Chamber of Mirrors:
A Socially Activated Game Exploits Pervasive Technology

Chamber of Mirrors offers a socially activated gaming experience built on a custom platform of interactive pervasive technologies. The authors review user tests and present techniques for overcoming the challenges of designing interactive applications for pervasive platforms.

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Smartphones have become the de facto wearable and pervasive computing technology for most people. However, no single device can ideally meet the potential for computing, interactivity, entertainment, and communication that pervasive computing envisions and enables. For example, compare a smartphone to the 65-inch monitor attached to a PC. Both can browse the Internet, play interactive games, communicate with friends, and show media content, but the phone has advantages in mobility, while the monitor-based system offers a richer media experience that can be shared with a large group. Similarly, on-body devices and sensors offer different affordances than devices embedded in the environment. Distributed, room-level sensors can more easily detect groups and social organizations, whereas on-body sensors more easily detect a particular person's specific actions.

Applications proposed for pervasive computing—such as those that facilitate social interactions, collaboration, and engagement; provide a narrative context to an experience; or enable connections to virtual spaces—generally require multiple types of devices and sensors. So, for pervasive computing to reach its potential, we must research the use of complex, heterogeneous systems and find working solutions to the challenges they present. Some smartphones have achieved commercial success by limiting complexity and enforcing consistent, simple, and user-friendly interfaces. However, we face steeper challenges in attempting to integrate, deploy, maintain, and agree upon standards for pervasive computing.

To better understand how users perceive and interact with a novel pervasive computing application, we designed, deployed, and evaluated a new multiperson game, called Chamber of Mirrors. The game is driven by social actions and requires the capabilities of a distributed computing, sensing, and interactive system, designed specifically for this research.

The Challenges

Several challenges emerge when considering how users will perceive and interact with a pervasive computing application:

- *Multiple learning curves*—a user must learn a new user interface for each different heterogeneous component to fully engage with the overall experience.
- *Context switching*—switching between spaces, such as real and virtual or social and private, can quickly pull a user out of the mind space of the experience and limit engagement. This challenge can be mentally and physically exhausting for both users and designers.
- *Conceptual complexity*—the exponentially growing complexity and infinite design

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Related Work in Pervasive Interactive Gaming

Of particular relevance to the Chamber of Mirrors project is the work of Kalle Jegers,[1] which focuses on cross-media user experience and has led to a discussion of player enjoyment in pervasive gaming—a direct correlation to one of our research goals. Steve Benford and his colleagues have started to understand the power of bringing gaming elements into the tangible world with the use of pervasive computing systems.[2] These works serve as a starting point for the development of Chamber of Mirrors and indicate the types of research contributions we hope to achieve. Additionally, Benford's prior work promoted the use of gaming to provoke reflection and to make computing systems more human-centric.[3]

In one of its many forms, the conceptual field of augmented reality, as exemplified by the ARQuake project,[4] overlays video game elements on top of reality through the use of a mobile device or a head-mounted display. This field has shown and continues to promise new forms of gaming and interaction that enhance our relationships with our environment.

The UberBadge[5] and its successor, the Sociometric Badge,[6] used a wearable, sensor-enabled badge to visualize the social space created from interpersonal interactions. These wearable devices enhanced the experience of a large group event using the collected social data. These projects are directly related to our research by their badge form factor and also by their bringing abstract social relational space into the real experiential world. Prior to these badge projects was the work of Vanessa Collela, who used badges to drive a learning experience through real-world interactions.[7]

The MIT Media Lab's Spinner project is relevant from a device topology perspective, as it integrates an application across several types of devices including wearable sensor devices, situated media devices with screens, cameras, and sensors, and back-end systems.[8] The project provides much inspiration for our research, because it uses human-centric sensing to drive an experience—in this case, a narrative video created using networked video cameras.

Finally, we looked at research with a similar goal of trying to define taxonomies for the design of multidevice interactive systems. This is a fairly newly emerging field, but early works on the subject, such as Lucia Terrenghi and her colleagues' taxonomy for multiperson-display ecosystems,[9] are starting to emerge. We hope to eventually generalize the Chamber of Mirrors project into a similar taxonomy for the design of multidevice technology-mediated experience design.

