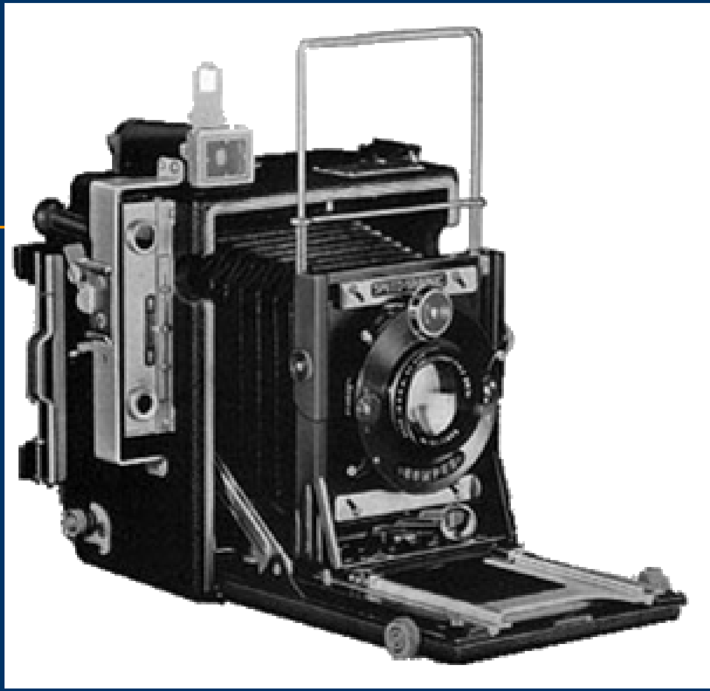
Computational Illumination

Course WebPage :

