Modern Approaches to Augmented Reality

Oliver Bimber

University of Weimar

Ramesh Raskar

Mitsubishi Electric Research Labs

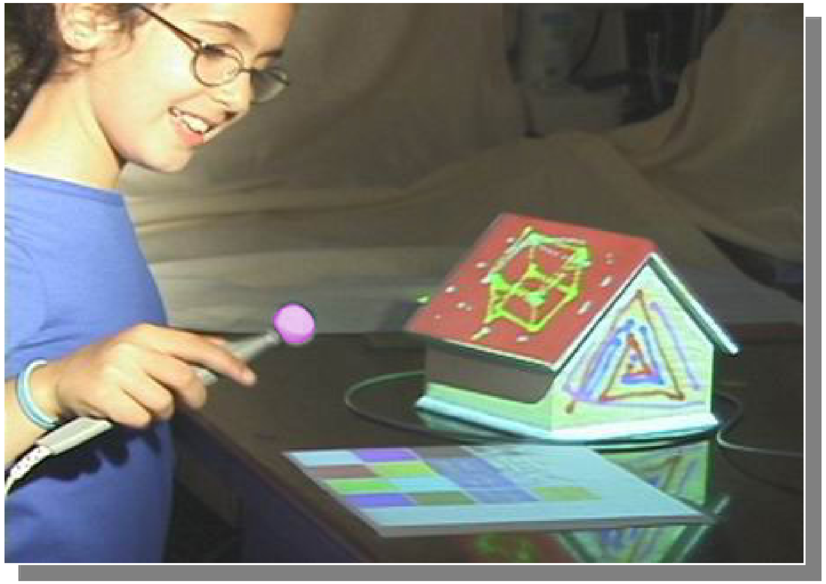
Course Page : http://Spatial-AR.com

Welcome

- AR Display Approaches
  - Traditional, Goggle-bound, Alternative
- Spatial Augmentation
  - Projectors, Non-planar, Mobile objects, Change appearance, Interaction
- Exploiting Optical Elements
  - Mirrors, Beam splitters, Holograms
- Applications
  - Prototypes in Art, Research and Industry

A Non-traditional Approach

- Painting with Light
  - [Bandyopadhyay, Raskar, Fuchs 2001]



Goals

- Understand advantages of Spatial AR
- Discuss issues in traditional AR approaches
- Explore alternative AR methods
  - Graphics, Vision, Optics techniques
  - Learn math of rendering and calibration
- See new applications in art and industry

- What we will not cover
  - Fundamentals of AR and VR

Speaker

Oliver Bimber is an Assistant Professor for Augmented Reality at the Bauhaus University Weimar, Germany. He received a Ph.D. in Engineering at the Technical University of Darmstadt, Germany under supervision of Prof. Dr. J. Encarnação (TU Darmstadt) and Prof. Dr. H. Fuchs (UNC at Chapel Hill). From 2001 to 2002 Bimber worked as a senior researcher at the Fraunhofer Center for Research in Computer Graphics in Providence, RI/USA, and as a scientist at the Fraunhofer Institute for Computer Graphics in Rostock, Germany. He initiated the Virtual Showcase project in Europe and the Augmented Paleontology project in the USA. In his career, Bimber received several scientific achievement awards and is author of more than thirty technical papers and journal articles. He was guest editor of the Computer & Graphics special issue on "Mixed Realities - Beyond Conventions", and has served as session chair and committee member for several international conferences.

His research interests include display technologies, rendering and human-computer interaction for Mixed Realities. Bimber is member of IEEE, ACM and ACM Siggraph.

Speaker

Ramesh Raskar is a Research Scientist at MERL-Cambridge Research. His research interests include projector-based graphics, projective geometry, non-photorealistic rendering and intelligent user interfaces. During his doctoral research at U. of North Carolina at Chapel Hill, he developed a framework for projector based 3D graphics, which can simplify the constraints on conventional immersive displays, and enable new projector-assisted applications. He has published several articles on immersive projector-based displays, spatially augmented reality and has introduced Shader Lamps, a new approach for projector-based augmentation. He is a member of the ACM and IEEE.

http://www.merl.com/people/raskar/raskar.html

Opportunities

- Think beyond goggle-bound AR
- Learn techniques using projectors, flat displays and optics
- Explore more realistic augmented environments
- Learn how to build your own spatial AR displays (only covered in tutorial notes).
- Learn how to extend your own software framework to support spatial AR displays
- Get an impression on applicability

Schedule

2:00	Overview	
2:10	Today's AR Display Approaches	(Bimber)
2:40	Spatial Augmentation	(Raskar)
3:30	Break	
3:45	Spatial AR using Optical Elements	(Bimber)
4:45	Prototypes	(Bimber and Raskar)
5:20	Discussion	

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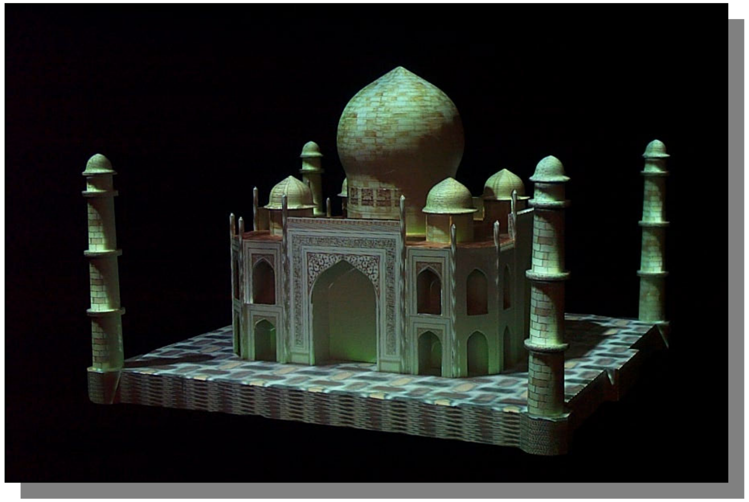
ShaderLamps

Virtual Reflectance

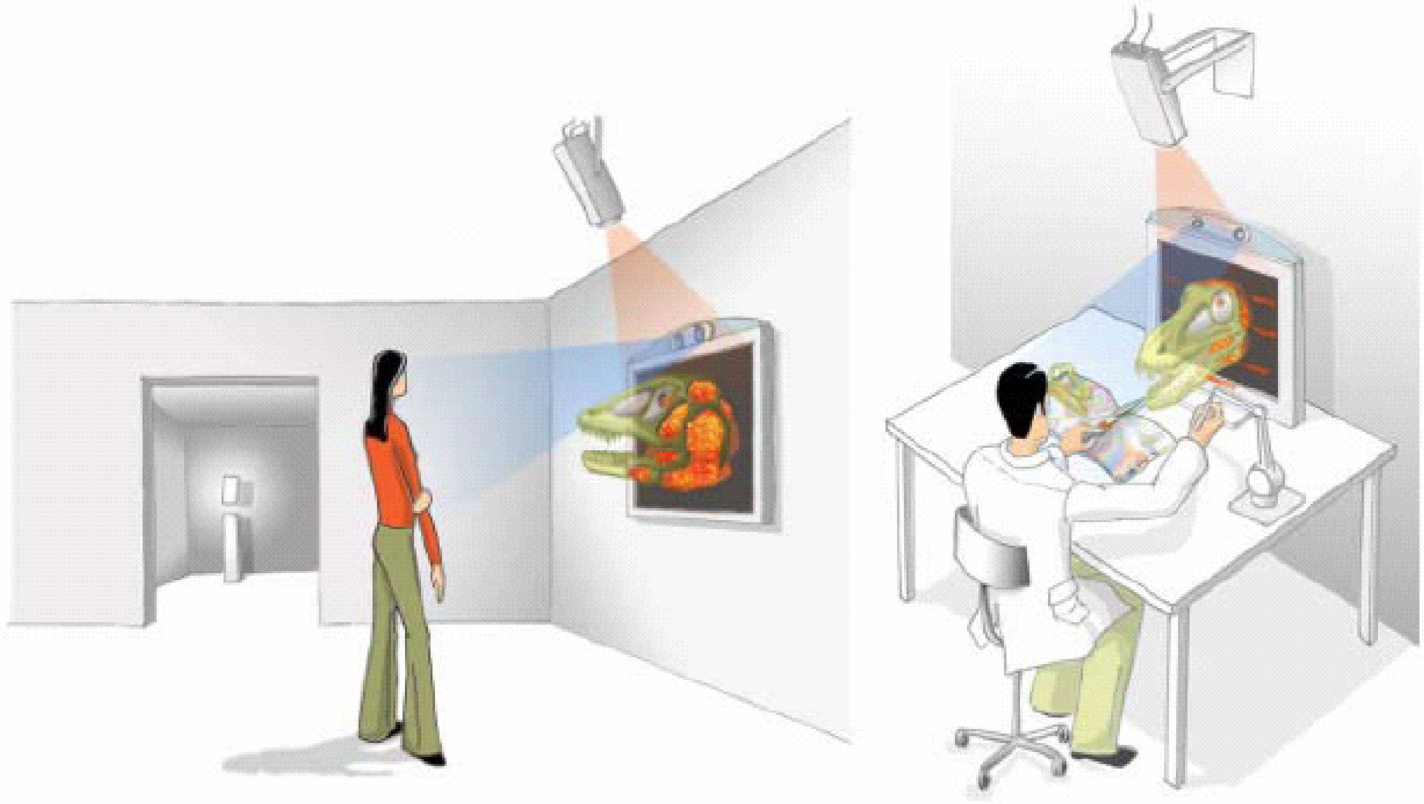
Virtual Illumination



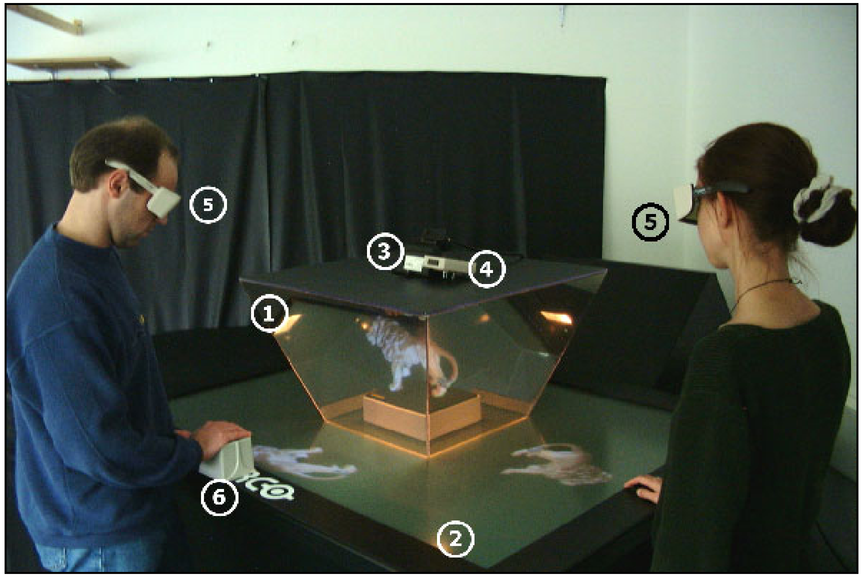
Virtual Motion

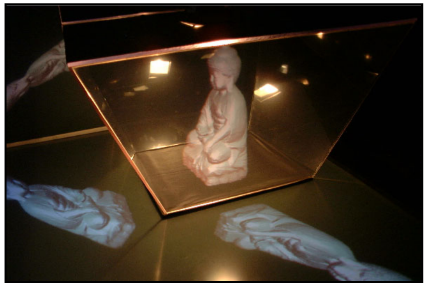
Interaction

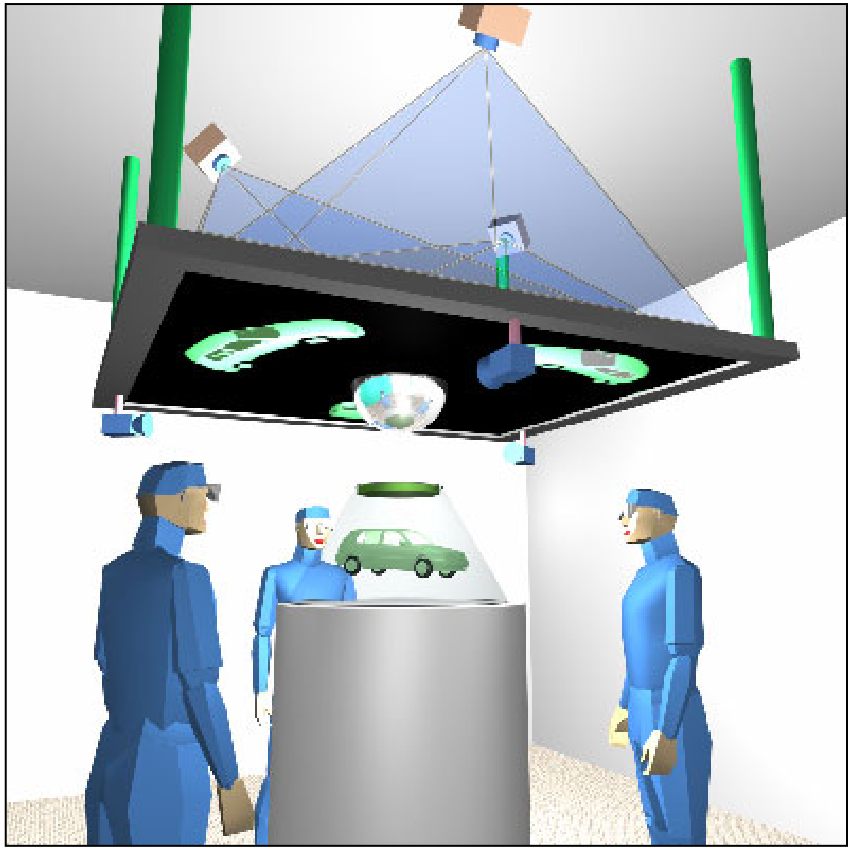
HoloGraphics



Virtual Showcase







Handheld AR

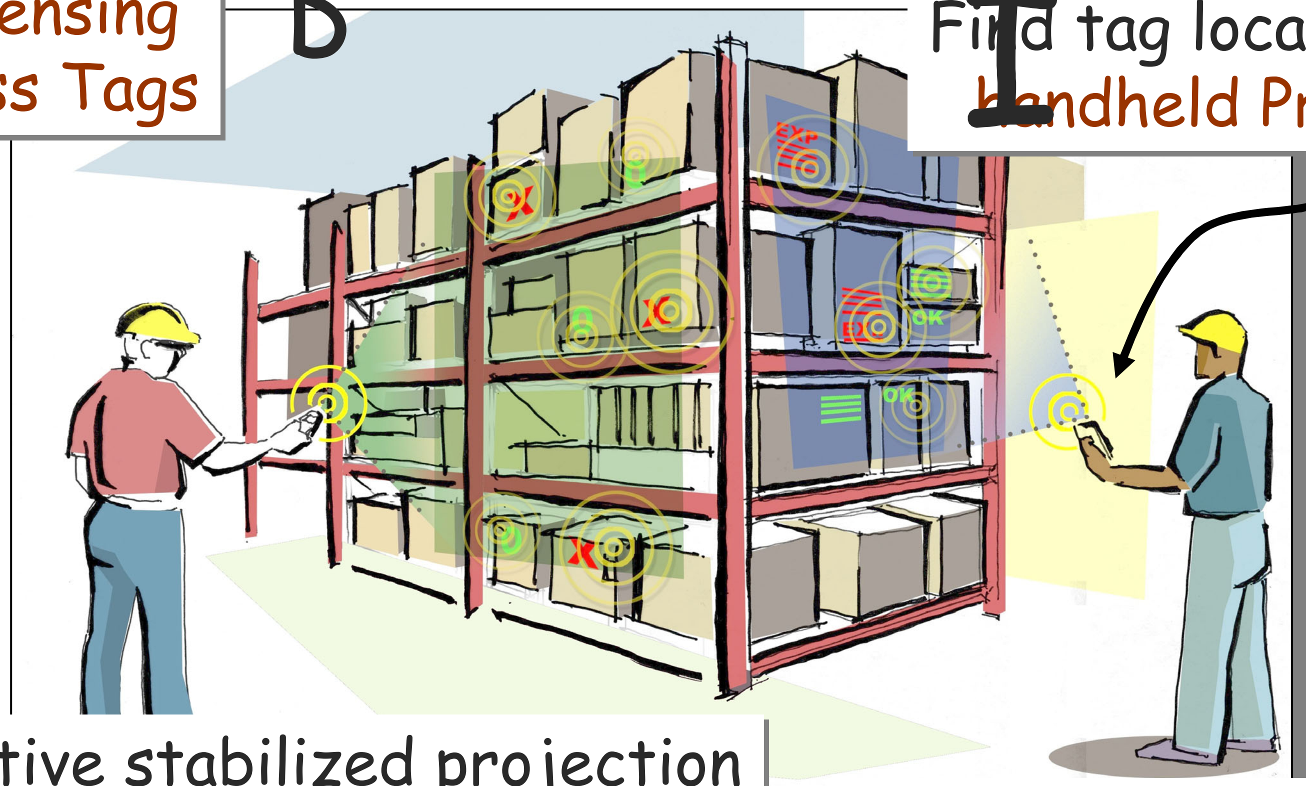
F F G

(Radio Frequency Id & Geometry)

I D I

Photosensing Wireless Tags

Find tag location using handheld Projector



Interactive stabilized projection

Many geometric ops

Survey

- How many of you are **users of VR system** ?
- How many of you are **users of AR system** ?
- How many of you are involved in AR **design/development** ?
- How many do **active programming** ?
- What **type of AR** do you use:
  HMD ? Handheld ? Projector ?
- **Field of work:**
  Academics? Industry ? Research ? Art ?

Feedback

- Please raise questions/comments during the presentation
- Send write other questions on a paper
- Fill in sheet with Email addresses

Part 2:

Today's Display Approaches for AR

(Bimber)

Modern Approaches to Augmented Reality

- Part 2 -

Introduction to Today's Displays Approaches for AR

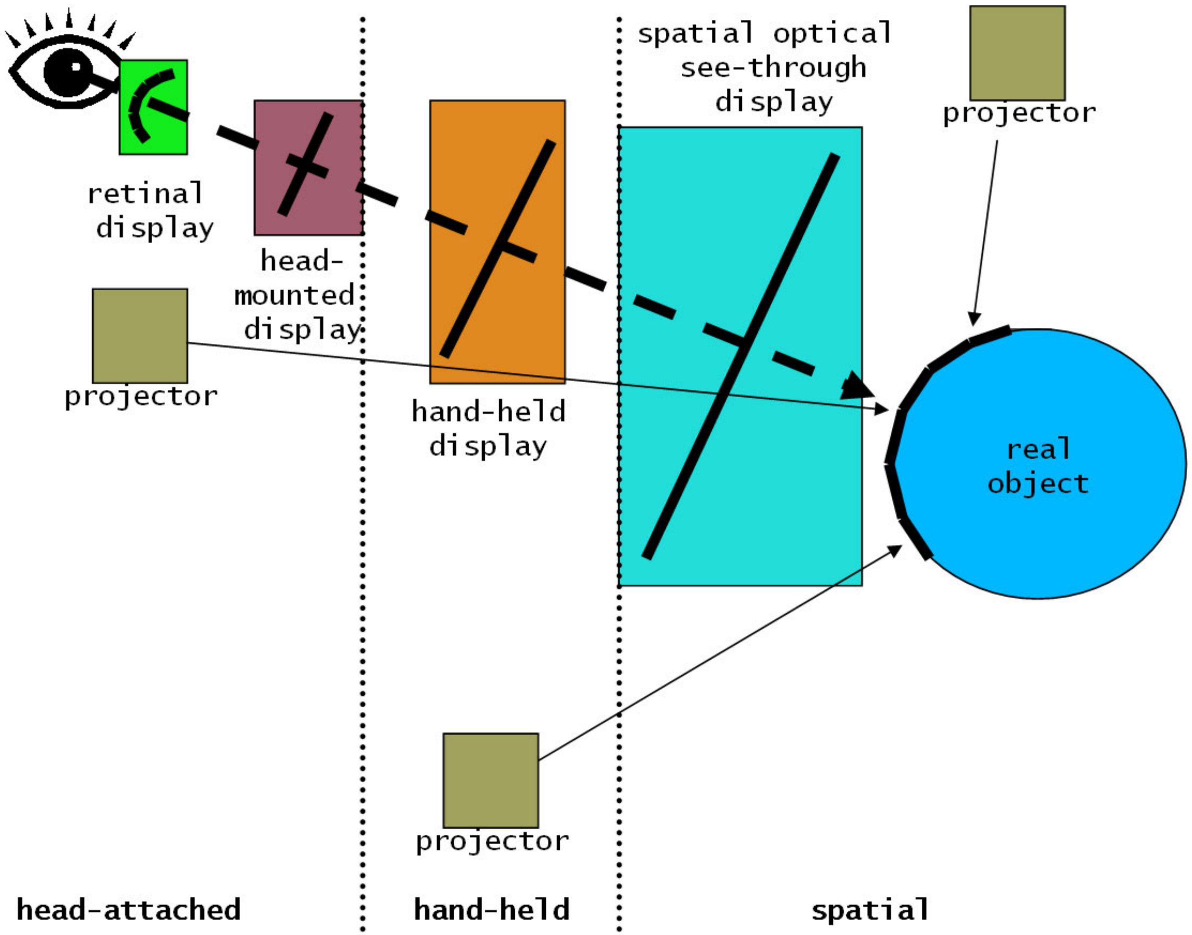
Outline

- Part 1: Tutorial Introduction and Overview (Ramesh)
- **Part 2: Introduction to today's displays approaches for AR (Oliver)**
- Part 3: New Directions in Spatial Augmentation (Ramesh)
- Part 4: Spatial Augmentation using Optical Elements (Oliver)
- Part 5: Prototypes and Experiences (both)

Ultimate AR Displays?

20th Century Fox / Lucasfilm Ltd.

Overview and Classification

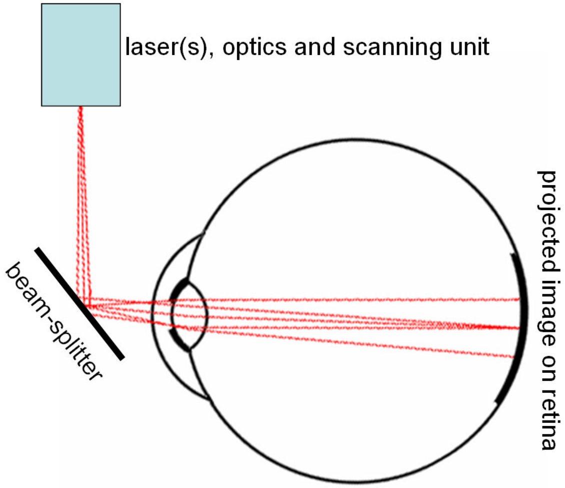


Retinal Displays

Pros:

- High brightness and contrast;
- Low power consumption (make them well suited for mobile outdoor applications);
- Support mobile applications;
- Support multi-user applications;
- Future generations also hold the potential to provide dynamic re-focus, full-color stereoscopic images, and an extremely high resolution and large field-of-view.

Microvision, Inc.



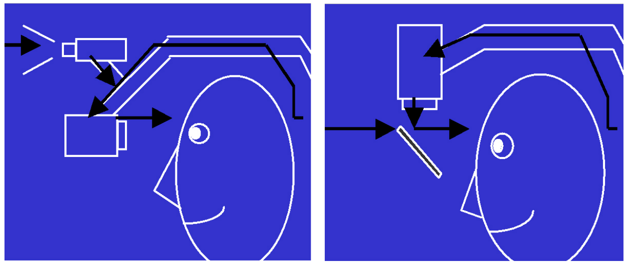
Cons:

- Only monochrome (red) images;
- The sense of ocular accommodation is not supported;
- Stereoscopic versions do not exist.

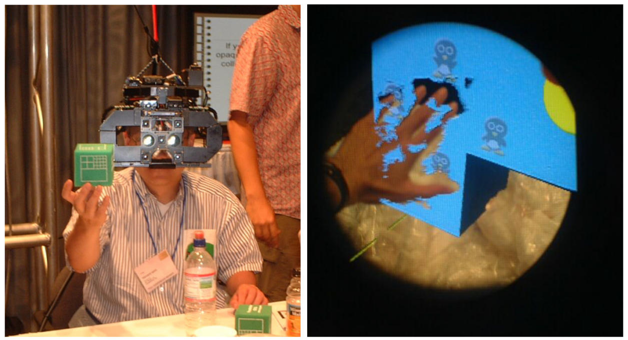
Head-Mounted Displays

Pros:

- Currently the dominant display technology for AR;
- Support mobile applications;
- Support multi-user applications;
- Some specialized versions support mutual occlusion (like Kiyokawa's ELMO)



Azuma. A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments, vol. 6, no. 4, pp. 355-385, 1997.



Kiyokawa, et al. An Optical See-through Display for Mutual Occlusion of Real and Virtual Environments. In proceedings of IEEE & ACM ISAR 2000, pp. 60-67, 2000.

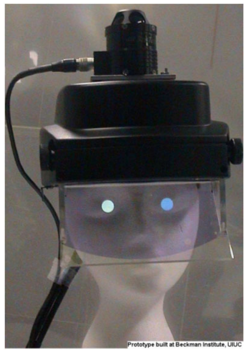
Cons:

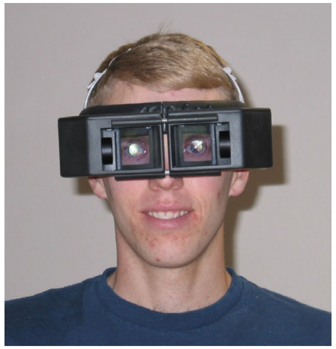
- Lack in resolution;
- Limited field of view;
- Heavy optics and vs. ergonomic devices;
- Constant image depth;
- Optical see-through: difficult (user and session dependent) calibration and precise head-tracking;
- Video see-through: image processing for optical tracking increases the end-to-end system delay;
- Conventional optical see-through devices are incapable of providing consistent occlusion.

Head-Mounted Projectors

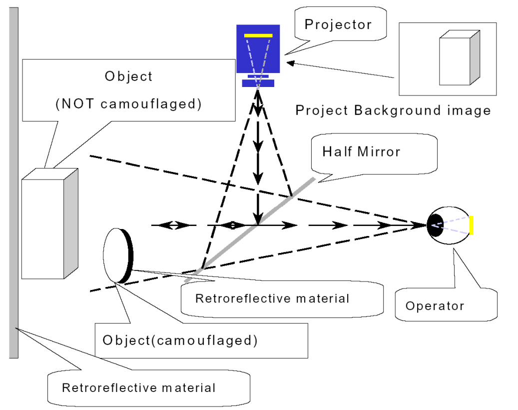
Pros:

- Support mobile applications;
- Support multi-user applications;
- Have the potential of combining the advantages of projection displays (i.e., resolution, FOV) with the advantages of traditional HMDs.





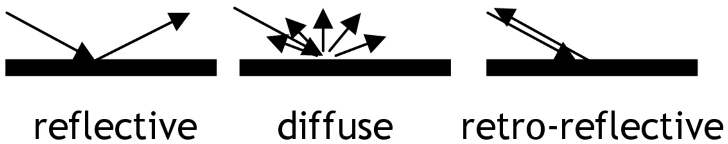
Hua, et al. Using a head-mounted projective display in interactive augmented environments. In Proceedings of IEEE and ACM International Symposium on Augmented Reality 2001, pp. 217-223, 2001.



Inami, et al. and Tachi, S., Visuo-Haptic Display Using Head-Mounted Projector, Proceedings of IEEE Virtual Reality 2000, pp.233-240, 2000.

Cons:

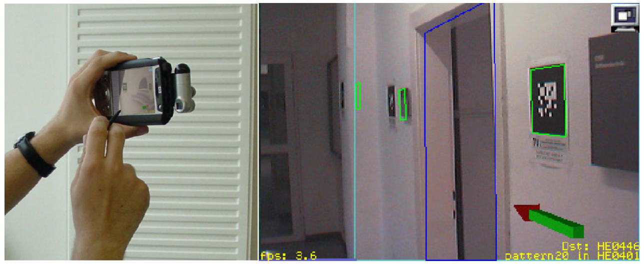
- Limited resolution and brightness;
- Head-mounted projective displays might require special display surfaces (i.e., retro-reflective surfaces) to provide bright images;
- For projective head-mounted displays, the brightness of the images depends on the environmental light conditions;
- Projective head-mounted displays can only be used indoors, since they require the presence of a ceiling.



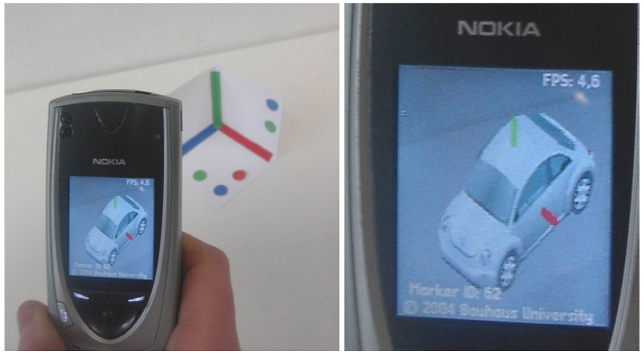
Hand-Held Displays

Pros:

- Realistic alternative to HMDs for mobile applications;
- Consumer devices such as PDAs and cellphones have the potential to address a mass-market;
- Support mobile applications;
- Support multi-user applications.



Wagner, D, et al. First steps towards handheld augmented reality. In proceedings of International Conference on Wearable Computers, pp. 127-136, 2003.



Moehring, et al.
Video See-Through and Optical Tracking with Consumer Cell Phones
In proceedings of International Symposium on Augmented and Mixed Reality (ISMAR'04), 2004.

www.uni-weimar.de/medien/AR

Cons:

- Image analysis and rendering components is processor and memory intensive;
- Limited screen size of most hand-held devices restricts the covered field-of-view;
- Optics and image sensor chips of integrated cameras in consumer hand-held devices is targeted to other applications and consequently provide a limited quality for image processing tasks;
- Compared to head-attached devices, hand-held devices do not provide a completely hands-free working.

Hand-Held Displays (cont.)

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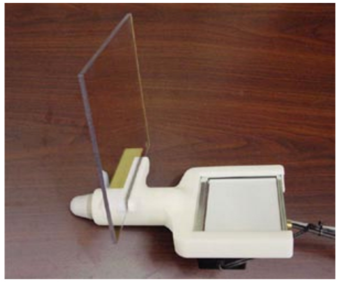
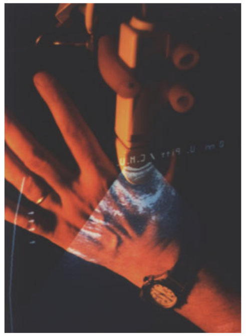
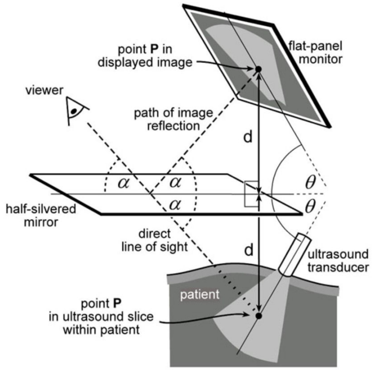



Stetten, et al. Real Time Tomographic Reflection: Phantoms for Calibration and Biopsy, In proceedings of IEEE/ACM International Symposium on Augmented Reality (ISMAR'01), pp. 11-19.

US and foreign patents are pending



Bimber, et al. Augmented Reality with Back-Projection Systems using Transflective Surfaces. Computer Graphics Forum (proceedings of EUROGRAPHICS 2000 - EG'2000), vol. 19, no. 3, pp.161-168, 2000.

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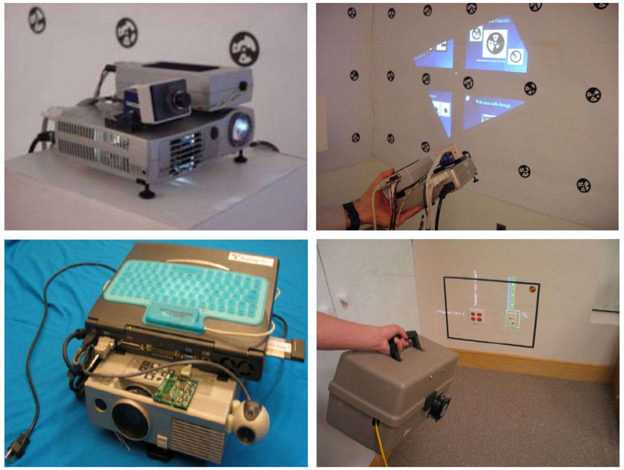
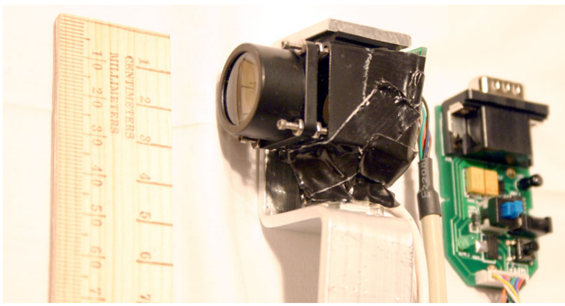


Raskar, et al. iLamps: Geometrically Aware and Self-Configuring Projectors. In Computer Graphics (proceedings of SIGGRAPH'03), 2003.



Raskar, et al. RFIG Lamps: Interacting with a Self-Describing World via Photosensing Wireless Tags and Projectors. SIGGRAPH '04, 2004.

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Screen-Based Video See-Through Displays

Pros:

- Common technique if mobile application does not have to be supported;
- Cost-efficient and easy to realize with off-the-shelf components.

www.uni-weimar.de/medien/AR

Cons:

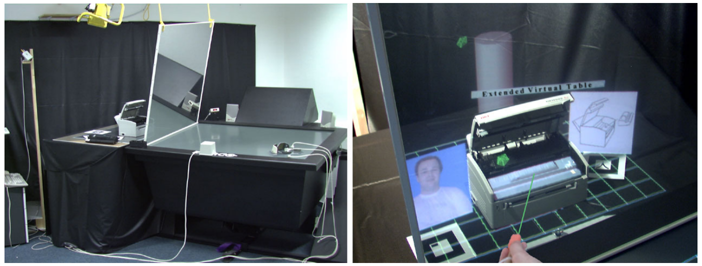
- Small field of view - screen-size is scalable if projection displays are applied;
- Limited resolution (especially of the real environment);
- Does not support mobile applications;
- Does not support multiple users;
- Does not support stereo;
- Mostly provides a remote viewing, rather than supporting a see-through metaphor;
- Direct interaction with the real environment and the graphical augmentation is usually not supported.

Spatial Optical See-Through Displays

Pros:

- Easier eye accommodation and vergence;
- Higher and scalable resolution;
- Larger and scalable field of view;
- Improved ergonomic factors;
- An easier and more stable calibration;
- Better controllable environment.

Bimber, et al. The Virtual Showcase. IEEE Computer Graphics & Applications, vol. 21, no.6, pp. 48-55,2001.



Bimber, et al. The Extended Virtual Table: An Optical Extension for Table-Like Projection Systems. Presence: Teleoperators and Virtual Environments, vol.10, no. 6, 2001, pp. 613-631.

Cons:

- Do not support mobile applications;
- In most cases, the applied optics prevents a direct manipulative interaction;
- Number of users is restricted;
- Mutual occlusion between real and virtual environment is normally not supported;
- Window violation (clipping of displayed image at screen / optics) is possible.

Spatial Optical See-Through Displays (cont.)

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- Easier eye accommodation and vergence;
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- Larger and scalable field of view;
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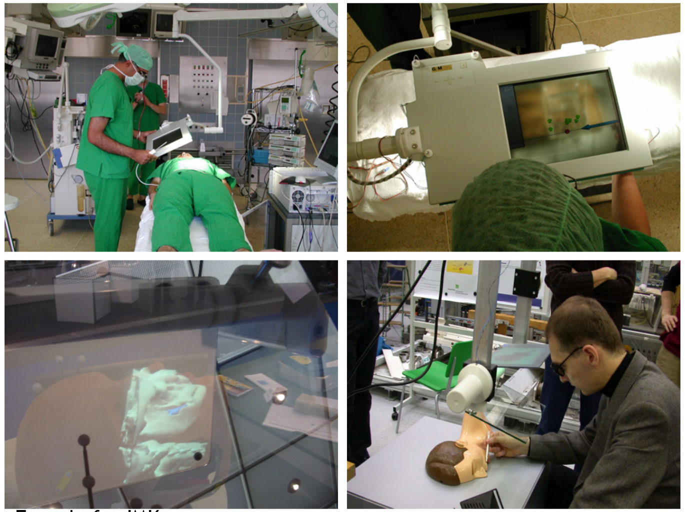
Schwald, et al. A Flexible Tracking Concept Applied to Medical Scenarios Using an AR Window. In proceedings of International Symposium on Mixed and Augmented Reality (ISMAR'02), pp. 261-262, 2002.



Fraunhofer IMK
(www.arsys-tricorder.de)

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Laser Magic Productions, www.laser-magic.com

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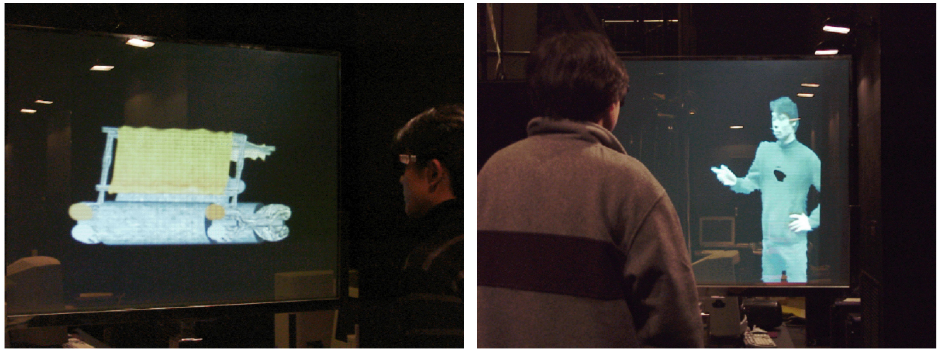

Ogi, et al. Invisible Interface for Immersive Virtual World. In proceedings of the Immersive Projection Technology Workshop (IPT'01), pp. 237-246, Stuttgart, Germany, 2001.

Spatial Optical See-Through Displays (cont.)

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Fogscreen Inc., http://www.fogscreen.com/

IO2 Technology, http://www.io2technology.com/

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Projection-Based Augmentation

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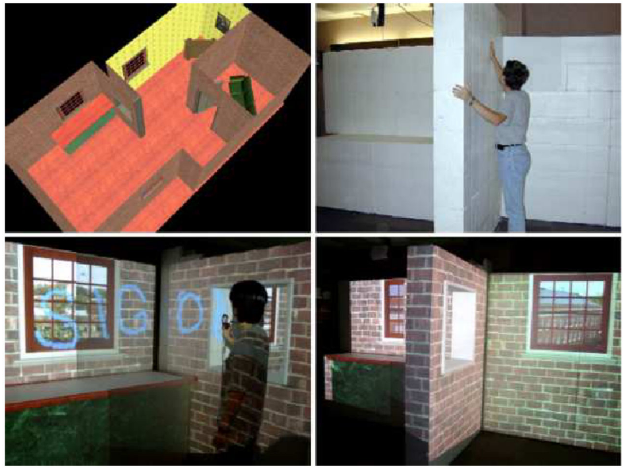
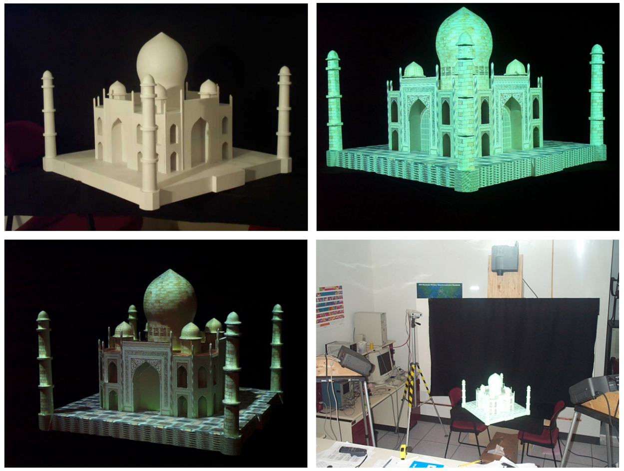


Low, et al. Life-Sized Projector-Based Dioramas. Symposium on Virtual Reality Software and Technology, 2001.



Raskar, et al. Shader Lamps: Animating real objects with image-based illumination. In Proceedings of Eurographics Rendering Workshop (EGRW'01), 2001.

Cons:

- Do not support mobile applications;
- Shadow-casting because of front-projection;
- Restrictions of the display area (size, shape, and color);
- Restricted to a single user in case of non-zero parallax;
- Conventional projectors can only focus on a single focal plane;
- The complexity of consistent geometric alignment and color calibration increases with the number of applied projectors.

Projection-Based Augmentation (cont.)

Pros:

- Easier eye accommodation and vergence;
- Higher and scalable resolution;
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Pinhanez. The everywhere displays projector: A device to create ubiquitous graphical interfaces. In Proc. of Ubiquitous Computing 2001 (Ubicomp'01), Atlanta, Georgia, 2000.

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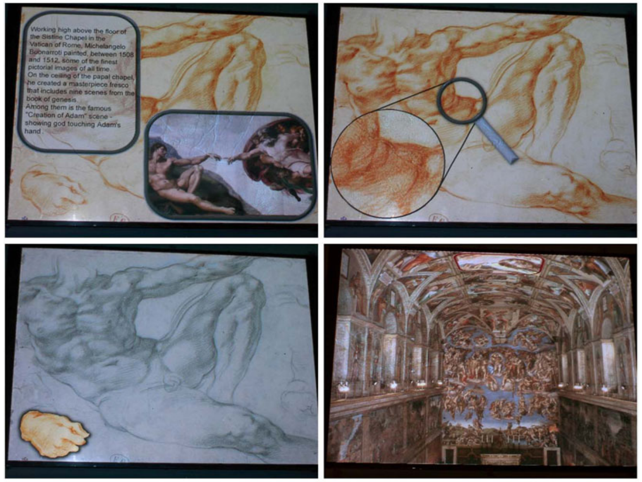

Bimber, e al. Superimposing Pictorial Artwork with Projected Imagery, To appear in IEEE MultiMedia, 2004

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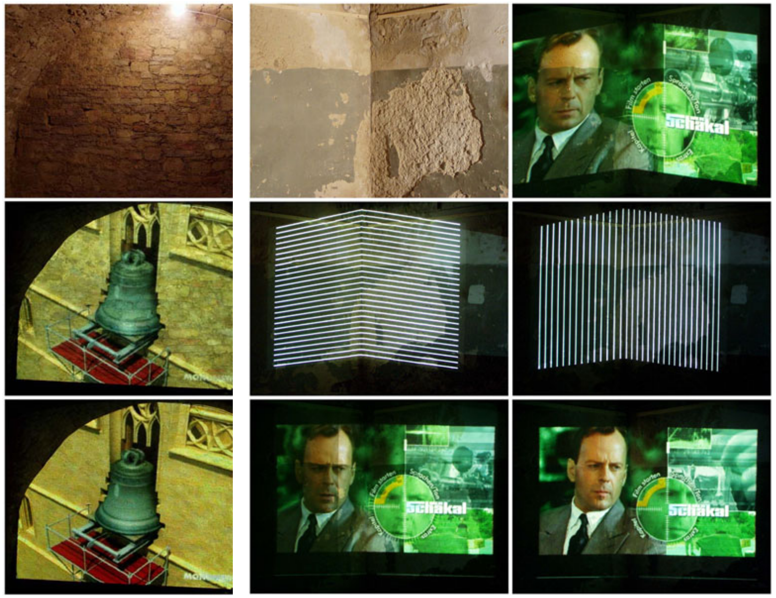

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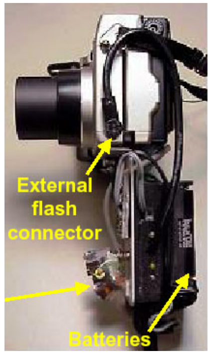
Bimber. et al.
Embedded Entertainment with Smart Projectors
Submitted to IEEE Computer, 2004

Enabling and Future Technologies

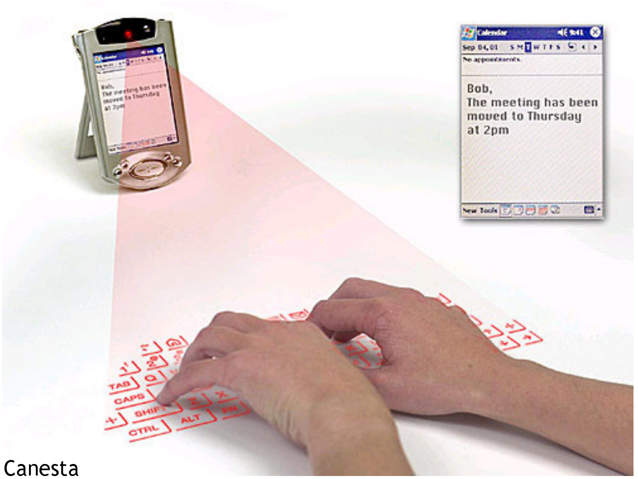
Future of Projectors

- Compact and portable;
- LEDs will replace lamps;
- Reflective (DLP, LCOS) will replace transmissive;
- Less power and less cooling;
- Extremely high frame-rates (up to 180Hz / 540Hz);
- Laser-projectors offer infinite focus and are unproblematic with ambient environment light.

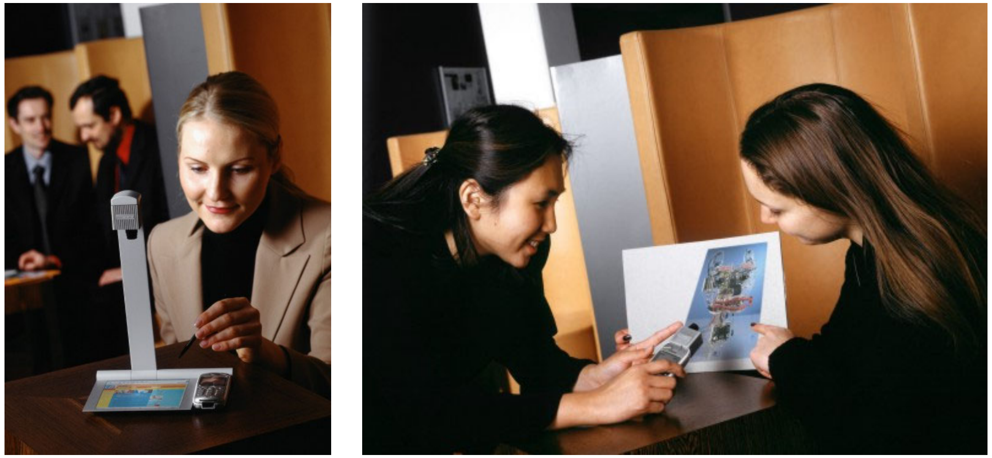
Symbol ET.



Strat, et al. M.M. Casual 3D Photography, Siggraph'03, Sketches and Applications



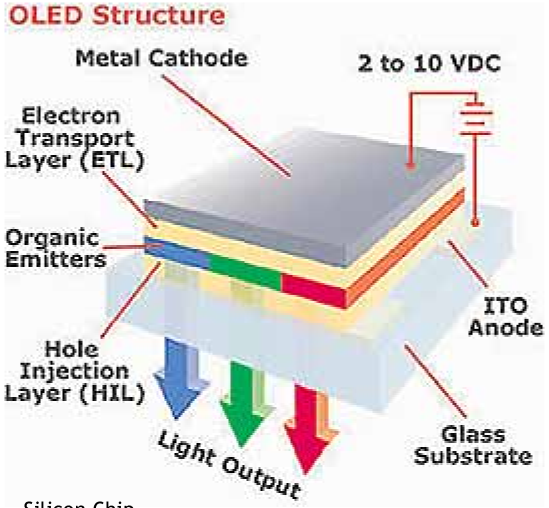
Canesta



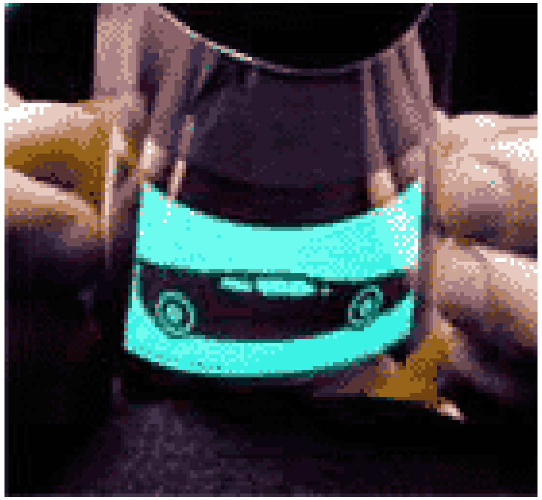
Siemens

OLEDs

- Two main classes
  - Small molecule OLEDs (molecules deposited with low pressure)
  - Polymer OLEDs (molecules suspended in liquid)
- Substrate is between transparent anode and metallic cathode
- Electric impulse causes substrate to glow
- May replace crystalline LEDs in HMDs;
- Large scale displays (500 inch displays or larger);
- High resolution (300 dpi or higher);
- Can be printed with ink jet;
- Don't require backlights (they are fluorescent)
- Low power consumption (currently LCDs require three times as much power than OLEDs);
- Thin layers (about a thousand times thinner than a human hair);
- Flexible displays;
- Can be viewed from a much wider angle (don't polarize light);
- Degrade over time (esp. different colors).



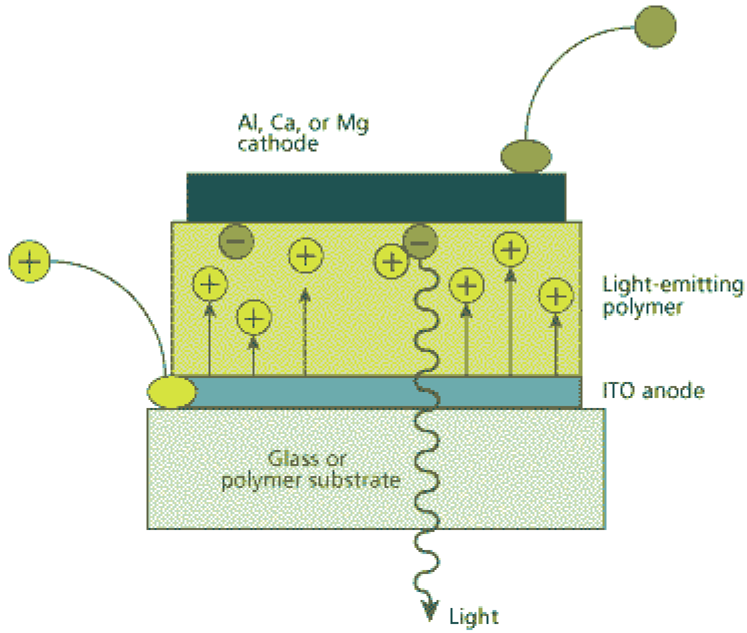
Silicon Chip



Stanford Univ.

LEPs

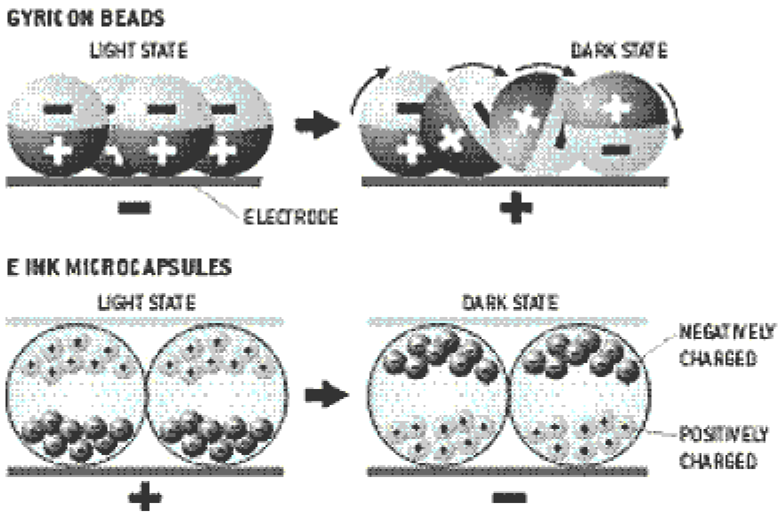
- Variation of OLED;
- Thin film of light-emitting polymer is applied onto a glass or plastic substrate coated with a transparent electrode;
- Ultra-fast responds time (sub-microsecond → may support active stereo!);
- Flexible (different shapes possible);
- Low power consumption;
- Can be fabricated on transparent glass or plastic surfaces;
- LEPs provide a high contrast (currently between 3-5 times higher than LCDs).



University of Groningen

Electronic Paper / E-Ink

- Electric charge moves magnetic colored capsules within the "paper" either toward or away from the surface in order to form an image;
- Capsules retain their positions until another charge is applied;
- It consumes no power if image is not changed;
- Current generation of electronic paper is a black-on-white technology.

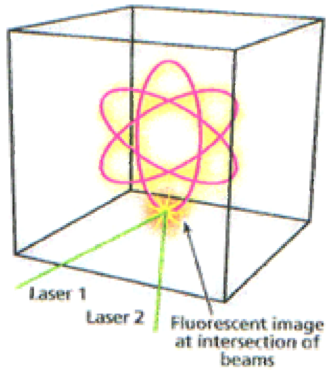


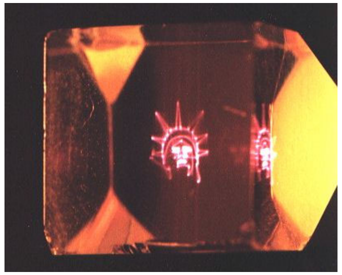
E Ink Corporation

Xerox, PARC

Solid-State Displays

- Generate visible photons within a transparent host material by exciting optically active ions with special energy sources;
- Crossing energy beams (infrared lasers, ultraviolet sources of radiation, or electron beams);
- Host materials are various gases, crystals and electro-active polymers;
- Host material must have following properties:
  - In its initial state it must be transparent;
  - It must emit visible light in its excited state;
  - Its inner structure must be homogenous;
  - It must have a refraction index similar to air to avoid distortion.
- Conceptual problems, such as the “ghost voxel problem” (when energy beams that are used to create voxels intersect with other beams and create unwanted voxels) have to be solved;
- Not (yet) possible in air.

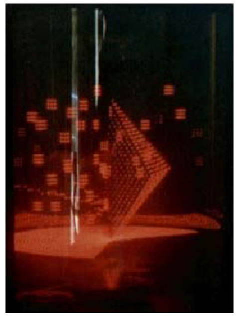




Downing, et al. A Three-Color, Solid-State, Three-Dimensional Display, Science, Vol. 273, pp. 1185-1189, 1996.

Volume Displays:

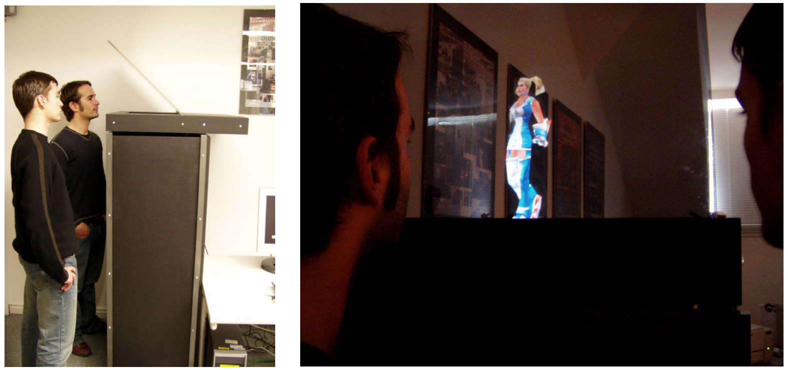
Langhans, et al. Solid FELIX: A static 3D-Laser Display, In Proceedings of Symposium on Electronic Imagining: Science and Technology (IS&T/SPIE), vol. 5006, 2003.



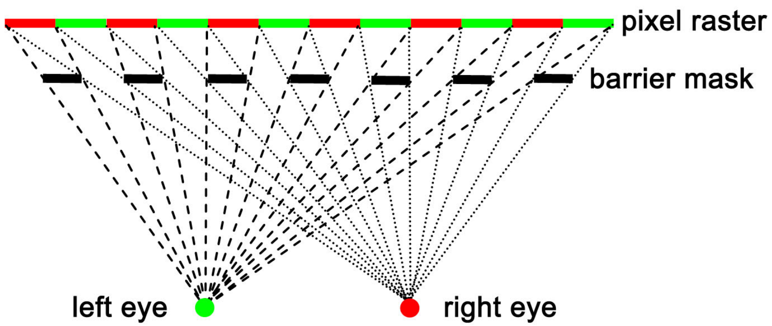
Jansson, et. al. A Three-Dimensional Computer Display, Computer Graphics in CAD/CAM Systems , Annual Conference, Cambridge, April 1979.

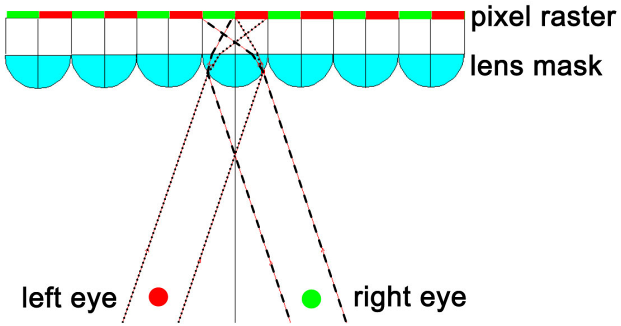
Parallax Displays

- Display screens (e.g., CRT or LCD displays) are overlaid with an array of light-directing elements for stereo-separation;
- Parallax barrier displays apply a controllable array of light-blocking elements (e.g., a light blocking film or liquid crystal barriers) in front of a CRT screen;
- Lenticular sheet displays that apply an array of optical elements (e.g., small cylindrical or spherical lenses) to direct the light for a limited number of defined viewing-zones;
- Commercially available;
- Multi-user capable.



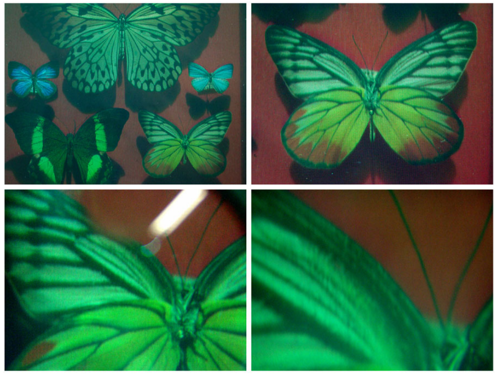
www.uni-weimar.de/medien/AR

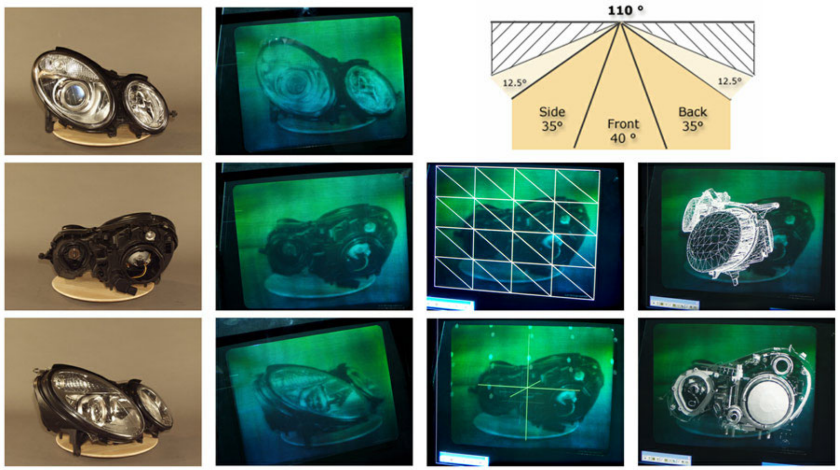




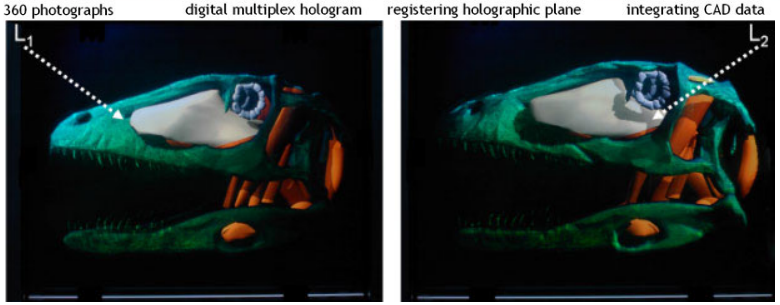
Holography

- Different types: optical, digital, electro-holograms;
- Ultra-high resolution (Terra-Pixels);
- Ultra-high information content (Terra-Bytes);
- Analog (no computational power required for display);
- Reconstruct entire wavefronts;
- Support all depth queues and an unlimited number of users;
- Are static;
- Can be combined with interactive computer graphics.





