Candid Interaction: Revealing Hidden Mobile and Wearable Computing Activities

Barrett Ens[12], Tovi Grossman[1], Fraser Anderson[1], Justin Matejka[1], George Fitzmaurice[1]

[1]Autodesk Research
{firstname.lastname}@autodesk.com

[2]University of Manitoba
bens@cs.umanitoba.ca

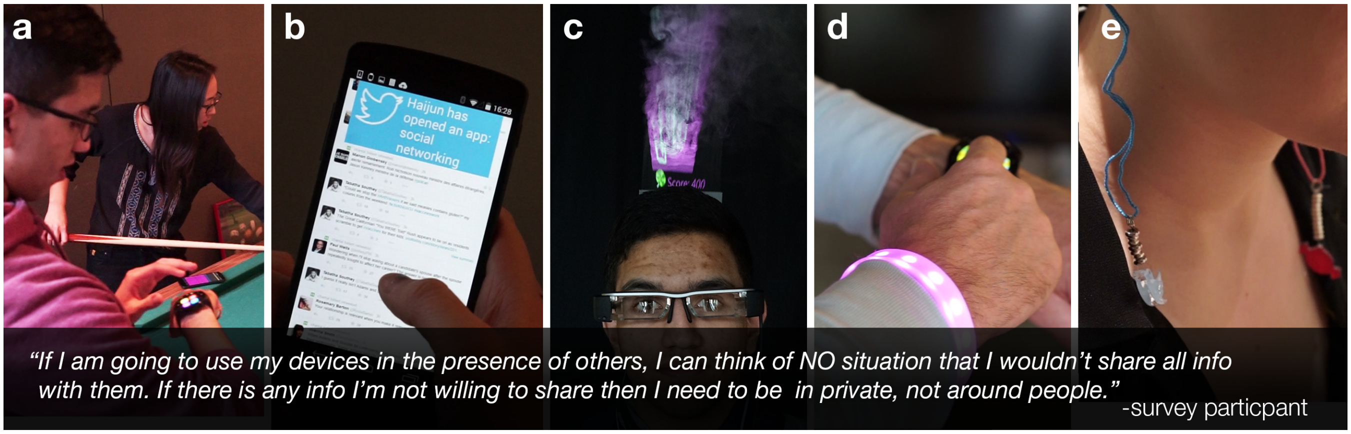

Figure 1. a) People often use mobile and wearable devices in the presence of others. b-e) We explore candid interaction through several prototypes for sharing device activity using a range of technologies. b) Grounding Notifications provide common ground through toast notifications. c) The Fog Hat projects wearable device activity onto a physical though cloud. d) A Status Wristband encodes activity into patterns of coloured light. e) Iconic Jewellery communicate app activity through motion.

ABSTRACT

The growth of mobile and wearable technologies has made it often difficult to understand what people in our surroundings are doing with their technology. In this paper, we introduce the concept of *candid interaction*: techniques for providing awareness about our mobile and wearable device usage to others in the vicinity. We motivate and ground this exploration through a survey on current attitudes toward device usage during interpersonal encounters. We then explore a design space for candid interaction through seven prototypes that leverage a wide range of technological enhancements, such as Augmented Reality, shape memory muscle wire, and wearable projection. Preliminary user feedback of our prototypes highlights the trade-offs between the benefits of sharing device activity and the need to protect user privacy.

INTRODUCTION

The rising prevalence of mobile devices is now echoed by the introduction of wearable devices such as smart watches and smart eyewear. The quick information access these devices provide is convenient but also causes computer interactions to encroach into the realm of public, social and workplace encounters. Common examples include checking messages during a meeting or playing digital games while lounging with friends (Figure 1a). Beyond the typical issues of such momentary distractions, the personal nature of wearable displays makes it increasingly difficult for others nearby to perceive how someone is using their technology.

Researchers have sought ways to promote the transparency of computing activity in collaborative settings. One strategy is to provide users with *awareness* about the state of the shared workspace and their collaborators' activities [11, 15, 16]. Awareness can be supplied by *feedthrough,* which conveys information about the interaction and its effects to others, analogous to feedback in single-user software [15]. While these concepts have gained traction in the domain of computer-supported cooperative work, they are not widely applied during everyday mobile and wearable device use.

We propose a new class of computing called *candid interaction*, where devices provide feedthrough about a user's interactions to others around them, specifically when that device is difficult to observe (Figure 1). For example, someone wearing smart glasses can make a companion aware that they are taking notes, as opposed to checking email during a conversation; or a meeting participant can subtlety let others know they are not distracted by their smartphone but instead looking up information on a relevant topic. Revealing the nature of our device usage to

UIST '15, November 08-11, 2015, Charlotte, NC, USA
 ISBN 978-1-4503-3779-3/15/11…$15.00
DOI: http://dx.doi.org/10.1145/2807442.2807449

those in our surroundings could make these interactions more socially acceptable [33]. This approach contrasts prior research which has attempted to facilitate social acceptance by hiding devices [4] or keeping interaction subtle [5, 27, 44].

There are many potential methods of providing awareness about device use. We explore a range of designs in this paper, from pragmatic to provocative. In a basic case we explore how current technology can provide feedthrough, while in other designs we incorporate novel technologies to exceed basic device capabilities, for instance with proxemics-based augmented reality, muscle wire activated motion jewellery and a mobile-projected thought cloud.

This paper makes several contributions: First, we introduce the novel concept of candid interaction for explicitly sharing awareness about mobile and wearable device activity during interpersonal encounters. Second, we present results from a survey of 100 participants to investigate what types of information people might be willing to share, and in what contexts. Third, we propose a design space for candid interaction to assist an exploration of its many possible manifestations. Fourth, we implement seven prototype designs that represent a wide coverage of our design space. Finally, we demonstrate our prototypes to groups who provide us with insights that will help guide deeper, future exploration of our design space.

RELATED WORK

Our work relies on concepts discovered in the development of multi-user software for collaborative work. In applying these concepts to everyday device interaction, we also draw from work on social acceptability and social interaction.

Awareness in Collaborative Systems

Provision of *awareness* information is a fundamental feature of collaborative software [30] and is theoretically supported by Clark and Brennan's theory of grounding [8]. This theory describes how 'common ground', or a basic set of shared knowledge between participants of a conversation is essential to the conversational efficiency. Monk [30] later used this theory to explain the need for designers to support grounding in electronically mediated communication.

