Alternative Approaches to Augmented Reality

Oliver Bimber

University of Weimar

Ramesh Raskar

Mitsubishi Electric Research Labs

Welcome

- Outline
- AR Display Approaches
  - Traditional, Goggle-bound, Alternative
- Non-trivial Projection
  - Non-planar, Mobile objects, Change appearance
- Spatial Optical See Thru Displays
  - Mirrors, Beam splitters
- Applications
  - In Art, Research and Industry

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
  - Interaction techniques and devices
  - Code and hardware details (in notes)

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.

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 and user feedback

Schedule

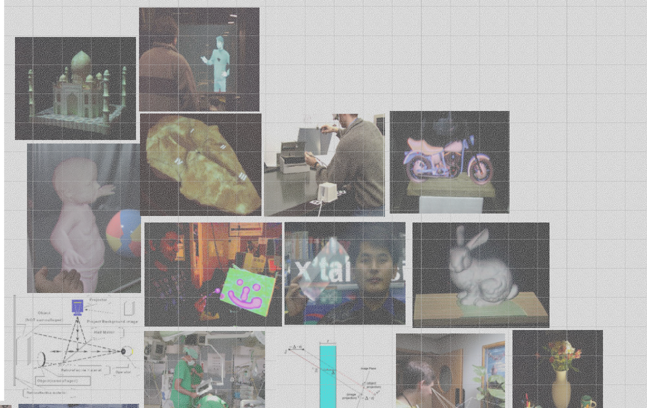
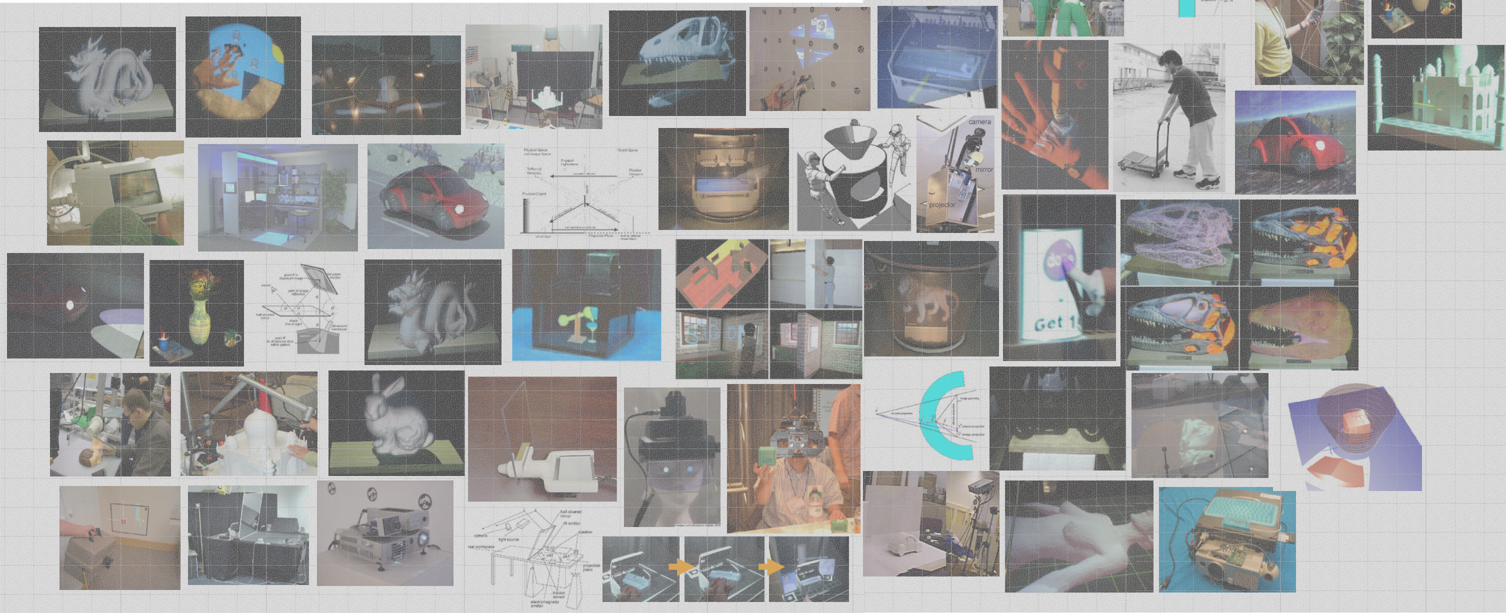
09:30	Overview	
09:40	Today's AR Display Approaches	(Bimber)
10:00	Non-trivial Projection Screens	(Raskar)
11:00	Break	
11:30	Spatial Optical See-thru Displays	(Bimber)
12:30	Applications	(Bimber and Raskar)
12:50	Discussion	

Course Pages : www.cs.unc.edu/~raskar/Projector/
www.uni-weimar.de/medien/AR

Part 2: Today's AR Display Approaches

(Bimber)

Part2:
Today's Display Approaches

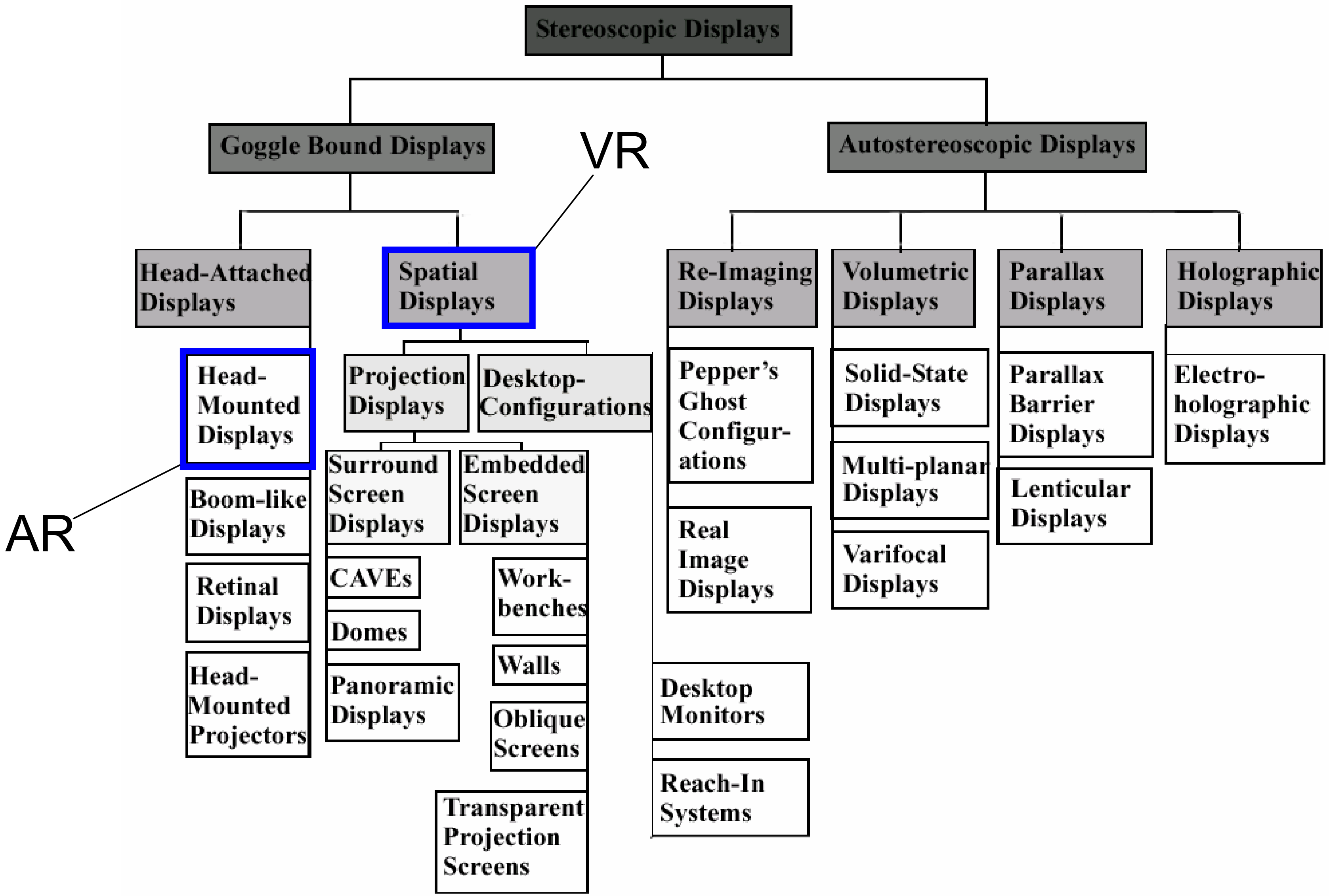



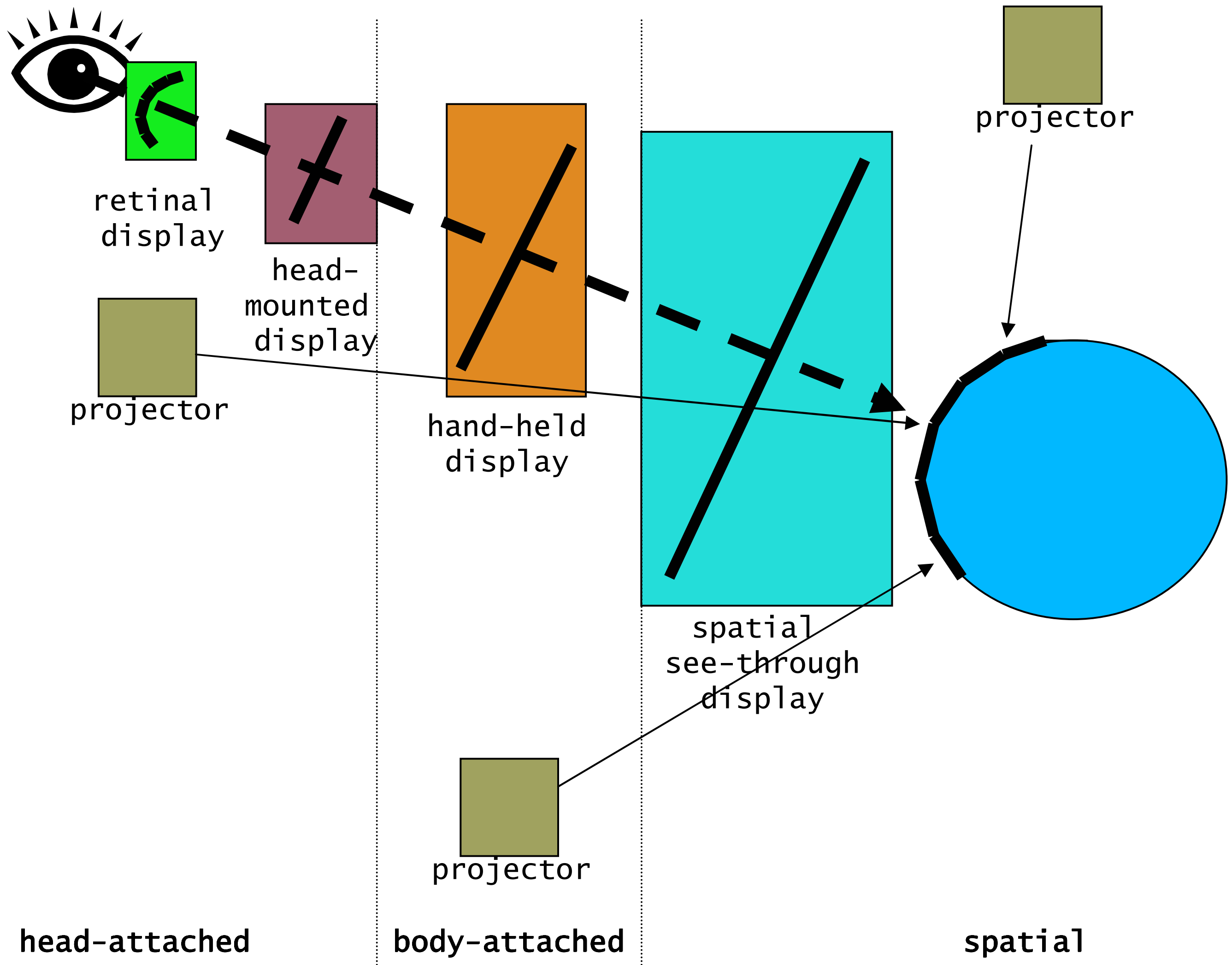
Outline

- Introduction
  - why looking for alternatives?
  - overview: stereoscopic displays
- Current Augmented Reality Displays
  - head-mounted displays
  - head-mounted projectors
  - hand-held and object oriented displays
  - spatial see-through displays
  - spatial projection displays
- Future Display Technologies
  - autostereoscopic and holographic displays
  - tiny projectors
  - foldable displays
  - volumetric displays

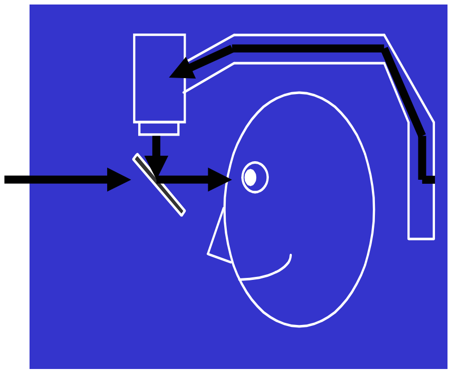
Why looking for alternatives?

- Head-mounted displays exist since almost 40 years (Sutherland, 1965-1968)
- Many technical and ergonomic issues are still not satisfactory:
  - fixed focal length / focus shifting
  - small field-of-view
  - low resolution
  - size/weight
  - difficult to calibrate (up to 12 DOF)
- But HMDs are the only displays available for AR, aren't they?

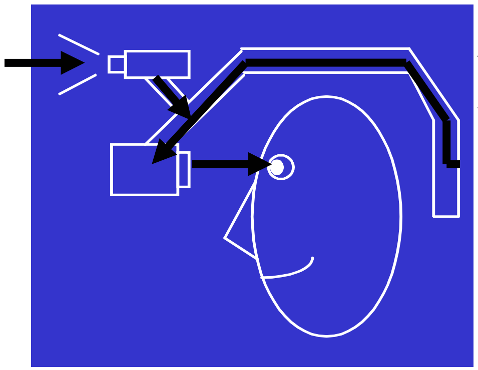

Stereoscopic Displays
Goggle Bound Displays
VR
Autostereoscopic Displays
Head-Attached Displays
Spatial Displays
Re-Imaging Displays
Volumetric Displays
Parallax Displays
Holographic Displays
Head-Mounted Displays
Projection Displays
Desktop-Configurations
Pepper's Ghost Configur-ations
Solid-State Displays
Parallax Barrier Displays
Electro-holographic Displays
AR
Boom-like Displays
Surround Screen Displays
Embedded Screen Displays
Multi-planar Displays
Lenticular Displays
Real Image Displays
Retinal Displays
CAVEs
Work-benches
Varifocal Displays
Domes
Walls
Head-Mounted Projectors
Panoramic Displays
Oblique Screens
Desktop Monitors
Reach-In Systems
Transparent Projection Screens


retinal display
head-mounted display
projector
hand-held display
spatial see-through display
projector
projector
head-attached
body-attached
spatial

Head-Mounted Displays



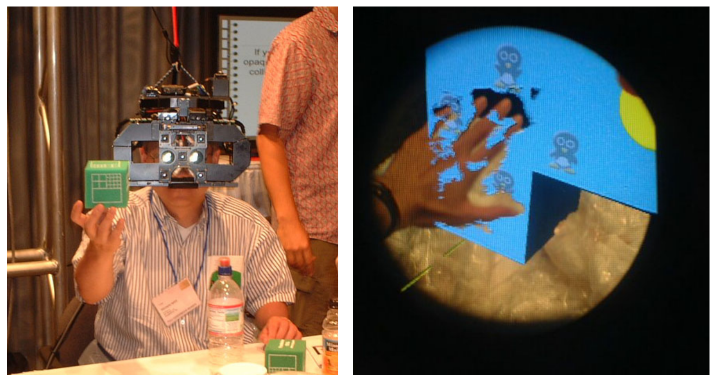
optical see-through



video see-through

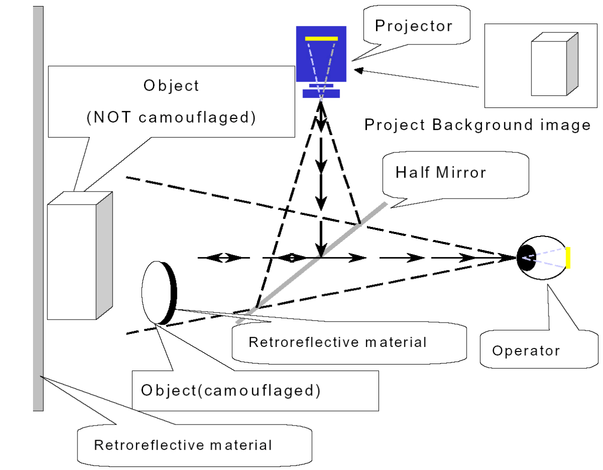
Courtesy: Azuma, R. T. A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments, vol. 6, no. 4, pp. 355-385, 1997.

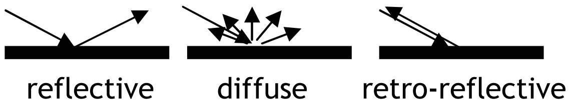
- mainly used
- availability
- easy to set up
- mobile applications



Courtesy:Kiyokawa, K., Kurata, Y. and Ohno, H. An Optical See-through Display for Mutual Occlusion of Real and Virtual Environments. In proceedings of IEEE & ACM ISAR 2000, pp. 60-67, 2000.

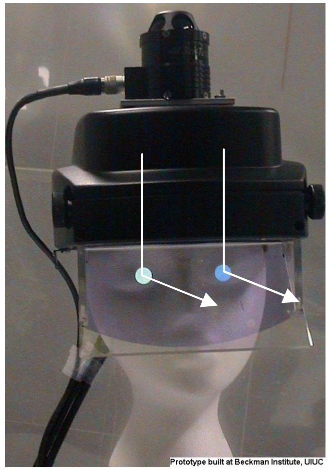
Head-Mounted Projectors





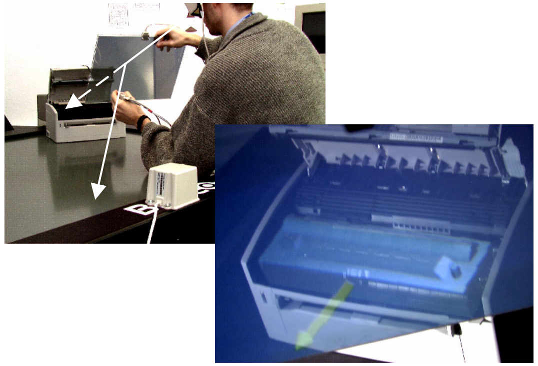
Courtesy: Inami, M., Kawakami, N., Sekiguchi, D., Yanagida, Y., Maeda, T. and Tachi, S., Visuo-Haptic Display Using Head-Mounted Projector, Proceedings of IEEE Virtual Reality 2000, pp.233-240, 2000.

Courtesy: Hua, H., Gao, C., Brown, L., Ahuja, N., and Rolland, J.P. 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.

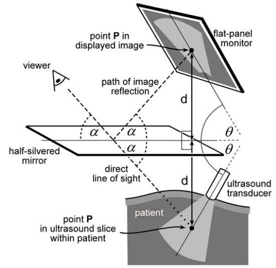


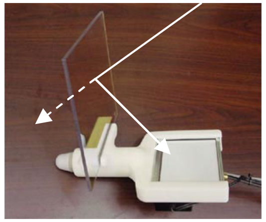
- support multiple user and stereo
- combines advantages of projectors and HMDs
- simple rendering (even for complex surfaces)
- are currently heavy and cumbersome
- require special display surface
- suffer from shadow-casting

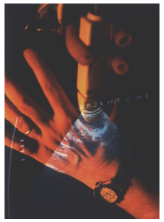
Hand-held and Object-Oriented Displays



Bimber, O., Encarnação, L.M., and Schmalstieg, D. 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.



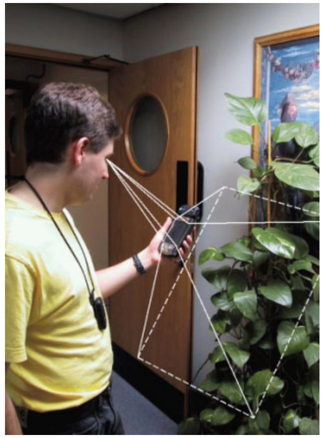




Courtesy: Stetten, G., Chib, V., Hildebrand, D., Bursee, J. Real Time Tomographic Reflection: Phantoms for Calibration and Biopsy, In proceedings of IEEE/ACM International Symposium on Augmented Reality (ISMAR'01), pp. 11-19.

US and foreign patents are pending

- very application specific
- some support mobile applications
- PDA and cell-phones are popular
- limited resolution and FOV



Courtesy: Newman, J., Ingram, D., and Hopper, A. Augmented Reality in a Wide Area Sentient Environment, In proceedings of IEEE/ACM International Symposium on Augmented Reality (ISMAR'01), , 2001, pp. 77-86.

Hand-held and Object-Oriented Displays

Courtesy: Kawakami, N., Inami, M., Sekiguchi, D., Yanagida, Y., Maeda, T. and Tachi, S. Object-Oriented Displays: A New Type of Display Systems -From immersive display to Object-Oriented Displays-, IEEE-SMC '99 Abstracts, Tokyo, Japan, p. 493, October, 1999.

Courtesy: Siio, I. Virtual Glassboat: For looking under the Ground. Human-Computer Interaction International (HCII'01), 2001, pp. 683-687

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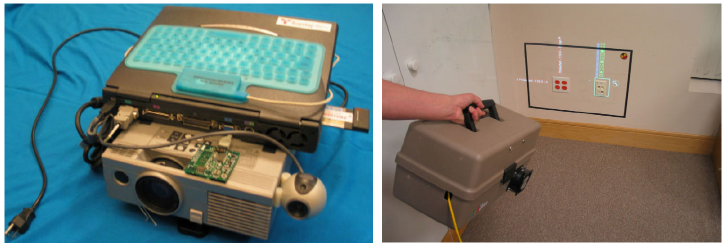
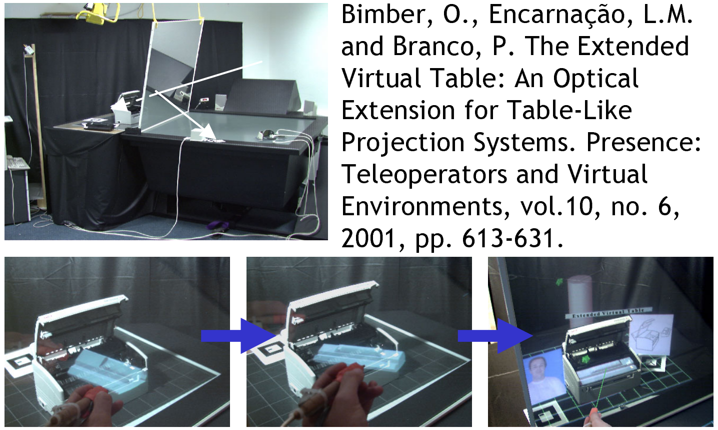
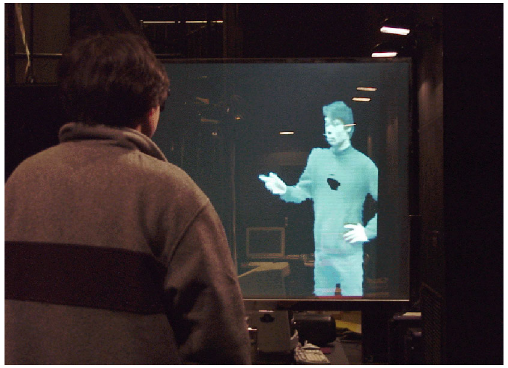


Courtesy: Raskar, R. van Baar, J., Beardsly, P, Willwacher, T., Rao, S., and Forlines, C. iLamps: Geometrically Aware and Self-Configuring Projectors. In Computer Graphics (proceedings of SIGGRAPH'03), 2003.

Spatial See-Through Displays



Bimber, O., Encarnação, L.M. and Branco, P. 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.

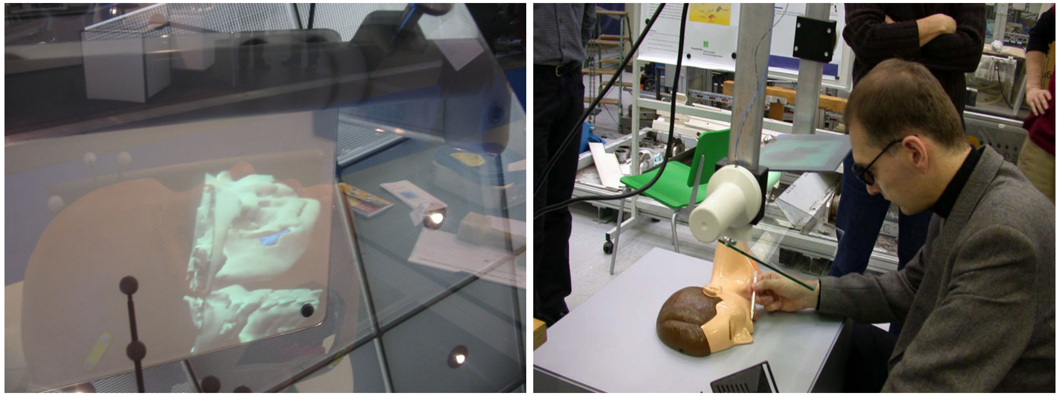


Courtesy: Ogi, T., Yamada, T., Yamamoto, K. and Hirose, M. Invisible Interface for Immersive Virtual World. In proceedings of the Immersive Projection Technology Workshop (IPT'01), pp. 237-246, Stuttgart, Germany, 2001.

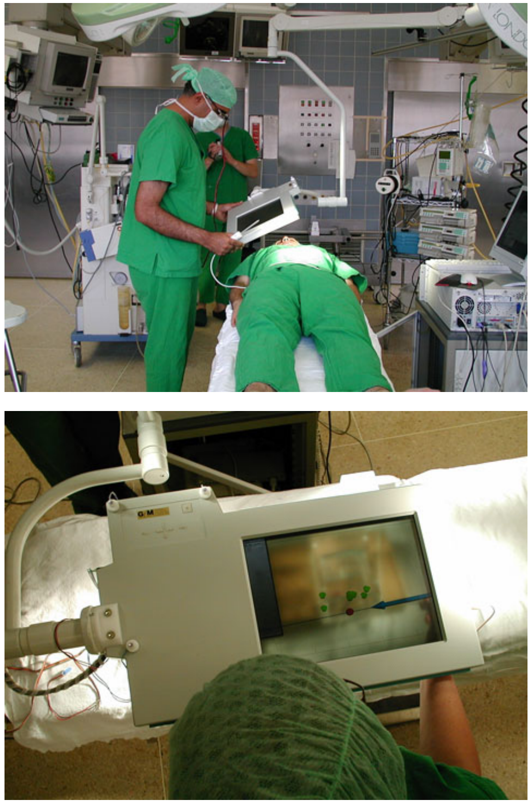
- scalable in resolution and size
- some are multi-user capable
- limited interaction possibilities
- do not support mobile applications

Bimber, O., Fröhlich, B., Schmalstieg, D., and Encarnação, L.M. The Virtual Showcase. *IEEE Computer Graphics & Applications*, vol. 21, no.6, pp. 48-55,2001.

Spatial See-Through Displays



Courtesy: Fraunhofer IMK
(www.arsys-tricorder.de)



Schwald, B., Seibert, H., Weller, T. 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.

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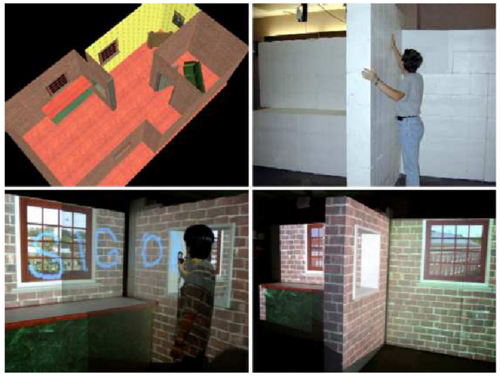
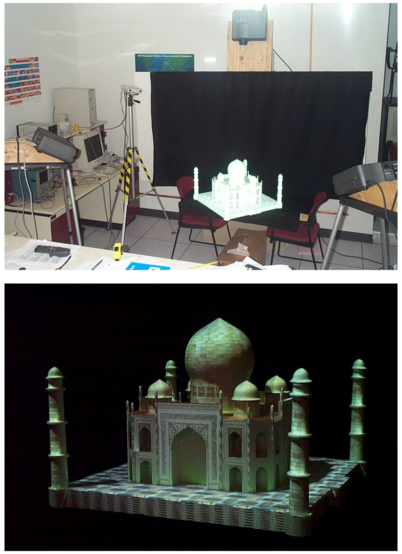
Spatial Projection Displays



Courtesy: Low, K., Welch, G., Lastra, A., and Fuchs, H. Life-Sized Projector-Based Dioramas. Symposium on Virtual Reality Software and Technology, 2001.

Raskar, R. Welch, G., Low, K.L., and Bandyopadhyay, D. Shader Lamps: Animating real objects with image-based illumination. In Proceedings of Eurographics Rendering Workshop (EGRW'01), 2001.



- large scale
- scalable in resolution and size
- no goggles required
- depend on display surface
- occlusion and self-occlusion
- multiple projectors have to be blended

Courtesy: Pinhanez, C. The everywhere displays projector: A device to create ubiquitous graphical interfaces. In Proc. of Ubiquitous Computing 2001 (Ubicomp'01), Atlanta, Georgia, 2000.

tiny projectors?

foldable displays?

What comes next?

autostereoscopy and holography?

images in thin air?

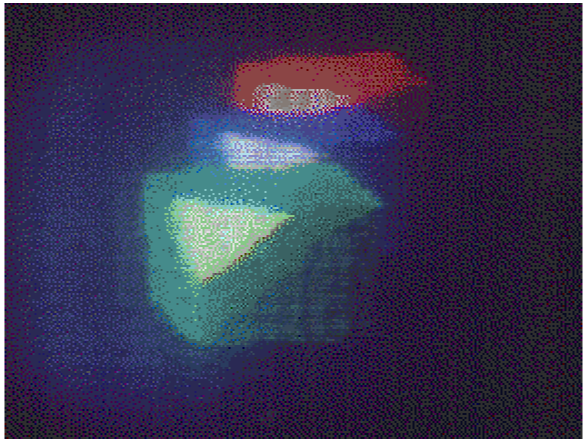
Autostereoscopy and Holography

C Display

Courtesy: SeeReal Technologies GmbH.

Holographic Video

Courtesy: Lucente, M. and Galyean, T.A., Rendering Interactive Holographic Images In Computer Graphics Proceedings (Proceedings of ACM SIGGRAPH'95), pp. 387-394, 1995.

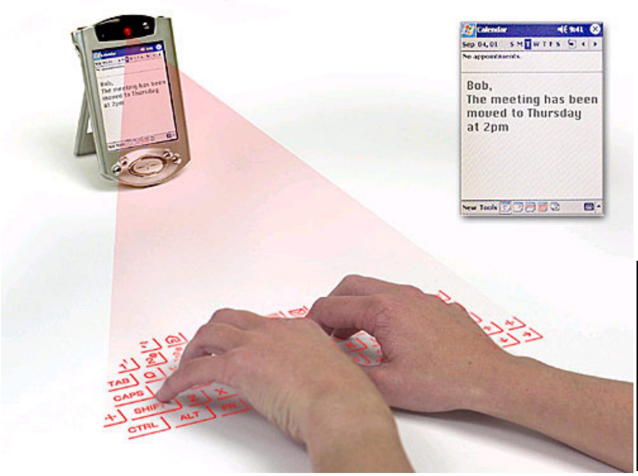


Courtesy: Fraunhofer Heinrich-Hetrz Institute.

Holographic Video

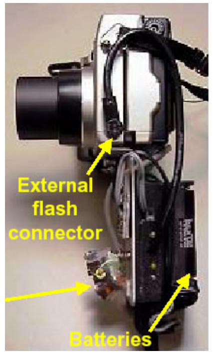
Courtesy: Spatial Imaging Group, Media Lab, MIT.

Tiny Projectors

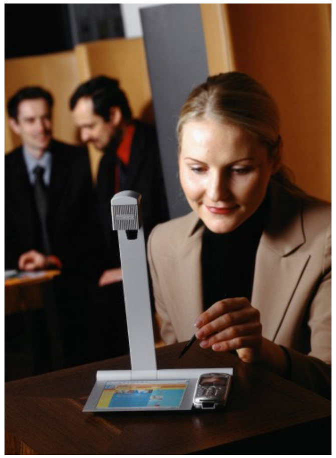


Courtesy: Canesta

Courtesy: Strat, A., V. and Oliviera, M.M. Casual 3D Photography, Siggraph'03, Sketches and Applications

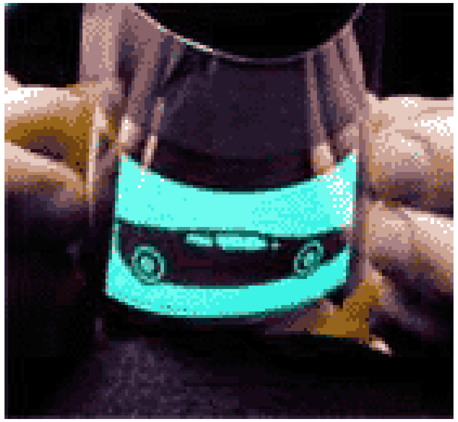


Courtesy: Symbol ET.



Courtesy: Siemens

Foldable Displays



OLED

Courtesy: Stanford

LEP

Courtesy: ?

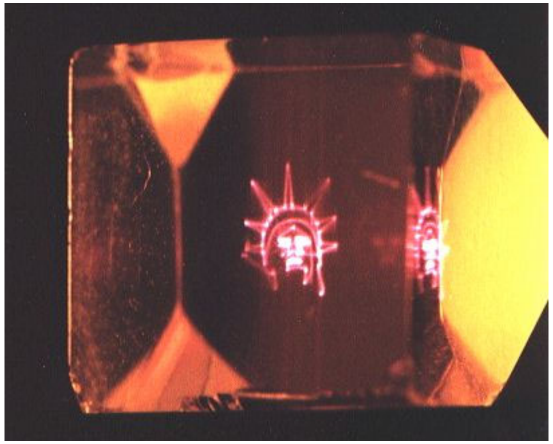
E-Ink

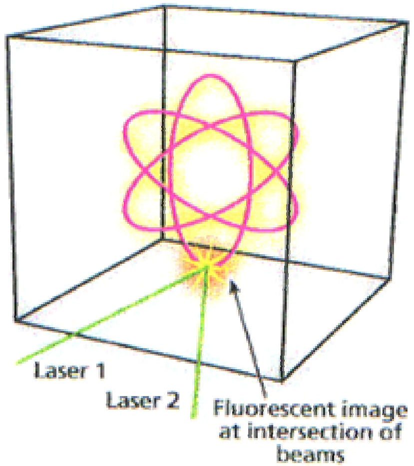
Courtesy: E Ink Corp.

Volume Displays

Courtesy: Langhans, K., Guill, C., Rieper, E. Oltmann, K., and Bahr, D. Solid FELIX: A static 3D-Laser Display, In Proceedings of Symposium on Electronic Imagining: Science and Technology (IS&T/SPIE), vol. 5006, 2003.

Courtesy: D. G. Jansson, E. P. Berlin et. al., "A Three-Dimensional Computer Display", *Computer Graphics in CAD/CAM Systems*, Annual Conference, Cambridge, April 1979.



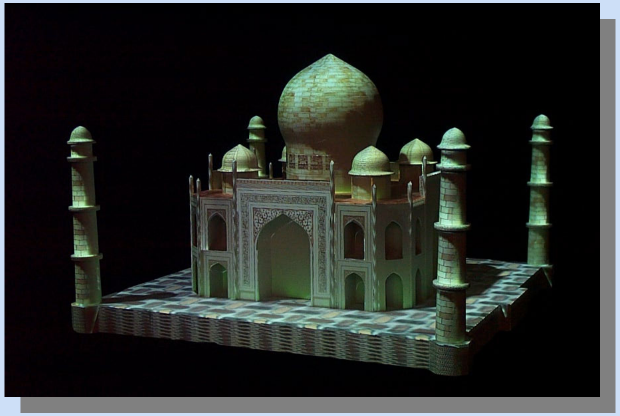


Courtesy: Downing, L. Hesselink, J. Ralston, R. Macfarlane, "A Three-Color, Solid-State, Three-Dimensional Display", Science, Vol. 273, pp. 1185-1189, 1996.

Thank You!

