Computational Camera & Photography:

Ramesh Raskar

MIT Media Lab

htttp://cameraculture.media.mit.edu/

Taking Notes

- Use slides I post on the site
- Write down anecdotes and stories
- Try to get what is NOT on the slide
- Summarize questions and answers

- Take photos of demos + doodles on board

  – Use laptop to take notes
  – Send before next Monday

Homework

- Take multiple photos by changing lighting other parameters. Be creative.
- Mix and match color channels to relight

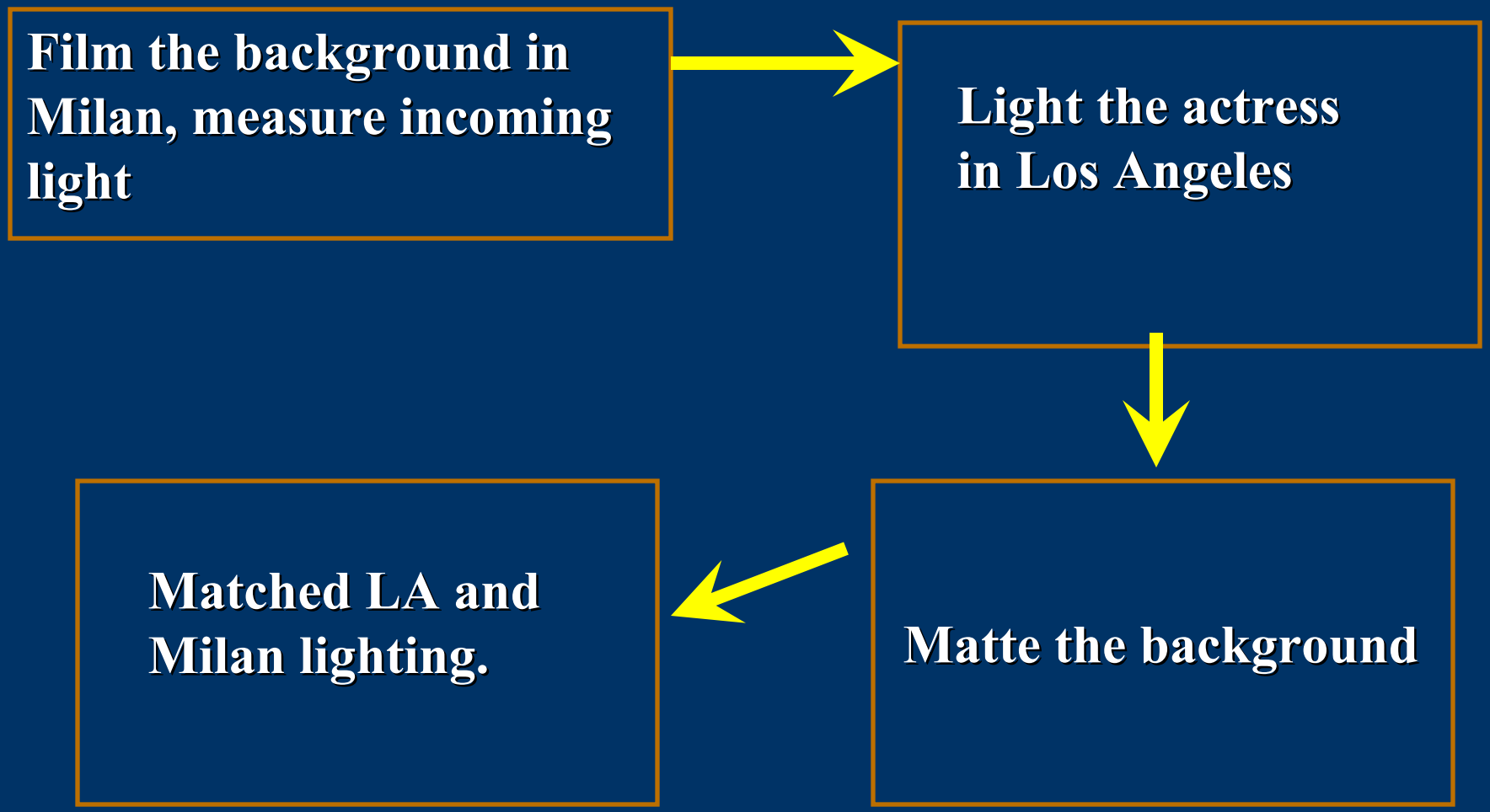
- Due Sept 25th
- Submit on Stellar (via link):
  - Commented Source code
  - Input images and output images PLUS intermediate results
  - CREATE a webpage and send me a link
- Ok to use online software
- Update results on Flickr (group) page

Debevec et al. 2002: ‘Light Stage 3’

Image removed due to copyright restrictions.
See Debevec, P., et al. “A Lighting Reproduction Approach to Live-Action Compositing.” *SIGGRAPH 2002 Proceedings*.

Image-Based Actual Re-lighting

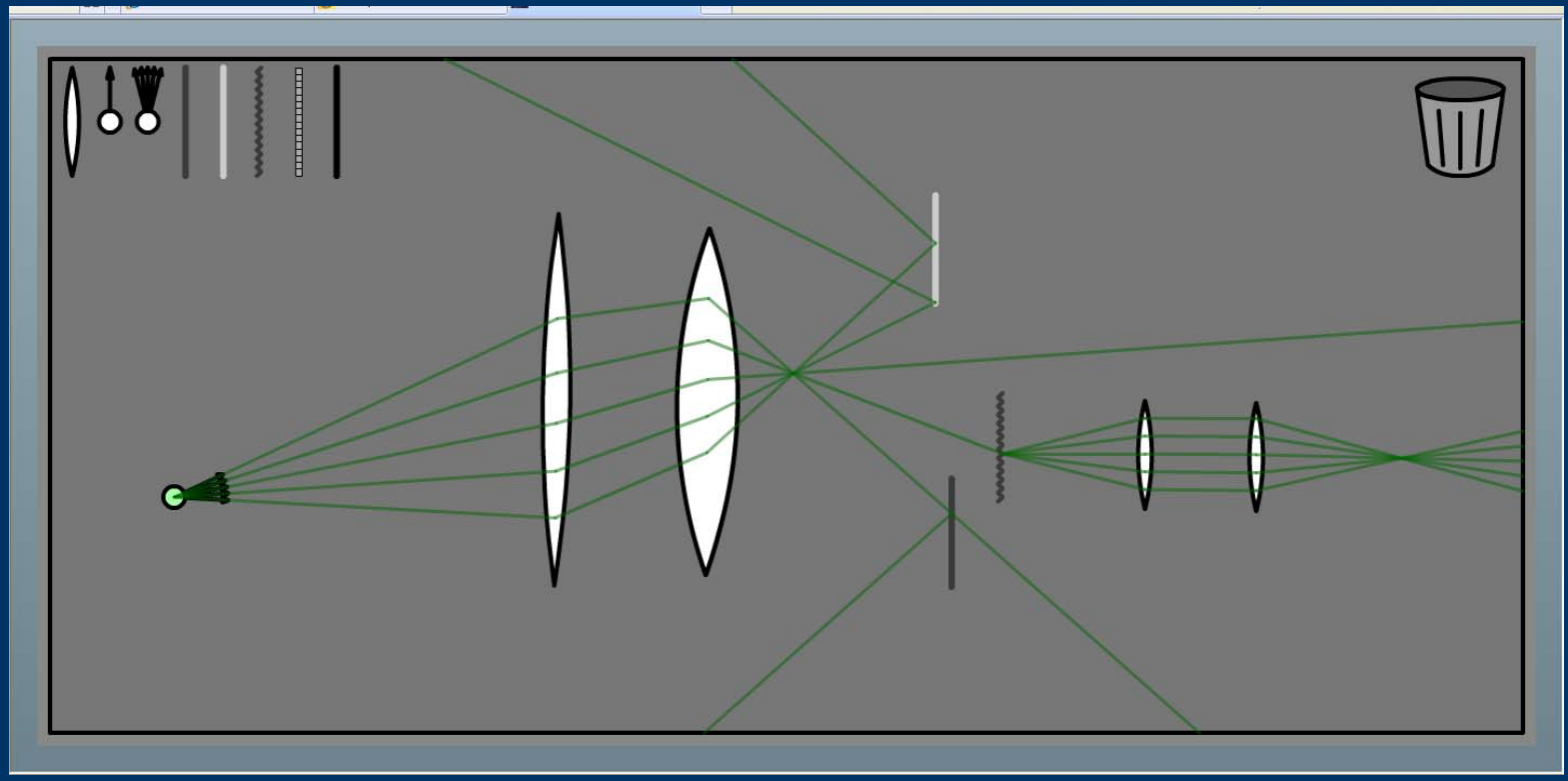
Debevec et al., SIGG2001



Images removed due to copyright restrictions.
See Debevec, P., et al. "Image-Based Lighting."
SIGGRAPH 2001 Course. http://www.debevec.org/IBL2001/

Second Homework

- Extending Andrew Adam's Virtual Optical Bench



Dual photography from diffuse reflections: Homework Assignment 2

Images removed due to copyright restrictions.
See Sen et al, "Dual Photography," SIGGRAPH 2005; specifically Figure 16 in the paper.

the camera's view

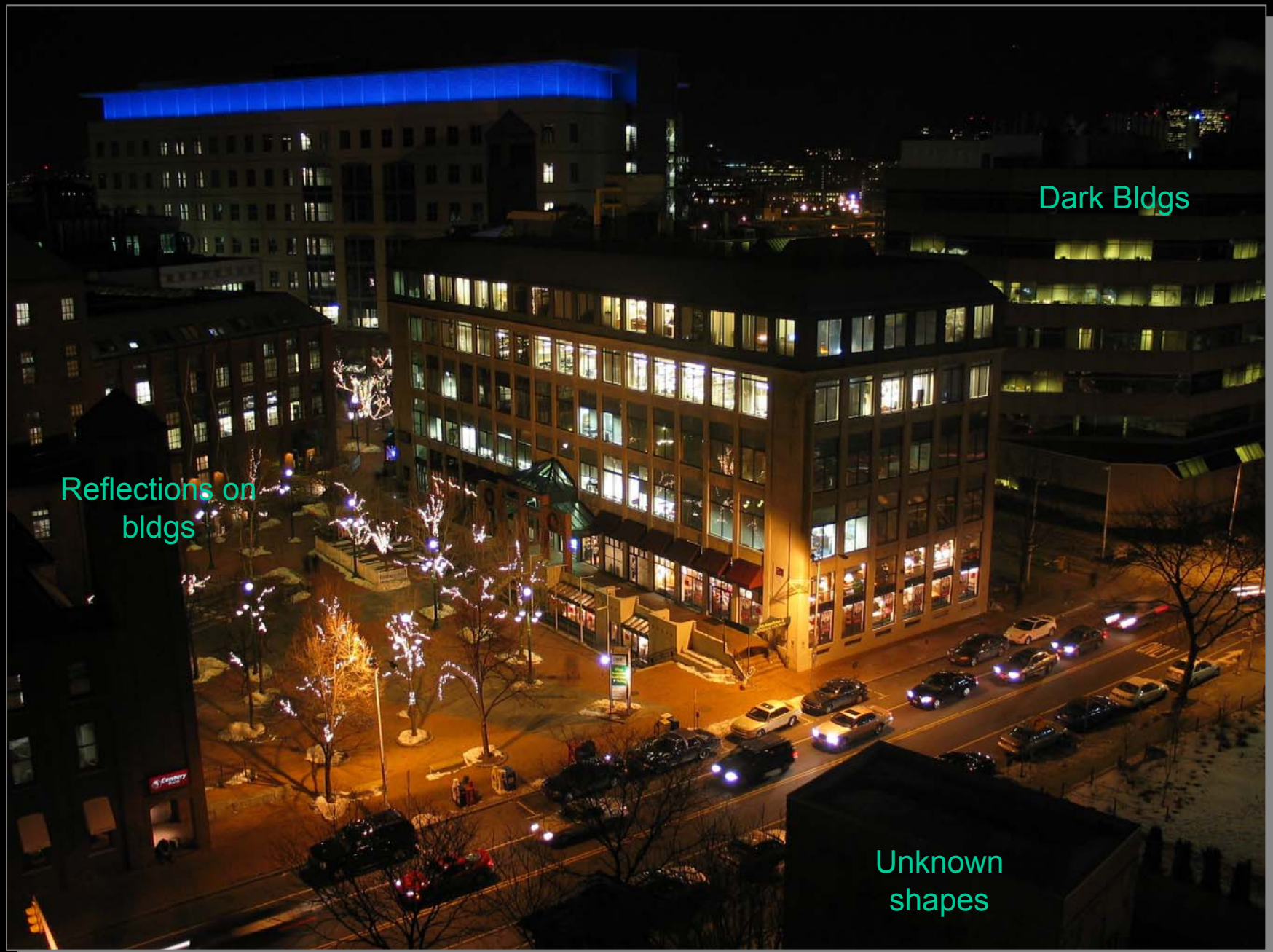
Sen et al, Siggraph 2005

Beyond Visible Spectrum

Images removed due to copyright restrictions.

