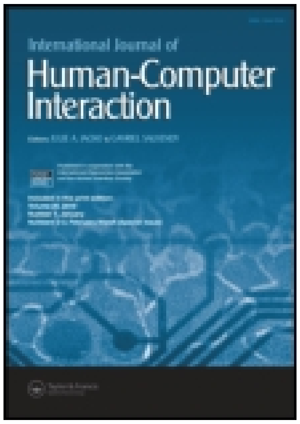

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Guidelines for Designing Awareness-Augmented Mobile DUIs

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Guidelines for Designing Awareness-Augmented Mobile DUIs

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Colocated groups using mobile devices do not share all of the benefits of face-to-face collaborators. Close interaction requires application support for awareness features, allowing participants to establish common ground. Following an overview of research on awareness and grounding, the results of an informal user study are presented, which demonstrate how current systems can deter users from engaging in close collaboration. Literature on awareness provides hope for improving this situation, but a naive transfer to mobile distributed user interfaces will not necessarily succeed. From prior art, a concise list of guidelines has been compiled to assist designers in providing awareness information to users of shared mobile workspaces. These guidelines can also serve as heuristics for the evaluation of future systems. An example is provided to demonstrate how these guidelines can be applied to the development of features for providing awareness of current location and browsing history to colocated users of mobile distributed user interfaces.

1. INTRODUCTION

The ubiquity of mobile devices has ushered in a new era of connectivity. Despite great advances in communication technology, people often remark on the ironic tendency of mobile users to disengage from the people around them. The small, personal interfaces of handheld computers do not facilitate collective use and draw one's focus away from a group. As a result, collaboration on mobile devices tends to involve loosely coupled "chunks" of parallel work distributed among the group. For example, two visitors conducting a joint search for a hotel in an unfamiliar city are likely to duplicate work unless they explicitly divide the search space beforehand. Even then, it is not a trivial task to verbally describe a location or to quickly navigate there. To facilitate their collaborative efforts, the pair may choose to abandon their mobile devices for another medium, such as a paper map. Colocated mobile users who want to engage in tightly coupled tasks require a means of bridging the virtual and physical divide that mobile devices create.

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Distributed user interfaces (DUIs) allow application workspaces to span across multiple devices, providing a bridge to connect the focus of several colocated users. Effective communication, however, depends on *common ground* between the participants. In conversation, people acquire sufficient common ground to state a collective purpose through grounding, a process involving tightly interlinked exchanges of information (Clark & Brennan, 1991). DUIs, however, present users with a small window into a potentially large workspace, severely limiting the collaborative context. To facilitate grounding, designers can augment the interface with a layer of visual awareness cues (Figure 1). Shared workspaces augmented with visually encoded information about other users, such as location, focus, and activity, have been shown to benefit the participants of collaborative tasks (Gutwin & Greenberg, 1998). However, such awareness provision features have been primarily demonstrated on desktop computers, and we cannot take for granted that existing design approaches will transfer to a mobile platform.

With advances in cloud computing we can expect mobile devices to become highly interlinked with an aim of assisting groups in performing a myriad of tasks. Designers of mobile DUIs would benefit from guidelines for augmenting mobile DUIs with awareness cues that will allow successful, tightly coupled collaboration. From a thorough survey of research on awareness in groupware and computer-supported cooperative work systems, we have drawn out a list of such recommendations, which we present in this article.

The following section explains how awareness and grounding are related and why awareness is essential for shared mobile workspaces. Next we present an informal user study, aimed at highlighting the deficits of mobile devices in collaborative tasks. Later, we present our list of design considerations to guide development of applications featuring shared mobile workspaces.

2. AWARENESS

Support for awareness is an important feature for collaboration in shared workspaces. Researchers have shown the utility of awareness cues in distributed interfaces and demonstrated their advantages both qualitatively (Gutwin, Roseman, & Greenberg, 1996) and quantitatively (Gutwin & Greenberg, 1998). A

