Computational Photography
(Trial lecture and VCF seminar)

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Visualization group @ II, UiB
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About

- PhD-student at the visualization group in department of informatics at University of Bergen, Norway.
- Hope to defend it June 25th 2013.
- This VCF-talk is my trial lecture
Goal of this Lecture

Provide an introduction to and overview of the field of computational photography

• Provide examples and applications
• Deeper description of some works
• Look at the future of computational photography
• Provide referenced for further reading

• Questions afterwards
Outline

• Background:
  • Classic photography 101
• Tour of Computational Photography
  • Epsilon photography
  • Coded photography
  • Essence Photography
• The future
• Resources, summarization, and conclusions
The Traditional Camera

The camera:

Shutter

Sensor

Iris / Aperture

Lens

From Popular Mechanics (http://www.spd.org/images/blog/117.jpg)
December 2008, photographer: Gregor Halenda
Photography – Painting With Light

- Captures light
  - From the subject, through the lens onto the sensor
  - Moderated by the aperture and shutter
  - Field-of-view: how much of the world is visible through the lens

Camera: Shutter and Sensor

Lens: Optics and Iris/Aperture

Subject
Classic Photography 101 – Exposure

- Exposure = amount of light falling on the sensor
- Function of shutter open time and aperture size
Classic Photography 101 – Aperture

- Limits the light going through the lens
- I.e. small opening => longer exposure time to get same exposure

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Illustration (right) copyright Dennis P. Curtin, used with permission http://www.shortcourses.com/use/using1-9.html
Classic Photography 101 – Aperture

- Depth-of-field

Classic Photography – Shutter

- Exposes the sensor for the light from the lens
- Freezing time or motion-blur

Closed shutter

Open shutter

Short shutter time

Long shutter time

Images copyright Endre M. Lidal
Classic Photography 101 – The Sensor

A lot of computation:

1. **Incoming light**
2. **Filter layer**
3. **Sensor array**
4. **Resulting pattern**

- **Gain**
- **ISO**
- **ADC**
- **Demosaic**
- **Sharpen**
- **White Balance**
- **Gamma/curve**
- **Compress**
- **JPEG-file**
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Computational Photography

“Computational Photography captures a machine-readable representation of our world to synthesize the essence of our visual experience.”

Ramesh Raskar, Associate Professor MIT Media Lab
Jack Tumblin, Research Associate Professor, University of Southern California

- Allows us to capture and synthesize images that could not be captured with traditional camera
- Beyond just computation for image processing, also capturing visually meaningful scene contents, i.e. a visual experience
Computational Photography

Inspired by illustrations from Zhou and Nayar 2011 and Raskar et al. 2008
Taxonomies


- Epsilon photography
- Coded photography
- Essence Photography

Zhou and Nayar (2011), Colombia Univ, present an alternative, and more extensive, taxonomy
Epsilon (Bracketing) Photography

Improving pixel sampling by bracketing camera parameters

- Increase the dynamic range – Exposure bracketing
- Increase the field of view / Super-resolution image – Panning the camera and stitching pictures together
- Increase depth of field – Fusion limited depth of field images at different focal planes
- Reduce noise – Combine pair of flash/no-flash images
- Increase frame rate, high speed imaging - Multiple cameras

Taxonomy:
- Epsilon photography
- Coded photography
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High Dynamic Range Photography

• Problem:
  • Sensors and display have limited dynamic tone range compare to the dynamic range found in nature

Images from “Gradient Domain High Dynamic Range Compression” by Raanan Fattal, Dani Lischinski, and Michael Werman
HDR Photography

- Exposure bracketing:
  - 3 – 9 (or more) low(ER) dynamic range photos

Images from “Gradient Domain High Dynamic Range Compression” by Raanan Fattal, Dani Lischinski, and Michael Werman
HDR Photography

Merging of the bracket images:

- Naïve: pick and combine “correctly” exposed pixels
  - Artifacts in contrasts and halos

- Better: (Debevec and Malik 1997)
  1. Construct/estimate a radiance map (== HDR image) of the scene
  2. Tone map the HDR image back to displayable gamut
Radiance Map

1. Construct a radiance map
2. Tone map the HDR image

- Radiance map is an estimate of how much light (radiance) from the screen is reaching each pixel
- Requires an estimate how the sensor responds to photon (radiometric response function) as this is individual for each camera model
- Typically stored as float value for each color component.

Image from “Recovering High Dynamic Range Radiance Maps from Photographs” by Paul E. Debevec and Jitendra Malik SIGGRAPH97
1. Construct a radiance map
2. Tone map the HDR image

Images from “Gradient Domain High Dynamic Range Compression” by Raanan Fattal, Dani Lischinski, and Michael Werman
Epsilon Photography Available Today!

The cell phone:

- First step towards epsilon photography in devices, through apps
  - HDR apps
  - Automatic panoramas
  - NPR image

Taxonomy:
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- Essence Photography
Coded Photography

- Encode scene properties into the image, utilizing modified lenses, sensors, illumination etc.,
  - Temporal coding – exposure mask
  - Spatial coding – aperture mask
  - Illumination coding – intra-view
  - Sensor coding – capturing the light field

Many of the works here seem counter intuitive at first, but have very clever solutions that simplifies a difficult reconstruction problem!