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

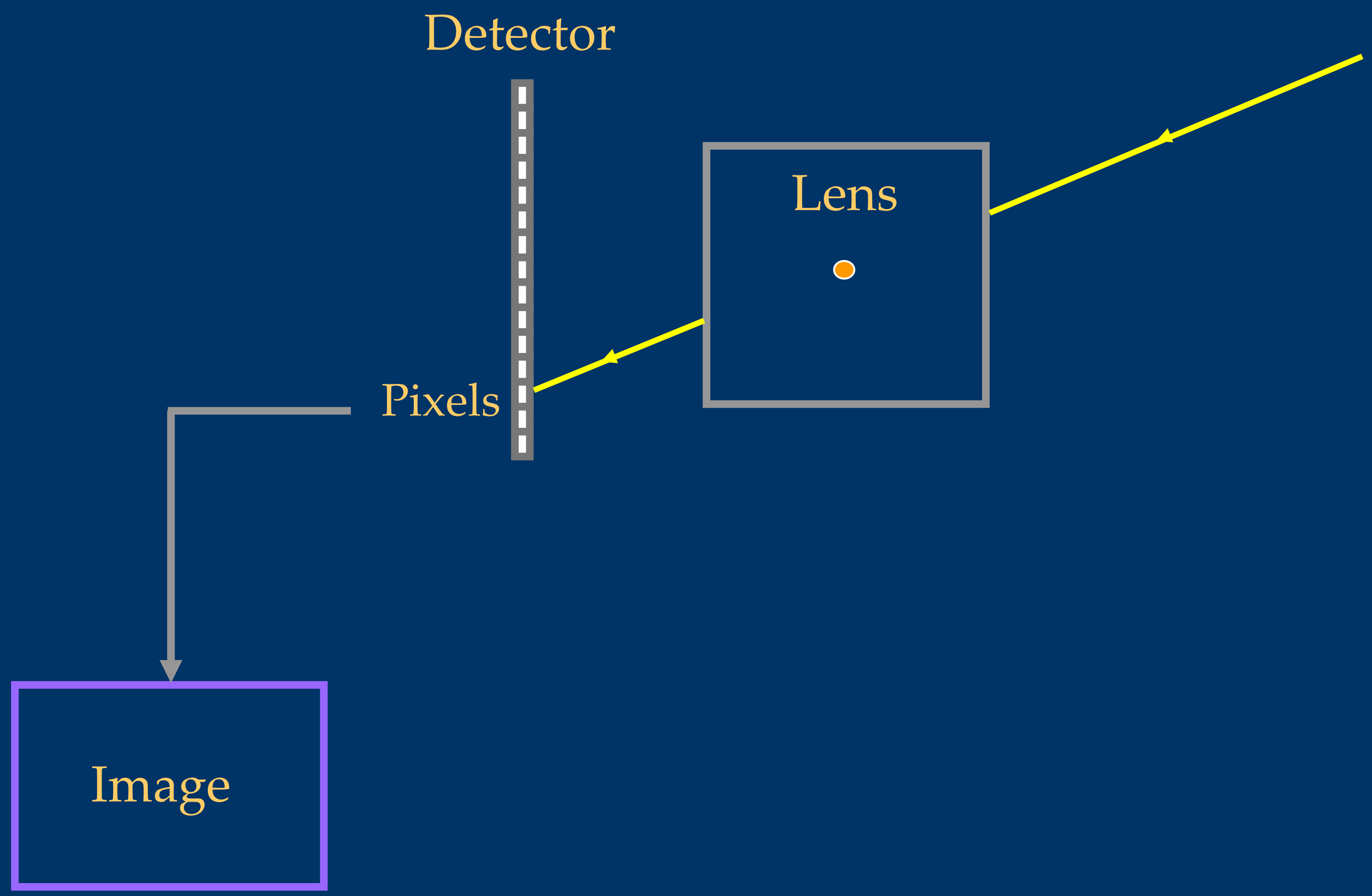
Ramesh Raskar

Mitsubishi Electric Research Labs

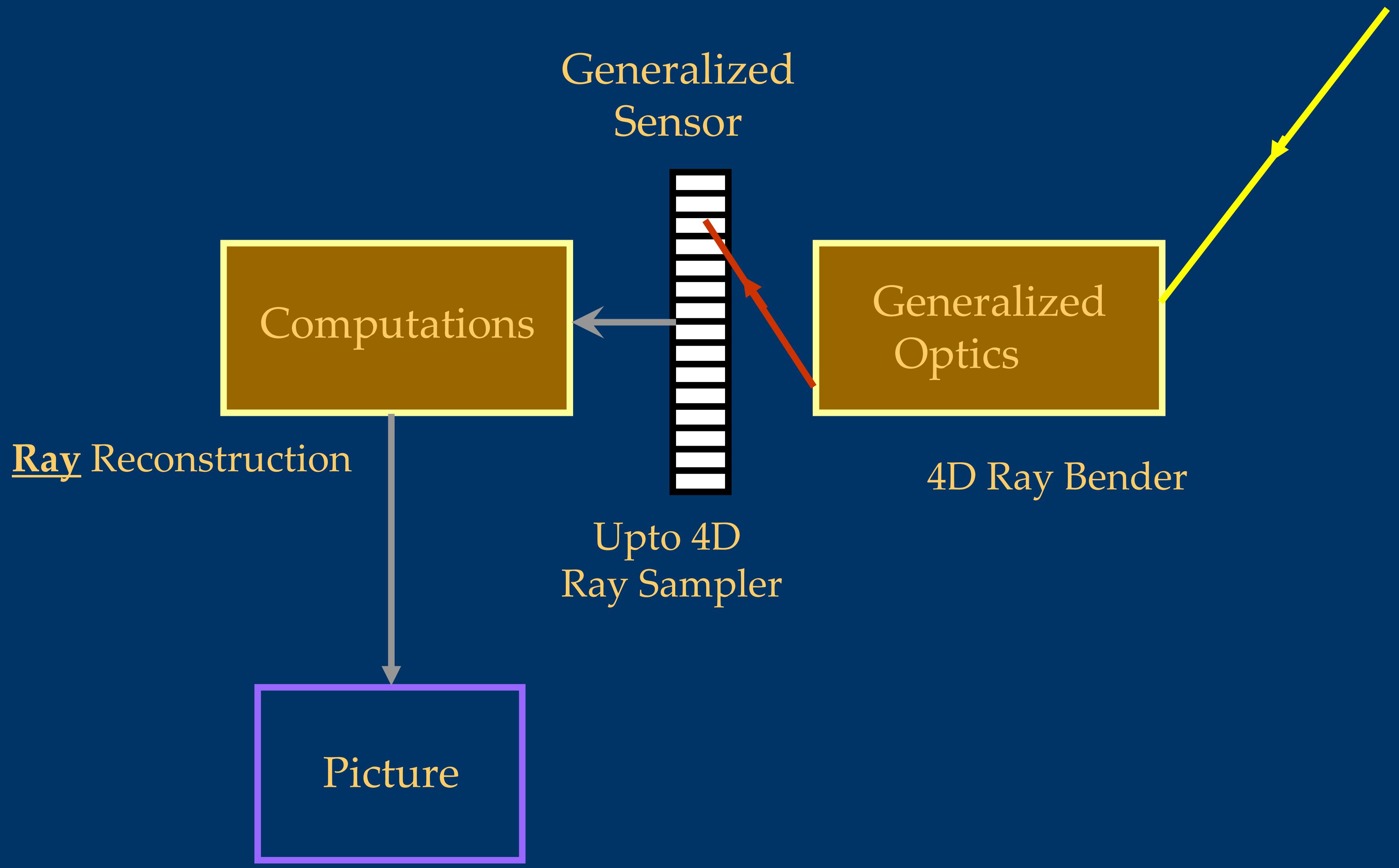


Computational Illumination

Traditional 'film-like' Photography

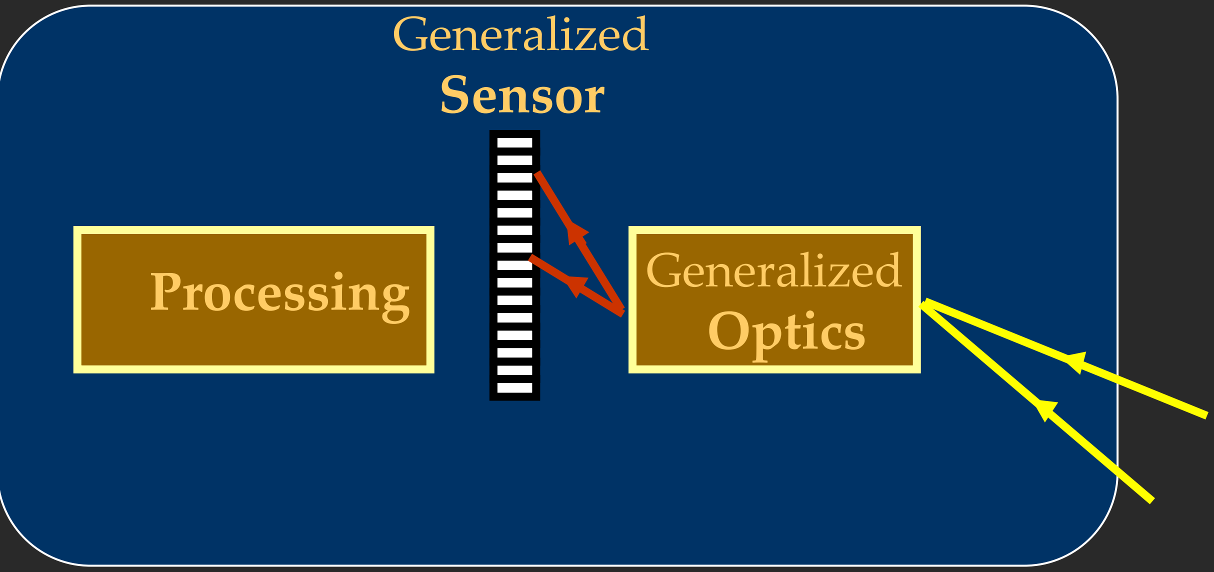


Computational Photography:
Optics, Sensors and Computations



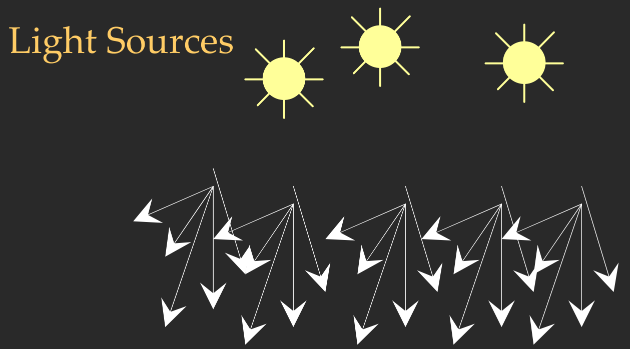
Computational Photography

Novel Cameras

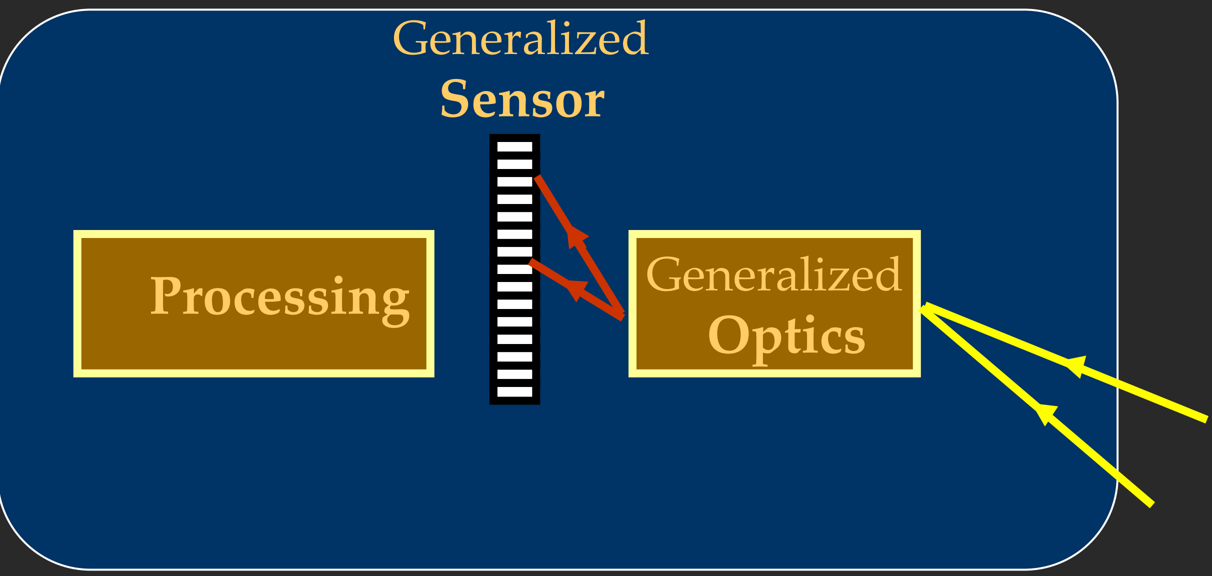


Computational Photography

Novel Illumination

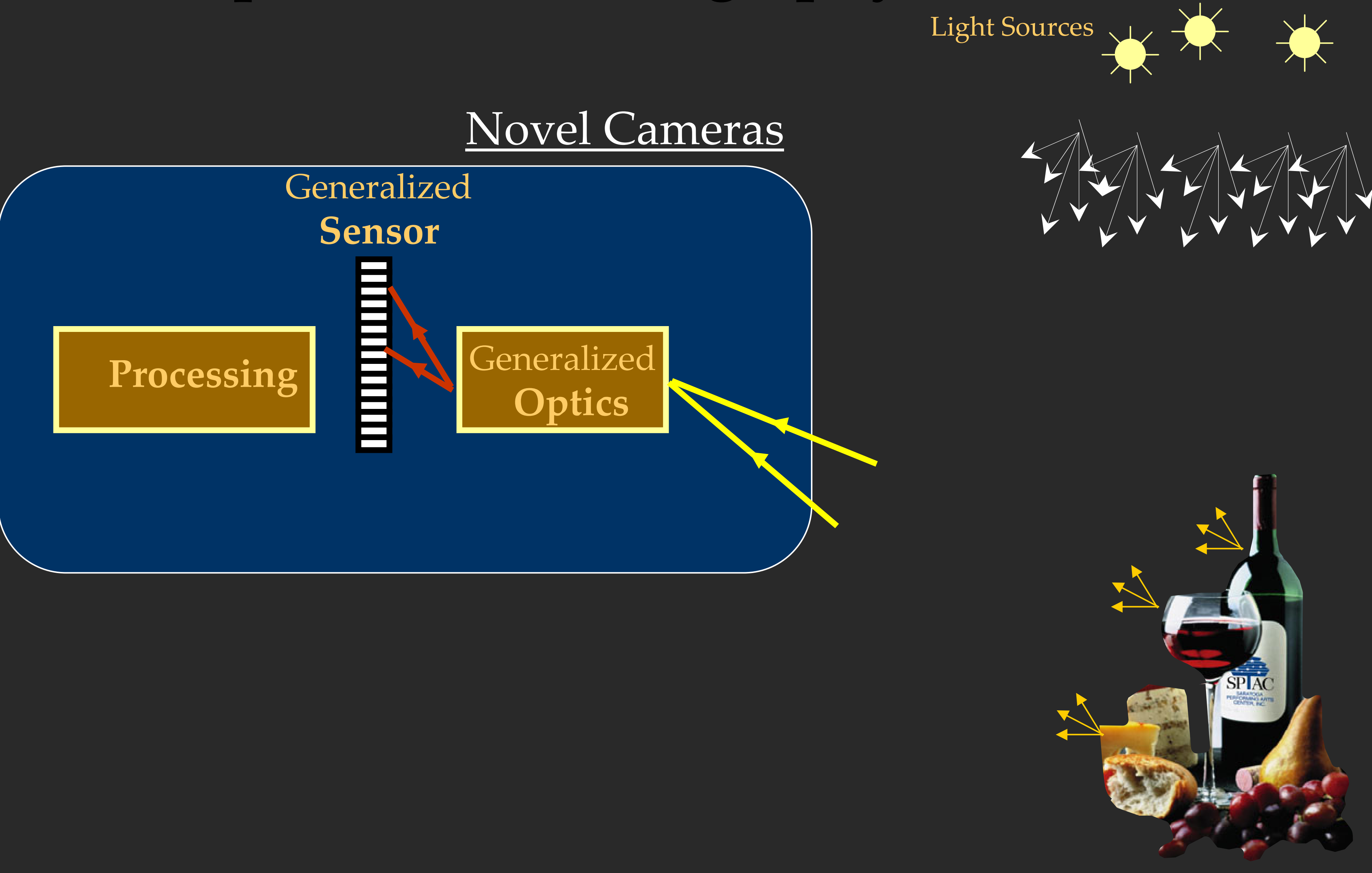


Novel Cameras



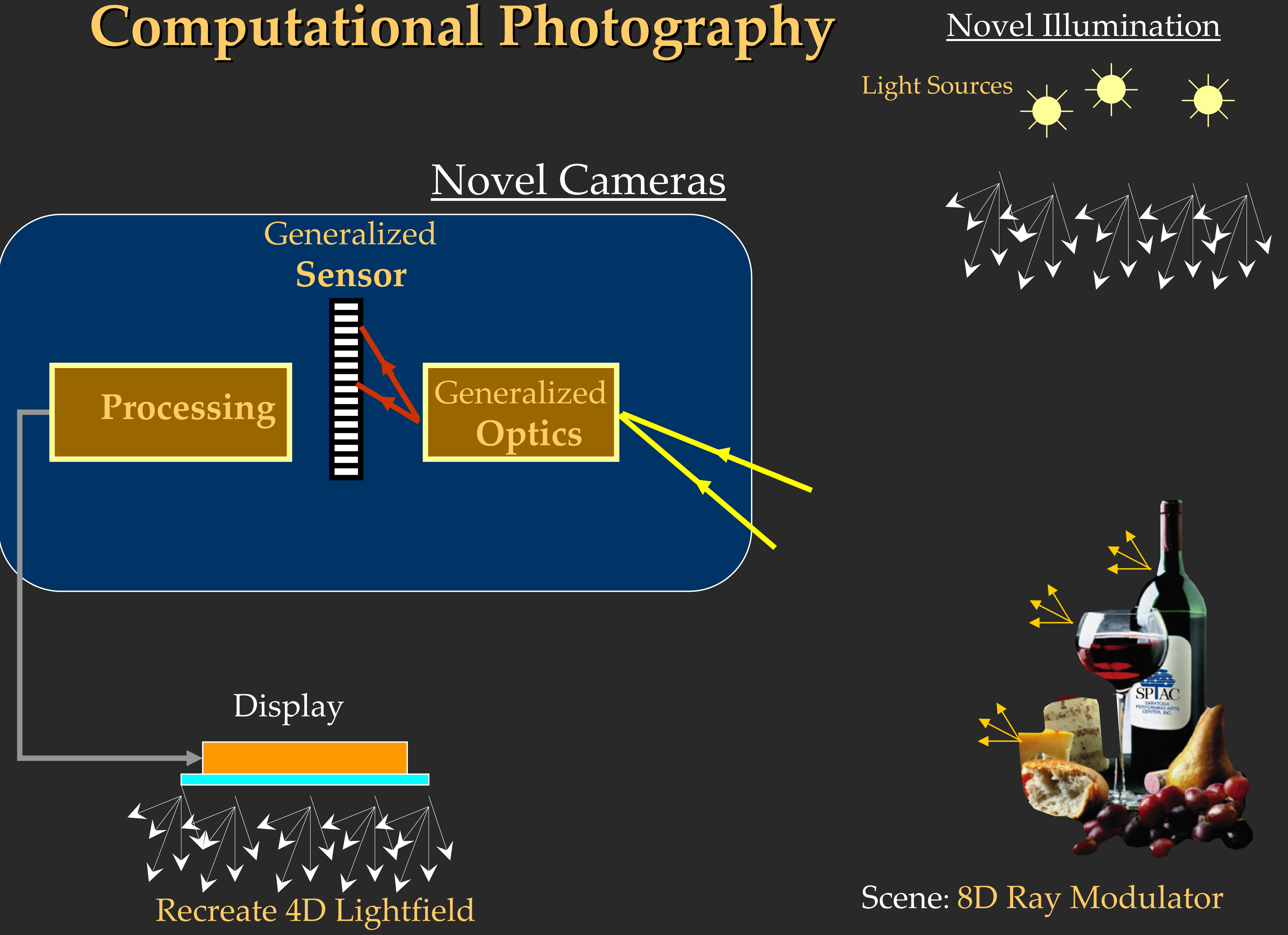
Computational Photography

Novel Illumination

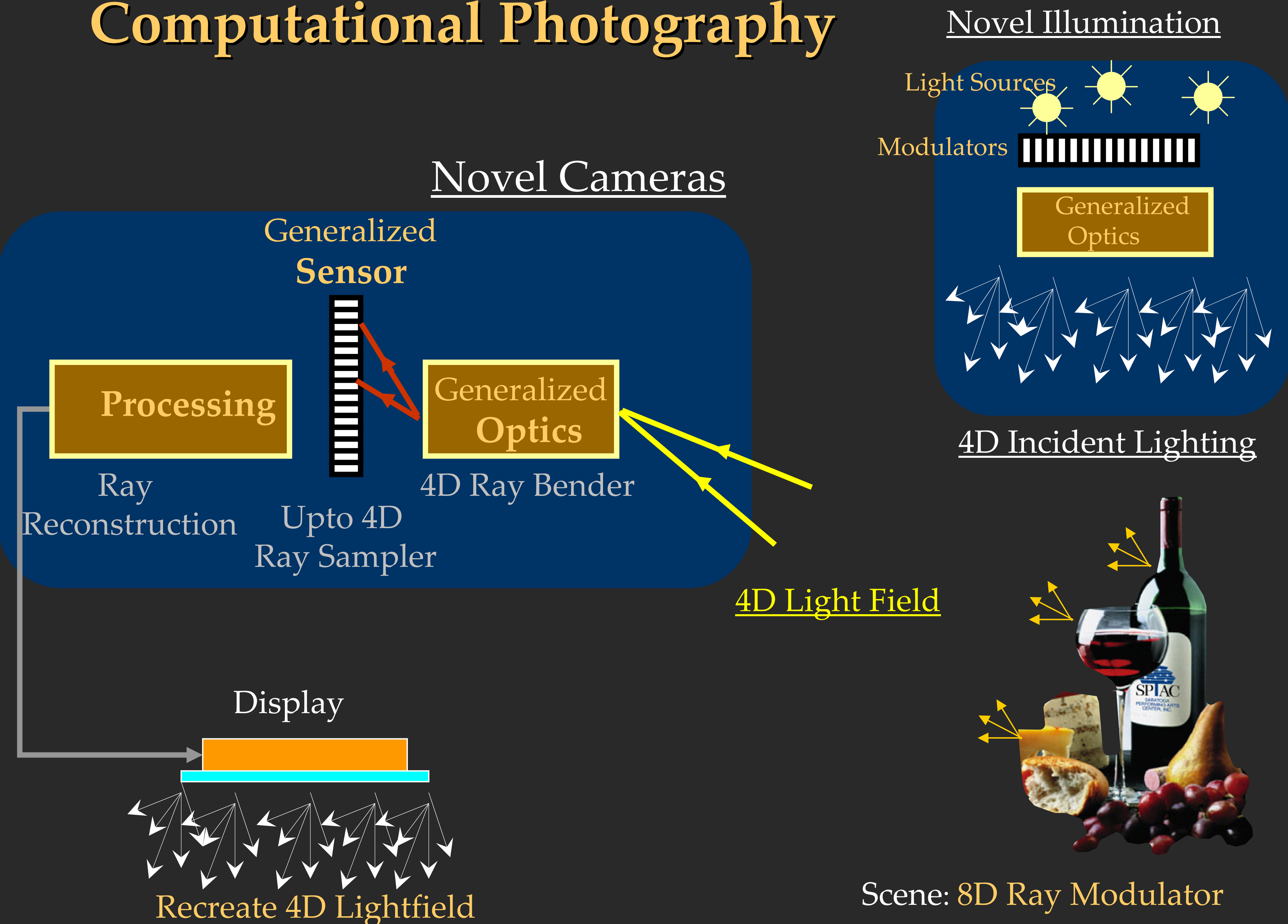


Scene: 8D Ray Modulator

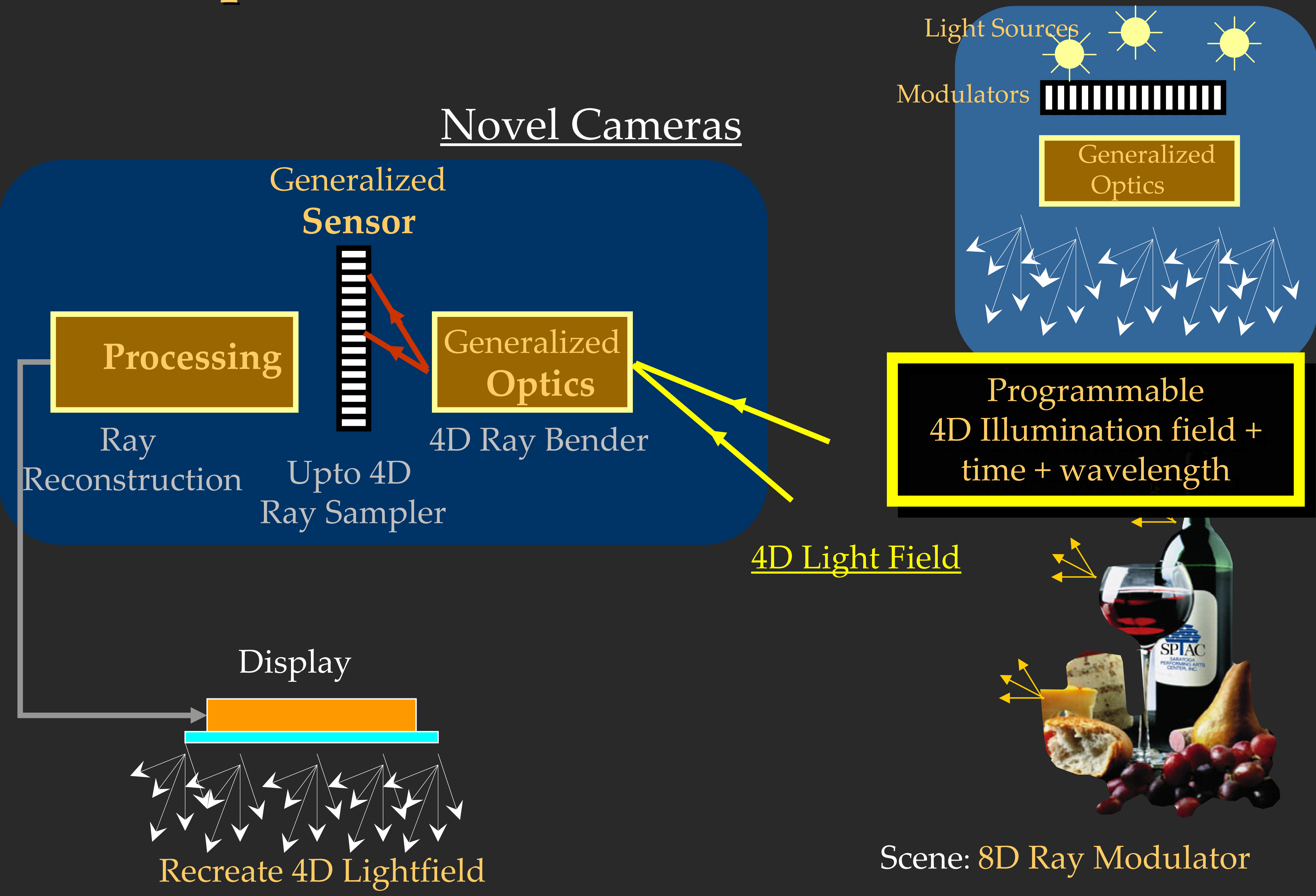
Computational Photography



Computational Photography



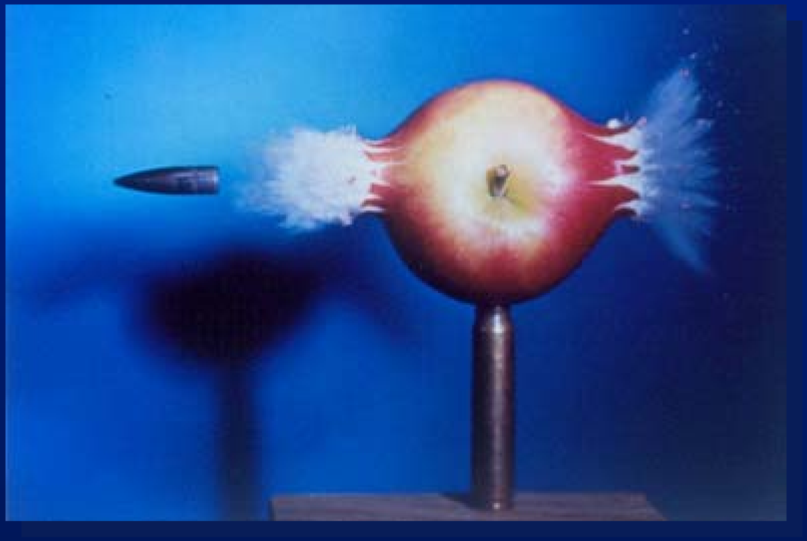
Computational Illumination

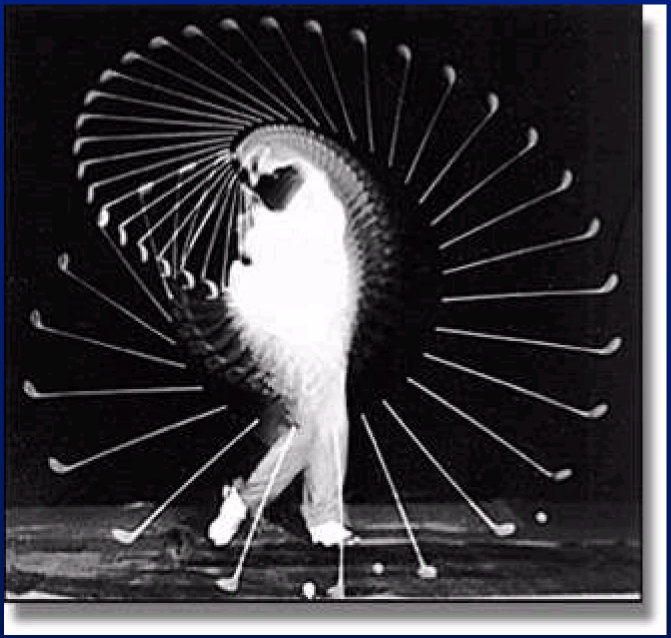


'Smarter' Lighting Equipment

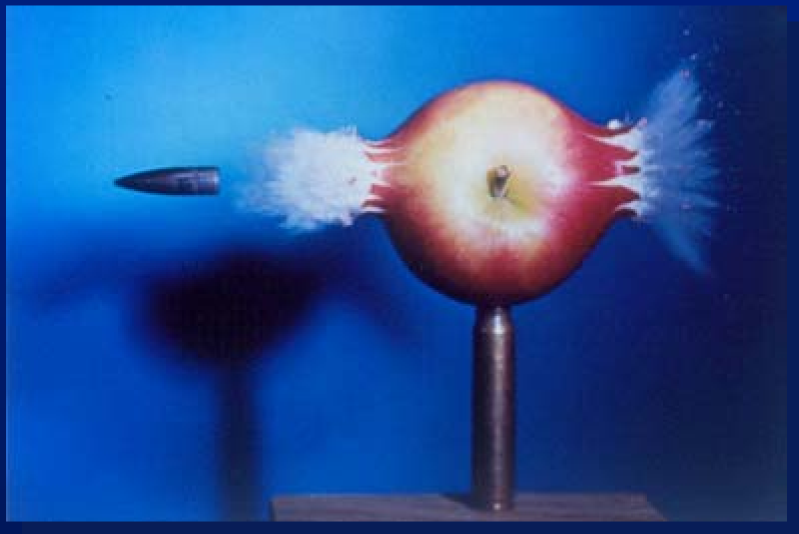
What Parameters Can We Change ?

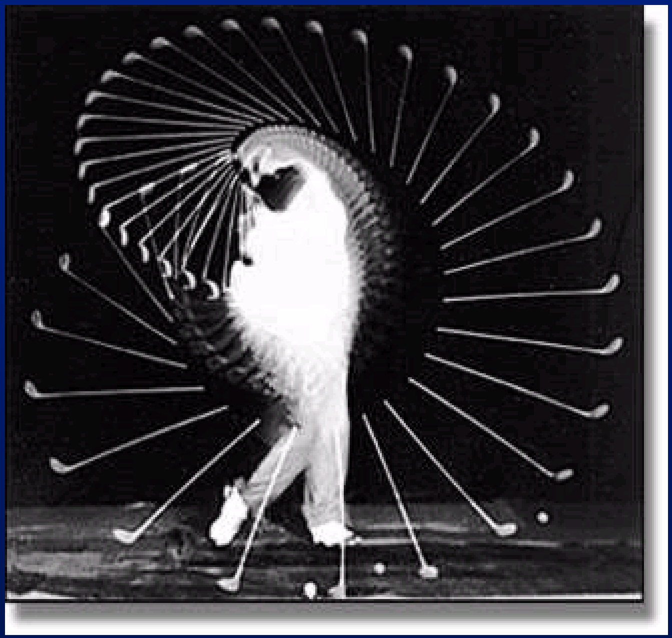
Edgerton 1930's





Edgerton 1930's





Stroboscope
(Electronic Flash)

Multi-flash
sequential photography

Computational Illumination:

Programmable 4D Illumination Field + Time + Wavelength

- Presence or Absence, Duration, Brightness
  - Flash/No-flash
- Light position
  - Multi-flash for depth edges
  - Programmable dome (image re-lighting and matting)
- Light color/wavelength

- Spatial Modulation
  - Synthetic Aperture Illumination
- Temporal Modulation
  - TV remote, Motion Tracking, Sony ID-cam, RFIG
- Exploiting (uncontrolled) natural lighting condition
  - Day/Night Fusion

Computational Illumination

- Presence or Absence, Duration, Brightness
  - Flash/No-flash
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  - Multi-flash for depth edges
  - Programmable dome (image re-lighting and matting)
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- General lighting condition
  - Day/Night

Denoising Challenging Images

Available light:

+ nice lighting

- noise/blurriness
- color

Flash:

+ details
+ color

- flat/artificial

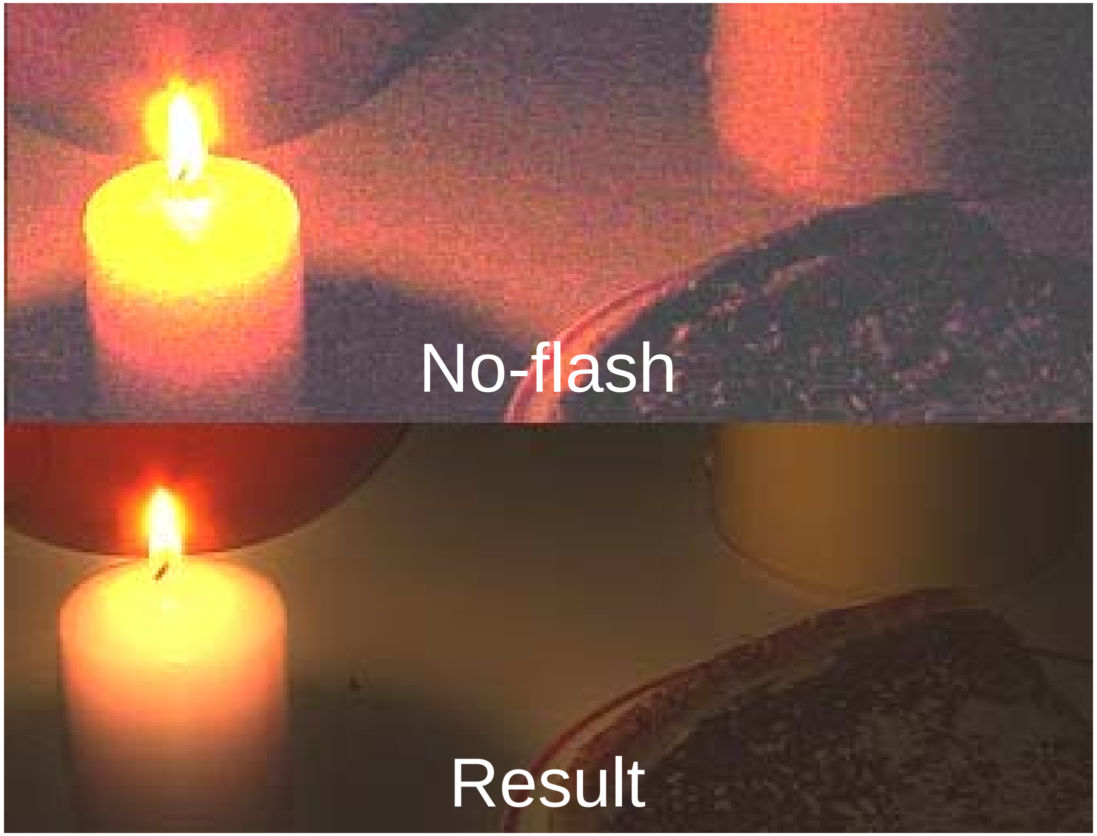
Elmar Eisemann and Frédo Durand , Flash Photography Enhancement via Intrinsic Relighting

Georg Petschnigg, Maneesh Agrawala, Hugues Hoppe, Richard Szeliski, Michael Cohen, Kentaro Toyama. Digital Photography with Flash and No-Flash Image Pairs

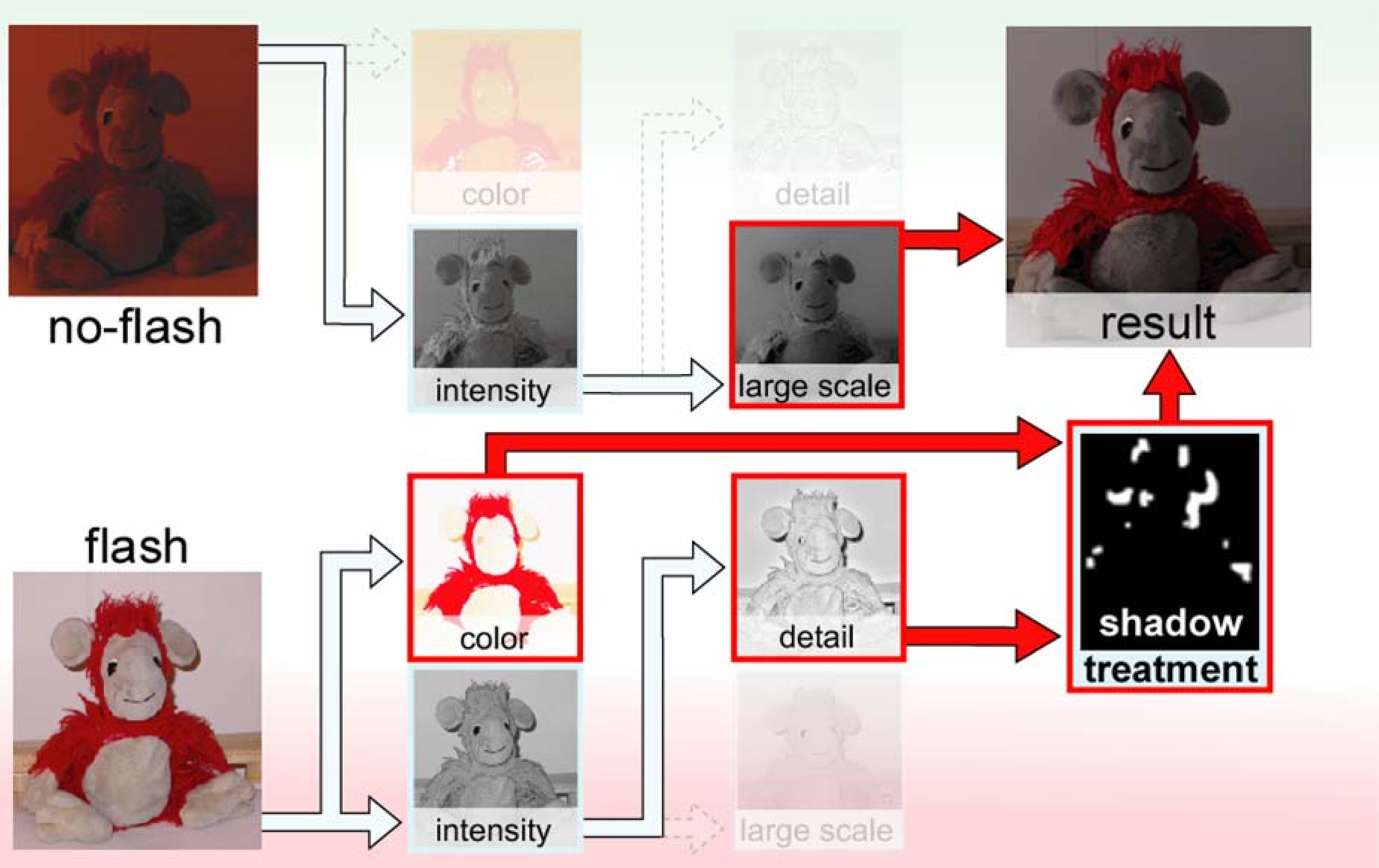
Denoise no-flash image using flash image

Transfer detail from flash image to no-flash image

+ original lighting
+ details/sharpness
+ color

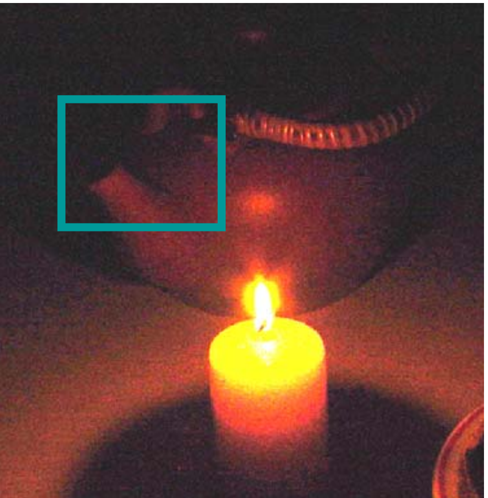


Cross-Bilateral Filter based Approach



Cross Bilateral Filter

- When no-flash image is too noisy
- Borrow similarity from flash image
  - ➢ edge stopping from flash image



Detail Layer

Intensity / Large-scale = Detail

Recombination: Large scale * Detail = Intensity

Need flash component!

Build Exposure HDR image

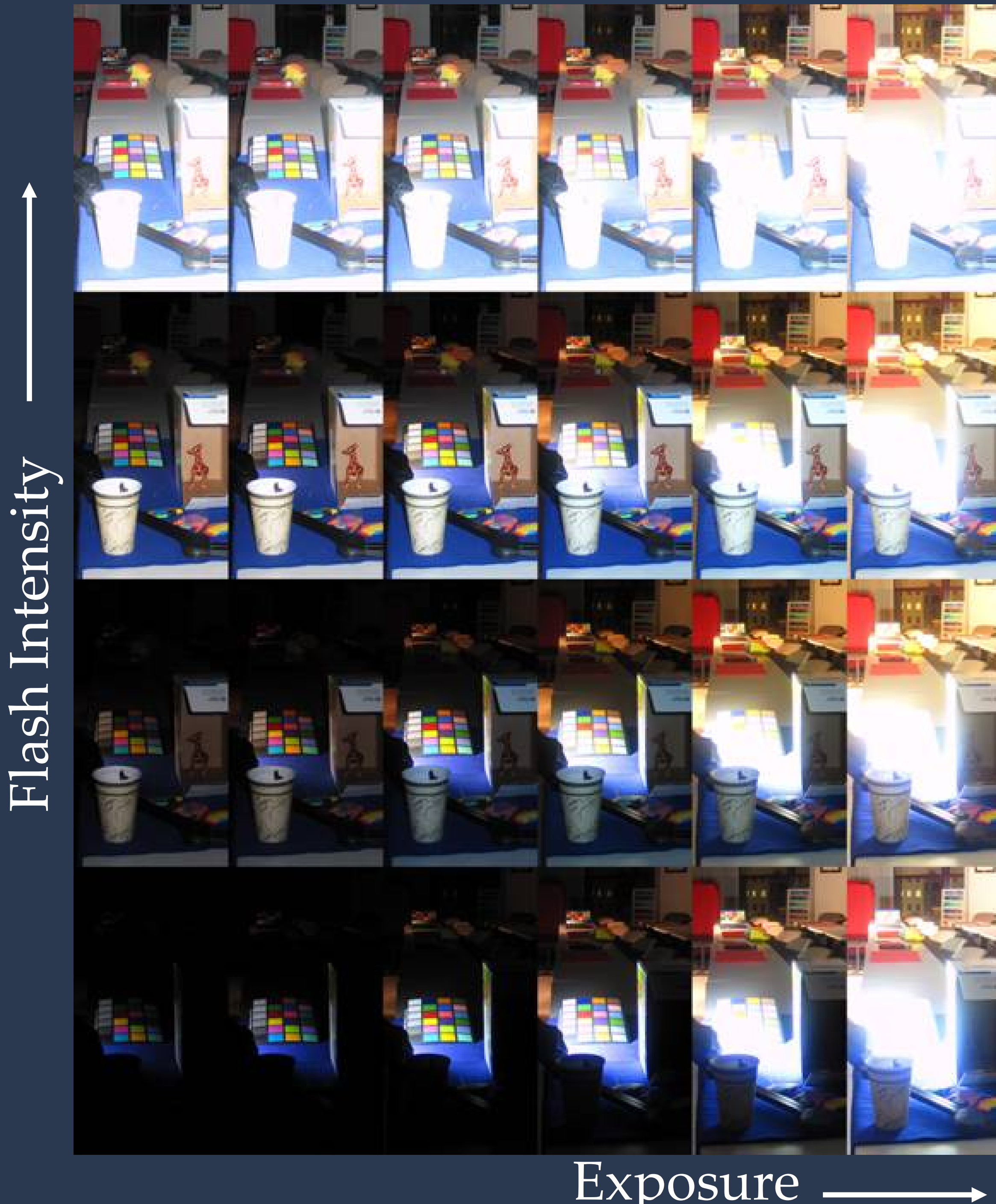
- Multiple images with different exposure
  - Debevec & Malik, Siggraph 97
  - Nayar & Mitsunaga, CVPR 00

Increasing Exposure →

Build Flash HDR image

Flash Intensity

Flash-Exposure Sampling

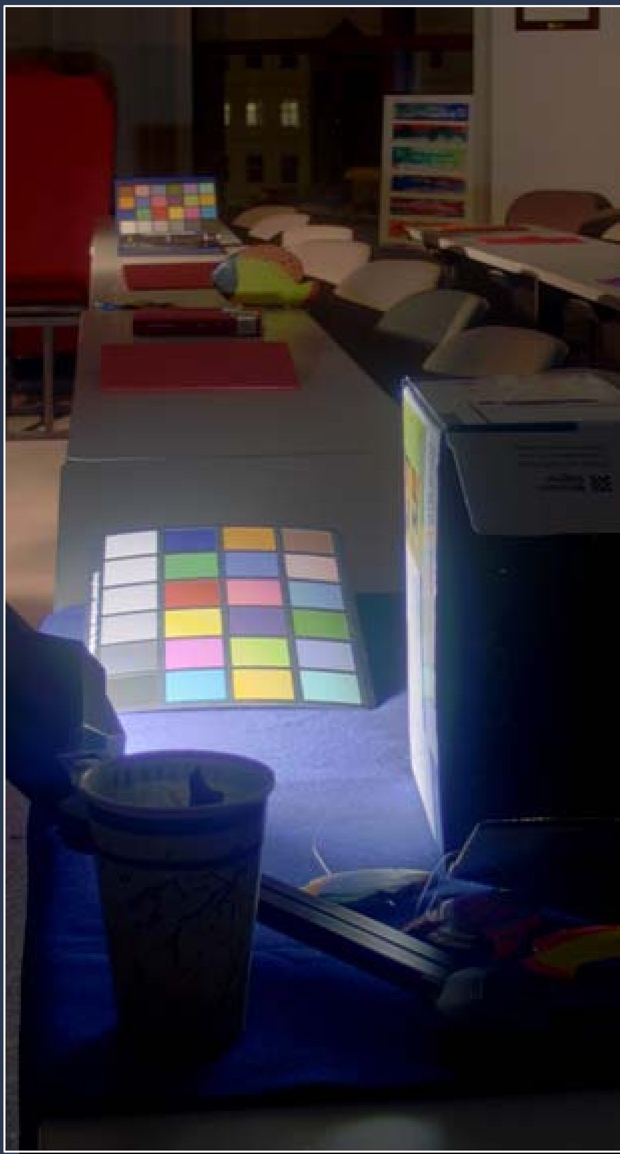


Build Flash-Exposure HDR image

Agrawal, Raskar, Nayar, Li
Siggraph05

Capturing HDR Image

Varying Exposure time



Varying Flash brightness

Varying both

Flash and Ambient Images

[Agrawal, Raskar, Nayar, Li Siggraph05]

