# Integrating Real and Virtual Worlds in Shared Space


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## Abstract

*In the Shared Space project, we explore, innovate, design and evaluate future computing environments that will radically enhance interaction between human and computers as well as interaction between humans mediated by computers. In particular, we investigate how augmented reality enhanced by physical and spatial 3D user interfaces can be used to develop effective face-to-face and remote collaborative computing environments. How will we interact in such collaborative spaces? How will we interact with each other? What new applications can be developed using this technology? These are the questions that we are trying to answer in research on Shared Space. This paper provides a short overview of Shared Space, its main directions, core technologies and applications.*



**Keywords:** augmented reality, physical interaction, computer vision tracking, collaboration, entertainment.


## 1. Introduction

In the Shared Space project, we explore, innovate, design and evaluate future computing environments that will radically enhance interaction between human and computers as well as interaction between humans mediated by computers. In particular, we investigate how augmented reality enhanced by physical and spatial 3D user interfaces can be used to develop effective face-to-face and remote collaborative computing environments.

Shared Space integrates a number of novel interface technologies, including:

*Augmented reality*. Augmented reality (AR), i.e. overlaying of virtual objects on the real world, allows us to integrate computer-generated and computer-controlled objects into surrounding us everyday physical reality [6]. Unlike virtual reality where the physical world is completely replaced with synthetic environments, in augmented reality environments, 3D computer graphics objects are mixed with physical objects to become in a sense an equal part of the real world.

*Collaborative computing*. Using computers can be a lonely experience: normally, there is no support for collaborative activities in which several people can work together. In the real world collaboration, objects and information can be simultaneously and asynchronously accessed by multiple participants at once, with communication discourse flowing freely between the participants. Shared Space aims to allow for a similar freedom of collaboration and impromptu level of interaction that we have in physical environments. We also aim to address some of the limitations of current collaborative interfaces. These limitations include the lack of spatial cues, the difficulty of interacting with shared 3D data, the introduction of artificial seams into a collaboration, and the need to be physically present at a computer to collaborate [8, 12].

*Physical interfaces.* Interaction in today's graphical user interfaces (GUIs) is often dubbed as *direct,* meaning that the user "picks" and "manipulates" interface objects using mouse similarly to how we actually pick and manipulate physical objects. When compared to early command line interfaces, interaction in current GUIs is indeed more direct; nevertheless, it can only be loosely compared to our interaction with the physical world. In fact, interface objects do not have physical properties, and "picking" and "manipulating" them are simply metaphors that help us understand how to use the interface by drawing from our everyday experiences. Shared Space investigates the use of *physical, tangible* interfaces [9] where instead of using a mouse and a keyboard the user can control computer by physically manipulating multiple simple physical objects that become a part of the user interface.

*Spatial 3D user interfaces*. 3D user interfaces, an important topic in virtual reality, explore how users can efficiently and effectively interact in spatial 3D computer-generated environments. In spatial interfaces as well as in the physical world, users are not constrained by the 2D metaphor of conventional desktop user interfaces but can interact freely in space. Shared Space is a 3D user interface that provides the user with rich spatial cues and combines spatial and physical interaction for easy control and manipulation of virtual objects.

*Computer vision tracking and registration.* Computer vision techniques have recently become very popular in user interface research [7] The core technologies employed in Shared Space – tracking and registering virtual objects in the physical world – are based on a heavy use of computer vision [2].

The rest of this paper is organized as follows. In the next section, we briefly discuss related work, followed by a more detailed discussion of the technologies involved in Shared Space: *augmentation*, *collaboration*, *interaction* and their implementation based on computer vision tracking and registration techniques. We then describe an application, which was demonstrated at SIGGRAPH99, that uses all of these technologies to build an entertainment application.

## 2. Related work

Shared Space has been inspired by a number of previous research projects in augmented reality and ubiquitous computing research, computer supported collaborative work (CSCW), 3D user interfaces and virtual reality, and tangible and physical computing [16]. Our research on Shared Space integrates many of these individual components into an effective interface that can support intuitive face to face 3D CSCW.

While the use of spatial cues and three-dimensional object manipulation are common in face to face communication, tools for three-dimensional CSCW are still rare. One approach is to add collaborative capabilities to existing desktop-based three-dimensional packages. However, a two-dimensional (2D) interface for three-dimensional collaboration can have severe limitations, for example users find it difficult to visualize depth cues or the different viewpoints of their collaborators [10].

