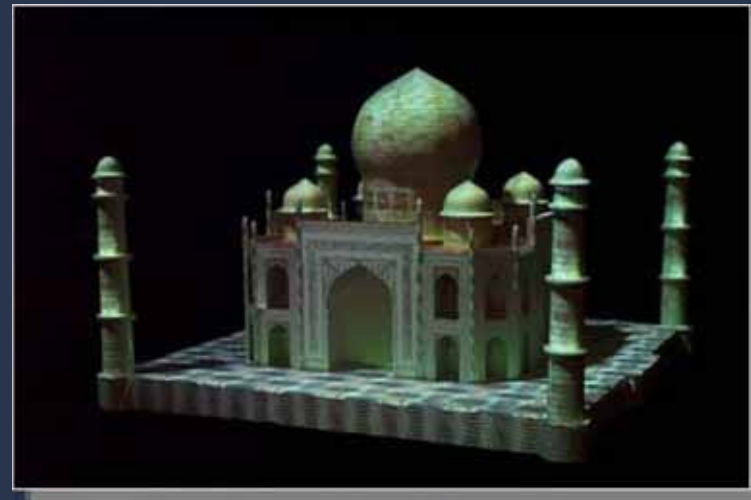
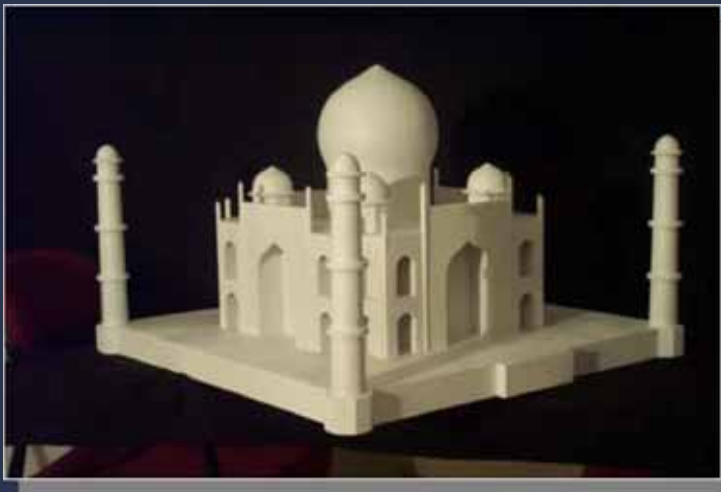


# Spatial Augmented Reality: Special Effects in the Real World



Ramesh Raskar

MIT Media Lab

Cambridge, MA

# Poor Man's Palace



# Poor Man's Palace



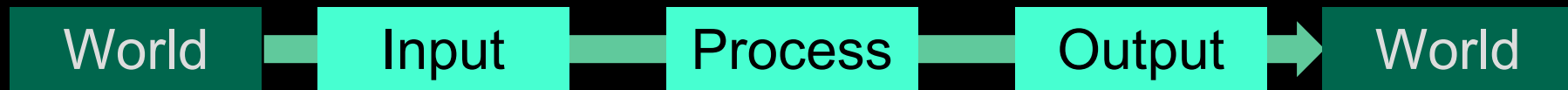
Augment the world, projectors and proxy geometry, controlling light every millimeter at every millisecond.

# Augmented Reality (AR)



Augmented Human: Beyond X-ray vision

# Augmented Reality (AR)



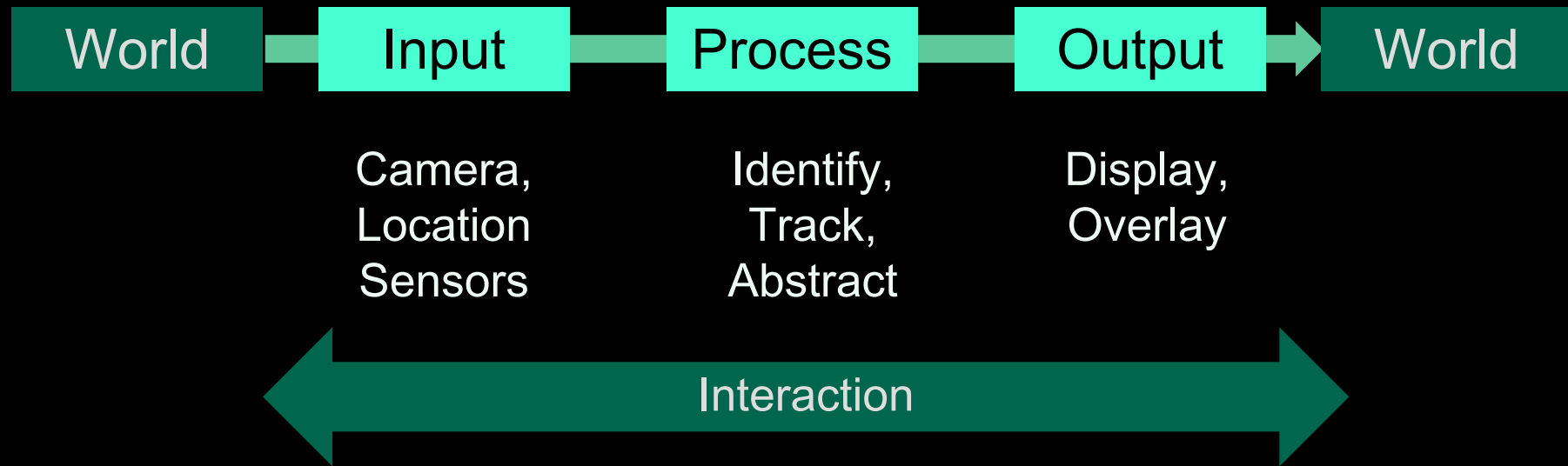
Sense beyond  
human ability

Abstract

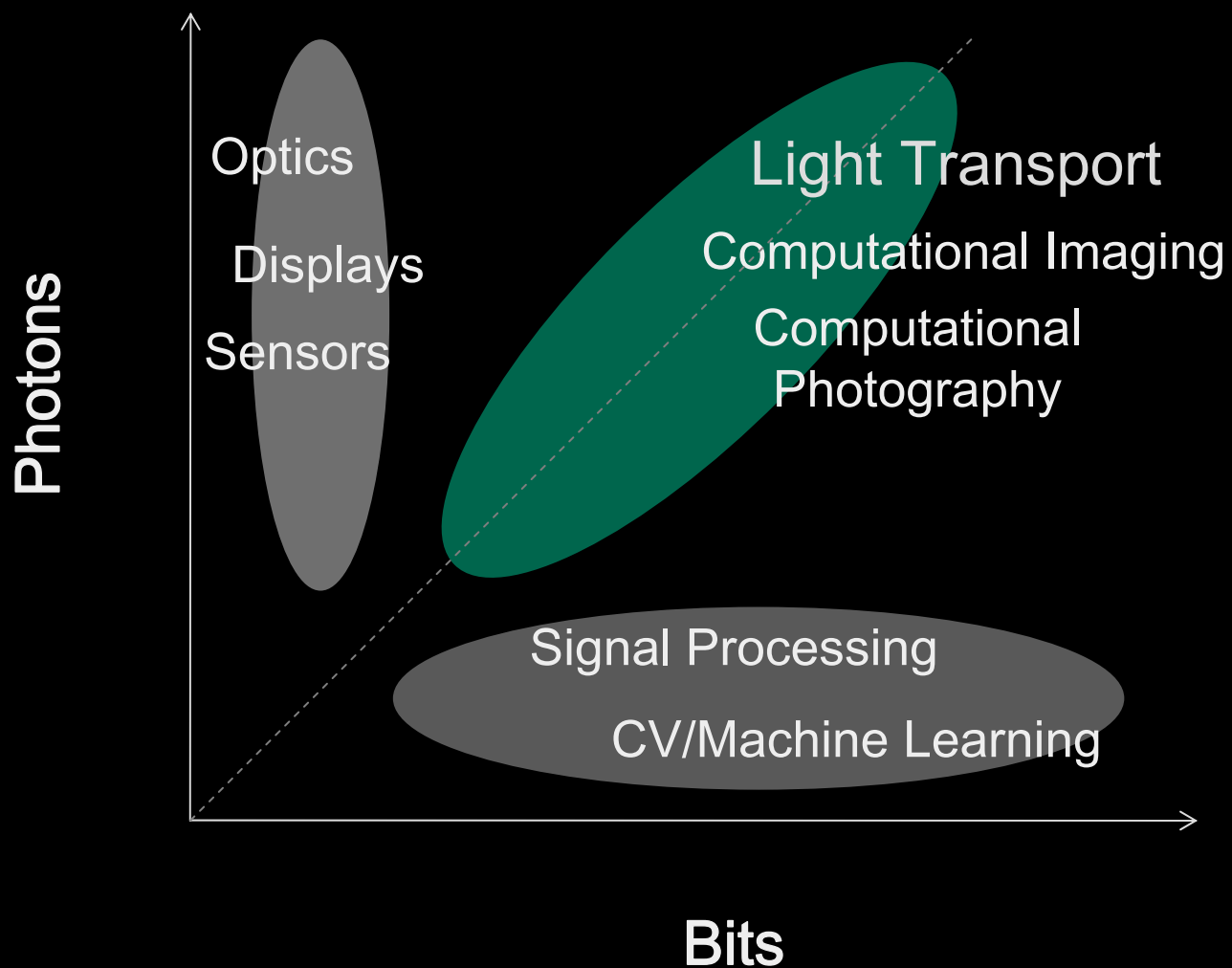
Present  
within human  
comprehensibility



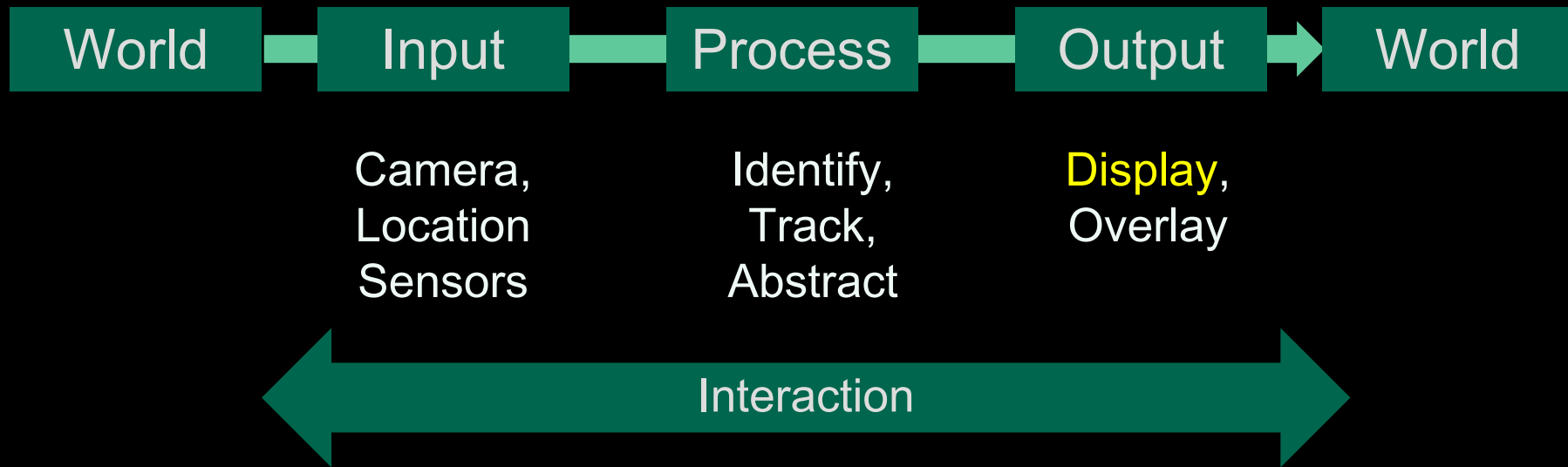
# Augmented Reality (AR)