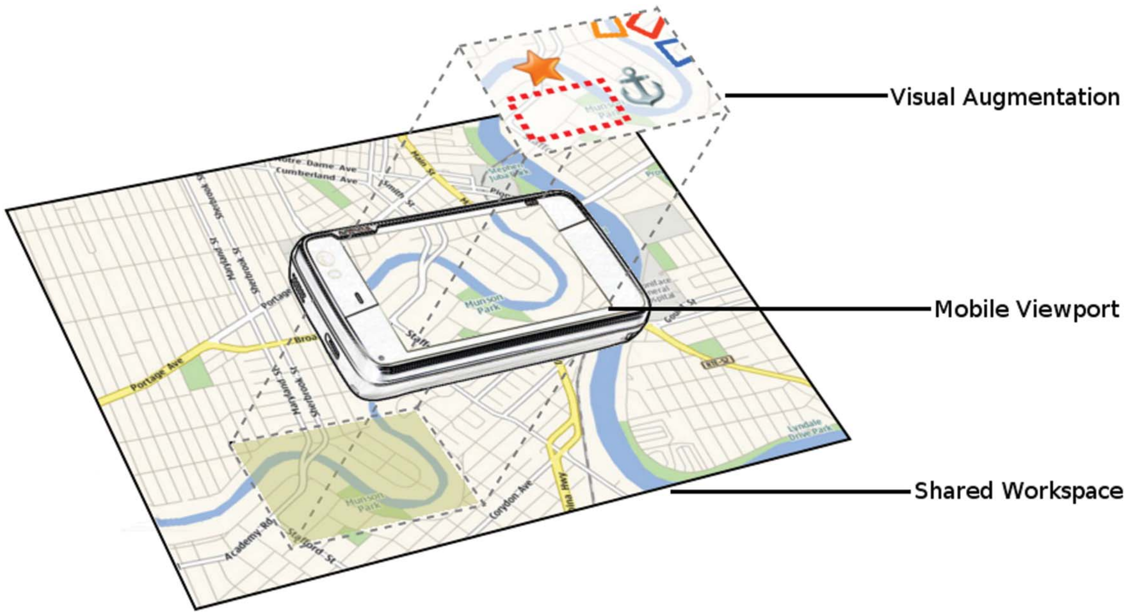

FIG. 1. A mobile viewport provides only a small window into a large shared workspace (color figure available online).

variety of mechanisms for providing awareness have been proposed, including overviews, telepointers, fish-eye views, and audio cues (Greenberg et al., 1996; Gutwin et al., 1996). These cues are designed to provide information such as who is present, the location of their focus within a shared workspace, and the actions they are performing within that workspace. The benefits of the awareness information these cues provide include a reduction in the overhead of verbal communication, the facilitation of coordinated actions, and smoother transitions between loosely and tightly coupled modes of interaction (Greenberg et al., 1996).

Many of the improvements to multiuser systems have been inspired by Clark's collaborative model of communication (Monk, 2003). Clark's theory is useful because it allows us to make predictions about the effects of different technologies on the effectiveness of communication. For example, people involved in a telephone conversation are affected by the imperfect fidelity of reproduced audio and by the inability to see one another's faces or gestures. These deficiencies result in increased effort on part of the participants when communication certain types of information.

The central concept of Clark's theory is common ground. Common ground is the information that is common between collaborators, such as the group's collective purpose, each member's role and professional background, the jargon they use, and the identity of objects with which they work. Such information is particular to the context in which the collaboration is taking place and is maintained through the act of grounding. Grounding is a multilevel process that not only involves the exchange of information but depends on mutual agreement about what the shared information is as well as

Alan:	Now, - um, do you and your husband have a j- car
Barbara:	- have a car?
Alan:	Yeah
Barbara:	No -

FIG. 2. An example of grounding in conversation from Clark and Brennan (1991).

confirmation that a message is equally understood. Figure 2 shows an example of such negotiation, from Clark and Brennan (1991).

There is an intermediary exchange between Alan's initial question and Barbara's eventual answer. By asking "– have a car?" Barbara not only confirms the question but gives Alan positive evidence that she understands. In return, Alan lets Barbara know that her understanding is correct and provides further evidence that he is aware of her understanding. Recursively tiered exchanges such as this happen continuously throughout conversation and involve all forms of verbal and nonverbal communication, including continuers (e.g., "um"), head movements, winks, deictic gestures, and body language.

Olson and Olson (2000) use Clark and Brennan's (1991) model of grounding constraints for communication media to explain why tightly coupled collaboration often fails. Clark and Brennan hypothesized that for a given medium, users will ground using the techniques that cost the *least collaborative effort*. Olson and Olson argued that colocated groups have the best means for achieving common ground because their communication is unimpeded by technological hurdles and can be enhanced by local cultural and geographical contexts.