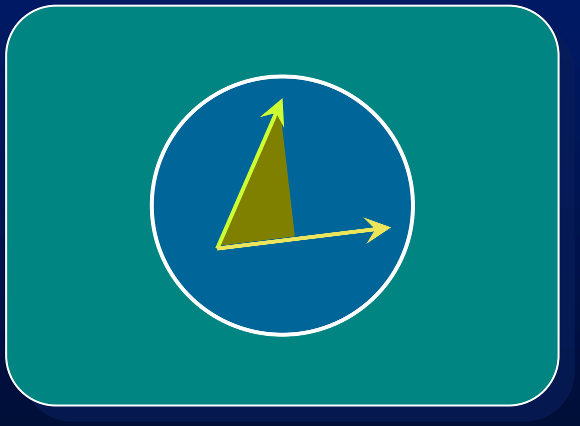
Ambient

Flash

Result

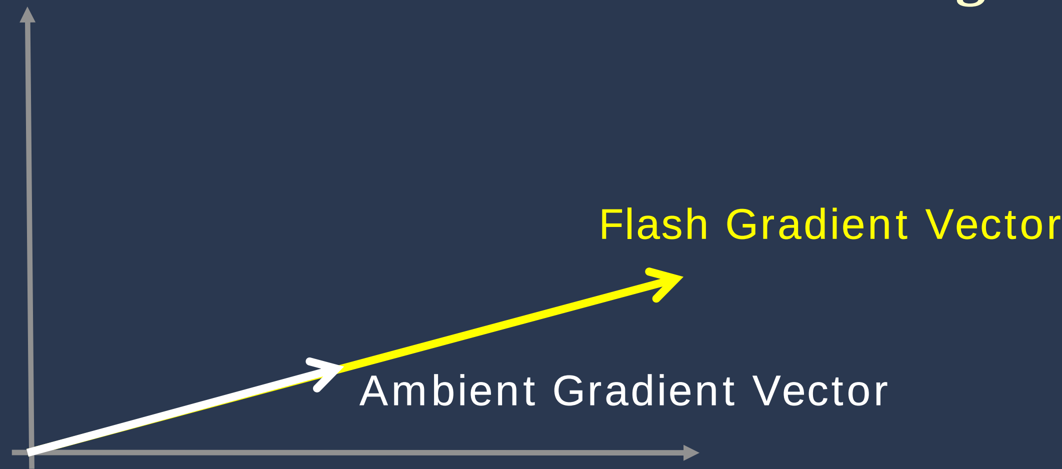
Reflection Layer

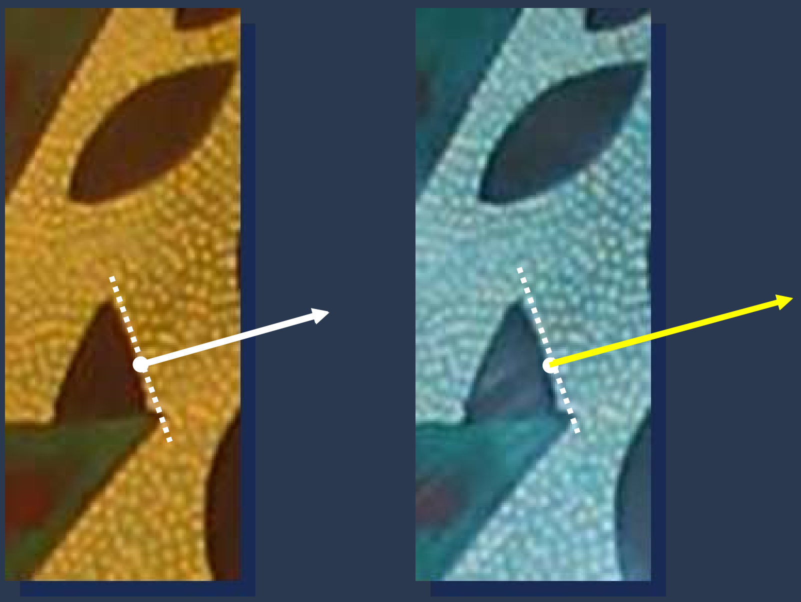
Intensity Gradient Vector **Projection**



Intensity Gradient Vectors in Flash and Ambient Images

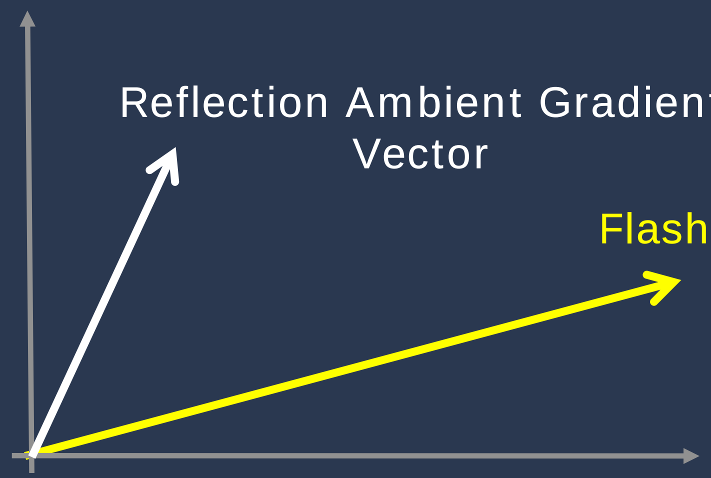
Same gradient vector direction



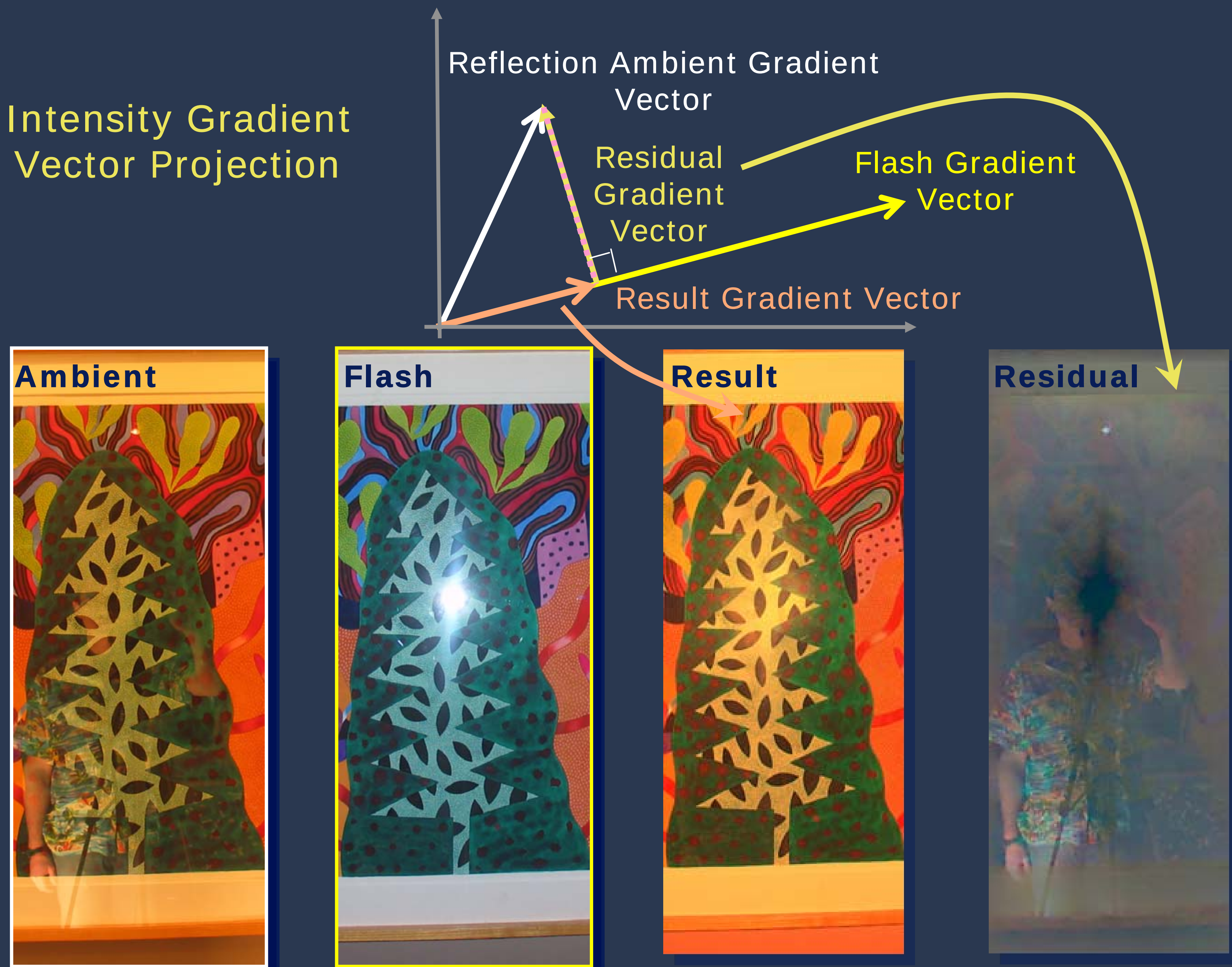


No reflections

Different gradient vector direction



With reflections



Intensity Gradient Vector Projection
Reflection Ambient Gradient Vector
Residual Gradient Vector
Flash Gradient Vector
Result Gradient Vector
Ambient
Flash
Result
Residual


Ambient
Flash
Projection
= Result
Residual
=Reflection Layer
Co-located Artifacts

Computational Illumination

- Presence or Absence, Duration, Brightness
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- Light position
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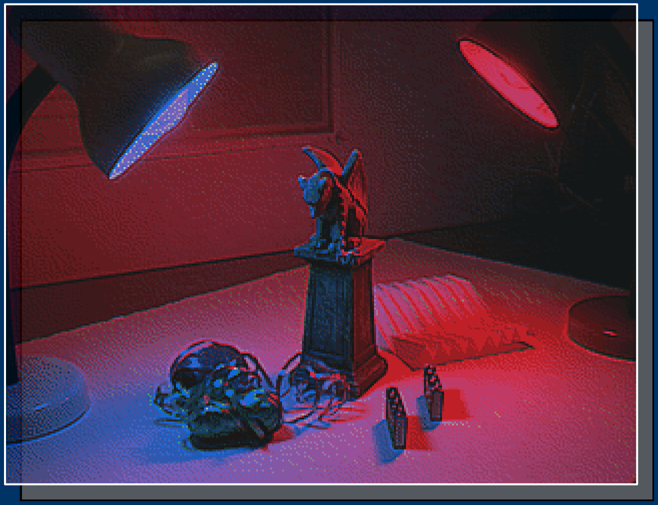
  – Multi-flash for depth edges
- Light color/wavelength

- Spatial Modulation
  – Synthetic Aperture Illumination
- Temporal Modulation
  – TV remote, Motion Tracking, Sony ID-cam, RFIG
- General lighting condition
  – Day/Night

Synthetic Lighting

Paul Haeberli, Jan 1992



Debevec et al. 2002: ‘Light Stage 3’

Image-Based Actual Re-lighting

Debevec et al., SIGG2001

Light the actress in Los Angeles

Film the background in Milan,
Measure incoming light,

Matched LA and Milan lighting.

Matte the background

Photomontage

courtesy of A Agrawala

courtesy of P. Debevec

Table-top Computed Lighting for Practical Digital Photography

Ankit Mohan, Jack Tumblin

Northwestern University

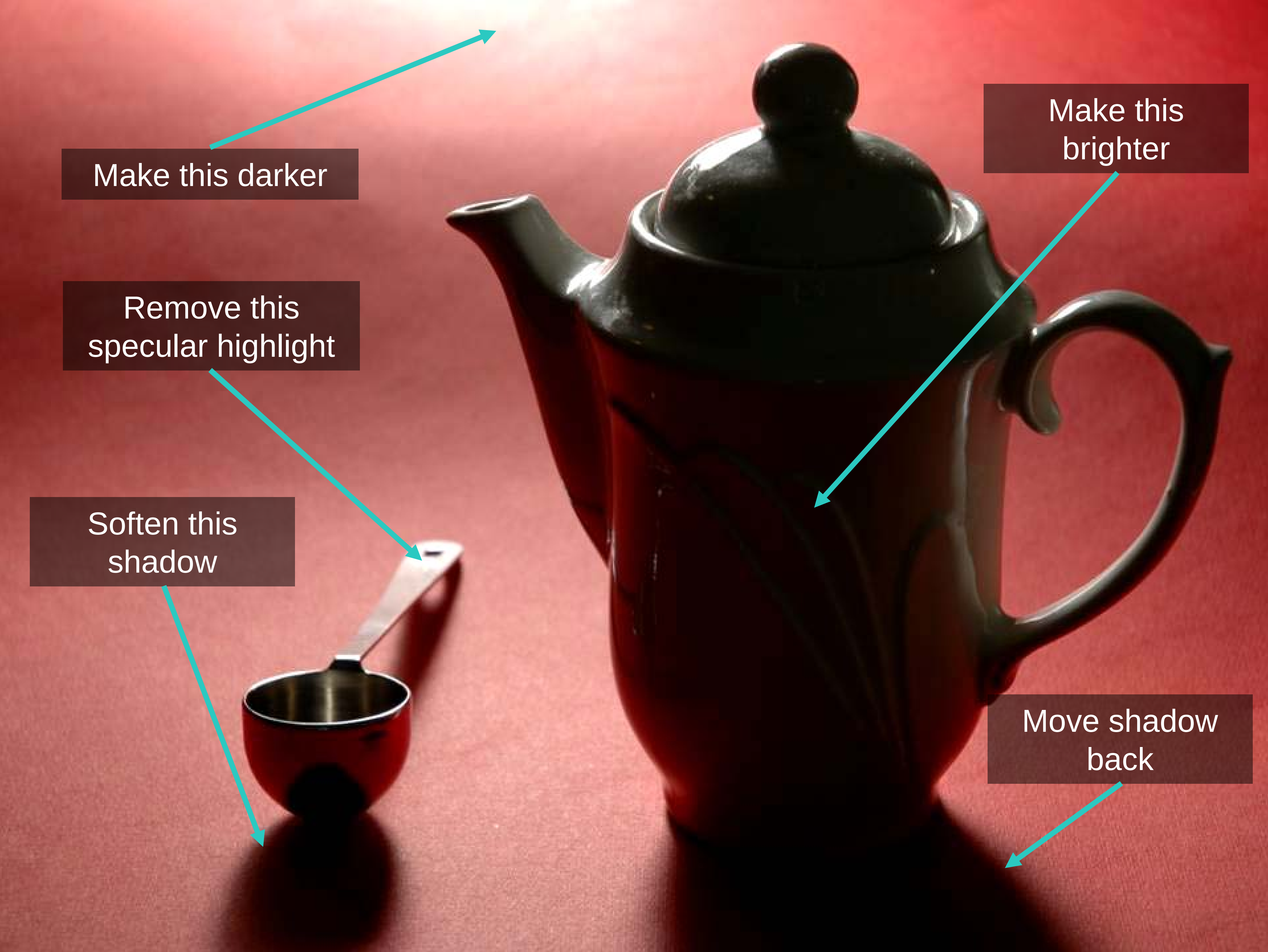
Bobby Bodenheimer

Vanderbilt University

Cindy Grimm, Reynold Bailey

Washington University in St. Louis

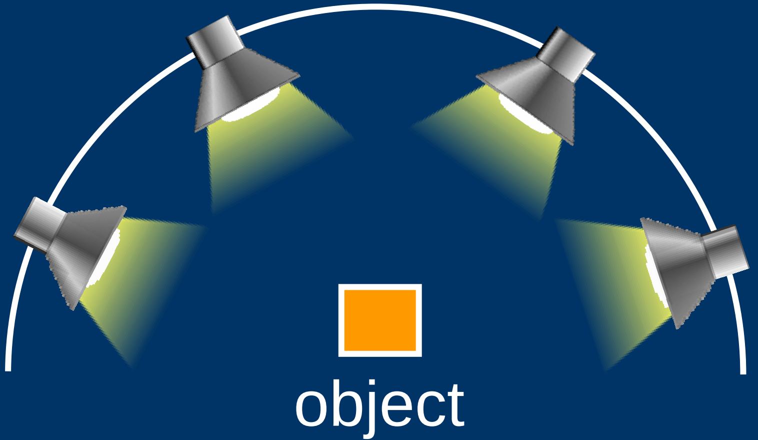
ACMSIGGRAPH eurographics symposium on rendering 2005


Make this darker
Make this brighter
Remove this specular highlight
Soften this shadow
Move shadow back