Part 3: Non-trivial Projection Screens

Non-trivial Projection Screens



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

Ramesh Raskar
Mitsubishi Electric Research Labs
Cambridge, MA

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

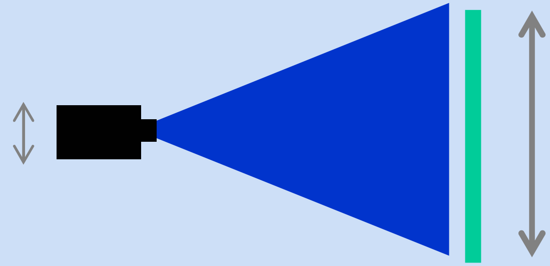
Non-trivial Projection Screens

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

Advantages of Projectors

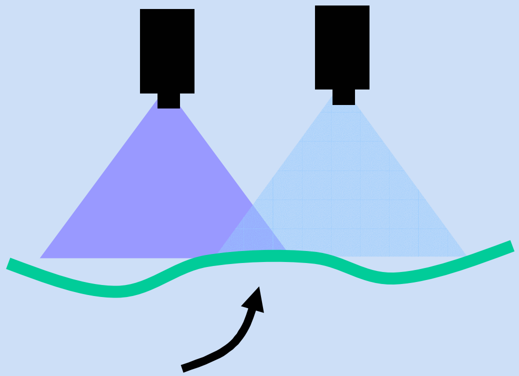
- Size of image

  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

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

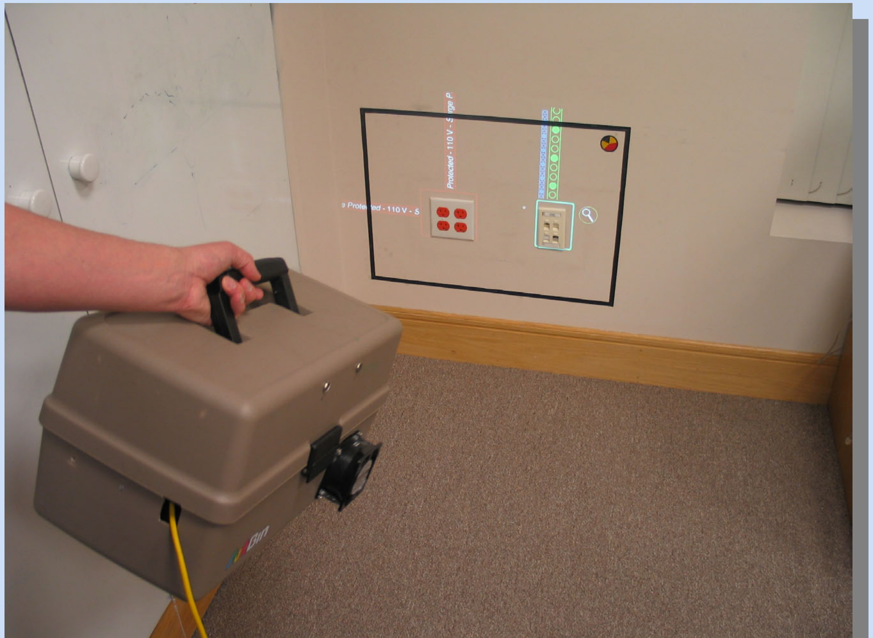
AR using HMD

Spatially Augmented Reality

Video or Optical see-through

SAR, Shaderlamps

Spatially Augmented Reality

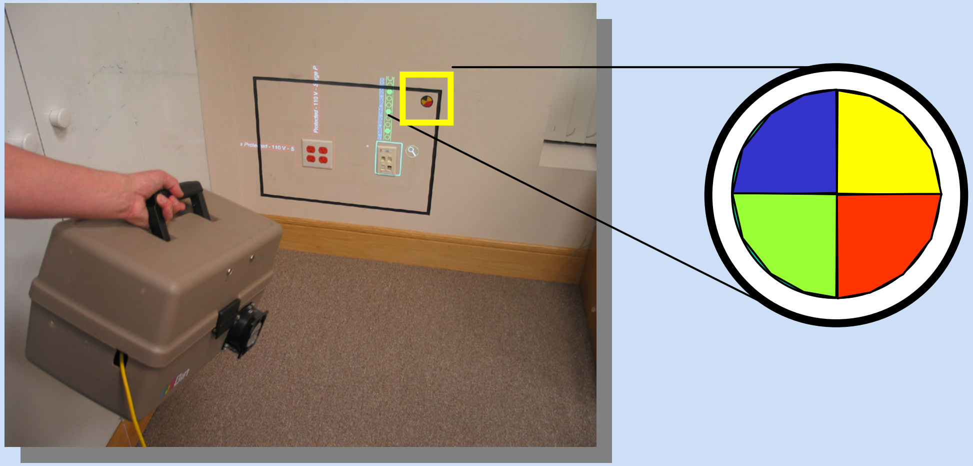


Video

Raskar et al, ‘iLamps: Geometrically Aware and Self-Configurable Projectors, SIGGRAPH 2003

AR with Projection

- Method
  - Passive markers
  - Identification of objects
  - Pose of projector
  - Gesture interaction



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

Limitations

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

Relevant Work

- Michael Naimark's *Displacements*
- Disney
- Son et Lumiere

- Luminous room (Media lab)
- HyperMask (Sony CSL)
- [Levoy 00]

Challenges

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

Projector-based AR
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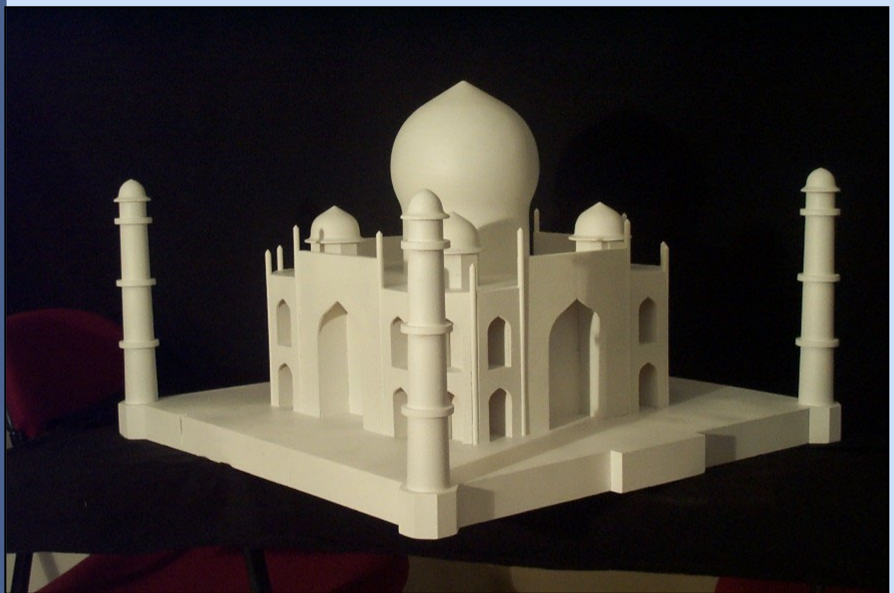
  - Moving Objects
  - Shape Adaptive Projection

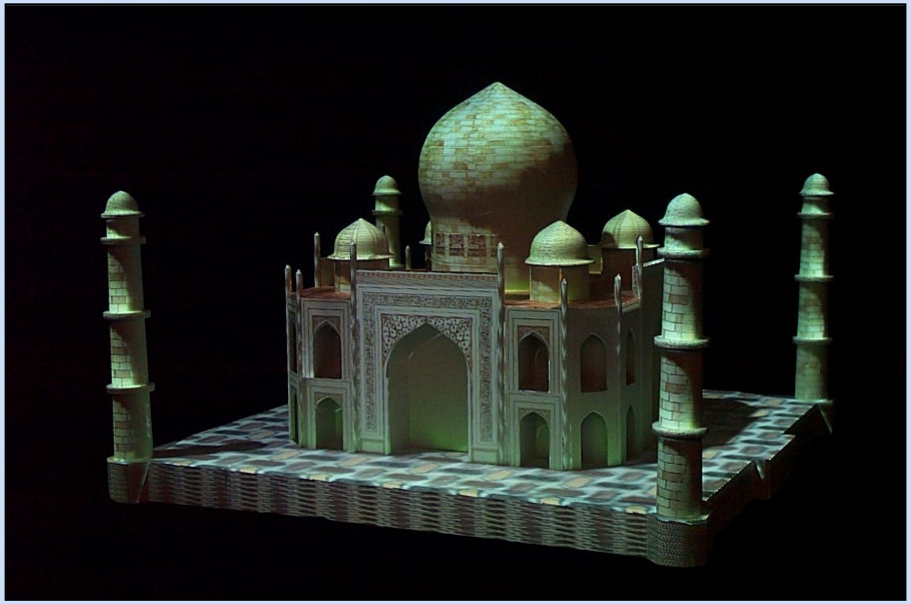
Shader Lamps
Motivation

View-dependent Appearance

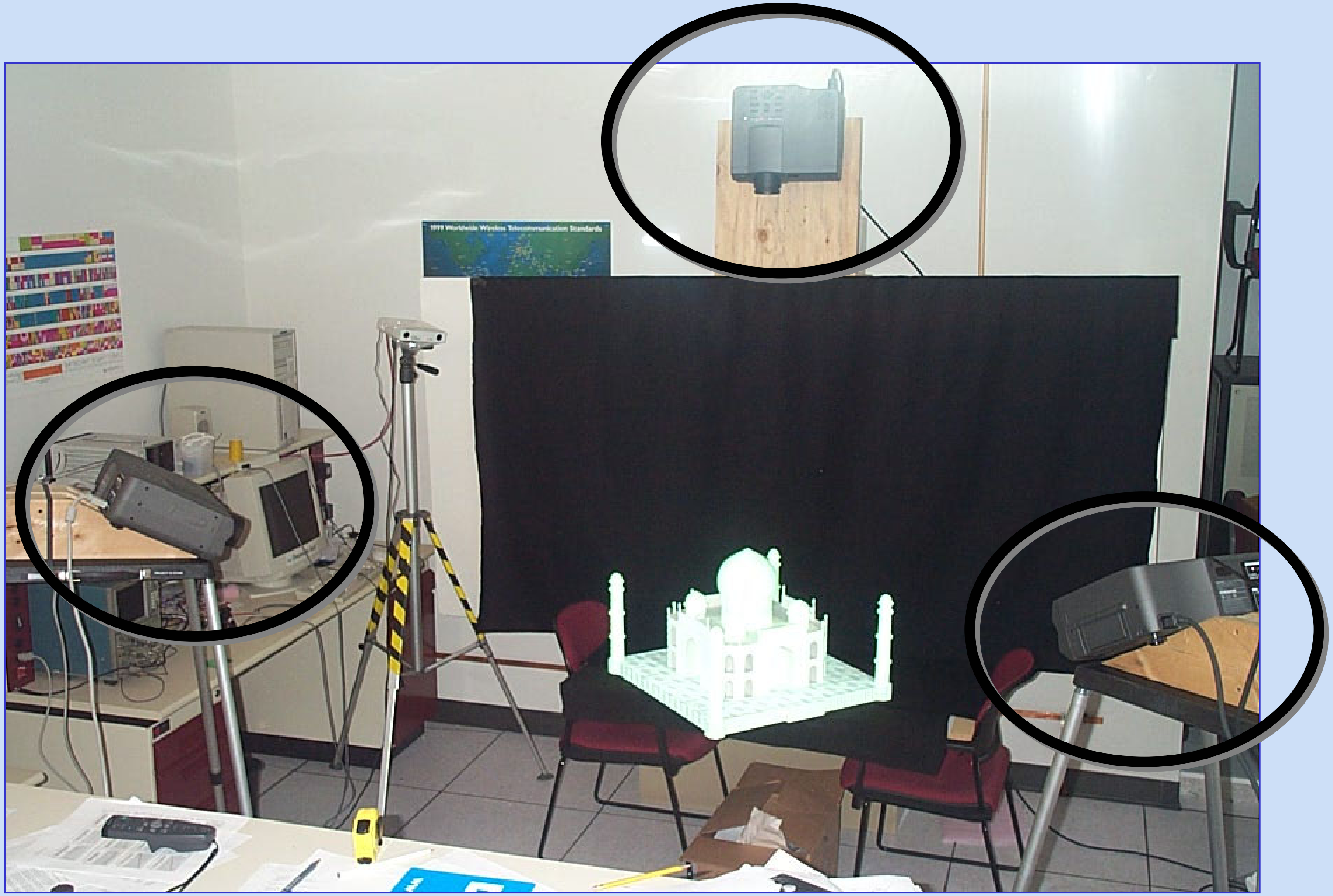
Shader Lamps
Image based Illumination

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

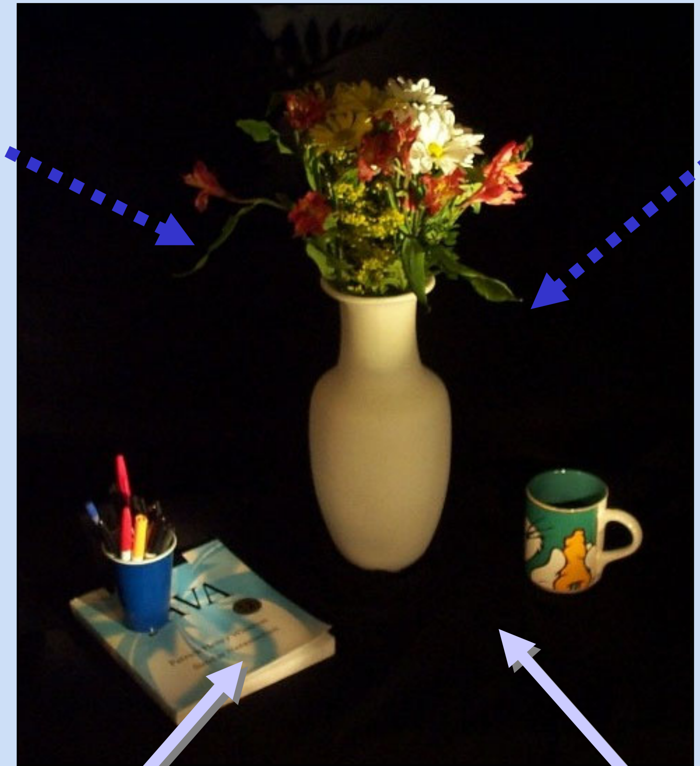




Raskar, Welch, Low, Bandyopadhyay, "Shader Lamps: Animating Real Objects with Image Based Illumination," Eurographics Rendering Worksop (EGRW 2001)



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

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

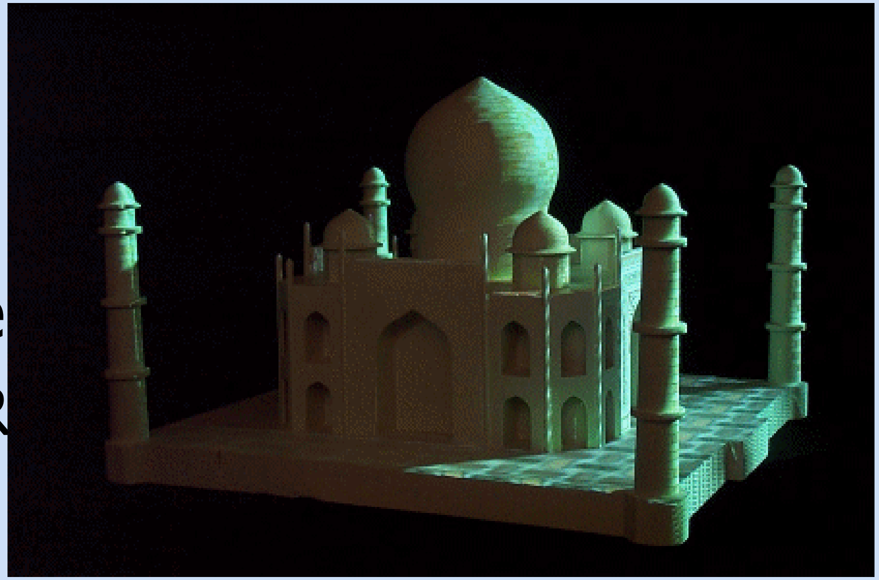
- <u>New</u>
  - Easy setup, Non-trivial objects
  - Real time 3D animation
  - Multiple projectors
  - BRDF

Challenges

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

Comments ? Questions ?

Projector-based AR
Outline



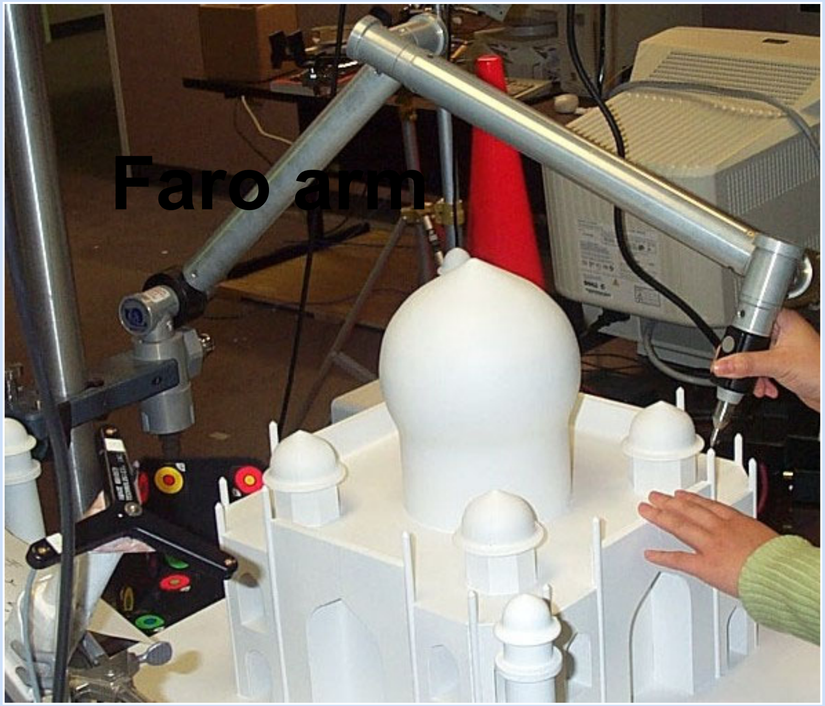
- Concepts and Hardware
  - Spatially Augmented R
  - Shader Lamps
- Rendering Techniques for non-trivial projection
  - Calibration
  - Changing Surface Appearance
  - Merging Overlapping Projection
  - Moving Objects
  - Shape Adaptive Projection

Steps

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

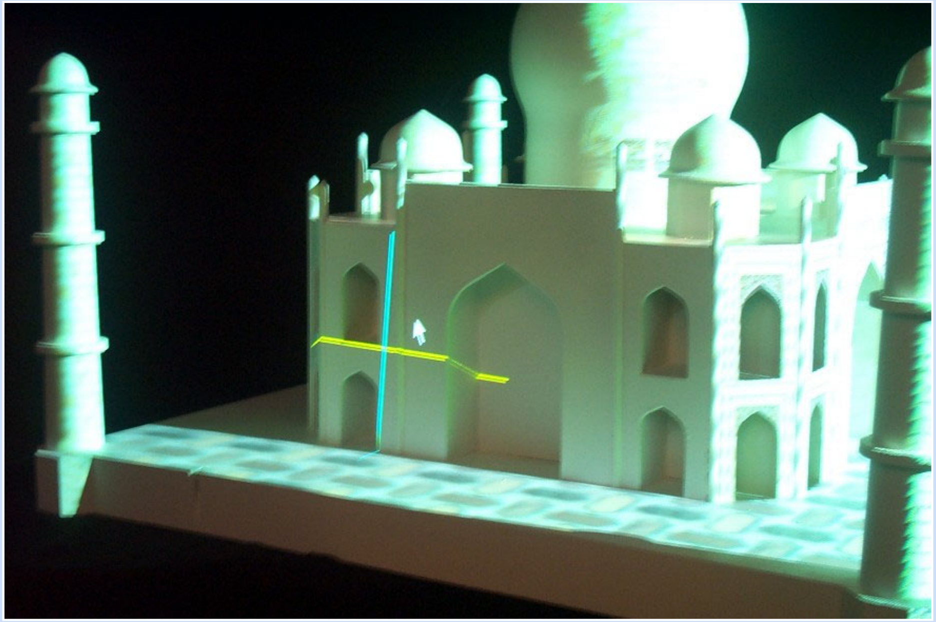
Steps

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



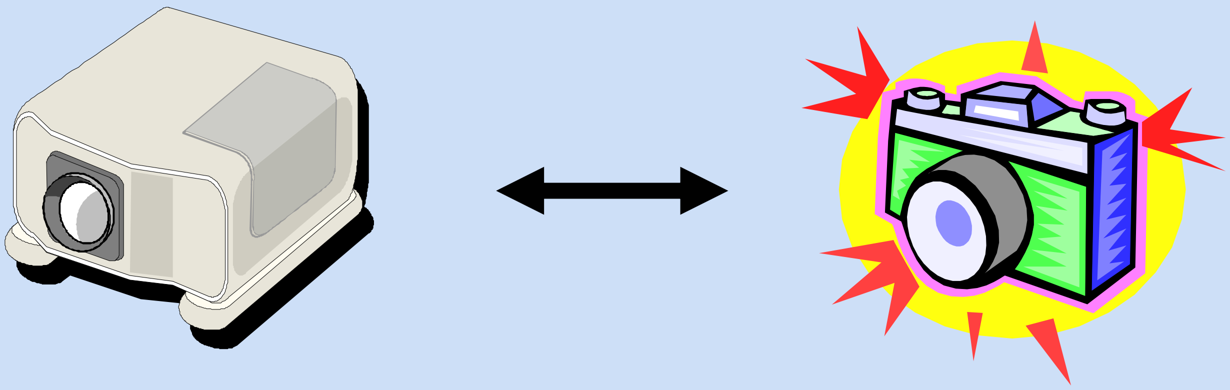
Steps

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



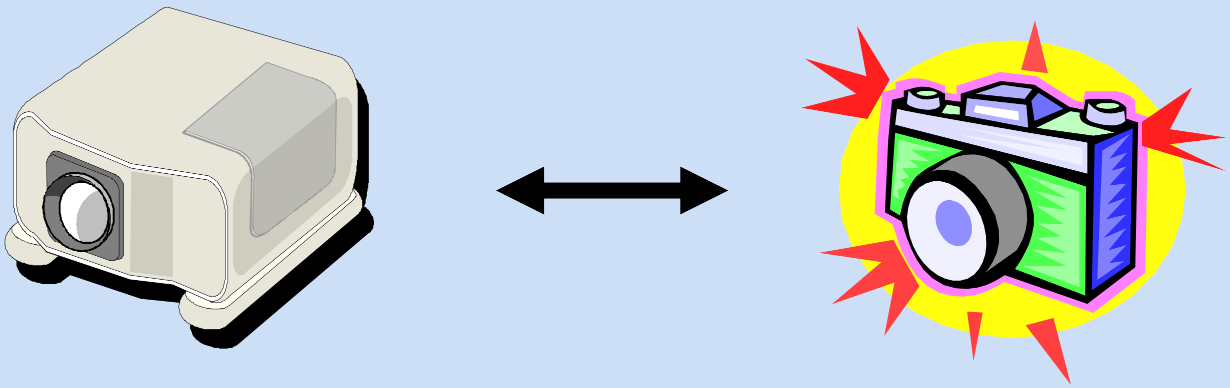
Motivation

- 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



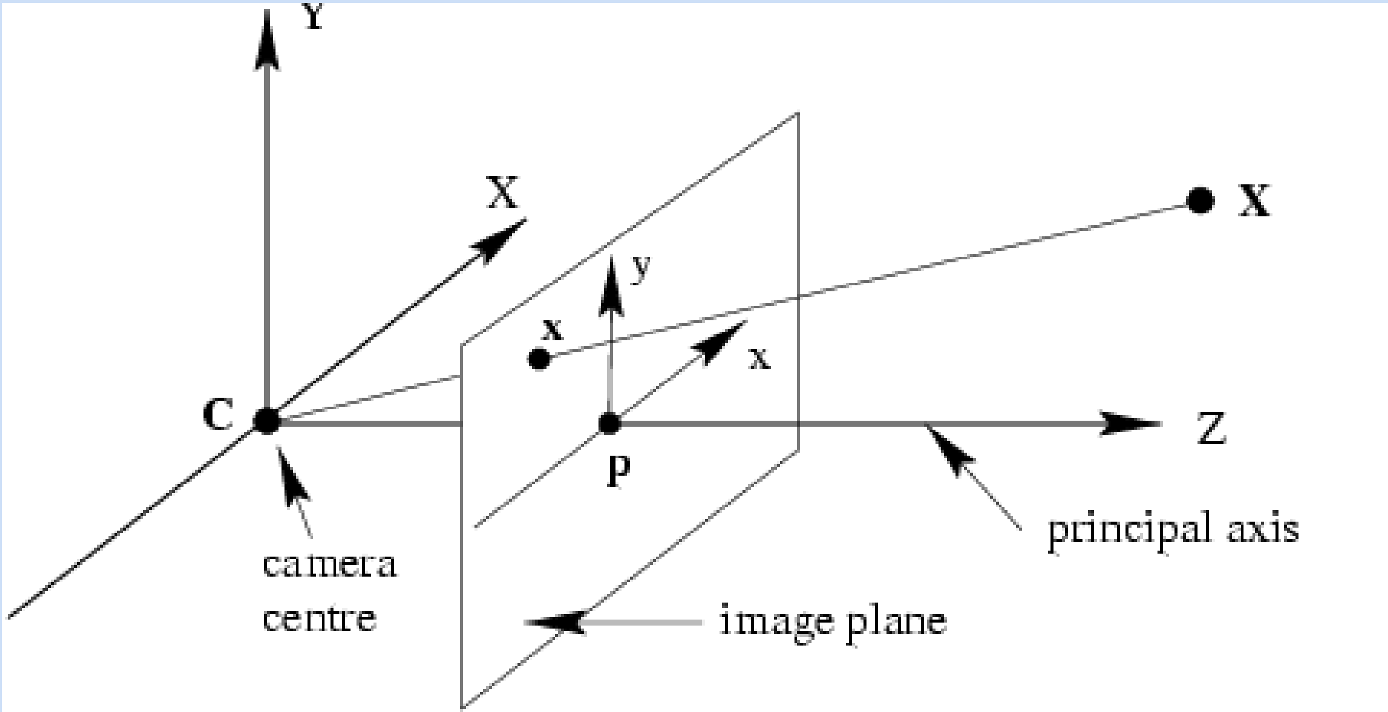
Camera (and Projector) anatomy

Camera center

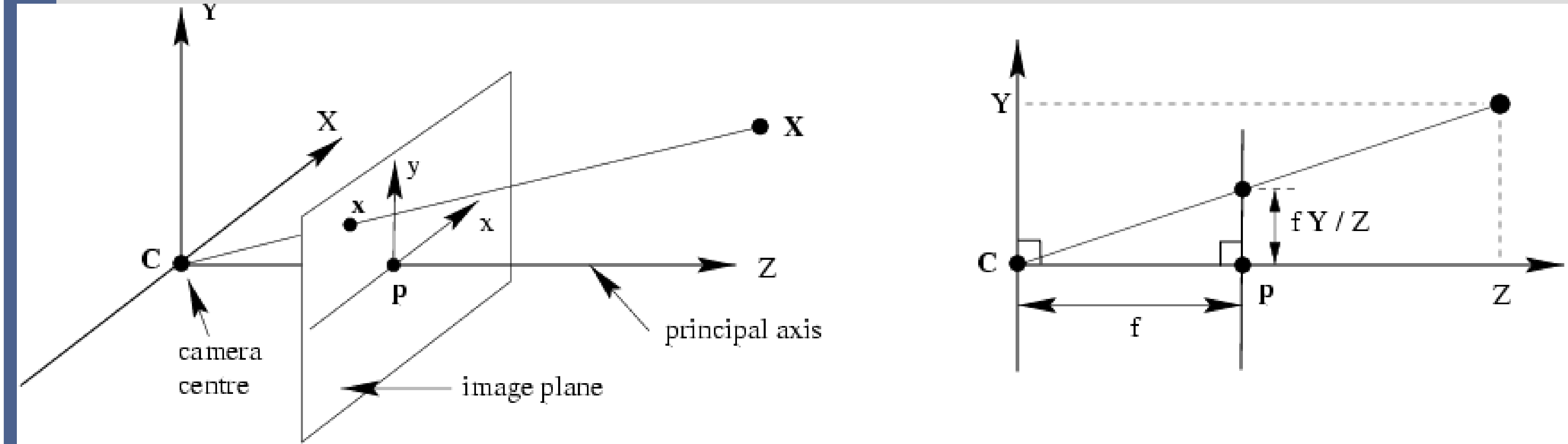
Principal plane

Principal point

Principal ray



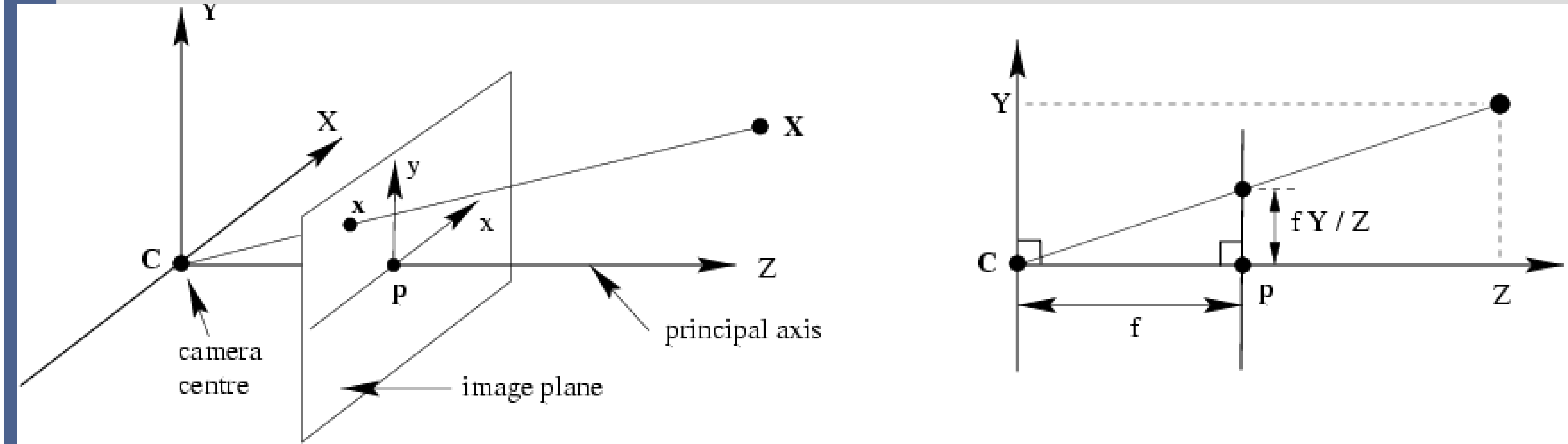
Pinhole camera (or Projector) model



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

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

Pinhole camera (or Projector) model



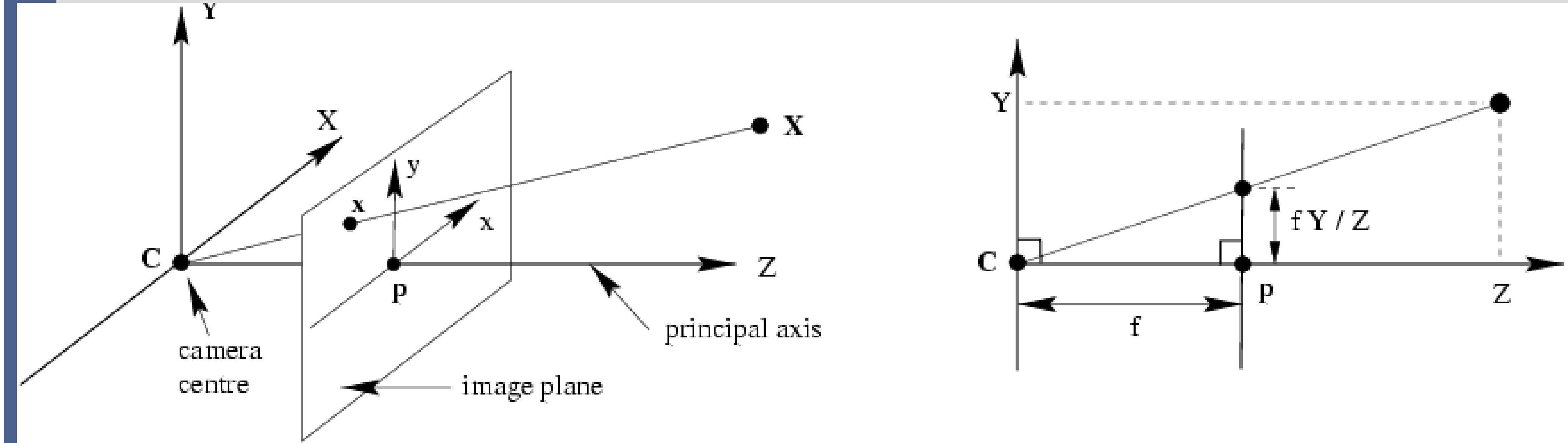
$$y = f\frac{Y}{Z}$$

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

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

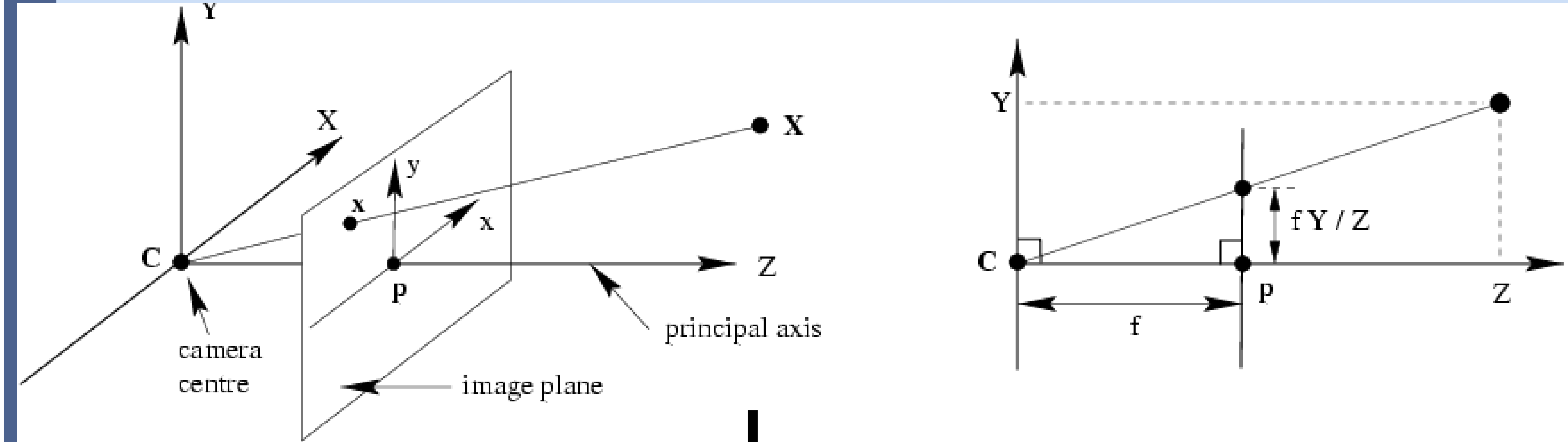
$$P = \mathrm{diag}(f, f, 1)[I \mid 0]$$

Pinhole camera (or Projector) model



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

Pinhole camera (or Projector) model



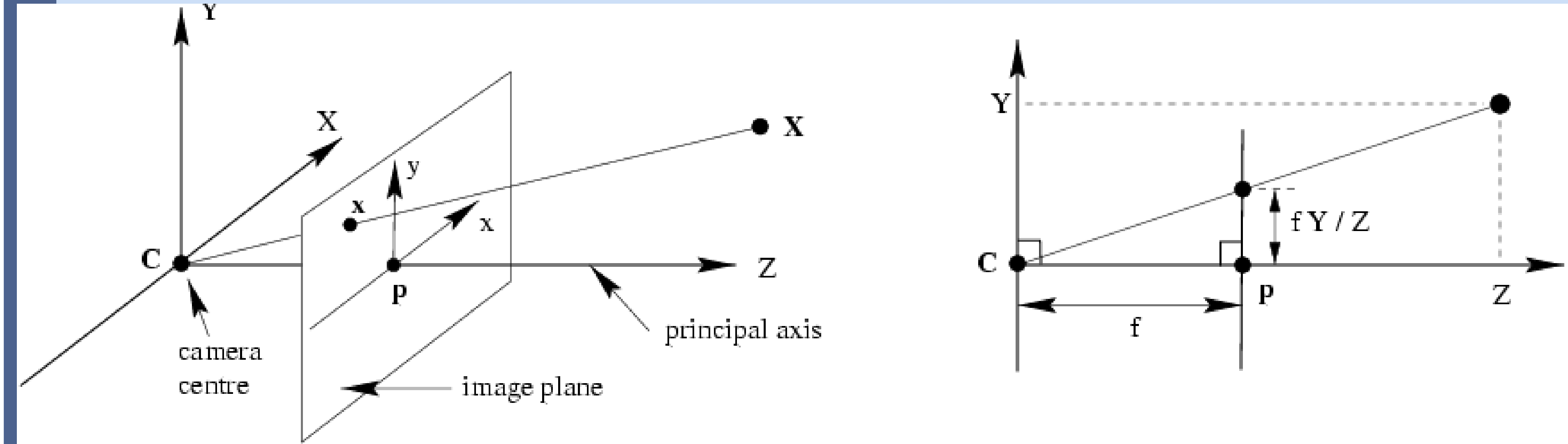
$$\begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} f & & & 0 \\ & f & & 0 \\ & & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

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

Vision

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

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
    - Find fiducials
    - Find pixels that illuminate them
  - Compute intensity correction
- Run time
  - Render images of 3D model
  - Intensity correction for object shape
  - Feathering for projector overlap

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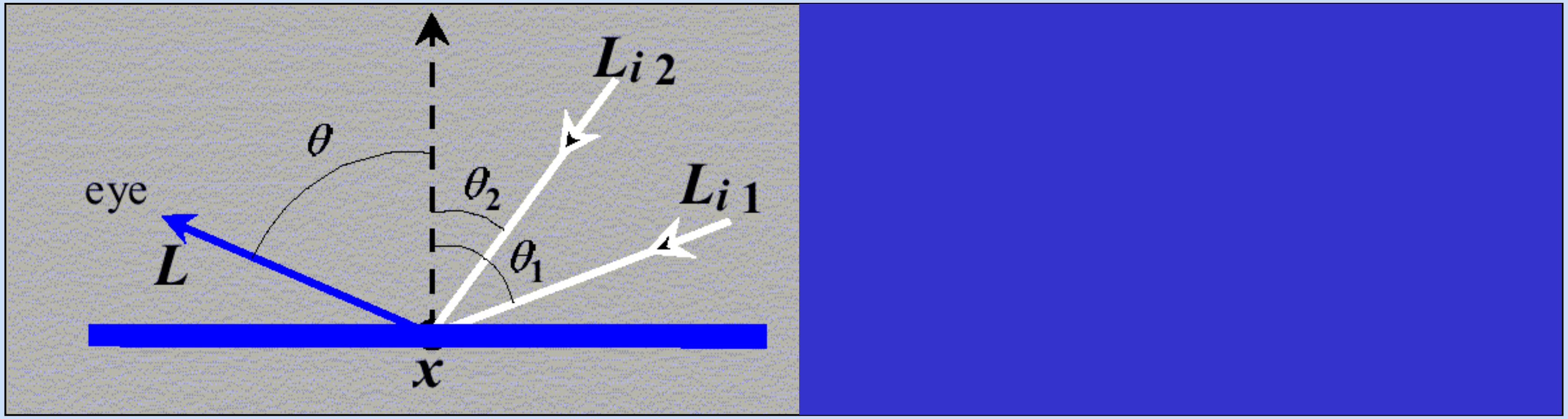
  - Moving Objects
  - Shape Adaptive Projection

Steps

- Preprocessing
  - Scan 3D object and create model, ***G***
  - Approximately position projector(s)
  - Find pose, ***P***
  - Compute intensity correction, $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$

Radiance Adjustment



Virtual

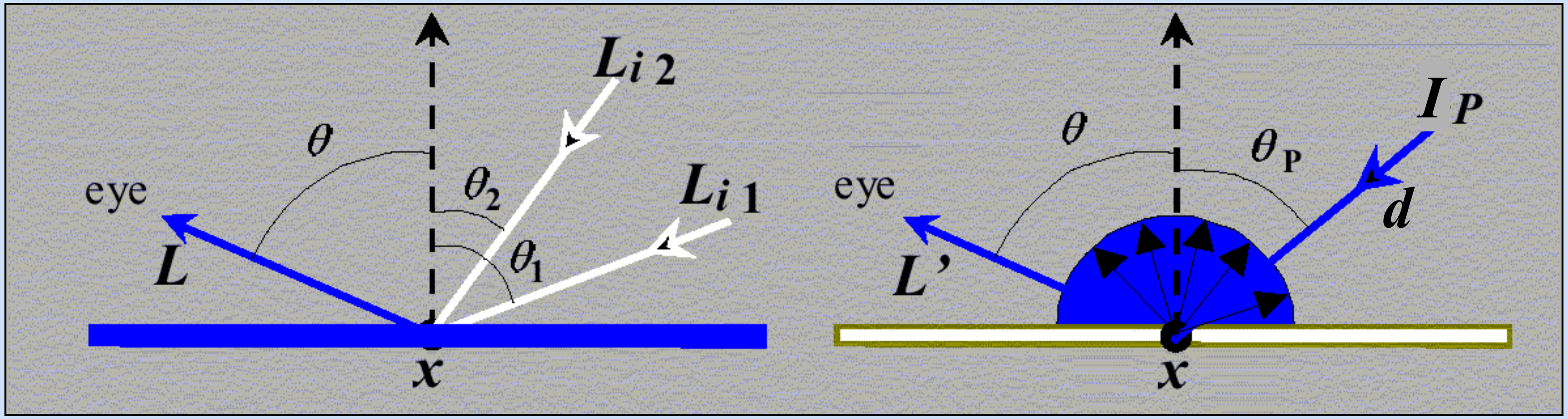
$$L(x,\theta) = \int F(x,\ \theta,\ \theta_i)\ L_i\,(x,\ \theta_i)\ d\omega_i$$

Desired radiance

BRDF

Incident radiance

Radiance Adjustment



Virtual

Real

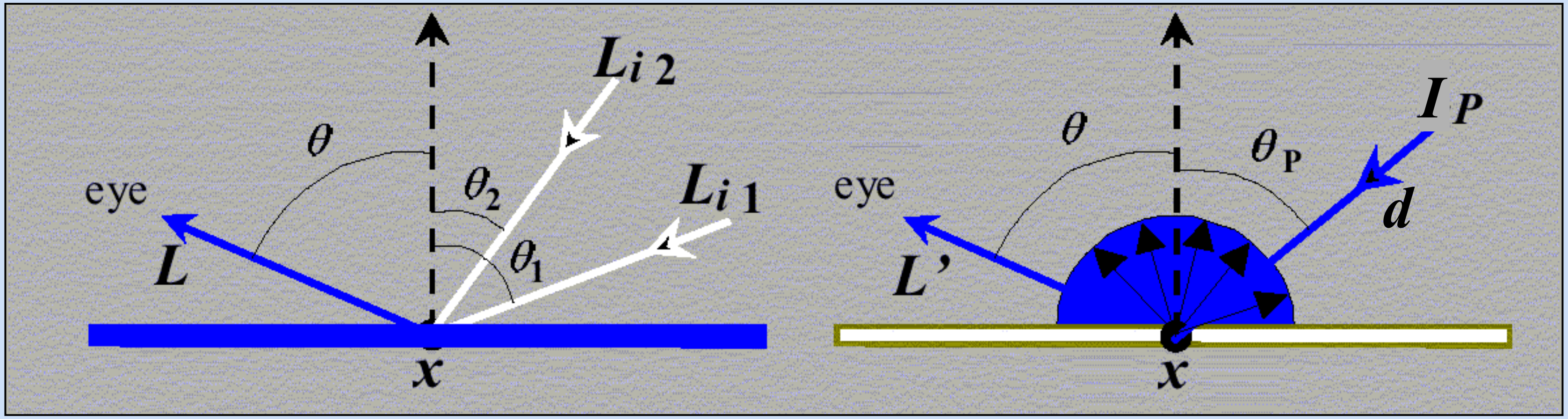
$$L(x,\theta) = \int F(x, \theta, \theta_i)\, L_i(x, \theta_i)\, d\omega_i$$

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

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

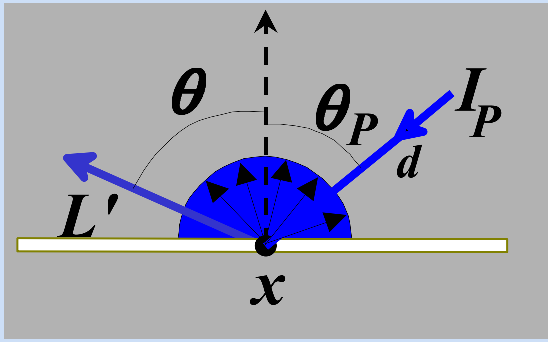
Reflectance

Intensity Correction

Per pixel factor

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

- 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



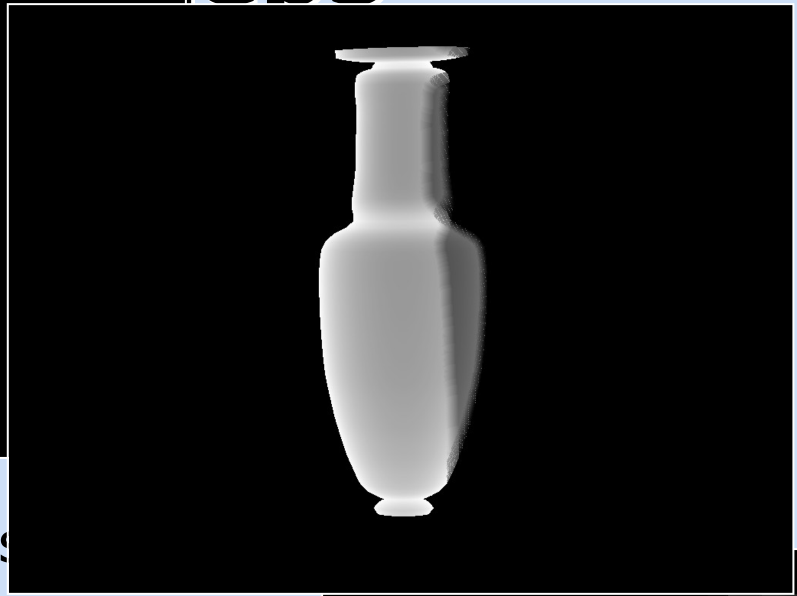
Steps

- 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***

...teps

- • 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 [***I***]
- Intensity correction, [***α***] *
- Feathering, [***β***] * [***α***] * [...

