicative cues, and this difficulty has given rise to the use of emoticons to clarify the meaning of verbal messages [101]. However, visual information can also be ambiguous, and text can be useful for conveying specific information or clarifying the meaning of visual information. The combination of verbal and visual information can be even more richly expressive than either alone.

1.2 Exploring lightweight, social communication using visual media and mobile phones

1.2.1 Hypothesis

People carry their mobile phones with them nearly everywhere, and we can harness these devices to support social communication in the varied and dynamic contexts into which they are brought. When traditional social media are brought off the desktop into the mobile milieu, the resulting interactions may become cumbersome. Yet, mobile interaction demands even lighter-weight interactions than those on the desktop. We posit that mobile tools can support expressive, lightweight communication through three design devices: leveraging users' existing tools and practices, streamlining essential interactions, and exploiting the rich affordances of visual media.

1.2.2 Design devices

We articulate three design devices that guide our research.

Leveraging existing tools and practices

By employing familiar tools and augmenting existing practices with support for communication, we can harness users' existing skills and knowledge, reducing the need for learning. This device also enables the design of interactions that feel natural and intuitive. By "piggybacking" capture and display on top of users' existing activities, we can support lightweight, or even automated, communication that fits into the flow of users' lives. For example, in the Emotipix study we embed a glanceable display into users' mobile workflow and automatically detect the act of taking a photograph, which triggers publication. By observing users' practices, we can also seek opportunities to expand support for communication in contexts in which existing mechanisms are inadequate. For example, in the UbiSketch study we explore ways to augment users' paper-based practices, such as note-taking or drawing, with support for communication.

Streamlining essential interactions

We provide the minimal set of essential features to streamline the process of capturing, publishing, and responding to media. We aim to do less rather than more, removing inessential features. Some heavier weight interactions are better left on the desktop. For example, in UbiSketch, we don't support features such as tagging, which users can perform via Facebook on the desktop if desired. Also, some "processing" can be delegated to users, simplifying interactions that don't require technological support, such as managing conversational structure (e.g., threading, reference, deixis). For example, in Emotipix, a user can publish a photograph in response to another photograph, but the application does not provide a way to explicitly specify this relationship. Instead, we rely on users' abilities to remember images and identify relationships between them.

We also avoid requiring interaction, except to control system behavior or to explicitly express intent, e.g., to publish information or send feedback. We minimize these essential interactions, requiring at most one “click”, and streamline the publication process by broadcasting information to a pre-defined set of recipients. For example, in the Emotipix study, shared photographs are displayed automatically as a slideshow in the phone’s background, captured photographs are published by default unless the user clicks a “cancel” button, and sending feedback on a photograph requires a single “click”. Also, when the interactive space extends beyond the handset, we avoid requiring visual attention to the handset to avoid dividing users’ attention. For example, the ShadowPuppets project aims to enable users and collaborators to focus on a projected display, avoiding the need to look at the handset to interact.

Exploiting the rich affordances of visual media

Visual media harnesses the power of the human visual system, which can process visual media at much greater speed and bandwidth than text. Also, visual media can convey a richer variety of nonverbal communicative cues, enabling users to express things that cannot be expressed concisely or easily in words. For example, UbiSketch enables users to convey messages captured via handwriting and drawing. We also provide options for verbal communication, since the combination of verbal and visual information has greater expressive power than either has alone. Verbal communication is especially useful for resolving ambiguity in visual media or efficiently communicating specific information. For example, Emotipix users can add titles to photographs, and UbiSketch users can hand write text in their sketches.

1.2.3 Research questions

This dissertation considers the following questions regarding tools for supporting lightweight social communication using visual media and mobile phones.

1. **Why and how do people communicate using these tools?**

   We will document individuals’ motivations, experiences, and interactions, such as how users express themselves, how viewers interpret and respond to information, and how viewers' responses feed back into the communication loop.

2. **What are the social consequences of using these tools?**

   We will consider how using tools for lightweight communication impacts participant groups' social relationships and practices, analyzing benefits, risks, and failure modes.

3. **What are the implications for the design of mobile systems for social communication?**

   We will explore how to design systems to expand and enrich lightweight social communication in the mobile milieu.

1.2.4 Methodology

In order to answer our research questions, we will explore interfaces and applications for lightweight social communication using visual media and mobile phones. We will employ user-centered design, grounding designs in users' needs and practices. To evaluate our ideas we will implement working prototype systems and conduct user studies, with quantitative and qualitative measures, such as grounded theory-based affinity analysis. These studies will contribute an exploration of the design space, providing insights into communication practices and the design of communication tools.

1.3 Design space: Goals and challenges

This dissertation explores the design space of lightweight social communication using visual media and mobile phones. In this section, we introduce and discuss the significance of four design dimensions: proximity (proximate or remote), interaction focus (input or output), media, and structures of participation (symmetry of participants' capabilities and dynamics of group structure). We primarily consider the dimensions of proximity and interaction focus, and we highlight the additional dimensions of media and structures of participation to further characterize the nature of our projects (introduced in Section 1.4).

Before introducing these design dimensions, we summarize some general design challenges in the space. As we have discussed already, mobile phone use is often embedded in other activities, so users' attention may be divided. Consequently, one goal is to design mobile tools that place low demands on users' attention, to avoid drawing them out of the local experience. On the technical side, mobile devices typically have limited resources, such as power, memory, and processing, so efficiency is important. Handsets' small form factors also constrain device-bound input and output techniques, and this challenge has prompted us to explore ways to extend the interactive space beyond the handset.

Next we introduce and discuss the design dimensions of proximity, interaction focus, media, and structures of participation.

1.3.1 Proximity: Proximate and remote communication

Mobile phones can support proximate communication, among collocated people, and remote communication, among geographically distributed people. In proximate communication, our primary goals are to avoid drawing users out of the local experience, perhaps even augmenting the local experience, and to lower social and technical barriers to communication. In remote communication, we similarly want to lower barriers to communication and reduce demands on users' attention, and we also want to support rich forms of expression. We note that since mobile phone use is often embedded in other activities, such as face-to-face social interactions, remote and proximate communications may not be independent.

A design challenge in proximate interactions, involving communication among collocated people, is to support multi-user input and output. There is no explicit support for collaborative input, and a person typically cannot interact with someone else's phone without physically touching it. Some people may not feel comfortable handing their personal device over to another person, particularly without a sufficient degree of familiarity. Also, the small screen size limits shared viewing, requiring one to hold up the phone or pass it around for others to see.

Our projects that focus on proximate interactions support synchronous, fleeting communication, aiming to augment local social interactions as they occur.

In remote interactions, communication is constrained by network bandwidth, latency, and connectivity, which may be intermittent. A consequent challenge is to make these things transparent to users or to expose the "seams" to users in meaningful ways [8]. Also, some kinds of communicative cues that are available in proximate communication are not available in remote communication [59]. Thus, another design challenge is to enable rich forms of expression across distance. Our projects that focus on remote interactions support asynchronous, persistent communication, to enable users to attend to communications at opportune moments and avoid disrupting their local activities.

1.3.2 Interaction focus: Input and output

We consider design goals and challenges on both the input and output "sides" of interaction. In this dissertation, *input* refers to signals sent from a human user to a computer system, and *output* refers to signals sent from a computer system to a human user. On the input side, we want to support ways of interacting that are easy and natural, enabling users to express themselves. On the output side, we want to support interactions that place low demands on users' attention and employ representations that express senders' messages in ways that receivers can readily interpret.

A number of design challenges concern input to mobile devices. For example, text entry via a mobile phone's hard or soft keypad is slow and error-prone [37]. Also, touchscreens have low input resolution and suffer from occlusion (the "fat finger" problem [109, 139, 5]). These limitations present practical challenges to the efficiency and granularity of self-expression.

On the output side, mobile phones' small screens make it cumbersome to view large amounts of information, requiring panning, scrolling, and/or zooming. Also, as we stated earlier, the small display size makes it difficult to share displayed information with others. A goal here is to maximize use of the display space and to support shared viewing in collocated usage scenarios. Also, since a mobile phone's display is not always on, it is challenging to present information in an ambient or "calm" way [135].

1.3.3 Media

By *media*, we refer to communication channels or tools that capture and transmit information. In this dissertation, we explore the use of four different types of media: photography, sketching, projection, and shadows (employing a projector/camera system). Each medium has distinct affordances for communication. For example, photography captures reflected light, enabling physical scenes to be quickly recorded, while sketching involves making marks on a surface, enabling a person to quickly externalize thoughts and ideas. A mobile projector phone can throw an image over a distance and display it at much large size than the phone's screen, supporting shared viewing and novel representational techniques, and shadow-based input to a mobile projector-camera system enables 3-dimensional, gestural interaction, supporting collocated collaboration. Users may prefer to employ different media in different contexts, and exploring variations can reveal particularities and generalities.

1.3.4 Structures of participation: Capabilities and groups

We discuss two aspects of participation structure: symmetry of participants' capabilities and dynamics of group structure. Participants' capabilities may be symmetric, meaning that each participant has the same capabilities for communicating with other participants. With this type of structure, there is a balance in the ability to communicate (how and with whom). For example, each user can respond in kind to every other users' messages, e.g., responding to photographs with photographs. One possible consequence of this structure is that senders may expect reciprocal responses from recipients. On the other hand, participants' capabilities may be asymmetric, meaning that participants do not have equivalent capabilities. For example, one user may be able to publish sketches while another can only view and comment on them. If some participants cannot communicate in ways that others can, then they may feel left out or un-empowered. Also, participants' expectations of each other may vary according to their respective capabilities.

The dynamics of group structure, ranging from static to dynamic, are also significant. If the group structure is static, then a sender can only communicate with a predefined set of receivers. On the other hand, if the group structure is highly dynamic, then the set of participants can be easily adjusted, e.g. based on message contents or physical location. Flexibility in group structure can support spontaneity and personalization, but can also increase security and privacy risks. For example, a sender may display information to unintended recipients.

1.4 Projects

In this dissertation, we explore the design space of lightweight social communication using mobile phones and visual media. We present four projects that represent distinct points in this space (Figure 1.1). These projects completely cover the space in the dimensions of proximity and interaction focus, with one project in each quadrant (Emotipix: remote output, UbiSketch: remote input, projector phones: proximate output, and ShadowPuppets: proximate input). Each project employs a distinct medium and a distinct participation structure.

1.4.1 Emotipix

In the Emotipix study, described in Chapter 2, we aim to reduce demands on users' attention by embedding an ambient display of photos and associated feedback in the background of the mobile workflow.

While mobile phones have become ubiquitous instruments of communication and social interaction, they still require explicit interaction, placing high demands on attention. Engaging the periphery of users' attention offers opportunities for social awareness and interaction while reducing demands on attention. We explore the design of tools for supporting mobile peripheral awareness with Emotipix, an application that turns the background (i.e., *wallpaper*) of a phone's display into a place for visual conversations.

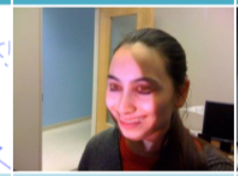
	Emotipix	UbiSketch	Projector Phones	Shadow Puppets
Example				
Proximity	Remote	Remote	Proximate	Proximate
Interaction Focus	Output	Input	Output	Input
Media	Photography	Sketching	Projection	Hand shadows
Capability Structure	Symmetric	Asymmetric	Asymmetric	Asymmetric
Group Structure	Static	Semi-Dynamic	Dynamic	Dynamic

Figure 1.1: We present four projects that represent points in the design space, highlighting the dimensions of proximity, interaction focus, media, and structures of participation (symmetry of capabilities and dynamics of group structure).

We conducted an exploratory 2-week user study with 6 pairs and one 4-person group, and found that Emotipix facilitated ongoing social practices. Our study shows that there is an unexploited opportunity to use mobile phones for peripheral awareness. We provide design recommendations for managing users' expectations, desires for control, and privacy in ambient mobile displays.

The Emotipix study represents a point in the remote-output part of the design space of lightweight social communication. Emotipix users can publish photographs to their friends' mobile phones. This project focuses primarily on the output side of interaction, aiming to reduce demands on viewers' attention by automatically displaying published photos in the phones' wallpaper. Users can be attuned to this information in the periphery of attention while attending to other, primary tasks in the mobile phone workflow. This project also considers the input side of interaction, automatically detecting photo capture, automating photo publication, and providing a lightweight 1-*click* feedback mechanism called *karma*.

Emotipix users have symmetric capabilities (Figure 1.2), sharing information with a small group of close friends or family, and group membership was fixed for the duration of the study . When a user publishes a photo, it is shared with each member of his / her *buddy* group. Any of the group members can send *karma* feedback on a photo, and this feedback is visible to all group members. The Emotipix application does not include explicit support for communication beyond the predefined group of friends, although participants can take photos with or show photos to other people face-to-face. Emotipix's participation structure, consisting of closed groups of participants with strong tie relationships, ensures a foundation of shared context for interpreting published photos.

	Users	Friends	Others
Users	✓ Photos ✓ Karmas	✗	✗
Friends	✗	✗	✗
Others	✗	✗	✗

Figure 1.2: Emotipix participant capabilities (row indicates sender, column indicates receiver)

1.4.2 UbiSketch

In the UbiSketch study, described in Chapter 3, we aim to enrich lightweight social communication by adding support for sketching, via familiar interactions with pens and paper.

Digital social media have transformed how we communicate and manage our relationships. Sketching as a social medium has been largely left behind, despite its portability, and given its unique affordances for visual communication this absence is a real loss. Sketches convey visuo-spatial ideas directly, require minimal detail to render concepts, and show the peculiarities of handwriting. Sketching holds the promise to enrich how we communicate, and its ubiquity is critical for sharing information at opportune moments.

We present the results of an exploratory field study of ubiquitous sketching for social media, documenting users' experiences with UbiSketch. This system integrates digital pens, paper, and mobile phones to support the transmission of paper sketches to online services. We learned that UbiSketch enabled participants to leverage sketching's unique affordances, that ubiquitous sketching creates a synergy with the practice of posting context-dependent information, and that it broadens and deepens social interaction.

The UbiSketch project represents a point in the remote-input part of the design space of lightweight social communication. In this project, we focus on the input side of interaction, expanding the phone UI to include paper and pens and enabling users to publish paper-based information to Facebook (and other social media channels) in real time. Users simply draw or write with a digital pen on specially-printed paper, tapping *paper buttons* to publish the information. Sketches are published as images on Facebook, and viewers can add text comments in response.

UbiSketch users shared sketches with their Facebook friends, including both weak and strong ties, and the group structure is semi-dynamic. Participants in our study could edit their friends list at any time, and this group structure is relatively flexible, compared with that of Emotipix. Yet each Facebook friendship must be pre-arranged by the consent of both parties, and removing a friend on Facebook is typically not done lightly, so this group structure is relatively static, compared with that of our projector phone study.

In this project, the structure of participants' capabilities is asymmetric (Figure 1.3). The participants in our study were able to publish sketches to Facebook via UbiSketch, and these sketches were visible to their friends and possibly friends-of-friends, depending on their Facebook privacy settings. Participants' friends could add comments to the published sketches, but could not publish sketches of their own via UbiSketch (although they could post sketches created and captured by other means).

	Users	Friends	Others
Users	✓ Sketches ✓ Comments	✓ Sketches ✓ Comments	? Sketches ? Comments
Friends	✓ Comments	✓ Comments	? Comments
Others	? Comments	? Comments	? Comments

Figure 1.3: UbiSketch participant capabilities (row indicates sender, column indicates receiver)

1.4.3 Projector phone use

In the study of projector phone use, described in Chapter 4, we address the difficulty of viewing and sharing information via mobile phones' small displays by exploring the use of personal, mobile projection.

Phones with integrated pico projectors are starting to be marketed as devices for business presentations and media viewing, and researchers are beginning to design projection-specific applications and interaction techniques to explore a broader array of possible uses. These devices enable users to project a display that is much larger than the phone's screen, to throw an image over a distance, and to quickly and easily adjust the handheld projector's orientation.

To begin to document how people use projector phones outside the laboratory, we present the results of a 4-week exploratory field study of naturalistic use of commodity projector phones. In our analysis, we consider how context, such as group size, relationships, and locale, influences projector phone use. A key observation is that users can readily exploit the new facilities of these devices to author interesting effects by employing representational techniques such as superimposition, juxtaposition, scaling, and animation. Thus, even the “basic” projector phone platform affords novel interaction modalities. Finally, we discuss the social implications of projector phone use for privacy and control, extrapolating from our observations to envision a future in which these devices are ubiquitous. With ubiquity, projector phone use may become problematic in public settings, motivating new rules of etiquette and perhaps laws. Yet it may also engender new forms of creative expression.

The projector phone project represents a point in the proximate-output part of the design space of lightweight social communication. In this project, we focus primarily on the output side of interaction, extending the mobile phone UI to include arbitrary elements of the physical world as display surfaces. We consider how personal mobile projection affords novel representational techniques and impacts face-to-face communication. We also consider the input side, documenting how the ease of orienting these handheld devices enables novel forms of authorship. The media that can be projected includes anything that can be displayed on a mobile phone's screen, since the projected display mirrors the screen.

Participants in this study had asymmetric capabilities (Figure 1.4). The study participants could project information, while others could only view it. Bystanders could not directly control the projection (except by borrowing the projector), and could only do so indirectly (e.g., verbally, or by occluding the projector).

The group structure is quite dynamic, since projector phone users can display information to anyone in their vicinity. This arrangement supports spontaneous participation and flexibility in group composition. Participants in a projector-based interaction need not even know each other in advance. However, it can also result in unintended viewing of information by an incidental audience.

	Users	Friends	Others
Users	✓ Projection	✓ Projection	✓ Projection
Friends	✗	✗	✗
Others	✗	✗	✗

Figure 1.4: Projector phone participant capabilities (row indicates sender, column indicates receiver)

1.4.4 ShadowPuppets

In the ShadowPuppets study, described in Chapter 5, we address the lack of support for collaborative interaction with projector phones by enabling collocated users to cast hand shadows as input.

Pico projectors attached to mobile phones allow users to view phone content using a large display. However, to provide input to projector phones, users have to look at the device, diverting their attention from the projected image. Additionally, other collocated users have no way of interacting with the device.

We present ShadowPuppets, a system that supports collocated interaction with mobile projector phones. ShadowPuppets allows users to cast hand shadows as input to mobile projector phones. Most people understand how to cast hand shadows, which provide an easy input modality. Additionally, they implicitly support collocated usage, as nearby users can cast shadows as input and one user can see and understand another user's hand shadows.

We describe the results of three user studies. The first study examines what hand shadows users expect will cause various effects. The second study looks at how users perceive hand shadows, examining what effects they think various hand shadows will cause. Finally, we present qualitative results from a study with our functional prototype and discuss design implications for systems using shadows as input. Our findings suggest that shadow input can provide a natural and intuitive way of interacting with projected interfaces and can support collocated collaboration.

The ShadowPuppets project represents a point in the proximate-input part of the design space of lightweight mobile communication, extending the input space beyond the handset by incorporating computer-vision based gesture recognition. This project focuses primarily on the input side of interaction, considering how a shadow-based input technique can support collocated collaboration. We also consider the output side of interaction, looking at how users perceive shadow gestures.

	Users	Friends	Others
Users	✓ Projection ✓ Shadows	✓ Projection ✓ Shadows	✓ Projection ✓ Shadows
Friends	✓ Shadows	✓ Shadows	✓ Shadows
Others	✓ Shadows	✓ Shadows	✓ Shadows

Figure 1.5: ShadowPuppets participant capabilities (row indicates sender, column indicates receiver)

ShadowPuppets interaction supports dynamic group structure, and participants have asymmetric capabilities (Figure 1.5). A projector phone owner, holding the projector, has the most control over the interaction. He / she controls the orientation of the projector and can interact with the system by casting hand shadows. Any bystanders who are sufficiently near the projector's beam can also provide input to the system by casting hand shadows. Other people in the vicinity may be able to view the display but unable to cast shadows, for example, because they are too far away from the projector's beam. ShadowPuppets' dynamic group structure supports spontaneity in participation, which risks not only unintended viewing but also unintended input.

1.5 Roadmap

The remainder of this dissertation is laid out as follows. We present the Emotipix study in Chapter 2, the UbiSketch study in Chapter 3, the projector phone study in Chapter 4, and the ShadowPuppets study in Chapter 5. Previous research related to each of these projects is discussed in the corresponding chapters. We present the conclusions of this dissertation in Chapter 6.

Chapter 2

Engaging the Periphery of Attention for Visual Communication on Mobile Phones

2.1 Introduction

Mobile phones have become ubiquitous; sophisticated camera phones that support taking and sharing photos are common in most of the developed world. The communication mechanisms (e.g., voice, SMS, MMS) now typical on these phones require explicit interaction, yet mobile phones also present opportunities for implicit interaction. People carry their phones with them nearly everywhere and interact with them regularly, and these devices could subtly provide additional information in the periphery during these interactions, without causing undue distraction.

In this chapter, we explore how to engage the periphery of users' attention for visual communication on mobile phones. Although peripheral displays have been studied extensively [36, 52, 88], few studies have looked closely at mobile peripheral displays [25, 43] and social practices with mobile peripheral displays have yet to be investigated.

We investigate these practices with Emotipix, an application that turns the background (i.e., wallpaper) of the phone's home screen into a place for conversations. Most phones support a wallpaper image, which users can explicitly set, and which typically serves a decorative purpose. Here, we explore appropriating this underutilized "screen real estate" to facilitate social awareness and visual communication in the periphery.

Engaging both the periphery and the center of attention is an essential component of Weiser's [135] seminal vision of ubiquitous computing. He defines the *periphery* as what we are attuned to without explicitly attending to and uses it to motivate "calm technology," systems that engage both the center and the periphery of one's attention and allow ready movement between them. Such systems allow flexibly attending to information without becoming overloaded. Further, Weiser argues that calm technology can create a sense of connectedness with the world and provide new opportunities for social interaction. Although it has been argued that calm computing should not be pursued to the exclusion of more engaging experiences [102], we contend that mobile peripheral displays have the potential to provide users with useful non-intrusive awareness as a natural component of phone use.

Emotipix aims to engage the periphery to support social awareness and conversation on mobile phones without causing information overload or disruption. It is designed to achieve these goals by placing the display in the background of the workflow, providing options for interaction without demanding their use, and requiring minimal explicit actions from the user. Emotipix displays an automated slide show of shared photos in the background, or *wallpaper*, of the phone's home screen. When users take pictures with their camera phones, the photos are automatically shared with the users' Emotipix *buddies*, small groups of friends or family. The photos then appear as wallpaper on their phones. A user can tap an icon on their phone's home screen to send *karma*, positive feedback about a photo. Emotipix simplifies photo viewing to glancing at your phone, photo sharing to simply taking a photo, and feedback to a single tap gesture.

In the remainder of this chapter, we document how users interact with Emotipix and with each other, as a consequence of using Emotipix. We examined the use of Emotipix for two weeks and present the results of this in-situ user study. We discuss how participants incorporated this new communication mechanism into their social practices and summarize design recommendations for effectively engaging the periphery for social awareness, connectedness, and communication on mobile phones.

2.2 Background and related work

2.2.1 Peripheral displays

Computer-based *peripheral displays* have been investigated for their ability to convey numerous types of information [20, 62, 81, 87]. Many of these systems present social information on large public displays and desktop displays [36, 52]. Other systems have used home displays to enable awareness of family members. The Whereabouts Clock [15] displays family members' locations, and Astra [84] displays photos, text, and drawings sent from mobile devices. In the Digital Family Portrait [88], awareness of family members' activities provides a sense of well-being.

Emotipix is particularly inspired by the KAN-G framework [75], which explores the notion of *affective awareness*, defined as a sense of being in touch with friends or family. KAN-G provides channel-based publish/subscribe photo sharing with networked digital cameras. Displays are placed in the kitchen and other dwelling spots, and buttons on the display (e.g., "Applause!") enable spontaneous feedback. This system highlights the importance of peripheral awareness and feedback in social interaction.

Dey and Guzman's presence displays [35] and the work by Kuwabara et al. on connectedness-oriented communication [70] have shown that peripheral displays can foster social awareness and connectedness. Kaye's work on low-bandwidth communication [66] has found that even a single click is meaningful when interpreted in the context of an intimate relationship. Emotipix similarly aims to foster social awareness and connectedness through visual, photobased communication and

1-click feedback.

Some recent research has explored using mobile peripheral displays. Ubifit Garden [25] employs a glanceable display in the background wallpaper of a mobile phone to encourage physical activity, and Ubigreen [43] similarly provides a glanceable mobile display to support green transportation habits. Emotipix explores using mobile peripheral displays for social awareness and communication, rather than personal information awareness. Since mobile phones already play a significant role in our social and communicative practices they provide an ideal platform for studying visual communication in the periphery.

2.2.2 Photo sharing

Much research has focused on digital photo sharing. Frohlich et al.'s [44] and Kirk et al.'s [68] studies of photo practices have revealed a need for technological support for social uses of digital photos and for easier remote sharing and feedback. Kindberg et al.'s study of camera phone use [67] has also confirmed the need for easier sharing in the moment. Okabe's study [93, 92] of camera phone usage in Japan notes that people share many personal and mundane photos, and that camera phones have changed what people consider photo-worthy. Voida [131] has explored the ways that people appropriate photos for communication in an online chat system and Sit et al. [111] have explored photos as conversational anchors.

Picture messaging (MMS) provides a channel for mobile visual communication, yet the content must be consciously formed and addressed to specific recipients, and the required effort may deter use [67]. Recipients likewise must explicitly open the messages one-by-one and consciously form replies when desired. Radar [28], SLAM [45], and Flickr[1] employ a group-based publish/subscribe model for photo messaging, thus removing the overhead of addressing specific recipients. Flipper [29], Zurfer [89], and MM2 [130] reduce barriers to mobile photo sharing by automating photo uploads and/or downloads, as in Emotipix. These tools, as regular phone applications, still require explicit, conscious interaction to use, e.g., one must open the application window or select pictures to view. Emotipix in

[1] www.flickr.com

contrast, employs peripheral displays of shared photos and a lightweight feedback mechanism.