## AR Centric View



# Augmented Reality (AR)



Cyborg, Bionic Eye, HMD

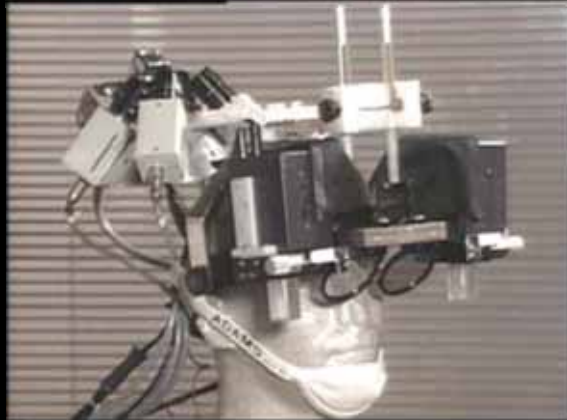


Henry Fuchs

## Camera + Viewmaster LCD Display



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



Courtesy: Azuma 1995



MicroOptical display  
Courtesy: Sam Ogden



Nomad display  
Courtesy: Microvision

# Boeing Aircraft Wiring Diagrams

# Projected Augmented Reality

© Andrei State

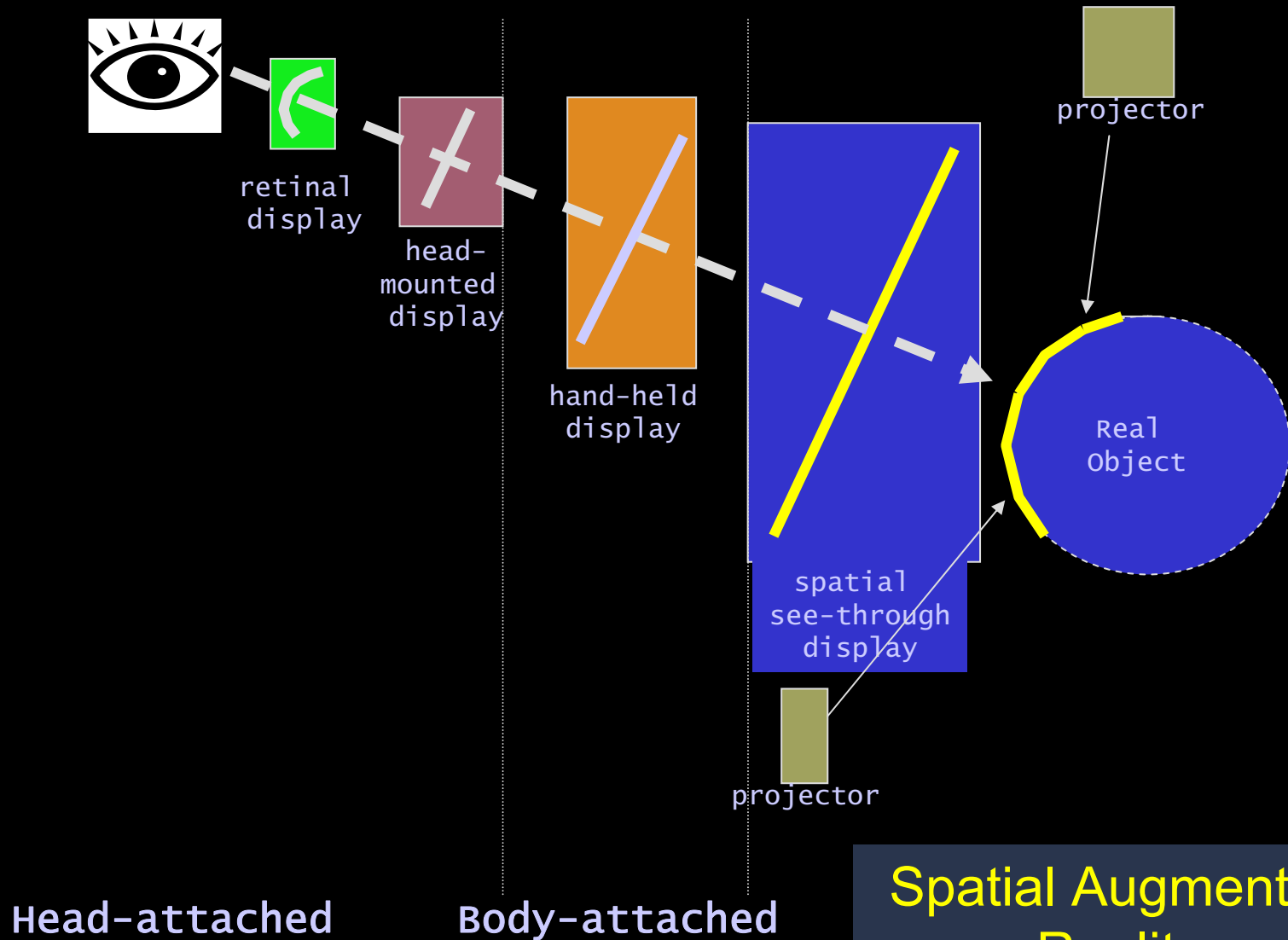


Head-mounted Display



Projectors

# Classification of AR : Image Overlay



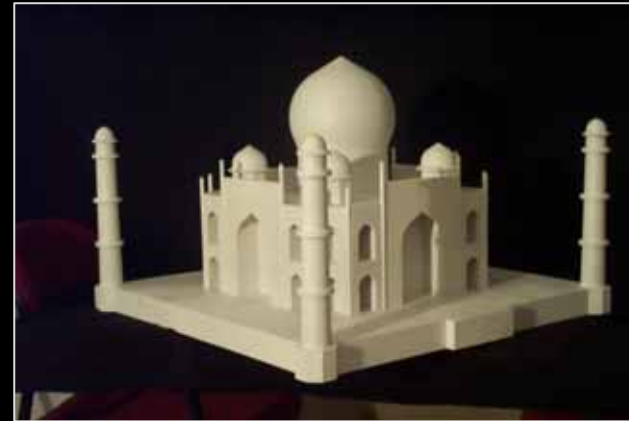
**Spatial Augmented Reality**  
1998

# ShaderLamps

Virtual Reflectance



Virtual Illumination



Virtual Motion



Interaction



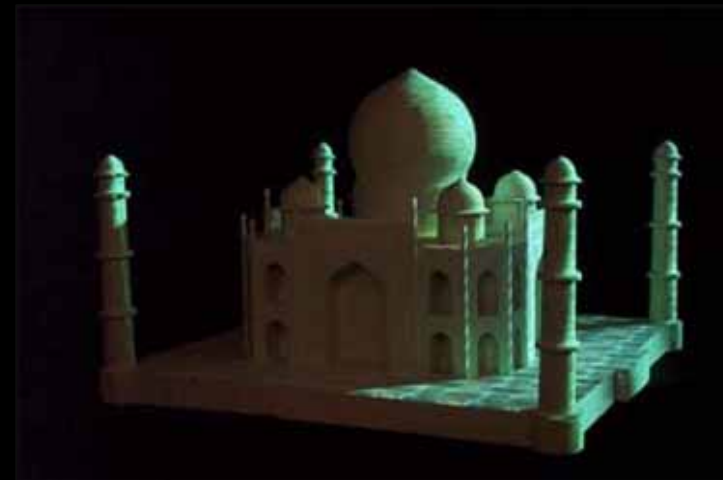
1997 - 2000

# ShaderLamps

Virtual Reflectance



Virtual Illumination



Virtual Motion



Interaction



1997 - 2000

# VienViewer (Luminetx)

Near-IR camera locates subcutaneous veins and project their location onto the surface of the skin.



Coaxial IR camera  
+ Projector



# NETRA: Near Eye Tool for Refractive Assessment

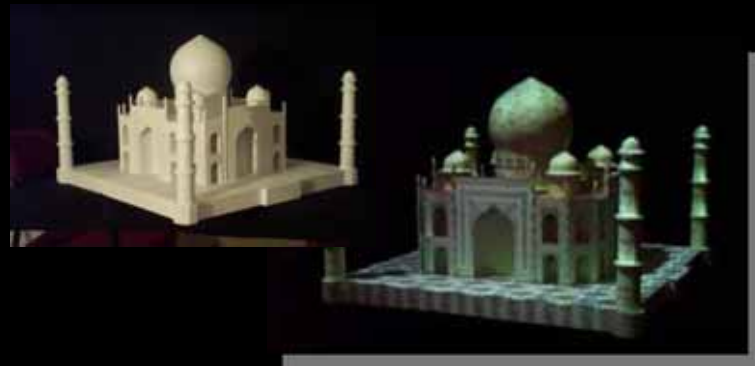
Pamplona , Mohan, Oliveira, Raskar, Siggraph 2010

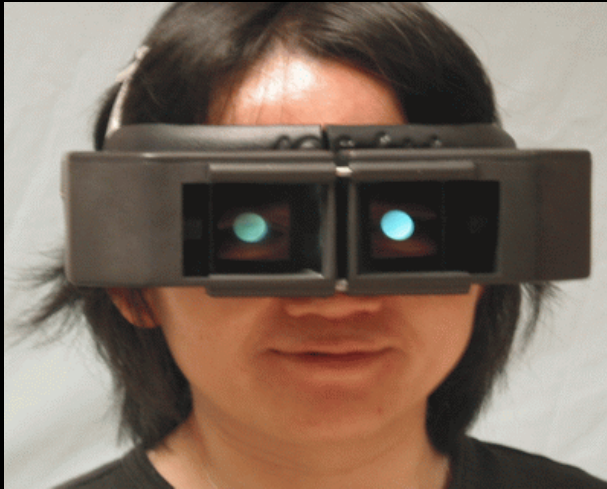


EyeNetra.com

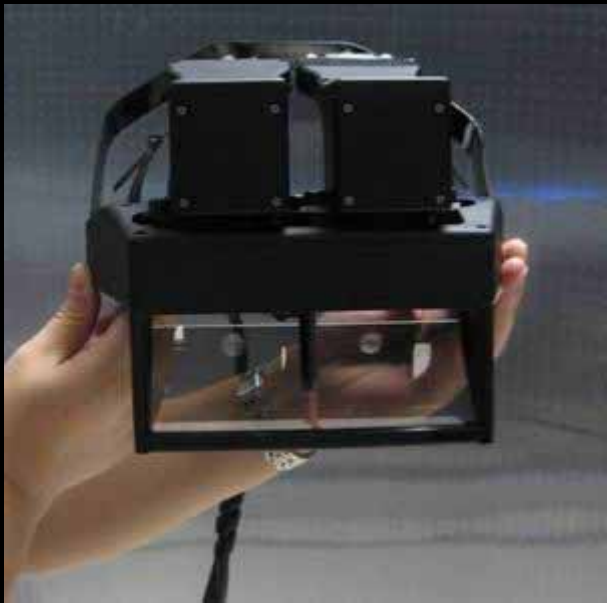
# Opportunities

- Information Annotation
  - Office, factory or assembly Training
- Entertainment
  - Animating objects, Museums, Special Effects, Laser Shows
  - Pre-viz with clay-models
- Advertising
  - Car showrooms, Furniture store
- Design and Ergonomics
  - Prototyping products, visualize material changes

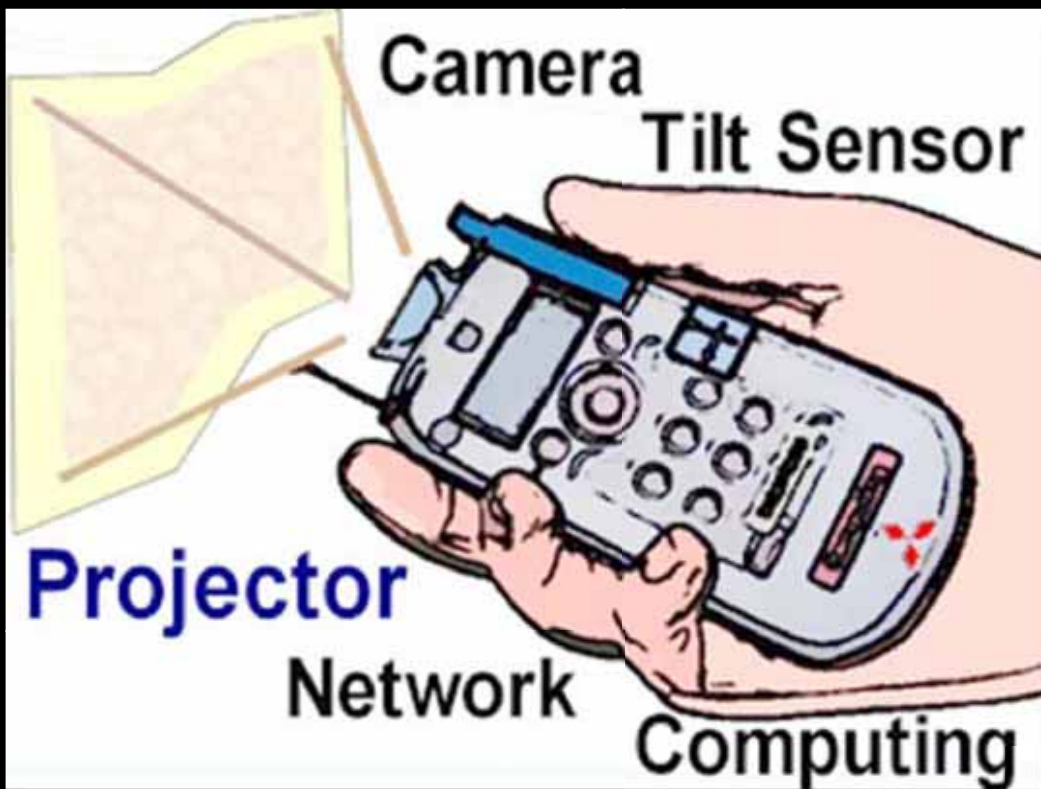




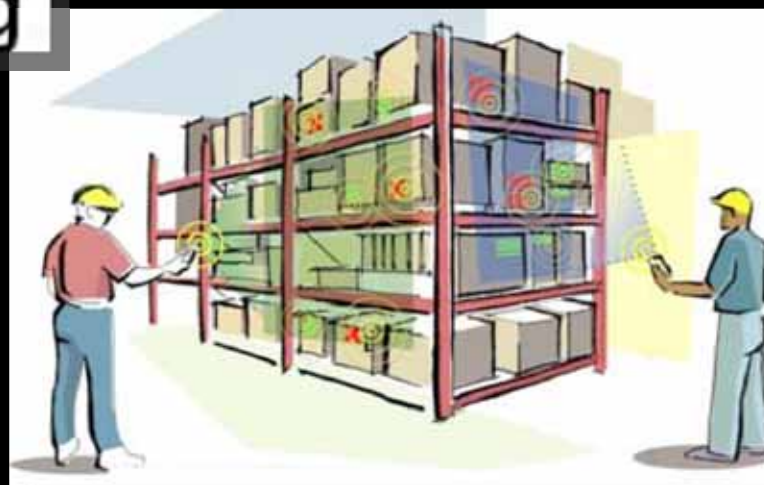
Jannick Rolland (U. Central Florida)  
Frank Biocca (Michigan St. U.)



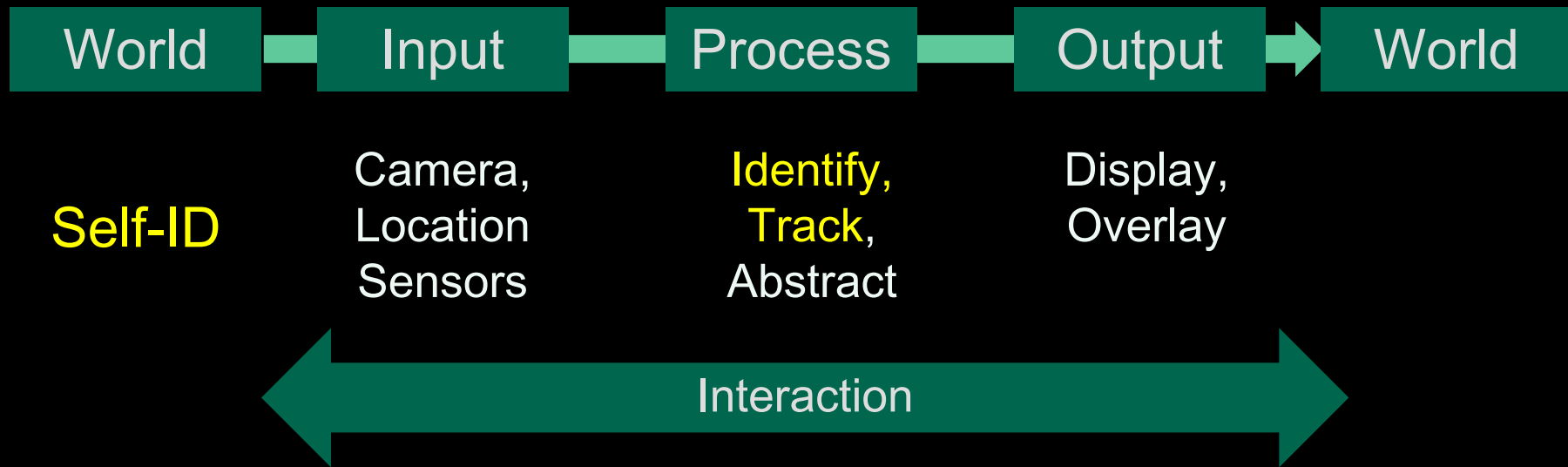
Hong Hua, U of Arizona  
Projective HMD



Intelligent Pocket Projector



# Augmented Reality (AR)

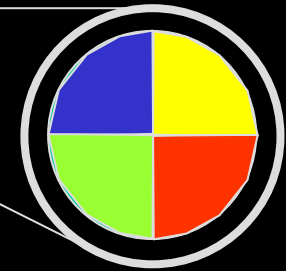
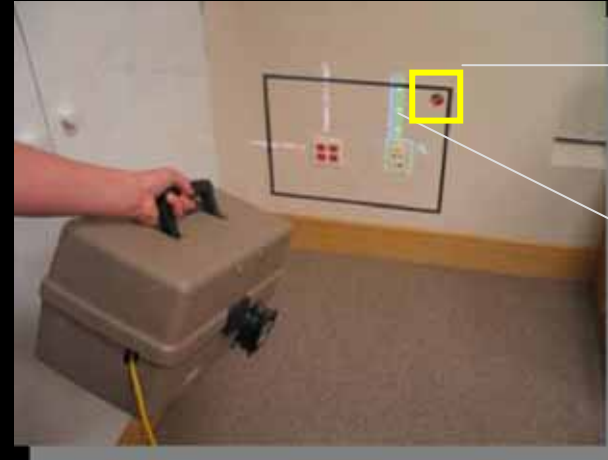


