Computational Photography
(Trial lecture and VCF seminar)

Endre M. Lidal

Visualization group @ II, UiB

May 31st 2013 (10:15-11:00)

About

- PhD-student at the visualization group in department of informatics at University of Bergen, Norway.
- Submitted my dissertation titled “Sketch-based Storytelling for Cognitive Problem Solving – Externalization, Evaluation, and Communication in Geology” April 12 2013
- 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

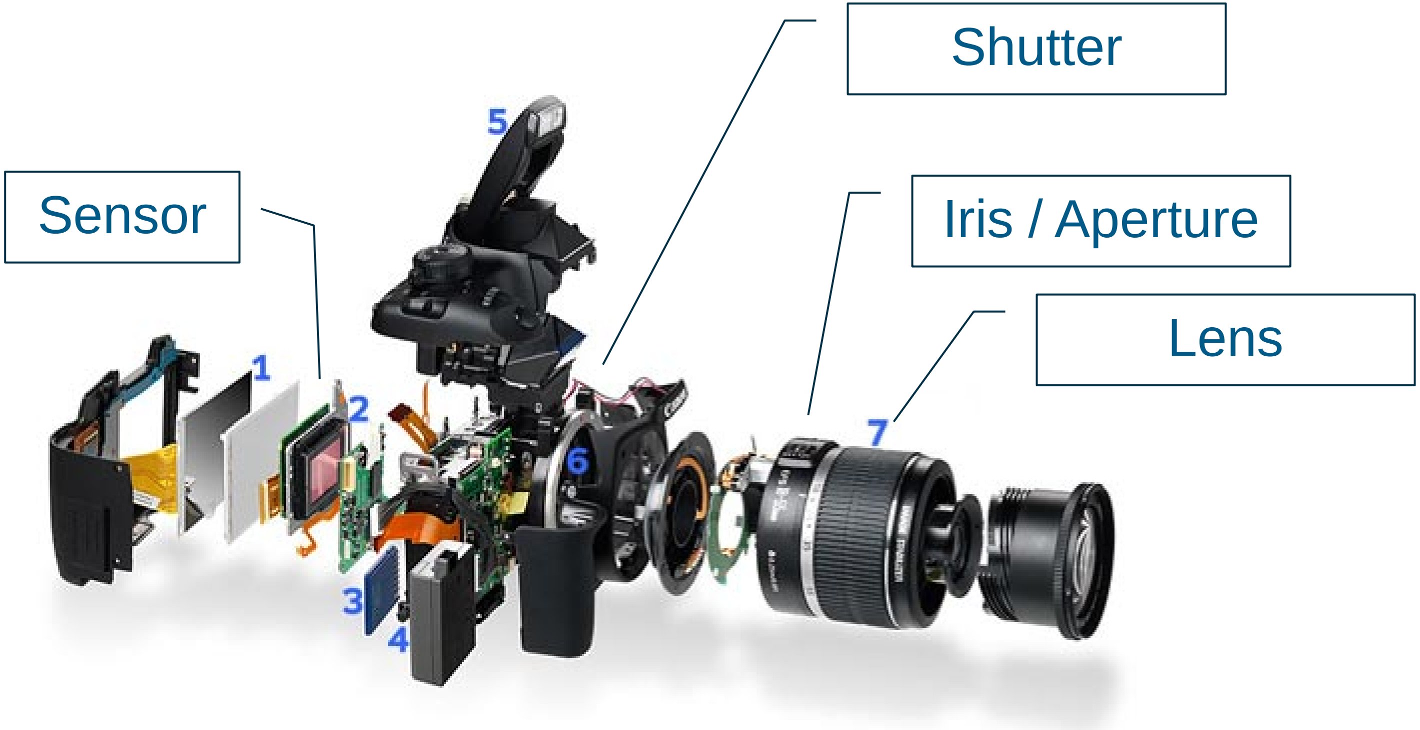
- Questions afterwards

Outline

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

The Traditional Camera

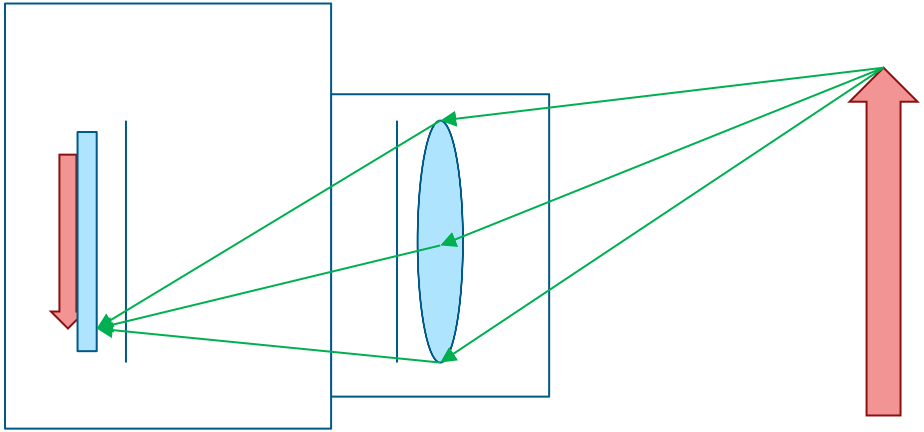
The camera:



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

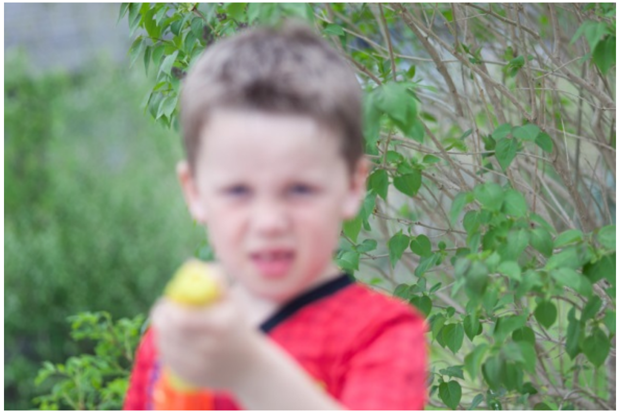
Subject

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



Images copyright Endre M. Lidal

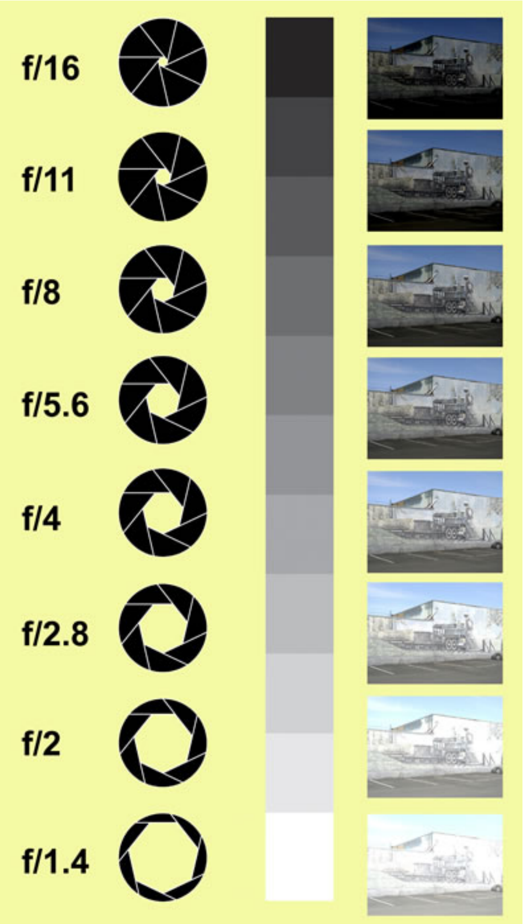
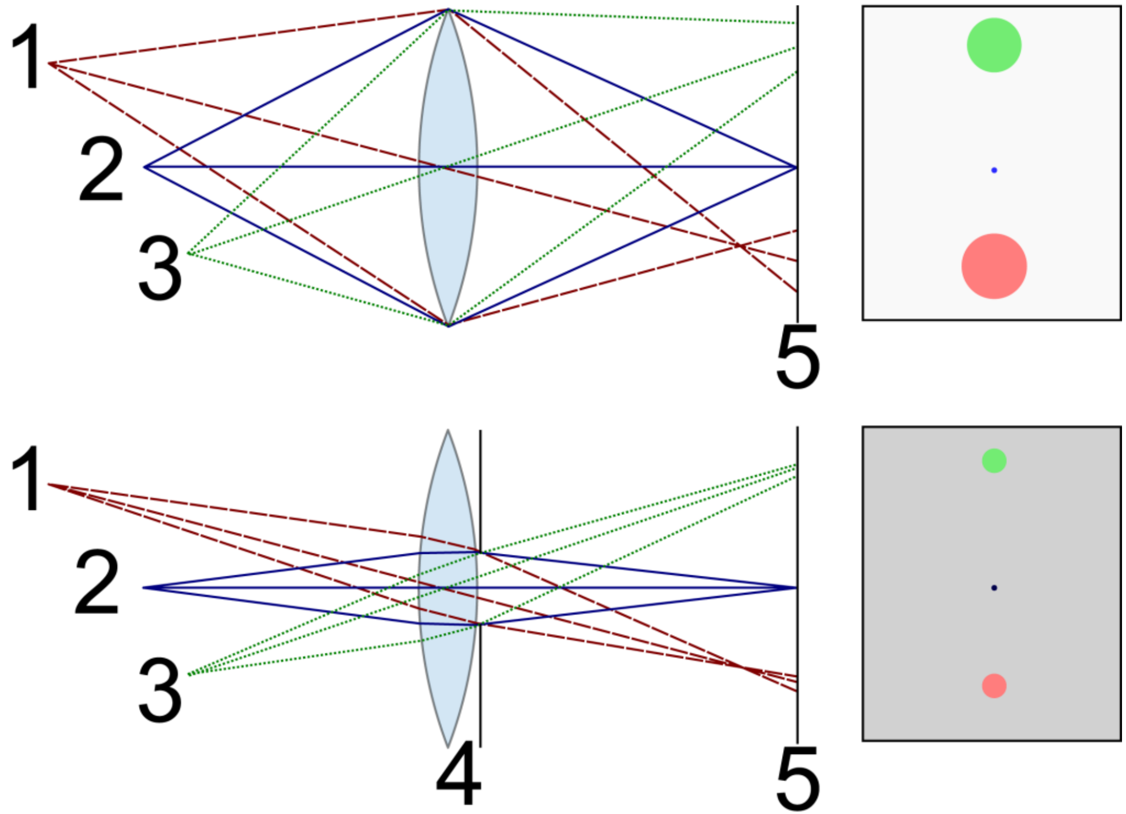


Illustration (right) copyright Dennis P. Curtin, used with permission http://www.shortcourses.com/use/using1-9.html

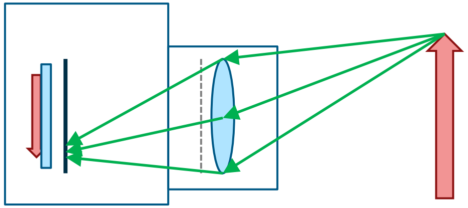
- Depth-of-field



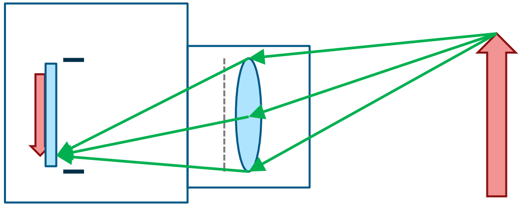
From Wikipedia https://en.wikipedia.org/wiki/Depth_of_field (CC-license)