Alternative techniques include using large stereo projection screens to project a three-dimensional virtual image into space, such as in the CAVE system [5]. Unfortunately, images can only be rendered from a single user's viewpoint in this setting, so only one person will see true stereo. While this might be satisfactory for some tasks, such as collaborative viewing, effective face to face CSCW using CAVE is impossible.

Mechanical devices can be used to create volumetric displays, such as scanning lasers onto a rotating helix to create a three-dimensional volumetric display [15]. However, these devices do not allow direct interaction with the images because of the rotating display surface.

Multi-user immersive virtual environments provide an extremely natural medium for three dimensional CSCW. Research on the DIVE project [4], GreenSpace [11] and other fully immersive multi-participant virtual environments has shown that collaborative work is indeed intuitive in such surroundings. Participants can seamlessly exchange and communicate gesture, voice and graphical information. However, most current multi-user VR systems are fully immersive, separating the user from the real world: notes, documents, tools and other artifacts of everyday life cannot be easily accessed from immersive virtual environments.

Unlike other methods for three-dimensional CSCW, augmented reality interfaces can overlay graphics and audio onto the real world. This allows for creation of AR interfaces that combine the advantages of virtual environments and possibilities for seamless interaction with real world objects and other collaborators.

Single user AR interfaces have been developed for computer aided instruction [6], medical visualization [1], information displays and other purposes. These applications have shown that AR interfaces can enable a person to interact with the real world in ways never before possible. However, although AR techniques have proven valuable in single user applications, there has been significantly less research on collaborative, multi-user applications. The AR2 Hockey [12] and the Studierstube project [14] are two of the few exceptions.

Figure 1: The HMD and a camera are used for registering and viewing virtual objects, e.g. a samurai model, that appear on top of the physical 2D markers.

On the interface side while the physical and tangible interfaces have been extensively explored [9], there have been few efforts at combining them with spatial interfaces.

Finally, computer vision techniques have been extensively used to track and register virtual objects in augmented reality applications. Our approach was inspired by the work of Rekimoto who developed a technique for robust tracking of 2D markers and registering 3D objects relative to them [13].

## 3. Shared Space

This section discusses key aspects of Shared Space, i.e., augmentation, collaboration, interaction, and implementation based on computer vision tracking and registration techniques.

### 3.1 Augmentation

Shared Space uses a see-through or opaque head-mounted display (HMD) with a lightweight camera mounted in front of the display (Figure 1). With the opaque display, the output from the camera is directed to the HMD so that the user has the illusion of looking through a display in the environment in front of him or her. The AR environment includes a number of marked objects with square fiducial patterns that have an identifying symbol in the middle of the pattern. When the user looks at the objects, computer vision techniques are then used to identify the specific marker, calculate head position and orientation relative to the fiducial marks, and display 3D virtual images so that they appear precisely registered with the physical objects. The details of the implementation are briefly described later in the paper, for a full description see [2].

### 3.2 Collaboration

Shared Space allows users to refer to physical notes, diagrams, books and other real objects while at the same time viewing and interacting with virtual images. More importantly, users can see each other's facial expressions, gestures and body language, thus increasing the communication bandwidth between the users. Furthermore, the Shared Space interface supports three-

Figure 2: In collaborative environment of the Shared Space, users can see and interact with physical and virtual objects, and also see the other participants.

Figure 3: Spatial interaction in Shared Space: users trigger animation of virtual objects (in this case alien and UFO) by bringing two cards together.

dimensional collaboration between face-to-face and remote users so that multiple users in the same or remote location can simultaneously work in both the real and virtual world (Figure 2). Since all users share the same database of virtual objects, they see the same virtual objects attached to the markers. The user can pick up and show the card to the other participants, pass or request virtual objects in the same manner that we do with physical objects in the real world.

### 3.3 Interaction

Shared Space explores the use of spatial and physical interaction in augmented environments: the user can directly manipulate virtual objects by manipulating marked physical objects with virtual objects "standing" on them (Figure 1). The system can robustly track the motion of the physical markers and keep the virtual object precisely aligned relative to the marker. Because several markers are tracked simultaneously and the relative positions of marked objects to other marked objects can be calculated, we could also exploit spatial relations between augmented objects. In the example in Figure 3, the user can trigger the animation of virtual objects (e.g. UFO and alien) by placing cards next to each other.