Early pioneers of collaborative software (e.g. [11, 16]) focused on development of features for sharing information about the state of a workspace and the interactions of others therein. Gutwin and Greenberg [15] later formalized a framework for workspace *awareness*. They specify the importance of *feedthrough* as a method of providing awareness about the manipulation of artifacts.

Recent research has also explored methods for signalling information outside of software systems, for instance by using cooperative [19, 34] or large, noticeable gestures [42]. Other work has explored methods for detecting the physical positions and orientations of group members [27] and leveraging this information in device interactions [29]. In our work, we apply the concepts of awareness and feedthrough to device interaction in everyday contexts that may not be explicitly collaborative.

Social Acceptability

As novel mobile interaction techniques were developed, researchers began to notice the importance of observer reactions. Rico and Brewster [41] found willingness to perform mobile device gestures varied by context and audience. Following this work, Reeves et al. [40] developed a framework for designing public interactions which considered observability of both the user's manipulations and the resulting effects. Later study of this categorization [33] found 'suspenseful gestures', observable manipulations with hidden effects, were perceived as less socially acceptable than others. Similarly, psychologists [31, 32] proposed a 'need-to-listen' effect when people overhear phone conversations; bystanders found conversations more noticeable if they could hear only one of the speakers.

Research since Rico and Brewster's study has confirmed that context affects acceptability [3] and found perceptions in public depends on configuration of the surrounding space [14]. Other research has investigated differences in the viewpoints of users and observers [2]. Beyond gestures, studies have also investigated the social acceptability of projection-based interfaces [9, 25]. With the introduction of wearables, researchers are also now interested in acceptability in the context of always-on cameras [10, 20]. In this paper we design our prototypes with social acceptability in mind, in particular users' perceptions about sharing device usage information in various contexts.

Public Displays for Social Interaction

Greenberg et al.'s work describes the complex relationship between personal information and public displays [13]. Since then, a number of concepts have been introduced for promoting social awareness using non-traditional displays, such as name tags [7], bracelets [23], clothing [22], shoulder bags [26] and even coffee mugs [24]. However, these displays are designed to forge relationships by displaying personal logos [23], representations of common links [7, 22], or images meant to inspire serendipitous conversation [24]. In contrast, we focus on sharing personal device activity to provide common awareness.

Recent work using smart watches as public displays [37] explores a design space that contains some elements that overlap with our work, such as information granularity and representation. These watches display public information such as weather or personal information sourced from the wearer or observer. However, this work assumes shared visibility of a single, small display type. We build on similar elements in our broader design space, which we use to explore a variety of devices and to reveal current or past device activity that may typically be hidden from observers.

MOTIVATION FOR CANDID INTERACTION

The goal of candid interaction is to provide awareness to others nearby about how someone is using technology. For example, a conversation may be interrupted by a message notification, or one participant of a conversation may consult a search engine and report the results to the other. In such situations, if appropriate contextual information is shared between participants, it can help to ground the interaction and prevent conversational overhead. However, sharing cues about device activities can be challenging when the device has a wearable form factor.

A theoretical grounding of this goal can be deduced from Reeves et al. [40] framework of interactions. This scheme categorizes interactions according to the observability of the user's manipulations and the resulting effects, as shown in Figure 2. Typically, interactions on wearable and mobile devices fall within the lower-right corner of this matrix, categorized as 'suspenseful' interactions (i.e. observable manipulations with hidden effects). Research has shown this region is less socially acceptability than the others [33].

Designers of subtle interaction [4, 5, 27, 44] promote social acceptance by designing inconspicuous interaction methods (i.e. making the *manipulations* hidden). Candid interaction uses an alternate strategy; it makes the *effects* of the manipulations *more observable*. Thus, interactions that may be otherwise problematic are moved into more acceptable territory (indicated by the solid arrow in Figure 2). In the following section, we perform a survey to better understand under what scenarios such awareness may be beneficial.

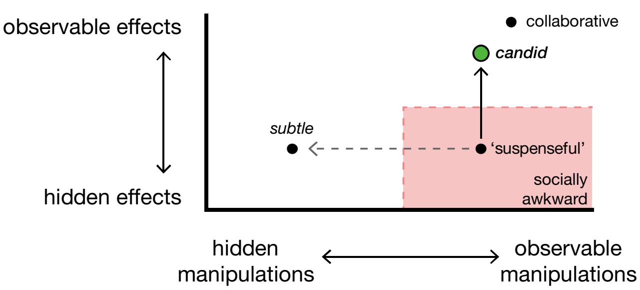

Figure 2. Relationship of candid interaction to other types of social interactions in dimensions of Reeves et al. [40].

SURVEY OF PRACTICES AND PERCEPTIONS

We conducted a survey to help understand how people currently share information about device usage, to learn typical perceptions about different devices and to gauge people's willingness to share information under different contexts. We posted a survey on Mechanical Turk, open to only US participants, containing a mixture of open-ended and 5-point Likert–type questions. We recruited only workers with a 95% approval rating and paid each $3.30 for an estimated 20 minutes time. We collected 100 responses (54 female participants; 18-68 years of age, M=33, SD=9.7). Most were regular laptop (94%) and smartphone (95%) users although fewer had either tried or used smart watches (28%) or smart glasses (10%).

Detecting Device Usage

In alignment with one of our initial motivations, we found that the perceived ability to discern user activity on a device is related to the size and visibility of the device's display (Figure 3). Friedman's test reveals a significant effect of device type ($\chi^2(3) = 152.99$, $p < .001$) and post-hoc Wilcoxon tests show differences between all pairs ($p < .05$). While traditional form factors such as laptops and smartphones afford observation of the user's activities, activity on devices such as smart watches and smart glasses can be more difficult to detect. One user noted "*The size of the screen and the location of the screen make a big difference in how to tell if someone is using the device*". Another opinion was based on personal experience: "*I have interacted with people using Google Glass, and it was very disorienting to try and figure out what they were doing.*"

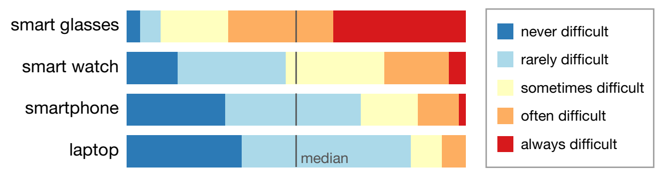

Figure 3. Participant responses on difficulty of determining device activity. Perceived difficulty is related to the size and visibility of the display.

