Computational Photography: Advanced Topics

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# Computational Photography, Advanced Topics

Debevec, Raskar and Tumblin

## Module 1: 105 minutes

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<tr>
<th>Time</th>
<th>Topic</th>
<th>Presenter(s)</th>
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<tr>
<td>1:45</td>
<td>A.1 Introduction and Overview</td>
<td>Raskar, 15 minutes</td>
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<td>2:00</td>
<td>A.2 Concepts in Computational Photography</td>
<td>Tumblin, 15 minutes</td>
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<td>2:15</td>
<td>A.3 Optics: Computable Extensions</td>
<td>Raskar, 30 minutes</td>
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<td>2:45</td>
<td>A.4 Sensor Innovations</td>
<td>Tumblin, 30 minutes</td>
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<td>3:15</td>
<td>Q &amp; A</td>
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<td>3:30</td>
<td>Break: 15 minutes</td>
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## Module 2: 105 minutes

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<tr>
<td>3:45</td>
<td>B.1 Illumination As Computing</td>
<td>Debevec, 25 minutes</td>
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<td>4:10</td>
<td>B.2 Scene and Performance Capture</td>
<td>Debevec, 20 minutes</td>
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<tr>
<td>4:30</td>
<td>B.3 Image Aggregation &amp; Sensible Extensions</td>
<td>Tumblin, 20 minutes</td>
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<td>4:50</td>
<td>B.4 Community and Social Impact</td>
<td>Raskar, 20 minutes</td>
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<td>5:10</td>
<td>B.4 Panel discussion</td>
<td>All, 20 minutes</td>
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Class Page: [http://ComputationalPhotography.org](http://ComputationalPhotography.org)
Computational Photography: Advanced Topics

A2: Core Concepts
(15 minutes)

Jack Tumblin
Northwestern University
Focus, Click, Print: ‘Film-Like Photography’

Light + 3D Scene:
- Illumination, shape, movement, surface BRDF, …

2D Image:
- ‘Instantaneous’ Intensity Map
- Rays
- Rays

Angle(θ, φ)

Position(x, y)

‘Center of Projection’
(P³ or P² Origin)
Perfect Copy: Perfect Photograph?

Scene Light Intensities

Display Light Intensities

'Pixel values'
(scene intensity? display intensity?
perceived intensity? 'blackness/whiteness'?)
‘Film-Like’ Photography

Ideals, Design Goals:

– ‘Instantaneous’ light measurement...
– Of focal plane image behind a lens.
– Reproduce those amounts of light.

Implied:

“What we see is \( \approx \) focal-plane intensities.”

well, no...we see much more!

(seeing is deeply cognitive)
Our Definitions

• ‘Film-like’ Photography:
  Displayed image \(\cong\) sensor image

• ‘Computational’ Photography:
  Displayed image \(\neq\) sensor image
  \(\cong\) visually meaningful scene contents

A more expressive & controllable displayed result, transformed, merged, decoded data from compute-assisted sensors, lights, optics, displays
What *is* Photography?

Safe answer:

A wholly new, expressive medium (ca. 1830s)

- Manipulated display of what we think, feel, want, …
  - Capture a memory, a visual experience in tangible form
  - ‘painting with light’; express the subject’s visual essence
  - “Exactitude is not the truth.” –Henri Matisse
What *is* Photography?

- A ‘bucket’ word: a neat container for messy notions (e.g. aviation, music, comprehension)
- A record of what we see, or would like to see, in tangible form.
- Does ‘film’ photography always capture it? Um, no...
- What do we see?
What *is* Photography?

**PHYSICAL**

3D Scene
- light sources, BRDFs, shapes, positions, movements, ...

Eyepoint
- position, movement, projection, ...

Light & Optics

Exposure Control, tone map

**PERCEIVED**

Scene
- light sources, BRDFs, shapes, positions, movements, ...

Eyepoint
- position, movement, projection, ...