Mobile devices, however, occupy some of the channels that colocated users use to exchange information. The physical device occupies a user's hands and eye focus and presents feedback that is essentially inaccessible to colocated occupants. To demonstrate how grounding is constrained in colocated mobile group work, we present the following informal study.

3. USER STUDY

As a part of our user-centered design process, we ran an informal study to allow us to observe how mobile users manage tightly coupled work with the tools of the status quo. We invited five groups of two participants each (for a total of 10 participants) to carry out a collaborative task. Afterward, we collected some of their thoughts about the suitability of a typical mobile environment for collaborative work.

To begin the study, the participants were seated at a table, and each was given a Nokia N900 smart phone. Paper and pens were made inconspicuously available. Participants were asked to plan an imaginary walking tour of downtown Winnipeg. This involved first locating each of five landmarks using Nokia's OviMaps application and then deciding among themselves on the preferred order in which to visit all of the landmarks. The only constraint was that they form a circuit by returning to the initial landmark at the end of the walking tour.

We designed the two-part task for the study to contain aspects of both loosely and tightly coupled work, with the potential for participants to switch between the two. The first part of the task is essentially a search, which can be performed easily in a loosely coupled fashion. The second part of the task, route planning, requires the participants to communicate between themselves and deliver a final decision based on consensus. These requirements call for tightly coupled interactions. We placed no restrictions on how the task was to be carried out, leaving participants to figure it out as they saw fit.

In the first part of the task, all five pairs carried out the searches individually on their separate devices. Although participants were free to choose to conduct the search in a more tightly coupled manner, say, by sharing one device, doing so would be awkward. Likewise, dividing the search between them would result in a less complete mental picture of the landmark layout than could be gained by individual searching, as neither would have access to the other's results. Some groups used the text search tool and entered waypoints to mark the landmarks, whereas others, who were more familiar with the city layout, found the landmarks by visual search only. Often, one participant would assist the other in locating a landmark by looking over their shoulder or showing their own viewport while making verbal and pointing references.

Pairs took different approaches in the second part of the task. In two of the groups, both participants put down their devices and drew a sketch of the landmark layout with pen and paper. In two other cases, the participants both referred to their individual device screen while making intermittent verbal suggestions. The final pair used a combination of paper and one of the devices. In all cases, the participants confirmed their final decision by tracing the route on one device together or on both devices individually.

So, how successful was the collaboration? One of the first things to consider in this scenario is the amount of redundant effort caused by work decoupling. The individual nature of the devices made participants more willing to duplicate effort than to share a user interface. The searching was effectively done twice, with very little interchange. When one participant did help the other to locate a landmark, it appears that their primary purpose was to help the other "catch up" before continuing with the task. Effectively, the users are manually keeping their application "state" in sync. In the second part of the task, the amount of coupling was determined by the approach. Groups that stuck with both devices would quietly come up with their own suggestions and exchange these with one another only at the end of the process. The pairs that chose to abandon the restrictive interfaces for paper and pen appeared to have engaged in a more tightly knit iterative process, involving pointing and countersuggestions.

In summary, our observations appear to confirm our hypothesis that tightly coupled collaborative work is not well supported by today's standard mobile devices. Small viewports are difficult to share, and device users tend to carry out parallel work. Periodic interchanges are made when is it necessary to confirm information or to check in on the progress of task milestones. When tightly coupled work is warranted, users are likely to either break the work down into loosely coupled subtasks or switch to another medium that is more facilitating.

It is likely that collaboration in situations like the one described here can benefit from DUIs that encompass shared workspaces. To provide means toward this end, we compiled a list of design guidelines for such interfaces, which we present in the following section.

4. DESIGN CONSIDERATIONS

We feel that shared mobile workspaces hold a strong potential for allowing colocated users to engage in tightly coupled, synchronous work. With an interest of building a suitable interface for such mobile shared workspaces, we found a lack of relevant guidance in the literature. The work presented in this section bridges the gap by providing potentially useful guidelines. These can either inform designers of collaborative mobile systems or guide evaluators in performing heuristic evaluations when faced with such interfaces. We divide our list of design considerations into two main categories—hardware constraints and human factors.