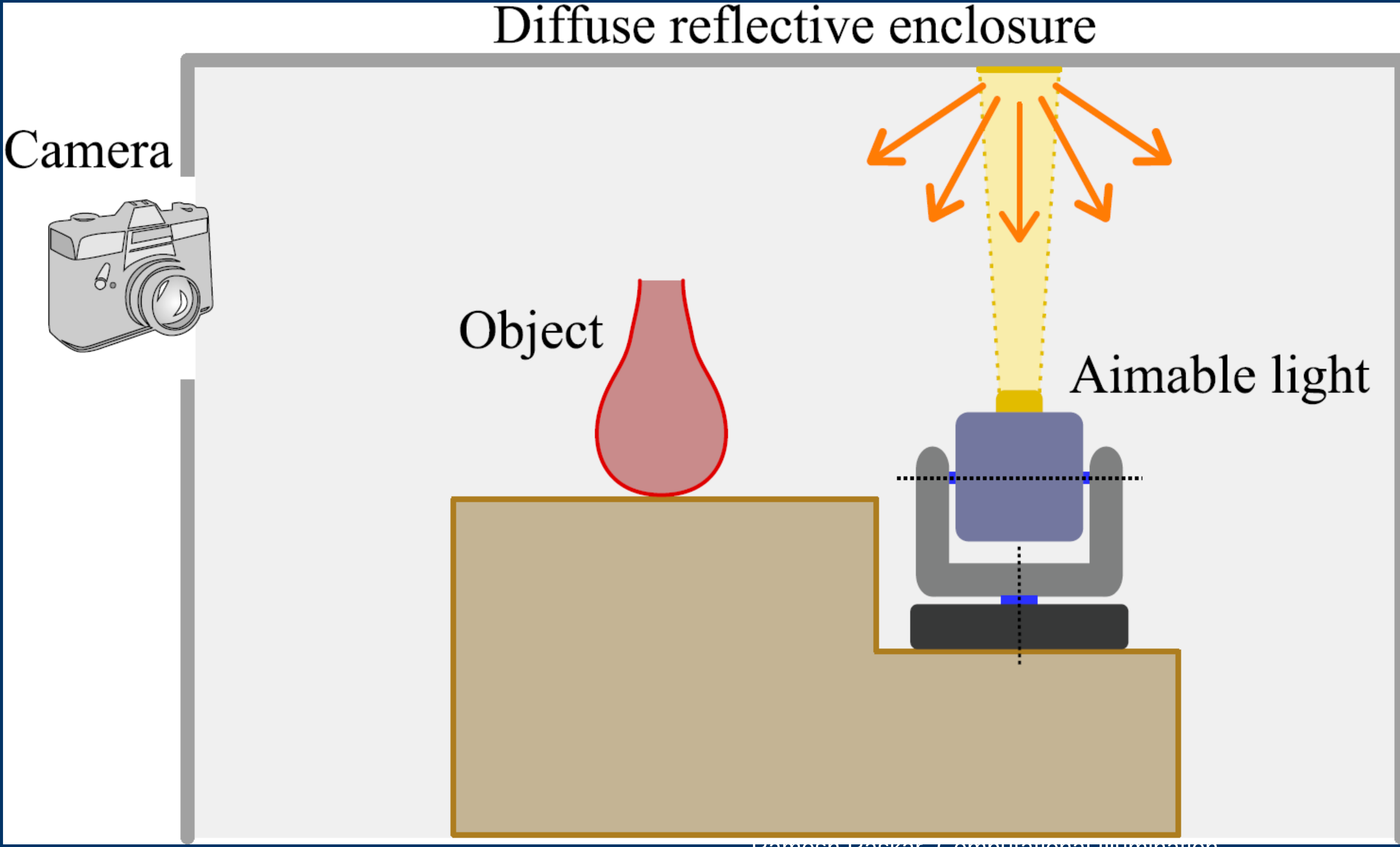
Sketch Your Desires, Optimize

Acquisition for Relighting

- Uniquely lit
  basis images
- Known light-positions

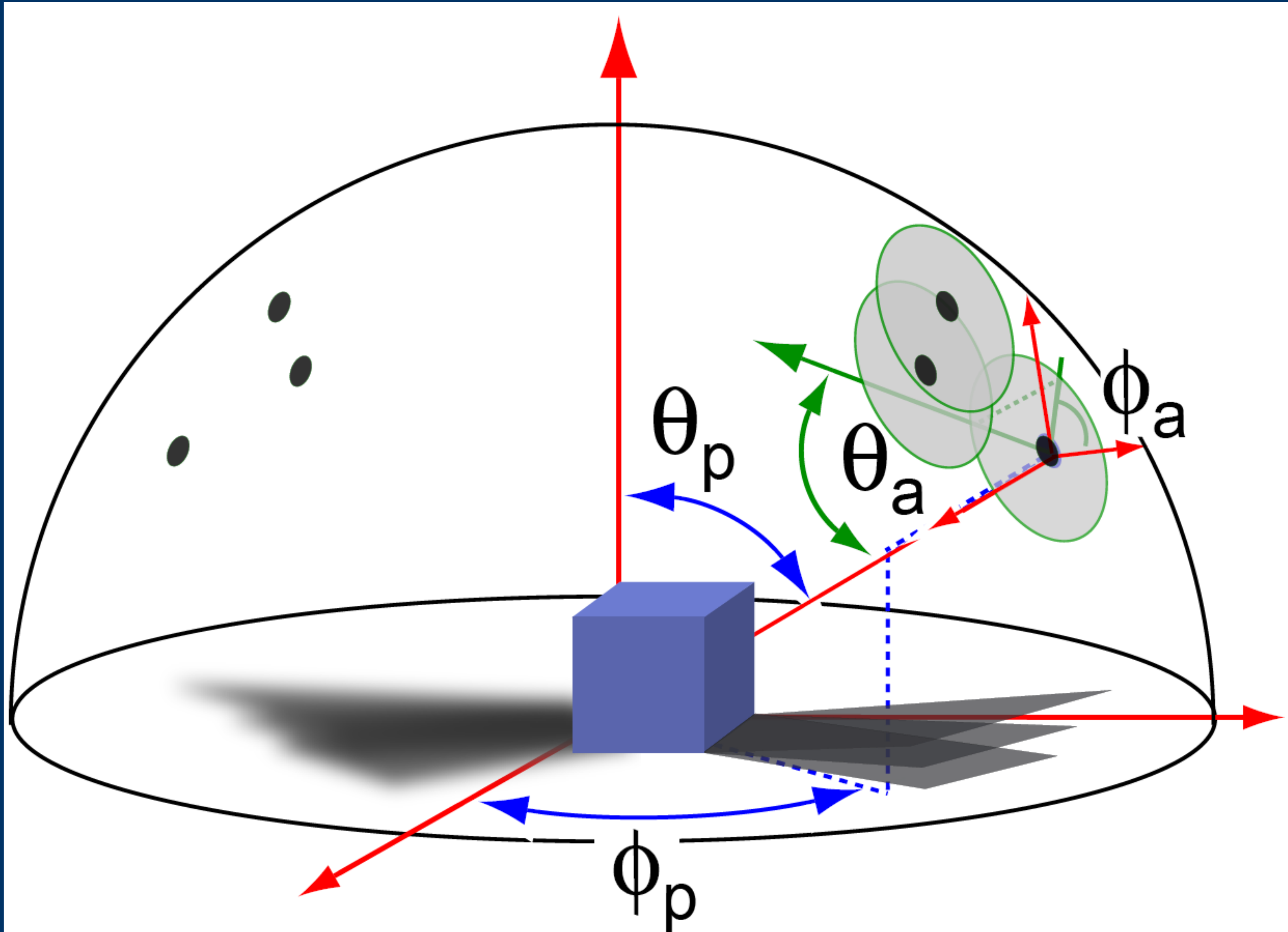


‘Aimed Spot’: low-risk movement



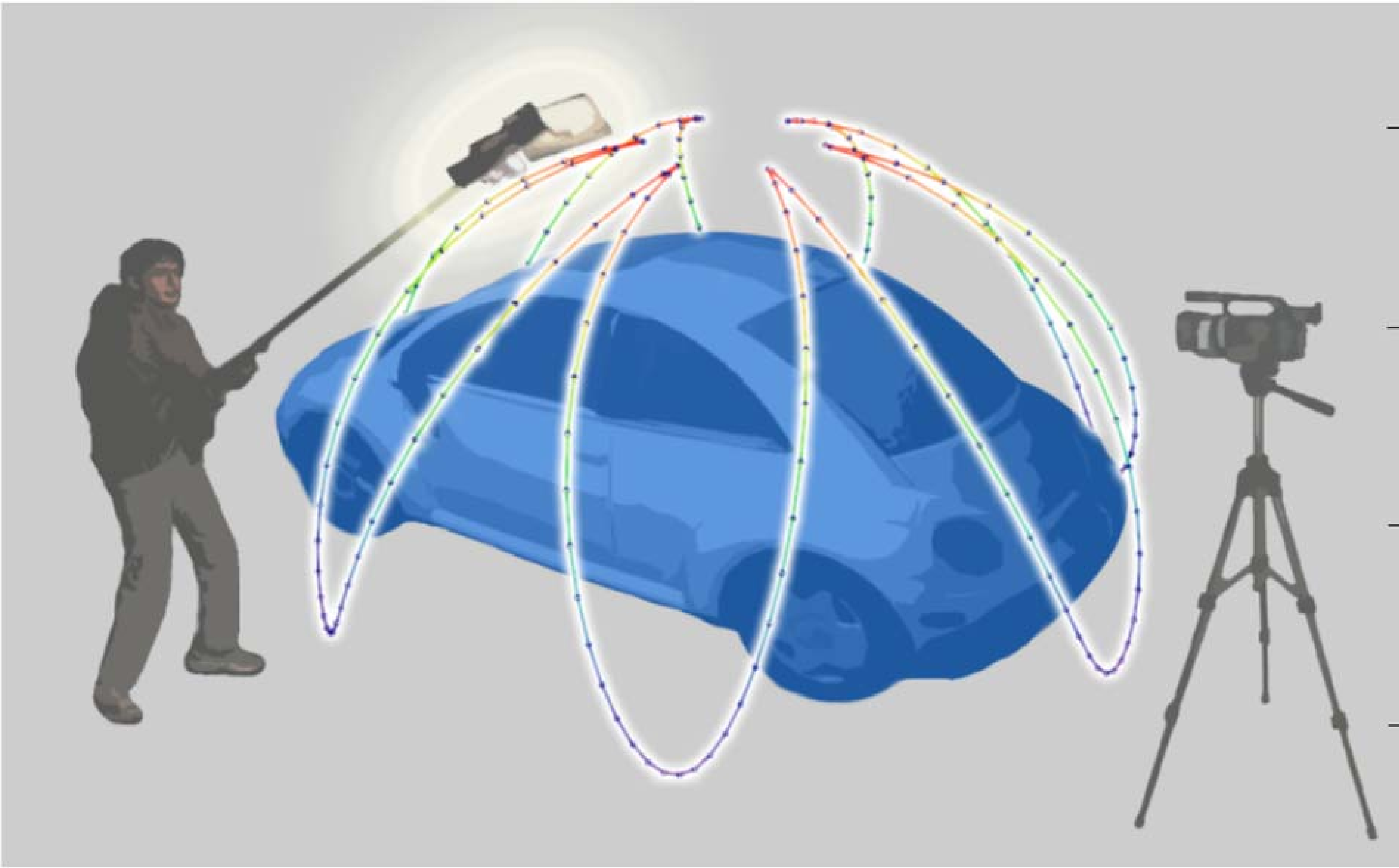
From Jack Tumblin

Overlapped Spots avoid aliasing

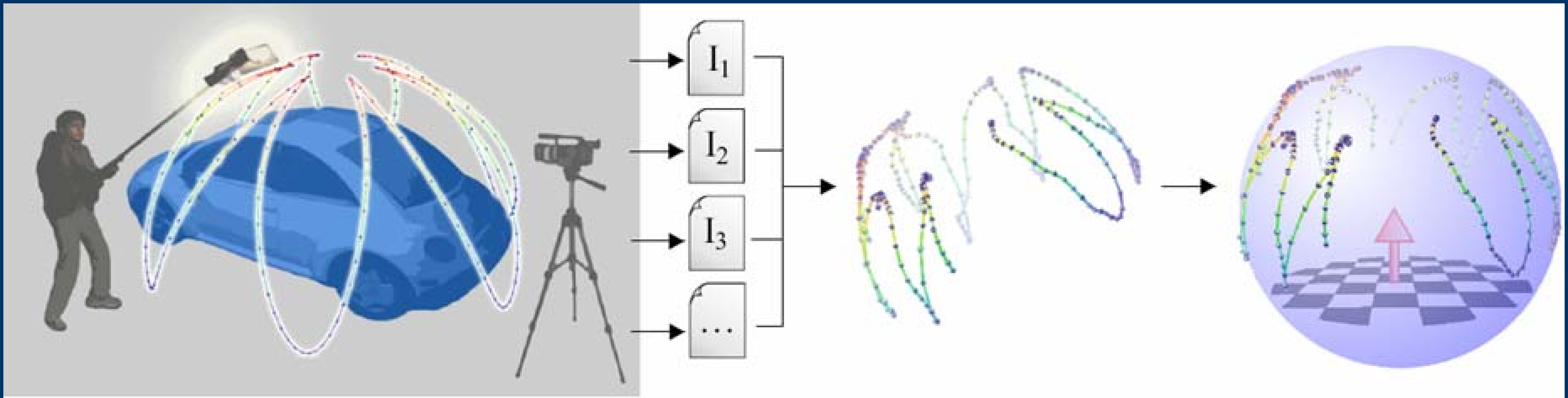


“Light Waving”

Tech Sketch (Winnemoller, Mohan, Tumblin, Gooch)



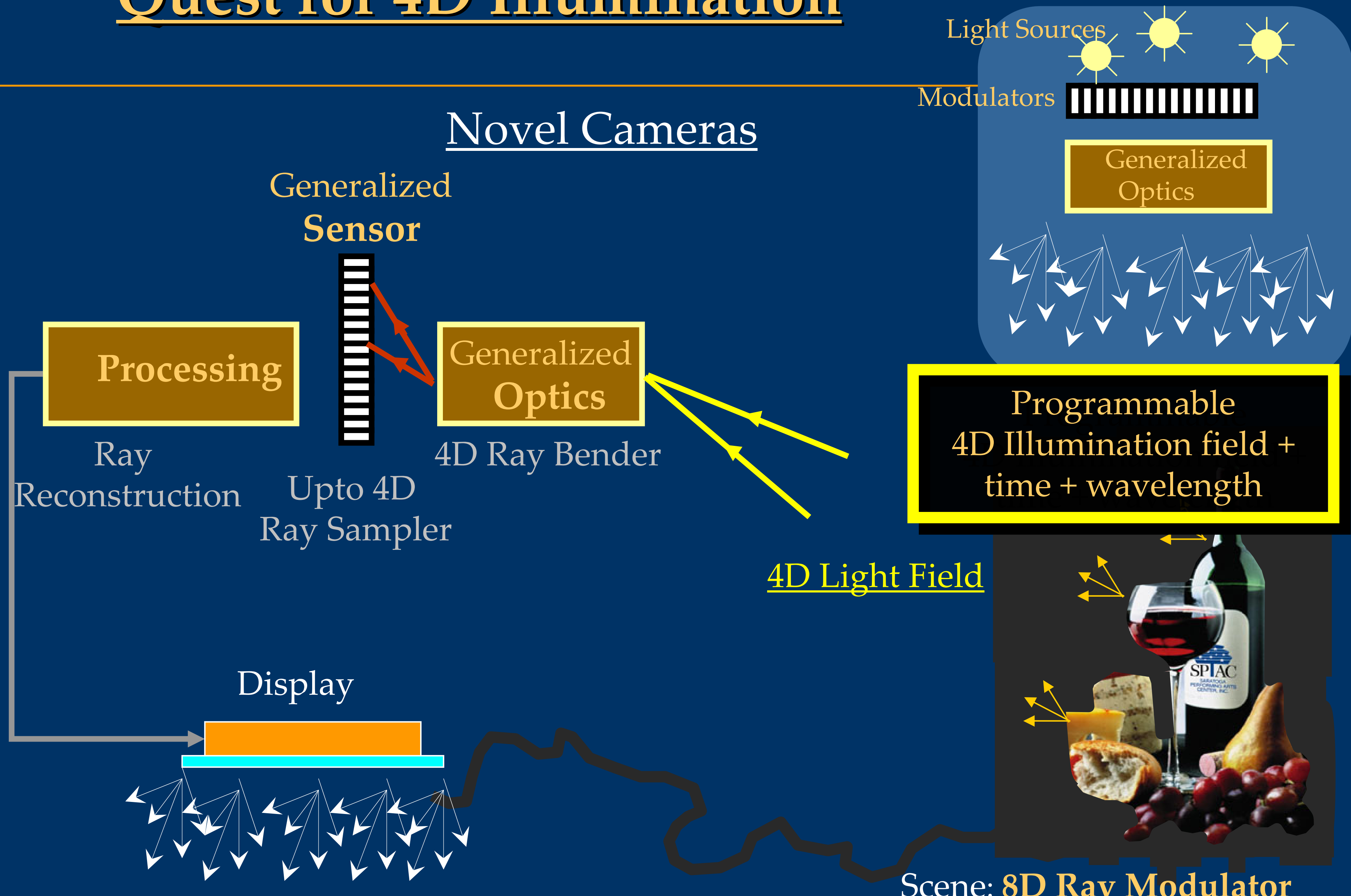
Light Waving: Estimating Light Positions From Photographs Alone



Holger Winnemöller, Ankit Mohan,
Jack Tumblin, Bruce Gooch
Northwestern University

Computational Illumination

Quest for 4D Illumination



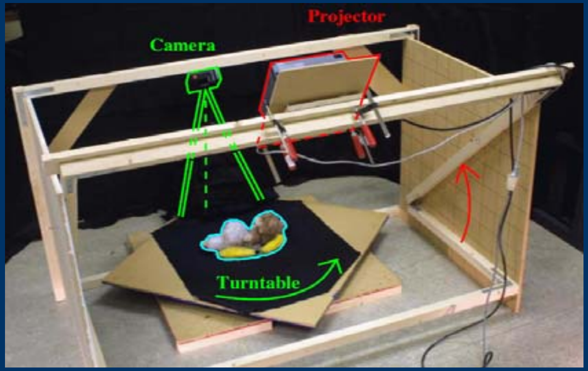
A 4-D Light Source

[Debevec et al. 2000]

[Masselus et al. 2002]

[Matusik et al. 2002]

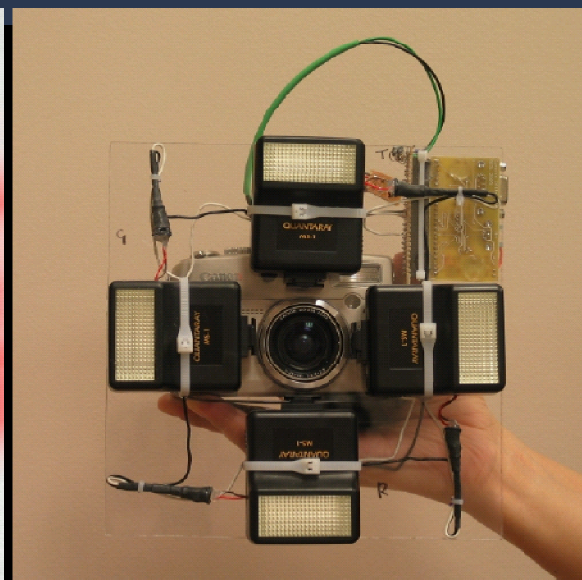
[Debevec et al. 2002]



[Masselus et al. 2003]

[Malzbender et al. 2002]

Non-photorealistic Camera: Depth Edge Detection and Stylized Rendering using Multi-Flash Imaging



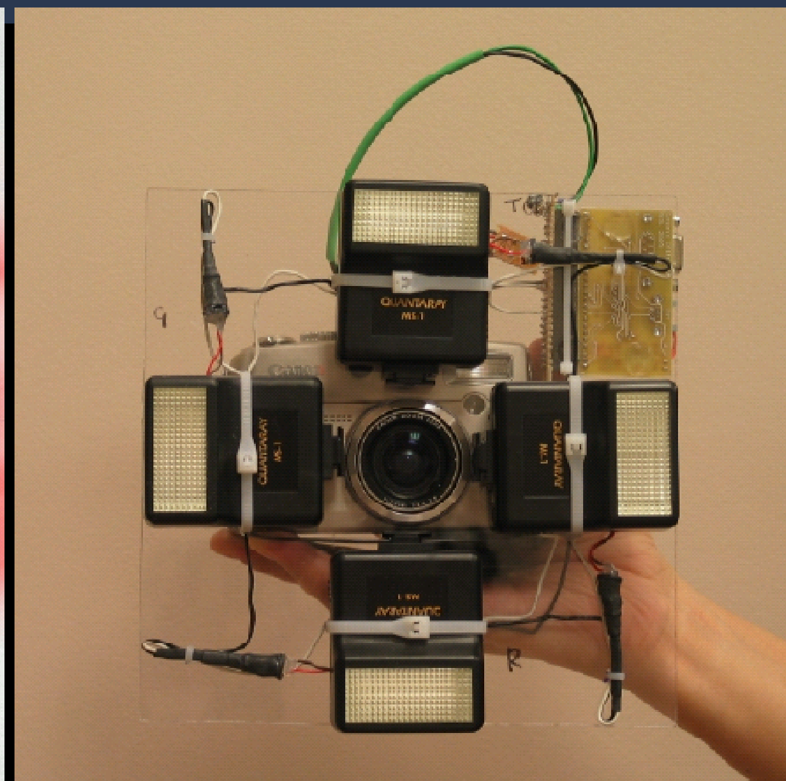
Ramesh Raskar, Karhan Tan, Rogerio Feris, Jingyi Yu, Matthew Turk

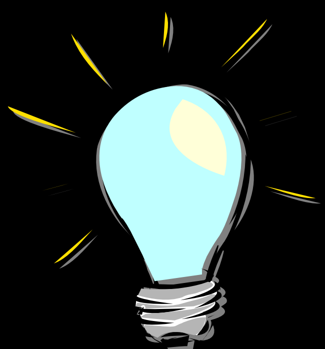
Mitsubishi Electric Research Labs (MERL), Cambridge, MA

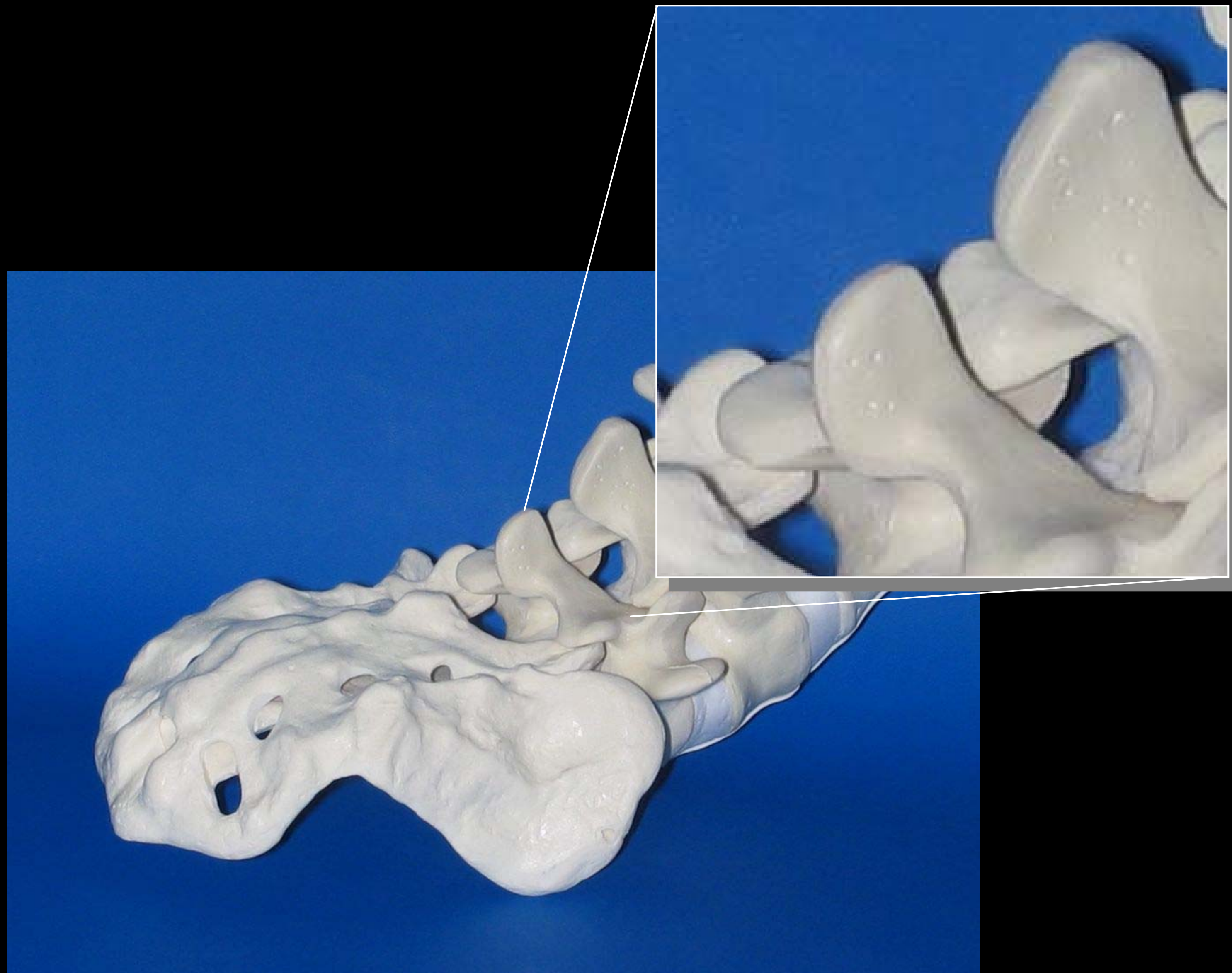
U of California at Santa Barbara

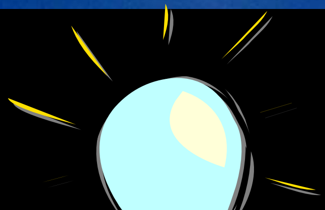
U of North Carolina at Chapel Hill

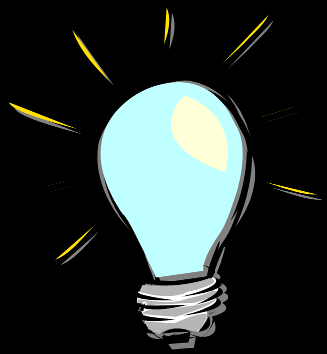
Depth Edge Camera







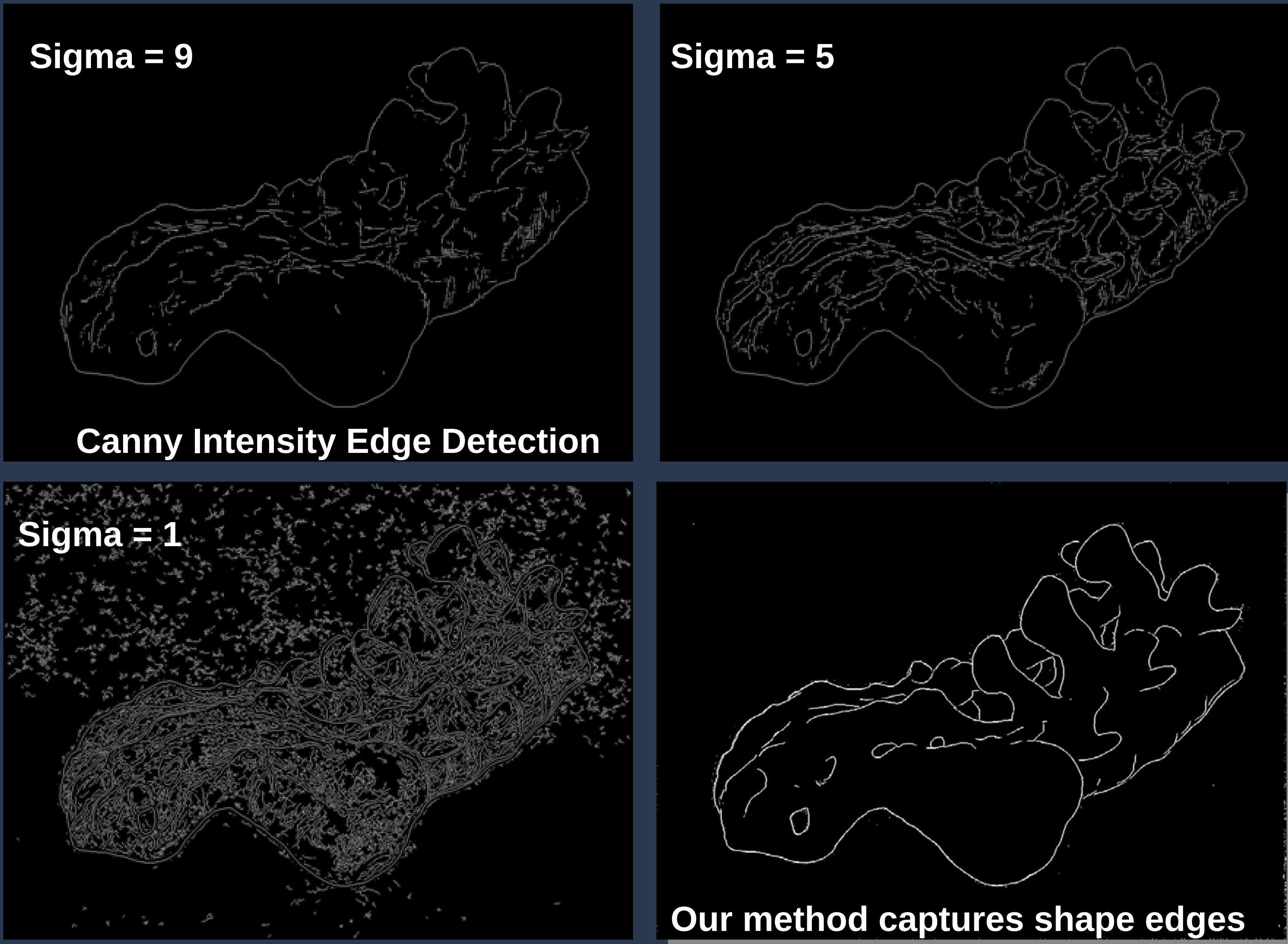


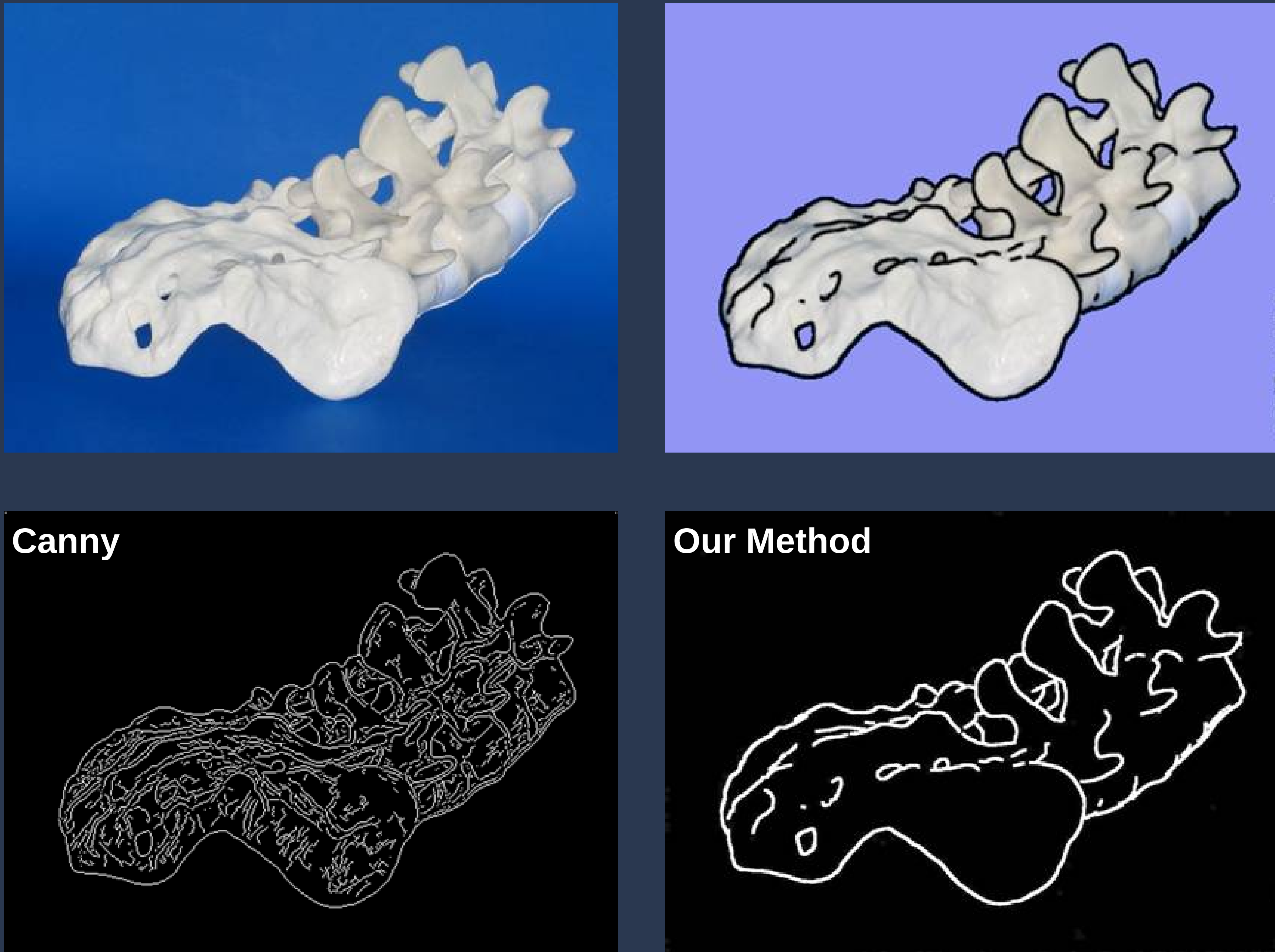




Depth Discontinuities

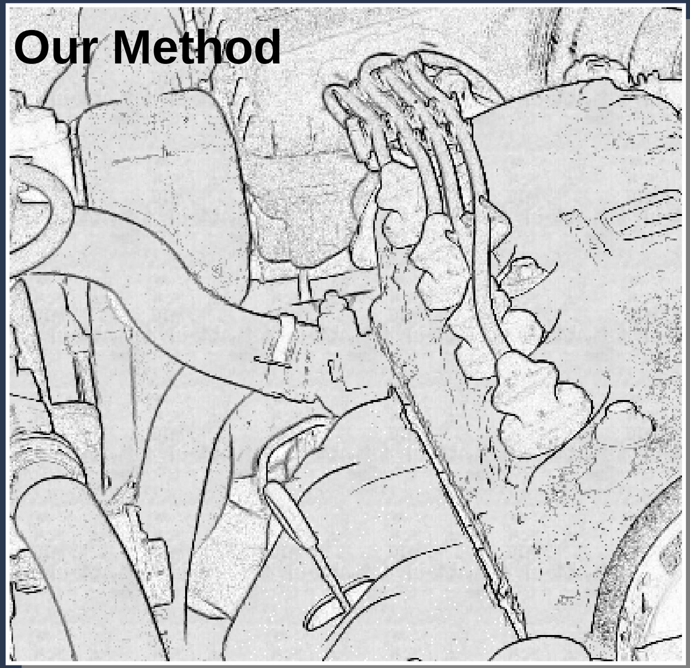
Internal and external
Shape boundaries, Occluding contour, Silhouettes