Attitudes about Device Usage

We found a strong diversity of opinions on the appropriateness of using devices during personal interactions. Of all respondents, 47% admitted they often use technology during meetings or conversations, however, 51% feel such behaviour is inappropriate. There appears to be a distinct division between two opposing groups, visible in Figure 4: Members of one group use devices during interpersonal discourse, with no qualms about doing so. In the opposing camp are people who refrain from using devices around others because they feel it is inappropriate.

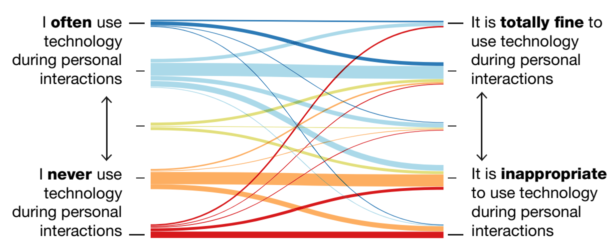

Figure 4. Correlation between responses on how often participants use technology during personal interactions and whether it is appropriate to do so (r_s = .561, $p < .001$). Colours represent responses on the left scale. Band thickness represents the number of responses in the adjoining path.

Willingness to Share

Similarly, participants were divided on how much information they would care to share or receive from others. Some participants commented: "*only when the information is relevant would I be willing to share it*"; and, "*It's none of their business and it could cause issues if it were found out that I was recording something*". Contrasting comments included: "*I will be willing to share that information in any situation. I think it's impolite NOT to mention it*"; and, "*I have nothing to hide and I would want my friend or coworker to feel comfortable*". Overall, 84% of participants would sometimes be willing to share information with others, and 50% of participants would prefer to have more information about how people are using technology.

These predilections vary according to context (Figure 5). A 3×3 ANOVA with aligned rank transforms [46] reveals significant effects of both setting ($F_{2,909} = 129.31$, $p < .001$) and activity ($F_{2,909} = 114.46$, $p < .001$). Post-hoc t-tests with Bonferroni corrections show differences between all pairs ($p < .05$). The interaction is also significant ($F_{4,909} = 2.879$, $p < .05$). In general, participants indicated a greater willingness to share information at work or with friends than in a public setting. Also, participants are less apt to share application content than information about camera or device use. There are clearly contexts where content sharing may be useful, however, designers must take care to protect user privacy, for example by allowing explicit control over the information.

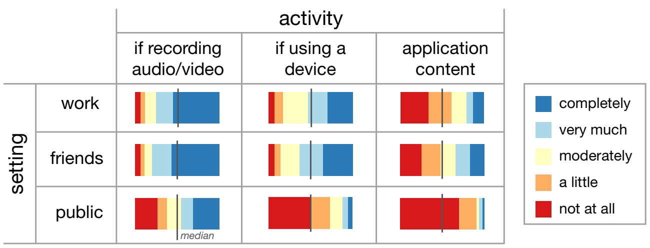

Figure 5. The amount of information participants are willing to share varies with situational context.

Prevalence of Ad-Hoc Sharing
Participants listed many ad-hoc methods they use routinely to provide others with awareness. These include speaking aloud, sharing screens, using social media and connecting to large displays. Several comments indicate empathic motivations, for example sharing information with someone "*just to make them feel more comfortable*" or "*to make it apparent that I wasn't texting.*" One participant mentioned they avoid the use of a soft keyboard when taking notes: "*I usually use the stylus so they know it's for notes.*"

Awareness of Being Recorded
There is growing interest in the social acceptability of camera use [10, 20] and the development of techniques for mitigating concerns [21, 43]. While not our primary focus, improving awareness of recoding status to others is a promising potential use of candid interaction.

A majority (66%) of participants indicated discomfort about people wearing devices with cameras in public. Some were concerned about their personal image ("*I would rather not have any missteps of mine end up as a YouTube video*"), while others were worried about malicious use ("*I'd be concerned about criminals say filming my ATM PIN*").

The majority of participants (79%) agreed they would feel more comfortable if there were a clear indication of whether the camera was turned on or off. Some participants had a total lack of concern. For example, stating that they "*don't mind being recorded by a stranger in public*".

Discussion
These survey results reveal openness toward sharing of some information and also a level of potential comfort to be gained from awareness of others' activities. However, while some may be willing to share their device activity in a wide variety of situations, others may only share sparingly under very specific circumstances. We have also learned that situational context is important and preferences can vary by time, place or situation. Thus, in designing for candid interaction we must take care to ensure that users have control over what is being shared at any time and are never forced to contribute information about their activities. We incorporate these and other principles into our design space and prototype designs described in the following sections.

DESIGN SPACE FOR CANDID INTERACTION
We propose a design space that encapsulates several key concepts that will drive our implementations for candid interaction. These dimensions result from a combination of prior literature and outcomes of our survey analysis. The design dimensions are described below and summarized in Figure 6. Some important terms are defined in Table 1.

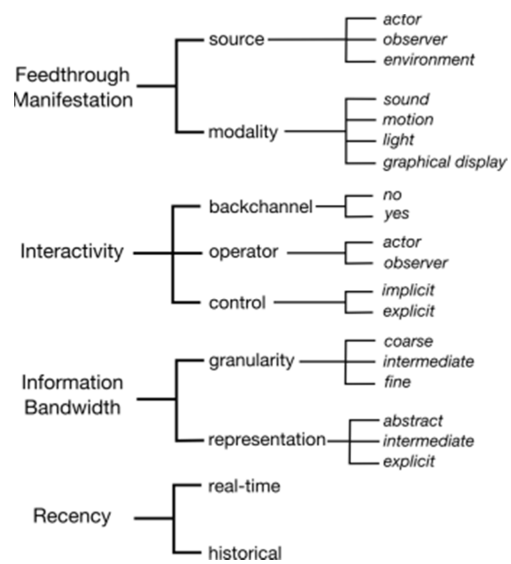

Figure 6. Design space for candid interaction.

Term	Definition
Actor	A person who is interacting with a device
Observer	A person near the actor who is at least partially aware of the actor's interactions
Feedthrough	Information about an actor's manipulation of software artifacts, intentionally provided to observers [15]
Backchannel	From linguistics [47], denotes a secondary communication channel from the observer to the actor.

Table 1. Definitions of terms important to our design space.

Feedthrough Manifestation describes the methods used to convey awareness information to the observer. The *source* of feedthrough may be a device held or accessory worn by either the actor or the observer. Alternatively, feedthrough may originate from the environment, for instance a tabletop display. Feedthrough *modality* can also vary. In our designs we explore sound, motion, light and graphical displays.