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possibilities offered by combining the best features of multiple interactive systems offers the potential for unique experiences. However, content with no obvious reference to existing entities can quickly lead to an *island of experience*, in which participants are so busy trying to comprehend the content and learn how to use the devices that they miss out on the novelty of the experience. On the other hand, if you force the design to be too referential to known experiences, you run the risk of failing to exploit the uniqueness that emerges from the liminal spaces created at the blending points of the different realms.

From these challenges, we identified the following research goals:

- develop insights for selecting and developing technologies to help integrate heterogeneous interactive systems, and
- identify design elements in pervasive interactive systems—in this case, pervasive gaming—that can increase participant enjoyment, engagement, or productivity.

Our design decisions in developing the Chamber of Mirrors game attempt to address the challenges and our research goals. (For similar work in this area, see the "Related Work in Pervasive Interactive Gaming" sidebar.)

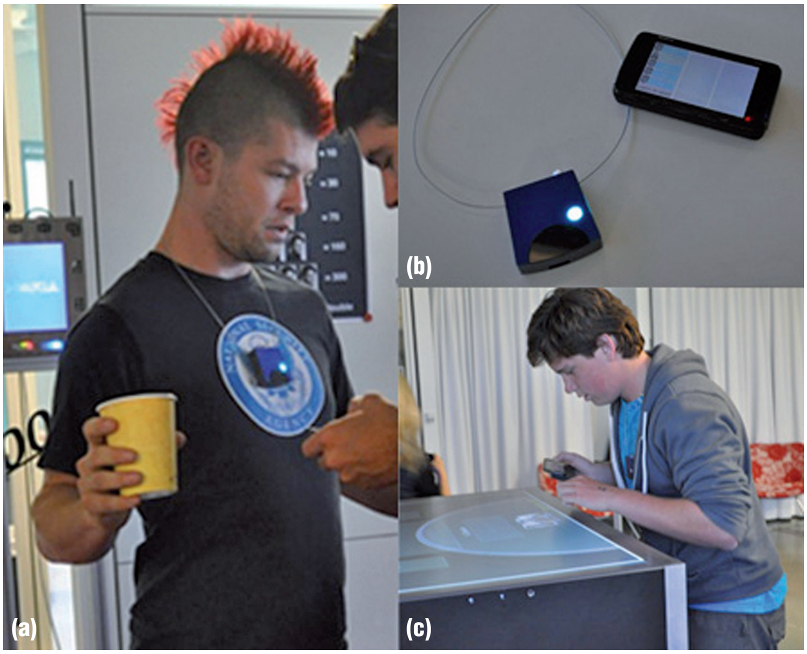


Figure 1. The badge for the pervasive computing platform. (a) A user wearing the badge, (b) a badge paired with a mobile device using Bluetooth, and (c) a user wearing the badge and using a multitouch table for collaborative actions while simultaneously using the mobile device for private actions. The badge lets both work with the user's specific data.

Platform Devices

To begin experimenting with and developing applications that exploit integration across different interactive systems, we created a platform comprising several device types. We selected devices that would help create applications that can exist in multiple conceptual spaces and develop user experiences that integrate the devices. This platform is continually available as a playground for experimenting with pervasive computing, sensor networks, human-centric sensing, interactive architecture, and technology-mediated experiences, such as Chamber of Mirrors.

We used the following individual devices to create our platform.

A Wearable Badge

We paired a small, sensor-rich wearable badge with a mobile device (see Figures 1a and 1b). The badge includes a three-axis absolute orientation sensor, accelerometer, and gyroscope and has Bluetooth, line-of-sight infrared, and 3-Mbps device-to-device RF wireless capabilities. The infrared (IR) channel adds optical tagging capabilities that let a device know when a badge is facing it, indicating what the person wearing the badge is looking at. An audio system is included with a microphone and digital signal processor.

The badge is necessary to provide data about the participant's social and physical behavior that would otherwise be unavailable.

A Mobile Device

We used the Nokia N900 phone as our mobile device. Figure 1b shows the phone paired with a badge, and Figure 1c shows a participant using a phone for private information while using a multitouch collaborative surface.