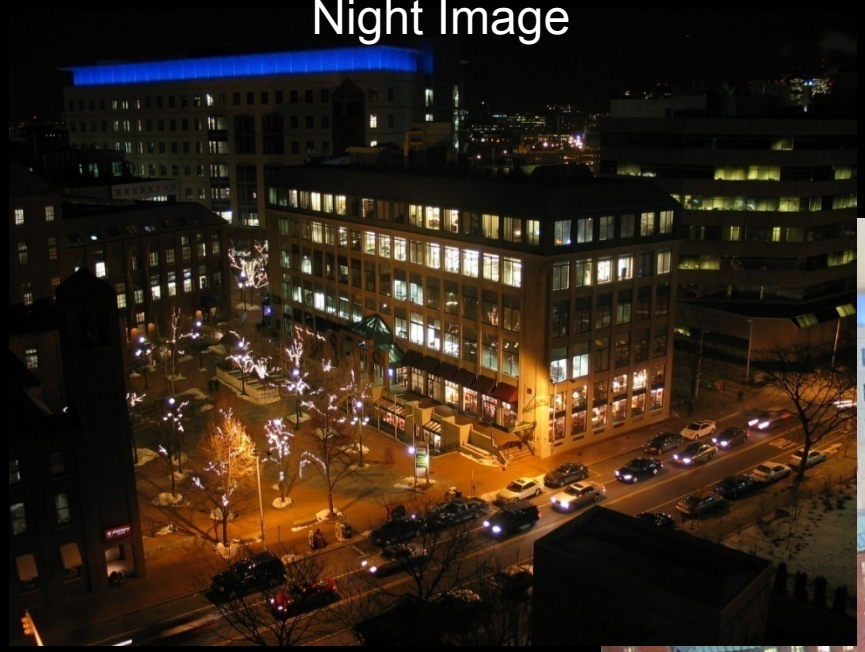
RedShift

Cedip


Dark Bldgs
Reflections on bldgs
Unknown shapes


‘Well-lit’ Bldgs
Reflections in bldgs windows
Tree, Street shapes

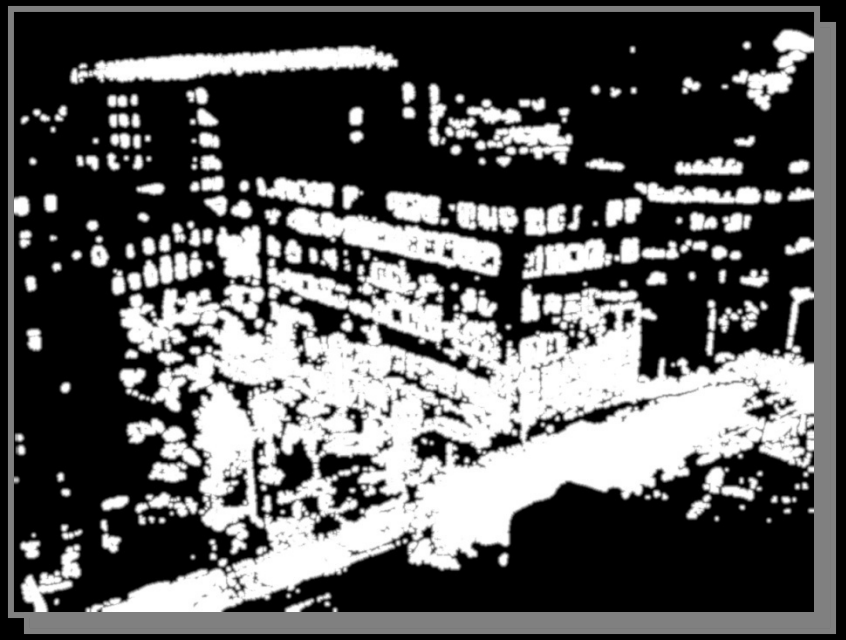
Night Image



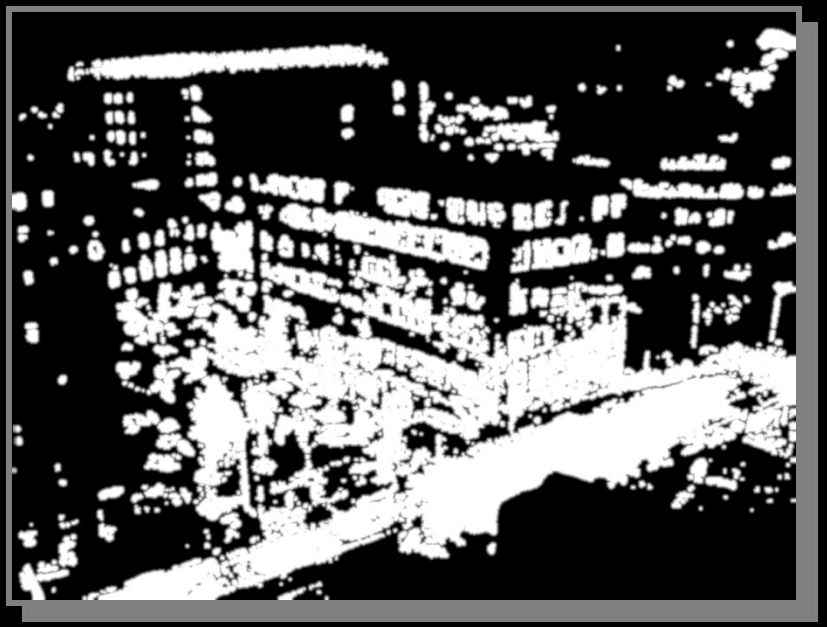
Background is captured from day-time scene using the same fixed camera

Context Enhanced Image

Day Image



Mask is automatically computed from scene contrast



But, Simple Pixel Blending Creates Ugly Artifacts

Pixel Blending

Our Method:
Integration of
blended Gradients

Surrealism

Image of this painting removed due to copyright restrictions.

Rene Magritte, ‘Empire of the Light’

Time-lapse Mosaics

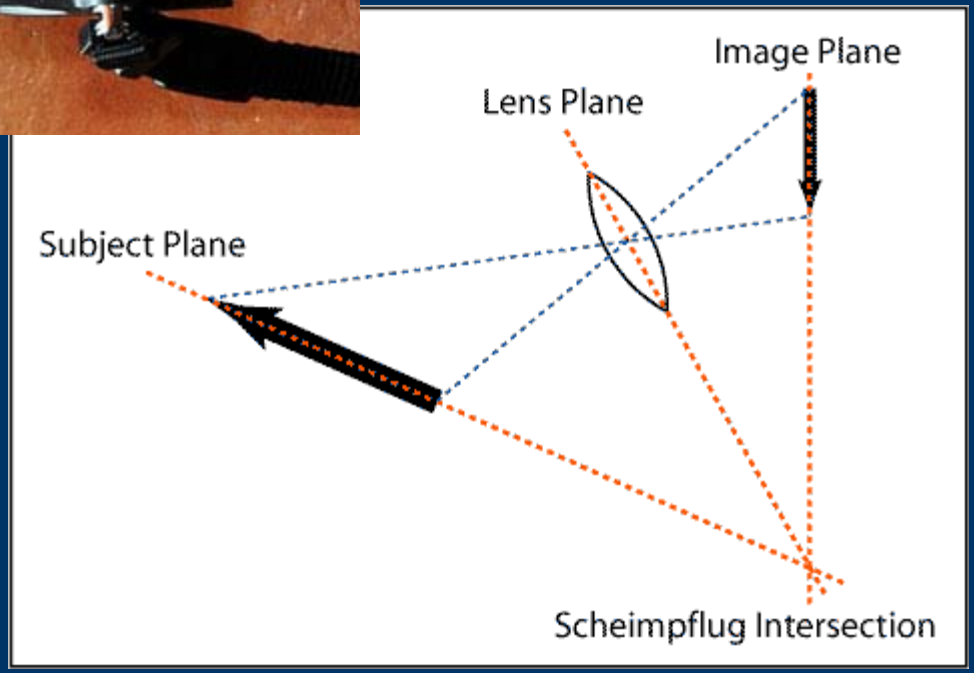
time

t

Courtesy of paul_goyette on Flickr.

Courtesy of paul_goyette on Flickr.

Scheimpflug principle



Plan

- Lenses
  - Point spread function
- Lightfields
  - What are they?
  - What are the properties?
  - How to capture?
  - What are the applications?

- What are annoyances in photography ?

- Why CCD camera behaves retroreflective?

- Youtube videos on camera tutorial (DoF etc)
  http://www.youtube.com/user/MPTutor

Anti-Paparazzi Flash

Image removed due to copyright restrictions.
See Berzon, Alexandra. "The Anti-Paparazzi Flash."
New York Times, December 11, 2005.

The anti-paparazzi flash: 1. The celebrity prey. 2. The lurking photographer. 3. The offending camera is detected and then bombed with a beam of light. 4. Voila! A blurry image of nothing much.

- Anti-Paparazzi Flash

Retroreflective CCD of cellphone camera

Images removed due to copyright restrictions. See Truong, K. N., et al. "Preventing Camera Recording by Designing a Capture-Resistant Environment." Ubicomp 2005.

Auto Focus

- Contrast method compares contrast of images at three depths,
  if in focus, image will have high contrast, else not

- Phase methods compares two parts of lens at the sensor plane,
  if in focus, entire exit pupil sees a uniform color, else not
- - assumes object has diffuse BRDF

Final Project Ideas

- User interaction device
  - Camera based
  - Illumination based
  - Photodetector or line-scan camera
- Capture the invisible
  - Tomography for internals
  - Structured light for 3D scanning
  - Fluorescence for transparent materials
- Cameras in different EM/other spectrum
  - Wifi, audio, magnetic, haptic, capacitive
  - Visible Thermal IR segmentation
  - Thermal IR (emotion detection, motion detector)
  - Multispectral camera, discriminating (camel-sand)
- Illumination
  - Multi-flash with lighfield
  - Schielren photography
  - Strobing and Colored strobing
- External non-imaging sensor
  - Camera with gyro movement sensors, find identity of user
  - Cameras with GPS and online geo-tagged photo collections
  - Interaction between two cameras (with lasers on-board)
- Optics
  - Lightfield
  - Coded aperture
  - Bio-inspired vision
- Time
  - Time-lapse photos
  - Motion blur

Kitchen Sink: Volumetric Scattering

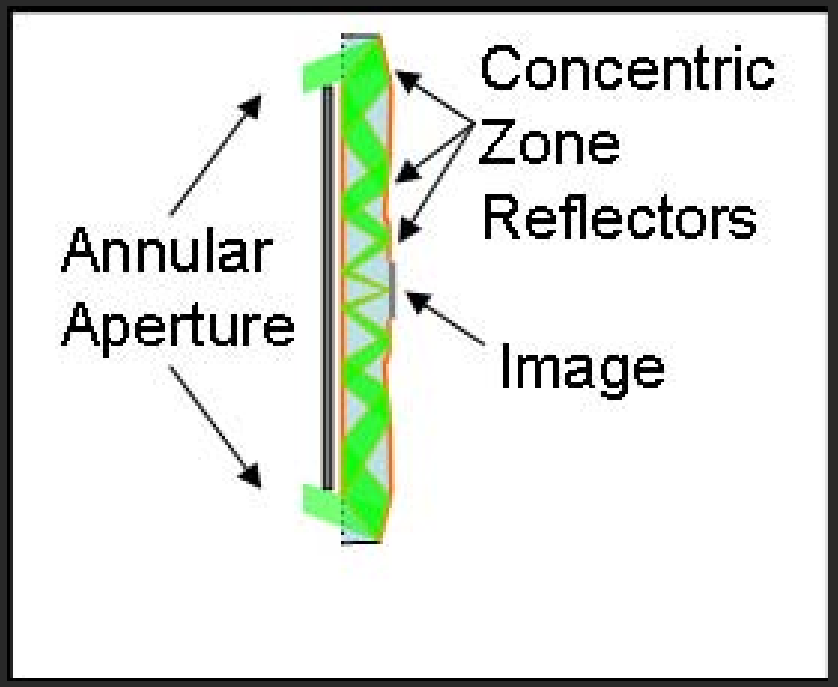
Volumetric Scattering:
Chandrasekar 50, Ishimaru 78

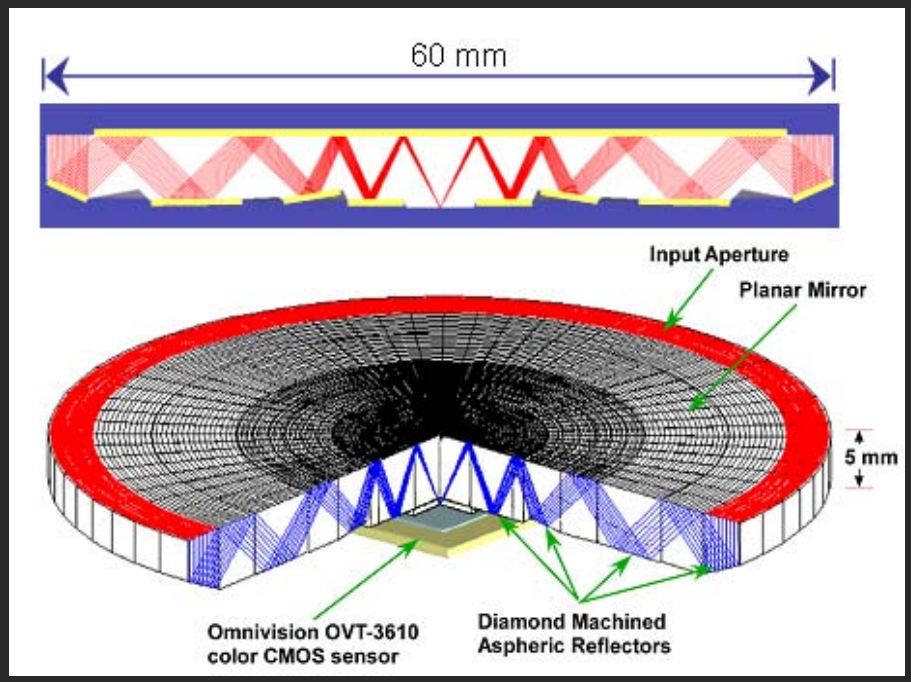
Three photos removed due to copyright restrictions.

Direct

Global

“Origami Lens”: Thin Folded Optics (2007)





Courtesy of Eric Tremblay. Used with permission.

“Ultrathin Cameras Using Annular Folded Optics, “
E. J. **Tremblay**, R. A. Stack, R. L. Morrison, J. E. **Ford**
Applied Optics, 2007 - OSA

Tools for Visual Computing

Photos removed due to copyright restrictions.
•Chambered eyes: nautilus, octopus, red-tailed hawk, scallop
•Compound eyes: sea fan, dragonfly, krill, lobster
•Optical methods: shadow, refractive, reflective
See Fernald, R. D. "Casting a Genetic Light on the Evolution of Eyes." *Science* 313 no. 5796 (September 29, 2006): 1914-1918.

Photonic Crystals

- ‘Routers’ for photons instead of electrons

- Photonic Crystal
  - Nanostructure material with ordered array of holes
  - A lattice of high-RI material embedded within a lower RI
  - High index contrast
  - 2D or 3D periodic structure

- Photonic band gap
  - Highly periodic structures that blocks certain wavelengths
  - (creates a ‘gap’ or notch in wavelength)

- Applications
  - ‘Semiconductors for light’: mimics silicon band gap for electrons
  - Highly selective/rejecting narrow wavelength filters (Bayer Mosaic?)
  - Light efficient LEDs
  - Optical fibers with extreme bandwidth (wavelength multiplexing)
  - Hype: future terahertz CPUs via optical communication on chip

- Image of small index of refraction gradients in a gas
- Invisible to human eye (subtle mirage effect)

Schlieren Photography

Diagram removed due to copyright restrictions.

Collimated Light

Knife edge blocks half the light
unless
distorted beam focuses imperfectly

Camera

Photo removed due to copyright restrictions.
“Full-Scale Schlieren Image Reveals The Heat Coming off of a Space Heater, Lamp and Person.”
http://www.mne.psu.edu/psgdl/FSSPhotoalbum/index1.htm

Sample Final Projects

- Schlieren Photography
  - (Best project award + Prize in 2008)
- Camera array for Particle Image Velocimetry
- BiDirectional Screen
- Looking Around a Corner (theory)
- Tomography machine
- ..
- ..