2.2.3 Mobile social awareness

Many researchers are exploring mobile social interaction. Taylor's study of SMS gift-giving practices among teenagers illustrates how social practices and new technologies evolve [123]. The study of Houston [24] has gathered requirements for designing systems that provide awareness and social support to motivate physical activity. Also, commercial mobile applications such as Facebook[2] and Twitter[3] now play major roles in providing ongoing social awareness.

Other work has explored how location-based technologies can enable new communication mechanisms and greater social awareness. For example, the study of Reno [112] has examined social practices of location disclosure, and the study of Connecto [3] has investigated how location and status sharing can help sustain group bonds.

2.3 Emotipix

2.3.1 Engaging the periphery on mobile phones

Mobile phones present opportunities for engaging the periphery for visual communication. People take their phones with them everywhere and look at them regularly. These ubiquitous, personal devices have the capability to capture and display images and to exchange them over communication networks.

There are, however, a number of peripheral engagement challenges specific to mobile phones. First, the phone's display may be out of sight or blanked to save power. To make information available in the periphery despite the display's intermittent visibility, this information should be visible when the user turns on the display. Second, the phone's display is small, which demands careful use of the limited peripheral display space. Third, the context in which people use their

[2]www.facebook.com
[3]www.twitter.com

phones is dynamic; people may be engaged in activities that place variable demands on their time and attention. To accommodate this variability, the interface should make information and interaction opportunities available without requiring that users attend to them. Also, the interface should facilitate access anytime and anywhere, despite lapses in network connectivity.

2.3.2 The Emotipix approach

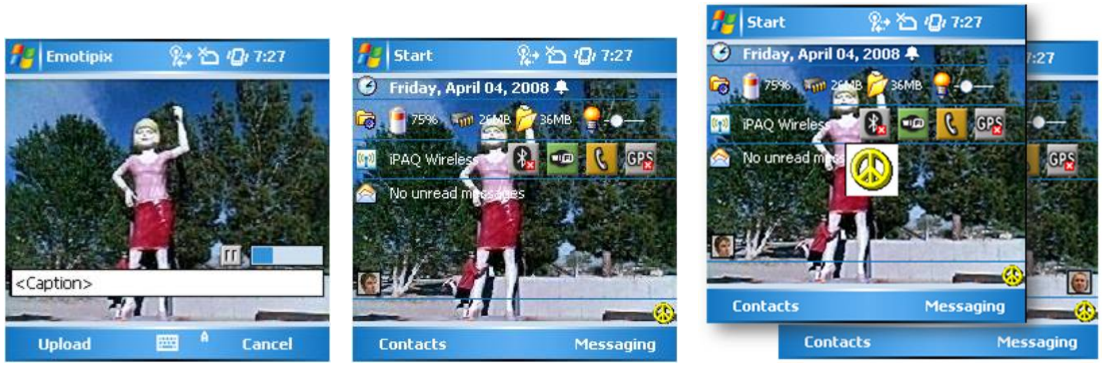
Emotipix offers users options for passive, lightweight, or more extended interaction, enabling users to engage with the system as deeply as they choose at any given moment.

Emotipix's peripheral display is placed in the background of the workflow, providing users with the option for passive interaction.

People carry mobile phones around and use them frequently throughout the day. The wallpaper image is visible on the phone's home screen at the initiation of use and again when the user ends an activity on the phone. Because the wallpaper is visible in the display's background as users initiate and transition between tasks, it is an opportune place to present peripheral information.

Emotipix users have the option for lightweight interaction.

Of course, a peripheral display must function well when used passively, yet it is important to provide a channel for lightweight feedback within the system. User feedback can complete the communication loop between photographers and viewers and can also be used to train the system to optimize content delivery to users' preferences [44]. To encourage feedback, yet preserve the user's ability to quickly shift attention between the peripheral display and the primary activity, we advocate a single-gesture feedback mechanism.



(a) (b) (c)

Figure 2.1: (a) Photos are uploaded automatically, unless cancelled. (b) Photos appear in the home screen's background. The publisher's sticker is at lower left; the Emotipix peace sign icon is at lower right. (c) Top: Tapping the Emotipix icon sends karma to a photo. A peace sign appears briefly to confirm. Bottom: After, the sender's sticker is at lower right.

Emotipix users have the option for extended interaction.

To adapt to the dynamic mobile usage context, we should provide opportunities for users to interact more extensively with the system when desired, for example, when they have time and attention available. In addition, the user has the obvious possibilities for communication directly on the phone.

2.3.3 User interface design

When a user captures a new photo, Emotipix displays a photo upload form (Fig. 2.1.a). The form does not require any response; if the user does not interact with the form, the photo will be automatically published after a timeout period has elapsed. The user can optionally stop the timer, add a caption, or cancel a photo upload.

The primary interface for viewing photos is the phone's home screen, called the "Today Screen" on Windows Mobile (Fig. 2.1.b). Emotipix photos appear in the background of the home screen as the wallpaper, and are updated once per minute to create an automated slideshow of shared photos. A default interval of one minute was chosen to provide regular updates without adversely affecting the phone's performance; users can also configure this parameter. Because the user interface is small, we display one full-screen photo at a time. The automated slideshow enables users to passively view photos, at the risk of missing photos; to mitigate this risk, photos are displayed repeatedly and can be browsed on the phone or the web.

A *sticker* (i.e., a tiny photo icon) superimposed on the lower left corner of each photo identifies the photo's publisher. Stickers superimposed along the lower right edge of a photo identify subscribers who have sent *karma*, (i.e., positive feedback), to the photo. Additionally, a caption, if provided, is superimposed. Thus, with a glance at the phone's home screen a viewer can see the photo, the publisher, the subscribers who have sent karma, and the caption. We superimpose this information to efficiently use the small display and to enable users to attune to it in the periphery. Stickers and captions are permanently affixed to photos. When a publisher sends karma to his/her own photo or when a user sends karma to a photo after having previously sent it karma, no stickers are affixed.

Users can interact with Emotipix via a small peace sign icon on the lower edge of the home screen. Tapping the icon associates karma with a photo: (1) permanently affixes the user's sticker in the corner of the photo (Fig. 2.1.c), (2) re-displays the photo (with sticker) to the user's buddies, and (3) increases the probability that the photo will be displayed in the future. Additionally, a tap-and-hold gesture on the Emotipix icon brings up a context menu. With this menu, users can adjust the rate of wallpaper updates, save a local copy of a photo, browse through an archive of cached photos, or initiate a phone call, text message, or picture message to a photo's publisher.

2.3.4 Implementation

Photo Publication

Emotipix employs simple channel-based publish/subscribe, managed by a server, for sharing photos. Each user has a single publication channel. Publishers are subscribed to their own channels, and subscriptions are symmetric. The Emotipix client automatically detects new photos by watching the phone's file system and uploads them to the server, where they are stored in a PostgreSQL database. The Emotipix server also provides a web interface, which enables users to upload any digital photos to Emotipix.

Client and Server

The Emotipix client, written in C# using the .NET Compact Framework, uploads new photos and karmas to the server. It also periodically downloads photos from the server and maintains an in-memory 16-photo cache, using a policy of replacing the longest-residing photo. The client communicates with the server, also written in C# using .NET, via asynchronous web services. During network lapses, the client displays cached images, and it retries failed communications after connectivity is restored.

Photo Prioritization

The Emotipix server maintains an outbound photo queue, for each subscriber, from which clients download photos. When a photo is published or receives karma, it is immediately enqueued for download. When a client requests a photo download for a subscriber whose queue is empty (i.e., no new photos or photos that just received karma are awaiting download) the server selects a photo from the database. A given photo's probability of selection decreases with age and increases with karma.

2.4 User study

We investigated the use of Emotipix through an exploratory 14-day user study with 16 participants, including 6 pairs and a 4-person group. Our study was designed to shed light on the following questions:

- Does Emotipix engage the periphery to facilitate social awareness and conversation, and if so, how?
- What individual and social practices emerge from the use of Emotipix?

- What lessons does use of Emotipix provide for mobile peripheral display design?

2.4.1 Participants

To investigate social awareness and communication, we recruited pairs and small groups of close friends or family to participate in the study. We recruited 16 participants (12 living in San Diego and 4 in other U.S. cities), via word of mouth, e-mail, and the web. They included 7 women and 9 men, ranging in age from 20 to 51 (median 25). They comprised six pairs (labeled A–F) and one group of four (labeled G); while the majority of our data pertains to pairs, we include data from the 4-person group to provide a counterpoint.

Group A was a married couple, a female student and a male engineer, in their twenties. Group B was a pair of co-workers, male and female, who were scientists in their early twenties. Pair C consisted of two male friends, a teacher and an engineer, in their forties. Group D was a couple in their twenties, a male graduate student living in San Diego and a female software engineer living in Redmond, Washington. Group E was a couple in their thirties, a male electric distribution analyst and a male caterer. Group F consisted of a mother and son, a 51 year old field services specialist and a 20 year old undergraduate student. Group G, four friends in their twenties, consisted of three women living in the San Francisco area and one man living in San Diego. The group included an environmental scientist, a programmer, a volunteer program assistant, and a business development intern. G1, G3, and G4 were close friends. G2 was close friends with G4 and acquainted with G1 and G3.

2.4.2 Hardware and software setup

We provided each participant with an HP Mobile Messenger hw6945 Pocket PC phone running Emotipix. The phones have a 1.3 MP camera, a 240×240 pixel touch screen, a stylus, and a QWERTY keypad. They have 50 MB of storage, 48 MB of memory, and GPRS and Wi-Fi connectivity. Participants were asked to use these phones in place of their own mobile phones. To minimize disruption to participants, we transferred their SIM cards and contacts to the provided phones. Participants all signed up for, and were reimbursed for, unlimited GPRS data service during the study.

2.4.3 Data collection

For data collection we employed questionnaires, interviews, experience sampling, diaries, and logging. At the study start, we conducted brief training sessions, collected demographic information, and asked participants to select nicknames and sticker images to represent themselves. The Emotipix client and server logged usage. We also captured some usage context with the Experience Sampling Method (ESM) [26]; on randomly chosen uses of a phone, the client displayed a multiple-choice survey, which asked why the person was using the phone and what they were doing at the time. Participants were also asked to log in daily to a web diary to report on their recent experiences with Emotipix. The diary interface displayed recent photos to assist recollection and elicit responses [129]. We instructed participants to use Emotipix and fill in the diaries at their discretion; they were not required to take photos or write in their diaries. At the end of the study we interviewed participants regarding their experiences.

2.5 Quantitative usage data

During the two-week study, participants published 356 photos overall, 337 from the phones and 19 from the web. This amounts to an average of 22.3 photos per person ($min = 3$, $max = 52$), or 1.6 photos per person per day. There was an average of 50.9 photos per group ($min = 16$, $max = 82$), or 3.6 photos per group per day. There were 354 karmas given to 165 photos (46.3% of published photos); images that received karma often received it more than once ($max = 12$). Photographers sent 168 karmas to their own photos (in this case the photo's karma score increases but no sticker appears). Fig. 2.2 shows daily publications, including photos and karmas, by group. Photo and karma activity was initially high, likely due to novelty effect, then leveled off, and finally dropped on the last day of the

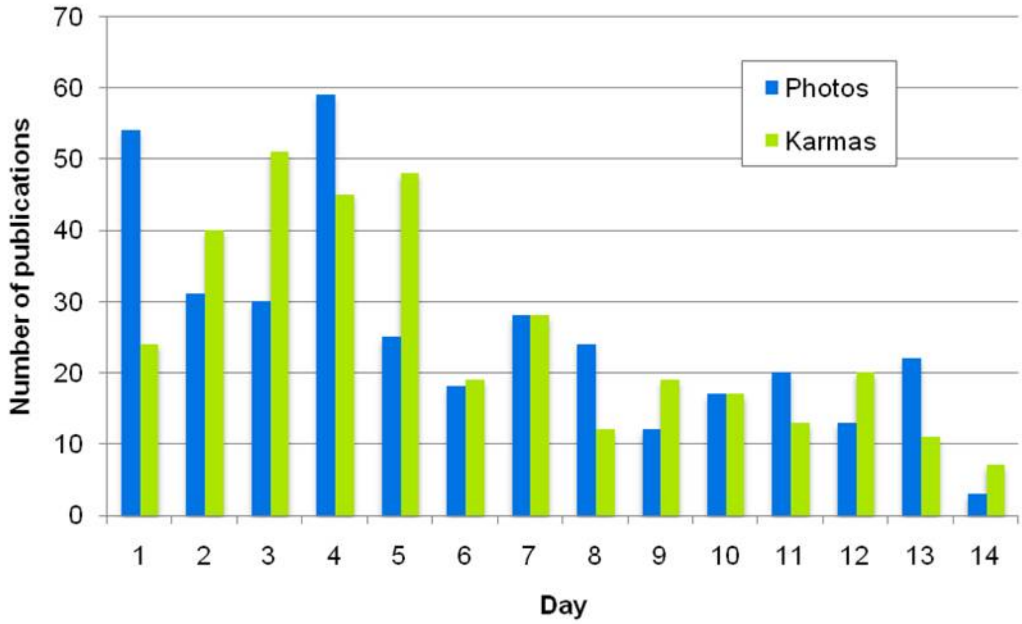


Figure 2.2: Publications per day

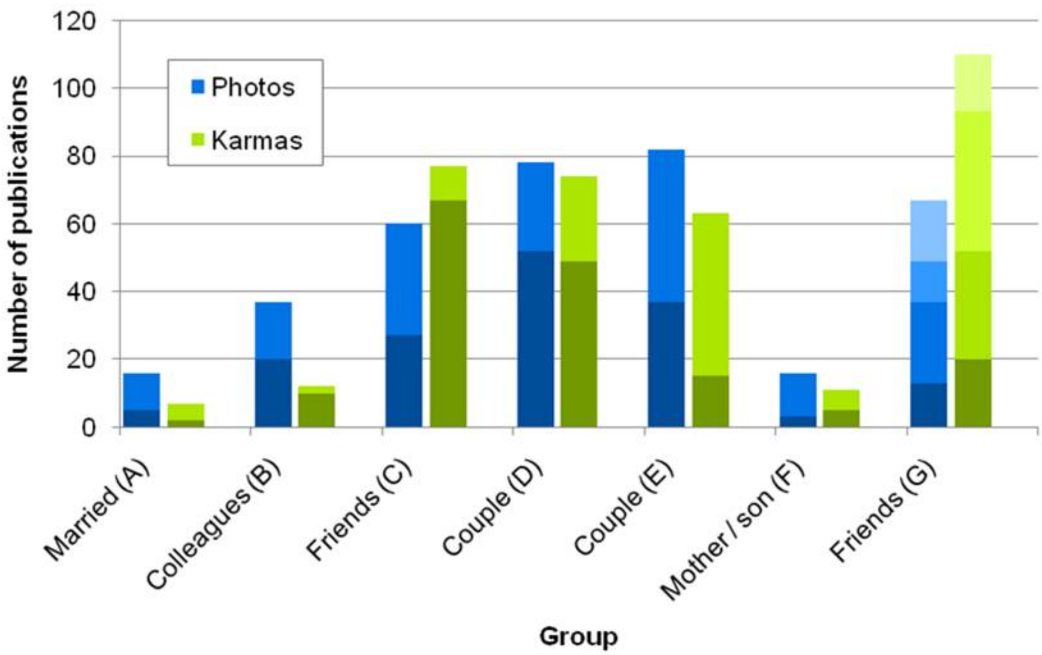


Figure 2.3: Publications per group

study, likely due to users' anticipation of the end of the study. Fig. 2.3 shows total publications by group, broken down by participants (in ascending order by label).

The Emotipix integrated photo browser was used by many participants, and was used heavily by a few; we logged 6,820 navigational interactions (e.g., forward, backward). The other integrated options for extended interaction received limited usage (only Emotipix activity was logged); 8 photos were discussed via MMS, 10 via SMS, and 1 via a phone call, and 7 photos were saved on the phone.

There were 3232 ESM surveys displayed on the phone, with 1010 being answered and 2222 being cancelled or ignored. From the number of displayed surveys, triggered randomly on phone use, we see that people used their phones frequently and thus had many opportunities to see the peripheral display. From the survey responses, we determined that these uses were embedded in a variety of contexts. The top three reasons given for using the phone were checking calls and messages (36%), calling or sending text messages (20%), and checking the time (13%), and the top three activity contexts were working or studying (31%), transit (16%), and killing time (14%).

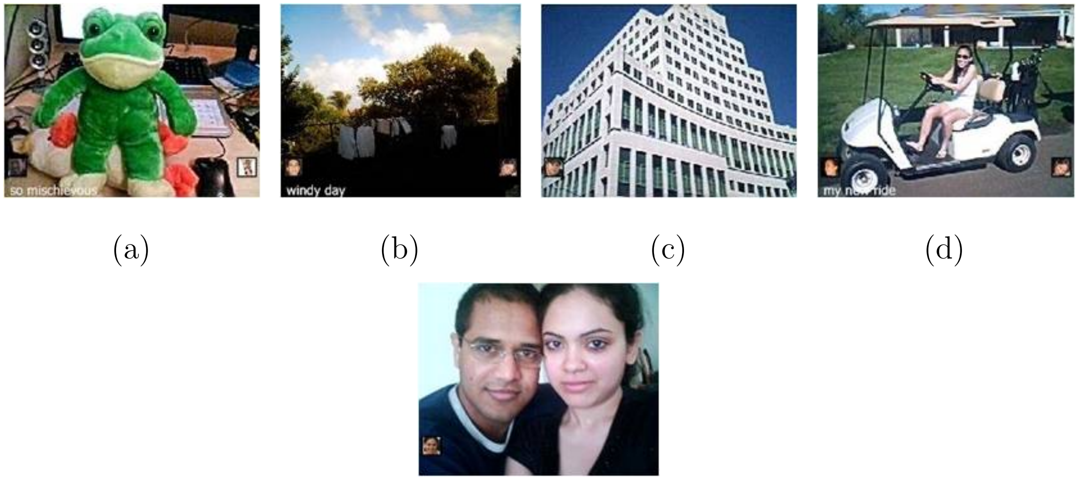
2.6 Results

We now turn to the qualitative data to gain insight into participants' interactions, as they pertain to communication and social practices. We analyzed the interview, diary, and photo data using elements from grounded theory [47], particularly inductive coding and affinity analysis. We first describe the participants overall experiences, i.e., how they interacted with and perceived Emotipix, and how Emotipix stimulated conversation. Then, we describe the topics of conversation and elements of conversational structure evinced in the use of Emotipix.

2.6.1 Overall experiences

Emotipix's display engaged the periphery

The Emotipix display engaged the periphery of users' attention. All 16 participants reported in interviews that, on the whole, they did not find Emotipix's



(a) (b) (c) (d)

(e)

Figure 2.4: (a) Easing conversation (captioned *"so mischievous"*), (b) Sharing the mundane (captioned *"windy day"*), (c) Aesthetics, (d) Sharing experiences (captioned *"my new ride"*), (e) Gift giving

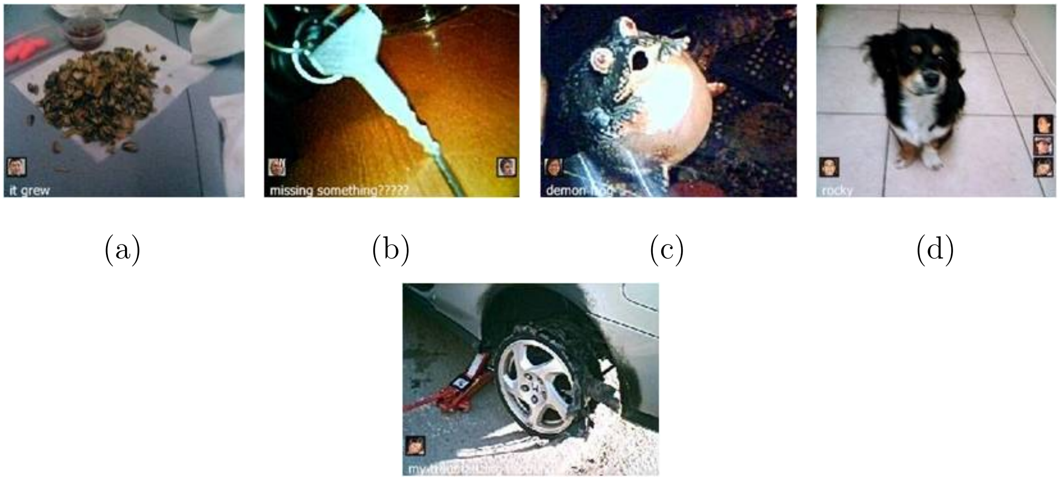
display distracting or disruptive to their workflow, even while regularly noticing it. B2 offered a typical comment: *"I took a second to glance at it, no big deal to me."* Seemingly because the mobile phone has replaced the wrist watch for many people, participants commonly reported seeing pictures while checking the time: *"I would look at the time and then I would be like, 'Oh, Emotipix is there"'* (D2). Participants also reported noticing images before and after sending or receiving calls and text messages, checking for missed calls or messages, and using other applications. They appreciated seeing the pictures frequently in the periphery, rather than having to explicitly seek them out: *"When I picked up the phone to do something I'd see all the pictures which I think is a nice thing, because to launch an application and having to view, you'd probably do it much less"* (A2). Occlusion could occasionally cause distraction. C2 said, *"It's distracting when a picture shows up and I think, 'What does that word say? I can't read the caption."'* To avoid this issue, the captioning mechanism could adapt to the photo's background color.

Despite the small size of the stickers persistently overlaid on photos, all participants reported that the stickers effectively conveyed information regarding who published or sent karma to photos. 14 participants reported that they noticed and enjoyed when their photos received karma. Karma was generally interpreted as an indication that one's friend had seen and liked a picture: *"I liked it when a picture I took was appreciated, especially if I took a lot of effort to take the photo"* (B1). Karma stickers could also convey affect: *"I was happy when D1 karma'd pics I took. I could imagine her smiling when she saw those pictures"* (D2). In the 4-person group, in addition to identifying the sender, karma could act as a recommendation and prompt a transition from the periphery to the center of attention: *"It made me pay more attention to pictures which had already been karma'd"* (G3).

Emotipix reduced the effort for conversation

All participants reported that Emotipix's automatic publication reduced the effort required to send photos, the peripheral display reduced the effort required to view photos, and the karma mechanism reduced the effort required to provide feedback. Overall, we found that Emotipix effectively eased conversation. Most participants reported using photos to visually communicate on their phones more than they did previously, as with Flipper, SLAM, and MMM2 [29, 28, 130], and expanding their definitions of which photos are worth sharing [93]. For example, D2 enjoyed exchanging photos with his girlfriend, of stuffed animals in funny poses (Fig. 2.4.a). He explained, *"I would never send her a picture message of that because it's just — it's not like, 'Oh my God, you have to see this' . . . I feel like [MMS is] for really important things."* C2 liked knowing that publishing photos would not disrupt his friend: *"I don't have to bother him or interrupt him . . . I could just do this visually."* B1 appreciated the ease of sending karma: *"It's cool you can just tap one quick tap and you're like, 'Oh that's a cool picture."'*

Because Emotipix required so little effort, there were a few occasions when people published photos or sent karma unintentionally. Accidental disclosure can have negative consequences. B1, who shared pictures with a colleague, related: *"It's a little scary that you cannot delete photos after the fact. I was worried the picture of my tattoo might show too much but it turned out ok."* This anecdote highlights the need for error avoidance, detection, and repair mechanisms. In



(a) (b) (c) (d)

(e)

Figure 2.5: (a) Humor (captioned *"it grew"*), (b) Explicit communication (captioned *"missing something?????"*), (c) Second turn of an adjacency pair (captioned *"demon frog"*), (d) Multiple karmas (captioned *"rocky"*), (e) Expecting a response (captioned *"my traumatizing morning"*)

addition to reducing the effort for conversation within the application, Emotipix stimulated conversation outside the application, with photos acting as topical resources: *"When we get together after several days, we seem to laugh about the pictures we've been sharing"* (C2). Emotipix also triggered conversations beyond our participant groups: *"It became something to talk about. You know, showing my friends the wallpaper"* (B2).

2.6.2 Topics of conversation

We developed a taxonomy, through inductive coding of the photo data, to categorize the subjects and uses of Emotipix photos. We were unable to directly use any existing taxonomies, such as Voida and Mynatt's themes for communicative appropriation of photos in instant messaging [131]. Their themes do not cover all practices we observed (e.g., "sharing experiences"), and some of their themes are not applicable to Emotipix (e.g., "image as amplification" of accompanying text). We describe participants' practices with each category (N.B., each photo could be labeled with more than one category, so the percentages add up to more than 100).

Sharing the mundane

49% of photos depicted aspects of everyday life, such as homes, workplaces, pets, family members, weather (Fig. 2.4.b), and meals. A2 explained, *"I'm not taking these pictures for me to look at later and say, 'Hey, I was working.' It is just to know that somebody else is looking at it and they know how I'm doing."* These mundane photos often conveyed an implicit status update or "thinking of you" message, and merely the act of sharing a photo was meaningful. Kuwabara et al. note that sharing implicit information, such as presence and status, may foster social connectedness [70]. Viewing mundane photos also helped participants feel more aware of friends' activities: *"I like how it definitely gave me a glimpse more into their everyday life and just what was going on around them if we couldn't physically be together"* (G3).

Aesthetics

11% of the photos were taken specifically for their aesthetic value, or beauty. Because Emotipix presents photos in a mobile phone display's background, as one might expect, some photos were taken to serve decorative purposes: *"I thought this would make a good wallpaper"* (B1). Other photos captured moments of natural beauty (e.g., a sunset) and artistic compositions (Fig. 2.4.c).

Sharing experiences

25% of Emotipix photos depicted an experience that the photographer intended to share with his or her partner(s). Although essentially all photos were taken with the intent of sharing, due to Emotipix's automated publication we limit this category to pictures of specific experiences. We included practical activities (e.g., E2 going house hunting), serendipitous encounters (e.g., D2 seeing a huge inflatable birthday cake on campus), and other non-mundane events (e.g., G4 playing golf for the first time, shown in Fig. 2.4.d). Interestingly, 3% of all photos illustrated and invited future shared experiences. For instance, D1 sent D2 a picture of a video game she had just purchased, suggesting that they play it together upon his next visit.