Cyborg, Bionic Eye, HMD



Henry Fuchs

# 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



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

# Self-ID via Barcodes



## ARToolKit

[Kato and Billinghurst 1999]



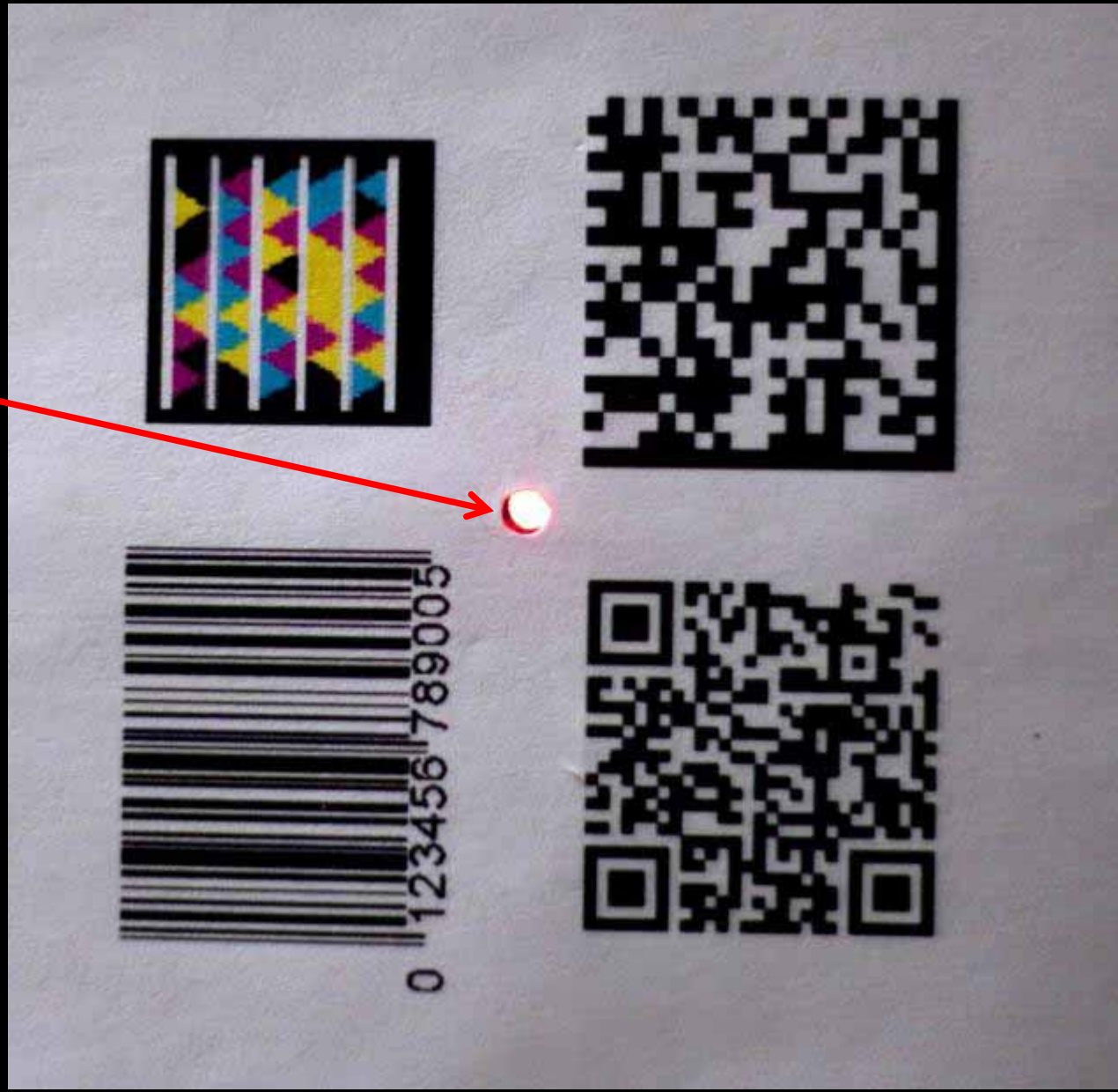
## ARtag

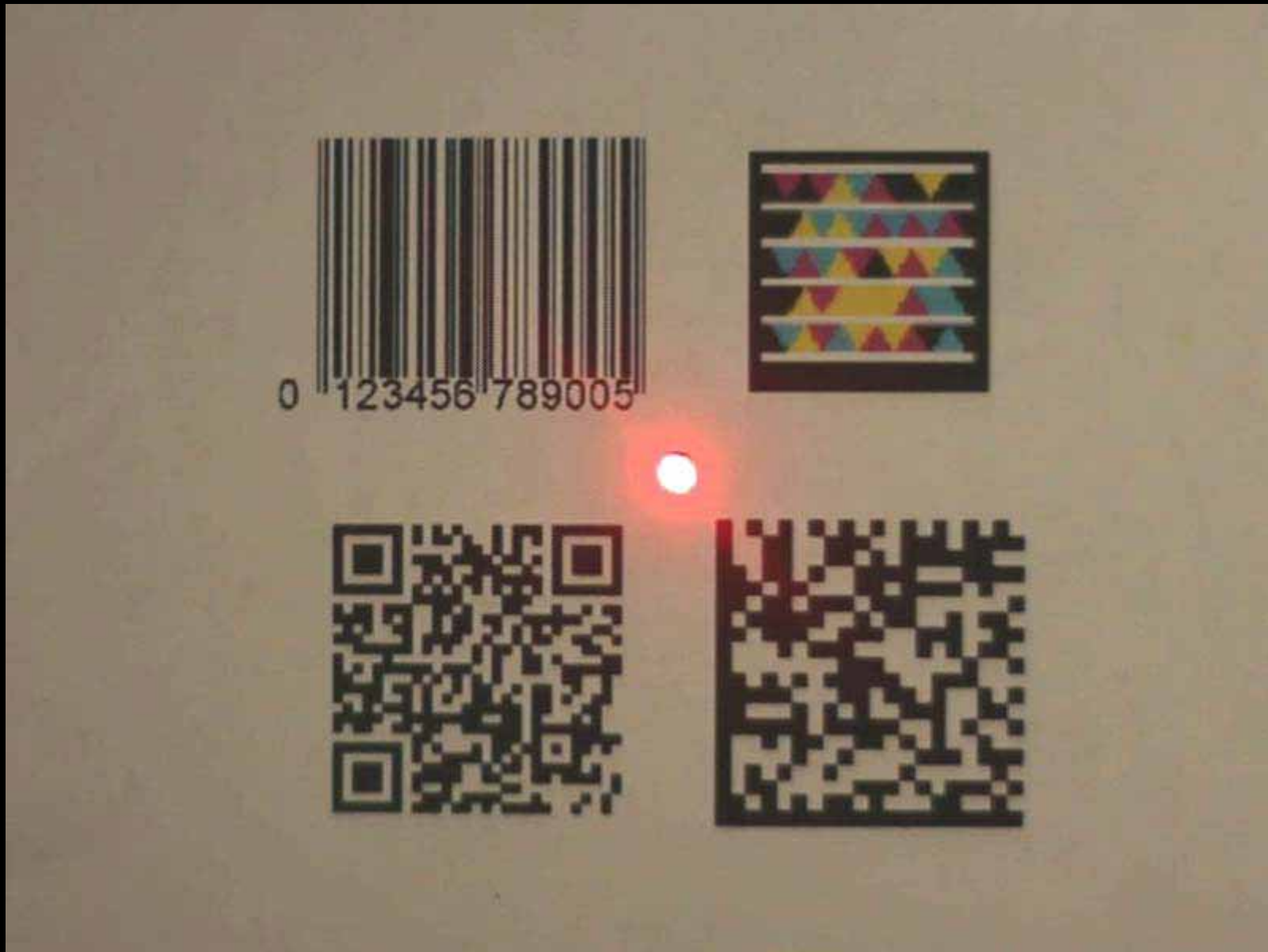
[Fiala 2005]

for  
Camera  
Phones



Bokode



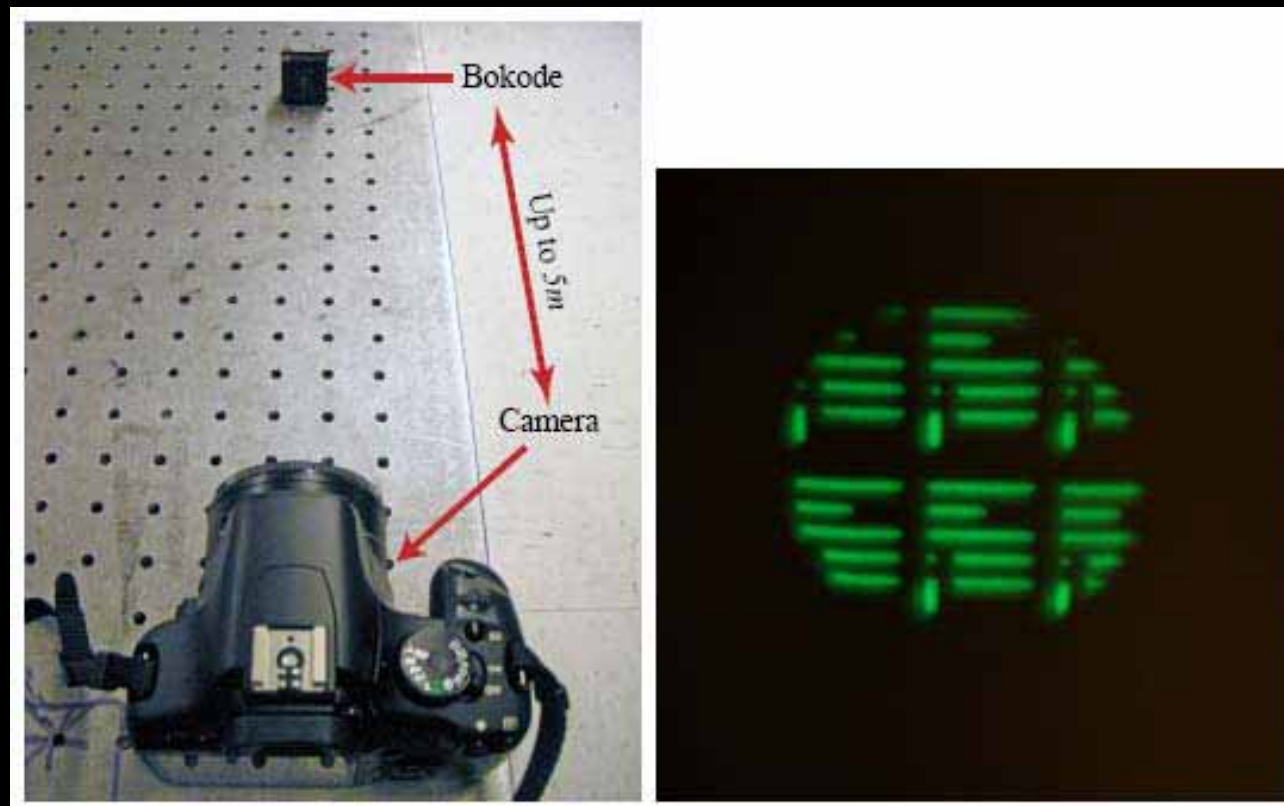


SIGGRAPH  
SIGGRAPH  
2009  
2009

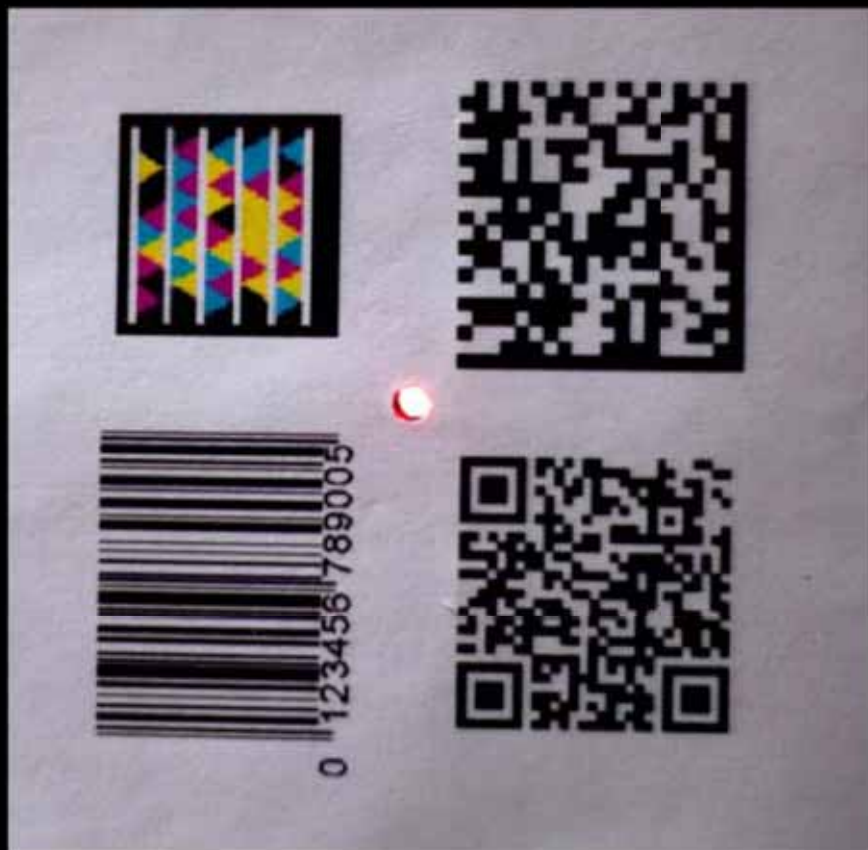


## Long Distance Bar-codes

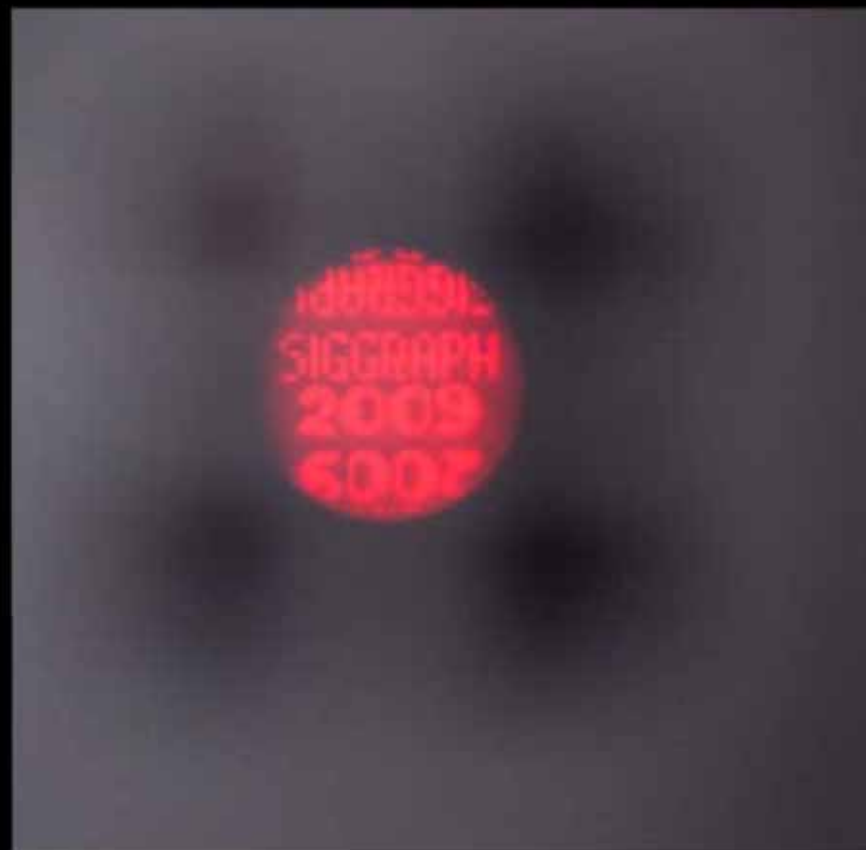
- Smart Barcode size : 3mm x 3mm
- Ordinary Camera: Distance 3 meter