Computational Illumination

- Dual Photography
- Direct-global Separation
- Multi-flash Camera

Photo of old film camera removed due to copyright restrictions.

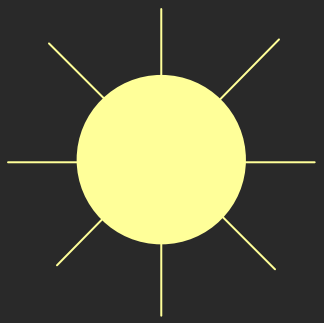
Figure by MIT OpenCourseWare.

Photo of traditional photo studio lighting devices removed due to copyright restrictions.

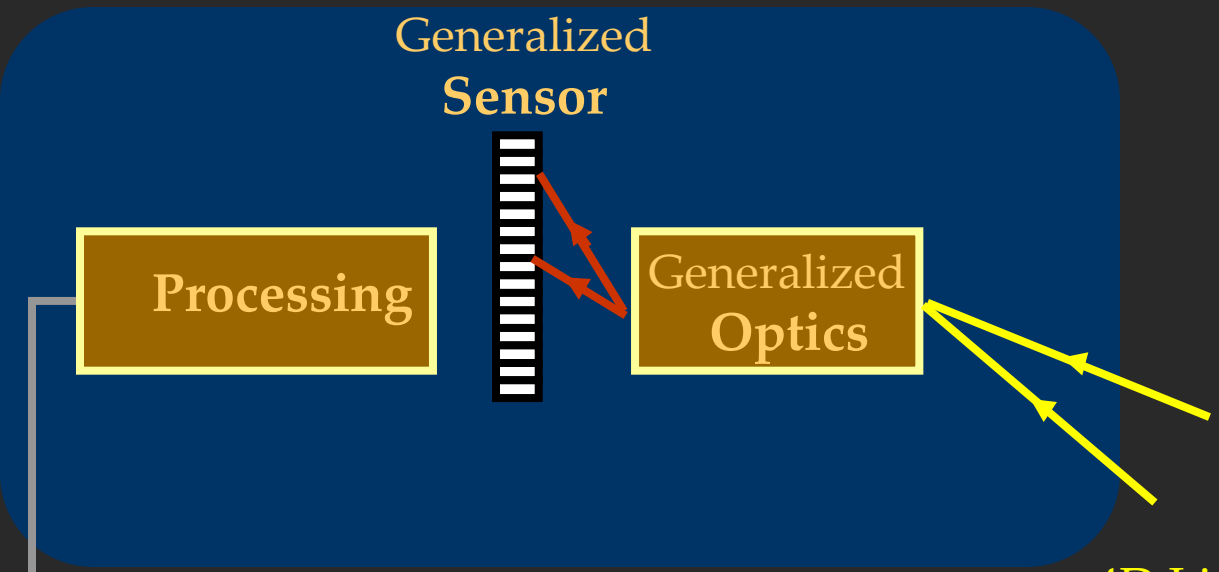
Computational Illumination

Computational Photography

Illumination



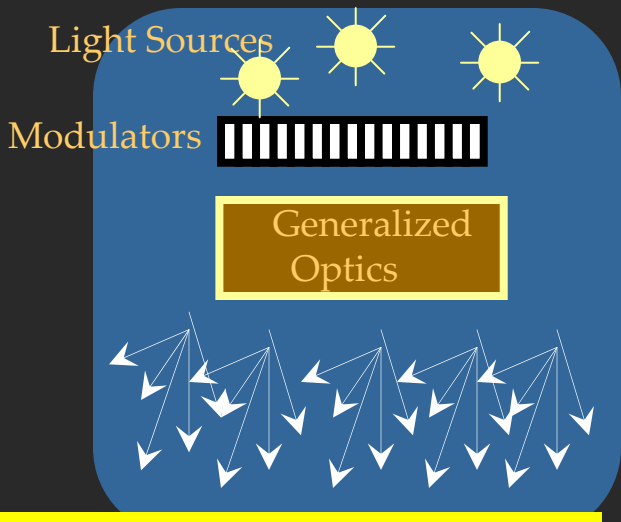
Novel Cameras



4D Light Field

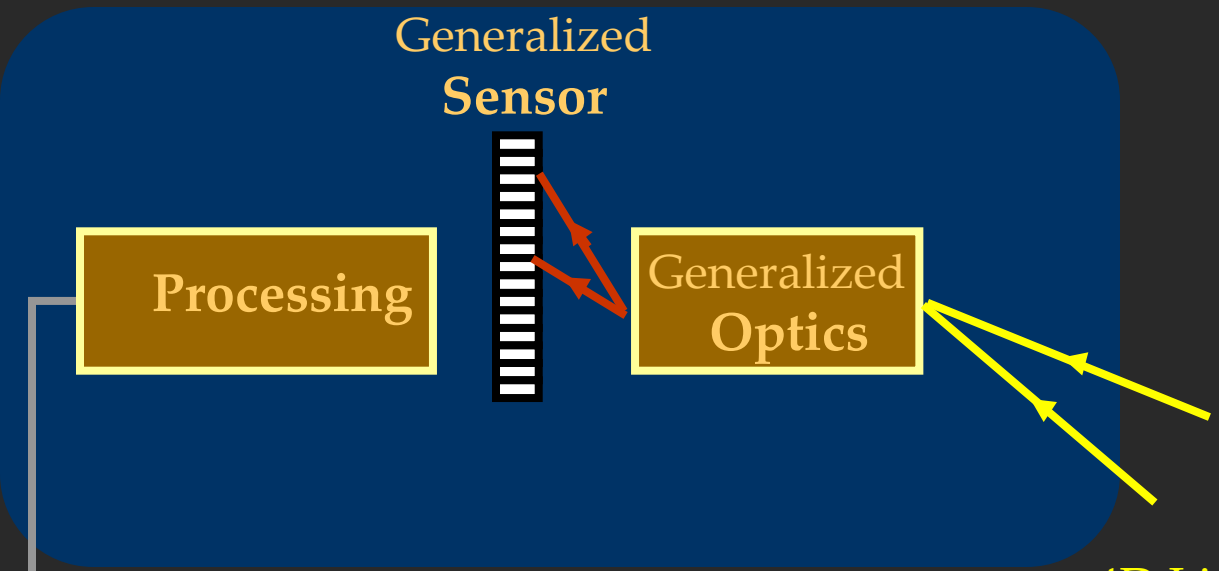
Computational Illumination

Novel Illumination



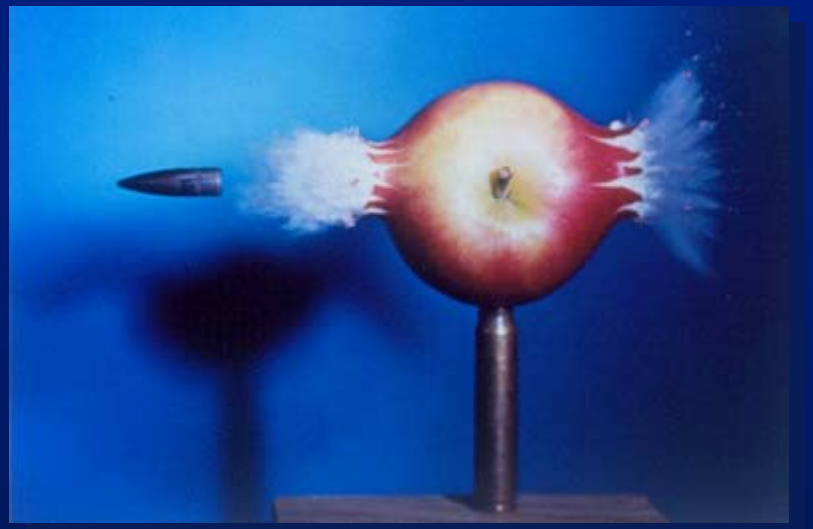
Programmable 4D Illumination field + time + wavelength

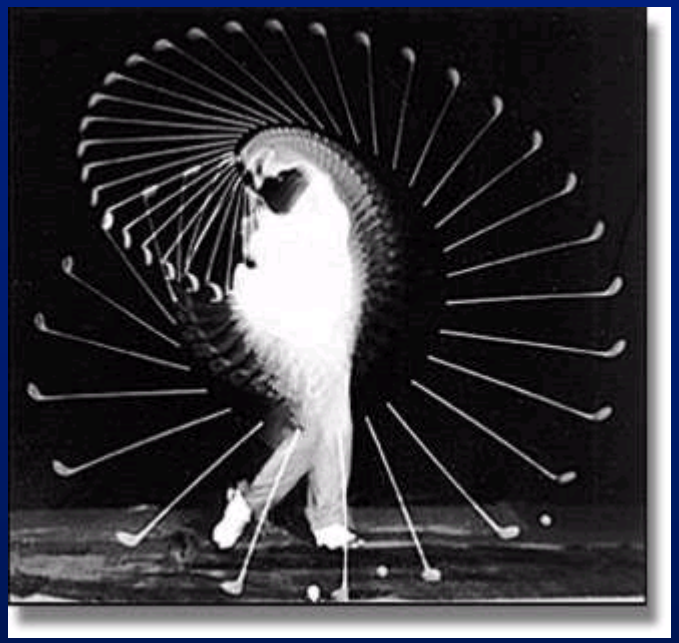
Novel Cameras



4D Light Field

Edgerton 1930's

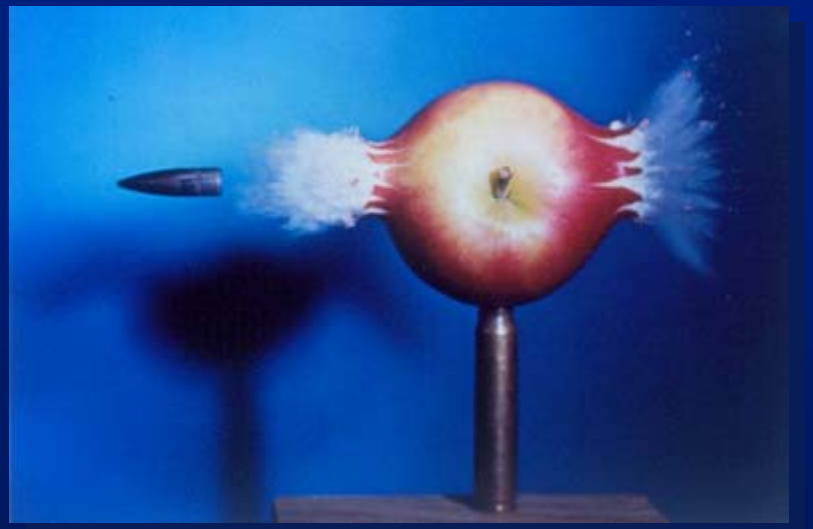


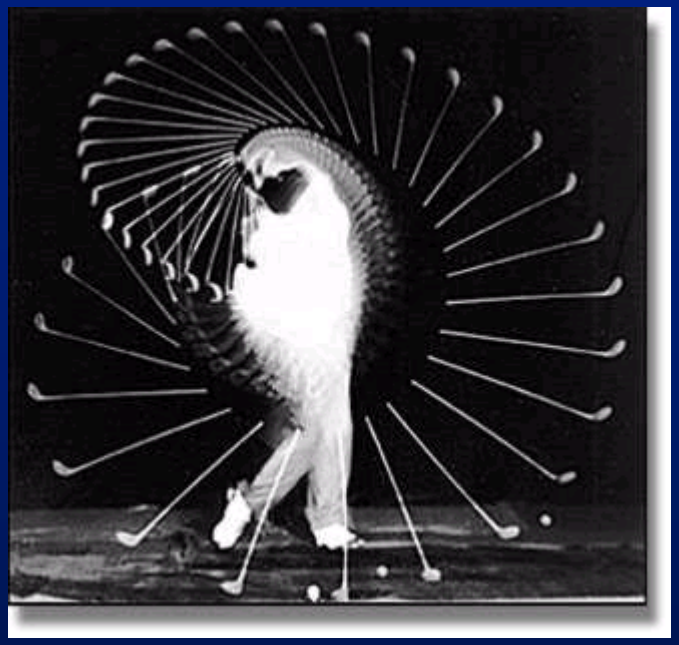


Not Special Cameras but Special Lighting

Edgerton, Harold E. MIT Museum, Cambridge MA. MIT Museum, Edgerton Digital Collections. http://edgerton-digital-collections.org

Edgerton 1930's





Stroboscope
(Electronic Flash)

Multi-flash
Sequential Photography

Edgerton, Harold E. MIT Museum, Cambridge MA. MIT Museum, Edgerton Digital Collections. http://edgerton-digital-collections.org

‘Smarter’ Lighting Equipment

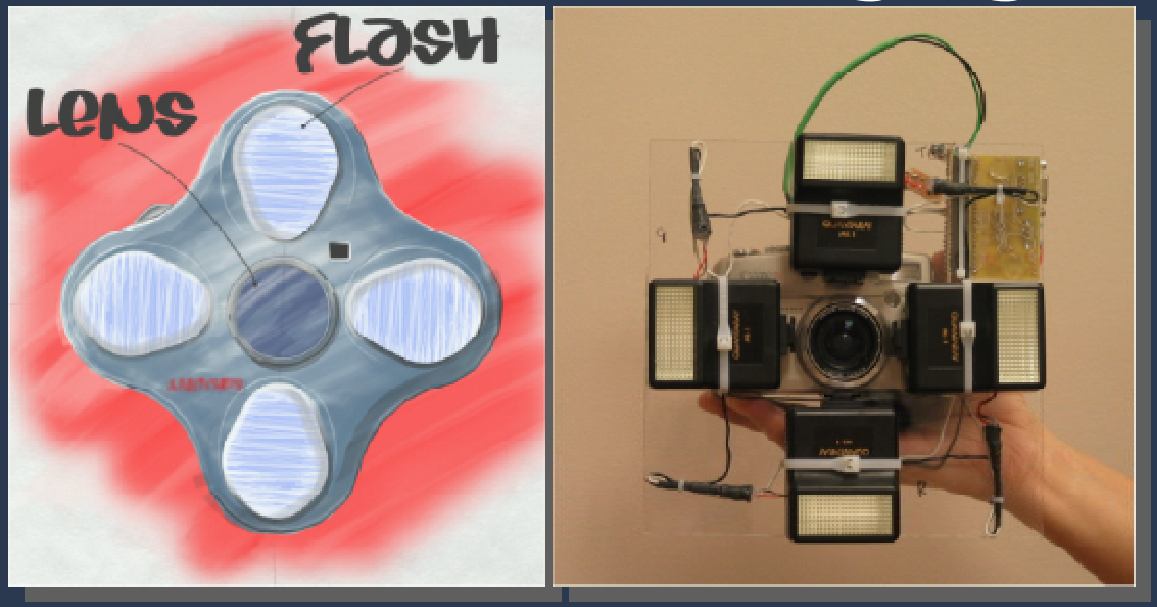
What Parameters Can We Change ?

