An Introduction to Augmented Reality

Dieter Schmalstieg
Vienna University of Technology
Austria

Based on the SIGGRAPH 2001 course held together with
R. Azuma, M. Billinghurst, T. Höllerer, H. Kato, I. Poupyrev

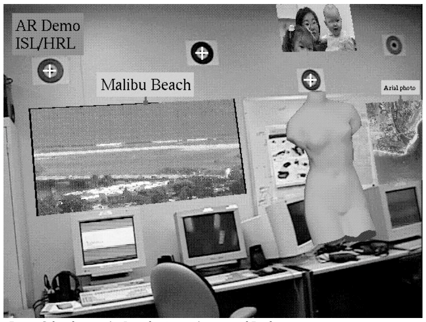
Syllabus

- **Overview**
- **Tracking for Augmented Reality**
- **Augmented Reality Interaction**
- **Collaborative Augmented Reality**
- **Heterogeneous user interfaces**
- **Mobile Augmented Reality**

Definition of Augmented Reality (1)

- **Virtual Environments (VE): Completely replaces the real world**
- **Augmented Reality (AR): User sees real environment; combines virtual with real**
- **Supplements reality, instead of completely replacing it**
- **Photorealism not necessarily a goal**

Example AR image



Youngkwan Cho, STAR system

Definition of Augmented Reality (2)

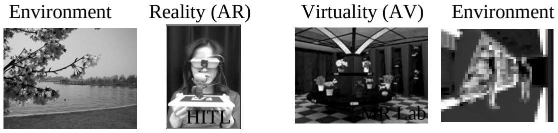
1) **Blends real and virtual, in real environment**
2) **Real-time interactive**
3) **Registered in 3-D**

- **Applies to all senses (auditory, haptic?)**
- **Not an HMD-specific definition**
- **Includes idea of removing part of real environment (a.k.a. mediated or diminished reality)**

Milgram’s Reality-Virtuality continuum

Mixed Reality

Real Environment | Augmented Reality (AR) | Augmented Virtuality (AV) | Virtual Environment



Reality - Virtuality (RV) Continuum

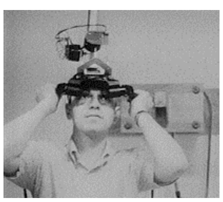
Adapted from Milgram, Takemura, Utsumi, Kishino. Augmented Reality: A class of displays on the reality-virtuality continuum

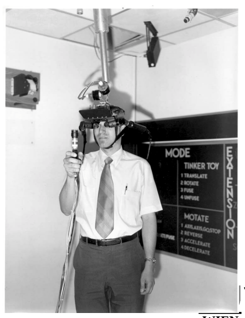
Why are researchers interested?

- Enhance perception of and interaction with the real world
- Potential for productivity improvements in real-world tasks
- Relatively new field with many problems, but much progress has occurred recently

A Brief (and incomplete) History of AR (1)

- 1960's: Sutherland / Sproull's first HMD system was see-through





A Brief (and incomplete) History of AR (2)

- Early 1990's: Boeing coined the term "AR." Wire harness assembly application begun.
- Early to mid 1990's: UNC ultrasound visualization project
- 1994: Motion stabilized display [Azuma]
- 1994: Fiducial tracking in video see-through [Bajura / Neumann]

A Brief (and incomplete) History of AR (3)

- 1996: UNC hybrid magnetic-vision tracker (first compelling environment)
- 1998: Dedicated conferences begin
- Late 90's: Collaboration, outdoor, interaction
- Late 90's: Augmented sports broadcasts
- 1998 - 2001: Mixed Reality Systems Lab
- 2000: Custom see-through HMDs

Growth of field: conferences

New conferences dedicated to this topic:

- International Symposium on Augmented Reality
  http://www.Augmented-Reality.org/isar
- International Symposium on Mixed Reality
  http://www.mr-system.co.jp/ismr
- Designing Augmented Reality Environments

Growth of field: projects

- Mixed Reality Systems Laboratory (Japan)
  http://www.mr-system.co.jp/
- Project ARVIKA (Germany)
  http://www.arvika.de/
- Ubicom Project (Delft University)
  http://www.ubicom.tudelft.nl

Some starting points

- **Jim Vallino's, Reinhold Behringer's pages:**

  http://www.cs.rit.edu/~jrv/research/ar

  http://www.augmented-reality.org

- **Ron Azuma's survey paper**

  Azuma, Ronald. A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments 6*, 4 (August 1997), 355-385.