Interactivity characterizes additional channels beyond the inherent one-way flow of feedthrough. *Backchannel* makes actors aware that they are being observed. The *operator* of interactive components can be either the actor or observer. Also *control* over information flow, for instance the level of sharing, can be implicit or explicit.

Information Bandwidth describes the flow of feedthrough. This dimension borrows terminology from Pearson et al. [37]. *Granularity* is the level of detail provided, which varies from coarse to fine. *Representation* describes how details are presented, ranging from abstract to explicit.

Recency depicts the presence of temporal information in feedthrough. Details are often presented in real-time as they occur. However, feedthrough can also contain historical information, such as a user's web search history.

Several regions of this design space reflect user needs identified in our survey. For example control mechanisms are needed to protect user privacy and to adjust preferences according to context. Backchannel may mitigate uncertainty about sharing activity by making users aware of when they are being observed. Also, granularity and representation of information can be manipulated by designers to provide an appropriate level of information for a given context.

CANDID INTERACTION ECOSYSTEM

Our goal is to develop a suite of feedthrough mechanisms that can enable candid interaction spanning the above design space. Our prototype ecosystem supports a range of mobile and wearable devices (Figure 7): a smartphone (Nexus 5), smart watch (LG Watch R) and smart glasses (Epson Moverio BT-200).

Figure 7. Our homogeneous platform has a similar look and feel on the (a) smartphone, (b) smart watch, and (c) smart glasses. (d) Feedthrough sliders control the extent of information sent and received about device activity.

We designed a mock OS to provide a homogeneous platform across these devices, which runs as a standalone Android application. The OS emulates a start screen and set of common mobile applications (Figure 7): a web browser, a social network client, a text editor, an email client, a candy crushing game and a camera app. Each application is interactive, with sufficient functionality to support our primary goal of exploring candid interactions.

These applications are instrumented with event triggers, described in the following section, that are used to initiate feedthrough. Once triggered, events are forwarded to the other devices through a Bluetooth piconet (Figure 8). The smartphone acts as a hub and forwards each event to the other devices. The phone forwards the events over a closed Wi-Fi network to a laptop computer, which drives projectors and forwards events by USB to microcontrollers.

Figure 8. The candid interaction ecosystem links mobile and wearable devices to a laptop computer, which operates microcontrollers and projectors in our prototypes.

PROTOTYPE FEEDTHROUGH MECHANISMS

We implemented seven prototype mechanisms for candid interaction, with a goal of maximizing coverage of our proposed design space. Through this exploration, we hope to learn the strengths and weaknesses of different approaches, providing a point of departure for future designs. In the following descriptions, design space dimensions are *italicized* and values are in *SMALL CAPS*.

Feedthrough Filters

Before describing our prototypes, we present Feedthrough Filters to provide *EXPLICIT CONTROL* over the extent of information shared. This consists of two sliders (Figure 7d). An *ACTOR* uses the sharing filter to control the granularity of information sent, while an *OBSERVER* can use the receiving filter control the extent of information received. Each slider has five levels: *none*, *minimal*, *low*, *moderate* and *full*, which accumulatively allow additional events. The events that are sent at each slider level are listed in Table 2.

Level	Notification Events Sent
none	`No events`
minimal	`photo_taken; video_record; video_stop`
low	`application_opened; application_closed`
moderate	`scroll_up; scroll_down; link_opened page_opened; query_performed;`
full	`select_text; edit_text; candy_crushed`

Table 2. Application event triggers increase in granularity with the level of the corresponding Feedthrough Filter.

Prototype #1: Grounding Notifications

Grounding Notifications are toast notifications (terse, short-lived pop-up messages) shown on an observer's device that provide 'common ground' about device activity. Each notification contains the actor's name, a description of the action that occurred, and is encoded with the corresponding

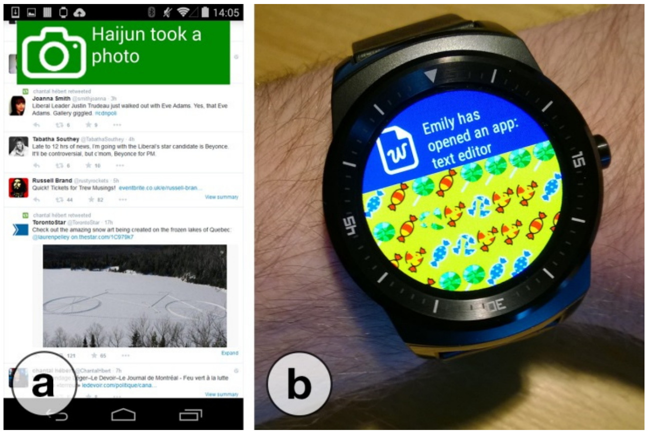

Figure 9. Grounding Notifications show device activity on a (a) smartphone, (b) smart watch, or smart glasses.

application icon and colour (Figure 9). This pragmatic mechanism demonstrates some key principles of candid interaction and covers several design space dimensions.

In this design, the *Feedthrough Source* is the *OBSERVER'S* device. Notifications are accompanied by a distinctive *SOUND*, which provides *Backchannel* to the actor when information is shared. Furthermore, feedthrough has an *EXPLICIT Representation* given in *REAL-TIME*.

To demonstrate a practical use case for candid interaction, we implemented an example of information sharing that commonly occurs using current ad-hoc methods: When an actor follows a search link, the observer is presented with an *interactive* page preview. Tapping the preview image open the link, and sends a *backchannel* notification to the actor. Tapping elsewhere discards the notification.

Prototype #2: Lockscreen Stripes

Our Lockscreen Stripes implementation shares app usage history of a smartphone. When the phone's accelerometer detects the device is placed on a table (Figure 10a), the screen shows a series of coloured stripes (Figure 10b). Each stripe's colour matches the corresponding application icon, with thickness proportional to the duration it was used.

This design is an example of how *HISTORICAL* information can be shared. This type of mechanism could be useful for helping an actor communicate to others that they were not

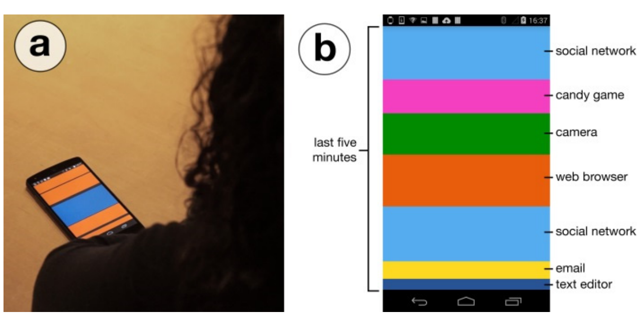

Figure 10. Lockscreen Stripes encode app usage history (a) into stripes displayed when a smartphone is laid at rest (b).

unduly distracted but that their device activity was related to an ongoing conversation or meeting. The *ABSTRACT representation* allows observers to absorb this information quickly, without interrupting the flow of a conversation. Since users may be wary to share their prior usage, we scale the timeline to show only the last five minutes of activity.