360 photographs | digital multiplex hologram | registering holographic plane | integrating CAD data

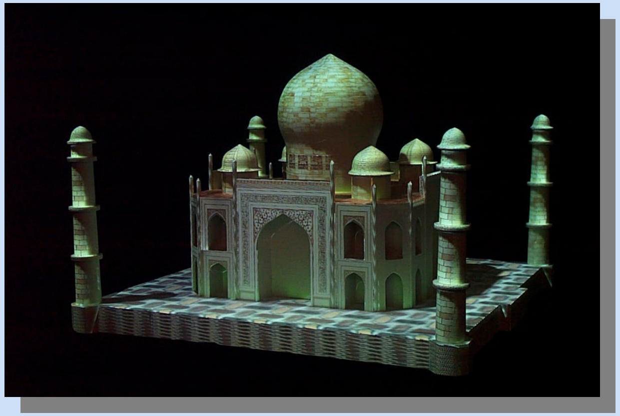


Bimber
Combining Optical Holograms with Interactive Computer Graphics
IEEE Computer (Cover Featuer), pp. 85-91, January 2004

Coming up next…

- Part 1: Tutorial Introduction and Overview (Ramesh)
- Part 2: Introduction to today's displays approaches for AR (Oliver)
- **Part 3: New Directions in Spatial Augmentation (Ramesh)**
- Part 4: Spatial Augmentation using Optical Elements (Oliver)
- Part 5: Prototypes and Experiences (both)

Spatial Augmentation



http://www.cs.unc.edu/~raskar/Projector/

Ramesh Raskar
Mitsubishi Electric Research Labs
Cambridge, MA

Schedule

2:00	Overview	
2:10	Today's AR Display Approaches	(Bimber)
2:40	Spatial Augmentation	(Raskar)
3:30	Break	
3:45	Spatial AR using Optical Elements	(Bimber)
4:45	Prototypes	(Bimber and Raskar)
5:20	Discussion	

Course Page : http://Spatial-AR.com

Feedback

- Please raise questions/comments during the presentation
- Send write other questions on a paper
- Fill in sheet with Email addresses

Projector-based AR
Outline

- Concepts and Hardware Prototypes
  - Spatially Augmented Reality
  - Shader Lamps
- Rendering Techniques for non-trivial projection
  - Calibration
  - Changing Surface Appearance
  - Merging Overlapping Projection
  - Moving Objects
  - Shape Adaptive Projection

Spatially Augmented Reality (SAR)

HMD-VR

Spatially Immersive-VR

e.g. CAVE

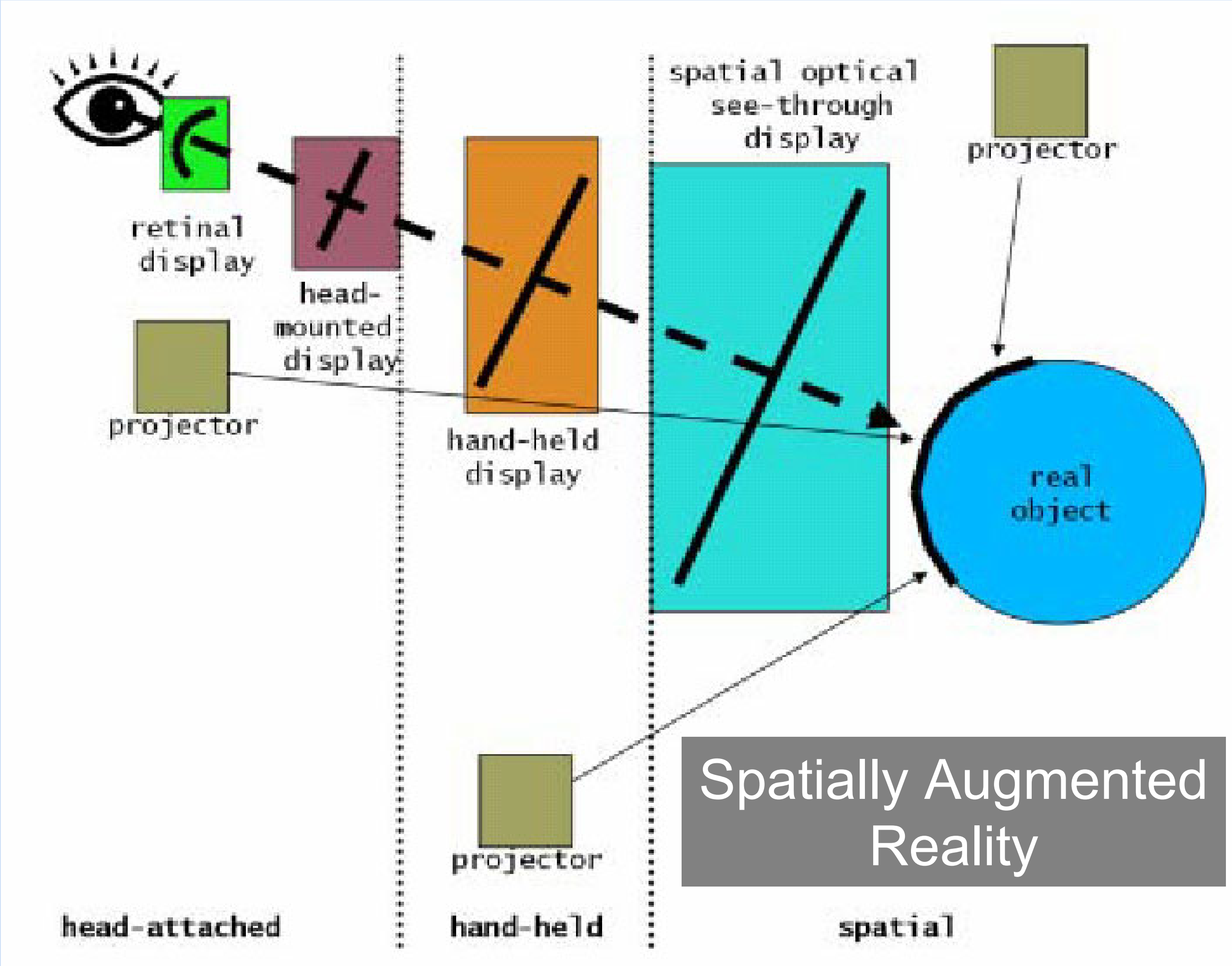
AR using HMD

Spatially Augmented Reality

Video or Optical see-through

SAR, Shaderlamps

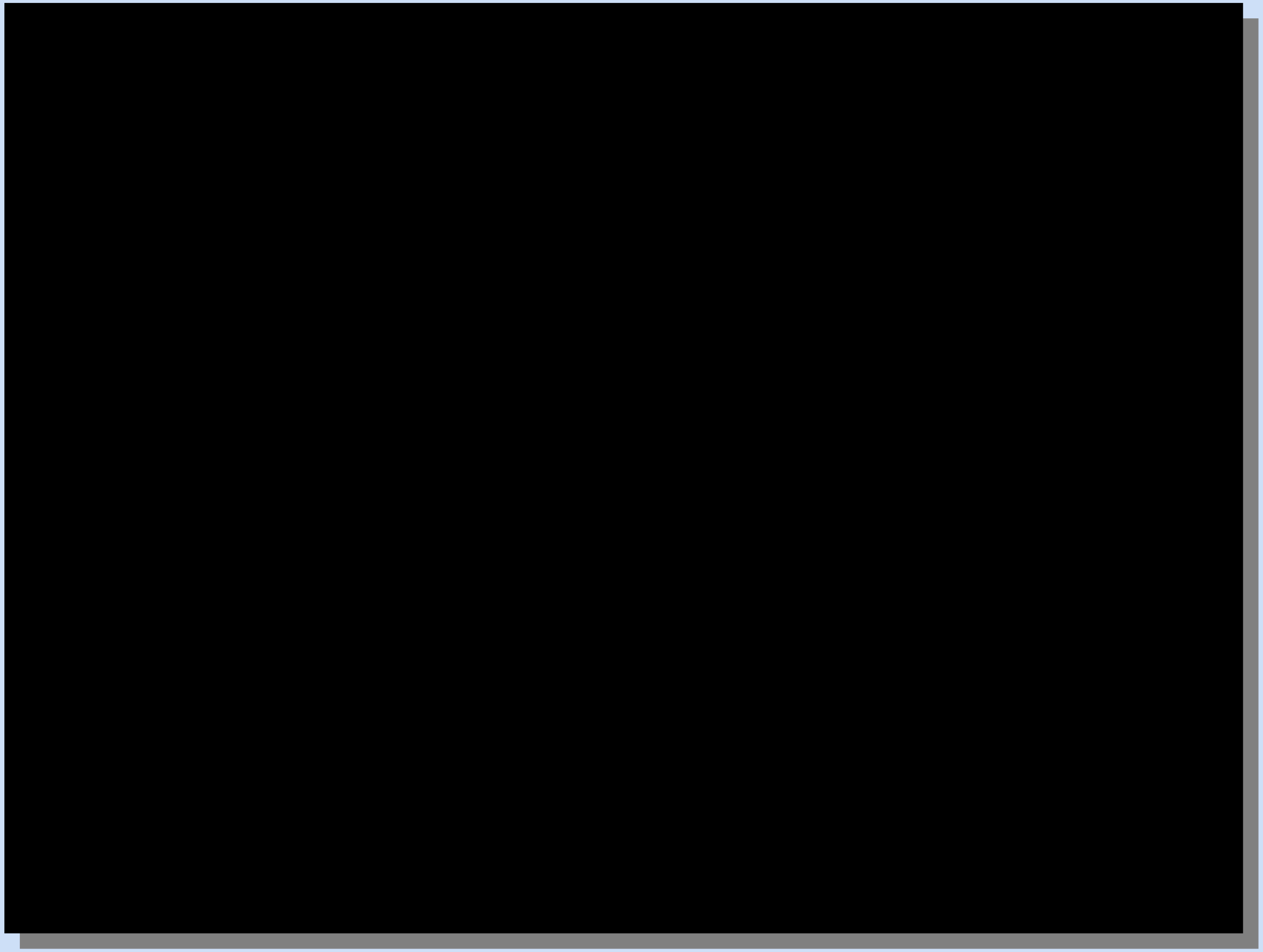
Classification of AR



Spatially Augmented Reality

Raskar, vanBaar, Beardsley, Willwacher, Rao, Forlines
'iLamps: Geometrically Aware and Self-Configurable Projectors',
SIGGRAPH 2003

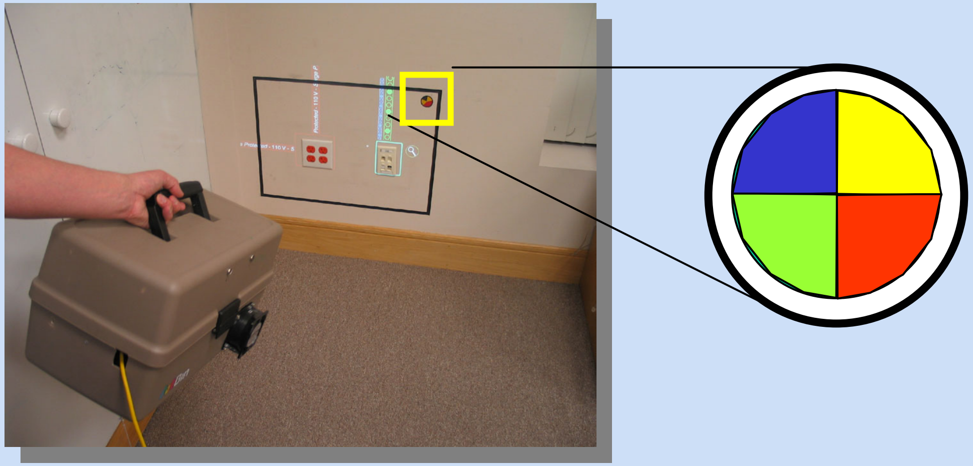
Prototype Handheld Projector



Non-trivial Projection Screens

- Painting with Light
  - [Bandyopadhyay, Raskar, Fuchs 2001]

AR Issues

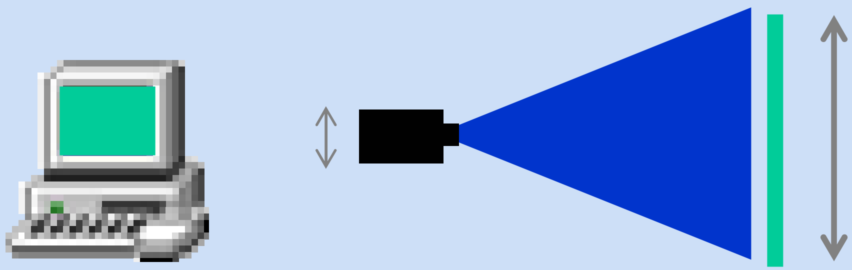


- Preprocessing:
  - Authoring
- Runtime:
  - **Identification:** Recognition of objects
    - Using markers and visual tags
  - **Registration:** Finding relative pose of display device
    - Dynamic estimate of translation and rotation
    - Render/Warp images
  - **Interaction:**
    - Widgets, Gesture recognition, Visual feedback

Advantages of Projectors

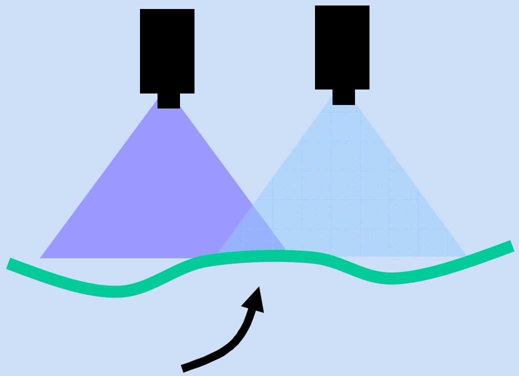
– Size of image

Image can be larger than device



– Combination of images

Images can be superimposed and added



– Shape of display surface

Displayed images may be non-planar

Disadvantages

- Projector limitations
  - Limited depth of field
  - Shadows
  - Affected by display surface reflectance
- Challenges
  - Calibration required
  - Rendering involves complex relationships

Advantages of Spatial Augmentation (SAR)

- Augmentation of objects not view
- Wide area, High resolution

Comparison

- Body-Worn Displays
  - Better ergonomics
  - Reduced tracking requirements
- Hand-held Displays
  - Avoids ‘last foot’ problem

Visually Rich Mediums

- Objects with Shape and Appearance
  - Not just CG
  - Statues and sculptures
  - Architectural tabletop models
  - Miniature sets for movies
  - Clay prototypes (cars)

Real + Virtual

- Real
  - Intuitive interface
  - Walk to move, zoom
- Virtual
  - Easy shape and color manipulation
  - Extreme views, undo

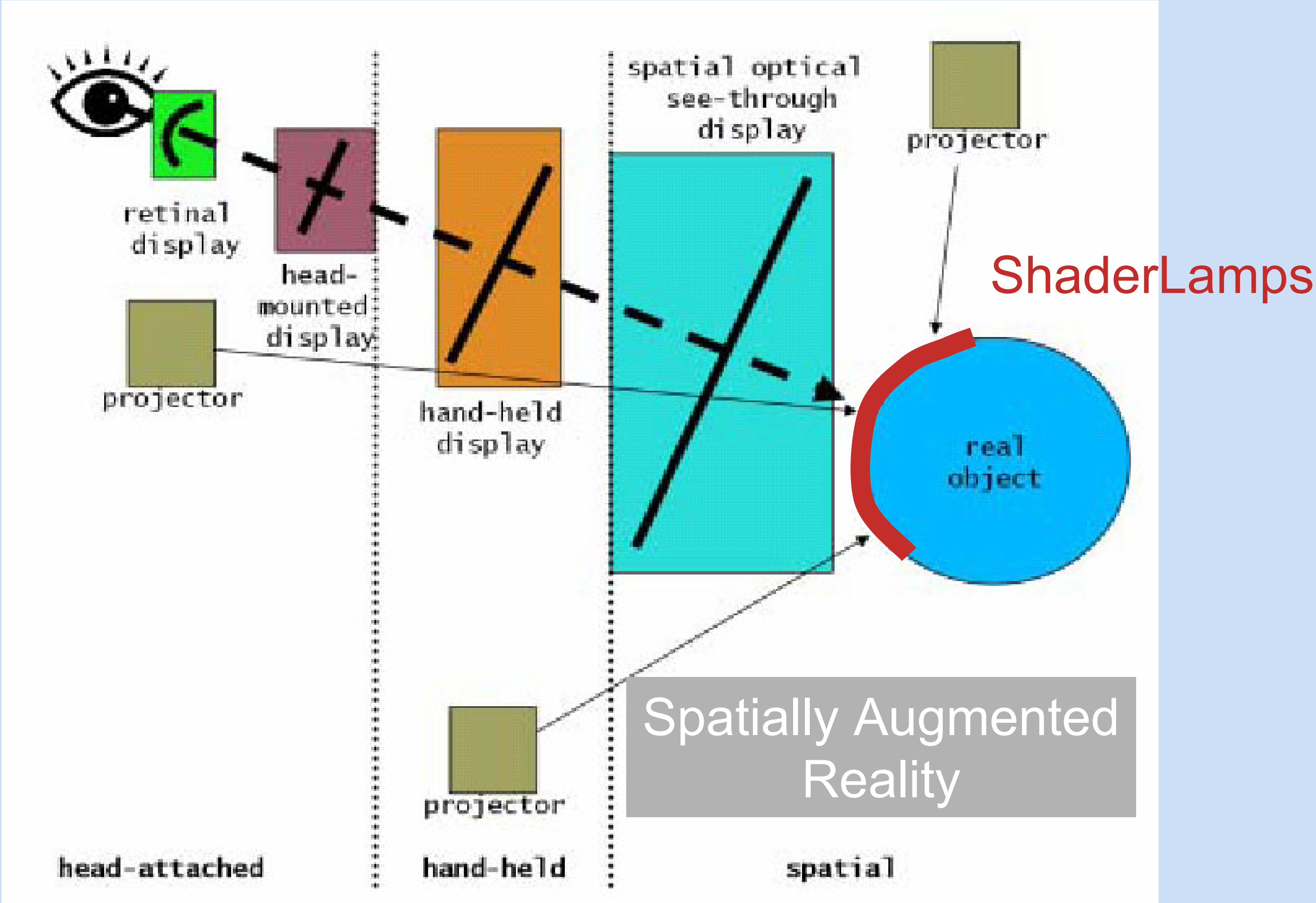
Real + Virtual

- Fidelity params
  - View (framerate, FOV, focus, stereo)
  - Shape (accuracy)
  - Color (spatial resolution, reflectance fidelity)
- Spatially Augmented Reality
  - Maintain high view fidelity
  - Approximate shape
  - Controlled reduction in color

Projector-based AR
Outline

- Concepts and Hardware Prototypes
  - Spatially Augmented Reality
  - Shader Lamps
- Rendering Techniques for non-trivial projection
  - Calibration
  - Changing Surface Appearance
  - Merging Overlapping Projection
  - Moving Objects
  - Shape Adaptive Projection

Classification of AR

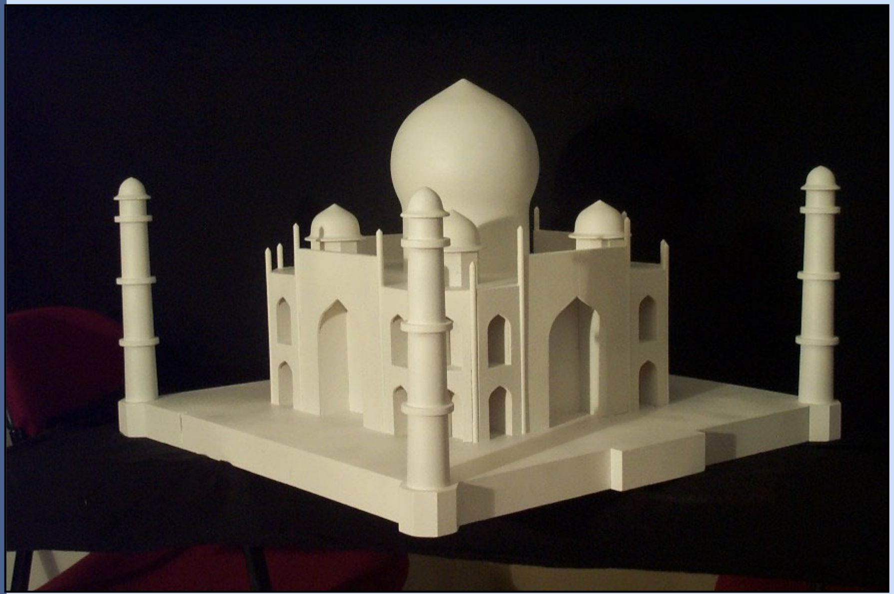
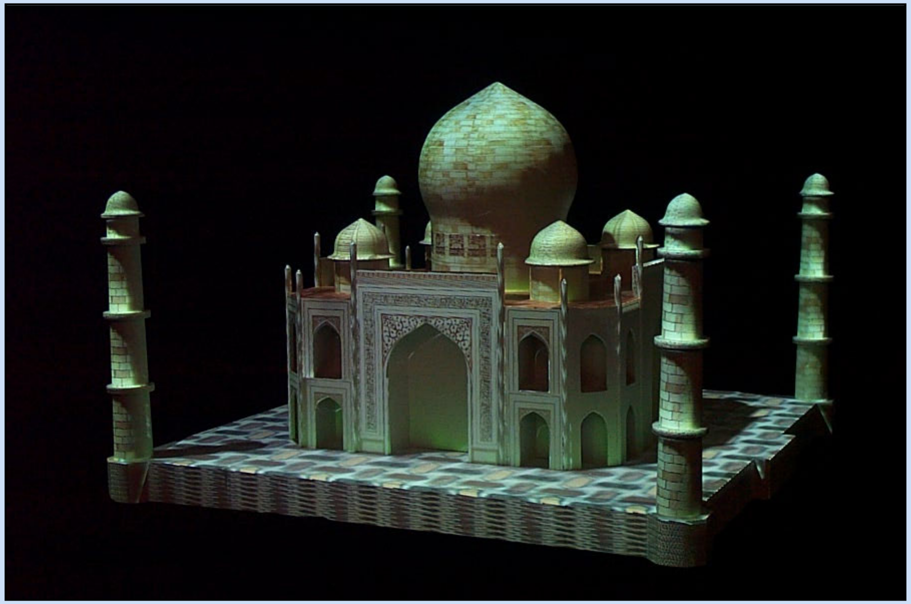


Shader Lamps
Motivation

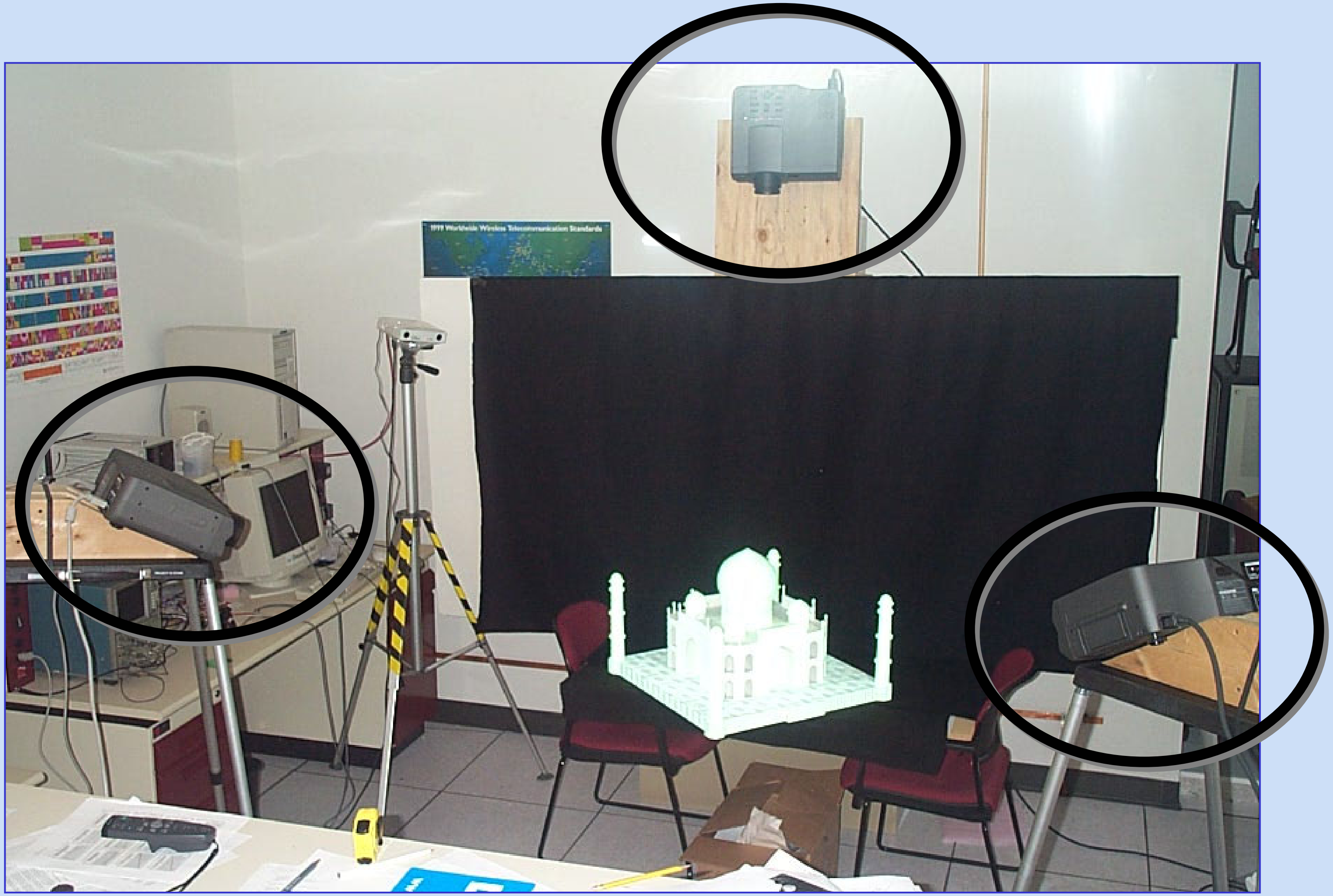
View-dependent Appearance

Shader Lamps
Image based Illumination

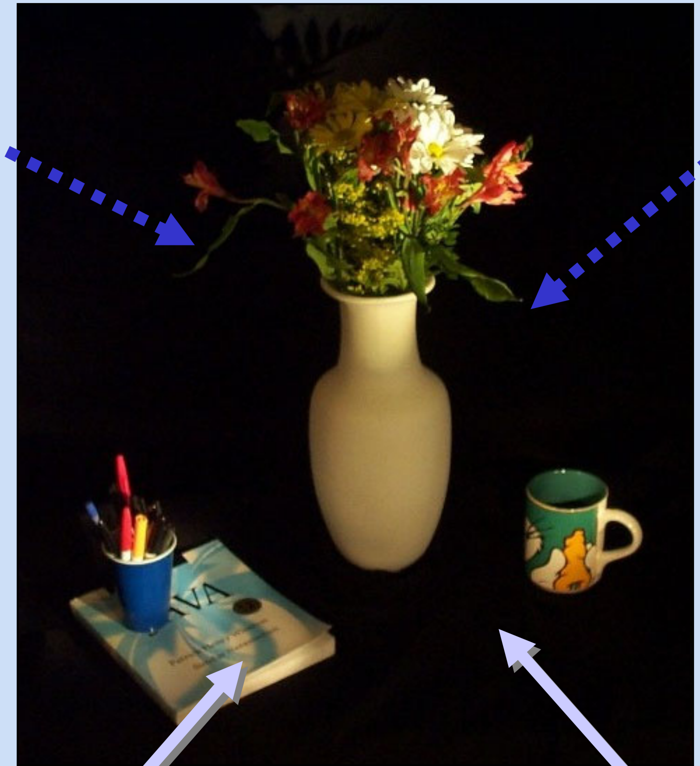
- Basic Idea
  - Render images and project on objects
  - Multiple projectors
  - View and object dependent color

Raskar, Welch, Low, Bandyopadhyay, "Shader Lamps: Animating Real Objects with Image Based Illumination," Eurographics Rendering Worksop (EGRW 2001)



Changing Appearance



Virtual light source

Projector

Projector

Applications

Indoors, under controlled lighting

- Architectural models
  - Augment walk-around scaled model of buildings
  - Project and ‘paint’ surface colors, textures
  - Lighting, sunlight, seasons
  - Internal structure, pipes, wiring
- Assembly line
  - Instructional text, images and procedures
- Entertainment
  - Live shows, exhibits, demonstrations

Examples

- Son et Lumiere

Projecting slide of augmented photo

Examples

- Disney's Haunted Mansion

  Pre-recorded video

Singing busts

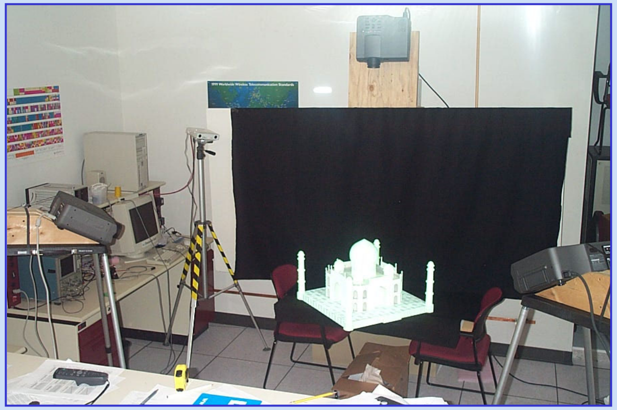
Madame Leota

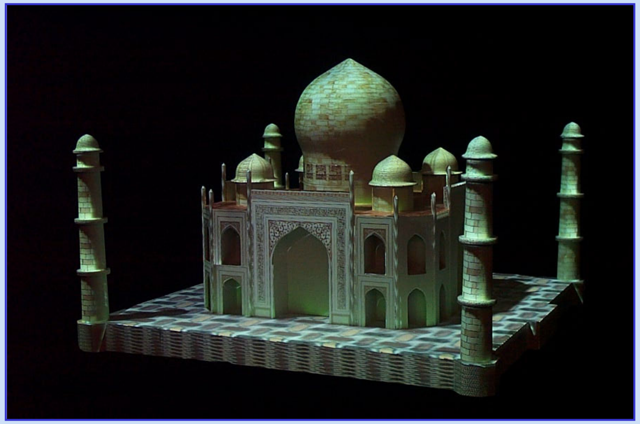
- Old
  - Large, rigid installations
  - A 2D image or video projection
  - Single projector
  - Texture

- New
  - Easy setup, Non-trivial objects
  - Real time 3D animation
  - Multiple projectors
  - BRDF

Challenges

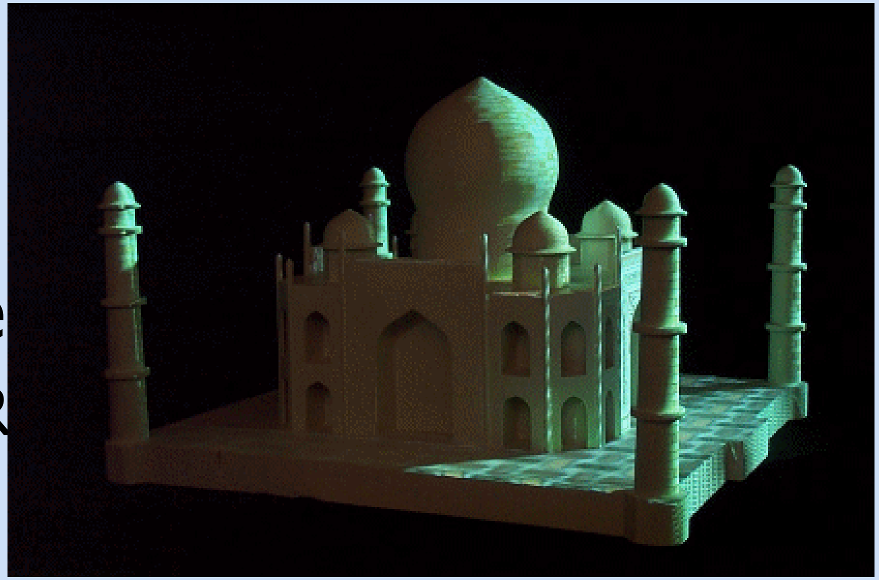
- Complete illumination
  - Image alignment
  - Special effects
    - Changing appearance and lighting
  - Complex geometry, self-occlusions
  - Merging multiple projectors





Comments ? Questions ?

Projector-based AR
Outline



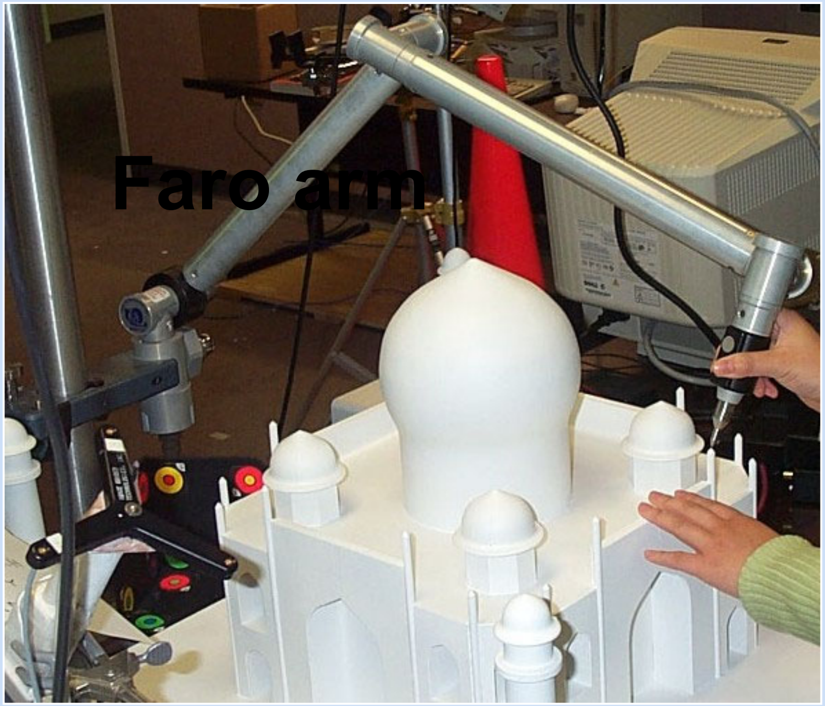
- Concepts and Hardware
  - Spatially Augmented R
  - Shader Lamps
- Rendering Techniques for non-trivial projection
  - Calibration
  - Changing Surface Appearance
  - Merging Overlapping Projection
  - Moving Objects
  - Shape Adaptive Projection

Steps

- Preprocessing
  - Scan 3D object and create model
  - Approximately position projector(s)
  - Compute pose, ***P***
    - Find features
    - Find pixels that illuminate them
  - Compute intensity correction
- Run time
  - Render images of 3D model
  - Intensity correction for object shape
  - Feathering for projector overlap

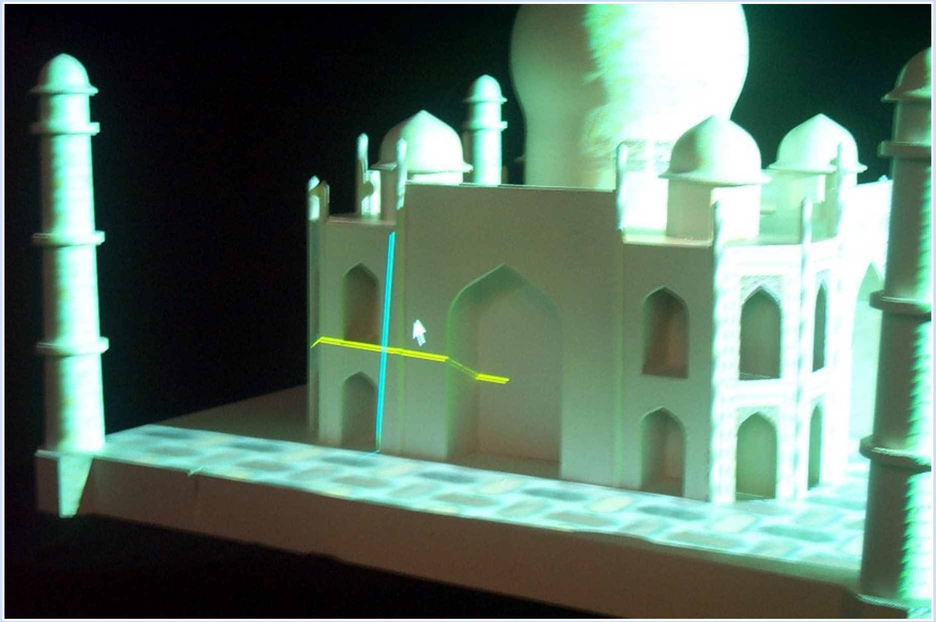
Steps

– Preprocessing
  - Scan 3D object and create virtual model, ***G***



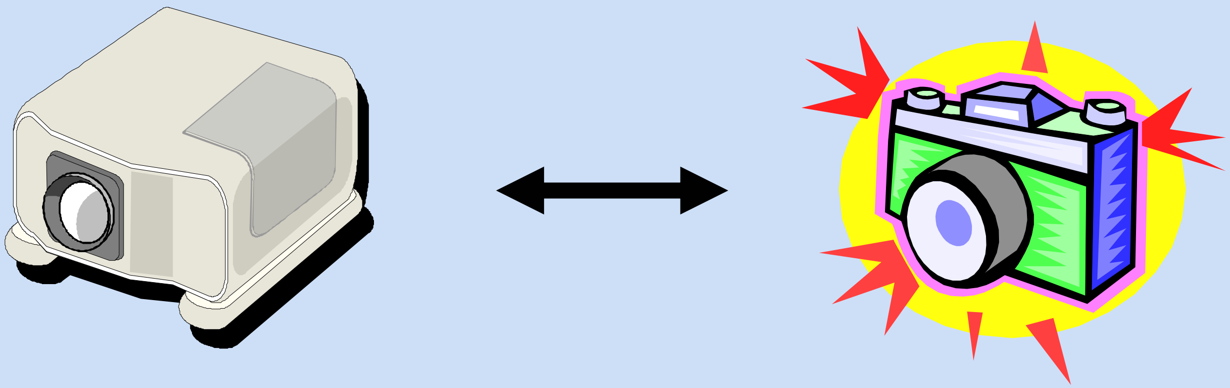
Steps

- Preprocessing
  - Scan 3D object and create model, ***G***
  - Approximately position projector(s)
  - Find pose, ***P***



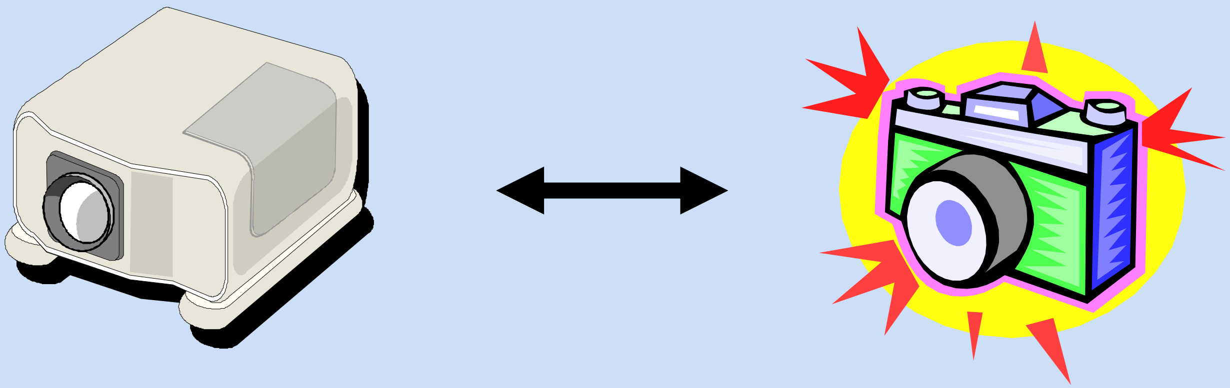
Motivation

- Projector - a 3D projection device
  - Projector is a dual of a camera
  - Relates 3D space and image in framebuffer
  - A useful abstraction : geometric projection model



Projector Model

- Pin hole model
  - Equations for perspective projection
  - Relationship between 3D and 2D
  - Intrinsic and Extrinsic Parameters



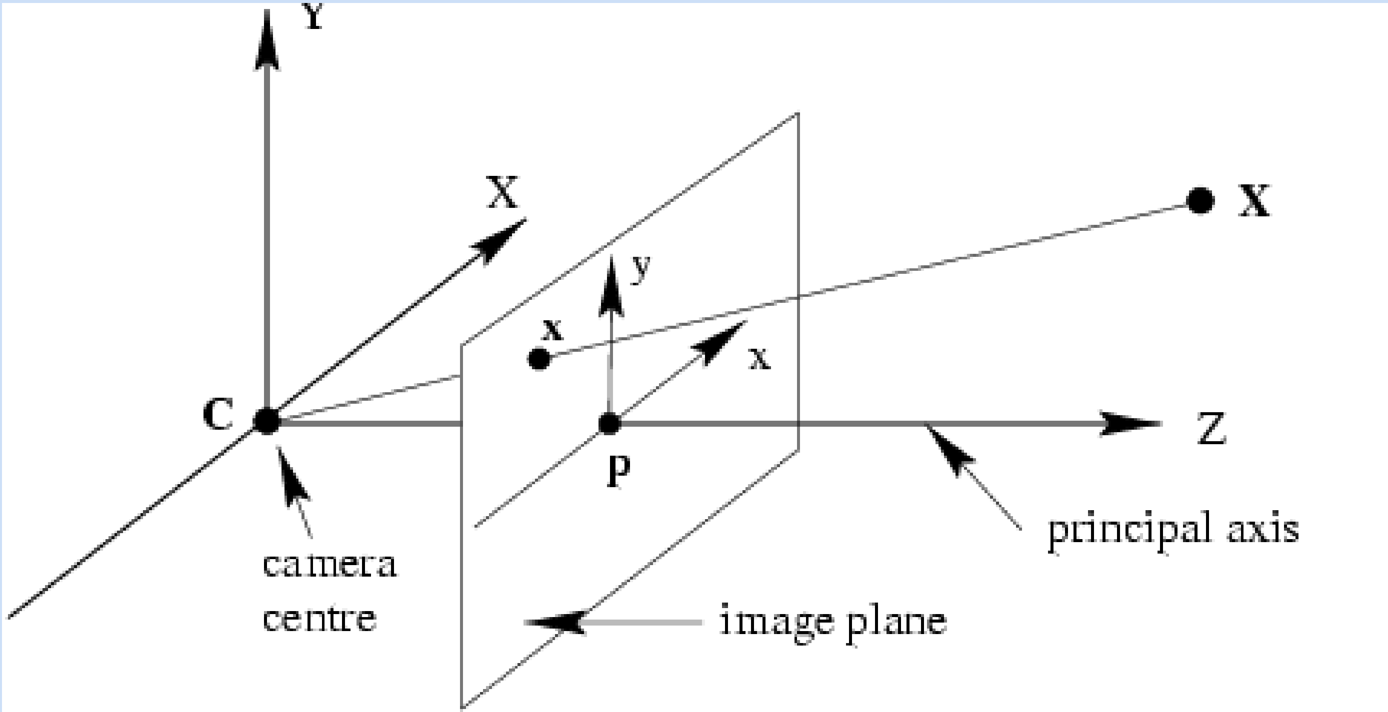
Camera (and Projector) anatomy

Camera center

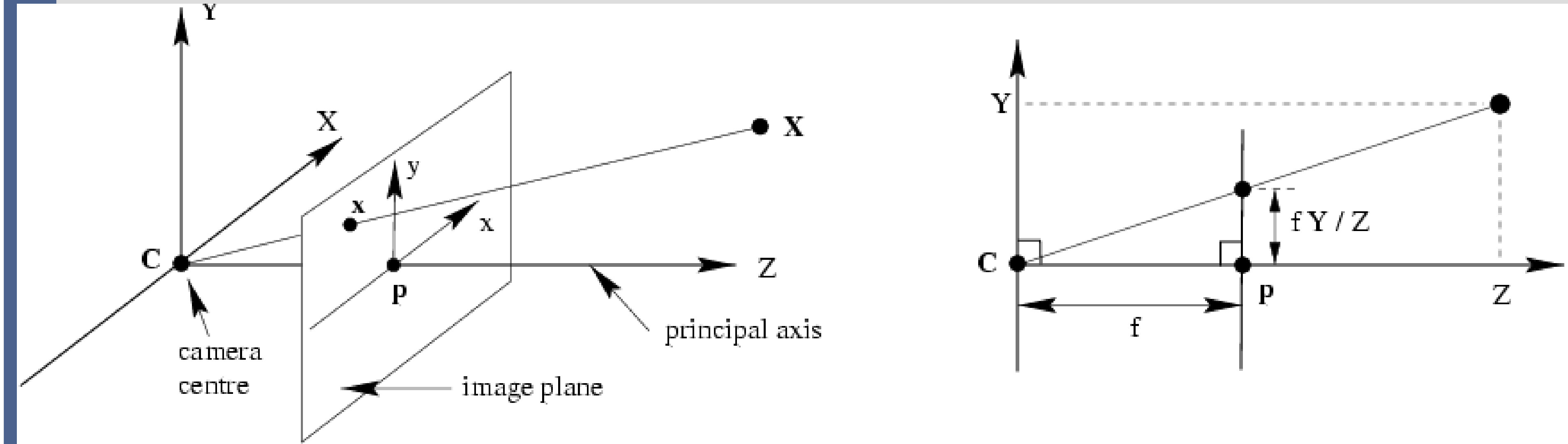
Image plane

Principal point

Principal axis



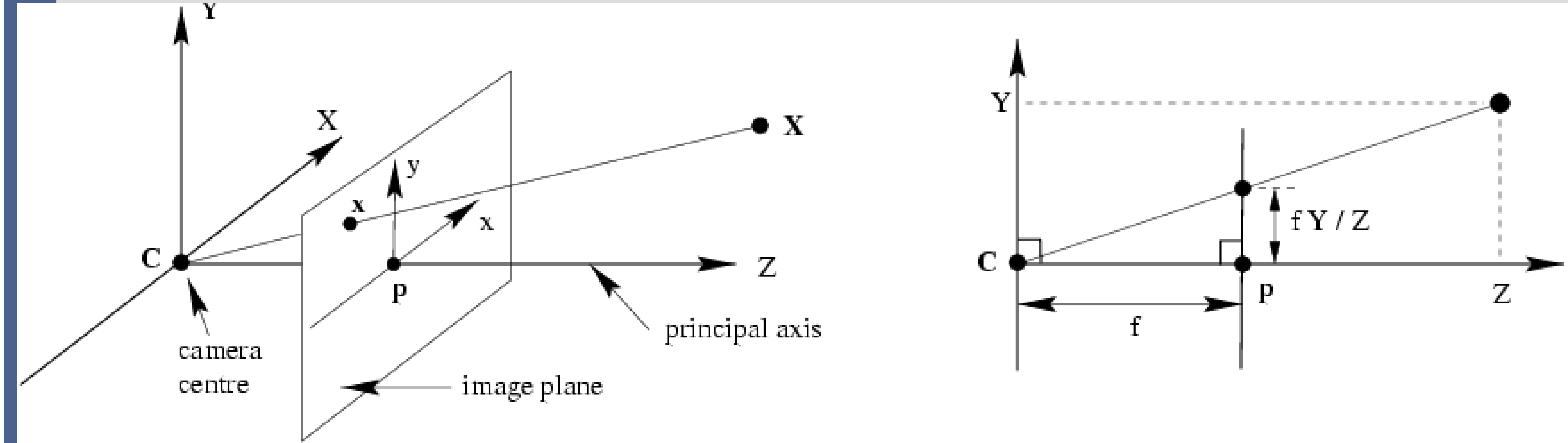
Pinhole camera (or Projector) model



$$y = f\,\frac{Y}{Z}$$

$$\begin{bmatrix} fY \\ Z \end{bmatrix} = \begin{bmatrix} f & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} Y \\ Z \end{bmatrix} \Rightarrow \begin{bmatrix} y \\ 1 \end{bmatrix} = \begin{bmatrix} fY \\ Z \end{bmatrix}$$

Pinhole camera (or Projector) model



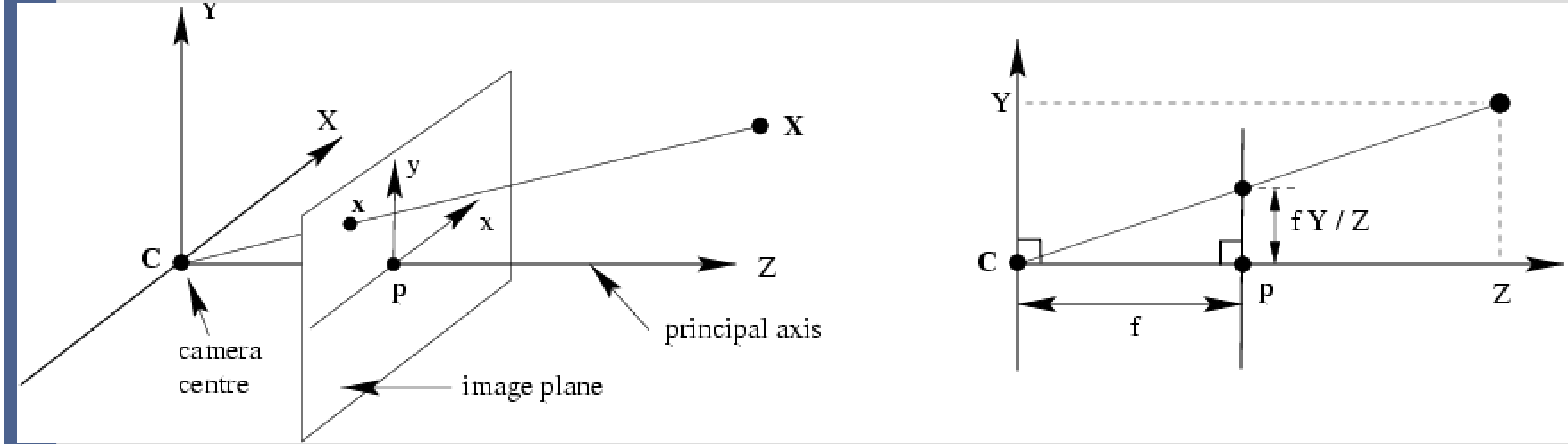
$$y = f\,\frac{Y}{Z}$$

$$\begin{bmatrix} fY \\ Z \end{bmatrix} = \begin{bmatrix} f & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} Y \\ Z \end{bmatrix}$$

$$\begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} f & & & 0 \\ & f & & 0 \\ & & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

$$P = \mathrm{diag}(f, f, 1)[I \mid 0]$$

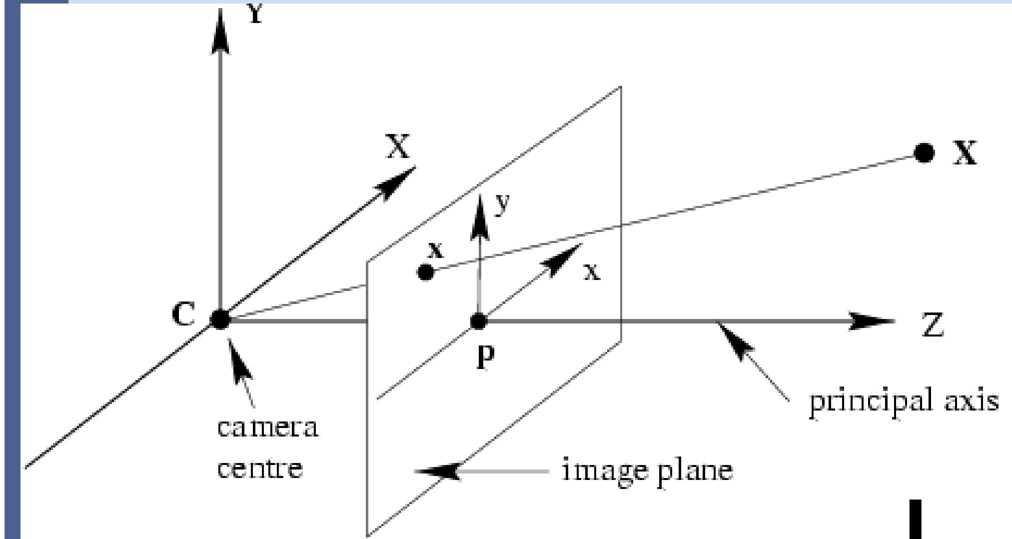
Pinhole camera (or Projector) model

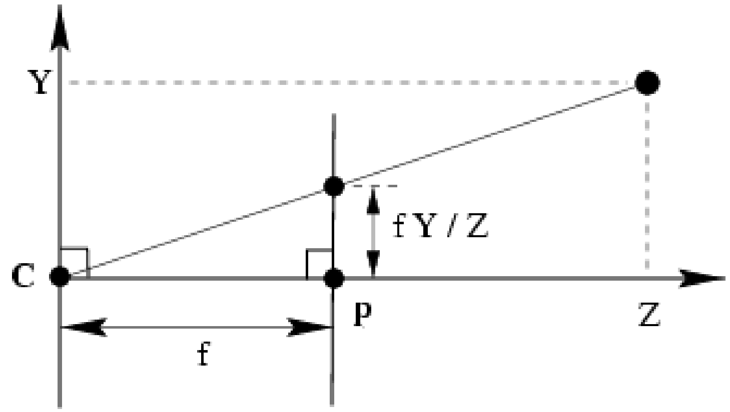


$$\begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} f & & & 0 \\ & f & & 0 \\ & & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

$$\mathrm{x} \cong \mathrm{PX}$$

Pinhole camera (or Projector) model





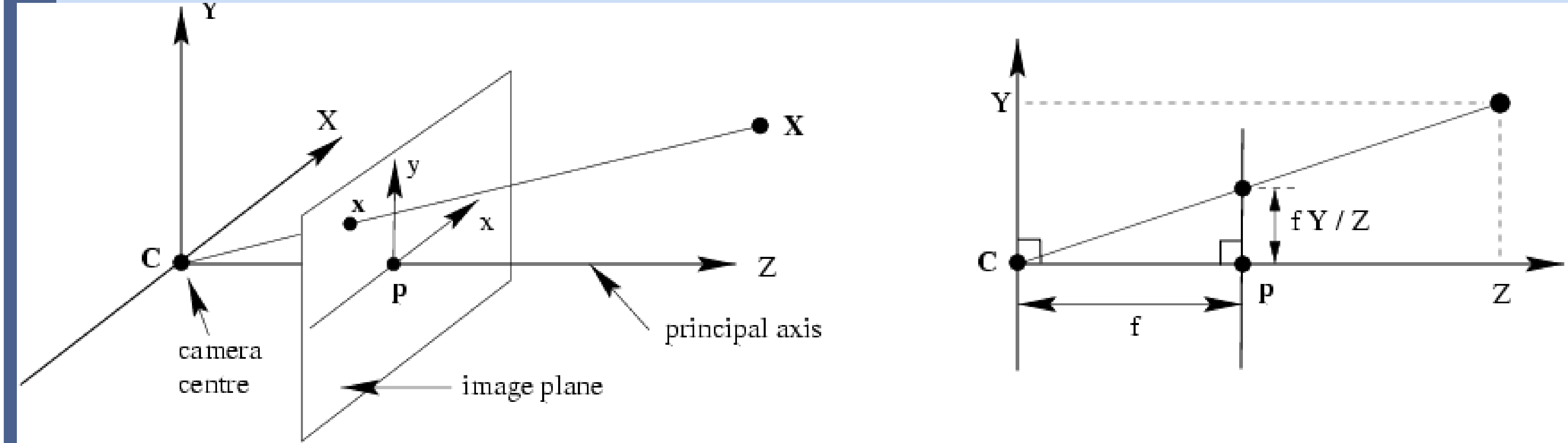
$$\begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} f & & & 0 \\ & f & & 0 \\ & & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

Vision

$$\begin{pmatrix} wx \\ wy \\ wz \\ w \end{pmatrix} = \begin{bmatrix} f & \cdot & \cdot & \cdot \\ \cdot & f & \cdot & \cdot \\ \cdot & \cdot & \cdot & 1 \\ \cdot & \cdot & 1 & \cdot \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

Graphics

Pinhole camera (or Projector) model



$$\begin{pmatrix} wx \\ wy \\ wz \\ w \end{pmatrix} = \begin{bmatrix} f & \cdot & \cdot & \cdot \\ \cdot & f & \cdot & \cdot \\ \cdot & \cdot & \cdot & 1 \\ \cdot & \cdot & 1 & \cdot \end{bmatrix} \begin{bmatrix} R_{11} & R_{12} & R_{13} & t_x \\ R_{21} & R_{22} & R_{23} & t_y \\ R_{31} & R_{32} & R_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

Mapping 3D to 2D

Vision		Graphics
$x = PX$		$x = PX$
$P = \begin{bmatrix} K & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix}$		$P = \text{ViewPort} * \text{ProjectionMatrix} * \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix}$
Internal Matrix	=	[ViewportMatrix * ProjectionMatrix]
External Matrix	=	ModelviewMatrix

Comments ? Questions ?

Projector parameter estimation method

- Calibration assistance tools
  - Calibration rigs and objects
  - Printed patterns
  - Blank walls and planes !