More starting points

- **Updated survey to appear in Nov. 2001 IEEE Computer Graphics & Applications**

  Azuma, Baillot, Behringer, Feiner, Julier, MacIntyre. Recent Advances in Augmented Reality.

- **Book**

  Barfield and Caudell. Fundamentals of Wearable Computers and Augmented Reality. Lawrence Erlbaum Associates (2001). ISBN 0-8058-2901-6

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Applications: medical

- **"X-ray vision" for surgeons**
- **Aid visualization, minimally-invasive operations. Training. MRI, CT data.**
  - Ultrasound project, UNC Chapel Hill.

Courtesy UNC Chapel Hill

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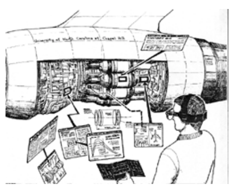
Applications: complex machinery

- **Instructions for assembly, maintenance and repair of complex equipment**
  - Aircraft [Boeing]
  - Printers [Columbia]
  - Engines
  - Automobile assembly
  - and others...

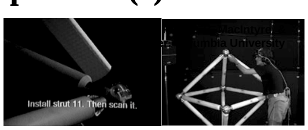
Assembly and maintenance pictures (1)

Boeing wire harness assembly.
Adam Janin wearing HMD.
Courtesy David Mizell, Boeing



Courtesy Andrei State, UNC Chapel Hill

Assembly and maintenance pictures (2)



Columbia University

Applications: annotating environment

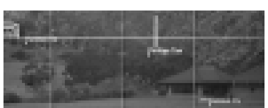
- **Public and private annotations**
- **Aid recognition, “extended memory”**
  - Libraries, maps [Fitzmaurice93]
  - Windows [Columbia]
  - Mechanical parts [many places]
  - Reminder notes [Sony, MIT Media Lab]
  - Navigation and spatial information access

Annotation pictures

© 1993 S. Feiner, B. MacIntyre, M. Haupt, & E. Solomon, Columbia University

Columbia University

© 1997 S. Feiner, B. MacIntyre, T. Höllerer, & A. Webster, Columbia University



HRL

Application: broadcast augmentation

- **Adding virtual content to live sports broadcasts**
  - “First down” line in American football
  - Hockey puck trails, virtual advertisements
  - National flags in swimming lanes in 2000 Olympics
- **Commercial application**
  - Princeton Video Image is one company

Application: aircraft operations

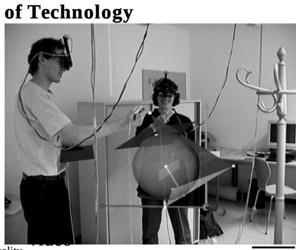
- **Helmet-mounted sights (short-range missiles)**
- **Virtual runway markers**
  - Runway incursions are a leading cause of aircraft accidents.
  - T-NASA head up display for runway incursions
  - Enhanced view for low visibility situations

Application: collaboration

AR allows users to collaborate inside the same real environment

HIT Lab & ATR

Studierstube, Vienna University of Technology



AR Systems Overview

- **Blending: Optical vs. Video**
- **Focus, contrast, portability**
- **Sensing and bandwidth**