Gift giving

7% of photos evinced gift giving, i.e., social exchange, practices among Emotipix users. Although many Emotipix photos could be considered gifts, as defined in Taylor and Harper's study of SMS use among teenagers [123], we limit this category to photos that were explicitly intended as such. For example, the couples in our study sometimes published pictures of themselves, alone or together (Fig. 4.4), as gifts. A1 sent several self-portraits to her husband A2, who said: *"I feel good when I get a picture . . . of A1 just at home. Just the part that she thought of taking a picture and sending me is like a nice thing."* Another type of gift giving that occurred mainly among the non-couples involved disclosing personal information, for example, sharing pictures of pets, tattoos, or one's parents' house.

Humor

27% of Emotipix photos contained humor, provoking laughter or amusement. 15% of the humorous pictures contained specific teasing, and 60% of the humorous photos were inside jokes. For example, B2 took photos of a growing pile of sunflower seed shells throughout one day to show B1 how many seeds he was eating, because she had recommended that particular snack to him (Fig. 2.5.a). Almost half (47%) of the humorous photos were elements of running jokes. When G1 was stuck in traffic, she took a picture of her car's speedometer at zero, captioned *"hooow fast I am going"* and her friend G4 posted a similar photo several days later.

Explicit communication

We did not expect Emotipix to be used for explicit communication, to convey specific information, since publishers could not guarantee if or when subscribers would see photos. Yet, 5% of the photos fell into this category. E2 published several photos of houses, which he looked at with a real estate agent, for his partner to see. Also, after C1 accidentally left his keys at C2's house, C2 published a photo of the keys (Fig. 2.5.b), captioned *"Missing something?."*

2.6.3 Conversational structure

Participants' communicative practices with Emotipix evinced elements of conversational structure, including turn-taking and balanced contribution [76]. Participants also attempted to steer conversations toward topics of mutual interest.

Participants took turns publishing photos. For instance, B2 published a photo in which his girlfriend's dog's eyes appeared to glow in the dark, captioned *"demon dog."* B1 responded with a picture of a funny-looking ceramic frog statue, captioned *"demon frog"* (Fig. 2.5.c). Within a conversational thread, the photos' topical coherence was sometimes sufficient to indicate their relationship, and as in this example, captions could be used to provide more explicit references. A single conversational turn could consist of a sequence of photos. On one occasion, C2 published nine photos in quick succession, constructing a narrative intended to convince C1 to go surfing.

Although the order of messages is an important element of conversational structure, order is not preserved in the Emotipix client. New photos are displayed in chronological order, but older photos are not. The original order is, however, preserved in the web interface to the photo archive. None of the participants commented on the lack of persistent ordering or requested system support for it.

A conversational turn could also consist of sending karma. A publisher may respond to karma by incorporating the feedback in deciding what photos to publish. G2's picture of his dog (Fig. 2.5.d) received karma from the other three members of his group, and he responded by publishing several similar pictures. Because a subscriber's karma sticker can appear only once on a photo, and publishers cannot directly respond, Emotipix avoids the incessant back-and-forth clicking described in Kaye's study [66]. A subscriber may also respond to another subscriber's karma. For instance, G2 published a photo of his new pair of shoes to show them off, and G3 sent karma to his photo to express her approval. G4 hoped to avoid further conversation on that topic so she withheld a response and encouraged G1 to do the same.

Turn taking, along with a sense of reciprocal involvement, motivated continued use of Emotipix by confirming that the conversation was balanced. Participants often felt compelled to reply to their partners' photos, to complete adjacency pairs. For example, D1 sent photos to provoke her partner to respond in kind: *"Sometimes it's just 'cause like I'm wondering what D2's doing, so I just send him a random picture and then if he sends me a random picture, then I can kinda tell"* (D1). A satisfactory response could take several forms: *"I think it is a good incentive to take a lot of pictures if there is enough feedback . . . and that feedback could be a direct comment about the picture itself or them taking more pictures"* (G2). Beyond the scale of individual messages, participants' practices reflected a desire for reciprocity, and social pressure was sometimes applied to encourage it. For example, early in the study G1 published a picture of G4 captioned, *"lame-o with no pics"* because she had not published any Emotipix photos yet.

2.7 Mobile peripheral display design

Our study of Emotipix, an application that exploits the periphery on mobile phones, provided not only valuable insights into potential uses of such systems, but also potential complications of their use. Common to the following complications is a theme of tension between peripherality and control.

2.7.1 System behavior vs. users' expectations

Some participants falsely expected Emotipix to behave like the existing, familiar communication mechanisms (e.g., SMS, MMS, email) that mobile phones typically support. In fact, they often described Emotipix photo publication as analogous to sending email or text messages: *"The pictures kind of substituted for text messaging for me"* (D1).

Complications could arise when Emotipix did not work as participants expected. For example, although we informed them that Emotipix did not guarantee *if* or *when* subscribers would see specific pictures, photographers expected their friends to see new pictures promptly. G4 published a picture of her blown-out car tire, and she became upset that G2 did not call her afterwards to ask how she was doing (Fig. 2.5.e). G2 recalled, *"I actually got in trouble for not asking, because I* *didn't see the picture . . . And I got [a text message] that said 'Oh, thanks for not asking if I almost died.' I'm like 'Why? I didn't know."'*

To mitigate these issues, as designers, we should attempt to better manage users' expectations. For example, because Emotipix introduces ambiguity into visual communication (i.e., one cannot know if someone has seen a photo unless they provide explicit feedback), the system could indicate this ambiguity explicitly (e.g., by indicating which buddies may not yet have seen a particular photo).

2.7.2 Users want control

Sometimes participants used social mechanisms to augment and control the system's behavior. Two participants used Emotipix's photo browser to ensure that they saw all new photos. C2 said, *"I would constantly go to Emotipix . . . and then cycle through all 16 [cached] pictures to see what I had missed."* Photographers sometimes alerted friends of new photos: *"You knew that eventually they would see it . . . You still wanted to get that message out — to text or call, 'Hey check out my new pics"'* (E1). Also, many participants wanted more control over which photos were displayed, so they repeatedly sent karma to their favorites. C1 explained, *"I karma'd the surfing ones 'cause — I really karma'd them because I wanted to see 'em again."*

In many respects these practices, which complement Emotipix's intended calmness, are in line with Rogers' assessment of how users appropriate technologies for their own ends [102]. Yet we do face a design challenge: how can we give users the control they desire without increasing unwanted distraction or requiring undue effort? Adding features and buttons could detract from the interface's simplicity and ease of use, yet as Weiser [135] pointed out, providing users with a sense of control is key to providing them with a sense of calm. We believe that a small number of additional buttons on the home screen and the upload screen, as well as a few offline configuration parameters, can help strike a balance among the tradeoffs involved.

2.7.3 Privacy

Any communication system has the potential for privacy problems because a recipient may share information in ways not desired by the sender. Emotipix expands the potential for undesired sharing in two ways. First, photos are automatically broadcast to all buddies, so the sender may not fully calculate the possible consequences of releasing a particular photo. Users may learn to mitigate this problem by limiting their inner circles, as is happening now with social networking applications like Facebook. Second, photos are displayed automatically, rather than at the receiver's choosing; and although the mobile phone is a personal device, it is possible that non-buddies will see photos on the phone's display when it is in use. However, the small size and narrow transmission angle of a phone's display minimize the potential for accidental viewing.

In line with enhancing user control, Emotipix could provide customized subchannels for publishing (e.g., “family”, “friends”). On the recipient side, display controls or filters could be provided akin to the various ring modes that phones now provide. Such features could enable the system to scale beyond small, cohesive, high-trust groups.

2.8 Conclusion

Our exploratory study of the use of Emotipix provides insights into the types of mobile communication for which the periphery is well suited. We have learned that a communication mechanism that engages the periphery on mobile phones is effective for supporting social awareness, connectedness, and conversation in a non-disruptive, calm manner. It provides opportunities for lightweight and more extended interaction without requiring their use. Additionally, a mobile glanceable display can introduce interesting ambiguity and serendipity into the experience; one does not know if, when, or where information will be seen. A communication mechanism that employs such an interface can lower social barriers to communication and stimulate conversation; yet at the same time, this mechanism is not appropriate for conveying time-dependent, critical, or private information.

We have also learned lessons applicable to the design of interfaces that engage the periphery in mobile visual communication. First, when introducing a new communication mechanism, we need to manage users' expectations as they learn to incorporate it into their existing practices. Second, we must manage the tension between enabling users to control the system's behavior and not obligating them to do so. Third, when we reduce the effort required to send and receive messages we should enable users to manage their privacy.

2.9 Acknowledgements

This chapter, in part, is a reprint of the material as it appears in the proceedings of HICSS 2010. Cowan, L., Griswold, W. G., Barkhuus, L., Hollan, J. D., IEEE Press, 2011. The dissertation author was the primary investigator and author of this paper.

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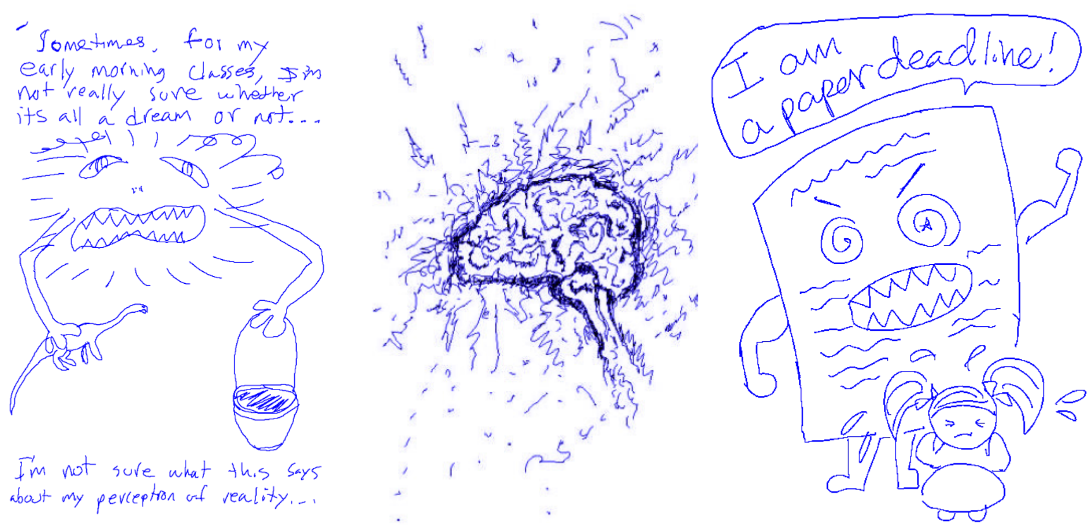
Chapter 3

Ubiquitous Sketching for Social Media

3.1 Introduction

Digital social media tools, such as e-mail, Twitter, and Facebook, have transformed how we communicate and manage our relationships with family, friends,



(a) (b) (c)

Figure 3.1: Figure 1. Ubiquitous sketching: (a) *Early morning classes*, (b) *Feeling overwhelmed*, (c) *An impending deadline*

and colleagues. Facebook alone facilitates the sharing of more than 30 billion pieces of information, including text and photos, each month.[1] Yet, although sketching has traditionally played an important role in communication, it is not currently used widely in social media. It is possible to post sketches by taking camera-phone photos of pen-and-paper sketches or sketching on touchscreen or tablet devices, but we could not find evidence of these activities in sustained practice on Facebook, suggesting that these modalities are somehow inadequate. Given the unique affordances of sketching for visual communication, its relative absence from social media is a real loss.

Like spoken and written language, sketching is a form of communication with self and others, and sketches can externalize ideas for remembering, sharing, discussing, and revising [127]. But uniquely, sketches convey visuo-spatial ideas directly, mapping elements and spatial relations in the world to elements and spatial relations on paper [127]. Thus, it is easier to explain some thoughts and ideas by sketching them than by attempting to verbally describe them. Moreover, Buxton observed that sketches are quick to make, timely (provided when needed), inexpensive, disposable, and show the peculiarities of individuals' handwriting [16]. Sketches require only minimal detail to render intended concepts, and their ambiguous nature encourages multiple interpretations and thus serves as a catalyst for conversation. Accordingly, people sketch to share ideas, to express feelings, and to relieve boredom, and doodling during lectures or meetings has been shown to aid memory and focus [1]. Sketching also creates external representations that are integral to design and artistic cognition [105, 22] and is used to explore concepts and make abstract ideas concrete [16, 74].

Sketching holds the promise to expand and enrich the ways that people communicate with their online social communities, and ubiquity is critical. People are increasingly accessing social media via their mobile devices, posting information at opportune moments. Over 200 million mobile users access Facebook, and they are twice as active as non-mobile users[1]. Traditional sketching can take place anywhere, and pen and paper are widely used, especially in comparison to digital

[1] http://www.facebook.com/press/info.php?statistics

tools for note taking, doodling, and communicating ideas [118]. With the advent of technologies for digitizing paper-based input, such as Anoto digital pens and paper,[2] we see an opportunity to leverage the affordances of pens and paper to facilitate ubiquitous sketching.

In this chapter we present the results of a 4-week exploratory field study of ubiquitous sketching for social media. To the best of our knowledge, this study is the first research to document this communication practice and the associated social interactions. We created UbiSketch, a system that integrates Anoto digital pens, paper, and 3G smart phones, to enable ubiquitous sketching and study lightweight, real-time, mobile, sketch-based communication. The results of our study indicate that ubiquitous sketching enables participants to leverage sketching's unique affordances in their mobile communications. Given that it did so, we learned that ubiquitous sketching created a powerful synergy with the common practice of posting context-dependent, personal information on social media, it broadened and deepened social interaction, and stimulated conversation.

3.2 Design space of ubiquitous sketching

There are many ways to achieve ubiquitous sketching, each with its unique affordances and compromises.

- *Sketching on paper and posting via camera-phone* affords flexibility in the choice of materials and requires no additional hardware. However, the quality of the posted sketches is subject to the lighting, care in capture (steadiness and positioning of camera), quality of camera, etc. An application could apply post-processing to increase contrast, sharpness, and remove color casts, but would be limited to recovering existing details in the image. Also, the additional effort required to produce a sufficiently high quality photo of a sketch is a deterrent to sharing. Further, photography is not socially appropriate in certain settings, such as classes and meetings, in which handwriting, doodling, and note-taking occur.

[2] http://www.anoto.com

- *Sketching on a touchscreen or tablet* affords direct capture and requires no additional hardware. However, this mechanism does not leverage existing paper-based sketching practices. Mobile device screens are typically small, finger or stylus input are often inaccurate, and a touchscreen's smooth, rigid surface does not provide the familiar experience and tactile feedback of drawing with pen and paper.
- *Sketching with digital pens and paper* affords direct capture of paper-based information, yet requires additional hardware. Nevertheless, this approach leverages the affordances of paper, including flexibility, high resolution, portability, material feel, and potentially large size, while simultaneously leveraging existing paper-based writing and drawing practices. Furthermore, digital pens can stream information to mobile devices in real time and provide other advanced features, such as time-based tracking of strokes and pressure, enabling further processing of sketch data.

Despite the positive affordances of touch-screens, tablets, or camera-phones, we could not find evidence of sustained sketch-sharing practices on Facebook, suggesting that the time/quality tradeoffs of these modalities are mismatched to support widespread use in popular social media. The type and nature of the interaction required by these devices, probably do not support sharing sketches through *in-the-moment*, lightweight interactions. Given the advantages we identified in digital pens and paper, including their accuracy, naturalness and convenience, we chose to explore this part of the design space. We defer investigation of other parts of the design space for future work.

3.3 Related work

Sketching

Paper has many unique affordances [107, 80, 79] that are advantageous for ubiquitous sketching. For example, it can be easily grasped, folded, and carried, and it's texture provides tactile feedback. Yet the difficulty of re-accessing, editing, rearranging, or sharing paper documents has motivated the exploration of digital alternatives. Sutherland's Sketchpad was the first system to introduce pen-based user interfaces to support sketching [120]. Following this work, research evolved to explore pen-based sketching through interactive tablets or pads, such as the Interactive Worksurface Project [85], the NPL electronic paper project [13], and SILK [72]. The ReBoard system supported sharing and re-access of information on whiteboards [12]. Besides these research projects, also commercial products and applications address digital sketching; for instance tablet-based systems based on Wacom[3] or the recent Apple iPad Autodesk app[4] support finger- or stylus-based sketching, while online apps like Graffiti[5] enable sketches to be posted online directly to the users' Facebook Wall.

Although these systems enable digital input and interactive feedback, the material properties of digital tablets and boards do not offer the same experience and feedback as sketching on paper, so users often have to adjust their drawing techniques accordingly [41]. We conjecture that the optimal solution is a hybrid system combining paper documents and digital resources [57]. Digital pens based on Anoto technology, which enables tracking of the pen's position on paper documents, support this model. Several pages of handwriting can be captured and stored within these pens or can be transmitted wirelessly to a separate device as a continuous stream of position information. To support developers in accessing Anoto technology and implementing paper-based interactions, several frameworks such as PADD [53], the iPaper framework [91], and PaperToolkit [145] have been introduced. Anoto technology has recently been used in a variety of applications: paper-digital cohabitation [23, 134], paper-based interactions with digital applications [110], support for field biology [144], natural note-taking [117], and speech therapy [96].

Social media

Wellman's studies of how networked computing systems affect and enable social communication over distance highlighted the importance of technolo-

[3]http://www.wacom.com
[4]http://m.autodesk.com/sketchbook
[5]http://www.facebook.com/graffitiwall

gies which connect people with mutual interests regardless of physical location [136, 137]. In recent years, social networking sites (SNSs) have emerged as important tools for supporting informal communication, with Facebook being the most representative example. While some specialized SNSs are oriented toward displaying high fidelity artwork (e.g., deviantART) or photographs (e.g., flickr), sketching has not yet achieved first class status as a communication medium on SNSs. Researchers have studied various aspects of SNS communication [55, 11] among a range of populations, including rural and urban communities [46] and university students [39]. Other work has studied how SNSs evolve over time and how people adapt accordingly [71], highlighting how important usage patterns emerge due to changes in the user's social context or the introduction of new features. Now, with the increasing functionality and ubiquity of mobile smart phones, SNS interaction is moving from users' desktops into the palms of their hands, and researchers are looking at how mobility influences communication within and around social networks [4].

Although paper commonly serves as a medium for social communication [107] via short notes (e.g., post-its) or more lengthy documents (e.g., letters), it does not traditionally support instantaneous communication over distance. Digital pens and paper open new communication possibilities, and Anoto introduced an early application for sending paper-based notes as MMS messages. In the next section we introduce UbiSketch, a mobile digital pen and paper application we created to study ubiquitous sketching. To the best of our knowledge, this work is the first to research ubiquitous paper-based sketching in the context of social media communications.

3.4 UbiSketch

UbiSketch exploits the affordances of Anoto digital pens, Anoto-augmented paper, and Bluetooth-enabled smart phones to extend the reach of paper-based sketching, supporting the real-time transmission of sketches to online services [133].

3.4.1 System architecture

The UbiSketch infrastructure is illustrated in Figure 3.2. It leverages iPaper [91], a framework for developing interactive paper applications, and adds support for mobile phones. Users interact by using Anoto digital pens and paper imprinted with the Anoto dot pattern, which enables tracking of the pen's position on the paper. Pen activity generates data, which is appended to the current sketch unless the user taps a *paper button* with the pen to trigger a specific event. Interactive paper buttons are implemented by mapping regions of the paper to input events. Analogous buttons are also provided in the phone UI. The system uses Anoto DP-201 digital pens, which stream data by bluetooth to the client, running on an LG Expo mobile phone. The client processes and temporarily stores the streamed information, and it is implemented in C# on .NET Compact Framework 3.5, on Windows Mobile 6.5.

The user publishes a sketch by tapping a specific button on the paper or phone UI. The client handles this input event by forwarding the current sketch and some supplementary data (GPS position and ID of the phone, digital pen, and paper document) to the UbiSketch server. The server further processes the recorded pen strokes and supplementary data to generate a JPEG image, and then pushes it to one or more publication channel(s). The published sketch faithfully renders the original sketch, except that digitized strokes do not vary in thickness based on the force applied to the pen.

The UbiSketch server has a plug-in architecture that enables the development and deployment of extensions to support new publication channels. As shown in Fig. 3.3, we have currently implemented support for three channels: Facebook (via the *SketchBook* plug-in and the *facebook-java-api*[6]), Twitter (via the *SketchTweet* plug-in and the *Twitter4J*[7] library), and email. SketchBook posts users' sketches to a dedicated photo album on their Facebook profiles. Subsequent social interactions, such as comments or *likes*, are directly supported by Facebook's interface. *SketchTweet* provides similar functionality for Twitter. Emailed

[6]http://code.google.com/p/facebook-java-api

[7]http://twitter4j.org

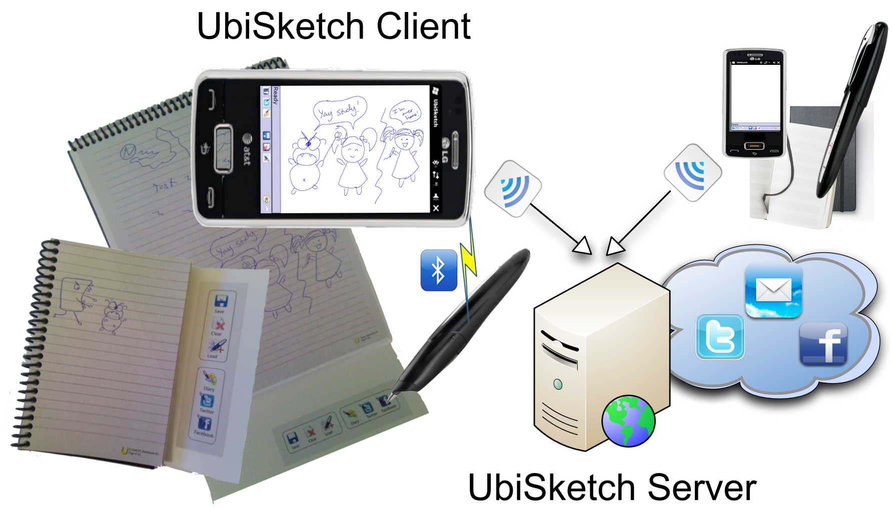


Figure 3.2: UbiSketch system overview

sketches are sent to the sketch's author for archiving or forwarding.

3.4.2 Exploratory pilot study

To inform the design of the paper user interface (UI) for ubiquitous sketching we ran an exploratory laboratory study with 11 participants (6 women and 5 men, age 22 to 55, avg. 32). We asked participants to draw one or more sketches and tap on *paper-buttons* to upload them via SketchBook.

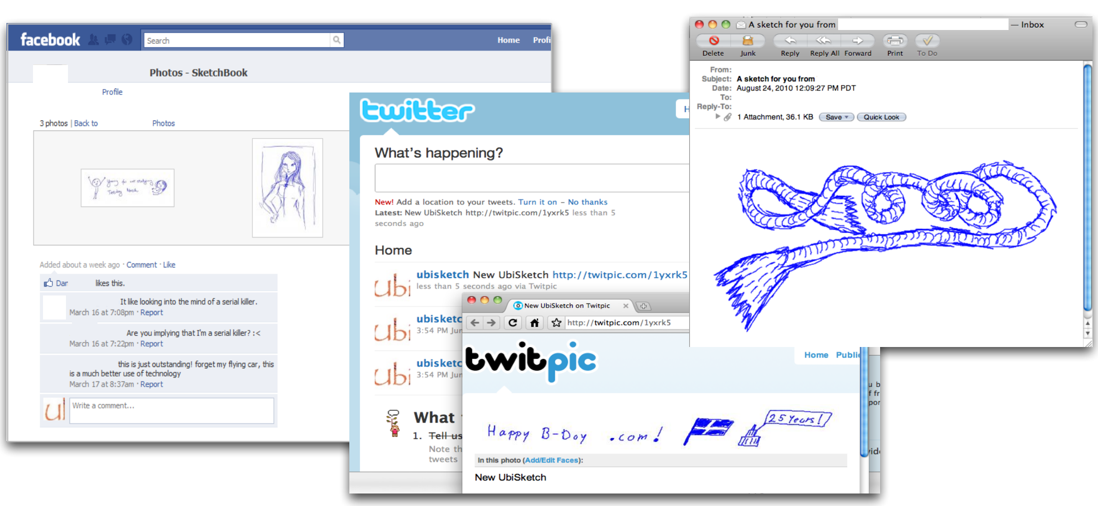


Figure 3.3: Publication channels: Facebook, Twitter, email

The published sketches, despite being created in a laboratory setting, led to conversations and social interactions on the Web and in person. After interacting with the provided UI prototypes, participants expressed these preferences: (1) The sketching area should be maximized and the digitized sketch should faithfully capture the details of the original, (2) The paper UI should be portable, simple, and easy to use, (3) The primary interface should be the paper (minimizing phone interaction), and (4) The phone UI should be employed to provide feedback. These preferences were fed into the final design, described below.

3.4.3 Paper user interface

The sketching area is maximized, utilizing the entire page. To balance size and portability, we offered two different paper formats: small (15cm × 10cm) and large (22cm × 28cm) notebooks. A *control panel* was printed on sticker paper and placed on the fold-out flap of each notebook's back cover, easily accessible from any page. We provided additional control panel stickers that users could place in convenient locations. As shown in Fig. 3.2 and Fig. 3.4, the control panel allows users to: save a sketch on the phone, clear the current sketch from the application, load a sketch (i.e., resume a sketch that was saved previously, to append or publish it), or publish a sketch to Facebook, Twitter, or email.