Prototype #3: Semantic Focus

Semantic Focus uses the analogy of a camera's focus control to 'blur' information when privacy is desired. This technique is inspired by the semantic zoom technique [45], which reveals more information as a user zooms in to an object of interest. A physical knob fixed to the back of a laptop computer (Figure 11a) controls an image projected onto the table by a top mounted projector in the *ENVIRONMENT* (Figure 11b). We demonstrate this technique with a laptop, but similar implementations could be realized on mobile or wearable devices. Future implementations could also use projectors built into mobile devices. The knob works by sending rotational information from an attached potentiometer to an Arduino Uno microcontroller.

Semantic Focus gives *EXPLICIT control* of *information bandwidth* to the *ACTOR.* Content can be blurred at two different levels of *granularity*. At the *COARSE* level, only the current application icon is shown (Figure 11d). At the *FINE* level, a *GRAPHICAL DISPLAY* of the full application content is shown (Figure 11f), allowing the actor's interactions to be observed. Since detail in the miniature view may be difficult to make out, we display a marquee [35] to show the most relevant information in the current application. For example, in the text editor, the current line of text being edited is shown. The coarse and fine levels both transition continuously from blurred to focused as the knob is rotated.

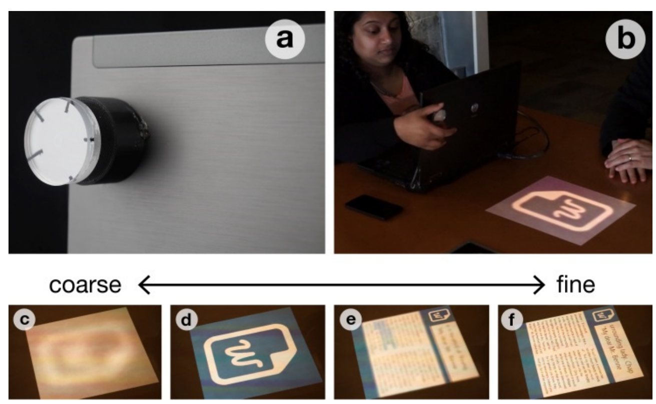

Figure 11. Semantic Focus. a, b) A physical knob controls the clarity of the projected image. c-f) The image gradually transitions from a blurred icon to a clear graphical display.

Prototype #4: Status Band

The Status Band (Figure 12a) communicates application activity through *LIGHT* patterns [18] from a wrist-worn bracelet [12, 23]. It is made from an addressable RGB LED strip attached to a metal watch clasp and controlled with an Arduino Lilypad. For comfort and aesthetic appeal we covered the LED with white silk.

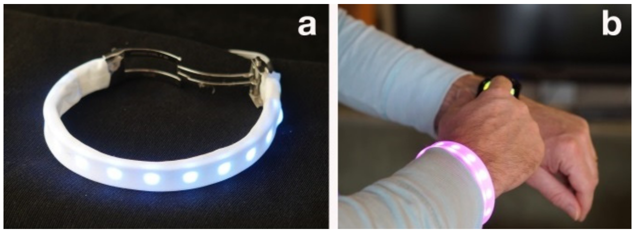

Figure 13. The Status Band apparatus (a) communicates device activity while the hand interacts with a device (b).

The bracelet is worn on the actor's dominant hand, which is typically used for swiping and tapping on a mobile or wearable device (Figure 12b). Thus if the observer cannot see the actor's primary device, they can instead see the band's abstraction of what the user is doing. While the band provides an *ABSTRACT representation,* the information can be presented with *FINE granularity*. For example, individual scroll events and character entries are depicted with distinct patterns. We created patterns for a range of events, which are coded by the application colour (Table 3, Figure 14).

Event	Light Pattern
`photo_taken`	2 quick bright white flashes with all lights
`video_record`	2 slow red flashes – on until stopped
`audio_record`	2 slow red flashes – every 2nd light remains on
`open_app`	slow brightness increase, repeated 3 times
`scroll_{up/down}`	chaser pattern around wrist
`link_opened`	every 2nd light brightens/dims slowly
`enter_text`	random twinkling
`crush_candy`	random twinkling

Table 3: Events and corresponding light patterns.

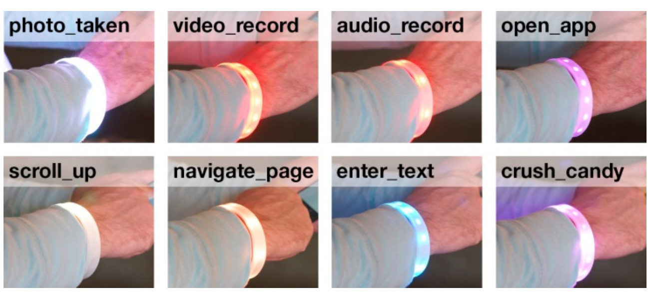

Figure 14. Light pattern representations of device events. Light colours match the associated app unless specified.

Prototype #5: Iconic Jewellery

To further explore the possible uses of *ABSTRACT representations*, we designed a set of Iconic Jewellery that communicates activity through the *modality* of *MOTION*. Each item is colour-coded to represent an individual application, with a laser-cut, acrylic icon attached as a pendant. The set includes a necklace (email app) and a pair of earrings (game and social network apps) (Figure 14a).

Each piece is constructed from a strand of Muscle Wire (nitinol), which 'remembers' a specific shape when annealed at a high temperature. The wire takes a relaxed form at room temperature (Figure 14b), but reverts to its remembered shape when reheated to roughly 100°C. We use a 12V electrical circuit activated through transistors and an Arduino Uno board. The wires are annealed into helical shapes, causing them to contract when a current is applied

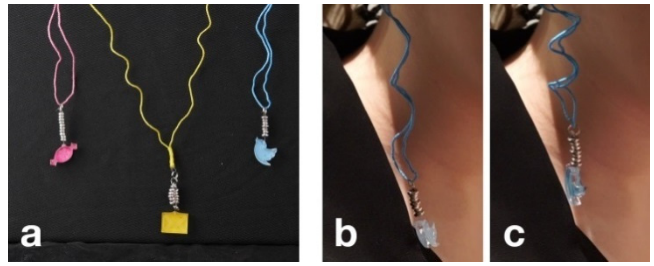

Figure 12. Iconic Jewellery reveals activity in an associated app (a) via motion. When the associated app is used, the jewellery moves from a relaxed (b) to contracted (c) state.