Optical see-through head-mounted display

Virtual images from monitors

Real World → Optical Combiners →

Examples of optical see-through HMDs

Sony Glasstron

Virtual Vision VCAP

Video see-through head-mounted display

Video cameras

Video

Graphics

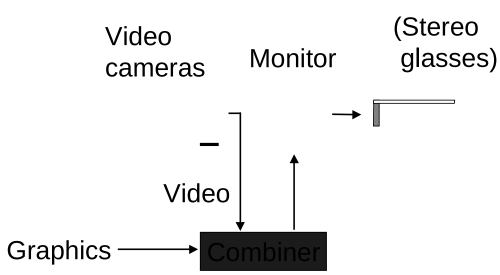
Monitors

Combiner

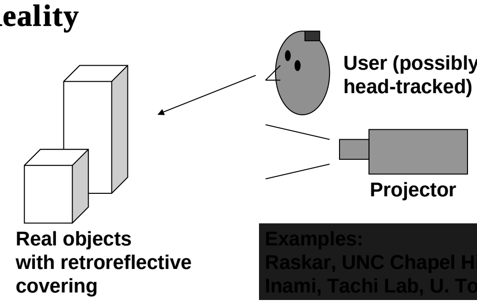
Example of video see-through HMD

MR Laboratory's COASTAR HMD
(Co-Optical Axis See-Through Augmented Reality)
Parallax-free video see-through HMD

Video monitor Augmented Reality

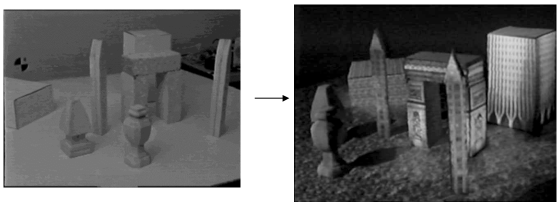


Projector-based Augmented Reality



[redacted]

Example of projector-based AR



Ramesh Raskar, UNC Chapel Hill

Strengths of optical AR

- **Simpler (cheaper)**
- **Direct view of real world**
  - Full resolution, no time delay (for real world)
  - Safety
  - Lower distortion
- **No eye displacement (but COASTAR video see-through avoids this problem)**

Strengths of video AR

- **True occlusion (but note Kiyokawa optical display that supports occlusion)**
- **Digitized image of real world**
  - Flexibility in composition
  - Matchable time delays
  - More registration, calibration strategies
- **Wide FOV is easier to support**

Optical vs. video AR summary

- **Both have proponents**
- **Video is more popular today?**
  - Likely because lack of available optical products
- **Depends on application?**
  - Manufacturing: optical is cheaper
  - Medical: video for calibration strategies

Focus and contrast

- **Focus**
  - Need to measure eye accommodation?
  - Autofocus video camera?
- **Contrast**
  - Desirable to match brightness
  - Real world has large dynamic range!
  - More difficult with optical?

Portability

- **VE: User stays in one place**
- **AR: User moves to task location**
  - Want to use in factories, outdoors, etc.
  - Less controlled environments
  - Very demanding of the technology

Is AR easier/harder than VR?

- **Rendering: easier**
- **Display (resolution, FOV, color): easier**
- **Tracking and sensing: harder**
  - Greater bandwidth requirements (video, MRI data, range data, etc.)
  - Support occlusion, general environmental knowledge
  - A big problem for registration!

Upcoming...

- **Tracking for Augmented Reality**
- **Augmented Reality Interaction**
- **Collaborative Augmented Reality**
- **Heterogeneous user interfaces**
- **Mobile Augmented Reality**

Other current research directions (1)

- **Ease of setup and use**
  - Avoid need for expert user
  - Reduce calibration requirements
- **Human factors and perceptual studies**
  - Potential conflicts and optical illusions
  - Eye displacement in video see-through

Other current research directions (2)

- **Proven applications**
  - Need demonstrated performance improvements
- **Photorealistic rendering**
- **AR in other senses**
  - Recent haptic demo [Walairacht ISMR2001]
- **Social acceptance**
  - User perception of privacy, trust, and fashion!

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The importance of tracking

- **Tracking is the basic enabling technology for Augmented Reality**
- **Without accurate tracking you can't generate the merged real-virtual environment**
- **Tracking is significantly more difficult in AR than in Virtual Environments**

"Tracking is the stepchild that nobody talks about."
- Henry Sowizral, Dec 1994 Scientific American

The Registration Problem

- **Virtual and Real must stay properly aligned**
- **If not:**
  - Compromises illusion that the two coexist
  - Prevents acceptance of many serious applications
  - Do you want a surgeon cutting into you if the virtual cut-marks are misaligned?

