Miners: Communication and Awareness in Collaborative Gaming at an Interactive Display Wall

Ulrich von Zadow, Daniel Bösel, Duc Dung Dam,
Anke Lehmann, Patrick Reipschläger, Raimund Dachselt
Interactive Media Lab Dresden
Technische Universität Dresden
Dresden, Germany
{firstname}.{lastname}@tu-dresden.de

ABSTRACT
Research on interactive wall displays has thus far focused mostly on professional use. However, as large displays with support for touch and other input modalities become more common, it becomes reasonable to assume use in more casual settings as well. We present *Miners*, one of the first collaborative games for a touch-sensitive display wall, and investigate multimodal, multi-user interaction in this context. In this fast-paced game, four players cooperate to rescue workers trapped in an underground cave, with each player being able to influence the game world in a different way. In an exploratory study using Miners, we found that players enjoyed the game and showed very high engagement. On the other hand, awareness suffered: Players often missed events in other areas. In addition, we found limited awareness of other players' actions and social cues. We report on these results in detail and discuss implications for touch-based wall interaction in general as well as in other application contexts.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords
Collaborative games, display wall, tangible interaction, wall interaction, multitouch, awareness

INTRODUCTION

As display technology advances, wall-sized interactive displays will become usable in more and more settings. Current high-resolution displays often support input modalities such as touch, pen and marker-based tangible input. Research in this area has focused mostly on professional use, e.g., for visualization [1]. Work on wall interaction has found them well-suited for collaboration [13], with physical navigation – locomotion to access data – being a central aspect [3, 15]. It is reasonable to assume that broader usage scenarios and more informal use will become feasible as equipment prices decline. At the same time, there is only little research that covers such casual use (e.g., [17]), and even less gaming [22] on touch-sensitive walls. While there is some research on casual use of large displays in the tabletop domain (e.g., [11, 25]), it is unclear whether the results apply to interactive vertical displays as well. This also applies to research on awareness: While others have, e.g., compared mouse and touch input on tabletops with regard to awareness of collaborators' actions [12], awareness is to our knowledge only mentioned in passing in wall-related work (e.g., [9, 14]).

Figure 1. Typical Miners gameplay scene

We therefore designed and implemented a fast-paced, collaborative multi-player game for a large wall display, *Miners* (Figure 1). Miners uses a bimanual, combined tangible-touch interface with physical navigation, where players interact in a game world similar to the game Lemmings. With Miners, we contribute novel game mechanics and an interaction concept which – to the best of our knowledge – has not been described before. To investigate aspects of collaboration and awareness in this exemplary setting, we conducted an exploratory observational study using this game. While players enjoyed the game and showed very high engagement, we also found a number of awareness and communication issues which we believe are relevant beyond our specific application case.

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MINERS

Miners is a game for four players that revolves around rescuing miners from a cavern displayed in cross-section on a wall display. Injured and initially immobile miners are dispersed through the dark cavern, and the goal of the players is to rescue them by sending additional miners down from the surface given limited time. Each of the players has a different tool to interact with: One player can build bridges, another ladders, the third has a pickaxe to remove obstacles, and the last can place lights. Consequently, players need to cooperate to succeed. Our game development was iterative, user-centered, and involved regular tests by new users to ensure easy learnability. To identify users (and thus determine the tool in use), we use tangible markers. These are held in one hand and open up a circular interaction lens when they touch the wall (Figure 2). The player can then touch inside the lens to activate the tool (and, e.g., build a bridge).

Each game level starts with a 30-second *Planning Phase* in which the mine is lit in its entirety, allowing the players to orient themselves. In this phase, no interaction with the game world or the miners is possible. In the following five-minute *Interaction Phase*, the mine is completely dark and lit only through player actions. To win, players need to bring all miners to the surface. Miners follow simple rules while moving: They walk in one direction, turning around when they reach an obstacle. They can fall without hurting themselves, but there are lava pits that injure them. When they meet a regular miner, injured miners in the caverns start walking as well. Significantly, the size of the wall display allows us to show the complete game board, making a minimap superfluous.