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***]

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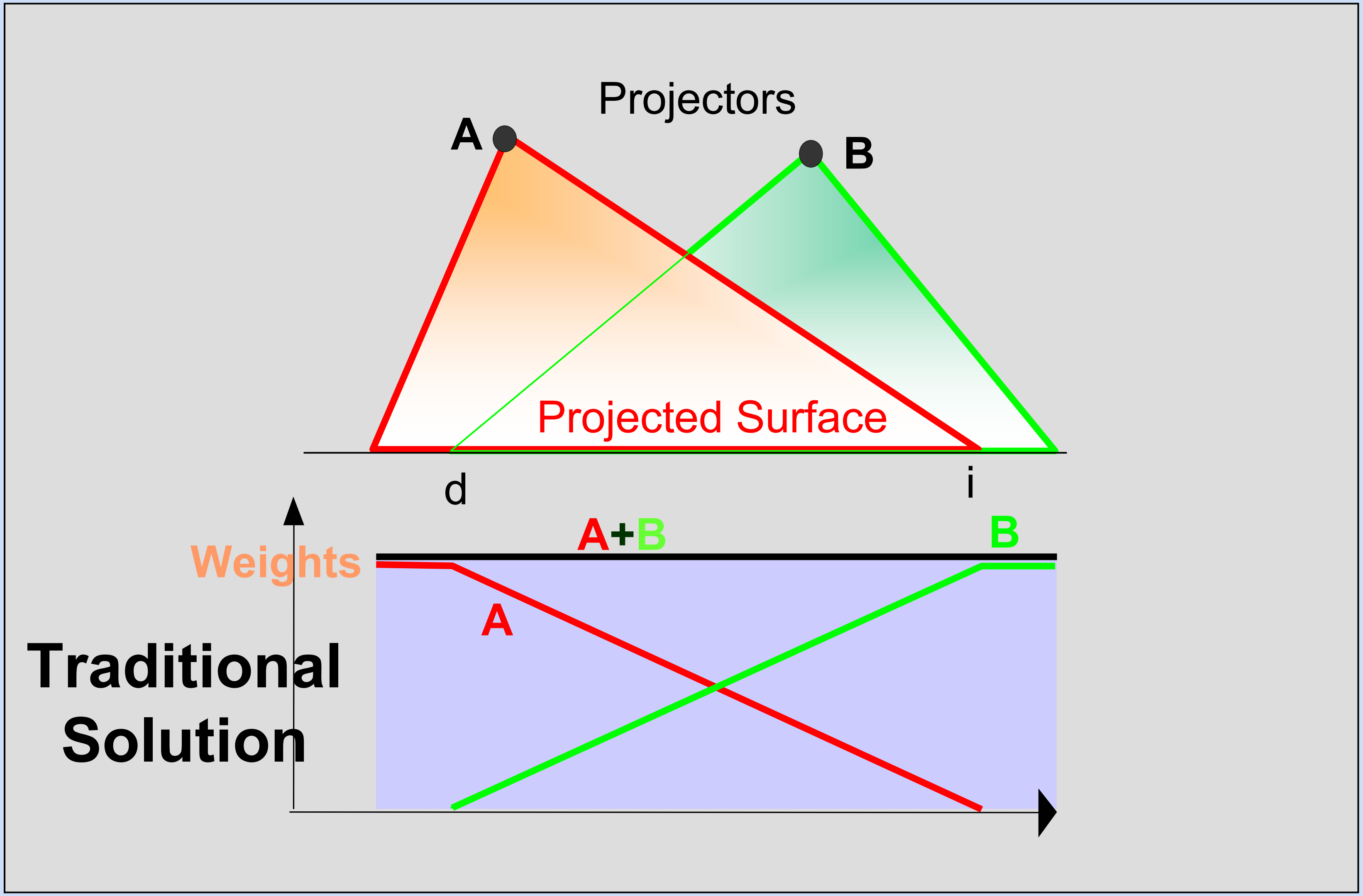
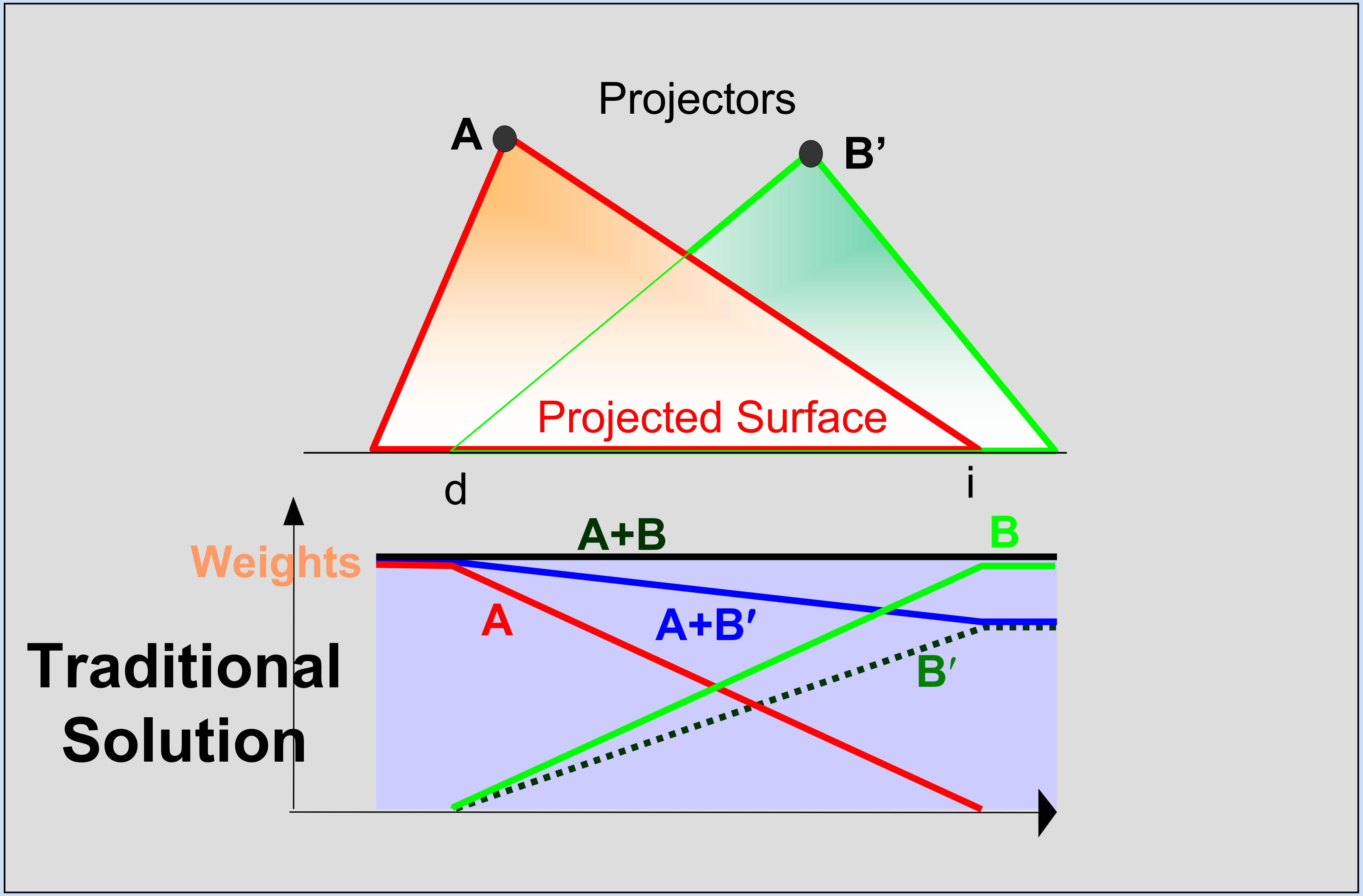
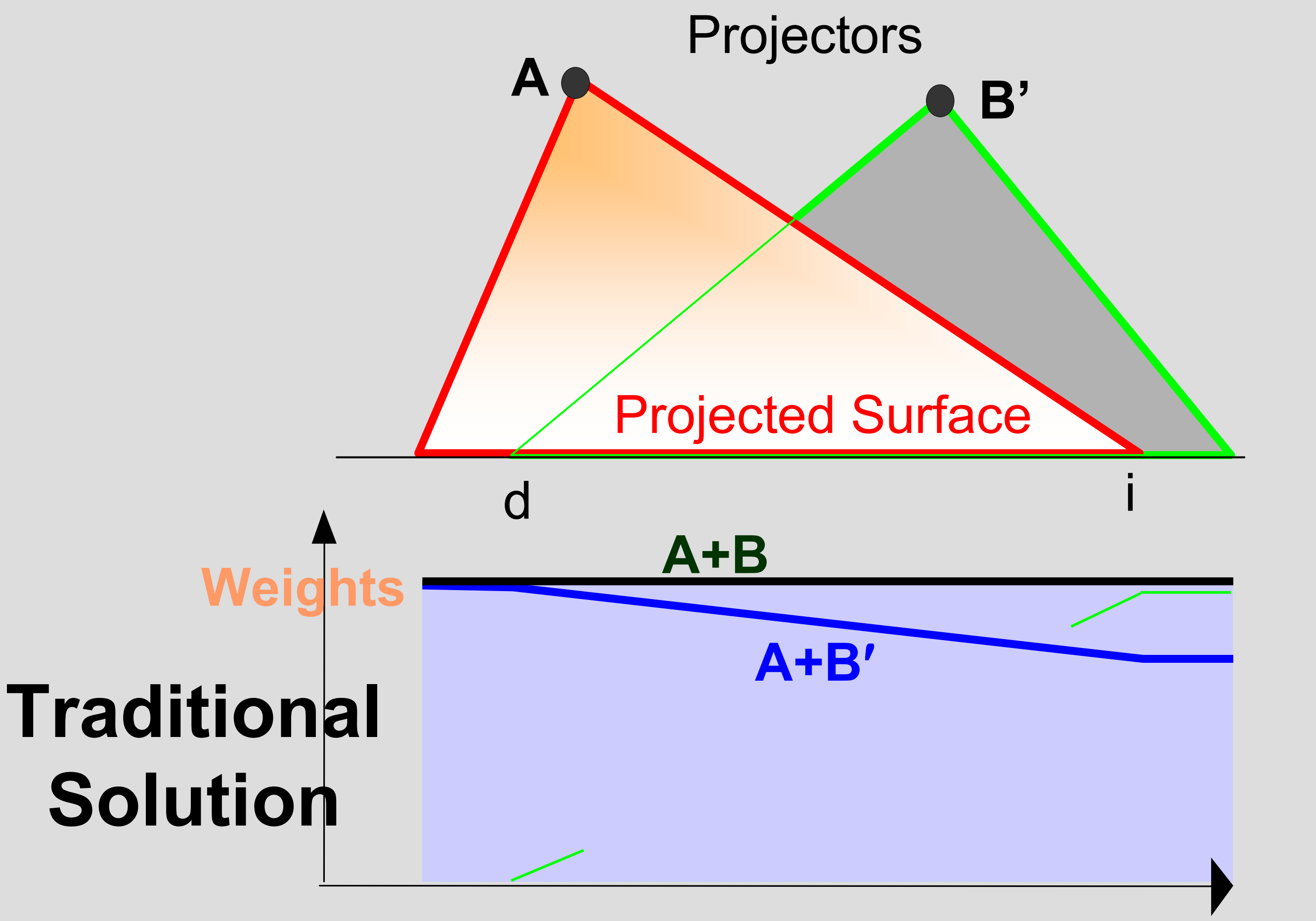
Feathering in Overlap



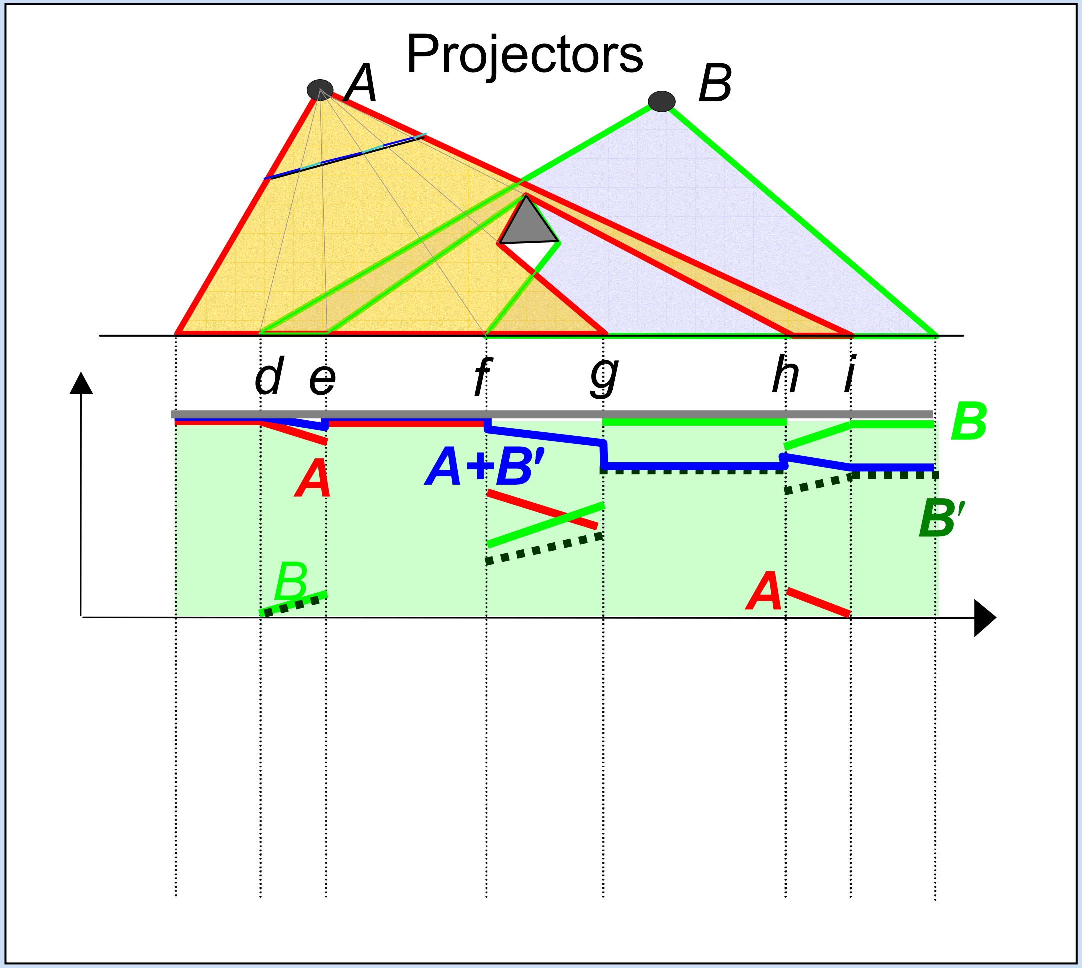
Feathering


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

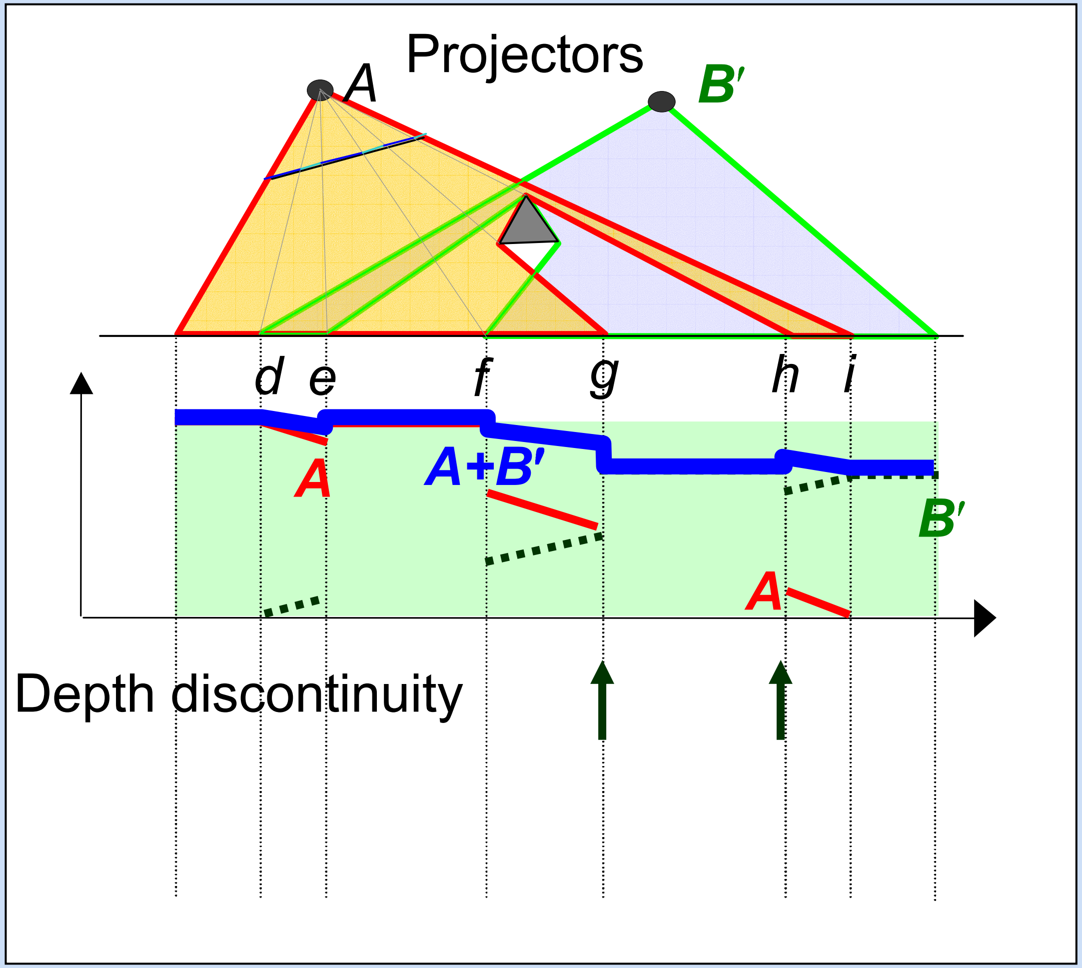
Feathering


Projectors
A
B’
Projected Surface
d
i
A+B
Weights
A+B’
Traditional Solution

Occlusions



Occlusion Problems



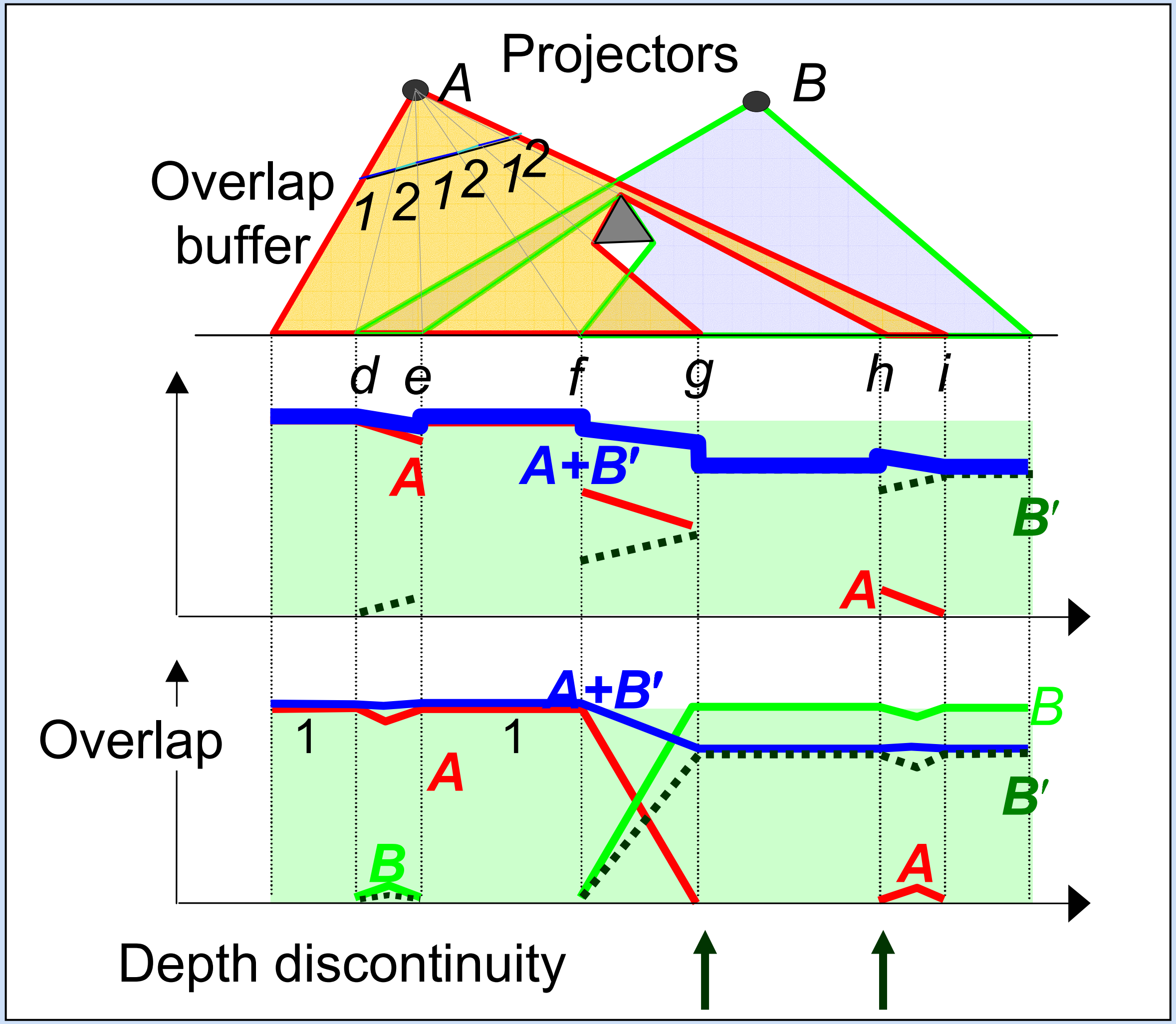
Occlusions and Shadows

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

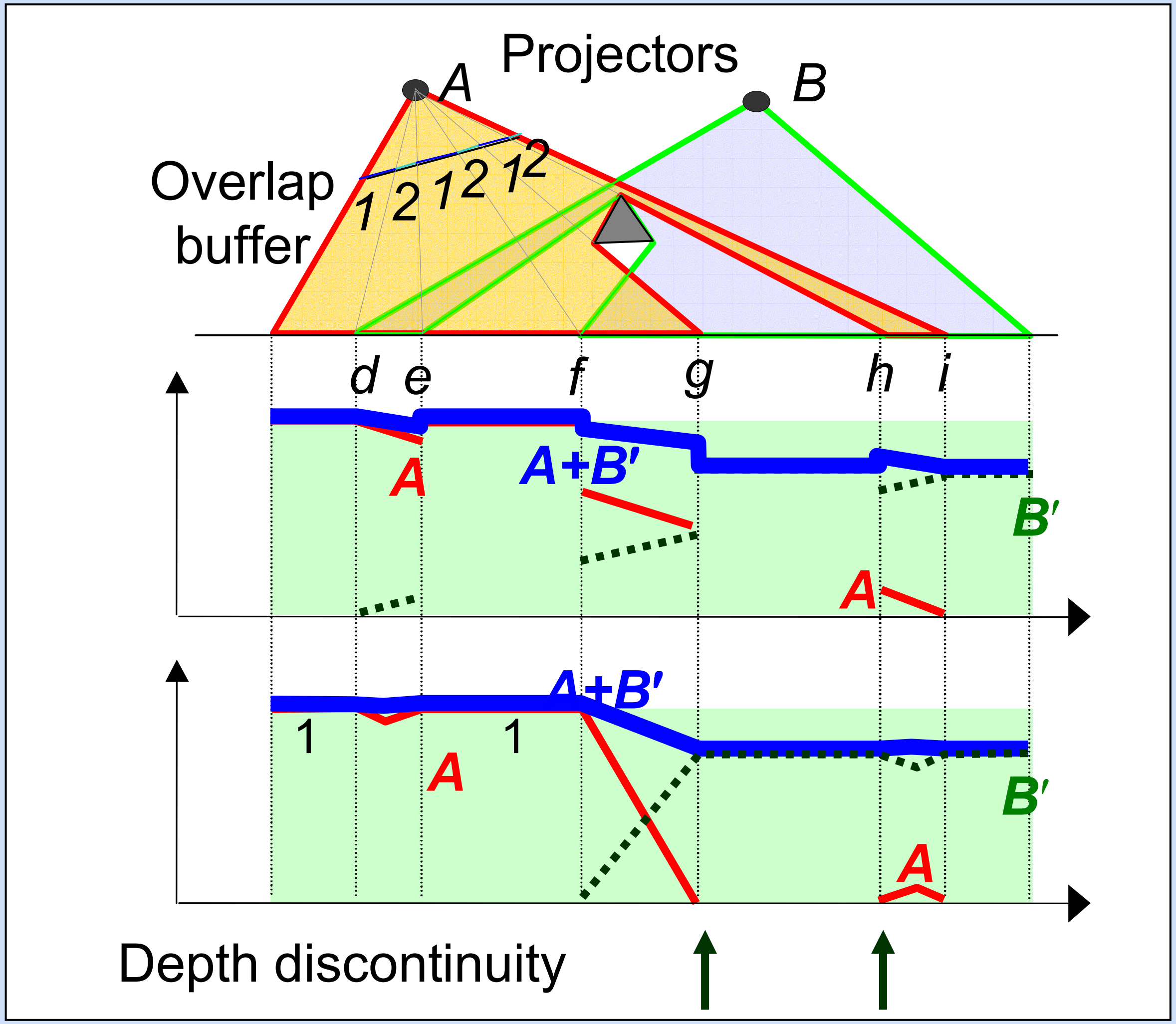
Feathering Algorithm

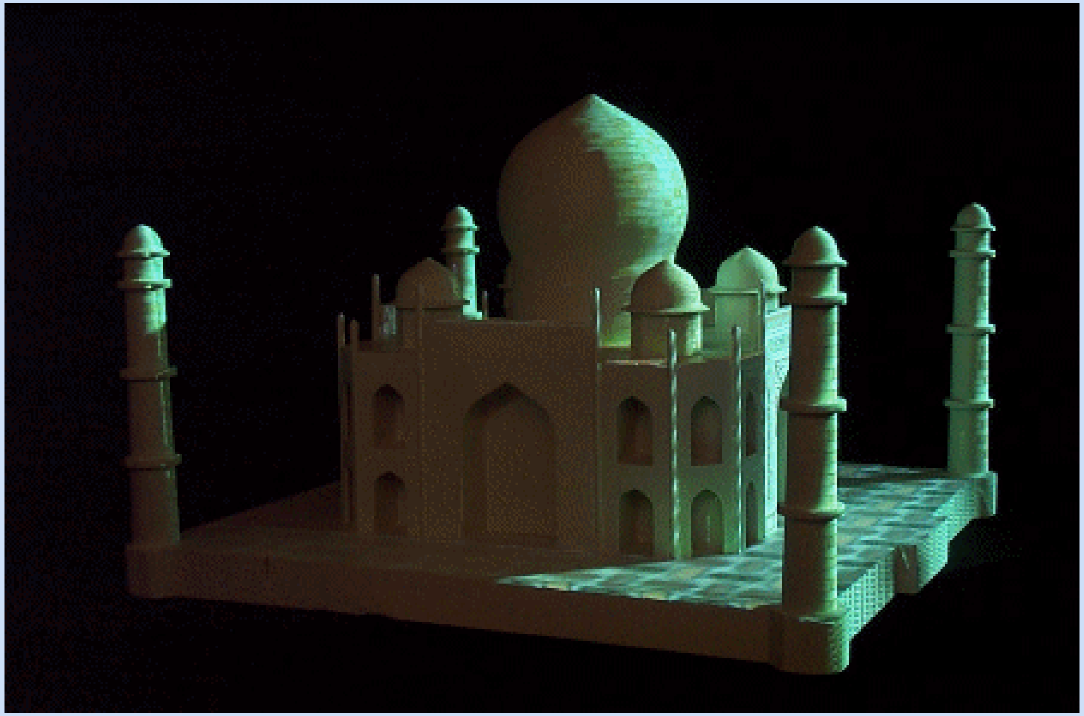
- Each Projector Image Space
  - Compute overlap count (0,1,2..)
  - Find depth discontinuity
  - For overlap region
    - Compute shortest distance to overlap = 1
    - Ignore paths crossing discontinuity
  - Weights = 1/(shortest distance)
- Normalize weights for corresponding pixels

New Feathering



New Feathering





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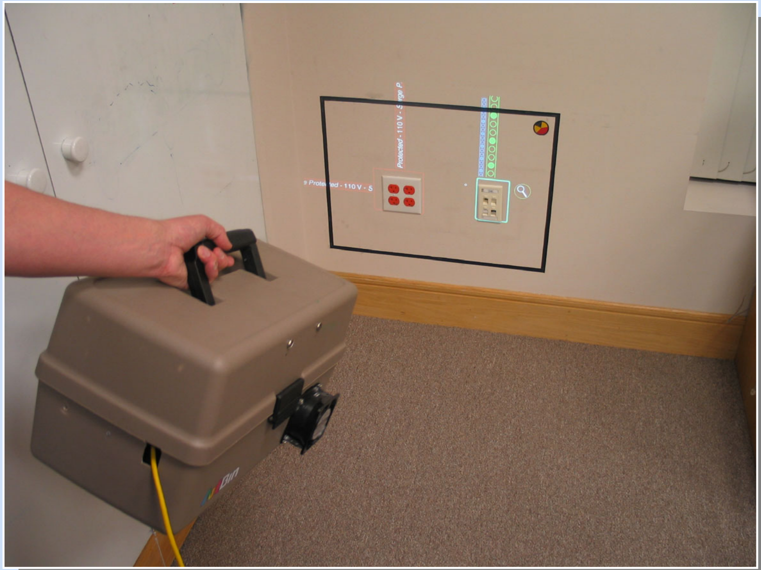
Moving Objects



Moving Surface

Moving Projector

Moving Viewer

Projector-based AR
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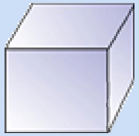
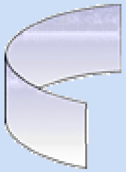
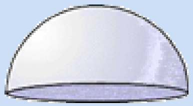
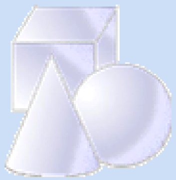
Shape Adaptive Projection

- Projection Screen Geometries
  - Planar 
  - Rectilinear 

Planar Homography

  - Cylindrical 
  - Spherical 

Quadric image transfer

  - Irregular 

Discretized Warping

Shape Adaptive Projection

Minimum Stretch Display

'Wallpaper the surface'

Shape cue allows perceptual unwrapping

Shape Adaptive Projection

Minimum Stretch Display

Video

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 $x + iy$

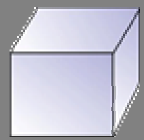
Orthogonal iso-*u* and iso-*v* contours

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

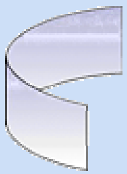
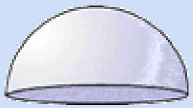
2. Align input texture vertical with world vertical

3. Render textured surface model from projector's pose

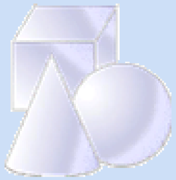
Projection Techniques

- Projection Screen Geometries
  - Planar 
  - Rectilinear 

  Planar Homography

  - Cylindrical 
  - Spherical 

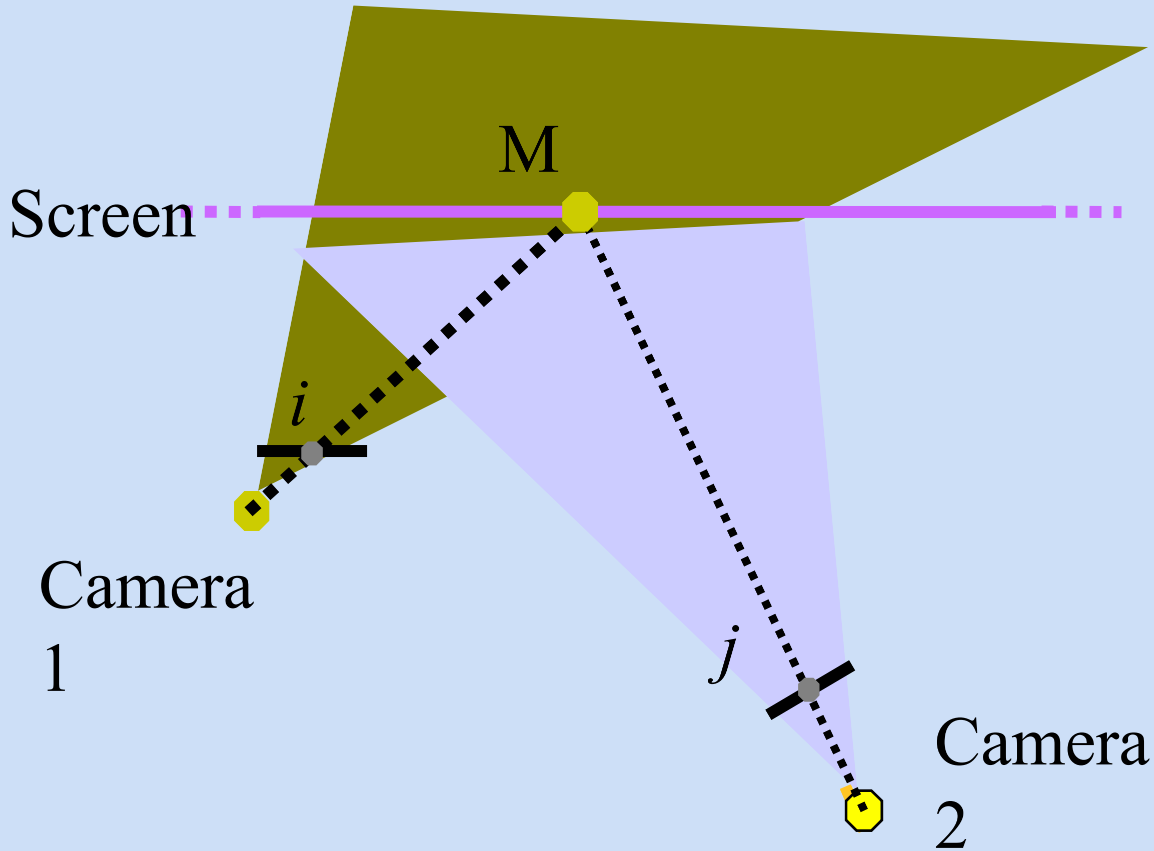
  Quadric image transfer

  - Irregular 

  Discretized Warping

Planar projective transfer
What is homography ?