Sources of registration errors

- **Static errors**
  - Optical distortions
  - Mechanical misalignments
  - Tracker errors
  - Incorrect viewing parameters
- **Dynamic errors**
  - System delays

Reducing static errors

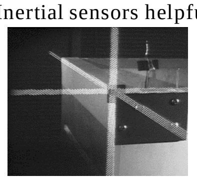
- **Distortion compensation**
- **Manual adjustments**
- **View-based or direct measurements**
  - [Azuma94] [Caudell92] [Janin93] etc.
- **Camera calibration (video)**
  - [ARGOS94] [Bajura93] [Tuceryan95] etc.

Reducing dynamic errors (1)

- **Reduce system lag**
  - [Olano95] [Wloka95a] [Regan SIGGRAPH99]
- **Reduce apparent lag**
  - Image deflection [Burbidge89] [Regan94] [So92] [Kijima ISMR 2001]
  - Image warping [Mark 3DI 97]

Reducing dynamic errors (2)

- **Match input streams (video)**
- **Predict**
  - [Azuma94] [Emura94] & others
  - Inertial sensors helpful



Azuma / Bishop, SIGGRAPH 94

Tracking technologies (as applied to AR)

- **GPS**
  - Regular ~30 meters, Differential ~3 meters
  - Carrier phase: centimeters but multipath and initialization problems
  - Line of sight, jammable
- **Inertial and dead reckoning**
  - Sourceless but drifts
  - Cost and size restrictions

Tracking Technologies (2)

- **Active sources**
  - Optical, magnetic, ultrasonic
  - Requires structured, controlled environment
  - Restricted range
  - Magnetic vulnerable to distortions
  - Ultrasonic: ambient temperature variations
  - Optical is often expensive

Tracking Technologies (3)

3rd Tech, Inc.

- **Scalable active trackers**
  - InterSense IS-900, 3rd Tech HiBall
- **Passive optical**
  - Line of sight, may require landmarks to work well. Can be brittle.
  - Computer vision is computationally-intensive

Tracking Technologies (4)

- **Electromagnetic compass, tilt sensors**
  - Passive and self-contained
  - Vulnerable to distortions
- **Mechanical**
  - Can be accurate but tethers user
- **Hybrid trackers**
  - Combines approaches to cover weaknesses
  - Yields the best results

TCM2

Wrap-up

- **Tracking is a key problem to AR**
- **Registration error**
  - Measures against static error
  - Measures against dynamic error
- **AR typically requires multiple tracking technologies**

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AR Interaction: Why it is Important?

Designing AR system = interface design

- *Interface output*: HMDs, tracking, registration, etc.
- *Interface input* : optical trackers, interaction techniques...

Objective is a high quality of user experience

- Augmentation is a tool not a final goal
- Appropriateness to tasks and applications
- Ease of use & learning of interface
- Performance and satisfaction

AR browsers: Virtual information in real context

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

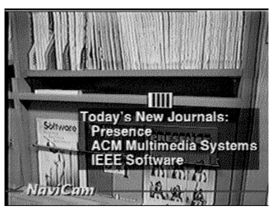
AR Info Browsers: Pros and Cons

Important class of AR interfaces

- Wearable computers
- AR simulation, training

Limited interactivity

- Modification of virtual content is difficult
- Virtual content authoring is difficult



Rekimoto, et al. 1997

3D AR Interfaces

Virtual objects displayed in 3D physical space and can be freely manipulated

- See-through HMDs and 6DOF head-tracking are required
- 6DOF magnetic, ultrasonic, etc. hand trackers for input

Interaction

- Viewpoint control
- Traditional 3D user interface interaction: manipulation, selection, adding, removing, etc.