Classic Photography – Shutter

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



Closed shutter

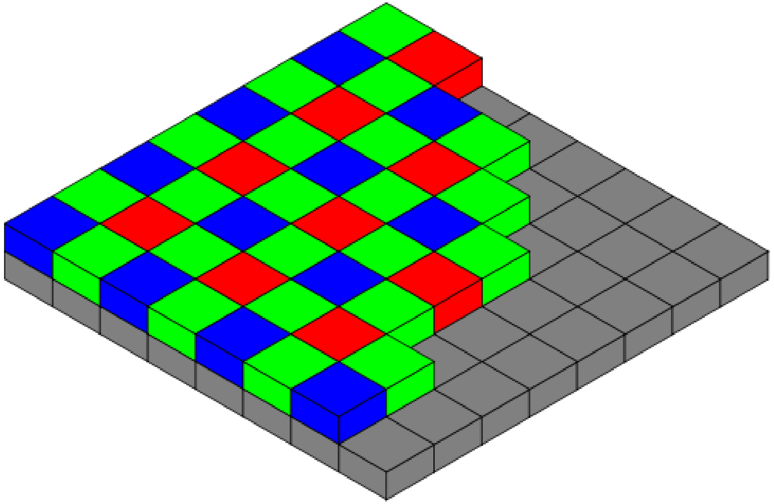


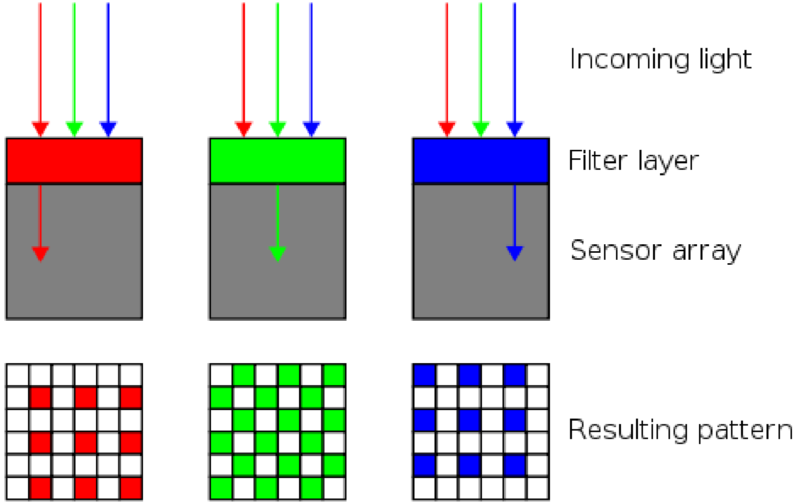
Open shutter

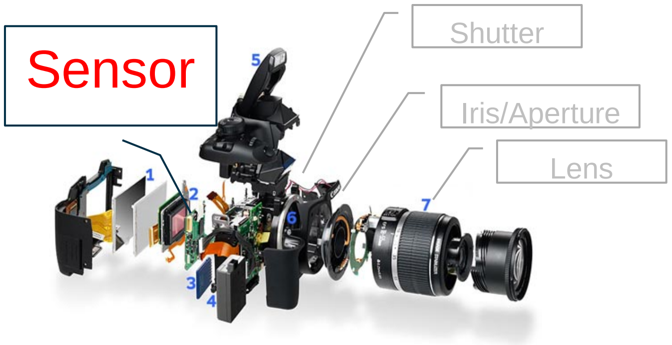
Short shutter time

Long shutter time

Classic Photography 101 – The Sensor







A lot of computation:

→ Gain ISO → ADC → Demosaic → Sharpen → White Balance → Gamma/ curve → Compress → JPEG-file

Outline

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- Tour of Computational Photography
  - Epsilon photography
  - Coded photography
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Computational Photography

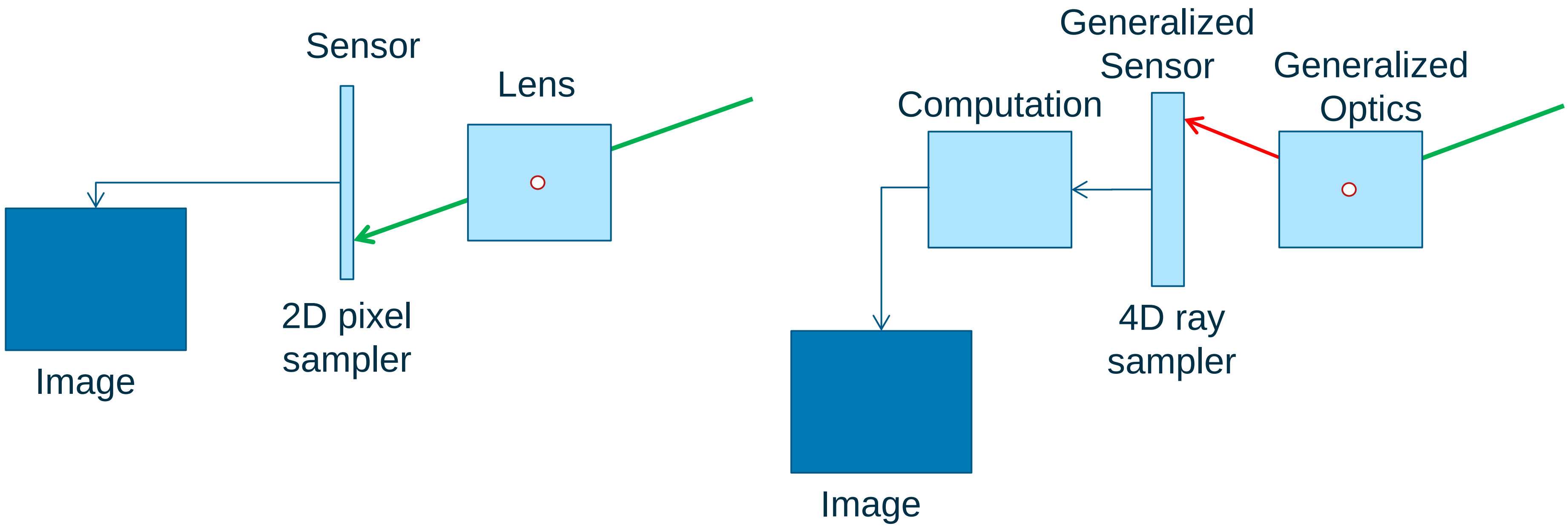
- *"Computational Photography captures a machine-readable representation of our world to synthesize the essence of our visual experience."*

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

R. Raskar, MIT (2006/2008):

- Epsilon photography
- Coded photography
- Essence Photography

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

Epsilon (Bracketing) Photography

Taxonomy:
- Epsilon photography
- Coded photography
- Essence 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

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.

