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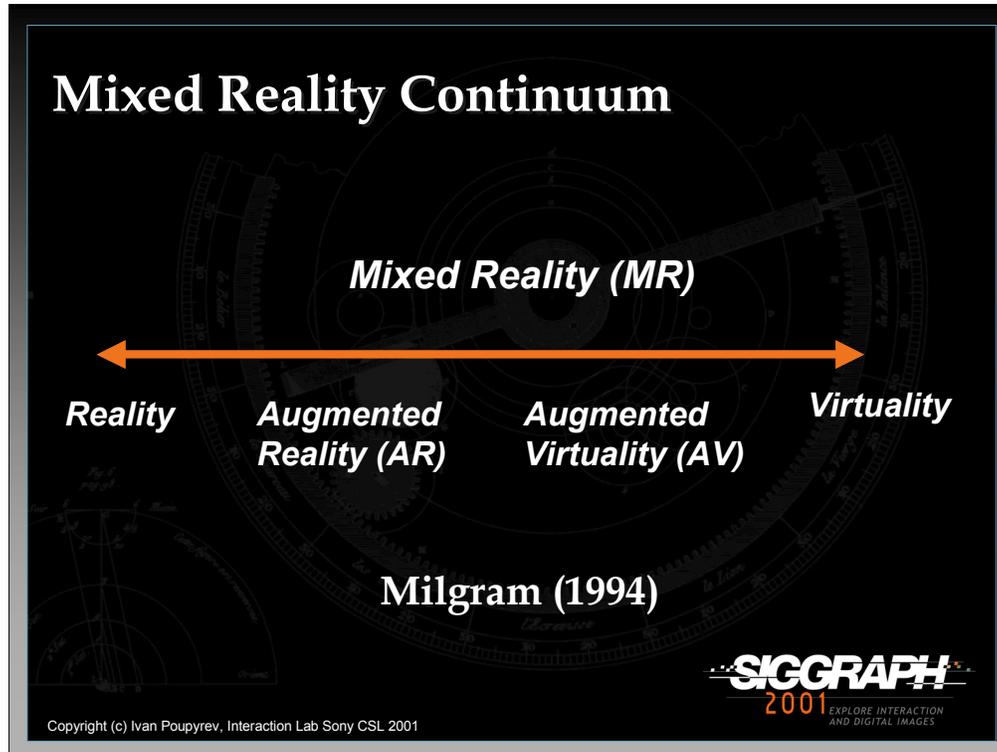
3D user interfaces outside computer

- **We live in 3D world**
 - seeing, hearing, touching and smelling are spatial skills
- **Computer-generated sensory stimulation already surrounds us - everyday part of the real world**
- **Augmenting physical space with interactive computer-controlled stimuli**
 - desktop 3D interfaces
 - augmented reality (AR)
 - ubiquitous computing
 - wearable computers
- **Designing 3D interface to the real world**

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We live in a 3D world. Most of our natural sensory abilities, e.g. seeing, hearing, touching and even smelling, are spatial and allow to distinguish spatial positions, directions, shapes and forms of stimuli. By augmenting physical spaces with computing devices and computer controlled sensory stimuli we can create 3D user interfaces that are embedded into the physical world around us. The research areas that has been investigating these new interfaces is augmented and ubiquitous computing research and in some of the research work they attempt to design a 3D user interface to the real word.



The future living environments and even today's living spaces will probably represent continuum between the purely physical reality and pure virtuality, an approach which Milgram described as a Mixed Reality continuum (1994).

Lecture Overview

- **Real-world 3D user interfaces**
 - Desktop 3D user interfaces – do not cover
 - Augmented Reality and ubiquitous computing
 - Properties/challenges in mixed reality interface
- **Mixed reality interfaces**
 - Traditional approach: AR as information browser
 - Spatial, 3D AR interfaces
 - Augmented surfaces and tangible interfaces
 - Tangible AR interfaces
 - Agent based AR interfaces
- **Future research directions**

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This slide outlines the contents of this lecture.

Desktop 3D interfaces

- **The most familiar 3D user interface**
 - 3D modeling applications
 - Computer games
 - Information visualization
 - 3D desktops for PC (Robertson, et al. 2000)
- **Adopting 2D devices, such as mouse to interact in 3D**



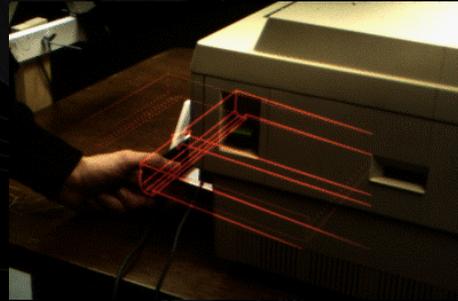
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The most familiar 3D user interfaces are desktop 3D interfaces that has been widely used in 3D modeling, computer games, information visualization, etc. The major challenge in these interfaces is to adopt 2D devices such as mouse and keyboard to perform 3D tasks, e.g. navigation. There has been a lot of techniques implemented in the 2D interfaces, and these interfaces are not covered in this lecture.