(Figure 14c). Embroidery thread wrapped tightly around the wire provides insulation, making it comfortably wearable.

A long burst of current is applied when an application is initially opened, causing the pendant to contract quickly and noticeably. The jewellery continues to move through more gentle cycles as long as there is ongoing activity within the app.

Prototype #6: Proxemic AR

Our Proxemic AR prototype uses augmented reality (AR) to reveal an actor's current activity. When an observer points their phone at the actor, or looks at them through their smart glasses, the device's camera detects the actor's face and overlays information on to the observer's view. The extent of information displayed is based on proxemics [17, 28, 29], which applies information about the distance and configuration between participants to facilitate interaction.

This technique is implemented using Android's face detection [36] library. The actor's distance is estimated from the width of the first detected face. In the smart glasses, this information is transformed to screen space and the overlay is rendered stereoscopically at the correct depth to match the actor's estimated distance.

In keeping with the fun spirit of many AR applications, information is presented in an *ABSTRACT representation* of a thought cloud and other objects floating above or around the actor's head. To access more detail, the observer is required to enter the actor's personal space. This gives the *OBSERVER IMPLICIT control* over feedthrough, but with a tradeoff of *backchannel* given by the observer's presence.

When observing from afar, information is presented with *COARSE granularity*, revealing only the icon of the actor's current application (Figure 15a, d). As the user approaches (within 3 m), the representation changes and observer begins to witness the actor's activity. For example in the social network app, the observer sees a bird circling the user's head, which audibly tweets with each event (Figure 15e). In the game app the observer sees each candy's type and hears it crushed as it appears to fly out of the actor's ears (Figure 15b). On entering the actor's personal space (1.5 m) the observer sees *FINE granularity* detail, for example recently viewed hashtags or the running game score (Figure 15c, f).

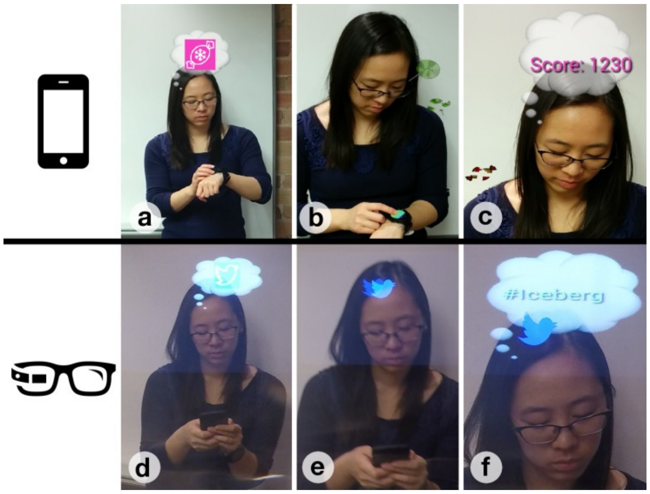

Figure 15. Proxemic AR augments the user's image with their device activity on a smartphone (a-c) or smart glasses (d-f). Granularity increases as the observer moves from far (a, d) through intermediate (b, e) to close (c, f) range.

Prototype #7: Fog Hat

The Fog Hat can be thought of as a material version of the proxemic AR prototype, displaying a 'physical thought cloud', with feedthrough projected onto a screen of mist [39] above the actor's head. This whimsical implementation consists of an ultrasonic humidifier, a length of flexible PVC pipe and a custom 3D printed manifold for directing the mist stream (Figure 16a). The image is back-projected from a Microvision SHOWWX+ laser projector The Fog Hat provides an interesting property of inherently obfuscating the displayed image, especially at the turbulent, top region (Figure 16b, c). Affixed to the fog manifold is a 5V fan, (Figure 16a) which can create additional turbulence to further obfuscate the mist display. An Arduino Leonardo microcontroller operates the fan and a relay switch that turns the mist on or off. The apparatus is tethered to a laptop and carried in a small backpack. We imagine that advances in miniaturization will eventually allow a similar device to be built into a more amenable form factor.

The Fog Hat incorporates multiple levels of *information bandwidth* with some using a marquee feature for sharing important information. The *granularity* is controlled by the actor's sharing level in the Feedthrough Filters panel. At the 'low' setting, only the icon of the current application is shown. At 'full', the display shows more information including a miniature page view and marquee.

Applications use different layouts to leverage the Fog Manifold's inherent turbulence; apps with low privacy needs, such as the web or game apps, place the marquee at the smooth region at the display's bottom, where text and images remain clearly legible. Apps that require greater privacy, such as the email app, place the marquee higher, in the more turbulent region. In this case typing activity is still conveyed to the observer, but the contents are obscured. Decreasing the filter setting to *minimal* or *moderate* increases privacy further by activating the fan (Figure 16d).

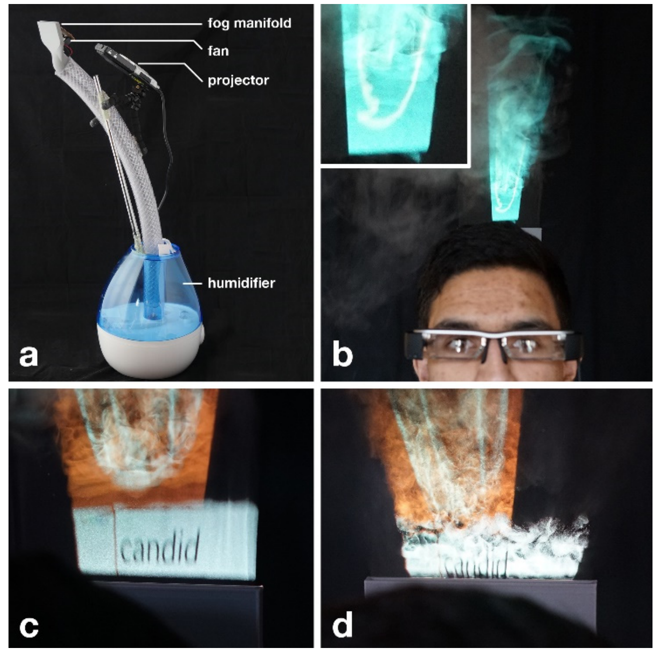

Figure 16. (a, b) The Fog Hat projects a graphical display above the user's head. (c, d) The content of the display can be further obfuscated by turbulence from a fan.

