Computational Photography
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Introduction to CSAIL
MIT Computer Science and Artificial Intelligence Laboratory
Cambridge, MA 02139, USA

MIT = Labs + Departments
aka “courses”

Mechanical Engineering (2)
Materials Science (3)
Chemistry (5)
Physics (8)
Brain & Cog. Sci. (9)
Chemical Engineering (10)
Aero & Astro (16)
Math (18)

Faculty and grad students wear two hats: lab + department

CSAIL PIs

CSAIL Boasting

• Distinctions
  – 4 Turing Awards, 2 Japan Prizes, 17 NAS/NAE members, 2 ACM Von Neumann medals, 5 IJCAI Computers and Thought Awards, many ACM Thesis Awards, 6 MacArthur Foundation Genius awards, 3 MIT-Lemelson prizes, 1 Knight of the British Empire, 1 Draper Prize, 2 Nevanlinna prizes, 3 Goedel prizes, 1 Millennium Technology Award.

• Innovations include
  – Time sharing, public key encryption, bit-mapped displays, computer chess, TCP/IP, personal workstations, computer algebra/mathematics, GNU, Web standards, many aspects of computer vision and robotics, …

• CSAIL hosts the World Wide Web Consortium

• Spin-off companies
  – Akamai, iRobot, Open Market, RSA Data Security, Cognex, SightPath, SpeechWorks, Silicon Spice, Peppercoin, …
Advice to the wise

- Do a UROP
  - Best way to learn about exciting technology
  - Great investment to get into grad school
  - You can even get credits or money for it!
- Get on Anne Hunter’s mailing list anneh@eecs.mit.edu

Computer Graphics Group
Frédéric Durand

Frédéric Durand

3D graphics: better, faster!

- Realistic materials
  - With easy acquisition
- Shadow computation
  - Eliminates staircase artifacts

Acquisition & editing of material appearance

- 6D function!

Fast preview for lighting

- Collaboration with Tippet Studio and Industrial Light and Magic (George Lucas’s special effect company)
- Typical Hollywood frame: 10 hour rendering time
- Goal: Accelerate lighting specification
- Automatically translate image-generation code to graphics hardware
**Frequency analysis of light transport**

**Challenges**
- Efficient & practical algorithms
  - Geometric emphasis
- Hardware
  - Camera designs
  - Graphics hardware
- Theory:
  - Signal processing, singularities
    - Image processing (2D)
    - Light transport (4D)
- Understand the problems
  - Physics, Perception, Visual arts

**Interdisciplinarity:** to understand what we do
- Within CS
  - Hardware, compilers, machine vision
- Math & Physics
- Art history, visual arts
- Perception
- We use their knowledge, but we also help them with validation
  - Co-authored article about perceptual theory of style
  - Collaborate w/ psychologists about material perception, visual attention

**It ain't just about science**
First week of April (after spring break)
- Award winner director Michel Gondry (Eternal Sunshine of the Spotless Mind, Bjork videos, Rolling Stones) artist in residence @ MIT
- Special effect guru and director Olivier Gondry artist in residence @ CSAIL

**Hollywood-quality image making for everyone!**
- Computational photography
- 3D graphics
- 2D to 3D
- Theory & application
- Interdisciplinary
  - Math, Physics, Perception, Art History
- Education
  - Graphics to motivate tough material
  - Yearly undergraduate research challenge

**Computational Photography**
Frédéric Durand
What is computational photography

• Convergence of image processing, computer vision, computer graphics and photography
• Digital photography:
  – Simply replaces traditional sensors and recording by digital technology
  – Involves only simple image processing
• Computational photography: Add arbitrary computation
  – More elaborate image manipulation, more computation
  – New types of media (panorama, 3D, etc.)
  – Camera design that take computation into account

Computational Photography

Compensate for limitations
• Imaging equipment might be low-quality
  – e.g. cell-phone or PDA camera.
  – Sensor noise, weak optics, sensor resolution
• Scene conditions might be challenging
  – Low light, high contrast, poor lighting quality.
• The user has no time or skill to touch up the image

Enable new application, new media
• 3D from 2D
• Visualize what was impossible to see

Real world dynamic range

• Eye can adapt from ~ $10^{-6}$ to $10^6$ cd/m$^2$
• Often $1 : 100,000$ in a scene