Mixed Reality Interfaces

- **Following Azuma definition of AR (1997)**
 - a) combine real and virtual objects
 - b) interactive in real time
 - c) virtual objects are registered in 3D physical world



KARMA, Feiner, et al. 1993

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This lecture will discuss mixed reality interfaces, e.g. interfaces that follow Azuma's definition: they superimpose virtual information on real world, they are interactive and spatial.



Therefore, I will not discuss interfaces such as Triangles (Gorbet, et al. 1998), which does in a sense combine virtual and real, but does not register virtual objects in 3D physical environment. Similarly, although large-scale projection screens are common in public spaces, and the virtual images that they display are sometimes registered to the surrounding environment, I would also not consider them as AR interfaces because they are not interactive.

Mixed and Augmented Reality Interfaces: Basic Technology

- **Tracking and registration**
 - reliable fast tracking of the user viewpoint in the
 - registration of virtual objects in physical world
 - 6DOF magnetic and computer vision tracking
- **Presentation and display technology**
 - See-through HMDs
 - Projection



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The basic technologies required to build reliable AR systems are tracking and registration techniques as well as display technology to present the virtual image to the user. The most often used tracking techniques are magnetic, optical and computer vision tracking. The most often used display technologies are see-through HMDs and projection screens.

Challenges in AR Interfaces

- **Conflict between real world and virtual**
 - Not neatly separated anymore
- **Limitations of displays**
 - Precise, fast registration & tracking
 - Spatially seamless display
- **Limitations of controllers**
 - Precise, fast registration & tracking
 - Spatially seamless interactivity



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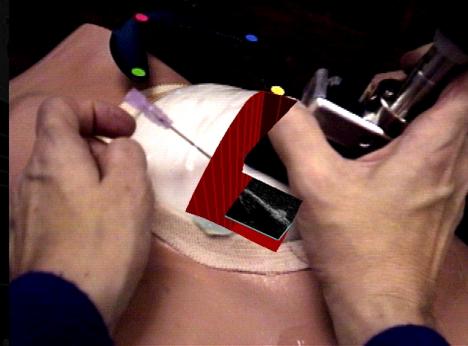
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AR has been traditionally used for visual augmentation, and it's only been relatively recently that there's growing interest in AR interaction issues. The most basic challenge in designing AR interfaces is a conflict between real and virtual: unlike in traditional VR the interfaces are not neatly separated into their own domains. More particularly, the design of AR interfaces is limited mostly by the properties and limitations of AR display technology and tracking and registration techniques. Optimally, the basic AR technologies should allow unobtrusive user interaction with virtual objects superimposed on 3D physical objects everywhere (hence the interface is everywhere). However, these technologies have their own particular properties and limitations, leading to very different interaction styles.

AR interfaces as 3D data browsers (I)

- **3D virtual objects are registered in 3D**
 - See-through HMDs, 6DOF optical, magnetic trackers
 - “VR in Real World”
- **Interaction**
 - 3D virtual viewpoint control
- **Applications**
 - Visualization, guidance, training



State, et al. 1996

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The AR data browsing was one of the first applications of AR interfaces. They were in some sense designed to superimpose VR on the real world. Indeed, the main goal of these AR data browsers is to correctly register and render 3D virtual objects relative to their real world counterparts and user viewpoint position. For example, the medical field has used these techniques to support doctors decisions during medical procedures by superimposing real time physiological data on the patient (Bajura, 1993) and to guide doctors by displaying possible needle paths (State'96). Possible applications for aircraft wiring at Boeing and training applications (Feiner, 1993) have been also proposed. These AR systems are based on see-through HMDs and 6DOF optical and magnetic trackers. Interaction is usually limited to the real-time virtual viewpoint control to correctly display virtual objects.