INITIAL SUBJECTIVE FEEDBACK

To gain some initial subjective feedback on our developments and elicit discussion on the topic of candid interaction, we conducted a set of informal interviews. We demonstrated our designs to five groups of two participants each and encouraged group members to wear and interact with the prototypes. Participants were recruited internally from our organization, ranged from 19-42 years of age (M=26, SD=8.9) and were equally distributed by gender.

Participants were generally open to the concept of candid interaction and commented positively on the wide variety of concepts we presented. The Semantic Focus prototype was among the most popular, perhaps due do familiarity with existing tools, as participants remarked it is "useful for collaboration". Similarly, participants thought the Status Band would be "socially acceptable" because it resembles items that people typically wear, although with some exceptions ("some men don't wear jewellery"). Some were unnerved by the unexpected motion of the Iconic Jewellery, however, one participant preferred it to the flashing lights of the wristband. The Fog Hat was also deemed potentially socially awkward, likely due in part to its large form factor.

Participants noted understanding of the need to balance the benefits of sharing with the desire for privacy. For instance, sharing usage information can potentially "dissolve discomfort about using devices" around others. However, it must be used judiciously to prevent "information overload". In alignment with our survey results (Figure 5), participants expressed greatest interest in sharing with friends or coworkers and would often choose to share only minimal detail about their activities. Some noted they would prefer to keep tabs on what is was being shared and suggested features such as explicit detail in the Feedthrough Filter settings or real-time controls to manually initiate sharing. Participants indicated a preference for abstract feedthrough in public settings. We also learned that excessive backchannel mechanisms have potential to be socially awkward; for instance several participants mentioned that pointing a smartphone toward others with Proxemic AR feels conspicuous. Some participants liked the idea of seeing others' activity incognito through the smart glasses, however, the device's limited viewing field requires observers to turn their head directly toward the subject.

LIMITATIONS AND FUTURE WORK

This paper has introduced the conceptual framework and design space to begin a deeper discussion on candid interaction. Our prototypes have only scratched the surface of potential applications for candid interaction. Some dimension values, such as *ENVIRONMENT* (*feedthrough source*) and *HISTORICAL* (*recency*) were only covered by a single design. Some of these prototypes are conceptual in nature and we don't expect to see implemented in the immediate future, although we hope they will inspire further work toward a deeper understanding of the design space for candid interaction.

The concepts we introduce in this work offer many areas prime for deeper exploration. We plan to explore a greater variety of interactive features to encourage interplay between actors and observers, although developing systems with robust awareness of intricate environmental and social contexts will be challenging. Techniques that prove useful in some contexts may introduce new awkwardness in others, for instance when sharing information with some members of a group but not others. Advanced design methods (e.g. [1, 6]) and studies with in-situ use of candid interaction devices will help determine actor and observer comfort levels with various feedthrough mechanisms and to determine what information people will be willing to share in different contexts. We are interested to learn which sharing techniques will find wide user acceptance and how social norms will evolve as such systems are introduced.

CONCLUSION

As computing devices continue to emerge in smaller and more personal form factors, device usage will continue to encroach on interpersonal engagement. A survey shows that there are situations when device users are interested in sharing and receiving information about such interactions. Context is a determining factor of when, how and what information should be shared. Our design space explores a variety of potential methods for approaching these issues.

Our survey and preliminary user evaluation offer several insights into the potential benefits and drawbacks of various approaches: 1) Users are cautious about the information they choose to share thus candid interaction methods must default to sharing minimal information without express consent; 2) Comfort levels about sharing are highly dependent on context, thus information and delivery methods must account for where interaction takes place and who is present; 3) Participants prefer to remain inconspicuous, particularly in public, where abstract methods are best suited; likewise, backchannel methods should not call unwanted attention to observers. We hope this work provides a cue for others to explore candid interaction methods and leads to greater sharing among mobile and wearable device users.

ACKNOWLEDGEMENTS

We thank Cory Mogk for animations used in Proxemic AR. We thank Wei Li and Pourang Irani for providing inspiration and John Yee for technical support.

REFERENCES

1. Abowd, G.D., Hayes, G.R., Iachello, G., Kientz, J.A., Patel, S.N., Stevens, M.M. and Truong, K.N. 2005. Prototypes and paratypes: Designing mobile and ubiquitous computing applications. *IEEE Pervasive Computing* 4, 4 (October 2005), 67-73.
2. Ahlström, D., Hasan, K. and Irani, P. 2014. Are you comfortable doing that? Acceptance studies of around-device gestures in and for public settings. *MobileHCI '14*, 193-202.
3. Akpan, I., Marshall, P., Bird, J. and Harrison, D. 2013. Exploring the effects of space and place on engagement with an interactive installation. *CHI '13*, 2213-2222.
4. Anderson, F., Grossman, T., Wigdor, D. and Fitzmaurice, G. 2015. Supporting Subtlety with Deceptive Devices and Illusory Interactions. *CHI '15,* 10 pages, in press.
5. Bailly, G., Müller, J., Rohs, M., Wigdor, D., and Kratz, S. 2012. ShoeSense: A new perspective on gestural interaction and wearable applications. *CHI '12*, 1239-1248.
6. Buchenau, M. and Suri, J.F. Experience prototyping. *DIS '00*, 424-433.
7. Borovoy, R., Martin, F., Resnick, M. and Silverman, B. 1998. GroupWear: nametags that tell about relationships. *CHI '98*, 329-330.
8. Clark, H.H. and Brennan, S.E. 1991. Grounding in Communication. In *Perspectives on Socially Shared Cognition*, Resnick, L.B., Levine, J.M. and Teasley, S.D. (eds.). American Psychological Association, Washington, 127-149.
9. Cowan, L.G., Weibel, N. Griswold, W.G., Pina, L.R. and Hollan, J.D. 2012. Projector phone use: Practices and social implications. *Personal Ubiquitous Computing.* 16, 1 (January 2012), 53-63.
10. Denning, T., Dehlawi, Z. and Kohno, T. 2014. In situ with bystanders of augmented reality glasses: Perspectives on recording and privacy-mediating technologies. *CHI '14*, 2377-2386.
11. Dourish, P. and Bellotti, V. 1992. Awareness and coordination in shared workspaces. *CSCW '92*, 107-114.
12. Fortmann, J., Müller, H., Heuten, W. and Boll, S. 2014. How to present information on wrist-worn point-light displays. *NordiCHI '14*, 955-958.