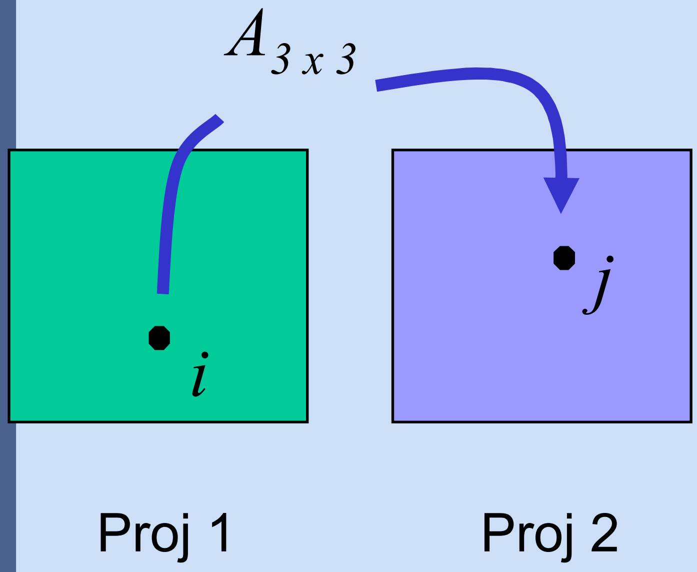
– Two images of 3D points on a plane are related by a 3x3 matrix



Planar Homography (in 2D)

Two images of 3D points on a plane

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



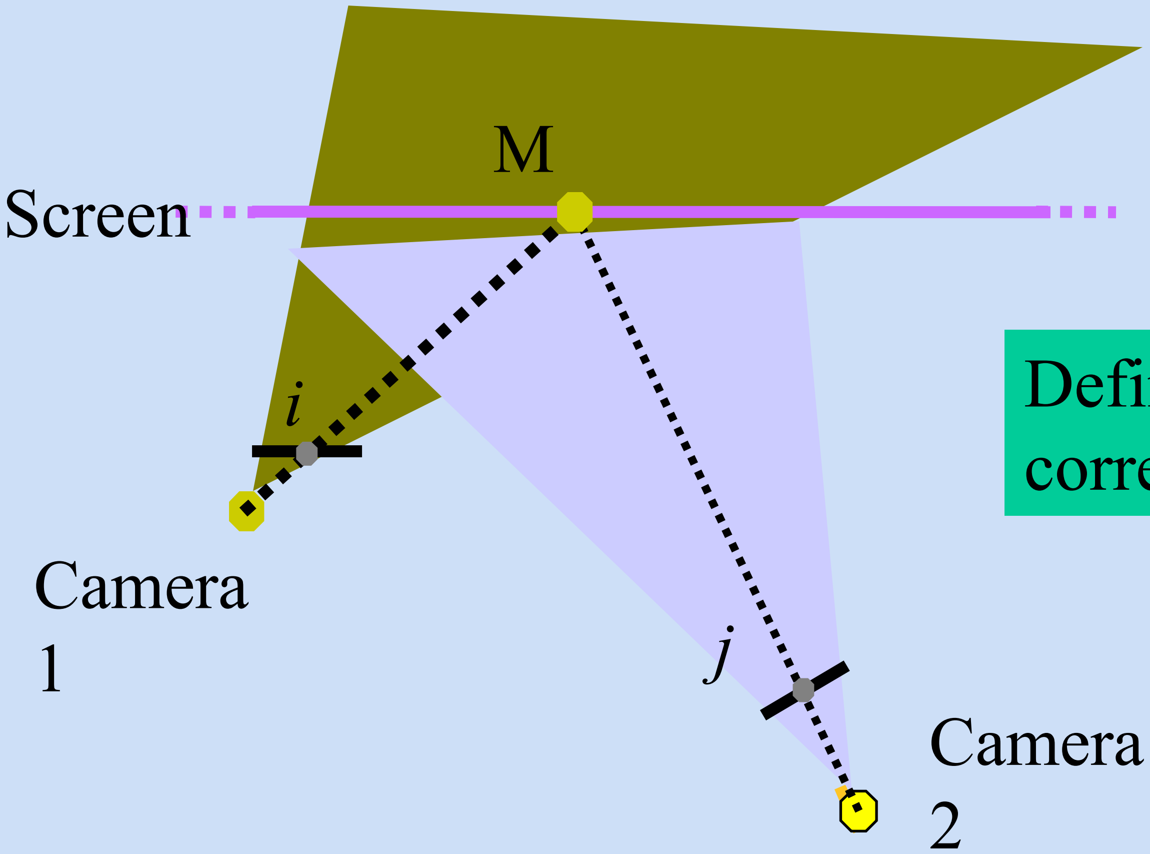
$$k \begin{bmatrix} j_x \\ j_y \\ 1 \end{bmatrix} = \begin{bmatrix} a1 & a2 & a3 \\ b1 & b2 & b3 \\ c1 & c2 & c3 \end{bmatrix} \begin{bmatrix} i_x \\ i_y \\ 1 \end{bmatrix}$$

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

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

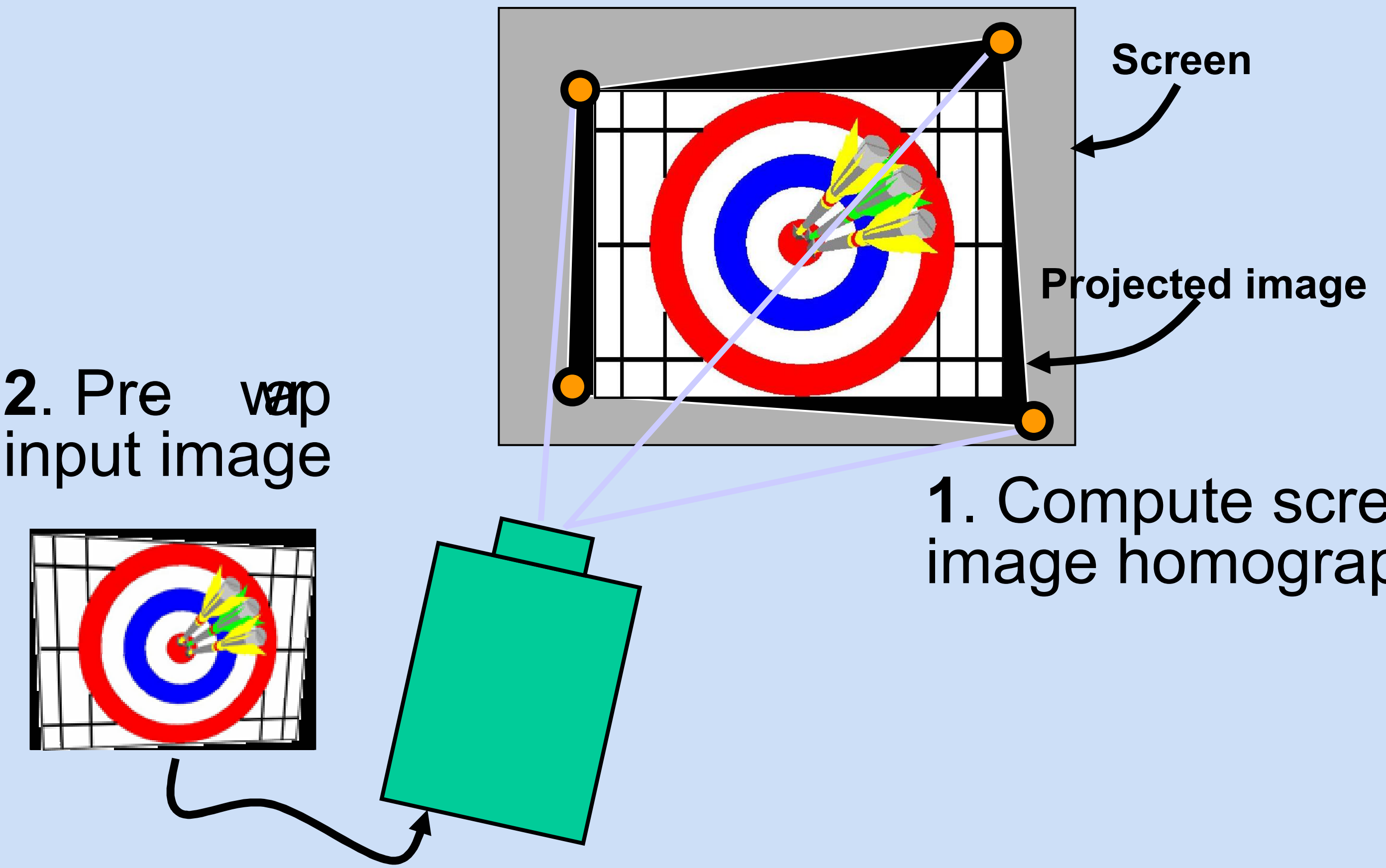
Planar projective transfer (homography)

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



Defined by 4 or more corresponding pixels

Keystone Correction

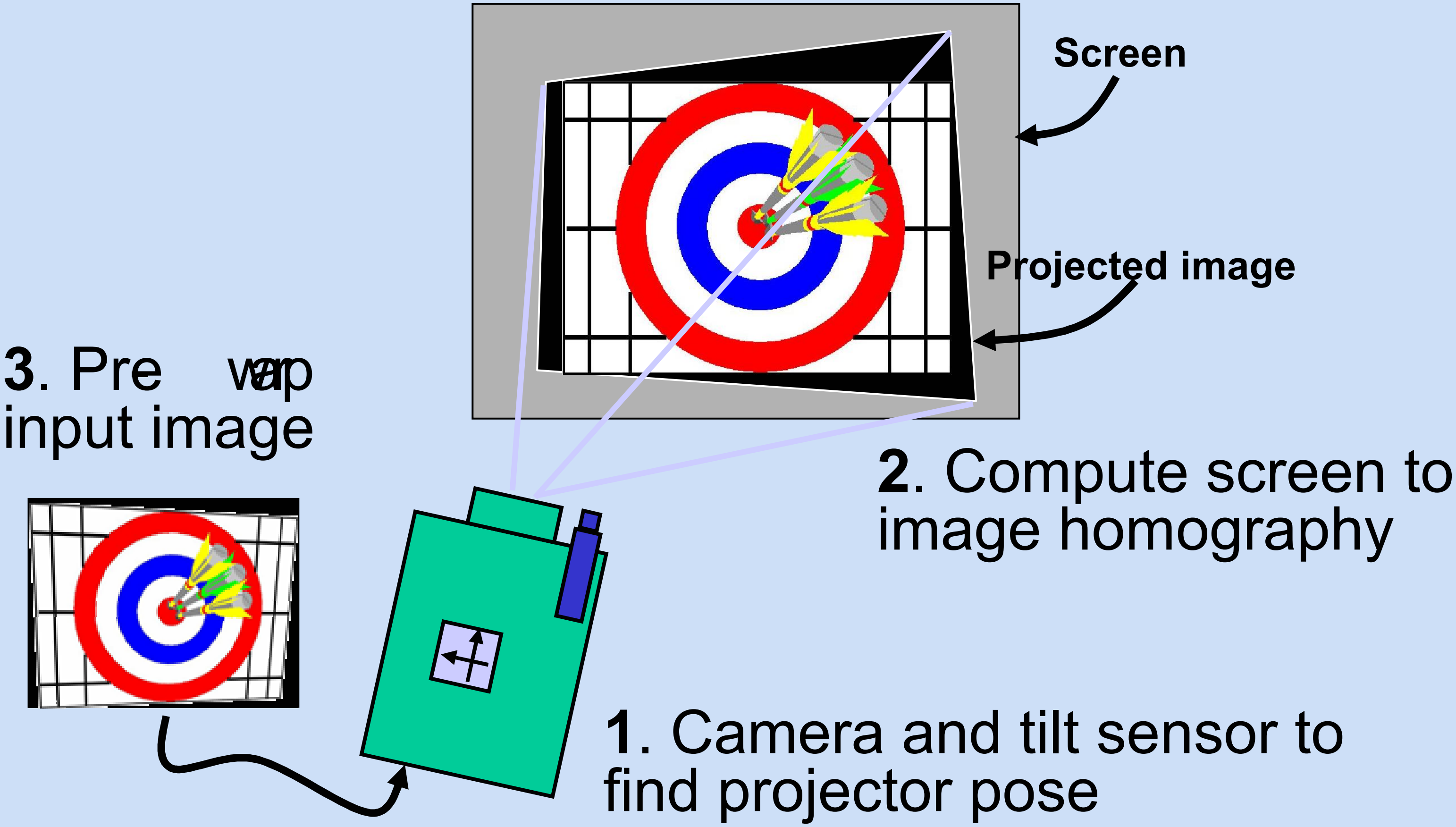


2. Pre warp input image

1. Compute screen to image homography

Automatic Keystone Correction with Camera and Tilt Sensor

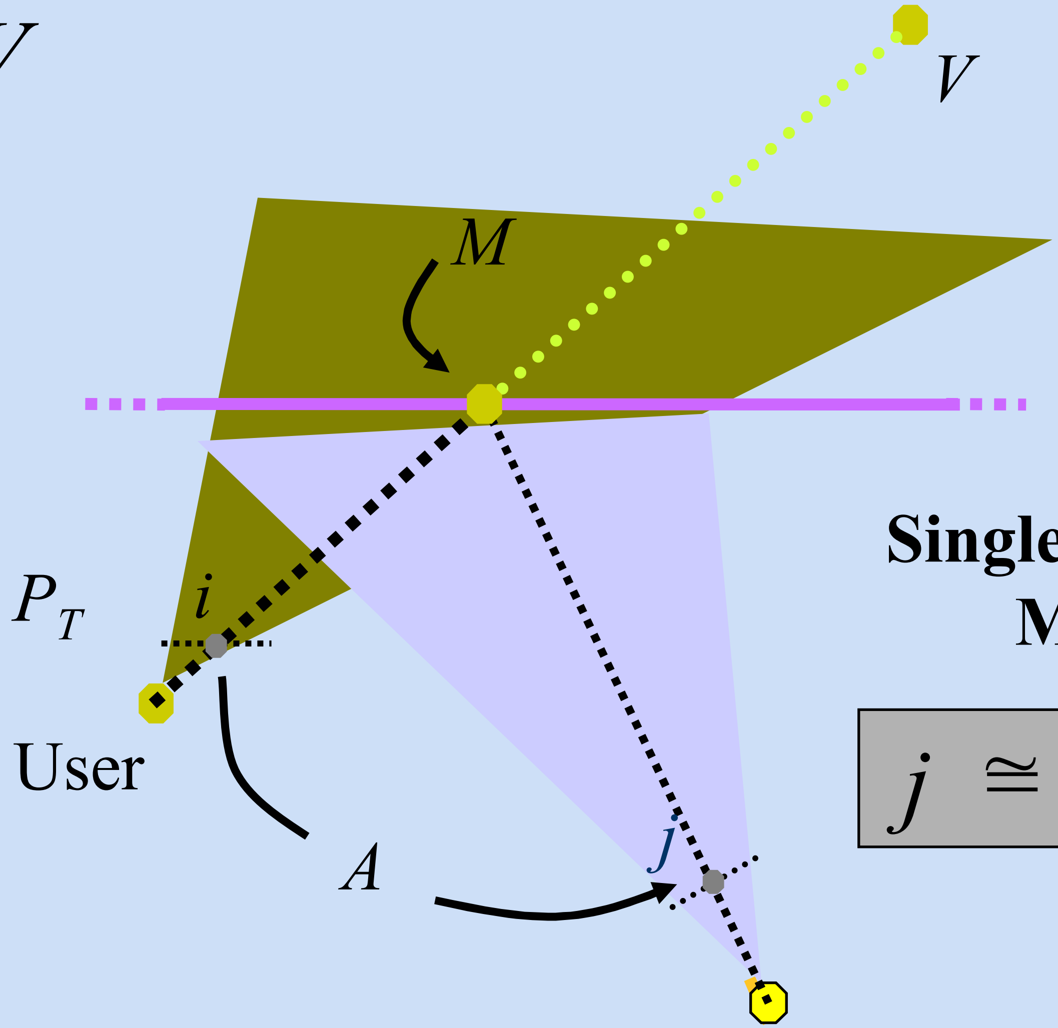
[Raskar and Beardsley01]



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

$i \cong P_T V$

$j \cong A\ i$



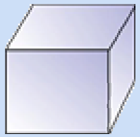
Single Projection Matrix !

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

Projection Techniques

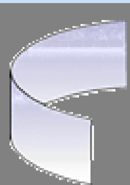
- Projection Screen Geometries
  - Planar

  - Rectilinear

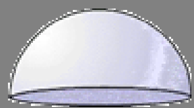


Planar Homography

  - Cylindrical

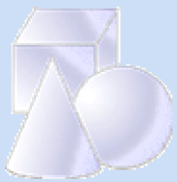


  - Spherical



Quadric image transfer

  - Irregular



Discretized Warping

Quardic curved shape Displays

Markets

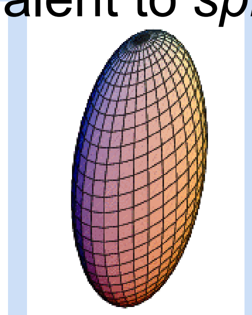
Planetarium

Curved screens

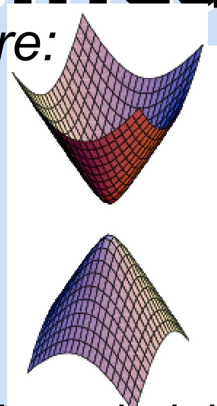
Curved projective transfer
Quadric classification

Projectively equivalent to *sphere:*

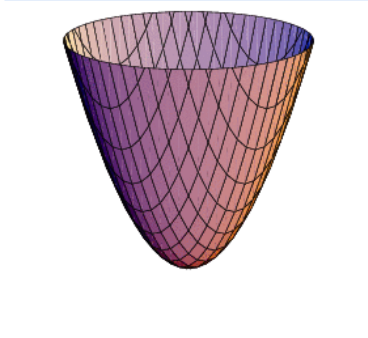
sphere



ellipsoid

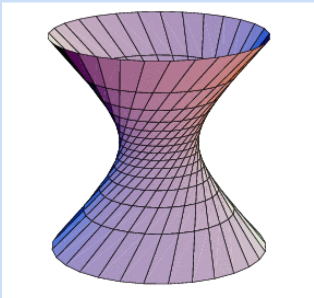


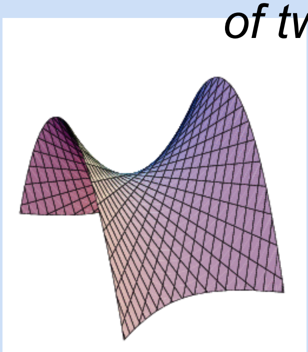
hyperboloid of two sheets



paraboloid

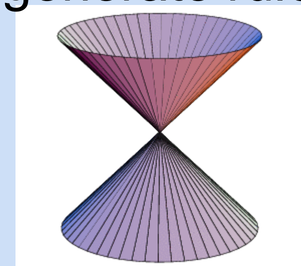
Ruled quadrics:



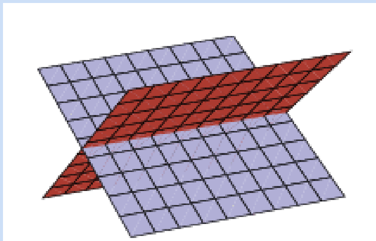


hyperboloids of one sheet

Degenerate ruled quadrics:



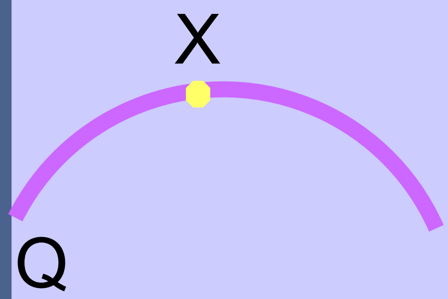
cone



two planes

Quadrics

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

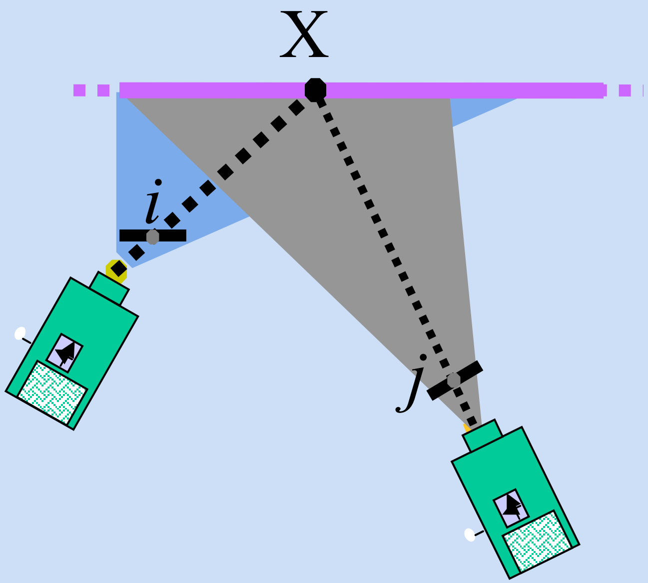


Q : 4x4 symmetric matrix, $Q = \begin{bmatrix} \bullet & \bullet & \bullet & \bullet \\ \circ & \bullet & \bullet & \bullet \\ \circ & \circ & \bullet & \bullet \\ \circ & \circ & \circ & \bullet \end{bmatrix}$

Nine d.o.f

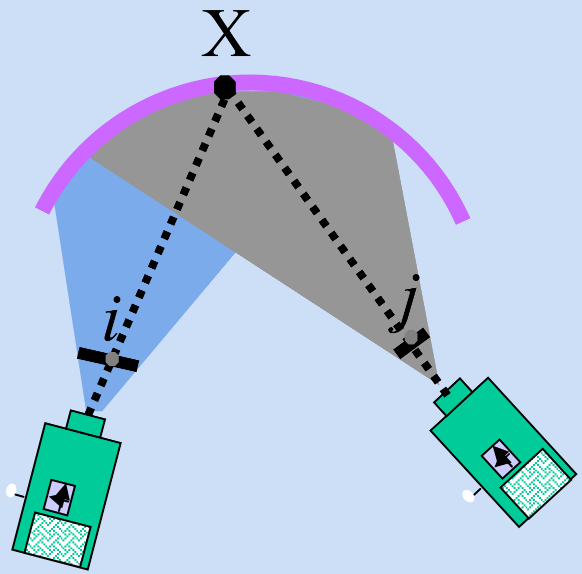
In general <u>9</u> points in 3D define quadric

Parametric Image Transfer



Planar Homography

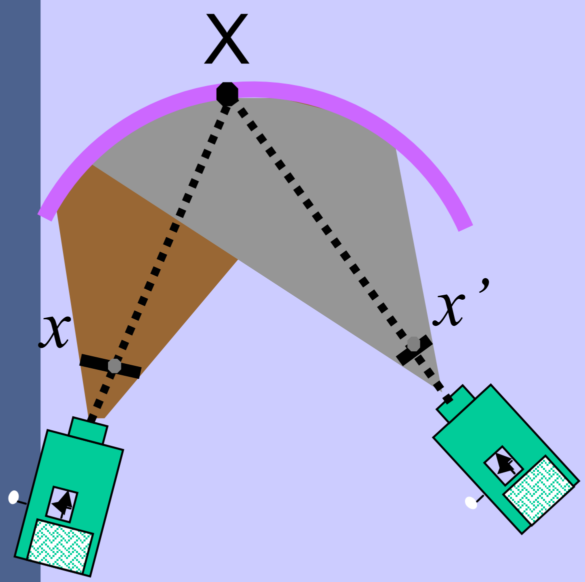
$$j \cong A_{3x3}\, i$$



Quadric Transfer

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

Simplified Quadric Image Transfer

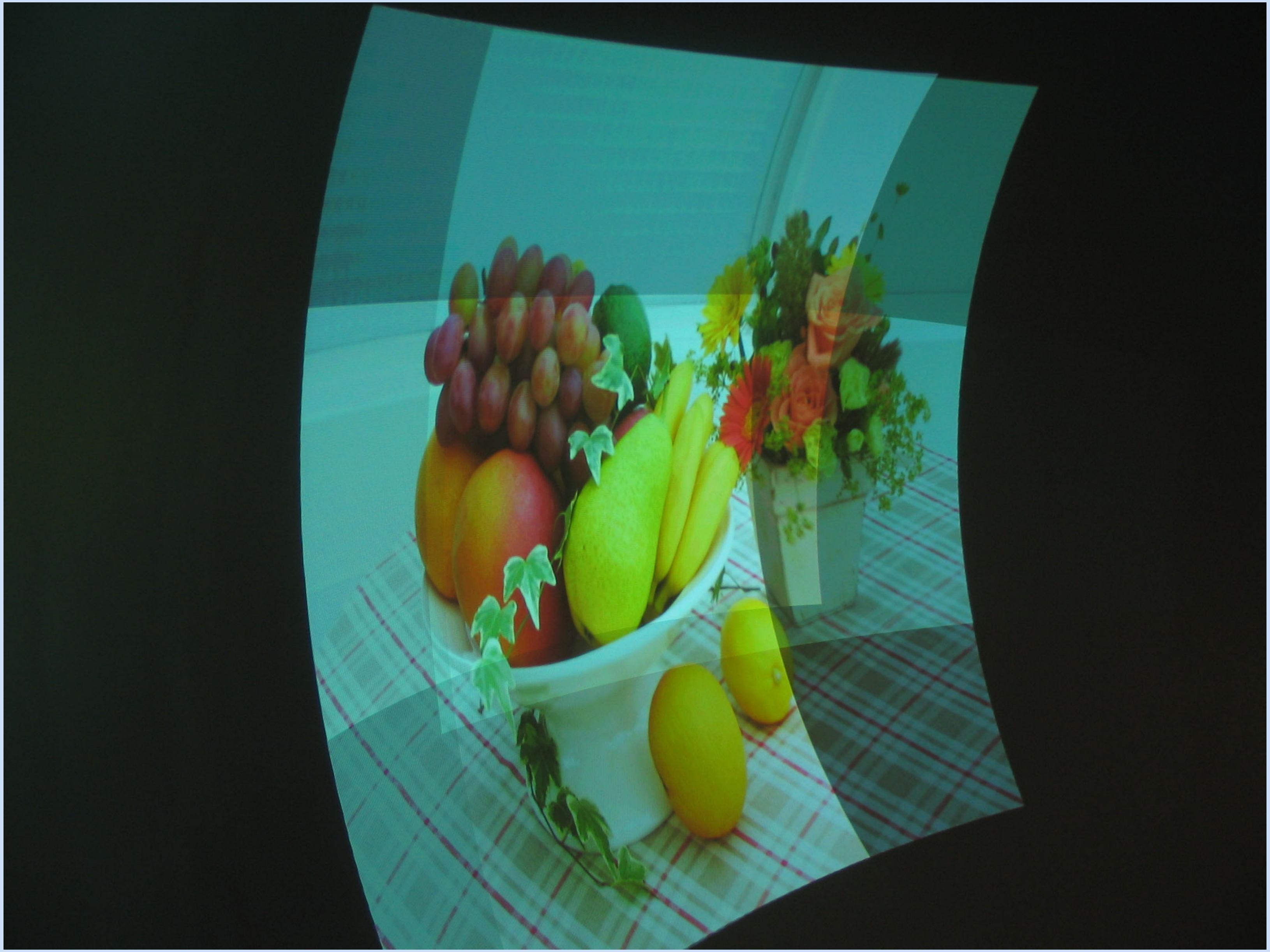


$$x' \cong Ax \pm \left(\sqrt{x^T E x} \right) e$$

17 param warp

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

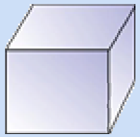
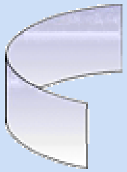
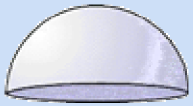
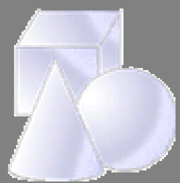
Overlap on Quadric Screens



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

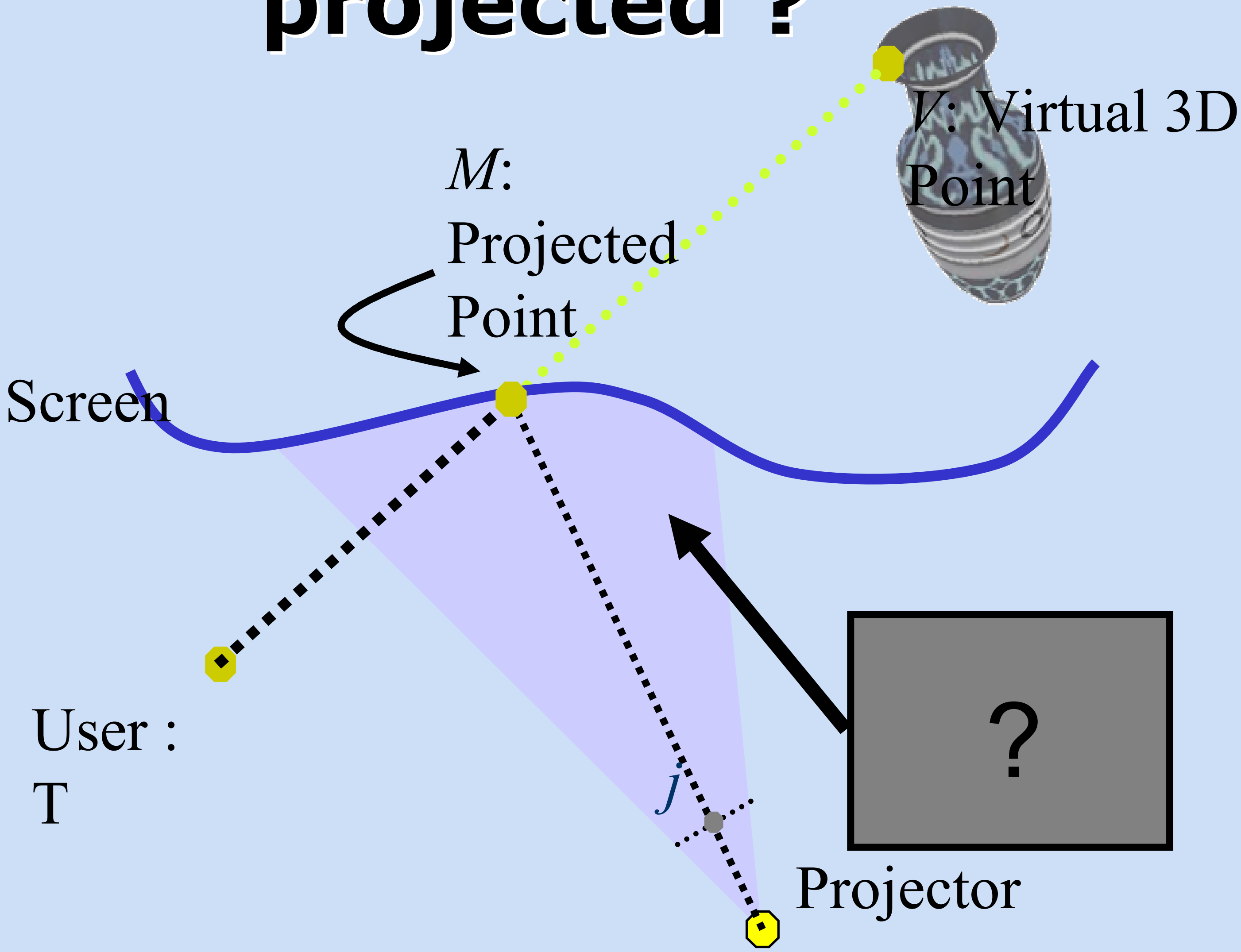
- Projection Screen Geometries
  - Planar 
  - Rectilinear 
  - Cylindrical 
  - Spherical 
  - Irregular 

Planar Homography

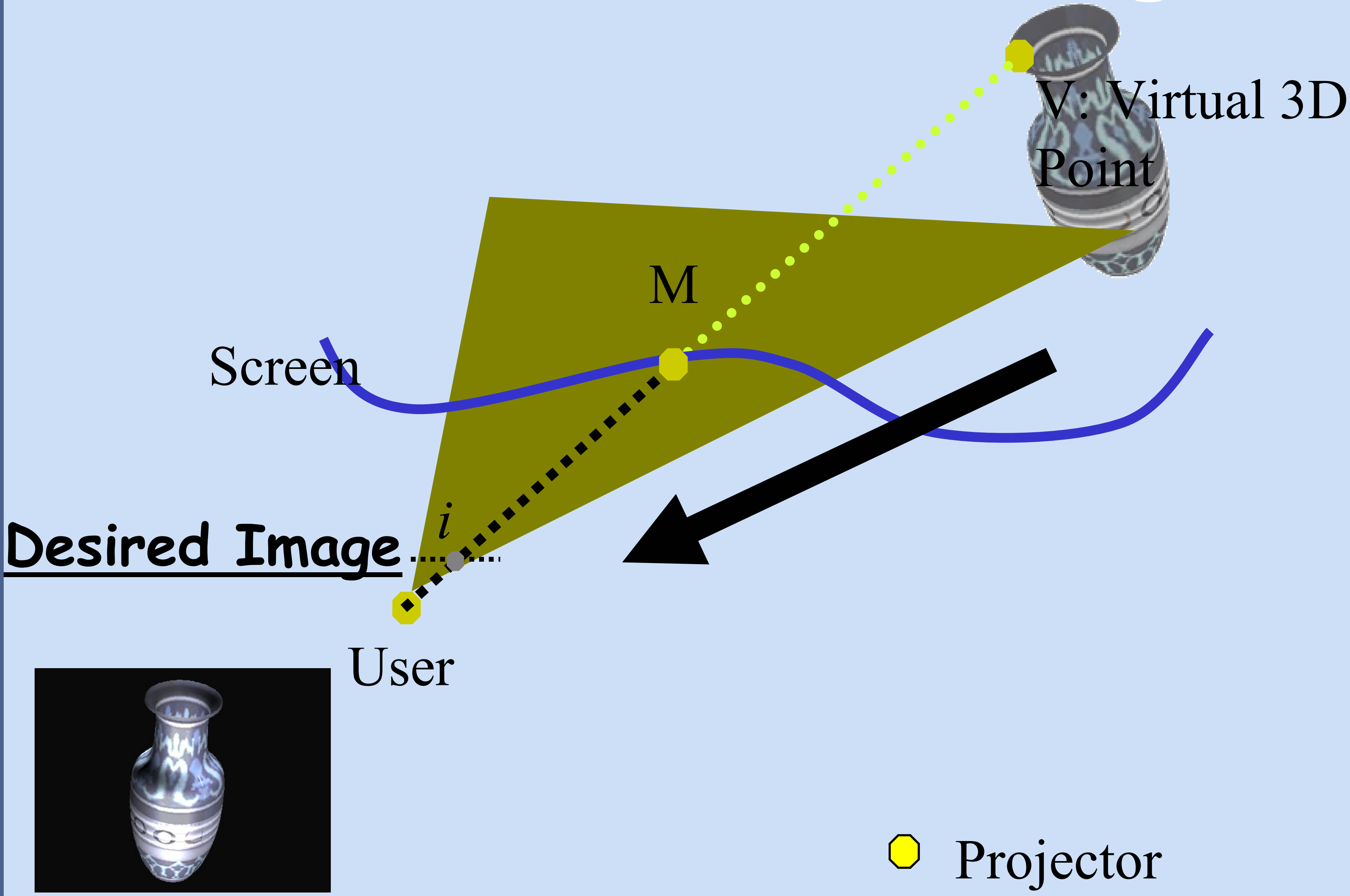
Quadric image transfer

Discretized Warping

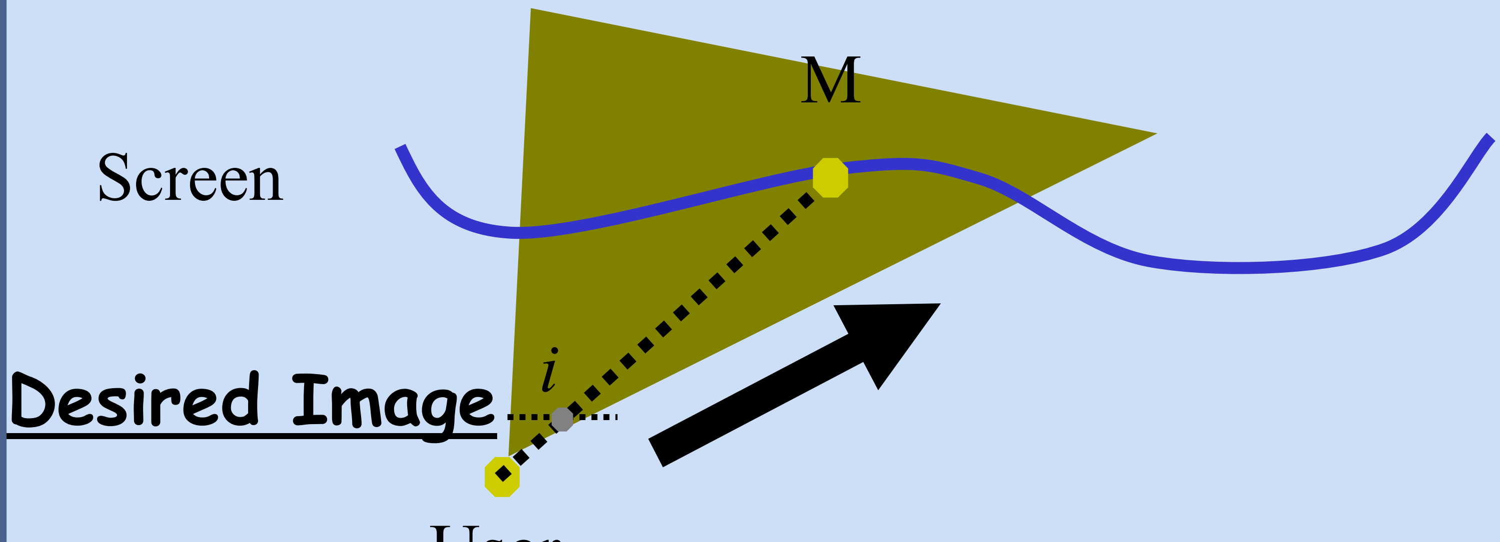
What image should be projected ?



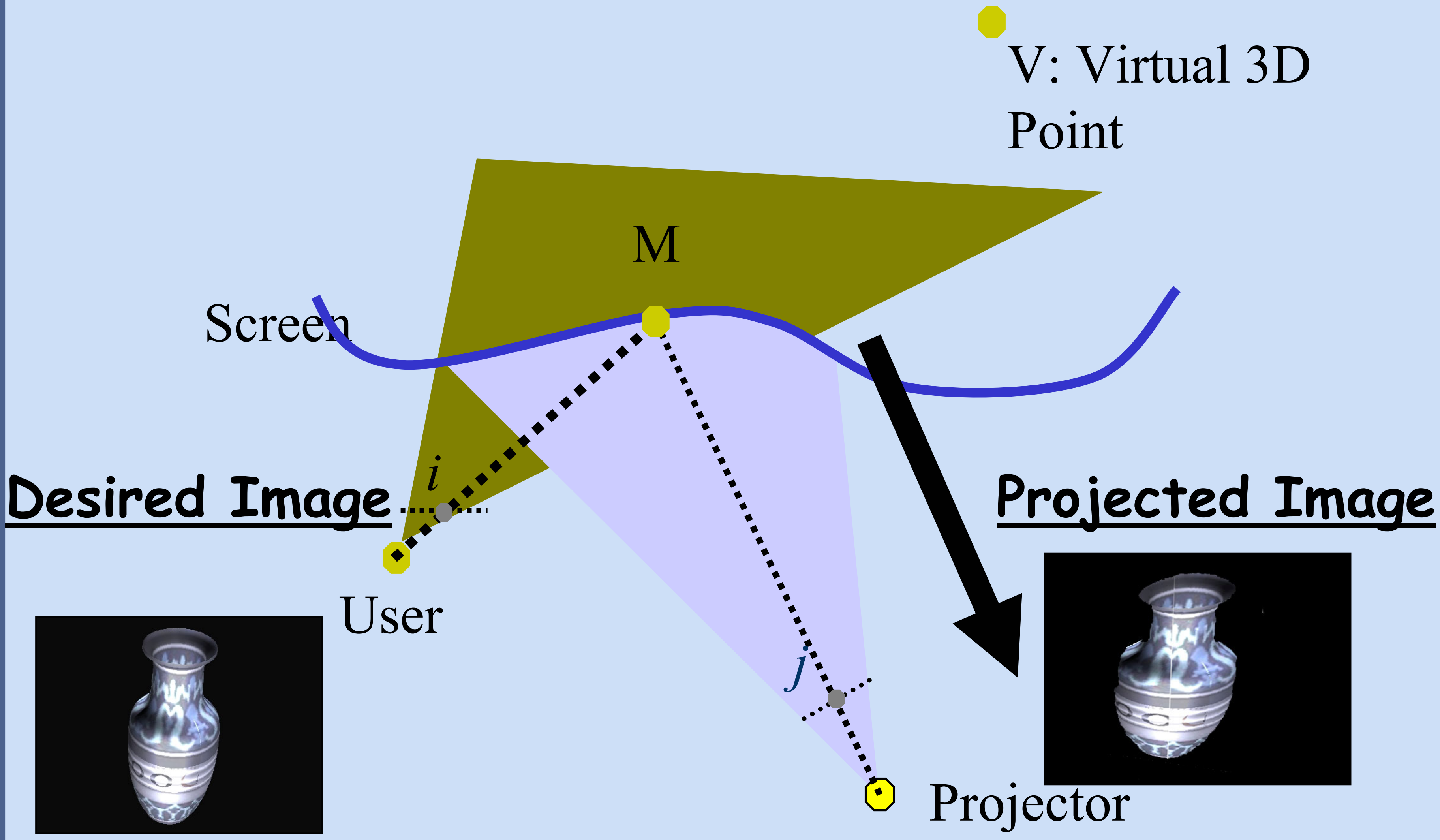
Step I :
Calculate 'desired' image



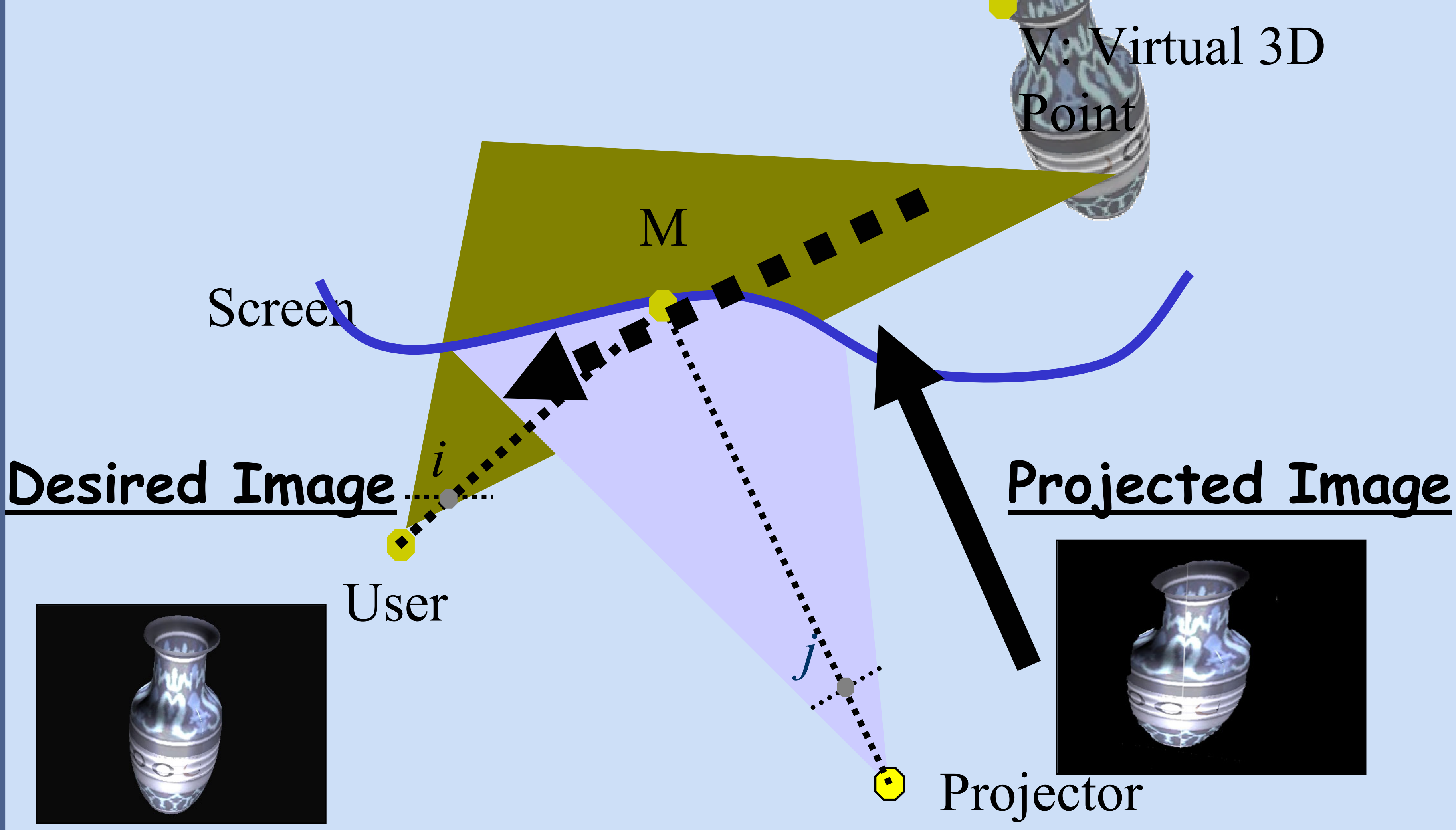
Step II : 'Project' the desired image from T