AR interfaces as context based information browsers (II)

- Information is registered to real-world context
 - Hand held AR displays
 - Video-see-through (Rekimoto, 1997) or non-see through (Fitzmaurice, et al. 1993)
 - Magnetic trackers or computer vision based
- Interaction
 - Manipulation of a window into information space
- Applications
 - Context-aware information displays



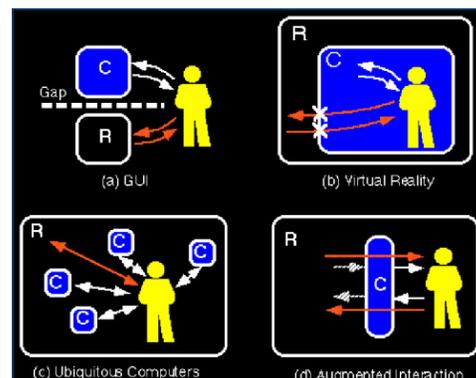
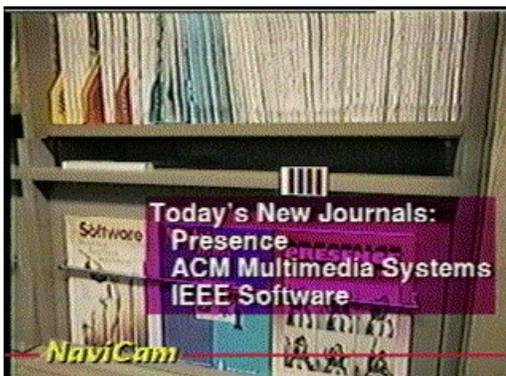
Rekimoto, et al. 1997



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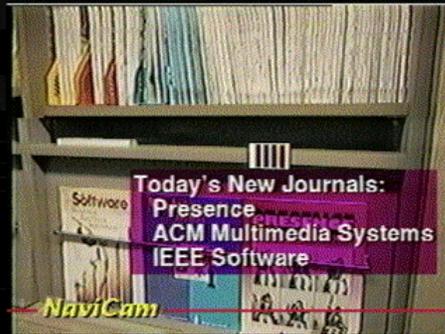
The data does not necessarily have to be 3D or modeled from the real world. Any information can be superimposed on the real world. Thus AR displays can present the data, e.g. text notes, voice or video annotations, etc, within a current real-world context. This approach was initially studied by Fitzmaurice (1993) in the Chameleon system and by Rekimoto (1997) in the NaviCam system. Hand-held displays were used to present information, using markers and a video see-through setup (Rekimoto, 1997) or magnetic trackers (Fitzmaurice, 1993). The interaction however was still limited to virtual viewpoint manipulation within the information space overlaid onto the physical world.

Rekimoto's NaviCam system and Augmented Interaction (1997)



AR Info Browsers (III): Pros and Cons

- **Important class of AR interfaces**
 - Wearable computers
 - AR simulation, training
- **Limited interactivity**
 - Modification and authoring virtual content is difficult



Rekimoto, et al. 1997

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Viewing information superimposed on the physical world does not cover the spectrum of human activities. We also need to have an active impact on both the physical and virtual worlds, to actively change it. However, AR interfaces that act only as information browsers offer little opportunity to modify and author virtual information.

3D AR Interfaces (I)

- **Virtual objects are displayed in 3D space and can be also manipulated in 3D**
 - See-through HMDs and 6DOF head-tracking for AR display
 - 6DOF magnetic, ultrasonic, or other hand trackers for input
- **Interaction**
 - Viewpoint control
 - 3D user interface interaction: manipulation, selection, etc.



Kiyokawa, et al. 2000

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The simplest and most natural approach to adding interactivity to information browsers is to use 6DOF input devices which are commonly used in VR interfaces, to allow the user to manipulate augmented virtual objects in 3D space. Virtual objects should still be presented in 3D using see-through head mounted displays, and magnetic or other tracking techniques. By interaction here I mean the traditional 3D interaction that is usually present in VR interfaces: 3D object manipulation, menu selection, etc. These features have been investigated by Kiyokawa et al. (2000) in SeamlessDesign, Ohshima et al. (1998) in AR2Hockey and Schmalsteig et al. (1996) in Studierstube, etc.

3D AR Interfaces (II): Information Displays

- How to move information in AR context dependent information browsers?
- InfoPoint (1999)
 - Hand-held device
 - Computer-vision 3D tracking
 - Moves augmented data between marked locations
 - HMD is not generally needed, but desired since there are little display capabilities



Khotake, et al. 1999

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InfoPoint (Khotake, 1999) adds 3D interaction to context-dependent information browsers, thereby providing the capability to move data within these environments. It's a hand-held device with a camera that can track markers attached to various locations in the physical environment, select information associated with the markers, and move it from one marker to another. InfoPoint does not require HMD, but because it has limited display capabilities, the feedback to the user is very limited.

3D AR Interfaces (III): Pros and Cons

- **Important class of AR interfaces**
 - Entertainment, design, training
- **Advantages**
 - Seamless spatial interaction: User can interact with 3D virtual object everywhere in physical space
 - Natural, familiar interfaces
- **Disadvantages**
 - Usually no tactile feedback and HMDs are often required
 - Interaction gap: user has to use different devices for virtual and physical objects

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3D AR interfaces are important and have been used successfully in entertainment and design applications (e.g. Oshima, 2000). However, there is also insufficient tactile feedback, and HMDs are required. The user is also required to use different input modalities when handling physical and virtual objects: the user must use their hands for physical objects and special-purpose input devices for virtual objects. This introduces interaction seam into the natural flow of the interaction.

