Puzzle Space: A Distributed Tangible Puzzle for Long Distance Couples

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Abstract
Long-Distance Relationships (LDRs) are fairly common nowadays where couples rely on computer-mediated tools to stay connected. Yet few systems have explored how couples can share fun and playful activities together over distance. In this paper, we present the design of Puzzle Space, a distributed tangible jigsaw puzzle that allows LDRs to play remotely and synchronously. With Puzzle Space, couples move puzzle pieces on a table surface where movements are shown on the remote partner's screen. We expect that Puzzle Space could enable us to explore if the hybrid of physical and digital content in shared playful activities can help long-distance couples to stay connected and maintain a strong relationship.

Author Keywords
Tangible user interface; long-distance relationships; jigsaw puzzle; computer vision; collaboration over distance

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

Introduction
Long-Distance Relationships (LDRs) involve distance separated couple or partners [8]. Relationship

Figure 1: Puzzle Space consists of two paper boxes, transparent plastic frames, physical puzzle pieces and webcams.

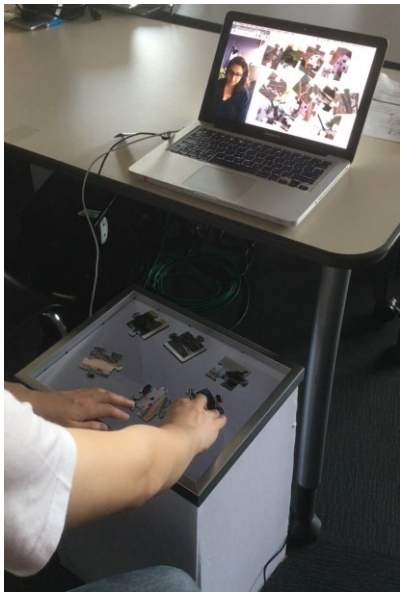

Figure 2: Players can manipulate the physical pieces on the box. The manipulation will be seen by the partner in digital form on the screen.

maintenance is difficult for LDRs because of geographical constraints. As a result, they often rely on computer-mediated communication systems to stay connected, e.g., video chat, text messaging. Yet these systems do not typically offer LDRs an opportunity to have fun and play together. Having shared leisure activities is an important part of long distance relationships [8]. For this reason, our research explores how we can connect long distance couples over distance through distributed playful activity.

In this paper, a tangible jigsaw puzzle called *Puzzle Space* is presented. The puzzle uses physical and digital puzzle pieces to allow LDRs to manipulate the puzzle pieces synchronously. Players collaborate to complete a digital image. Next we introduce the related work and then describe the design of Puzzle Space.

Related Work

Long-Distance Relationships

Social scientists have found relationships will deteriorate if couples do not have regular maintenance activities [3]. Managing conflicts and sharing tasks are two important activities for relationship maintenance [3]. Researchers also found that LDRs tend to avoid conflicts and disagreements which can cause couples to idealize about their relationship [9]. We also see that video chatting systems like Skype and FaceTime are commonly used in LDRs to communicate and share activities because partners enjoy seeing one another over distance [8]. A large number of communication systems have been designed for LDRs as a result. For example, Cubble [7] is a multi-device approach that utilizes both software and artifacts for sharing emotions and short text messages for LDRs. LumiTouch [4], a semi-ambient photo frame device for LDRs, allows couples to share a sense of presence. Another example is WearLove [6], a wrist-based device and game application for affective communication. Despite the large amount of design research on LDRs, there is a lack of focus on designs that support shared leisure activities and synchronous playful interaction over distance.

Tangible User Interfaces & Remote Collaboration

Compared to traditional Graphic User Interfaces (GUIs), TUIs involve direct and hands-on interaction on physical artifacts that could be a more efficient way for spatial tasks [1]. We chose TUI for our prototype because puzzles involve spatial thinking and problem-solving skills [11], many researchers have explored how TUIs can be used to foster remote collaboration. For example, PSyBench [2] provides a shared physical space for distance-separated users to collaborate with strong physical presence. We used the same idea of manipulating objects synchronously but our prototype shows the feedback on digital content rather than the physical object. PlayTogether [10] is a tabletop game system that uses projected imagery to allow remote users to play together. Our system is similar, however, PlayTogether does not allow partners to see each other, which is important for LDRs. Our system design is also inspired from Tactile Letters [5], a tabletop tangible probe using computer vision and texture artifacts for dyslexic children. Like Tactile Letters, we used fiducial markers for mapping physical objects to digital content.