The mobile device is necessary because it can display private information for the participant, letting the application support contextual and personally significant activities.

An Interaction Portal

We used interactive portals called "mirrors" as sensate multimedia kiosks that we could quickly deploy by mounting them to walls and windows or by positioning them with stands and struts (see Figure 2a). Figure 2b shows a user interacting with a mirror. The mirror can identify the user by his or her badge and present personalized information.

The mirrors are necessary for the system and for the Chamber of Mirrors game because they add interaction and multimedia to specific locations and create a distributed platform that augments and actuates the space.

An Interactive Table

The BrickTable is a multitouch, collaborative, interactive table (see Figure 2c). Similar to the mirrors, it has tags that can identify specific participants and where they are around the table. We added the BrickTable to the system to provide a point of collaboration and physical meeting place.

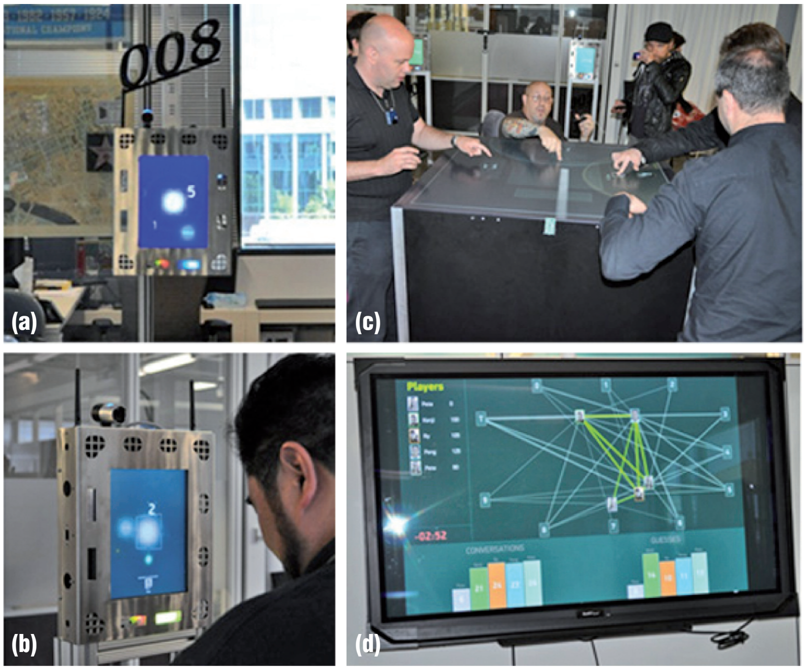
A Status Display

We also added to the system a large public display, shown in Figure 2d, to present information to all inhabitants of the instrumented area. Display screens can act as scoreboards or game clocks, visualize social and physical data, or present visual content such as narrative elements for an interactive experience.

The Chamber of Mirrors Game

The goal of Chamber of Mirrors is to identify which player each of the 10 mirrors positioned around the room represents. Each mirror secretly selects a player to follow and then puts visual clues on its screen to suggest which player it's following (see Figure 3). In other words, the players observe each other's social and physical actions, matching them to the

Figure 2. The platform's portal and interactive table. (a) Mirror #008 mounted on a strut and hanging from the ceiling, (b) the badged user interacting with a mirror, (c) the multitouch, multiuser BrickTable in collaborative use, and (d) a status display showing overall game status and social connection data.



graphical clues presented on the mirrors, and attempt to guess which player these clues represent.

To guess a specific player, you must first approach and socially interact with that player. During the interaction, your mobile device will privately ask you if you'd like to use the person you're interacting with as your guess. Secretly hitting the touchscreen to confirm this selection can help protect your guessing strategy from other players. Once you've selected the player, you approach the mirror that you believe is following the person you guessed.

If a guess is incorrect, the mirror shows all the previous incorrect guesses as an additional clue and continues to follow the same mystery player. If your guess is correct, you're rewarded with a card that has a picture of the player you guessed. Cards are automatically collected in a virtual wallet, privately visible on each player's mobile device. The mirror will then begin to follow a different player, starting with an empty screen.