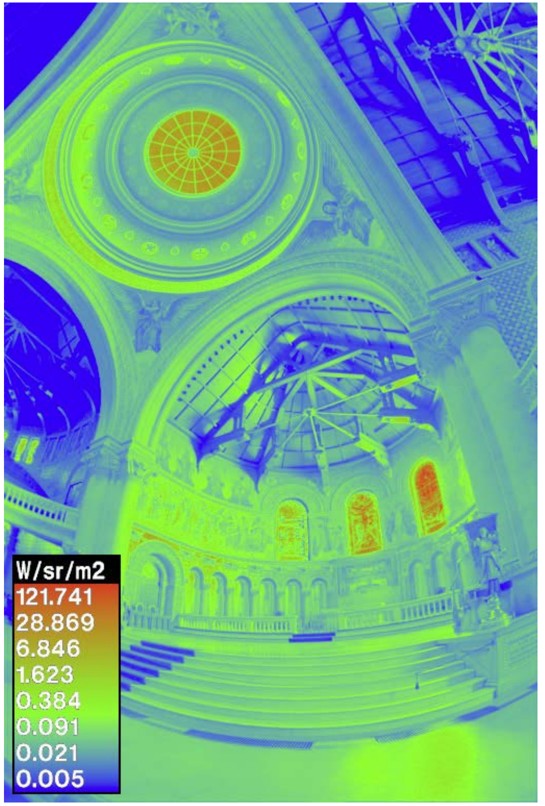
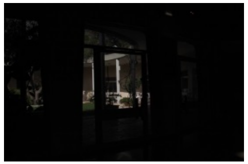
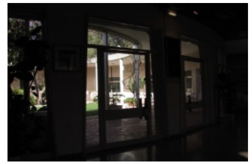


Image from "*Recovering High Dynamic Range Radiance Maps from Photographs*"
by Paul E. Debevec and Jitendra Malik SIGGRAPH97

Tone Mapping

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!

Taxonomy:
- Epsilon photography
- Coded photography
- Essence Photography

The cell phone:

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

Coded Photography

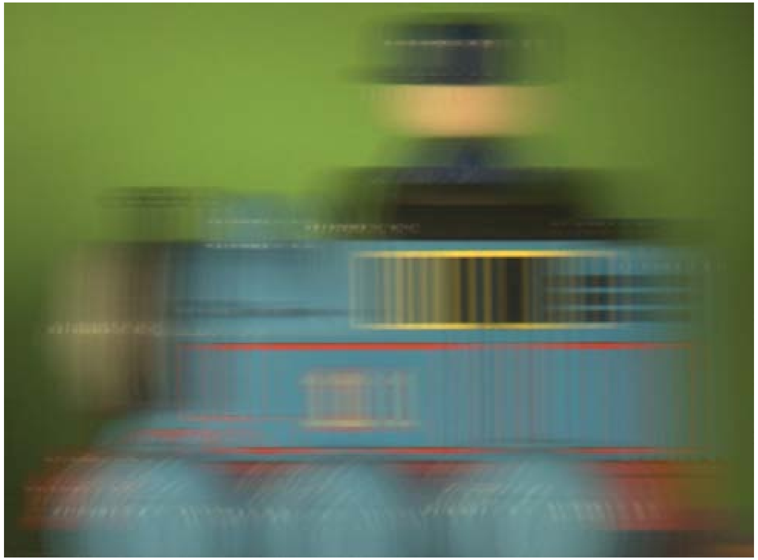
- Encode scene properties into the image, utilizing modified lenses, sensors, illumination etc.,
    - Temporal coding – exposure mask
    - Spatial coding – aperture mask
    - Illumination coding – intra-view
    - Sensor coding – capturing the light field

Taxonomy:
- Epsilon photography
- Coded photography
- Essence Photography

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

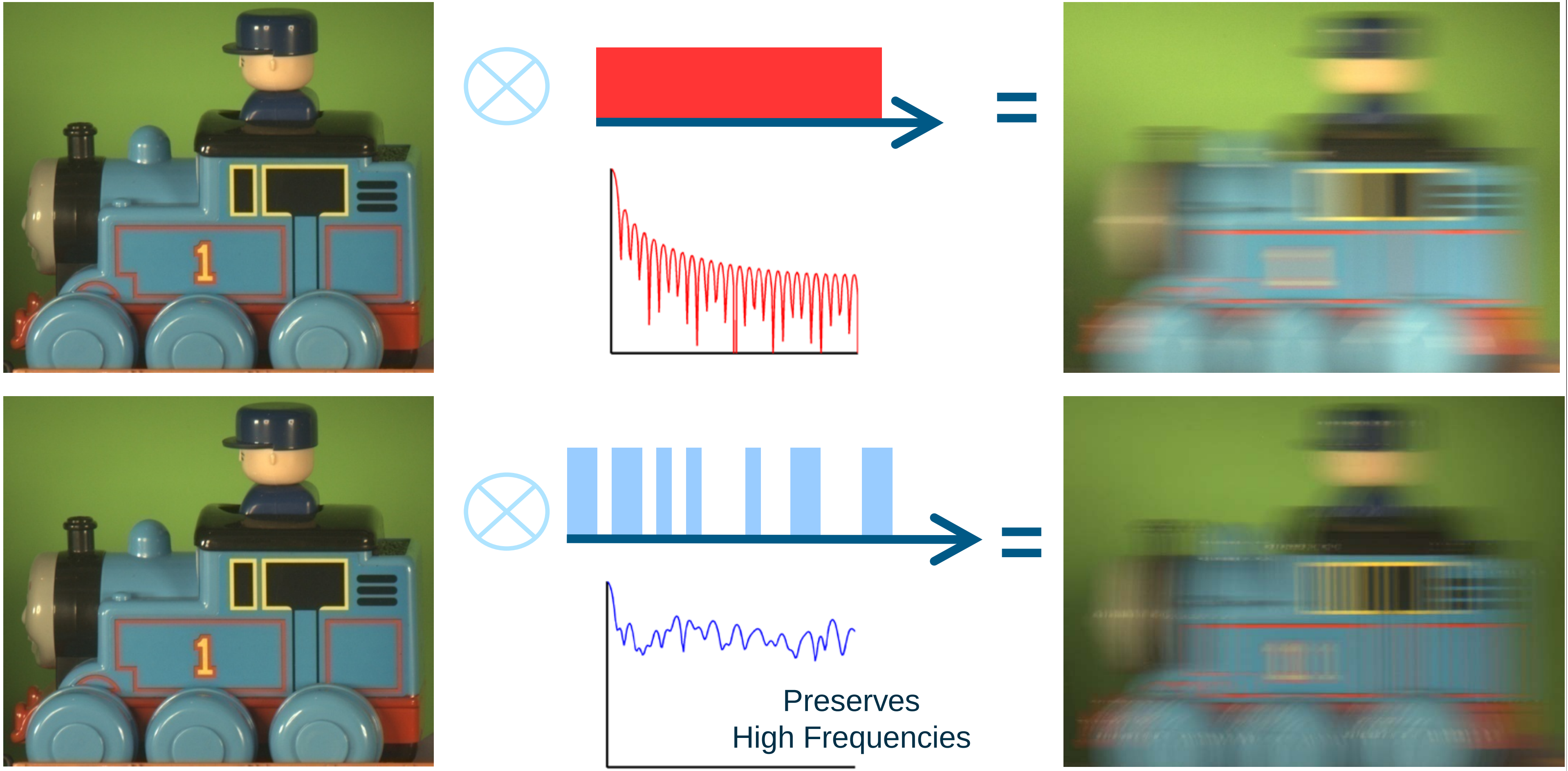
Coded Exposure Photography: Motion Deblurring using Fluttered Shutter