Step II :
Render this scenario from *P*



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



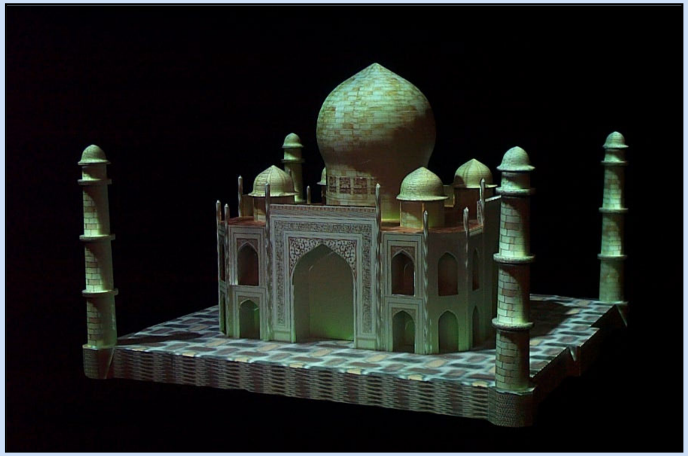
Non-planar Display

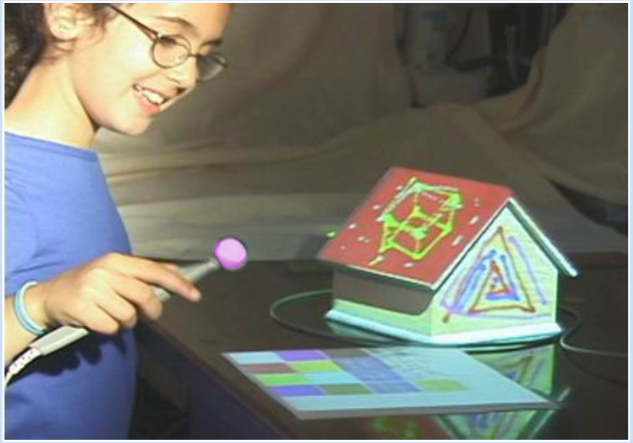
- Perspectively correct image for head-tracked user
- Details in [Raskar et al 'Office of the Future' Siggraph 1998]

- 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

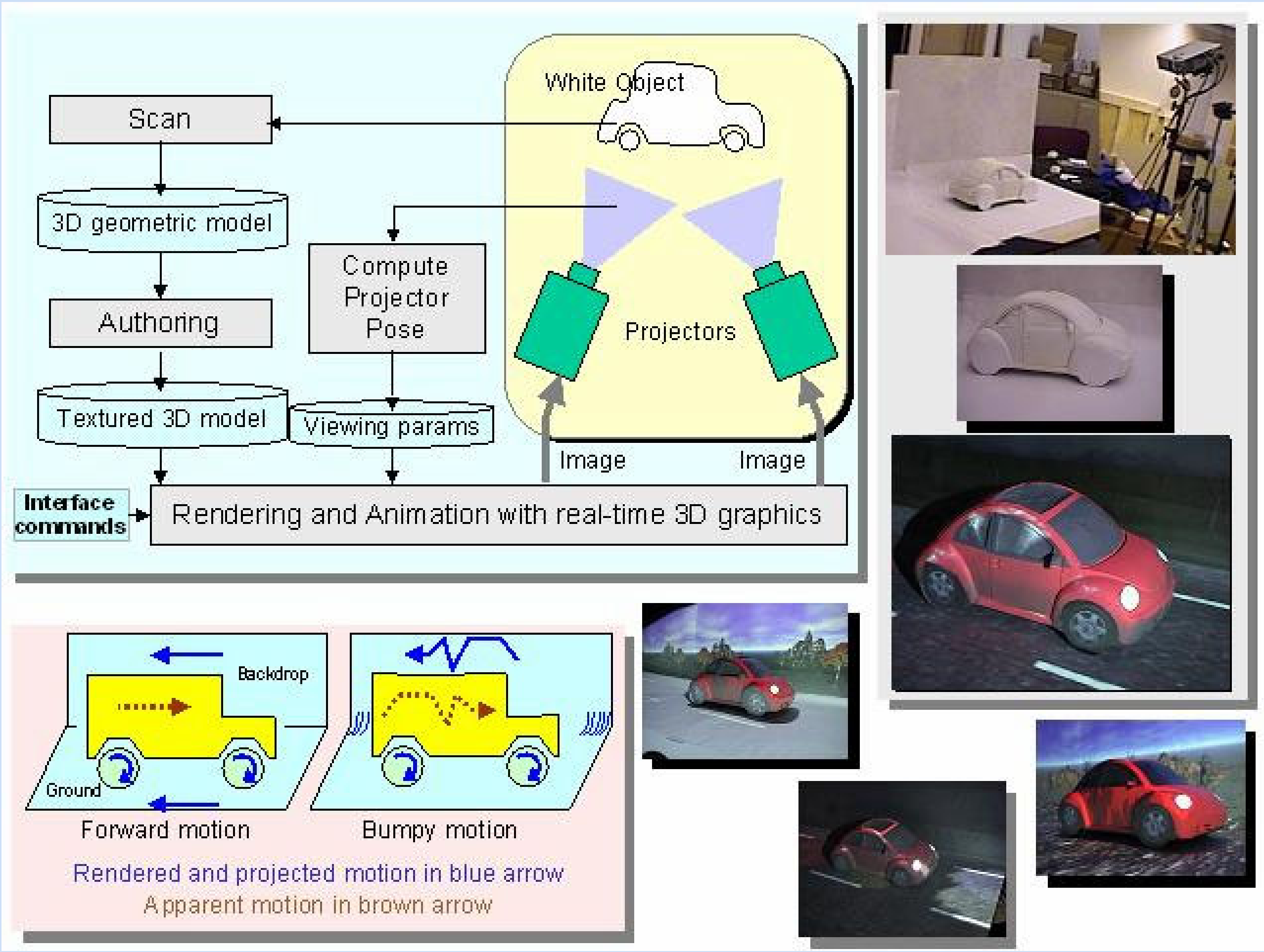
- More Examples ..





More info : www.ShaderLamps.com , Code available

Apparent Motion

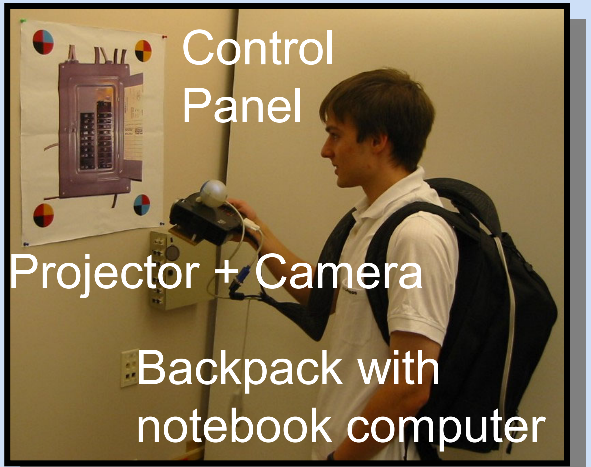


Ramesh Raskar, Remo Ziegler, Thomas Willwacher, "Cartoon Dioramas in Motion," Proc. ACM Symposium on Nonphotorealistic Animation and Rendering (NPAR 2002)

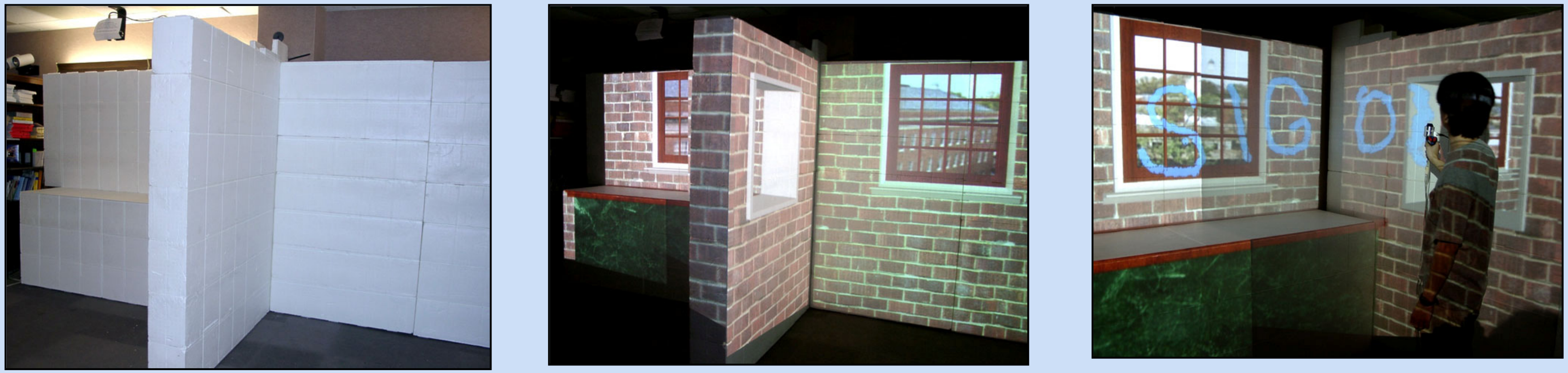
Training and Maintenance
(Projector-based Augmented Reality)

Raskar, Beardsley, Forlines

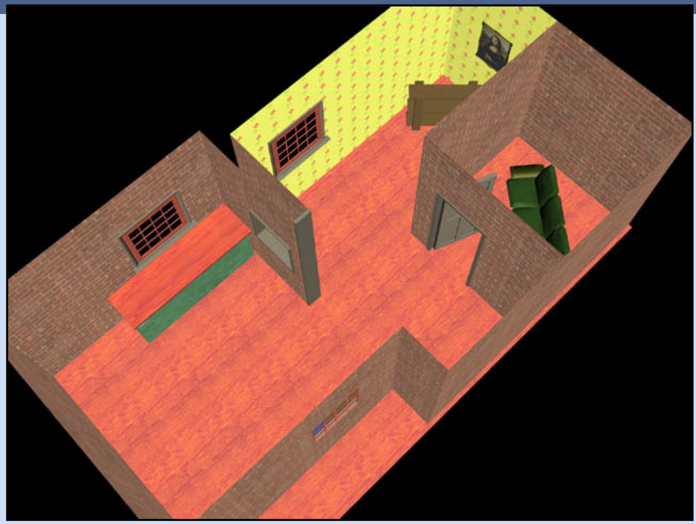
- Automatically add projected information
  - Training videos
  - Instruction manuals
- Detect pose and identity from pie-codes



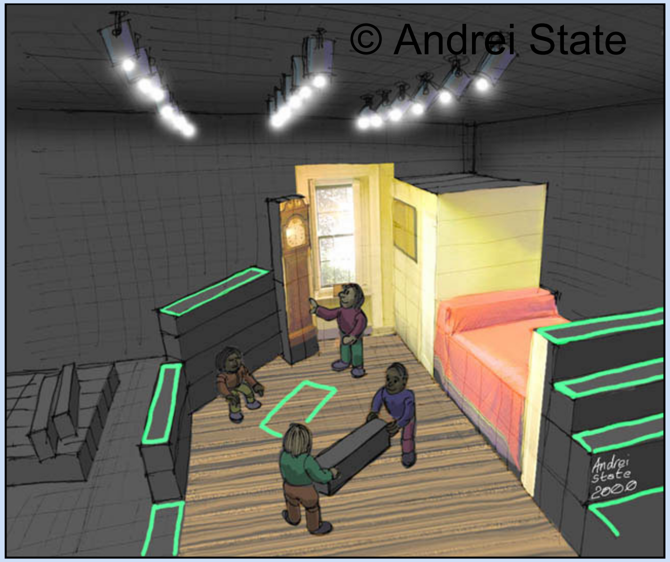
- Recreate Large Environments
  - ‘BeingThere’, walk-around
  - Human sized environments
  - Museums, Exhibitions



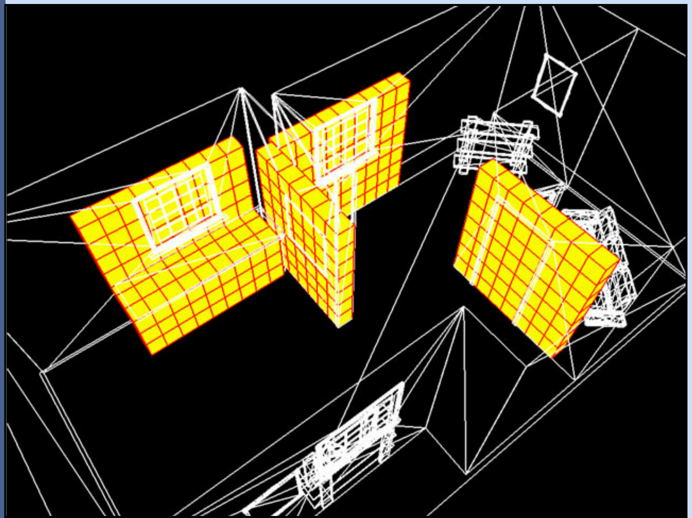
Kok-Lim Low, Greg Welch, Anselmo Lastra, Henry Fuchs. “Life-Sized Projector-Based Dioramas,” Proc. ACM Symposium on Virtual Reality Software and Technology 2001 (VRST 2001), November 2001.

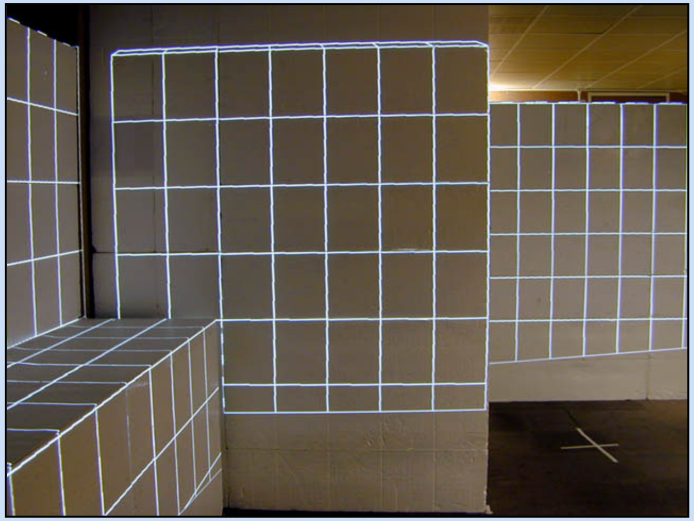


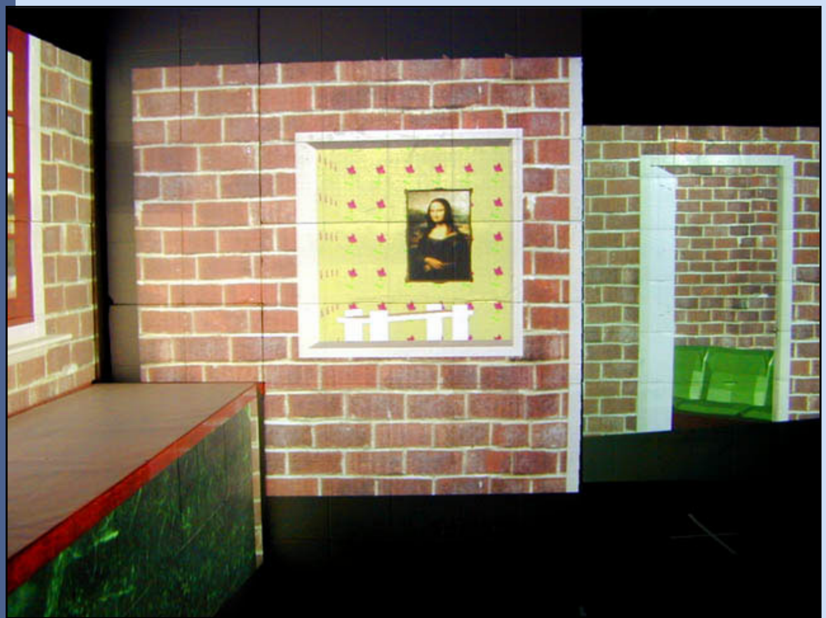
Desired Virtual Model

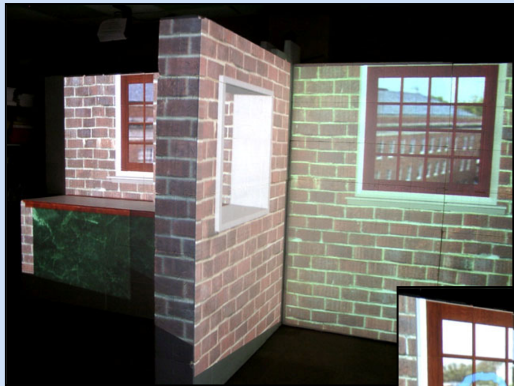


Projected Guidance for Placement

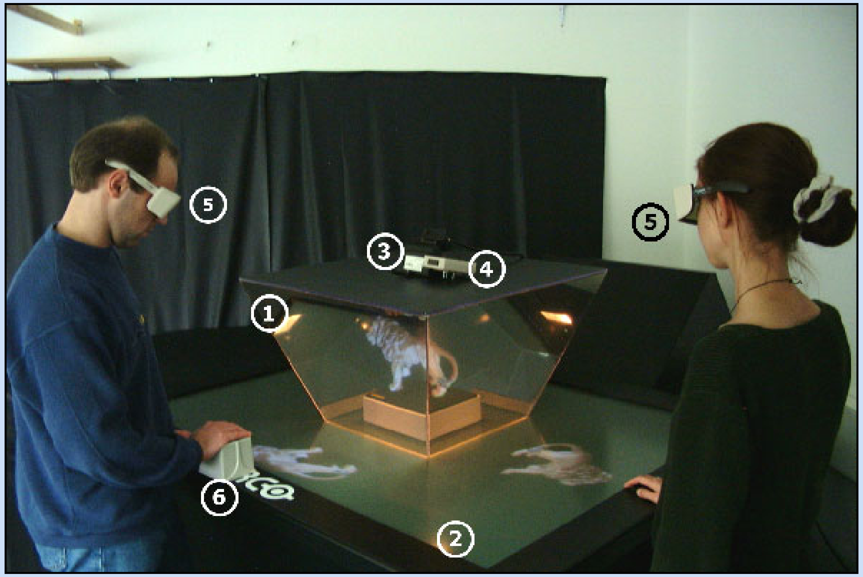


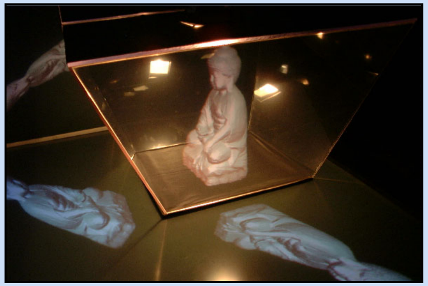


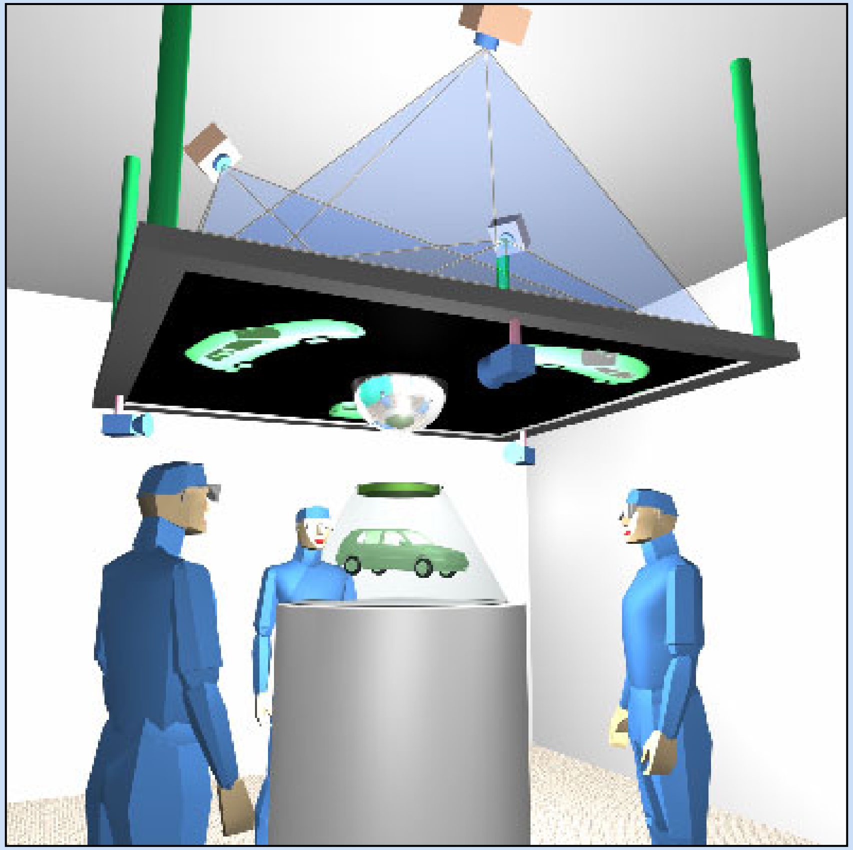




Projector-based AR



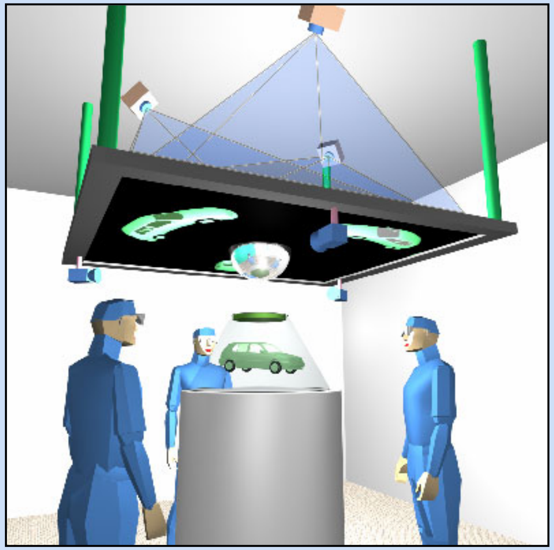


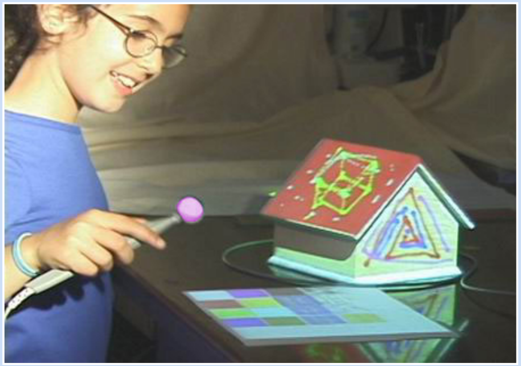


Bimber, O., Fröhlich, B., Schmalstieg, D., and Encarnação, L.M. ‘The Virtual Showcase’. *IEEE Computer Graphics & Applications*, vol. 21, no.6, 2001.

Course: Alternative Approaches to Augmented Reality

- Oliver Bimber and Ramesh Raskar
- Eurographics, Sept 1st
- Granada, Spain





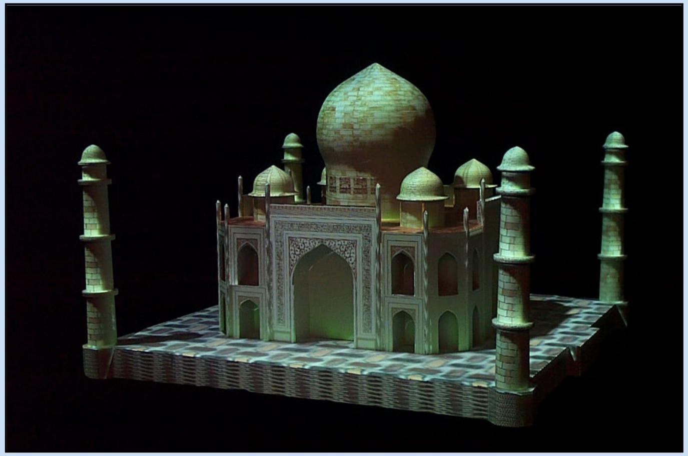
More info : www.cs.unc.edu/~raskar/Projector/

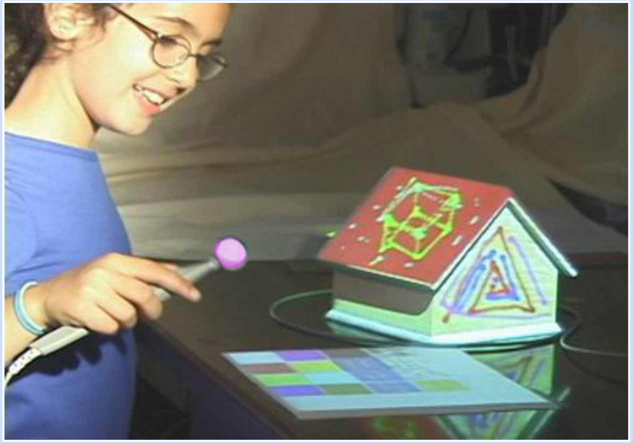
Acknowledgements

- 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

Schedule

09:30	Overview	
09:40	Today's AR Display Approaches	(Bimber)
10:00	Non-trivial Projection Screens	(Raskar)
11:00	Break	
11:30	Spatial Optical See-thru Displays	(Bimber)
12:30	Applications	(Bimber and Raskar)
12:50	Discussion	

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

Extra Slides

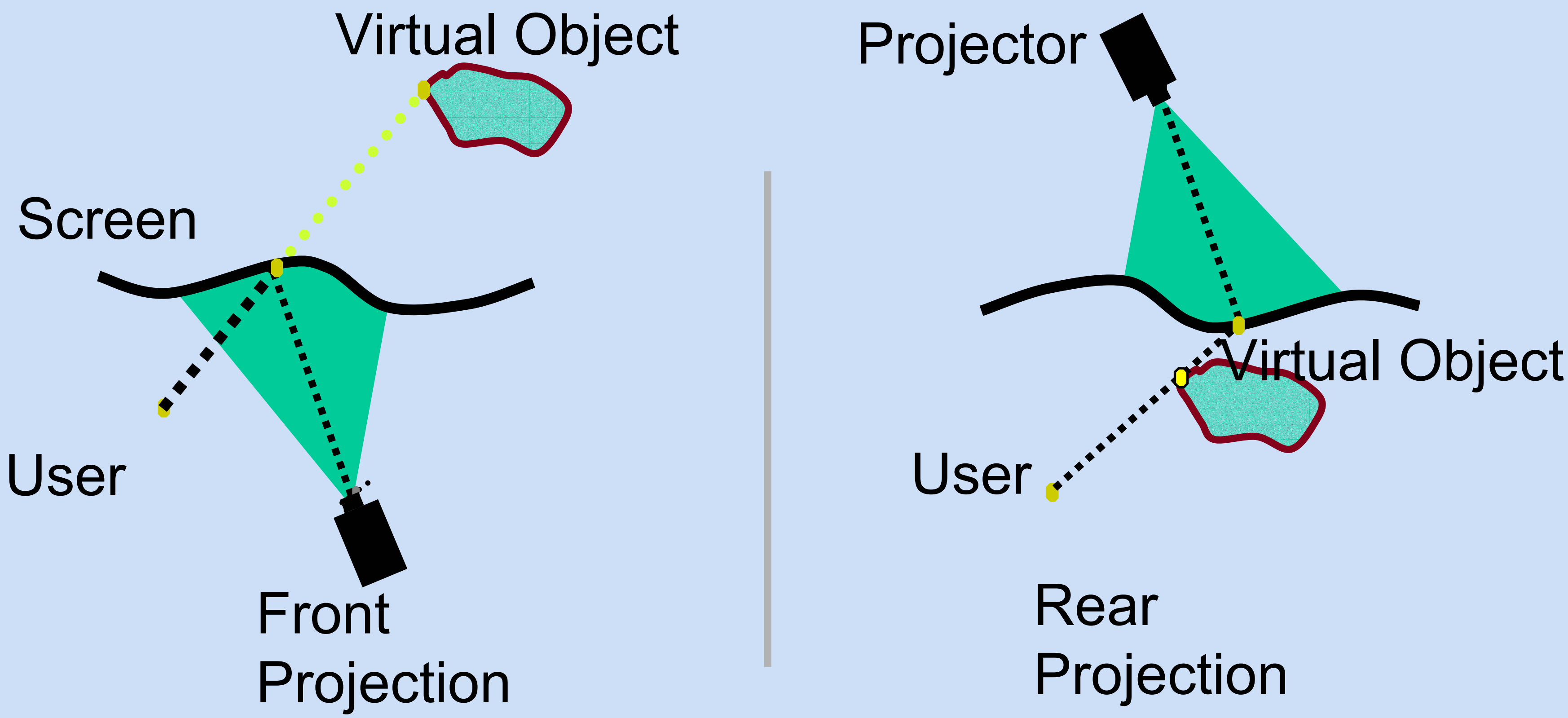
Display and User

	Static User (Sweetspot)	Head-tracked User
Planar Display	Traditional	Immersive Workbench, CAVE
Non-planar Display	Curved screen, Dome screen	Most General Case

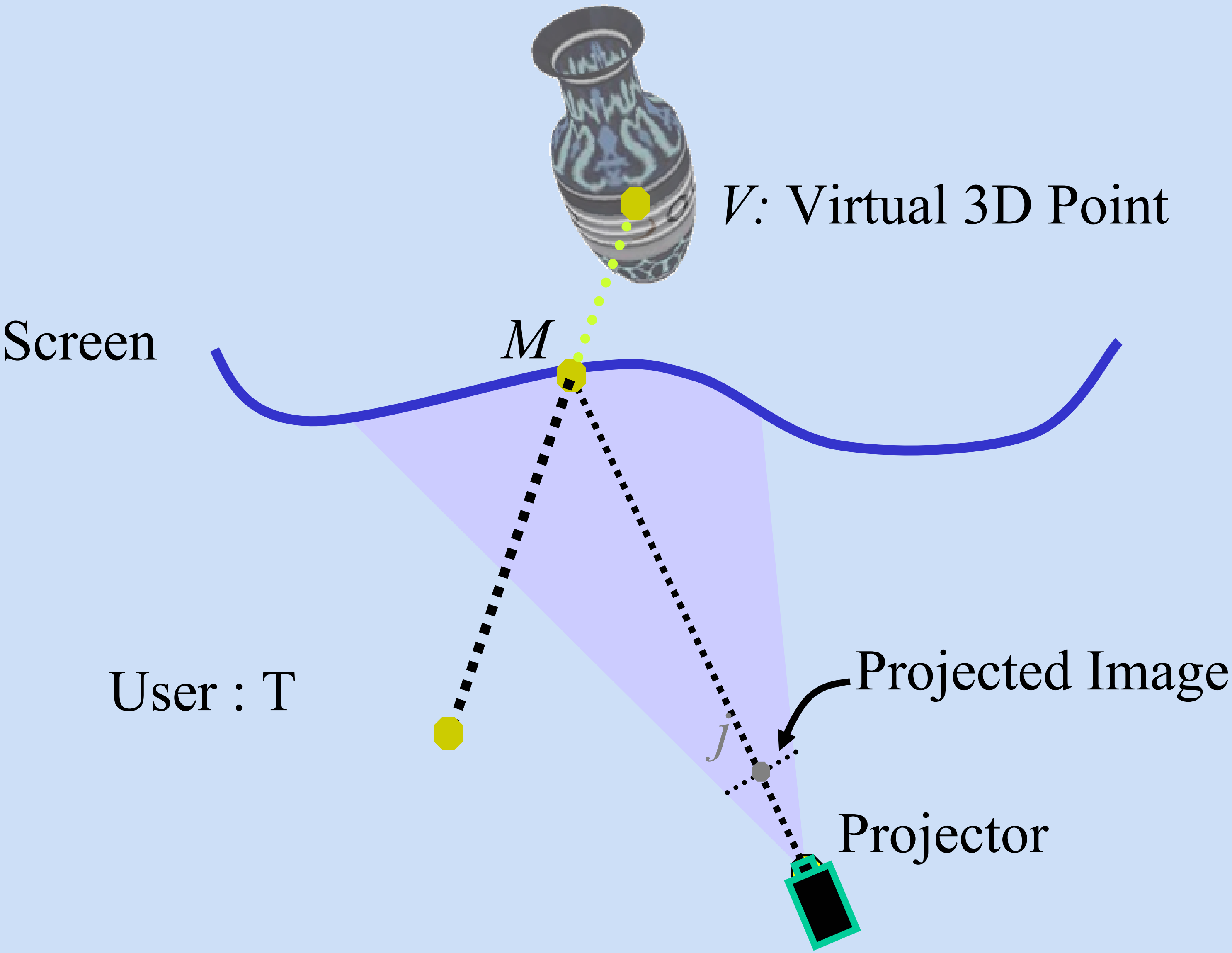
Interactive Display Continuum

- Projector
  - Front or rear projection
- User
  - Static or head tracked moving
- Display surface
  - Planar, non-planar, closed object
- Virtual model
  - In front of or behind screen, dynamic

Display Configurations



Display Components



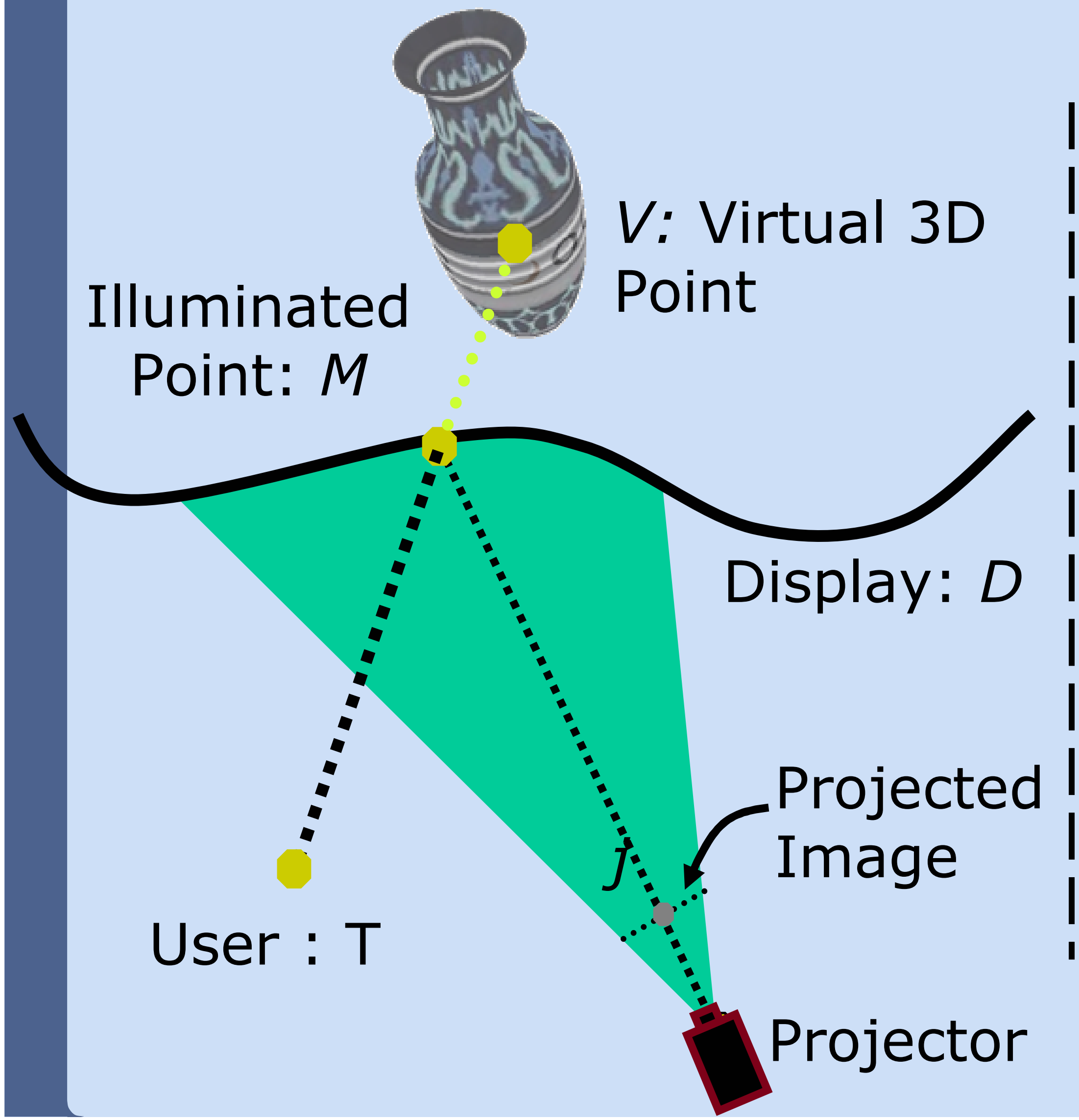
A Single Unified Approach

- 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



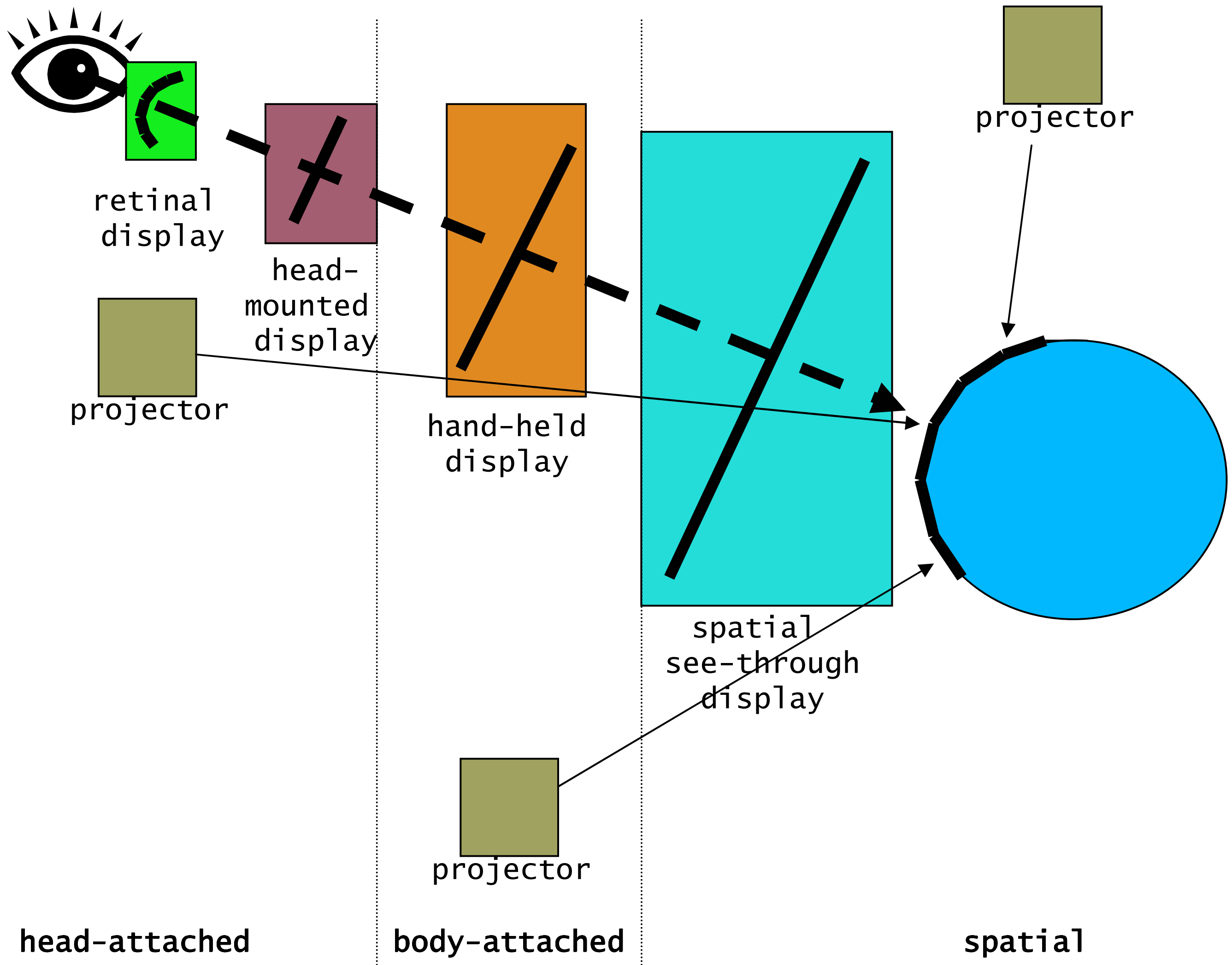
M = *intersect* (TV , D)

j = *Projection* (M)

Part4:
Spatial Optical See-Through Displays

Outline

- Introduction
  - head-mounted vs. spatial
  - video see-through vs. optical see-through
  - example: the virtual showcase
- Rendering
  - pipeline rendering
    - single planar beam-splitters
    - multiple planar beam-splitters
    - multiple screens
    - refraction on planar plates
  - image warping
    - curved beam-splitters
    - image-based refraction
  - projector-based illumination
    - consistent occlusion
    - consistent illumination


retinal display
head-mounted display
projector
hand-held display
spatial see-through display
projector
projector
head-attached
body-attached
spatial

Head-Mounted vs. Spatial

Head-Mounted	Spatial
Constraints in scalability (miniature displays)	Scalable (resolution/FOV)
Unbalanced ratio between cumbersome and high quality optics	Light weight / no glasses, displays integrated in environment
Fixed focal length / focus shifting	Easier eye accommodation (focus)
Increased incidence of discomfort provoked by simulation sickness	Reduced incidence of discomfort provoked by simulation sickness
Difficult calibration (up to 12DOF)	Easier calibration (3-6DOF)
All-purpose	Application specific
Multi-user support	Constraints in number of users (usually 1-4)
Mobile applications	Static displays

Video See-Through vs. Optical See-Through

Video See-Through

- Resolution and FOV of entire environment depends on video equipment
- Pixel-precise registration (depends on resolution of video equipment)
- Increased end-to-end delay caused by image processing (resolution vs. speed)
- High level of consistency can be achieved (occlusion, illumination, etc.)
- Stereo-viewing is problematic (video-stream(s) of real environment)

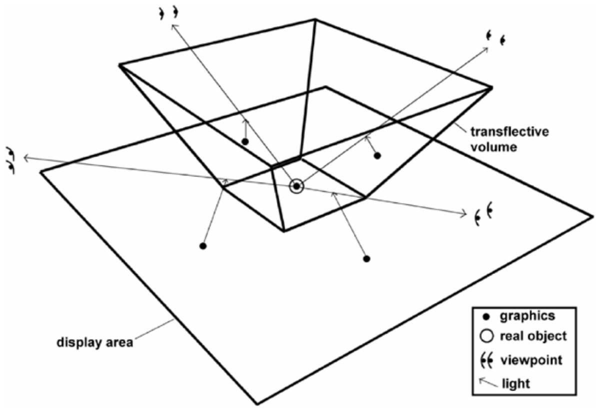
Optical See-Through

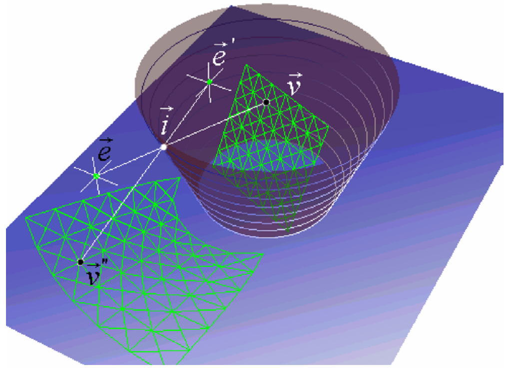
- No limitations of real environment's resolution and FOV
- Registration depends on precision of tracking system and display optics
- More time can be spend on rendering graphics (quality)
- Consistent presentation is problematic (occlusion, illumination, etc.)
- Stereo-viewing is easily supported

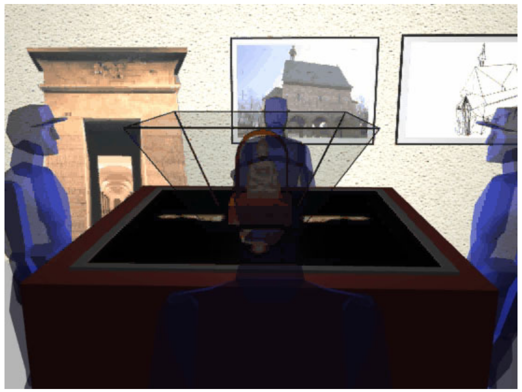
Example: The Virtual Showcase

- Spatial optical see-through
- Multi User
- Seamless surround view
- Same form-factor as traditional showcases in museums
- Supported by European Union IST-2001-28610

Bimber, Fröhlich, Schmalstieg, and Encarnacao. Real-Time View-Dependent Image Warping to correct Non-Linear Distortion for Curved Virtual Showcase Displays. *Computers & Graphics*, *2003*.

