Computational Camera & Photography:

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http://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.
Image-Based Actual Re-lighting

Debevec et al., SIGG2001

Film the background in Milan, measure incoming light

Light the actress in Los Angeles

Matched LA and Milan lighting.

Matte the background

Images removed due to copyright restrictions.
Second Homework

- Extending Andrew Adam’s Virtual Optical Bench

Courtesy of Andrew Adams. Used with permission.
Images removed due to copyright restrictions. See Sen et al, “Dual Photography,” SIGGRAPH 2005; specifically Figure 16 in the paper.
Beyond Visible Spectrum

Images removed due to copyright restrictions.

RedShift

Cedip
Image Fusion for Context Enhancement

Raskar, Ilie, Yu

‘Well-lit’ Bldgs

Reflections in bldgs windows

Tree, Street shapes
Background is captured from day-time scene using the same fixed camera.

Night Image

Day Image

Context Enhanced Image
Mask is automatically computed from scene contrast
But, Simple Pixel Blending Creates Ugly Artifacts
Our Method:
Integration of blended Gradients
Surrealism

Rene Magritte, ‘Empire of the Light’
Time-lapse Mosaics
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
Image removed due to copyright restrictions.

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

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 lightfield
- 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

Three photos removed due to copyright restrictions.

“Ultrathin Cameras Using Annular Folded Optics, “
E. J. Tremblay, R. A. Stack, R. L. Morrison, J. E. Ford
Applied Optics, 2007 - OSA
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
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
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/psgd1/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
Computational Illumination

Ramesh Raskar, Computational Illumination
Computational Photography

Novel Cameras

Generalized Sensor

Processing

Generalized Optics

4D Light Field

Illumination
Computational Illumination

Novel Cameras

Generalized Sensor

Processing

Generalized Optics

Novel Illumination

Light Sources

Modulators

Generalized Optics

Programmable 4D Illumination field + time + wavelength

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)

Flash
Shutter Open

Multi-flash
Sequential Photography

‘Smarter’ Lighting Equipment

What Parameters Can We Change?

Four photos of lighting setups removed due to copyright restrictions.
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

Courtesy of MERL. Used with permission.
What are the problems with ‘real’ photo in conveying information?

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

Courtesy of MERL. Used with permission.
Shadows
Clutter
Many Colors

Highlight Shape Edges
Mark moving parts
Basic colors

Courtesy of MERL. Used with permission.
A New Problem

Shadows
Clutter
Many Colors

Highlight Edges
Mark moving parts
Basic colors

Courtesy of MERL. Used with permission.
Gestures

Input Photo

Canny Edges

Depth Edges

Courtesy of MERL. Used with permission.
Courtesy of MERL. Used with permission.
Depth Discontinuities

Internal and external
Shape boundaries, Occluding contour, Silhouettes

Courtesy of MERL. Used with permission.
Canny Intensity Edge Detection

Our Method

Photo
Result

Courtesy of MERL. Used with permission.
Imaging Geometry

Shadow lies along epipolar ray

Courtesy of MERL. Used with permission.
Shadow lies along epipolar ray,
Epipole and Shadow are on opposite sides of the edge

Courtesy of MERL. Used with permission.
Shadow lies along epipolar ray,

Shadow and epipole are on opposite sides of the edge

Courtesy of MERL. Used with permission.
Depth Edge Camera

Light epipolar rays are horizontal or vertical

Courtesy of MERL. Used with permission.
Input

Left Flash

Right Flash

Courtesy of MERL. Used with permission.
Negative transition along epipolar ray is depth edge
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!
Congratulations on completing the task! Here is the text representation of the document:

- **Left**
- **Top**
- **Right**
- **Bottom**
- **Depth Edges**

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
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.
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.

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.
Computational Illumination: Programmable 4D Illumination Field + Time + Wavelength

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  - Dual Photography, Direct/Global Separation, Synthetic Aperture Illumination
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  - 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

SIGGRAPH 2005
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

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

Courtesy of Nathan Jacobs and Robert Pless. Used with permission.
Image Fusion for Context Enhancement and Video Surrealism

Ramesh Raskar  Adrian Ilie  Jingyi Yu

http://web.media.mit.edu/~raskar/NPAR04/
Background is captured from day-time scene using the same fixed camera

Night Image

Day Image

Context Enhanced 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.

Ramesh Raskar, CompPhoto
**Computational Illumination:**

*Programmable 4D Illumination Field + Time + Wavelength*

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