Tangible interfaces and augmented surfaces (I)

- **Basic principles**
 - Virtual objects are projected on a surface
 - back projection
 - overhead projection
 - Physical objects are used as controls for virtual objects
 - Tracked on the surface
 - Virtual objects are registered to the physical objects
 - Physical embodiment of the user interface elements
 - Collaborative



Digital Desk. 1993

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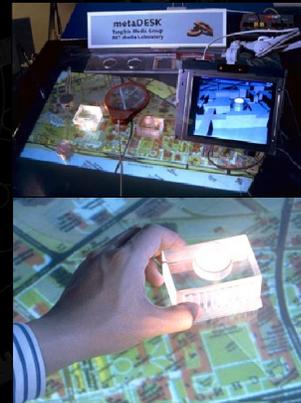
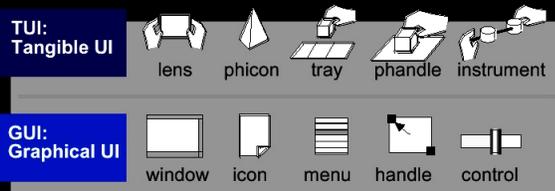
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The alternative approach to 3D AR is to register virtual objects on the surfaces, using either overhead or back projection. The user can then interact with virtual objects by using traditional tools, such as a pen, or specifically designed physical icons, e.g. phicons, which are tracked on the augmented surface using a variety of sensing techniques. This approach was first developed during the Digital Desk project (Wellner, et al. 1993) and has been further developed by other researchers such as Fitzmaurice, et al, 1995, Ullmer, et al. 1997, Rekimoto, 1998.

Tangible Interfaces and Augmented Surfaces (II)

- **Graspable interfaces, Bricks system (Fitzmaurice, et al. 1995) and Tangible interfaces, e.g. MetaDesk (Ullmer'97):**

- Back-projection, infrared-illumination computer vision tracking
- Physical semantics, tangible handles for virtual interface elements

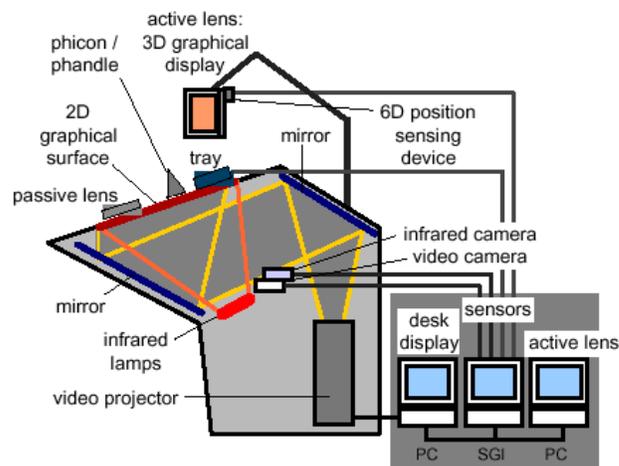


metaDesk. 1997



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An example of such a system is a metaDesk by Ullmer, et al. 1997. In this system, the image is back-projected on the table and the surface of the table is back-illuminated with infrared lamps. Physical objects on the table reflect the infrared lights and their position and orientation on the table surface can be tracked using an infrared camera located under the table (see figure below). Therefore, this system can track physical objects and tools and register virtual images relative to them, which allows us to manipulate and interact with the virtual images by using these physical, tangible handles. Different objects can be discerned on the table and used to control different interface functionality.

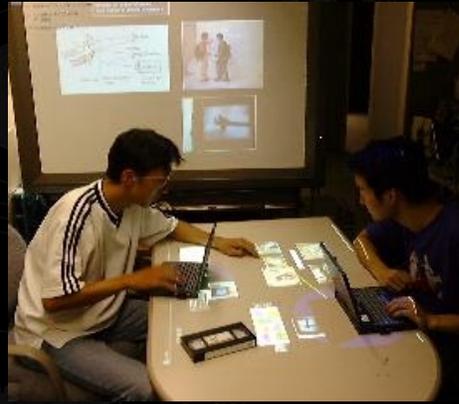


Configuration of the metaDesk (Ullmer, et al. 1997)

Tangible Interfaces and Augmented Surfaces (III)

- **Rekimoto, et al. 1998**

- Front projection
- Marker-based tracking
- Multiple projection surfaces
- Tangible, physical interfaces + AR interaction with computing devices



Augmented surfaces, 1998

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Another approach is to use an overhead projection system such as in Rekimoto, et al. (1999) and Underkoffler, et al. (1998). Physical objects are tracked on the table by using markers attached to them. An overhead camera and computer-vision techniques enable us to estimate the objects' 2D positions on the table. The physical objects can then be used for interactions on the table, e.g. by manipulating them, we can select and move virtual objects. Rekimoto et al. (1999) further extended this, by linking multiple projection surfaces, and using traditional computer devices, for example laptop computers, to interact with virtual objects.