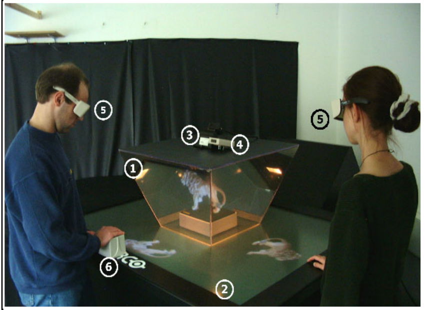


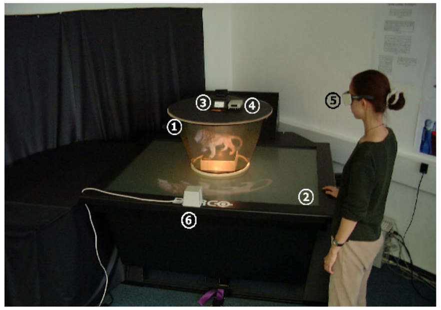




Bimber, Fröhlich, Schmalstieg, and Encarnacao. The Virtual Showcase. *IEEE Computer Graphics & Applications*,2001.

2000-2001

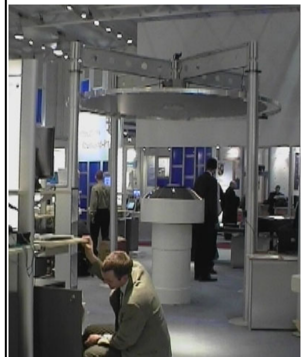

Fraunhofer IGD, Rostock


Fraunhofer IGD, Rostock


Siggraph, LA


Fraunhofer CRCG, Providence

2002


Fraunhofer IGD, Rostock,
CeBit, Hannover


Bauhaus Univ. Weimar


Siggraph, San Antonio
Fraunhofer CRCG, Providence


Bauhaus Univ. Weimar


Vienna University

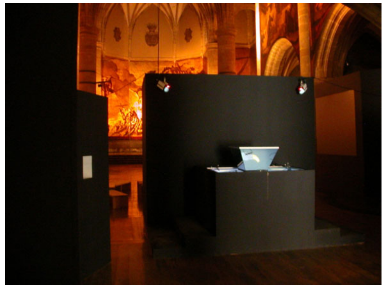
2003


Learntec, Karlsruhe


VicomTech, San Sebastian


Fraunhofer IMK,
Bonn


CeBit,
Hannover

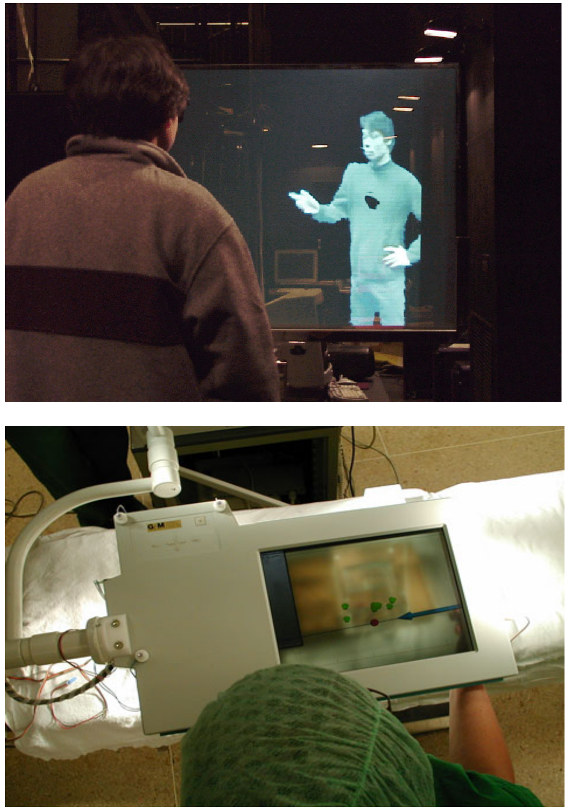

Museo de San Telmo de
San Sebastian, Spain

MUTEC, Munich

Bauhaus Univ., Weimar

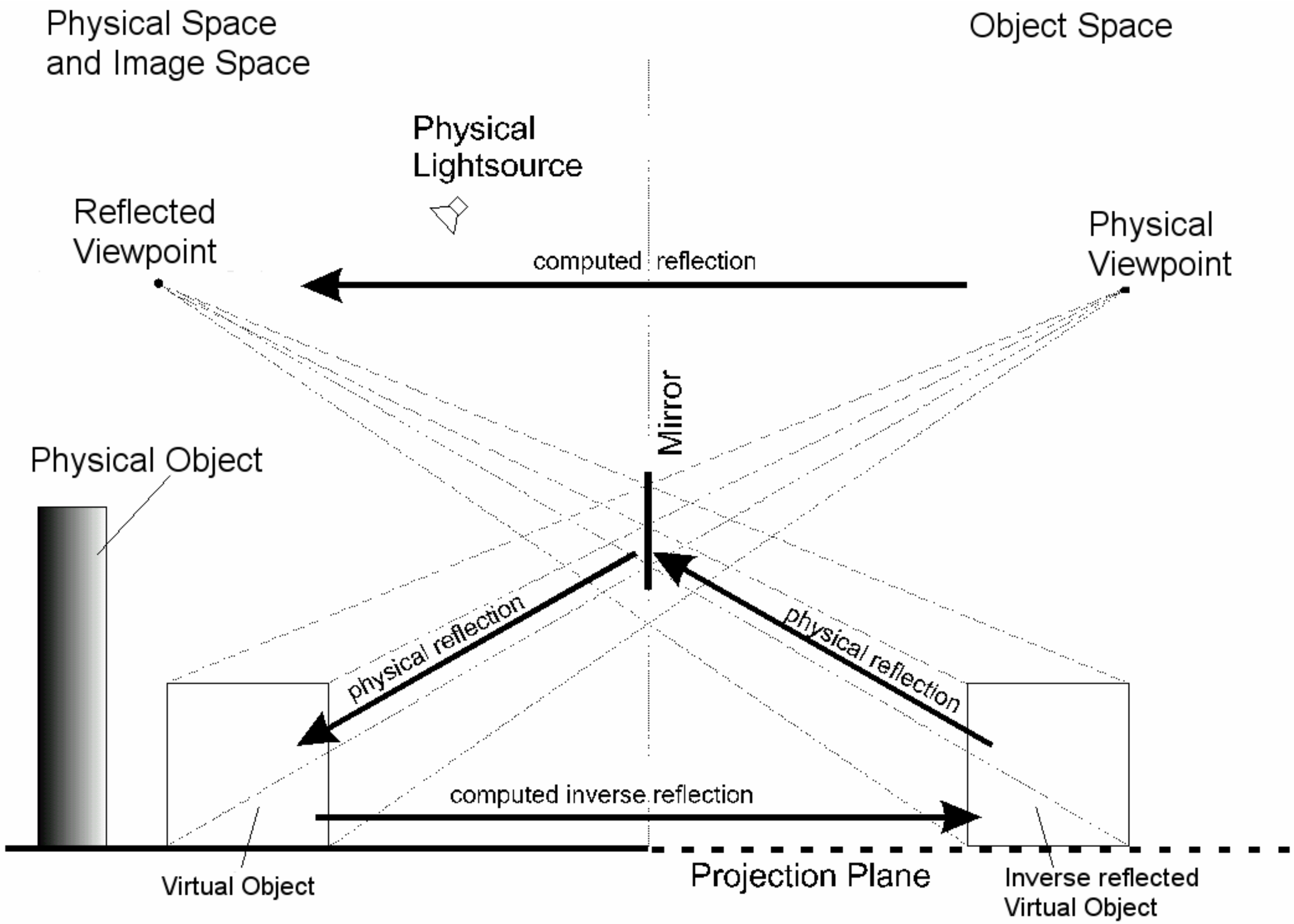
Optical Combiners

half-silvered mirrors



semi-transparent screens

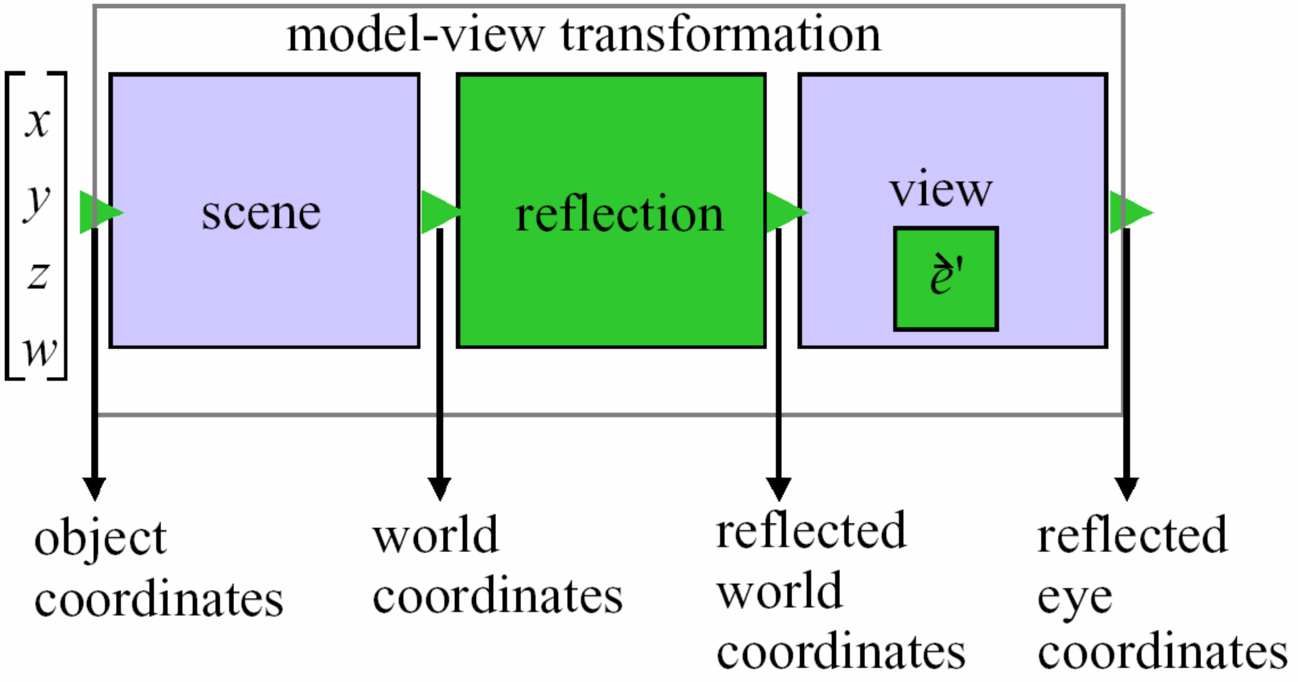
Single Planar Beam-Splitter



Bimber, O., Encarnação, L.M., and Schmalstieg, D. 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.

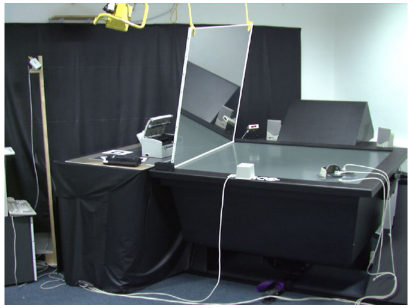
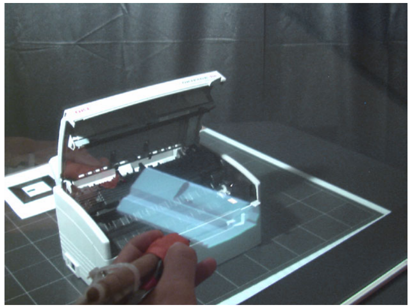
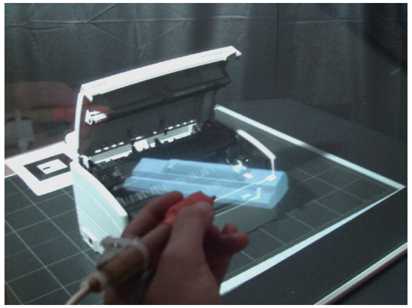
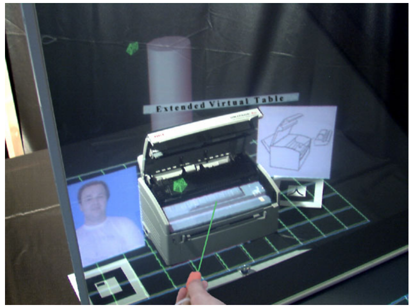
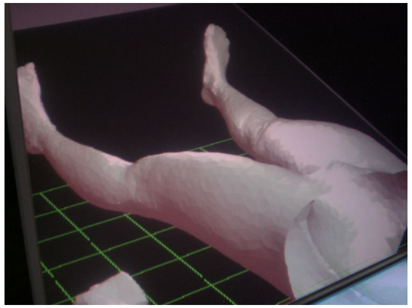
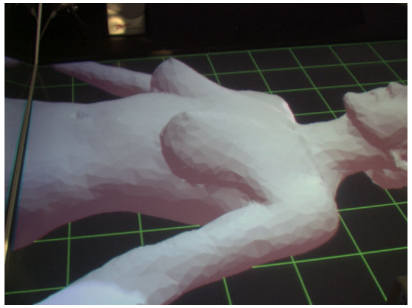
Single Planar Beam-Splitter

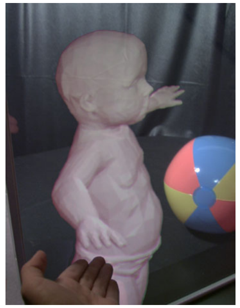
$$R = \begin{bmatrix} 1-2a^2 & -2ab & -2ac & -2ad \\ -2ab & 1-2b^2 & -2bc & -2bd \\ -2ac & -2bc & 1-2c^2 & -2cd \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad [N,d]=[a,b,c,d]$$



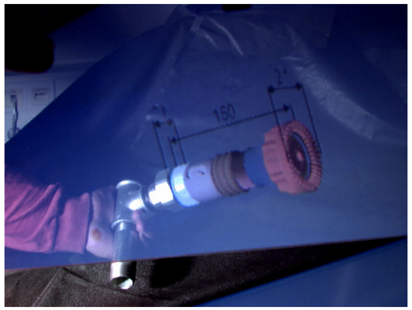
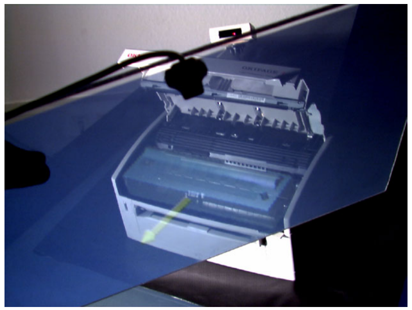
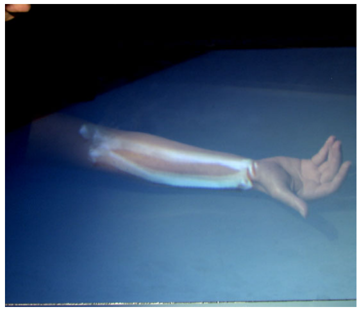
Bimber, O., Fröhlich, B., Schmalstieg, D., and Encarnação, L.M. The Virtual Showcase. *IEEE Computer Graphics & Applications*, vol. 21, no.6, pp. 48-55,2001.

Single Planar Beam-Splitter

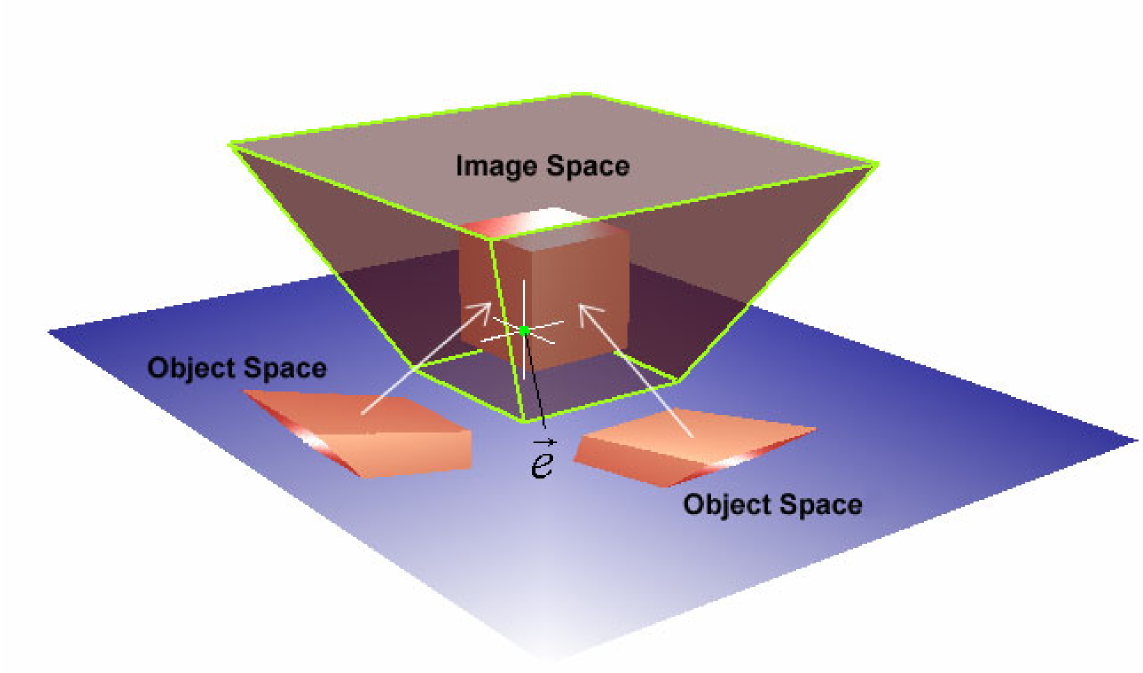


The Extended Virtual Table

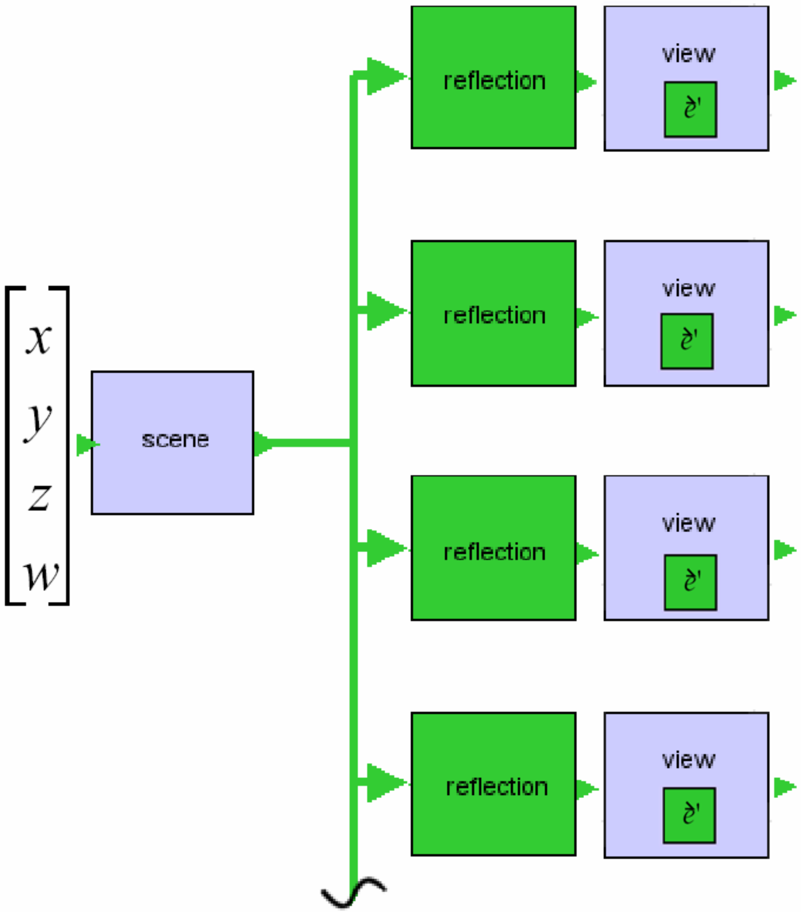
Transflective Surfaces

Multiple Planar Beam-Splitter



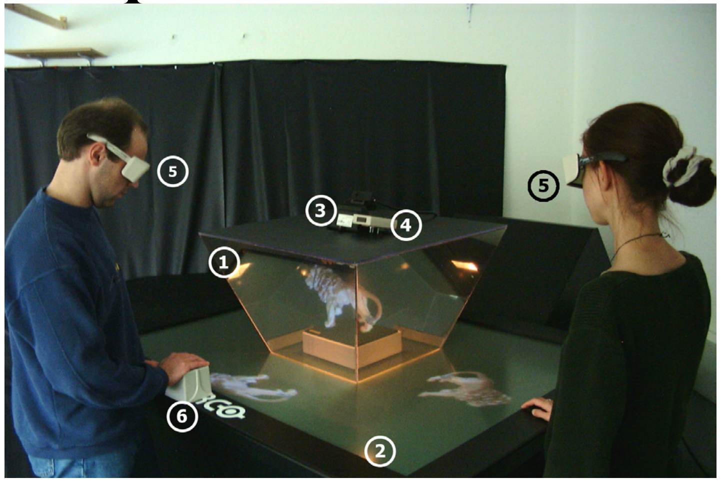
Bimber, O., Fröhlich, B., Schmalstieg, D., and Encarnação, L.M. The Virtual Showcase. *IEEE Computer Graphics & Applications*, vol. 21, no.6, pp. 48-55,2001.

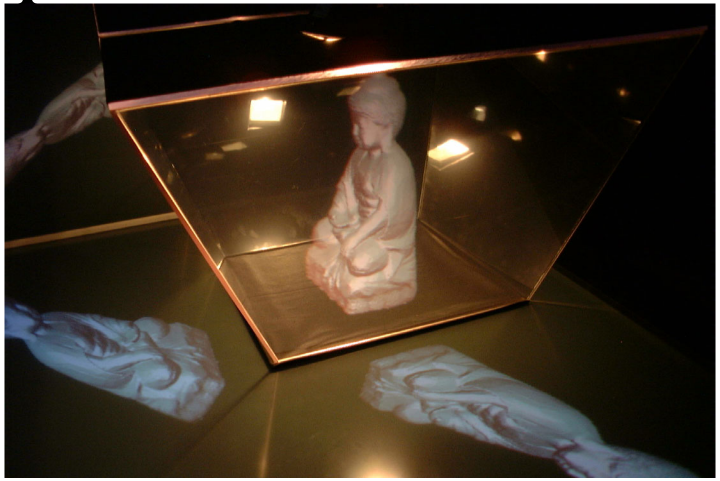
Multiple Planar Beam-Splitter

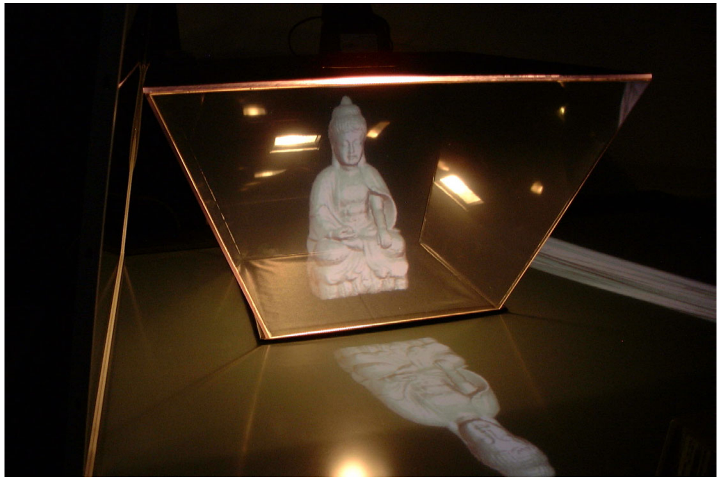


Bimber, O. Interactive Rendering For Projection-Based
Augmented Reality Displays. Ph.D. Dissertation,
Darmstadt University of Technology, October, 2002

Multiple Planar Beam-Splitter





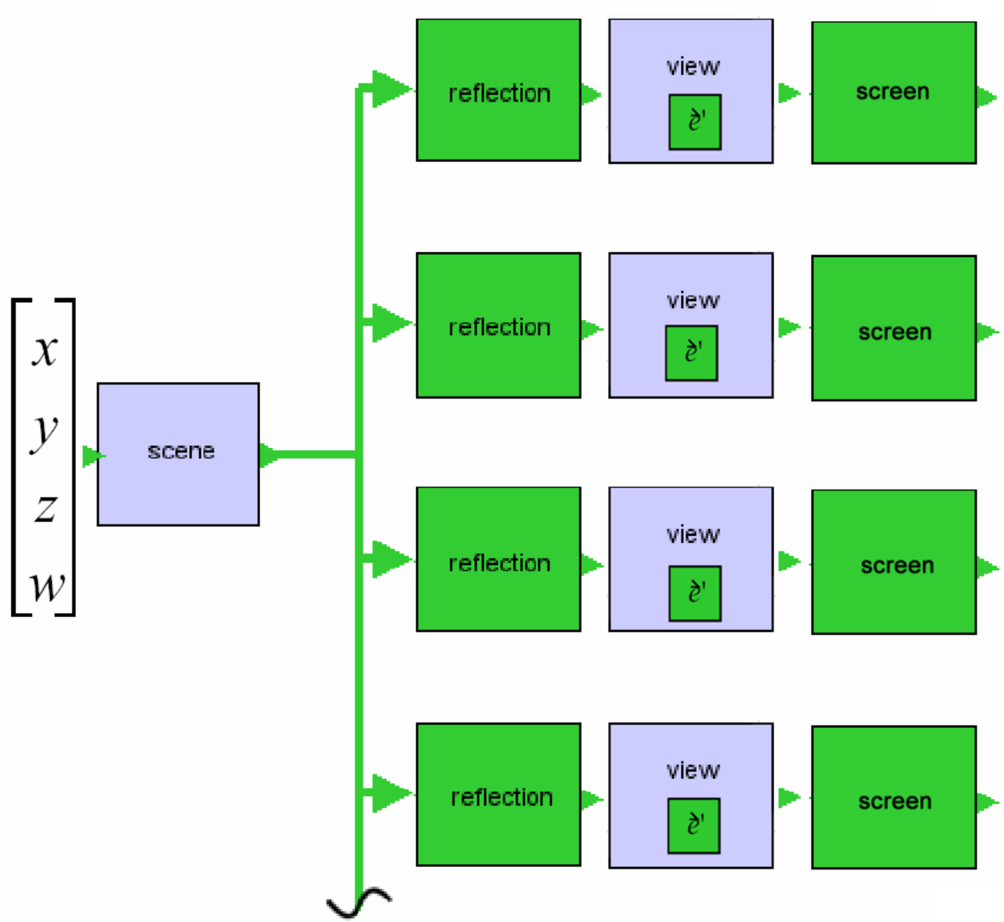


Single User

Multiple Users

The Virtual Showcase

Multiple Screens

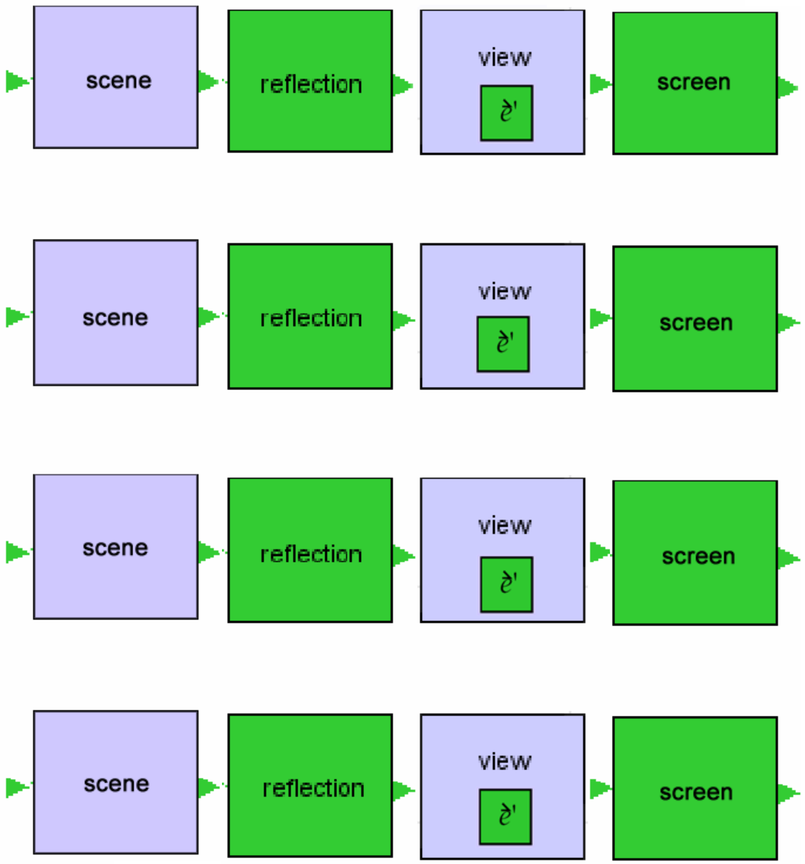


Bimber, O. Interactive Rendering For Projection-Based Augmented Reality Displays. Ph.D. Dissertation, Darmstadt University of Technology, October, 2002

Multiple Screens

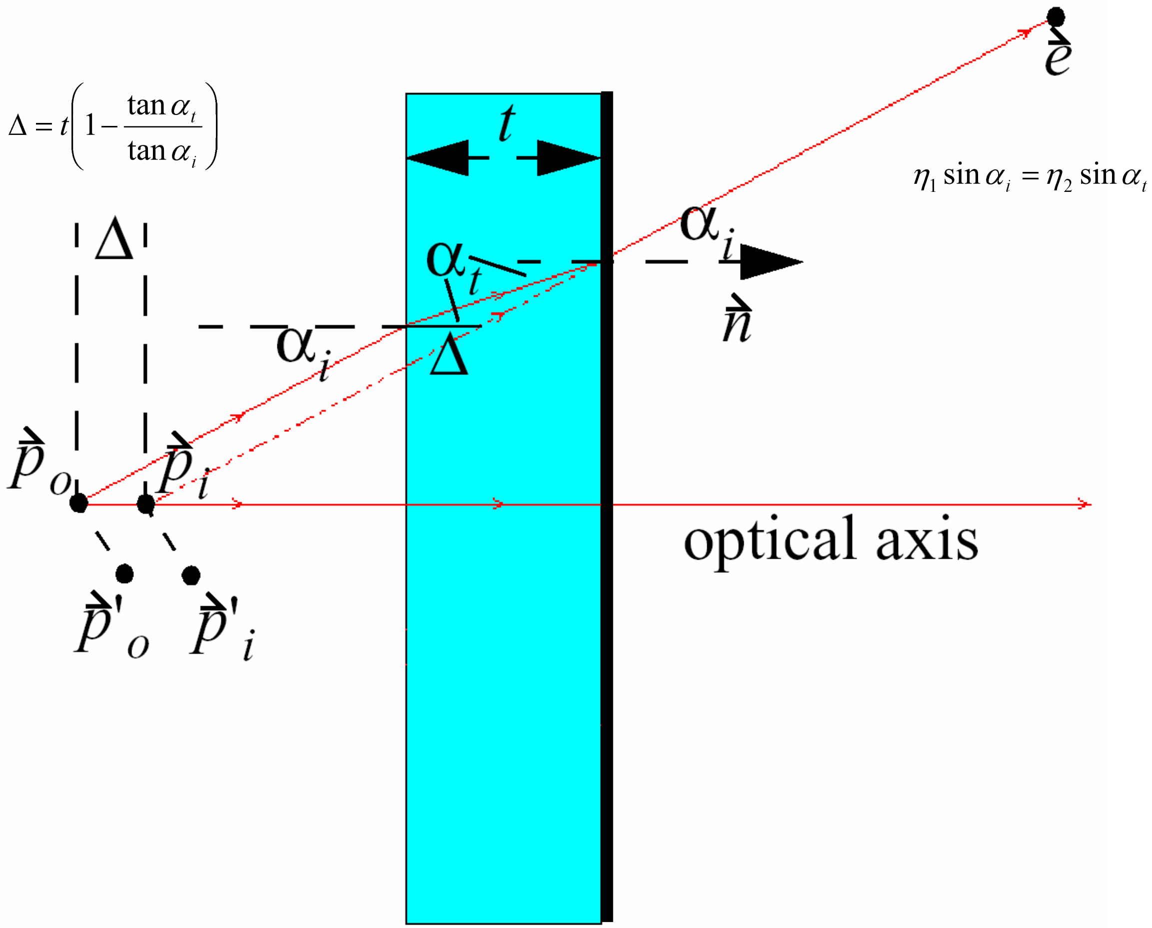
The Virtual Showcase

Multiple Scenes



Bimber, O. Interactive Rendering For Projection-Based Augmented Reality Displays. Ph.D. Dissertation, Darmstadt University of Technology, October, 2002

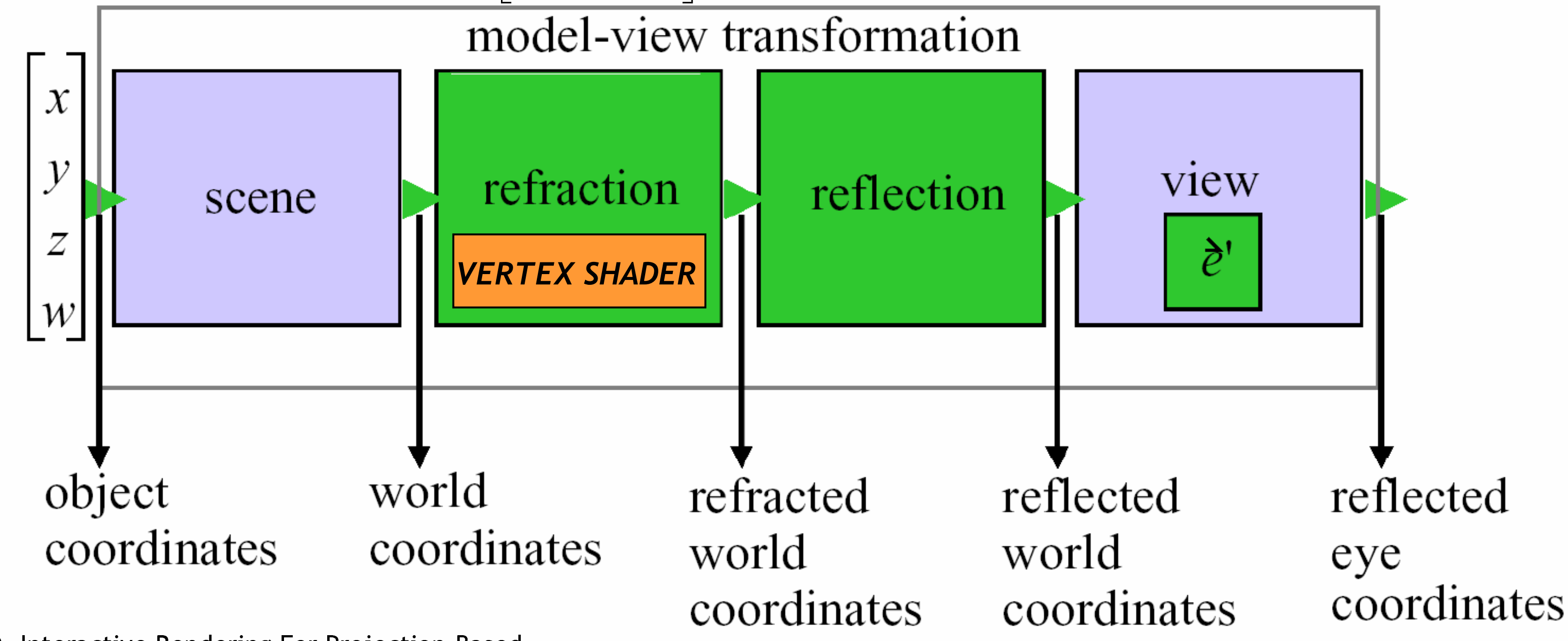
Refraction on Planar Plates



Bimber, O., Encarnação, L.M. and Branco, P. 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.