4.1. Hardware Constraints

Small screens (HC-1). The inherently small viewports of pocket-sized devices present a challenge for all mobile application developers. The display content may represent only a tiny portion of a large document. When multiple users have independent views into a large shared workspace, they can easily lose track of one another's location and activity, making tightly coupled collaboration difficult.

As a strategy for providing location awareness in shared workspaces, many researchers have developed ways to extend the effective area of a user's interaction space without sacrificing their access to fine detail. Some examples of techniques that have been studied include multiple public and private windows (Dourish & Bellotti, 1992), fish-eye views (Greenberg, Gutwin, & Cockburn, 1996), and multiuser scrollbars (Baecker, Nastos, Posner, & Mawby, 1993). Possibly the most useful and commonly implemented and effective (Gutwin et al., 1996) technique is the overview, a miniature representation of a large workspace that provides information about the relative positions of users and key objects. All of these techniques, however, are less than ideal for the mobile device setting. Overviews and multiple windows consume limited screen space, whereas scrollbars are clumsy and are generally avoided by mobile interface developers. Fish-eye views overcome some of the limitations of overviews, such as context switching costs, lack of workspace detail, and the consumption of screen space but introduce spatial distortion that counters their net benefits.

Several alternative techniques for localizing off-screen objects have more recently been developed for use specifically on devices with small screens, including scaled and annotated arrows (Burigat, Chittaro, & Gabrielli, 2006), City Lights (Zellweger, Mackinlay, Good, Stefik, & Baudisch, 2003), Halo (Baudisch & Rosenholtz, 2003), and Wedge (Gustafson, Baudisch, Gutwin, & Irani, 1998). These techniques use different methods to visually encode both directional and distance information, providing compact support for off-screen object visualization. Whereas user studies (Baudisch & Rosenholtz, 2003; Burigat et al., 2006; Gustafson et al., 2008) have shown the competing advantages of different techniques for off-screen object visualization, no evaluation has, to our knowledge, been made of their application for user awareness in mobile shared workspaces.

Regardless of the method employed, the provision of spatial awareness information is essential to effective interaction in a large shared workspace (Greenberg et al., 1996).

Individual and shared modes of input and output (HC-2). Since the personal computer became commonplace in the 1980s, application development has been aimed mainly at single users. The most popular input devices, keyboards and mice, allow only a single user to provide input, although large desktop monitors allow for one or more passive observers. The practical use of mobile devices, on the other hand, is restricted to a single user. Small screens are awkward to share and difficult for multiple users to view simultaneously.

Tabletop systems and large displays allow output to be viewed by several users at once. Tabletops are useful for collaboration, as they afford input from multiple users; however, they introduce new problems for designers such as display orientation (Alallah, et al., 2010) and disambiguation between users (Dietz & Leigh, 2001). Input for large displays generally remains restricted to a single user, although multiuser input modes have been studied, for instance, by Amershi and Morris (2008) with multiple mouse pointers and web-based mobile input.

For the purpose of mobile shared workspaces, we can divide use cases into those with a shared display and those with separate viewports. A group of mobile device users connected to a shared workspace will have both separate input and output. A large display connected to the same workspace can provide a shared output mode. It is also possible to implement the system so that the output is split between the shared display and the mobile viewports, creating a hybrid output mode. In this case, context switching between displays becomes an issue of concern, as shifting between displays has been shown to add a cognitive overhead for users (Hang, Rukzio, & Greaves, 2008).

Whether the output mode is shared, separate, or mixed, the designers of awareness features must take into consideration any factors that arise from the chosen interaction mode.

4.2. Human Factors

Coupling of work (HF-1). Groups work in a variety of fashions, and the method of collaboration chosen is highly dependent on the type of work being done, the individual preferences of the participants, and their roles or relationships. Closer collaboration requires more intensive communication, which must be supported by heightened awareness and grounding. The hallmark of tightly coupled collaboration is the fast-paced exchange of interlinked ideas and information. This interchange maintains common ground between group members and is supported by observations, gestures, deictic references, and verbal utterances. Loosely coupled collaboration occurs when people branch out into parallel tasks while maintaining their collective purpose. Face-to-face collaborators engaged in loosely coupled work maintain a lessened state of awareness by communicating their immediate goals and activities and through passive observation (Clark & Brennan, 1991; Greenberg et al., 1996; Neale, Carroll, & Rosson, 2004).