Steps

- Preprocessing
  - Scan 3D object and create model
  - Approximately position projector(s)
  - Compute pose, ***P***
    - Find fiducials
    - Find pixels that illuminate them
  - Compute intensity correction
- Run time
  - Render images of 3D model using matrix ***P***
  - Intensity correction for object shape
  - Feathering for projector overlap

Projector-based AR
Outline

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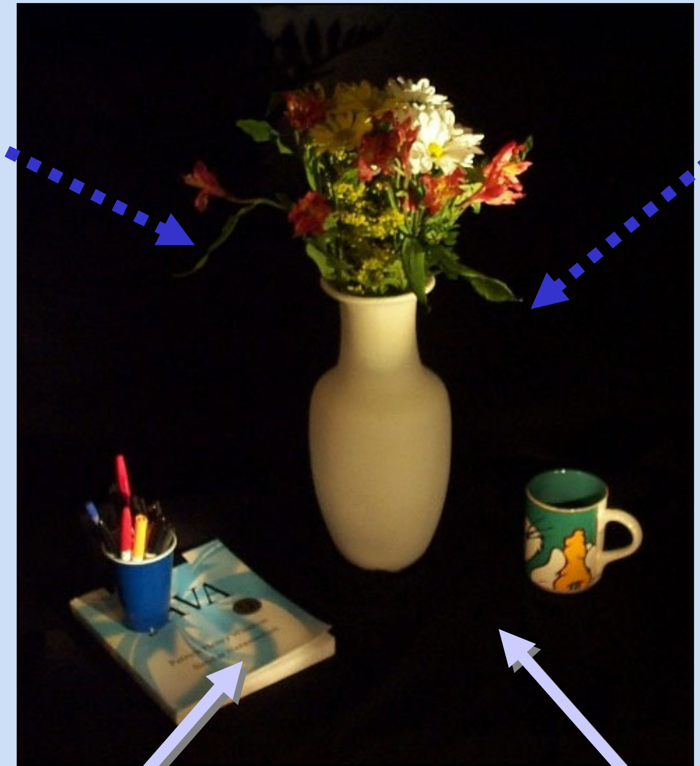
Changing Appearance



Virtual light source

Projector

Projector

Steps

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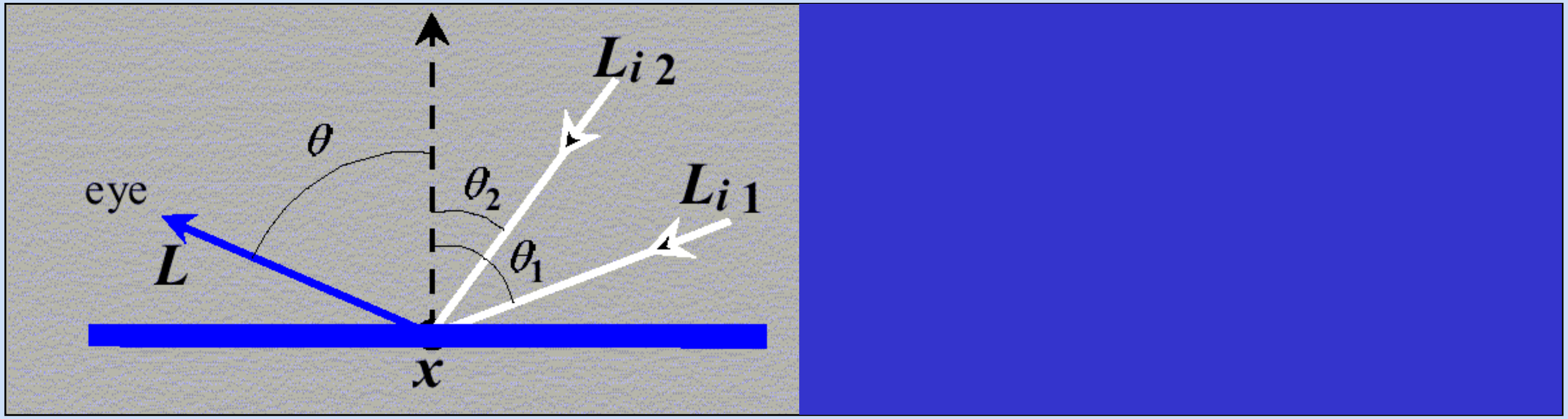
Radiance Adjustment



Virtual

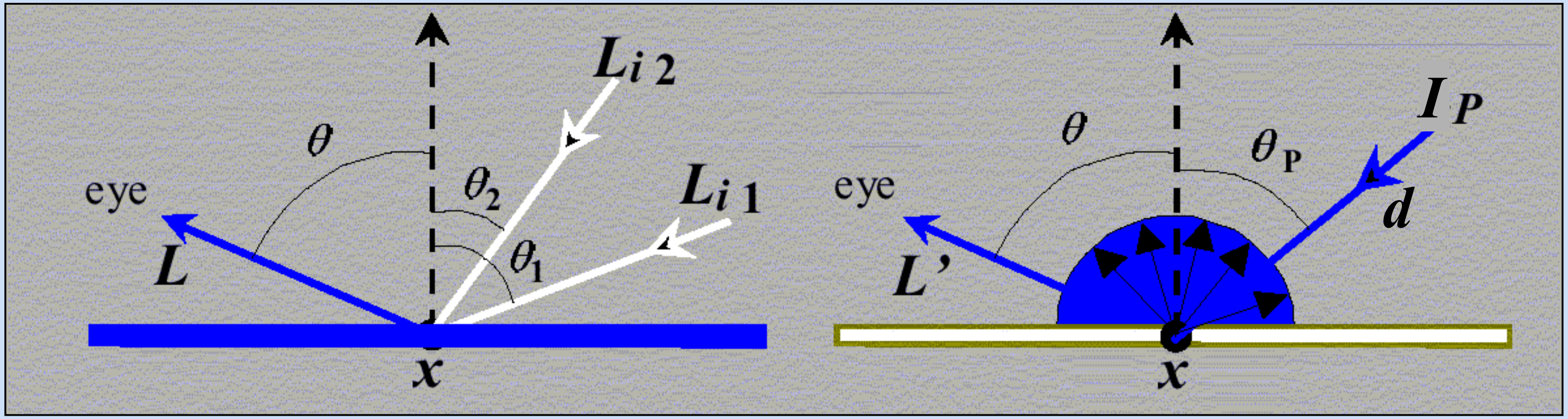
$$L(x,\theta) = \int F(x,\ \theta,\ \theta_i)\ L_i\,(x,\ \theta_i)\ d\omega_i$$

Desired radiance

BRDF

Incident radiance

Radiance Adjustment



Virtual

Real

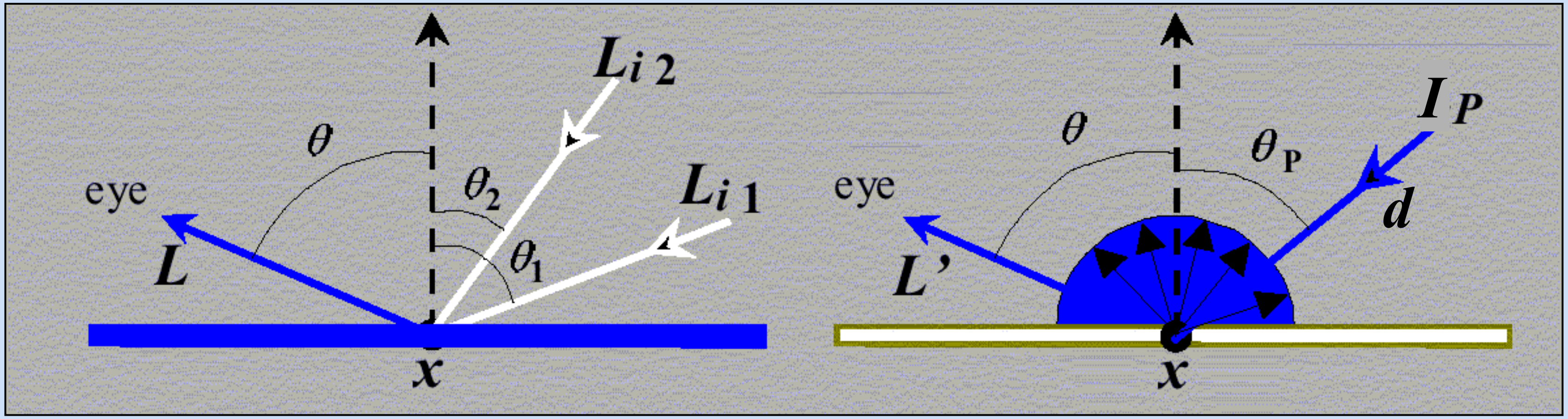
$$L(x,\theta) = \int F(x, \theta, \theta_i) L_i (x, \theta_i) d\omega_i$$

$$L'(x,\theta) = \frac{k(x) \cos(\theta_p)}{d(x)^2} I_p (x, \theta_p)$$

Resultant radiance

Pixel intensity

Radiance Adjustment



Virtual

Real

$$I_p(x, \theta_p) = \frac{d(x)^2}{k(x)\ \cos(\theta_p)} L(x, \theta) \quad , \quad k(x) > 0$$

Pixel intensity

Intensity correction

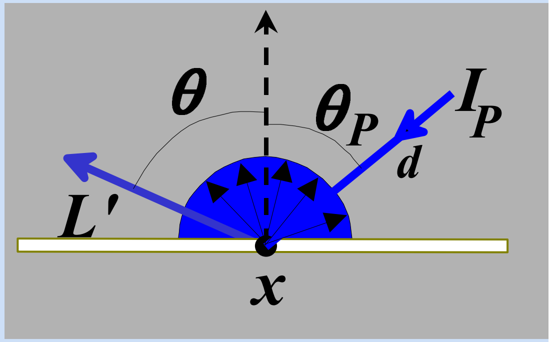
Desired radiance

Reflectance

Intensity Correction

Per-pixel factor Rendered Image

$$I_p(x, \theta_p) = \frac{d(x)^2}{k(x)\ \cos(\theta_p)} L(x, \theta)$$

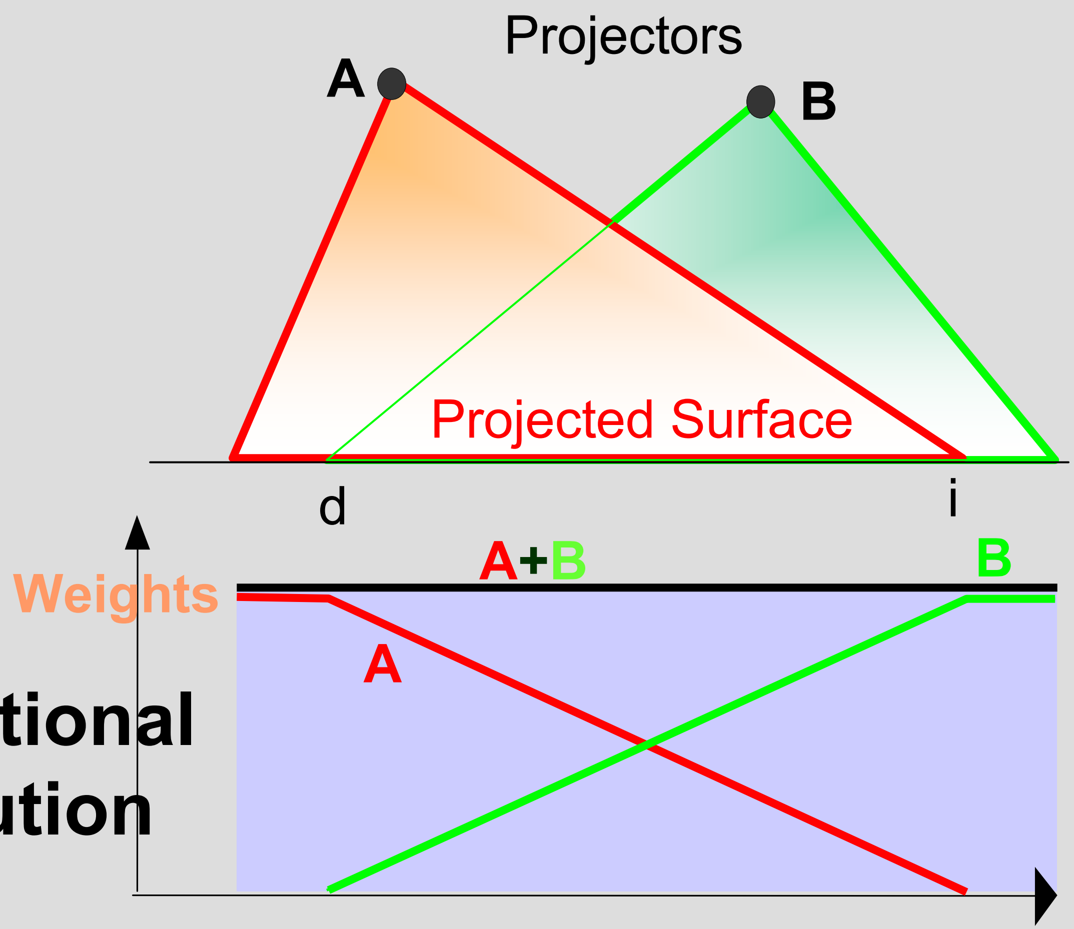


– Rendering with
  - Light at c.o.p. : $\cos(\theta_p)$
  - Diffuse reflectance : k
  - Distance attenuation : $1/d(x)^2$
  - $\theta_p > 60^0$ cut off

Projector-based AR
Outline

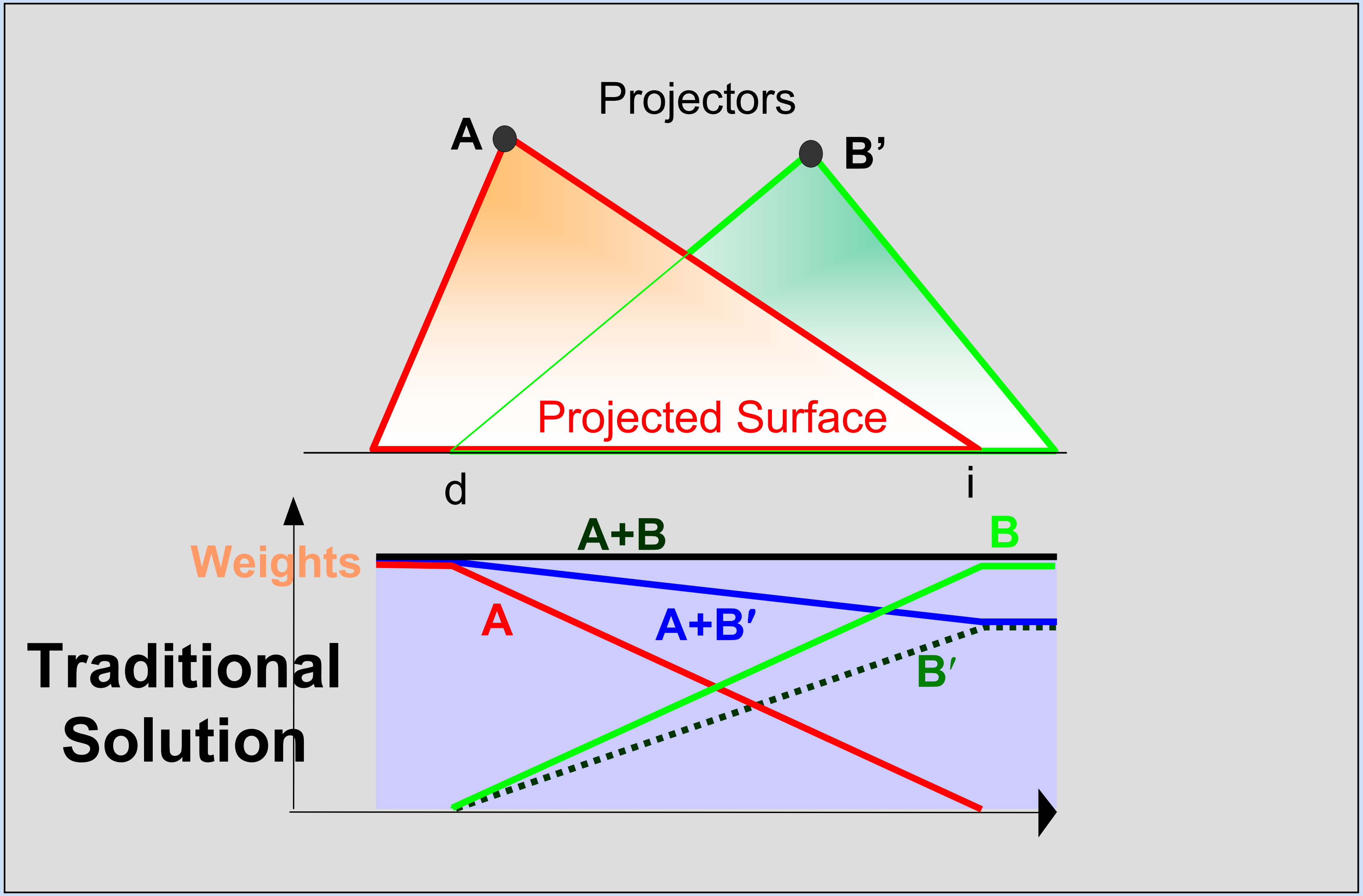
- Concepts and Hardware Prototypes
  - Spatially Augmented Reality
  - Shader Lamps
- Rendering Techniques for non-trivial projection
  - Calibration
  - Changing Surface Appearance
  - Merging Overlapping Projection
  - Moving Objects
  - Shape Adaptive Projection

Feathering in Overlap

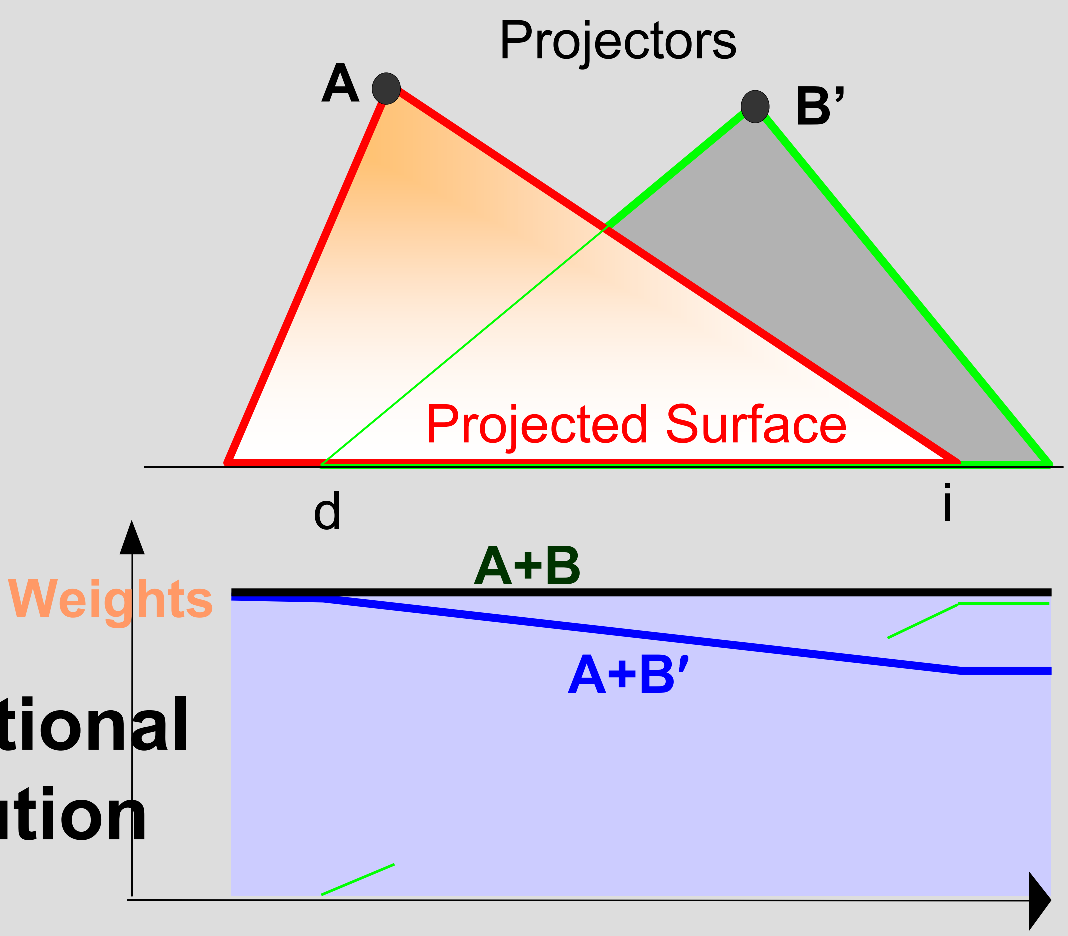


Traditional Solution

Feathering

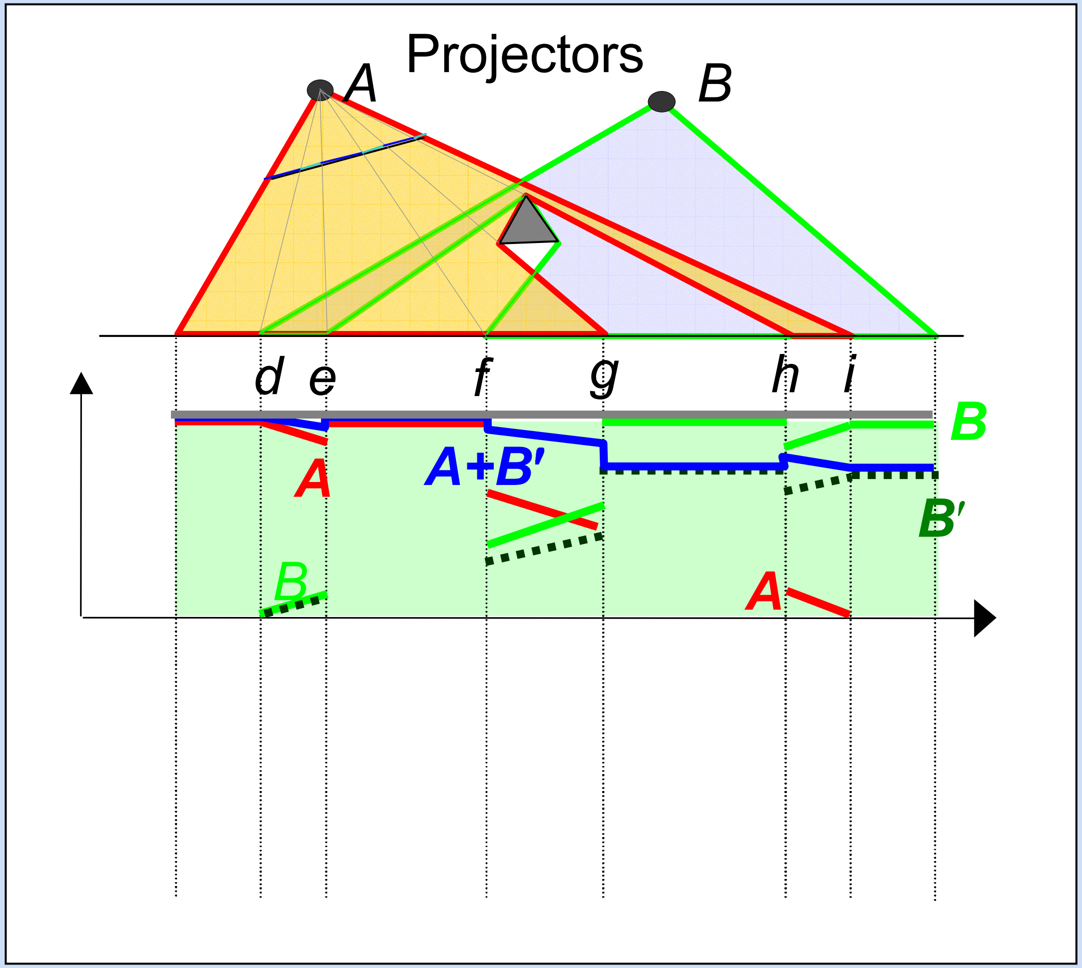

Projectors
A
B'
Projected Surface
d
i
Weights
A+B
B
A
A+B′
B′
Traditional Solution

Feathering

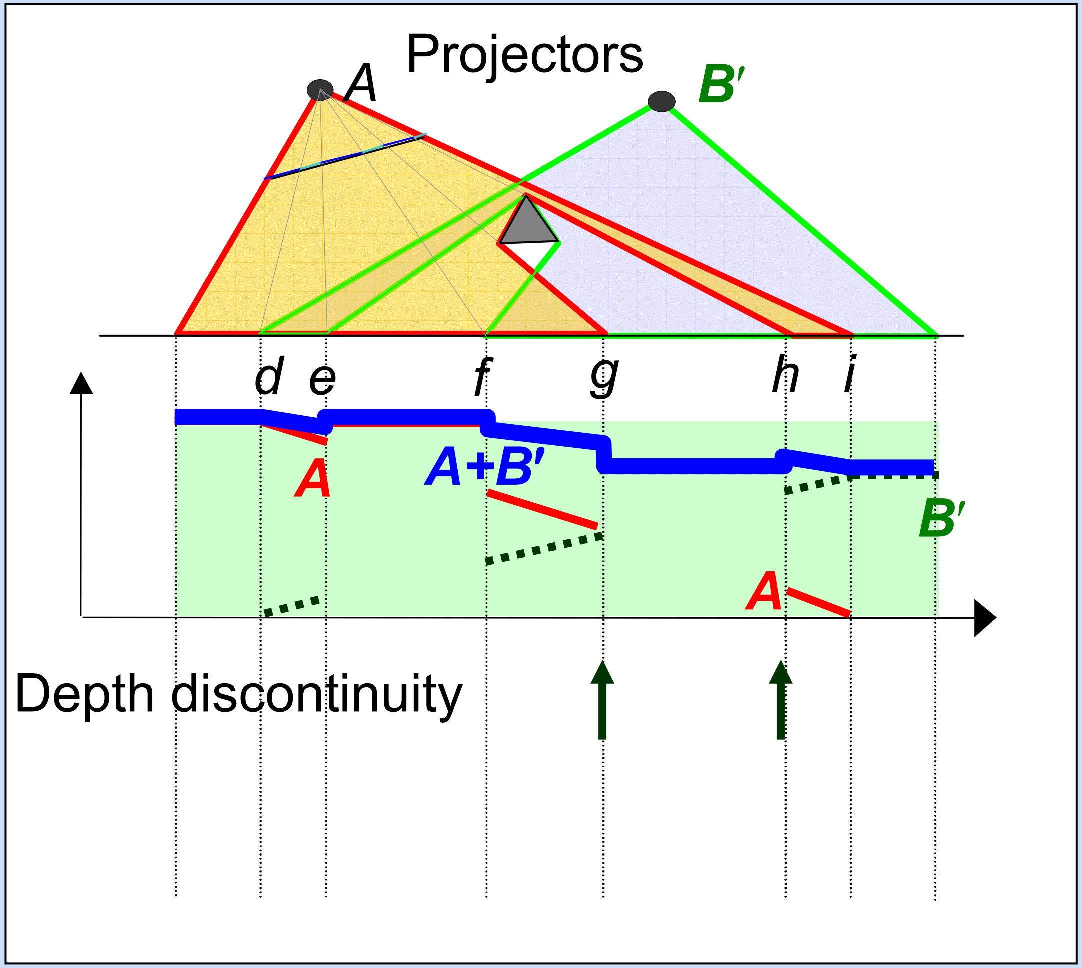


Traditional Solution

Occlusions



Occlusion Problems



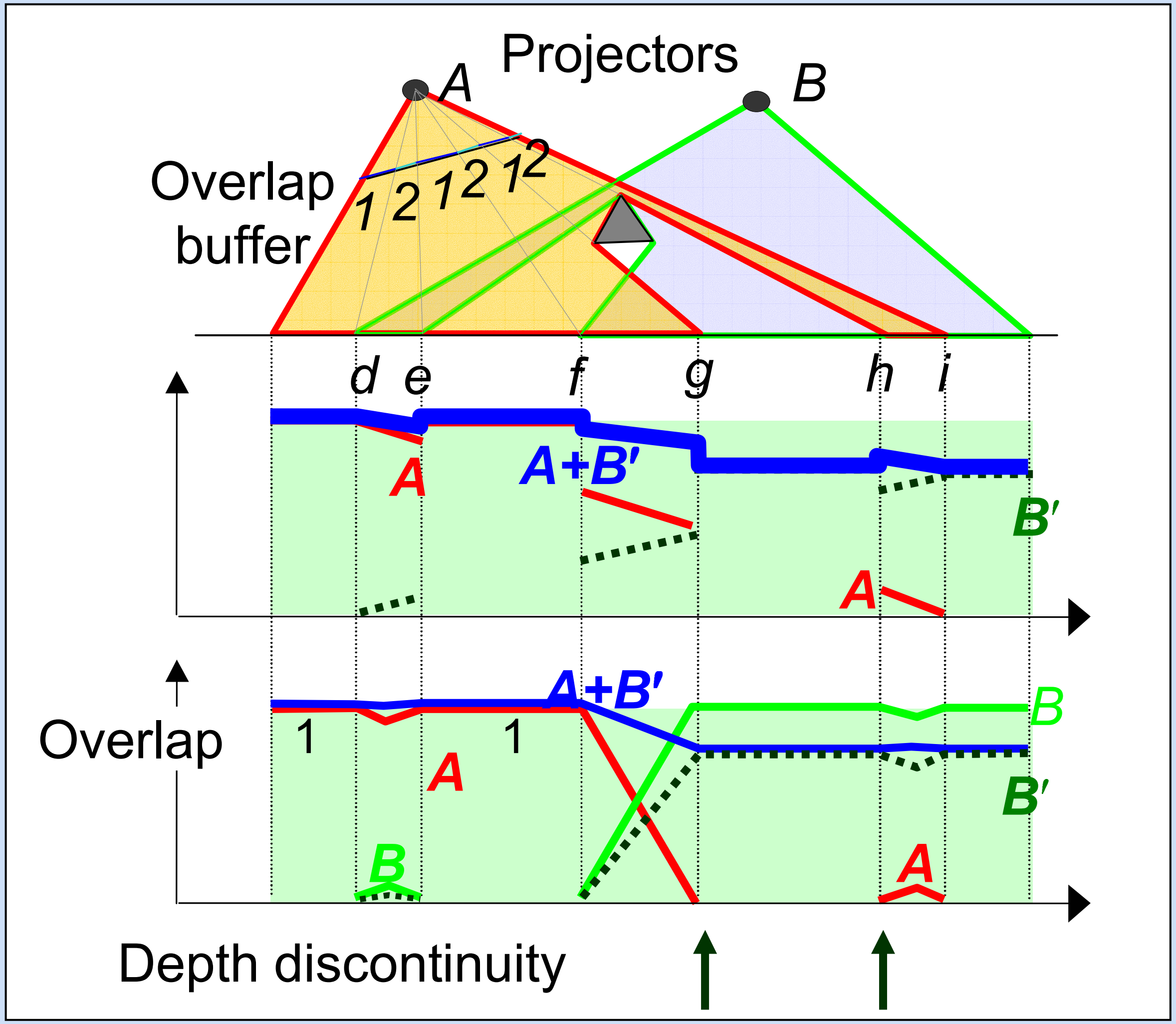
Occlusions and Shadows

- Dealing with depth discontinuity
- Goal
  - Sum of weights = 1
  - Weights along surface are smooth
  - Weights in image are smooth

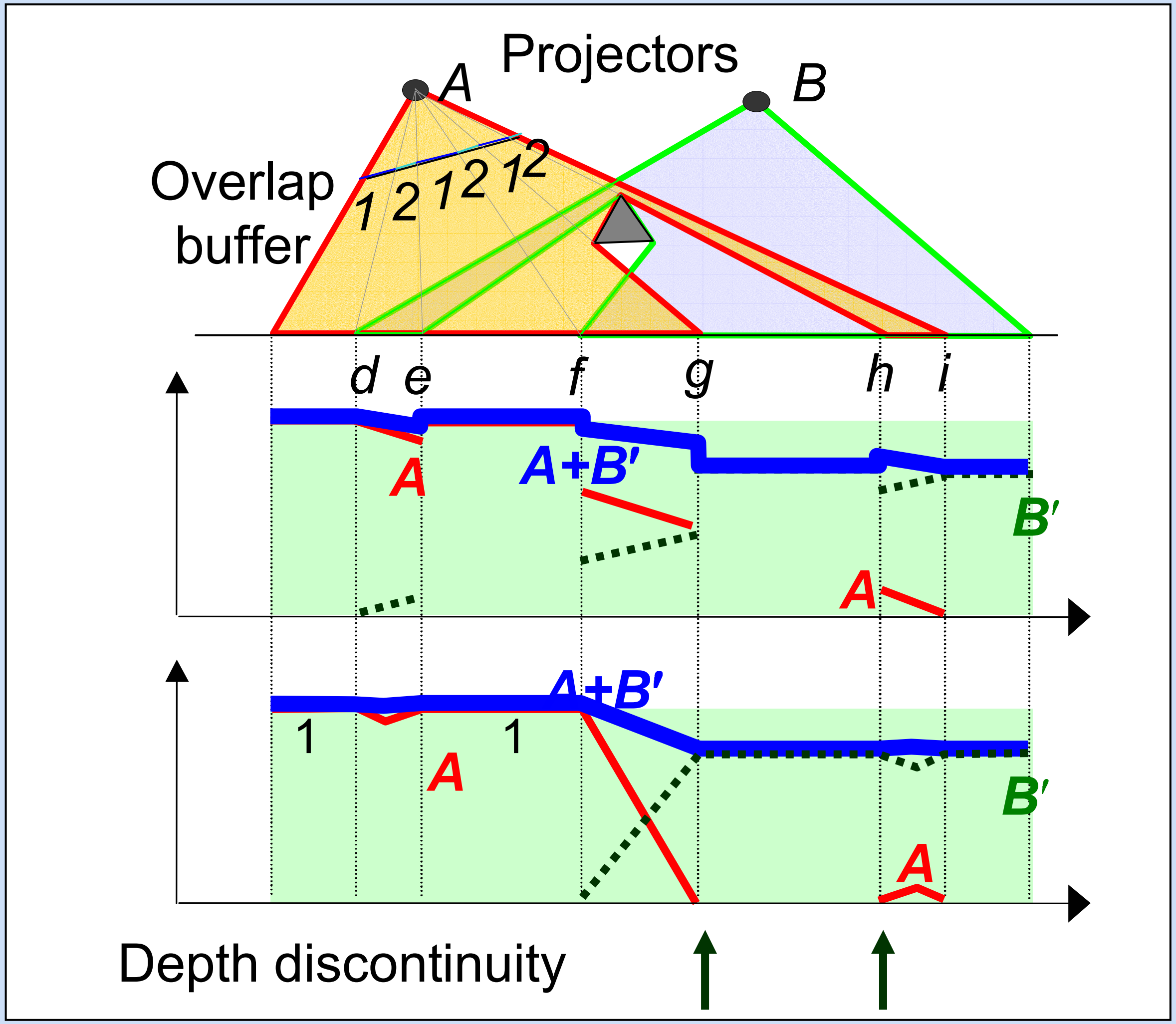
Feathering Algorithm

- Each Projector Image Space
  - Compute overlap count (0,1,2..)
  - Find depth discontinuity
  - For overlap region
    - Compute shortest distance to overlap = 1
    - Ignore paths crossing discontinuity
  - Weights = 1/(shortest distance)
- Normalize weights for corresponding pixels

New Feathering

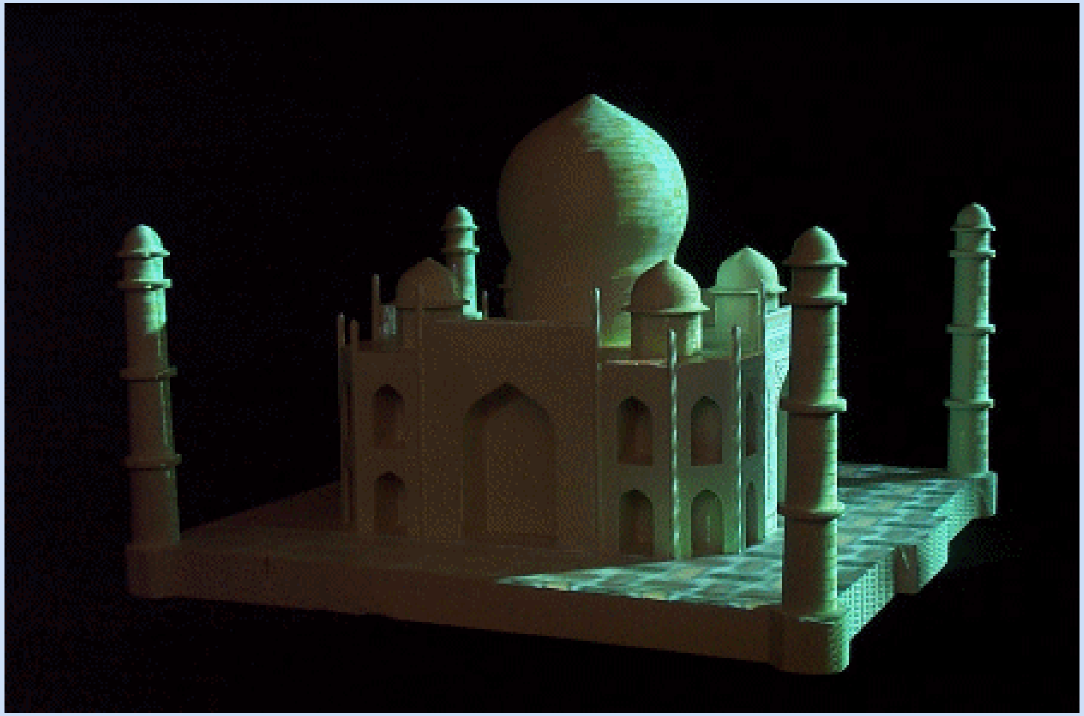


New Feathering



Virtual Illumination

Shadows, Shading and Blending



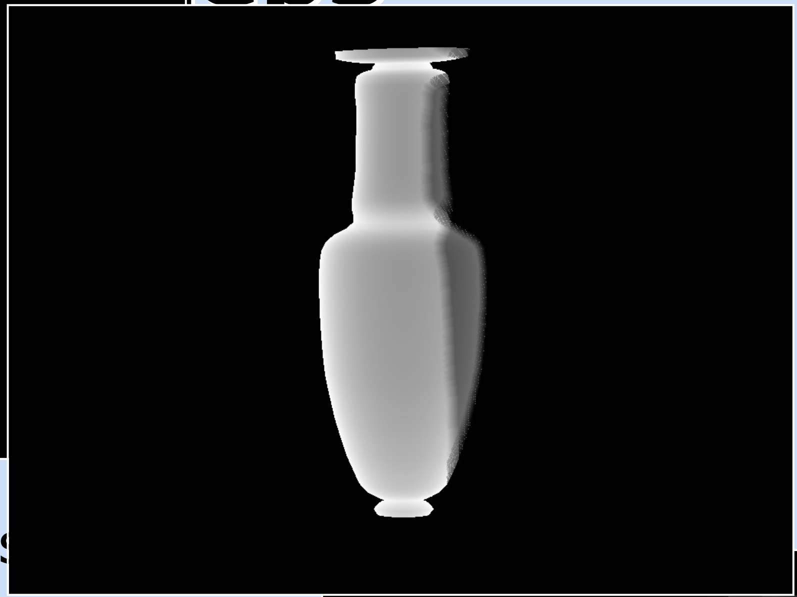
Steps

- Preprocessing
  - Scan 3D object and create model, ***G***
  - Approximately position projector(s)
  - Compute pose, ***P***
  - Compute intensity correction, ***α***
- Run time
  - Render image [***I***] using model ***G*** from pose ***P***

eps

- Compute intensi
- Run time
  - Render image [***I***]
  - Apply intensity correction for object shape [***α***]*[***I***]
  - Apply feathering for projector overlap, [***β***]*[***α***] *[***I***]

eps



- Compute pose
- Compute intens

– Run time

- Render image [$\boldsymbol{I}$]
- Intensity correction, [$\boldsymbol{\alpha}$] *
- Feathering, [$\boldsymbol{\beta}$] * [$\boldsymbol{\alpha}$] * [

Steps

- Preprocessing
  - Scan 3D object and create model, ***G***
  - Approximately position projector(s)
  - Compute pose, ***P***
    - Find fiducials
    - Find pixels that illuminate them
    - Find projector pose
- Run time
  - Render 3D model ***G*** from ***P*** , [***I***]
  - Intensity correction for object shape [$\boldsymbol{\alpha}$] * [***I***]
  - Feathering for projector overlap [$\boldsymbol{\beta}$] * [$\boldsymbol{\alpha}$] * [***I***]

Projector-based AR
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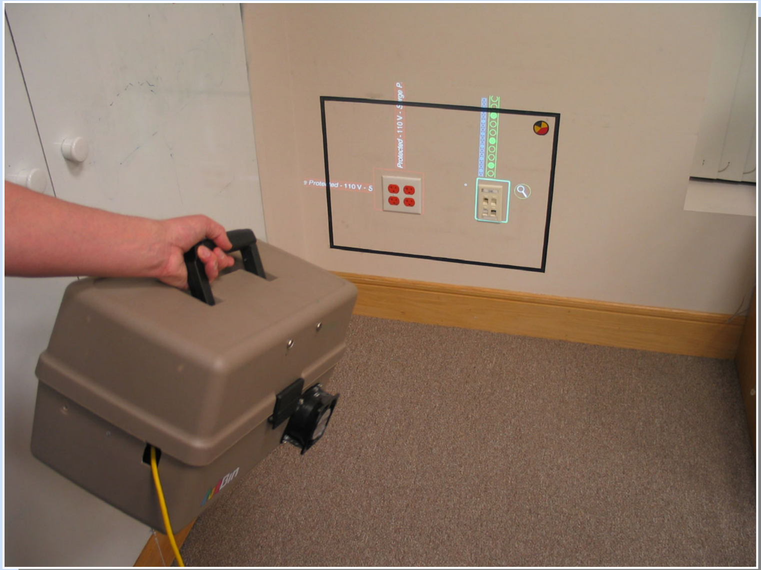
  - Merging Overlapping Projection
  - Moving Objects
  - Shape Adaptive Projection

Moving Objects

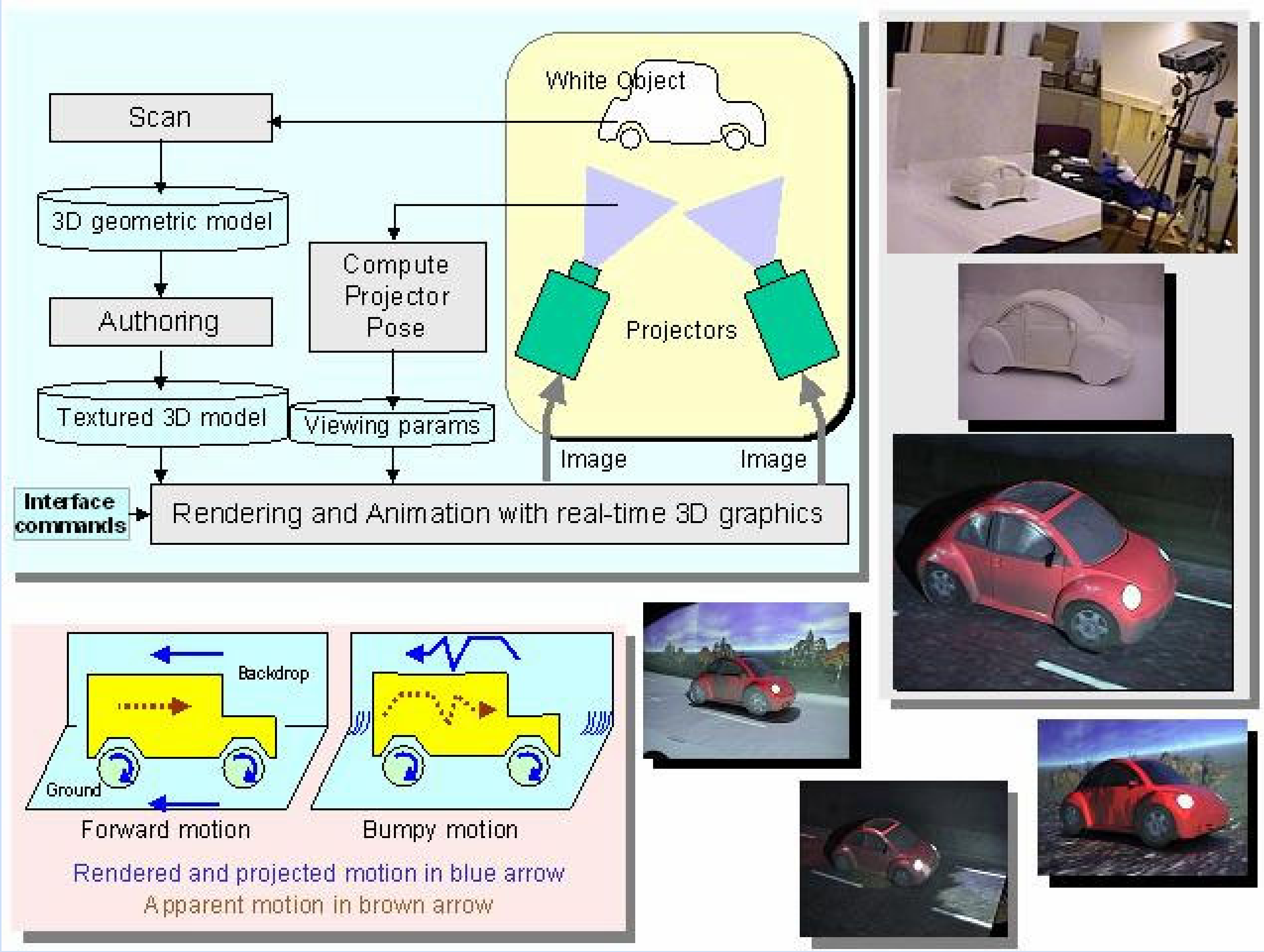


Moving Surface

Moving Projector

Moving Viewer

Apparent Motion



Ramesh Raskar, Remo Ziegler, Thomas Willwacher, “Cartoon Dioramas in Motion,” Proc. ACM Symposium on Nonphotorealistic Animation and Rendering (NPAR 2002)

Virtual Motion

Projector-based AR
Outline

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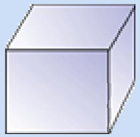
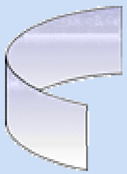
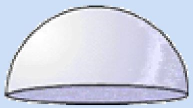
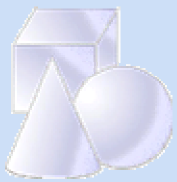
Shape Adaptive Projection

- Projection Screen Geometries
  - Planar 
  - Rectilinear 
  - Cylindrical 
  - Spherical 
  - Irregular 

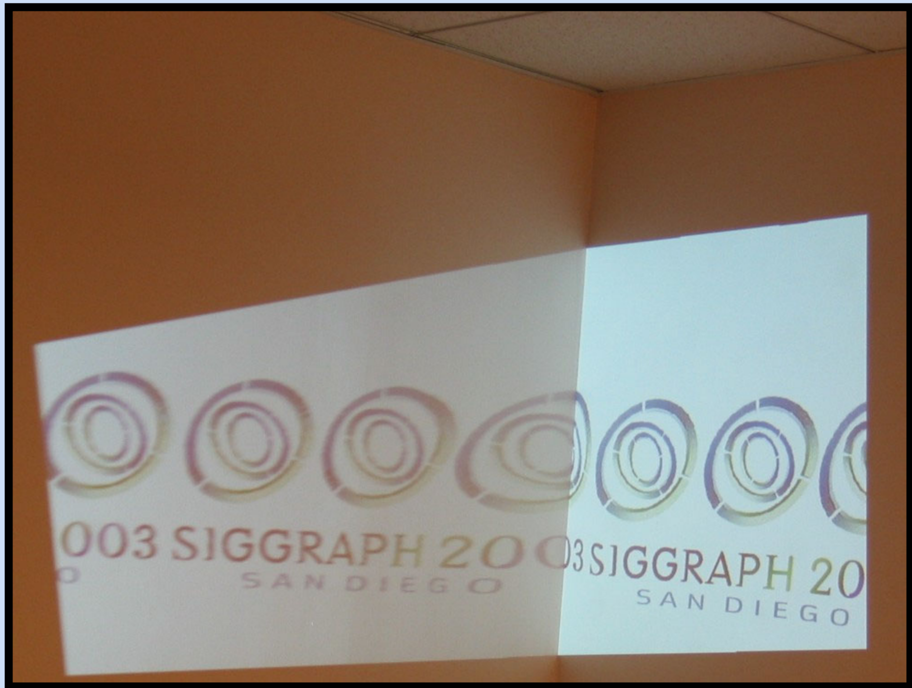
Planar Homography

Quadric image transfer

Discretized Warping

Shape Adaptive Projection

Minimum Stretch Display



'Wallpaper the surface'

Shape cue allows perceptual unwrapping

Shape Adaptive Projection

Raskar, vanBaar, Beardsley, Willwacher, Rao, Forlines
'iLamps: Geometrically Aware and Self-Configurable Projectors',
SIGGRAPH 2003

Shape Adaptive Projection

Problem : Given input image texture, pre-warp so that

(i) displayed image has minimum distortion

(ii) image vertical aligns with world vertical

Approach :

(i) conformal mapping

(ii) sense surface geometry, pose and vertical

1. Least square conformal mapping [Levy 2002]

Texture coords $u + iv$

Surface coords $x + iy$

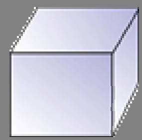
Orthogonal iso-*u* and iso-*v* contours

$$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y} \qquad \frac{\partial u}{\partial y} = -\frac{\partial v}{\partial x}$$

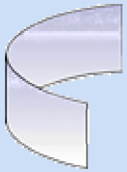
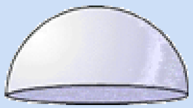
2. Align input texture vertical with world vertical

3. Render textured surface model from projector's pose

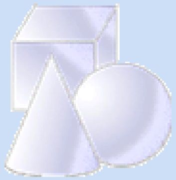
Projection Techniques

- Projection Screen Geometries
  - Planar 
  - Rectilinear 

  Planar Homography

  - Cylindrical 
  - Spherical 

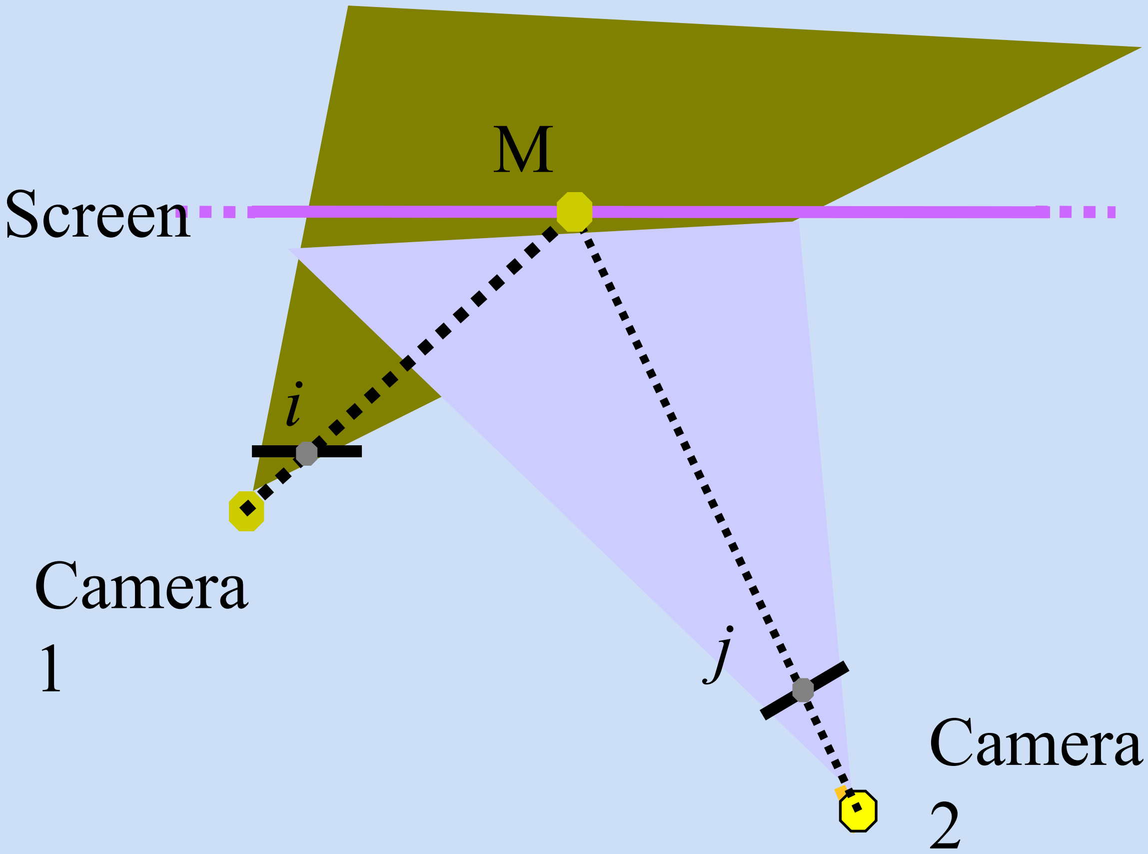
  Quadric image transfer

  - Irregular 

  Discretized Warping

Planar projective transfer
What is homography ?