### 3.4 Tracking and registration

Shared Space uses a computer vision based tracking and registration algorithm designed and implemented by Hirokazu Kato [2]. Figure 4 shows the basic scheme of the algorithm.

## 4. Applications and user experiences

A number of applications have been developed and explored using various components and configurations of the Shared Space technology, including mobile conferencing space for remote collaboration (AR Conference Space [3]) and a collaborative entertainment application, which was demonstrated at the Emerging Technologies exhibit at the SIGGRAPH99 conference. The goal of this demonstration was to show how augmented reality could be used to enhance face to face collaboration in a way that could be used by novices with no training.

A multi-player game similar to the game concentration was designed. We presented visitors with sixteen 5x7 inch playing cards with tracking patterns on one side, and the visitors were required to match cards. Three people could play simultaneously and when they turned the cards over they saw a different 3D virtual object on each card, such as a witch, horse, alien, or crab (Figure 3 and Figure 4). The goal of the game was to match objects that logically belonged together, such as an alien and a flying saucer. When cards containing logical matches were placed side by side, an animation was triggered involving the objects on the card. For example, when the card with the virtual witch on it was placed next to the card with a virtual broom on it, the witch would to jump on the broom and start to fly around in a circle. Sound cues have been also used to help players to identify correct matches: a unique musical sequence was played for each successful match. Since the players were all co-located they could easily see each other, and the virtual objects.

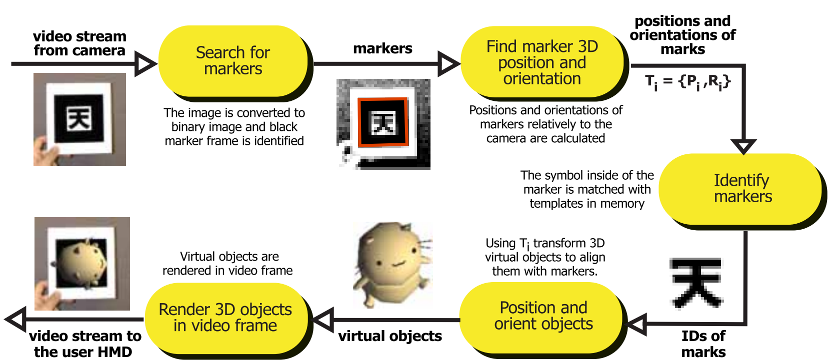


Figure 4: Shared Space tracking and registration technique.

Over the course of the week of August 7-13 at SIGGRAPH, around 3000 conference participants tried the exhibit. Users had no difficulty using the AR interfaces and exhibited the same sort of collaborative behavior seen in typical face to face interaction with physical objects. For instance, during the game players would often spontaneously collaborate with strangers who had a matching card, request and pass cards around as well as collaboratively view objects and completed animations. Furthermore, since the matches were not obvious, users would often request and receive help from other collaborators at the table.

The physical, tangible nature of our interface made collaborative interaction very easy and intuitive. Users passed cards between each other, picked up and viewed virtual objects from all angles and almost always expressed surprise and enjoyment when they got a match and the static virtual objects came to life. By combining a tangible, physical interface with 3D virtual imagery, we found that even young children could play and enjoy the game (Figure 5). Users did not need to learn any complicated computer interface or command sets – the only instructions people needed to be given to play the game were to turn the cards over, not cover the tracking patterns, and find objects that matched.

Users also commented on how much they liked the image recognition and on how little lag there was in the system. This comment is interesting because there was actually a significant (200-300ms) delay, however, the users became so immersed they did not notice this.

Figure 5: The Shared Space at the SIGGRAPH99

## 5. Conclusions

In our work on Shared Space, we combine real and virtual worlds to create compelling 3D collaborative experiences in which the technology transparently supports normal human behaviors. It is this transparency that is a key characteristic of the Shared Space research and should enable the continued development of innovative collaborative AR interfaces in the future. More information on the Shared Space can be found at: http://www.hitl.washington.edu/research/shared_space/ or http://www.mic.atr.co.jp/~poup/research/ar/

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