Although there is ongoing research on this (e.g., [27]), most current touch-sensitive surfaces do not detect who is interacting. Therefore, we support player-specific interaction using tangibles to open an *Interaction Lens* specific to that player (Figure 2). The lens temporarily lights up the immediate surroundings, and touches inside the lens trigger actions. When two interaction lenses overlap, the area turns red and interaction becomes impossible. This constitutes a convenient means of bimanual interaction: In general, the user's non-dominant hand creates an interaction zone, allowing the dominant hand to interact. To our knowledge, using tangibles for this purpose, while similar to, e.g., Schmidt et al.'s IdLenses [20] and Kister et al.'s BodyLenses [15], is novel in a game context.

Bridge and Ladder components have a limited lifetime, so they need to be placed shortly before miners arrive. Further, the number of concurrently placed Bridge, Ladder and Light components is limited, with the current use count displayed at the top of the Interaction Lens. Besides removing obstacles, the Pickaxe can also be used to destroy placed components. While any tool produces a small, temporary light, the Light tool can place permanent lamps that illuminate a larger area.

Our game is designed to put a focus on teamwork and communication and clearly requires a group effort to succeed. It therefore implements typical cooperative game mechanics such as heterogenous resources, common goals and collaborative tasks [18, 21, 24]. At the same time, it is interesting because enforces physical navigation close to the display wall, uses bimanual tangible+touch interaction, and thus has the potential to significantly change mechanisms for collaboration.

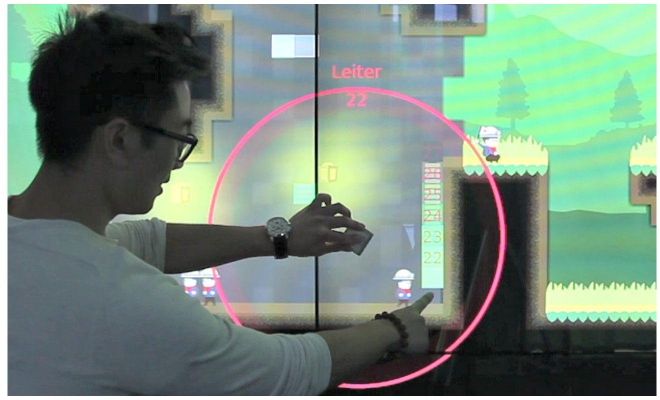

Figure 2. Miners interface: The player opens an Interaction Lens using the tangible in his left hand. Touches in this lens then activate his tool.

Miners is implemented in Python using the media application framework libavg[1]. Our prototype runs on a display wall consisting of twelve 55" multi-touch displays with a total dimension of 5x2 meters and 24 megapixels resolution. The wall supports touch and pen input as well as marker-based tangibles.

RELATED WORK ON GAMES

A number of papers have covered gaming at large display walls. Most involve interaction at a distance using various input modalities; touch is seldom used. Multi-player games include Polar Defence, Tabula Rasa and PyBomber. While Polar Defence [7] uses text messaging in a public walk-up-and-use setting and focuses on engaging bystanders, Tabula Rasa [8] is a two-player game with a single player interacting at a large display using a game controller and the second player interacting using touch at a separate tabletop. Machaj et al. investigate 4- and 12-player interaction at a large display wall using Wiimotes as input devices in PyBomber [16]. This game involves physical navigation, and the authors find some of the same issues with occlusion that we do. Additionally, Hoare et al. [10] investigated a single-user wall game for children using a smartphone camera for interaction, and Vepsäläinen et al. [23] report on an in-the-wild deployment of a game for a large public display controlled using smartphones. None of these publications involve interaction close to the wall, nor do they report results on awareness.

The only wall game involving touch known to us is Toprak et al.'s [22] Bubble Popper, which focuses on physical contact between players as gameplay mechanic. To our knowledge, Miners is the first cooperative multi-user game based on a touch-sensitive display wall.