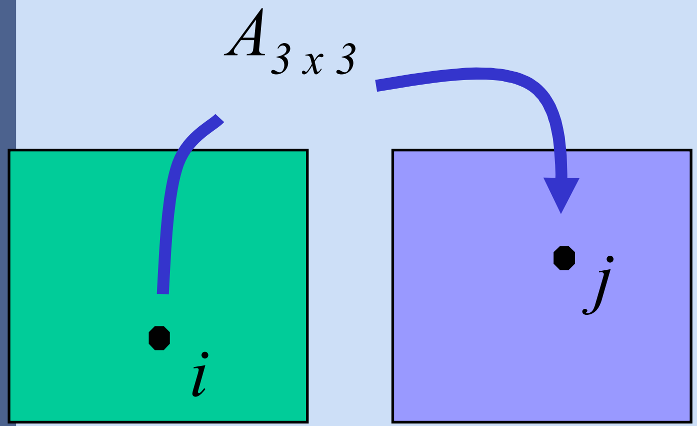
– Two images of 3D points on a plane are related by a 3x3 matrix



Planar Homography (in 2D)

Two images of 3D points on a plane

Related by a 3x3 matrix $j \cong A_{3\,x\,3}\, i$



Proj 1 Proj 2

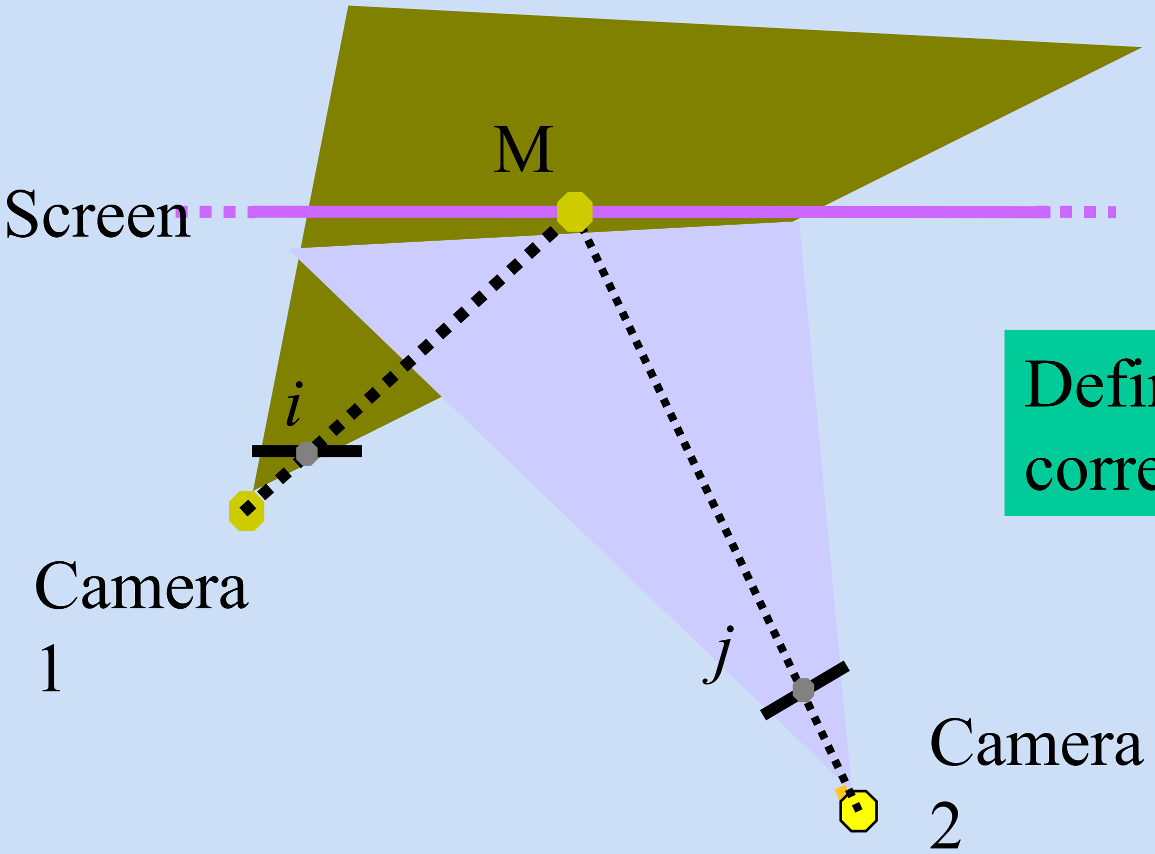
$$k \begin{bmatrix} j_x \\ j_y \\ 1 \end{bmatrix} = \begin{bmatrix} a1 & a2 & a3 \\ b1 & b2 & b3 \\ c1 & c2 & c3 \end{bmatrix} \begin{bmatrix} i_x \\ i_y \\ 1 \end{bmatrix}$$

$$j_x = (\boldsymbol{a} \cdot i) / (\boldsymbol{c} \cdot i)$$

$$j_y = (\boldsymbol{b} \cdot i) / (\boldsymbol{c} \cdot i)$$

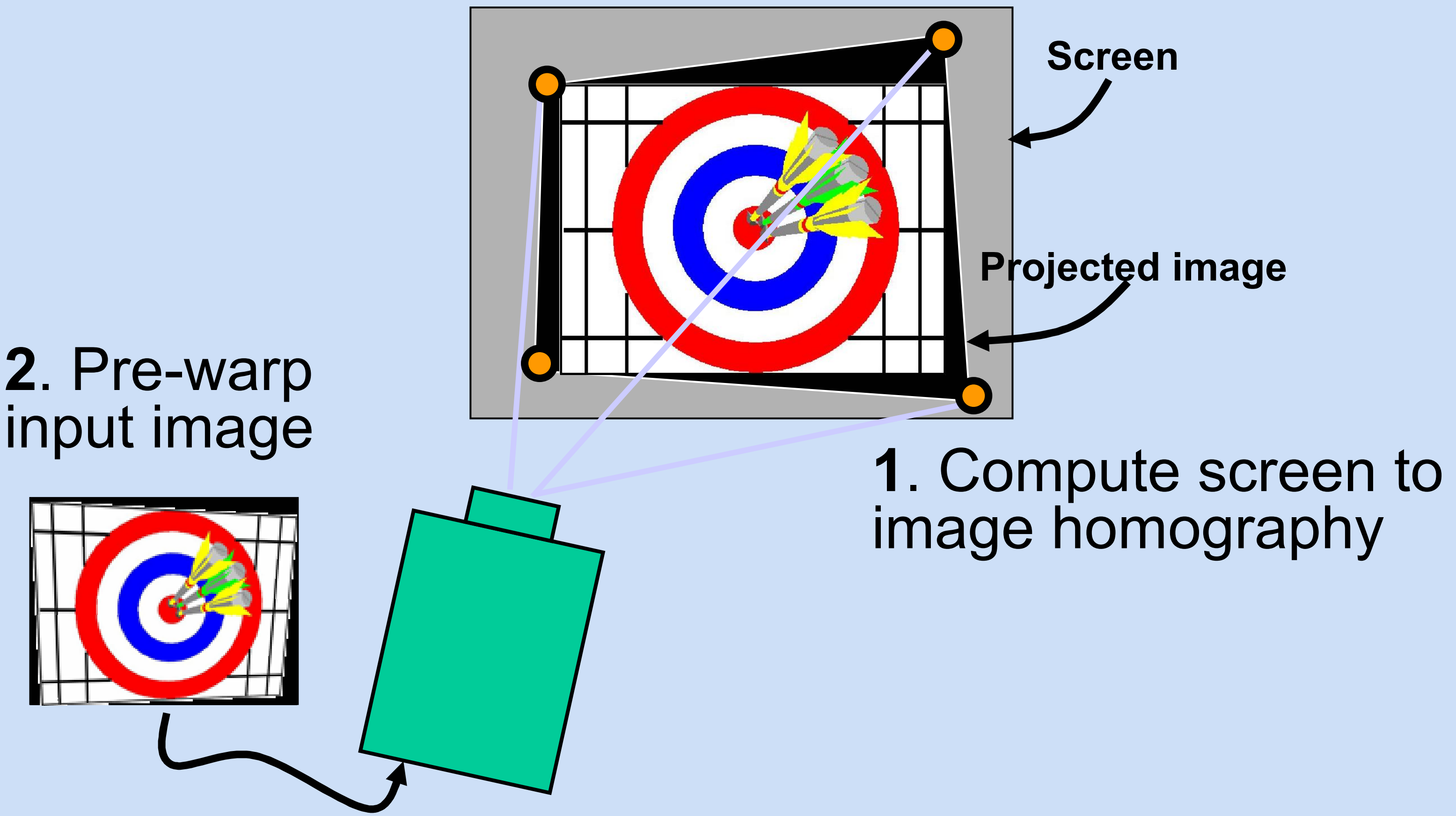
Planar projective transfer (homography)

- Two images of 3D points on a plane are related by a 3x3 matrix



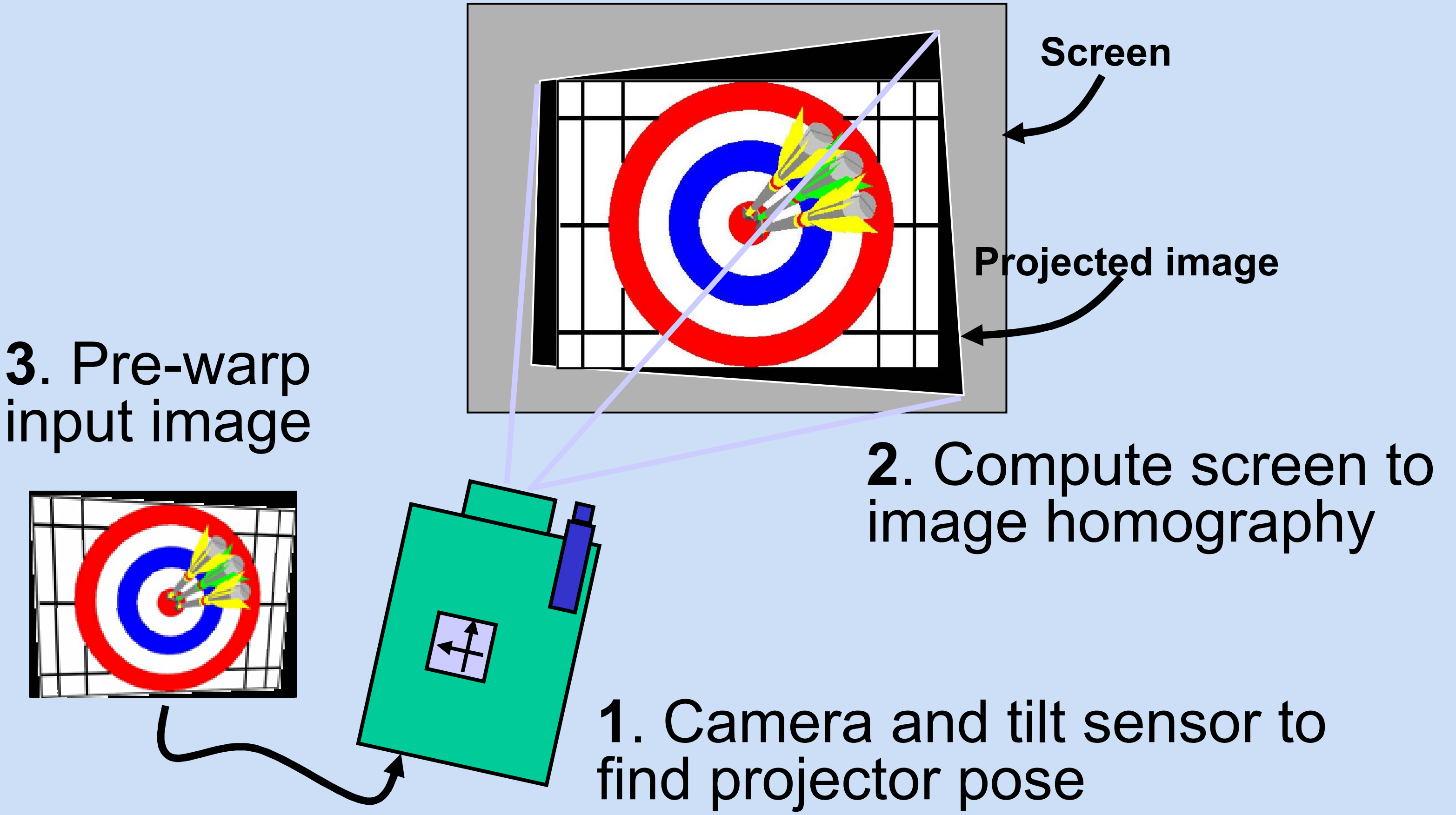
Defined by 4 or more corresponding pixels

Keystone Correction



Automatic Keystone Correction with Camera and Tilt Sensor

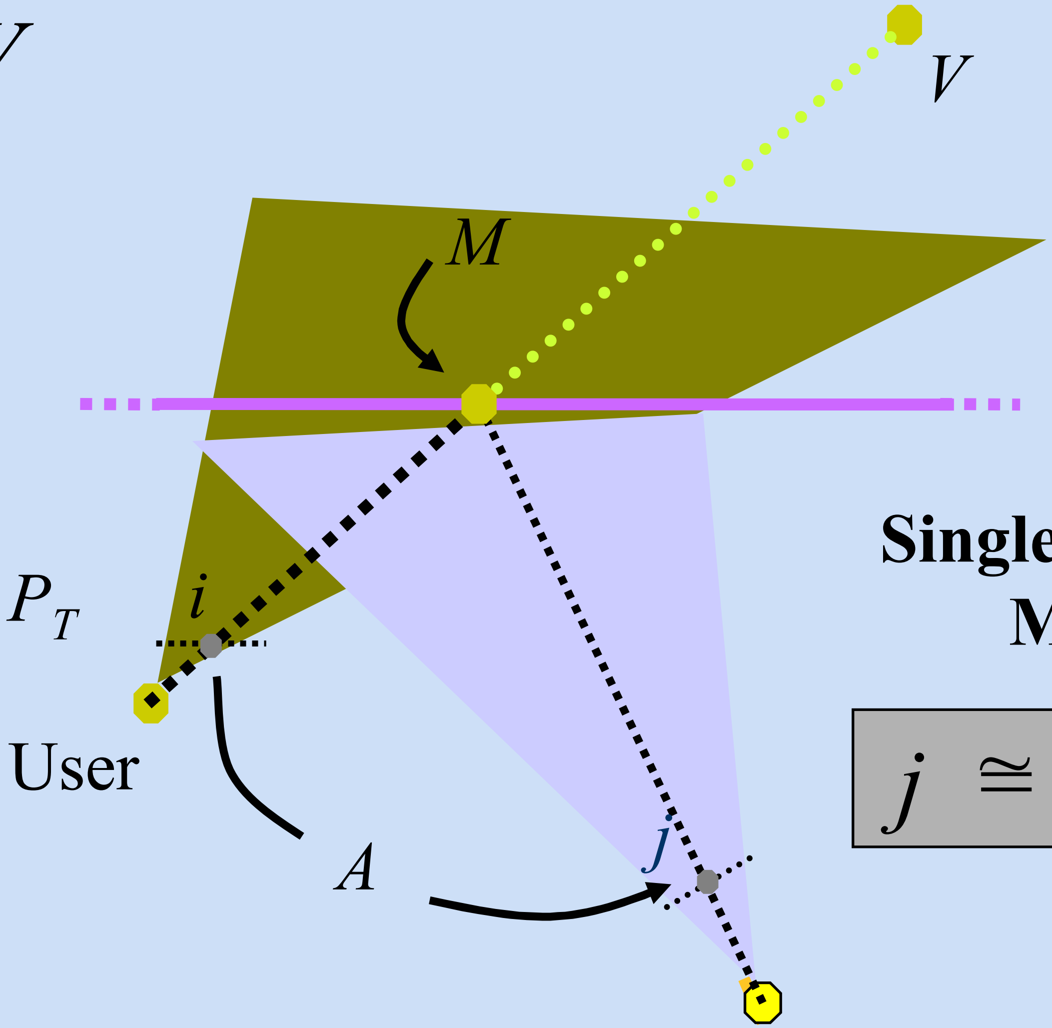
[Raskar and Beardsley01]



Planar display surface
Use homography (A_{3x3})

$$i \cong P_T V$$

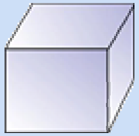
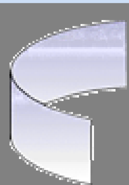
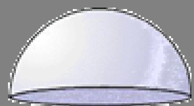
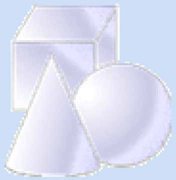
$$j \cong A\, i$$



Single Projection Matrix !

$$j \cong [A\, P_T]\, V$$

Projection Techniques

- Projection Screen Geometries
  - Planar 
  - Rectilinear 
  - Cylindrical 
  - Spherical 
  - Irregular 

Planar / Rectilinear | Planar Homography

Cylindrical / Spherical | Quadric image transfer

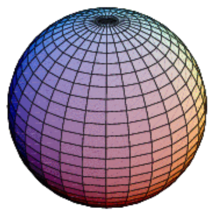
Irregular | Discretized Warping

Quardic curved shape Displays

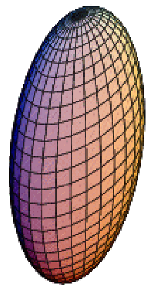
Raskar, vanBaar, Willwacher, Rao
'Quadric Transfer for Immersive Curved Displays',
EuroGraphics 2004

Curved projective transfer
Quadric classification

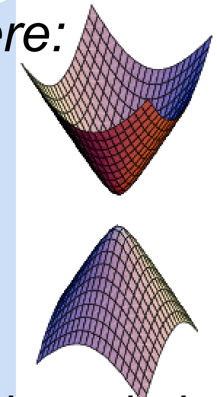
Projectively equivalent to *sphere:*



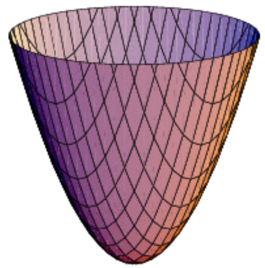
sphere



ellipsoid

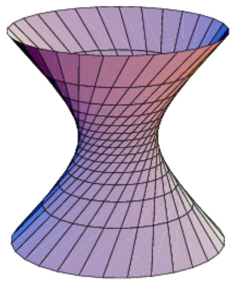


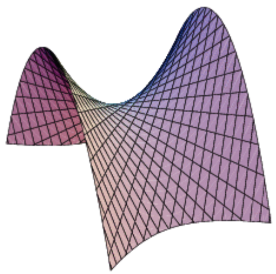
hyperboloid of two sheets



paraboloid

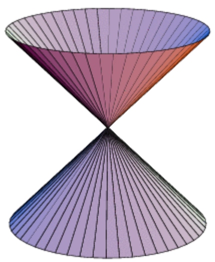
Ruled quadrics:



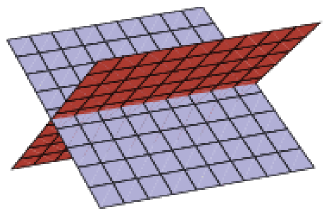


hyperboloids of one sheet

Degenerate ruled quadrics:



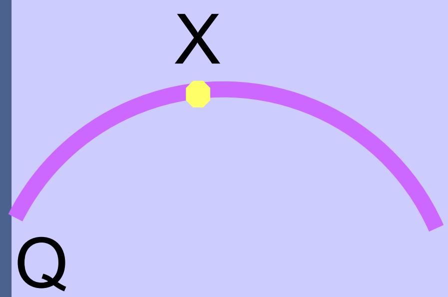
cone



two planes

Quadrics

$X^T Q X = 0$ For 3D points X on Quadric

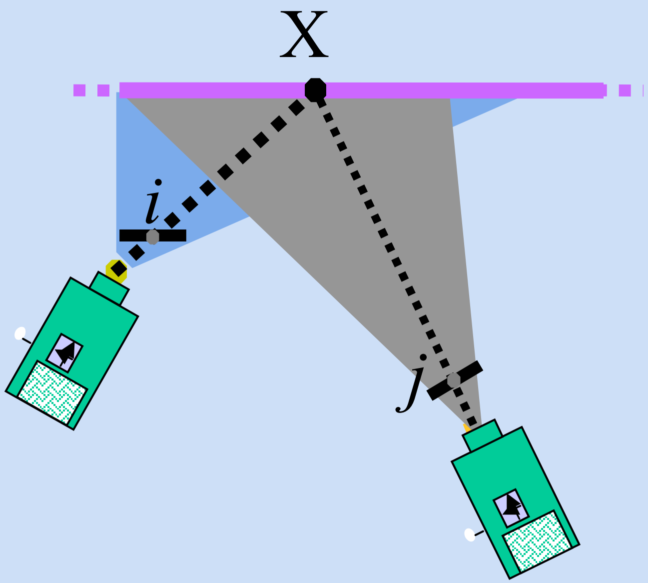


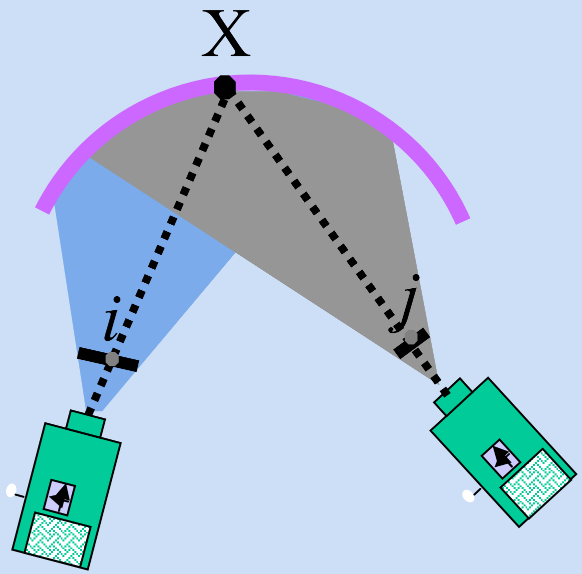
Q : 4x4 symmetric matrix, $Q = \begin{bmatrix} \bullet & \bullet & \bullet & \bullet \\ \circ & \bullet & \bullet & \bullet \\ \circ & \circ & \bullet & \bullet \\ \circ & \circ & \circ & \bullet \end{bmatrix}$

Nine d.o.f

In general 9 points in 3D define quadric

Parametric Image Transfer





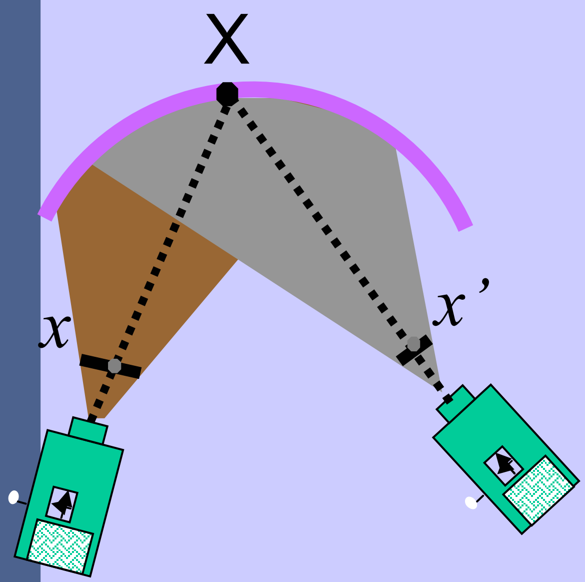
Planar Homography

$$j \cong A_{3x3}\, i$$

Quadric Transfer

$$j \cong A_{3x3}\, i \pm \left(\sqrt{i^T E\, i}\right) e$$

Simplified Quadric Image Transfer

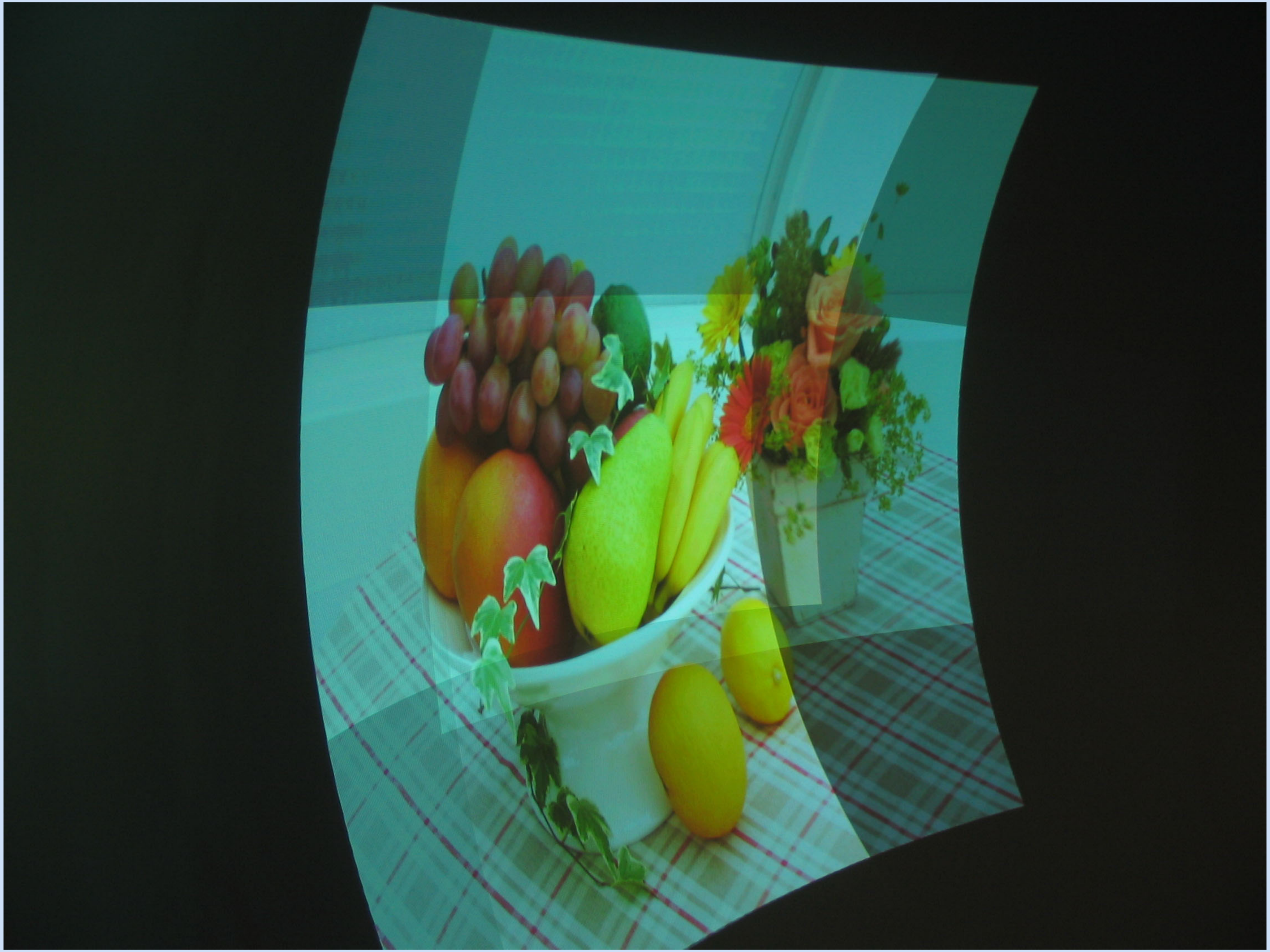


$$x' \cong Ax \pm \left(\sqrt{x^T E x}\right) e$$

17 param warp

Planar homography:	4 corresponding pixels
Quadric transfer:	9 corresponding pixels

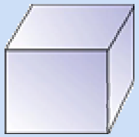
Overlap on Quadric Screens



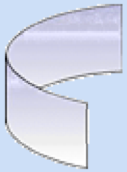
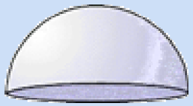
Vertex Shader for Quadric Transfer in Cg

- vertout main(appin IN, uniform float4x4 **modelViewProj**, uniform float4 constColor, uniform float3x3 **A**, uniform float3x3 **E**, uniform float3 **e**) {
- vertout OUT;
- float4 m1 = float4(IN.position.x, IN.position.y, IN.position.z, 1.0f);
- float4 m, mi ; float3 m2,mp; float scale;
-
- m = mul(**modelViewProj**, m1);
- m2.x = m.x/m.w; m2.y = m.y/m.w; m2.z = 1;
- scale = mul(m2, mul(**E**,m2));
- mp = mul(**A**,m2) + sqrt(scale)*e;
- mi.x = m.w * (mp.x)/(mp.z);
- mi.y = m.w * (mp.y)/(mp.z);
- mi.zw = m.zw;
- OUT.position = mi;
- OUT.color0 = IN.color0; // Use the original per-vertex color specified
- return OUT;
- }

Projection Techniques

- Projection Screen Geometries
  - Planar 
  - Rectilinear 

  | Planar Homography

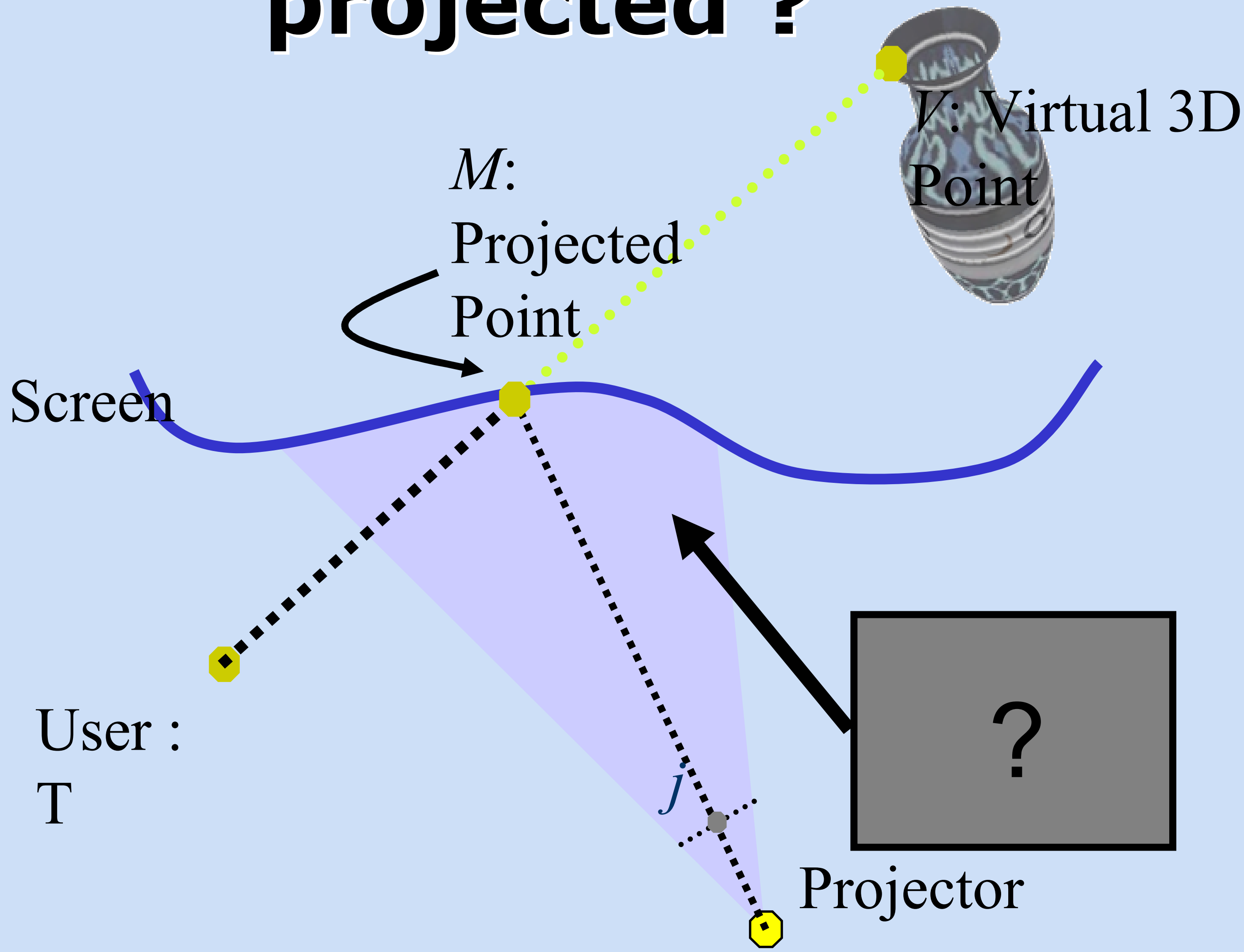
  - Cylindrical 
  - Spherical 

  | Quadric image transfer

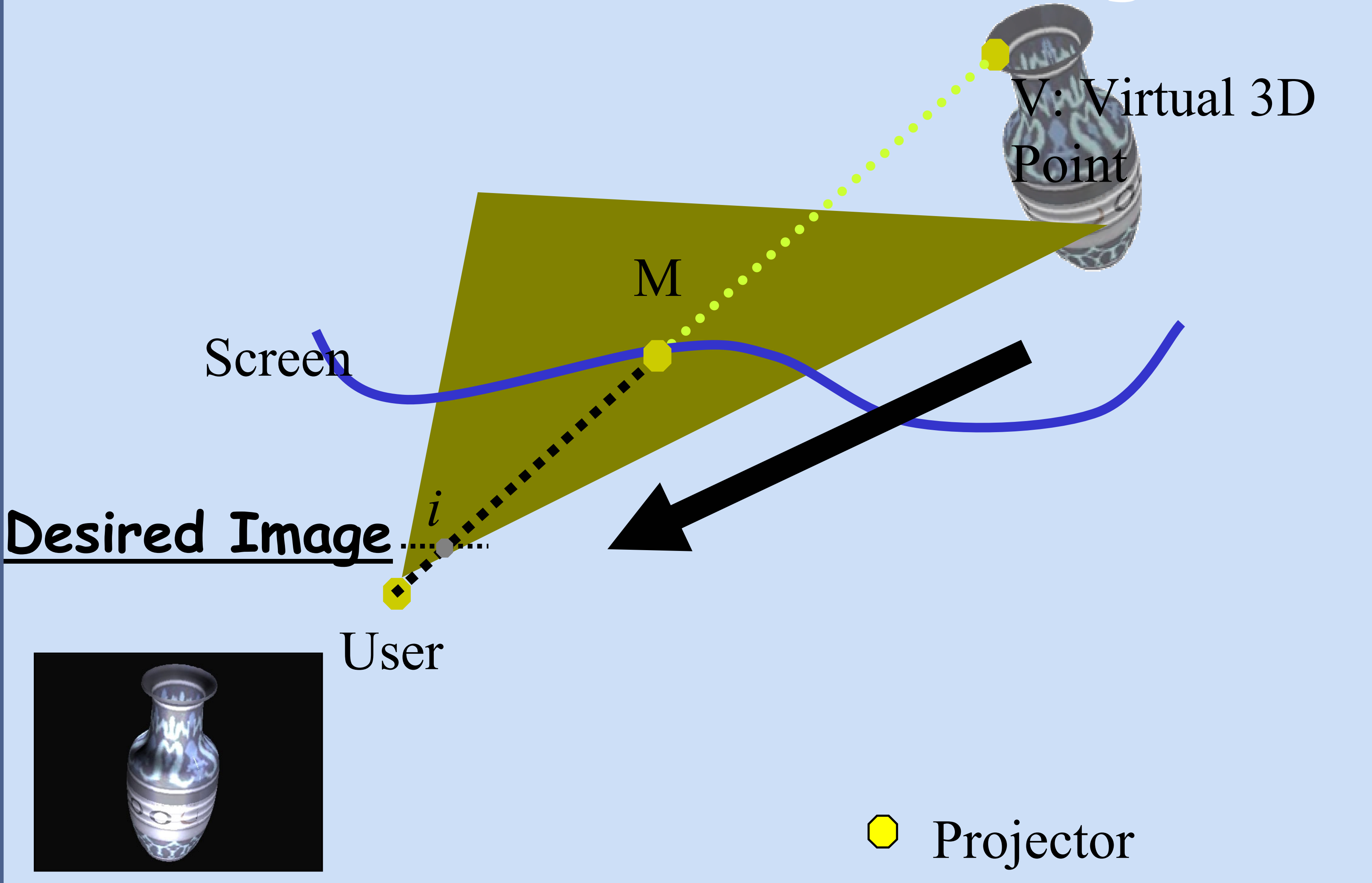
  - Irregular 

  | Discretized Warping

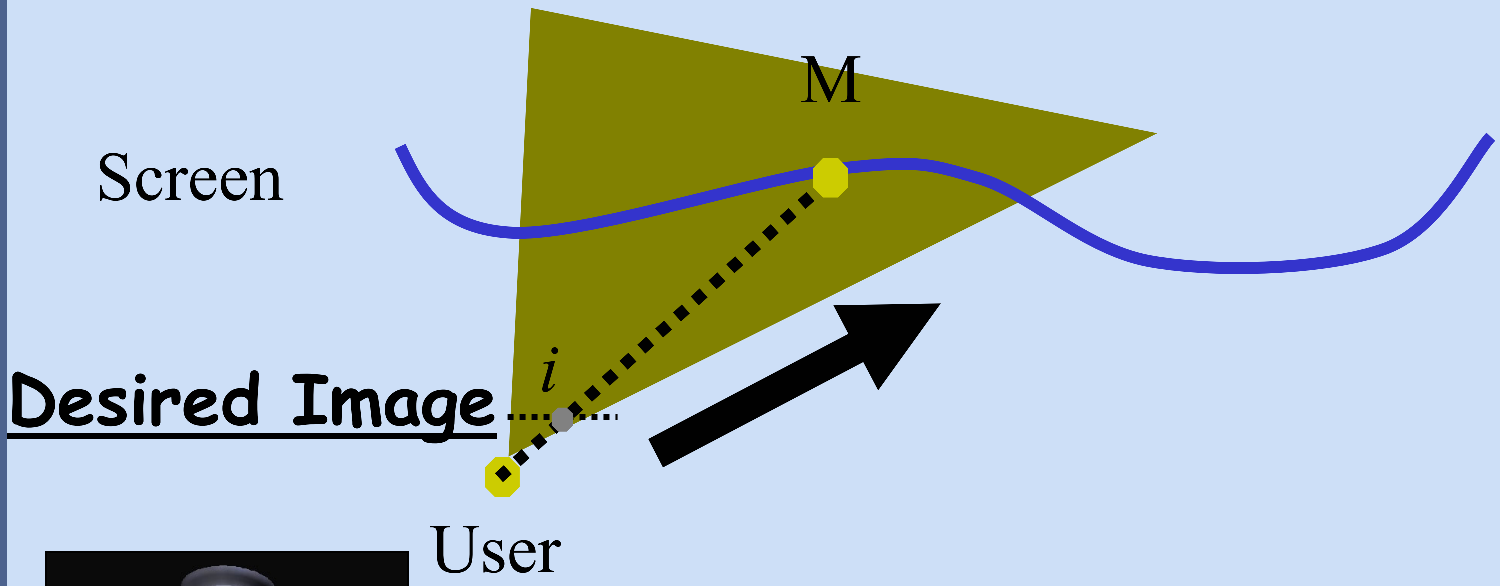
What image should be projected ?



Step I : Calculate 'desired' image

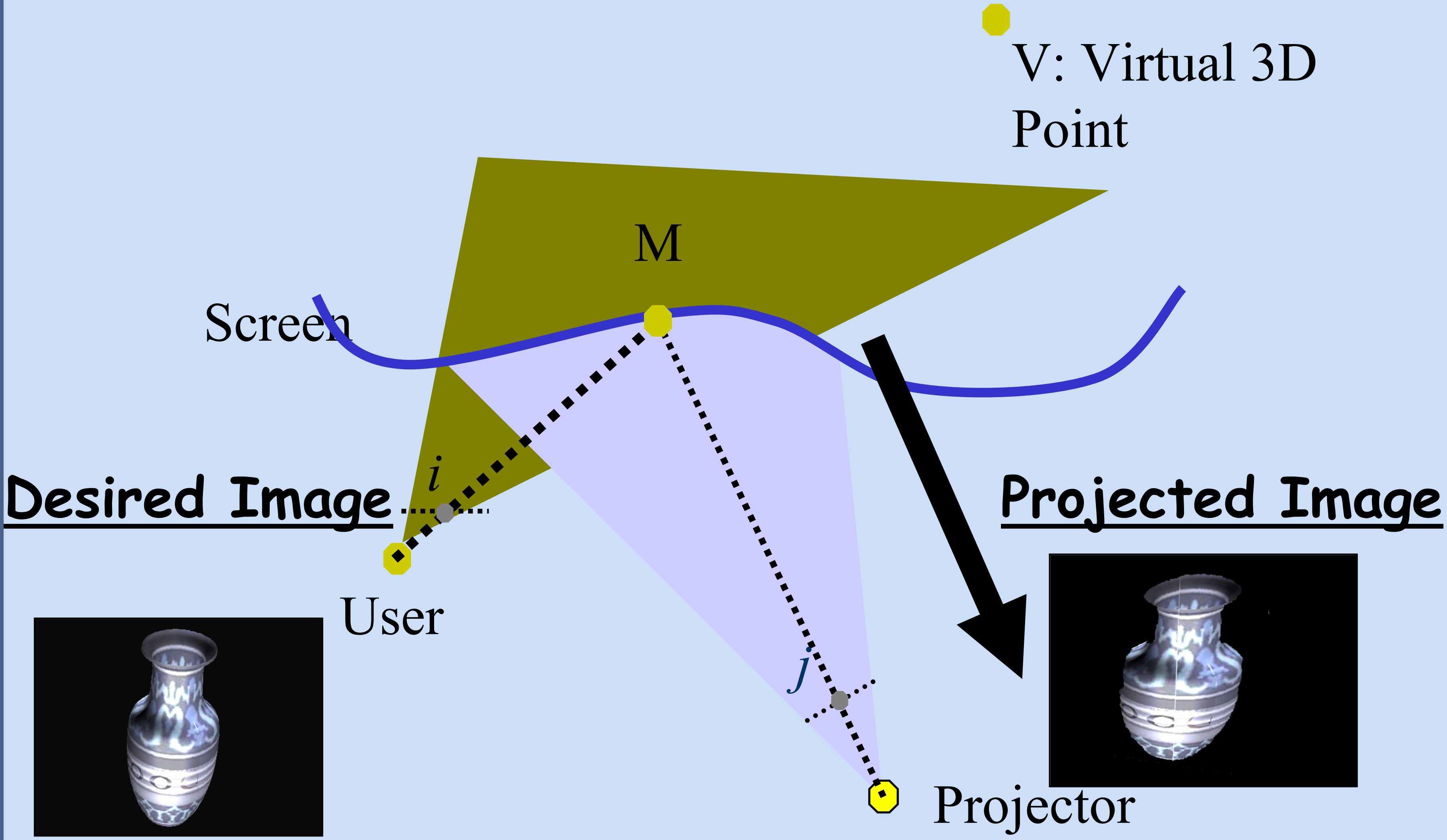


Step II : ‘Project’ the desired image from T

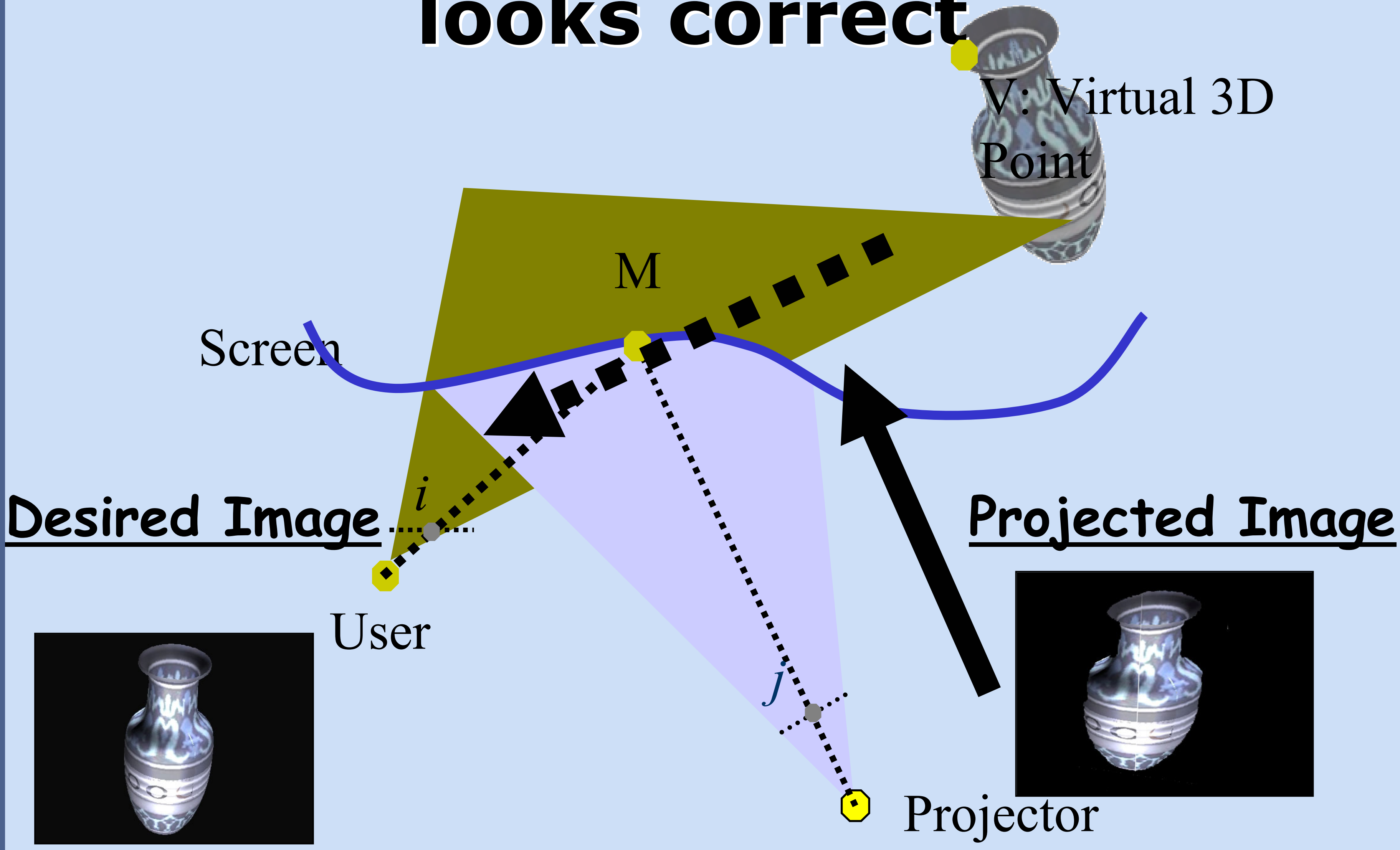


Projector

Step II : Render this scenario from *P*



Result: Projecting a pre-warped image, so it looks correct



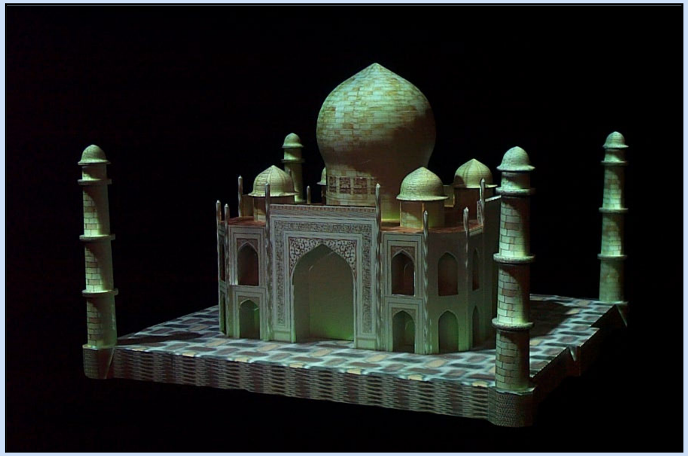
Non-planar Display

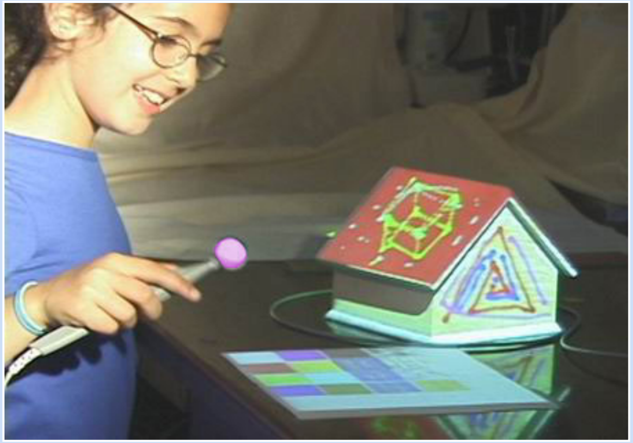
- Perspectively correct image for head-tracked user
- Details in [Raskar et al ‘Office of the Future’ Siggraph 1998]

- Step I
  - Compute desired image
  - Load in texture memory
- Step II :
  - With *projective texture,* map on display portal
  - Render projector’s view of display portal

Projector-based Augmentation

- More Examples ..

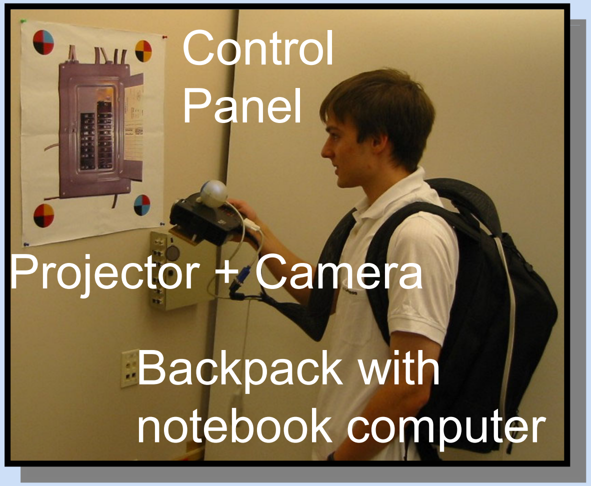




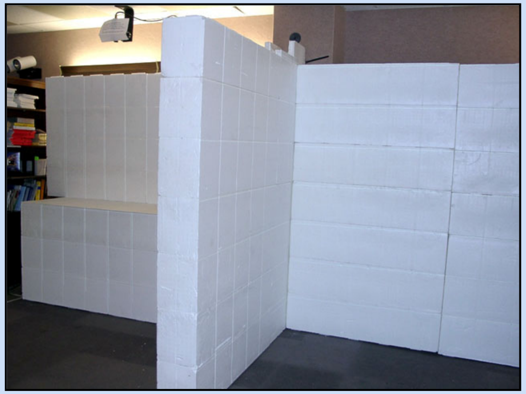
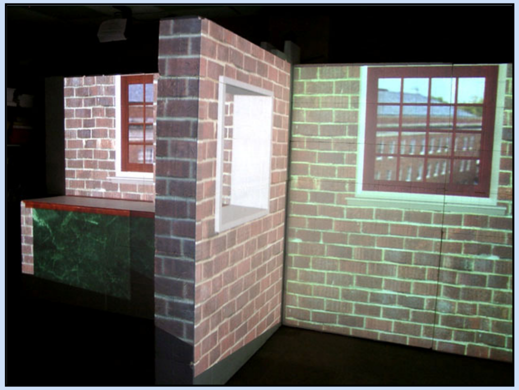
More info : www.ShaderLamps.com , Code available

Training and Maintenance
(Projector-based Augmented Reality)
Raskar, Beardsley, Forlines

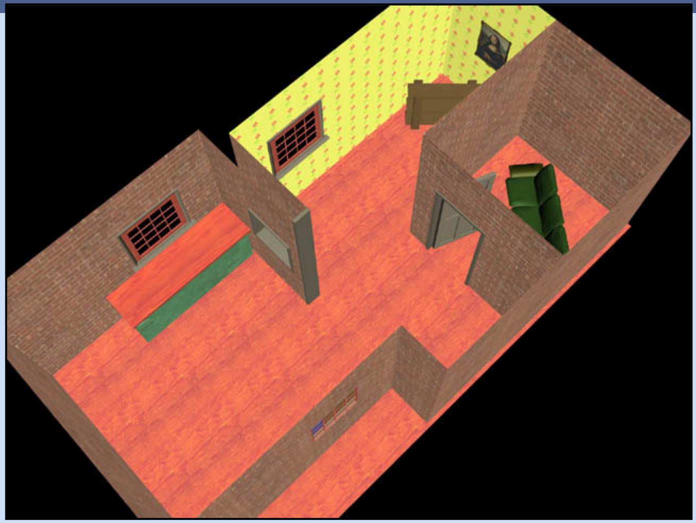
- Automatically add projected information
  - Training videos
  - Instruction manuals
- Detect pose and identity from pie-codes



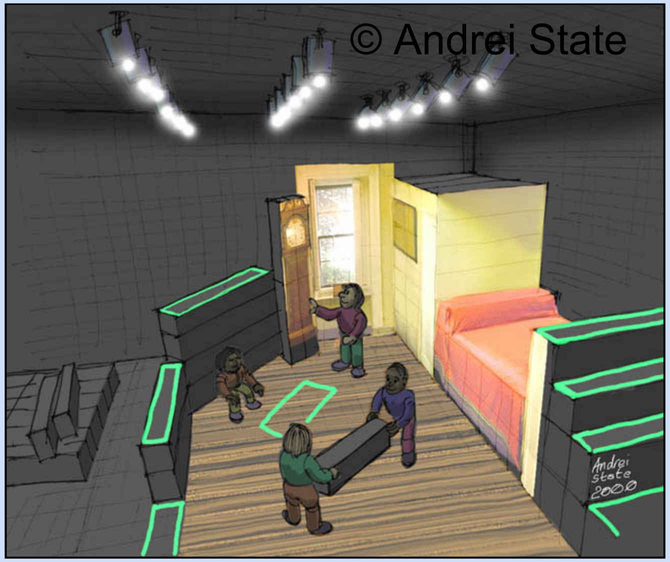
- Recreate Large Environments
  - 'BeingThere', walk-around
  - Human sized environments
  - Museums, Exhibitions

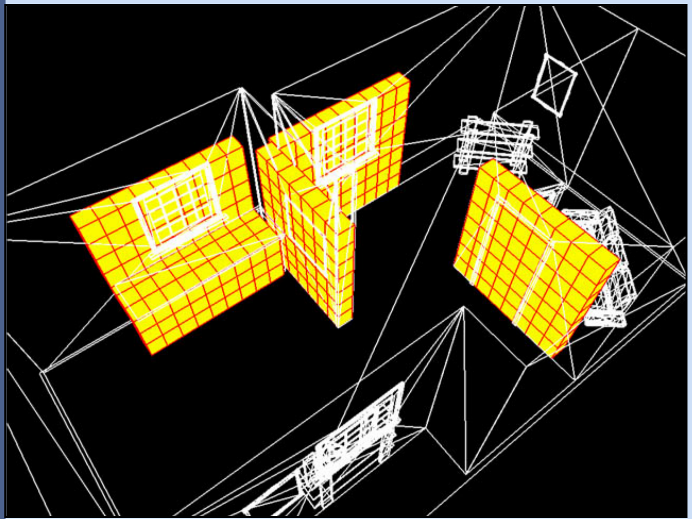

Kok-Lim Low, Greg Welch, Anselmo Lastra, Henry Fuchs. "Life-Sized Projector-Based Dioramas," Proc. ACM Symposium on Virtual Reality Software and Technology 2001 (VRST 2001), November 2001.

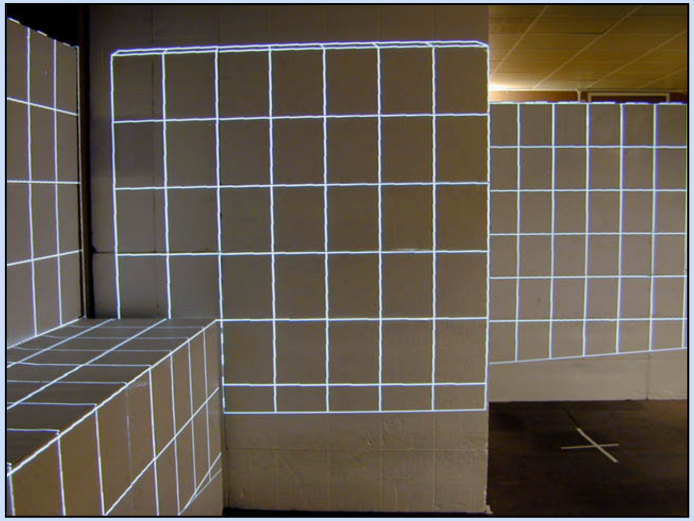


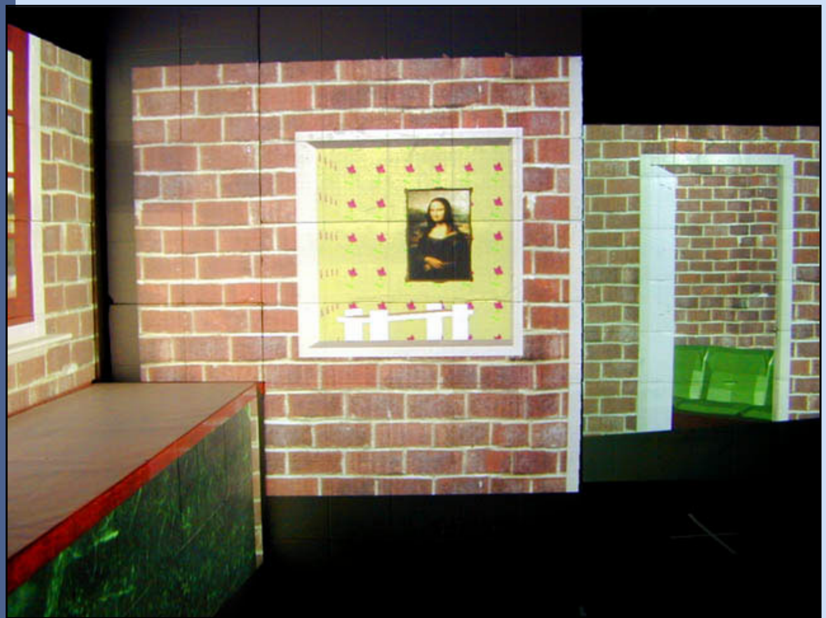
Desired Virtual Model

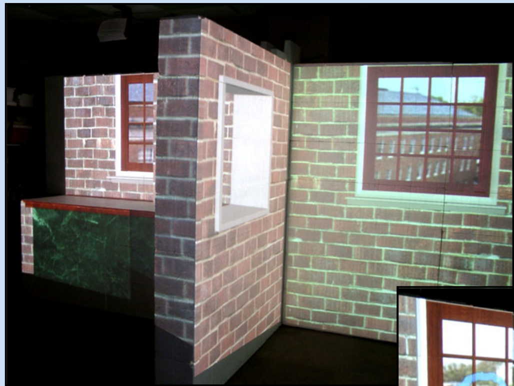


Projected Guidance for Placement

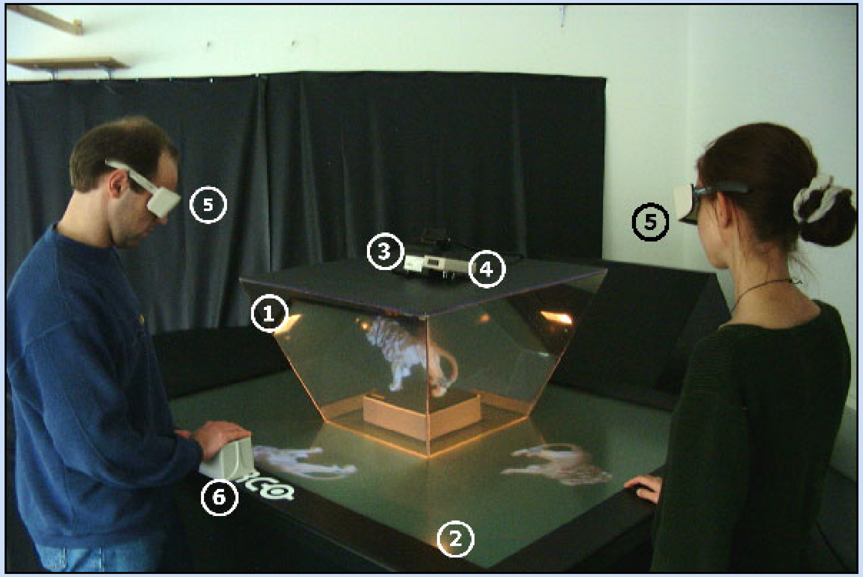


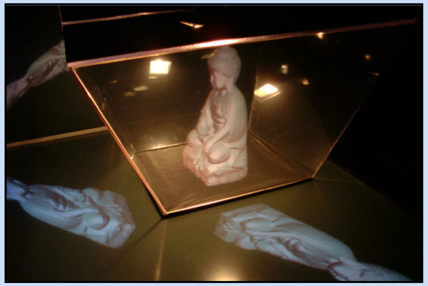


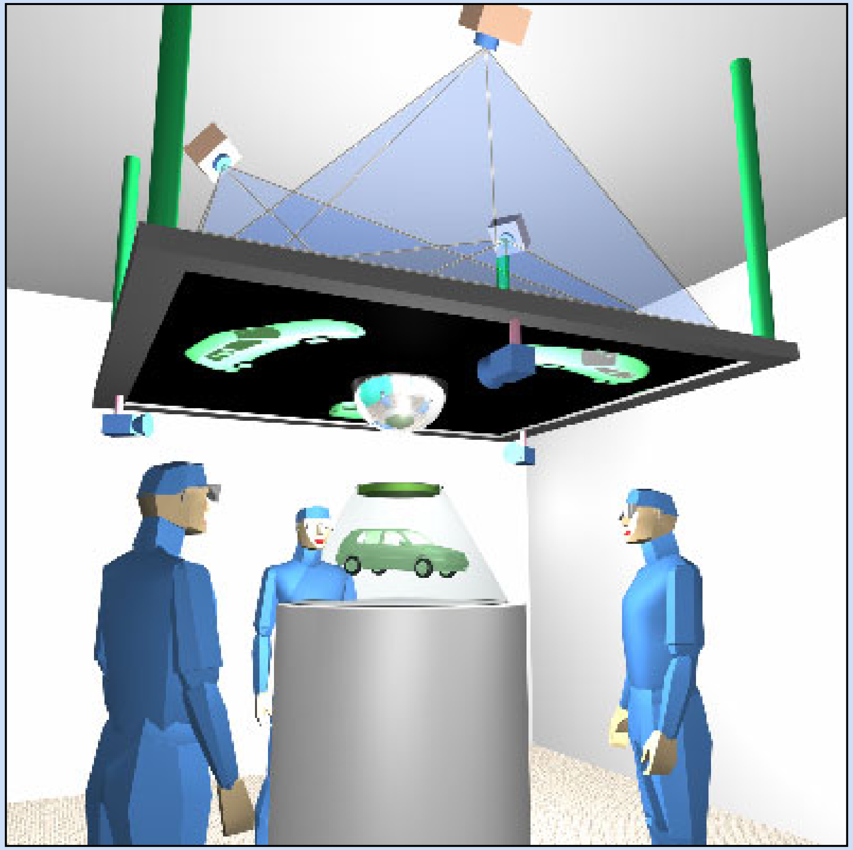




Projector-based AR







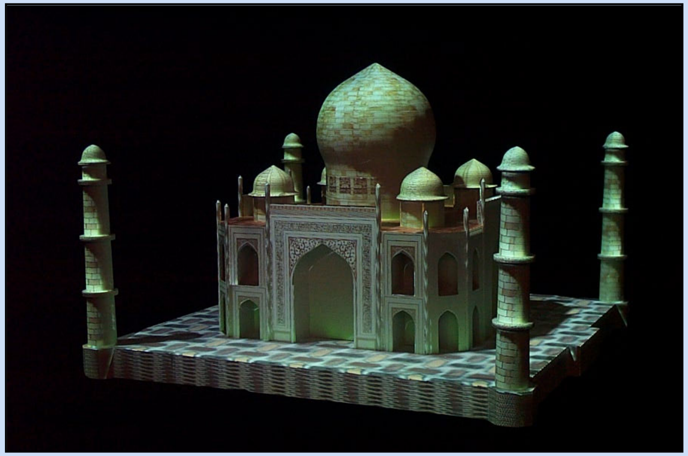
Bimber, O., Fröhlich, B., Schmalstieg, D., and Encarnação, L.M. 'The Virtual Showcase'. *IEEE Computer Graphics & Applications*, vol. 21, no.6, 2001.