13. Greenberg, S., Boyle, M., and Laberge, J. 1999. PDAs and shared public displays: Making personal information public, and public information personal. *Personal Technologies*, 3, 1-2, 54-64.
14. Grubert, J. and Schmalstieg, D. 2013. Playing it real again: A repeated evaluation of magic lens and static peephole interfaces in public space. *MobileHCI '13*, 99-102.
15. Gutwin, C. and Greenberg, S. 2002. A descriptive framework of workspace awareness for real-time groupware. *CSCW* 11, 3 (November 2002), 411-446.
16. Gutwin, C., Roseman, M. and Greenberg, S. 1996. A usability study of awareness widgets in a shared workspace groupware system. *CSCW '96*, 258-267.
17. Hall, E.T. 1966. *The Hidden Dimension*. Doubleday, N.Y.
18. Harrison, C., Horstman, J., Hsieh, G. and Hudson, S. 2012. Unlocking the expressivity of point lights. *CHI '12*, 1683-1692.
19. Hinckley, K. 2003. Synchronous gestures for multiple persons and computers. *UIST '03*, 149-158.
20. Hoyle, R., Templeman, R., Armes, S., Anthony, D., Crandall, D. and Kapadia, A. 2014. Privacy behaviors of lifeloggers using wearable cameras. *UbiComp '14*, 571-582.
21. Jung, J. and Philipose, M. 2014. Courteous Glass. *UbiComp '14 Adjunct Proceedings*, 1307-1312.
22. Kan, V., Fujii, K., Amores, J., Jin, C.L.Z., Maes, P. and Ishii, H. 2015. Social textiles: Social affordances and icebreaking interactions through wearable social messaging. *TEI '15*, 619-624.
23. Kanis, M., Winters, N., Agamanolis, S., Gavin, A. and Cullinan, C. 2005. Toward wearable social networking with iBand. *CHI '05*, 1521-1524.
24. Kao, H.L. and Schmandt, H.L. 2015. MugShots: A mug display for front and back stage social interaction in the workplace. In *TEI '15*, 57-60.
25. Ko, J.C., Chan, L.W. and Hung, Y.P. 2010. Public issues on projected user interface. *CHI EA '10*, 2873-2882.
26. Liu, C.M. and Donath, J.S. 2006. Urbanhermes: Social signaling with electronic fashion. *CHI '06*, 885-888.
27. Lucero, A., Lyons, K., Vetek, A., Järvenpää, T., White, S. and Salmimaa M. 2013. Exploring the interaction design space for interactive glasses. *CHI EA '13*, 1341-1346.
28. Marquardt, N., Ballendat, T., Boring, S., Greenberg, S. and Hinckley, K. 2012. Gradual engagement: Facilitating information exchange between digital devices as a function of proximity. *ITS '12*, 31-40.
29. Marquardt, N., Hinckley, K. and Greenberg, S. 2012. Cross-device interaction via micro-mobility and f-formations. *UIST '12*, 13-22.
30. Monk, A. 2003. Common ground in electronically mediated communication: Clark's theory of language use. *HCI Models, Theories, and Frameworks*. Carroll, J.M. (ed.). Kaufmann, San Francisco, 265-290.
31. Monk, A., Carroll, J., Parker, S. and Blythe, M. 2004. Why are mobile phones annoying? *Behaviour & Information Technology*, 23, 1 (January 2004), 33-41.
32. Monk, A., Fellas, E. and Ley, E. 2004. Hearing only one side of normal and mobile phone conversations, *Behaviour & Information Technology*, 23, 5, 301-305.
33. Montero, C.S., Alexander, J., Marshall, M.T. and Subramanian, S. 2010. Would you do that? Understanding social acceptance of gestural interfaces. *MobileHCI '10*, 275-278.
34. Morris, M.R., Huang, A., Paepcke, A. and Winograd, T. 2006. Cooperative gestures: multi-user gestural interactions for co-located groupware. *CHI '06*, 1201-1210.
35. Morris, M.R., Lombardo, J. and Wigdor, D. 2010. WeSearch: Supporting collaborative search and sensemaking on a tabletop display. *CSCW '10*, 401-410.
36. Orlosky, J., Kiyokawa, K., Toyama, T. and Sonntag, D. Halo Content: Context-aware view management for non-invasive augmented reality. *IUI '15*, 369-373.
37. Pearson, J., Robinson, S. and Jones, M. 2015. It's about time: Smartwatches as public displays. *CHI '15*, 1257-1266.
38. Portnoff, R.S., Lee, L.N., Egelman, S., Mishra, P., Leung, D. and Wagner, D. 2015. Somebody's Watching Me? Assessing the Effectiveness of Webcam Indicator Lights. *CHI '15*, 2015.
39. Rakkolainen, I., and Palovuori, K. 2002. WAVE - A Walk-thru Virtual Environment. *IEEE VR '02, Immersive Projection Technology Symposium*.
40. Reeves, S., Benford, S., O'Malley, C. and Fraser, M. 2005. Designing the spectator experience. *CHI '05*, 741-750.
41. Rico, J. and Brewster, S. 2010. Usable gestures for mobile interfaces: Evaluating social acceptability. *CHI '10*, 887-896.
42. Reetz, A. and Gutwin, C. 2014. Making big gestures: Effects of gesture size on observability and identification for co-located group awareness. *CHI '14*, 4087-4096.
43. Roesner, F., Molnar, D., Moshchuk, A., Kohno, T. and Wang, H. 2014. World-driven access control for continuous sensing. *CCS '14*, 1169-1181.
44. Serrano, M., Ens, B. and Irani, P. 2014. Exploring the use of hand-to-face input for interacting with head-worn displays. *CHI '14*, 3181-3190.
45. Wang, L. and Mueller, K. 2004. Generating sub-resolution detail in images and volumes using constrained texture synthesis. *VIS '04*, 75-82.
46. Wobbrock, J.O., Findlater, L., Gergle, D. and Higgins, J.J. 2011. The aligned rank transform for nonparametric factorial analyses using only anova procedures. CHI '11, 143-146.
47. Yngve, V. 1970. On getting a word in edgewise. *Papers from the Sixth Regional Meeting of the Chicago Linguistic Society*, Chicago University Press, 567-577.