Furthermore, Dourish and Bellotti (1992) observed that the division of work and its related roles are reorganized dynamically by collaborators. They suggested that shared workspaces should not be role restrictive but must allow for smooth transitions between tightly and loosely coupled modes of collaboration.

Distraction (HF-2). One major challenge of awareness provision is to provide sufficient information for grounding without overwhelming the user with irrelevant information. Ellis, Gibbs, and Rein (1991) noted that when a DUI provides shared feedback as a result of one member's action, others in the group may not possess the contextual frame of reference for correctly interpreting the feedback, potentially leading to distraction. Gutwin et al. (1996), however, countered this argument with their observation that users tend to remain undistracted when they are able to maintain contextual awareness of their collaborators actions. Thus, it is the responsibility of the designer to provide adequate peripheral awareness and to minimize distracting feedback in situations where contextual common ground cannot be easily maintained.

Action and perception (HF-3). Gutwin et al. (1996) supported the idea that a user's actions are inextricably linked to their perception. Participants of their user studies expressed frustration when presented with awareness information without an effective means for acting on that information. From this we conclude that awareness cues should be implemented in conjunction with closely related functionality. For example, as one user is informed of the workspace location of another, that user should also be provided access to a navigation feature that will quickly take him or her there.

Continued attention (HF-4). An important element of grounding is continued attention (Clark & Brennan, 1991). The appearance of one's engagement in a group activity provides positive evidence that they are paying attention and understand the message that another is attempting to communicate. In conversation, continued attention is indicated mainly by eye gaze, a channel that is occupied by the viewport in mobile collaboration. Nonetheless, a DUI should provide users with social awareness (Greenberg et al., 1996) cues that let them know who is engaged at any time within a shared workspace.

Passive and active information sharing (HF-5). Dourish and Bellotti (1992) suggested that awareness information is more effective when provided passively by a system. The recipient of the information is in a better position to filter the incoming information stream for items they deem relevant than the sender is to predict what is appropriate to send. This argument is supported by Clark and Brennan's (1991) principle of least collaborative effort: If the provision of awareness information requires excessive effort on behalf of the participants, they will seek simpler means of grounding, or else switch to a different medium altogether.

On the other hand, there are situations in which it is not possible for a system to collect information passively, such as in predicting the future actions of a participant. In such cases, the information must be actively shared by a collaborator if and when they think it is appropriate (Gutwin et al., 1996).

Reviewability (HF-6). Reviewability facilitates grounding by providing users with a history of their transactions, a benefit not always available to face-to-face collaborators. The utility of reviewability features is evident in the wide range of single-user applications that incorporate them, such as web browsers and text editors. In a shared workspace, having access to a record of others' past actions may facilitate grounding by alleviating the need for participants to maintain a detailed context of others, as they are free to seek the information they need whenever they choose. For example, if two users are searching in parallel for a hotel, seeing one another's browsing histories will allow them to avoid areas that have already been searched.

Scale (HF-7). A mobile device provides only a small viewport into a potentially very large workspace. The smaller size and limited resolution of a mobile screen means that people are likely to view smaller sections of a document and navigate more than they would on a large computer monitor. One function that assists in spatial perception and navigation of a workspace is the ability to zoom in or out to the appropriate level of detail. Having multiple users in a shared workspace simultaneously invites the possibility for users to view the same information at different contextual levels. If users know that someone else is viewing the same object as they, they may intuitively assume they both are privy to the same details. To avoid the deterioration of common ground and maintain smooth communication, it is important for a mobile DUI to provide intrascalar awareness.

5. APPLYING OUR DESIGN CONSIDERATIONS

In the design of useful and usable applications with mobile shared workspaces, we cannot expect existing principles to transfer naively to the mobile platform. Careful consideration of the aforementioned design considerations (summarized in Table 1), with the mobile platform in mind, will lead to designs with a higher potential. To demonstrate the application of these design considerations, we present a high-level discussion concerning the support of two types of awareness cues for mobile shared workspaces: location awareness and browsing history.

5.1. Location Awareness

The workspace location of a collaborator is a fundamental piece of information for maintaining common ground about their activity. A user's location provides implicit information about his or her actions and intentions. Knowledge of objects in the user's vicinity is also a prerequisite for successfully conveying referential identity in verbal communication.