Depth
Edges


Sigma = 9
Canny Intensity Edge Detection
Sigma = 5
Sigma = 1
Our method captures shape edges


Canny
Our Method


Photo


Our Method

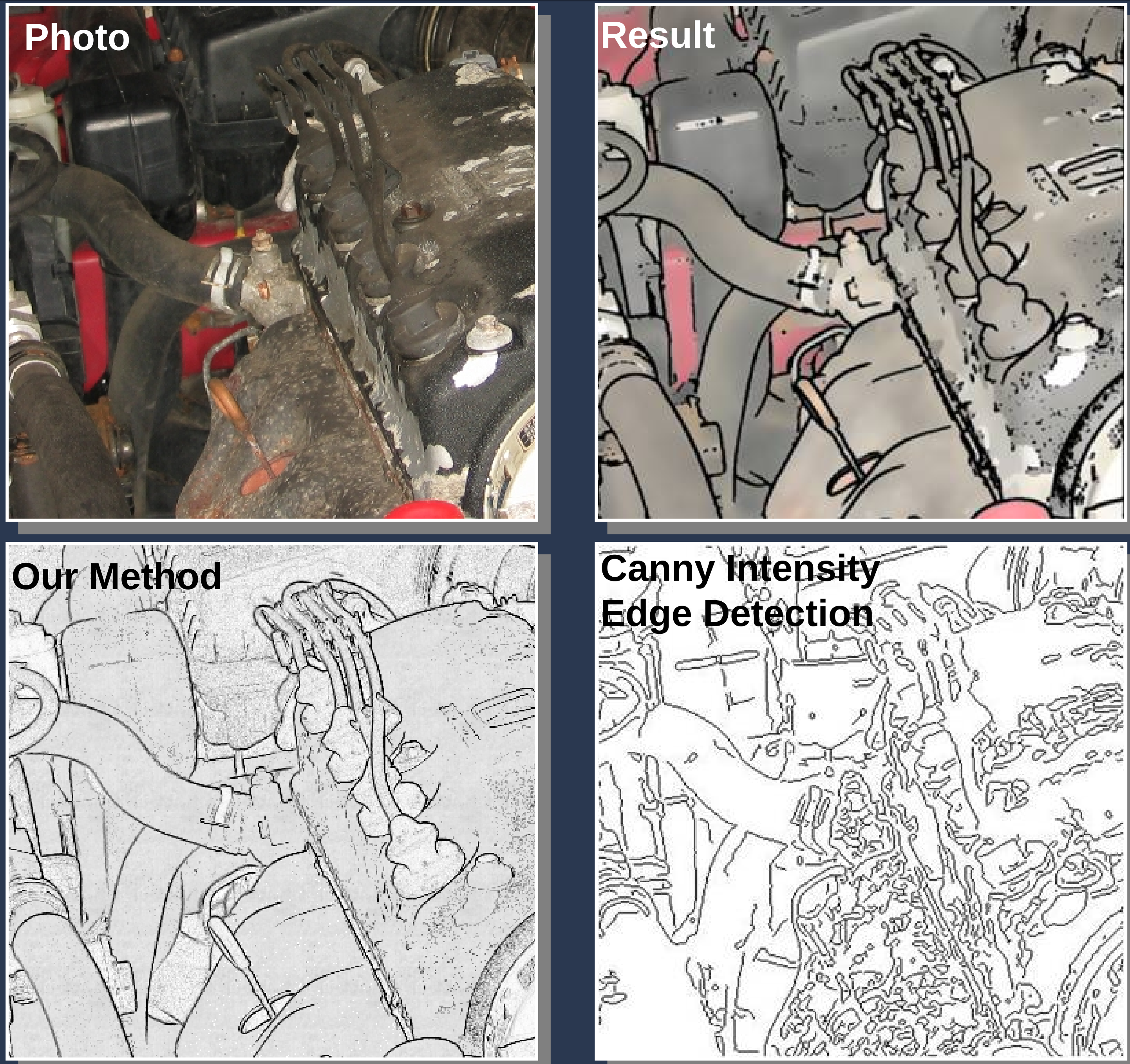
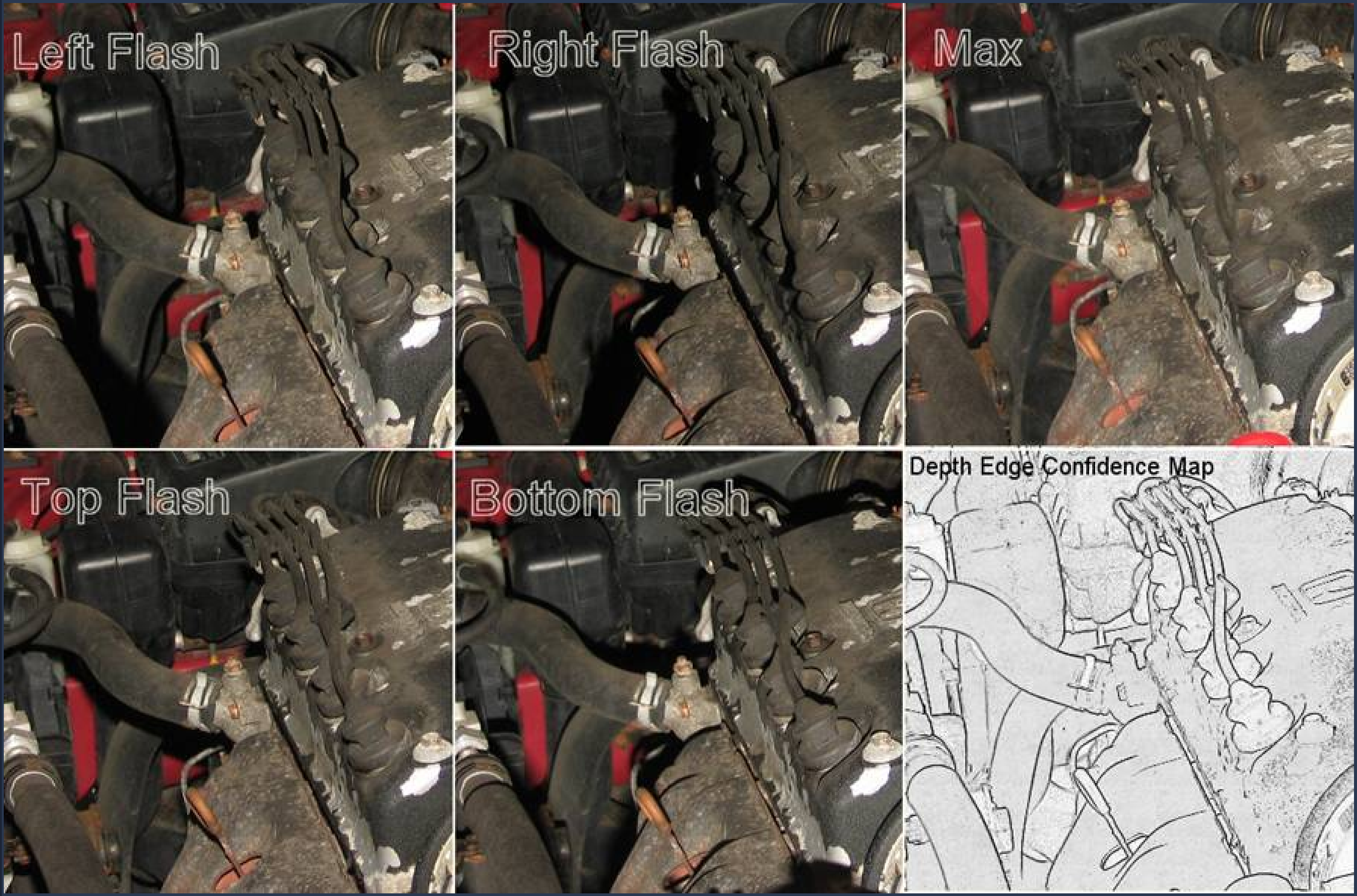
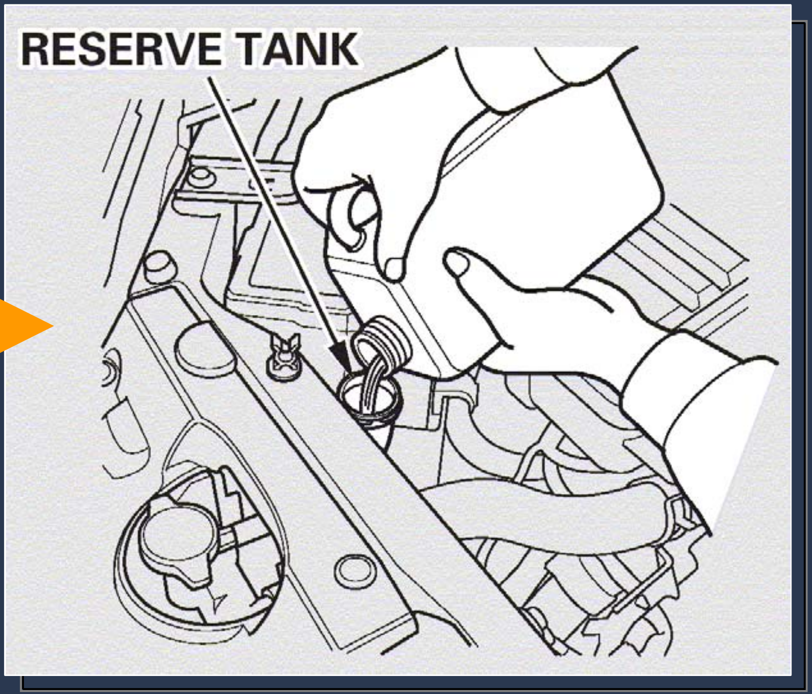


Photo
Result
Our Method
Canny Intensity
Edge Detection


Left Flash
Right Flash
Max
Top Flash
Bottom Flash
Depth Edge Confidence Map



Shadows

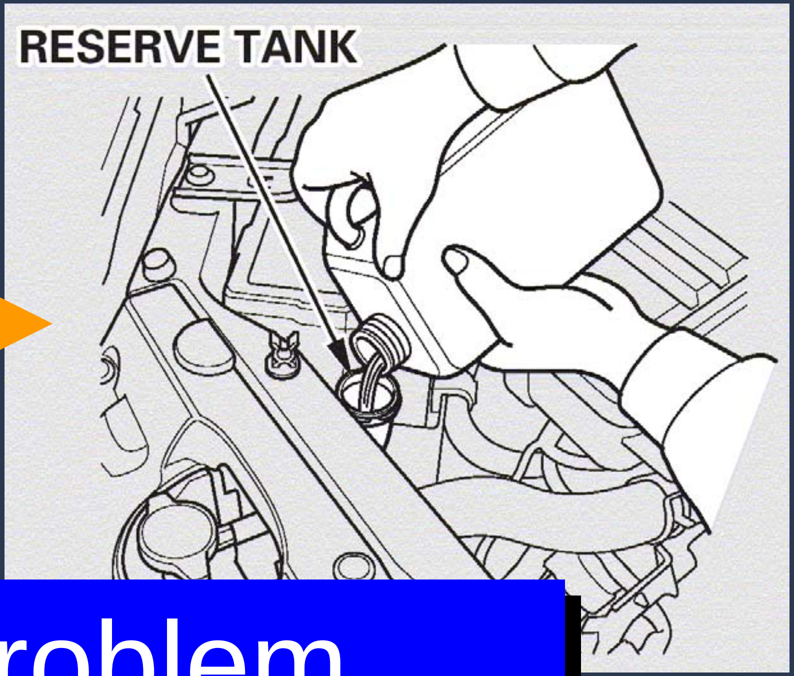
Clutter

Many Colors

Highlight Shape Edges

Mark moving parts

Basic colors



A New Problem

Shadows

Clutter

Many Colors

Highlight Edges

Mark moving parts

Basic colors

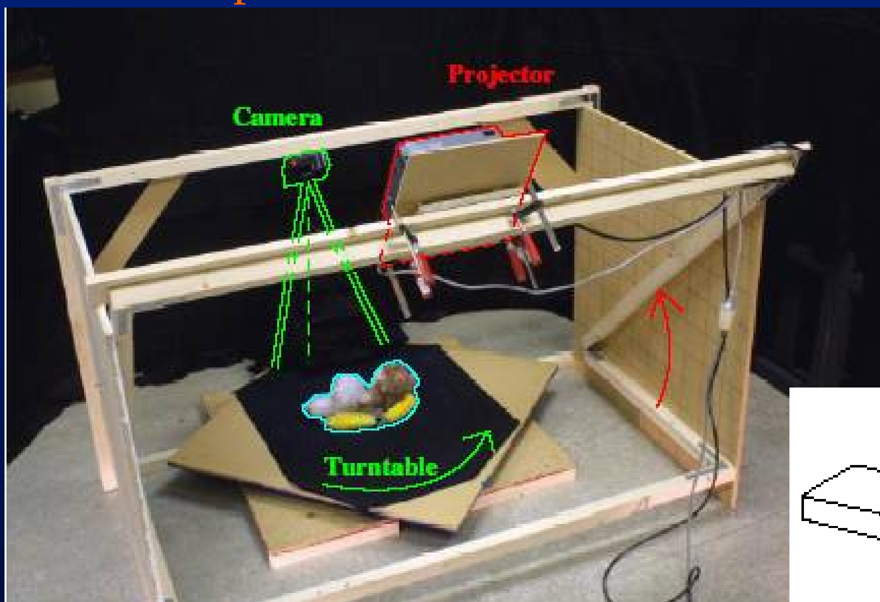
Computational Illumination

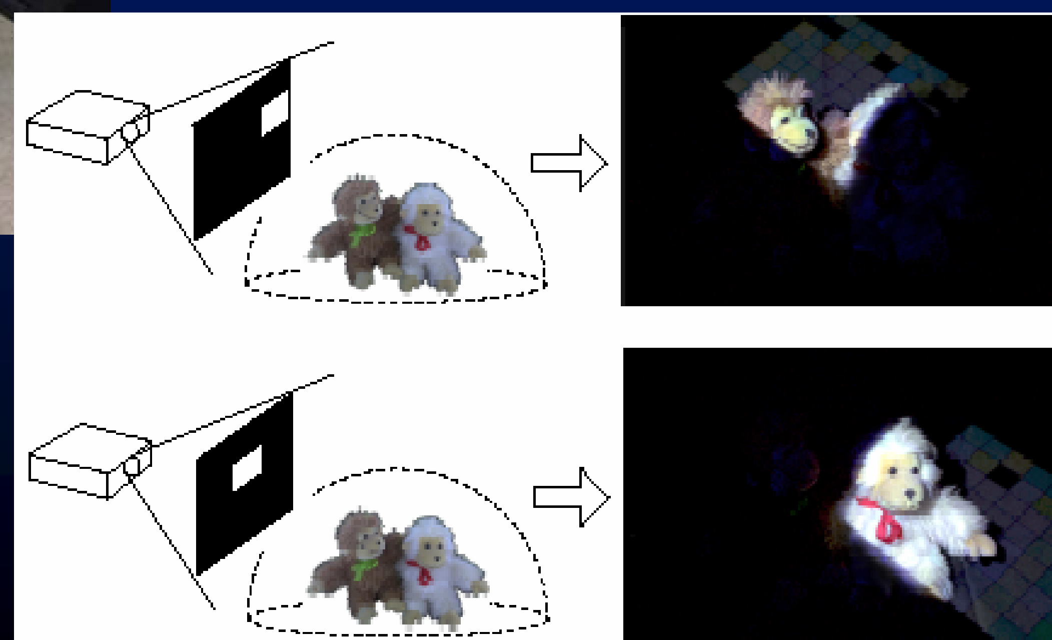
- Presence or Absence
  - Flash/No-flash
- Light position
  - Multi-flash for depth edges
  - Programmable dome (image re-lighting and matting)
- Light color/wavelength

- Spatial Modulation (Intra-flash 2D Modulation)
  - Synthetic Aperture Illumination
- Temporal Modulation
  - TV remote, Motion Tracking, Sony ID-cam, RFIG
- General lighting condition
  - Day/Night

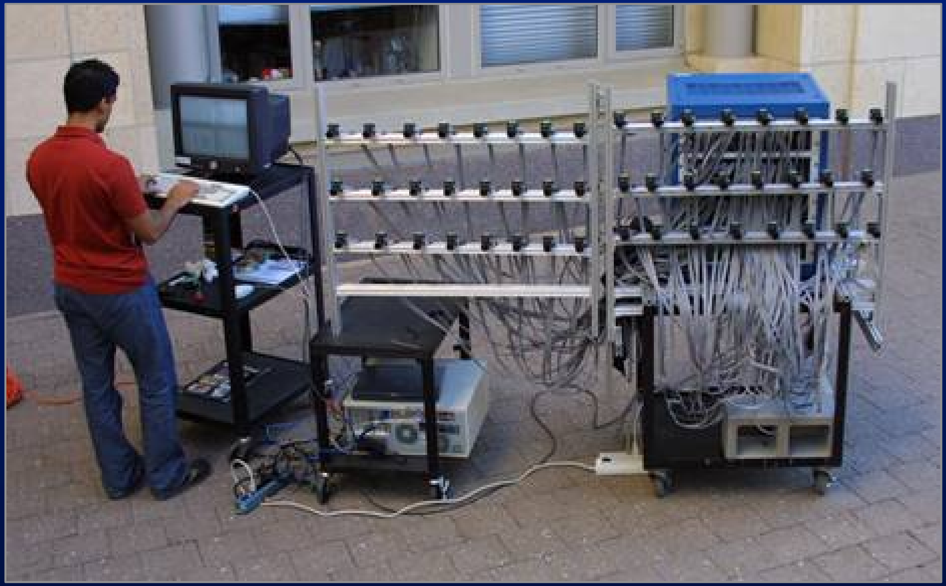
6-D Methods and beyond...

Relighting with 4D Incident Light Fields Vincent Masselus, Pieter Peers, Philip Dutre and Yves D. Willems SIGG2003



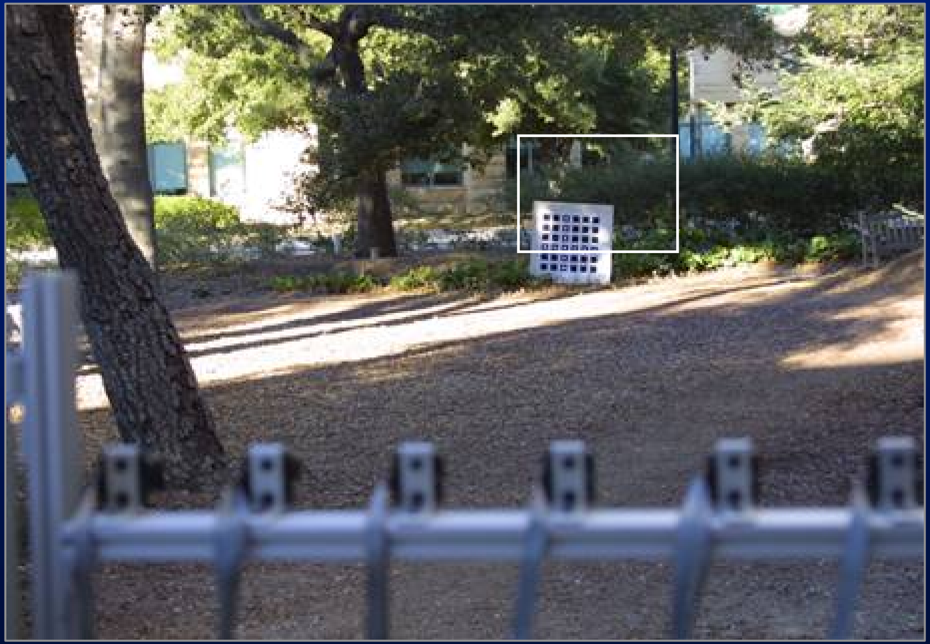


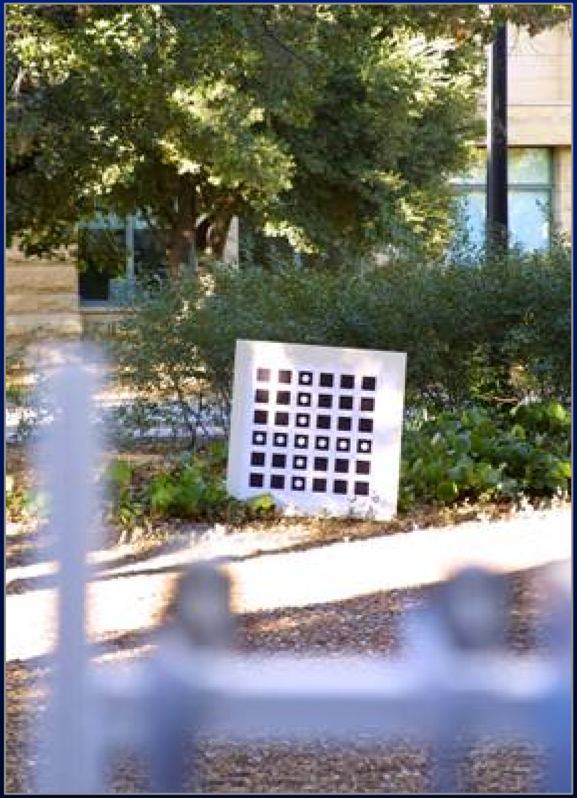
Synthetic Aperture Illumination: Comparison with Long-range synthetic aperture photography



• width of aperture	6’
• number of cameras	45
• spacing between cameras	5”
• camera’s field of view	4.5°