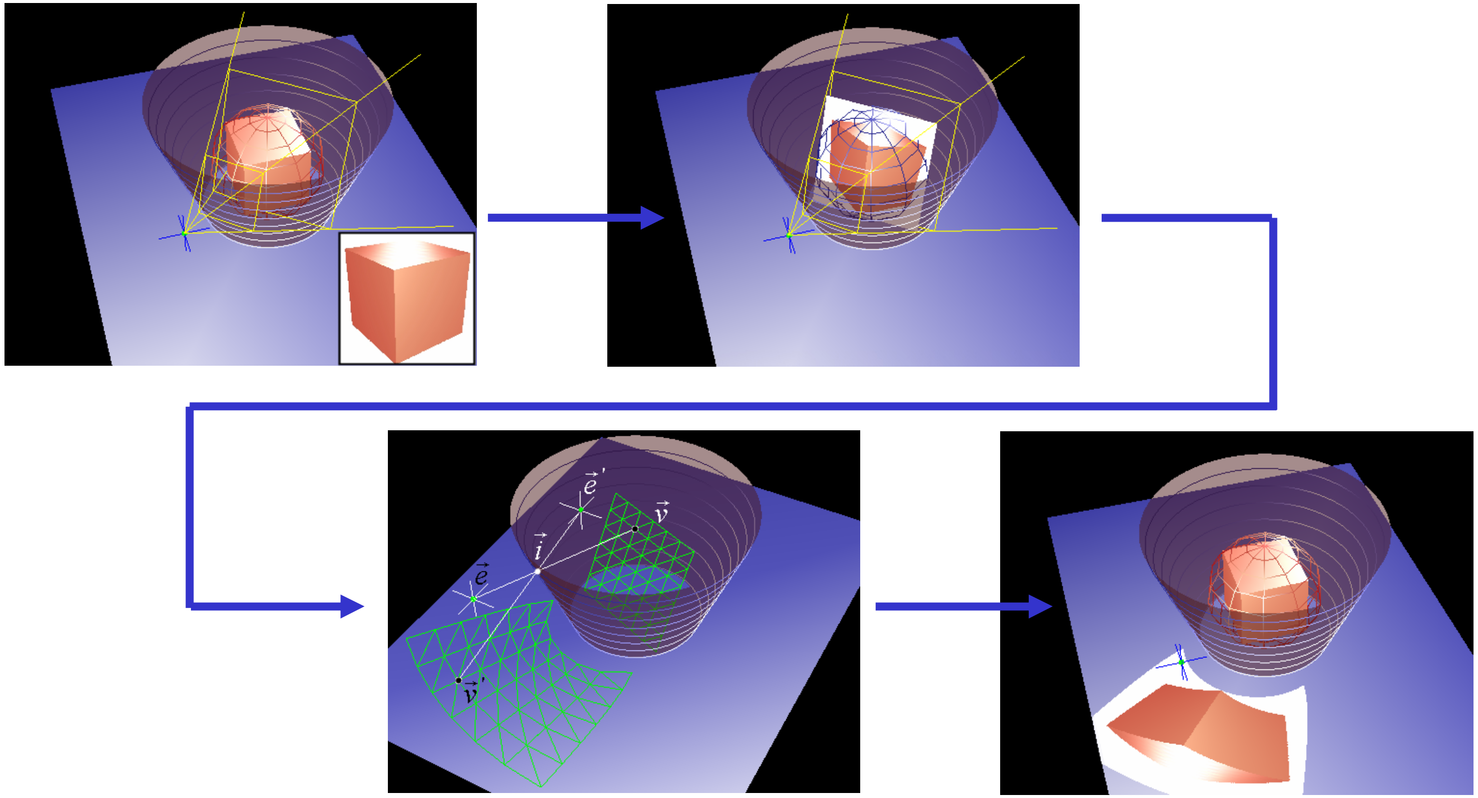
Refraction on Planar Plates

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

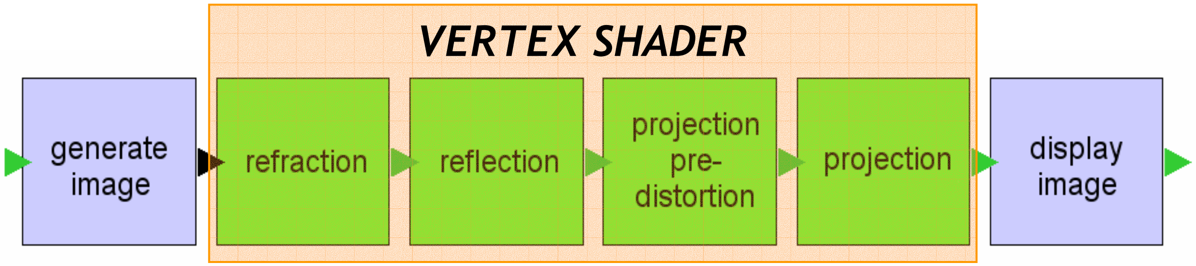


Bimber, O. Interactive Rendering For Projection-Based Augmented Reality Displays. Ph.D. Dissertation, Darmstadt University of Technology, October, 2002

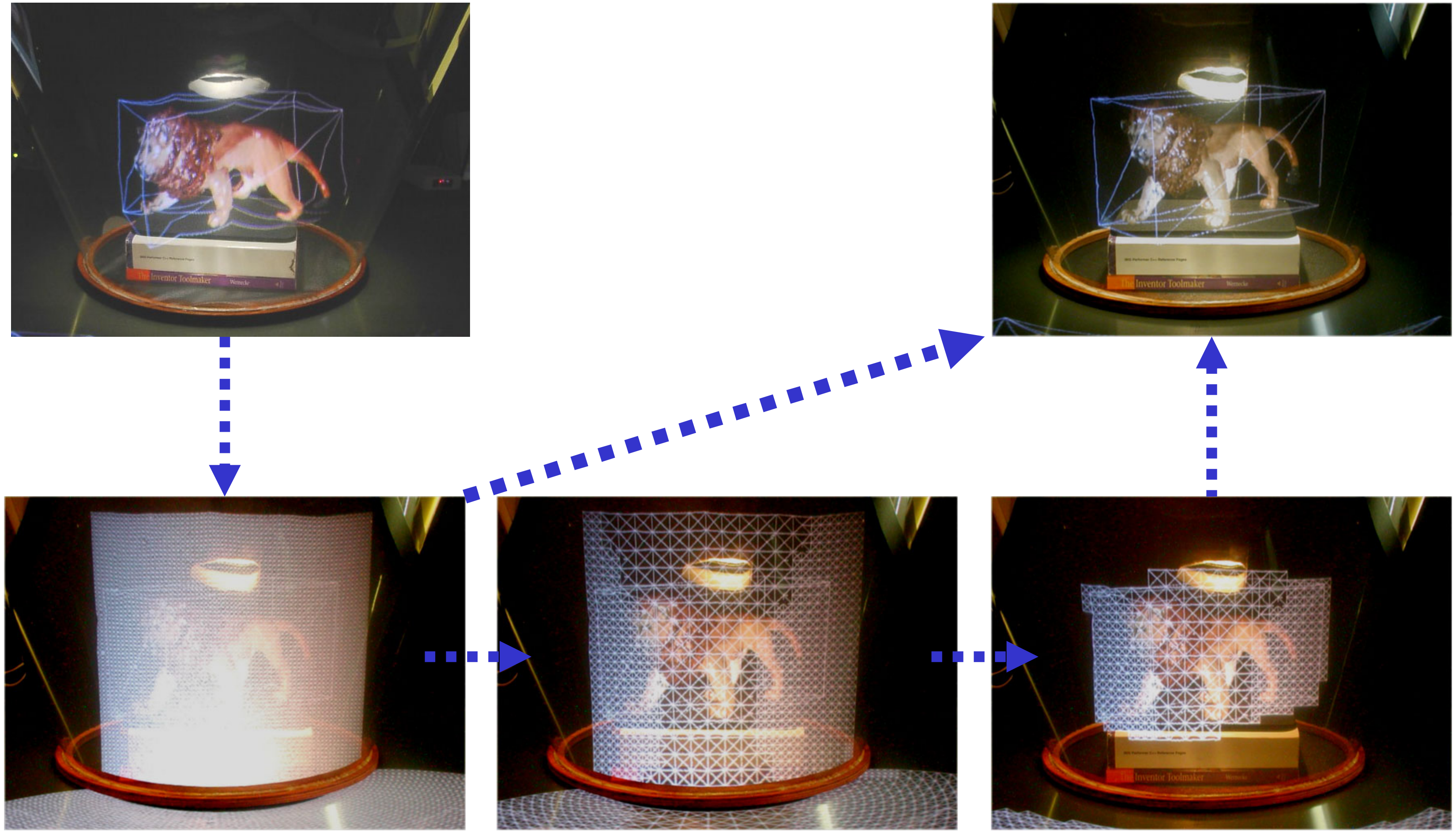
Curved Beam-Splitters



Bimber, O., Fröhlich, B., Schmalstieg, D., and Encarnação, L.M. The Virtual Showcase. *IEEE Computer Graphics & Applications*, vol. 21, no.6, pp. 48-55,2001.

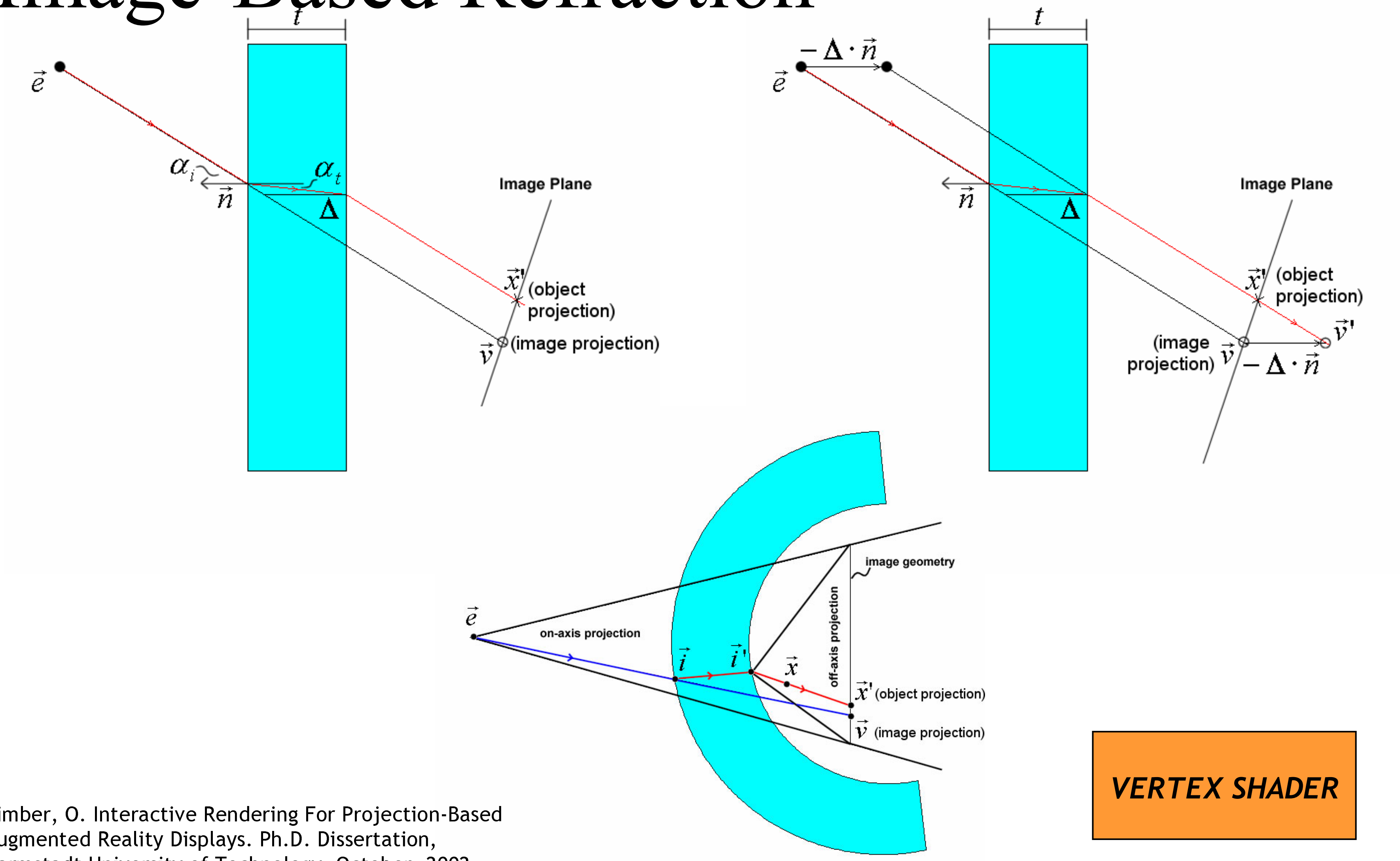


Curved Beam-Splitters



Bimber, O., Fröhlich, B., Schmalstieg, D., and Encarnação, L.M. Real-Time View-Dependent Image Warping to correct Non-Linear Distortion for Curved Virtual Showcase Displays. Computers and Graphics - The international Journal of Systems and Applications in Computer Graphics, vol. 27, no.4, 2003

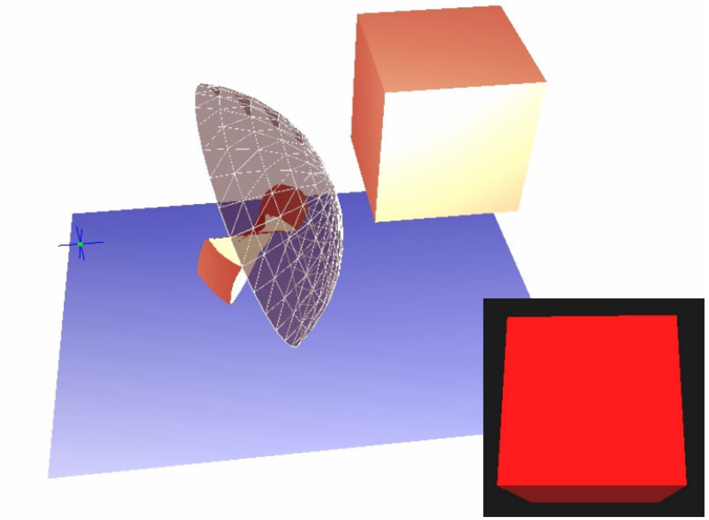
Image-Based Refraction

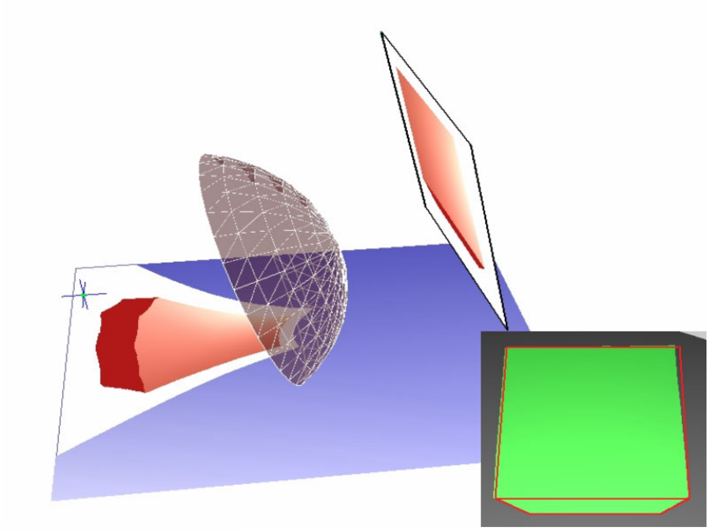


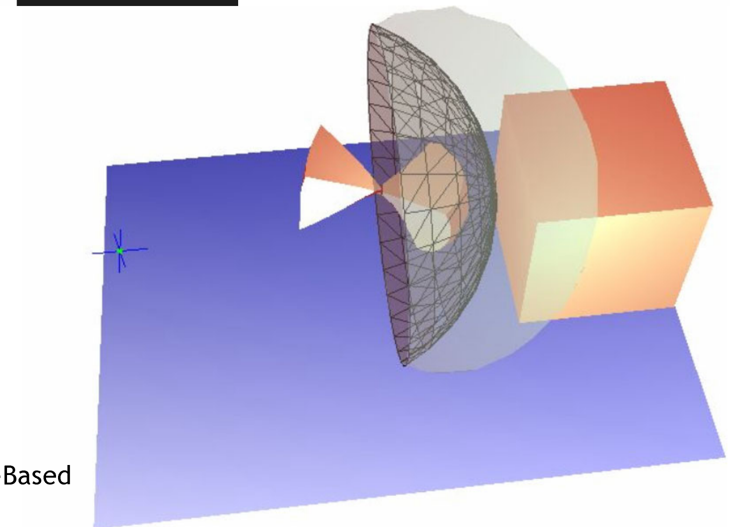
VERTEX SHADER

Bimber, O. Interactive Rendering For Projection-Based Augmented Reality Displays. Ph.D. Dissertation, Darmstadt University of Technology, October, 2002

Concave Beam-Splitters

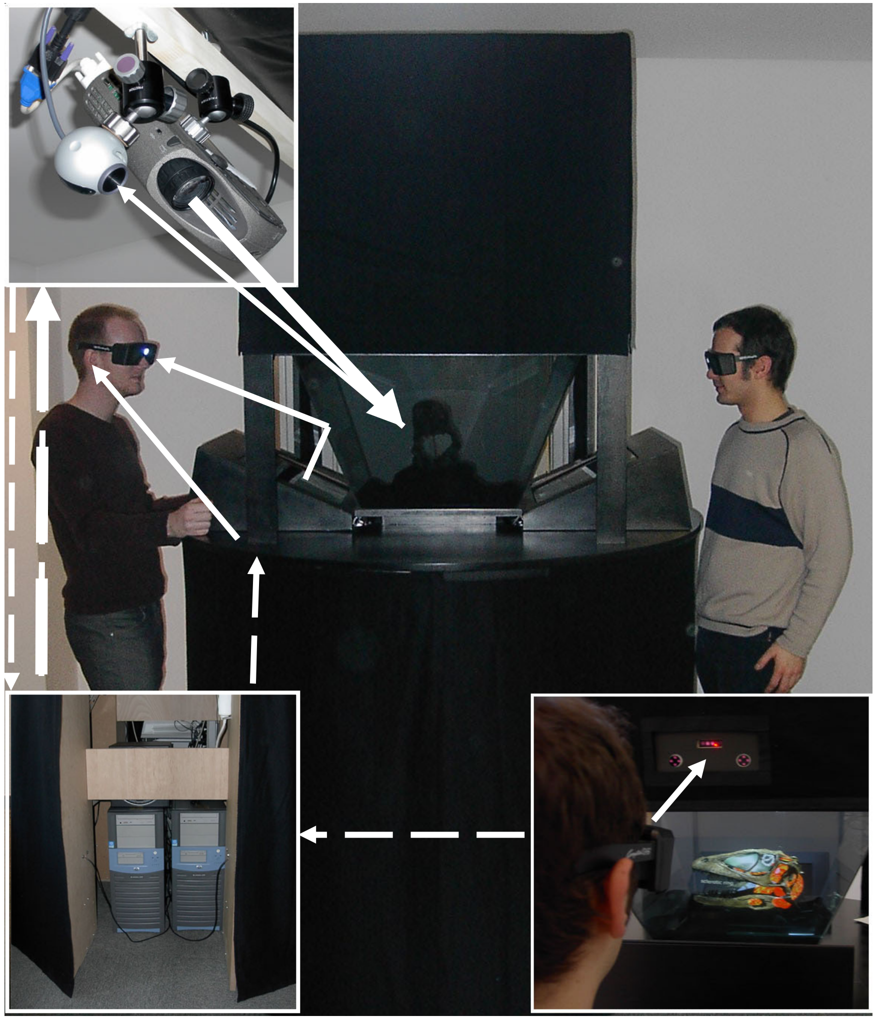






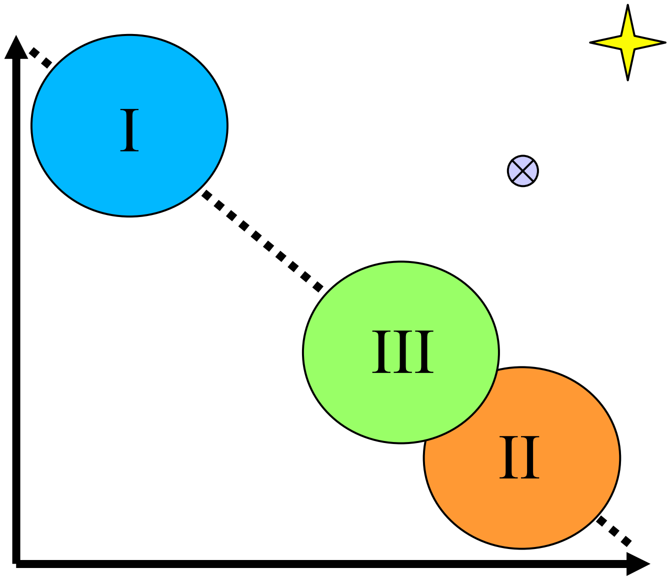
Bimber, O. Interactive Rendering For Projection-Based Augmented Reality Displays. Ph.D. Dissertation, Darmstadt University of Technology, October, 2002

Projector-Based Illumination



Realism

Consistency
(high quality graphics, acceptable registration calibration and tracking results, matching occlusion and illumination effects, etc.)



Interactivity
(low end-to-end latency, real time graphics, real time tracking, etc.)

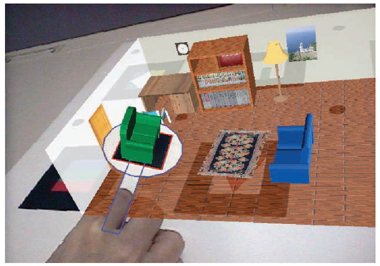
I: image/video-based, desktop systems, special effects for movies, architecture, etc.

Courtesy: Samuel Boivin

II: optical see-through, HMDs, mobile applications, etc.

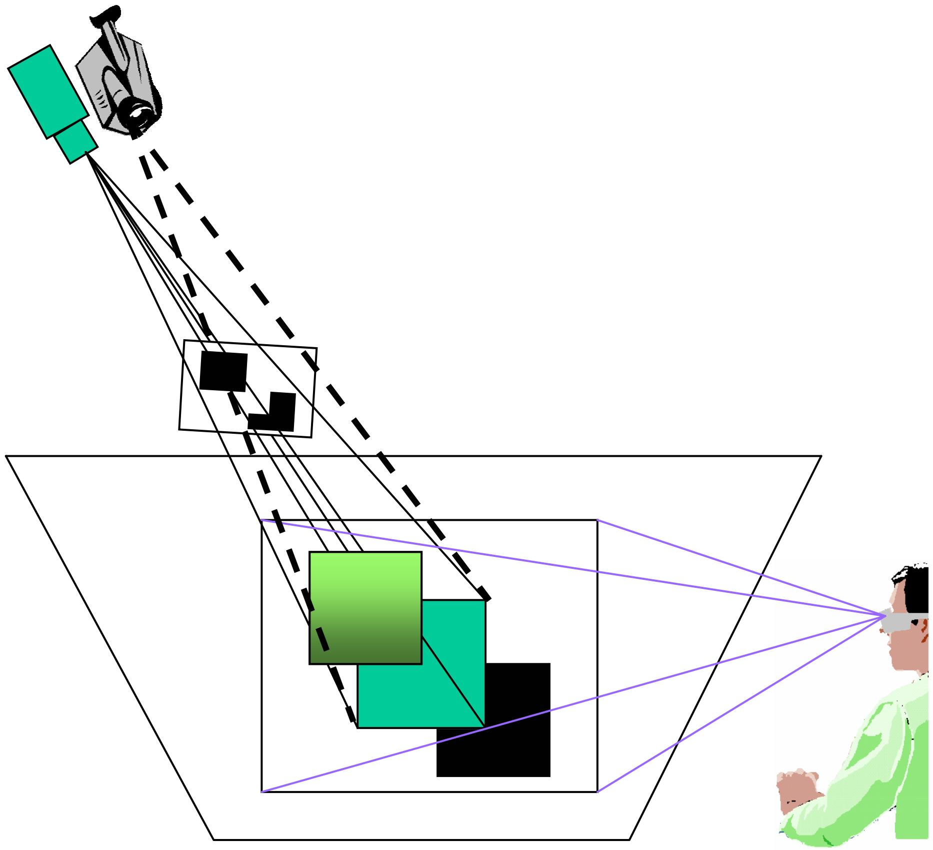
Courtesy: Naval Research Lab

III: video see-through, HMDs, mobile applications, etc.

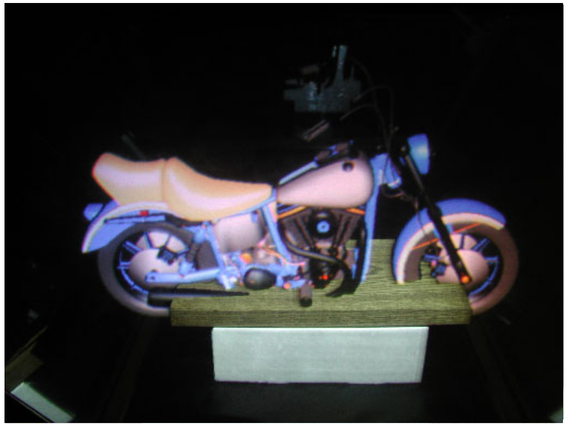


Courtesy: Hirokazu Kato

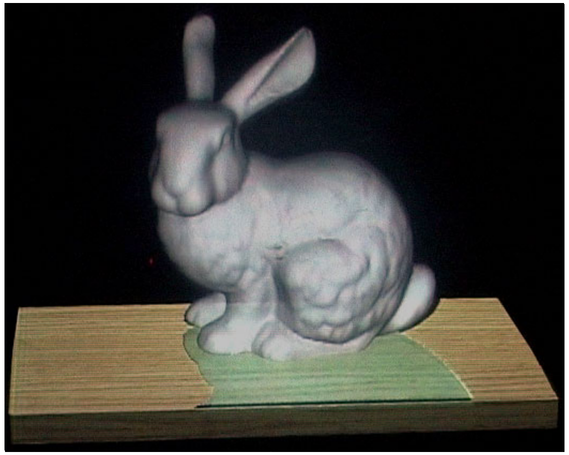
Consistent Occlusion



Bimber and Fröhlich. Occlusion Shadows: Using Projected Light to Generate Realistic Occlusion Effects for View-Dependent Optical See-Through Displays. *ACM/IEEE ISMAR*, 2002.

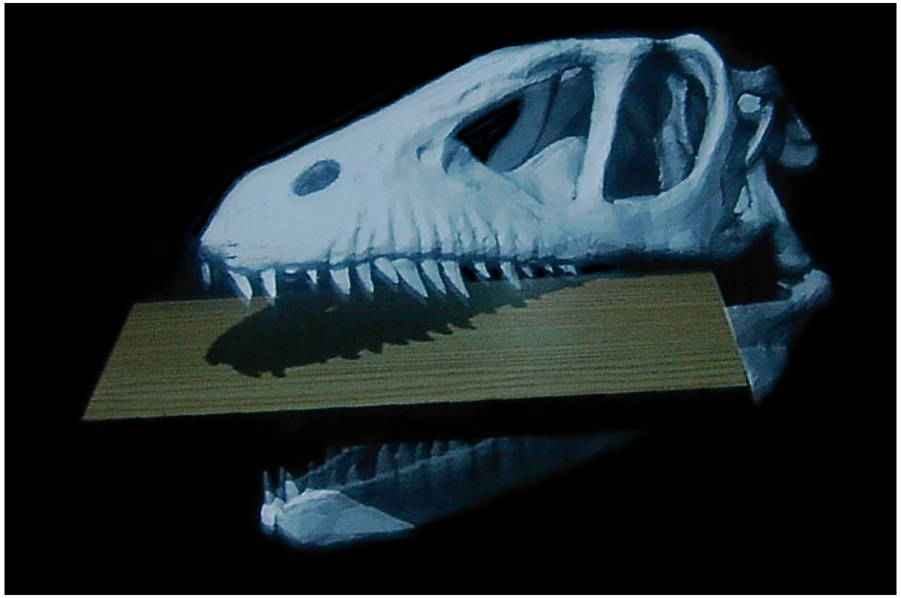


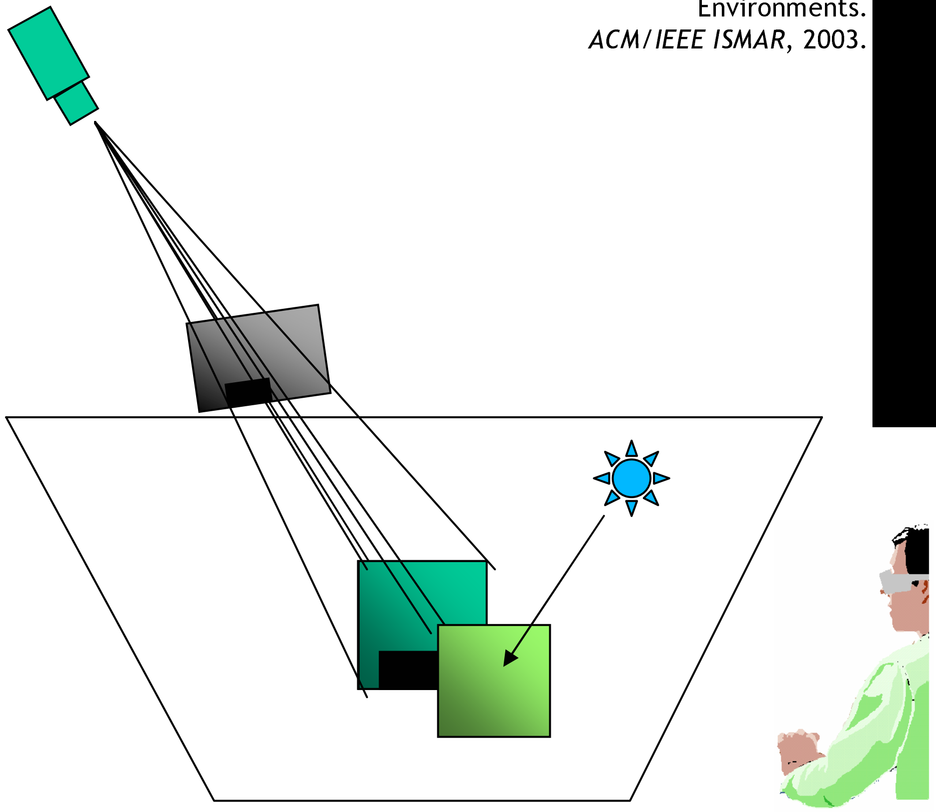
Bimber, Grundhöfer, Wetzstein, and Knödel. Consistent Illumination within Optical See-Through Augmented Environments. *ACM/IEEE ISMAR*, 2003.



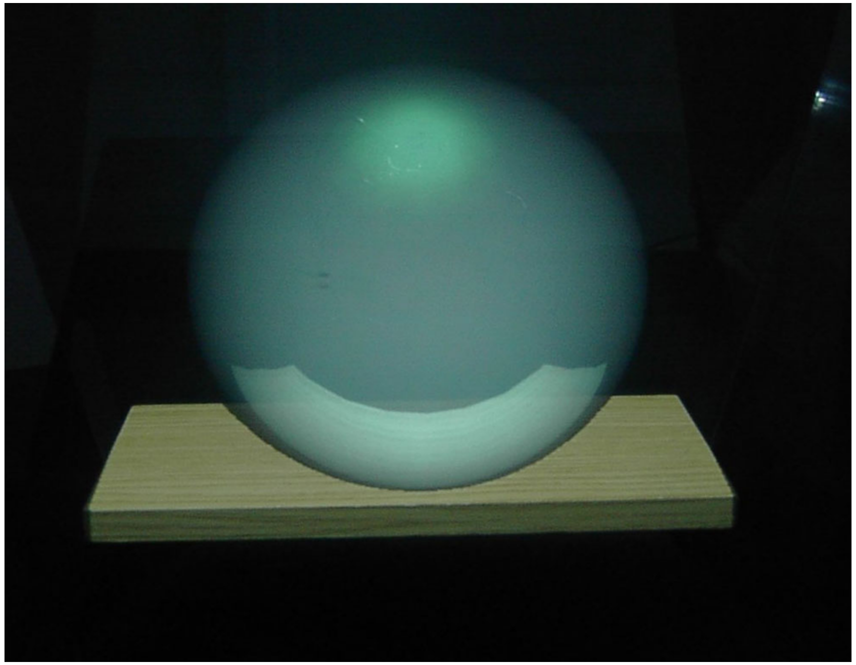
Consistent Illumination

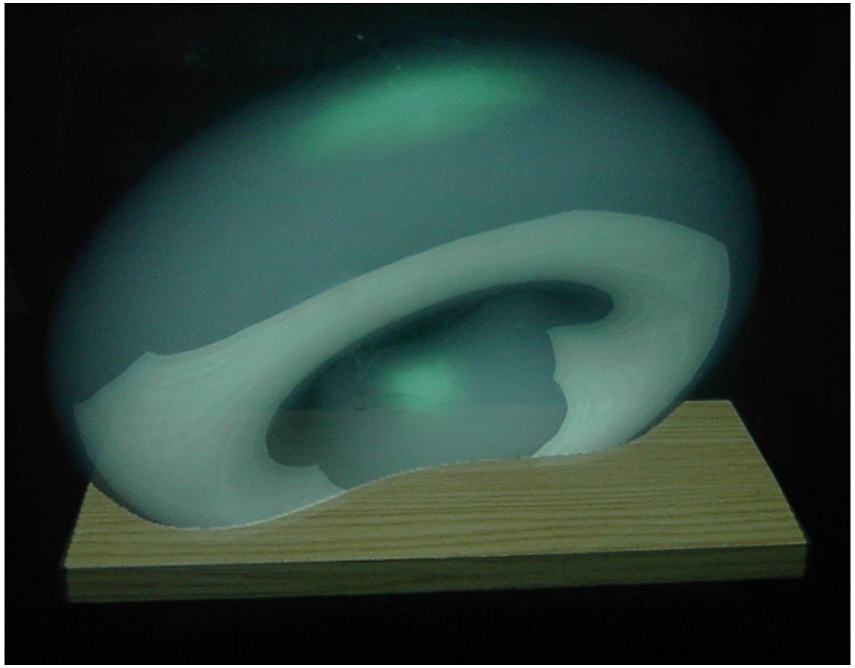
Bimber, Grundhöfer, Wetzstein, and Knödel. Consistent Illumination within Optical See-Through Augmented Environments. *ACM/IEEE ISMAR*, 2003.





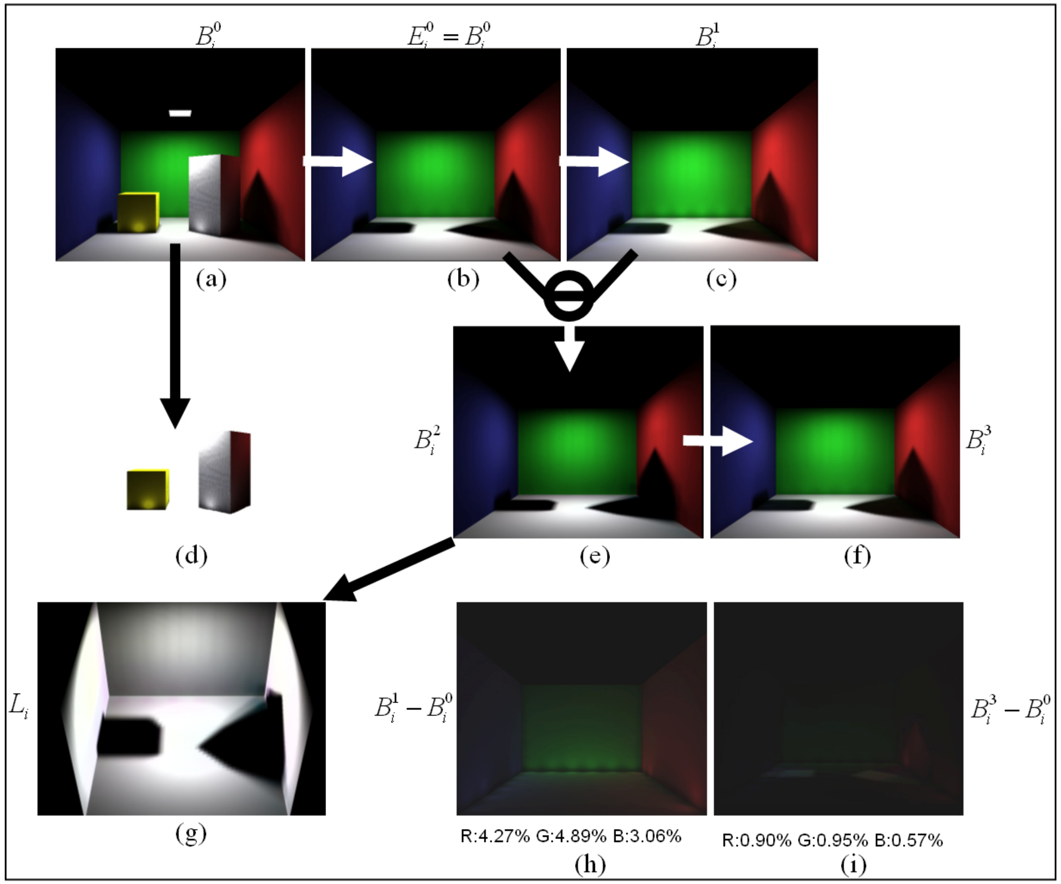
Reflections

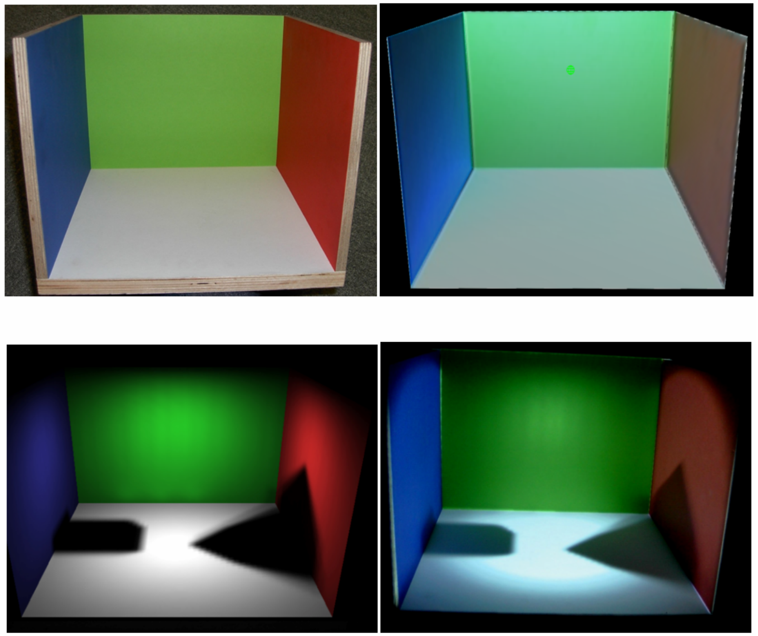




Bimber, Grundhöfer, Wetzstein, and Knödel. Consistent Illumination within Optical See-Through Augmented Environments. *ACM/IEEE ISMAR*, 2003.

Augmented Radiosity





Bimber, Grundhöfer, Wetzstein, and Knödel.
Consistent Illumination within Optical See-Through Augmented Environments.
ACM/IEEE ISMAR, 2003.

Thank You!