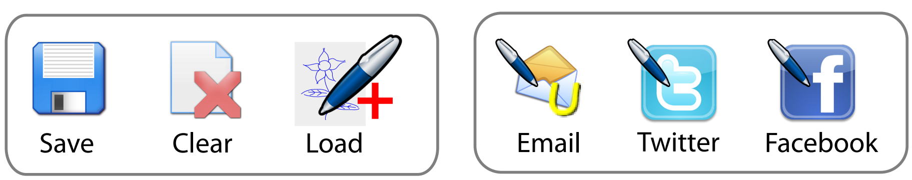


Figure 3.4: UbiSketch control panel

3.4.4 Mobile phone user interface

The mobile phone UI is intended to be secondary to the paper UI, providing optional visual feedback. As users sketch on paper, a digital rendering of the sketch is automatically displayed on the phone. As the sketch evolves, the rendering is dynamically adjusted to the maximum size that will fit on the screen to make optimal use of the display space. The phone UI also contains a control panel (identical to the paper version) and a status bar that displays feedback in response to users' input. For example, after a user taps a button to publish a sketch, the status bar indicates that the sketch is being published and eventually reports when the publication succeeded.

3.5 User study

We conducted an exploratory field study to document the interplay of ubiquitous sketching and social media. We were specifically interested in answering the following questions:

- Why and how do participants communicate through ubiquitous sketching?
- How does using UbiSketch affect sketch publication, and how does social media affect sketch publication?
- How does sketch publication impact social interactions, and how do these impact sketching practices?

3.5.1 Methods

To observe naturalistic usage practices, we ran a 4-week field study. With each participant, we conducted a pre-study training session, in which we defined the study task — sketch as they would normally, but using the pen and paper we provided. We compensated participants up to $105 for simply carrying the equipment, and no incentive was offered for publishing sketches; the compensation was independent of sketching activity. We provided each participant with an LG-Expo smart-phone, an Anoto DP-201 digital pen, and two notebooks (small and large) containing Anoto-augmented paper. We conducted a pre-study interview, weekly mid-study interviews, and a post-study interview, presenting each participant's own sketches and those of any participating friends to ease recall and elicit discussion. All interviews were audio-recorded and transcribed. Throughout the study, we collected the published sketches and — with the consent of the participants and their friends — logged the resulting Facebook interactions (comments and *likes*). We performed quantitive analysis on the logged data, including UbiSketch usage and Facebook interactions, and performed affinity analysis, based in grounded theory [27], on the sketches and interviews.

3.5.2 Participants

We recruited 10 participants who sketched and used Facebook (4 female and 6 male, ages 22 to 46, avg = 31.9). To explore usage in different social structures, we selected one individual, three pairs, and one three-person group. The participants' Facebook friends also participated indirectly through interactions associated with the published sketches. We identify participant groups as follows: a unique letter (A–E), followed by group size (1–3). We identify participants by their group ID followed by a "–" and a digit (1–3).

In group A3, A3-2 and A3-3 are married and live in the U.S. about 2,000 miles (3,200 km) from their close friend A3-1. A3-2 (male, age 26) is a chef/photographer, A3-3 (female, age 27) is a seminary graduate student, and A3-1 (female, age 27) is a computer science graduate student. Pair B2 consists of two brothers who live an hour's drive apart. One is an artist and teacher (B2-1, male, age 43), and the other is a salesperson and holistic health instructor (B2-2, male, age 46). C2 is a pair of friends who live near each other in a U.S. metropolitan area: an artist/teacher (C2-1, male, age 37) and a computer programmer (C2-2, male, age 36). Pair D2 consists of undergraduates: (D2-1, male, age 24) and (D2-2, female, age 22). They are friends and classmates who live near one another and see each other regularly. E1-1 (female, age 31) is a stay-at-home mom and jewelry artisan also living in the U.S.

The participants all doodled and hand-wrote notes on paper, but their drawing practices varied: 7 drew regularly, 2 drew occasionally, and 1 never drew. Participants occasionally shared sketches face-to-face but rarely online. The member of group A3 occasionally physically mailed each other pen-and-paper sketches, the 4 student participants sometimes showed their doodles to classmates, and the artist C2-1 posted photos of his paintings on his Website. Two participants had scanned sketches, edited them in Photoshop, and posted them on Facebook, yet they found the digitizing practice to be time-consuming and cumbersome, so they undertook the process infrequently, no more than several times a year.

Facebook was the primary online social networking site for all participants, and none used Twitter. Eight had between 132 and 219 friends, and 2 had larger social networks (651 and 1419 friends). Five read content throughout the day, and the remaining 5 read it once or twice a day. Two participants posted content at least 3 times a day, while the remaining 7 posted weekly or less. They primarily posted status updates or comments, and they occasionally posted photos, links or events. Participants accessed Facebook in a variety of ways, depending on the context: 6 sometimes used mobile phones, 7 sometimes used laptops or tablet PCs, and 4 sometimes used desktop computers.

3.5.3 Limitations

As participants became comfortable with our system the complexity of their sketches increased, and publishing a complex sketch generated a high volume of network traffic. Situations in which only slow networks (such as Edge) were available induced long transmission times and caused timeout problems on the server side, preventing complex sketches from being published. This problem appeared in our study in Week 2, and in Week 3 we released a software update (compressing sketch data before transmission), which solved the problem. Aside from this technical issue, the study and the deployed system generally ran as expected.

3.6 Results

We present the results of our field study, providing data on UbiSketch usage, users' practices and experiences, and social interactions associated with sketches on Facebook. We also highlight the experiences of three example participants.

3.6.1 UbiSketch usage and social activity

We analyzed the usage of UbiSketch over the 4 weeks in terms of the total number of sketches published by our participants. A total of 241 sketches were published with UbiSketch, and individual usage varied (min = 3, max = 55, avg = 25, $stdv$ = 18.9). Of the published sketches, 78% went to Facebook and 22% went to email. Figure 3.5 presents weekly publication statistics, which indicate that sketching practices were sustained throughout the study well past the initial burst of activity, likely due to novelty effects. The reduced usage in weeks 2 and 3 was influenced by the technical problems identified above. Usage then increased, with 23.7% of the overall publication occurring in week 4.

Of all published sketches 64.5% contained text and images, 30.7% contained only images, and 4.8% were text-only. In 29.4% of sketches text conveyed a specific message (e.g., "Happy Birthday"), while in 46.3% of them it was used to label elements or to clarify the overall meaning for viewers.

Participants used UbiSketch in a variety of locations (home, work, school, a cafe, a friend's home, outdoors, and in motor vehicles) and settings (in class, in transit, while cooking, at work, at church, during leisure activities, while simply drawing, and even walking). They sketched on a variety of surfaces, including a table, a bed, the floor, lap, knees, or in the hands. Nine out of ten participants typically kept UbiSketch's phone out while sketching, periodically referring to it for visual feedback: to check on the digital rendering of the sketch, or to mon-

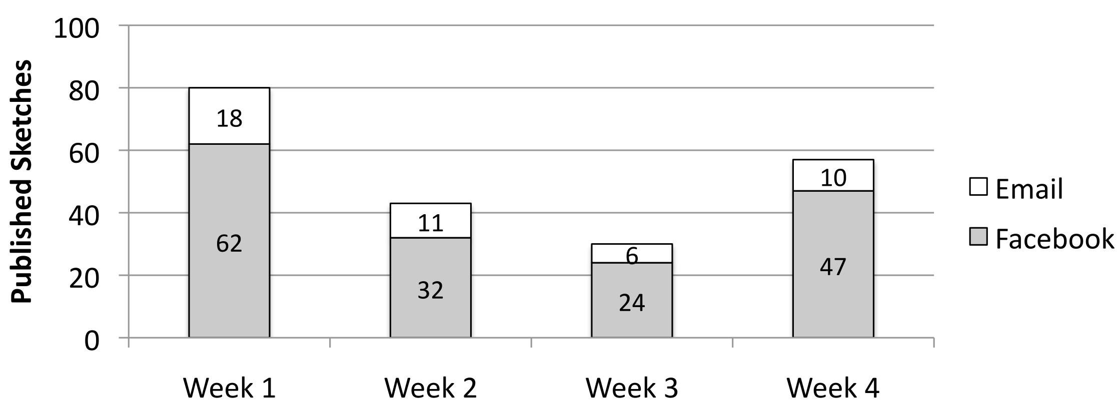


Figure 3.5: Sketches published per week

itor the application's status (e.g., publication progress, and troubleshoot in case of connectivity issues). The remaining participant, D2-1, kept the phone in his backpack while sketching. A3-1 kept her own smart phone out, in addition to the UbiSketch phone, so that she could tag people in the sketches on Facebook. Eight participants exclusively interacted with the paper UI (control panel), while two sometimes used the phone's UI as well. Six participants exclusively used the small notebook, two exclusively used the large one, and two used both. They carried the equipment in pockets, purses, or backpacks.

Seven of the ten participants sometimes sketched collaboratively with friends and family. Some of these sketches were influenced by suggestions regarding their content, and 13% of them were directly authored by friends. 10% of all sketches were created by children (Fig. 3.6); three of the participants' young children (ages 3–6) sketched under their parents' supervision. Friends' or family members' sketches were usually identified by text labels or by Facebook comments.

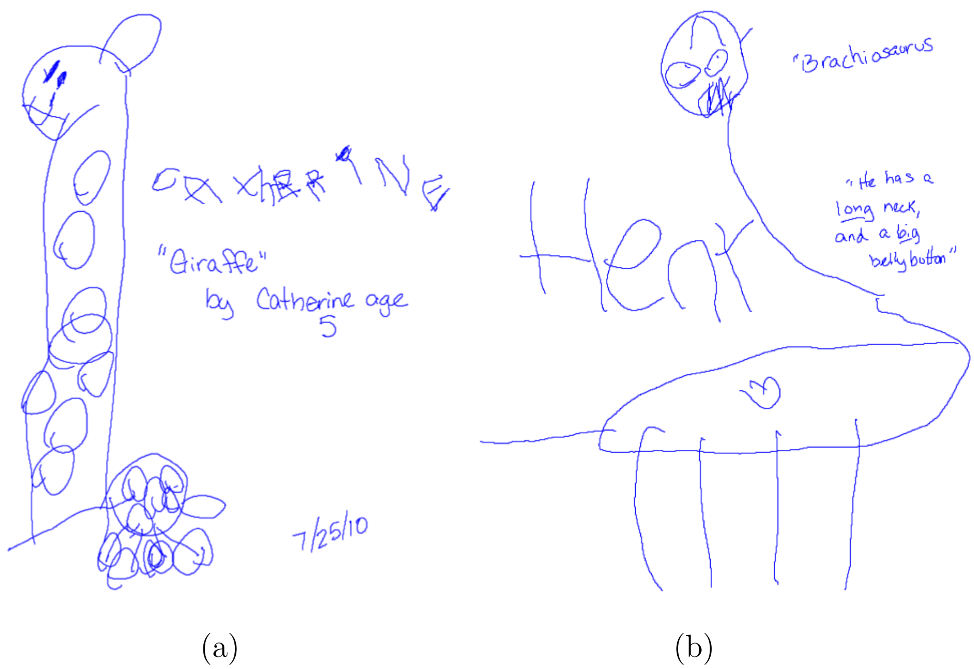


Figure 3.6: Children's sketches

The sketching experience

According to all the participants, sketching with a digital pen felt more natural — like using an ordinary pen and paper — especially compared with drawing on a touchscreen or tablet. A3-2 valued the paper's tactile feedback, *"when you're trying to draw without the feel of actual resistance that the paper gives you, it's like you're ice skating with a pen."* C2-1 enjoyed the familiarity: *"It's not like I'm drawing on a computer screen, you have that natural feeling of paper and pen, which we all know."* However, several participants complained about the pen's width and its ambiguous vibratory feedback.

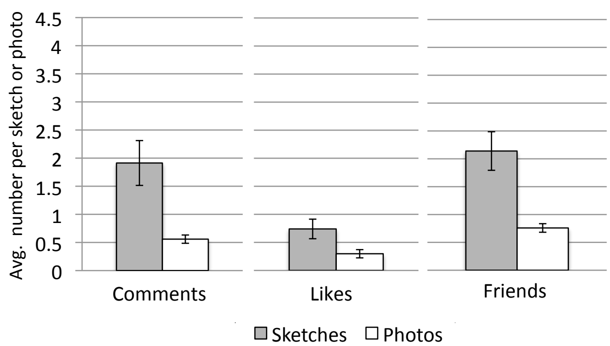
Participants were generally positively surprised and highly appreciative of the immediateness and directness of publication. E1-1 related, *"It does what you want it to do, and what you're used to. There's not that interface between doing what you want to do and doing what it's actually doing."* A3-2 described his and his wife's (A3-3) initial surprise at UbiSketch's directness: *"You touch the pen to it, and [the sketch] is on Facebook. You're like, 'Whoa . . . this is unreal'."*

Some participants adapted their drawing styles to UbiSketch's constraints. For example, stroke thickness and color did not vary with pen pressure, so A3-2 adopted a simple graphic style to avoid the need for shading. Similarly, B2-1 drew continuous strokes whenever possible because, *"[the digital lines] don't always meet up the same way [as on paper]".*

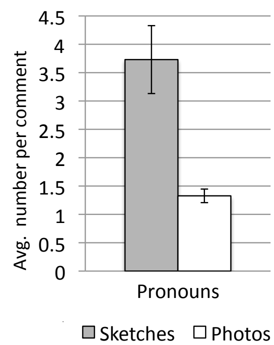
Impact on social interaction on Facebook

We analyzed data collected from participants' Facebook profiles to understand how sketches, in particular as compared to photos, impacted social interactions. Fig. 3.7.a compares the average number of comments, *likes*, and friends that commented or *liked* per sketch versus per photo (control group). To avoid the perturbance of sketches on photo behavior, we used the 48 weeks of photo data preceding the study. In order to validate our analysis we performed independent T-tests on the collected data (number of comments, likes, and commenting friends) that confirmed the statistical significance of the results for all three dimensions (P-value < 0.01). Compared to prior photo practices, participants' sketches received more comments and *likes*, and a larger group of friends responded. We conclude that ubiquitous sketching drove substantially more attention and social interaction than photos.

We ran an additional analysis on the contents of the comments on the sketches and photos. Building on previous work [14], we quantified the personalness of sketches and photos by counting the number of specific personal pronouns, such as 'I', 'we', and 'you'. Figure 3.7.b highlights how sketch comments, on average, contained significantly more personal pronouns than photo comments (T-test: $p < 0.01$). We conclude that sketches enable people to be more personal than photos.



(a) Social participation



(b) Pronoun use

Figure 3.7: Social Interaction: Sketches vs. photos on Facebook (error bars show 95% confidence interval of the mean)

3.6.2 Example users

We describe three participants' experiences in detail to illustrate some examples of UbiSketch usage. Although further study would be required to identify general patterns, these users' distinctive experiences give a sense of the possibilities of ubiquitous sketching. We analyze and discuss the implications of participants' experiences in the next section.

Participant C2-1: The artist

C2-1 is an artist who sits in a cafe and draws in a sketchbook for an hour every day. His sketchbooks are private, and he rarely shows them to anyone.

In his work he uses recurring shapes and visual themes, which he describes as a visual language that he uses to express himself. His sketches tend to be abstract, energetic, and highly aesthetic.

With UbiSketch, C2-1 has continued his existing practice of sketching in a cafe, simply swapping his ordinary sketchbook and pen with those we provided. He shares all of his sketches on Facebook, because he wants to connect more with people through his art and enjoys the new experience of publishing his sketches rather than keeping them hidden. He gets lots of feedback from friends and family, who comment on and *like* his sketches, and enjoys hearing from people with whom he would not ordinarily share or discuss his art and people with whom he does not ordinarily interact on Facebook.

He has changed the content of his sketches somewhat since he began publishing them online, shifting from a purely aesthetic style to a more expressive, narrative style. He thinks more about what he wants to tell people, rather than just drawing for practice, just for himself. For example, he has expressed his feelings of being overwhelmed as the father of a newborn baby (Fig. 1(b)), his discomfort during hot weather (Fig. 3.8.a), and concerns about his upcoming eye surgery (Fig. 3.8.b). His sketches never contain words, yet he adds a title or comment to each sketch on Facebook, in a post-publishing step, to hint at the significance of the sketches' often abstract contents.

The UbiSketch interface has also impacted his drawing style. He likes how the nature of the drawing interface constrains his sketches to be relatively simple, small, and quickly drawn. He also appreciates how the inability to erase or undo pen strokes frees him from dwelling on details and getting caught up in striving for perfection.

Participant D2-1: The doodler

D2-1 is an undergraduate student who doodles in his notebook during class. Doodling helps him stay alert in early morning classes and provides a creative outlet to pass the time when he's bored. He rarely shares his sketches, except sometimes with friends who are sitting near him in class. He believes that he is not good at

(a)

(b)

Figure 3.8: The artist: *Feeling hot* and *Fearing an upcoming surgery*

drawing, yet he draws prolifically.

With UbiSketch, D2-1 continues to doodle in class, but now he shares his doodles on Facebook. He brings his UbiSketch notebook and his ordinary class notebook, and uses the Anoto pen both to sketch in one and take notes in the other. He prefers to organize the material in separate notebooks and simply moves his hand back and forth between them. Because he typically creates quick, simplistic doodles, UbiSketch has not greatly impacted D2-1's sketching style.

D2-1's doodles, such as Fig. 1(a) and Fig. 3.9, consist primarily of handwritten text accompanied by quirky, cartoonish drawings, which together tell a rambling, stream-of-consciousness story in words and pictures. He describes dreams, past and recent experiences, current feelings, and the adventures of fictional characters he invents. His sketches generally contain the implicit message that he is bored during class and is reaching out to his friends. He enjoys getting feedback on Facebook from his friends, and uses UbiSketch as a sort of diary that talks back.

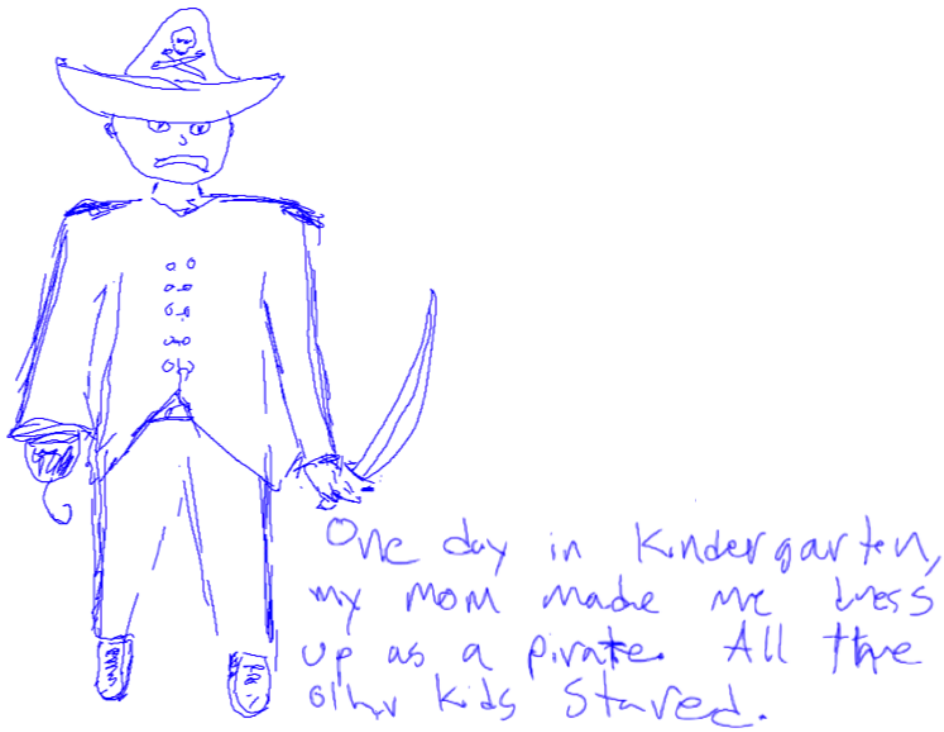


Figure 3.9: The doodler: *Pirate*

Participant A3-1: The socializer

A3-1 is a graduate student with a long history of sharing comic strips with her old friends, A3-2 and A3-3, a married couple who live in a distant city. Years ago, they created a set of cartoon avatars to represent themselves, and they periodically draw comic strips portraying their real and fictional adventures and physically mail them to each other. They also draw these comics together when they get together in person for vacations or holidays. Hardly anyone else knows about their comics, except for close friends and family members who have seem the comics at their homes.

UbiSketch brings Group A3's long-standing, but relatively private, practice of sharing sketches to Facebook, where more of their friends can see them. A3-1's sketches frequently depict her triad's avatars, as exemplified in Fig. 3.10, along with avatars representing other friends and family members. After posting a sketch to Facebook, she often tags people depicted in it so that they'll be notified — using sketches to send "thinking of you" messages to particular friends, who often respond with comments or *likes*.

She also uses UbiSketch as a form of visual microblogging, updating her friends on how she is feeling and what is going on in her life (e.g., an impending deadline (Fig. 1(c)), a fun vacation, or an outing with friends). In the past, she would intend to create lengthy comics, but there were many that she never got around to finishing or sending to her friends. Because she can publish sketches easily and immediately with UbiSketch, she now shares more short vignettes in-the-moment.

A3-1 sketches in many different contexts, such as while at work, at home, in transit, and out with friends, and she sometimes sketches collaboratively with friends and family — letting them draw, drawing together, and incorporating their suggestions into her drawings. Her sketches usually primarily contain drawings along with some hand-written words, used to label elements of the scene or clarify the activities being depicted.

Figure 3.10: The socializer: Remote friends' avatars drawing together

3.7 Discussion

We now discuss what we have learned about ubiquitous sketching, as realized by UbiSketch.

3.7.1 Leveraging the communication affordances of sketching

Sketching enabled users to communicate things that they could not, or would not, express with words or photos. Sketching has unique affordances for visual communication that text cannot replicate. E1-1 related, *"There are certain things you just can't type up with words,"* and A3-2 used UbiSketch *"whenever words wouldn't do something justice."* And in some cases, even if one could express something with text, one might not feel comfortable doing that. D2-1 remarked, *"In this kind of format, I feel like it's socially okay for me to say whatever it is that I'm feeling . . . But if I actually write it out as a status thing . . . then it's just kind of awkward."* Because A3-3 felt more comfortable expressing herself through drawings than through text, she was able to share more about her life on Facebook. She explained, *"I didn't really post many updates to Facebook before UbiSketch . . . I could let people into what was going on with me because drawing was so much more fun than saying, 'Hi, I'm having a good day"'* (Fig. 3.11). She added that her friends sometimes perceived her as a serious person and that sketching enabled her to reveal a more playful, funny side of her personality. Sketching also affords different kinds of communication than photography, enabling people to express thoughts and feelings that do not have physical forms. For example, the participants in Group A3, who lived in distance cities, created sketches that expressed a sense of wanting to be together (Fig. 3.10). A3-1 explained, *"we can't take [photos] together when they're that far away, but we can still draw pictures where we're all together"*.

Participants found the medium of sketching to be especially powerful for creatively expressing their emotions. For example, C2-2 sketched himself bent into the shape of a pretzel to illustrate how he felt after helping a friend install insulation

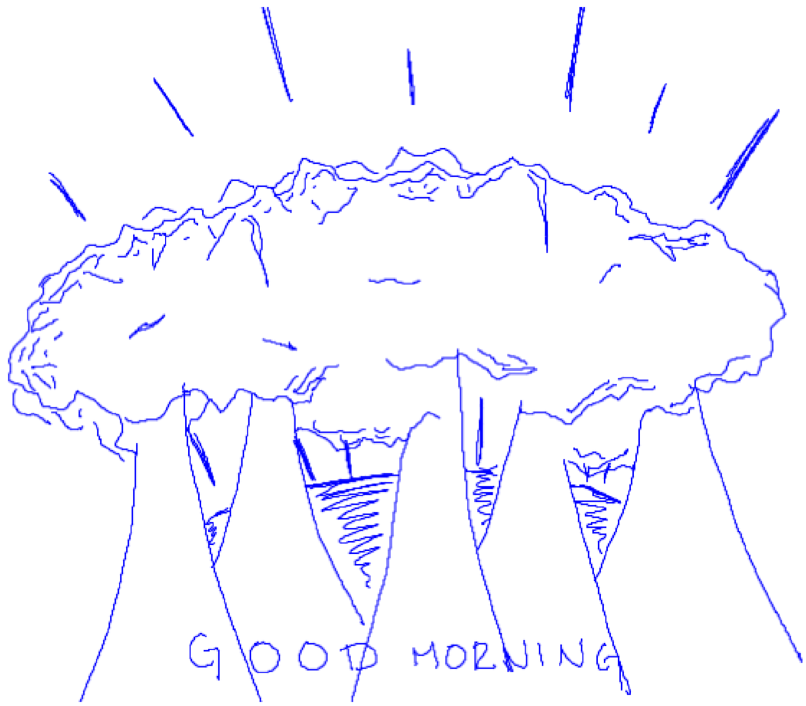


Figure 3.11: *Good morning*

(Fig. 3.12). C2-1 made light of his concern about his upcoming surgery in a sketch he titled "Strabismus Massacre Feared Dead" (Fig. 3.8.b). He related that the sketch is *"showing you the over-the-top silliness of the fear of this surgery,"* and added, *"I'm sure it will be fine and not a big deal, but in my mind it's this horrible thing."* Also, A3-1 vented her stress about an impending deadline in a series of sketches depicting the deadline as a monster attacking her (Fig. 1(c)).