Computational Illumination:

Programmable 4D Illumination Field + Time + Wavelength

- Presence or Absence, Duration, Brightness
  - Flash/No-flash
- Light position
  - Relighting: Programmable dome
  - Shape enhancement: Multi-flash for depth edges
- 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, Time Lapse, Glare

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



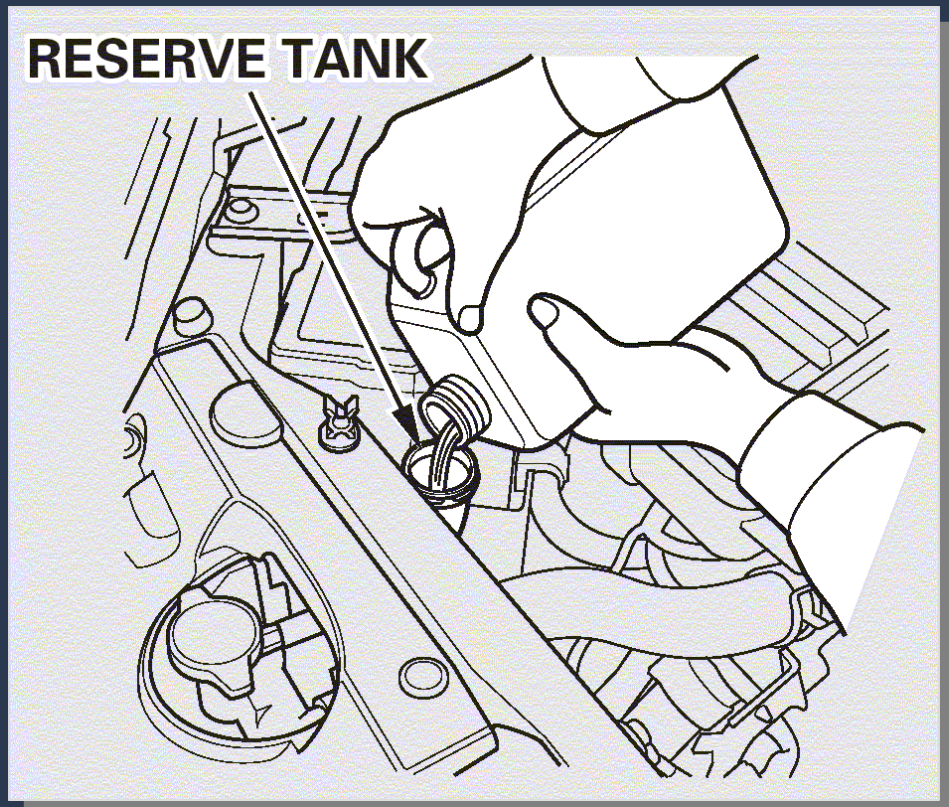
Ramesh Raskar, Karhan Tan, Rogerio Feris, Jingyi Yu, Matthew Turk

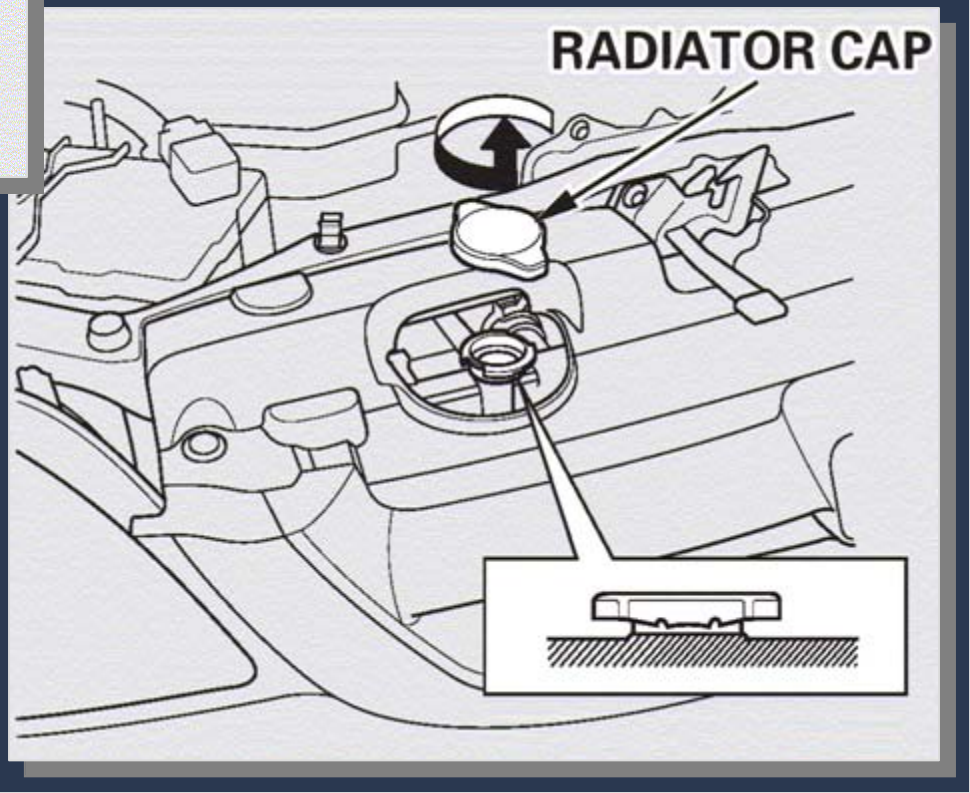
Mitsubishi Electric Research Labs (MERL), Cambridge, MA

U of California at Santa Barbara

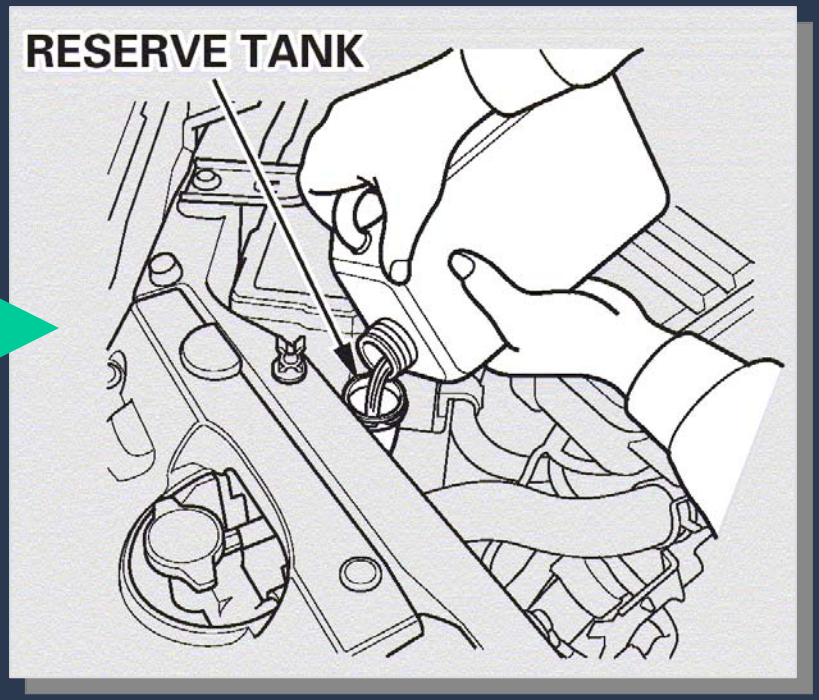
U of North Carolina at Chapel Hill

Courtesy of MERL. Used with permission.



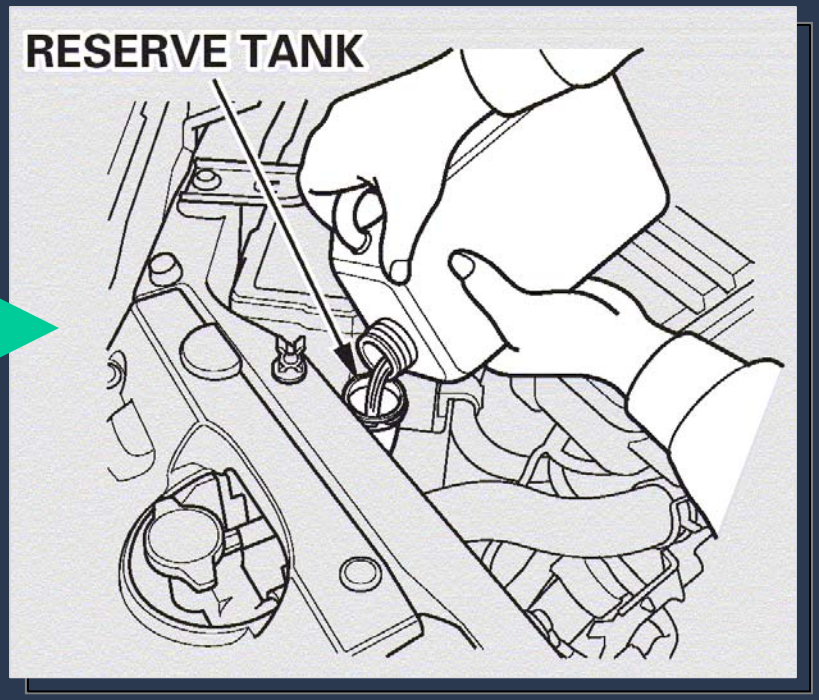


Car Manuals



What are the problems with ‘real’ photo in conveying information ?

Why do we hire artists to draw what can be photographed ?