Part 5: Current Areas of Application

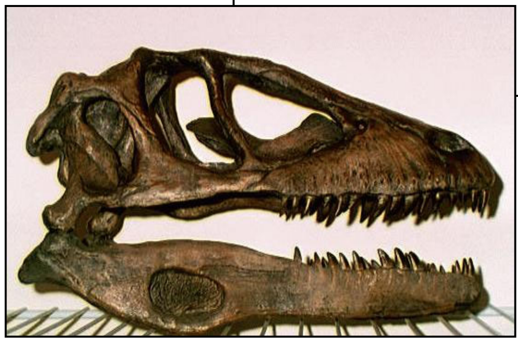
Part5: Current Areas of Application

Outline

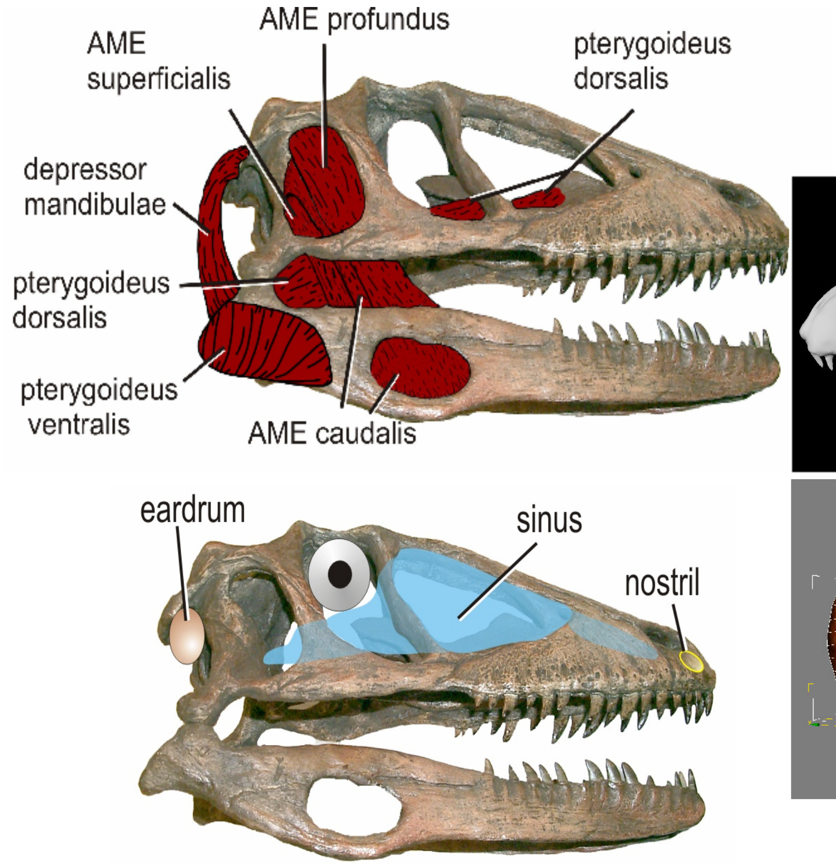
- Scientific visualization and digital storytelling within a museum context
  - the Augmented Paleontology case study
    - setup
    - user feedback
    - professional feedback
  - past and upcoming museum installations
- Future tools for science and education
- Vehicle Simulation
  - user feedback
- Industrial maintenance and training
- Large area spatial augmentation for museums

Augmented Paleontology

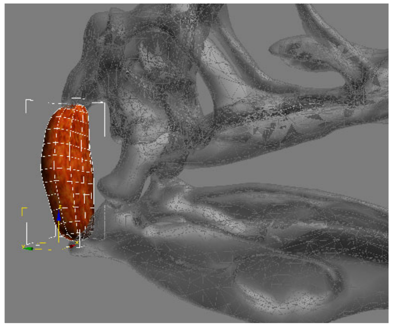
- Paleontologists compare anatomy of living animals with fossils to find out how dinosaurs looked like and how the lived and behaved
- Case Study:
  - augmenting a skull of Deinonychus with reconstructed soft tissues and missing bones
  - present research results to novice audience
- Together with:
  - Lawrence M. Witmer, Ohio University
  - Stephen M. Gatesy, Brown University



Augmented Paleontology

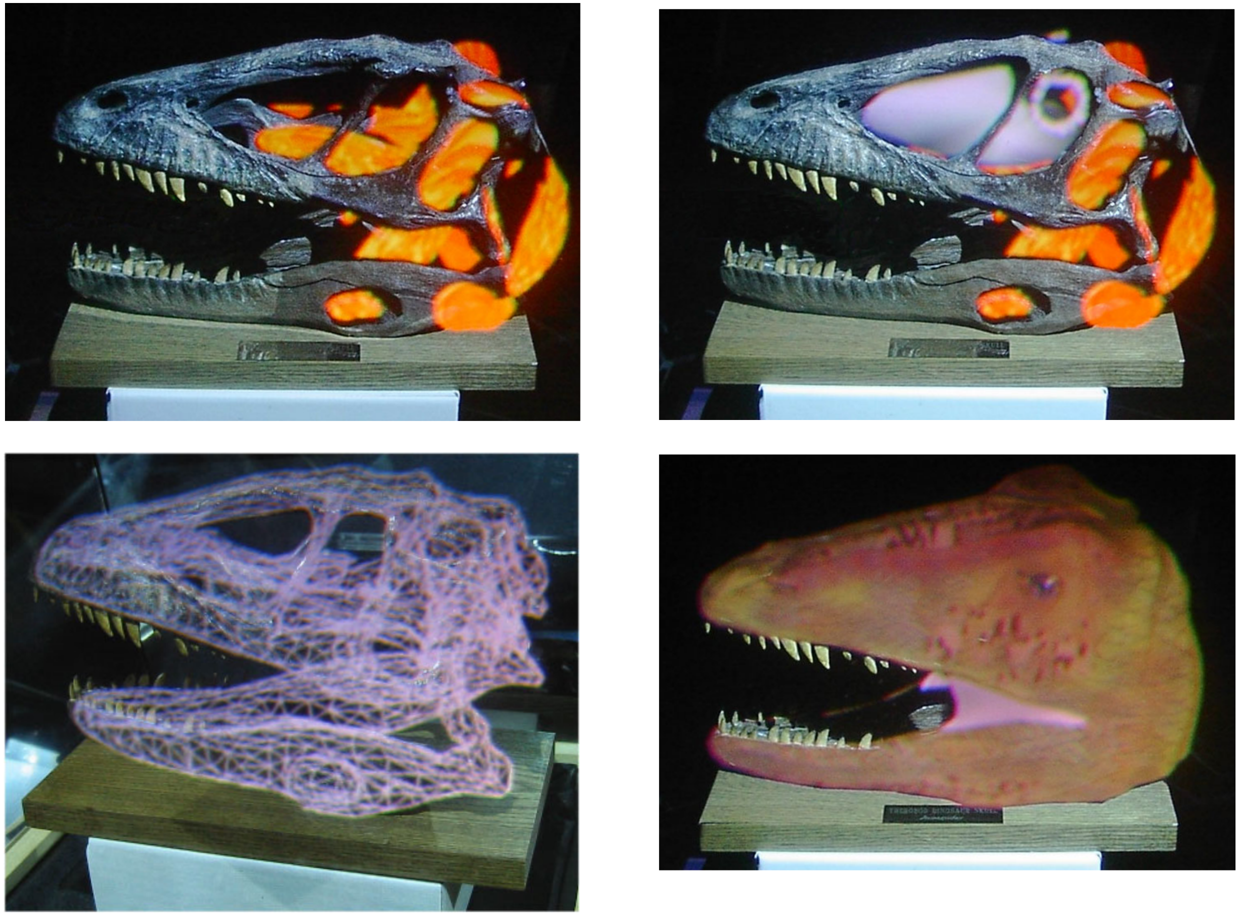


Lawrence M. Witmer, Ohio University



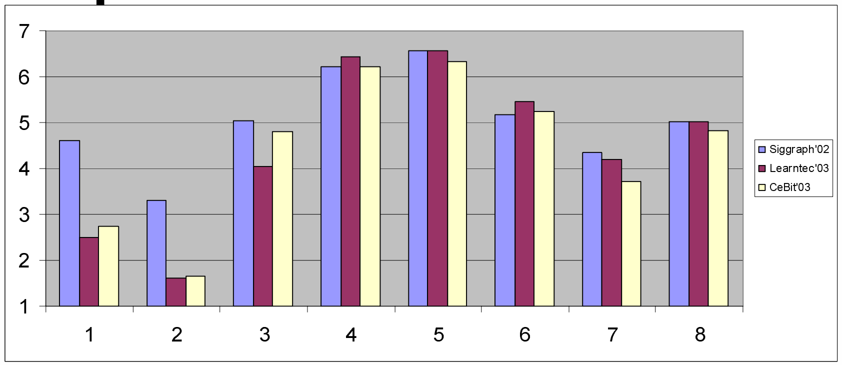
Julia Wolin, Rhode Island School of Design

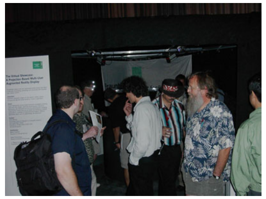
Augmented Paleontology



Bimber, Gatesy, Witmer, Raskar, Encarnação. Merging Fossil Specimes with Computer Generated Information, *IEEE Computer*, September 2002.

User Feedback
→ Previous Experience and Acceptance





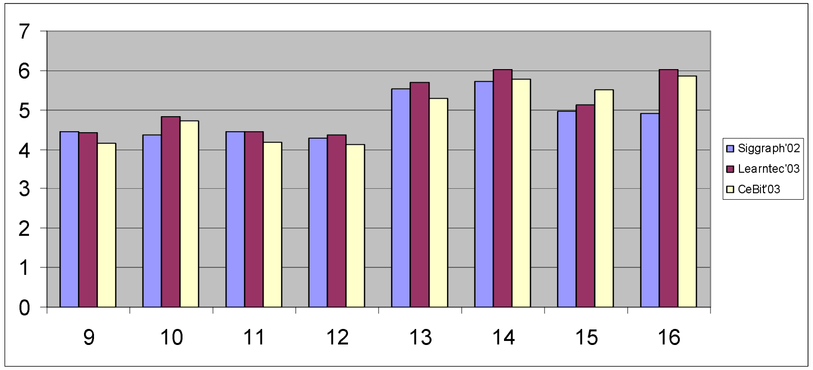
•**Siggraph'02:** 5 days, ~1500 users, 16-78 years of age (average 35 years), 385 valid questionnaires

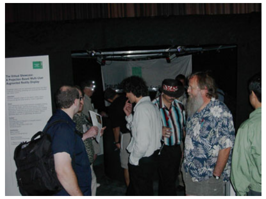
•**Learntec'03:** 4 days, ~650 users, 18-72 years of age (average 34 years), 264 valid questionnaires

•**CeBit'03:** 8 days, ~2100 users, 11-66 years of age (average 28 years), 266 valid questionnaires

1. Do you have any previous experience with Virtual Reality? (1= none, 7= many)
2. Do you have any previous experience with Augmented Reality? (1= none, 7= many)
3. Do you have any previous experience with Computer Games? (1= none, 7= many)
4. Would you try out the same or a similar technology again? (1= not at all, 7= yes, very much so)
5. Do you think such technology is suitable for Museum exhibits? (1= not at all, 7= yes, very much so)
6. Did the virtual representation and the supporting technology deteriorate in any way your experience with the real object? (1= yes, very much so, 7= not at all)
7. Would you pay a higher entrance fee in order to see Virtual Showcase technology in a museum? (1= not at all, 7= definitely, if reasonable)
8. Would you prefer to go to a Virtual Showcase display rather than a traditional artifact exhibit of the same object in a museum? (1= not at all, 7= definitely)

User Feedback
→ Visual Impression





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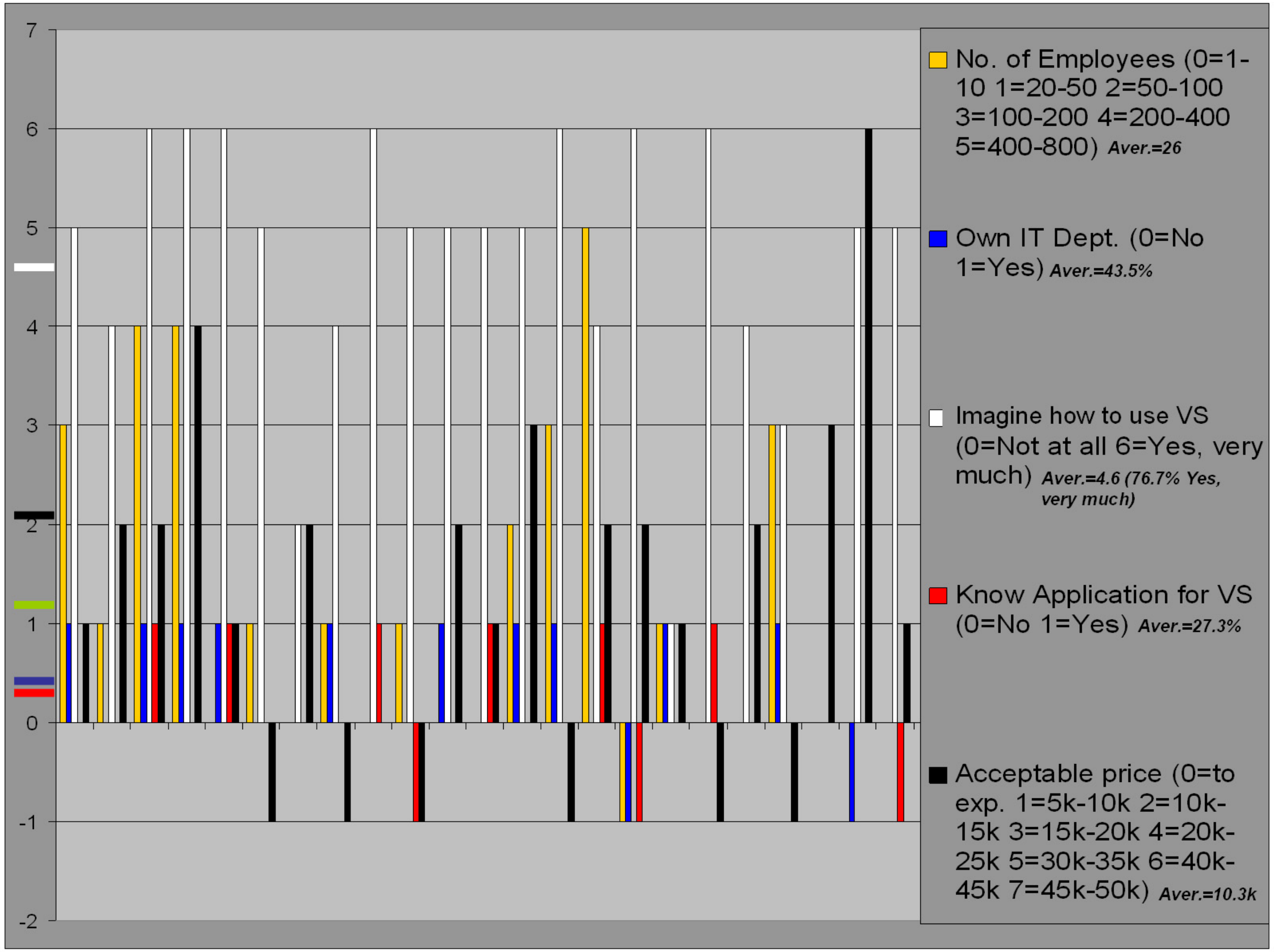
9. How would you rate the comfort of the 3D glasses? (1= bad, 7= very good)
10. Did you have the impression that the virtual objects belonged to the real object (dinosaur skull), or did they seem separate from it? (1= separate from the real object, 7= belonged to the real object)
11. Was watching the virtual objects just as natural as watching the real world? (1= completely unnatural, 7= completely natural)
12. Did you have the impression that you could have touched and grasped the virtual objects? (1= not at all, 7= absolutely)
13. Did the virtual objects appear to be (visualized) on a screen, or did you have the impression that they were located in space? (1= on screen, 7= in space)
14. Did you have the impression of seeing the virtual objects as merely flat images or as three-dimensional objects? (1= only as image, 7= as three-dimensional object)
15. Did you pay attention at all to the difference between real and virtual objects? (1= not at all, 7= yes, very much so)
16. Did you have to make an effort to recognize the virtual objects as being three-dimensional? (1= yes, very much so, 7= not at all)

Professional Feedback

→ Museums Curators

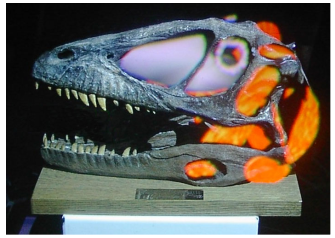


- **MUTEC'03:** 3 days, ~150 users, 14 valid questionnaires

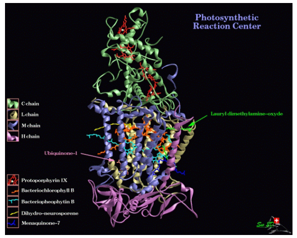
Past and Future Installations

- Museo de San Telmo de San Sebastian, Spain (March-June’03)

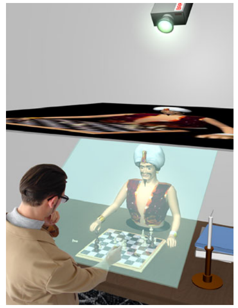
- Siemens Forum Munich, Germany, (November ’03, Part of Cybernarium)



- Deutsches Museum Bonn, Germany (late ’03 / early ‘04)

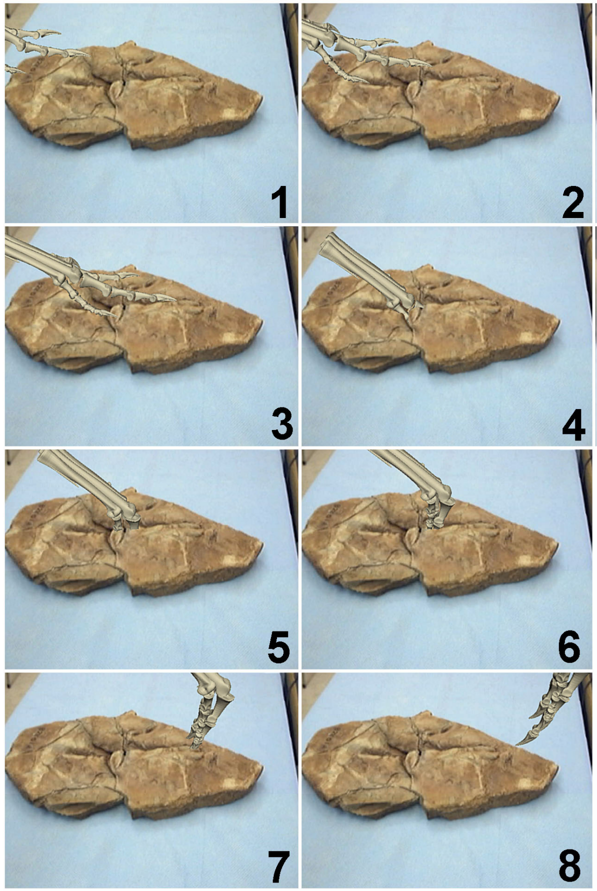


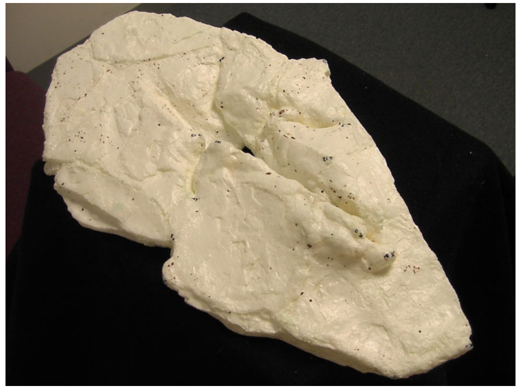
- Technisches Museum Wien, Austria (late ’03 / early ‘04)

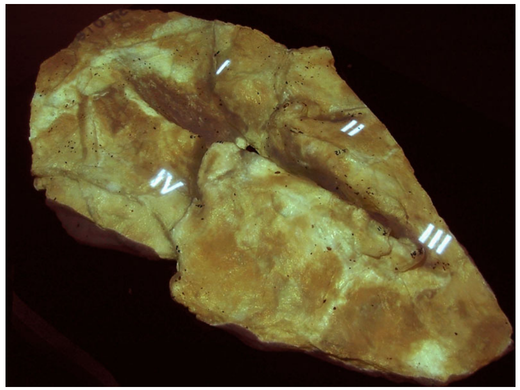


- Museu Dom Diogo de Sousa, Portugal (late ’03 / early ‘04)

Future Tools for Sciences and Education

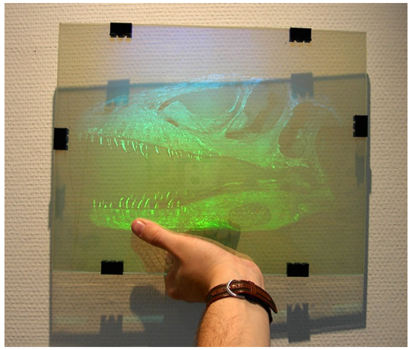




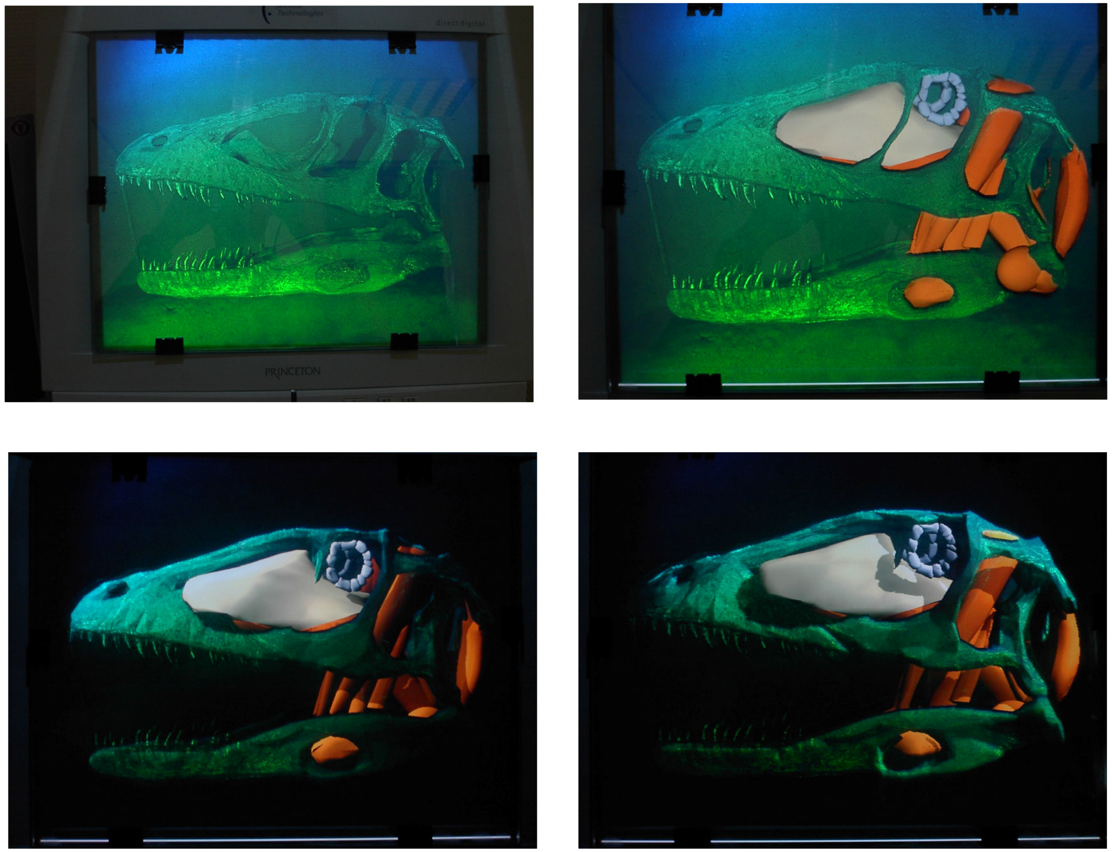


Bimber, Gatesy, Witmer, Raskar, Encarnação. Merging Fossil Specimes with Computer Generated Information, *IEEE Computer*, September 2002.

Future Tools for Sciences and Education

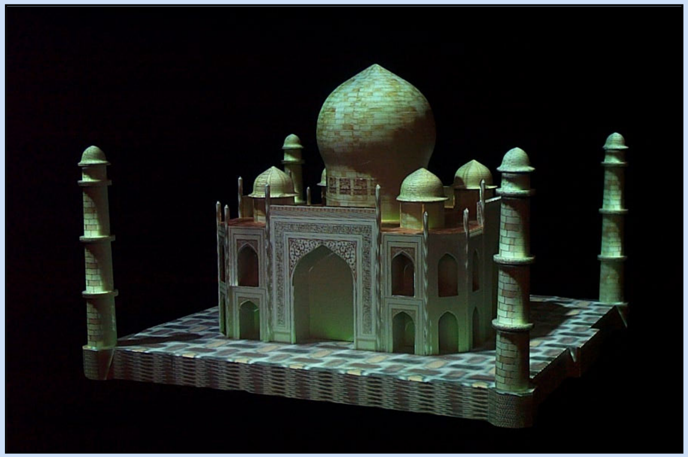


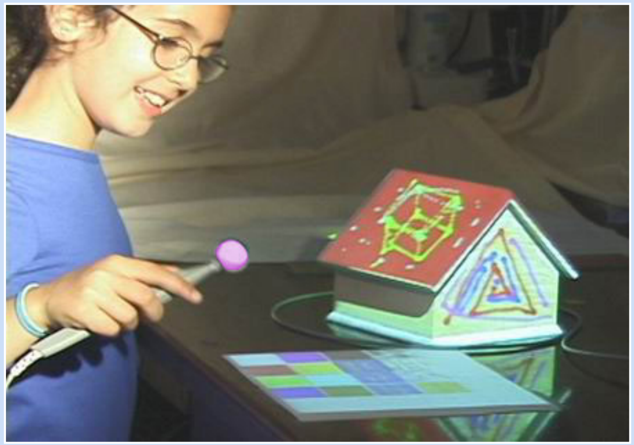
Bimber. Combining Optical Holograms with Interactive Computer Graphics. *Submitted to IEEE Computer*, 2003.



Projector-based Augmentation

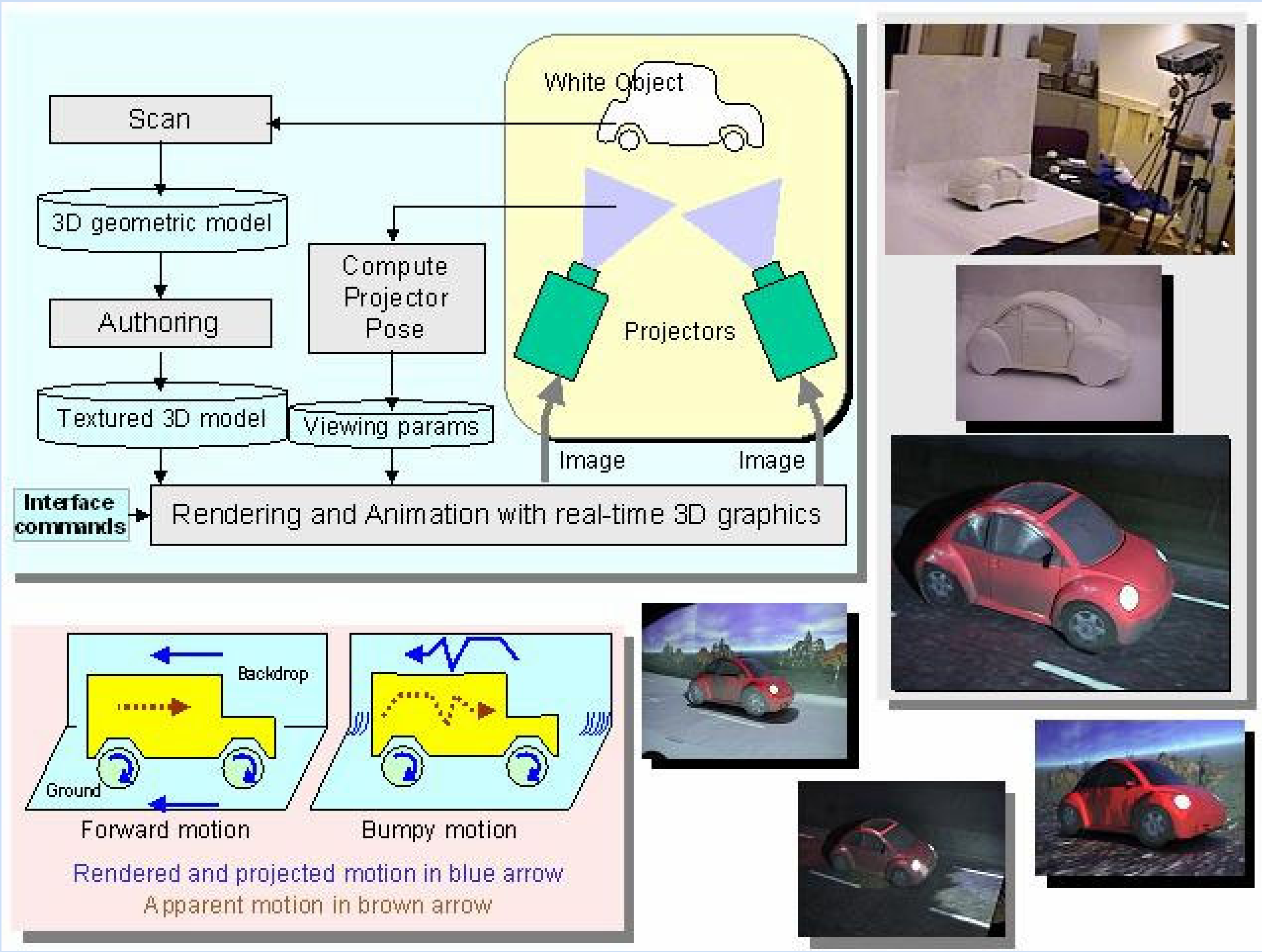
- More Examples ..





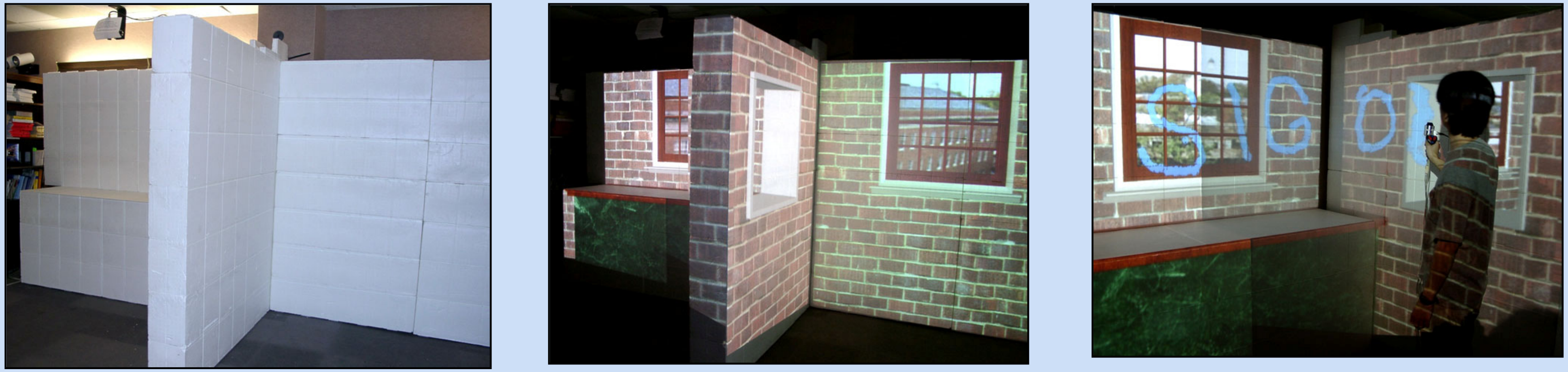
More info : www.ShaderLamps.com , Code available

Apparent Motion

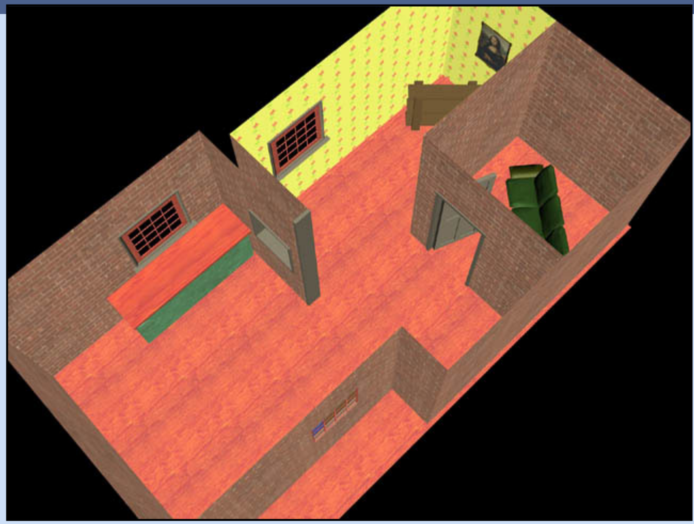


Ramesh Raskar, Remo Ziegler, Thomas Willwacher, "Cartoon Dioramas in Motion," Proc. ACM Symposium on Nonphotorealistic Animation and Rendering (NPAR 2002)

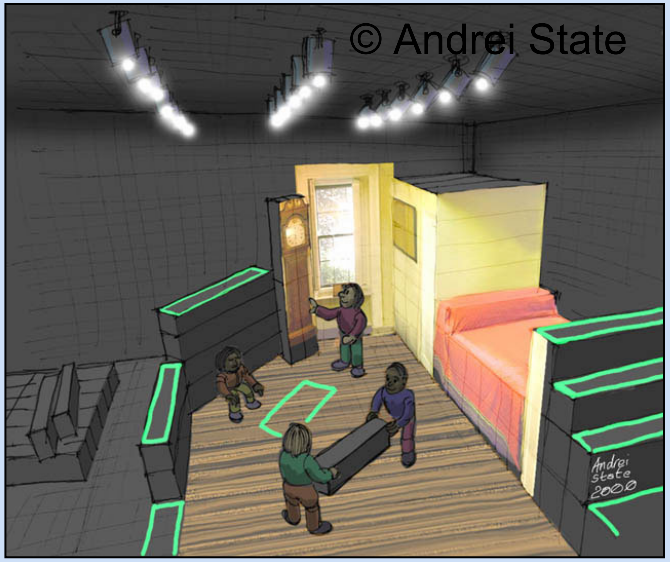
- Recreate Large Environments
  - ‘BeingThere’, walk-around
  - Human sized environments
  - Museums, Exhibitions



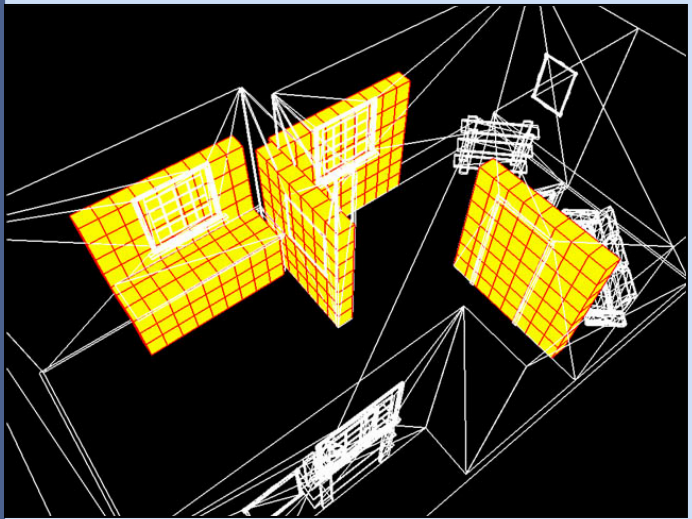
Kok-Lim Low, Greg Welch, Anselmo Lastra, Henry Fuchs. “Life-Sized Projector-Based Dioramas,” Proc. ACM Symposium on Virtual Reality Software and Technology 2001 (VRST 2001), November 2001.

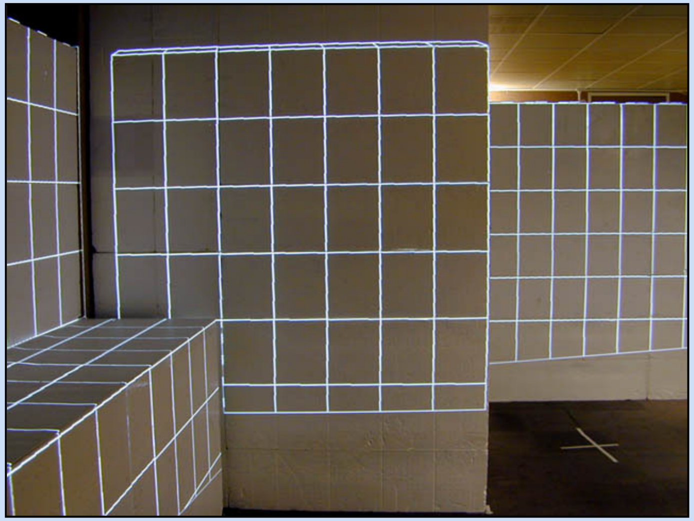


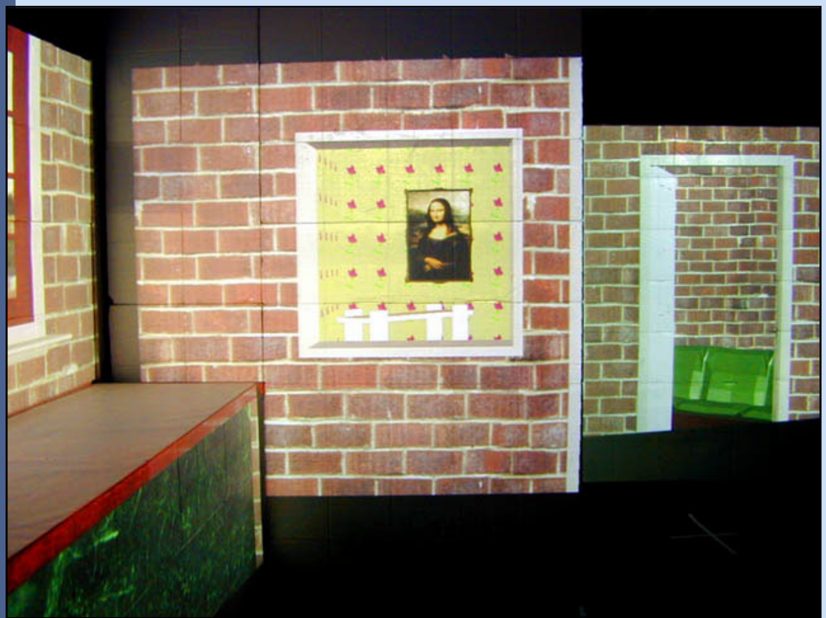
Desired Virtual Model

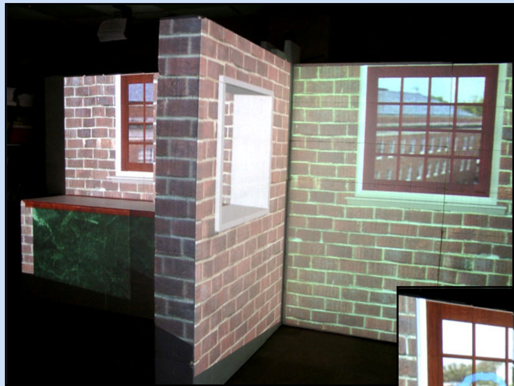


Projected Guidance for Placement









Acknowledgements

- MERL
  - Jeroen van Baar, Paul Beardsley, Remo Ziegler, Thomas Willwacher, Srinivas Rao, Cliff Forlines, Paul Dietz
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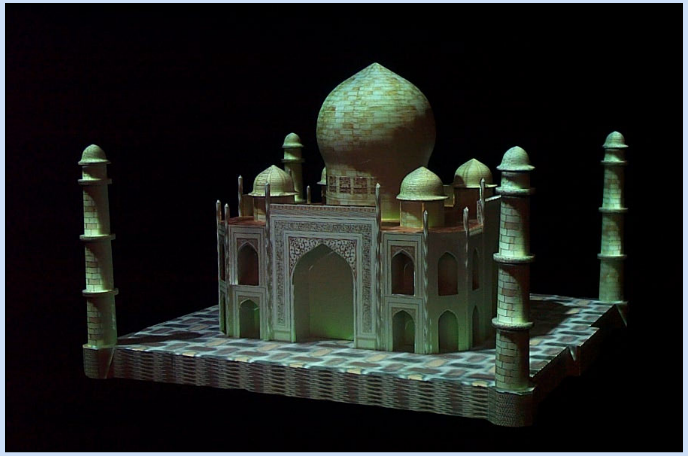
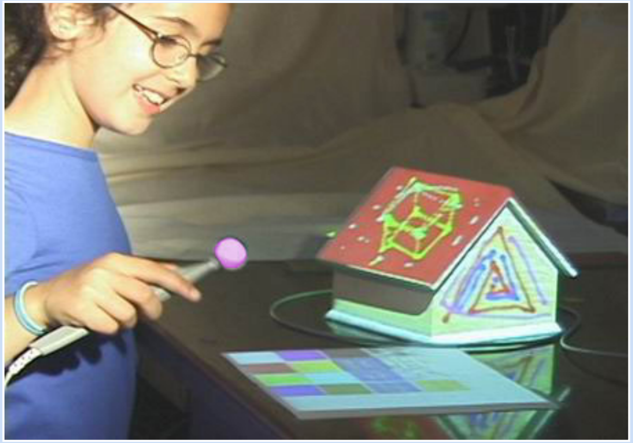
  - Henry Fuchs, Herman Towles
  - Wei-chao Chen
- Mitsubishi Electric, Japan
  - Yoshihiro Ashizaki, Masatoshi Kameyama, Masato Ogata, Keiichi Shiotani
- Images
  - Oliver Bimber (Virtual Showcase images)
  - Marc Pollefeys (UNC Chapel Hill)
  - Apologies
    - (Not able to include recent work by others)

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

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

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 and user feedback

Schedule

09:30	Overview	
09:40	Today's AR Display Approaches	(Bimber)
10:00	Non-trivial Projection Screens	(Raskar)
11:00	Break	
11:30	Spatial Optical See-thru Displays	(Bimber)
12:30	Applications	(Bimber and Raskar)
12:50	Discussion	

Course Pages : www.cs.unc.edu/~raskar/Projector/
www.uni-weimar.de/medien/AR

Conclusion

- AR Display Approaches
  - Traditional, Goggle-bound, Alternative
- Non-trivial Projection
  - Non-planar, Mobile objects, Change appearance
- Spatial Optical See Thru Displays
  - Mirrors, Beam splitters
- Applications
  - In Art, Research and Industry