USER STUDY

To learn about the behavior of groups closely collaborating at a large display wall, we conducted an exploratory, largely qualitative study using Miners. We focused on two major

[1] http://www.libavg.de

research questions: First, how do the physical environment (a large display wall) and interaction modality (tangible+touch, interaction close to the wall) impact collaboration? Second, do the insights from prior work on wall displays – especially those pertaining to awareness and collaboration – hold in a casual, fast-paced game environment? This is interesting because collaborative games in other environments don't have this amount of body involvement and physical navigation.

Method

Our study involved four groups of four players each (recruited from the local university, ages 19-30, 25% female, avg. 45 min per group, various levels of acquaintance within the groups.), with an additional two groups in a pre-study to adjust study parameters. Subjects are designated using 1A-4D in the following, with the initial digit signifying the group and the letter indicating a specific group member. After an explanation of the game and signing informed consent, subjects played a total of five levels: a tutorial level, three levels with increasing difficulty, and a final level where speaking was prohibited to provoke use of non-verbal communication. We conducted a semi-structured interview with each group, each participant answered a short questionnaire (see the most important questions in Figure 3), and we video-taped the sessions. Finally, we recorded head position and direction of the participants using an Optitrack system (head positions and directions are not evaluated in this work). There were at least three observers per group, which discussed and compared notes immediately after each session to iteratively build understanding.

Based on these observations and related work [6, 21], one person conducted a video analysis, with the results again discussed among all researchers. During analysis, we looked for interaction and awareness issues, observed players' focus of attention and mechanisms for communication (verbal, gestural, eye contact). We further analysed communication content and studied the movement of players in front of the wall.

Findings

In general, subjects enjoyed the game very much, with two of the groups asking to play again post-study without being prompted. This was visible in high engagement and motivation, as well as bodily involvement such as running or kneeling down to interact or to get out of the way. It was also reflected in the questionnaire results (Figure 3): The game was rated very highly for fun, with an average of 6.125 (SD: 0.806) on a 7-point scale. In interviews, several players commented that

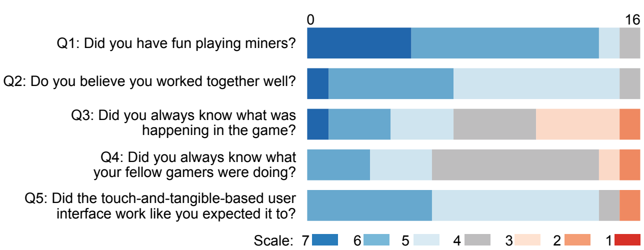

Figure 3. Excerpt of the questionnaire results with 7 signifying strong agreement, 1 strong disagreement.

they particularly liked the physical aspects of the game, including the whole-body movement needed, and that the sheer size of the wall helped immersion. The Interaction Lens-based interface as well as the basic game mechanics were generally understood during the tutorial level, but some specifics (e.g., the minimum tunnel height above ladders) took longer for players to grasp.

Note that given the number of study participants, the quantitative results should not be overinterpreted and are therefore only reported in excerpts. On the other hand, the qualitative results were largely uniform across the four groups, so we assume that additional participants would not have yielded additional insights.

Positioning and Locomotion

During the planning phase, players generally stood at an overview distance from the wall and discussed possible interactions, while respecting others' personal zones. This changed in the interaction phase: When players cooperated well, they stood in a group close to the wall, sharing a focus of attention and following miners moving through the caves. Interaction proceeded in turns, with the Light tool often scouting the way. However, there were frequent departures from this ideal: Players would often break off of the group to pursue individual goals or scout ahead.

Through video analysis, we found three possible states for players (with many fluid changes between states and between shared and individual foci of attention):

- *Active*: Directly interacting. Close to the wall and generally focused on their Interaction Lenses. Generally, no more than two people could interact at once.
- *Ready*: Still close to the wall, but focused on the active players' interaction lenses. Ready state players were able to interact at moment's notice.
- *Observing*: One or two steps behind the Active and Ready state players. Observing players hovered on the periphery, getting an overview of the other players and the game state but unable to interact immediately. In general, occlusion by other players caused Observing state players to keep changing their viewpoint by moving. These players were also most likely to take on leader or coordinator roles.

Figure 1 shows a typical configuration: The two center players are in Active state, the left player is Ready, and the right player is Observing. Note that states are closely related to the role the players take on as well as their physical distance from the wall and the observed center of interaction.