Shadows

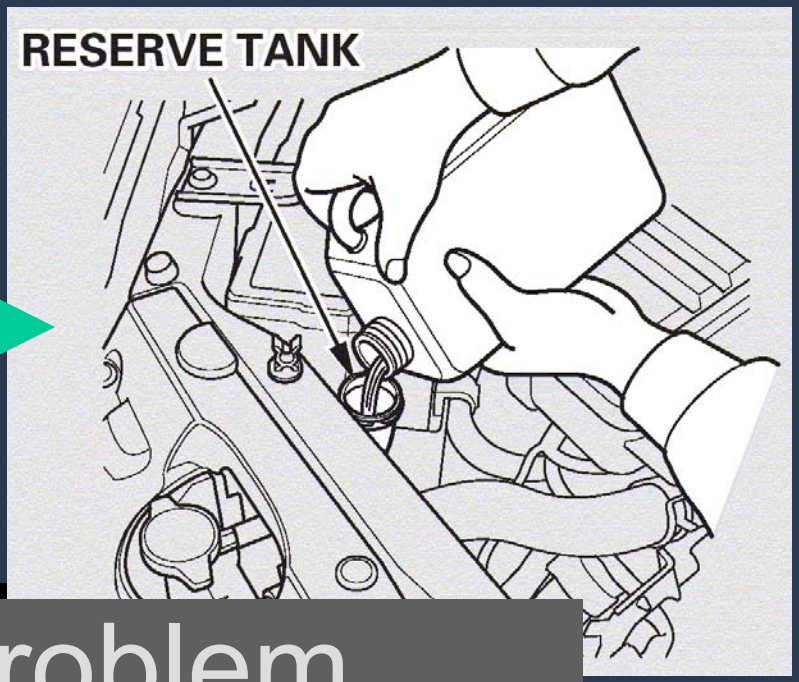
Clutter

Many Colors

Highlight Shape Edges

Mark moving parts

Basic colors



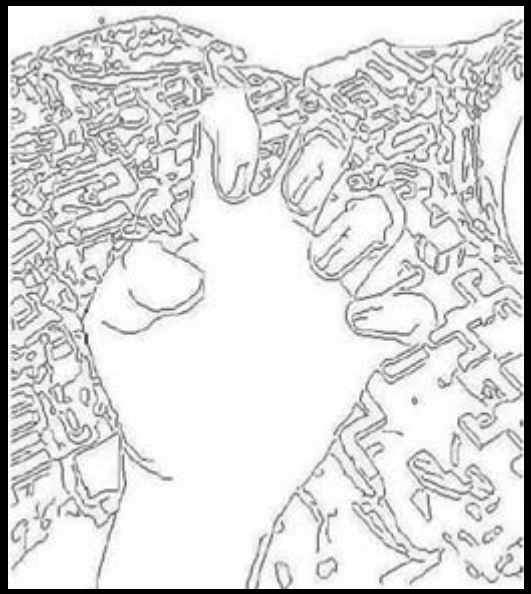
A New Problem

Shadows	Highlight Edges
Clutter	Mark moving parts
Many Colors	Basic colors

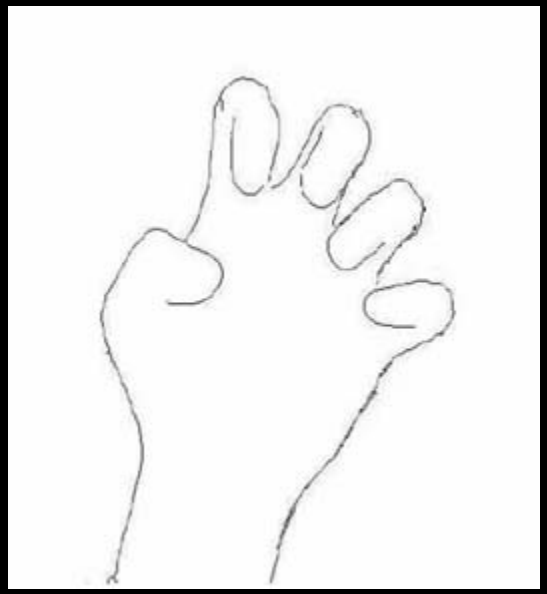
Gestures

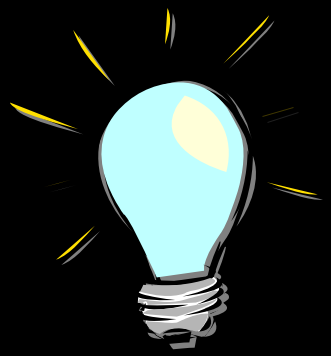
Input Photo

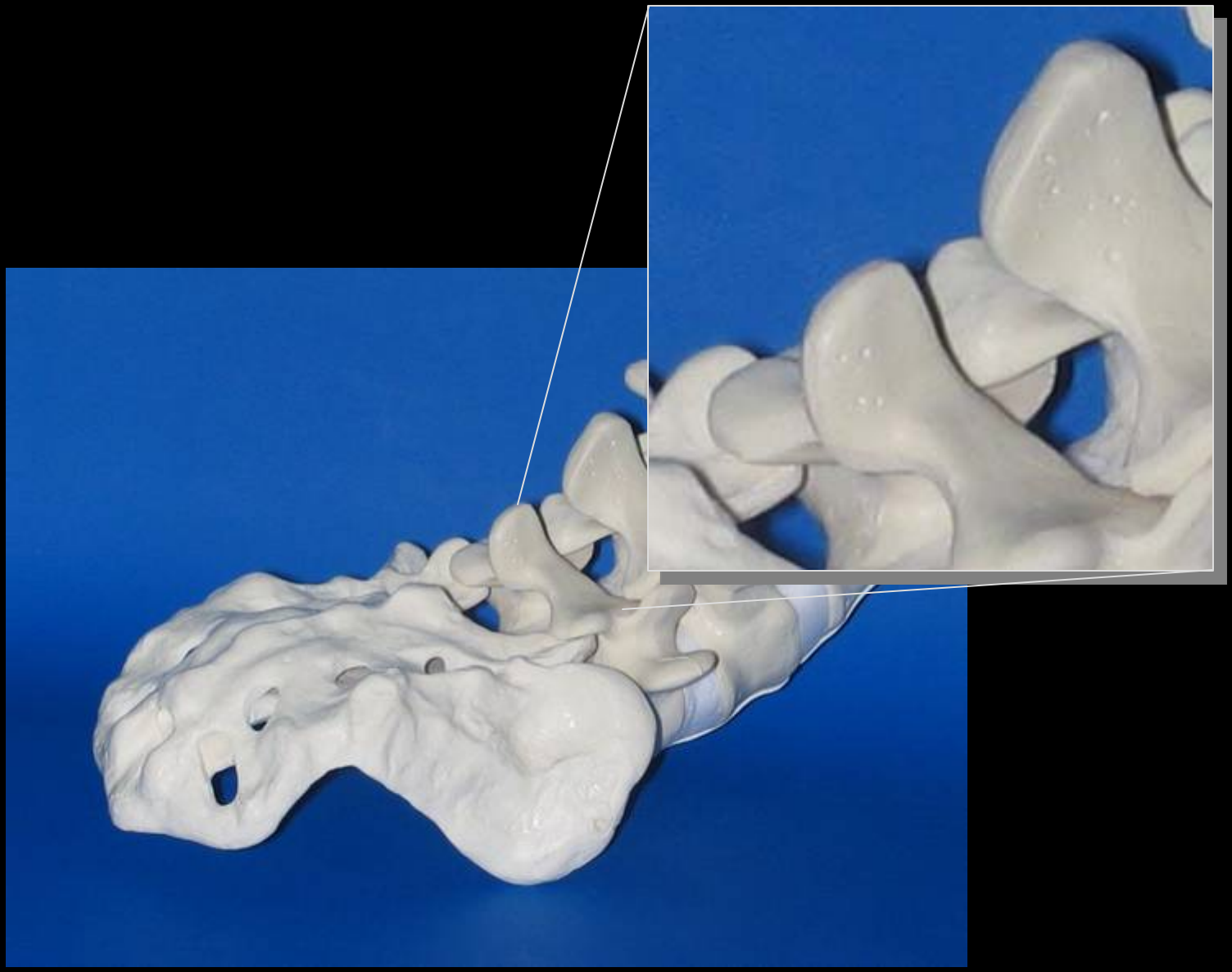
Canny Edges



Depth Edges







Courtesy of MERL. Used with permission.

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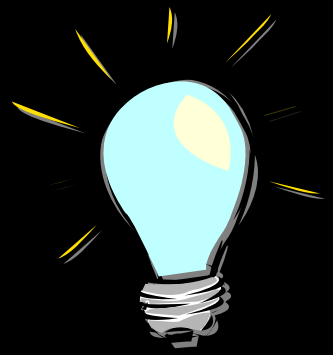

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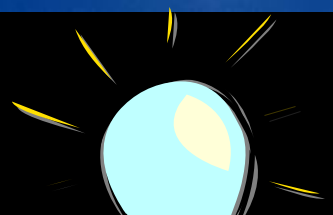
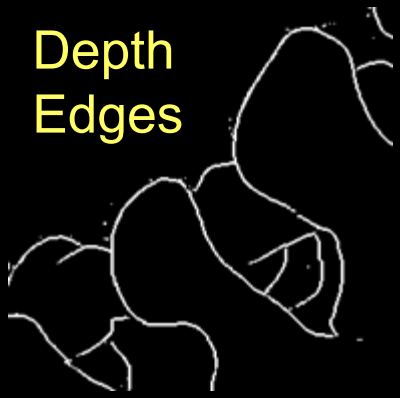
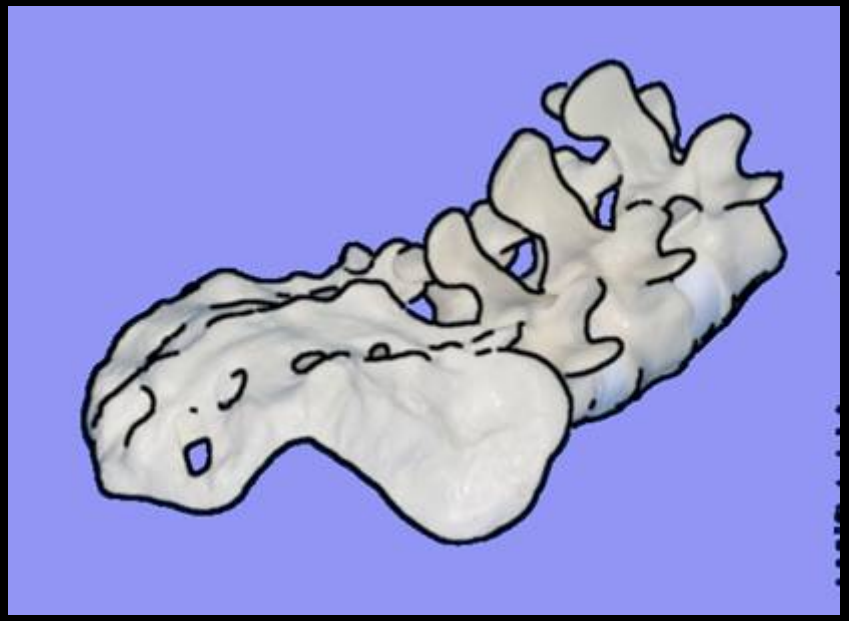


Courtesy of MERL. Used with permission.

Depth Discontinuities

Internal and external
Shape boundaries, Occluding contour, Silhouettes





Canny

Our Method

Courtesy of MERL. Used with permission.

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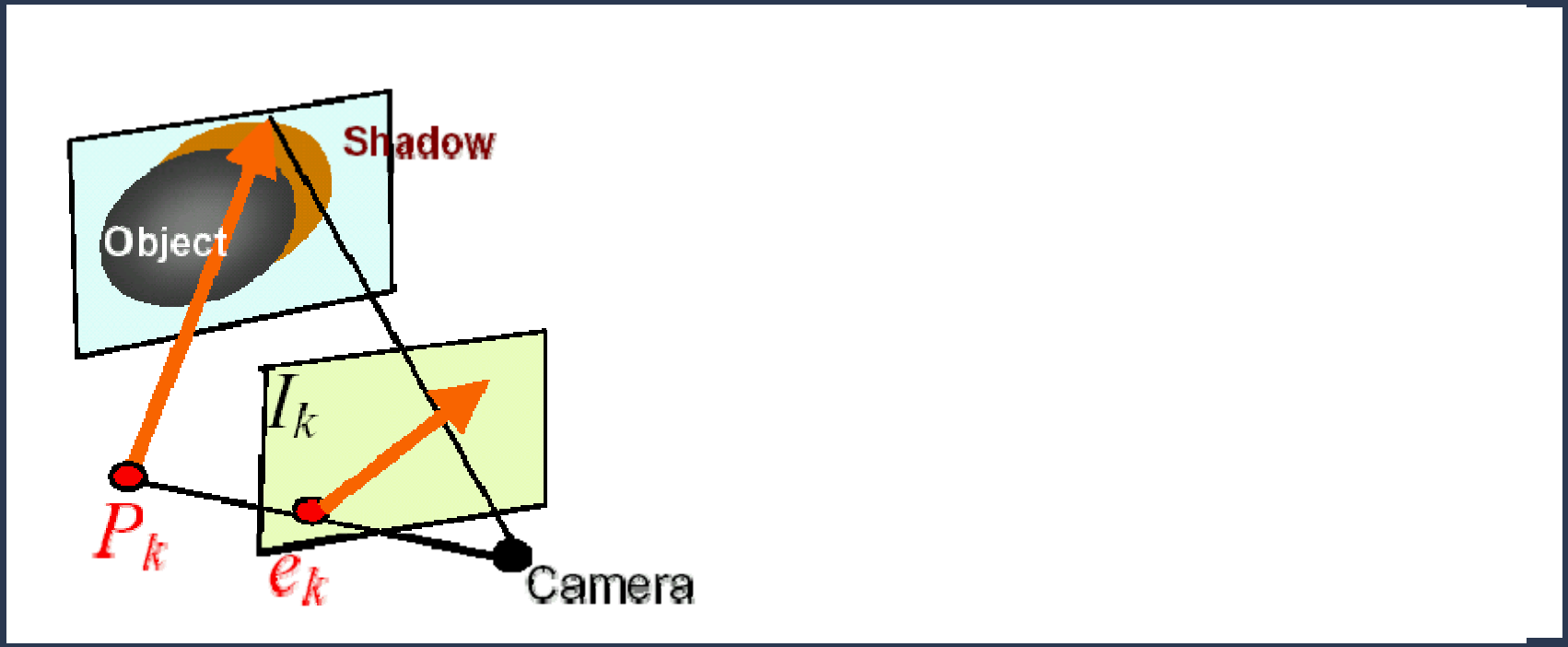
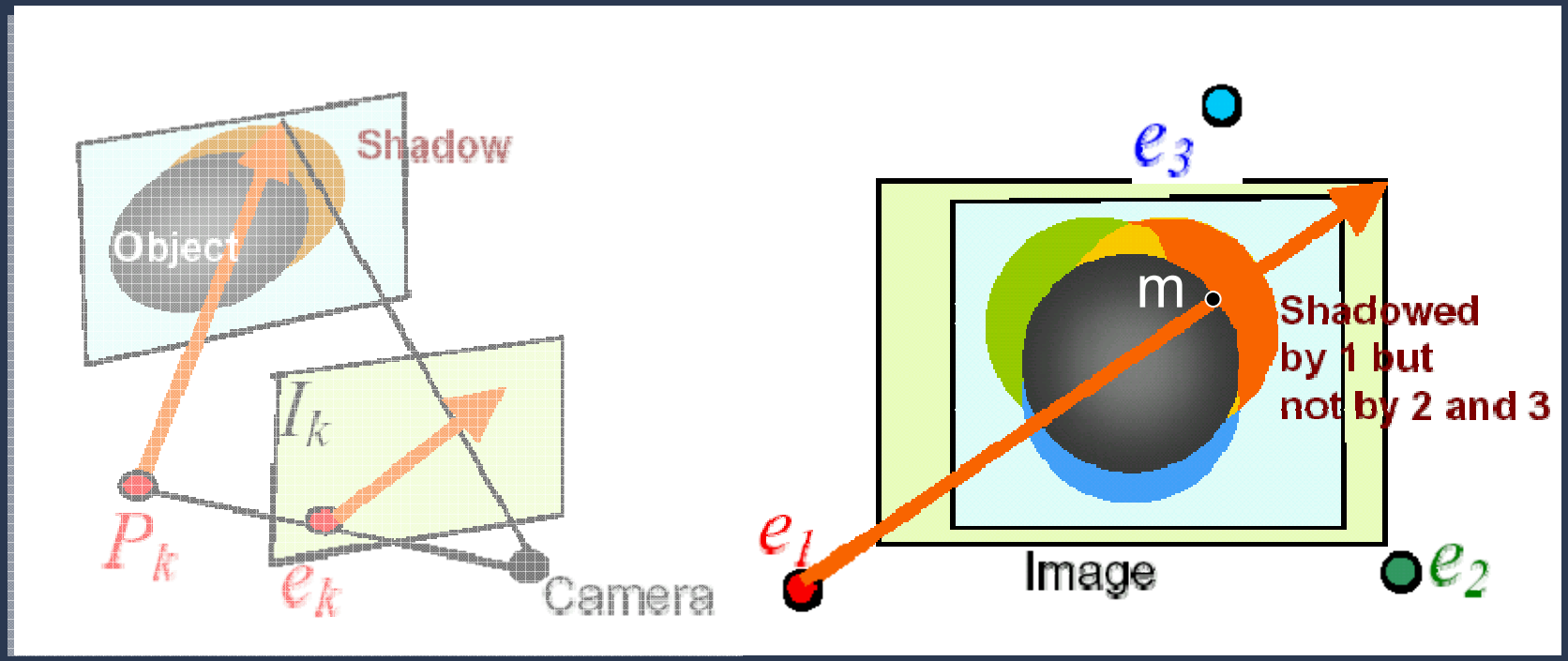
Imaging Geometry