When a player approaches the BrickTable, his or her cards are automatically laid out on the table's surface. You can then trade the cards with other players or cash them in for points (see Figure 4). Points are awarded according to how many of the same card are cashed in at a time—for example, a single card is worth 10 points, but if a single player

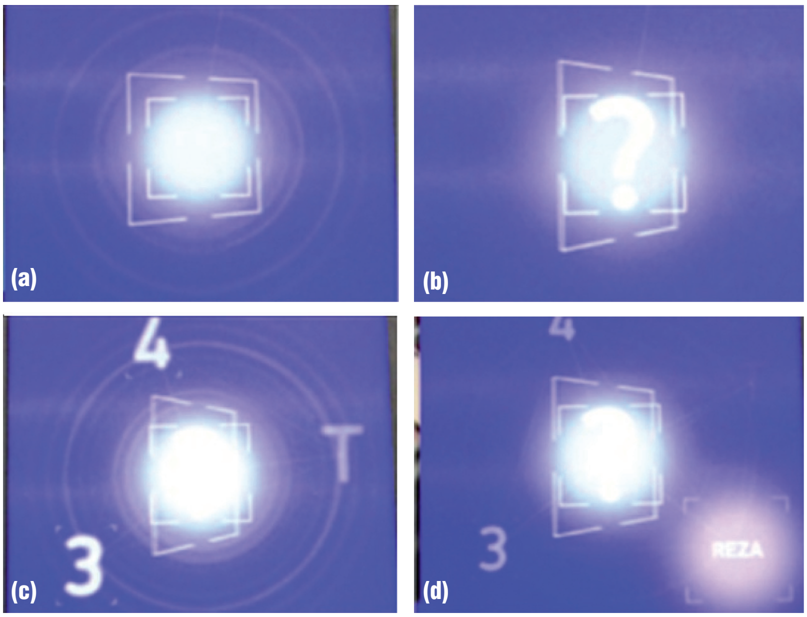


Figure 3. Graphical clues hint at the player each mirror is secretly following. (a) Concentric circles emanate according to amplitude and frequency of the mystery player's voice. (b) Boxes move and rotate according to the mystery player's physical motion. (c) Numbers appear when the mystery player approaches a mirror, and the letter T appears when the player approaches the BrickTable. (These clues fade over time, so in this example, the mystery player went from the BrickTable to mirror 4 and is currently at mirror 3.) (d) An orb with another player's name appears when the mystery player starts a conversation with the named player. It also fades over time, to indicate history.

Figure 4. When a player approaches the BrickTable, his or her cards are automatically laid out on the table's surface. The player can then trade the cards with other players or cash them in for points.

turns in five of the same card, it's worth 300 points. Additionally, if a player cashes in cards with his or her own picture—which can only be acquired by trading, because the guessing mechanism requires social interaction with the player to be guessed—then the cards are worth double. So, the scoring system leads to trading; which leads to social interaction, guessing, and awareness; which in turn drives the players to collaborate and create game strategies to acquire specific cards.

Design Decisions

We designed the game and system on which it runs in parallel, both representing our effort to begin a research program aimed at demonstrating and evaluating enjoyable, human-centric interactive experiences on integrated, pervasive systems. To touch upon all of our platform's interactive systems, we designed the game to

- react to social and physical behavior (enabled by the badge),
- contain situated interactions (enabled by the mirrors' distributed deployment),
- allow the development of hidden strategies (enabled by the mobile device), and
- promote collaboration (enabled by the BrickTable).

Furthermore, to tackle the challenge of multiple learning curves, we used a common behavior-driven interface. As the players began to learn how their actions drove the game content, they didn't have to learn different interfaces for each device, so they quickly became proficient (from a technical perspective) at playing the game. Also, context switching wasn't an issue, because the mirrors, BrickTable, and game mechanisms provided enough of a common thread to unify the experience across the various interactive contexts, creating a single context for interaction while playing the game. Similarly, conceptual complexity wasn't much of an issue, because people were already familiar with the concept of cards from other, more traditional games. The cards were a common element that moved though the different interactions, so they helped unify the devices.