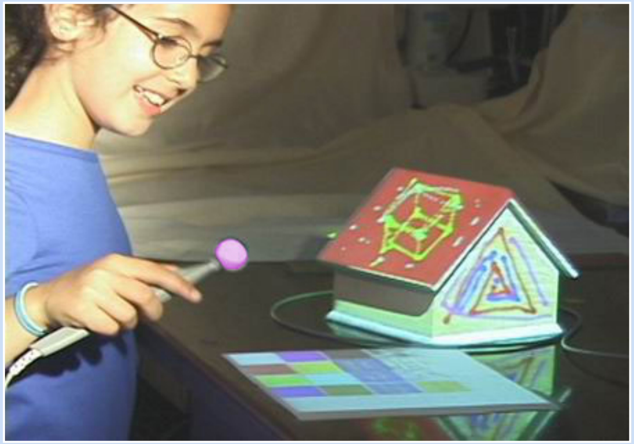
Acknowledgements

- MERL
  - Jeroen van Baar, Paul Beardsley, Remo Ziegler, Thomas Willwacher, Srinivas Rao, Cliff Forlines, Paul Dietz
- Office of the Future group at UNC Chapel Hill
  - Greg Welch, Kok-lim Low, Deepak B'padhyay, Aditi Majumder, Michael Brown, Ruigang Yang
  - Henry Fuchs, Herman Towles
  - Wei-chao Chen
- Mitsubishi Electric, Japan
  - Yoshihiro Ashizaki, Masatoshi Kameyama, Masato Ogata, Keiichi Shiotani
- Images
  - Oliver Bimber (Virtual Showcase images)
  - Marc Pollefeys (UNC Chapel Hill)
  - Apologies
    - (Not able to include recent work by others)

Projector-based Augmentation

- Useful paradigm for 3D graphics
- New methods to make it practical
- Many open problems and applications



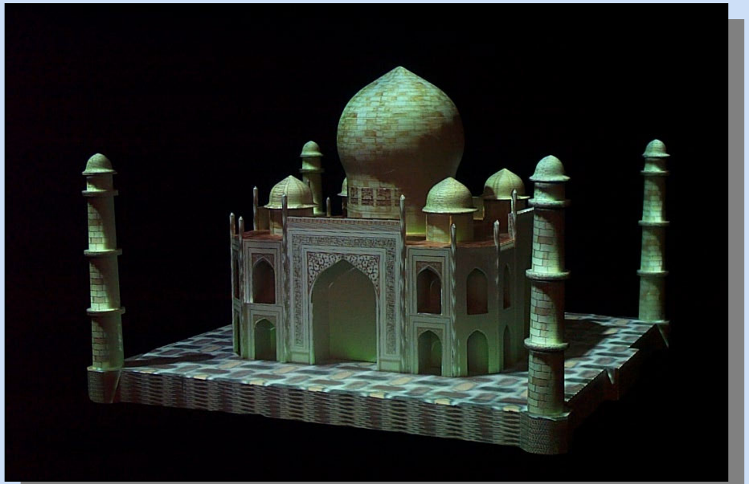


More info : www.ShaderLamps.com , Code available

Projector-based AR

Virtual Reflectance

Virtual Illumination

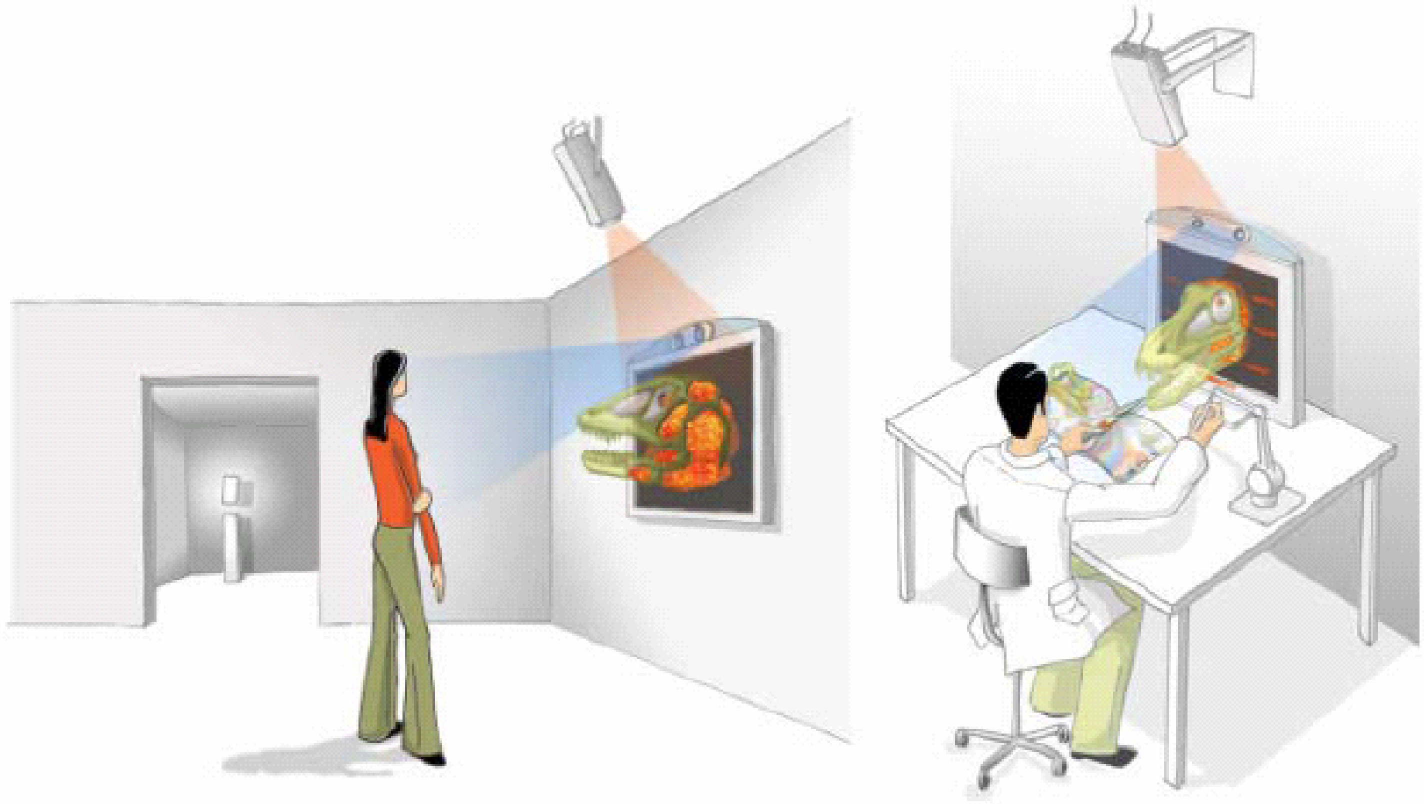


Virtual Motion

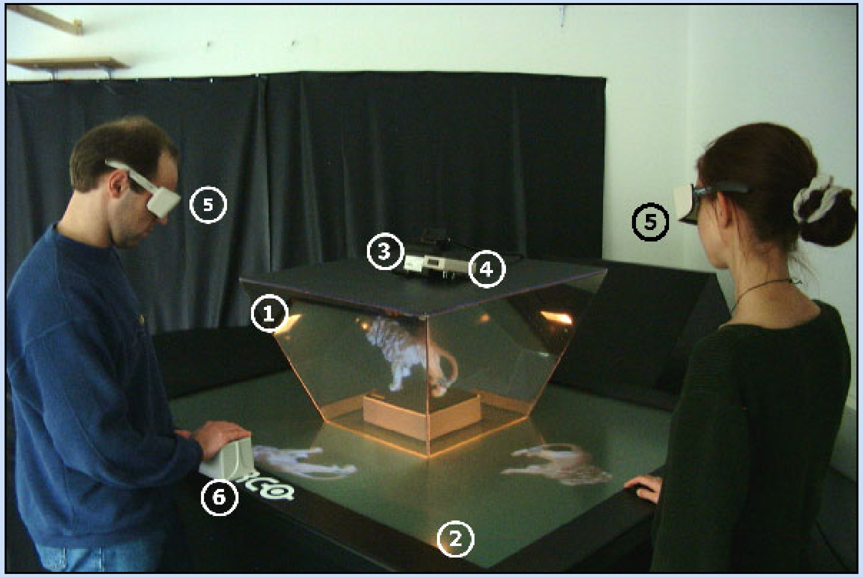
Interaction

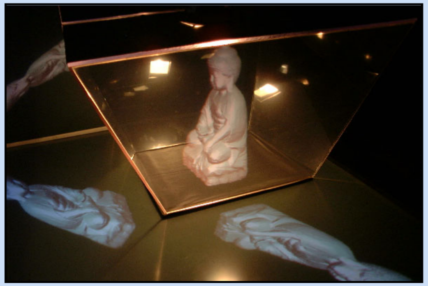
www.ShaderLamps.com

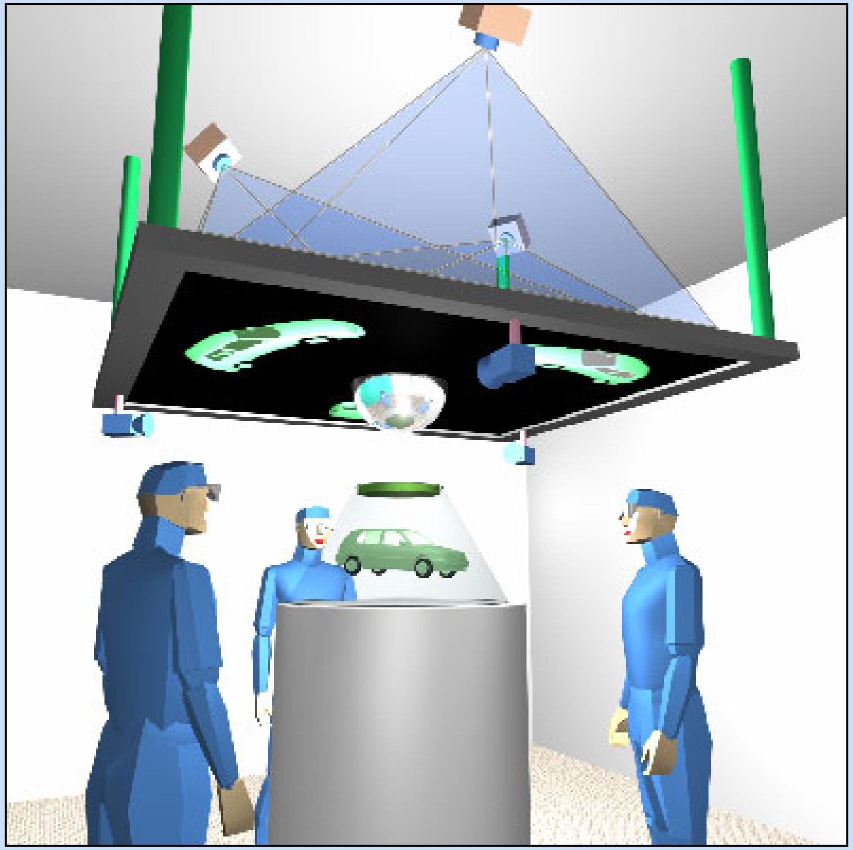
HoloGraphics



Virtual Showcase







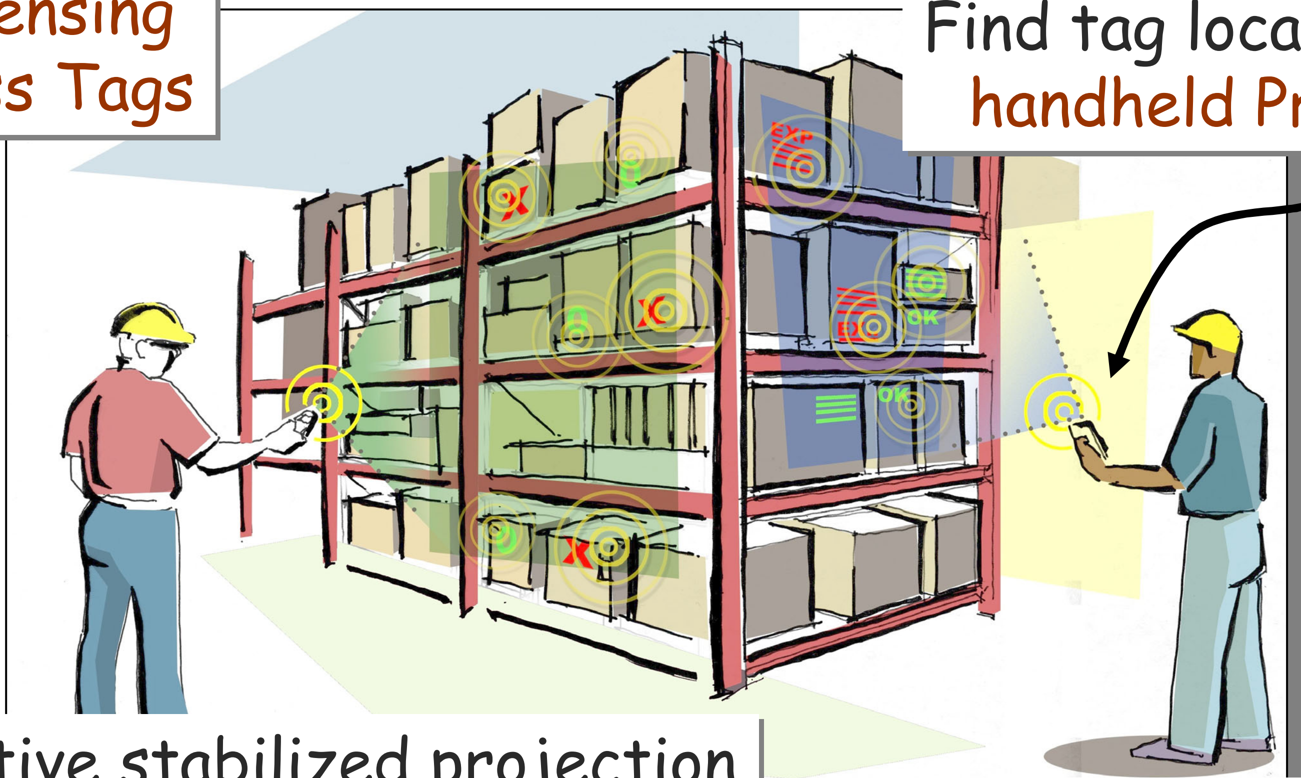
Handheld AR

RFID → **RFIG**

(Radio Frequency Id & Geometry)

Photosensing Wireless Tags

Find tag location using handheld Projector



Interactive stabilized projection

Many geometric ops

Schedule

2:00	Overview	
2:10	Today's AR Display Approaches	(Bimber)
2:40	Spatial Augmentation	(Raskar)
3:30	Break	
3:45	Spatial AR using Optical Elements	(Bimber)
4:45	Prototypes	(Bimber and Raskar)
5:20	Discussion	

Course Page : http://Spatial-AR.com

Feedback

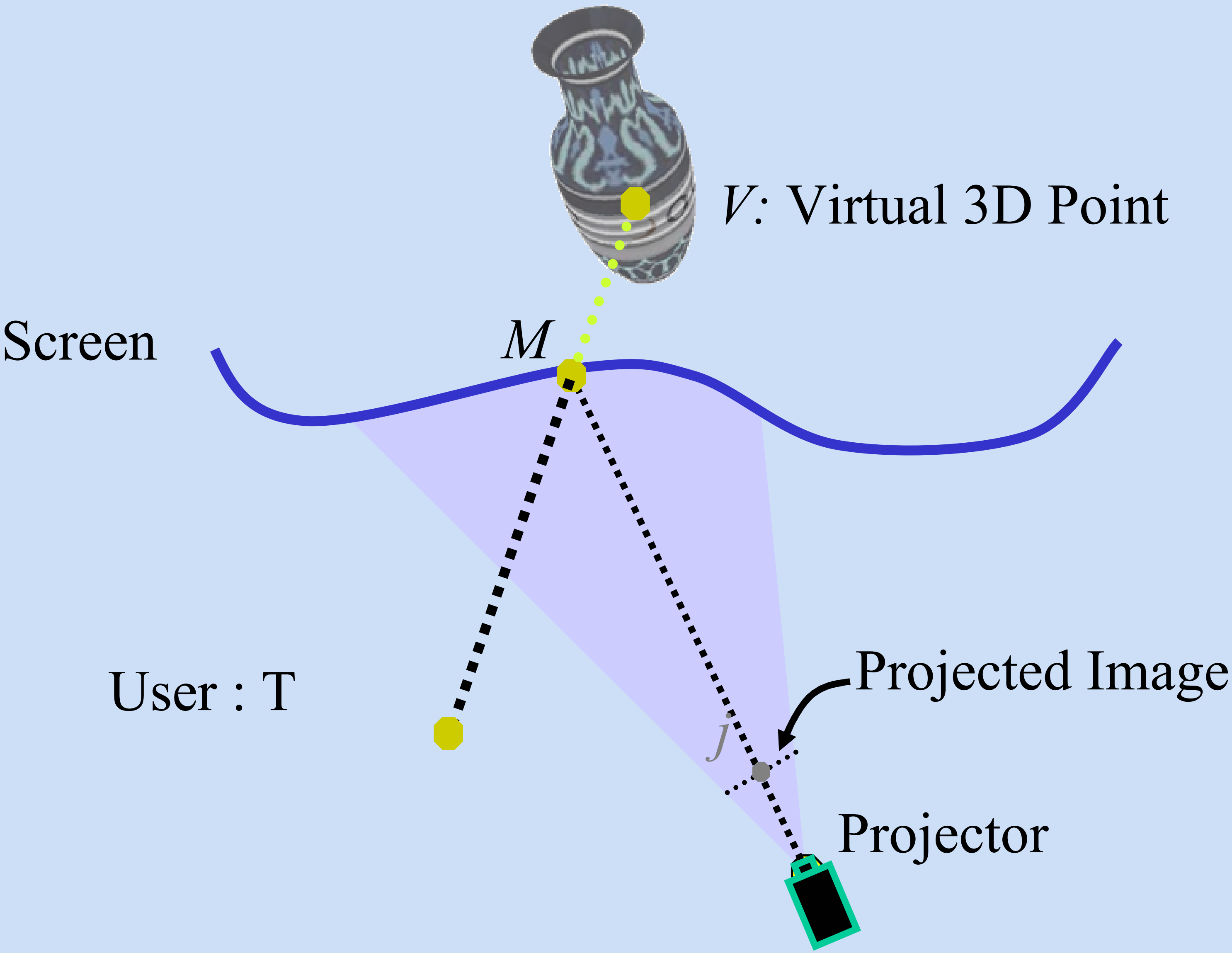
- Please raise questions/comments during the presentation
- Send write other questions on a paper
- Fill in sheet with Email addresses

Extra Slides

Limitations

- Surface reflectance
- Secondary scattering, ambient
- Depth of focus
- Shadows (user)
- Dynamic range
- Non-opaque virtual objects

Display Components



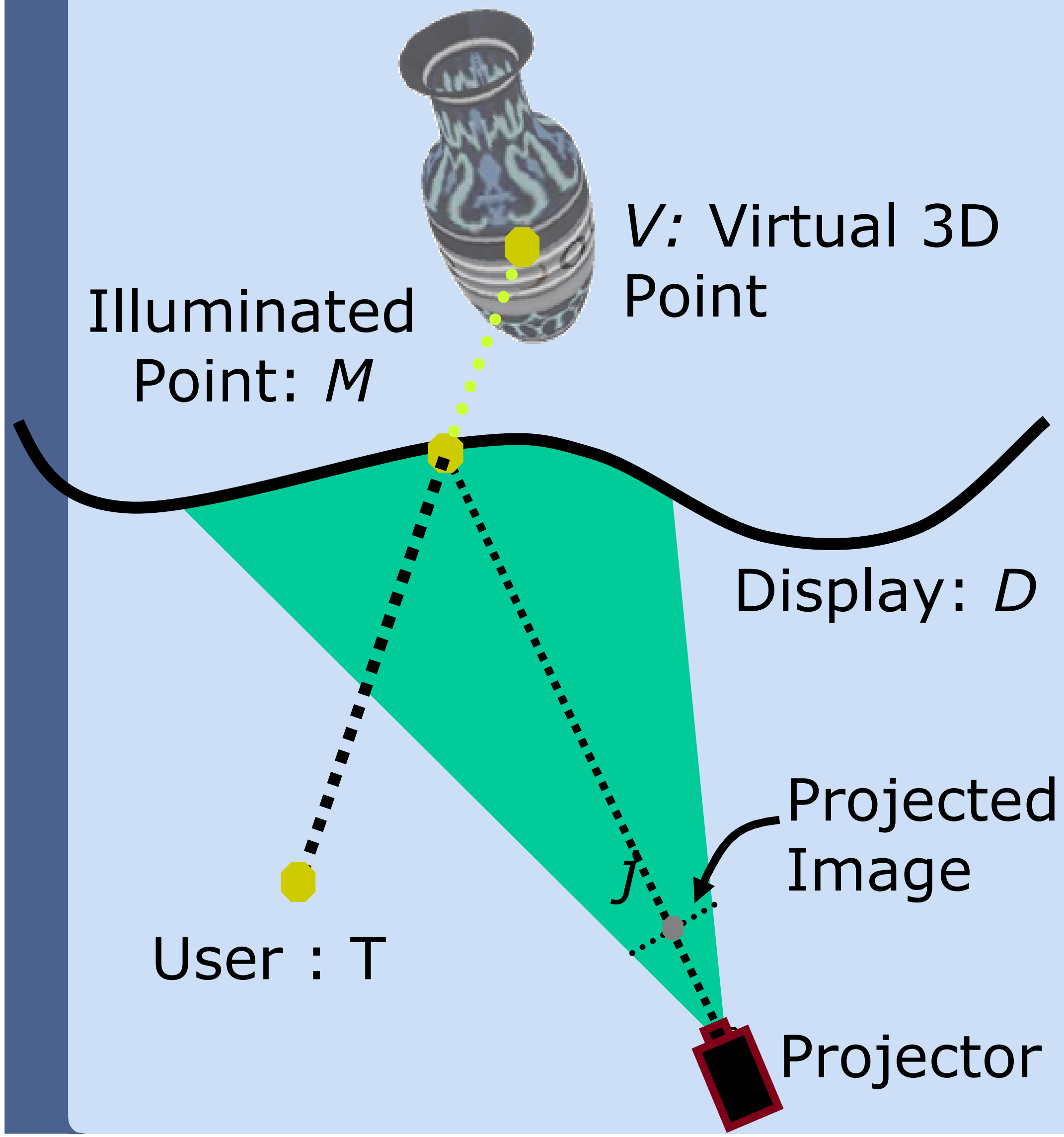
A Single Unified Approach

- Step I : View user view thru display portal and map onto display portal
- Step II : Render projector's view of augmented display portal

Conceptual Framework

- Given:
  - Analytic projection model for projector
  - 3D representation of display surface
  - User location
- Relationship between
  - Virtual object and
  - Projected images

Geometric Relationship



M = *intersect* (TV , D)

j = *Projection* (M)

Modern Approaches to Augmented Reality

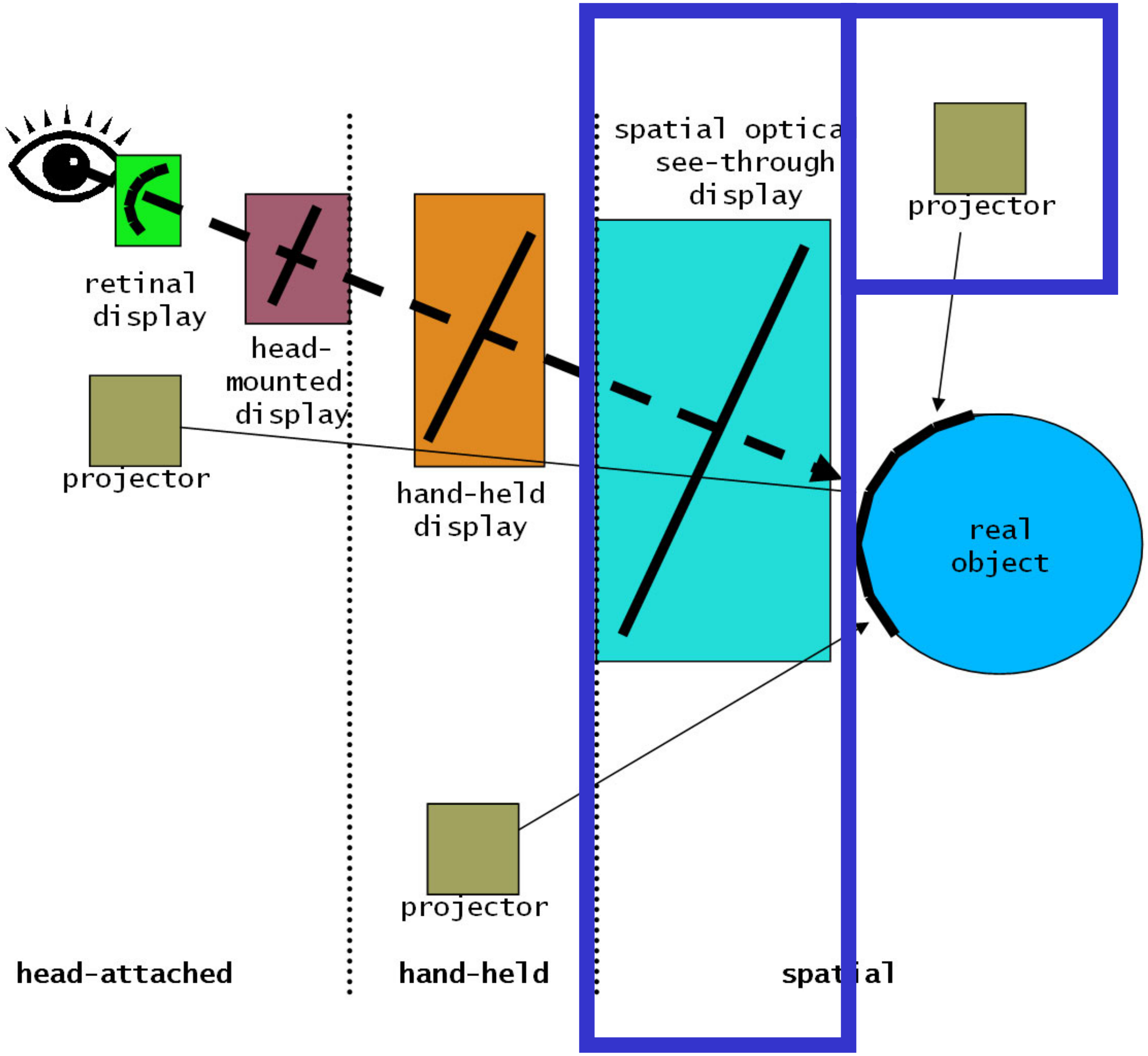
- Part 4 -

Spatial Augmentation using Optical Elements

Outline

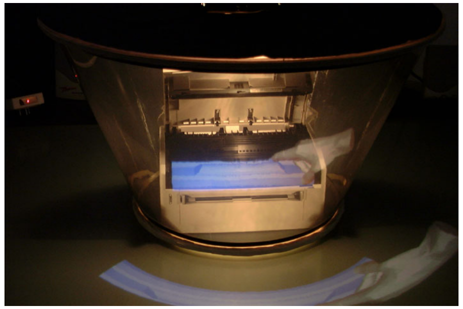
- Part 1: Tutorial Introduction and Overview (Ramesh)
- Part 2: Introduction to today's displays approaches for AR (Oliver)
- Part 3: New Directions in Spatial Augmentation (Ramesh)
- **Part 4: Spatial Augmentation using Optical Elements (Oliver)**
- Part 5: Prototypes and Experiences (both)

Roadmap

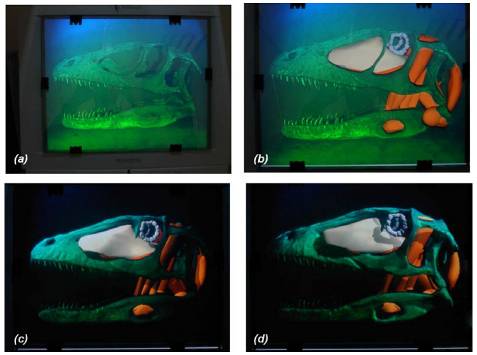

retinal display
head-mounted display
projector
hand-held display
spatial optical see-through display
projector
real object
projector
head-attached
hand-held
spatial

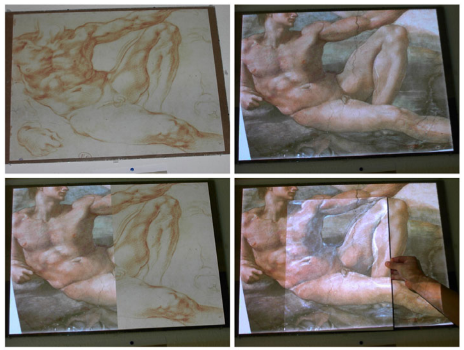
Optical Combiners

- More common
  - Transparent Screens
    - Planar
    - Multi-plane
  - Mirror Beam-Splitters
    - Planar
    - Multi-plane
    - Curved

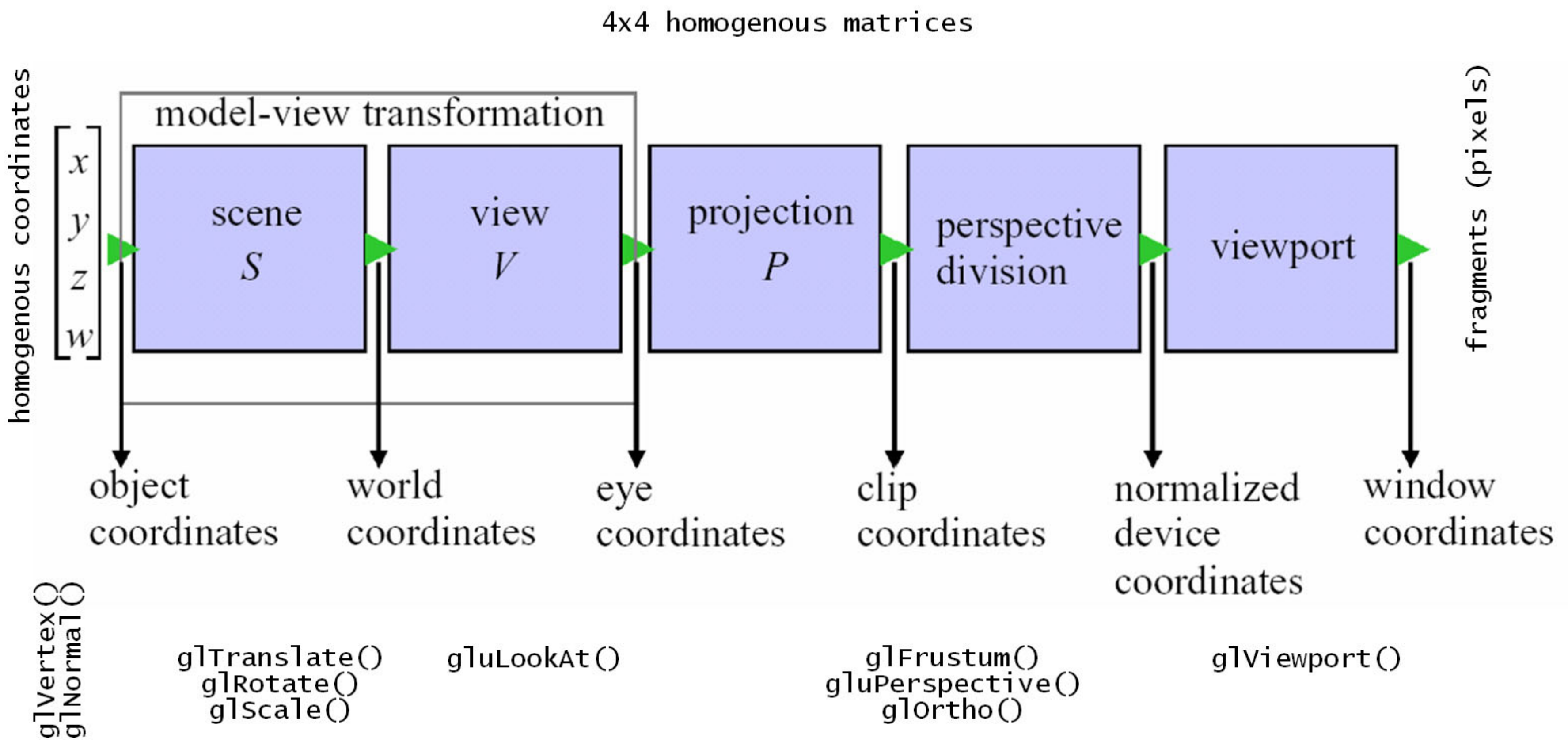


- Less common
  - Fog
  - Air
  - Other gasses
  - Liquids
  - Holograms

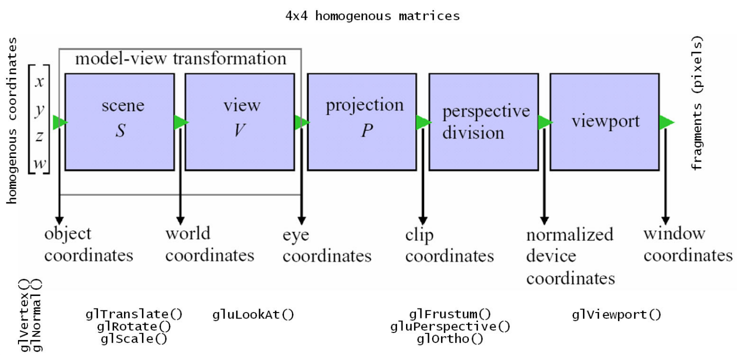


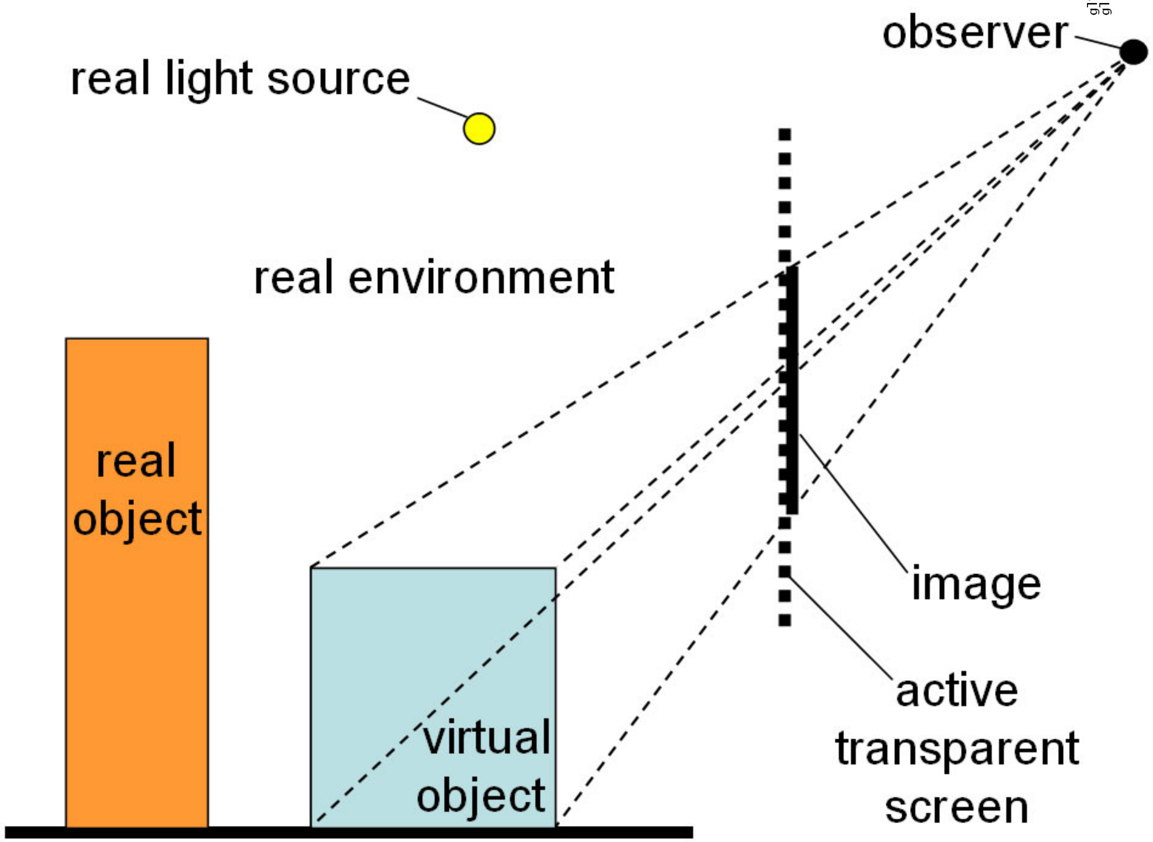


Fixed Function Pipeline Rendering

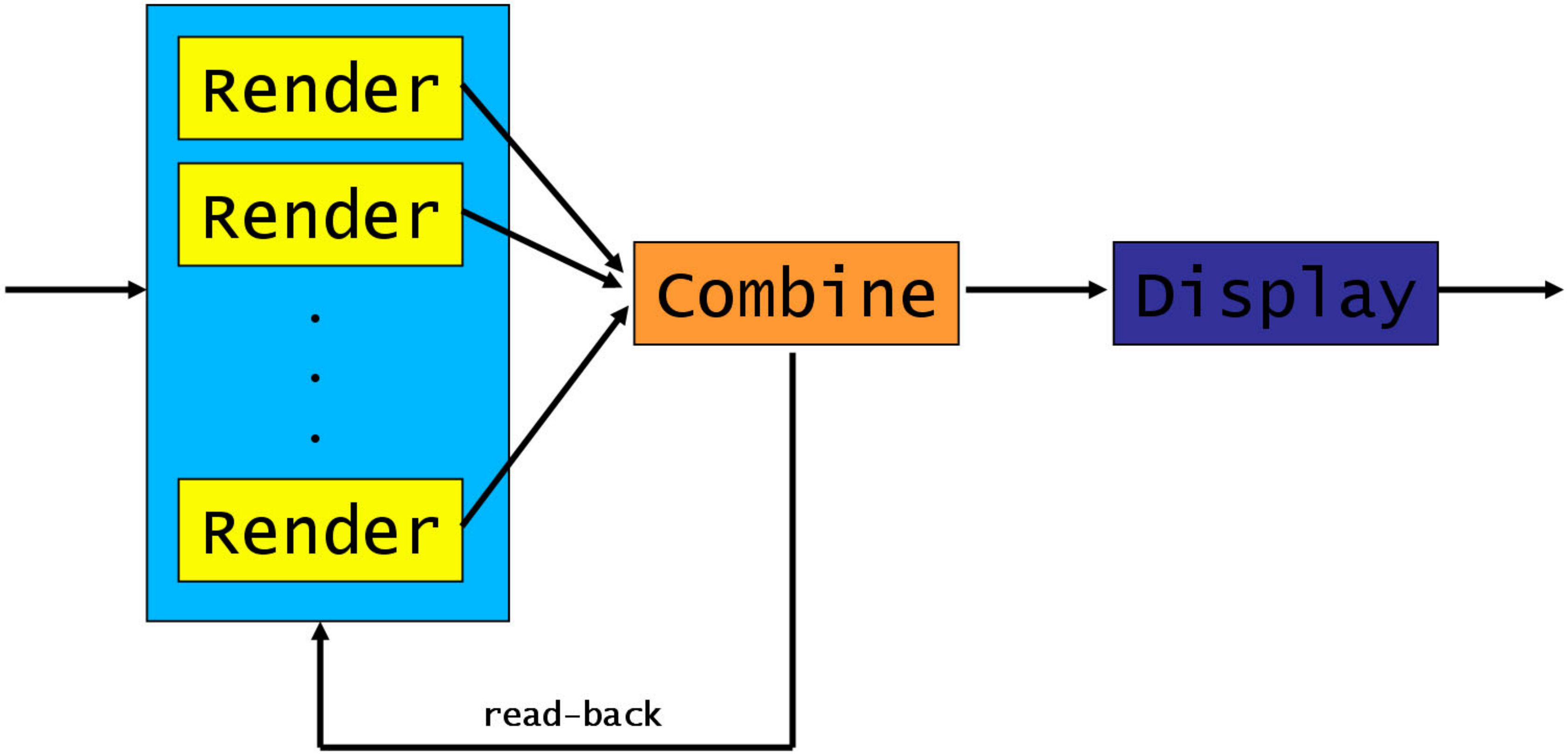


Transparent Screens

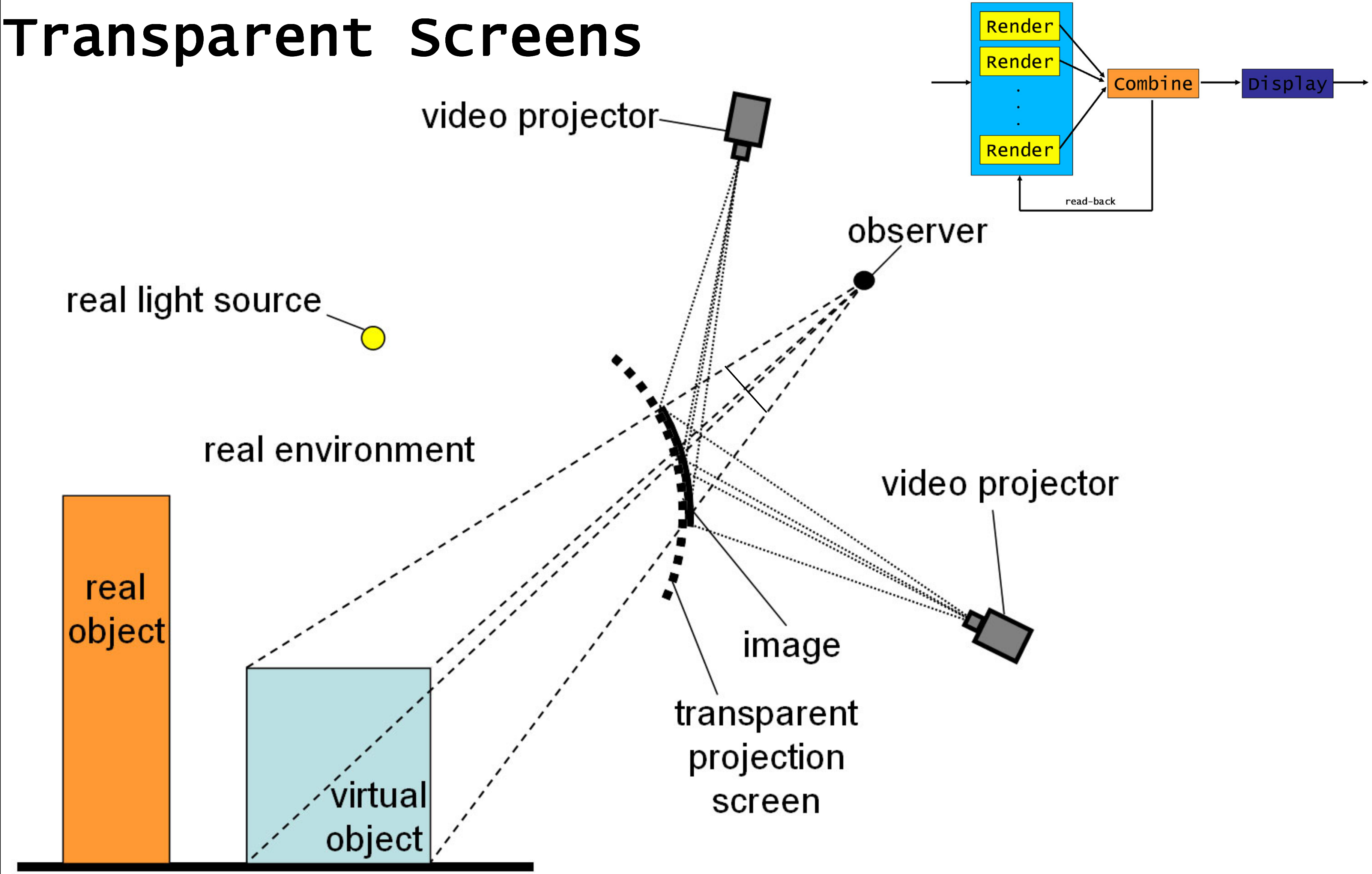




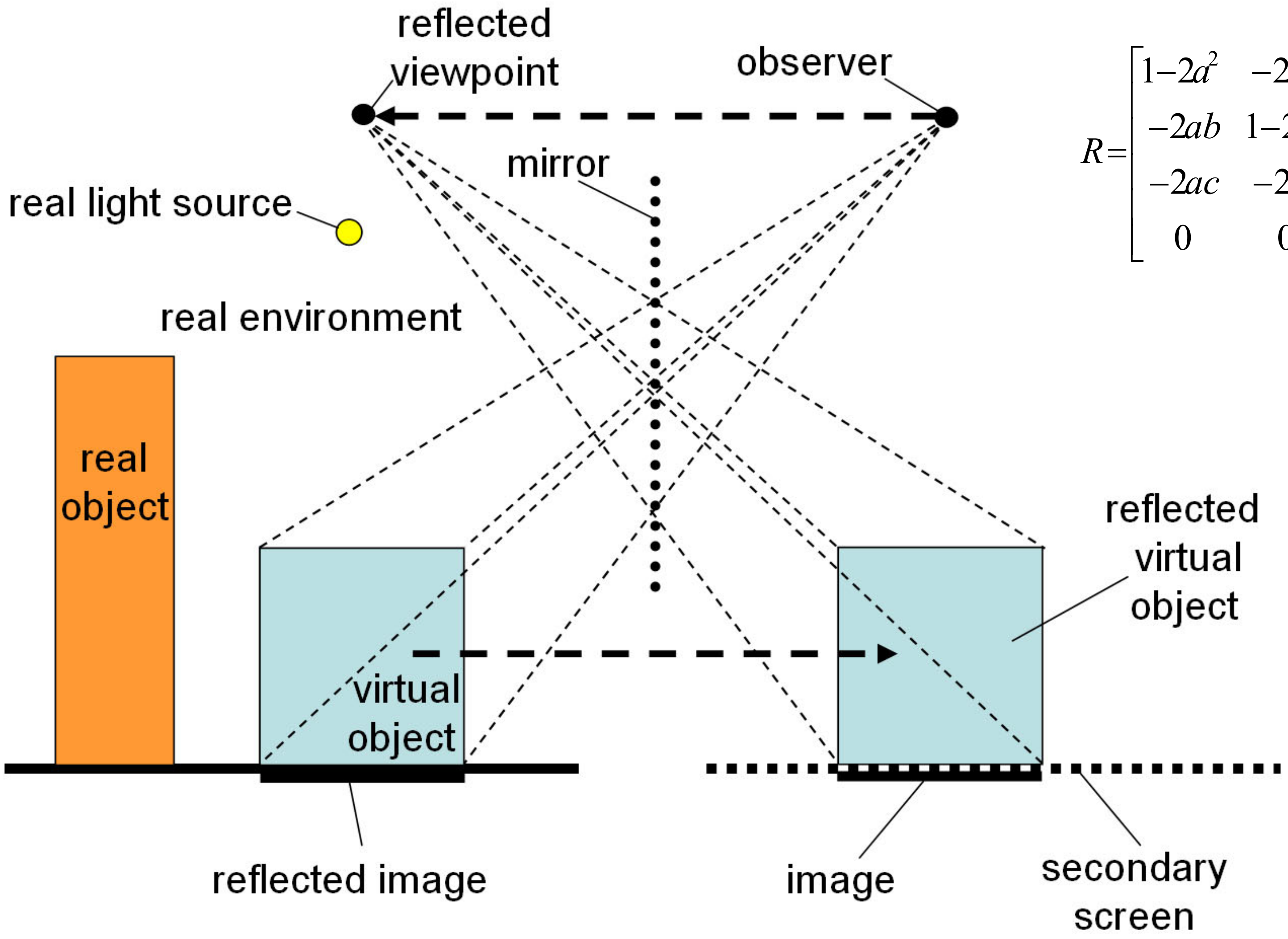
Multi-Pass Rendering



Transparent Screens

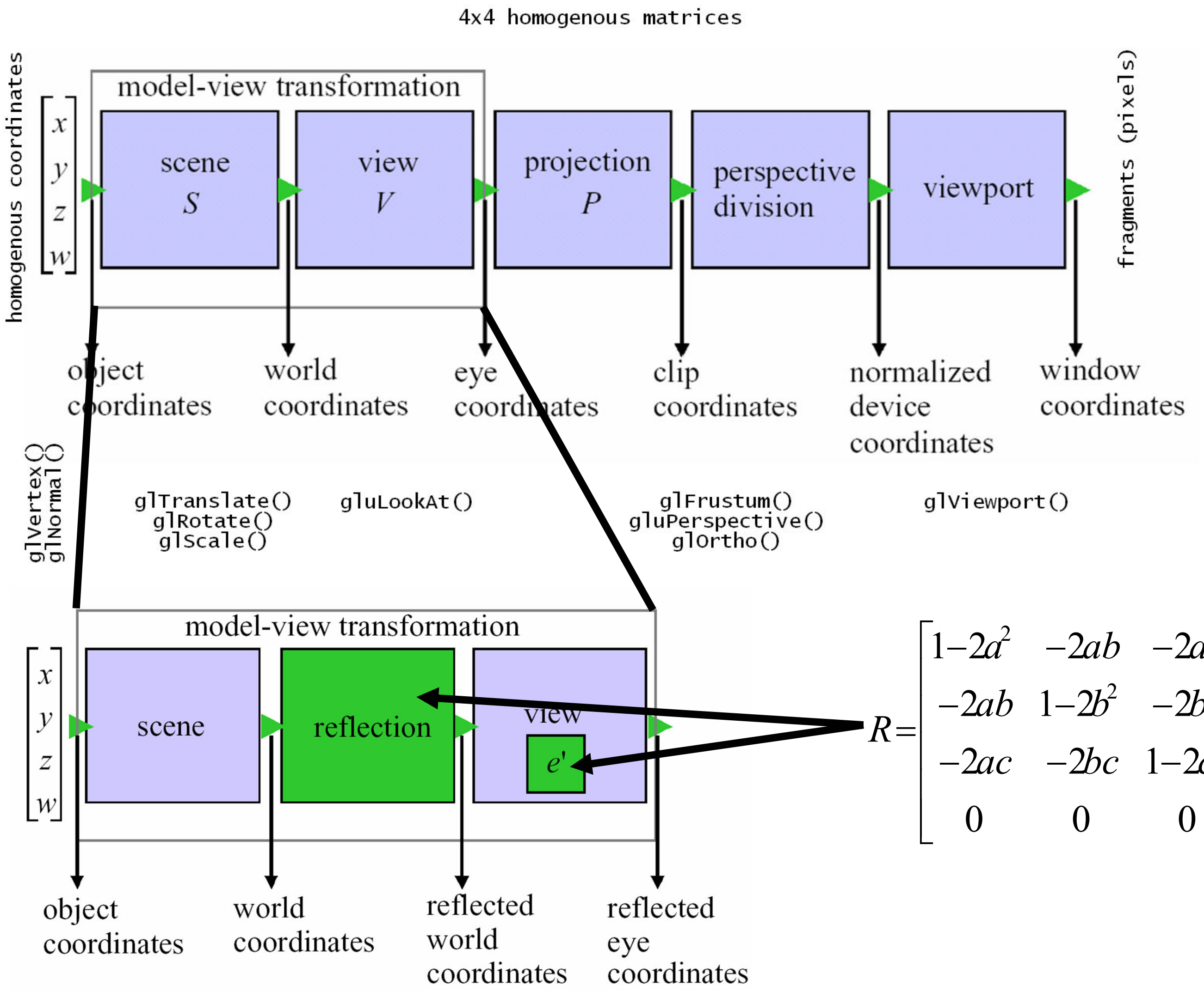


Reflection @ Planar Mirror Displays



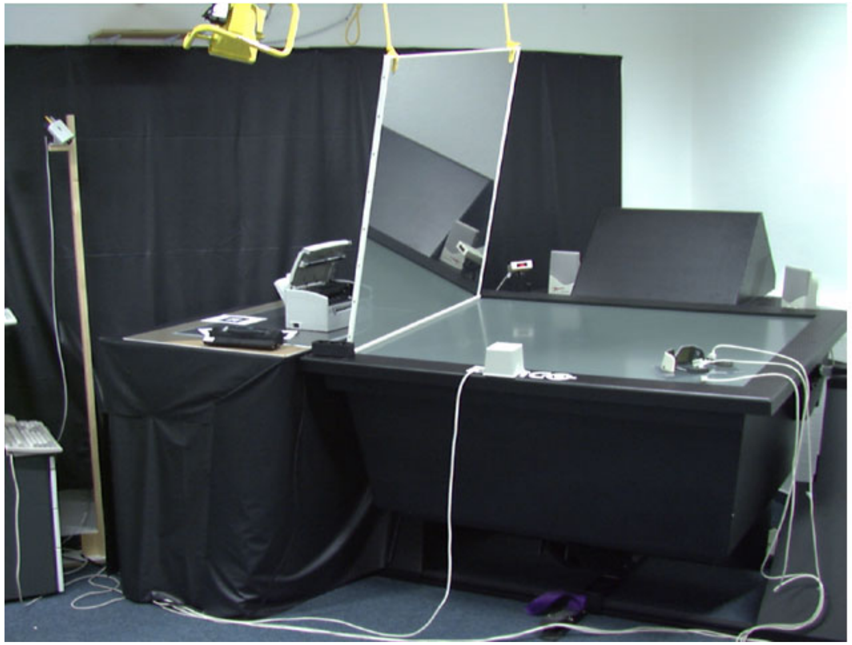
$$R=\begin{bmatrix} 1-2a^2 & -2ab & -2ac & -2ad \\ -2ab & 1-2b^2 & -2bc & -2bd \\ -2ac & -2bc & 1-2c^2 & -2cd \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

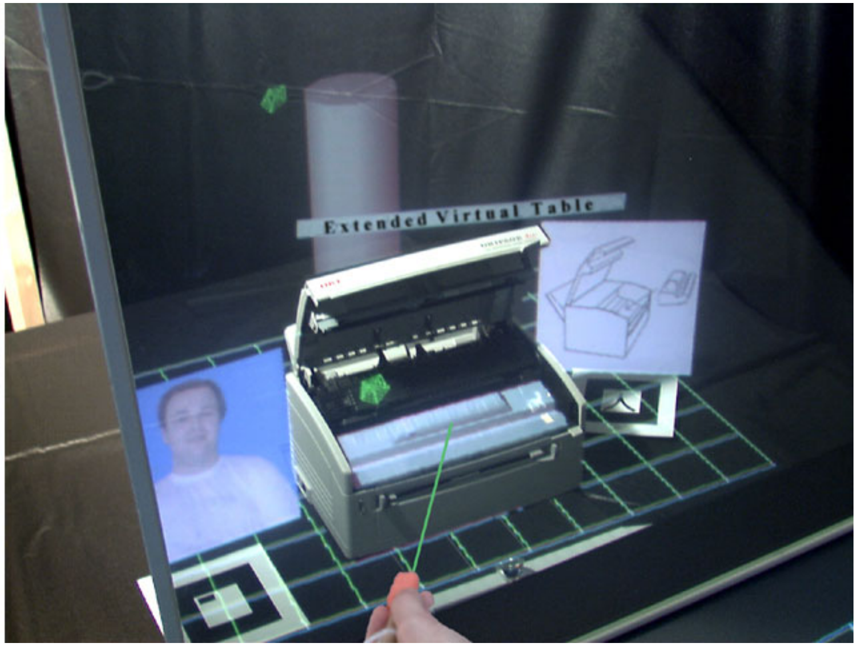
Reflection @ Planar Mirror Displays



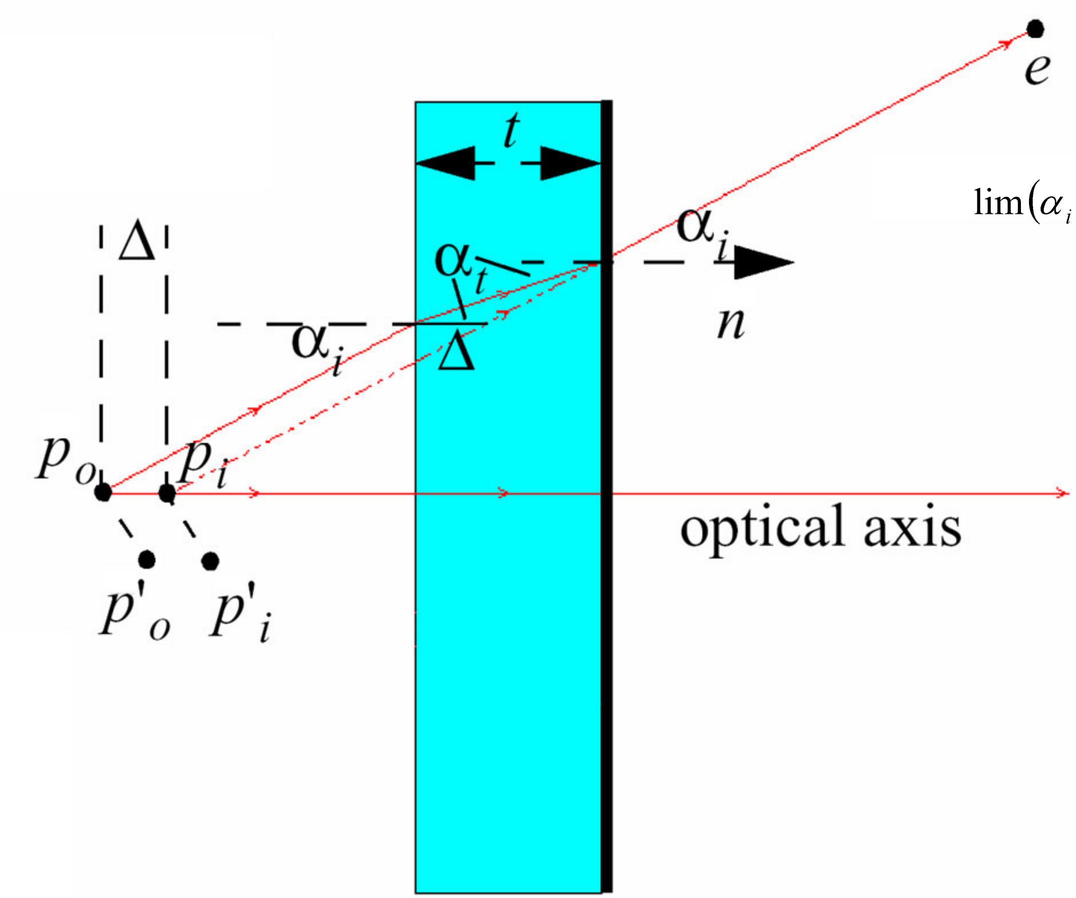
$$R=\begin{bmatrix} 1-2a^2 & -2ab & -2ac & -2ad \\ -2ab & 1-2b^2 & -2bc & -2bd \\ -2ac & -2bc & 1-2c^2 & -2cd \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Reflection @ Planar Mirror Displays





Refraction @ Planar Mirror Displays



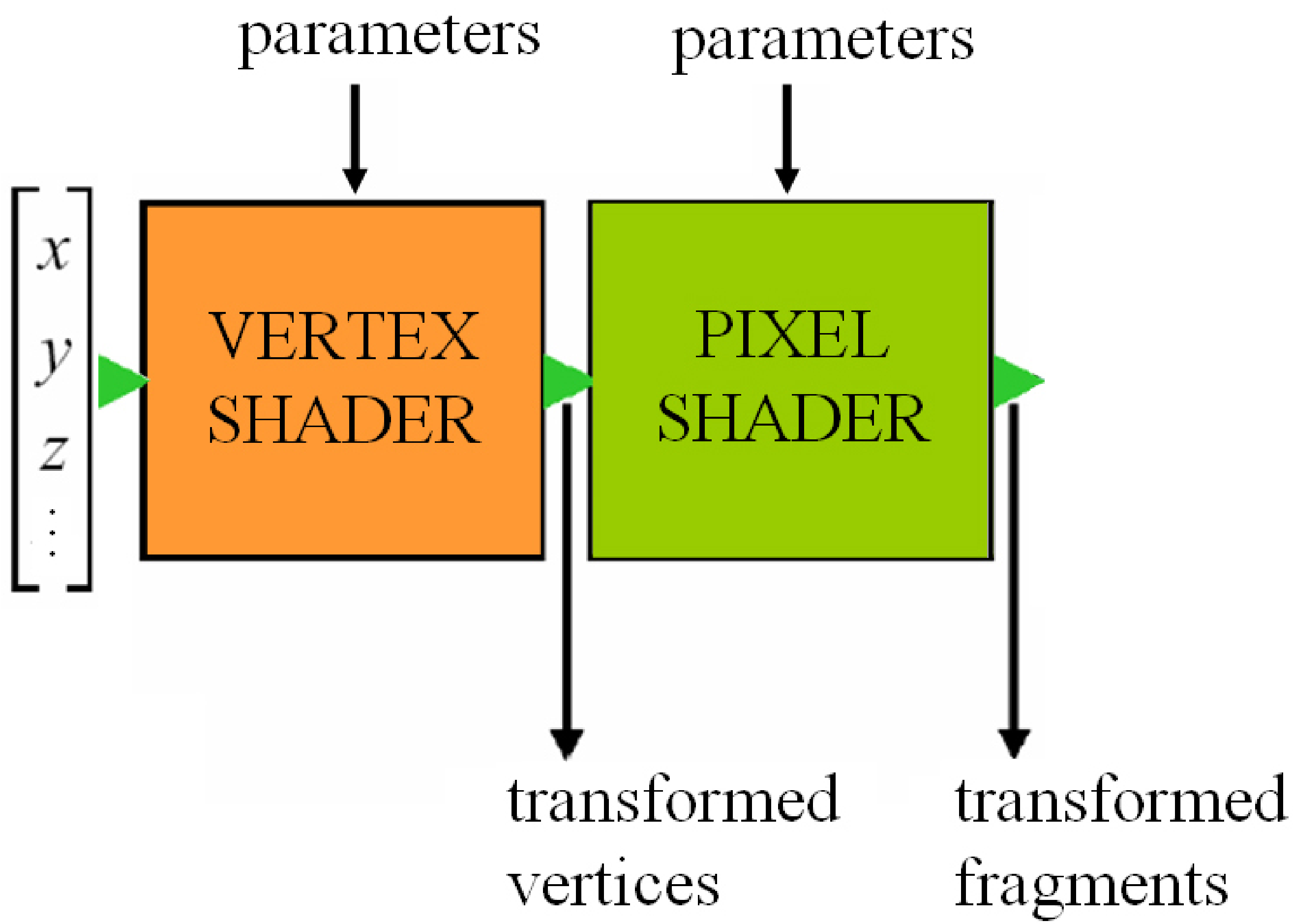
$$\Delta = t\left(1 - \frac{\tan\alpha_t}{\tan\alpha_i}\right)$$

$$\lim\left(\alpha_i \rightarrow \frac{\pi}{2}\right) \Rightarrow \Delta = t$$

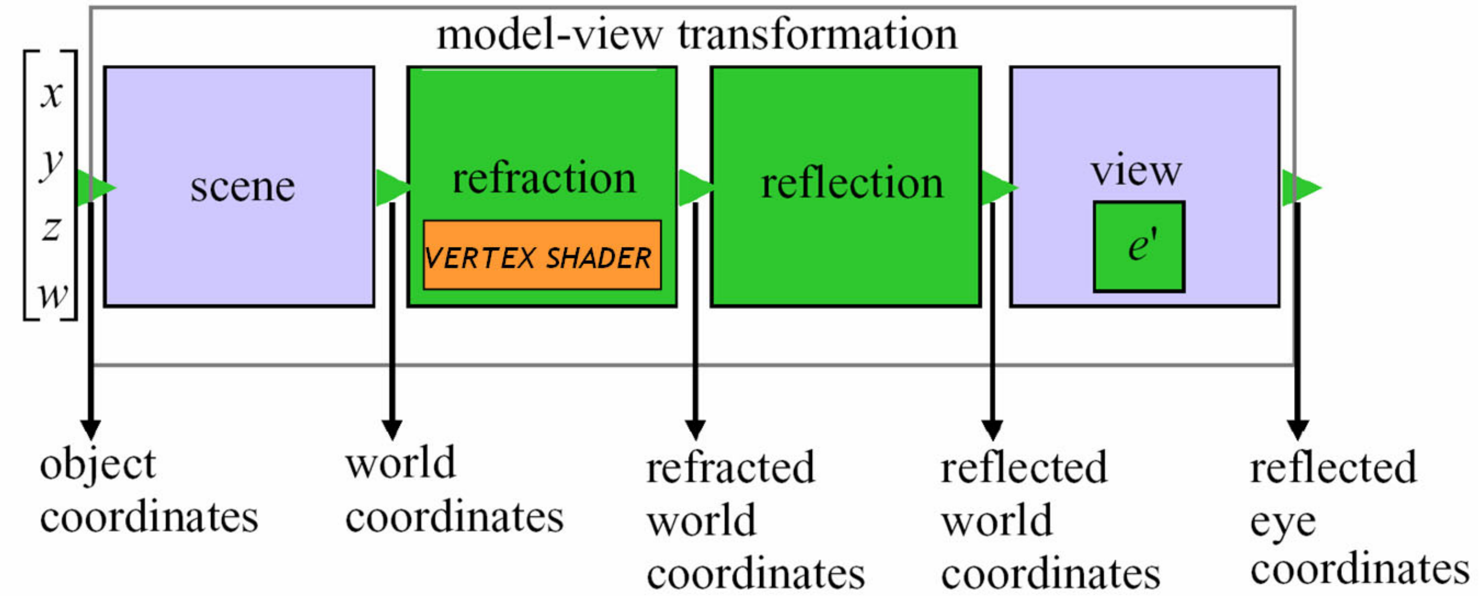
$$\lim(\alpha_i \rightarrow 0) \Rightarrow \Delta = t\left(1 - \frac{\sin\alpha_t}{\sin\alpha_i}\right) = t\left(1 - \frac{1}{\eta_2}\right) = const.$$

$$F = \begin{bmatrix} 1 & 0 & 0 & \Delta a \\ 0 & 1 & 0 & \Delta b \\ 0 & 0 & 1 & \Delta c \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