In addition to providing authors with unique affordances for self-expression, sketching gave viewers unique insights into authors' thoughts and feelings. In the prior example of A3-1's paper deadline, she used UbiSketch because she thought sketches would enable her friends to relate to her situation more effectively than textual status updates would. She explained, *"It's easier to see yourself in that [situation] and think 'I've been there',"* and when her friend A3-3 viewed the sketches she agreed, *"There's just no better way, and I knew exactly how she felt."* A3-3 also related how her husband's sketches were easier for her to understand than his verbal communication: *"Normally, he's trying to verbally describe his thoughts to me and I get so lost . . . the pictures make a lot more sense."* She explained

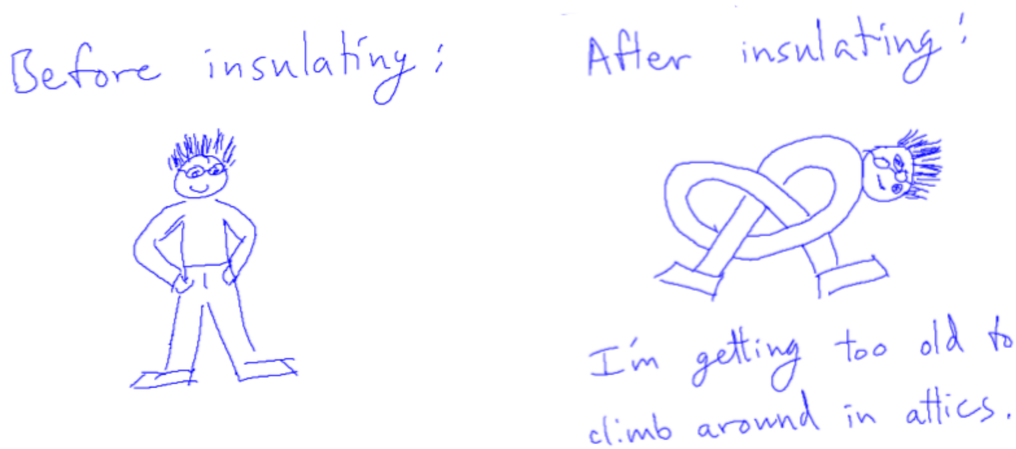
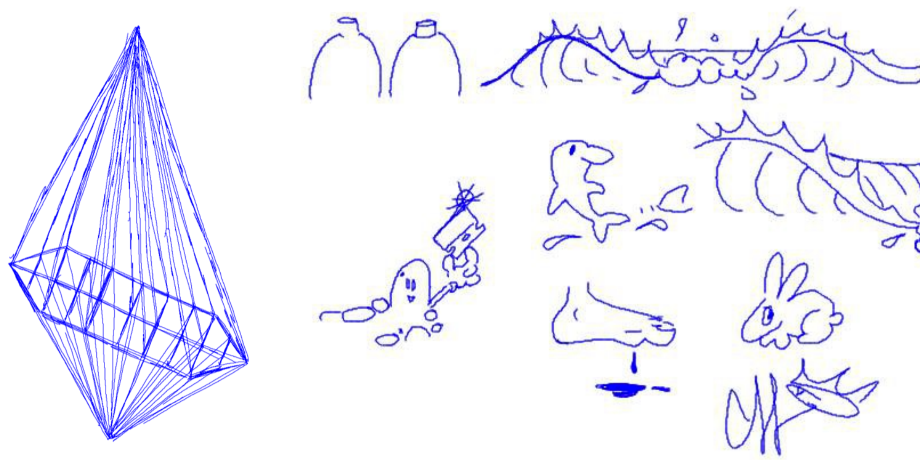


Figure 3.12: *Feeling like a pretzel*

that because she felt that *"the sketches just expressed a whole lot more"* than her friends' other online updates, she consequently paid more attention to the sketches. This perception could be a factor in the increased social interaction we observed on Facebook with sketches, compared to text and photos (Fig. 3.7).

Participants used many representational techniques to convey messages within their sketches. They constructed the meaning of their sketches with hand-written text and drawn images, often in combination. B2-1 sometimes hand-wrote words to *"add information to a sort of ambiguous drawing,"* explaining that he used text in his sketches *"only to back up the drawings."* E1-1 annotated her young daughter's sketches to externalize information for remembering and sharing (Fig. 3.6.a), relating, *"she explained to me what she was drawing, and I made little notes."* In contrast, D2-1 published many handwritten notes in which text was primary. Sketched images often contained symbolism. For example, five participants used recurring cartoon avatars (e.g., Snoopy, a *"creepy cat creature"*) to represent themselves. Participants also expressed themselves figuratively, as exemplified by one of C2-1's sketches (Fig. 3.13.a); the elements of the drawing appear stretched, and he explained, *"I was feeling really worn out and stretched thin."*

Participants also leveraged structure within individual sketches and across multiple sketches to convey information. They used the spatial layout of vignettes within a single sketch to organize stories, as in B2-1's account of his day at the beach (Fig. 3.13.b). They also published sequences of sketches to construct narratives, as in D2-1's fictional sequence showing a shark approaching and attacking a boat (Fig. 3.14). Also, C2-1 published a series which documented the temporal evolution of a single drawing as he created it. His friend C2-2 created a steganographic sketch in 4 parts, published sequentially, intending for specific viewers to superimpose the images in their minds and see the hidden message.

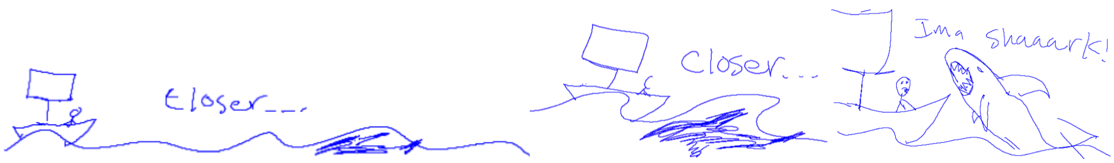


(a) (b)

Figure 3.13: Visual expression: (a) *Stretched thin* and (b) *A day at the beach*

3.7.2 The synergy of ubiquitous sketching and social media

UbiSketch's lightweight interface for capturing sketches and publishing them in real time brought sketching from the privacy of paper notebooks and sketchbooks into the public domain of social media. The artist C2-1 recounted before the study, *"A lot of my work just ends up being hidden away in a sketchbook,"* and he was glad that UbiSketch enabled him to connect with people through his work. As one might expect, the publication of sketches influenced sketch authorship. For example, A3-2 explained how he filtered his sketches for the audience: *"Just like you would filter out things that you would say over a social network, you filter out the things that you would draw."* Also, D2-1 tried to draw *"something that other people would possibly be interested in"* instead of *"random doodle stuff."* And C2-1



(a) (b) (c)

Figure 3.14: A sequential narrative: *Shark attack*

created more *"diaristic"* and *"personal"* sketches, explaining, *"It's my Facebook page. I suppose I should be doing things about me."*

A number of factors enabled UbiSketch to bring sketching into the public realm. One factor was the ease of sharing, which lowered social barriers, effectively changing authors' perceptions of what was worth sharing. D2-1 didn't previously share his sketches, explaining, *"They're nothing to write home about. So why would I make an effort to show people?"* Yet with UbiSketch he shared many sketches, because *"there's really no cost to [sharing them], so . . . it's kind of a casual thing."* The Facebook milieu also contributed to authors' comfort with sharing sketches, as B2-1 related: *"No one's really judging it very heavily."*

Immediacy was another crucial factor in sharing sketches. C2-1 explained, *"I really like being able to draw something and have it immediately on a digital image, and then be able to immediately post it,"* adding that if additional steps were required to publish a sketch, *"I would never do that."* A3-2 agreed: *"Without [UbiSketch], I definitely would not have ever published any of those sketches online."* E1-1 explained that sharing in-the-moment was critical to realizing her intentions to share her children's drawings: *"Often they'll draw little stuff, and I'll save it and mean to mail it to my mom, and I never do . . . [With UbiSketch] it was done, and I sent it."*

UbiSketch's mobile, real-time publication mechanism enabled participants to share time-dependent information, and Facebook's *news feed* and the common practice of posting about contemporaneous events encouraged it, creating a powerful synergy. Immediacy was critical to conveying this sort of information: *"Once a day passed, there [would be] no point in posting it up. It just wouldn't have the same meaning"* (A3-3). A3-2 agreed, *"It's all about living in the moment and* *using it when it's opportunistic. It's really important to be able to publish it in that same context."* UbiSketch's immediacy supported micro-publication of *"really small snapshots ... trying to capture the moment"* (A3-3). A3-3 explained that these sketches helped him and his friends maintain a sense of awareness and connectedness: *"it's just another way to say I know you're there and I'm thinking about you and here's what's going on with me."*

3.7.3 Stimulating conversation and social interaction

Ubiquitous sketching stimulated conversation and social interaction, both online and in-person. Our quantitative data indicates that, compared with prior photo practices, participants published more sketches on Facebook, and their sketches received more comments and *likes* (Fig. 3.7). Our qualitative data confirms these results. A3-3 remarked that her Facebook interactions increased because she posted more: *"Being able to post the sketches, I ended up having a lot more interaction with people ... comments and conversations."* Facebook comments were often encouraging, sympathetic, or funny. For example, E1-1's mother expressed her enjoyment at seeing her grandchildren's drawings: (*"oh Grandma Just loves your pitcher"*). D2-1 related how sketches became topical resources for face-to-face conversations with *"here-friends that also look on my Facebook."* The prevalence of collaborative sketching further suggests that ubiquitous sketching creates social interactions in the physical world as well as the digital.

Ubiquitous sketching also broadened participation in Facebook interactions, as evidenced by the increased number of friends commenting on a given sketch (Fig. 3.7), and our qualitative data confirms this result. D2-1 expressed surprise at the set of people who commented: *"My close friends, I expected that ... but random [people] I wouldn't have expected."* A3-3 remarked that several lines of comments back and forth with some people was more interaction than she'd had with them in years, and even such a seemingly small increase could be significant. For example, C2-1 forged a new connection with his brother-in-law, relating, *"To have him see my work and comment on it and seem interested ... it was gratifying to connect with him. He's not someone I connect with in any way."*

Viewers' feedback on sketches also impacted authors' sketching practices. For example, B2-2 remarked that positive feedback *"made [him] really want to draw more."* Sometimes feedback had a direct impact on what participants drew, such as when B2-1 responded to his friend's comment (*"Curse you right-handed butter knives"*) with a drawing of a left-handed butter knife. A3-1 also subtly suggested that her friends A3-2 and A3-3 should publish more sketches by depicting them drawing in one of her sketches (Fig. 3.10). She also commented (*"CARTOON!"*) on A3-2's intriguing Facebook status (*"just saw a pig give birth"*) to encourage him to elaborate, and her effort was successful. She related, *"The [UbiSketch] picture showed up later, and I was very happy."*

Participants and their friends expressed interest in expanding support for ubiquitous sketching. Participants wanted to enable their friends to share sketches, as D2-1 explained: *"It shouldn't just be one person drawing and everyone commenting. It's more fun if everyone's drawing and you can comment on each other."* And friends expressed similar sentiments in their comments, wanting to use UbiSketch themselves. For example, one of E1-1's friends commented, *"I love this!! I wanna draw, now!"*. Despite their interest in posting sketches on Facebook and the availability of other means to do that (e.g., camera-phones), none of them did.

3.8 Conclusion

When other media went online, sketching was left behind. To consider a remedy for this loss, we created a working prototype system, called UbiSketch, which integrates digital pens, paper, and mobile phones. We conducted an exploratory field study of ubiquitous sketching for social media, as realized by UbiSketch, and we summarize our results:

- *With UbiSketch, participants with a wide variety of practices, styles, and skills were able to leverage the unique affordances of sketching for visual communication.* In the study, participants conveyed thoughts and feelings that they could not or would not otherwise express using other modalities, such as text or photos.
- *A lightweight sketching interface and instantaneous publication mechanism cre-*

ates a synergy with prevailing social media. The study participants shared sketches in-the-moment. They micro-published personal, context-dependent information, fitting the practices typical of today's social media applications.

- *Ubiquitous sketching broadens and deepens social interaction, stimulating conversation.* Compared with prior photo practices, participants posted more sketches on Facebook, their sketches received more comments and *likes*, more friends responded, and the comments were more personal.

All told, with ubiquitous sketching, the digital medium can embrace an additional form of communication, bringing it one step closer to fulfilling the promise of capturing the full spectrum of human experience.

3.9 Acknowledgements

Chapter 2, in part, has been submitted for publication of the material as it may appear in Mobile HCI 2011. Cowan, L., Weibel, N., Pina, L. R., Griswold, W. G., Hollan, J. D., ACM Press, 2011. The dissertation author was the primary investigator and author of this paper.

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Chapter 4

Projector Phone Use: Practices and Social Implications

4.1 Introduction

Pico projectors are increasingly being embedded in consumer electronic devices, such as mobile phones (e.g. LG Expo and Samsung Galaxy Beam) and digital cameras (e.g. Nikon Coolpix s1000pj). Pico projector sales are predicted to increase from half a million units (worth $117 million) in 2009 to 142 million units (worth $13.9 billion) in 2018, with sales of embedded units expected to be double that of stand-alone units [103]. As sales increase, the prices are expected to drop to as low as $20 by 2011, and projectors are likely to become standard cell-phone components [83]. Projector phones may become as common as camera-phones.

Commodity projector phones are being marketed primarily to business consumers, for presentations and ad hoc meetings. Although proposed consumer applications are limited to media viewing, researchers are beginning to design new applications and projection-specific interaction techniques to explore a broader array of possible uses. Observations of how people use projector phones outside the lab are crucial to informing the design of future devices, interfaces, and applications.

In this chapter, we present the results of a 4-week, 10-participant study of how people use commodity projector phones "in the wild". To the best of our knowledge, this work is the first long-term, unconstrained, exploratory field study of projector phone use. We present observations from our study, describing users' experiences and highlighting emergent practices. In our analysis, we consider how context, such as group size, relationships, and locale, influences projector phone use. A key observation is that users can readily exploit the new facilities of projector phones to author interesting effects by employing representational techniques such as superimposition, scaling, translation, and motion. Thus, even the "basic" projector phone platform affords novel interaction modalities. We discuss the implications of projector phone use for etiquette, privacy, and control, highlighting potential benefits, risks, and failure modes. We further extrapolate from our observations, to envision a future in which projector phones are ubiquitous. The results of our exploratory study are intended to document naturalistic practices, inform design, and expose areas for further research.

4.2 Related work

Camera projector systems have been extensively studied. Seminal work in this area, including Wellner's DigitalDesk [138] and Underkoffler et al.'s Luminous Room [128], used fixed, overhead cameras and projectors to digitally augment users' interaction with the physical environment. The Everywhere Displays system [95] explored the concept of ubiquitous graphical interfaces, using steerable projectors to create multiple interactive surfaces within an environment.

Researchers later investigated techniques for interacting with handheld projected displays. Raskar et al. [99, 100] studied geometry and location-aware projection. Other researchers have proposed moving cursors and activating selections via the handheld device [7], touching the projection surface with fingers or overlapping multiple projections [119], or moving the projector to direct the beam of a "spotlight" within a virtual information space [98]. Cao et al. [17, 18] expanded on this spotlight metaphor, employing handheld projectors and pens to define and interact with virtual information spaces embedded in the physical environment in single and multi-user scenarios.

Recent work has explored applications and interaction techniques for small, mobile, portable or wearable projectors. Blasko et al. [9] explored interaction with a simulated wrist-worn projector via forearm movement and a touch-sensitive wrist-worn device. Also, in Willis and Poupyrev's MotionBeam metaphor, the motion of the projector expresses the motion of the projected object [140]. Mistry et al. [86] studied tangible and gestural interaction with WUW, also known as SixthSense, a wearable camera projector system. Harrison et al. [56] analyzed vibrations to detect taps on the skin, and demonstrated using their Skinput technique to interact with an interface projected on the body.

Researchers have also explored projector-device ensembles to increase interactive space. Bonfire [65] integrates projectors with a laptop to extend interaction to the table. Similarly, PenLight [115] and MouseLight [116] use projection to increase the interactive space for digital pens, providing visual feedback for interaction with paper.

Recent advances in hardware have enabled researchers to study mobile phones with attached pico projectors. The Maurauders Light system [77] projects buddies' locations onto paper maps, leveraging the phones' location-sensing capabilities and large projected displays. Greaves and Rukzio [50] comparatively evaluated mobile phone screens and projected displays for photo browsing tasks and found that users preferred projector-based over phone-based interaction. They also developed a framework for collaborative media viewing and sharing with projector phones [51]. Cowan and Li's ShadowPuppets system [31] (Chapter 5) explored using shadow gestures for collocated collaborative interaction with projected displays of mobile devices.

Numerous short-term field studies have focused on mobile phone use and related social practices [63, 67, 97]. In the personal-projection space, Greaves et al. [49] conducted a 3-day field study in which the researchers projected maps and media in public places, and Wilson et al. [142] conducted a study in which they periodically prompted users over a 1- or 2-day period to project supplied media content. We previously considered social applications of projector phones through a scenario-based design exploration [30]. To the best of our knowledge, extended field studies have not yet been conducted to document naturalistic use of projector phones.

4.3 User study: How do people use projector phones in the wild?

In our study, we were seeking to discover what people could and would do in the course of their daily activities. In particular, would people use projector phones for business presentations and media viewing, or would they go beyond that? If so, how, and what are the possible implications for future use and design? To provide evidence that a particular use is possible and actually happens, observation of real-world use is required. Consequently, we chose to conduct a small-scale 4-week exploratory study in the wild. While such a study design is appropriate for our research questions, in order to draw additional conclusions about typical or average behaviors and unusual phenomena a more extended study would be required.

Participants: We recruited 10 participants, 4 female and 6 male, ages 22 to 46 ($average = 31.9$). We assigned each participant a pseudonym, starting with letters A through J. Anna is a computer science graduate student, Ben is an artist/teacher, Charles is a salesperson/holistic health instructor, Darryl is a chef/photographer, Faye is a seminary graduate student, Emily is a stay-at-home mom/jewelry artisan, Gabriel and Helen are undergraduate students, Irving is an artist/teacher, and James is a computer programmer.

Methods: This study was exploratory in nature, intended to discover uses and sample phenomena. In order to ensure that the observed projector phone uses arose naturally, the study imposed minimal constraints on the users. The participants received no guidance on how they should use the projector. We simply provided a projector phone with unlimited data service, showed the participants how to activate the projector function, and asked them to carry it with them as much as possible for the duration of the study. We gave participants the choice of carrying the provided phone instead of or in addition to their own mobile phone, and all opted to carry both.

We ran this study in parallel with a study of UbiSketch [33, **?**] (Chapter 3), an application that enables the sharing of paper-based sketches on social networks via mobile phones. With UbiSketch, a user draws or writes with an Anoto [2] digital pen on paper, the pen digitizes the sketch, streaming information by Bluetooth to a mobile phone, and the mobile phone forwards it to services on the Internet, such as Facebook, Twitter, or email.

We conducted pre-study training sessions and interviews to assess participants' previous experience using mobile projectors. We then conducted weekly follow-up interviews regarding their experiences. At the end of the study, we had a final interview with each participant. We analyzed this qualitative data using elements of grounded theory, grouping participants' responses by affinity, and we present results that emerged from the data.

Apparatus: The LG Expo (Fig. 4.1.a) is a Windows Mobile smart phone with a touch screen, stylus, and QWERTY keyboard. The phone weighs 147 grams, and its dimensions are 114 $\times$ 56 $\times$ 15 mm. It has an integrated, removable projector, which weighs 50 grams and attaches onto the back of the phone, approximately doubling the phone's depth. The HVGA resolution (480 $\times$ 320) DLP pico projector's brightness is rated at 5 lumens, and it is focused manually by manipulating a physical slider. The projector is activated by sliding open a physical panel above the projector and then sliding a GUI widget on the touch screen to confirm. Closing the physical panel deactivates the display. Projected content is identical to that of the LCD display (Fig. 4.1.b).

The Expo's projection is not visible in bright light. In moderate lighting conditions, an approximately 6 ft projected image is easily visible from a 10 ft throw, and in darker conditions the size and throw distance can be more than doubled. Our tests indicate that the phone's battery power (1500 mAh) lasts around 2 hours when the projector is on, and the phone can be plugged in for sustained projection. The Expo's camera and projector cannot be operated simultaneously and are oriented orthogonally.

Pre-study data: Eight of the participants had never used a pico projector or projector phone before. Two of the participants had used a projector phone previously: Anna had experimented with a friend's once, and Ben had more extensive experience, having used one for several months. Of the 8 participants who had not used pico projectors, 3 had used large portable projectors: Darryl and Faye owned one that they used to watch movies and play video games at their home or at friends' homes, to make presentations at school or work, and to create backdrops for artistic photography, and Irving had used one to present slideshows to his students. 6 of the 8 without projector phone experience had seen one in person or in an advertisement or video demonstration, and 2 had never seen one at all. All 8 expressed interest in using a projector phone, citing the following reasons: *"it's new and sounds cool,"* it could project a display much larger than that of a typical mobile phone screen, and it would enable them to use their phones more socially, with friends, children, or students.

4.4 Observations

Out of the ten participants, five used the LG Expo's integrated projector throughout the study for a variety of reasons. Anna explained that she used it *"because it was attached to my phone and it was cool."* Charles concurred, using the

(a) (b)

Figure 4.1: (a) LG Expo projector phone, (b) Projected display mirrors LCD screen

projector *"because it was there,"* and adding: *"If I had one on my standard phone, I would use it all the time."* Ben enjoyed showing off the novelty of the device, explaining, *"The wow factor is high."* Several participants cited the large size of the display: *"the freedom to make that image bigger"* (Ben), *"it gets bigger than my laptop screen"* (Charles), and *"the screen on the phone is so little"* (Darryl). Four of the five participants who used the projector carried it with them at all times and kept it attached to the phone. Anna explained why she carried the projector: *"You never know when you might need a projector, and I didn't want to be caught without one."*

The remaining five participants did not use the projector, beyond some initial experimentation, despite expressing interest in using it. Some participants explained that they did not use the projector because they forgot about it or did not have a reason to use it, suggesting the lack of an enticing application. Others explained that they did not have the projector with them at the time they wanted to use it. We believe that more participants might have used the projector if it was integrated into their primary mobile phone, since availability of the device is key to supporting spontaneous interaction. Four of the five participants who did not use the projector did not always carry it with them, and none of them kept the projector attached to the phone. These participants explained that they did not keep the projector attached because it was too bulky to fit in a purse or pocket, it was too heavy, they were concerned about breaking it, or they thought leaving it attached would drain the phone's battery faster.

Projector usage varied in duration and frequency. Figure 4.2 illustrates this

Participant	**Frequency of use per week**	**Duration of use per instance**
Anna	3–4 times	1–5 minutes
Ben	5–6 times	5–10 minutes
Charles	9–13 times	10–30 minutes
Darryl	1–2 times	10–30 minutes
Emily	3–4 times	5–10 minutes

Figure 4.2: Projector usage: frequency and duration

usage by the five participants that used the projectors throughout the study. Ben and Charles, who used the projectors regularly, grew quite partial to them. Ben expressed: *"I love the projector phone . . . I don't even want a phone that doesn't have a projector in it now."* Charles concurred, saying, *"I'm in love with that projector. I think it's the coolest thing since sliced bread."*

Participants projected the display onto a variety of surfaces, including people, people's clothing, and architectural elements (e.g., walls, floors, ceilings, windows, and building facades), and generally whatever was at hand in the environment (e.g., dishes and tablecloths in a restaurant). They also projected while on the go, from within moving cars and while walking. As Ben explained, *"It's so natural to project on any surface 'cause [the projector] is right in your hand and wherever you move it, you're projecting."*

Participants had differing opinions about the types of projection surfaces they preferred. Ben preferred *"a lighter, smoother surface"* because the projection was easier to see, and Anna concurred. In contrast, Darryl preferred a surface with more texture. He explained that when he projected while using UbiSketch, the projected sketch acted as a conceptual bridge between the physical and digital worlds: *"Paper has texture, the Internet has no texture, so to have a digital projection on a wall that inevitably does have some kind of feel to it . . . It was kind of a nice segue for me to go from perceiving it on paper to perceiving it digital, having it projected digitally in the tangible plane"* (Darryl).

The projected content primarily consisted of photos and videos, including self-authored media. Four of the participants projected UbiSketch sketches, during or after sketching (Fig. 4.3). Darryl explained that the projector did not affect the way he interacted with applications because the phone did not support projection-specific interaction: *"It didn't do a lot for the actual function of the phone because it's all touch screen [interaction], so you need to be looking at the screen anyway to be able to play with a lot of things."*

Participants expressed some dissatisfaction with the device. For example, Darryl complained that the limited brightness of the projector precluded daytime, outdoor use, saying, *"On anything but a really dingy day, it's a little bit under*

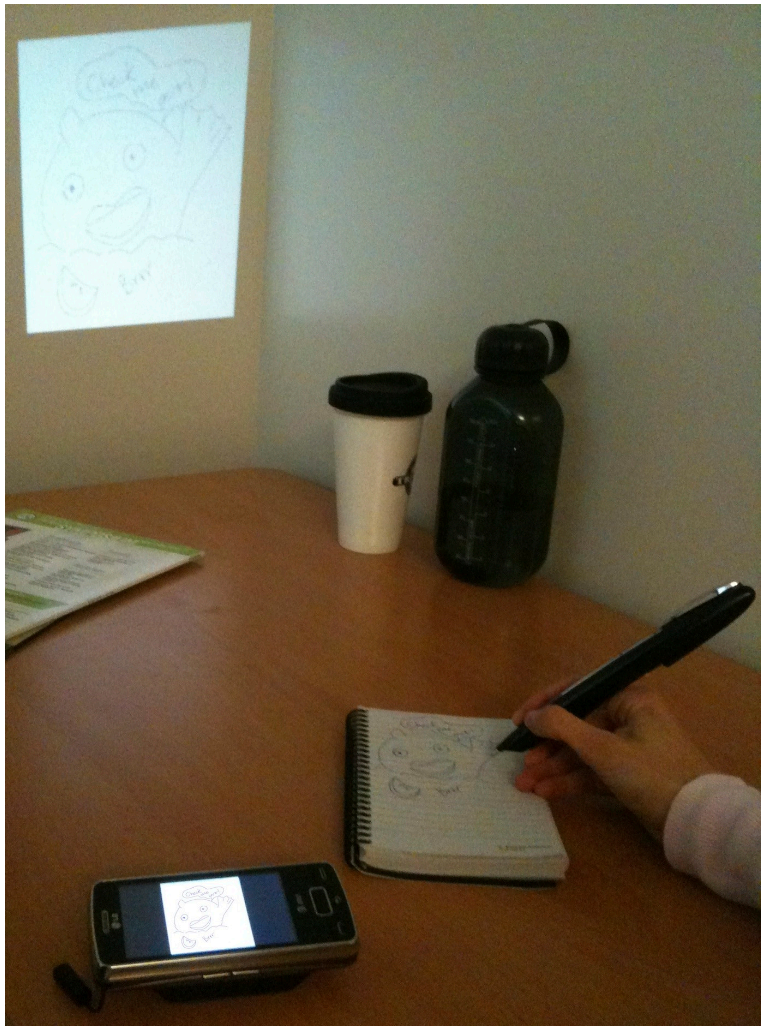


Figure 4.3: Projecting while using UbiSketch. Phone screen and projected display show digitized version of paper sketch

power to compete with the sun." Ben concurred, adding, *"In the daytime, you just can't show it to anybody. It's like, 'Well, if you turn all the lights off."'* Many participants also complained about the projector's power consumption, which rapidly drained the phone's battery, and how hot the projector became during prolonged use.