Gutwin at al. (1996) successfully employed overviews to inform users about their collaborators' current locations within a shared document. Information about another user's current location and activity provides the continued attention requirement in HF-4. However, the spatial footprint of an overview is likely to make a mobile developer think twice about using it. Alternate methods for providing visual information about objects in the workspace have been developed specifically for small viewports. Comparison studies have shown that some of these techniques, such as Halo (Baudisch & Rosenholtz, 2003), enable users to build a mental model in a manner comparable to overviews (Burigat et al., 2006), making them good contenders as cues for encoding location awareness. However, with HF-2 in mind, Wedge might make a better choice than Halo. If an interface contains references to other objects besides the couser's location, it could quickly become cluttered. Wedge has been shown to perform as well as Halo while remaining more resilient to clutter (Gustafson et al., 2008). An upper bound on the number of off-screen objects that can be clearly visualized at one time has yet to be experimentally determined.

TABLE 1
A Summary of Design Considerations for the Provision of Awareness Information on Mobile Devices

Subset	ID	Name	Primary Consideration
Hardware constraints	HC-1	Small Screens	Visual cues can supply awareness of information and activity beyond the screen edge
	HC-1	Output Mode	Designs must take into consideration whether users have access to a shared display or separate viewports only
Human factors	HF-1	Coupling of Work	Workspaces should allow users to switch between tightly and loosely coupled modes of collaboration
	HF-2	Distraction	Visual cues should be restricted to domains where users are able to maintain contextual awareness of the situation
	HF-3	Action and Perception	Visual cues should be linked to functionality that is closely related to the information they provide
	HF-4	Continued Attention	Application users must be aware of the current focus of attention and high-level activity of other participants
	HF-5	Passive/Active Information Sharing	Basic awareness should be provided without explicit attention being required of users. Exceptions exist where the system cannot predict a user's intent
	HF-6	Reviewability	Access to information about another user's previous activities can prevent redundant effort
	HF-7	Scale	Zooming is an important navigational feature of small viewports. Information about scale of view can mitigate confusion from conflicting levels of detail

To tie action to perception (HF-3), our design must support common actions that are related to location awareness. Some examples of user functions we might support are (a) navigating directly to a user's or object's location, (b) a "glance" mode for quickly viewing the workspace around a user or object without navigation away from the current location, and (c) access to more detailed information about an object without the need to navigate to that object.

5.2. Browsing History

Access to others' browsing history allows a collaborator to retrace another's steps and can support the reviewability requirement outlined in HF-6. Also, in consideration of HF-1, this type of awareness is useful for coordinating loosely coupled work, for example when users divide the workspace between them for parallel search activity. For efficiency in this task, collaborators will prefer to avoid areas that have already been searched by others, which is only possible if the users share common ground about where searching has previously taken place. Navigation history can provide the common ground that is required.

Presenting history information on a small viewport is a considerable design challenge, as a user's view is limited to a small portion of the workspace. It may be that only information about the visible area is required. Presenting information about other document areas could easily lead to clutter and distraction, which would violate HF-2. The design choices should support the passive and active information transfer modes outlined in HF-5.

5.3. Sharing Output

Many of the design constraints outlined for location awareness and browsing history are a result of the small viewports of mobile devices. One way to ease these restrictions is to provide a shared output mode, as described in HC-2. This shared output could potentially be provided with the small and portable mobile projectors that have recently become commercially available. A shared view would alleviate some of the effects of clutter and a larger display space would make it easier to provide location and browsing history awareness information.

6. CONCLUSION

Shared workspaces offer a platform for rich group interaction on mobile devices. Awareness cues are an essential feature of DUIs and allow collaborators to find the common ground they need for tightly coupled work. Our collection of guidelines, distilled from years of high-profile literature, will hopefully support the development of such systems and lead to effective designs. These same guidelines can also provide a firm basis for heuristic evaluations of such systems when they become prevalent.

Our future work will include the implementation of model applications, allowing us to test our assumptions about user needs. We will create designs appropriate for a mobile setting through iterative user-centered design and validate these with qualitative and quantitative studies. We will also study how users benefit from awareness provision in colocated mobile settings and outline their effects on synchronous collaborative work.

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