Tangible Interfaces and Augmented Surfaces (IV)

- **Advantages**
 - Seamless interaction flow – user hands are used for interacting with both virtual and physical objects.
 - No need for special purpose input devices
- **Disadvantages**
 - Interaction is limited only to 2D surface
 - Spatial gap in interaction - full 3D interaction and manipulation is difficult

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In tangible interfaces and augmented surfaces, the same devices are used for interactions in both the physical and virtual world. I am talking here about human hand and traditional physical tools. Therefore, there is no need for special-purpose input devices, such as in case of 3D AR interfaces. The interaction, however, is limited to the 2D augmented surface. Full 3D interaction is possible, although difficult, and hence there is a spatial seam in the interaction flow.

Orthogonal nature of AR interfaces (Poupyrev, 2001)

	3D AR	Augmented surfaces
Spatial gap	No interaction is everywhere	Yes interaction is only on 2D surfaces
Interaction gap	Yes separate devices for physical and virtual objects	No same devices for physical and virtual objects

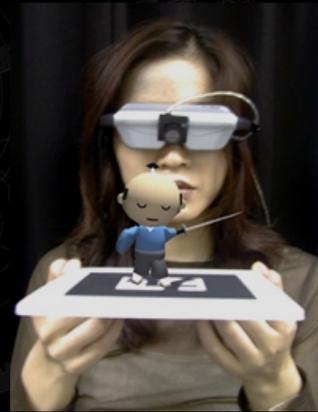
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It has been observed that the properties of 3D AR interfaces and augmented surfaces are somewhat orthogonal (Poupyrev, et al. 2000). 3D AR provides users with a spatially continuous environment, where 3D objects can be displayed and accessed from everywhere in space. At the same time, it introduces a seam into the interaction flow, requiring different devices for physical and virtual interactions. Augmented surfaces provide seamless interaction and the user can interact with virtual objects using physical tools or their hands. However, this does not allow for seamless spatial interaction, since the interaction is limited to the 2D space of the augmented surfaces.

Tangible AR interfaces (I)

- **Virtual objects are registered to marked physical “containers”**
 - HMD
 - Video-see-through tracking and registration using computer vision tracking
- **Virtual interaction by using 3D physical container**
 - Tangible, physical interaction
 - 3D spatial interaction
- **Collaborative**



Shared Space, 1999

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Using tangible augmented reality interfaces (Billinghurst, et al. 2000, Kato, et al. 2000, Poupyrev, et al. 2001) researchers are attempting to bridge the gap between 3D AR and augmented surfaces. Virtual objects are registered to marked physical objects in 3D using HMDs, video-see through AR registration techniques (using a camera mounted on the HMD), and computer-vision tracking algorithms. The user manipulates the virtual objects by physically manipulating the physical, tangible containers that hold them. Multiple users are able to interact with the virtual objects at the same time.

Tangible AR (II): generic interface semantics

- **Tiles semantics**

- data tiles
- operation tiles
 - menu
 - clipboard
 - trashcan
 - help

- **Operation on tiles**

- proximity
- spatial arrangements
- space-multiplexed



Tiles, 2001

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Tangible AR interfaces allow us to define generic interface elements and techniques, similar to GUI or tangible interfaces (Ullmer, 1997). This generic functionality has been investigated in the *Tiles* system (Poupyrev, et al. 2001). Tiles interface attempted to design a simple yet effective interface for authoring MR environments, based on a consistent interface model, by providing tools to add, remove, copy, duplicate and annotate virtual objects in MR environments.

The basic interface elements are *tiles* that act as generic tangible interface control, similar to icons in a GUI interface. Instead of interacting with digital data by manipulating it with a mouse, the user interacts with digital data by physically manipulating the corresponding tiles. There are three classes of tiles: *data tiles*, *operator tiles*, and *menu tiles*. All share a similar physical appearance and common operation. The only difference in their physical appearance is the icon identifying the tile type. This enables users who are not wearing an HMD to identify them correctly. *Data tiles* are generic data containers. The user can put and remove virtual objects from data tiles; if a data tile is empty, nothing is rendered on it.

-continued on the next page

Operator tiles are used to perform basic operations on data tiles, including *deleting* a virtual object from a data tile, *copying* a virtual object from a data tile to the clipboard or from the clipboard to a data tile, and requesting *help* and displaying annotations associated with a virtual object on the data tile. The operator tiles are identified by virtual 3D widgets attached to them.