Ramesh Raskar, Amit Agrawal, and Jack Tumblin
ACM SIGGRAPH 2006



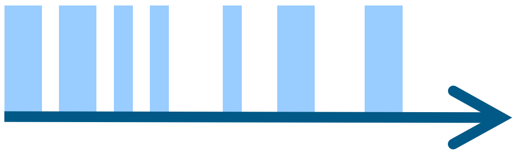
The fluttered shutter

Blurring by Convolution

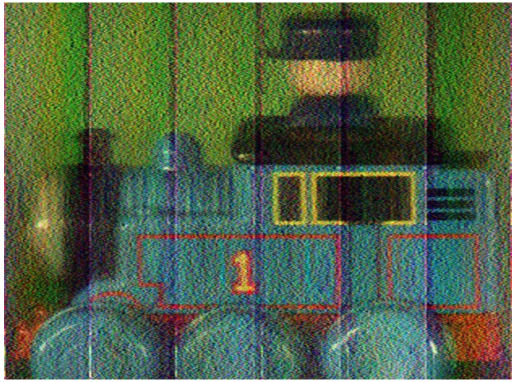


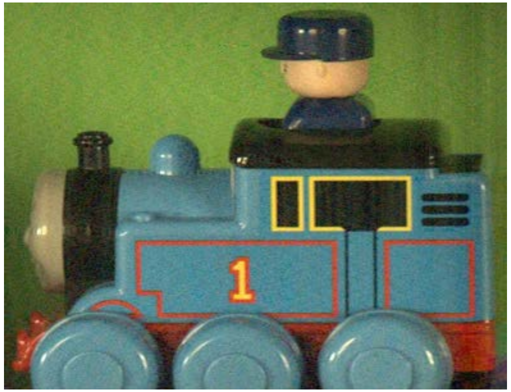
Images from "*Coded Exposure Photography: Motion Deblurring using Fluttered Shutter*"
Ramesh Raskar, Amit Agrawal, and Jack Tumblin

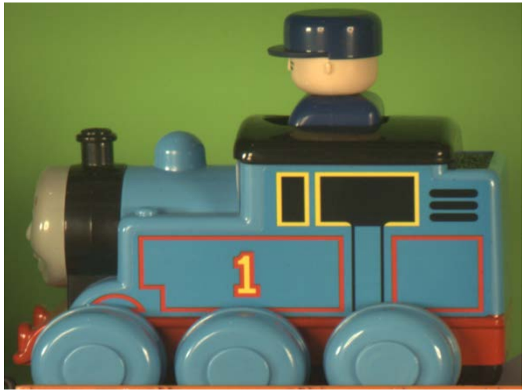
Deconvolution



Ground truth
Static image







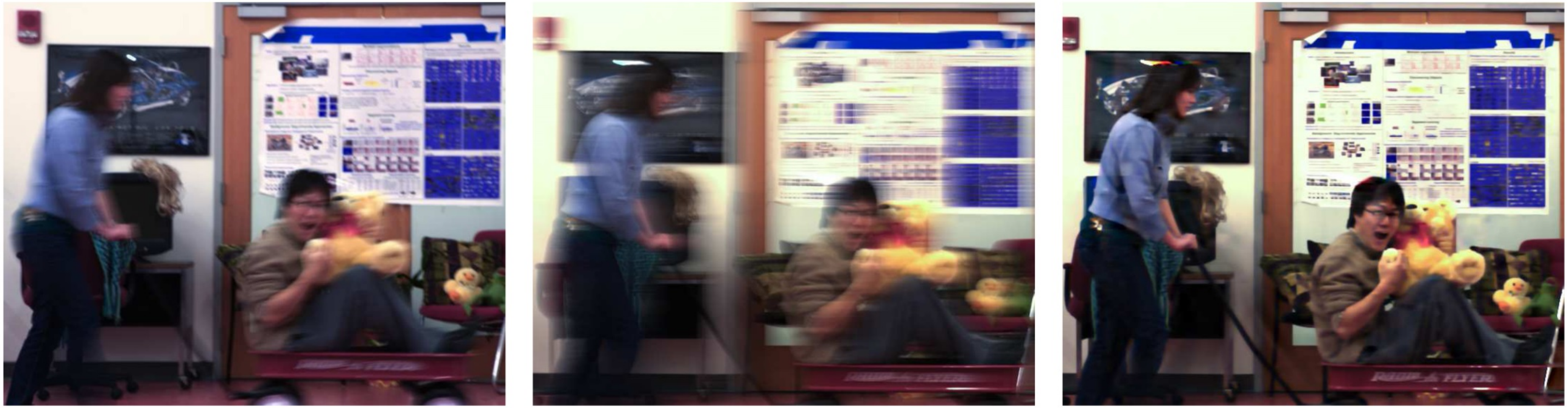
Images from “*Coded Exposure Photography: Motion Deblurring using Fluttered Shutter*”
Ramesh Raskar, Amit Agrawal, and Jack Tumblin