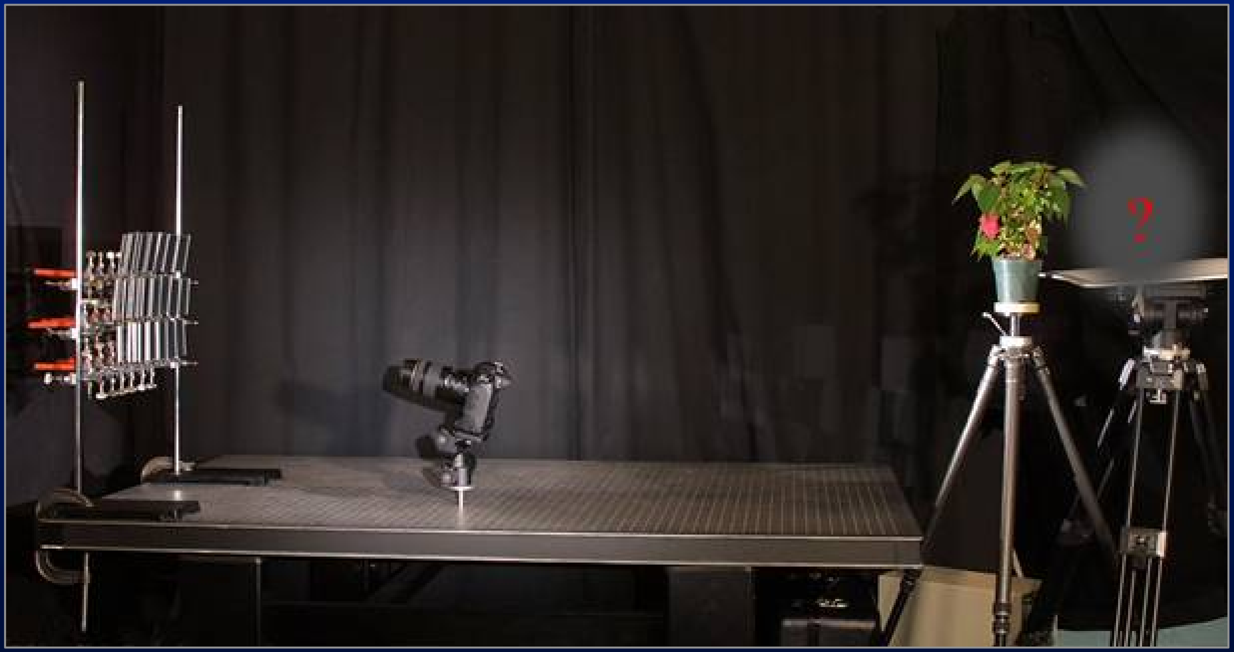
The scene





- distance to occluder 110’
- distance to targets 125’
- field of view at target 10’

Synthetic aperture photography using an array of mirrors

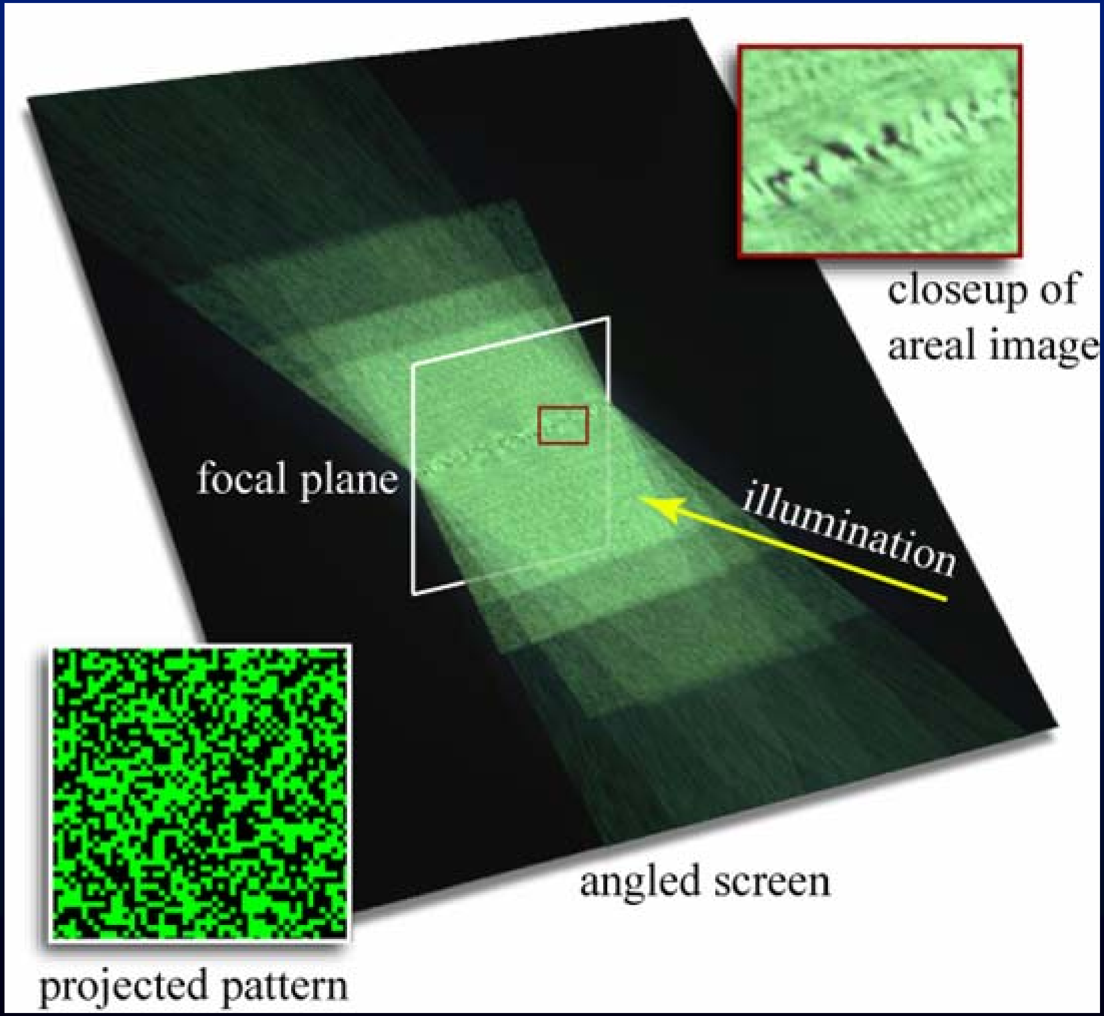


- 11-megapixel camera (4064 x 2047 pixels)
- 18 x 12 inch effective aperture, 9 feet to scene
- 22 mirrors, tilted inwards $\rightarrow$ 22 views, each 750 x 500 pixels

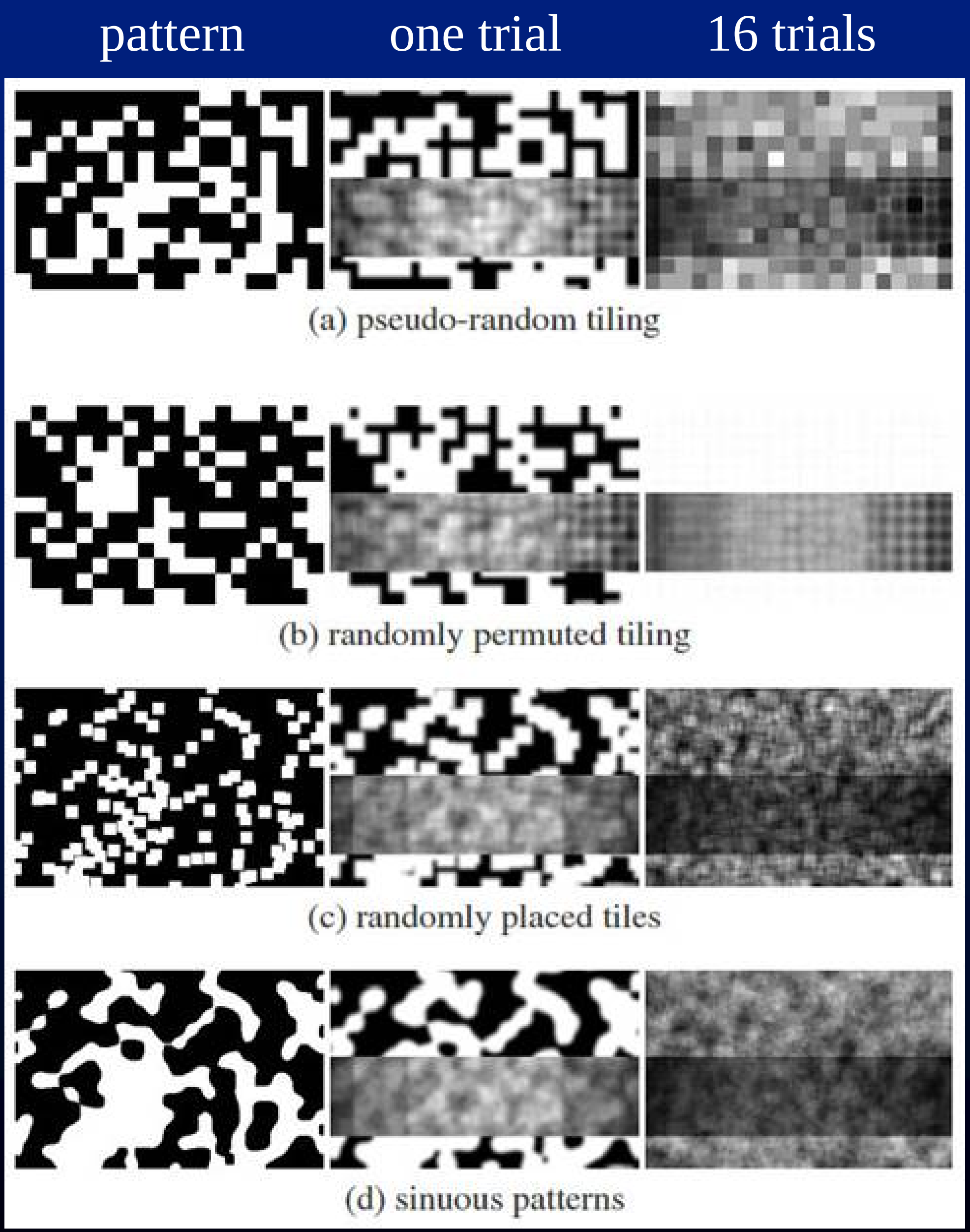
Synthetic aperture illumination

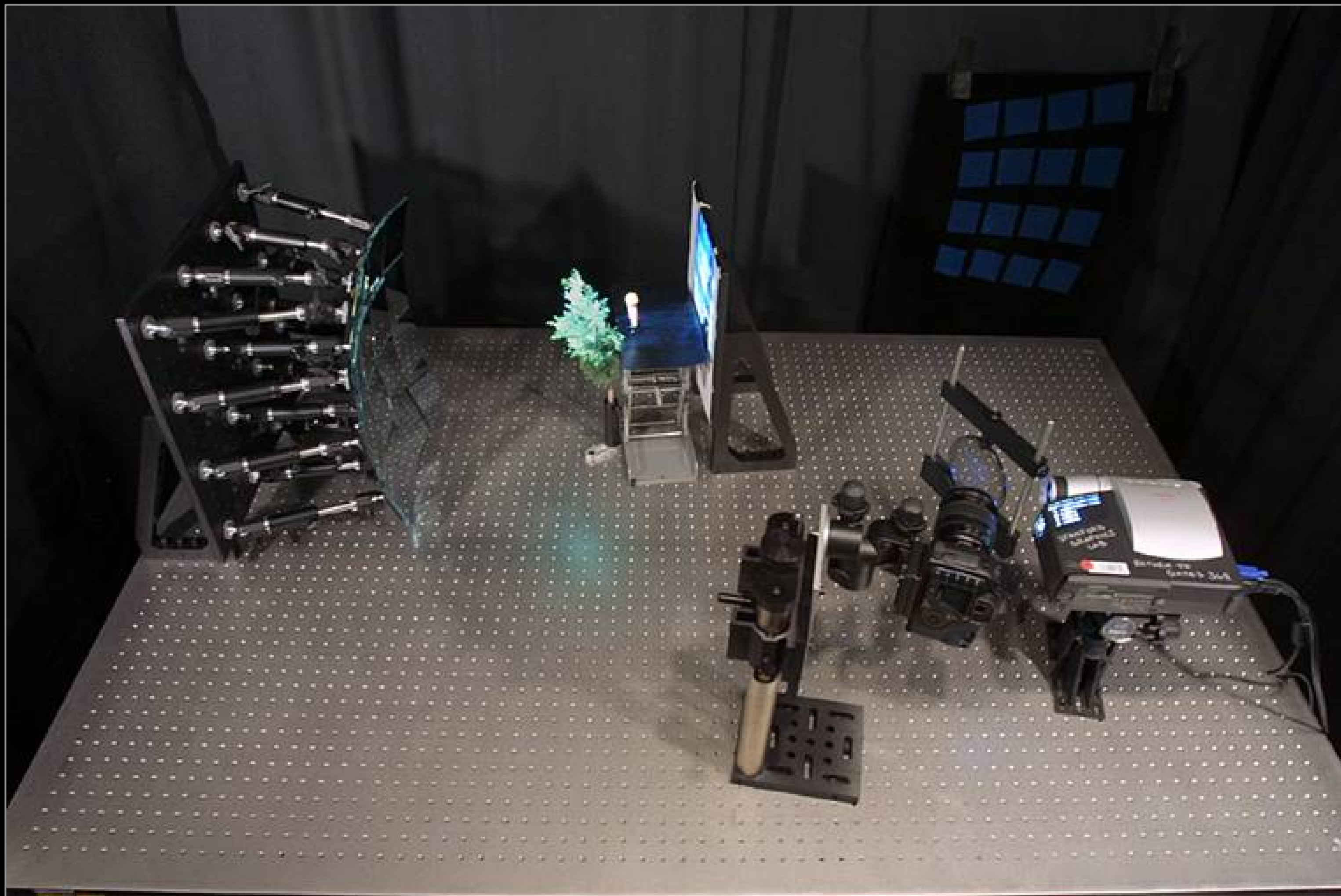
- technologies
  - array of projectors
  - array of microprojectors
  - single projector + array of mirrors

What does synthetic aperture illumination look like?

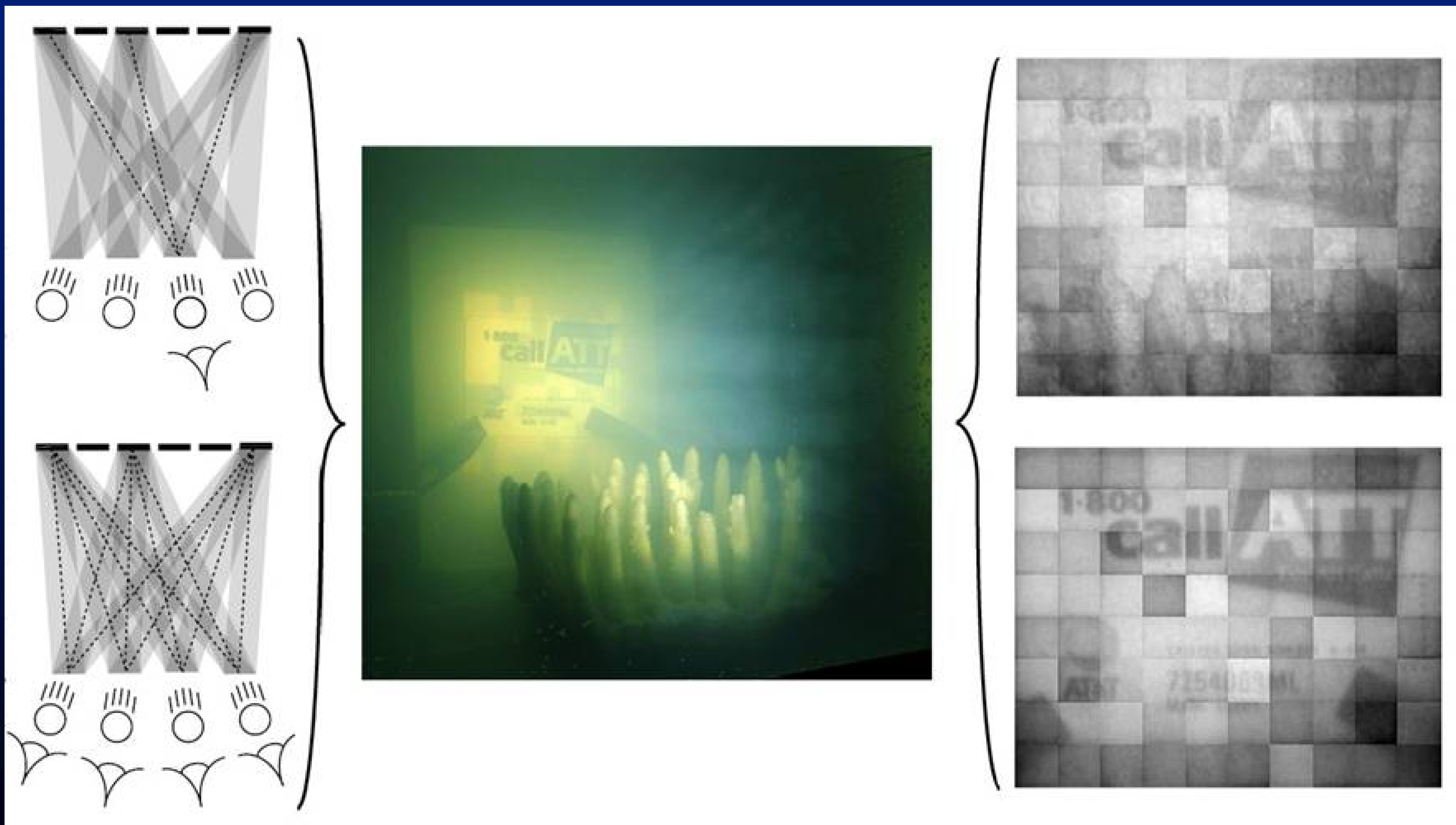


What are good patterns?





Underwater confocal imaging with and without SAP



Computational Illumination

- Presence or Absence
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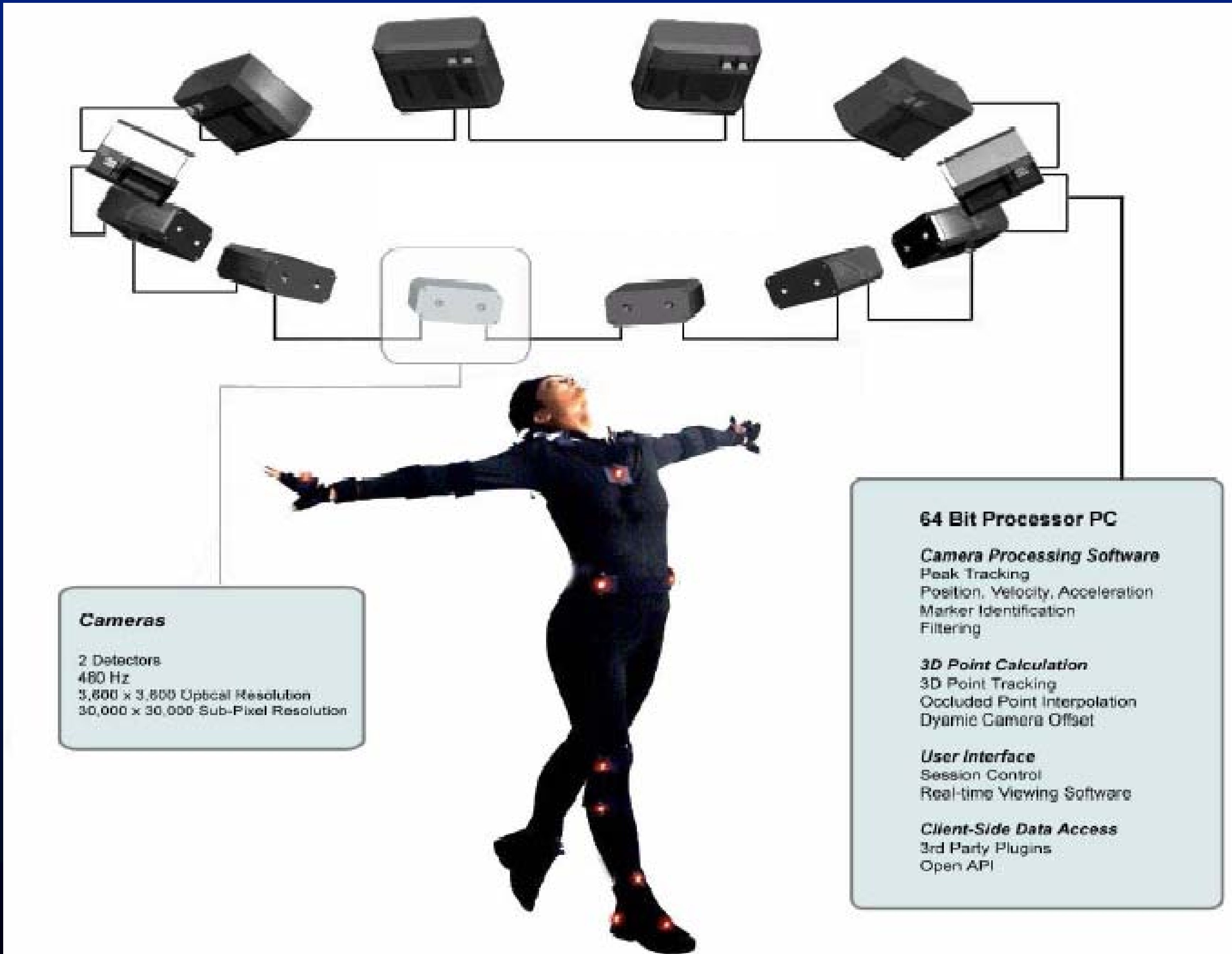
  - Day/Night

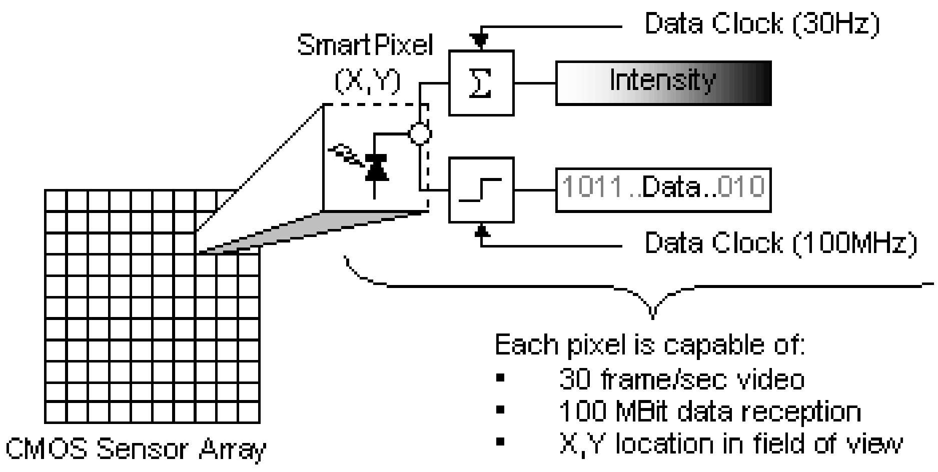
Demodulating Cameras

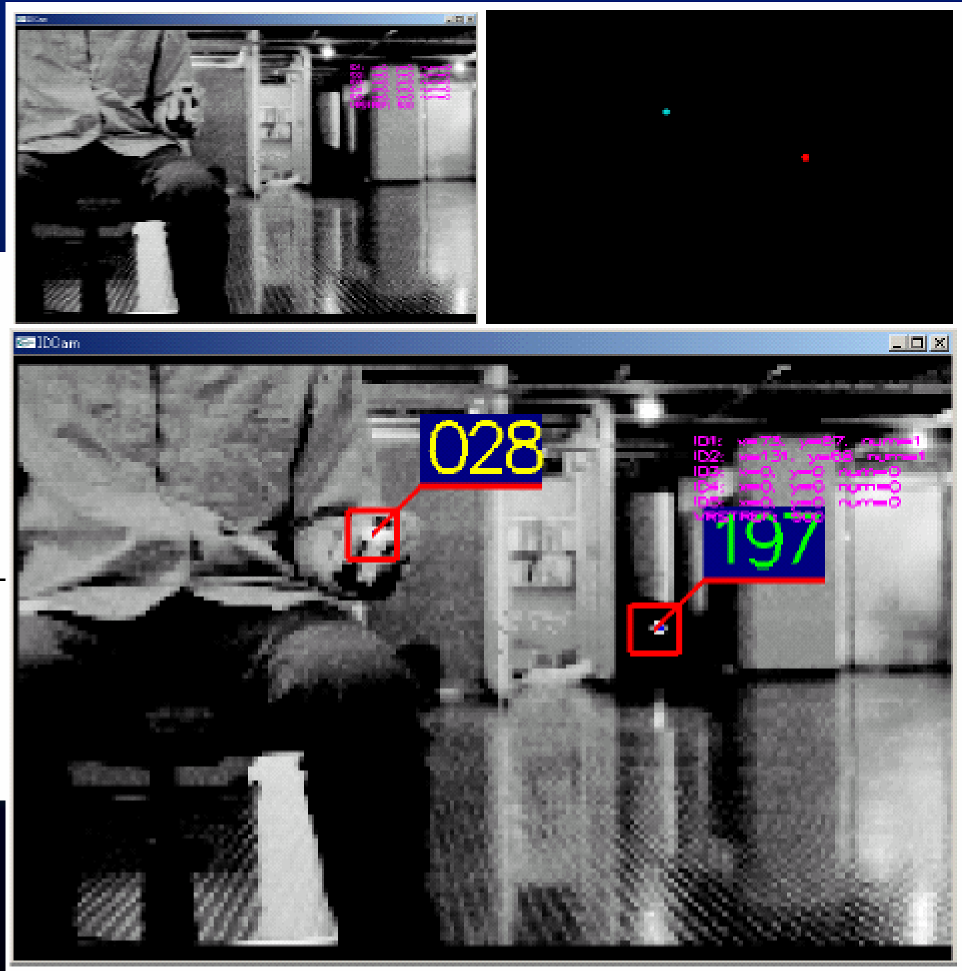
- Motion Capture Cameras
  - Visualeyez™ VZ4000 Tracking System
  - PhaseSpace motion digitizer