Shadow lies along epipolar ray

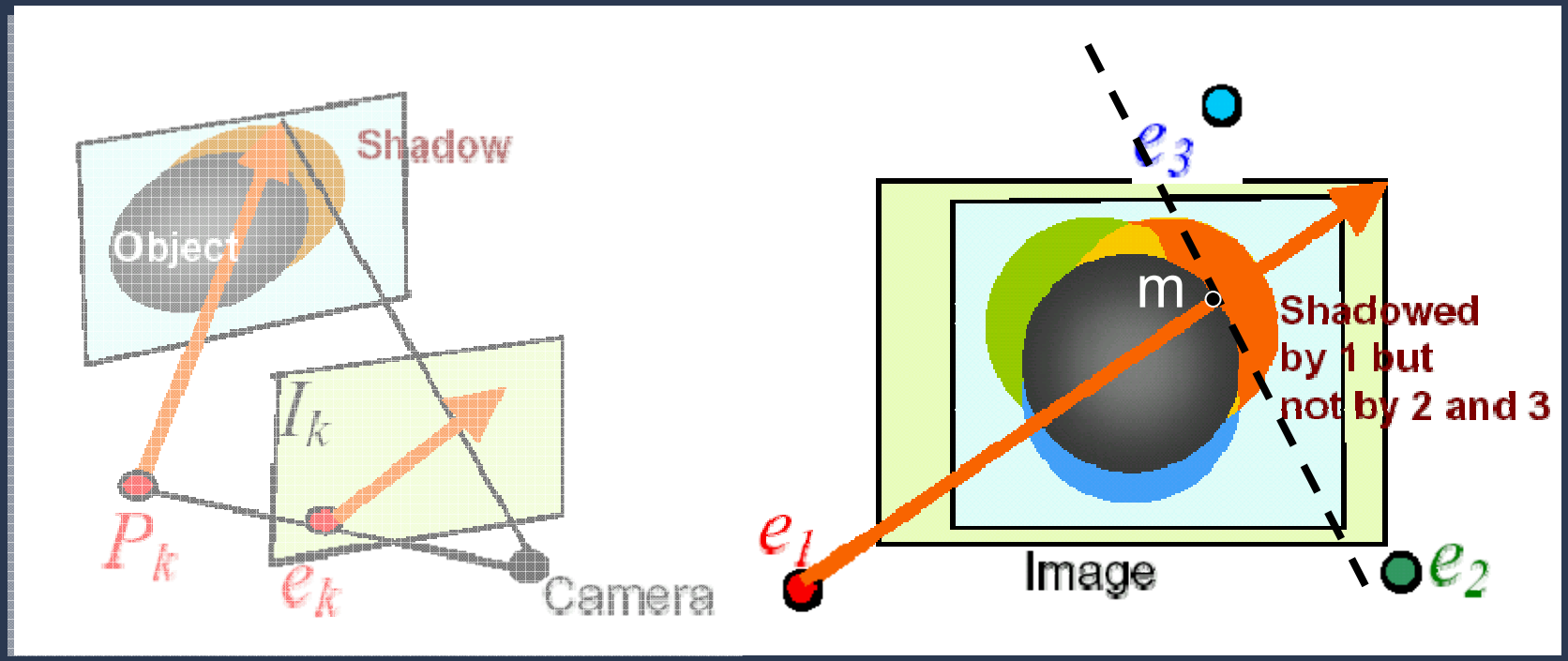
Imaging Geometry



Shadow lies along epipolar ray,

Epipole and Shadow are on opposite sides of the edge

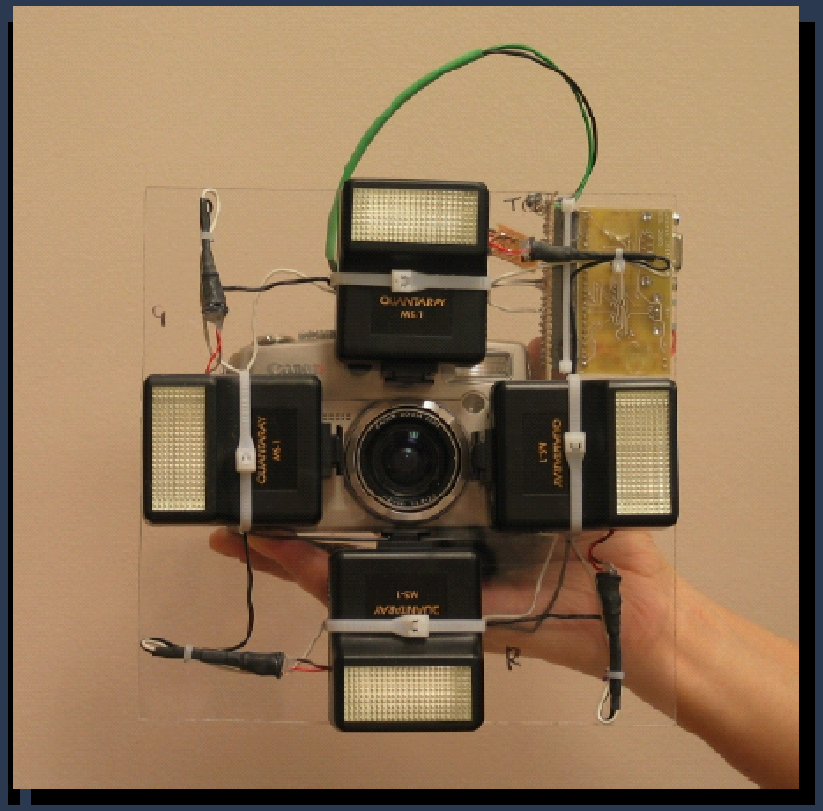
Imaging Geometry



Shadow lies along epipolar ray,

Shadow and epipole are on opposite sides of the edge

Depth Edge Camera



Light epipolar rays are horizontal or vertical

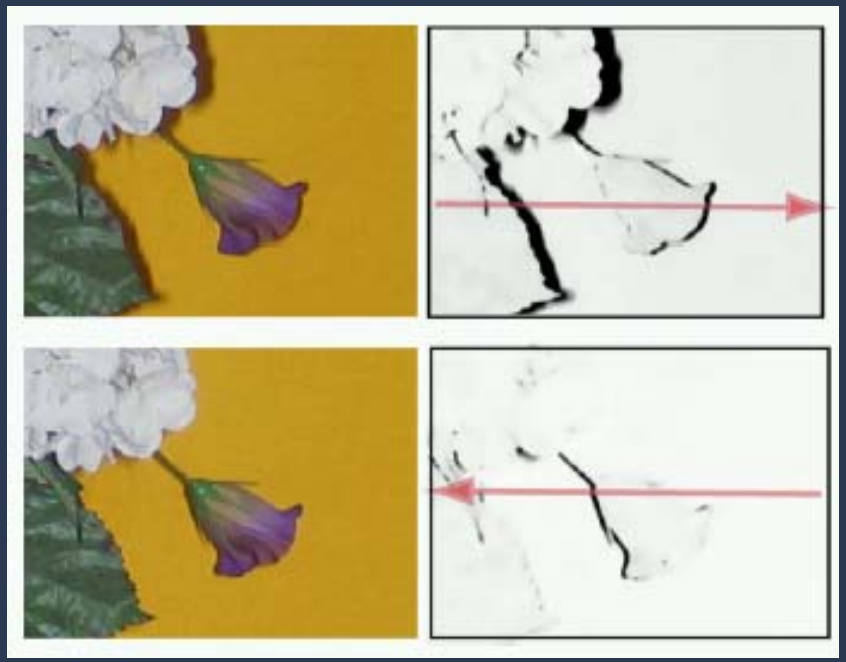
Input

Left Flash

Right Flash

Input | Normalized

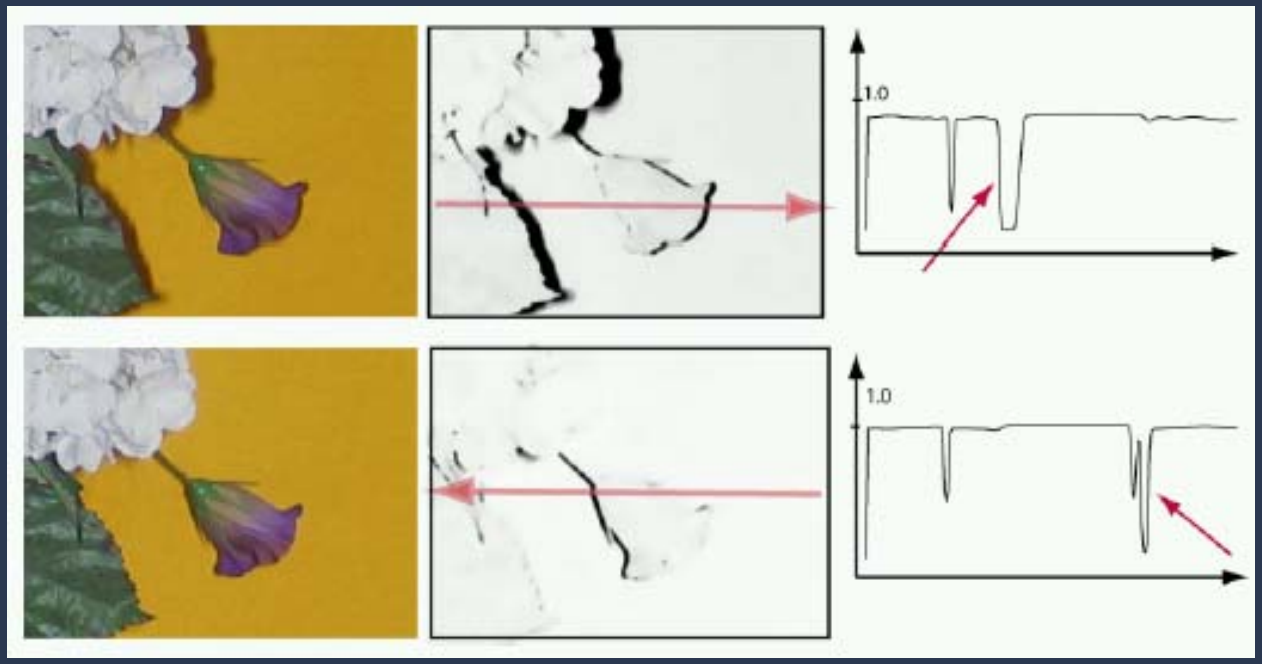
Left Flash | Left / Max



Right Flash | Right / Max

Input	Normalized	Plot

Left Flash Left / Max



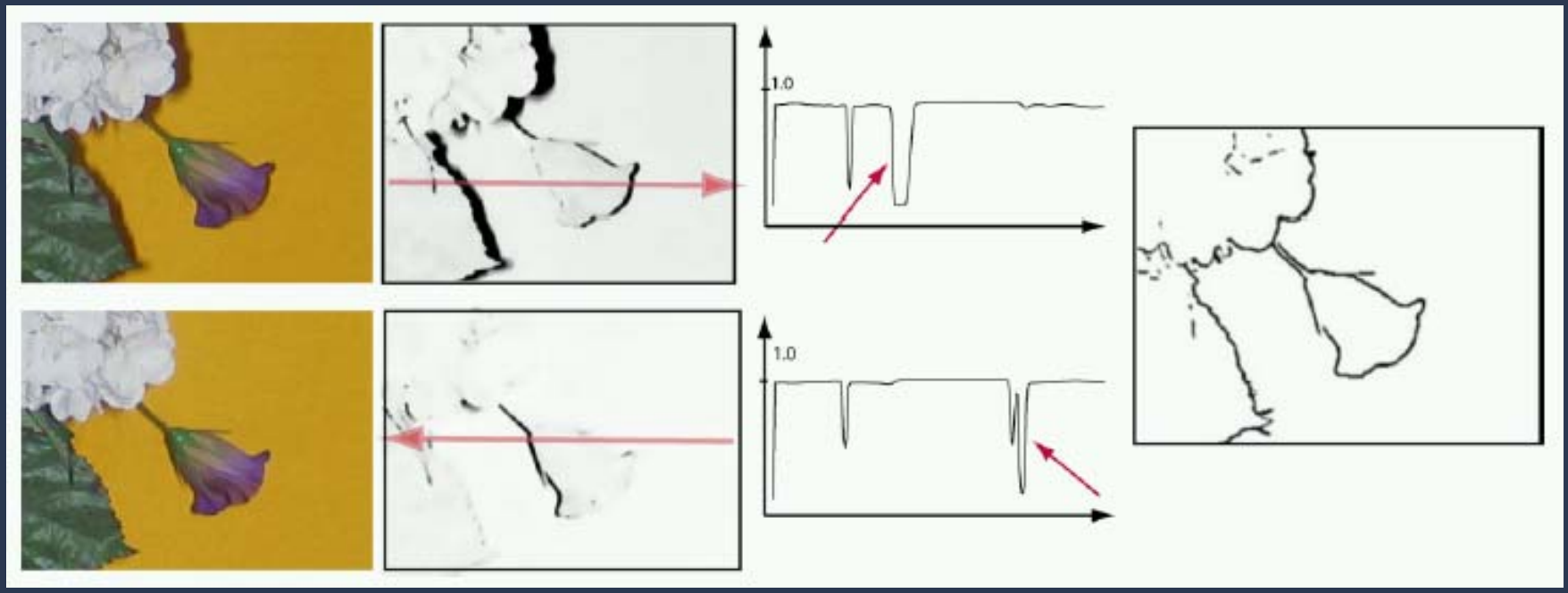
Right Flash Right / Max

Courtesy of MERL. Used with permission.

Negative transition along epipolar ray is depth edge

Input	Normalized	Plot	U{depth edges}

Left Flash Left / Max



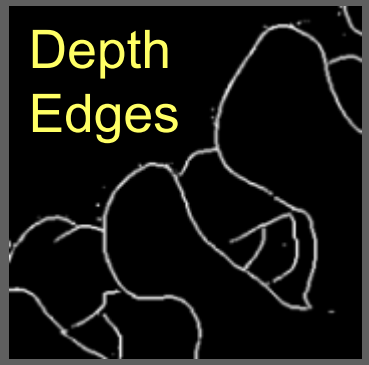
Right Flash Right / Max

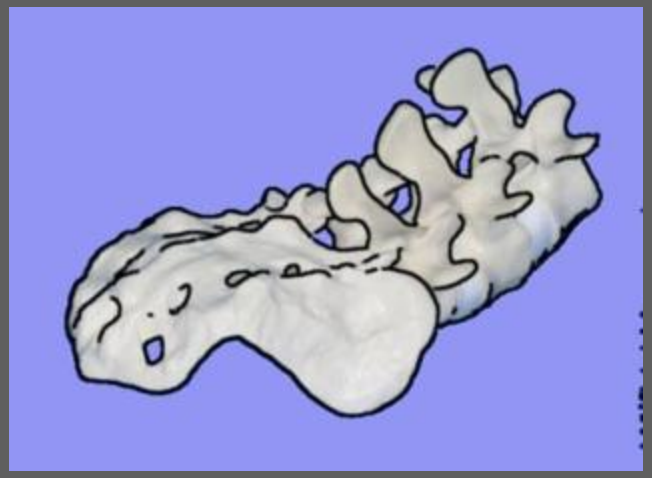
Negative transition along epipolar ray is depth edge