# Coding in Angle: Defocus not Zoom

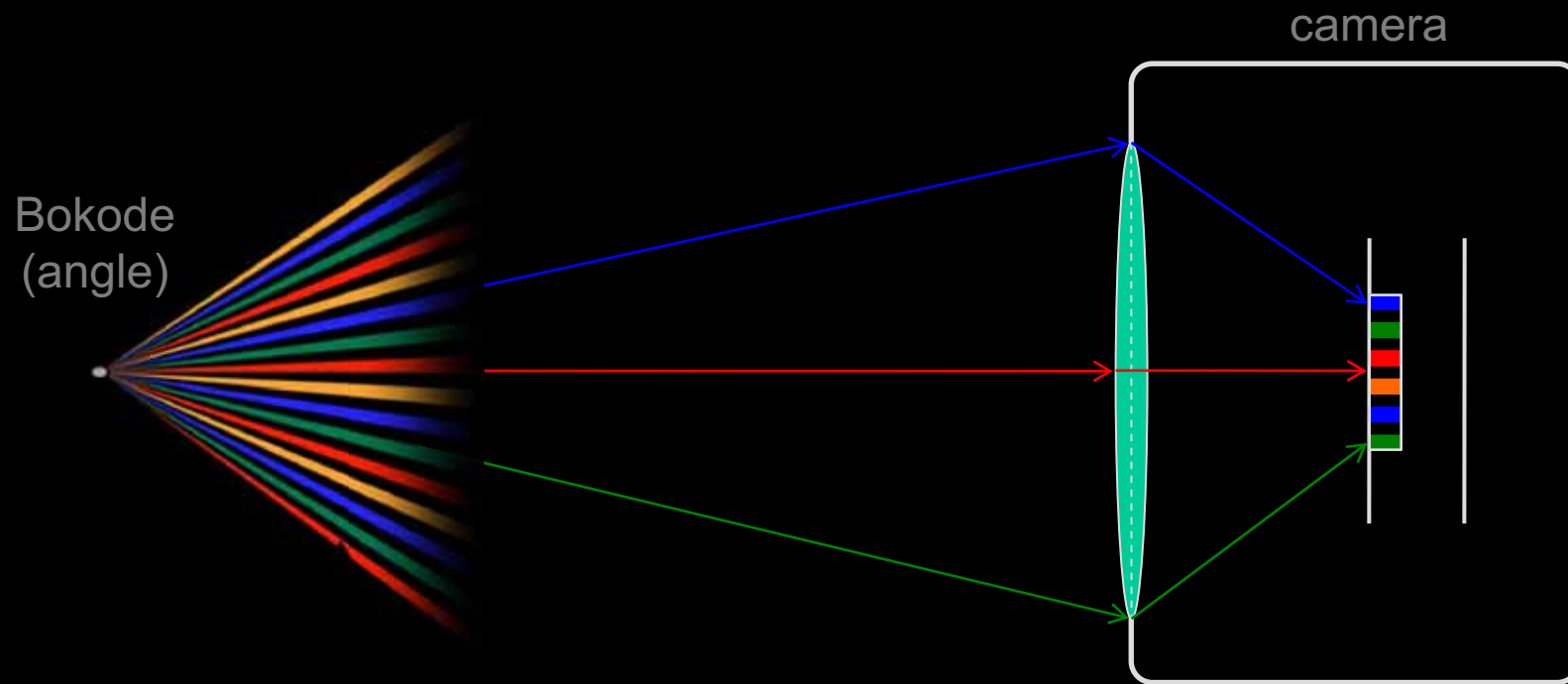


In Focus Photograph



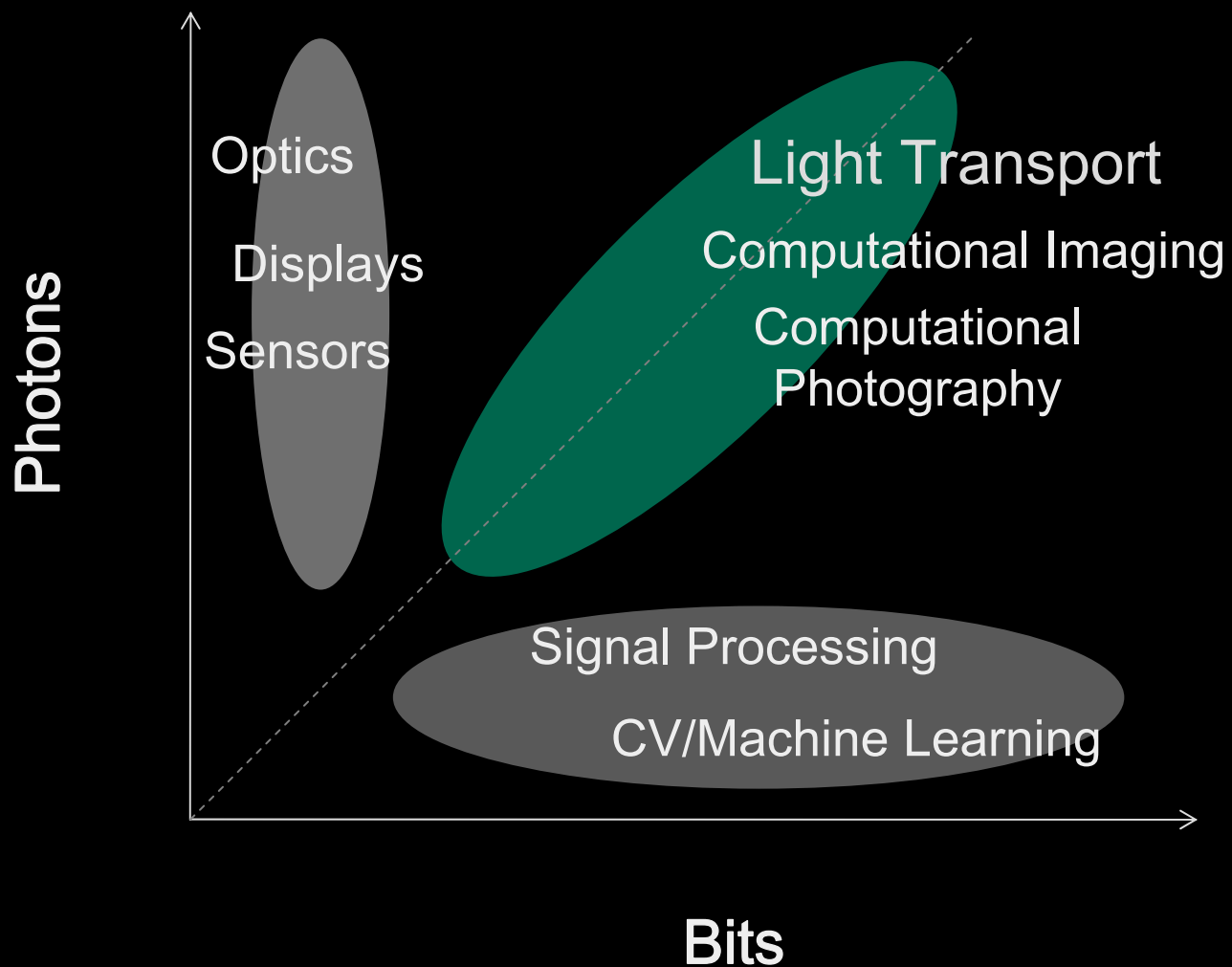
Out of Focus Photograph

# Encoding in Angle, not space, time or wavelength

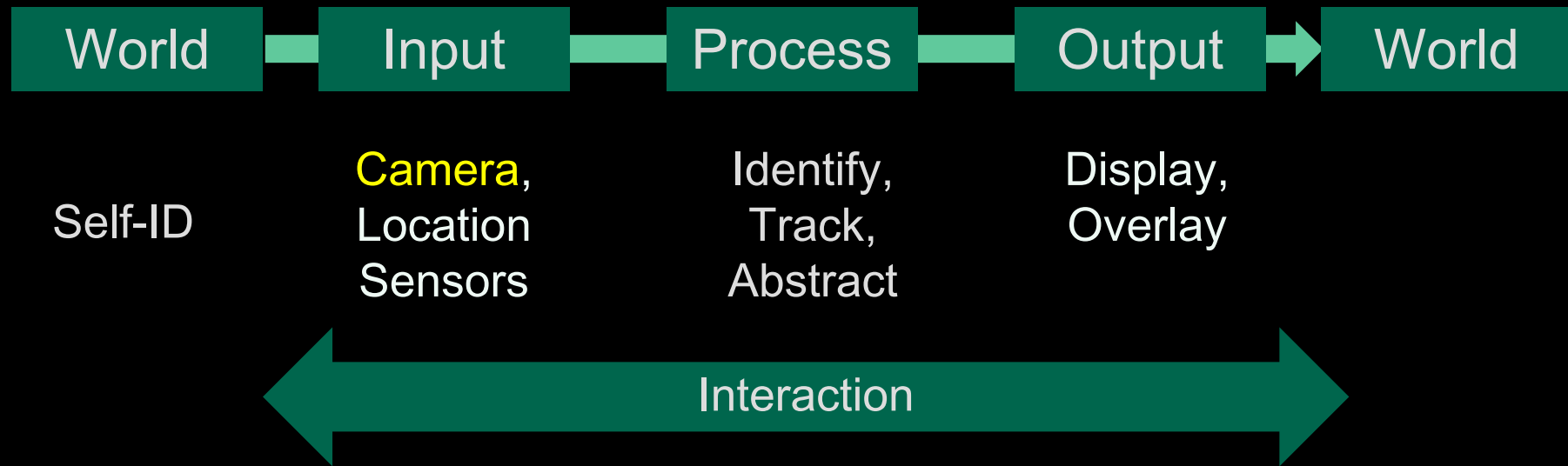


circle of confusion → circle of information

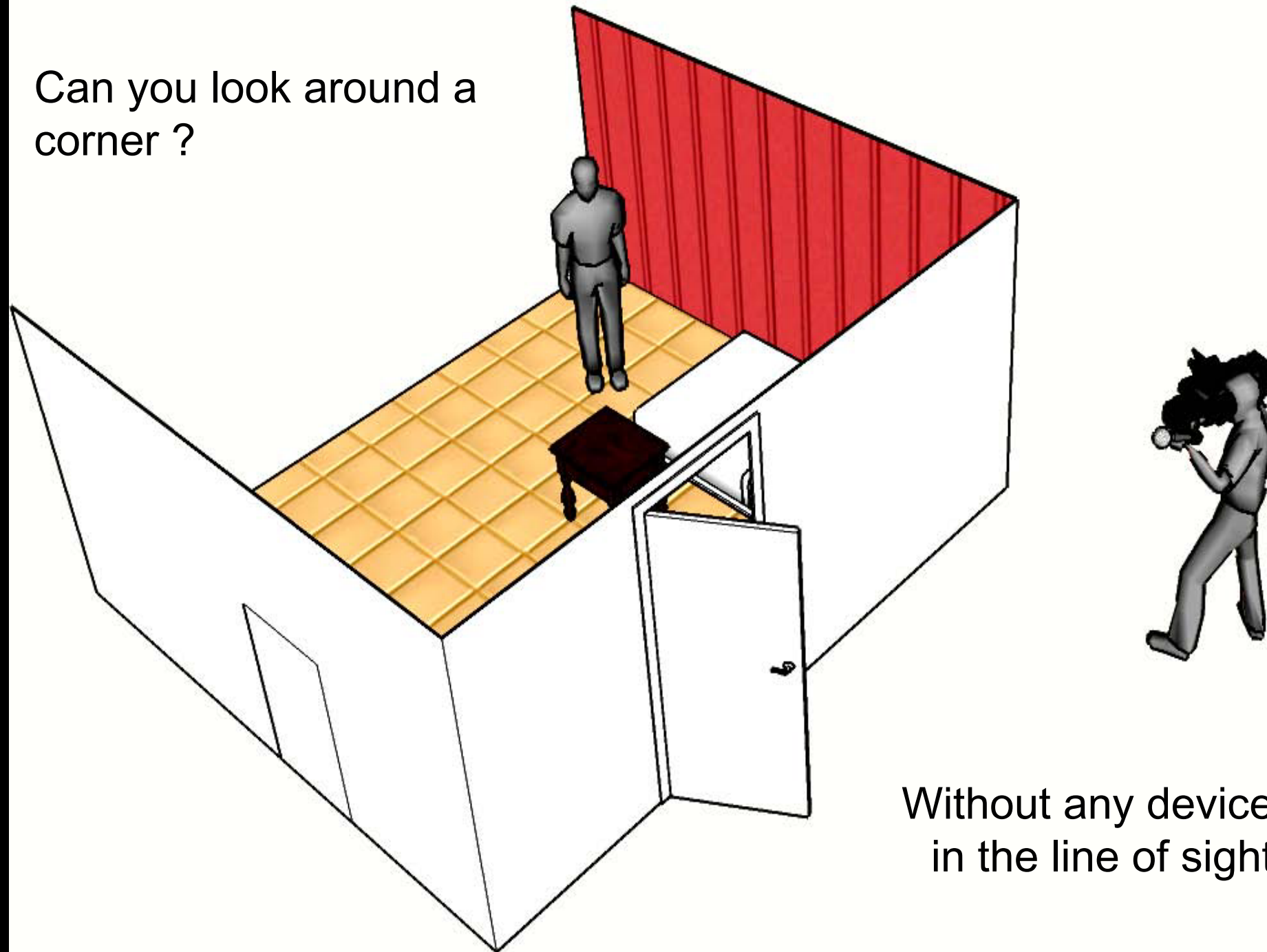
# AR Centric View



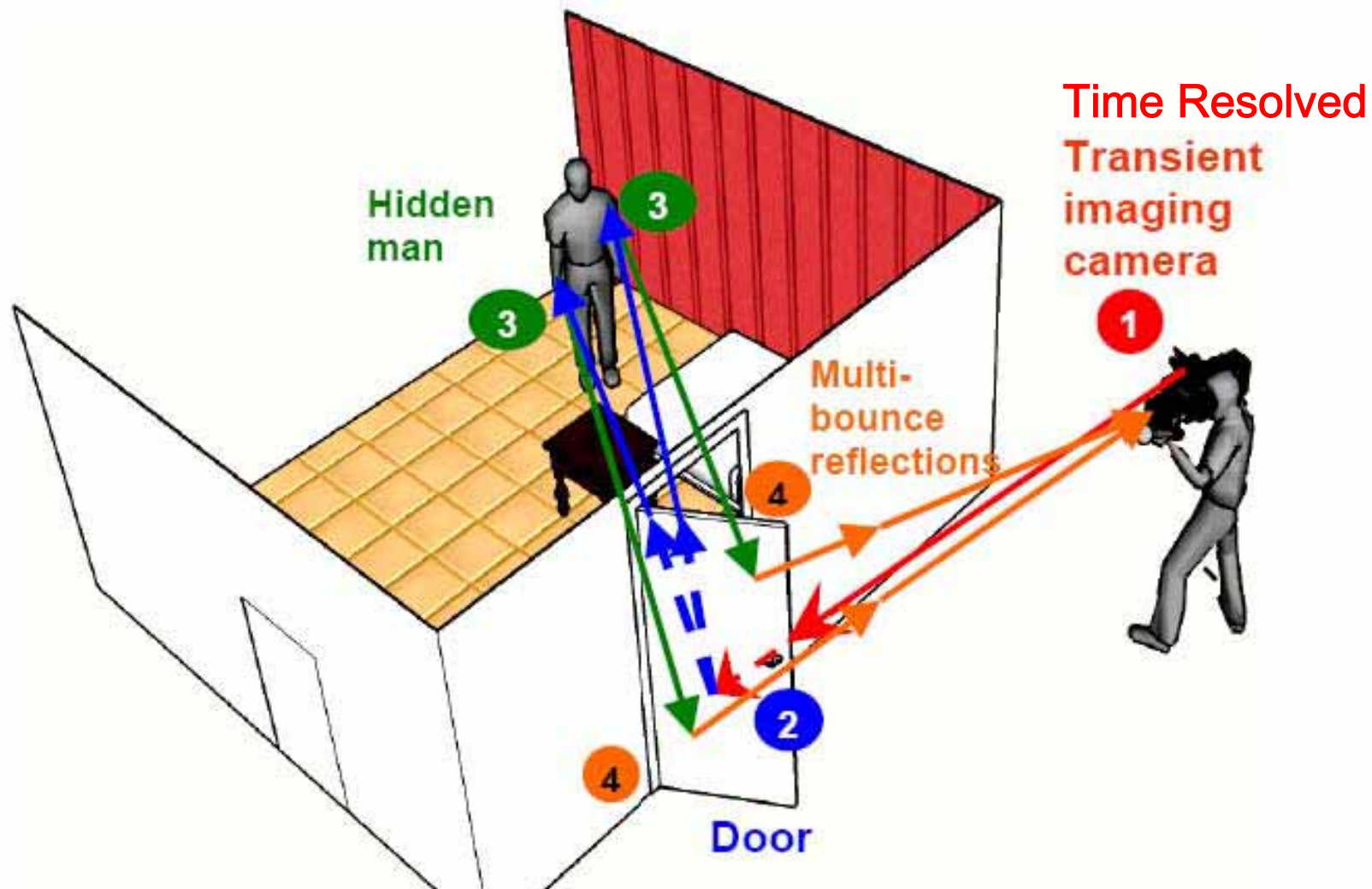
# Augmented Reality (AR)



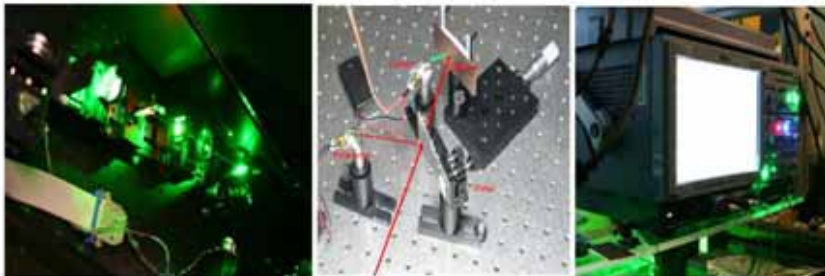