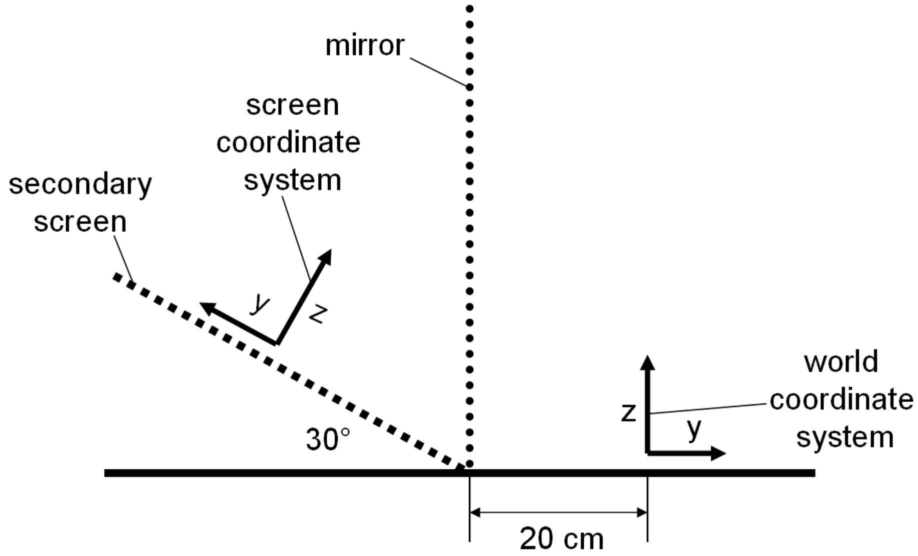
Programmable Pipeline Rendering

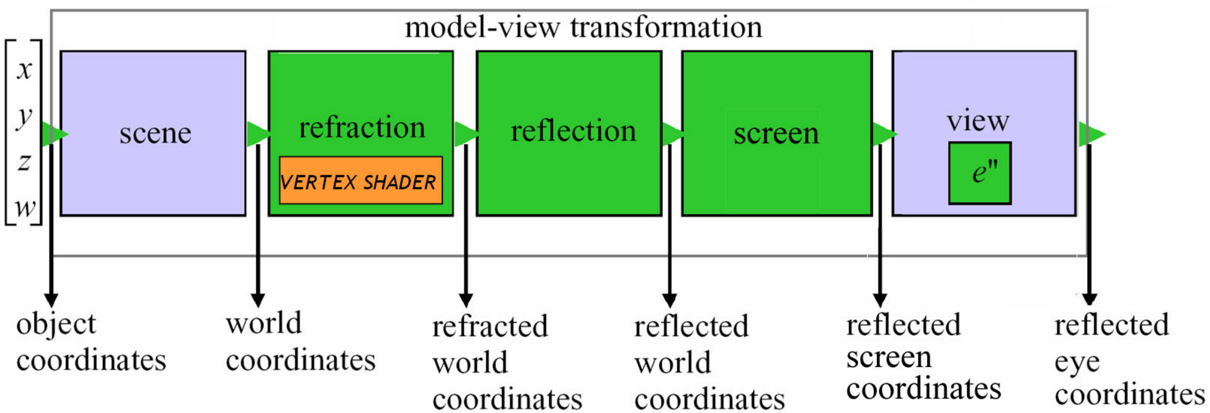


Refraction @ Planar Mirror Displays

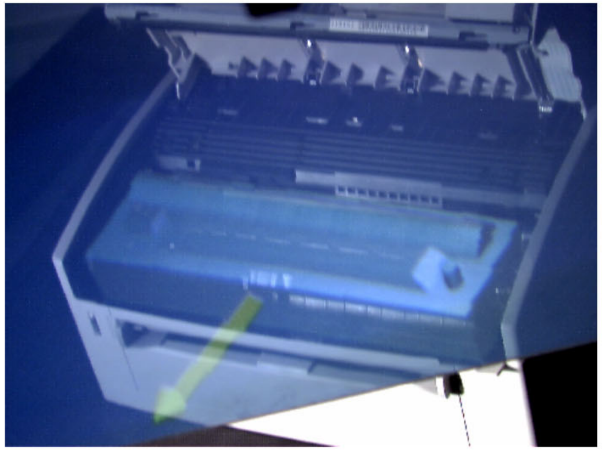


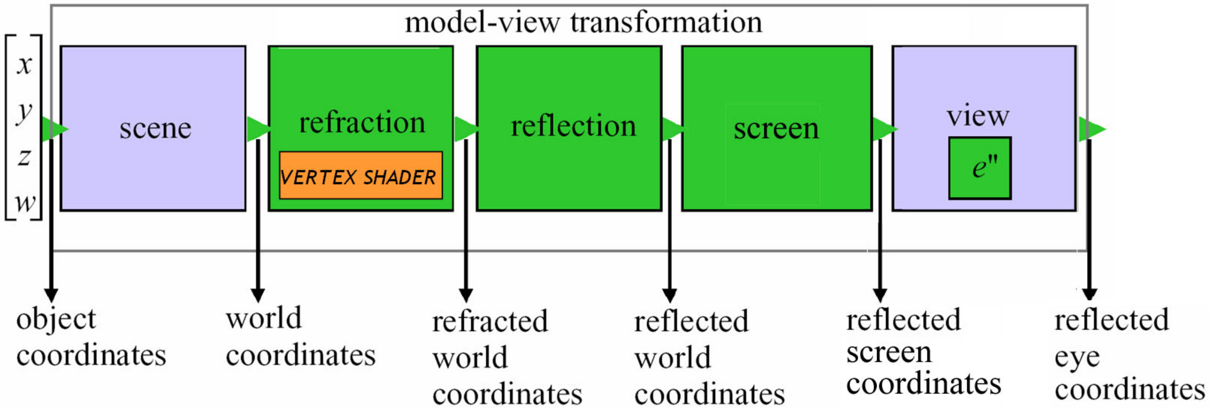
Screen Transformations



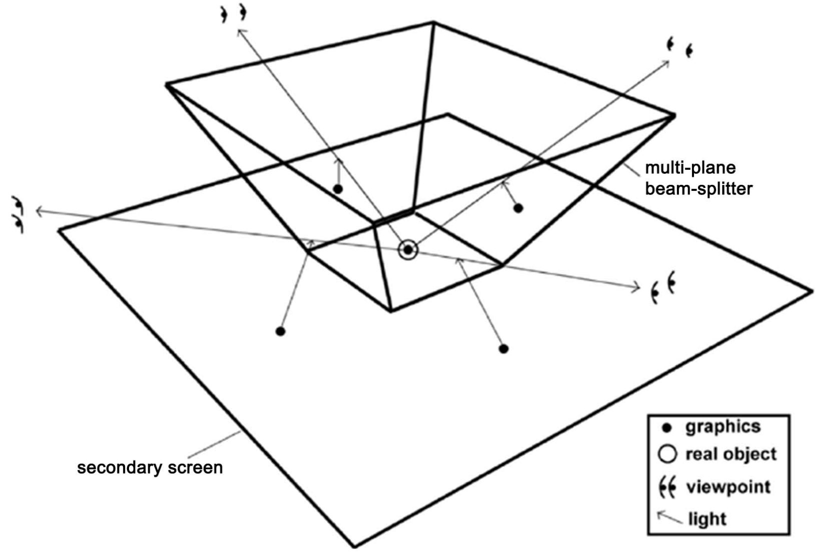


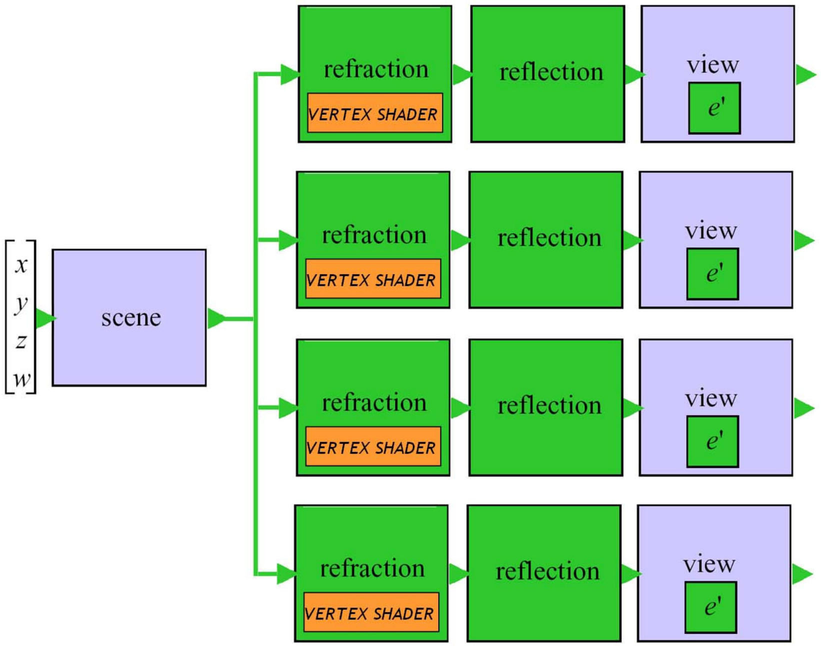
Moving Components



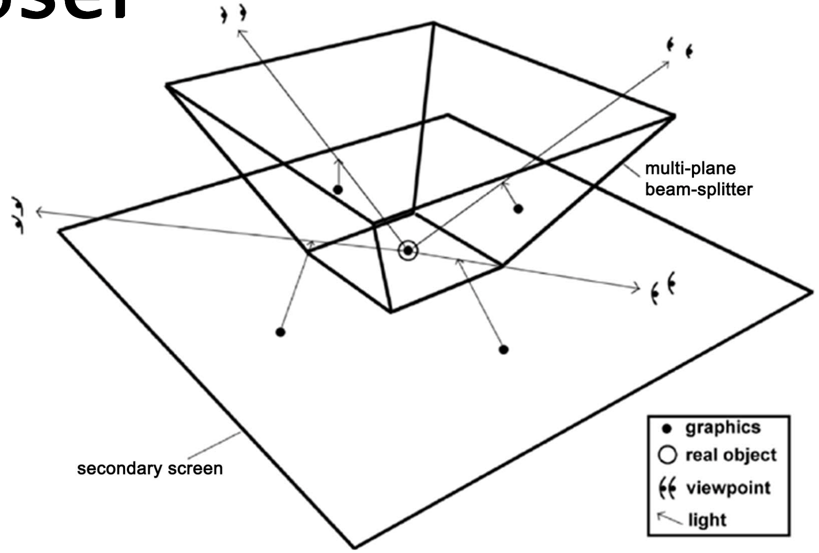


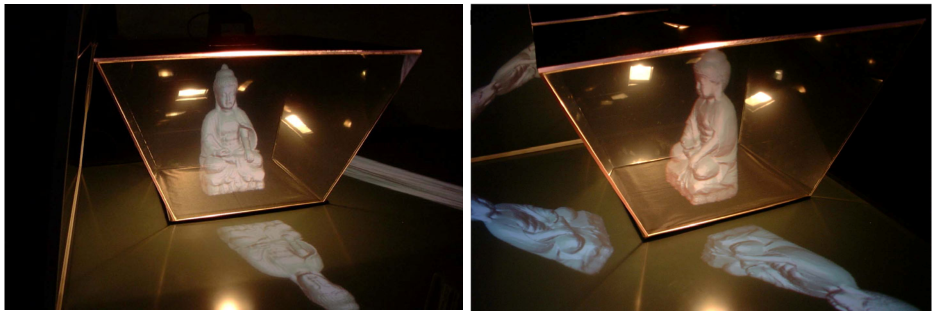
Multi-Plane Mirror Displays: Single User

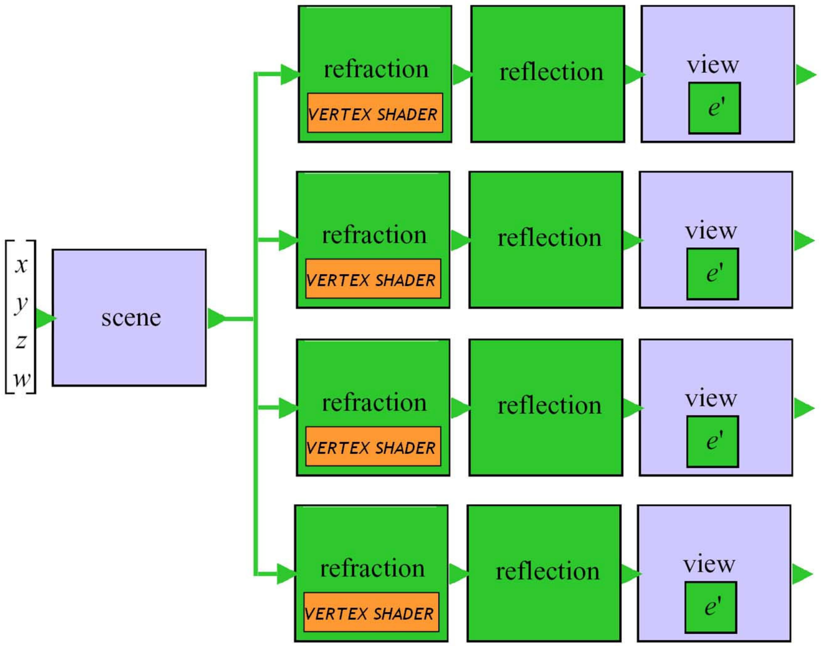




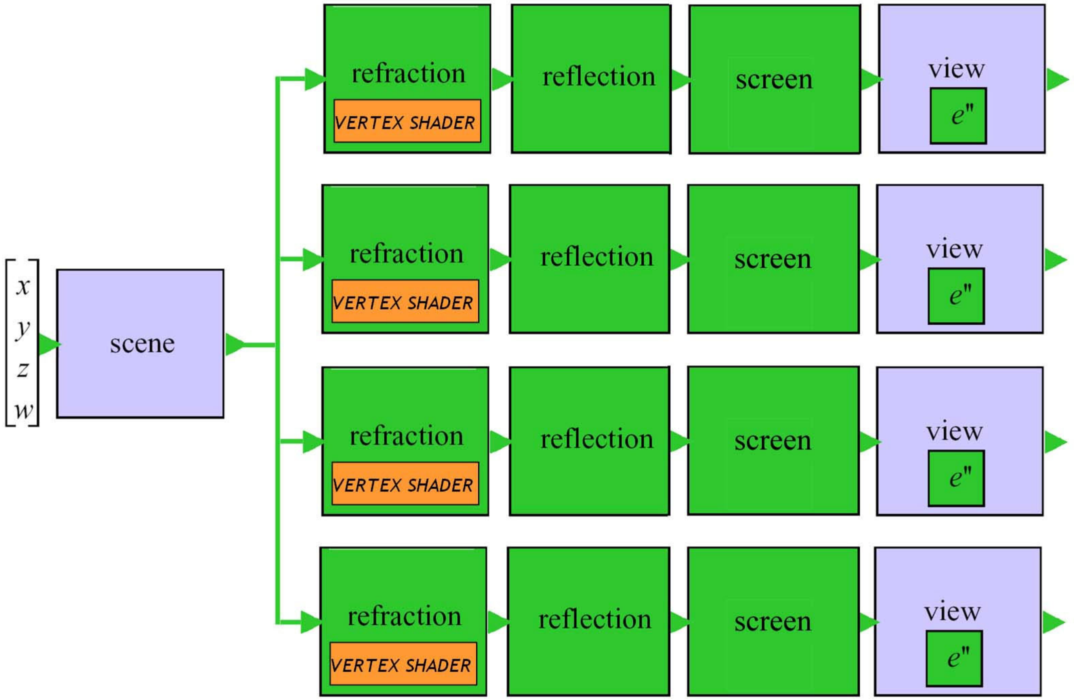
Multi-Plane Mirror Displays: Multiple User

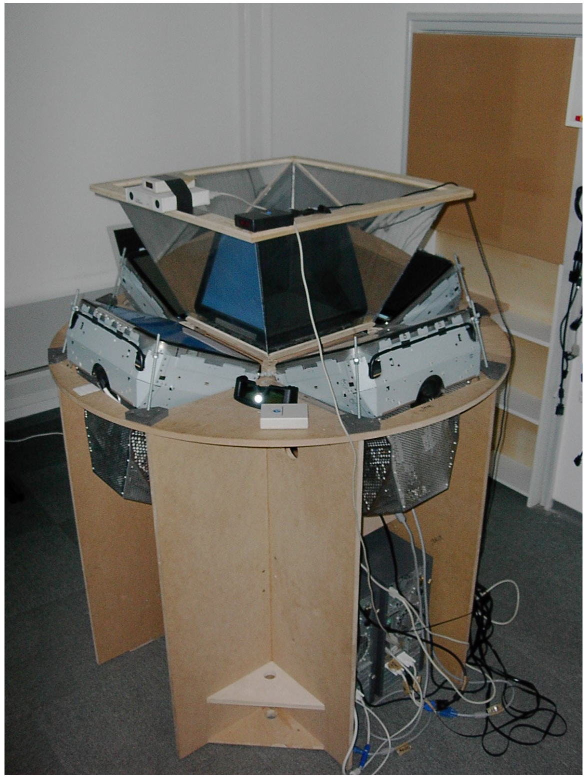




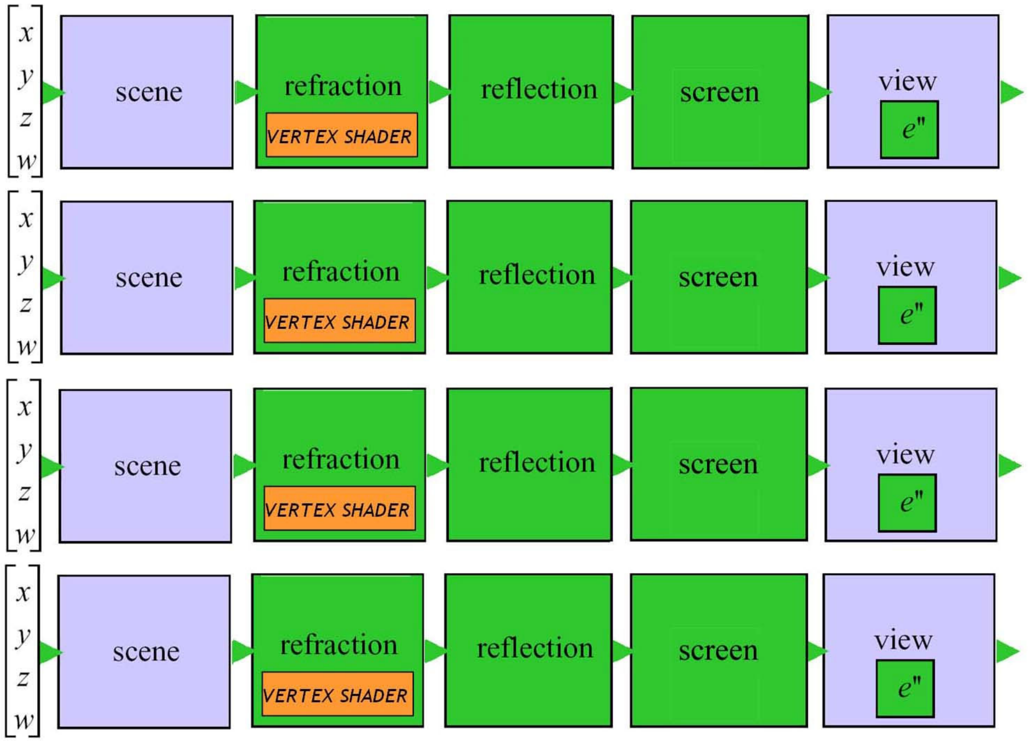


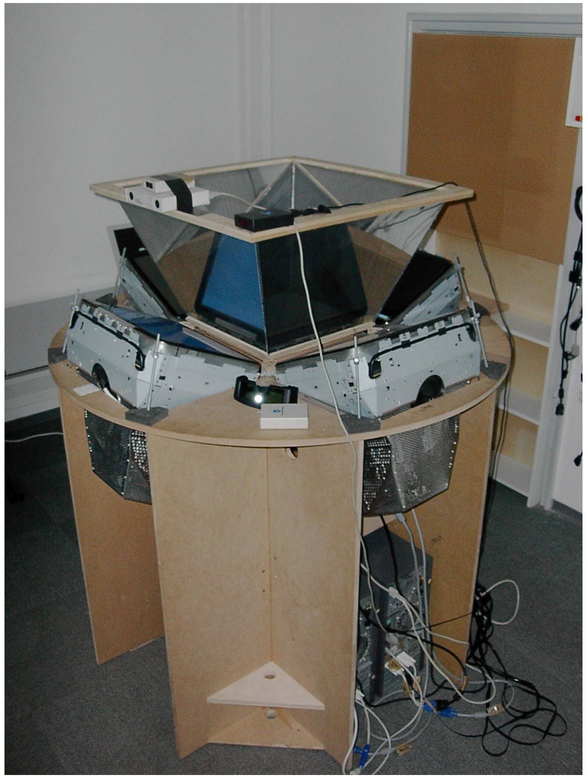
Multi-Plane Mirror Displays: Multiple Screens



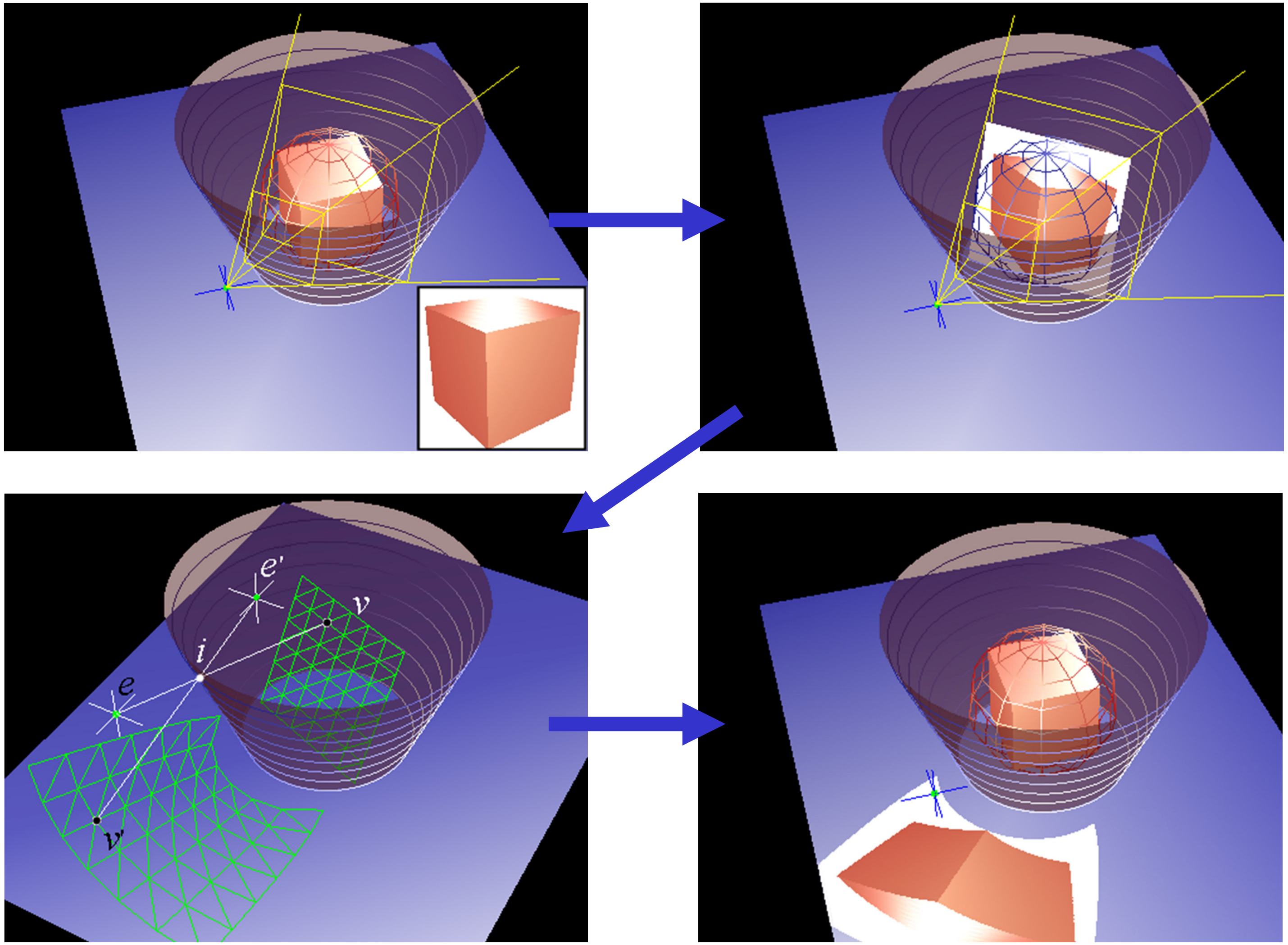


Multi-Plane Mirror Displays: Individual Scenes

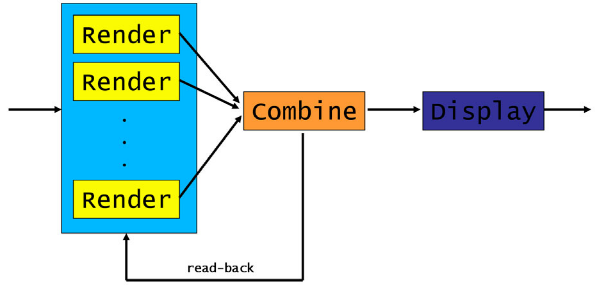


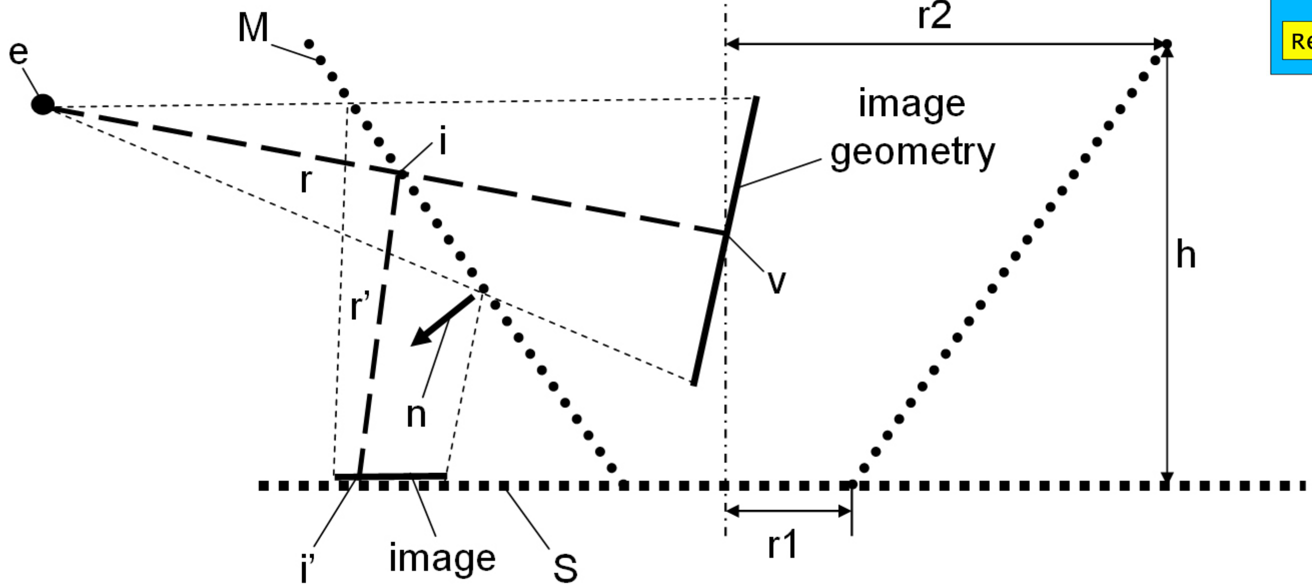


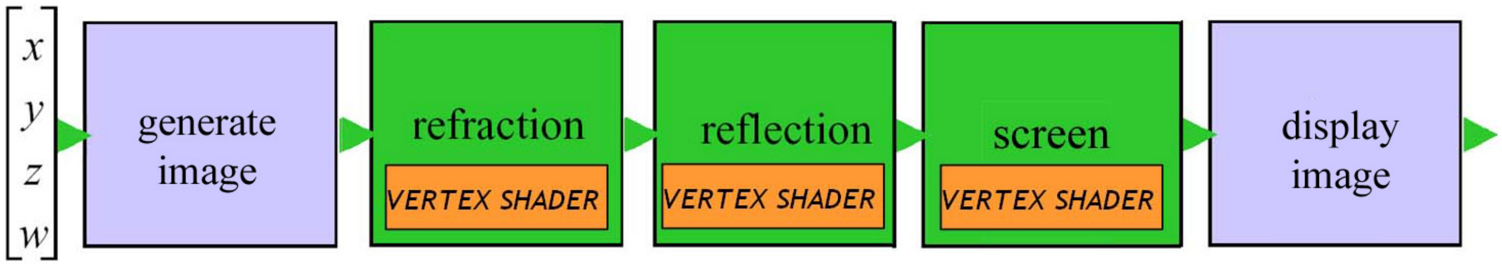
Reflection @ Curved Mirror Displays



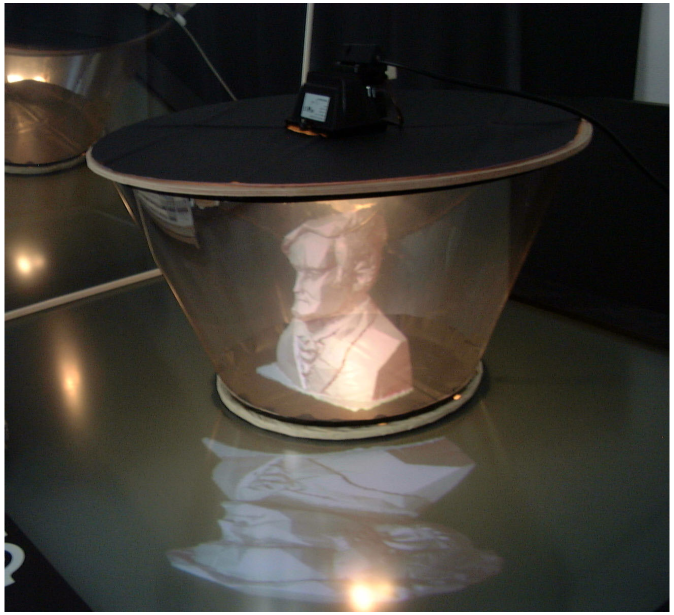
Reflection @ Curved Mirror Displays

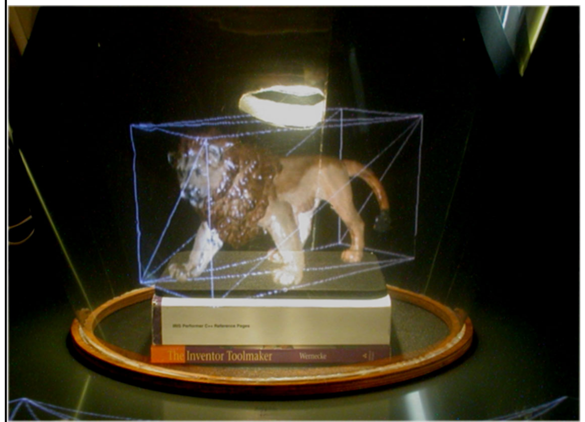
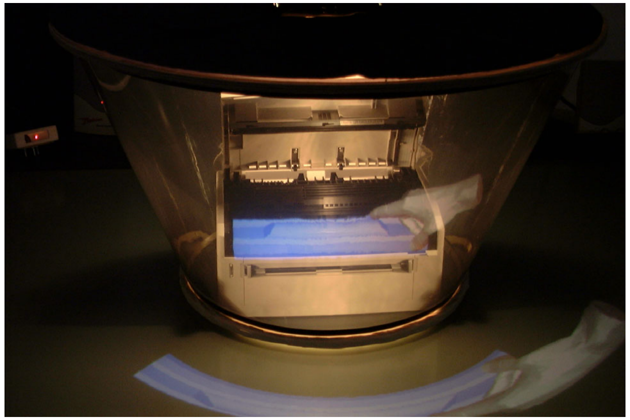
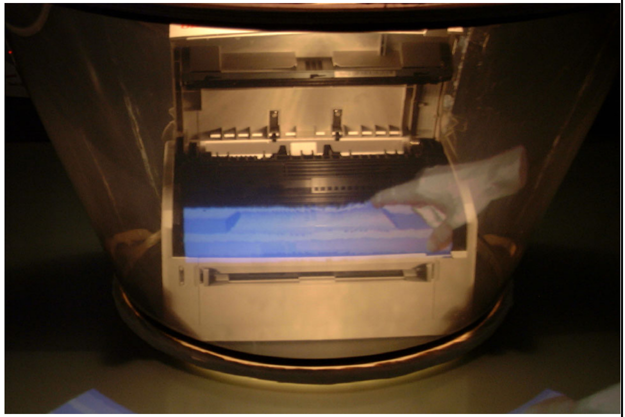




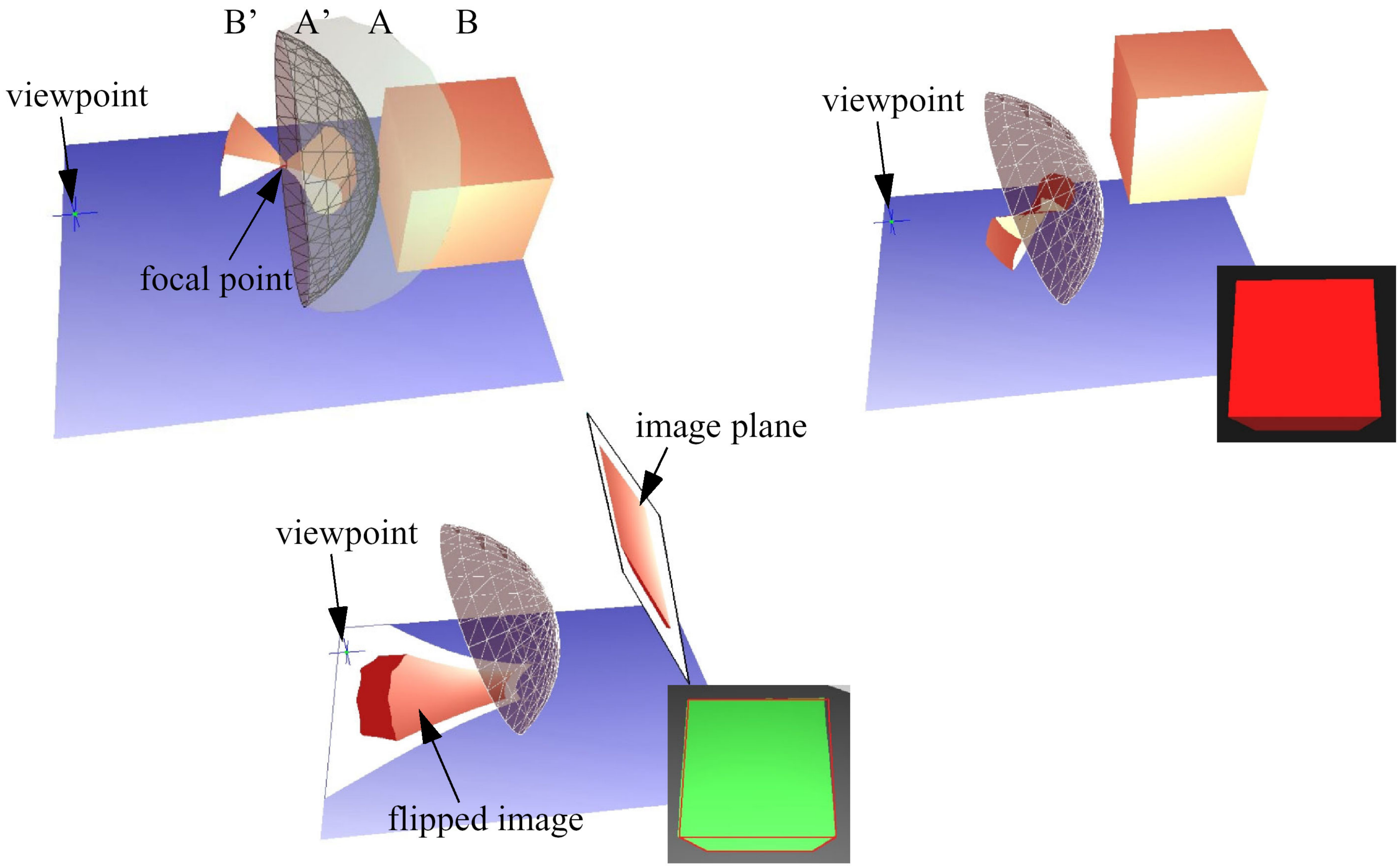


Reflection @ Curved Mirror Displays

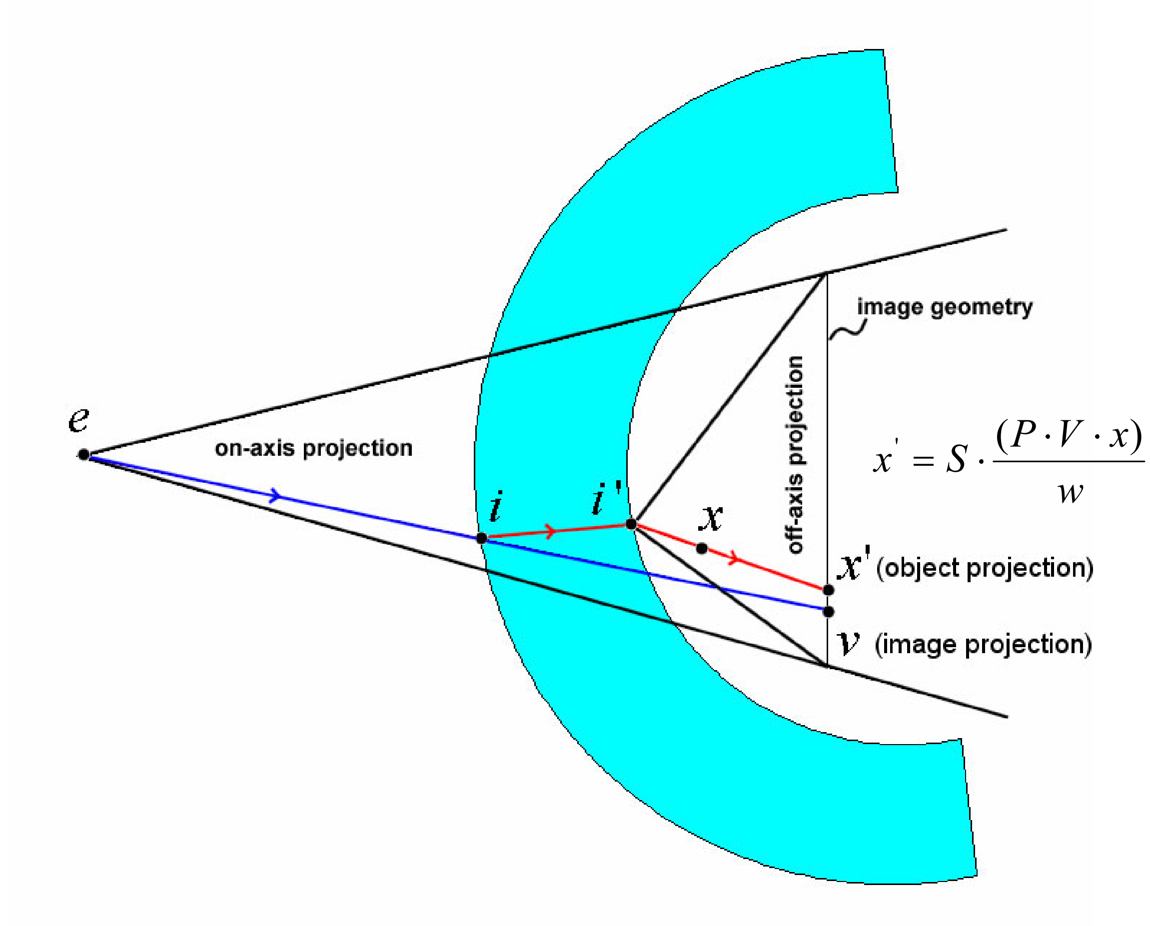


Reflection @ Curved Mirror Displays

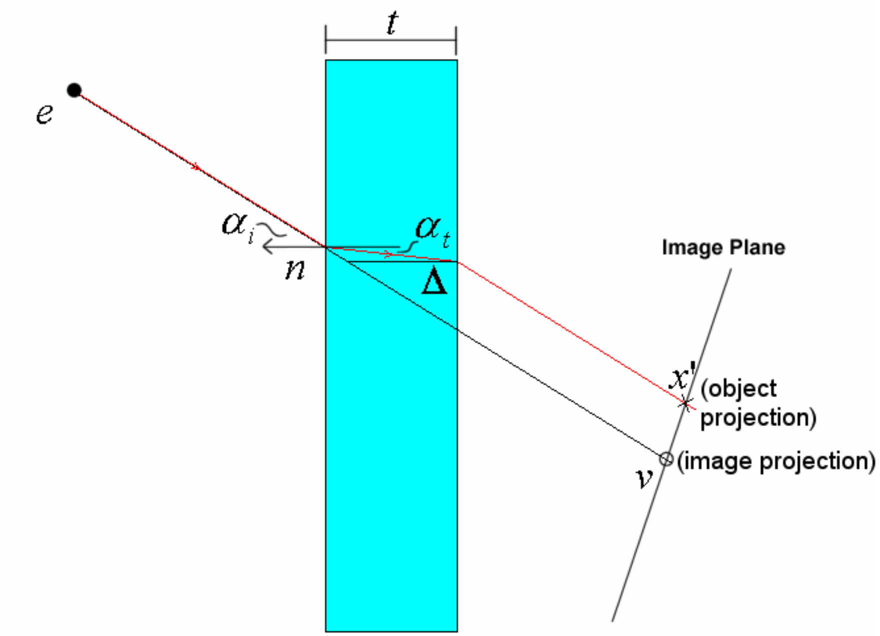


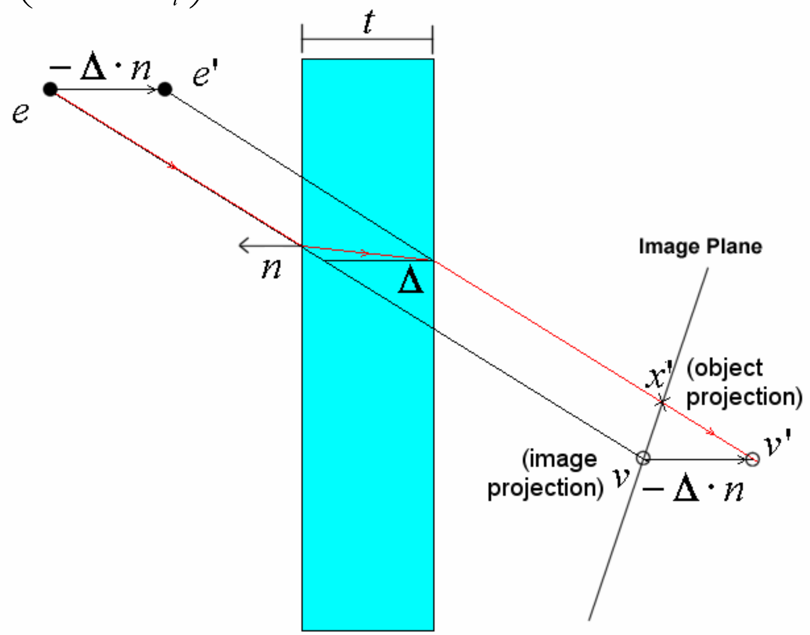
Refraction @ Curved Mirror Displays



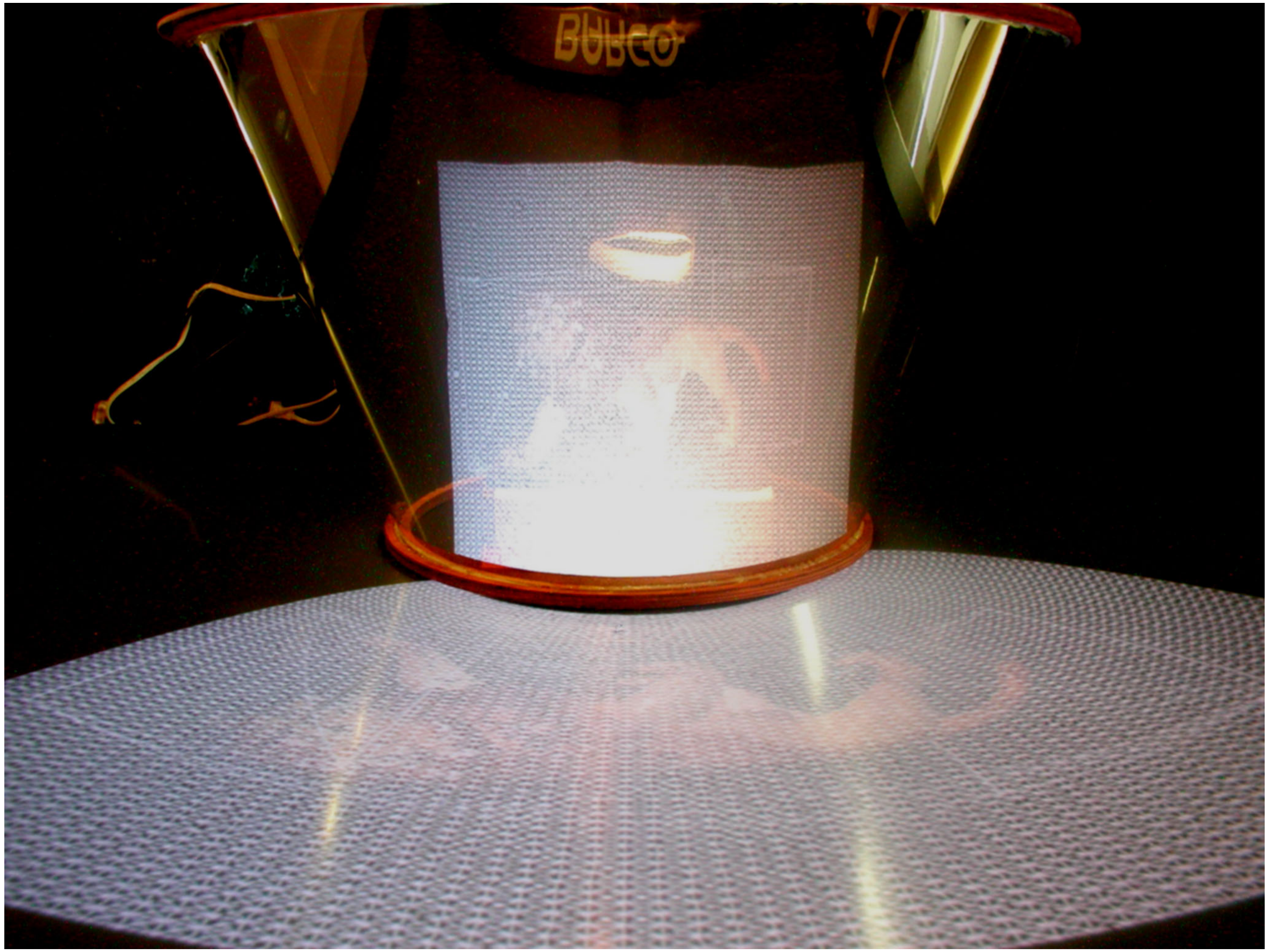
Refraction @ Planar Mirror Displays (cont)

$$\Delta = t\left(1 - \frac{\tan \alpha_t}{\tan \alpha_i}\right)$$

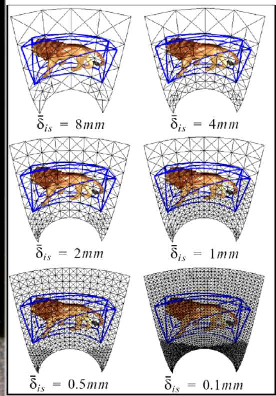


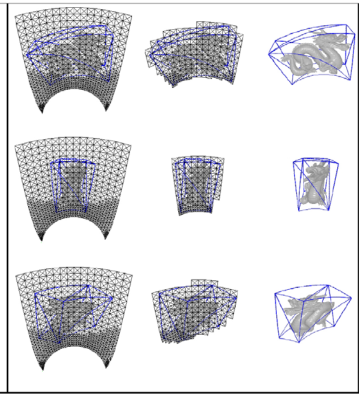


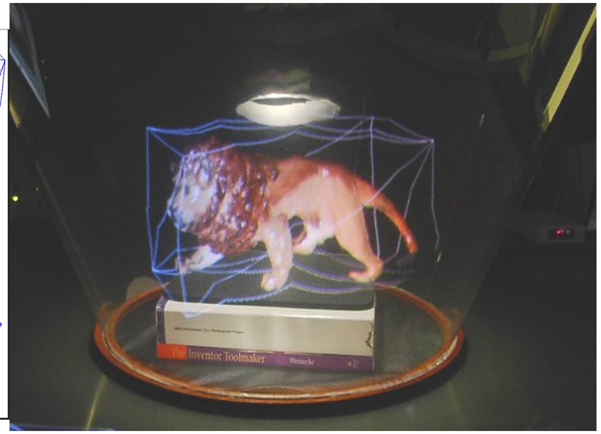
Curved Mirror Displays: Multiple Users

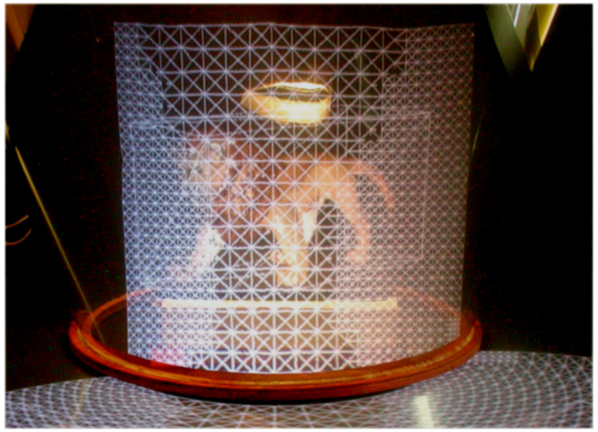


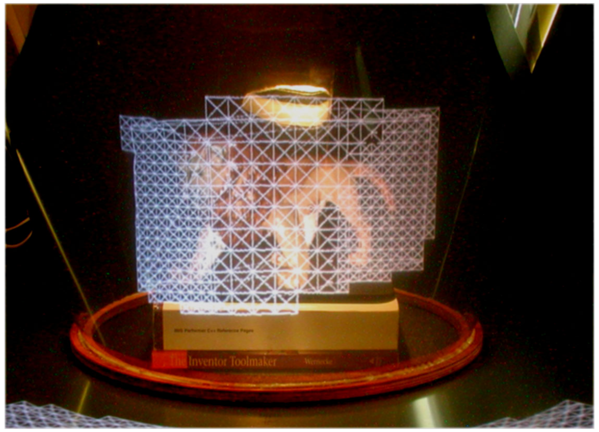
Curved Mirror Displays: LOD Rendering

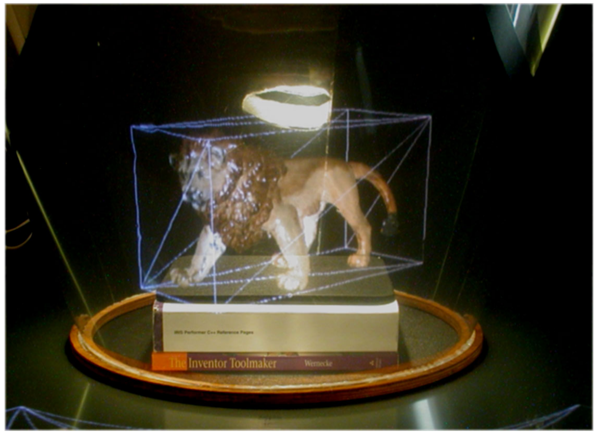




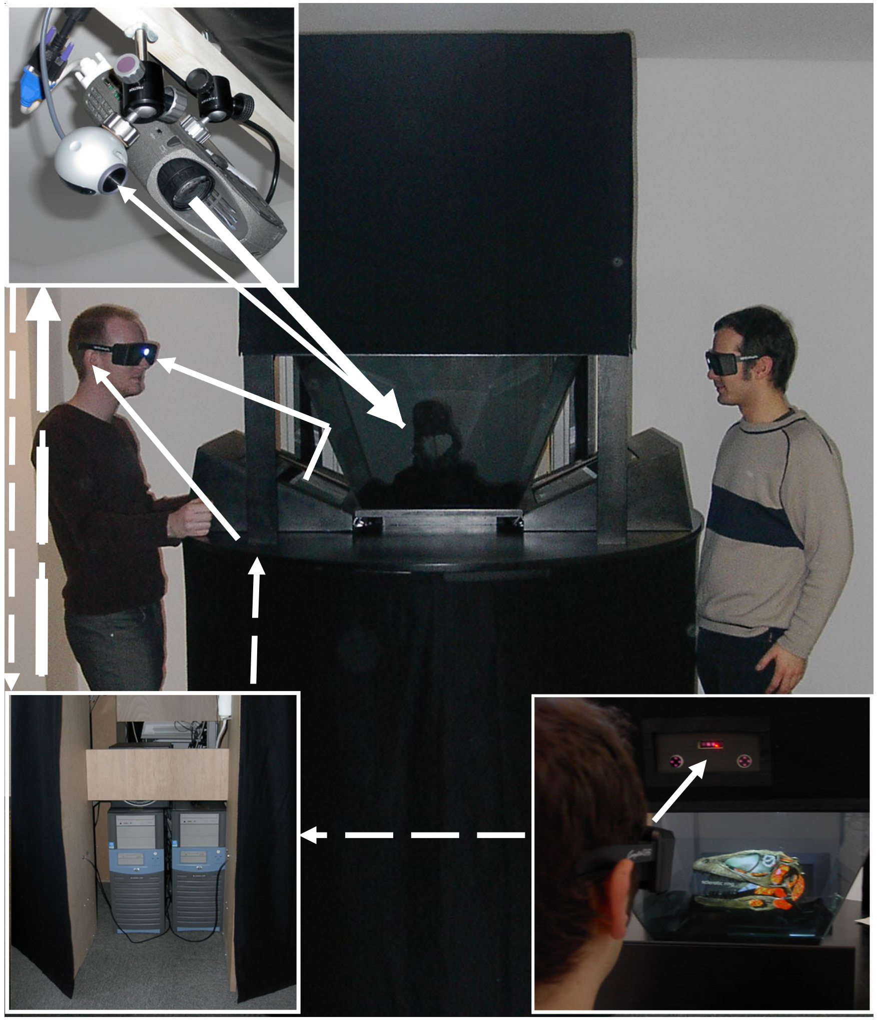




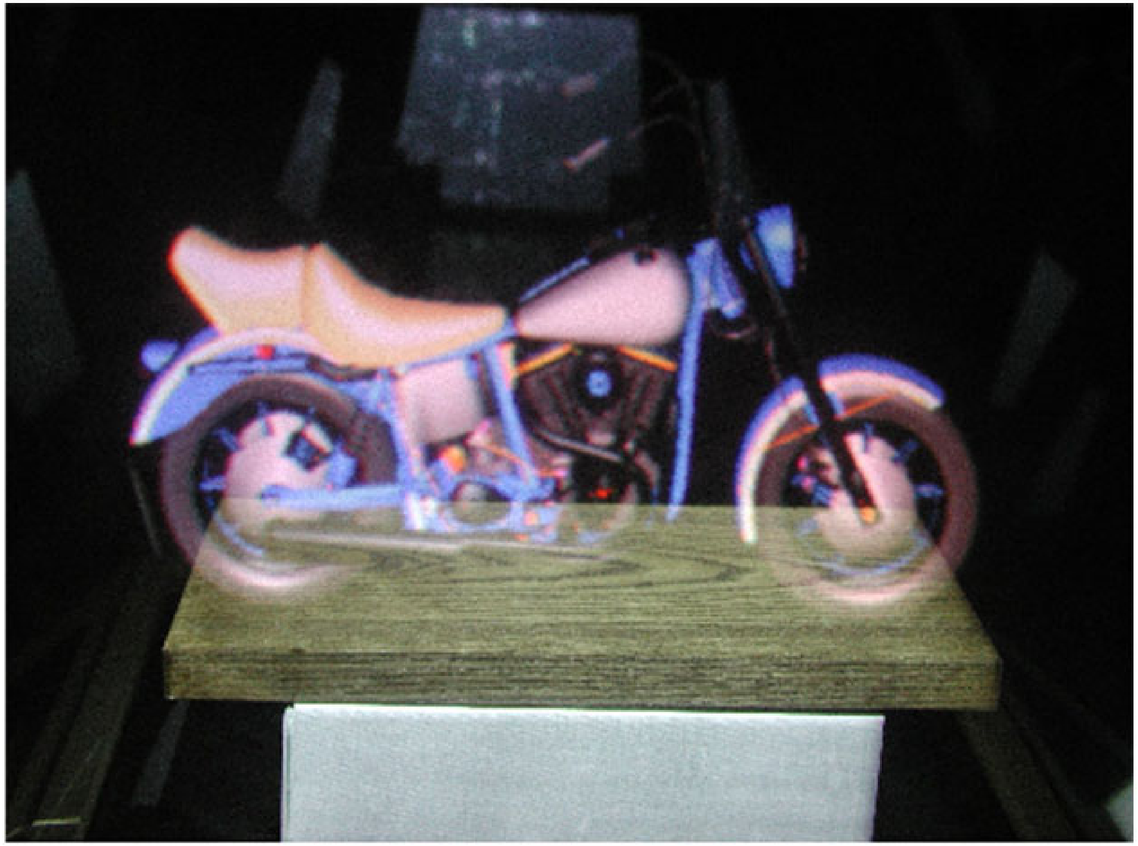




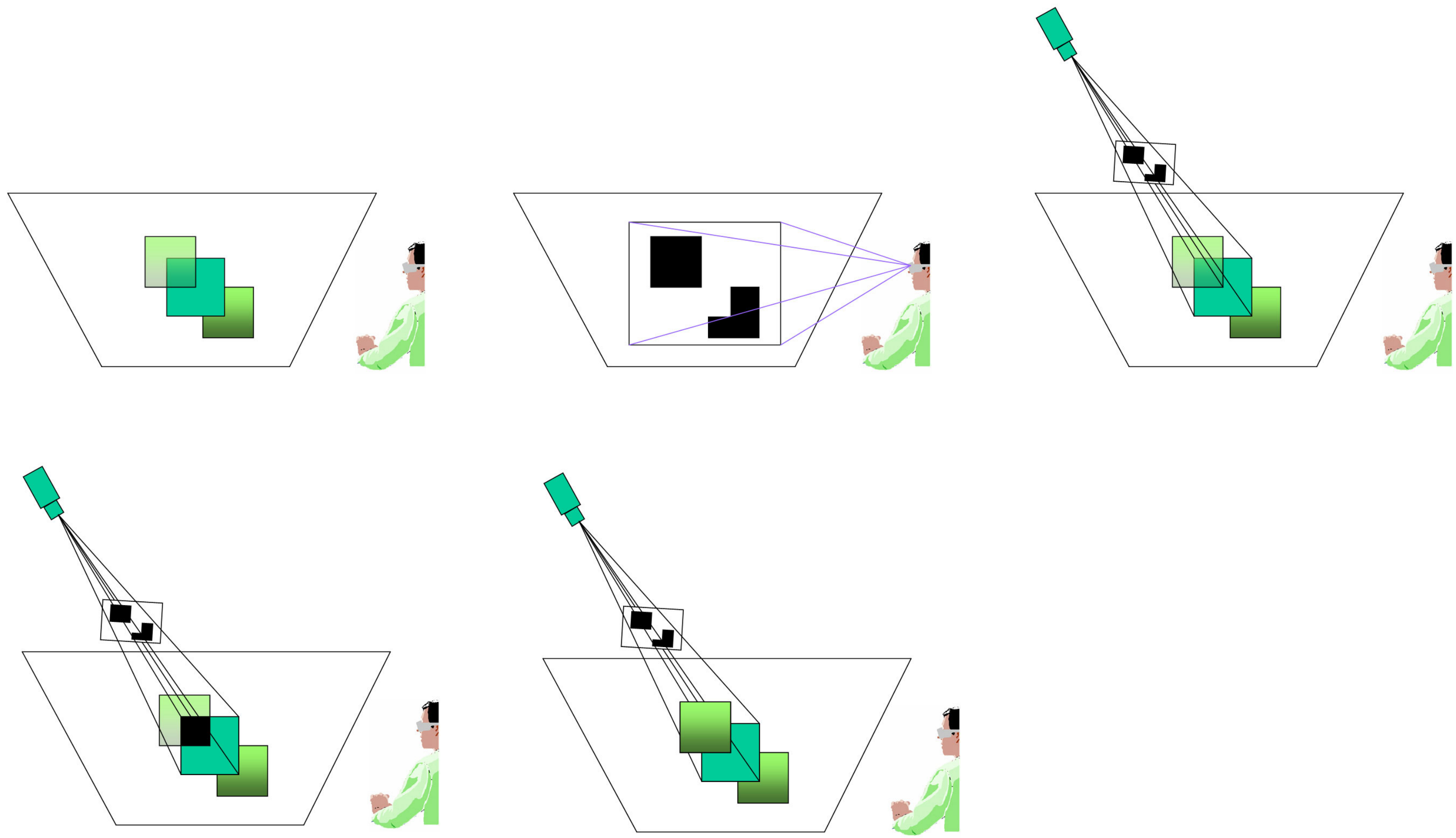
Projector-Based Illumination: Example Virtual Showcase