Pursuant of our research goals, we wanted the game to present a unique and enjoyable experience. By encouraging participants to observe the social and physical behavior of others, we diverged from typical online interactive entertainment and moved into a more social and human-centric realm.

Evaluation and User Impressions

To evaluate the system and experience, we ran a user study with 24 participants. The participants ranged in age from 16 to 60 years old and were fairly even in terms of gender. Approximately 25 percent of the participants claimed to regularly participate in interactive entertainment, 40 percent were familiar with situated and mobile technologies, and 90 percent enjoyed social activities such as icebreaker games. None were previously familiar with this exact game or system.

We divided the participants into five groups, with four to five participants in each group. We then provided a brief introduction to the game and distributed the badges and mobile devices. Each game ran for around 45 minutes, during which we observed and recorded the users, logged all sensor data and communications between devices, and asked participants to fill out an exit survey.

The feedback from the participants was overwhelmingly positive (see the "Participant Quotes" sidebar). When asked, "Was this an enjoyable experience?", on a five-point Likert scale (with 5 being strongly agree and 1 strongly disagree), the average response was 4.35 (standard deviation 0.67).

Figure 5 shows the results of asking participants whether they considered this experience to be a social experience, a game experience, or a technology demo. Most agreed that this was more than just a technology demo, indicating our success in building a social game experience using technology—not just the new technology itself. According to one participant, the experience was "a game that encourages social interaction through the observation of dynamics between participants and interaction between the user and [his or her] surrounding environment." Another person described it as "a complex system of paying attention to [others'] behavior while remaining discreet in your behavior," while someone else explained that "you score points for social awareness and interaction."

It's the sign of an engaging game when individual users proactively develop their own personal style of play—as one participant said, "My primary strategy was to interact with someone's badge, then immediate[ly] find my name on a screen. … I tried to return to the same person over and over again." Other players used social interactions as a way to progress in the game: "[I] ended up intentionally performing or causing actions to get them to reflect on a screen. There was no guessing." Some players developed strategies that included tactics for defense and deception: "I only allowed people to guess me if I had something they wanted to trade for."

We instrumented the system to collect live statistics while running each round of the game. These statistics were visualized on the status display as part of the experience and logged to a database. We could then use these statistics to iterate on our design. For example, after the first few test runs, the average number of cards traded was two, while the average number of cards cashed in for points was 20, indicating that we needed to tweak the game to promote more trading. We increased the value of a player's own card and the bonuses for sets of matched cards, and trading increased in subsequent matches.

The statistics also revealed that the players who scored the most points were the most socially active. The player with the game's highest score (2,130 points) had 58 conversations and traded 17 cards with other players, which is significantly higher than the game averages of 37 and eight, respectively. When we asked participants if the game encourages social interaction, 36 percent strongly agreed, 32 percent agreed, 4 percent neither agreed nor disagreed, and 8 percent disagreed.

We also asked participants if using the different technologies was intuitive. As Figure 6 indicates, we achieved our goal of integrating the behaviorally driven interface across the various devices at the overall game level, because, on average, the individual devices weren't rated as difficult to use. These difficulty ratings were fairly close for all the devices. The mirrors had the highest disagree value, owing to their rigidity in position not accommodating different player heights.

Participant Quotes

The following quotes exemplify participant feedback:

The experience was really a blast. It feels like the future of gaming. Giving people a reason to play in a novel way and [it] is mobile; [it] is a wonderful social game.

The idea of using sensors to track movement and social [behavior] for games and entertainment has huge potential, and [I] think you are off to a great start with this.

This was fun and I would like to do it with a larger group of players. I think with a larger group I could form strategic alliances and beat [everyone] else. I think it would be a huge chaotic mess of fun with 30 people or more, though you might need a few more scoring/trading tables.

I was impressed with the responsiveness of the displays and how quickly live data traveled throughout the various devices. I think because of familiarity with text messaging, [we] expect remote communication to have at least a mild delay.