Can you look around a corner ?



Without any device  
in the line of sight



Preliminary hardware prototype of the proposed Transient imaging camera

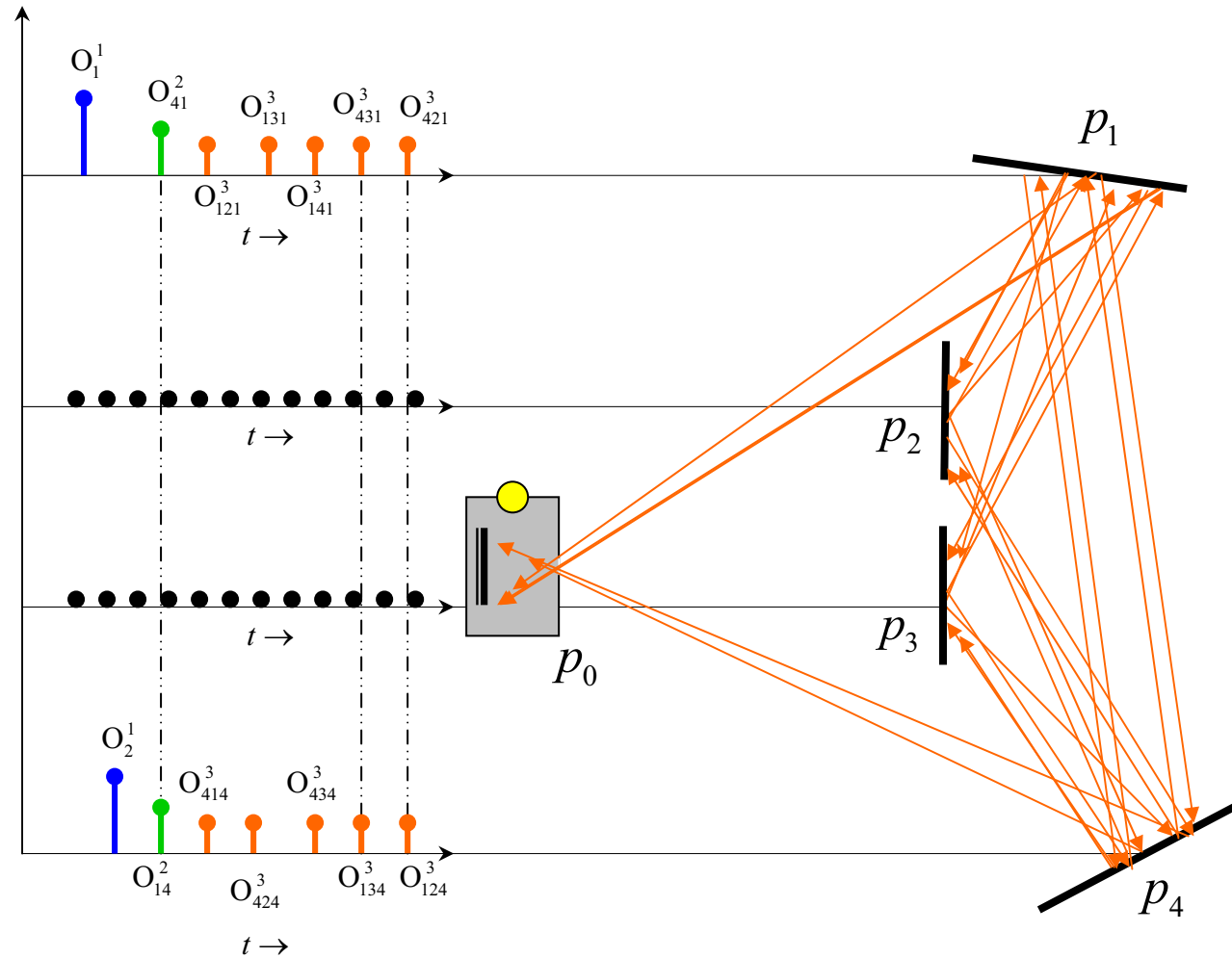


We successfully built the first hardware prototype to experimentally validate the Transient light transport theory. This is only

Marr Prize #2

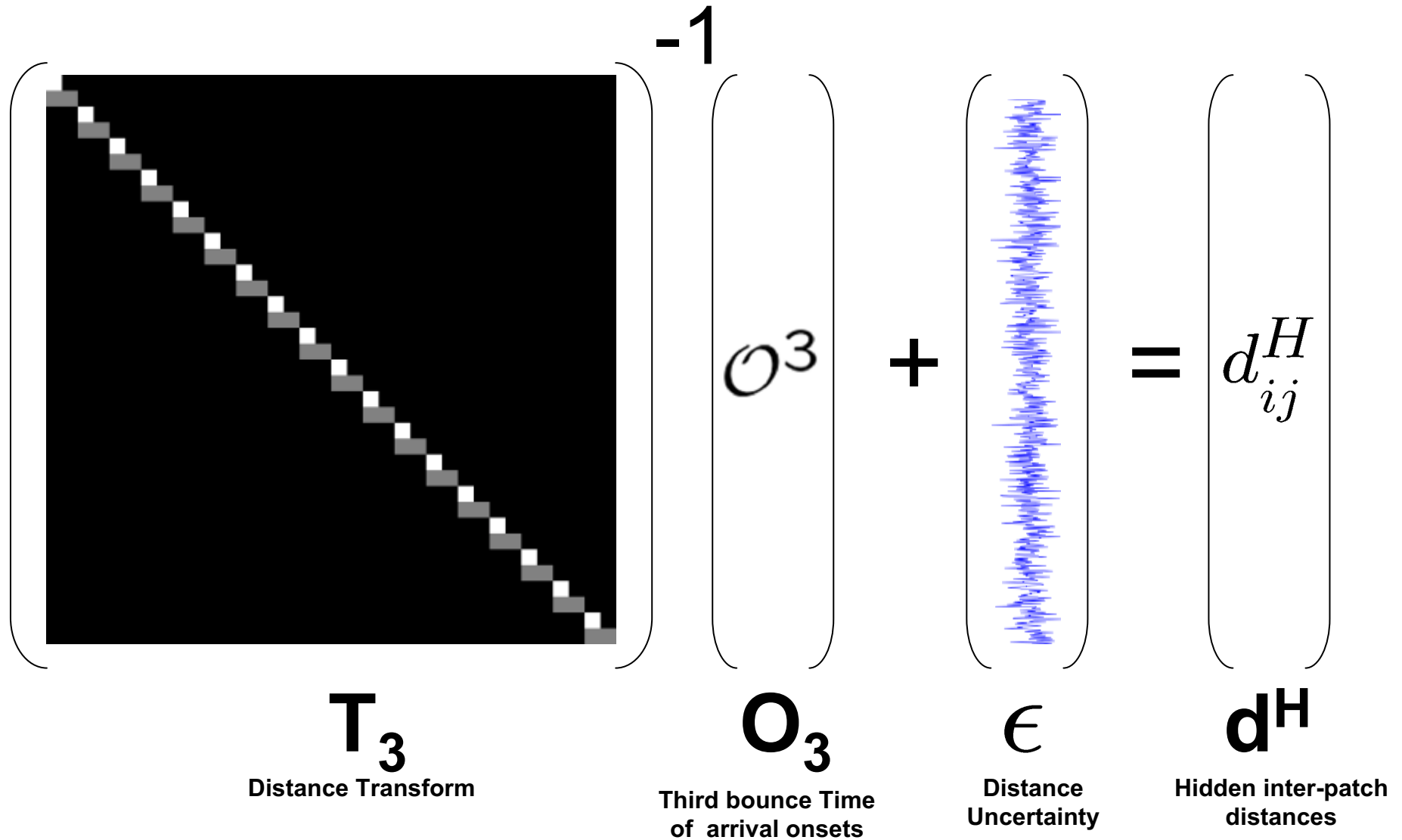
Kirmani, Hutchinson, Davis, Raskar  
ICCV'2009

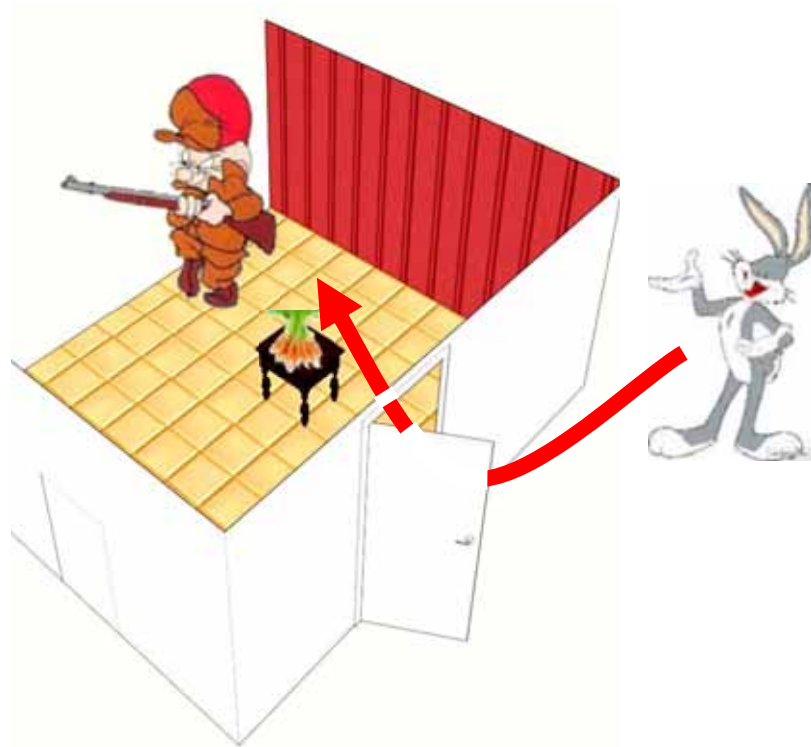
# Key Idea: Use Third and Higher bounces