Taxonomy:
- Epsilon photography
- Coded photography
- Essence Photography
Coded Exposure Photography: Motion Deblurring using Fluttered Shutter
Ramesh Raskar, Amit Agrawal, and Jack Tumblin
ACM SIGGRAPH 2006

The fluttered shutter
Blurring by Convolution

Images from “Coded Exposure Photography: Motion Deblurring using Fluttered Shutter”
Ramesh Raskar, Amit Agrawal, and Jack Tumblin
Images from “Coded Exposure Photography: Motion Deblurring using Fluttered Shutter”
Ramesh Raskar, Amit Agrawal, and Jack Tumblin
Motion Blur

Motion-Invariant Photography SIGGRAPH 2008
Anat Levin, Peter Sand, Taeg Sang, Cho Fredo, Durand, and William T. Freeman

Computer Science and Artificial Intelligence Lab (CSAIL), MIT
Motion-Invariant Photography

- Moves the camera while the picture is taken
  - Image becomes “equally” blurred with known blurring kernel
- Parabolic (in time) movement

Images from “Motion-Invariant Photography” Anat Levin et al.
Limited to 1D Movements

Images from “Motion-Invariant Photography” Anat Levin et al.
Depth of Field / Defocus Blur

Dappled Photography: Mask Enhanced Cameras for Heterodyned Light Fields and Coded Aperture Refocusing
Ashok Veeraraghavan, Ramesh Raskar, Amit Agrawal, Ankit Mohan, and Jack Tumblin
ACM SIGGRAPH 2007
Image from “Dappled Photography: Mask Enhanced Cameras for Heterodyned Light Fields and Coded Aperture Refocusing, Ashok Veeraraghavan et al.”
Light Field

• Function describing amount of light traveling in the scene (measures radiance along rays)

• Post-capture possibilities:
  • Refocus, depth of field adjustments, re-lighting, etc
Light Field Capturing

- Microlens array on top of a traditional sensor
  - 292 x 292 lenses => 292 x 292 pixels in final image
  - 4000 x 4000 sensor => 14 x 14 ray directions each pixel

Images from "Light Field Photography with a Hand-Held Plenoptic Camera" Ren Ng, Marc Levoy, Mathieu Brédif, Gene Duval, Mark Horowitz, and Pat Hanrahan
Light Field Capturing

Result:

Images from “Light Field Photography with a Hand-Held Plenoptic Camera” Ren Ng, Marc Levoy Mathieu Brédif, Gene Duval, Mark Horowitz, and Pat Hanrahan
Light Field Capturing

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Essence Photography

- Capturing the high level understanding of the scene, beyond only mimicking the human eye

- Multi perspective images
  - Wrap-around views

- Explore the large online collections
  - Explore the world
  - Learning/statistics from image collections and utilize this for image improvements

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Andrew Davidhazy
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Traditional Cameras Obsolete?

- Leica M – monochrome

Photos by Geir Brekke, [http://foto.no/cgi-bin/articles/articleView.cgi?articleId=45421](http://foto.no/cgi-bin/articles/articleView.cgi?articleId=45421) (used with permission)
Do We Need a Camera at All?

- A camera without optics?

Lytro : Light Field Capturing Camera

- Lytro image and image
- Founded by Ren Ng
The Frankencamera: An Experimental Platform for Computational Photography

Frankencamera

- Provides a portable and programmable camera for computational photography experimentation and research
- Based on an open architecture and API
- Controls and synchronizes
  - Sensor and image processing pipeline
  - External devices (flash, lens etc)
- Implemented for custom build platform and for Nokia N900 cell phone

The Future

Computational Photography

Novel Cameras

Processing

Generalized Sensor

Reconstruction

Ray Up to 4D Ray Sampler

4D Ray Bender

4D Light Field

Novel Illumination

Light Sources

Modulators

Generalized Optics

4D Incident Lighting

Scene: 8D Ray Modulator

Display

Recreate 4D Lightfield

The Future – Research

- Technical program Track on: “Computational Light Capture”
- IEEE International Conference on Computational Photography (ICCP), since 2009
- Mobile Computational Photography 2014 (San Francisco 2 - 6 February 2014)
Eulerian Video Magnification for Revealing Subtle Changes in the World (SIGGRAPH 2012)

Hao-Yu Wu, Michael Rubinstein, Eugene Shih, John Guttag, Frédo Durand, and William T. Freeman
CSAIL, MIT, Quanta Research Cambridge, Inc.
VIDEOS
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Researchers in the CP field

- Marc Levoy (Stanford)  

- Shree K. Nayar (Columbia University)  

- Ramesh Raskar (MIT Media Lab)  

- William T. Freeman (MIT Computer Science and Artificial Intelligence Laboratory)  
Resources for Further Inquiries

Books:

2010
Richard Szeliski,
Microsoft Research

Free version online:
http://szeliski.org/Book/

2010
Rastislav Lukac
Foveon, Inc./Sigma
(editor)

2014 (upcomming)
Ramesh Raskar
Jack Tumblin
Resources for Further Inquiries

Journals:

- International Journal of Computer Vision (Springer): Special Issue Call for Papers: Computational Photography (Feb 2013)

- Journal of Electronic Imaging (SPIE): Special Section Guest Editorial: Mobile Computational Photography January 2013

- IEEE Computer Graphics and Applications (January/February 2011)

Resources for Further Inquiries

Courses:

• MIT: http://cameraculture.media.mit.edu/courses
• Brown: http://cs.brown.edu/courses/csci1290/
• and many others
Conclusions

• Computation + photography = many ingenious works
  • Improved photography in low light conditions, deblurring, HDR, panoramas
  • More decisions can be made after the picture is taken – depth-of-field, focus, blurring, perspective shift

• Still: A distinction between technology and art
  • Leica Monochrome vs. Lytro

• We will nevertheless see more and more computation in our cameras, in apps and in firmware
This Talk is Based on these Resources

In addition to the papers mentioned on the slides:


- B. Hayes “Computational Photography”, American Scientist March-April 2008, Volume 96, Number 2


- Richard Szeliski “Computer Vision”, Springer 2010

- Wikipedia
THANK YOU FOR YOUR ATTENTION

Questions?