Motion Blur

Motion-Invariant Photography SIGGRAPH 2008

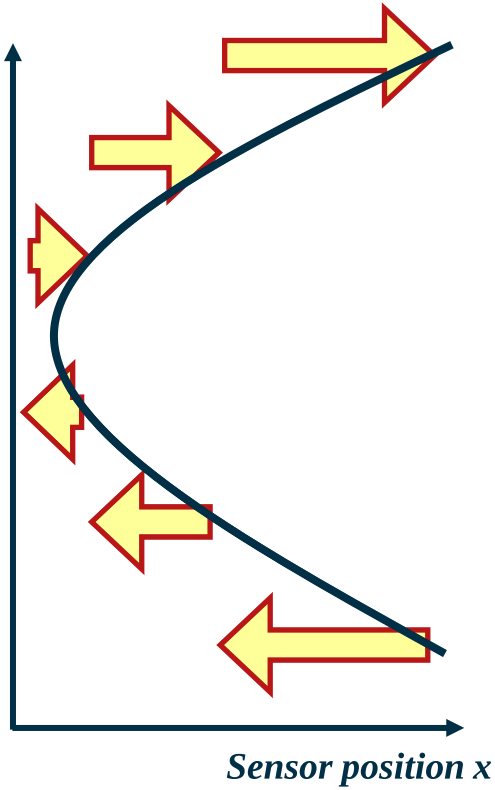
Anat Levin, Peter Sand, Taeg Sang, Cho Fredo, Durand,
and William T. Freeman

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

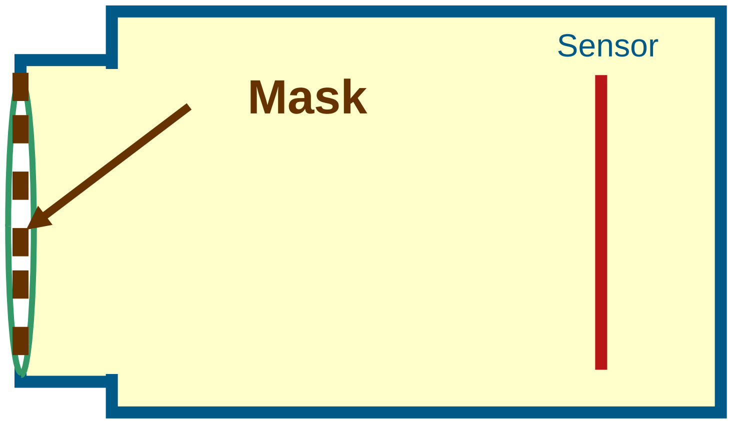
Images from “*Motion-Invariant Photography*” *Anat Levin et al.*

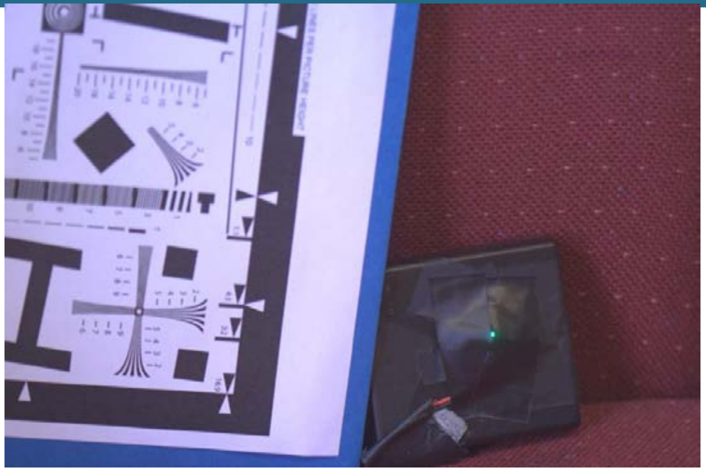
Depth of Field / Defocus Blur

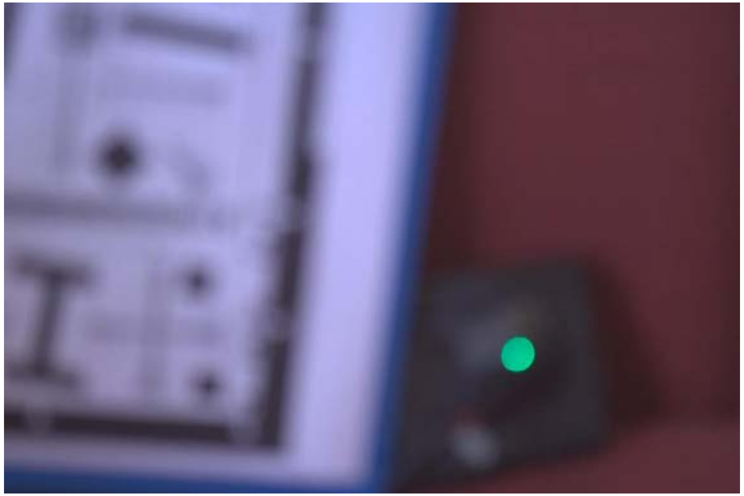
Dappled Photography: Mask Enhanced Cameras for Heterodyned Light Fields and Coded Aperture Refocusing