Kiyokawa, et al. 2000

3D AR Interfaces: Pros and Cons

Important class of AR interfaces

- Entertainment, design, training

Advantages

- User can interact with 3D virtual object everywhere in space
- Natural, familiar interaction

Disadvantages

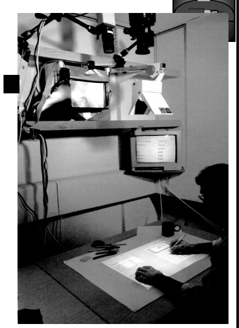
- Usually no tactile feedback
- HMDs are often required
- **Interaction seams**: user has to use different devices for virtual and physical objects


Oshima, et al. 2000

Tangible interfaces and augmented surfaces

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
- Collaborative


Digital Desk. 1993

Tangible Interfaces and Augmented Surfaces: Pros and Cons

- **Advantages**
  - The same device is used both for interacting with virtual and physical objects: human hand
    - No need for special purpose input devices
- **Disadvantages**
  - Interaction is limited only to the 2D surface
    - 3D interaction and manipulation is difficult

Orthogonal nature of AR interfaces (Poupyrev, 2001)

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

Tangible AR: generic interface semantics

Tiles semantics

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

Operation on tiles

- proximity
- spatial arrangements
- space-multiplexed

Tiles, 2001

video

Tangible AR: Pros and Cons

Advantages

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

Disadvantages

- Required HMD

Wrap-up

- **Browsing interfaces**
  - simple (conceptually!), unobtrusive
- **3D AR interfaces**
  - expressive, creative, require attention
- **Tangible and augmented surfaces**
  - Embedded into conventional environments
- **Tangible AR**
  - avoids seams, but requires track-able objects

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Today's Collaboration Technology

Video Conferencing

- lack of spatial cues
- limited participants
- 2D collaboration

Collaborative VEs

- separation from real world
- reduced conversational cues

Assumes remote collaboration!

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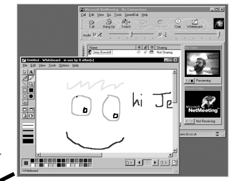
Interaction seams

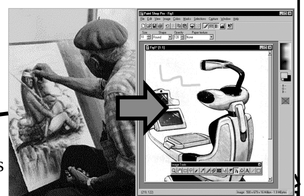
Seam (Ishii et. al.)

- spatial, temporal, functional discontinuity

Types of Seams

- Functional
  - different functional workspaces
- Cognitive
  - different work practices





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Seams in collaboration

Functional Seams:

- Mediated differs from F-to-F Conversation
  - Loss of Gaze Information
  - Degradation of Non-Verbal Cues

Cognitive Seams:

- Learning Curve Effects
- User Frustration

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Collaborative AR Systems

Face to Face Collaboration

- Studierstube
- Shared Space

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Studierstube (Schmalstieg et. al.)

- **"Studierstube" = "study room"**
- **collaborative AR**
- **virtual objects, natural communication**
- **independent views of the data**
  - POV, layers, annotations
- **new forms of 3D interaction**
  - Pen, PIP, tangible input devices

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Studierstube Features

Seamless Interaction
Natural Communication

Attributes:
- Virtuality
- Augmentation
- Cooperation
- Independence
- Individuality

Merges Task and Communication Space

video

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Shared Space (Siggraph 99)

Goal
- create compelling collaborative AR interface usable by novices

Exhibit content
- matching card game
- face to face collaboration
- physical objects
  - 5x7" cards

video

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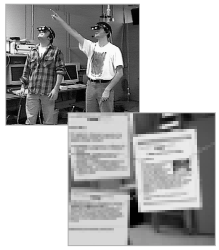
Related Work

TransVision (Rekimoto)
AR² Hockey (MRSL)
RV Border Guards (MRSL)
Collaborative Web Space (Billinghurst)



Wrap-up

Face to face collaboration

- Studies show AR preferred over immersive VR
- AR facilitates seamless / natural communication

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Heterogeneous AR?

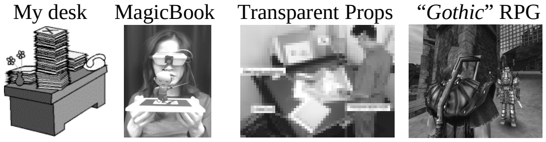
- AR combines real + virtual
  $\rightarrow$ implicitly heterogeneous
- But "AR" is not even a precise definition

AR ≠ AR!