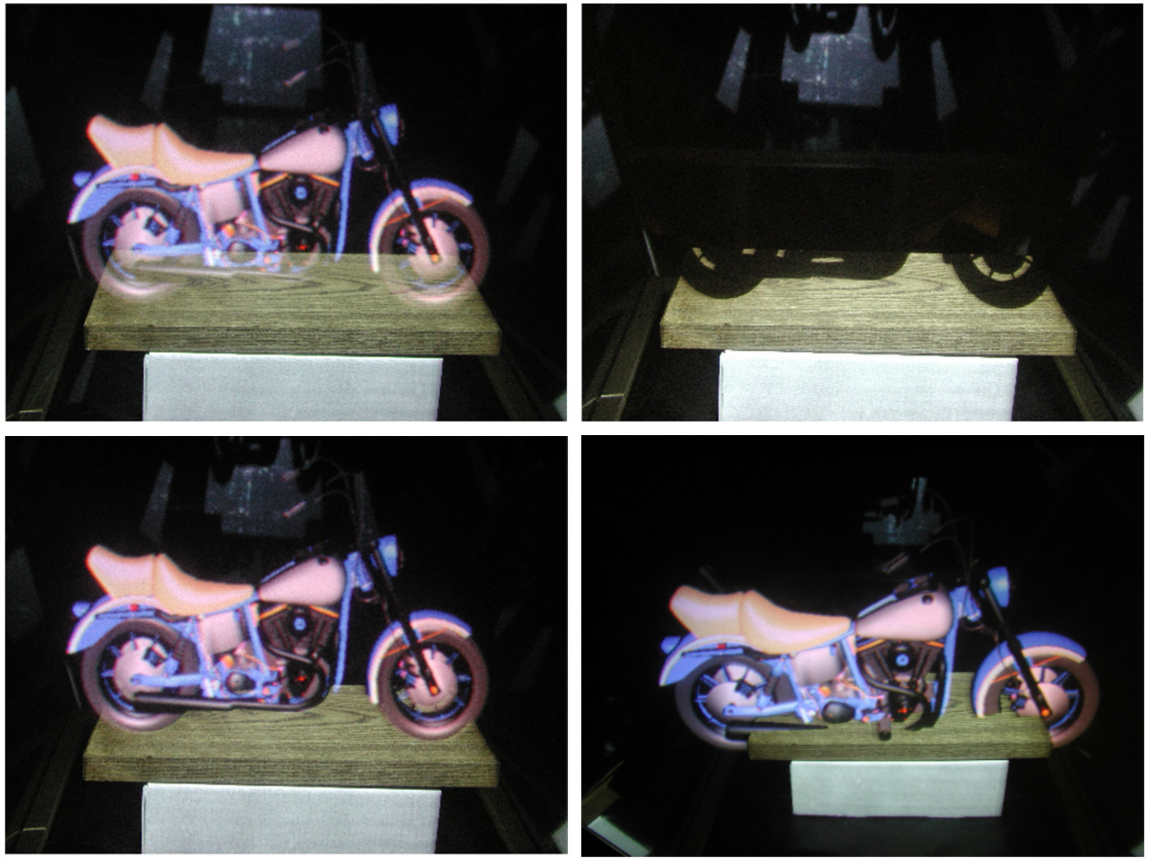
Mutual Occlusion: Single User Occlusion Shadows

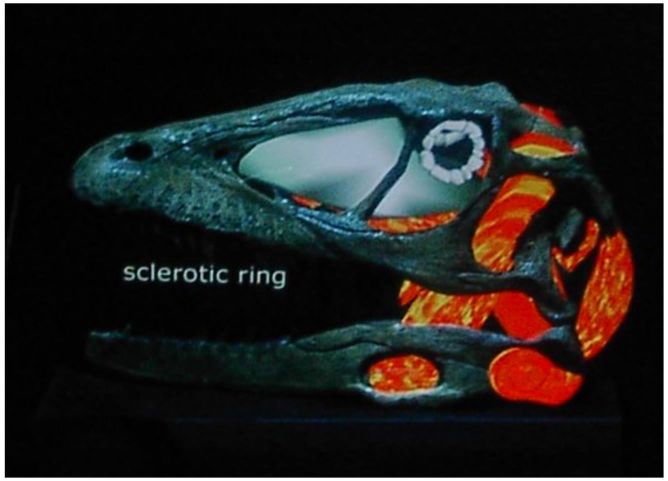


Mutual Occlusion: Single User Occlusion Shadows

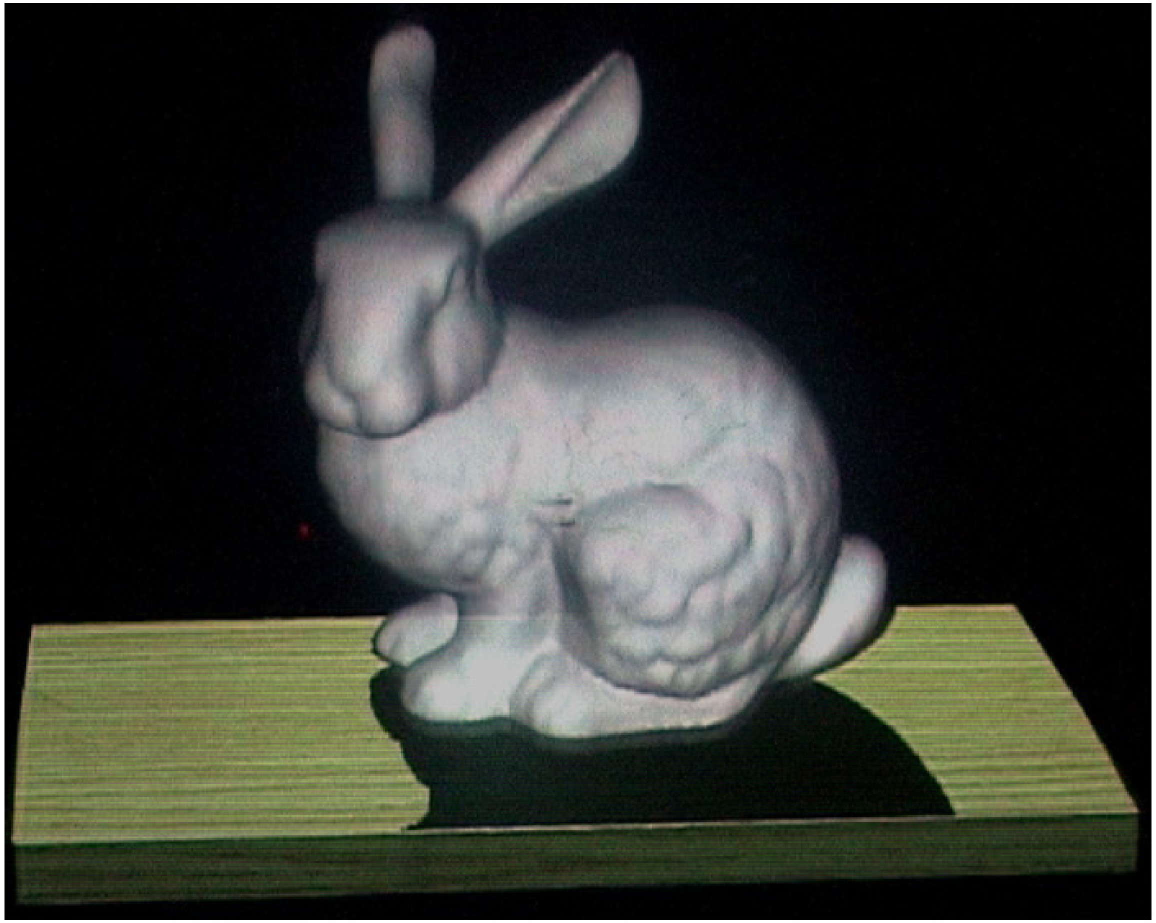


Mutual Occlusion: Single User Occlusion Shadows

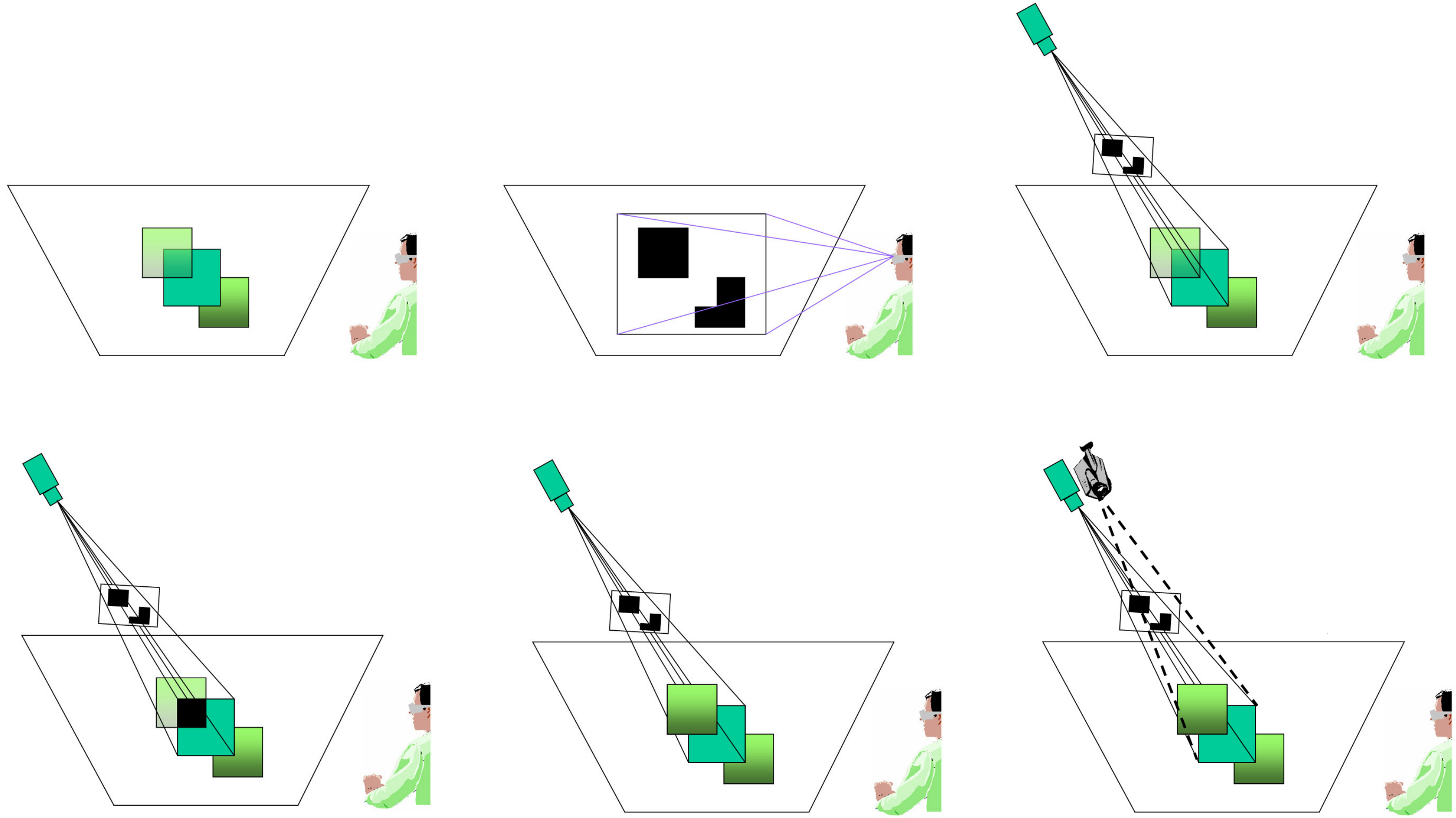




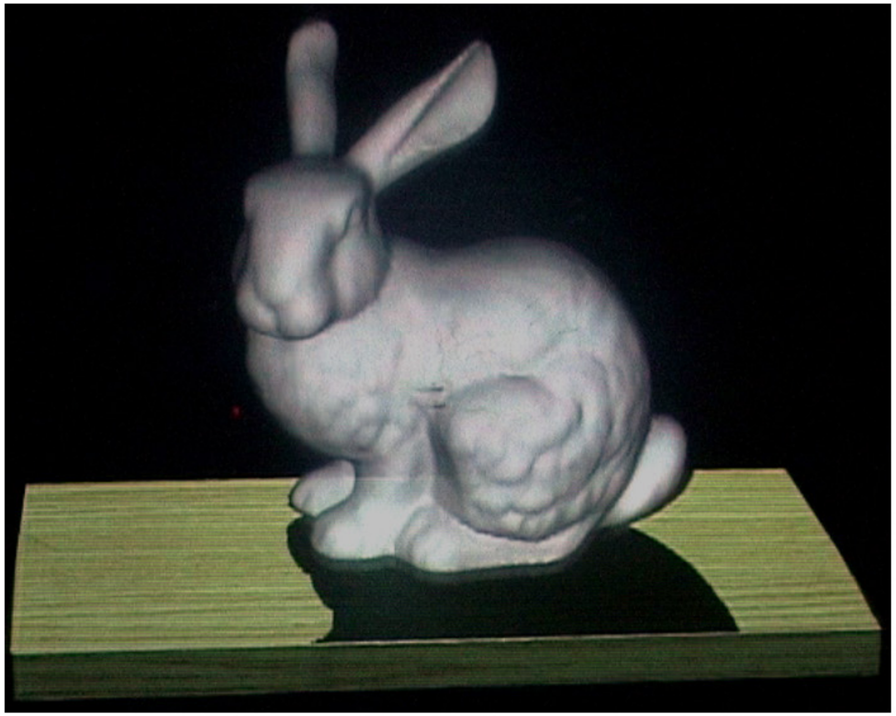
Mutual Occlusion: Multi User Occlusion Shadows

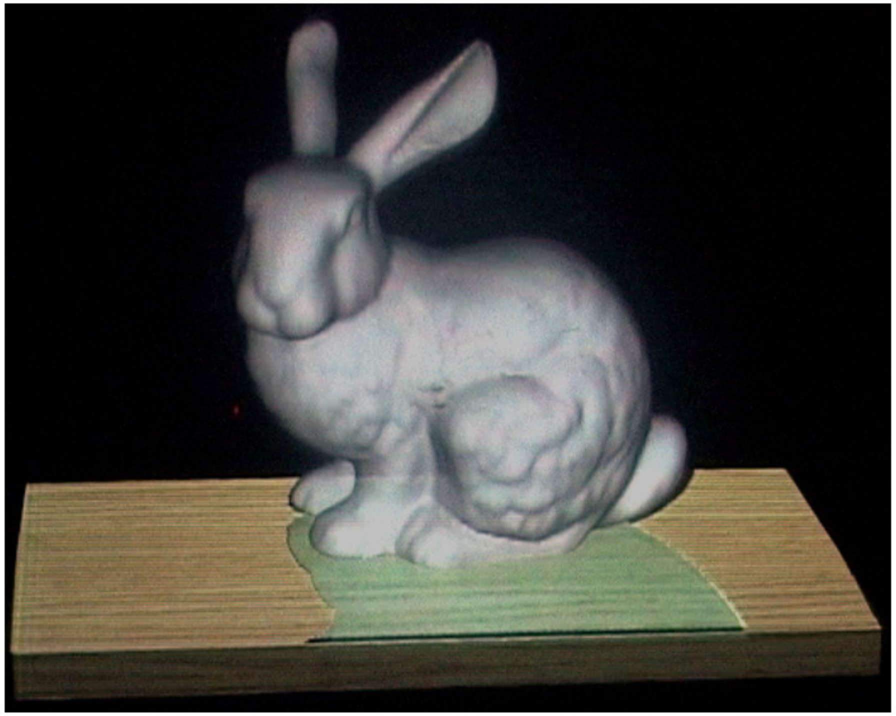


Mutual Occlusion: Multi User Occlusion Shadows

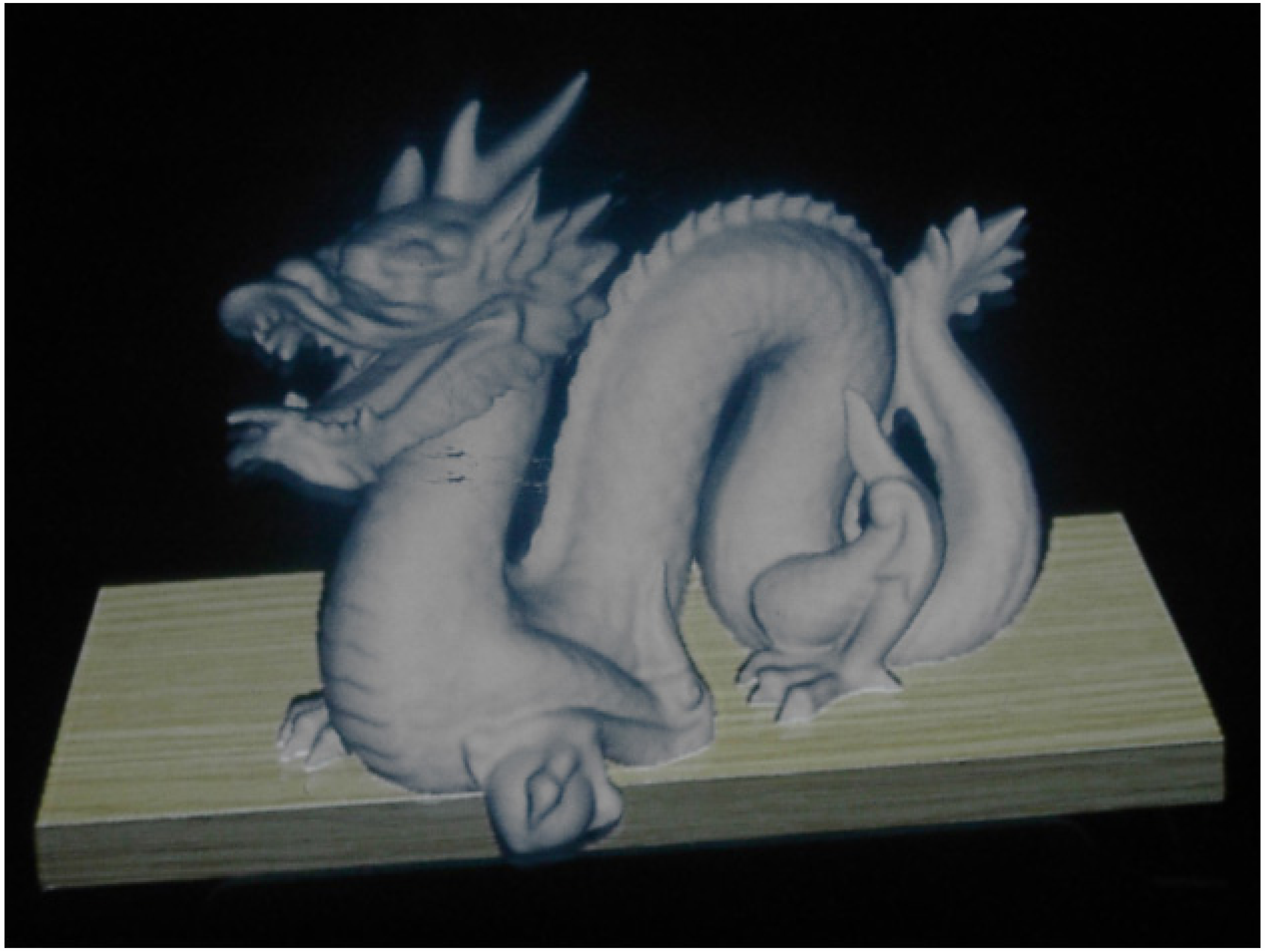


Mutual Occlusion: Multi User Occlusion Shadows

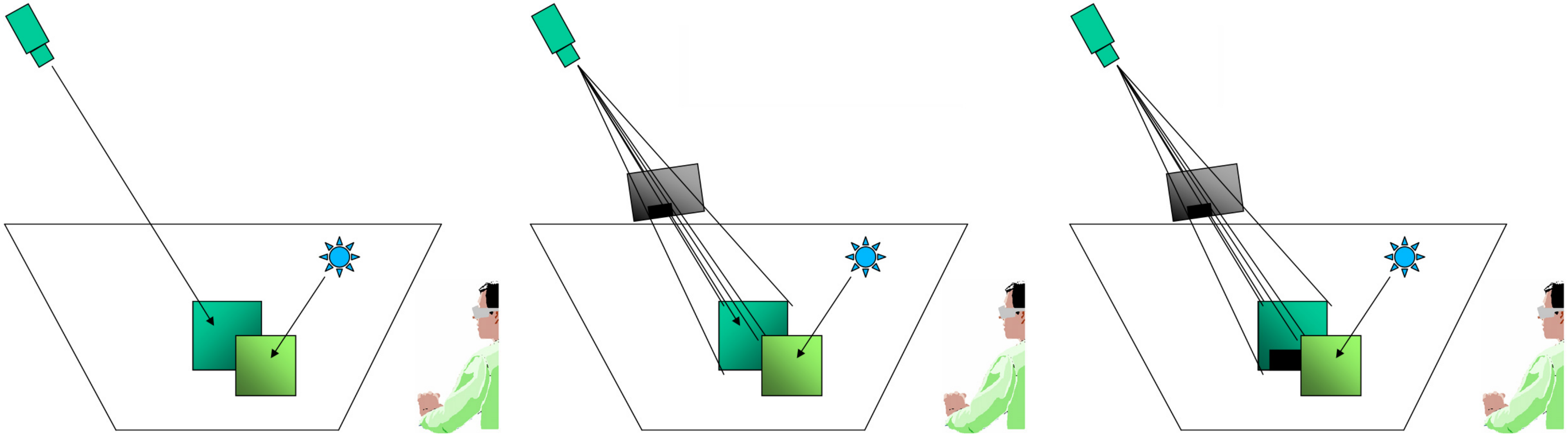




Consistent Local Illumination



Consistent Local Illumination



$$I_i = \frac{1}{r_i^2}\cos(\theta_i)(D_l D_m)_i$$

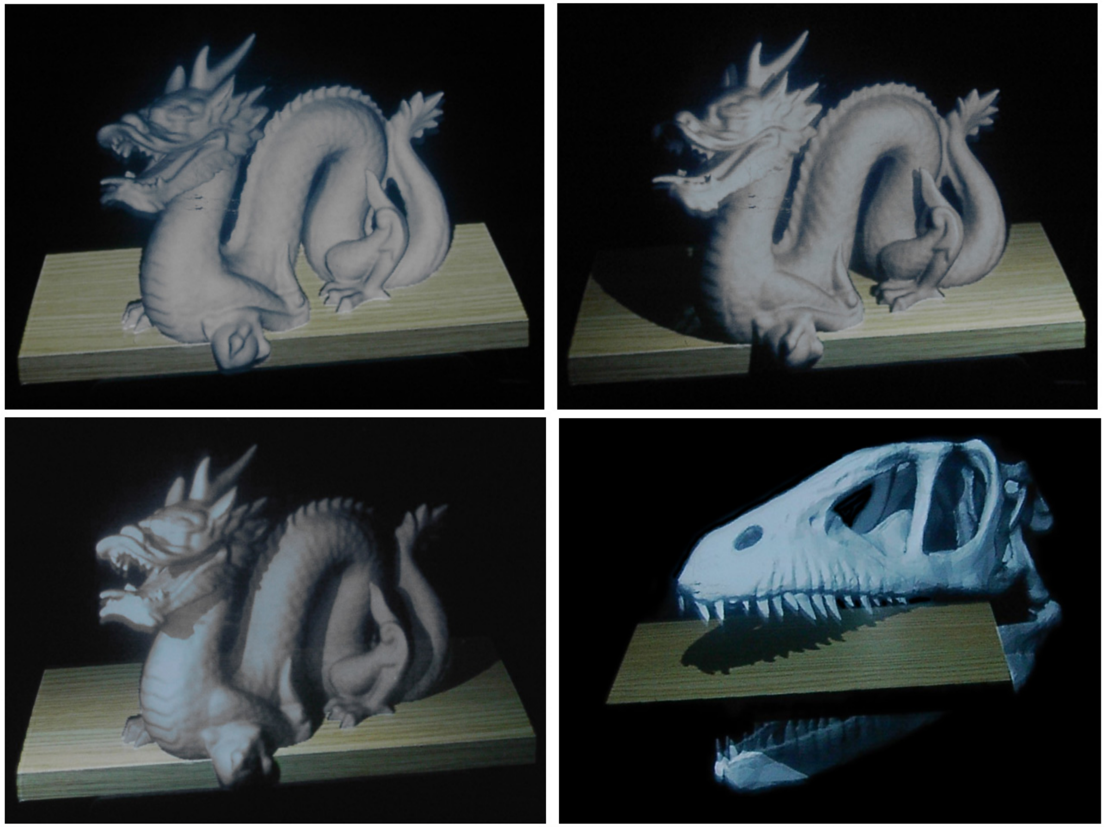
From viewpoint of projector:

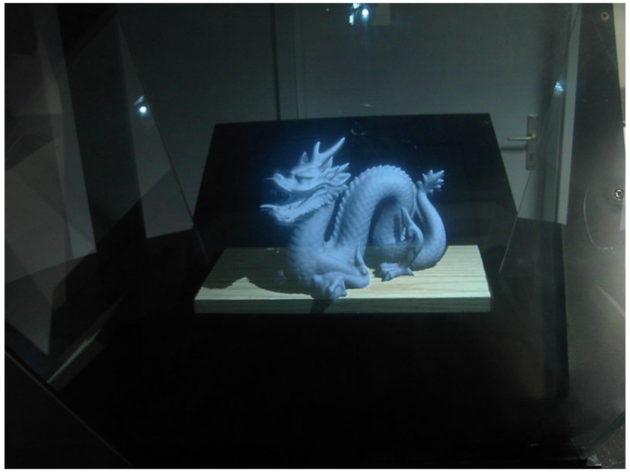
I_{int_1} → rendered real scene with virtual shading and shadows, D_m=1

I_{int_2} → rendered real scene with point light source at projector position, D_m=1, D_l=1c

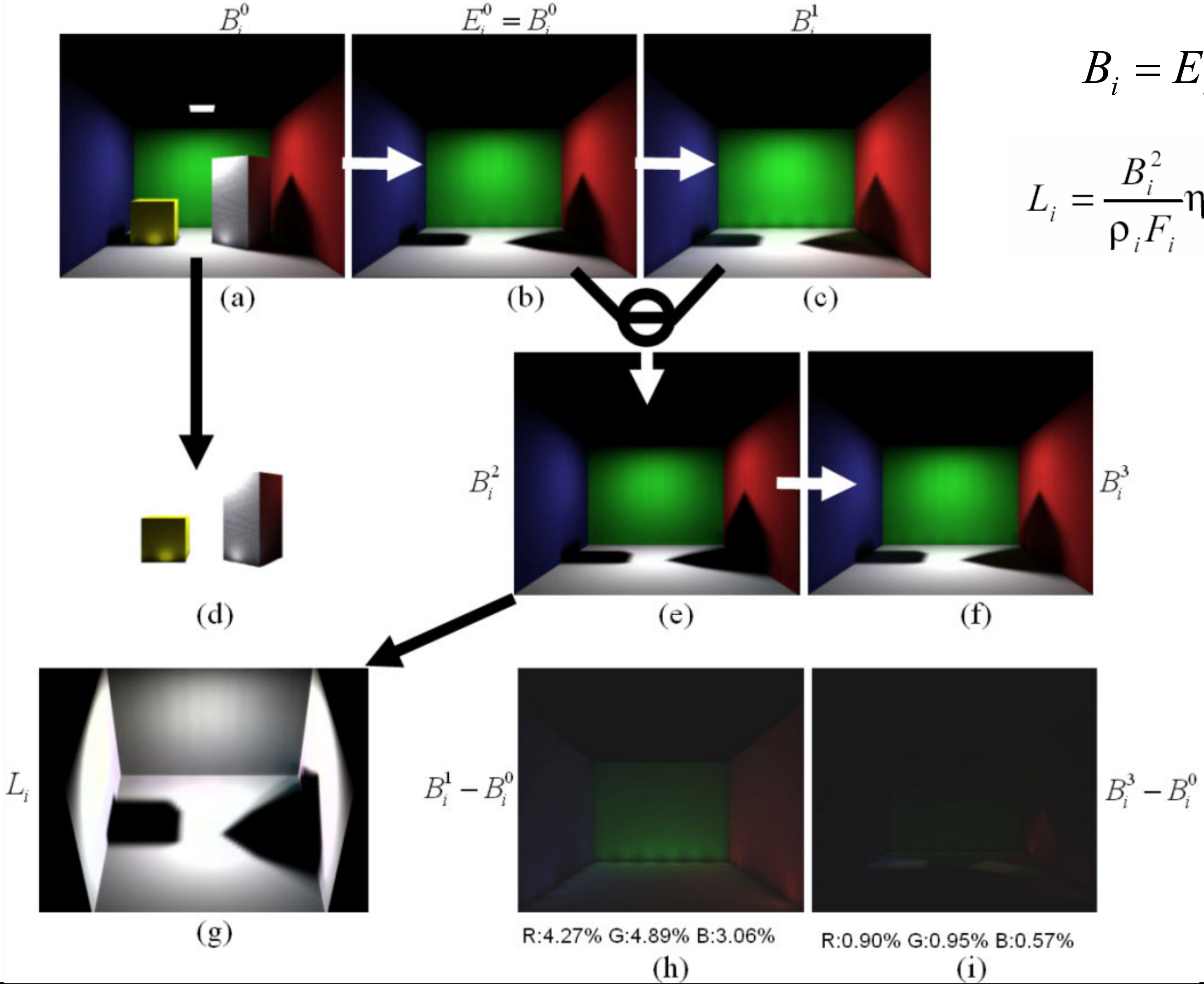
Display L= I_{int_1}/I_{int_2} (*Pixel Shader*)

Consistent Local Illumination





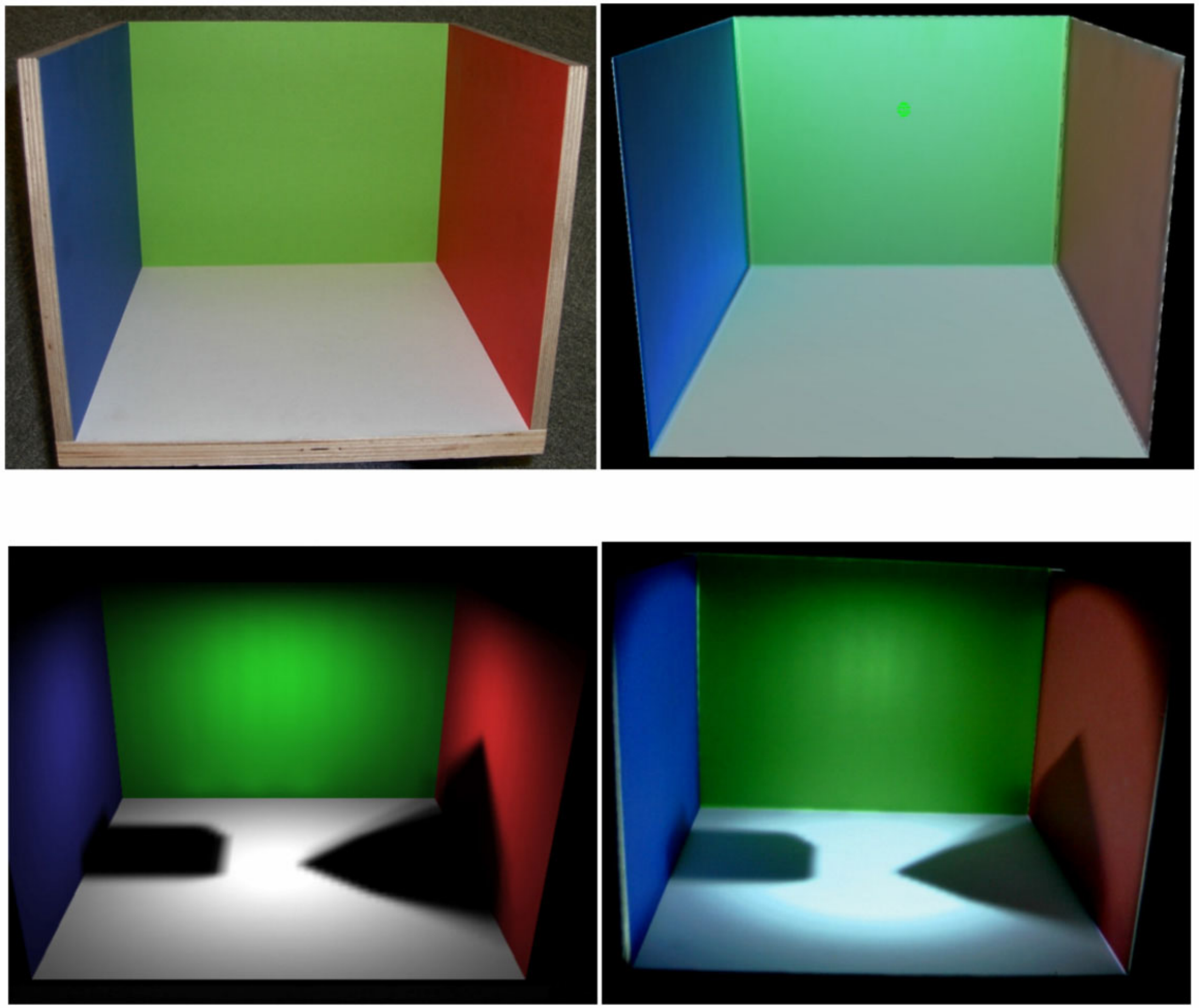
Consistent Global Illumination



$$B_i = E_i + \rho_i \sum_{j=1}^{n} B_j F_{ij}$$

$$L_i = \frac{B_i^2}{\rho_i F_i}\eta \longleftarrow F_i = \frac{\cos(\theta_i)}{r_i^2} h_i$$

Consistent Global Illumination



Coming up next…

- Part 1: Tutorial Introduction and Overview (Ramesh)
- Part 2: Introduction to today's displays approaches for AR (Oliver)
- Part 3: New Directions in Spatial Augmentation (Ramesh)
- Part 4: Spatial Augmentation using Optical Elements (Oliver)
- **Part 5: Prototypes and Experiences (both)**

Modern Approaches to Augmented Reality

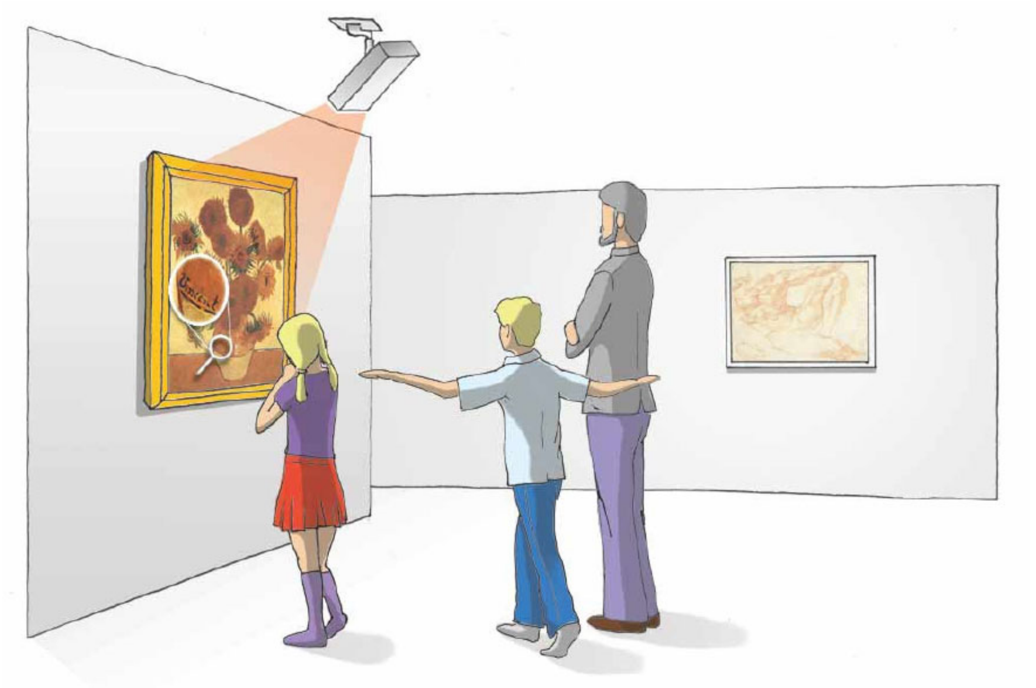
- Part 5 -

Prototypes and Experiences

Outline

- Part 1: Tutorial Introduction and Overview (Ramesh)
- Part 2: Introduction to today's displays approaches for AR (Oliver)
- Part 3: New Directions in Spatial Augmentation (Ramesh)
- Part 4: Spatial Augmentation using Optical Elements (Oliver)
- **Part 5: Prototypes and Experiences (both)**

Augmenting Paintings

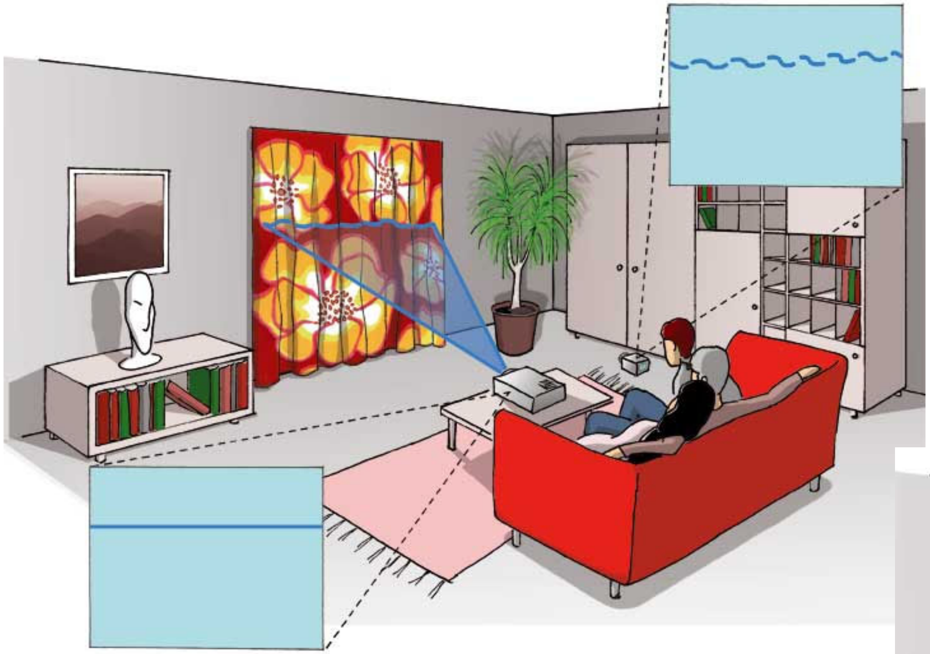


To appear in IEEE MultiMedia, 2004

Augmenting Paintings

Video 1 Video 2

Smart Projector

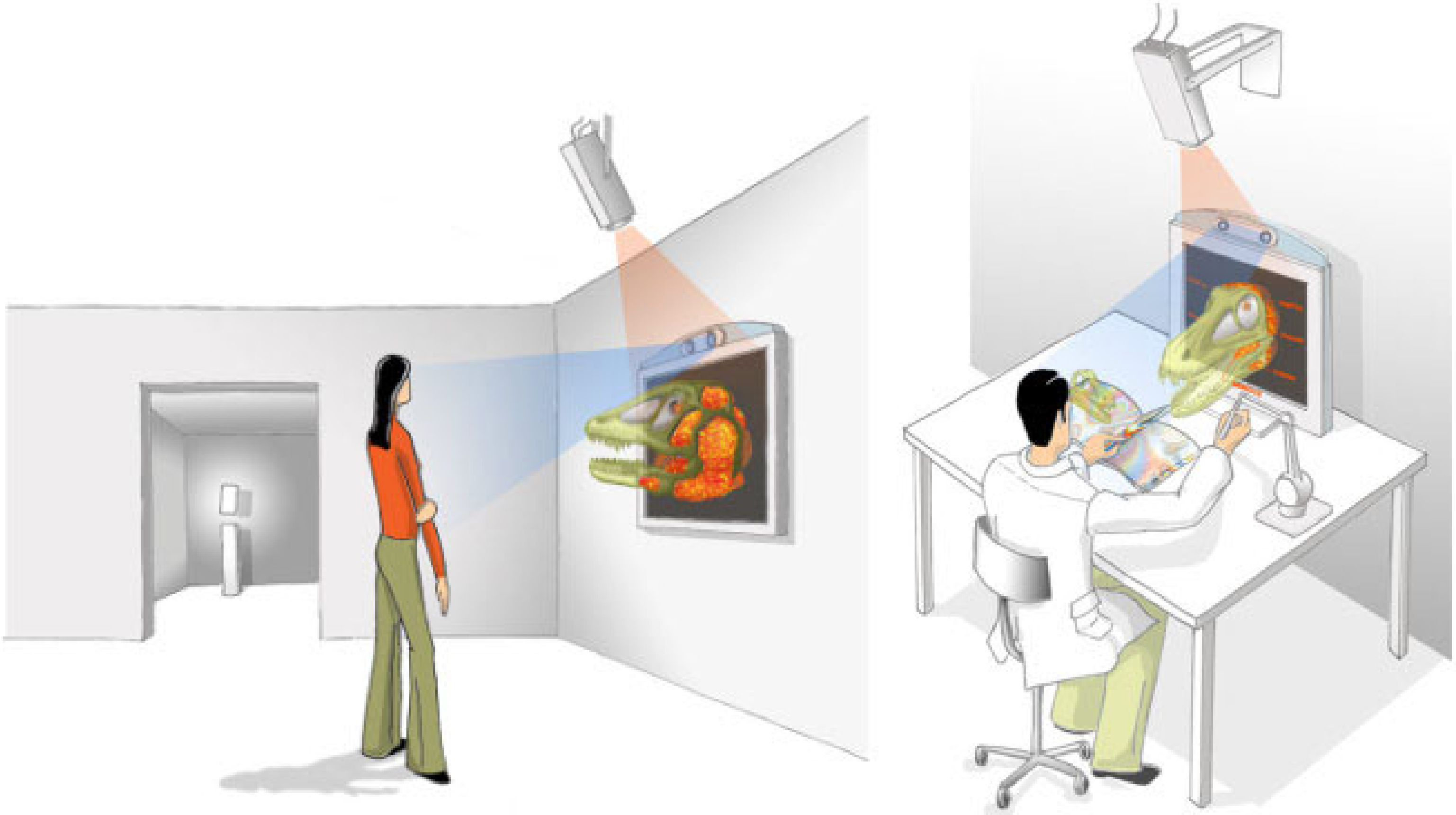


Submitted to IEEE Computer, 2004

Smart Projector

Video

HoloGraphics



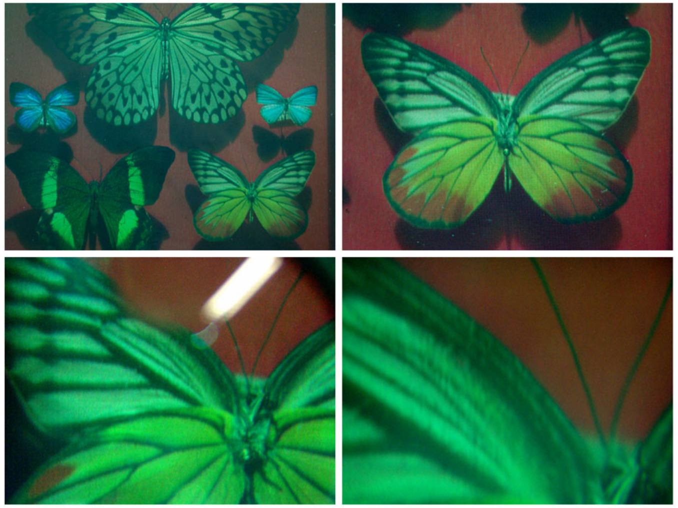
IEEE Computer, January 2004

HoloGraphics

- Computer Graphics:
  - Resolution: mega-pixels
  - Information content: mega-bytes
  - Performance: 20-30fps
  - Users: one/two/three
  - Interactive

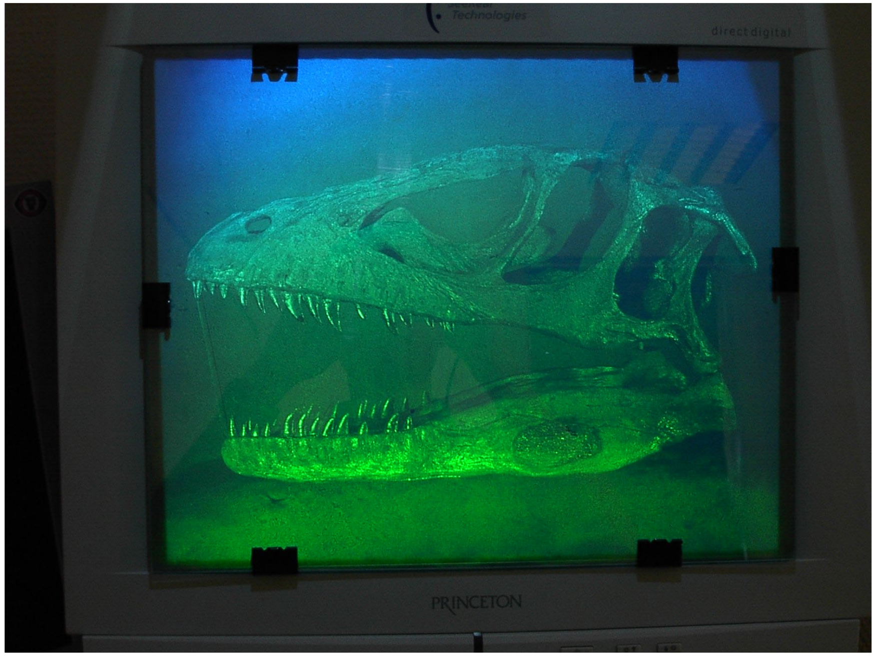

Stanford Univ.

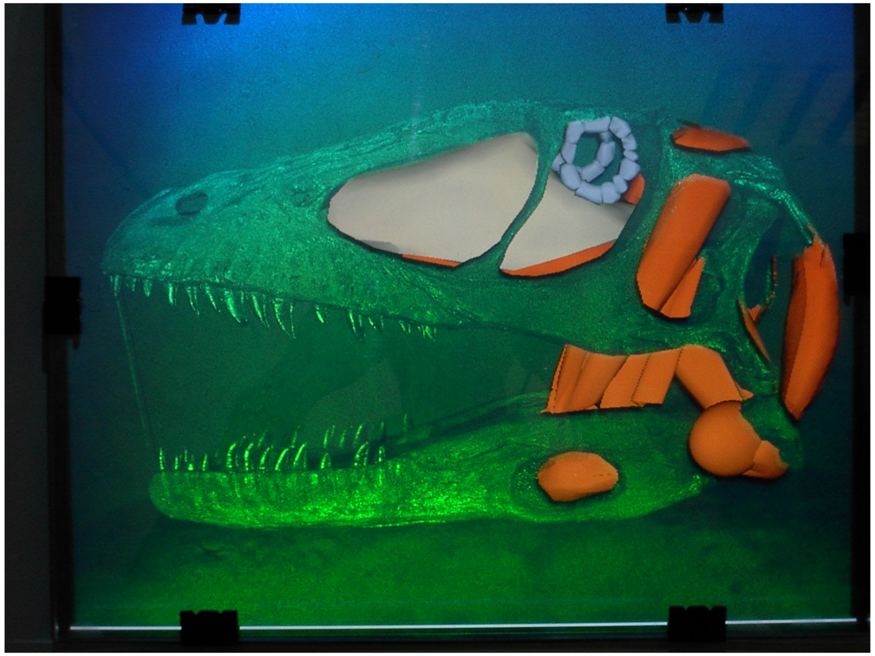
- Holograms
  - Resolution: terra-pixels
  - Information content: terra-bytes
  - Performance: real-time (analog)
  - Users: unlimited
  - Not interactive



- →20-30 terra-bytes per second on a terra pixel display

HoloGraphics

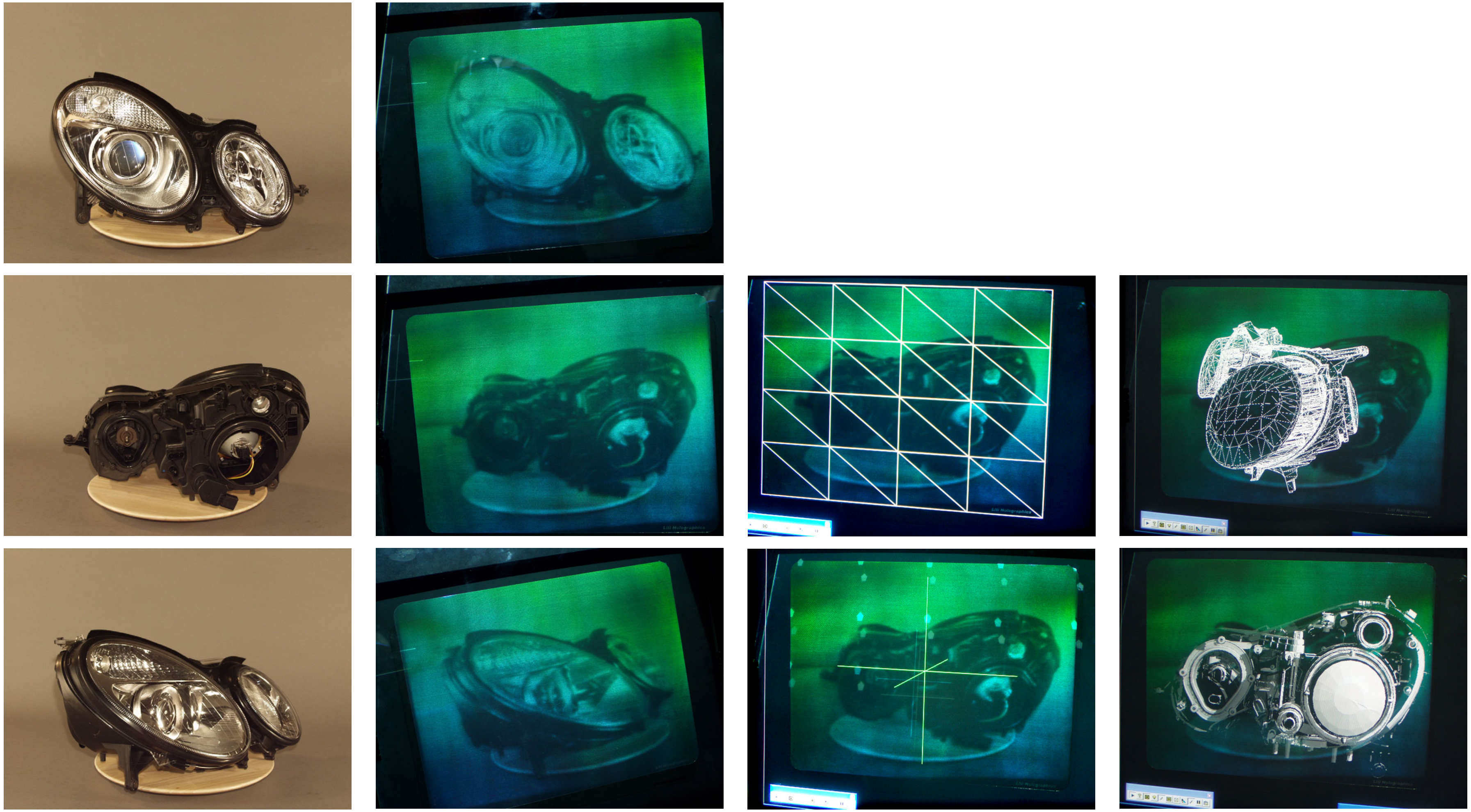




HoloGraphics

HoloGraphics

HoloGraphics



360 photographs

digital multiplex hologram (< PAL resolution)

registering holographic plane calibrating projector

integrating CAD data

HoloGraphics

Virtual Showcase

Since 2001:

more than 11 exhibitions

more than 120,000 users

4 months unattended running time

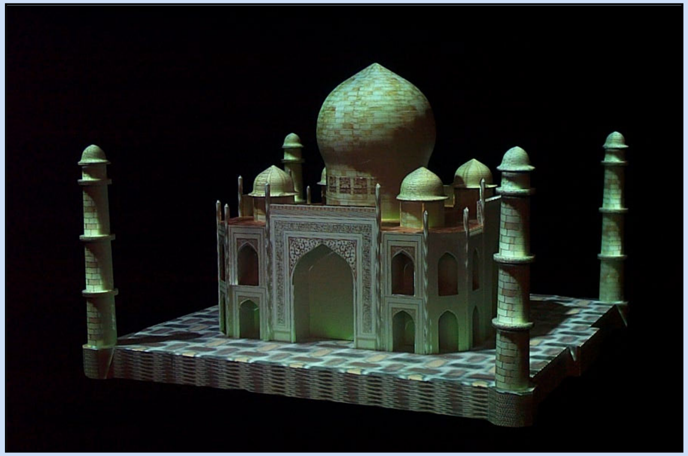
all papers, videos, pictures, etc.

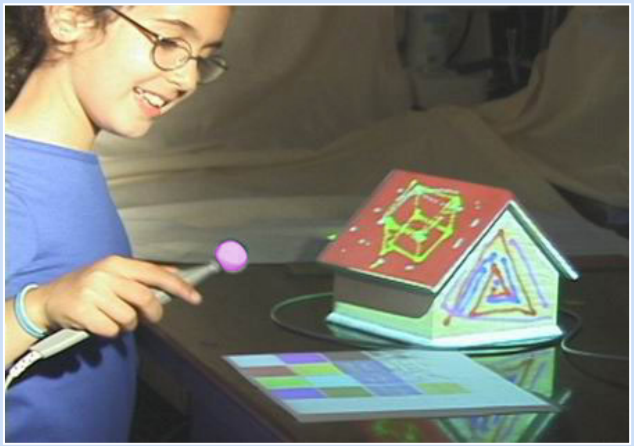
available at

www.uni-weimar.de/medien/AR

Prototypes: Spatial Augmentation

- More Examples ..