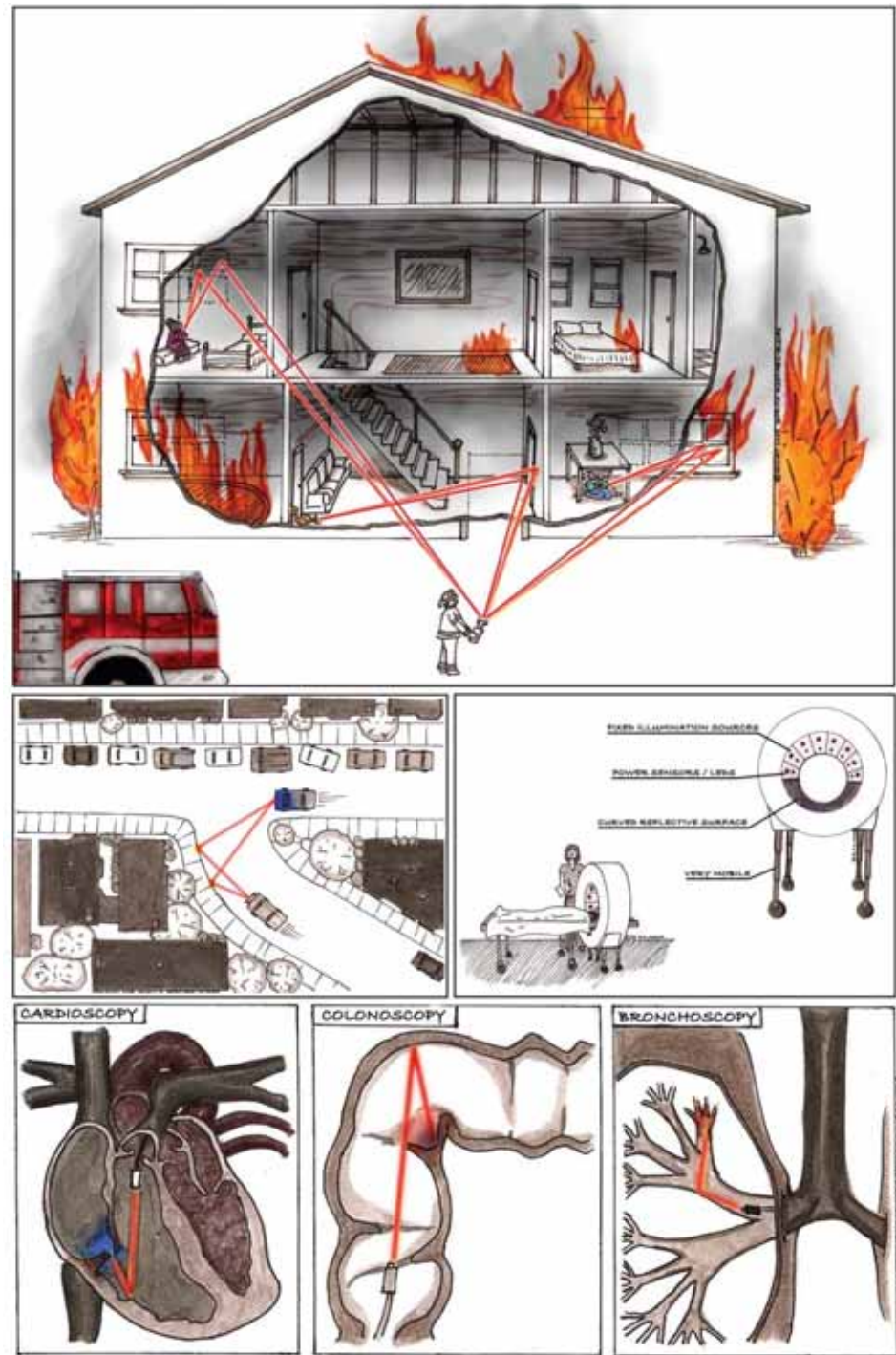
We made use of **Proximity prior**, **Euclidean distance** constraints and **Estimated visible patch distances** to label third bounces

# Key Idea: Use Third and Higher bounces





Time Resolved  
Transient Imaging



# Discussion Topics

## Signal Processing

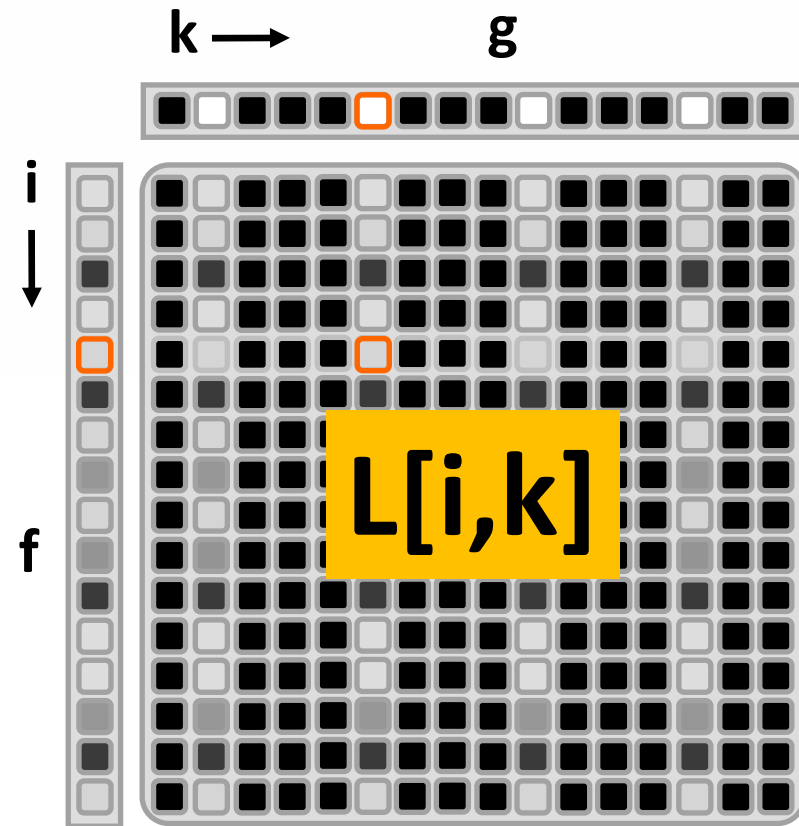
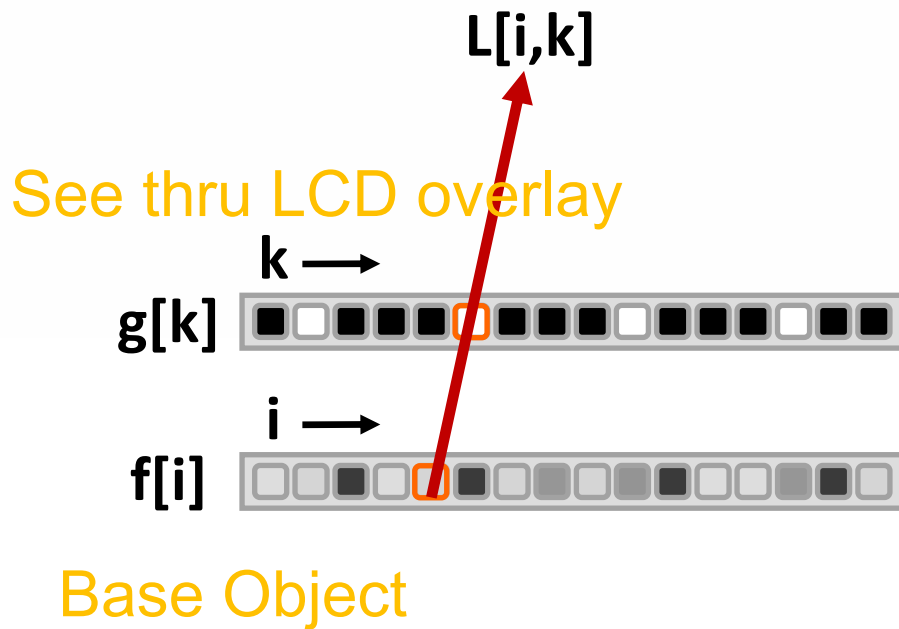
- Overlay = Rank 1 Lightfield
- See thru effect = Rays due to 'Outer Product' of 2 Images
- How to exploit sparsity to compute the overlaid image?

## Materials

- Sensing, Adaptive, Reactive and Morphing
- Slow Display with Sticky Pixels

# Light Field Analysis of Overlays

Visible Lightfield



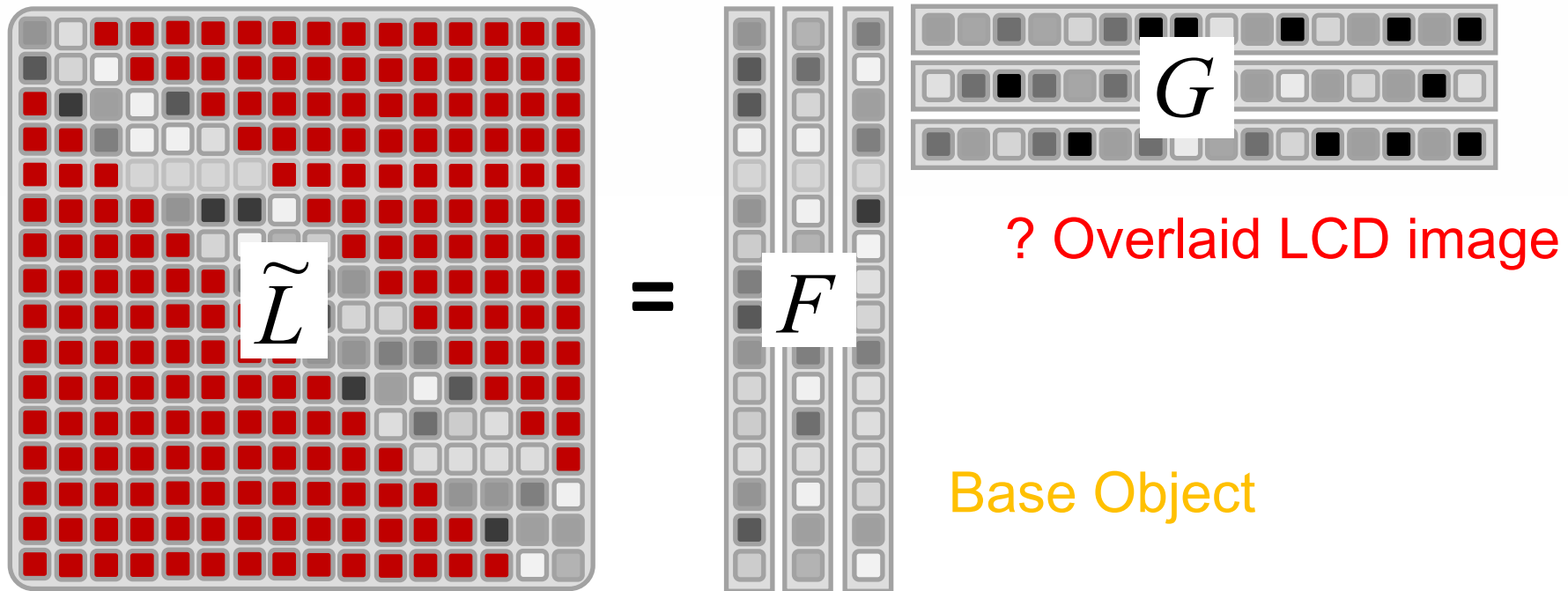
$$L[i,k] = f[i] \cdot g[k]$$

$$L = f \otimes g$$

Outer Product

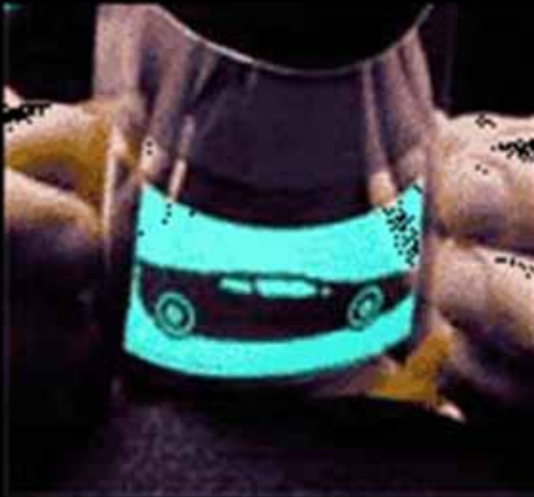
# How to exploit sparsity to compute overlay?

Sparse Lightfield



$$\arg \min_{F, G} \frac{1}{2} \|L - FG\|_W^2, \text{ for } F, G \geq 0$$

# Materials: Displays Contenders



Organic  
LED



Light  
Emitting  
Polymers



E-Ink

# Dream Material: Sticky Pixels

Project Once, pixels persist, day/night

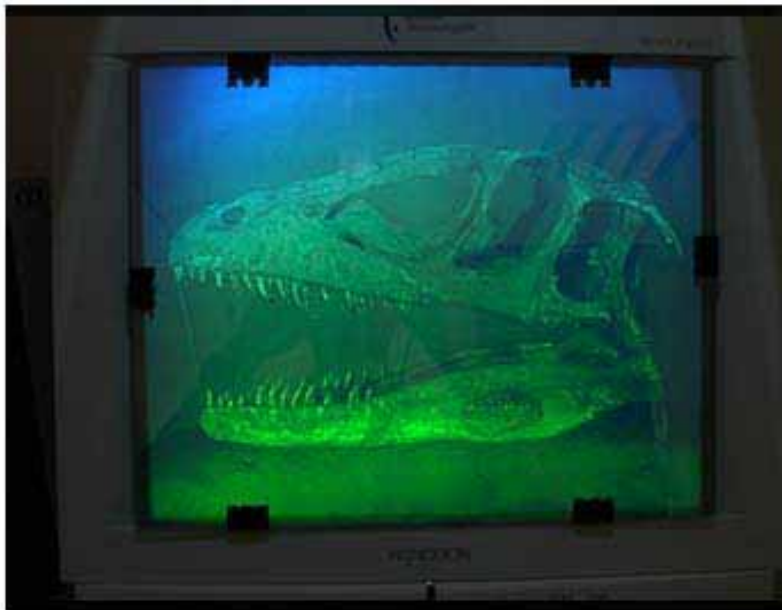


# Beyond Simple Shading of White Objects

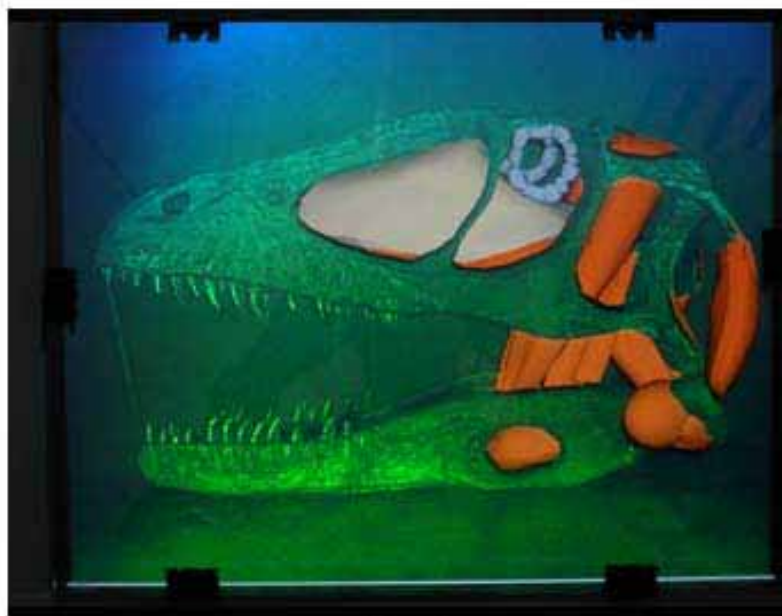
- Complex Reflectance
  - Specular or arbitrary BRDF surfaces
  - View-dependent appearance
- Participating Media
  - Simulating or in presence of smoke, fog
- Complex Geometry
  - Spaghetti
- Motion
  - Animation of real surfaces
- NPR, Distortions, Perceptual factors
  - Great future areas ..