- There are multiple flavors of AR

Milgram's continuum revisited

My desk | MagicBook | Transparent Props | "*Gothic*" RPG



[Billinghurst01] [Schmalstieg99]

Reality ← ***Augmented reality (AR)*** — ***Augmented virtuality (AV)*** → ***Virtuality***

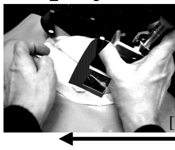
All these options make sense for certain applications

Make heterogeneous user interfaces!

- **Take-home message:**
  - Don't get stuck with a single "paradigm"
- **Many possibilities make sense**
- **Mix & match to make the best user interface**

There's more continua to choose from...

Display continuum



Ultra-sound biopsy

[State96]

Automated teller machine

ATM (Automated Teller Machine)

"Classic" Augmented Reality
- Users carry their computers
- See-through head mounted display, hand-held display

Ubiquitous computing
- Computers are embedded in environment
- Access to networked resources
- Active surfaces

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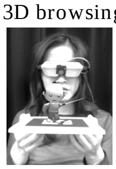
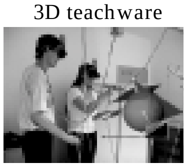
User continuum

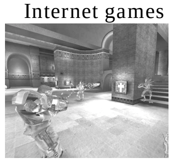
3D browsing



3D teachware



Internet games



Single user

Collaborating users, co-located

Collaborating users, remote

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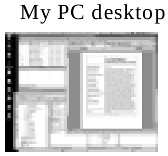
Application continuum

Computer game

My PC desktop



Single-tasking
Dedicated environment

Multi-purpose
Multi-tasking

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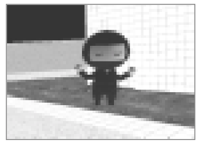
Combinations make sense

E.g., *Magic Book* uses 2 places along real-virtual continuum



video

Augmented reality and immersive virtual reality

Used at the same time by 2 users!

Bring together UI paradigms

Besides AR, there are e.g.,

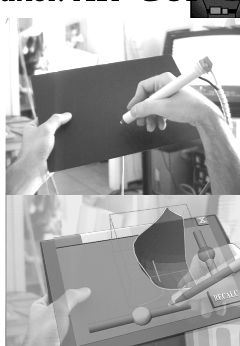
- **Tangible User Interface**
- **Graphical User Interface**
- **Mobile indoor and outdoor UI**

Some sample combinations...

Personal Interaction Panel: AR+GUI

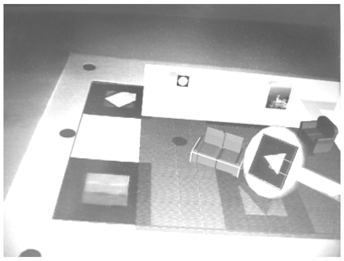
Properites: [Szalavári97]

- Pen and pad props
- Two-handed interaction
- Tactile feedback
- General and versatile
- Natural embedding of 2D in 3D
- Simple, cheap hardware



video

VOMAR: Tangible + AR



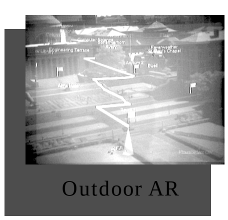
[Kato00]

DataTiles: Tangible + GUI

[Rekimoto01]

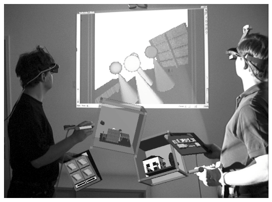
MARS: GUI + Indoor + Outdoor AR

[Höllerer99] Campus information system



Multiple simultaneous paradigms

- **Overcome boundaries between UI**
- **Bridging Space**

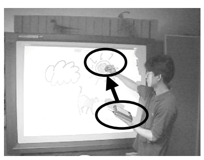


Studierstube [Schmalstieg00]
Mix AR with projections

Bridging Space (1/5)

Multi-computer direct interaction

[Rekimoto97]



[Rekimoto98]