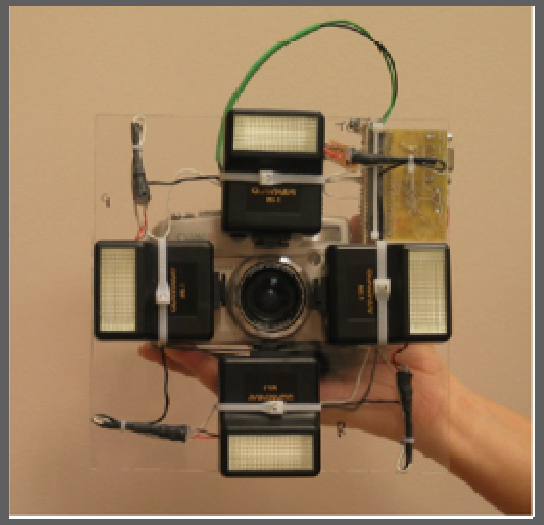
```
% Max composite
maximg = max( left, right, top, bottom);

% Normalize by computing ratio images
r1 = left./ maximg;              r2 = top ./ maximg;
r3 = right ./ maximg;            r4 = bottom ./ maximg;

% Compute confidence map
v = fspecial( 'sobel' ); h = v';
d1 = imfilter( r1, v ); d3 = imfilter( r3, v );  % vertical sobel
d2 = imfilter( r2, h ); d4 = imfilter( r4, h ); % horizontal sobel

%Keep only negative transitions
silhouette1  = d1 .* (d1>0);
silhouette2 = abs( d2 .* (d2<0) );
silhouette3 = abs( d3 .* (d3<0) );
silhouette4  = d4 .* (d4>0);

%Pick max confidence in each
confidence = max(silhouette1,  silhouette2, silhouette3,  silhouette4);
imwrite( confidence, 'confidence.bmp');
```

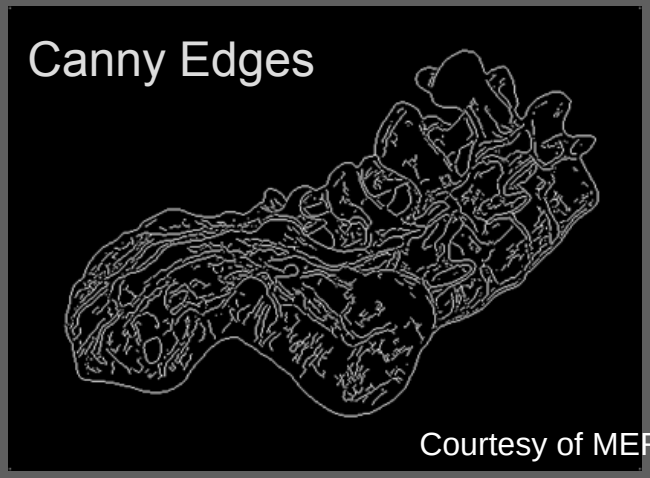
No magic parameters !

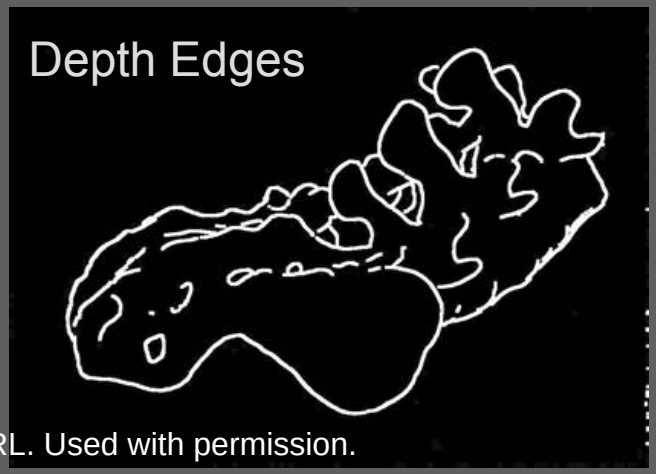
Courtesy of MERL. Used with permission.











Courtesy of MERL. Used with permission.

Flash Matting

Sequence of processed images removed due to copyright restrictions.
See Figure 4 in http://research.microsoft.com/en-us/um/people/jiansun/papers/FlashMatting_SIGGRAPH06.pdf

Jian Sun, Yin Li, Sing Bing Kang, and Heung-Yeung Shum. “Flash Matting.” SIGGRAPH 2006

Multi-light Image Collection

[Fattal, Agrawala, Rusinkiewicz] Sig'2007

Image of Swiss Chard leaves removed due to copyright restrictions.
See Fig. 1 in Fattal, R., M. Agrawala, and S. Rusinkiewicz.
"Multiscale Shape and Detail Enhancement from Multi-light Image Collections."
Proceedings of SIGGRAPH 2007.

Input Photos

ShadowFree,
Enhanced
surface detail,

but Flat look

Some Shadows
for depth

but Lost visibility

Sequence of flower photos removed due to copyright restrictions.
See Fig. 12 in Fattal, R., M. Agrawala, and S. Rusinkiewicz.
"Multiscale Shape and Detail Enhancement from Multi-light Image Collections."
Proceedings of SIGGRAPH 2007.

Fuse maximum gradient
from each photo,
Reconstruct from 2D
integration
all the input images.

Enhanced shadows

Multiscale decomposition using
Bilateral Filter,
Combine detail at each scale
across all the input images.

Computational Illumination:

Programmable 4D Illumination Field + Time + Wavelength

- Presence or Absence, Duration, Brightness
  - Flash/No-flash (matting for foreground/background)
- Light position
  - Relighting: Programmable dome
  - Shape enhancement: Multi-flash for depth edges
- Light color/wavelength
- Spatial Modulation
  - Dual Photography, Direct/Global Separation, Synthetic Aperture Illumination
- Temporal Modulation
  - TV remote, Motion Tracking, Sony ID-cam, RFIG
- Exploiting (uncontrolled) natural lighting condition
  - Day/Night Fusion, Time Lapse, Glare

Dual Photography *

Pradeep Sen, Billy Chen, Gaurav Garg, Steve Marschner
Mark Horowitz, Marc Levoy, Hendrik Lensch

Stanford University *Cornell University

SIGGRAPH2005
Los Angeles, CA

August 2, 2005

Slides discussing this paper removed due to copyright restrictions.
Paper available online (19 MB) at
http://www.ece.unm.edu/~psen/Papers/DualPhotography.pdf

Visual Chatter in the Real World

Shree K. Nayar

Computer Science
Columbia University

With: Guru Krishnan, Michael Grossberg, Ramesh Raskar

Eurographics Rendering Symposium
June 2006, Nicosia, Cyprus

Support: ONR

Slides discussing this research removed due to copyright restrictions.
Papers and related resources available online at
http://www.cs.columbia.edu/CAVE/projects/separation/

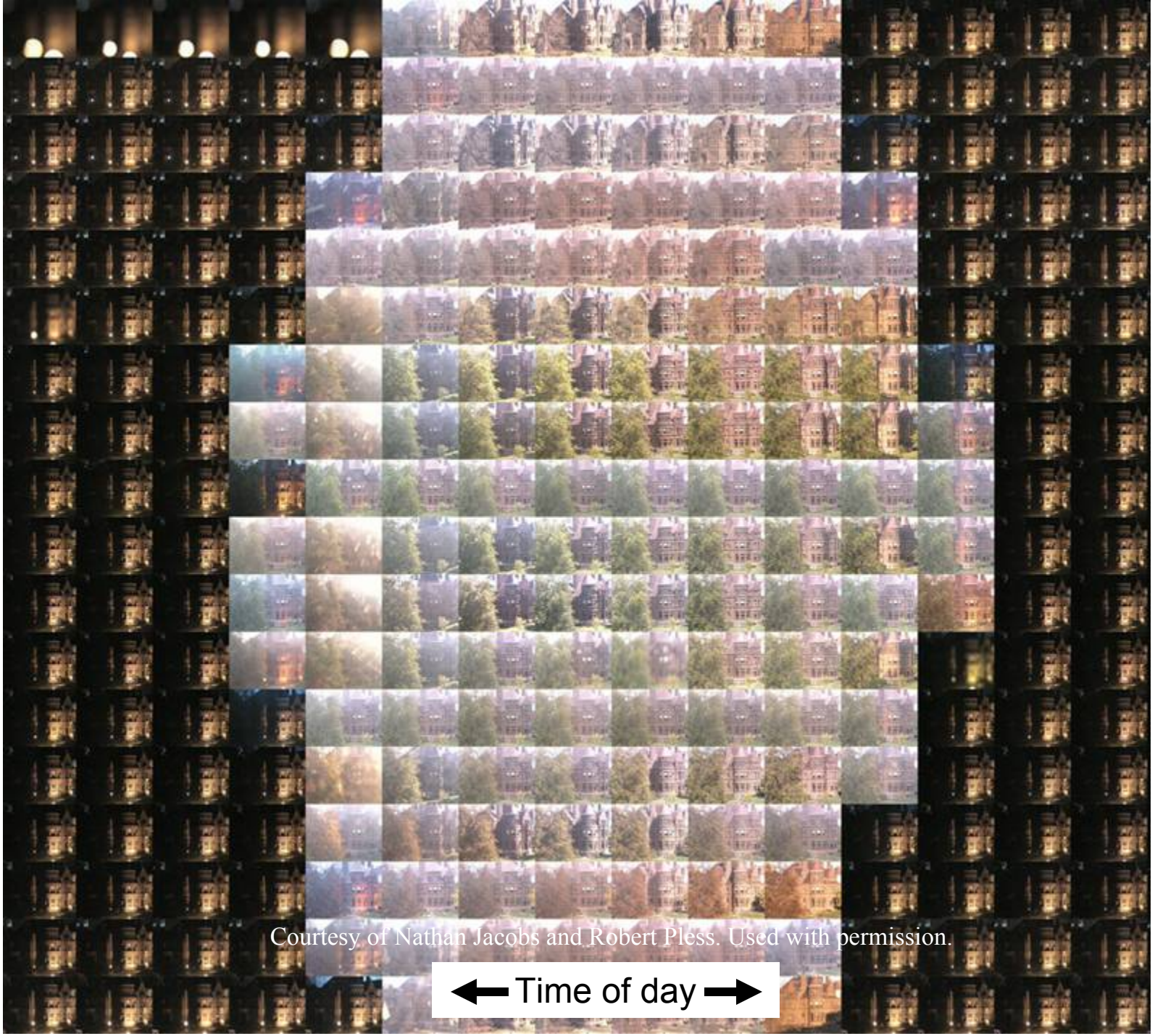
The Archive of Many Outdoor Scenes (AMOS)

Images from ~1000 static webcams, every 30 minutes since March 2006.

Variations over a year and over a day

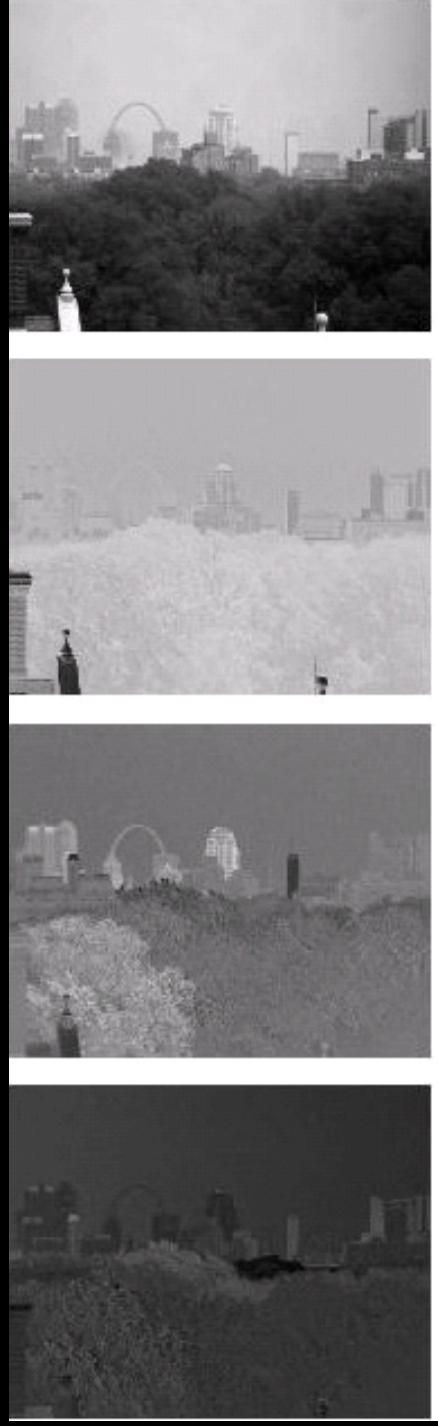
Courtesy of Nathan Jacobs and Robert Pless. Used with permission.