Cameras
2 Detectors
480 Hz
3,600 x 3,600 Optical Resolution
30,000 x 30,000 Sub-Pixel Resolution
64 Bit Processor PC
Camera Processing Software
Peak Tracking
Position, Velocity, Acceleration
Marker Identification
Filtering
3D Point Calculation
3D Point Tracking
Occluded Point Interpolation
Dyamic Camera Offset
User Interface
Session Control
Real-time Viewing Software
Client-Side Data Access
3rd Party Plugins
Open API

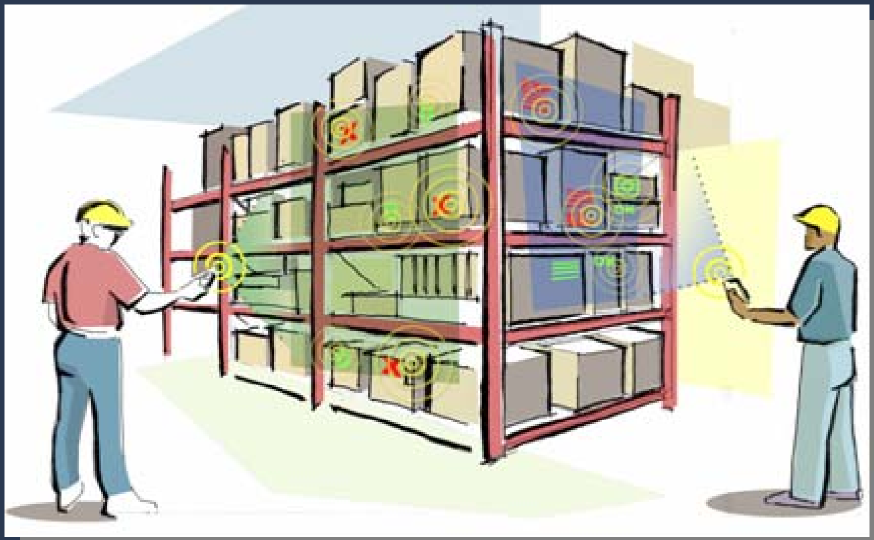
Demodulating Cameras

- Decode signals from blinking LEDs + image
  - Sony ID Cam
  - Phoci





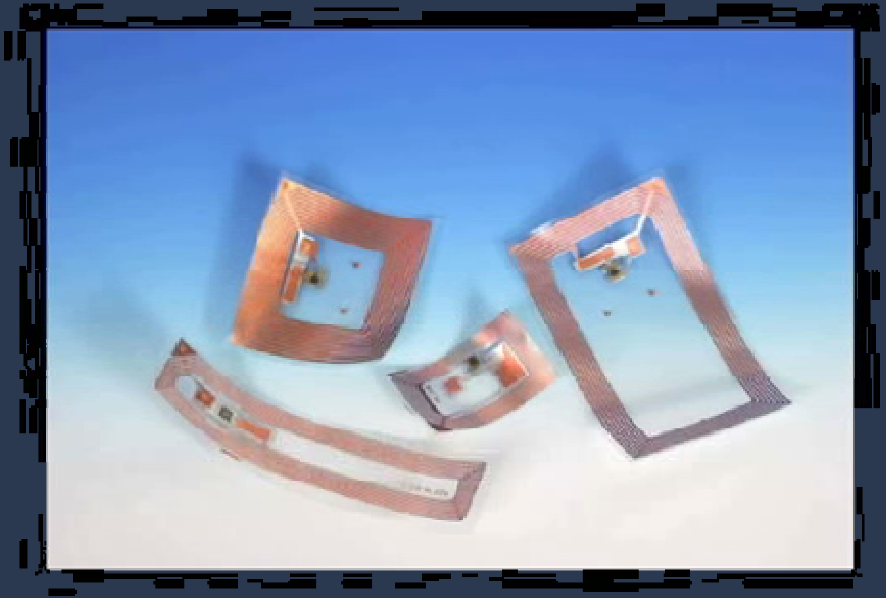
R F I G Lamps :
Interacting with a Self-describing World via Photosensing Wireless Tags and Projectors

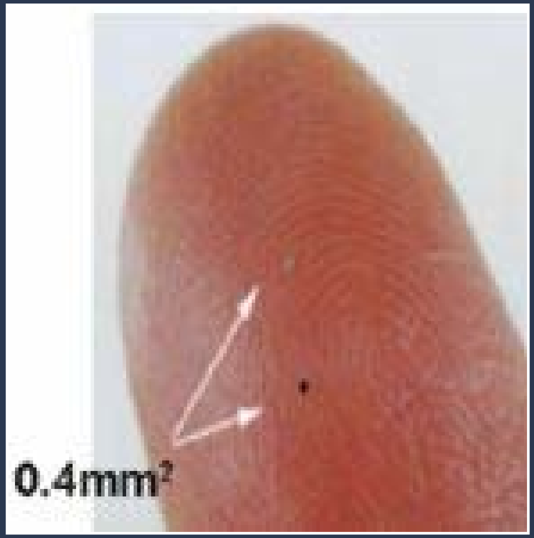


Ramesh Raskar, Paul Beardsley, Jeroen van Baar, Yao Wang, Paul Dietz, Johnny Lee, Darren Leigh, Thomas Willwacher

Mitsubishi Electric Research Labs (MERL), Cambridge, MA

Radio Frequency Identification Tags (RFID)





No batteries,

Small size,

Cost few cents

Warehousing

Routing

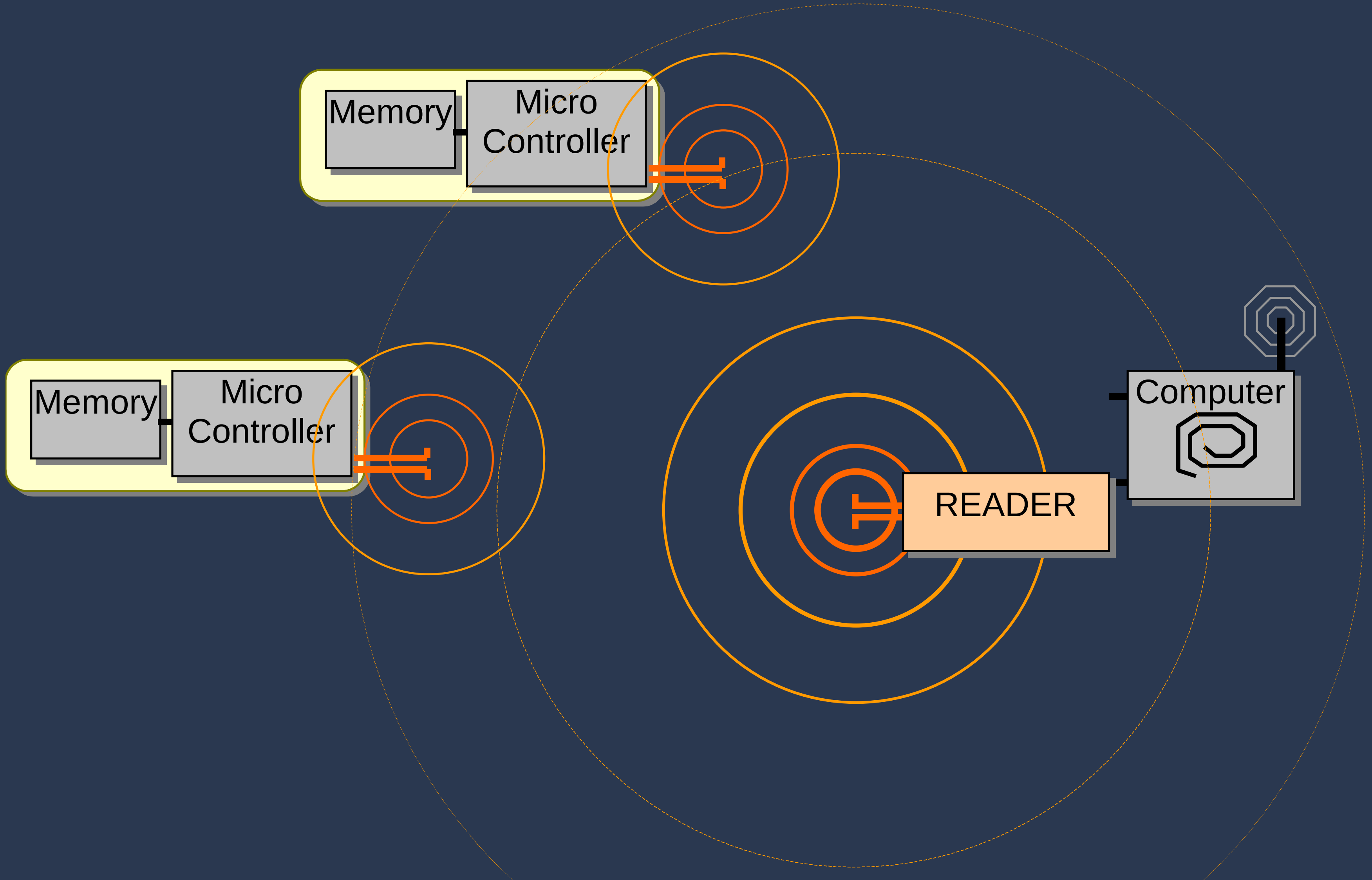
Livestock tracking

Library

Baggage handling

Currency

Conventional Passive RFID



Tagged Books in a Library

✓ **Id**

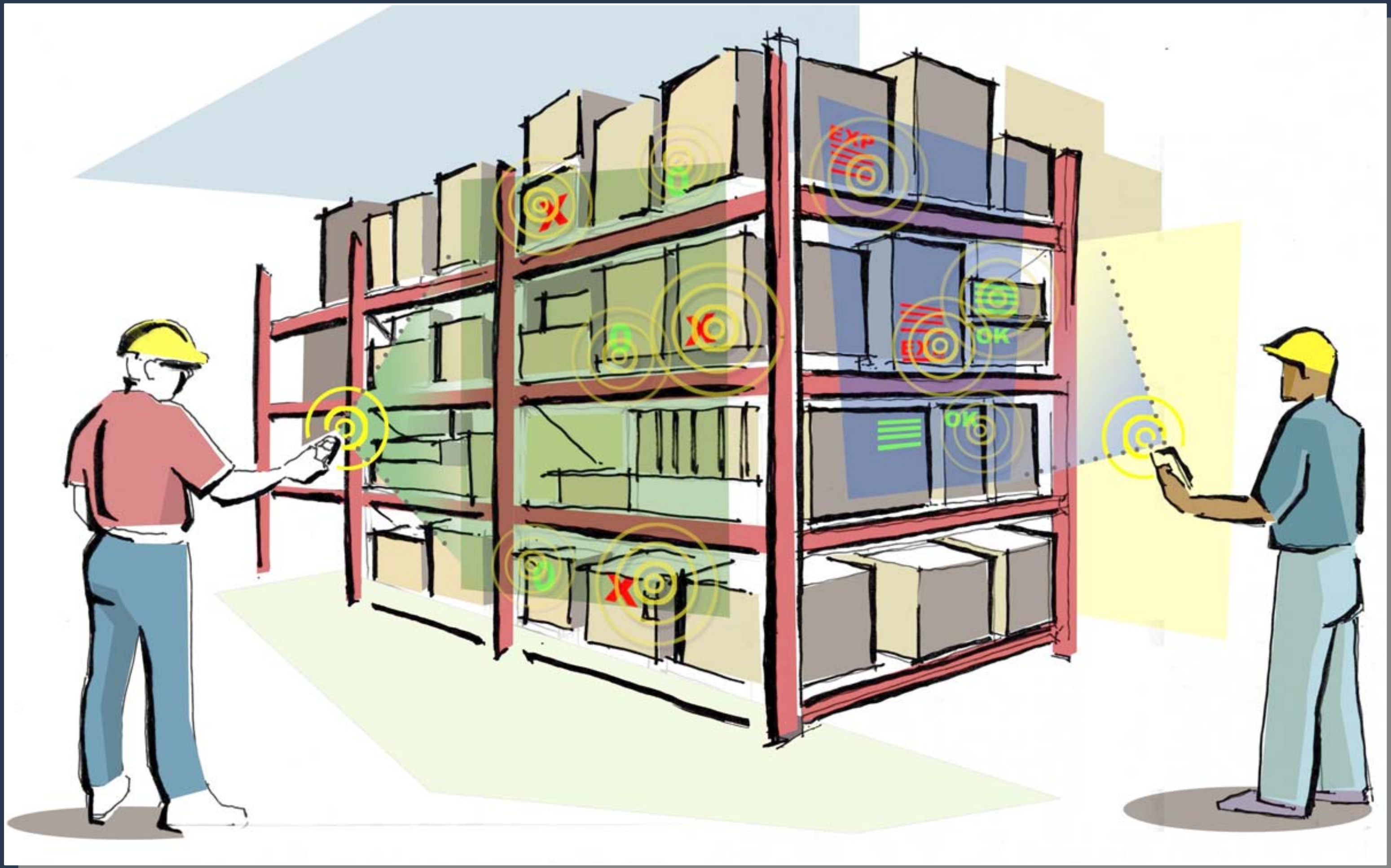
Easy to get list of books in RF range

✘ **No Precise Location Data**

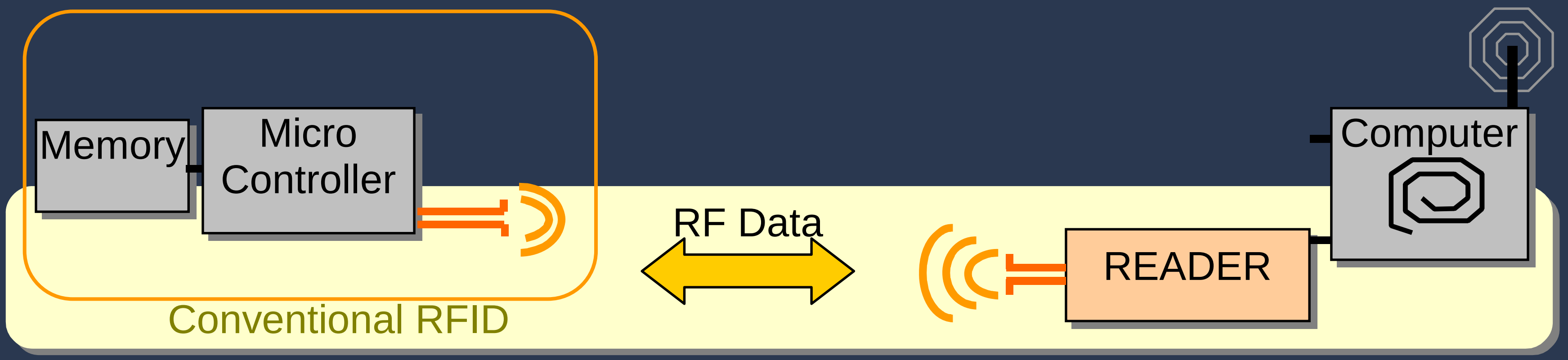
Difficult to find if the books in sorted order ?

Which book is upside down ?

Where are boxes with Products close to Expiry Date ?



Conventional RF tag



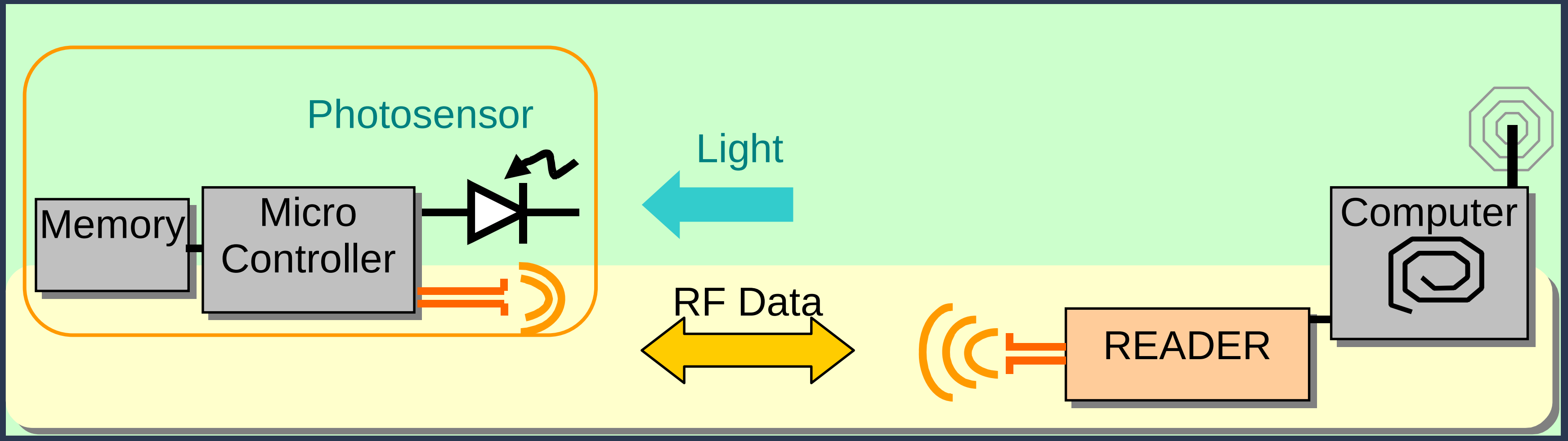
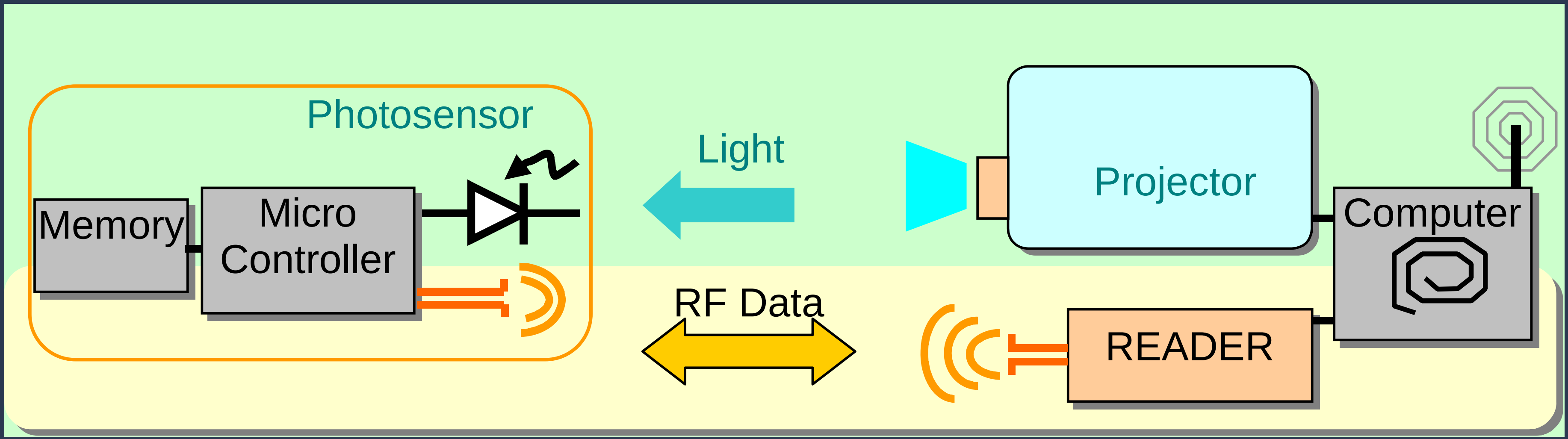


Photo-sensing RF tag



Photosensor ?

Compatible with RFID size and power needs

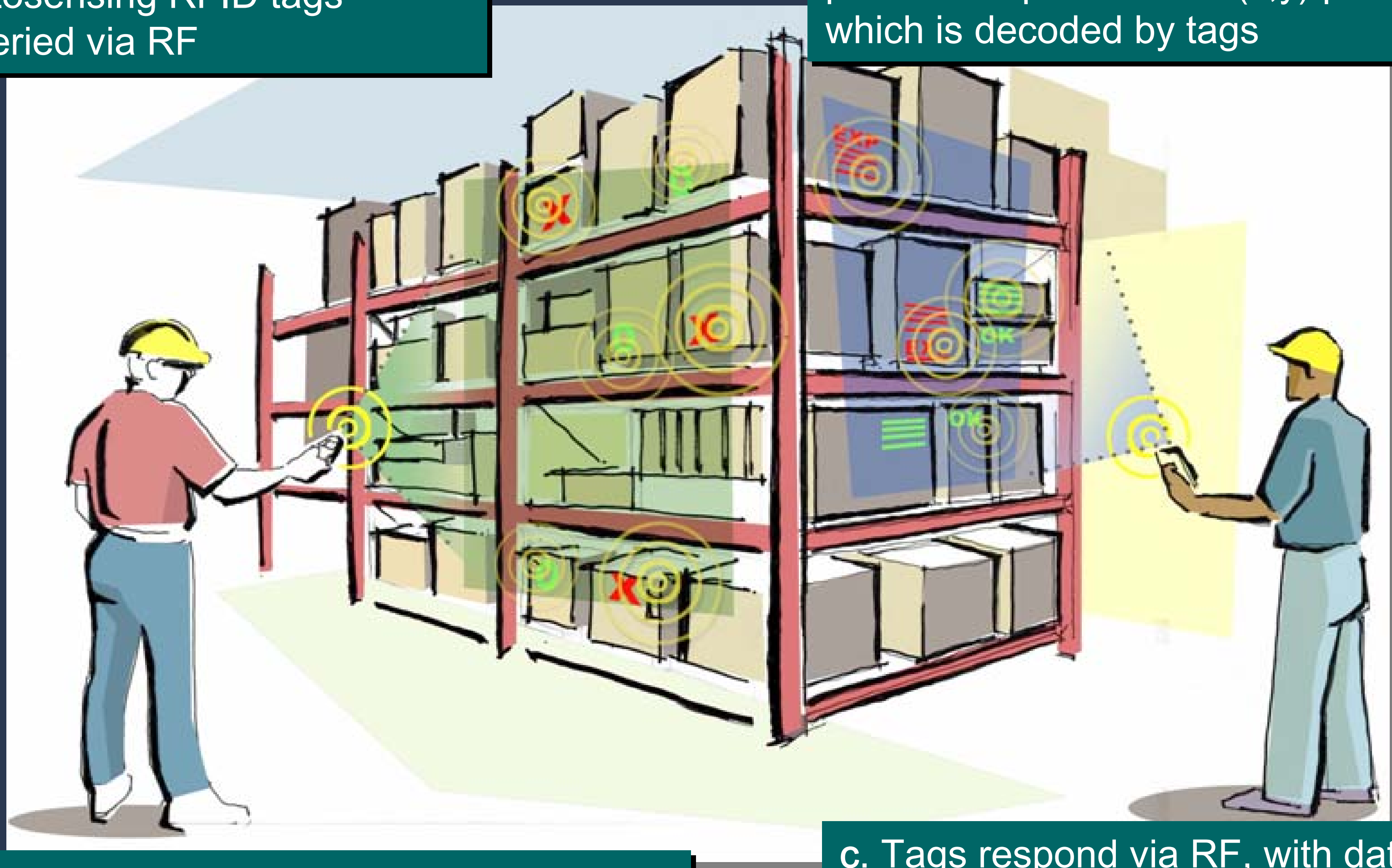
Projector ?