Participants did not commonly interact via the phone's touch screen, e.g., to browse for content, while projecting. A typical scenario would involve searching for content via the touch screen, then activating the projector to display the content, and temporarily suspending projection during any further touch screen interactions. Users often did not turn the projector off and on during these transient interactions, since this would require too much effort. Instead, they would tangibly and directly occlude or avert the projector's beam, e.g., by covering it with a hand, or re-orienting it to reduce its visibility.

4.4.1 Usage scenarios

We now describe private, semi-private, and public scenarios of use, drawn from our field study. Analysis and discussion follow in the next section.

Private

As one might expect, all the participants reported using the projector simply because it afforded a large display, relative to the size of their mobile phone, laptop, or television screens, and because it was portable. For example, when Ben's girlfriend watched television in the living room, he would sometimes watch projected videos in the bedroom to avoid conflict. He used the phone rather than his laptop, since the projected display was larger and the laptop was comparatively cumbersome to move around the house. He explained that he would typically take his phone into the bedroom for transient viewing, to watch *"things that are under ten minutes mostly, like quick, little things."* Charles also watched videos, enjoying the ability to project a display anywhere. For example, he liked to lie in bed and watch videos on the ceiling. He would typically plug the phone into a charger for sustained, non-mobile use.

Darryl sometimes projected in conjunction with UbiSketch; while sketching on paper, he would project the digital version of his sketch onto a nearby wall. He explained that he did this to enlarge the sketch, to *"see a bigger representation than what was on paper of what I was drawing."* He also found it easier to refer to the large projected sketch to confirm that the digitized version matched the original, to *"make sure things showed up where they should"*, rather than *"trying to pick out details on the phone."*

Charles used UbiSketch to create and digitize paper-based sketches, and then used the projector to scale them up and transfer them onto canvas. He explained, *"You do a sketch. You project it onto a canvas and draw the sketch onto a big, real canvas."* He preferred to sketch on a small scale because it felt natural and comfortable, and the projector made it easy to scale sketches up. He remarked, *"I may as well just project what I want to do and do the drawings small, because my hand works really well on a small scale."* He suggested that graffiti artists could use a similar approach to project artwork onto public surfaces.

Anna used the projector to show her husband something she'd drawn for him with UbiSketch. She sketched a cartoon fish that was in a commercial that they enjoyed, and later projected it onto the ceiling over their bed. She animated the projected fish while she and her husband sang the song from the commercial, explaining, *"I made the fish dance on the ceiling."* By reenacting the commercial, they shared an inside joke.

Charles showed his friend a video of sharks a local surfer had filmed. He rested the projector on a piece of furniture on one side of his bedroom and pointed it toward the opposite wall behind the bed, where he was sitting. He explained that the experience felt immersive: *"When it's projected on a screen right by my bed, it has that whole sense of I'm really in it . . . It was like swimming in the water . . . swimming with sharks. I don't want to do it in real life, but that was fun."* Because the video was projected onto himself and the wall behind him, Charles felt that he was virtually swimming with the sharks in the video.

Semi-Private

In one of Anna's initial experiments with personal projection, she had a friend project a self-portrait onto her face. They played with aligning the projected photo with her face, adjusting distances, angles, and lighting, and then another friend took a photo, which they posted on Facebook (Fig. 4.4). Anna and her friends found the image of her actual face merged with her projected face to be quite creepy, looking in some ways real yet in other ways unnatural; it was hard to distinguish between the real and virtual elements of the scene. They laughed a lot during the playful process of creating the photo.

Emily and her family sometimes projected while sketching with UbiSketch

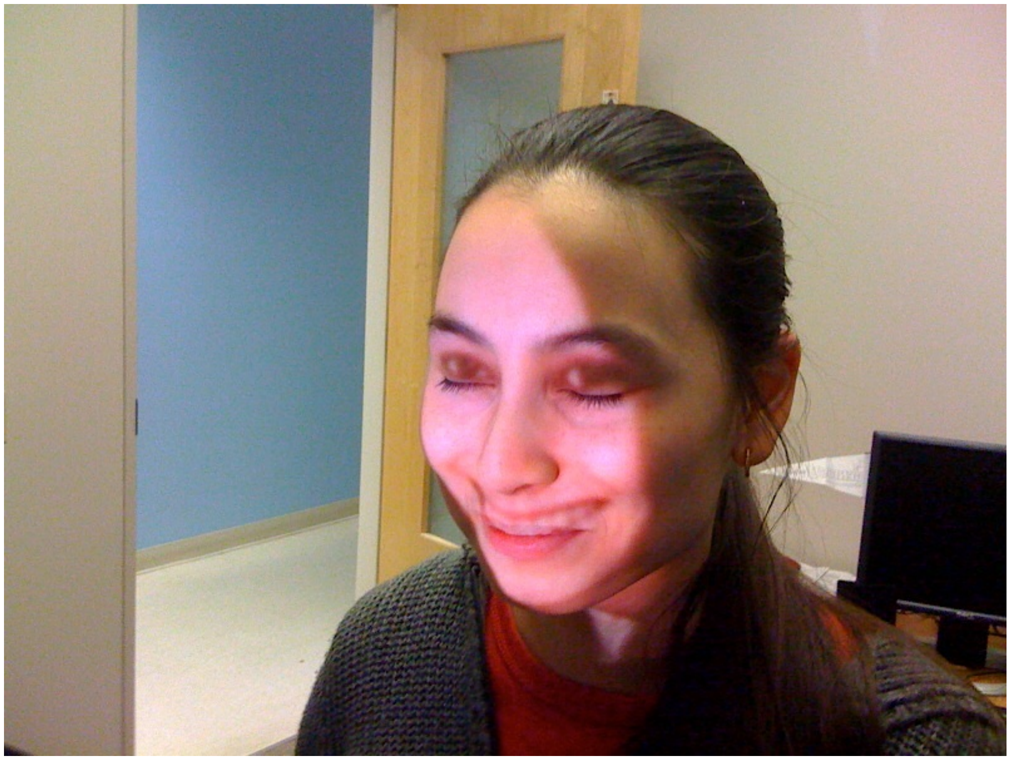


Figure 4.4: Projected face (eyes open, smiling) on real face (eyes and mouth closed)

at family gatherings. She described one scenario: *"My sister-in-law was drawing, and so she put [the projection] up so we could all look at what she was drawing."* The large display enabled everyone in the room to watch, discuss, and share in the experience. Emily explained, *"It was really neat to do it while she was drawing, because then everyone could see it ... People were commenting on what was being drawn."* Without projection, only a few nearby people would have been able to see what her sister was drawing on a small piece of paper.

Charles used the projector in a mischievous way at work, explaining that he did so to be funny and to show off. He related, *"I'll be sitting at my desk and I'll shine something on someone, like on their back and stuff ... I do that kind of stuff to make other people laugh and make them really, really jealous that I have [a projector]."* He described one incident in which he projected a video of fire onto his manager's back: *"Everybody was laughing. And then I hid [the projection] and said, 'So were your ears burning?' ... Everybody was snickering in the background.*

(a) (b)

Figure 4.5: Projecting at Disneyland while (a) walking on Main Street USA, and (b) riding on Peter Pan's Flight

It was quite comical."

Public

Some of the participants in the study enjoyed using their projector phones to playfully interact with strangers in public settings. Ben used the projector to pass time when he was waiting in line for rides at Disneyland. For example, he projected a picture of Yoda, the Star Wars character, onto the walls of the enclosed waiting area of Space Mountain, a space-themed roller coaster. He explained, *"It's all dark, so you can project really readily in there."* He described the reactions of the other people in line, saying, *"Oh, they freak out. They absolutely freak out. They just want to know what you have and where to get one. And they want to play with it."* He enjoyed attracting the attention of people around the room, and started conversations with those waiting nearby.

Ben also used the projector while walking around outside at Disneyland in the evening (Fig. 4.5.a), or while riding on dark indoor rides, such as Peter Pan's Flight (Fig. 4.5.b). He enjoyed playfully adding his own content to the carefully-controlled environment of the theme park, yet he was aware of how it could affect other visitors: *"That changes everyone on that ride's experience of that ride. What if we all had those phones? We'd all be influencing [each other's experiences.] I* *guess it makes for an interesting, always changing outcome. But, also, it's kind of intrusive."* One of his friends felt uncomfortable when Ben projected on rides, because she was concerned about the effect on other visitors, yet his brother Charles enjoyed it, relating how he felt during one experience: *"I was laughing so hard, because that was so cool."*

Once, while Ben was showing something to a friend by projecting it onto their table at a restaurant, he accidentally shined the projector all over the room, explaining, *"You move the camera this much, and this much movement here relates to, like, half the room."* He noted the projector's potential for intrusiveness, calling it *"a nuisance"* and *"disruptive."* He added, *"That phone can take over the room. You can have everyone's attention in, like, five seconds . . . Other people were completely distracted from their dinner due to me playing with my little phone."* While relating this experience, Ben expressed concern about the future ubiquity of personal projection, saying, *"I was just thinking how it's gonna be in the future when everyone has one of those . . . There's gonna be no filter on what images people are seeing all around them . . . Laws are gonna have to be made."* Although he enjoyed wreaking a bit of havoc, he saw the potentially serious impact of personal projection, noting, *"It's really fun, but it seems to have the levity of something very serious and almost a weapon."*

On occasion, Ben also mischievously projected content onto the sides of neighbors' houses at night, when the phone's beam was visible at large size. Charles expressed a similar desire to project from the window of his apartment onto a nearby building's facade, which he was unable to do because the area was well lit. He explained why he would enjoy interacting with strangers' in this way, saying, *"It's because it's just so fun . . . to make a big thing that people would drive by and go, 'What the?' . . . 'Why is there a big thing projecting out the window? Why is this happening?' "* A similar motivation to playfully interact with strangers led Ben to project out the windows of moving cars, onto the road and onto the sides of nearby trucks.

Ben also enjoyed playfully projecting at an outdoor, evening concert, sometimes onto the backs of strangers' shirts. His girlfriend felt uncomfortable when he did that and was concerned about how people would react. At the same event, Ben also considered projecting a picture of a donut onto or near a group of policemen, but decided against it after discussing it with his girlfriend, for fear of repercussions.

4.5 Analysis

From the above observations, we can immediately see that the participants went far beyond the anticipated passive uses of projector phones, employing an array of display techniques for a range of applications. Affinity analysis revealed several categories of projector phone usage. We first analyze how context influenced projector phone interaction. Then, we analyze how users authored interactions, describing novel dimensions of projector phone authorship and the representational techniques employed.

4.5.1 Context

As one might expect, contextual factors, such as the privacy of the setting, the group size, and participants' relationships, influenced projector phone interaction. In our study, we observed individual and pair interactions in private settings, pair and small-group interactions in semi-private settings, and pair and small-group interactions in public settings.

Projection in private settings, such as bedrooms, involved individuals or pairs. Individual uses were instrumental, for control, or for convenience. For example, Darryl and Charles used the projector as an instrument for enlarging digitized sketches. Ben took the projector into the bedroom for control and convenience while his girlfriend watched television in the living room. In the absence of an audience, individuals did not need to be concerned about projecting appropriate content, conveying a specific message, or presenting themselves to an audience.

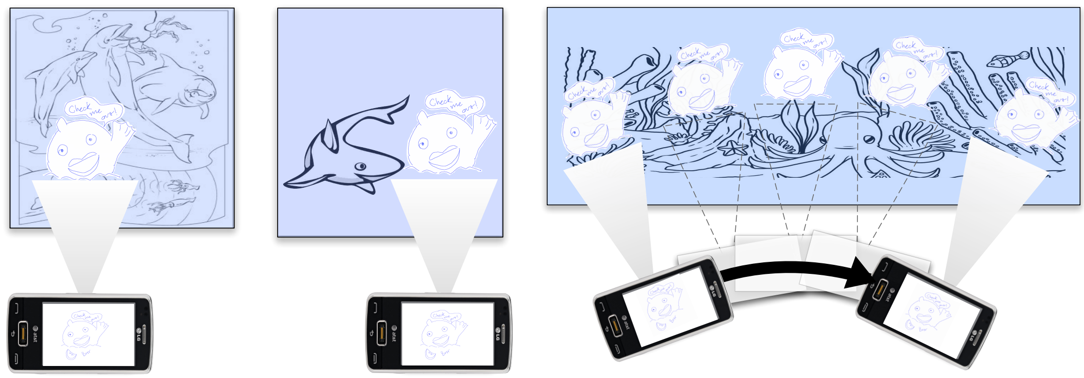
Pair interaction in private settings involved sharing content of mutual interest or related to the pair's relationship. For example, Charles showed his friend a video about sharks since both were interested in surfing. Anna and her husband playfully shared an inside joke, reenacting a commercial they both enjoyed. In dyadic use, the presence of a companion influenced users' choice and delivery of content, and users could leverage the pair's shared interests, knowledge, and experiences in the interaction.

Projector phone interaction in semi-private settings, such as workplace offices or home living rooms, involved small groups of people ranging in familiarity. Uses included sharing experiences, play, and exploration. For example, Emily projected to enable a group of her family members to share in the creation of a sketch. Anna and a small group of friends and colleagues playfully projected a self-portrait onto her face to explore blending physical and digital information, while Charles projected content onto his colleagues' backs to tease them. In semi-private use in the presence of participants of varying intimacy levels and possibly incidental viewers, the interaction became a more public performance and the content was less personal.

Projection in public settings involved both pairs and small groups, along with bystanders included in the interaction. Public uses were expressive, entertaining, intended to spark conversation, or mischievous. For example, Ben projected onto the sidewalk while waiting at Disneyland to entertain himself and his friends and attract others' attention. He also projected onto strangers at a concert as a provocative form of joking. In public settings, in the presence of friends and strangers — willing and unwilling participants — users oriented interactions toward both audiences.

4.5.2 Authorship and representation

The participants of our study went beyond simply choosing what digital media content to project and then passively presenting and/or viewing it. These participants actively and dynamically authored how to project content, in order to convey particular meanings or shape social interactions. A projector phone's mobility and its ability to throw an image over a distance enable novel dimensions of authorship, supporting a unique concentration of representational facilities in a single artifact. We highlight some of these dimensions, the representational



(a) (b) (c)

Figure 4.6: Representational techniques: (a) superimposition, (b) juxtaposition, (c) animation

techniques they afford, and how these techniques are used in combination.

In particular, we describe how a projector phone's small size and the ease of orienting its projected display support what Luff and Heath term "micro-mobility" [78]. Users can not only carry projector phones from place to place, they can readily position and orient projected information during interactions. With a handheld projector, users can adjust the orientation of the display by simply moving their hands. In contrast, a larger projector typically remains in a fixed position while in use.

Surface

The projection surface(s), including all elements within the projector's beam, adds a physical dimension to the projected content. The surface has material properties, such as texture, color, and geometry, which determine how it reflects light and add tangibility to digital content. For example, Darryl projected sketches onto a wall that had *"some kind of feel to it"* to add texture to the digitized sketches and perceptually bridge the physical and digital worlds. The surface may also have other affordances or provide metaphorical significance. A user can quickly and easily re-orient the projector toward a different surface to adjust this dimension, whereas with a static projector the surface (typically a screen) does not change during use.

Because a projector throws an image over a distance, decoupling the device from the display, projected information can be superimposed onto (Fig. 4.6.a), or juxtaposed next to (Fig. 4.6.b), things in the physical environment. For example, when Charles superimposed an underwater scene onto himself, the effect was immersive. The surface and the content can contribute to a blended meaning, as when Charles projected fire onto a colleague's back to imply that she was burning. In addition, superimposition and juxtaposition can support comparison, making it easier to identify similarities and differences. Darryl used this strategy to identify errors in digitized sketches.

Throw distance and display size

The distance from the projector to the surface determines the size of the projected display, which can scale far beyond the size of the phone's LCD screen. With increasing throw distance, the size of the projection increases and the brightness decreases. The size of a projected image can represent its actual or metaphorical importance, quantity, or size.

The display size can be adjusted directly and tangibly by moving the projector toward or away from the surface, e.g. by moving one's hand, walking, or pointing the projector toward a nearer or farther surface. On an ordinary display, such as a phone's screen, as you enlarge an image beyond the size of the display it is clipped. In contrast, when you enlarge a projected image by increasing the throw distance, the entire image gets bigger. A change in size can represent literal or figurative growth or reduction, or indicate a change in emphasis.

Scaling can enable visualization at human scale, supporting comprehension and interaction. For example, Darryl's projected sketches were larger and easier to see at a glance than those on the phone's screen. Here, Darryl combined representational techniques, juxtaposing an original analog image and a magnified digital image. In addition, Charles used UbiSketch and the projector phone to digitally mediate the physical enlargement of a sketch, transferring it from paper, to phone, to canvas.

Lateral motion

A user can position projected content by moving and orienting the projector in three-dimensional space to translate, scale, rotate, and/or warp the projected image. The throw distance can amplify the effects of these actions, enabling a small change in the projector's orientation to cause a large change in the appearance of the projected display. In contrast, in a traditional setup the projector remains fixed during use, and with an ordinary display the motion is not amplified.

These novel affordances of projector phones can support animation. For example, Ben projected a Snoopy cartoon around the walls inside his home to make the character fly, simply rotating the projector in his hand to make the projected display move quickly around the room. Here, as well as when Anna made a projected cartoon fish *"dance on the ceiling"*, we see how the relative motion of the projector can represent animation of the projected information (Fig. 4.6.c). When Ben projected from a moving car onto the side of a moving truck, tracking its position with the projected beam, the projected information did not appear to be moving because its position relative to the truck did not change.

Visibility

Users can dynamically adjust the visibility of the projected display and its source. While projecting, users can hide specific information or interactions, such as browsing for content, by occluding the projector — turning it off, covering it with a hand, or averting it with a simple hand motion. The ease and directness of showing or hiding the projected display is a novel feature of personal projection.

Projected information may also be oriented such that it is visible to, or occluded from, particular viewers. For example, Emily projected while sketching so that her family could share in the activity. In contrast, Charles projected onto people's backs to tease them; those who were in on the joke could see what he projected, while those on whom the joke was being played could not. Charles' example highlights how users exploit micro-mobility in projector phone interactions to share, hide, and orient information. Users can also adjust the projected display's size to control its visibility.

A user can choose whether or not to reveal his or her identity. Anonymity may sometimes be desirable, for example, to reduce one's accountability in political, artistic, or playful interactions. In this vein, Charles suggested projecting out a window from inside his apartment, and Ben projected onto distant surfaces and from within crowds of people at Disneyland.

4.6 The future

Analysts predict that projectors will soon be standard features embedded in mobile phones, much like cameras today. Further, we expect that specialized interaction techniques, in which the projected display is a space for input and output, will be widely adopted. We envision a future in which projector phones are ubiquitous and projected displays support interaction, rather than just passive viewing.

Participants in our study enjoyed showing off their projector phones and using them to attract attention from friends as well as strangers. However, as these devices become ubiquitous, their novelty will fade, as will the division between those who have projector phones and those who do not. Further, when personal projection becomes commonplace, the act of projecting will no longer attract attention from people who are simply curious about a technology they have never seen before.

Even as novelty fades, the increased density of projector phone use could result in greater intrusiveness [6]. Projection can be disruptive to incidental viewers, potentially cluttering the visual space or even offending. People may see one's projected display without wanting to, which is analogous to forced eavesdropping on mobile phone conversations today. The projected information could be inappropriate, or people might simply not wish to see it. Crowding could lead to contention over shared space. Also, multi-user and/or multi-projector usage scenarios will likely become more common, potentially increasing the risk of intrusiveness.

As projector phones become ubiquitous, etiquette will necessarily develop to socially manage when, where, and how it is appropriate to use them. Different notions of acceptable behavior will be defined by the context. For example, shining a projected display onto someone's body might require a sufficient level of intimacy, or at least that person's consent, or it could be considered impolite. Also, it might be appropriate to project content around the room at a party or onto one's table at a restaurant, but not around the room at a restaurant. Yet as Ben remarked about his restaurant experience, it can be hard to manage disruption of incidental viewers. Due to the broadcast nature of projection, those doing the broadcasting are accountable for what and how they choose to project and the possible effects on viewers. Additional social controls, such as private or governmental regulations, may also be enacted where etiquette is not sufficient.

Projector phones also have privacy implications. A standard phone's display can only be seen at close range due to the small screen size and narrow viewing angle, which imparts a degree of privacy. In contrast, a projected display can be larger and visible from a greater distance, potentially risking the privacy of projected content. In our study, participants seemed to understand what they should or should not project in a given context, and they did not express any privacy concerns. Yet their experiences highlight potential failure modes.

A projector phone user can quickly and easily orient and scale the projected display, which can be beneficial but can also risk unintended disclosure. For example, when Ben unwittingly shined the projector around the restaurant rather than toward the table he shared with his friend, the interaction changed from semi-private to public and the projected information was revealed to unintended viewers. Unless a user is in a private setting in which only intended viewers are present, this sort of privacy breach is a possible concern.

Further, as technology matures, projection space will become interactive. Techniques for interacting with projector phones at a distance could increase the risk of unauthorized access and require additional security measures. An unauthorized user could potentially gain control of the device by interacting with the projected display, and active control presents a greater threat to security than passive viewing.

Researchers have already been exploring techniques that enable users to interact with projected displays by moving the projection device, touching the projection surface, or gesturing in the air between the device and the surface [9, 18, 31]. Multi-user and multi-projector interaction techniques, which leverage the projectors' beams for shared input and output, have also been studied. Many of these techniques support collaborative interaction, and we anticipate that mobile phones will increasingly become tools for collocated collaboration. Social protocols will likely develop for managing shared control.

As specialized interactive techniques become more widely adopted, the nature of users' interactions while projecting will change. Consider how participants in our study avoided interacting with the phone's touch screen or buttons while projecting, averting or occluding the projector during those interactions. It can be difficult to hold the projector's beam steady while performing GUI interactions, and the user might need to re-orient the device to comfortably see the screen and manipulate the controls. We expect that specialized interaction techniques will support more sustained, complex usage scenarios. These interaction techniques can further enable users to create, and not merely consume, content via projected displays.

Projection can be a powerful medium for creative expression, and in recent years, artists and political activists have been employing portable projectors. For example, Graffiti Research Lab's Laser Tag [48] system enables artists to project graffiti onto large, distant buildings with powerful projectors, and Greenpeace activists have projected political images onto a nuclear power plant. Also, artist Julius von Bismarck created the Image Fulgurator [132], an apparatus that briefly projects an image while a flash photo is being taken, so that the projected image appears in the photo without the photographer's immediate knowledge. And, the MobiSpray system turns a mobile phone into a virtual "spray can" that can control a graffiti application, enabling users to paint the physical world with projected imagery [104].

As small, mobile, personal projectors become ubiquitous, these forms of art and activism will become more accessible, since large, costly projectors will no longer be required. In our exploratory study, we have already begun to see playful, mischievous, and expressive uses of projection in public spaces. For example, Ben projected onto the sides of his neighbor's houses and contributed to the ambient entertainment at an amusement park. In the future, we anticipate that individuals and groups will employ personal projection for artistic and political expression.

4.7 Conclusion

Personal projection enables rich forms of discovery and expression that leverage the affordances of the physical and digital worlds. Participants in our study projected to share information and activities with co-present people and to transfer information between the digital and physical realms. They also played with bringing these realms into and out of alignment to aid cognition, blend concepts, and augment reality.

The uses observed in our study went far beyond the anticipated passive uses of projector phones. Users authored effects actively and dynamically by manipulating projector phones in tangible and direct ways, exploiting their support for micro-mobility and their ability to throw images out over a distance. These personal projection devices afforded a variety of representational techniques, such as superimposition, juxtaposition, scaling, and animation. The somewhat unexpected usage scenarios revealed in our study can inform the design of novel applications and interaction techniques for projector phones.

With ubiquity, everyone will have access to one or more personal, mobile, large displays. Yet projector phone use may become problematic in public settings, motivating new rules of etiquette and perhaps laws. Also, specialized applications and interaction techniques will turn projector phones into tools for tangible interaction, collocated collaboration, and creative expression. In a future with ubiquitous personal projection, managing the privacy of projected information and controlling access to projected interfaces will become increasingly important.

4.8 Acknowledgements

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Chapter 5

ShadowPuppets: Supporting Collocated Interaction with Mobile Projector Phones Using Hand Shadows

5.1 Introduction

Sharing information displayed on a mobile device's small screen with collocated people can be difficult. Pico projectors make it easier for mobile phone users to share visual information with those around them using a projected image, which can be much larger than the device's screen. However, current commodity projector phones only support input via the handset's user interface. As a result, users must look at the handset to interact with the phone's buttons or touch screen, dividing attention between the handset and the projected display. This context switching can distract presenters and viewers from ongoing conversations taking place around the projected display. Additionally, viewers may find it difficult to interpret what the presenter is doing as he interacts with the handset, and they have no direct way of providing input to the system themselves.

We present ShadowPuppets, a mobile projector phone system that allows

Figure 5.1: Interacting with ShadowPuppets prototype.

users to provide input to the system by casting shadows (Fig. 5.1). Users hold the mobile projector phone in one hand while casting shadows with the other hand, and shadows are detected using an attached camera. ShadowPuppets, like some previous research systems [17, 18], precludes the need for visual attention to the device and supports ad hoc interaction with uninstrumented environments. Additionally, shadow interaction enables bystanders to provide input by casting hand shadows, without requiring additional equipment. Potentially, multiple collocated users could interact simultaneously.

We conducted a formative survey asking 19 smartphone users about the mobile phone applications they commonly use when collaborating with others in collocated settings. The maps and photo browsing applications were the most popular applications in these settings. These results formed the basis for guiding the design of shadows for our ShadowPuppets prototype.