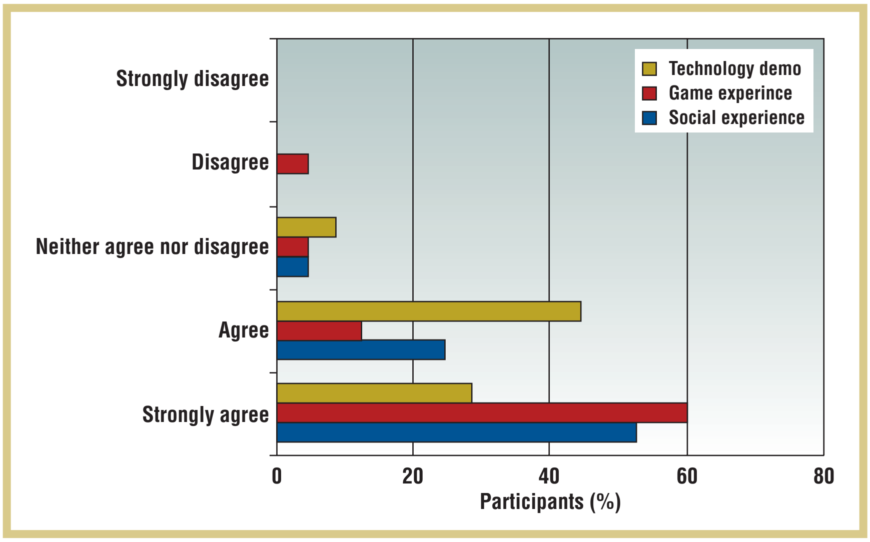


Figure 5. Most participants strongly agreed that this was more of a game or social experience than just a technology demo. Many of these same participants also agreed that it was a technology demo, but gave this a lower agreement score.

Limitations and Lessons Learned

The evaluation revealed a limitation in detecting proximity by relying on a clear line of sight between a badge and an IR transmitter. There were several situations where detections failed simply because the IR elements couldn't "see" each other: players were too tall or too short (see Figure 7), or they leaned over the table. These situations

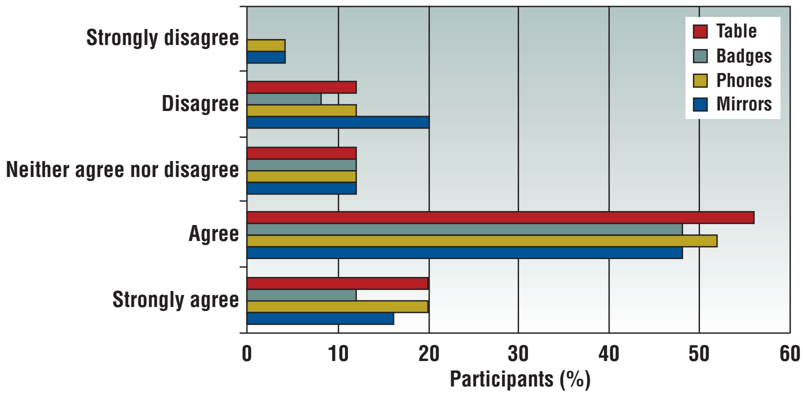


Figure 6. Participants rated the intuitiveness and ease of interacting with the different devices. Most participants agreed that the various devices were easy to use, indicating that we successfully integrated the behaviorally driven interface across the various devices at the overall game level. The mirrors were the only device that had a slightly higher disagree value, most likely because of their fixed size, height, and mounting position.