Directional transfer, AR with Image overlay

Raskar, Beardsley, vanBaar, Wang, Dietz, Lee, Leigh, Willwacher

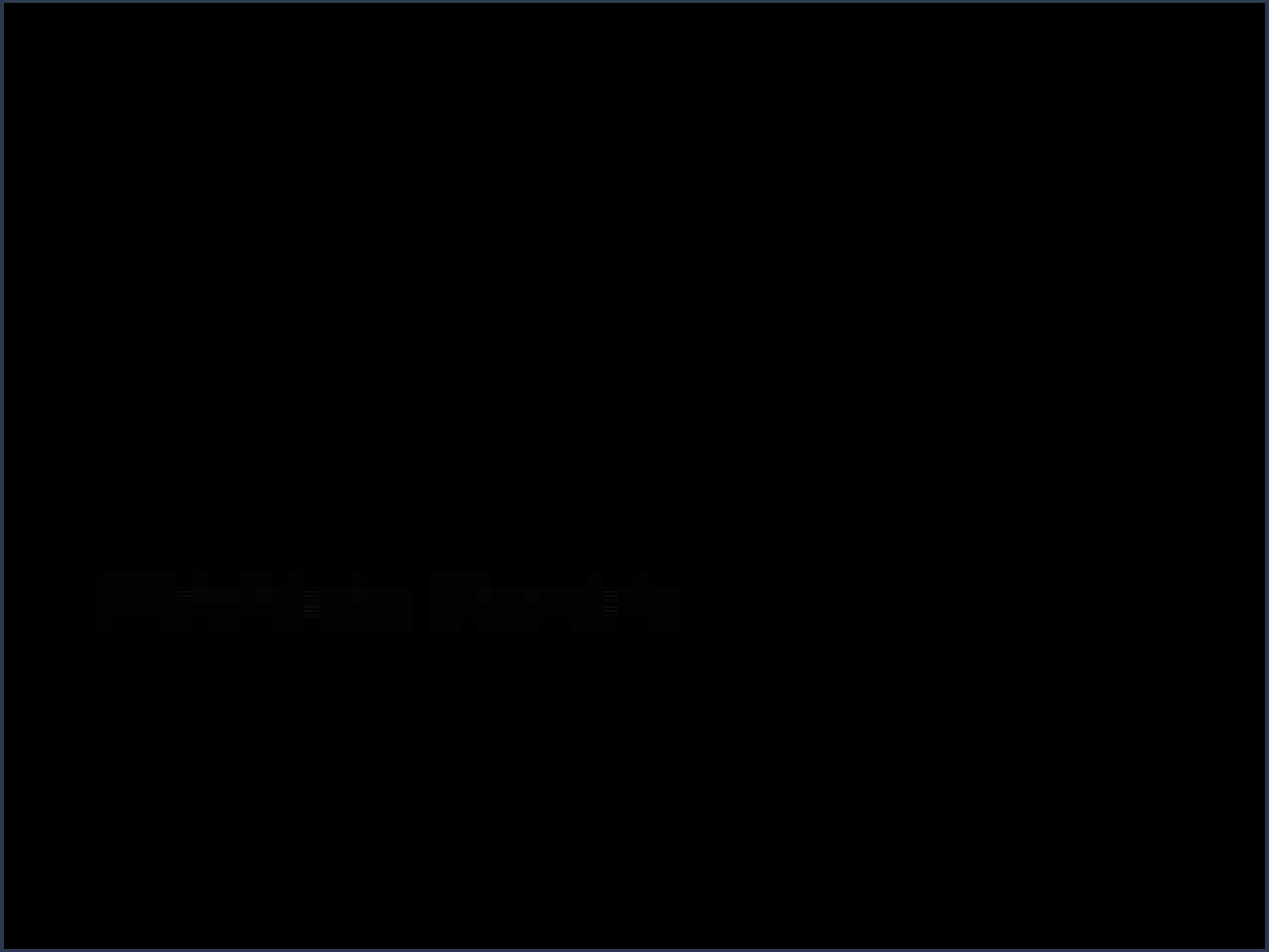
b. Projector beams a time-varying pattern unique for each (x,y) pixel which is decoded by tags

a. Photosensing RFID tags are queried via RF



d. Multiple users can simultaneously work from a distance without RF collision

c. Tags respond via RF, with date and precise (x,y) pixel location. Projector beams ‘O’ or ‘X’ at that location for visual feedback



RFID

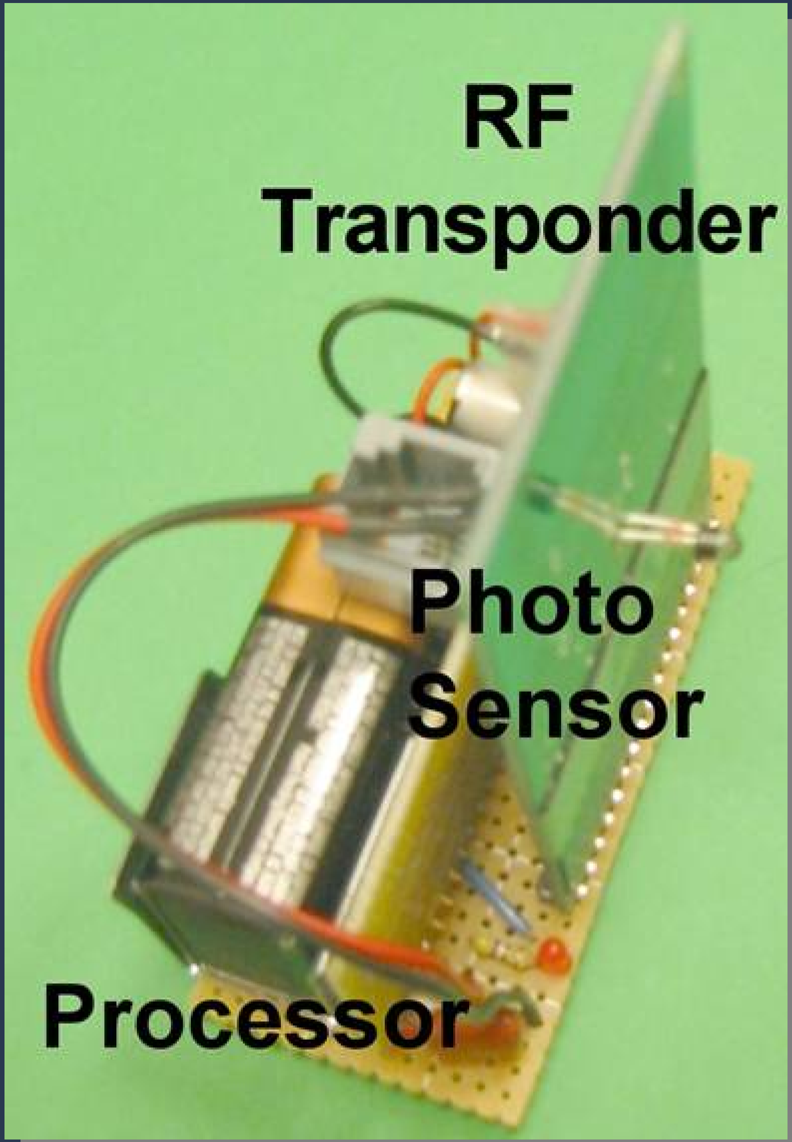
(Radio Frequency Identification)

⬇

RFIG

(Radio Frequency Id and Geometry)

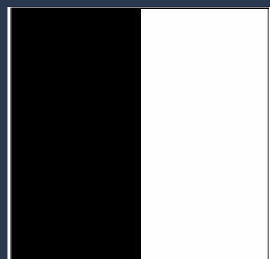
Prototype Tag



RF tag + photosensor

Projected Sequential Frames

Pattern MSB | Pattern MSB-1 | – – – – | Pattern LSB

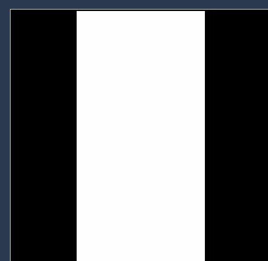


- Handheld Projector beams binary coded stripes
- Tags decode temporal code

Raskar, Beardsley, vanBaar, Wang, Dietz, Lee, Leigh, Willwacher

Projected Sequential Frames

Pattern MSB | Pattern MSB-1 | – – – – | Pattern LSB



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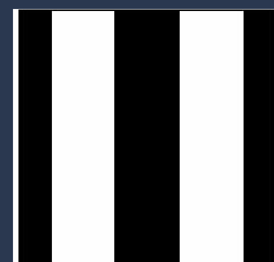
Projected Sequential Frames

Pattern MSB | Pattern MSB-1 | – – – – | Pattern LSB



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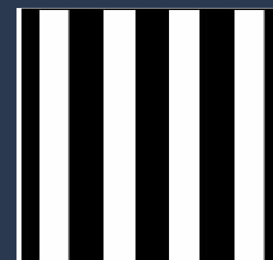
Projected Sequential Frames

Pattern MSB | Pattern MSB-1 | – – – – | Pattern LSB



- Handheld Projector beams binary coded stripes
- Tags decode temporal code

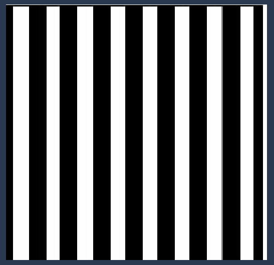
Projected Sequential Frames

Pattern MSB

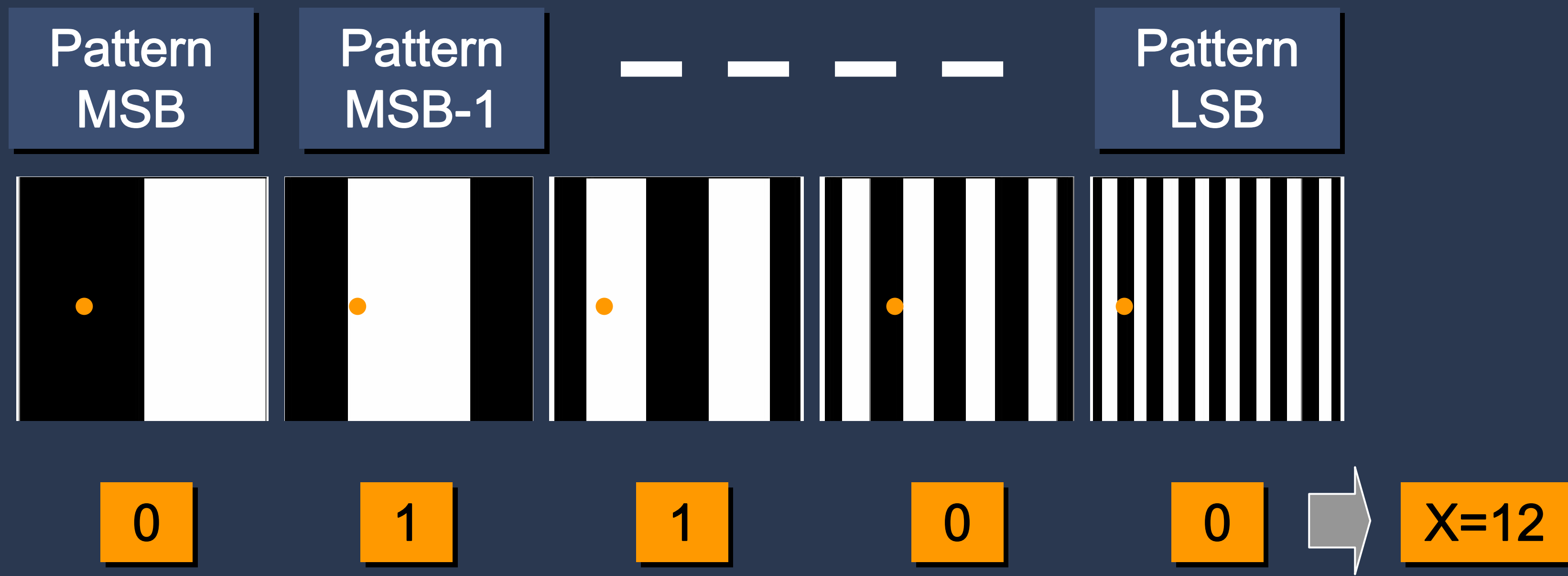
Pattern MSB-1

– – – –

Pattern LSB



- Handheld Projector beams binary coded stripes
- Tags decode temporal code



For each tag

a. From light sequence, decode *x* and *y* coordinate

b. Transmit back to RF reader *(Id, x, y)*

Visual feedback of 2D position

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

b. Illuminate those positions

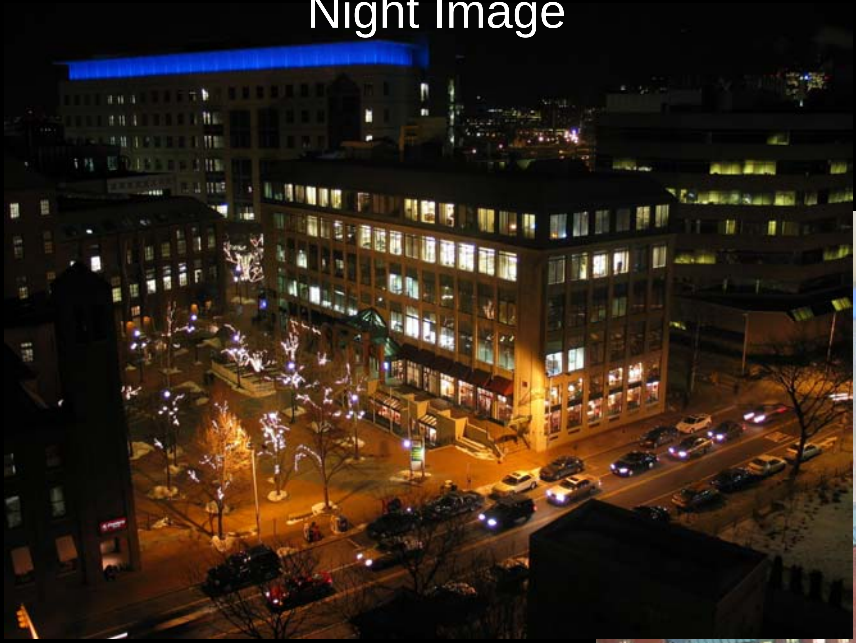
Computational Illumination

- Presence or Absence
  - Flash/No-flash
- Light position
  - Multi-flash for depth edges
  - Programmable dome (image re-lighting and matting)
- Light color/wavelength
- Spatial Modulation
  - Synthetic Aperture Illumination
- Temporal Modulation
  - TV remote, Motion Tracking, Sony ID-cam, RFIG
- Natural lighting condition
  - Day/Night Fusion

A Night Time Scene:
Objects are Difficult to Understand due to Lack of Context

Enhanced Context :
All features from night scene are preserved, but background in clear

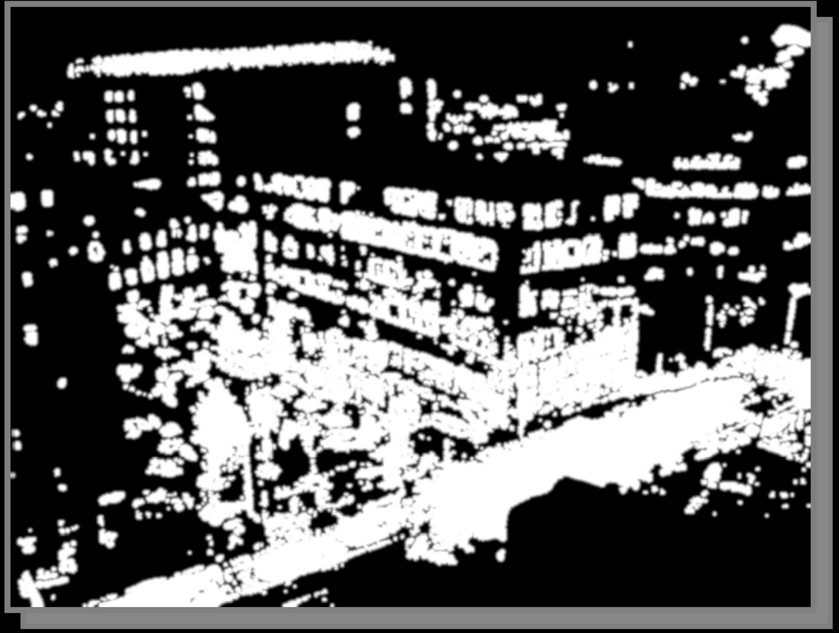
Night Image



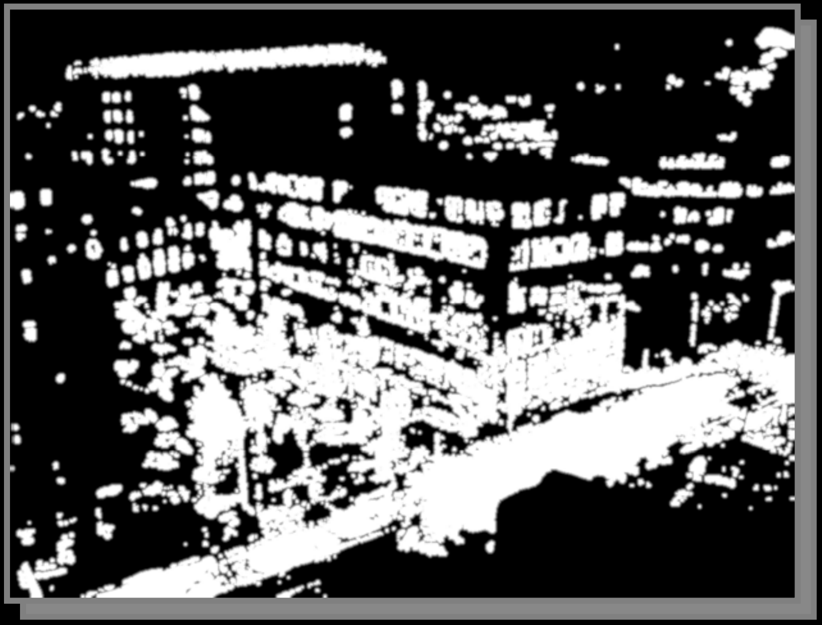
Background is captured from day-time scene using the same fixed camera

Result: Enhanced Image

Day Image



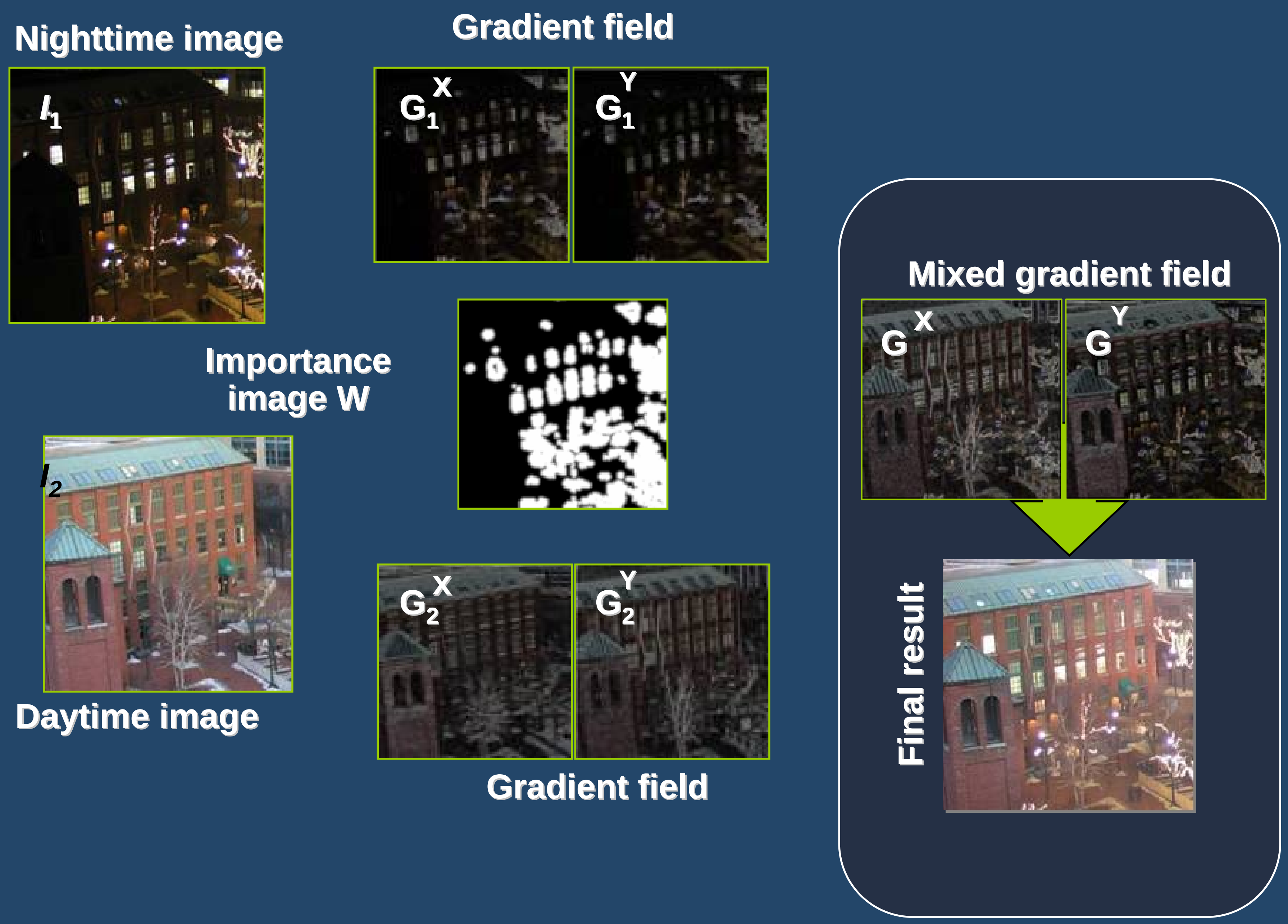
Mask is automatically computed from scene contrast



But, Simple Pixel Blending Creates Ugly Artifacts

Pixel Blending

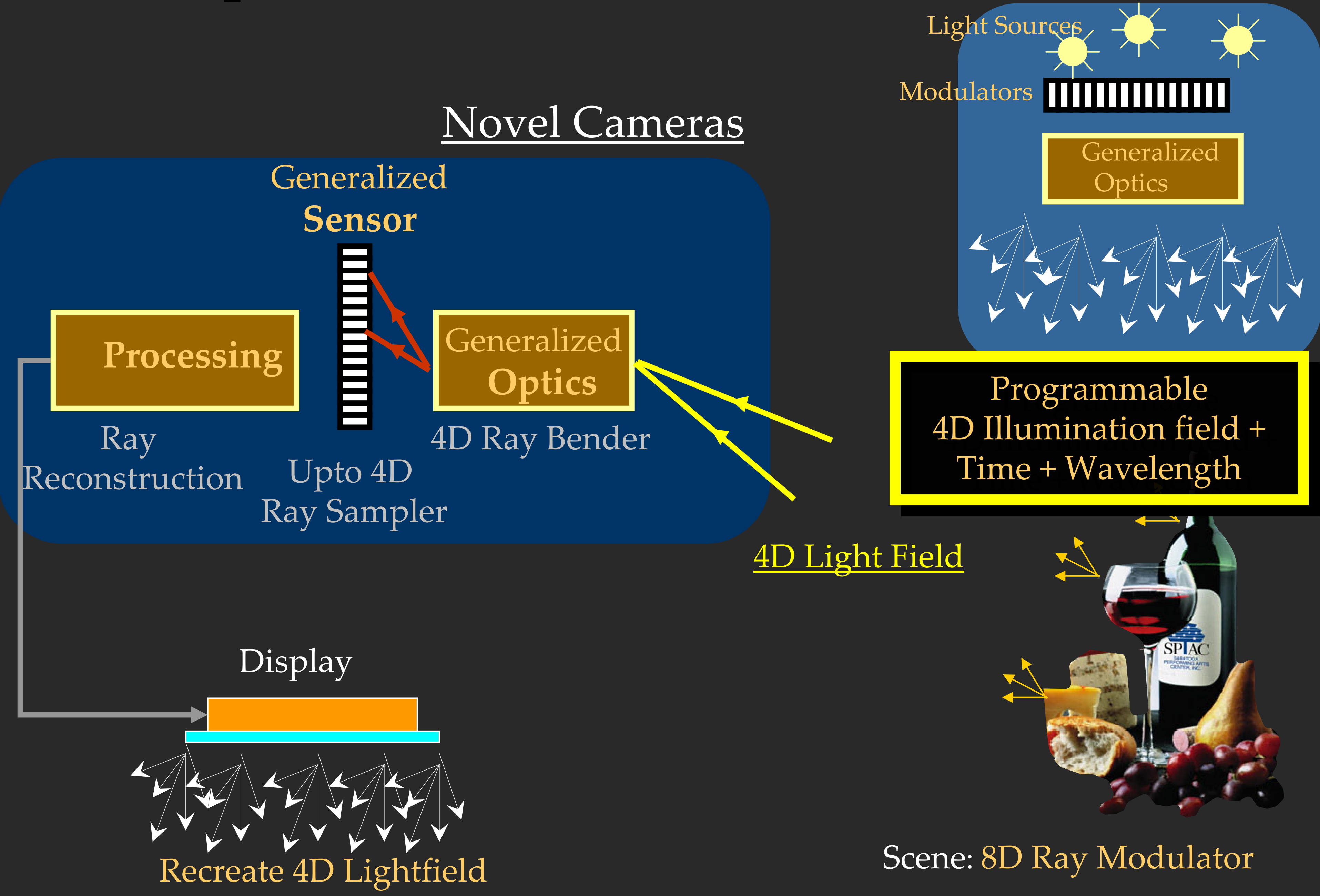
<u>Our Method</u>:
Integration of
blended Gradients


Nighttime image
I1
Gradient field
G1 X
G1 Y
Importance image W
Daytime image
I2
G2 X
G2 Y
Gradient field
Mixed gradient field
G X
G Y
Final result

'Smarter' Lighting Equipment

Programmable Parameters

Computational Illumination



Computational Illumination:

Programmable 4D Illumination Field + Time + Wavelength

- Presence or Absence, Duration, Brightness
  - Flash/No-flash
- Light position
  - Multi-flash for depth edges
  - Programmable dome (image re-lighting and matting)
- Light color/wavelength

- Spatial Modulation
  - Synthetic Aperture Illumination
- Temporal Modulation
  - TV remote, Motion Tracking, Sony ID-cam, RFIG
- Exploiting (uncontrolled) natural lighting condition
  - Day/Night Fusion