Significantly, no more than three players could share a focus of attention in Active or Ready states at once for space reasons. This is visible in Figure 1, where the Observing player would have had a hard time interacting without physically displacing one of the other players. In the Active and Ready states, there was also no evidence of territoriality [2] and much interaction in very close proximity (Player 4B: "Twister-like") – even among strangers. Players physically got in each other's way, but several players stated that this actually added to the fun in the interview.

Figure 4. Awareness issues: The player at the right cannot see what the other players are doing.

Awareness

We observed many instances of tunnel vision, where players were unaware of the game state or other players' actions. In addition, the corresponding questions in the survey (Figure 3, Q3 and Q4) got much less positive results than the other questions. This was less an issue when players shared a single focus of attention. Conversely, it was most severe when players interacted apart from the group close to the wall (e.g., Figure 4), where only the game state in the player's immediate center of attention was seen. In some instances, players missed changes directly outside their respective Interaction Lenses. Global game state such as the time left was in most cases ignored completely, with players acting surprised when the time was up. Interestingly, even the 'Game Over' state, where the complete wall darkens and a corresponding text is displayed that spans several displays, was ignored once in the study (Player 3B continued interaction attempts for more than 5 seconds) and several times during playtesting.

In Observing state, players were in most cases aware of the events in their general area. This was visible in the videos and commented on several times in the interviews (2B: "I could get an overview by stepping back", 2C: "Stepping back worked, but there were occlusion issues", 4C: "I had the choice to either interact or get an overview"). Also, Observing players were sometimes able to help with awareness issues that the immediately involved players had. One example of this would be the display of a tool usage count which was missed by the interacting player, with the observer pointing out the issue.

Communication

Communication in Miners was generally used to to tell a player to use her tool, to explain game mechanics, or to discuss strategy. As mechanisms, we observed:

- Verbalisation: Often short and in command form ("Ladder here!"), with very context-dependent content.
- Pointing: Generally using the complete arm. Pointing was mostly seen in the planning phase, less often during hectic gameplay.
- Interaction Lens: Players would place their tangible on the wall to show locations, sometimes moving it around to mark an area.
- Bodily contact such as a tap on the shoulder, usually to gain someone's attention.

In the planning phase, verbalisation and pointing were commonly used. There were no issues with getting other players' attention. Again, this changed during the interaction phase, where getting other's attention was an issue, and, in consequence, players ignored other's needs regularly. Notably, there was very little eye contact between players, since players mostly focused on the wall and the game state. Eye contact was also not used as often as expected when asking for attention (e.g., when action by another player was needed), and co-verbal gestures were seldom used for communication.

There were issues with getting attention in all groups, with repeated and in some cases drastic measures taken to resolve this. In approximate order of urgency, we observed the following methods of getting attention:

- Calling the player's or the tool's name.
- Repeated tool names (e.g., 1C: "Pick, pick", 3B: "Light light light"), louder words and commands (e.g., 1A: "Get going!", 3B: "Quickly!").
- Light bodily contact.
- Exertion of force: We observed one case where a player didn't react to other cues and was forcefully pushed in the direction required.

In addition, when getting attention failed, other players would often intervene.

Not surprisingly, in the level without speaking, communication became even harder and getting others' attention was very difficult. In many cases, gestures were used to communicate intent (e.g., 'ladder' indicated by an up-down hand movement.), but this was often ignored since the intended recipient's attention was elsewhere.

DISCUSSION

Our case study describes interactions and behavior specific to one game, and by themselves it is not clear to what degree the findings can be applied to more general cases. However, some of our results are interesting because they confirm and emphasize findings by other researchers in a new usage context. In addition, several aspects have been seen in other areas but not put into a broader perspective – the most important of these being that social awareness is likely limited when interacting close to a wall display.