<table>
<thead>
<tr>
<th>Real world</th>
<th>1:10</th>
<th>1:100</th>
<th>1:1000</th>
<th>1:10,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-6}$</td>
<td></td>
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<td></td>
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<tr>
<td>$10^6$</td>
<td></td>
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</tbody>
</table>

High dynamic range
**Picture dynamic range**

- Typically 1:20 or 1:50
  - Black is ~50x darker than white
- Max 1:500

<table>
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<tr>
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**Contrast reduction**

- Match limited contrast of the medium
- Preserve details

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**Example:**

- Photo with a Canon G3
  - Jovan is too dark
  - Sky is too bright

**Traditional photo craft: Fill-in**

- Flash to illuminate the interior
- Brings interior intensity to level of exterior

**Traditional craft: dodging and burning**

- Locally darken or lighten
- Mask to expose some areas less

Does masking make an area
A: Darker
B: Brighter

**Traditional craft: dodging and burning**

- **Clearing Winter Storm**
  by Ansel Adams

**Does masking make an area**
A: Darker
B: Brighter
Traditional craft: dodging and burning
• The artist at work
• Problems with dodging and burning
  – Tedious
  – Must move mask to avoid artifacts
  – Haloing for complex edges

Half of the job: acquisition
• Not my job! (Charlie Sodini’s job)
• Multiple exposure photo [Debevec & Malik 1997]

The second half: contrast reduction
• That’s my job
• Input: high-dynamic-range image
  – (floating point per pixel)

Naïve technique
• Scene has 1:10,000 contrast, display has 1:100
• Simplest contrast reduction?

Naïve: Gamma compression
• $X \rightarrow X^\gamma$ (where $\gamma=0.5$ in our case)
• But… colors are washed-out. Why?

Gamma compression on intensity
• Colors are OK, but details (intensity high-frequency) are blurred
Oppenheim 1968, Chiu et al. 1993
- Reduce contrast of low-frequencies
- Keep high frequencies

The halo nightmare
- For strong edges
- Because they contain high frequency

Our approach
- Do not blur across edges
- Non-linear filtering

Gaussian filtering
- Spatial Gaussian $f$

$$J(x) = \sum f(x, \xi) \cdot I(\xi)$$

Bilateral filtering
- Spatial Gaussian $f$
- Gaussian $g$ on the intensity difference

$$J(x) = \frac{1}{k(x)} \sum f(x, \xi) \cdot g(I(\xi) - I(x)) \cdot I(\xi)$$

Live demo
- Whatever GHz Pentium 4
- Industrial interest
  - Embedded in the camera
  - In the download software
  - For surveillance
Anecdote about tone mapping evaluation

- Recent work has performed user experiments to evaluate competing tone mapping operators
  - [Ledda et al. 2005, Kuang et al. 2004]
- Interestingly, the former concludes my method is the worst, the latter that my method is the best!
  - They choose to test a different criterion: fidelity vs. preference
- More importantly, they focus on algorithm and ignore parameters

Flash Photography (Elmar Eisemann)

- Available light is not always enough, image is blurry/noisy
- Flash photos look harsh, ambiance is not nice
- Our work combines the two to get the best of both

Edit materials and lighting

- With Oh, Chen and Dorsey
A Simple Relighting Example

- With Oh, Chen and Dorsey

From 2D to 3D graphics

- Creating 3D models from one single photo
- Technology used for Star Wars Episode II (former student re-implemented it at ILM)

Workflow

- Input image
- Apply depth
- Cloning brush holes
- Edit, relight

Results – Hotel Lobby

Crazy camera

- 3 cameras share the same optical axis
- Separate foreground and background

Motion Magnification

Ce Liu  Antonio Torralba  William T. Freeman
Frédo Durand  Edward H. Adelson

Computer Science and Artificial Intelligence Laboratory
Massachusetts Institute of Technology
Motion Microscopy

Original sequence

Magnified sequence

Is the Baby Breathing?

Original Sequence

Thank you!

Motion Magnification

Ce Liu, Antonio Torralba, William T. Freeman, Frédo Durand, Edward H. Adelson

Computer Science and Artificial Intelligence Laboratory

Massachusetts Institute of Technology