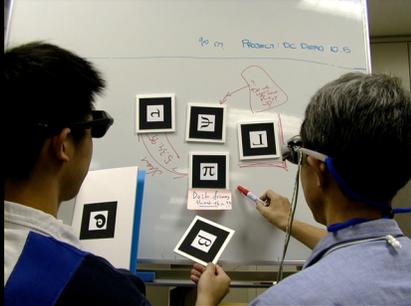
Menu tiles make up a book of the tiles attached to each page. This book works like a catalogue or a menu. As users flip through the pages, they can see the virtual objects attached to each page, choose the required instrument and then copy it from the book to any empty data tile.

Operations *between tiles* are invoked by putting two tiles next to each other (within a distance less than 15% of the tile size). For example, to copy an instrument to the data tile, users first find the desired virtual instrument in the menu book and then place an empty data tile next to the instrument. After a one-second delay to prevent accidental copying, a copy of the instrument smoothly slides from the menu page to the tile and is ready to be arranged on the whiteboard. Similarly, if users want to remove data from the tile, they put the trashcan tile close to the data tile, thereby removing the data from it.

Operation	Result
Menu operations	
 +  = 	
Clipboard operations	
 +  = 	
 +  = 	
 +  = 	
Trashcan operations	
 +  = 	
 +  = Not defined	
 +  = 	
Help operations	
 +  =  Message	
 +  =  Help	
 +  = Not defined	

Tiles semantics and operations on them (Poupyrev, et al. 2001)

Tangible AR (III): Space-multiplexed

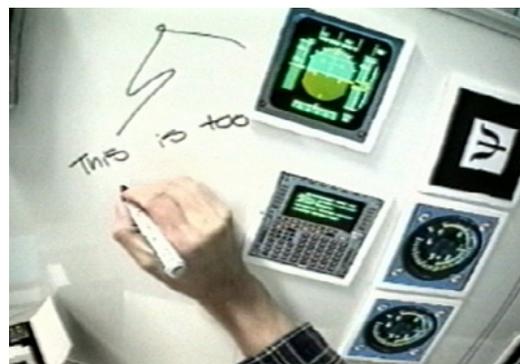


Data authoring in Tiles (Poupyrev, et al. 2001). Left, outside view of the system; right, view of the left participant.

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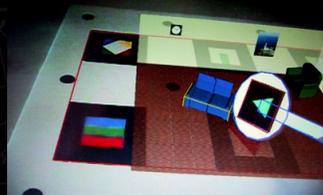
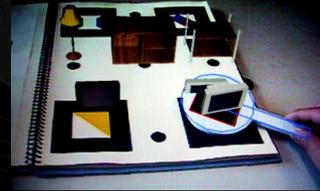
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Tangible AR environments provide an easy-to-use interface for the quick authoring of AR environments. For example, Poupyrev, et al. 2001, designed an interface for the rapid layout and prototyping of aircraft panels, thereby, allowing both virtual data and traditional tools, such as whiteboard markers, to be used within the same environment. This is an example of a space-multiplexed interface design using tangible augmented reality interfaces.



Annotating data in Tiles (Poupyrev, et al. 2001)

Tangible AR (IV): Time-multiplexed interaction



Data authoring in WOMAR interfaces (Kato et al. 2000). The user can pick, manipulate and arrange virtual furniture using a physical paddle.

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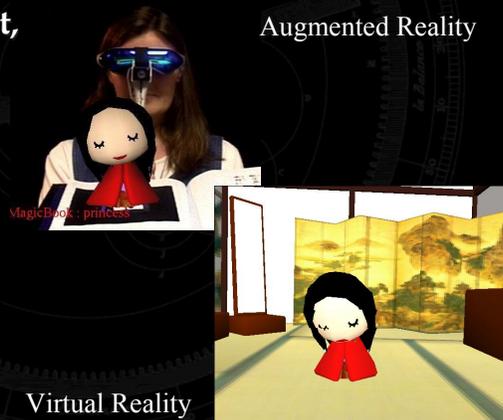
The VOMAR project (Kato, et al. 2000) explored how a time-multiplexed tangible AR interface could be designed. In the project, a single input device was used that allowed users to perform different tasks in a virtual-scene assembly application. The application was a layout of virtual furniture in a room, although the same interface could be applied to many domains. When users opened the book they saw a different set of virtual furniture on each of page, such as chairs, rugs etc. A large piece of paper on the table represented an empty virtual room. They could then copy and transfer objects from the book to the virtual room using a paddle, which was the main interaction device. The paddle is a simple object with an attached tracking symbol that can be used by either hand and enables users to use static and dynamic gestures to interact with the virtual objects. For example, to copy an object from the book onto the paddle users simply placed the paddle beside the desired object. The close proximity was detected, and the object was copied onto the paddle. The VOMAR system demonstrated how simple 6DOF interaction devices can be developed using the Tangible Augmented Reality approach.