Jacobs, Roman, and Robert Pless, WUSTL CVPR 2007,



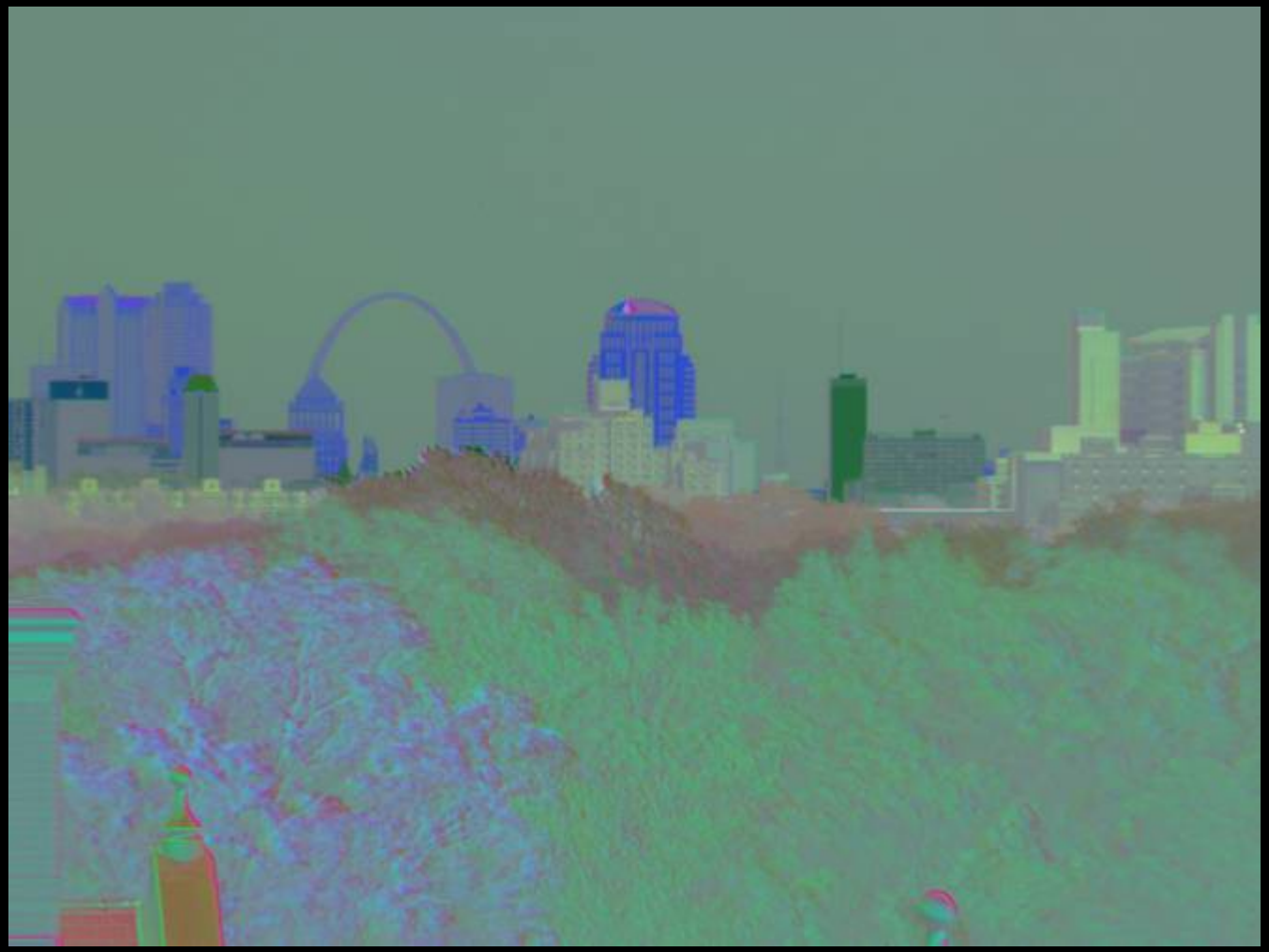
Analysing Time Lapse Images

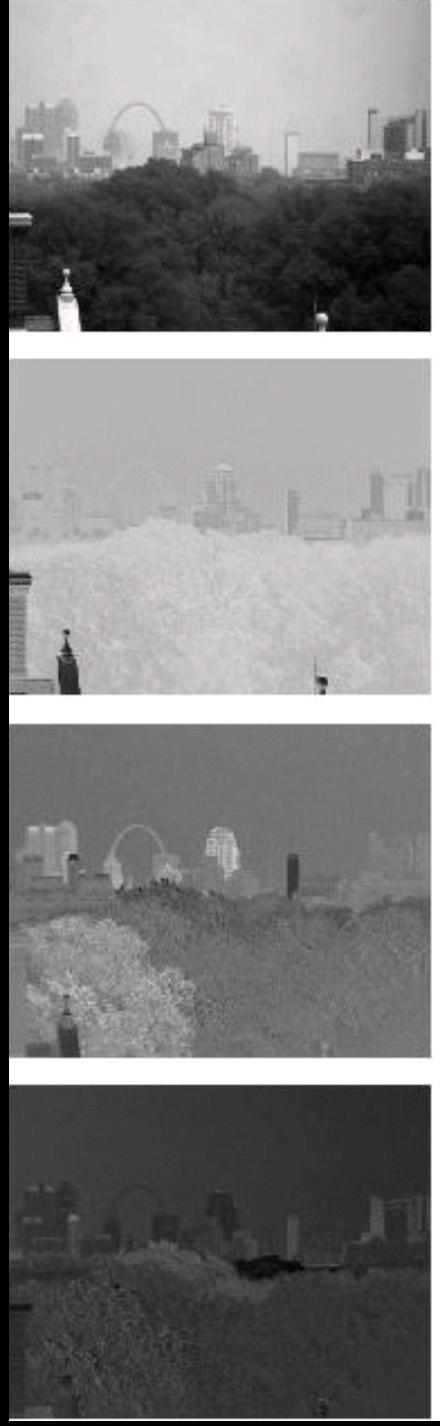
- PCA
  - Linear Variations due to lighting and seasonal variation
- Decompose (by time scale)
  - Hour: haze and cloud for depth.
  - Day: changing lighting directions for surface orientation
  - Year: effects of changing seasons highlight vegetation
- Applications:
  - Scene segmentation.
  - Global Webcam localization. Correlate timelapse video over a month from unknown camera with:
    - sunrise + sunset (localization accuracy ~ 50 miles)
    - Known nearby cameras (~25 miles)
    - Satellite image (~15 miles)



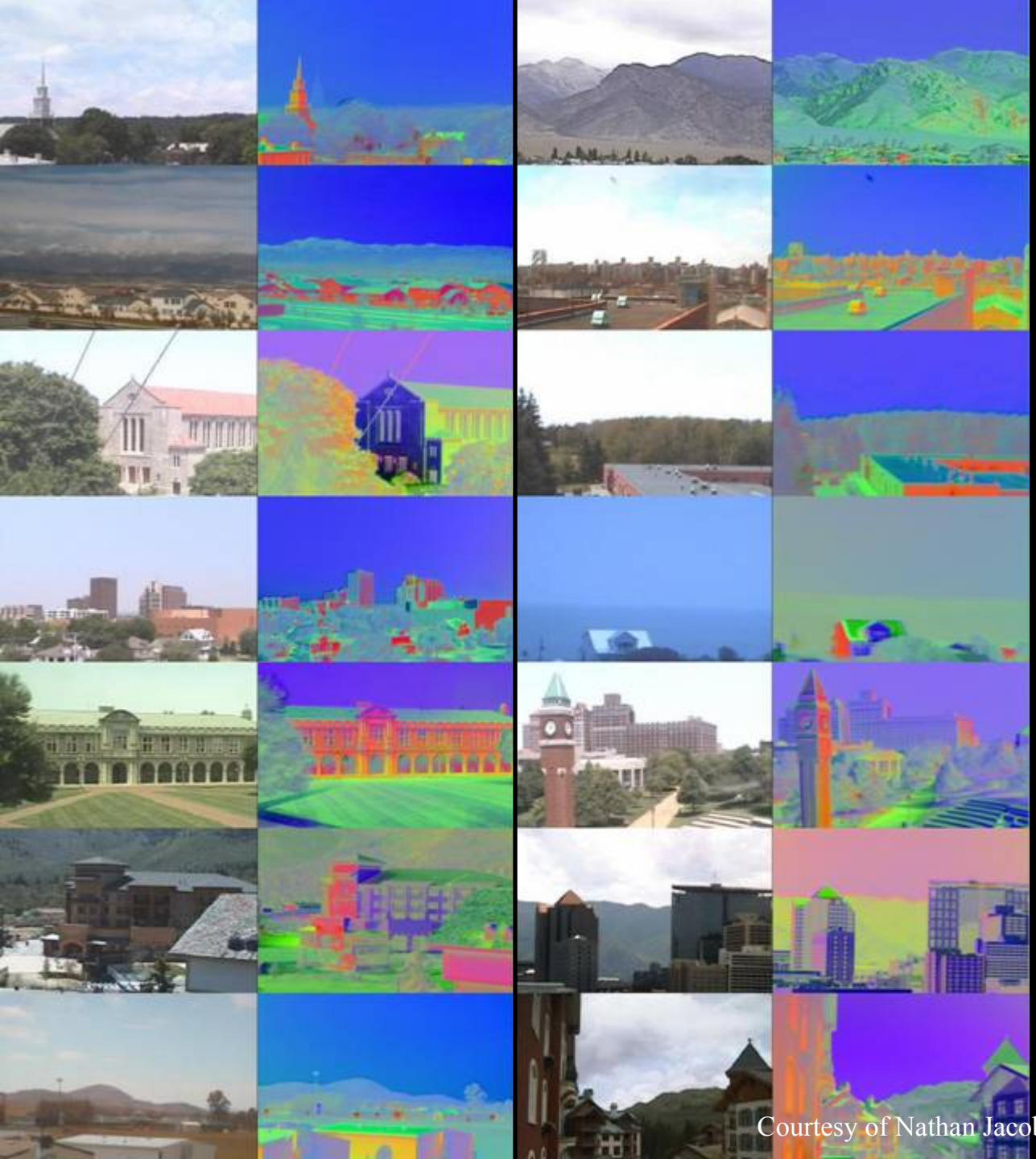
Mean image + 3 components from time lapse of downtown st. louis over the course of 2 hours

2 Hour time Lapse in St Louis:
Depth from co-varying regions





Courtesy of Nathan Jacobs and Robert Pless. Used with permission.



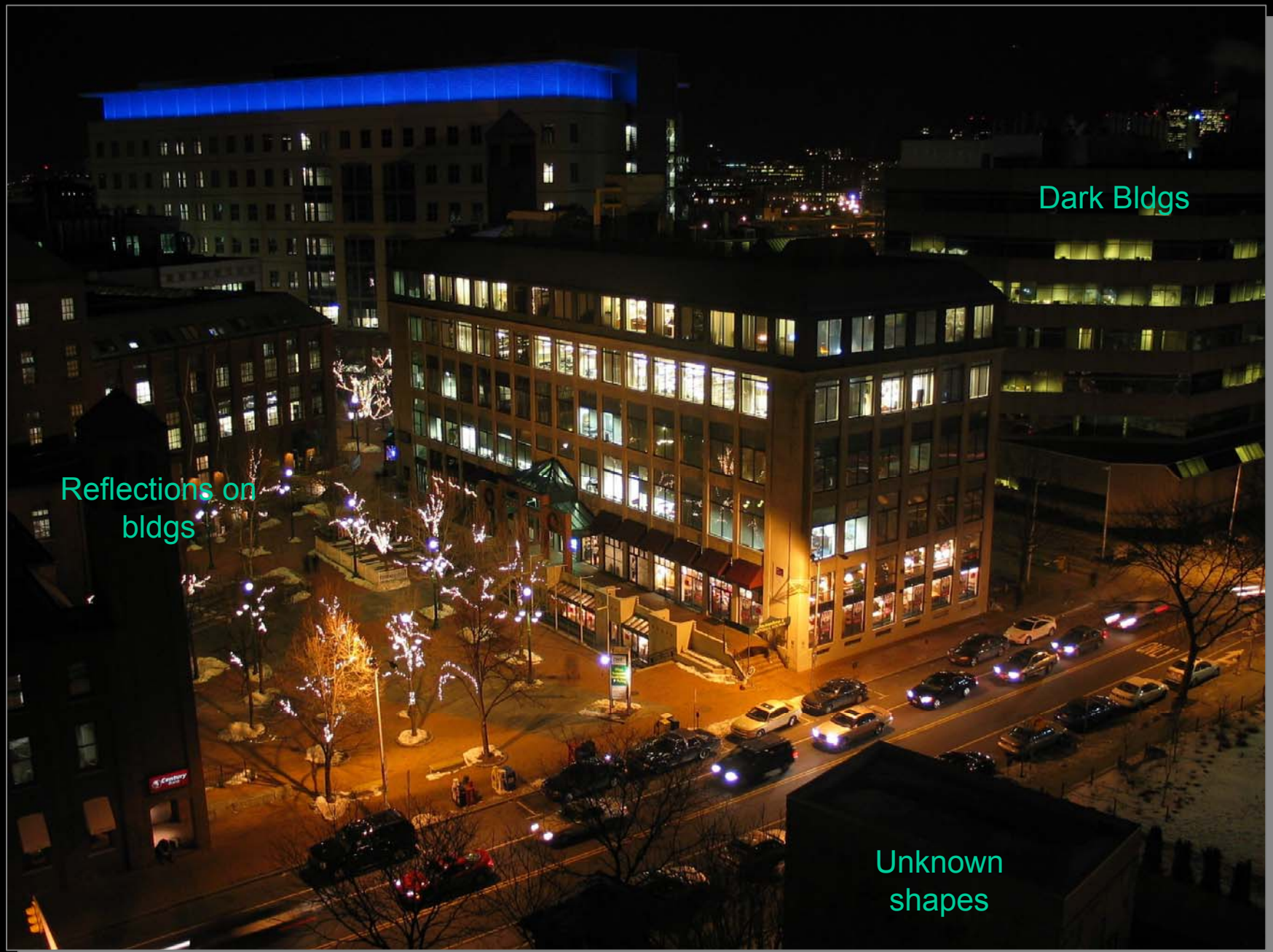
Surface Orientation

False Color PCA images

Image Fusion for Context Enhancement and Video Surrealism

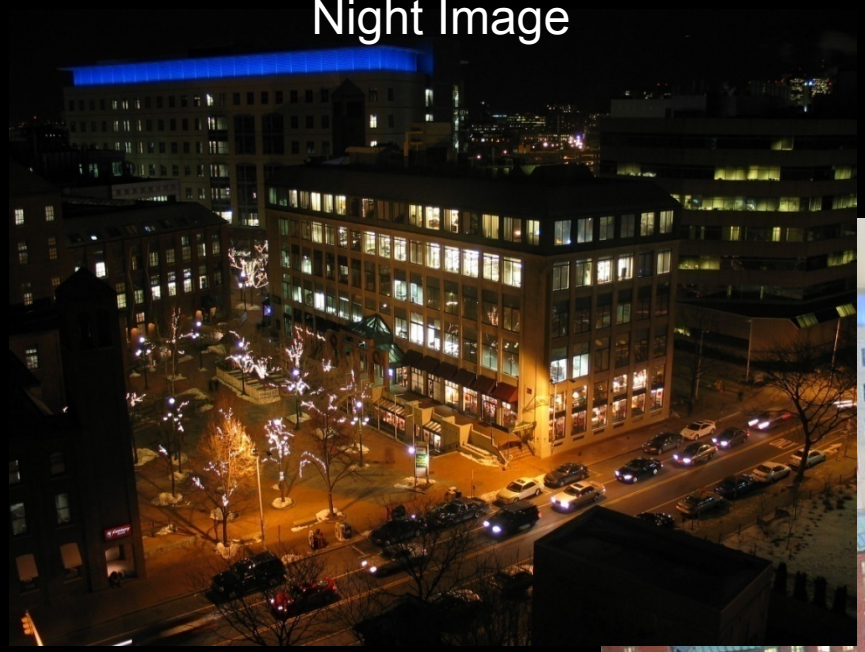
Ramesh Raskar Adrian Ilie Jingyi Yu

http://web.media.mit.edu/~raskar/NPAR04/


Dark Bldgs
Reflections on bldgs
Unknown shapes


‘Well-lit’ Bldgs
Reflections in bldgs windows
Tree, Street shapes

Night Image



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

Context Enhanced Image

Day Image

http://web.media.mit.edu/~raskar/NPAR04/

Factored Time Lapse Video

[Sunkavalli, Matusik, Pfister, Rusinkiewicz], Sig'07

Image removed due to copyright restrictions.
See http://people.csail.mit.edu/wojciech/FTLV/index.html

Factor into shadow, illumination, and reflectance.
Relight, recover surface normals, reflectance editing.

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MAS.531 Computational Camera and Photography

Fall 2009