Awareness

One fundamental fact about wall interaction is that when users are close to the wall, they see only a small part of the interface. It is clear that this is a potential cause for *blindness to changes in the display contents*, and findings by other researchers support this: Among others, Sabri et al. [19] observed issues with awareness of peripheral information with larger displays in a single-user game played on different-sized displays, Andrews et al. [1] hypothesize that change blindness will become an issue when interacting at close proximity to wall displays, and Bezerianos et al. [4] find that content further away is hard to perceive because of reflections, low contrast, and distortions when users are close to the wall. In the case of our game, where people can only interact when close to the wall, these findings become even more evident.

Additionally, our observations show a related but separate issue: Users interacting within touching distance of the wall suffered from limited *awareness of other users*. This pertains to awareness of other's interactions with the software as well as awareness of social cues such as gestures, body posture, facial expressions and eye contact. There are some hints at similar issues in related work. E.g., Jakobsen and Hornbæk [14] found "more negative signs of awareness" when interacting close to a large vertical display, and Hawkey et al. [9] found similar awareness issues at a vertical display when one participant was further away than the other.

However, the issues we observed were much more pronounced. High engagement with the game world and stress caused by the time-critical interaction, as well as the Interaction Lens concept probably contributed to this. Also, Miners only supports interaction when in direct proximity to the wall. Still, we assume that awareness issues will appear elsewhere: If users remain close to the wall, the wall takes up the complete field of view, preventing users from perceiving social cues (gestures, body posture, facial expressions, eye contact) of others in addition to causing blindness to interface changes. In contrast, consider the other main collaborative single-device setting, the tabletop: Tabletop users can see each other's arms, so pointing and touch interactions remain visible. In addition, body posture and gestures can be observed through peripheral vision and eye contact can be established more easily (see, e.g., [25, 26]). These mechanisms facilitate collaboration and are missing in our as well as likely most other wall-based scenarios with direct interaction. A further contributing factor may have been that our wall is significantly larger than in many other studies (e.g., [5, 8, 9, 14]) and thus allowed for multiple foci of interaction and true physical navigation.

In a game such as Miners, the issues observed add to the challenge and don't necessarily detract from the players' enjoyment. Still, in general, a challenge in wall interaction will probably be to design interaction mechanisms that counteract change blindness and social awareness issues. Others (e.g., [3, 19]) have suggested moving information closer to the respective user, and this does help in the case of blindness to interface changes. However, it does not alleviate social awareness issues, and we believe that one important tool here is to allow interaction when at a distance from the wall, e.g., using freehand gestures, remote controllers (e.g., [10, 16]) or body movements [15].

Positioning and Locomotion

Some of our findings regarding positioning and locomotion were likely the result of our specific scenario – including, e.g., the lack of territoriality and work in close proximity.

On the other hand, the observation that no more than three players were able use touch interaction with a single center of attention at once in Miners probably applies to other scenarios as well, since it involves natural physical limits. Additional users would have had a hard time reaching the display, even when interacting in very close proximity (cf. Figure 1). In fact, the issue can be seen in other work as well, (e.g., Clayphan et al. [5], Fig. 9) , though it is only hinted at in the text.

Finally, we believe that our observations of occlusion issues for players at a distance are important. Others have found similar issues as well [14, 16], so this is probably a general phenomenon when users interact at differing distances. Consequently, when designing a system involving interaction at differing distances to a display wall, occlusion needs to be taken into account. In fact, since there was nearly always someone in the way, occlusion issues should be treated as a rule, not an exception. As one solution, we propose displaying additional overview content above user's heads when appropriate, where they can be seen even if others stand in front of the wall.

CONCLUSION

We have presented the first cooperative, multi-user game for a touch-sensitive display wall. *Miners* is a fast-paced game that employs a novel bimanual tangible+touch interface for multimodal interaction. We performed an exploratory study to investigate communication and awareness in this context, and results indicate a very high level of engagement and fun while playing. Also, our study revealed awareness issues for users interacting close to the wall: Not only changes in display contents, but also others' interactions and social cues were often ignored. Further, players that stepped back to get an overview expericenced occlusion issues. In our opinion, it is probable that both awareness and occlusion issues are applicable to more general use cases. Therefore, for further work, we propose additional comparative studies to isolate dependent variables, e.g., by comparing touch-only with touch and distant interaction for collaborative work.

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