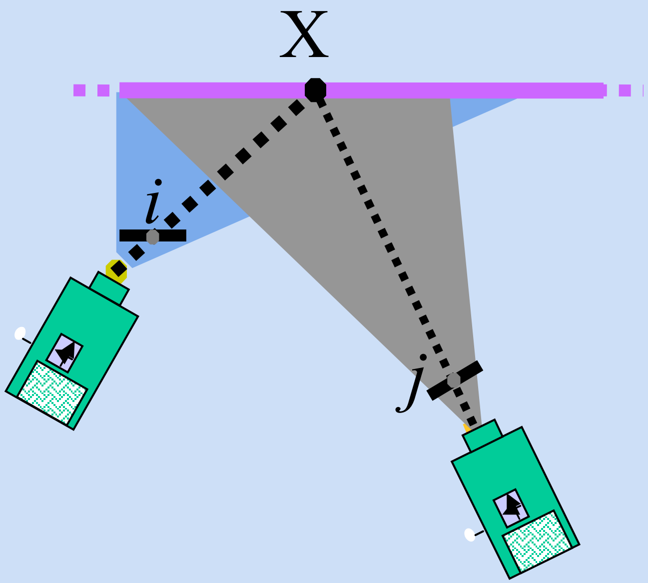


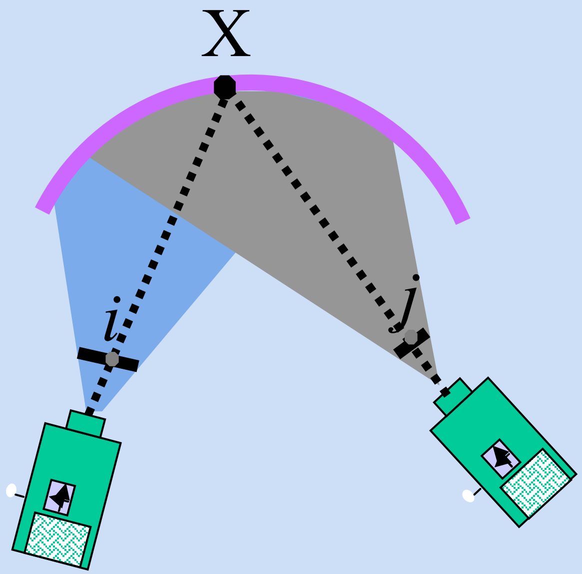
More info : www.ShaderLamps.com , Code available

Quardic curved shape Displays

Raskar, vanBaar, Willwacher, Rao
'Quadric Transfer for Immersive Curved Displays',
EuroGraphics 2004

Parametric Image Transfer





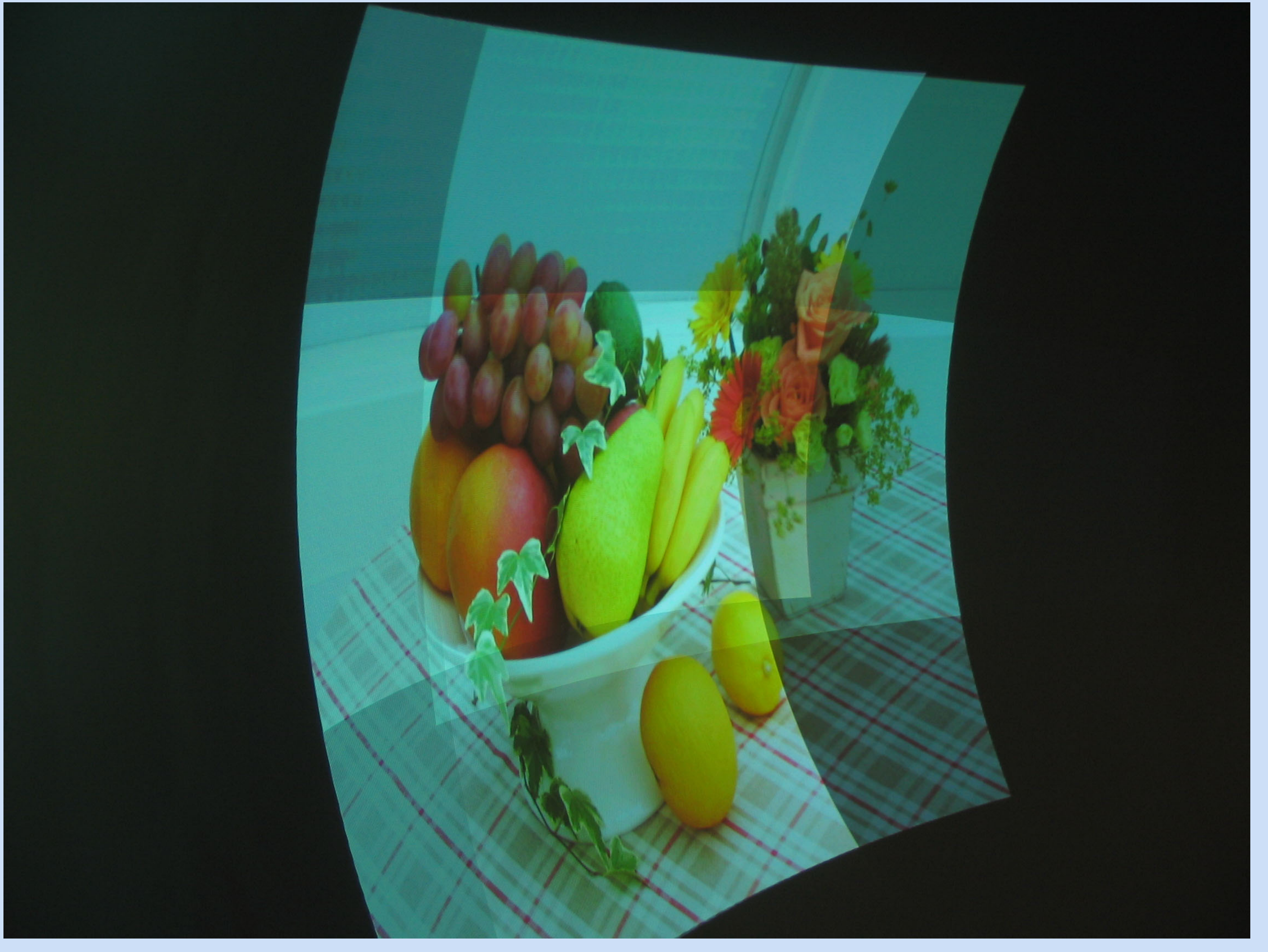
Planar Homography

$$j \cong A_{3x3}\, i$$

Quadric Transfer

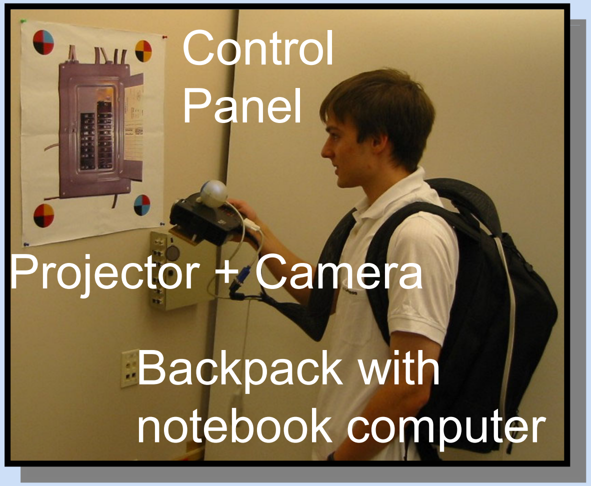
$$j \cong A_{3x3}\, i \pm \left(\sqrt{i^T E\, i}\right) e$$

Overlap on Quadric Screens

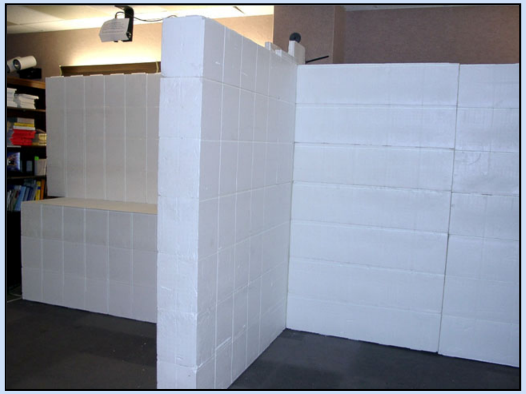
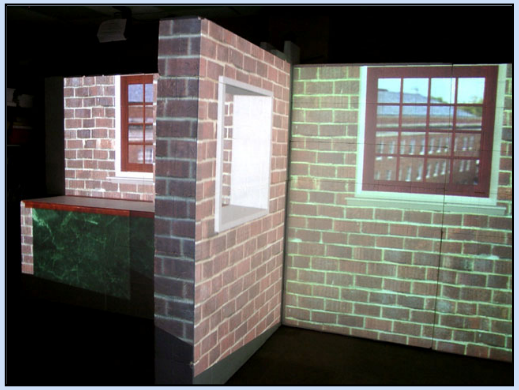


Training and Maintenance
(Projector-based Augmented Reality)
Raskar, Beardsley, Forlines

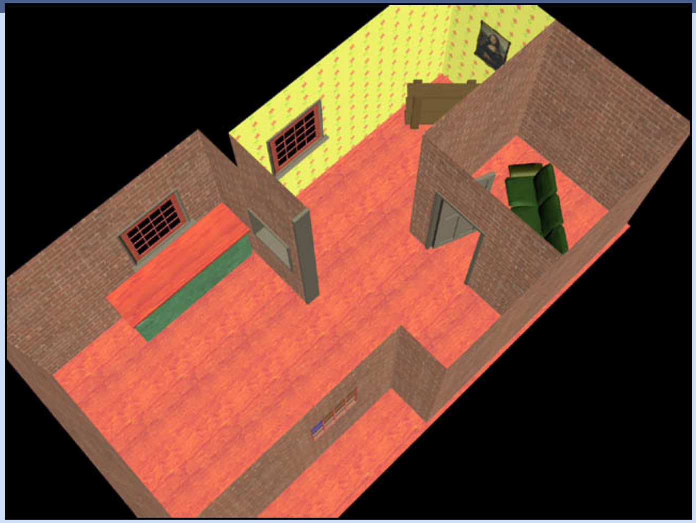
- Automatically add projected information
  - Training videos
  - Instruction manuals
- Detect pose and identity from pie-codes



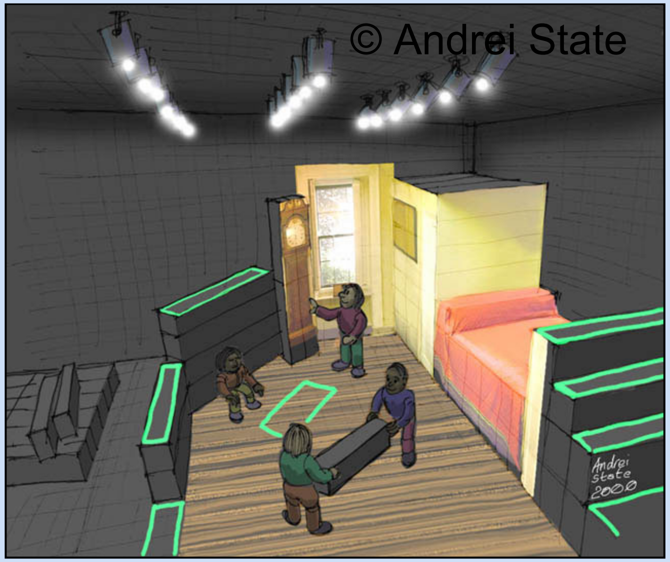
- Recreate Large Environments
  - ‘BeingThere’, walk-around
  - Human sized environments
  - Museums, Exhibitions

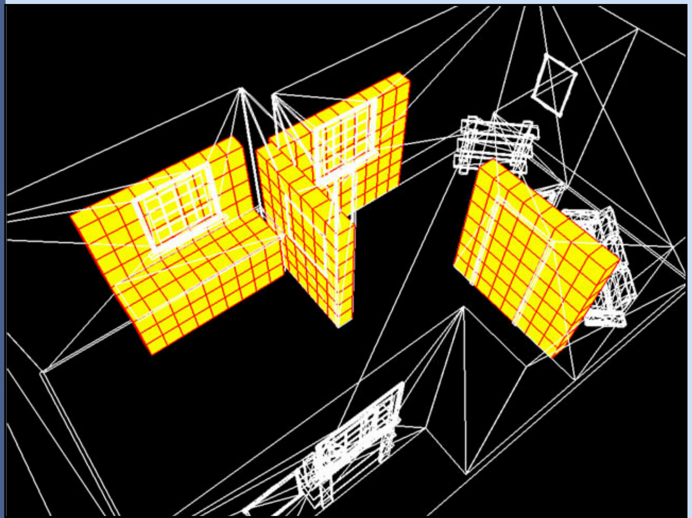

Kok-Lim Low, Greg Welch, Anselmo Lastra, Henry Fuchs. “Life-Sized Projector-Based Dioramas,” Proc. ACM Symposium on Virtual Reality Software and Technology 2001 (VRST 2001), November 2001.

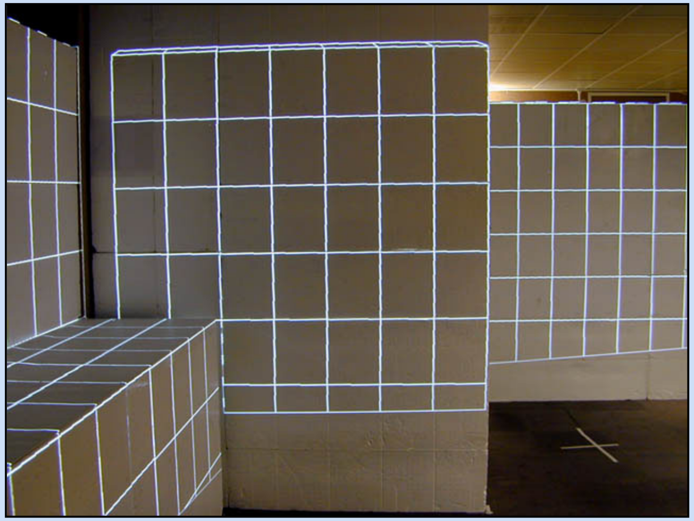


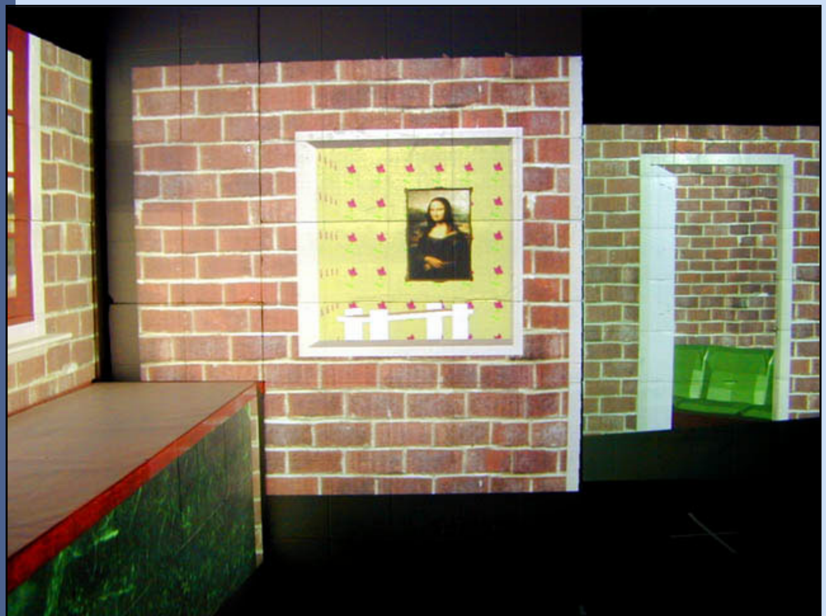
Desired Virtual Model

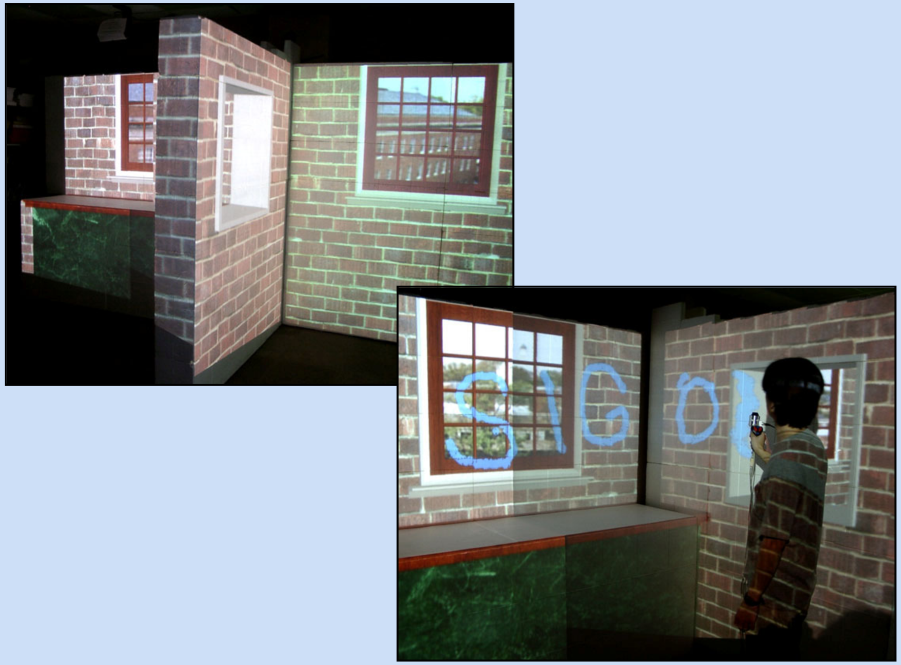


Projected Guidance for Placement

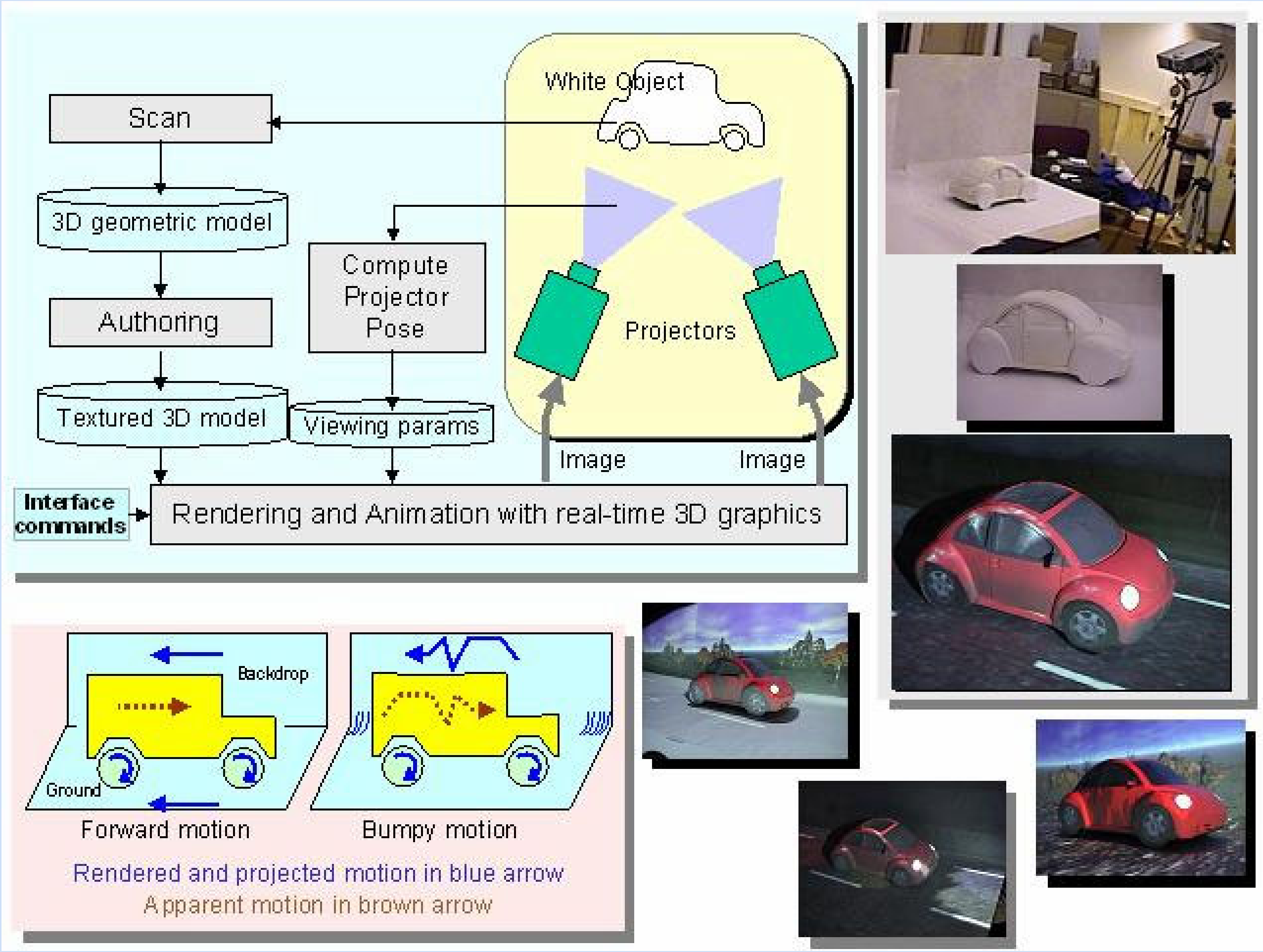








Apparent Motion



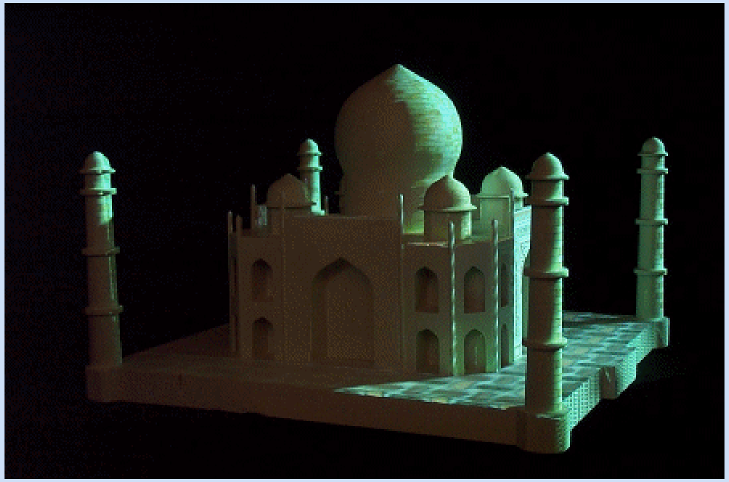
Ramesh Raskar, Remo Ziegler, Thomas Willwacher, "Cartoon Dioramas in Motion," Proc. ACM Symposium on Nonphotorealistic Animation and Rendering (NPAR 2002)

Virtual Motion

ShaderLamps

Virtual Reflectance

Virtual Illumination



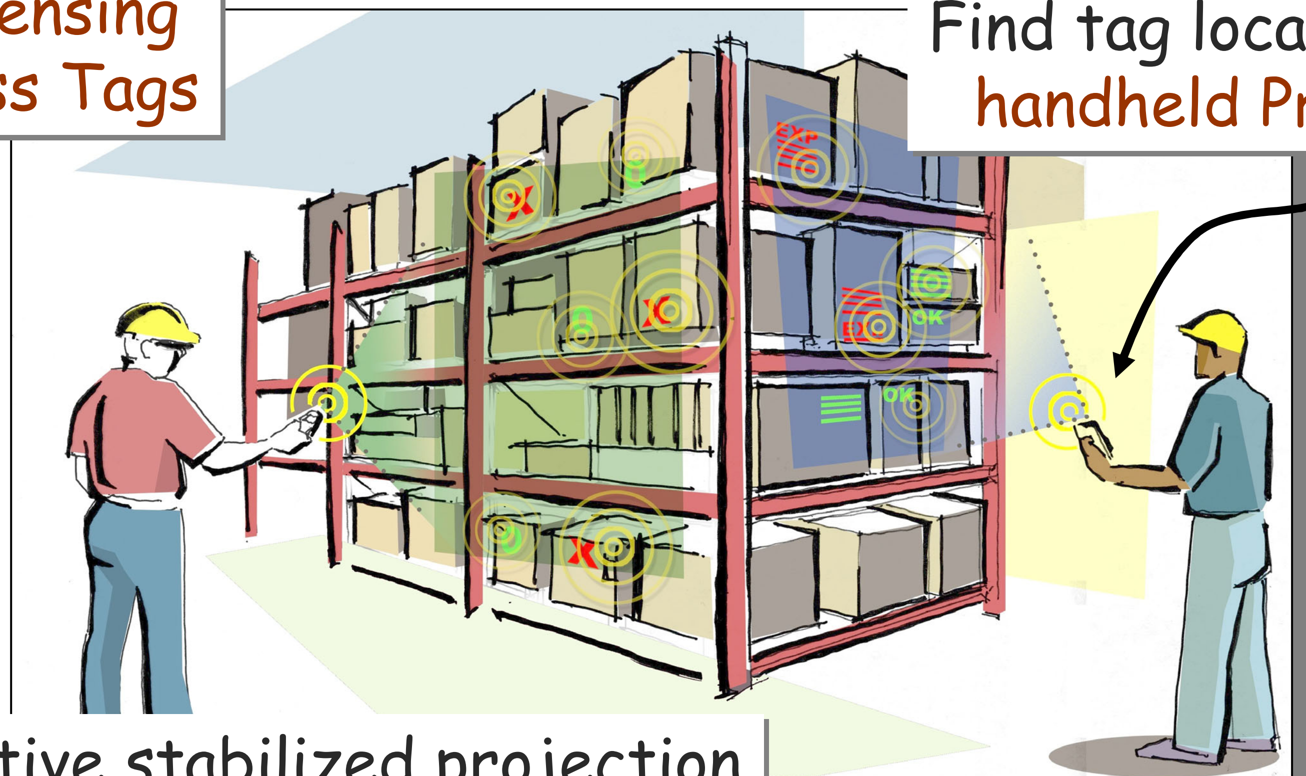
Virtual Motion

Interaction

www.ShaderLamps.com

RFID ➡ RFIG

(Radio Frequency Id & Geometry)



Photosensing Wireless Tags

Find tag location using handheld Projector

Interactive stabilized projection

Many geometric ops

Siggraph 2004

Warehousing

Routing

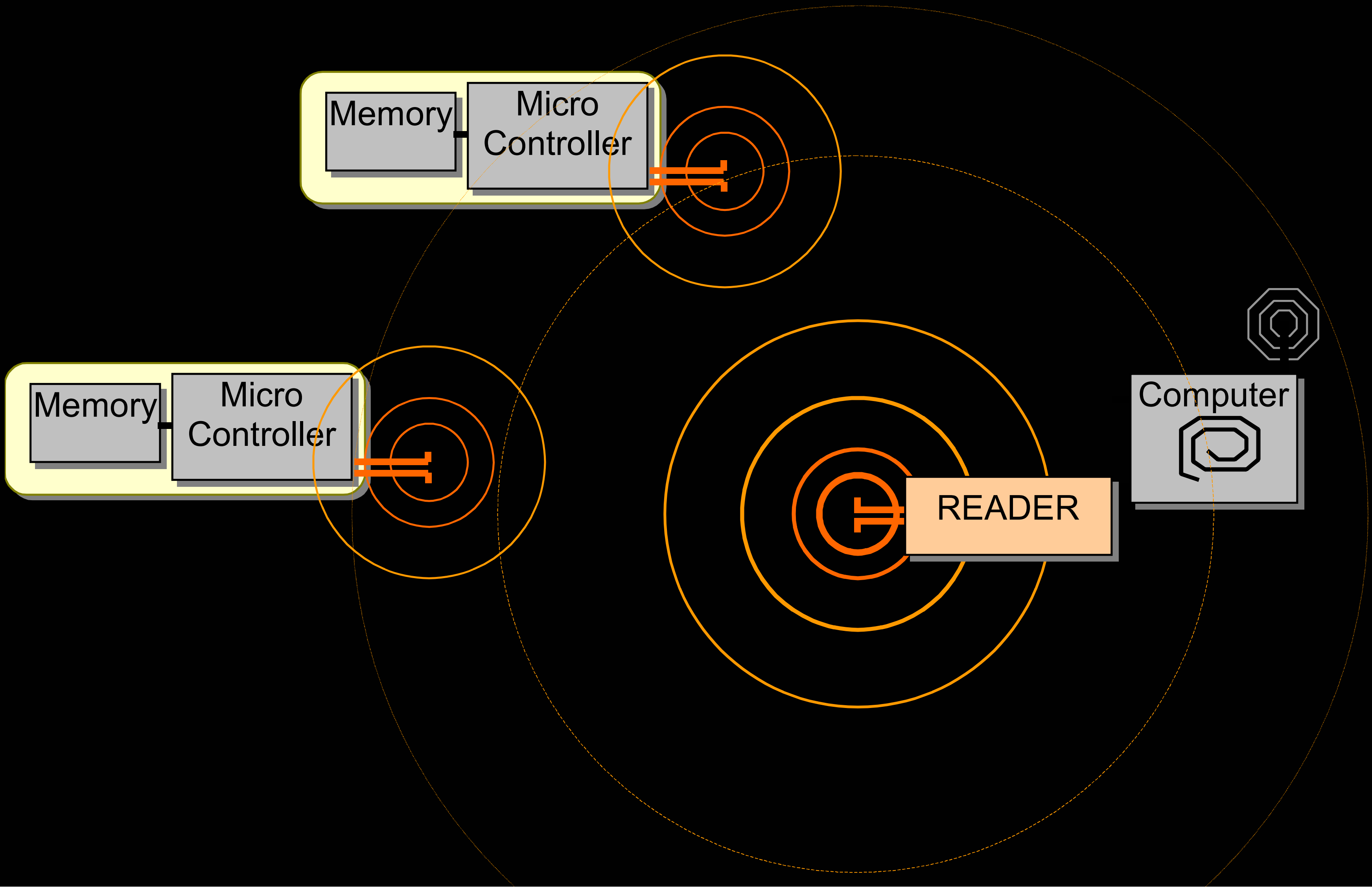
Livestock tracking

Library

Baggage handling

Currency

Conventional Passive RFID



Tagged Books in a Library

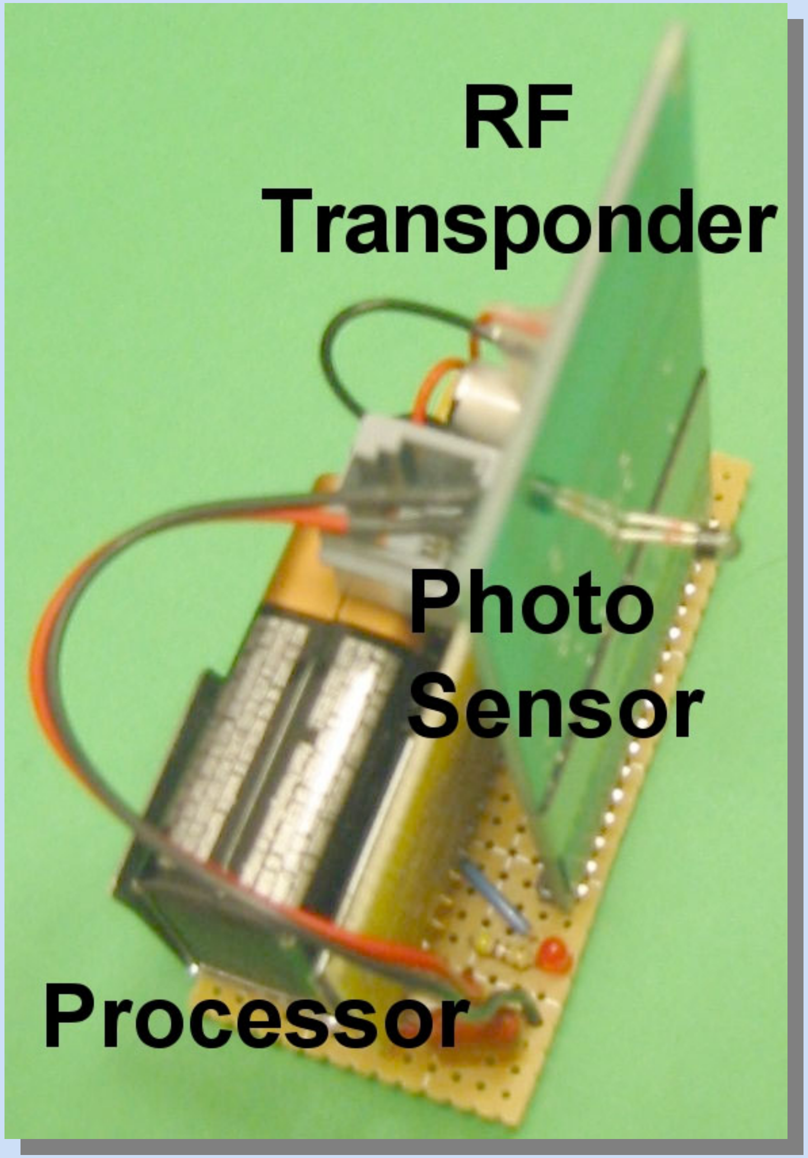
✓ **Id** : List of books in RF range

✘ **No Precise Location Data**

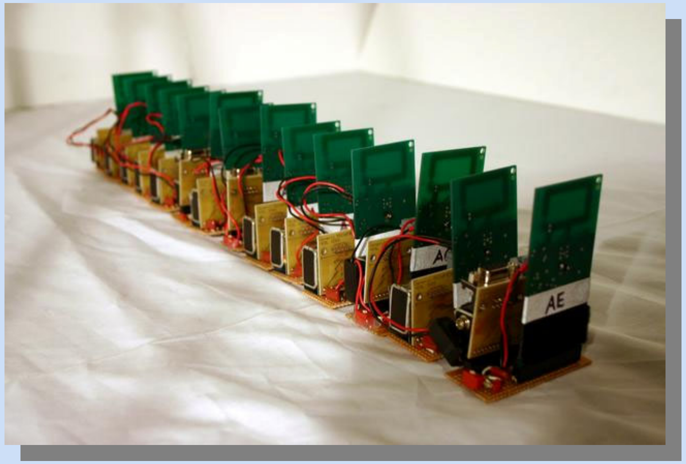
Are books in sorted order ?

Which book is upside down ?

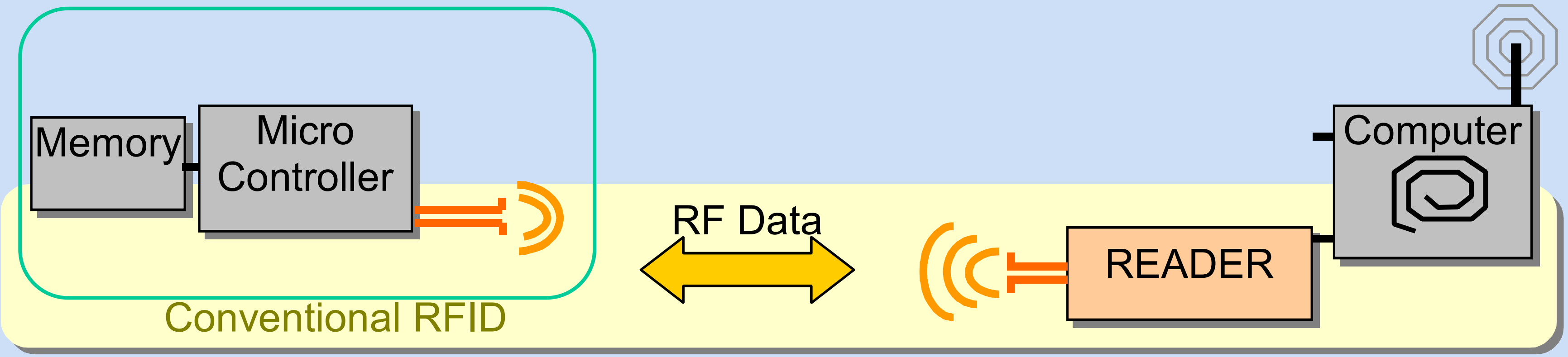
Prototype Tag



RF tag +
photosensor



Conventional RF tag



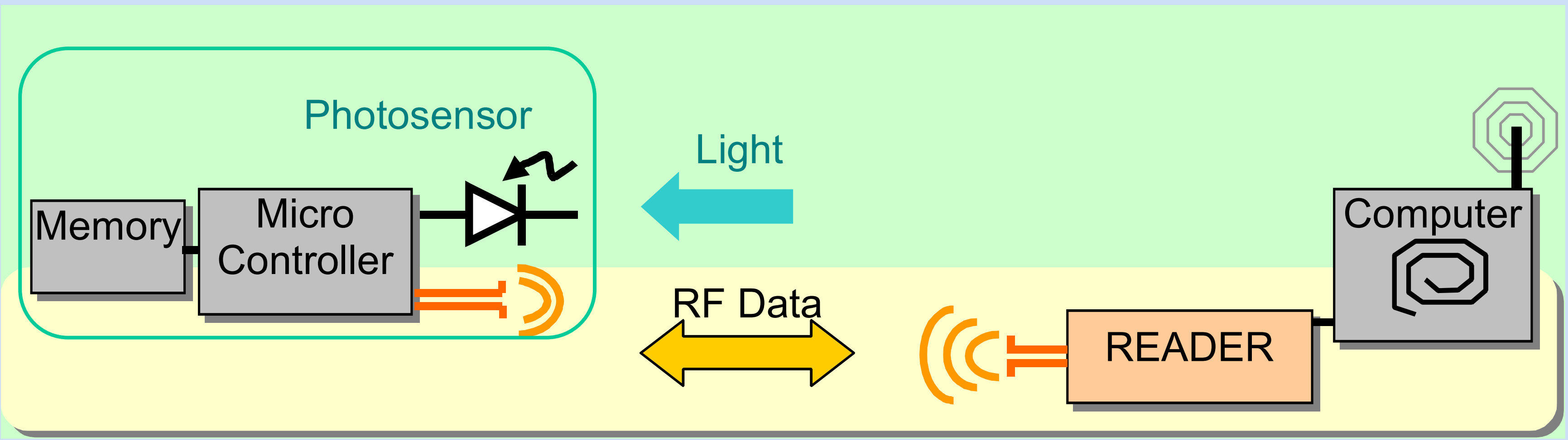
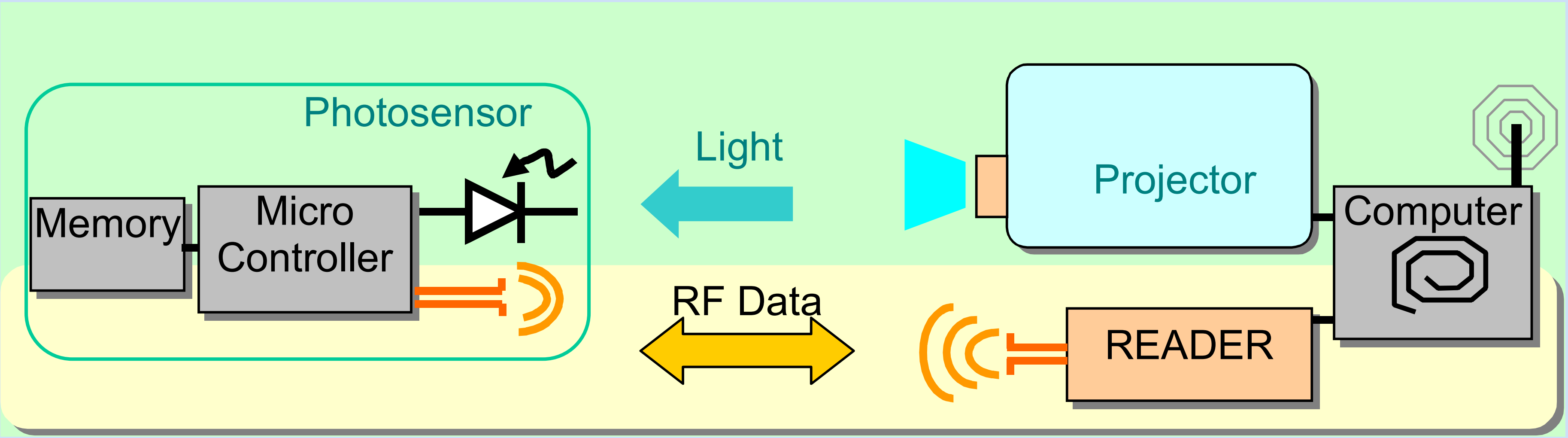
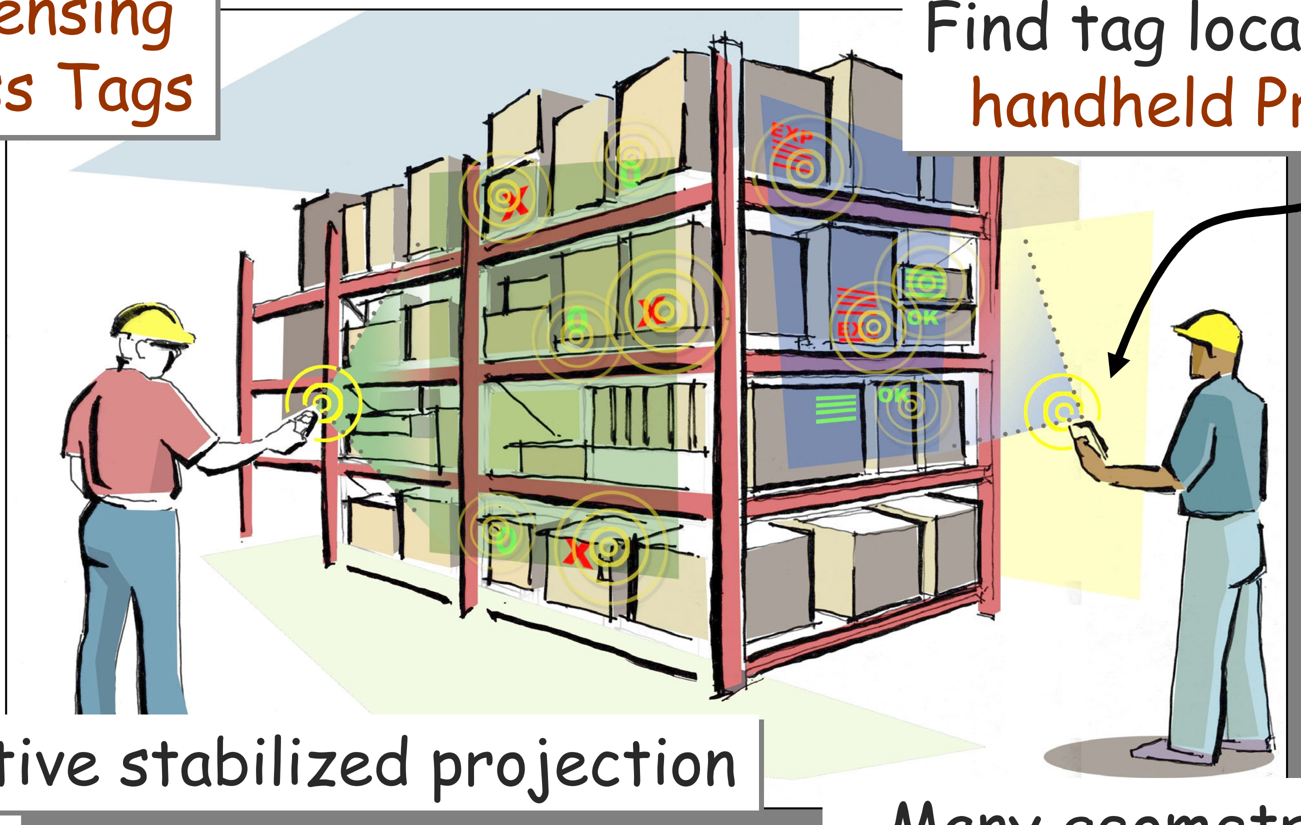


Photo-sensing RF tag


Photosensor
Memory
Micro Controller
Light
Projector
Computer
RF Data
READER

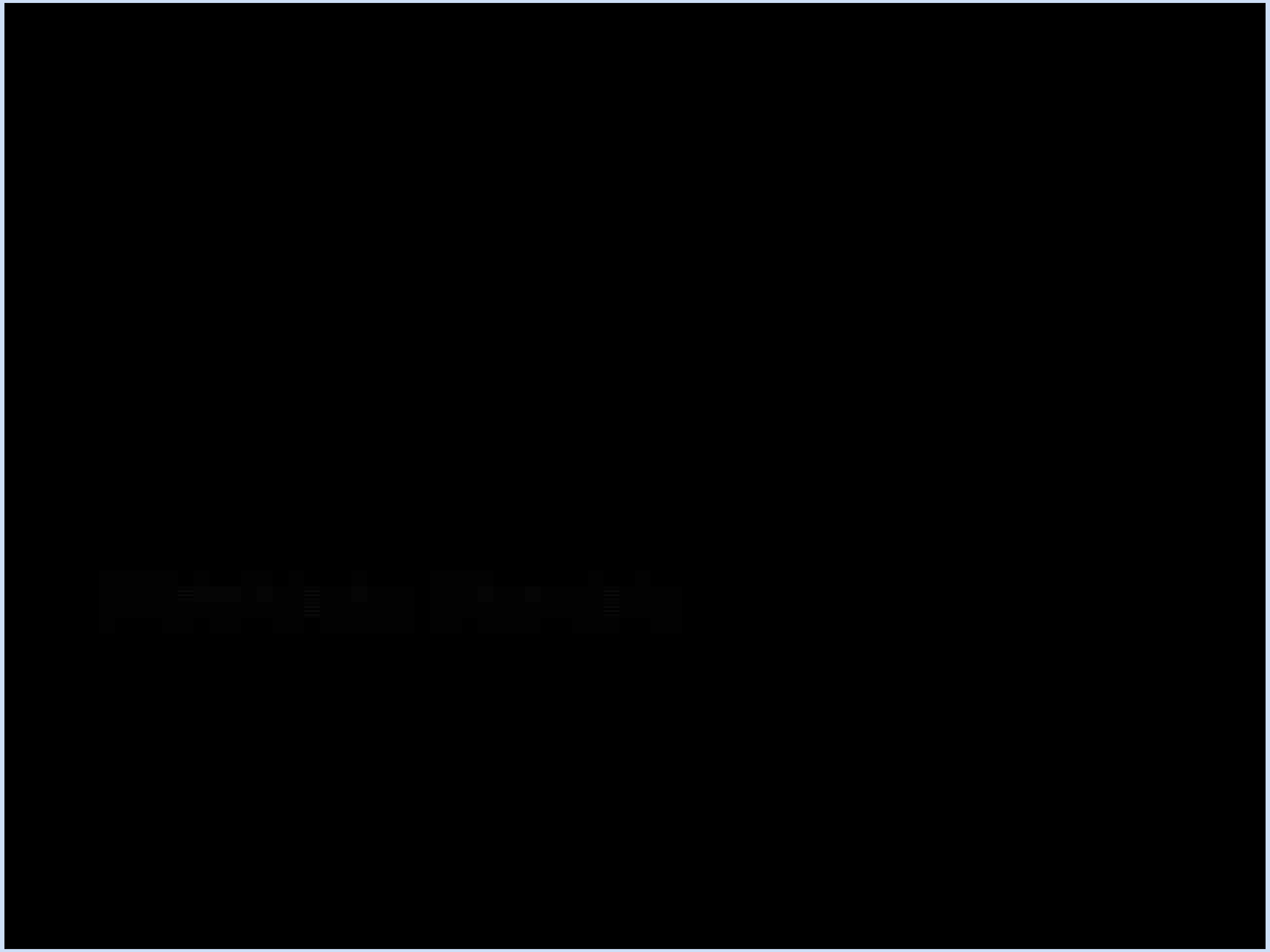
RFID ➔ RFIG

(Radio Frequency Id & Geometry)



Siggraph 2004

AR with Photosensing RFID and Handheld Projector



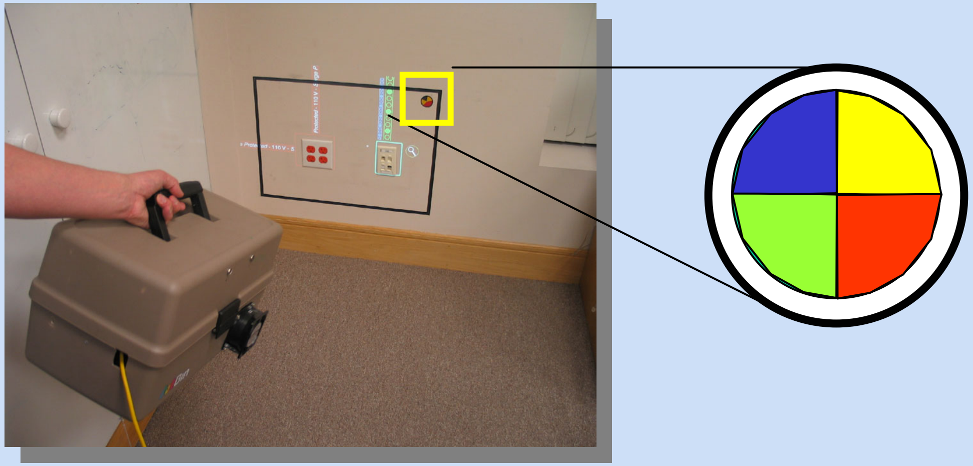
RFID

(Radio Frequency Identification)

RFIG

(Radio Frequency Id and Geometry)

AR Issues



- Preprocessing:
  - Authoring
- Runtime:
  - **<u>Identification</u>:** Recognition of objects
    - Using markers and visual tags
  - **<u>Registration</u>:** Finding relative pose of display device
    - Dynamic estimate of translation and rotation
    - Render/Warp images
  - **Interaction:**
    - Widgets, Gesture recognition, Visual feedback

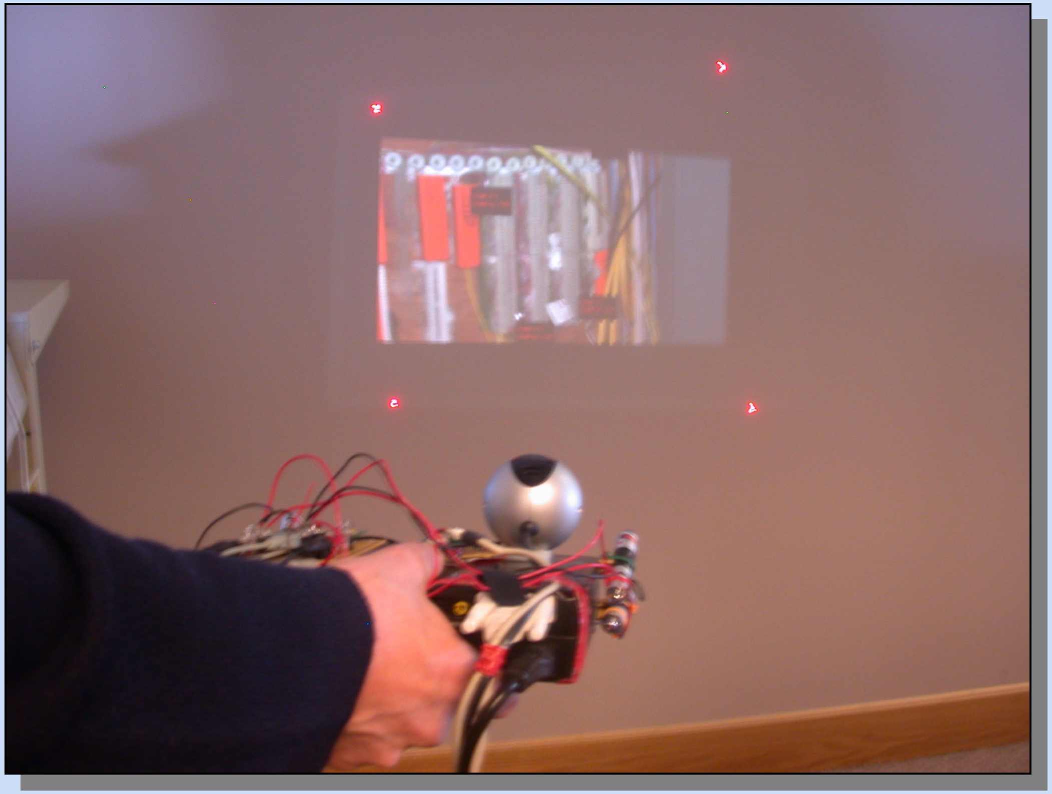
Visual feedback of 2D position

a. Receive via RF {(x_1,y_1), (x_2,y_2), …} pixels

b. Illuminate those positions

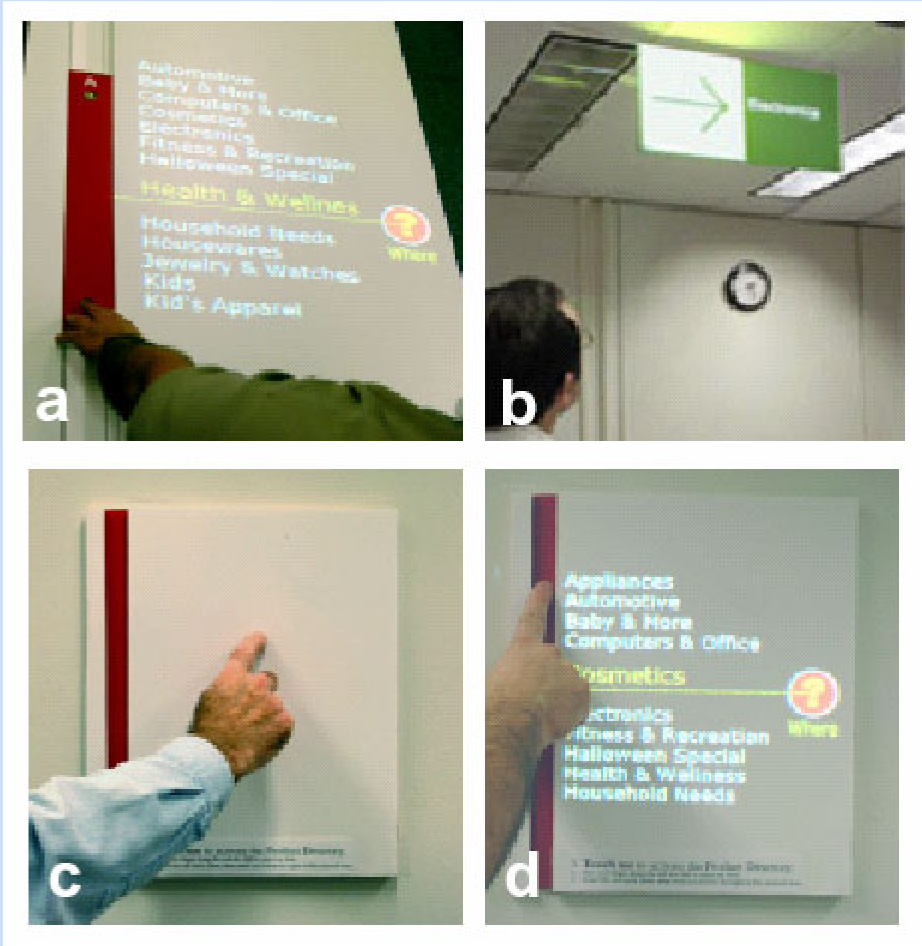
Interactive Projection

Adaptive Projection



'Copy and Paste'
Geometric and Photometric compensation

Steerable Projector

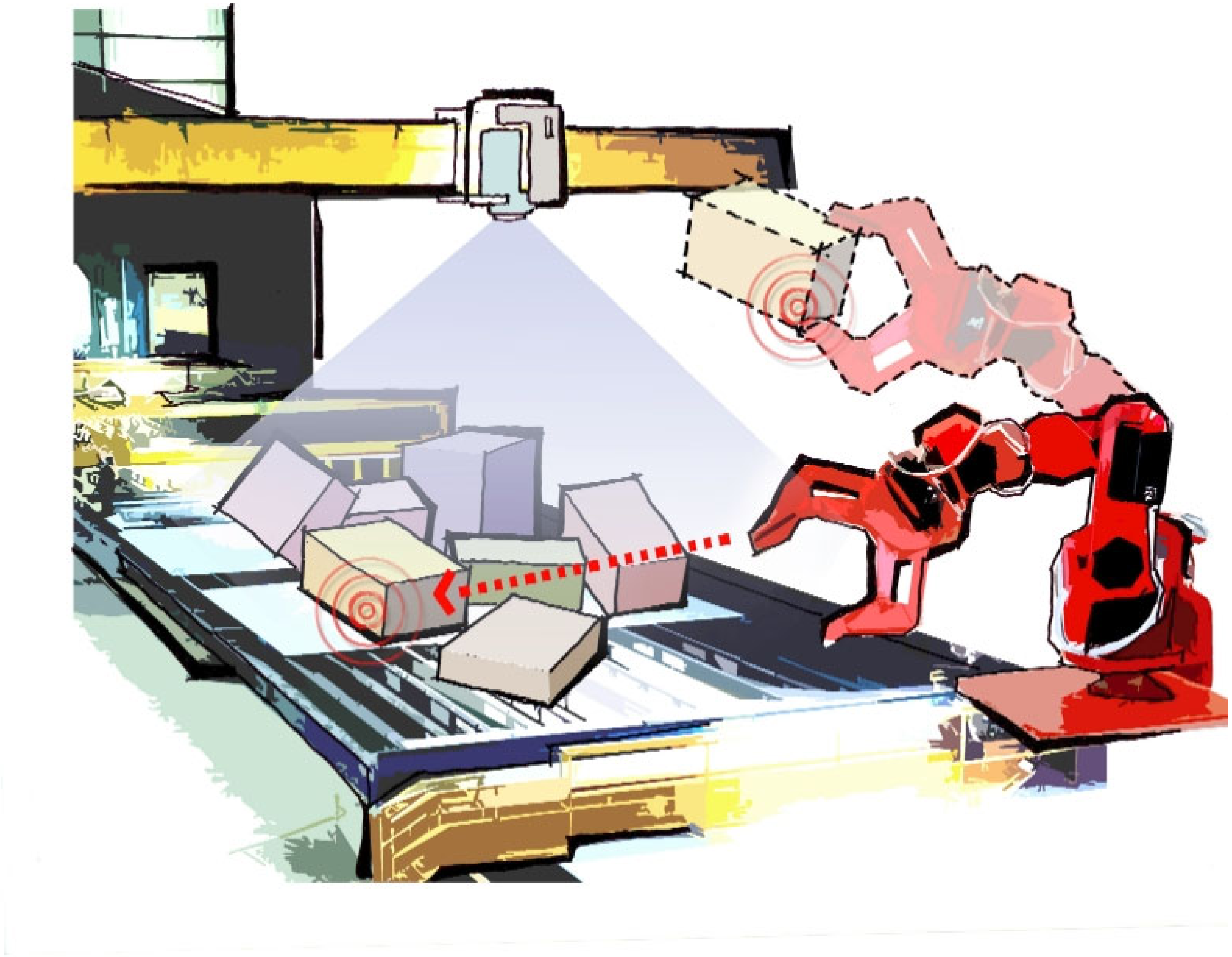


Pinhanez et al 2003

Machine AR

- AR for cameras and machines
- Face Dome [Debevec 2001]
- 4D lighting [MPI, MERL]

Robot ‘Laser’ Guidance
Picking and Sorting Tagged Objects



Acknowledgements

- MERL
  - Jeroen van Baar, Paul Beardsley, Remo Ziegler, Thomas Willwacher, Srinivas Rao, Cliff Forlines, Paul Dietz, Joe Marks
- Office of the Future group at UNC Chapel Hill
  - Greg Welch, Kok-lim Low, Deepak B'padhyay, Aditi Majumder, Michael Brown, Ruigang Yang
  - Henry Fuchs, Herman Towles
  - Wei-chao Chen
- Mitsubishi Electric, Japan
  - Yoshihiro Ashizaki, Masatoshi Kameyama, Masato Ogata, Keiichi Shiotani
- Images
  - Marc Pollefeys (UNC Chapel Hill)
  - Apologies
    - (Not able to include recent work by others)

Goals

- Understand advantages of Spatial AR
- Discuss issues in traditional AR approaches
- Explore alternative AR methods
  - Graphics, Vision, Optics techniques
  - Learn math of rendering and calibration
- See new applications in art and industry

Opportunities

- Think beyond goggle-bound AR
- Learn techniques using projectors, flat displays and optics
- Explore more realistic augmented environments
- Learn how to build your own spatial AR displays (only covered in tutorial notes).
- Learn how to extend your own software framework to support spatial AR displays
- Get an impression on applicability

Discussion

- AR Display Approaches
  - Traditional, Goggle-bound, Alternative
- Spatial Augmentation
  - Projectors, Non-planar, Mobile objects, Change appearance, Interaction
- Exploiting Optical Elements
  - Mirrors, Beam splitters, Holograms
- Applications
  - Prototypes in Art, Research and Industry

Feedback

- Course website http://Spatial-AR.com
- Please complete the survey form

- Feedback form
  - What material would you like to see ?
  - Would you like more programming details ?
  - What are your future directions of AR work ?

Schedule

2:00	Overview	
2:10	Today's AR Display Approaches	(Bimber)
2:40	Spatial Augmentation	(Raskar)
3:30	Break	
4:00	Spatial AR using Optical Elements	(Bimber)
4:45	Prototypes	(Bimber and Raskar)
5:20	Discussion	

Course Page : http://Spatial-AR.com