# Projecting on Holograms

Oliver Bimber



Hologram



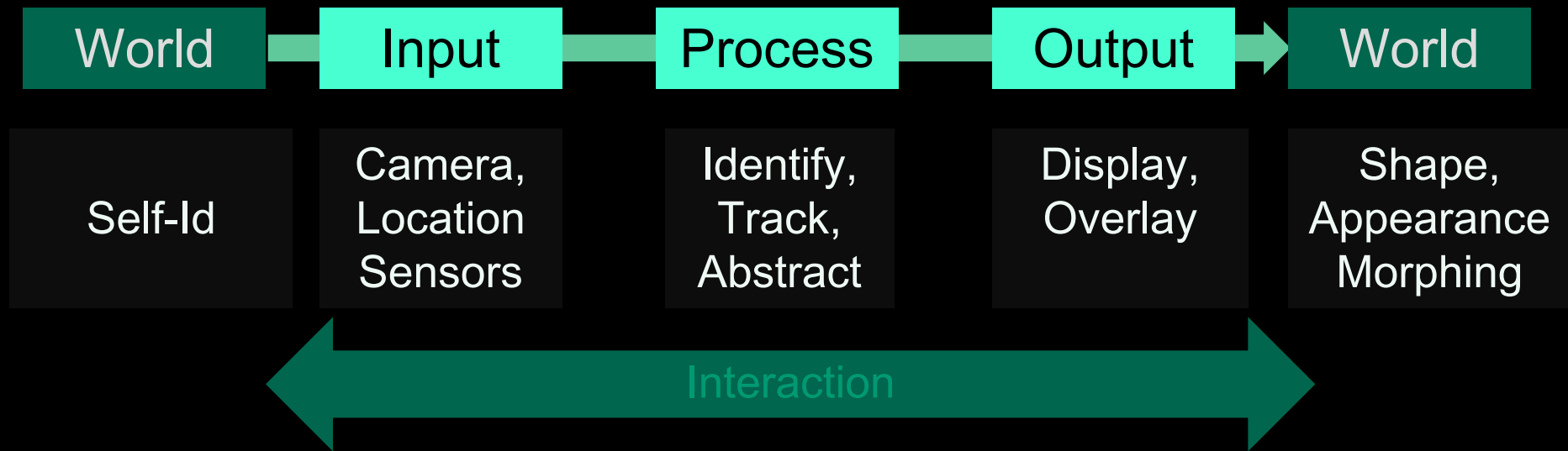
Projected + Hologram

# Acknowledgements

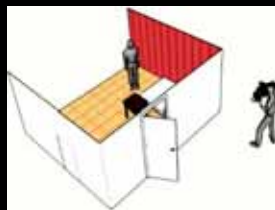
- Camera Culture Group, MIT Media Lab
- MERL
  - Jeroen van Baar, Paul Beardsley, Remo Ziegler, Thomas Willwacher, Srinivas Rao, Cliff Forlines, Paul Dietz, Joe Marks, Darren Leigh
- Office of the Future group at UNC Chapel Hill
  - Greg Welch, Kok-lim Low, Deepak B'padhyay, Aditi Majumder, Michael Brown, Ruigang Yang
  - Henry Fuchs, Herman Towles
  - Wei-chao Chen
- FOE Organizers
  - + Ron Azuma

# Fake World

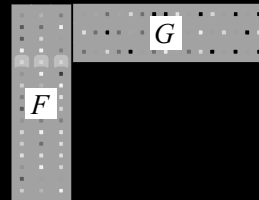
# Spatial Augmented Reality



Bokode



Transient Imaging



Rank Constraints



Pocket Proj



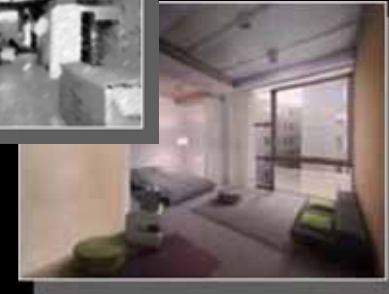
RFIG



NETRA

# Spatial Augmented Reality

- Special Effects in Real World
  - Poor Man's Palace
  - Beyond Flat Displays
  - Upgrade the world
- Tools
  - Untethered solution for fusion
  - Geometry, Photometry, Id
  - Sense, Control, Compensate
  - Projectors, RFID, Sensors
- Open Problems
  - All senses: haptic, olfactory, proprioception
  - Natural phenomenon, complex BRDF, other displays
  - Signal Processing: Efficient overlays exploiting rank
  - Materials: display, sticky pixels
- Next Challenge: Photorealistic AR around us



**END**

# Extra Slides

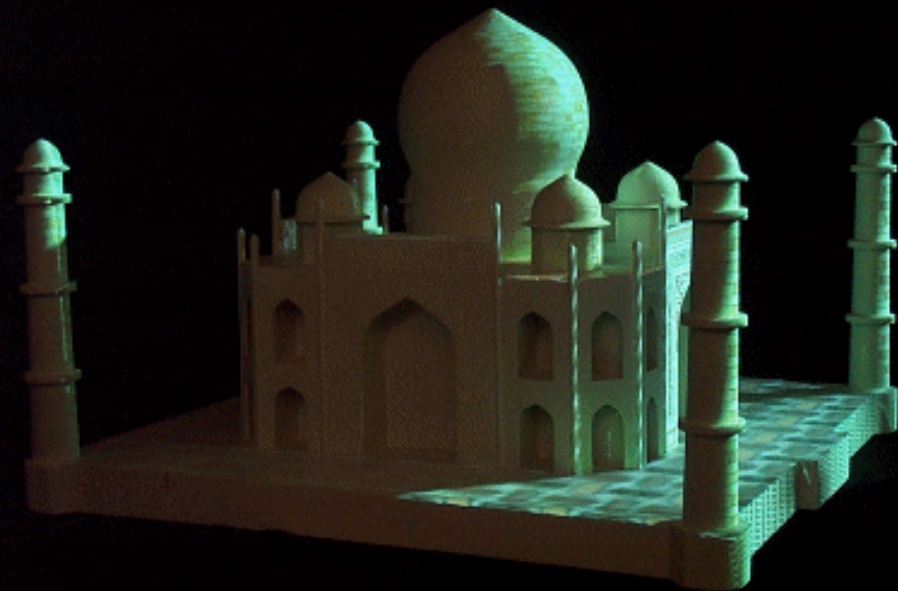
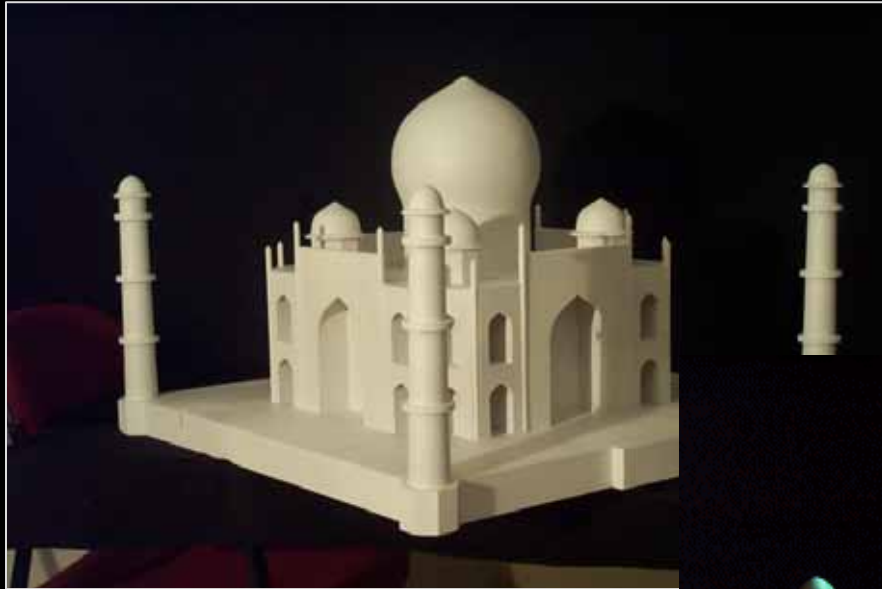
# Spatial Augmented Reality

- Why
  - Special Effects in the Real World
  - Display beyond a flat screen
  - Upgrade our surroundings (tagging)
- Tools for Augmentation
  - Projectors, Sensors, Barcodes, RFID
- Illusion
  - Beyond Visual Senses
  - Signal Processing
  - Materials