Our first user study was focused on determining what types of shadows such a system should support, from the perspective of a user trying to interact with the system. In this study, we showed our participants video clips of different effects for both Maps and PhotoBrowser applications that would happen in response to hypothetical user actions (i.e. panning left on a map), though no shadow was shown. Participants were then asked to produce the shadow that they felt most appropriate for causing that effect. The shadows we observed provided an initial set of shadows to explore.

Since ShadowPuppets was motivated as a method for collocated interaction, we were also interested in how observers would interpret shadows. Our second user study focused on this observer perspective. We presented participants with videos of hand shadows and then asked them to determine what kinds of effects the actor in the video was trying to cause.

In a final qualitative study, we documented how collocated users interacted with our functional ShadowPuppets prototype and reflected on their experiences. Our findings suggest that shadows can provide a natural and intuitive way of interacting with projected interfaces and can support collocated collaboration.

5.2 Related work

We build on related work on mobile projector camera systems and gestural computing. We also consider how shadows have been leveraged in interactive systems, and discuss relevant research on awareness in groupware.

5.2.1 Augmenting the environment with mobile projectors

The seminal Everywhere Displays system [95] used steerable projectors to create multiple interactive surfaces within an environment. Researchers later investigated techniques for interacting with handheld projected displays: moving and pressing buttons on the device [7], touching the projection surface with fingers [119] or moving the projector like a *"spotlight"* within a virtual information space [98]. Cao et al. expanded on this metaphor, employing passively tracked pens and projectors to define and interact with information spaces and creating techniques for collocated collaboration with multiple projectors [17, 18].

Researchers have also explored projector-device ensembles as a way of increasing interactive space. Bonfire [65] integrates projectors with a laptop to extend the interactive space to the table. Similarly, PenLight [115] and MouseLight [116] increase the interactive space for digital pens, providing visual feedback for interaction with paper.

Harrison et al. [56] analyzed vibrations to detect taps on the skin, and demonstrated using their technique to interact with an interface projected on the body, and Mistry et al. [86] relied on computer vision for interaction with a wearable camera-projector system. In the projector phone space, Greaves and Rukzio [50] found that users preferred projector-based interaction over phone-based interaction. Cowan et al. [32] (Chapter 4) documented commodity projector phone use "in the wild", finding that even without projection-specific input techniques these devices afforded novel interaction modalities.

5.2.2 Gestural interaction techniques

Gestural interaction addresses many of the issues we examine. A mobile touchscreen, such as the Touch Projector [10], can be used to interact with distant displays but requires all users to have a handheld device. Computer vision has been used for uninstrumented detection of gestures, such as pointing [21] and pinching [141]. Gustafson et al. [54] explore screenless, spatial, gestural interaction with Imaginary Interfaces, relying on users' memory in lieu of visual feedback. However, it can be difficult for observers to interpret a user's intent based on his gestures, without visual feedback, and interpretability is important for collaboration.

5.2.3 Usage of shadows in interactive computer systems

Shadows have been employed in interactive systems for both input and output because they are intuitively understood by users. Shoemaker et al. [108] explored using real and virtual shadow representations of users to extend user's reach and enhance the interpretability of indirect interaction with large wall displays, and Snibbe and Raffle [113] analyzed the use of virtual shadow silhouettes to represent participants in interactive museum exhibits. Hilliges et al. [58] motivate the use of shadow feedback for 3D interaction above tabletops and ShadowGuides [42] employed virtual shadows, visual representations of user's raw input, to guide users in learning tabletop gestures. Computer vision techniques have been developed for robustly detecting shadows [60] and shadow detection has been leveraged for estimating 3D hand positions [106], detecting surface contacts [64], and tracking above-the-surface interactions with multi-touch tables [38].

5.2.4 Awareness and presence in groupware

Much work has focused on awareness and presence in groupware, to support anticipation and interpretation of others' intentions and actions. The VideoArms system [121], which employed representations of users' arms, emphasized the role of embodiment for awareness in collocated and remote collaboration and Pinelle et al. [94] found that relative interaction and an arm-like virtual embodiment were preferred for tabletop groupware. Ishii et al [61] emphasized the value of "gaze awareness," awareness of what one's partner is looking at and attending to. Also, several systems, including VideoWhiteboard [122] and Distributed Designers' Outpost [40], have used shadows superimposed on the work surface to provide awareness of remote collaborators' activities.

5.3 Survey: What activities do people do collaboratively on their mobile phones?

We interviewed 19 volunteers (9 female), aged 21–56 ($median = 31.5$) from within our institution about their smartphone usage habits. This survey was intended to guide the design of the ShadowPuppets system by highlighting potential usage scenarios. Interviews lasted 15 minutes. During the interviews, we asked users how often they perform various activities on their smartphones. We also asked how often they perform these activities collaboratively, in collocated settings. Finally, we asked participants to pick the top three activities that were most important to them in the context of collocated collaboration, and asked them to describe some recent scenarios.

Fig. 5.2 plots the activities that were rated most important by respondents for collocated collaboration. Viewing photos, using maps, taking photos, and searching the web rated highest.

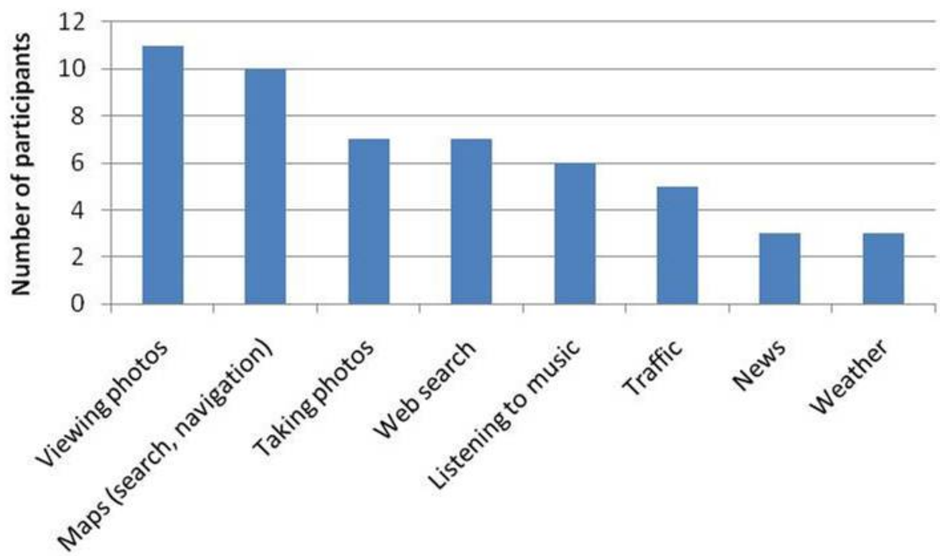


Figure 5.2: Number of participants out of 19 who rated the respective feature as most important for collocated collaboration on their mobile phone.

Since photo and map viewing were rated as the most important and most frequently performed collocated collaborative activities, we decided to study those applications further in the context of ShadowPuppets. It is less readily apparent how photo capture and web search (which requires extensive text entry) could benefit from gestural interaction with a projected display, even though these were highly rated as well.

5.3.1 Strategies for collocated collaboration

Respondents' reported strategies for face-to-face collaboration involving mobile phones varied widely. Their strategies fell into four categories: (1) one person controls the phone and verbalizes information for others, (2) one person holds up the phone for others to view, (3) the phone is passed around, and (4) someone shares a link or reference and others view the information their own phones.

Strategies were selected based on group size, closeness of participants, availability of technology, the nature of the information, and other contextual factors. Respondents also varied in their perceptions of device control and privacy: some would physically pass around their handsets while others guarded their mobile phones closely.

5.4 User Study 1: What kind of hand shadows should be used?

One of the motivations for using hand shadows as a gestural input into our system was that users already know how to generate shadows with their hands. Although all users know *how* to cast different shadows, it was unclear *what* shadows users would expect to cause the different effects that an application might support.

The purpose of this study was to see what kinds of shadows users would expect to cause various effects in the interface. We structured our study based on Wobbrock et al.'s [143] study of user generated gestures for surface computing. In this study, participants were shown video clips of effects (e.g., a map panning left) for a *Maps* and a *PhotoBrowser* application and asked to generate hand shadows they felt would cause those effects.

5.4.1 Interfaces and operations

Based on our survey results, we chose *Maps* and *PhotoBrowser* as our interface conditions. For each of these conditions, we considered 7 operations: 4 *Pan* operations (*Up, Down, Left, Right*), 2 *Zoom* operations (*In, Out*), and *Selection.* We chose these operations because they are commonly performed by users interacting with these applications, and because they could be readily conceptually mapped to spatial gestures.

For the *PhotoBrowser* application, *Pan Left* and *Pan Right* are used to view the previous and next photo, *Pan Up* and *Pan Down* are used to scroll through a list of thumbnails, *Zoom In* and *Zoom Out* are used to change the view of a photo, and Select may be used to choose a thumbnail or interact with a menu. Similarly, in the *Maps* application, users can *Pan* (we constrain the operation to 4 directions), *Zoom In* or *Out* on the map, and *Select* a marker or icon on the map or a menu option. While shadow gestures could potentially support more numerous operations, we constrained the study to existing mobile applications, rather than exploring the breadth of possible interactions. Future work could unlock the potential of the ShadowPuppets approach. A primary challenge for scaling this technique to a larger number of gestures is to design gestures that the computer vision system can recognize and that users can readily learn, perform, and interpret.

5.4.2 Task

Participants were shown a video of an *effect* of what might happen in response to some user action. They were then prompted to cast the shadow that they felt would be most appropriate for causing that effect.

Immediately after casting the shadow, participants were asked to rate two statements on a 7-point Likert scale (1=disagree, 7=agree). The first read, *"The shadow I cast was a good match for causing this effect."* The second read, *"The shadow I cast was easy to make."*

5.4.3 Apparatus

A C# program was used to present videos of the effects of gestures to users. We used a *Microvision SHOWWX* laser pico projector to display the videos. The users and their shadows were video recorded.

5.4.4 Participants

Sixteen volunteers (9 female) ranging in age from 24 to 56 years (*median* = 28.5) were recruited from within our institution. All participants were right-handed. We did not recruit left-handed participants because we expected that some of the tasks might be harder, depending on which hand was holding the projector. Half of our participants owned mobile phones with multi-touch capabilities.

5.4.5 Hypothesis

We expected that most participants would cast similar shadows for any given effect. We also hypothesized that owners of multi-touch phones would cast different types of shadows, given their experience with gestural interfaces.

5.4.6 Experimental design

We used a within-participants factorial design. The independent variables were *Applications* (*Map* and *PhotoBrowser*), *Roles* (*Owner* and *Collaborator*), and *Effects* (*Pan Up, Pan Left, Pan Right, Pan Down, Zoom In, Zoom Out,* and *Select*).

Presentation of *Application* was counterbalanced across participants. We considered mixing tasks from the two *Application* conditions together. However, that might have caused users to converge on the same set of gestures for both contexts, a behavior that we were independently interested in. For each application, we considered two *Role* conditions: *Owner* and *Collaborator*, with order of presentation counterbalanced across participants. In the *Owner* condition participants held the projector in their left hands and gestured with their right hands, standing 6 feet from the projection surface. In the *Collaborator* condition participants did not hold the projector and stood forward and to the left of the projector, 3 feet from the projection surface. Because *Collaborators* had both hands free, they could use either or both hands to cast shadows. Within each condition, the various *Effects* were presented in random order.

In summary, the experimental design was: 2 *Applications* (*Map* and *PhotoBrowser*) 2 *Roles* (*Owner* and *Collaborator*) 7 *Effects* (*Pan Up, Pan Down, Pan Left, Pan Right, Zoom In, Zoom Out* and *Select*). This resulted in 28 videos shown to 16 participants for a total of 448 shadows.

5.4.7 Goodness of match and ease of making gesture

We examined the participants' ratings using the Mann-Whitney test. Participants rated their shadows in the *Collaborator* condition ($median$ = 6) with significantly higher goodness ratings ($U = 21468.00$, $z = 2.74$, $p < .01$) than in the *Owner* condition ($median$ = 6). They also rated their shadows in the *Collaborator* condition ($median$ = 7) with significantly higher easiness ratings ($U = 21201.50$, $z = 2.944$, $p < .01$) than in the *Owner* condition ($median$ = 6).

Owners of multi-touch mobile phones rated their shadows significantly higher on the goodness rating ($median = 6$, $U = 21201.50$, $z = 2.944$, $p < .01$) than non-owners ($median$ = 6). Owners of multi-touch devices also rated their shadows significantly easier ($U = 20102.00$, $z = 3.821$, $p < .001$) than non-owners ($median$ = 6).

5.4.8 Most common gestures

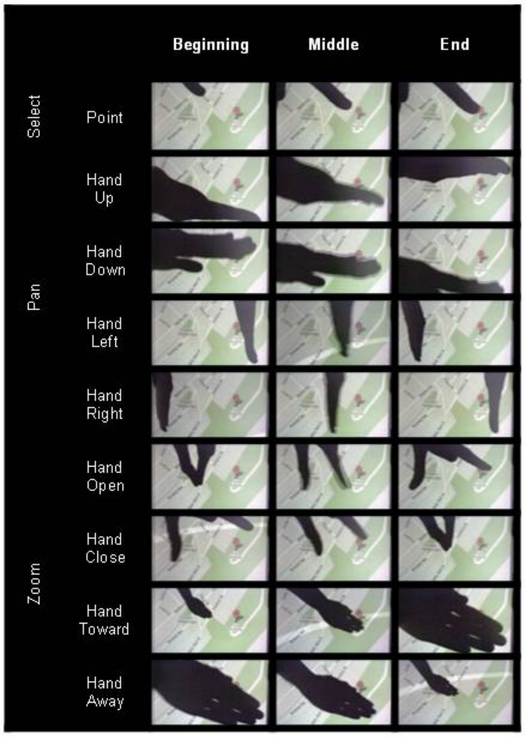
Here we highlight some of the more common shadows made in response to the different effects. The most popular gestures are highlighted in Fig. 5.3. In general, participants would perform similar gestures for a particular effect regardless of the role of *Owner* or *Collaborator*.

Collaborator

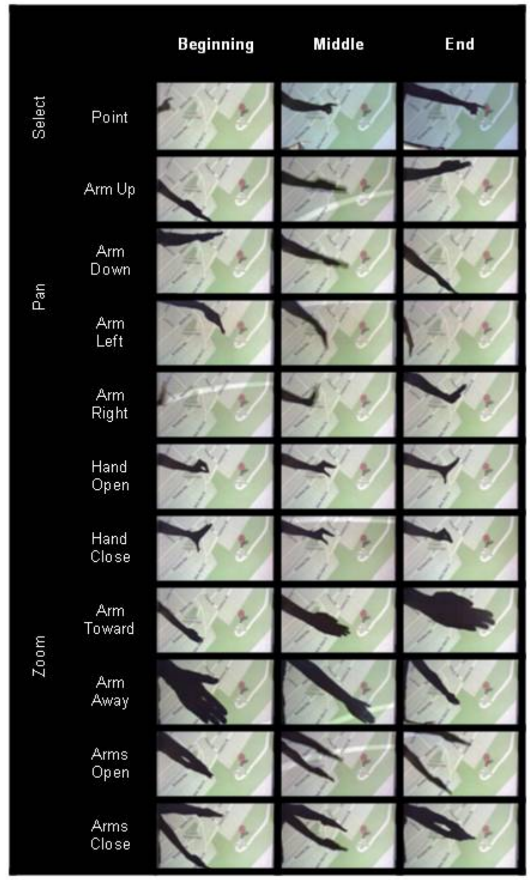
Pan: Participants would move their hand or arm across the projection in the direction they wanted to pan. Twelve of 16 participants performed this type of gesture. This is shown as *Arm Up/Down/Left/Right* in Fig. 5.3.

Zoom: Participants were split on their zooming technique when standing near the wall. Nine of 16 participants performed large opening and closing gestures with their arms (*Arms Open/Close*). Three participants performed an opening or closing of their hand (*Hand Open/Close*). Four participants would move their hand toward or away from the projector (*Arm Toward/Away*).

Select: Fourteen participants performed some variant of pointing for selection (*Point*). Of these fourteen, ten would hold their finger near the marker and



(a)



(b)

Figure 5.3: The most common shadows generated by users for panning, zooming and selection. (Left) shows the shadows made in the *Owner* condition. (Right) shows the shadows made in the *Collaborator* condition. These are representative of shadows generated by users in Study 1 and formed the basis for the video clips used in Study 2.

dwell, while others would wiggle or tap their finger to indicate selection.

Owner

Pan: Similar to the *Collaborator* condition, 12 participants moved their hand in the direction they wanted to pan (*Hand Up/Down/Left/Right*).

Zoom: Eleven participants performed some form of pinching (*Hand Open/ Close*) to zoom in and out. Four participants moved their hand toward or away from the projector (*Hand Toward/Away*) to zoom.

Select: Participants used the same form of selection as in the *Collaborator* condition, with 14 participants performing some form of pointing (*Point*).

5.4.9 Discussion

The results of this study show that there was high agreement for many gestures, and similar shadows were cast for both the *Maps* and *PhotoBrowser* applications. Yet multiple gesture aliases may be helpful for supporting different usage scenarios (e.g. right or left-handed) when there is low agreement [143]. For example, there was some disagreement among users regarding pan direction, e.g. some users wanted to move their hands up to *Pan Up* while others wanted to move their hands down to cause the same action. Also, some users thought of zooming as expanding/contracting (performed by opening or closing the hand or arms in pinch-style gestures) while others thought of it as pushing/pulling (performed by moving the hand or arm toward or away from the projector). In cases like this, the designer can either make an arbitrary choice or provide aliases from which users can choose.

Users typically wanted to perform symmetric gestures to perform inverse operations, but this was not always comfortable. Moving the right hand from left to right to *Pan Right* (*Owner* condition) was difficult when holding the projector in the left hand. Similarly, trying to move the arm right to left can be difficult when standing on the left side of the projection (*Collaborator* condition).

Most participants preferred the *Collaborator* condition (14 for *Maps* and 13 for *Photos*). They preferred *Collaborator* because their hand shadows were smaller relative to the display. As a result, they were able to control their shadows with finer granularity, and their shadows occluded less of the display. This was also reflected in significantly higher goodness and easiness ratings. Participants also described *Collaborator* as more *"intuitive"* since their shadows typically remained within the frame. In contrast, when they were holding the projector in the *Owner* condition, they had to first locate the projection frame and then position their hands appropriately. Participants also described *Collaborator* as more *"familiar"* and *"comfortable."* The participants who preferred *Owner* cited feeling more in control.

Even though we told participants that we were studying how to use shadow gestures for interaction, many of them described the experience as *"like using a touch screen."* They viewed shadows as a kind of virtual touch on the projection surface, i.e., the shadows were the contact points on a virtual, distant touchscreen.

Users typically mentioned familiar metaphors to describe their shadow gestures, which seemed to provide some benefits of virtual reality. They drew on the direct manipulation GUI paradigm (*"using a trackball or mouse," "clicking," "using a scrollbar"*) and on the physical world (*"grasping," "pushing," "pulling," "pinching," "tapping," "clicking,"* and *"pointing"*). Only one user made a symbolic gesture (drawing a "z" with her finger to zoom).

In many cases, our user-centered design approach resulted in direct translations of familiar multi-touch gestures, drawn from participants' prior knowledge and experiences. Direct translations, however, may sometimes be appropriate and are common starting points in new domains.

5.5 User Study 2: Do users understand our language of hand shadows?

The previous study helped guide the set of shadows that our system should support. However, it remained to be seen whether casual observers would be able to determine the desired effect when shown a shadow gesture. As we alluded to earlier, this would be a potential benefit of using shadows for collocated interaction.

The purpose of this study was to see whether participants would be able to identify what action a user was trying to perform based on his hand shadow.

We also hoped to gain insight on an observation from the previous study regarding different shadows. For certain effects, multiple types of shadows were observed. Were some shadows more understandable than others?

In the previous user study we showed users an effect and elicited the gesture that would cause it. In this study, we did the inverse. We presented participants with a video clip of a shadow being cast and asked them what effect they thought it would cause. We were motivated to run this follow-up study, as suggested by Wobbrock et al. [143], to gauge the intuitiveness of the gestures elicited in the previous study.

5.5.1 Task

We presented short video clips (about 2 seconds in duration) of an actor making hand gestures that cast shadows on a static image of a map projected onto a wall. For each video of a shadow gesture, we asked the participant to describe what he thought the actor was trying to do with the map. In the video, the map did not actually respond to the shadow gestures (rendering this task harder than understanding interaction with a working system that provided immediate feedback). Rather than give users options of different effects to choose from, we left it as an open-ended response. This more closely reflected a real-world situation whereby one user has to determine what another user is trying to do based on their shadow gestures.

5.5.2 Participants

We recruited 16 volunteers (8 female) aged 20–57 ($median = 28.5$) from within our institution. Eleven were smartphone owners, and 5 were owners of multi-touch mobile phones. No participants were reused from User Study 1, since prior experience could bias participants' understanding.

5.5.3 Gestures

Based on the results of our previous study, we selected a set of gestures for each effect to present to users. Participants in User Study 1 performed many distinct gestures, and we aggregated them to create canonical gestures, trying to balance ease of recognition for users and for the system. Hence we recorded videos of an actor performing these canonical gestures, rather than using videos of participants' "raw" gestures captured during the previous study.

The set of gestures in the *Collaborator* condition include 4 panning gestures (*Arm Left, Arm Right, Arm Up, Arm Down*), 3 variations on *Zoom In* and *Zoom Out* (*Hand Open* and *Hand Close*, *Arms Open* and *Arms Close*, *Arm Toward* and *Arm Away*), and selection (*Point*). The set of gestures in the *Owner* condition include 4 panning gestures (*Hand Left, Hand Right, Hand Up, Hand Down*), 2 variations on *Zoom In* and *Zoom Out* (*Hand Open* and *Hand Close*, *Hand Toward* and *Hand Away*), and selection (*Point*) triggered by dwell.

5.5.4 Experimental design

In our previous study, people used similar gestures for interacting in the *Maps* and *PhotoBrowser* conditions, so in this study, we considered only one condition. We arbitrarily decided to use *Maps*. We presented the gesture videos using the same two role conditions as in User Study 1: *Collaborator* and *Owner*. Order of presentation was counterbalanced across participants. Within each condition, operations were presented in random order. Each participant observed 20 shadows: 11 shadows in the *Collaborator* condition, and 9 shadows in the *Owner* condition.

5.5.5 Results

Gender had an effect on goodness ratings with females rating (*median* = 6) the shadows significantly higher (U = 9675.50, z = 3.914, $p < .001$) than males (*median* = 6). There were no significant differences in goodness ratings for the different zooming techniques. We aggregated responses across participants, and found that participants rated the *Owner* condition (*median* = 6) significantly higher (U = 10692.50, z = 2.492, $p < .05$) than the *Collaborator* condition (*median* = 6).

In a post-study questionnaire, we asked each participant which role condition they preferred overall. Five users preferred *Collaborator*, citing the finer granularity (the hand shadow appears smaller, enabling more precise gestures) and the clarity from two handed usage. Eleven users preferred *Owner*, because the gestures were more clearly defined (framed by the projection area) and more similar to familiar touchscreen gestures.

gesture	pan up	pan down	pan left	pan right	zoom in	zoom out	select	other
hand up	15							draw path
hand down		15						move pin down
hand left			15					move pin left
hand right				16				
hand open					14	1		measure distance
hand toward					15		1	
hand away						14	2	
hand close					2	14		
point				1			15	

Figure 5.4: Effects (column) perceived by participants for each of the different gestures (row) used in the *Owner* condition. Shaded boxes (diagonal) indicate effects we expected to see for each particular gesture.

Fig. 5.4 and Fig. 5.5 tally the effects that our participants associated with different gestures. There was high agreement among users that particular shadows should cause particular effects, and these effects were the ones we expected. On the whole, the effects associated with the different hand shadows reflected similar findings to User Study 1. The outliers associated slightly different effects with certain hand shadows due to ambiguities arising from body mechanics. For example, one person thought the *Collaborator Arm Up* and *Collaborator Arm Down* gestures were intended to rotate the map because, in the video, the user's arm moves up or down relative to the shoulder's axis. Similarly, viewers expressed confusion when gestures for performing inverse operations were not symmetrical. For example, in the videos for *Owner Hand Left* and *Owner Hand Right*, the hand is facing different directions, which feels more natural.

gesture	pan up	pan down	pan left	pan right	zoom in	zoom out	select	other
arm up	15							rotate
arm down		14						rotate, move pin
arm left			16					
arm right				15				move pin
hand open					16			
arms open					15	1		
arms toward					15			go back to prev location
hand closed					1	15		
arms closed					2	14		
arm away					1	14	1	
point				1			15	pan right

Figure 5.5: Effects (column) perceived by participants for each of the different gestures (row) used in the *Collaborator* condition. Shaded boxes (diagonal) indicate effects we expected to see for each particular gesture.

Like in User Study 1, there was some confusion regarding gestures for *Zoom In* and *Zoom Out*. We believe that in an interactive system, this ambiguity will resolve itself.

5.6 ShadowPuppets prototype

We built a functional prototype to enable us to study the social implications of ShadowPuppets. The system consists of a Logitech 1.3 MP webcam attached to a *Microvision SHOWWX* laser pico projector (Fig. 5.1). Due to low refresh rates associated with the video-out functionality of mobile phones, we used a laptop to drive the display of our prototype . This prototype is intended to simulate a future version running on a mobile phone. The camera and projector are 6cm apart, reasonable for a handheld device.

5.6.1 Gesture recognition

Our ShadowPuppets prototype was written in C++ using OpenCV. At startup, a calibration step is performed to detect the outer edges of the projected image and the grayscale value of the projection surface. Each frame is thresholded to extract the shadow pixels (pixels with grayscale values close to that of the projection surface).

Connected components within the shadow pixels are detected and then filtered, keeping only the blobs with areas above a threshold, to reduce noise. The system detects a pan or zoom gesture when the average second derivative of the shadow pixels' centroid position or total area over a window of time is above a threshold, and it detects a select gesture when these metrics are below a threshold. We use the second derivatives to avoid the need for an explicit clutching mechanism. The system recognizes one gesture at a time, and a timeout is inserted after recognition to avoid falsely interpreting recoil actions as gestures.