Tangible AR (V): AR - VR Transitory Interfaces

- **Magic Book (Billinghurst, et al. 2001)**

- 3D pop-up book: a transitory interfaces

- Augmented Reality interface
- Portal to Virtual Reality
- Immersive virtual reality experience
- Collaborative



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The MagicBook project (Billinghurst, et al. 2001) explored how a tangible AR user interface can be used to smoothly transport users between reality and virtuality. The project did this by using a normal book as the main interface object. Users could turn the pages of the book, look at the pictures, and read the text without any additional technology. However, if they looked at the pages through an Augmented Reality display, they would see 3D virtual models appearing out of the pages. The AR view is, therefore, an enhanced version of a 3D “pop-up” book. Users could change the virtual models simply by turning the pages, and when they saw a scene they particularly liked, they could fly into the page and experience the story as an immersive virtual environment. In VR they were free to move about the scene at will and interact with the characters in the story or return back to the real world. The tangible user interface therefore provides a technique for the seamless blending of virtual reality experience to everyday user activities.

Tangible AR (V): Conclusions

• Advantages

- Seamless interaction with both virtual and physical tools
 - No need for special purpose input devices
- Seamless spatial interaction with virtual objects
 - 3D presentation of and manipulation with virtual objects anywhere in physical space

• Disadvantages

- Required HMD
- Markers should be visible for reliable tracking

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There are several advantages of tangible AR interfaces. First, they are *transparent interfaces* that provide seamless two-handed 3D interaction with both virtual and physical objects. They do not require participants to use or wear any special purpose input devices or tools, such as magnetic 3D trackers, to interact with virtual objects. Instead users can manipulate virtual objects using the same input devices they use in the physical world – their own hands – which leads to seamless interaction between digital and physical worlds. This property also allows the user to easily use both digital and conventional tools in the same working space.

Tangible AR allows *seamless spatial interaction* with virtual objects anywhere in their physical workspace. The user is not confined to a certain workspace but can pick up and manipulate virtual data anywhere just, like real objects, and arrange them on any working surface, such as a table or whiteboard. The digital and physical workspaces are therefore continuous, naturally blending together.

AR Groove: Tangible AR without HMD

- AR Groove (Poupyrev, et al. 2000)
 - Overhead camera tracking
 - AR workspace on screen in front of the users
 - Spatial gestures for musical control
 - 3D AR widgets extend tangible controllers