Pick-and-drop

Bridging Space (2/5)

EMMIE [Butz99]

- Shared virtual “ether“ metaphor
- Incorporate existing standard applications

Bridging Space (3/5)

Active Surfaces

[Rekimoto99]

- Space between objects bridged by display surface

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Bridging Space (4/5)

Office of the Future

[Raskar98]

- Office environment augmented with embedded front projection
- All surfaces are used

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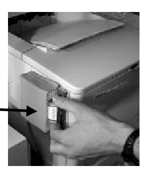
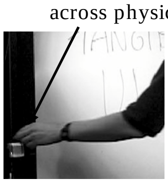
Bridging Space (5/5)

mediaBlocks [Ullmer98]

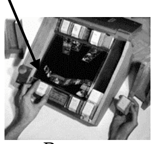
- Wooden blocks with ID tags
- Carry "data containers" across physical space



Printer



White board



Browser

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Wrap-up

- **Many UI paradigms combinations make sense**
  - AR, desktop, tangible, immersive…
- **Choose from several UI dimensions**
  - Real⇔virtual, # of displays, users, applications…
- **Build interesting user interfaces**
  - Space bridging metaphor
  - Use most appropriate UI for any task
  - Don't think in categories, be creative!

Syllabus

- **Overview**
- **Tracking for Augmented Reality**
- **Augmented Reality Interaction**
- **Collaborative Augmented Reality**
- **Heterogeneous user interfaces**
- **Mobile Augmented Reality**

Mobile AR – Motivation

Mobile, wearable computing opens up new possibilities

- location-aware / situated computing

Now, the interface is truly everywhere

- AR is a powerful UI for this type of computing

Mobile AR – Background

Post-WIMP interfaces:

- **3D**
  - Desktop 3D, Desktop VR, Fishtank VR
  - Projection-based VR
  - Head-mounted VR → **Mobile AR**
- **Multimodal** Speech, Gestures, Audio, Haptic → **Mobile AR**
- **Situated**
  - Mobile, Wearable → **Mobile AR**
  - Multi-Device, Pervasive
  - Tangible, Embodied

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Mobile AR – Background

Steps Toward Wearable Computing

Computer Form Factor	*User Relationship*
Room	**Enter**
Wall	**Share**
Desk	**Sit at**
Box	
Laptop	**. . . and carry before/after**
Palmtop	**Hold**
Clothing	**Wear**

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Implications of Wearability

(after S. Mann, B. Rhodes, T. Starner)

Mobility

- usable / used indoors and outdoors

Intimacy

- sense the wearer's body, communicate privately

Context sensitivity

- take into account changing environment

Constancy

- Permeation of UI into wearer's life

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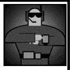
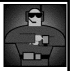
What is Mobile AR?



Ways of augmenting a mobile user's environment

- wearable display, no tracking whatsoever
- body-stabilized wearable display (orientation tracking only)
- location-dependent audio augmentation (with or without spatialized audio)
- location-dependent screen-stabilized augmentation (possibly monocular)
- location-dependent body-stabilized augmentation (on a projection cylinder / sphere surrounding the user)
- stereo head-tracked, position tracked, AR with full overlay registration

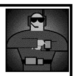
Mobile AR – Challenges (1/2)



Mobile AR is difficult

- "Basic" wearable computing is already a technical challenge. Mobile AR adds a lot of extra complexity: orientation & long-range position tracking, possibly 3D graphics…
- Ruggedness required ("wear and tear!" ☺)
- Outdoor AR is a particular challenge (wide range of operating conditions, little control over environment).