Ashok Veeraraghavan, Ramesh Raskar, Amit Agrawal, Ankit Mohan, and Jack Tumblin

ACM SIGGRAPH 2007







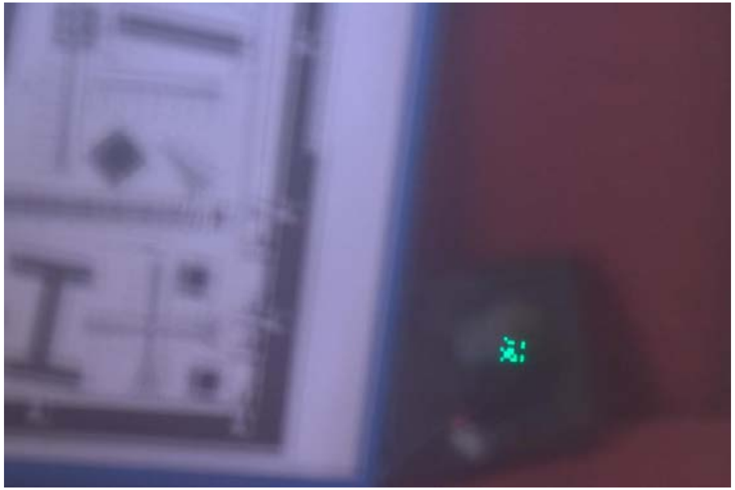


Image from "*Dappled Photography: Mask Enhanced Cameras for Heterodyned Light Fields and Coded Aperture Refocusing, Ashok Veeraraghavan et al.*

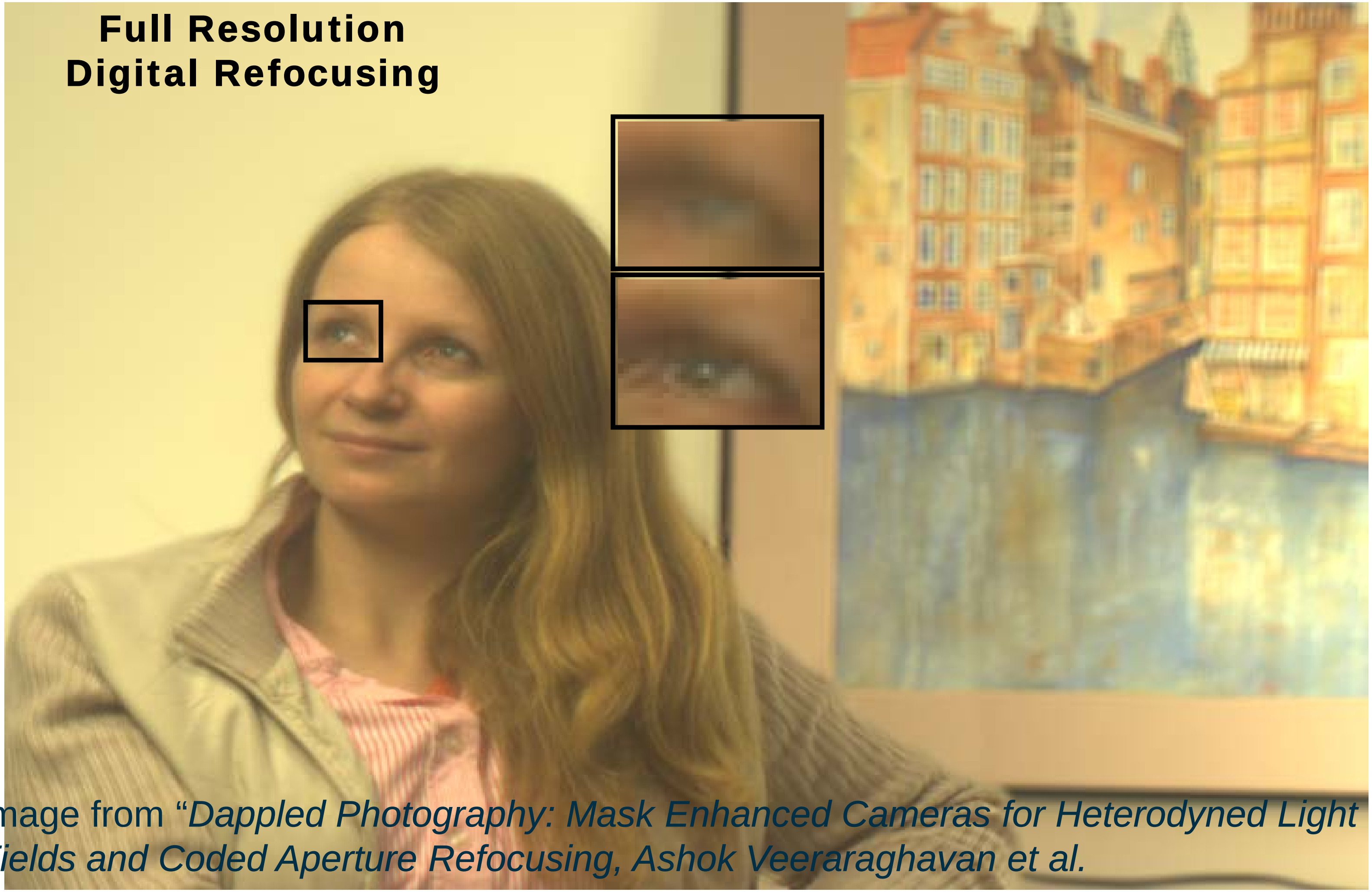
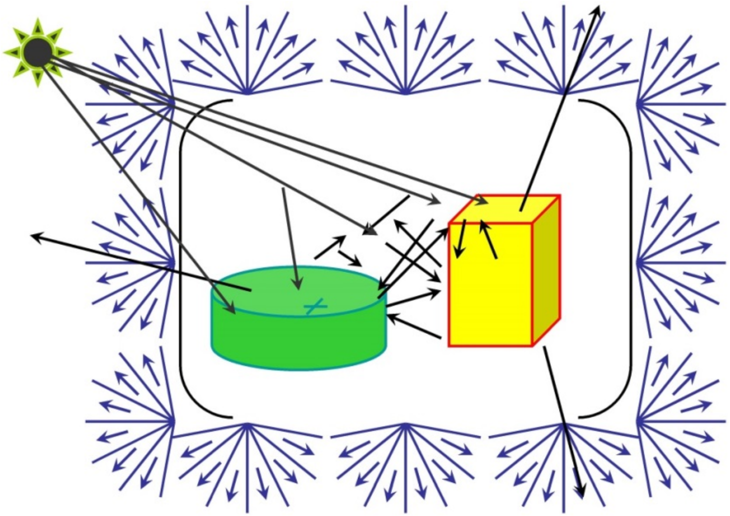