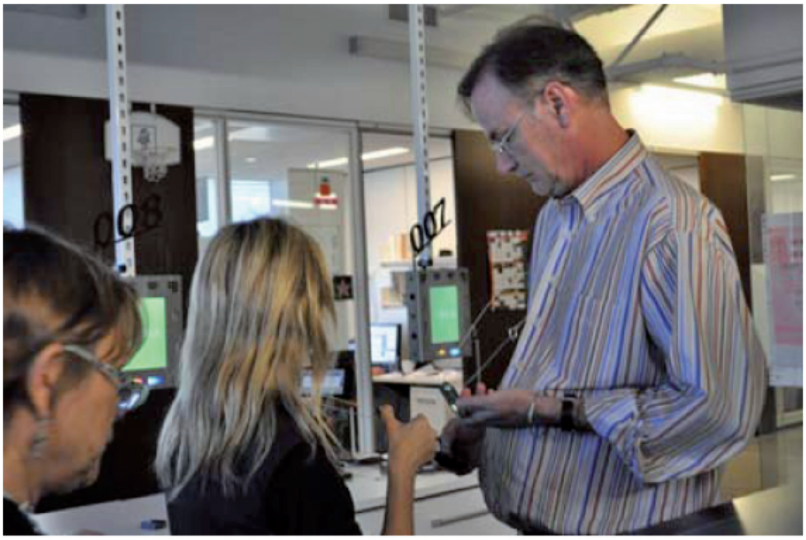


Figure 7. Differences in player height posed a problem, because the IR elements couldn't "see" each other. This is easily remedied in future iterations.

caused frustration, because the players then couldn't capture guesses, make guesses, or keep their cards on the table.

To compensate, many players began holding and aiming their badges rather than simply wearing them. We can fix this design oversight by increasing the number and coverage of IR transmitters and also supplementing proximity detection via other non-line-of-sight technologies, such as short-range RFID.

Also, when we tried running the game with 10 or more players, we had some technical issues with the increased bandwidth requirements. This made the game feel less responsive and ruined the experience. Once we addressed these technical scaling issues, we had some physical scaling issues, such as crowding, people running into each other, and insufficient room at the BrickTable. More importantly, with more players, it became nearly impossible to develop strategies and collaborations because of the increased number of options for cards—to say nothing about how much more difficult it was to guess the mystery player. Five players proved to be the ideal number for our space and initial game design.

It quickly became clear that the overall game design was the only thing making the technology usable by uninitiated users. Attempts to test the individual components and devices with test subjects not participating in the full game experience were worthless and usually degenerated into discussions about IR sensitivity and angles. The game participants, on the other hand, used the same components effortlessly, emphasizing how challenging and significant it is to reduce the contextual complexity of a pervasive system used for interactive applications.

Evaluation and Research Contributions

Twenty-four uninitiated users participated in a new gaming experience, and almost all of them considered it a unique, enjoyable, and engaging social experience, indicating that we successfully overcame many of the challenges associated with designing interactive content on complex pervasive systems.

Our evaluation shows that the players, without prompting, created and executed individual game-winning strategies. If the interactions weren't responsive or intuitive, players wouldn't have been able to quickly get up to speed and move from device to device or remain engaged with the game—and engagement was key to developing and executing the strategies. Furthermore, the strategies exploited the various modes of interaction—private on the mobile device; social with the instrumented badges, situated with the mirrors; and collaborative with the table.

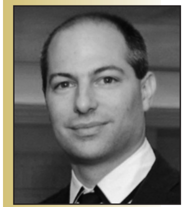
Chamber of Mirrors and the technology platform on which it runs prove that novel experiences can be developed that exploit the affordances of pervasive systems and that can overcome the challenges associated with such complex systems. For example, we used a person's natural physical and social behavior (such as moving around, approaching different areas, and talking to people) to drive the overall application and as input to individual devices. This eliminated much of the complexity associated with switching from one interactive facility to the next. Chamber of Mirrors acts as a case study for pervasive experience design by revealing such insights.

We're working on several new experiments using similar technologies to identify common trends and general concepts that can be worked into taxonomies for designing pervasive interactive environments and applications.

We knew we had created an engaging experience when, after already extending the game time, participants still wanted to continue playing. We're particularly inspired by the fact that almost all the participants were excited about the uniqueness of the experience and yet still learned the game's interfaces and concepts to the point of being able to develop strategies. It was a major accomplishment to design an application that exploits the technical complexity of a variety of devices while remaining intuitive and requiring minimal instruction.

Maintaining a system with this many moving parts is challenging, and each group of new players revealed new challenges, from supporting players of different sizes and shapes to players with differing physical capabilities. We continue to work on game accessibility and robustness to extend its reach to more potential players. The air of excitement surrounding each run of the Chamber of Mirrors game has inspired us to continue developing new examples of pervasive interactive media experiences.

the AUTHORS



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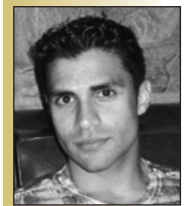

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