Vision

**Image**

\[ I(x,y,\lambda,t) \]

**Display**

\[ RGB(x,y,t_n) \]

Photo: A Tangible Record
Editable, storable as Film or Pixels

Photo: A Tangible Record
Editable, storable as Film or Pixels
Ultimate Photographic Goals

PHYSICAL

3D Scene
light sources, BRDFs, shapes, positions, movements, ...

Eyepoint
position, movement, projection, ...

Light & Optics

Sensor(s)

Computing

Visual Stimulus

Vision

PERCEIVED or UNDERSTOOD

3D Scene?
light sources, BRDFs, shapes, positions, movements, ...

Eyepoint?
position, movement, projection, ...

Meaning...

Photo: A Tangible Record
Scene estimates we can capture, edit, store, display
Photographic Signal: Pixels Rays

• Core ideas are ancient, simple, seem obvious:
  – Lighting: ray sources
  – Optics: ray bending/folding devices
  – Sensor: measure light
  – Processing: assess it
  – Display: reproduce it

• Ancient Greeks:
  ‘eye rays’ wipe the world
to feel its contents…

http://www.mlahanas.de/Greeks/Optics.htm
Claim: Computing can improve every step
Review: How many Rays in a 3-D Scene?

A 4-D set of infinitesimal members.

Imagine:

- Convex Enclosure of a 3D scene
- Inward-facing ray camera at every surface point
- Pick the rays you need for ANY camera outside.

2D surface of cameras, + 2D ray set for each camera → 4D set of rays.

(Levoy et al. SIGG’96) (Gortler et al. ‘96)
4-D Light Field / Lumigraph

Measure all the **outgoing** light rays.
4-D Illumination Field

Same Idea: Measure all the *incoming* light rays
4D x 4D = 8-D Reflectance Field

Ratio: $R_{ij} = \frac{\text{outgoing ray}_i}{\text{incoming ray}_j}$
Because Ray *Changes* Convey Appearance

- These rays + all these rays give me…

- MANY more useful details I can examine…
Expressive Time Manipulations

What other ways better reveal appearance to human viewers?
(Without direct shape measurement?)

Can you understand this shape better?

*Time for space wiggle. Gasparini, 1998.*
Missing:

Viewpoint Freedom

“Multiple-Center-of-Projection Images” Rademacher, P, Bishop, G., SIGGRAPH '98
Missing: **Interaction**…

Adjust everything: lighting, pose, viewpoint, focus, FOV,…

Winnemoller EG 2005: after Malzbender, SIGG2001
Mild Viewing & Lighting Changes;
(is true 3D shape necessary?)

Convincing visual appearance:
Is Accurate Depth really necessary?

a few good 2-D images may be enough…

"Image jets, Level Sets, and Silhouettes"
Lance Williams,
talk at Stanford, 1998.
Future Photography

Novel Cameras

- Generalized Sensors
- Ray Reconstructor
- Generalized Processing
- 4D Ray Sampler
- General Optics: 4D Ray Benders

Novel Displays

- Generalized Display
- Recreated 4D Light field
- Viewed 4D Light Field
- Scene: 8D Ray Modulator

Novel Illuminators

- Lights
- Modulators
- General Optics: 4D Ray Benders

4D Incident Lighting
‘The Ideal Photographic Signal’

I CLAIM IT IS:

All Rays? Some Rays? **Changes** in Some Rays

Photographic ray space is vast and redundant
>8 dimensions: 4D view, 4D light, time, \(\lambda\),

? Gather only ‘visually significant’ ray changes?

? What rays should we measure?
? How should we combine them?
? How should we display them?
Beyond ‘Film-Like’ Photography

Call it ‘Computational Photography’:
To make ‘meaningful ray changes’ tangible,

- Optics can do more…
- Sensors can do more…
- Light Sources can do more…
- Processing can do more…

by applying low-cost storage, computation, and control.