Mobile AR – Challenges (2/2)



Limited Resources

- A wearable platform has limited computation power
- Size, weight, and power restrictions:
  - Military backpacks can weigh about 60 pounds (27 kg), military helmets 4-5 pounds (~2kg)
  - For a system to *appeal* to users, the weight has to be *drastically* lower and the ergonomics have to be right.
  - Batteries, batteries, batteries (esp. for 3D graphics)

Mobile AR – Hardware

Hardware requirements (tracking covered in next section):

- **Head-worn display**
  - Optical see-through vs. video feed-through, monocular vs binocular, stereo vs mono, resolution, field of view
  - Extra brightness for outdoors. Optical see-through: adjustable opacity
- **Computing Platform**
  - Computing power, 3D graphics capabilities, extensibility
  - Size, ergonomics, availability (off-the-shelf vs. build yourself), price
- **Complementary hand-held/palm-top/wrist displays**
  - For outdoors: readability in direct sunlight
- **(Other) input devices**
  - Mice, 3D pointing, microphones, cameras

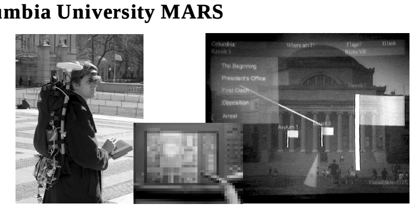
Mobile AR Systems
Outdoor AR

Existing Outdoor Systems

- focus on tracking:
  - HRL, Rockwell, USC, Mixed Reality Systems Lab, …
- focus on systems / UI:
  - Columbia University, University of South Australia, Naval Research Lab, Mixed Reality Systems Lab
  - Papers / Posters at ISAR and ISMR symposia

Mobile AR Systems
Outdoor AR

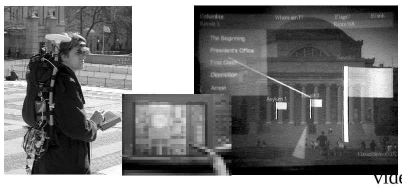
Columbia University MARS



- Touring Machine ('97), Situated Documentaries ('99)
- Indoor/Outdoor Collaboration ('99),
- Filtering ('00, with NRL), View Mgmt ('01)

Mobile AR Systems
Outdoor AR

Columbia University MARS



video

- Touring Machine ('97), Situated Documentaries ('99)
- Indoor/Outdoor Collaboration ('99),
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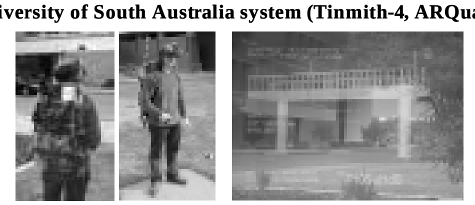
Mobile AR Systems
Outdoor AR

University of South Australia system (Tinmith-4, ARQuake)



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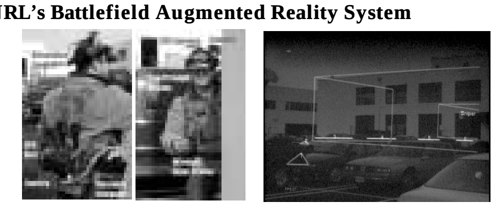
- Terrestrial Navigation ('98), VR/AR ('99)
- ARQuake ('00): Outdoor/Indoor game, vision-based tracking corrections (ARToolkit)

Mobile AR Systems
Outdoor AR

NRL's Battlefield Augmented Reality System



Naval Research Laboratory

- BARS ('00), Information Filtering ('00)
- Focuses on stereo 3D Vector graphics (also supports polygonal 3D models)

Mobile AR Systems

Outdoor AR

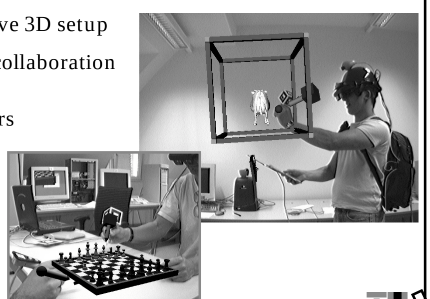
Mixed Reality Systems Lab

© Mixed Reality Systems Laboratory Inc.

- TOWNWEAR (Towards Outdoor Wearable Navigator With Enhanced & Augmented Reality)
- Head orientation tracking with fiber optic gyroscope and vision-based drift corrections

Mobile Studierstube

- Fully interactive 3D setup
- Spontaneous collaboration of mobile and stationary users



THANK YOU!

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Dieter Schmalstieg
Vienna University of Technology
Austria

video - end