Selection (***Point***)

To detect pointing shadow-gestures, we detect fingertips using an approach similar to Manresa et al. [82]; we look for points on the convex hull that are separated by defects, using the point separated by the deepest defects as our estimate of the fingertip.

When the location of this fingertip is stable over a window of time, we trigger a selection event. The projected map indicates selection by displaying a pop-up box with information about the selected point. The pop-up is removed when another form of input is detected.

Panning (***Hand Up, Hand Down, Hand Left, Hand Right***)

We track the acceleration of the shadow blob's centroid, taking the average over a sliding window (tuned empirically) of video frames to smooth the sensed data. If the average acceleration in the vertical or horizontal direction is above a threshold, then we fire a *Pan* event (*Up, Down, Left,* or *Right*), choosing the direction with highest average acceleration. The projected map provides visual feedback, panning in the indicated direction. Similar to existing map applications, we use high initial velocity with constant acceleration in the direction opposite of motion.

Zooming (*Hand Toward, Hand Away, Hand/Arms Open, Hard/Arms Close*)

Our prototype supports two methods of zooming. Users can either move their shadow towards/away from the wall, or they can perform pinching.

To detect moving the shadow towards/away from the wall we track the second derivative of the change in area of the shadow blob. Again, we use the average over a sliding window for smoothing, and if this average is above a threshold we detect a *Zoom* input event.

Recognition of pinch-style zooming gestures was implemented by detecting finger points, similar to selection. When a transition from one fingertip to two fingertips was observed in close proximity, we fired a *Zoom* event. Unfortunately, in our pilot studies we found that the hand often occluded the shadow in the camera, making detection of this technique unreliable. Because of its unreliability, we left it out of our final user study. Increasing the distance between the camera and projector would reduce occlusion but would also increase the size of the device. A potential future approach could combine shadow and hand detection or consider shared axis approaches.

Implementation challenges

Pico projector-based shadow gesture recognition faces some general challenges. Shadow detection requires sufficient contrast between the shadow and the projected content, and may suffer if ambient light is bright.

5.7 User Study 3: Experiences with the ShadowPuppets prototype

We conducted a laboratory-based pairs study with our ShadowPuppets prototype to gain insight into users' experiences when using shadow gestures for collocated collaboration. We hoped to learn how it feels to perform the gestures with an interactive system, and what social and technical issues arise when two users interact with the system together. Our prototype supports a simple maps application that responds to ShadowPuppets hand shadow gestures, and we observed pairs of participants using it.

5.7.1 Task

We first briefly demonstrated how to use each supported gesture to interact with the maps application. The prototype supports 7 different types of shadows (for both roles *Collaborator* and *Owner*): *Hand/Arm Right* to *Pan Right*, *Hand/ Arm Left* to *Pan Left*, *Hand/Arm Up* to *Pan Up*, *Hand/Arm Down* to *Pan Down*, *Hand/Arm Toward* to *Zoom In*, and *Hand/Arm Away* to *Zoom Out*.

During the study, one participant performed gestures in the *Collaborator* condition, while the other participant gestured in the *Owner* condition, as described previously. We asked the participants to interact with the map for 10 minutes using ShadowPuppets, then trade roles (*Collaborator/Owner*) and interact with the map for another 10 minutes. In a post-study interview, we asked participants to describe how it felt to perform each class of gesture: *Panning, Zooming,* and *Selection*. We also asked the participants to reflect on their preferences, between the *Collaborator* and *Owner* conditions, and their overall experiences using ShadowPuppets as a pair. We asked participants to think aloud during the task.

5.7.2 Participants

We recruited 8 volunteers (3 female), aged 24–30 (median 27), in 4 pairs of acquaintances, from within our institution. Five participants were reused from

User Study 2. Seeing shadow gestures on video beforehand was not likely to bias participants' experiences performing them, since gestures would be demonstrated for training purposes.

5.7.3 Results

All participants learned the gestures quickly; they were able to remember them after viewing a single demonstration of each, and described them as *"intuitive"* and *"making sense."* 7 of 8 participants had positive overall impressions, describing shadow gestures as *"natural," "cool,"* and *"useful."* The 8th participant explained that he does not like any gestural interfaces because they are imprecise.

Participants envisioned using shadow gestures to interact at-a-distance during presentations while teaching, while in a meeting, or while sharing photos or videos with friends. One participant, a projector phone user, volunteered that she would want to use shadow gestures individually to get the full benefits of a large projected display, avoiding having to interact with it via the phone's screen.

Panning

All participants volunteered that panning felt *"comfortable," "natural,"* and *"intuitive."* One participant felt that the gestures were too large, and would prefer if a smaller physical movement would results in a larger movement of the map. Six participants wanted to have more control over how much or how fast to pan, suggesting that the distance and speed of the gesture should correspond to the distance and speed of the pan. Four participants suggested implementing a clutching mechanism, e.g. a hand gesture such as *"grabbing,"* to control when a gesture should activate an input event. Four participants experimented with moving the projector relative to the shadow to pan.

Zooming

All the participants described zooming as intuitive and feeling good. One participant (who also participated in the inverse gesture study) commented that he had hated the *Hand Toward/Away* gestures in the videos but that doing it was a lot more intuitive, *"like bringing the map closer to you or pushing it away from you."*

Selection

All the participants liked using pointing for selection. Two participants suggested making a *"tapping"* finger motion to activate selection (as suggested in Study 1). Another participant remarked that shadows are especially good for pointing because it's unambiguous what you are pointing at. He explained that *"when you're in a group and just pointing, the perspective is different for different people, but shadows make it much clearer since everyone sees the same shadow."*

Collaborator/Owner conditions

Six participants preferred the *Collaborator* condition because they didn't have to hold the projector steady while gesturing. Four of the participants said that holding the projector and gesturing felt awkward, and one participant noted that the shadow was too large to control since a small movement had a big effect. Two participants preferred the *Owner* condition because they felt that the person holding the projector had priority to make gestures and had more control: *"I don't think you have as much control if you're not holding it."*

Social aspects of collaboration with ShadowPuppets

All the participants liked that more than one person could interact with and manipulate the map, and thought shadow gestures would be good for group interaction. All the participants said that while interacting, they primarily focused their attention on the shadows on the projected display, while attuning to their partners in their peripheral vision.

Because the prototype does not support multiple gestures simultaneously, participants in each pair took turns, negotiating control verbally or by body language (*"if they look like they're going to do something"*). When both participants tried to gesture simultaneously, several strategies were employed for managing conflict: they verbally negotiated, both participants backed off and then tried again after an interval, or they *"went over the top of each other and the map did its own thing."* One pair of participants experimented with collaboratively coordinating their actions, with one moving the projector relative to the other's hand.

During the interaction task, one participant in the Owner condition intentionally thwarted his partner's gestures by pointing the projector away from her, and unintentionally caused the same problem in the Collaborator condition by standing in front of the projected display and occluding it. After the task, when asked how they would prevent the other person from doing something, participants said they would make a confounding gesture (*"making the opposite gesture"*, *"waving my arms around"*, or *"doing the chicken dance"*), move the projector to point in a different direction (as observed), or occlude the projector by covering it with a hand or standing in front of it.

5.8 Reflections on shadow-based input

Initial experiences with ShadowPuppets indicate that the system shows promise for supporting collocated interaction. Both participants in each pair were able to view and interact with the projected interface, maintaining awareness of each other's actions while focusing on the shared display. Our studies highlight the following issues.

5.8.1 Challenge of designing for performers and observers

Supporting both performers and observers of shadow gestures presents a challenge, since they may have conflicting experiences and goals. To facilitate collocated collaboration shadows should be intuitive and comfortable to perform, and also easy for viewers to interpret. Yet these goals may be at odds with one another. For example, users in Study 1 found it easier to control their gestures in the *Collaborator* role, while users in Study 2 found shadows cast in the *Owner* role to be clearer. Similarly, in Study 1 users sometimes performed asymmetric gestures to perform inverse operations in a way that felt comfortable, while users in Study 2 found those gestures harder to interpret.

5.8.2 Need for fine-grained interactions

As a first step toward understanding the use of shadow gestures as input, we have examined coarse-grained interaction. Although, we explicitly focused on this part of the design space, users wanted more precision. For example, we selected a set of 7 relatively coarse operations to study and implement, and presented them to users in general terms (e.g., *"pan left"* rather than *"pan left such that the marker on the map is centered"*). Yet in Study 3, participants wanted their shadows to perform more precise operations (e.g., controlling the range and speed of panning and zooming), and in Study 2 they often interpreted gestures more precisely than we intended.

5.8.3 Most popular gestures may not be best

We posit that the most popular gestures are not necessarily the best. For example, the gestures with highest agreement scores in User Study 1 may simply be the most familiar. People are biased by what is familiar to them and new ways of interacting may not occur to them immediately. For example, many users suggested pinching gestures, direct translations of familiar iPhone-style multi-touch gestures, while only 25% of users suggested motion in the *throw* dimension (toward or away from the projector). Users' prior expertise also led them to rate pinching gestures higher on the goodness and easiness ratings. Yet in User Studies 2 and 3, we found that *Hand Toward/Away* and *Arm Toward/Away* were intuitive to most users. If we had only considered the results of User Study 1, we might not have even explored those gestures at all. As Norman proposed, user-centered design may not always be the right approach [90].

5.9 Conclusion and future work

In this chapter we presented ShadowPuppets, a system that allows collocated users to provide input to a mobile projector based system by casting hand shadows.

We made four contributions. First we presented the results of a user study examining what types of shadows users expect to cause different effects. Second, we examined what kinds of effects users expect different hand shadows to cause. Third, we presented the design and implementation of the ShadowPuppets prototype, allowing collocated users to interact with a projected display. Finally, we presented the results of a user study of our prototype, suggesting issues that arise with using shadow-based input.

As future work, we plan to examine how to combine some of the coarse-grained interaction techniques described here with other techniques that provide fine-grained control.

5.10 Acknowledgements

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Chapter 6

Conclusion

6.1 Summary

Humans are inherently social. Digital social media tools are transforming how we exchange information and manage our relationships, and they provide capabilities for lightweight communication. Communication needs can arise anytime and anywhere, and the mobile phones we carry with us can support us in meeting them, yet interactions that are lightweight on the desktop may become cumbersome on mobile devices due to their small screens and keypads. Also, interaction with mobile devices is often embedded in other activities, so users' attention may be divided. Therefore, mobile interactions must be even more lightweight than those designed for the desktop. Mobile tools must be specifically designed to address the challenges of the mobile milieu in order to preserve the lightweight characteristics of interactions.

Supporting lightweight interaction is key to enabling social communication anytime and anywhere. If sending a message is too cumbersome, then a user may defer sending it or simply never send it. Also, lighter weight mobile tools can reduce the risk of distracting users from what's going on around them.

Communication tools can leverage the power of the human visual system to support lightweight communication. By exploiting this system's high speed and bandwidth, we can reduce the time and attention required to communicate. Visual media can leverage this power, and can also enable concise, rich forms of expression.

We posited that mobile tools can support expressive, lightweight communication through three design devices: leveraging users' existing tools and practices, streamlining essential interactions, and exploiting the rich affordances of visual media. By leveraging existing tools and practices, we can design natural, lightweight interactions that fit into the flow of users' lives. We also provide a minimal set of essential features and streamline the process of capturing, publishing, and responding to messages. We avoid requiring interaction except to control system behavior or explicitly express intent, and we minimize these essential interactions. Next, we exploit visual media's affordances for communication, harnessing the power of the human visual system and the richness of visual expression.

To evaluate our ideas, we explored the design space of tools for supporting lightweight social communication using visual media and mobile devices. We considered the significance of four design dimensions: proximity (proximate or remote), interaction focus (input or output), media, and structures of participation (symmetry of participants' capabilities and dynamics of group structure). In our analysis, we considered how and why people communicate using these tools, the social consequences of using them, and the implications for design.

We described four projects representing points in this design space, covering the space in the dimensions of proximity and interaction focus (Emotipix: remote output, UbiSketch: remote input, projector phones: proximate output, and ShadowPuppets: proximate input). In the Emotipix study, described in Chapter 2, we aimed to reduce demands on users' attention by embedding an ambient display of photos and associated feedback in the background of the mobile workflow. In the UbiSketch study, described in Chapter 3, we aimed to enrich lightweight social communication by adding support for sketching, via familiar interactions with pens and paper. In the projector phone study, described in Chapter 4, we addressed the difficulty of viewing and sharing information via mobile phones' small displays by exploring the use of personal, mobile projection. In the ShadowPuppets study, described in Chapter 5, we addressed the lack of support for collaborative interaction with projector phones by enabling collocated users to provide input by casting hand shadows.

6.2 Reflecting on the hypothesis

We now reflect on our hypothesis that mobile tools can support expressive, lightweight communication through three design devices: leveraging users' existing tools and practices, streamlining essential interactions, and exploiting the rich affordances of visual media.

6.2.1 Leveraging existing tools and practices

Overall, leveraging existing tools and practices was effective for supporting lightweight communication. For example, participants in the UbiSketch study shared sketches they created during classes, replacing or supplementing their existing pens and notebooks with the digital pens and specially-printed notebooks we provided, and participants in the Emotipix study regularly saw photos in the backgrounds of their mobile phones' screens while checking the time. Also, according to participants in the ShadowPuppets study, the shadow gestures we designed (leveraging users' familiarity with shadows and spatial hand gestures) felt natural to perform and were intuitively understood.

However, the technology interventions we introduced in our studies sometimes caused changes to users' tools and practices. For example, the digital pens employed in the UbiSketch study were somewhat different from ordinary pens — they required charging, felt wider to hold, and sometimes provided ambiguous vibratory feedback (to indicate that the pen's camera could not see the Anoto dot pattern on the paper, for one of several possible reasons). Also, users sometimes changed their practices after the introduction of our technology interventions or used the technology in unexpected ways. For example, one participant in the UbiSketch study began using the provided notebook and pen in addition to his existing ones in order to physically separate his sketches and class notes. Also, some participants in the Emotipix study began to explicitly check their phones for new photos in the *wallpaper*, rather than simply glancing at the background in the course of their mobile workflows, and to look through the cached photos to check if they had missed any. These practices were complementary to Emotipix's intended "calmness".

6.2.2 Streamlining essential interactions

Overall, streamlining essential interactions was effective for supporting lightweight communication. Participants in the Emotipix study were able to easily view photos without becoming distracted, and Emotipix's automated publication mechanism lowered barriers to photo sharing. Also, participants' communications evinced conversational structure despite the lack of any explicit software infrastructure to support that. Participants in the UbiSketch study were able to easily publish paper sketches to social media channels with a single *tap* of the pen on a *paper button*, and several remarked that they liked not being able to erase or *undo* ink strokes because it freed them from getting caught up in details and striving for perfection (and it was also consistent with ordinary pen-and-paper drawing). And ShadowPuppets precluded the need for visual attention to the handset, enabling pairs interacting with the prototype to focus their attention on the projected display and each other, avoiding distraction.

However streamlining interaction could also have drawbacks. For example, in the Emotipix study we saw how automated publication risked accidental disclosure. Photos were published automatically by default, unless a user canceled the publication, and in a few cases photos were published unintentionally. This issue was further compounded by the lack of a *delete* feature. Also, in the UbiSketch study, some participants would have liked to have an *undo stroke* feature to enable incremental revision of sketches (e.g., to preclude the need to start over to fix a mistake).

6.2.3 Exploiting the rich affordances of visual media

Visual media were effective for supporting rich, lightweight communication, yet each medium we employed had a distinct set of affordances and drawbacks.

With Emotipix, publishers were able to quickly capture physical scenes in photos, and viewers were able to quickly glance at photos. However, the photos were displayed at small size and low resolution on mobile phone screens, limiting their expressive capabilities. UbiSketch users were able to externalize thoughts by sketching, which enabled them to express things that they could not easily, concisely, or comfortably express in words, and viewers were typically able to understand the sketches' contents and relate to the authors' sentiments. Pure drawings could sometimes be ambiguous though, and handwritten words and textual comments were often added for clarification. In the projector phone study, we observed that handheld projectors enabled users to employ a variety of representational techniques, leveraging the projector's position and orientation, the projected content, and elements of the physical environment to convey information. However, we also saw how these devices could intrude on the experiences of bystanders, making them involuntary participants in interactions. In the ShadowPuppets system, hand shadows provided embodied representations of users, supporting immediate visual feedback, like a cursor, and awareness of collocated interactions. However, shadows occluded the projected display, and users sometimes leveraged this property to prevent others' shadow gestures from being recognized.

6.3 Contributions

We now discuss the contributions of the dissertation and of each project.

6.3.1 Contributions of the dissertation

This dissertation contributes the results of four projects, which consider how tools for lightweight mobile communication can avoid distracting users from the local environment, enable rich forms of expression, lower barriers to social interaction, and support collocated interaction. Critically, we observed that seemingly effortless, lightweight interactions can support meaningful communication. This dissertation makes the following contributions.

- **Design space.** We mapped out a design space of lightweight social communication using visual media and mobile phones. We conducted four projects to explore this space, covering it in the dimensions of proximity and interaction focus, and we considered how various design decisions impact communication.

- **Design devices.** We contributed three design devices (leveraging existing tools and practices, streamlining essential interactions, and exploiting the affordances of visual media), which we validated by implementing functional prototype systems and conducting user studies. These techniques can be employed to design tools for supporting lightweight, expressive communication in the mobile domain and perhaps beyond.

We would like to look at additional parts of the design space (e.g., synchronous, remote communication). Also, further work is needed to evaluate the applicability of these design devices to other domains, to consider if they generalize beyond social communication using mobile phones. For example, they could be employed in the design of tools for supporting collaborative work.

6.3.2 Contributions of the Emotipix project

The Emotipix project explored using glanceable, ambient, mobile displays that place low demands on users' attention to support social communication. To study engaging the periphery of users' attention for communication, we created the Emotipix prototype application. Emotipix streamlines photo publication, which is automatically triggered when a user captures a cameraphone photo, displays shared photos in an automated slideshow in the background of a mobile phone's screen, and enables users to provide feedback (which becomes visibly embedded in the associated photo) with a single *tap*. We conducted an exploratory field study, with 16 participants over 2 weeks, which made the following contributions.

- **Periphery of attention.** We learned that that engaging the periphery of attention for social communication on mobile phones is effective for supporting social awareness, connectedness, and conversation in a non-disruptive, calm manner. Users were able to view displayed photos at-a-glance in the background of the mobile workflow while checking the time or transitioning between tasks.

- **Managing expectations.** A mobile glaceable display can introduce interesting ambiguity and serendipity into communication; a sender does not know when or even if a particular message will be received. This type of interface can lower perceived barriers to communication yet is not appropriate for conveying time-dependent or critical information. We learned that it is important to manage users' expectations as they begin to use ambient displays for communication to mitigate the risk of social complications resulting from misconceptions (e.g., expecting friends to respond to a message they have not yet seen).

- **Automation and user control.** We learned that it is challenging to manage the tension between system automation and user control in the design of personal, mobile, ambient displays. The Emotipix system displays published photos in an automated glanceable display intended to avoid disrupting users, yet users wanted more control. For example, publishers sometimes explicitly alerted their friends of new photos and viewers wanted to ensure that they saw all published photos, cycling through the cache to see if they had missed any.

A number of challenges remain for future work on mobile ambient displays. One question is how to give users more options for control without sacrificing "calm" and increasing the risk of distraction. Another question is how to display more complex kinds of information (e.g., information from multiple applications or historical overviews of dynamic information) in a single mobile ambient display, perhaps by dividing the display spatially or temporally.

6.3.3 Contributions of the UbiSketch project

The UbiSketch project explored ubiquitous sketching, enabling users to share paper-based information on social media in real time. We began by mapping out the design space of ubiquitous sketching and analyzing the tradeoffs within this space. We discussed the affordances of several approaches to capturing sketches, such as cameraphone photography, touchscreen and tablet devices, and digital pens and paper, and given the advantages of digital pens and paper, including their accuracy, naturalness and convenience, we chose to explore this part of the design space.

We wished to gain insight into how ubiquitous sketching impacts social communication, so we created the UbiSketch prototype, which integrates digital pens, paper, and mobile phones. UbiSketch enables users to share paper-based sketches on social media (Facebook, Twitter, and email) with a single *tap* of a pen on a *paper button*.

We conducted an exploratory field study of ubiquitous sketching, as realized by UbiSketch. We documented ten participants' practices over four weeks and analyzed the interactions that resulted from posting their sketches on Facebook. The UbiSketch field study made the following contributions.

- **Affordances of sketching.** We learned that UbiSketch enabled participants to leverage the unique affordances of sketching for visual communication. By sketching, they were able to easily express some thoughts and feelings that would have been more difficult or socially awkward to express in other modalities, such as text or photos.

- **Synergy with social media.** We found that the ease and immediacy of publishing sketches with UbiSketch enabled participants to share information in-the-moment, creating a synergy with prevailing social media practices. For example, they published context-dependent information, micro-messages, and personal status updates.

- **Stimulating social interactions.** We observed that ubiquitous sketching, compared with prior photo-based practices, broadened and deepened social interactions on Facebook. Participants posted more sketches, their sketches received more feedback (comments and *likes*) from friends, a wider group of friends responded, and the posted comments were more personal.

In the future, we would like to investigate other parts of the design space of ubiquitous sketching, perhaps running a comparative study to increase our understanding of how capture and publication mechanisms impact users' experiences. Also, we are interested in exploring how static and dynamic representations of sketches can be employed to convey additional kinds of information. For example, we would like to visually indicate the force applied while drawing through static representations, such as stroke color or thickness, and we would like to dynamically represent timing through animation (e.g., *replaying* of sketches).

6.3.4 Contributions of the projector phone project

In this project we considered the use of projector phones, which enable users to project displays that are much larger than mobile phones' screens, making it easier to share displayed information with collocated people. To begin to document usage practices, we conducted a four-week exploratory field study. The projector phone project made the following contributions.

- **Contextual factors.** We documented how contextual factors influenced projector phone interactions. As one might expect, individuals in private settings were unconcerned about an audience, and pairs in private settings leveraged their shared interests, knowledge, and experiences in their interactions. In usage by small groups in semi-private settings, the interaction became a more public performance and the content became less personal. Pair and small-group interactions in public settings were expressive, entertaining, or mischievous, and users oriented their interactions toward both friends and strangers.

- **Active authorship.** We observed that participants' uses of projector phones went far beyond the passive uses for which these devices have been marketed. Projector phones support *micro-mobility*, enabling users to readily position and orient projected information during interactions. Users leveraged this facility to actively author effects by manipulating handheld projectors in tangible, direct ways to show, hide, or orient their displays.

- **Representational techniques.** Projector phones' support for *micro-mobility* and their ability to throw images over a distance supported a unique concentration of representational facilities. These personal, mobile projection devices afforded a variety of representational techniques, such as superimposition, juxtaposition, scaling, and animation. Thus, even the "basic" projector phone platform affords novel interaction modalities.

- **Envisioning the future.** We envisioned a future in which projector phones are ubiquitous and projected displays become spaces for both input and output. With ubiquity, projector phone use may become problematic in public settings, motivating new rules of etiquette and perhaps laws. Also, as projected displays become increasingly interactive, projector phones will become even more powerful tools for supporting collaboration and creative expression. Yet, with ubiquity and interactivity, managing the privacy of projected information and controlling access to projected interfaces will become increasingly important.

As projector phones become increasingly ubiquitous and interactive, we are interested in documenting how usage practices evolve. Also in future work, we would like to explore using personal mobile projectors to support ambient displays (e.g., for use in the home at night). We are also interested in exploring how handheld projectors can be employed to support creative processes, such as design, animation, and storytelling.

6.3.5 Contributions of the ShadowPuppets project

The ShadowPuppets project looked at enabling collocated users to provide input to a mobile projector-based system by casting hand shadows. The ShadowPuppets project made the following contributions.

- **Expected shadows.** We presented the results of a user study examining what types of shadows users expect to cause different effects, such as panning, zooming, and selection (for interaction with maps and photos). There was high agreement among users on what kinds of shadow gestures they expected to cause selection (pointing) and panning (movement in the direction to pan), and there was lower agreement on zooming. Users' zooming gestures were split among three styles (1-handed pinching, 2-handed pinching, and motion toward or away from the projector), suggesting the need for gesture aliases. Based on users' suggestions, we designed a set of shadow gestures employed in the remainder of our studies.

- **Expected effects.** We examined what kinds of effects users expect different hand shadows to cause. We found that there was general agreement on the expected effects of particular gestures and that the gestures designed in our first study were intuitive to viewers.

- **Prototype system.** We presented the design and implementation of the ShadowPuppets prototype, which employs simple computer vision techniques to recognize shadow gestures and allows collocated users to interact with a projected display by casting shadows.

- **Users' experiences.** We presented the results of a study of users' initial experiences interacting in pairs with the ShadowPuppets prototype, which suggested that ShadowPuppets shows promise for supporting collocated interaction. We found that both participants in each pair were able to interact with the prototype, and pairs were able to manage shared control through verbal negotiation and body language. We also observed that interaction with ShadowPuppets did not require visual attention to the handset and that users were able to maintain awareness of the projected display and of each other.

In this project we focused on coarse-grained interaction, and future work is needed to design techniques for finer-grained interaction (e.g., controlling the range and speed of panning and zooming). Also, techniques for handling the change in *shadow gain* at different distances from the projector would be valuable, enabling users to perform gestures of the same size independent of distance (although this technique might be more appropriate for abstract gestures than for deictic spatial gestures). Future work is also needed to consider multi-projector usage scenarios and issues related to security (e.g., preventing unauthorized remote control).

6.3.6 Closing remarks

We explored the design space of lightweight social communication using visual media and mobile phones, evaluating three design devices: leveraging users' existing tools and practices, streamlining essential interactions, and exploiting the rich affordances of visual media. We implemented functional prototype systems and conducted user studies, with quantitative and qualitative measures, which validated our techniques. Our design devices were largely successful in supporting lightweight, expressive mobile communication, and some surprising results pointed to areas for future work.

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