Display Factors Influencing Co-located Collaboration

Regan L. Mandryk
School of Computing Science
Simon Fraser University
Burnaby, BC, V5A 1S6
Canada
{rlmandry @sfu.ca}

Stacey D. Scott
Department of Computer Science
University of Calgary
Calgary, AB, T2N 1N4
Canada
{sdscott@acm.org}

Kori M. Inkpen
Faculty of Computer Science
Dalhousie University
Halifax, NS, B3H 1W5
Canada
{inkpen@cs.dal.ca}

ABSTRACT
Understanding how various system features, such as input devices and displays, impact teamwork can form a basis to compare different collaborative systems. This paper concentrates on factors of physical display technology that influence co-located collaboration. We present seven such display factors: *orientation of display*, *arrangement of users at the display*, *size of display*, *proximity to the display*, *privacy of the display*, *superimposition of display space on the input space*, and *number of displays*. To illustrate their impact on teamwork, we describe how the display factors influence the mechanics of collaboration identified by Gutwin and Greenberg [2].

Keywords
Co-located collaboration, display factors, teamwork, SDG

INTRODUCTION
A variety of systems and applications have been developed for co-located collaborative computing environments. It is challenging to synthesize this body of research into theories of face-to-face interaction. Not only are different results produced by the variety of applications and environments, but the vast differences of interpersonal interactions create unique and unreplicable collaborative situations. Identifying display factors that can be controlled would allow comparisons across collaborative systems and help to elucidate their influence on collaborative processes.

Display factors such as the orientation, size, and number of displays can enhance or impede users' interpersonal interactions. Gutwin and Greenberg [2] have identified seven *mechanics of collaboration*, which are low-level actions and interactions that must occur in order to complete a shared task. The mechanics of collaboration are: explicit and consequential communication, coordination, planning, monitoring, assistance, and protection.

Explicit communication refers to intentional non-verbal and verbal interactions among collaborators. *Consequential communication* is information unintentionally conveyed by people's actions and by artifacts as they are manipulated. *Coordination of action* includes the sharing of resources and tools and how well people predict another's behaviour. *Planning* indicates how users divide up the task and reserve areas for their own use. *Monitoring* is how people gather information about their collaborators. *Assistance* provided to group members could be opportunistic or explicitly requested, and *protection* is safeguarding one's own work from the effect of other's actions.

DISPLAY FACTORS INFLUENCING CO-LOCATED COLLABORATION
We have identified seven display factors that we believe influence the mechanics of collaboration. These factors are based on formal and informal observations drawn from our own research as well as other relevant literature of co-located collaborative technologies.

Orientation of Display
The orientation of a display surface can have a considerable impact on collaboration. The orientation of vertical displays (e.g. walls) is the same for all users, whereas users sitting at different sides of a horizontal display (e.g. table) see different views. Having different views of an object can impact the planning, coordination, and monitoring of a task [5]. Orientation of individual objects within the display may also vary. For example, on most vertical surfaces objects are displayed level to the ground (e.g., paintings) whereas, on horizontal surfaces physical artifacts are frequently not square to the surface borders (e.g., paper notebooks) [1]. In addition, horizontal surfaces support the placement of transient objects, such as mugs and notepads, while vertical surfaces do not.

Arrangement of Users at the Display
Whether collaborators are sitting face-to-face or shoulder-to-shoulder influences interactions both with the display and with each other. Our observations suggest that face-to-face computing aids explicit non-verbal communication such as eye contact and gesturing. Users sitting across from each other tended to look at each other and make eye-contact frequently while those sitting shoulder-to-shoulder exhibited only a few instances of eye contact [3,5]. Users facing each other at a tabletop display can see both the display and each other, influencing several mechanics of collaboration such as monitoring and coordination of action. These aspects are improved because users can more easily see their collaborator's current and intended actions. Users sitting side-by-side however may have other collaboration benefits since they view the display space from similar perspectives.

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Size of Display

When comparing display technologies, it is important to consider their size. The greater screen size of wall and table displays offers more screen real estate, and allows more people to gather around and view the contents of a display. This can facilitate the planning of a collaborative task by providing room for users to simultaneously work on different subcomponents. The public nature of large displays also promotes serendipitous collaboration [1]. Colleagues passing by a large display can easily see what the display's user is working on, facilitating the monitoring process, as well as increasing the opportunities for gaining assistance from these colleagues.

Proximity to the Display

Regardless of the size of the display, participants may be closer or farther depending on the physical configuration. People sitting away from a wall display, such as the audience at a conference talk, often treat the display surface as non-interactive. Displays within physical reach, such as tables, whiteboards, or monitors, are easier to interact with directly, facilitating gesturing to individual objects on the display. Gestures can improve explicit communication by facilitating the use of deictic references in conversation.

Privacy of the Display

Privacy of the display affects the level of awareness in a collaborative environment. Large, vertical displays are often used to present "group" information, such as current design plans. Group displays facilitate monitoring, coordination of action, assistance, and planning within the collaborative environment. In a design environment, designers can see and comment on their peers' designs [1], while managers can easily monitor the state of a project and plan accordingly. Small displays with narrow viewing angles, such as handhelds computers, do not promote multiple people viewing information simultaneously [4]. In general, displays that afford shared viewing facilitate an increased awareness of activities, but there is a trade-off with the ability to display private information.

Superimposition of Display Space on the Input Space

Whether or not input occurs in the same physical space as the display will impact the collaborative activity. Touch screens and styli input superimpose the input and display spaces whereas input devices such as mice, keyboards, and trackballs do not. Situating input within the context of the display improves consequential communication. If your collaborator initiates an inappropriate selection of an object located in your peripheral vision, you are more likely to notice their arm moving than a small cursor on the display. In this environment, collaborators can easily monitor each others' interactions, protect their work, and coordinate their actions accordingly. Explicit communication is also enhanced in this environment because it is conducive to the use of gestures and deixis [3].

Number of Displays

Collaborating around one shared display, several individual displays, or a combination of both changes the nature of interpersonal communication. A group gathered around a whiteboard focus on the same physical location and on the same content. When collaborators each have their own handhelds or laptops, they are often focused on different physical locations and, depending on the level of software support for the collaboration, different content. Monitoring is easier when sharing a display, facilitating coordination of action in a shared task [5]. We have observed that users of individual displays tend to focus on their display and not on each other. Consequently, they are less likely to see physical gestures and actions being performed by others, impeding both explicit and consequential communication within the group. However, coordination of action and privacy may be easier with multiple individual displays.

CONCLUSIONS AND FUTURE WORK

This paper introduced seven display factors which influence co-located collaboration. We identified how these display factors can impact the mechanics of collaboration identified by Gutwin and Greenberg [2]. Formal and informal observations have provided insight into the impact of the display factors on these mechanics of collaboration. Through continued research in this area, we hope to develop a more comprehensive understanding of the subtle affects of each display factor on the mechanics of collaboration. This knowledge could inform the design of more suitable technology for a variety of collaborative environments such as home, school, and work settings.

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