The Design of Puzzle Space

Puzzle Space contains two interconnected puzzle tables that can be placed in different locations (Figure 1). The main goal of Puzzle Space is to have two partners complete a digital jigsaw puzzle.

Figure 3: Each piece has a unique fiducial marker pattern.

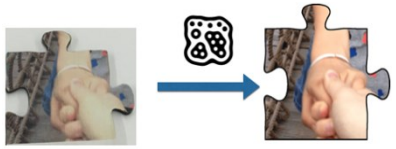

Figure 4: Fiducial marker is used for mapping between physical form and digital form of a same puzzle piece.

Figure 5: The webcam (red circle) is placed at the bottom of the box for detecting fiducial markers on the back of puzzle pieces.

Playful interaction through puzzle play

Puzzle Space allows two users to play jigsaw puzzles together over distance. The tabletop box contains puzzle pieces on top of it at each location. A computer display placed next to the boxes shows the digital puzzle pieces from both the player and his/her partner. As a player moves the physical pieces, the corresponding digital piece will move on the screen synchronously. A video chat window is enabled near the digital puzzle window. Players can see each other's face and talk to each other over the video link. Figure 2 shows the scenario of two users playing Puzzle Space. They can also pick up the physical piece to show to the partner in front of the webcam. The puzzle requires task sharing and negotiation of two players. Players succeed when they complete the whole image.

The implementation of Puzzle Space

We used a laser cutter to make 20 jigsaw puzzle pieces out of a A4-size fiberboard. We placed a fiducial marker on the back of each physical puzzle piece (Figure 3). The fiducial marker is for mapping between digital and physical form of the piece. We color-printed the photo on a A4 paper and used a sculpting knife to cut the jigsaw pattern on the paper. The digital pieces have the same jigsaw pattern and image content as the physical pieces (Figure 4). Inside the tabletop box, we placed a webcam facing upwards to detect the fiducial markers (Figure 5). A computer vision engine called reacTIVision [12] is used for the detection. The puzzle implementation was developed in Processing [13].

The pieces are divided randomly in two parts (10 pieces for each player). One player can only manipulate his/her own physical puzzle pieces. We set up a User Datagram Protocol (UDP) server to connect the two locations. The video chat window uses a web-based WebRTC application.

Design Rationale

We chose a jigsaw puzzle as the central component of Puzzle Space because puzzles are familiar to many people and naturally afford collaboration. They also require spatial thinking and problem solving skills [11] that could help couples share tasks and negotiate conflicts. The puzzle images used for the system show past shared experiences by couples like traveling. We expect these photos will help LDRs recall the memory of their shared experience, which could be a motivation to play the puzzle.

The manipulations on physical puzzle pieces include placement, removal, translocation and rotation. These actions are considered to be natural and easy manipulations for physical user interfaces (PUIs) and TUIs but are difficult for mouse-clicks in GUIs [1]. The surface area of the box is larger than the A4-size puzzle image. We expect that players may spend more time on indirect placements (using mental operations to determine where a piece fits) and exploratory actions (simplify the task by changing the environment, e.g., stacking pieces) which involves spatial thinking, visual search and comparison[1]. We expect that these actions could increase the chance of communication and task sharing between couples.

Conclusion and Discussion

This paper describes our design of Puzzle Space, a distributed tangible puzzle for long distance relationships. We expect that our system can help distance-separated couples maintain their relationships in a novel and entertaining way. In the future, we plan

to extend our system to include visual and audio feedback as well as hint mechanisms. The main contribution of Puzzle Space is identifying requirements and design rationale for an exemplar of a distributed form of playful interaction which could be used to study its impact on LDRs.

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