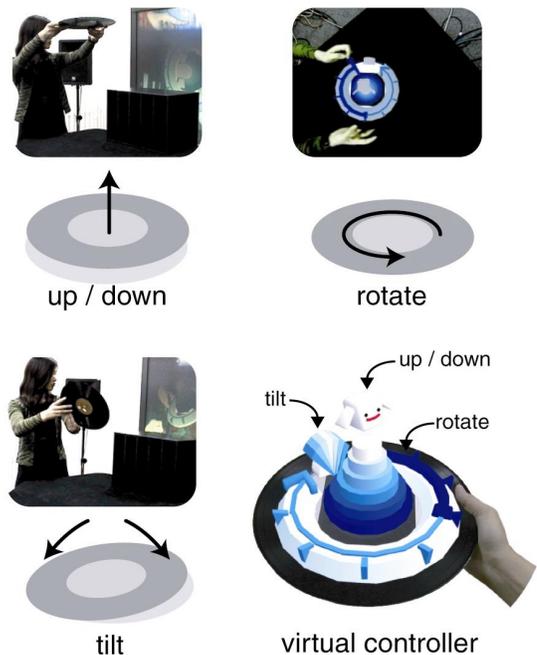


Augmented Groove, 2001



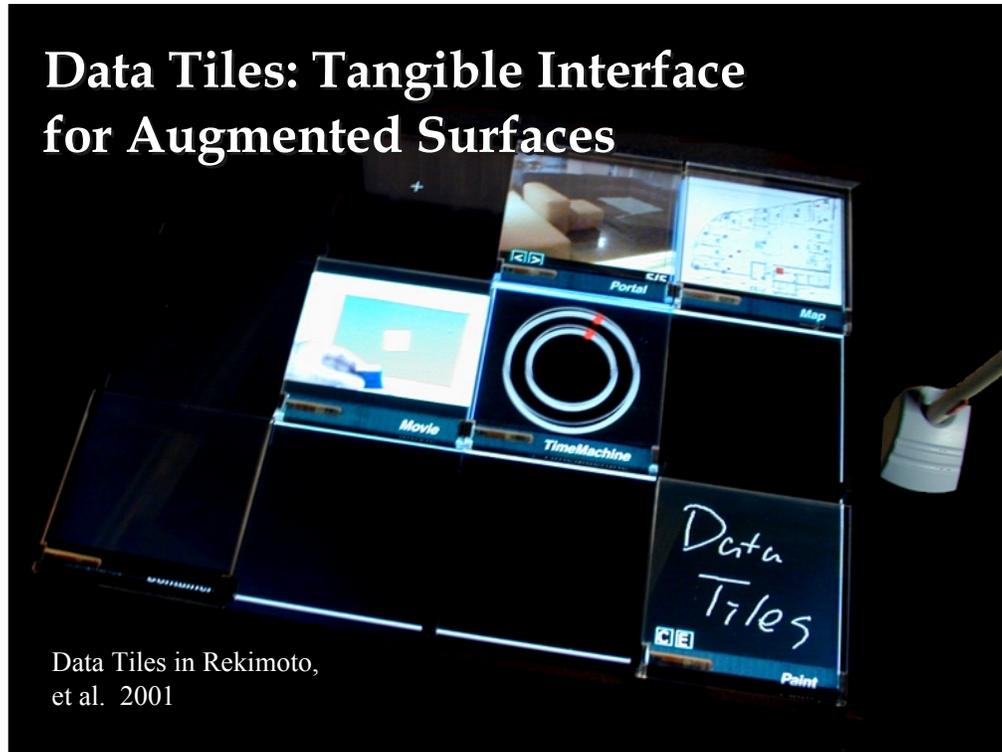
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AR Groove (Poupyrev et al., 2000) is a simple music controller for playing music that used tangible AR without HMDs. In AR Groove, the camera was installed on top of the table, and it tracked marked LP records. The performer controlled the music by manipulating vinyl LP records, and the user's spatial gestures, expressed through object manipulations, were mapped into musical modifications. Three simple gestures were used to control performance: *vertical translation*, *tilt*, and *rotation*. At the same time, the performer was presented with a simple visual display on the state of the controller, which provided immediate feedback on the process of performance. No HMDs, wires or special-purpose input devices were needed to play the music.



Gestures defined in AR Groove and virtual controller (Poupyrev, et al. 2000)

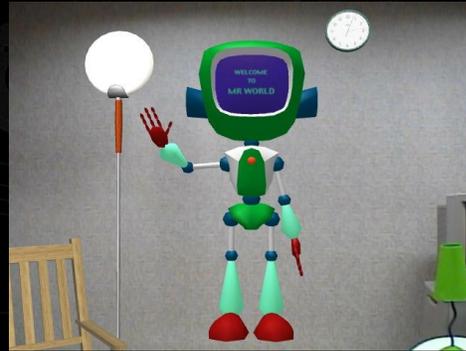
Data Tiles: Tangible Interface for Augmented Surfaces



An interesting approach related to tangible AR was also designed and investigated in the DataTiles system by Rekimoto, et al. 2001. In this system, the user could arrange and interact with the virtual data by using transparent tiles that were placed on a flat sensor-enhanced display, through which the image was presented to the user.

Agents in AR

- **Conversational AR agents:
Indirect interaction in AR**
 - ALIVE (Maes, et al. 1997)
 - Projection based, no HMD
 - Welbo (Anabuki, et al, 2000)
 - HMD-based
 - Speech and gesture interface
 - Embodiment, 3D interaction
- **Gesture and speech
recognition is still not
perfect**



Welbo AR agent,
copyright MR Lab, 2000

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The final approach to designing AR interfaces is to use embodied agents, an approach which has been investigated in systems such as ALIVE (Maes, 1995) and Welbo (Anabuki, et al. 2000). The agent interface allows for gesture and speech command in AR environment. The user can ask agents to perform simple tasks such as moving furniture in the environment. The problem with these interfaces is that current techniques for gesture and speech recognition have not been perfected and some tasks cannot be effectively carried out by using verbal commands.

Wrap up

- **What have we learned?**
 - Why AR interfaces?
 - Traditional approach to AR interaction
 - 3D AR interfaces
 - Augmented surfaces and tangible AR interfaces
 - Orthogonality of 3D AR and AR surfaces
 - Tangible Augmented Reality interfaces
 - AR Agents-based interfaces
- **What is the future of AR interfaces?**

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My talk has discussed some of the topics listed above.

Future research directions

- **Robotic AR interfaces**
- **Richer sensory displays**
 - Audio
 - Tactile
 - Smell and taste
- **Biometric controls**
 - Brain controls
 - Direct image transfer to the image centers
 - EMG controls, etc.



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The future is exciting.

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