# Changing Appearance

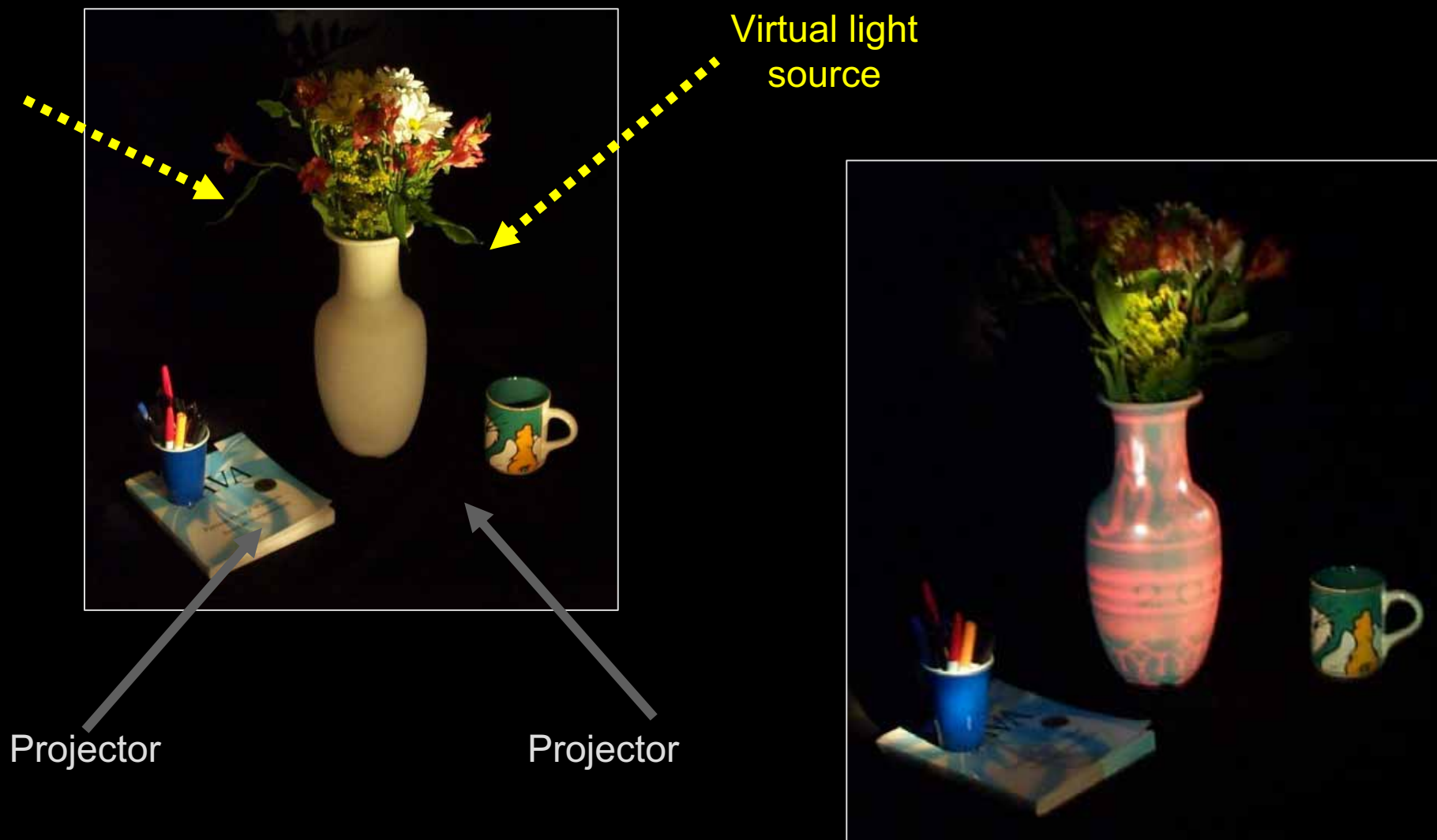


# Changing Virtual Illumination

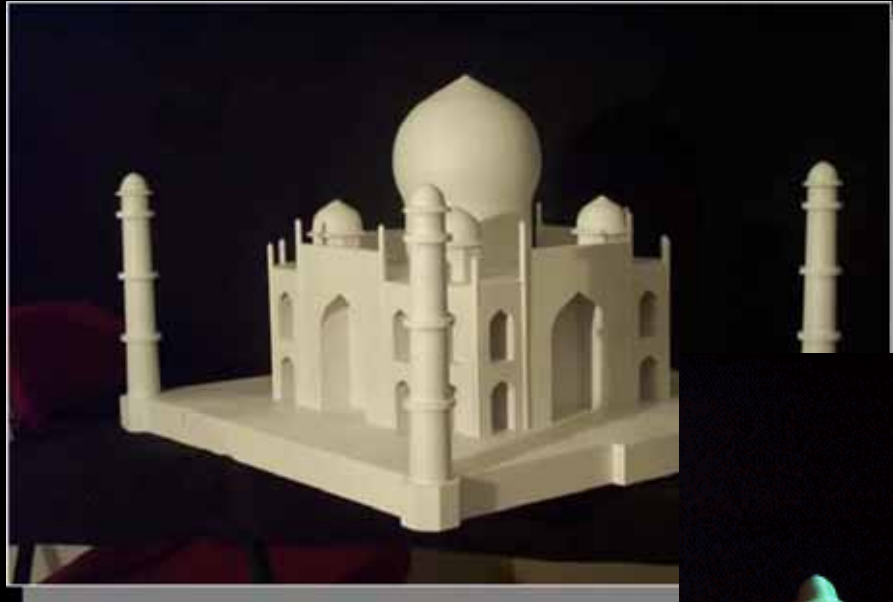




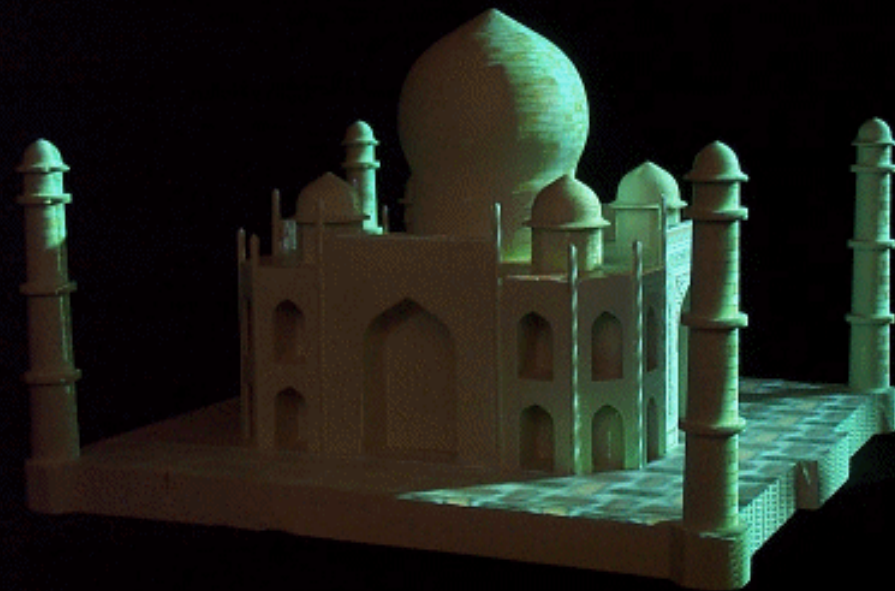
# Changing Appearance



# Changing Virtual Illumination



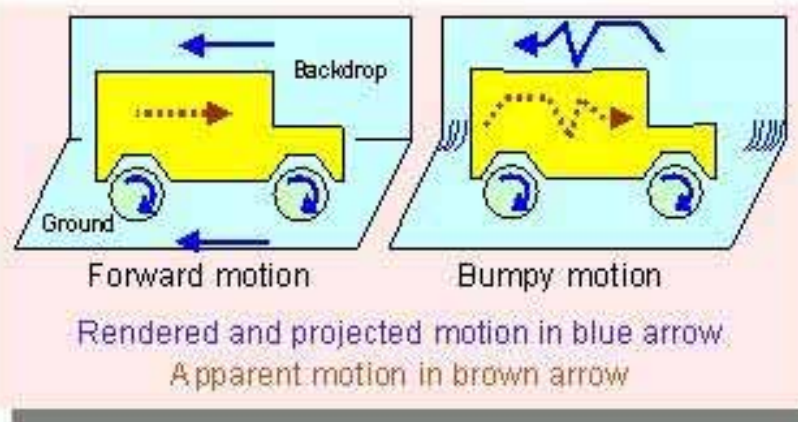
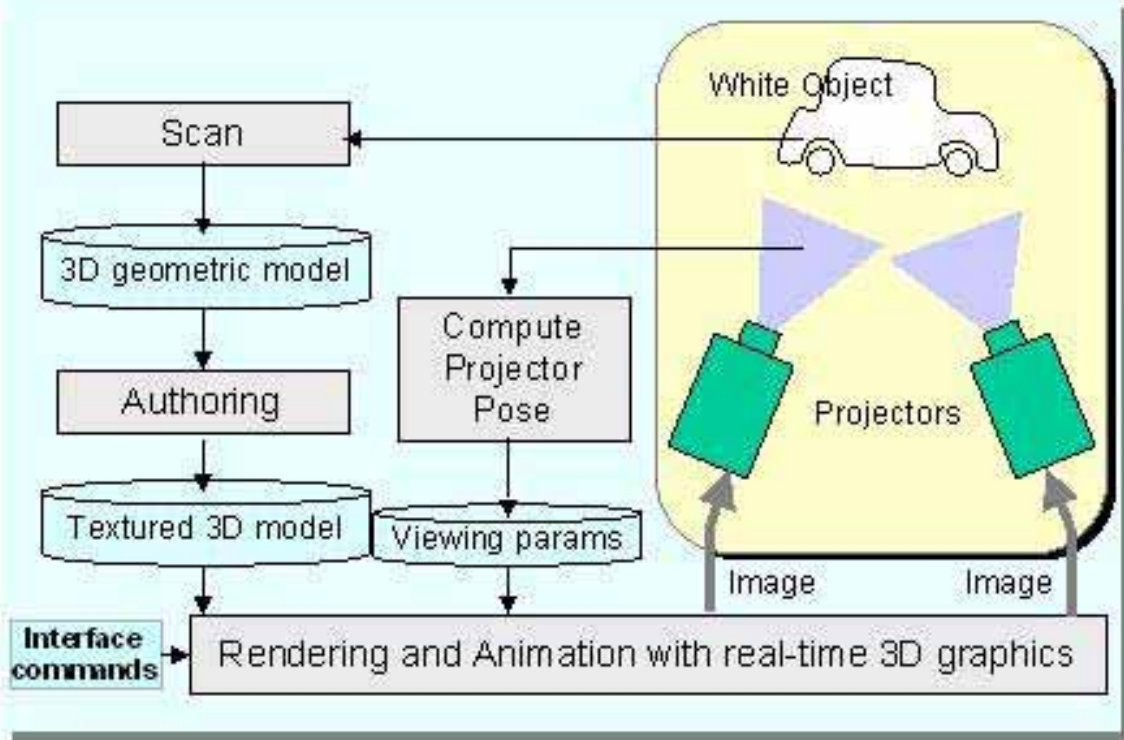
Raskar, Welch, Low, Bandyopadhyay,  
“**Shader Lamps**” (2000)



# Virtual Motion



# Virtual Motion



Raskar, Ziegler, Willwacher, "Cartoon Dioramas in Motion," (NPAR 2002)

# Dynamic Augmentation



Projecting on Tracked Objects

# Augmentation of "five senses"

- Visual Displays
- Auditory Displays
- Haptic Displays
- Olfactory Displays
- Taste Displays ?
- Sixth Sense ..



Extending  
sensory  
modalities

# Augmentation of “five senses”

- Visual Displays
- Auditory Displays
- Haptic Displays
- Olfactory Displays
- Taste Displays ?

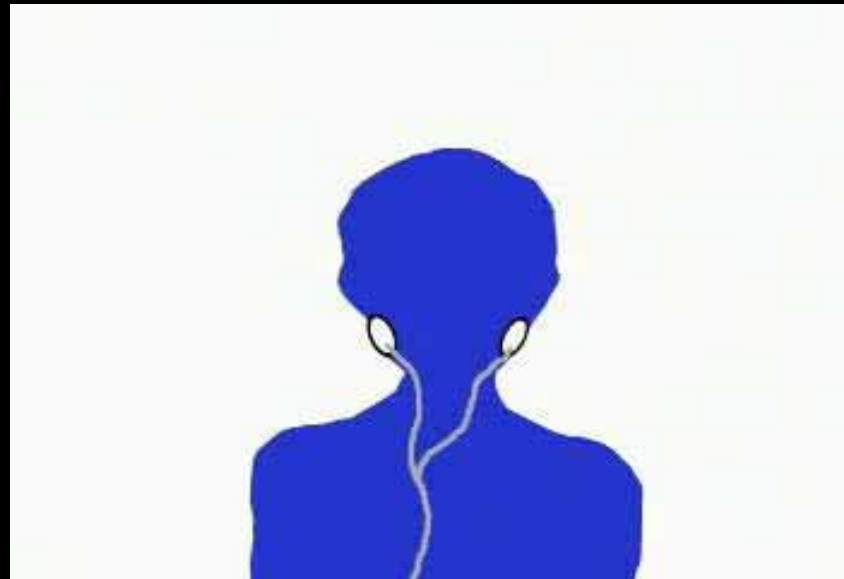


Extending  
sensory  
modalities

- Vestibular, Proprioception ..

# Sense of Balance

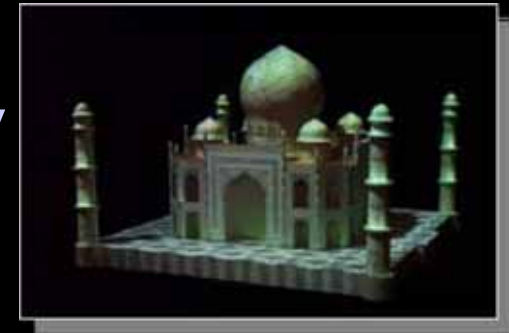
## Galvanic Vestibular Stimulation



Masahiko Inami (UEC)

# Spatial Augmented Reality

- Why
  - Special Effects in the Real World
- Tools for Augmentation
  - Projectors, Sensors, RFID
- Illusion
  - Beyond Visual Senses



# Spatial Augmented Reality

- Why
  - Special Effects in the Real World
- Tools for Augmentation
  - Projectors, Sensors, RFID
- Illusion
  - Beyond Visual Senses
  - Signal Processing
  - Materials

# 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

# Authoring Taj Mahal

- Preprocessing
  - Scan 3D object
  - Roughly align projectors
  - Compute correction
- Run time
  - Render images of 3D model
  - Correct

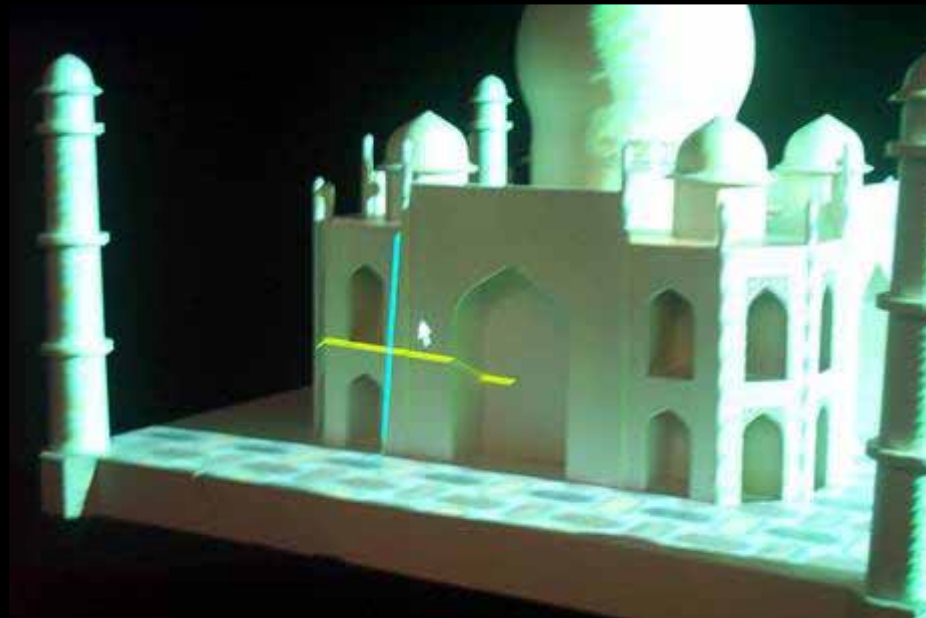


- Preprocessing
  - Scan 3D object and create virtual model



## – Preprocessing

- Scan 3D object and create model
- Roughly align projector(s)
- Calibrate by finding pose

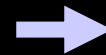


## – Preprocessing

- Scan 3D object and create model
- Approximately position projector(s)
- Calibrate by finding pose

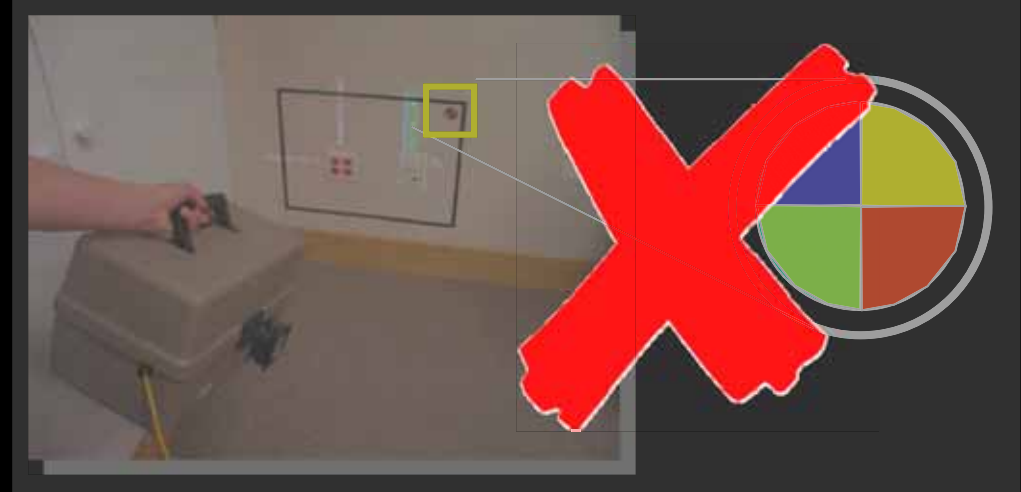
## – Run-time

- Render images of 3D model
- Correct



# 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



RFID ?

Warehousing



Routing



**RFID**

Livestock tracking



Library



Baggage handling



Currency



# Tagged Books in a Library

- ✓ **Id** : List of books in RF range



✗ **No Precise Location Data**

Are books in sorted order ?

# AR Issues

- Preprocessing:

- Authoring

- Runtime:

- **Identification:** Recognition of objects

- Using markers and visual tags

- **Registration:** Finding relationships

- Dynamic estimate of translation and rotation
- Render/Warp images

- **Interaction:**

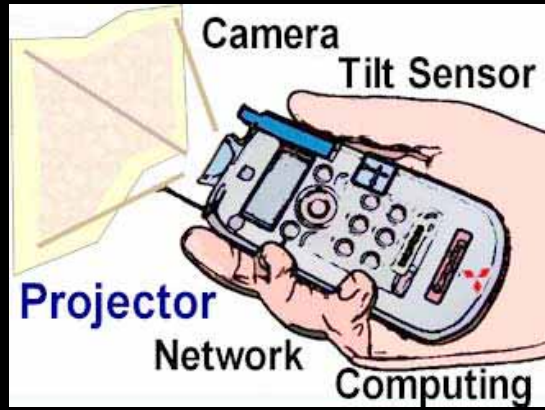
- Widgets, Gesture

RFID

Photosensing RFID

Projector for visual feedback

# Handheld Projector



**Pocket Projector 2004-05**



**iLamps 2002**



**RFIG Lamps 2003-04**