Image from “*Dappled Photography: Mask Enhanced Cameras for Heterodyned Light Fields and Coded Aperture Refocusing, Ashok Veeraraghavan et al.*

Light Field

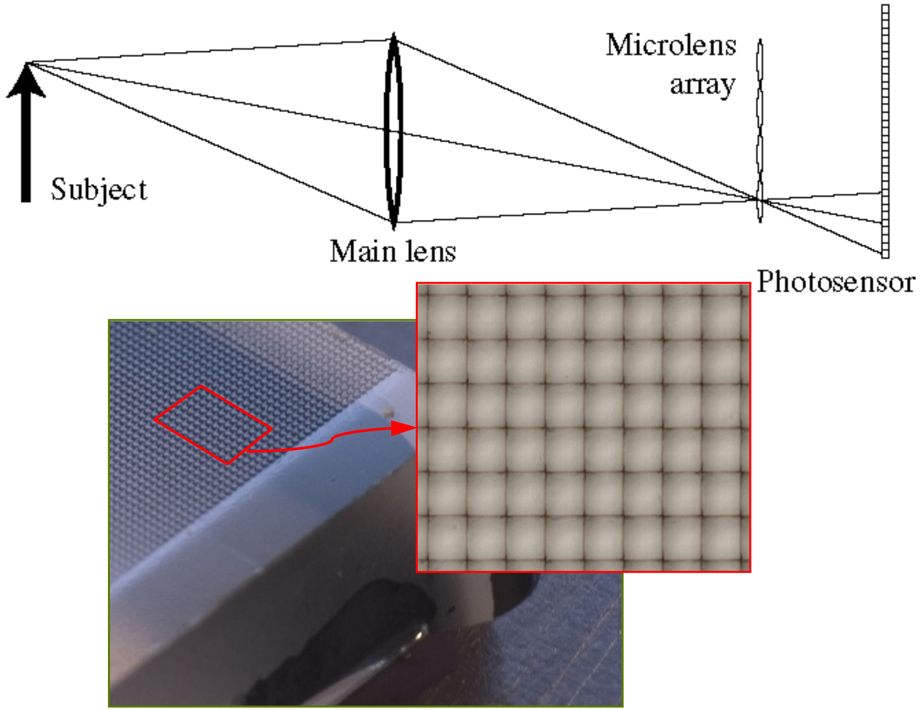
- Function describing amount of light traveling in the scene (measures radiance along rays)
- Post-capture possibilities:
  - Refocus, depth of field adjustments, re-lighting, etc

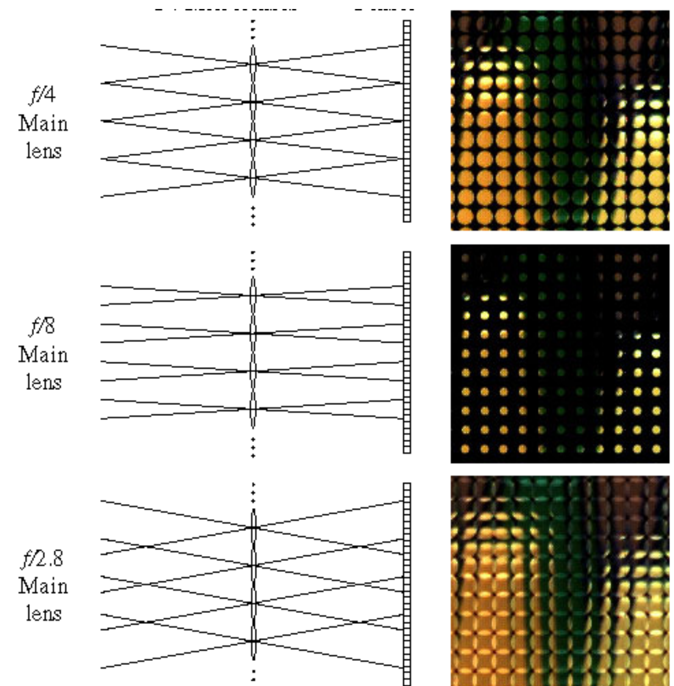


Illustrations from “Computational Photography: Epsilon to Coded Photography” R. Raskar

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

Result:

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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

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

Taxonomy:
- Epsilon photography
- Coded photography
- Essence Photography

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 (used with permission)

Do We Need a Camera at All?

- A camera without optics?

Buttons (2006) Sascha Pohflepp http://www.blinksandbuttons.net/

Lytro : Light Field Capturing Camera

- Lytro image and image
- Founded by Ren Ng

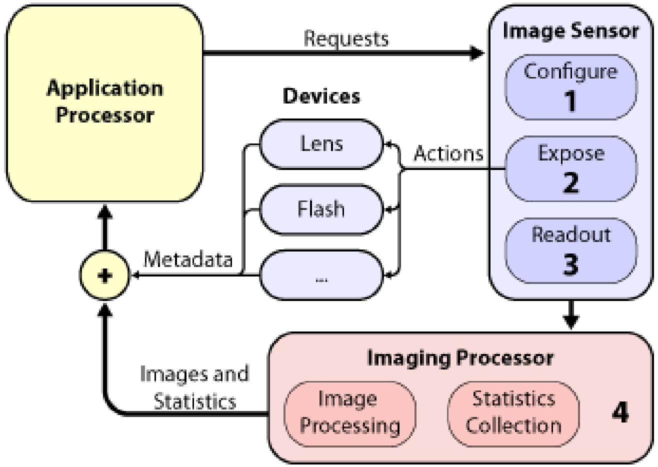
Computational Cameras

The Frankencamera: An Experimental Platform for Computational Photography

Adams, A., Talvala, E., Park, S. H., Jacobs, D. E., Ajdin, B., Gelfand, N., Dolson, J., Vaquero, D., Baek, J., Tico, M., Lensch, H. P., Matusik, W., Pulli, K., Horowitz, M., and Levoy, M.

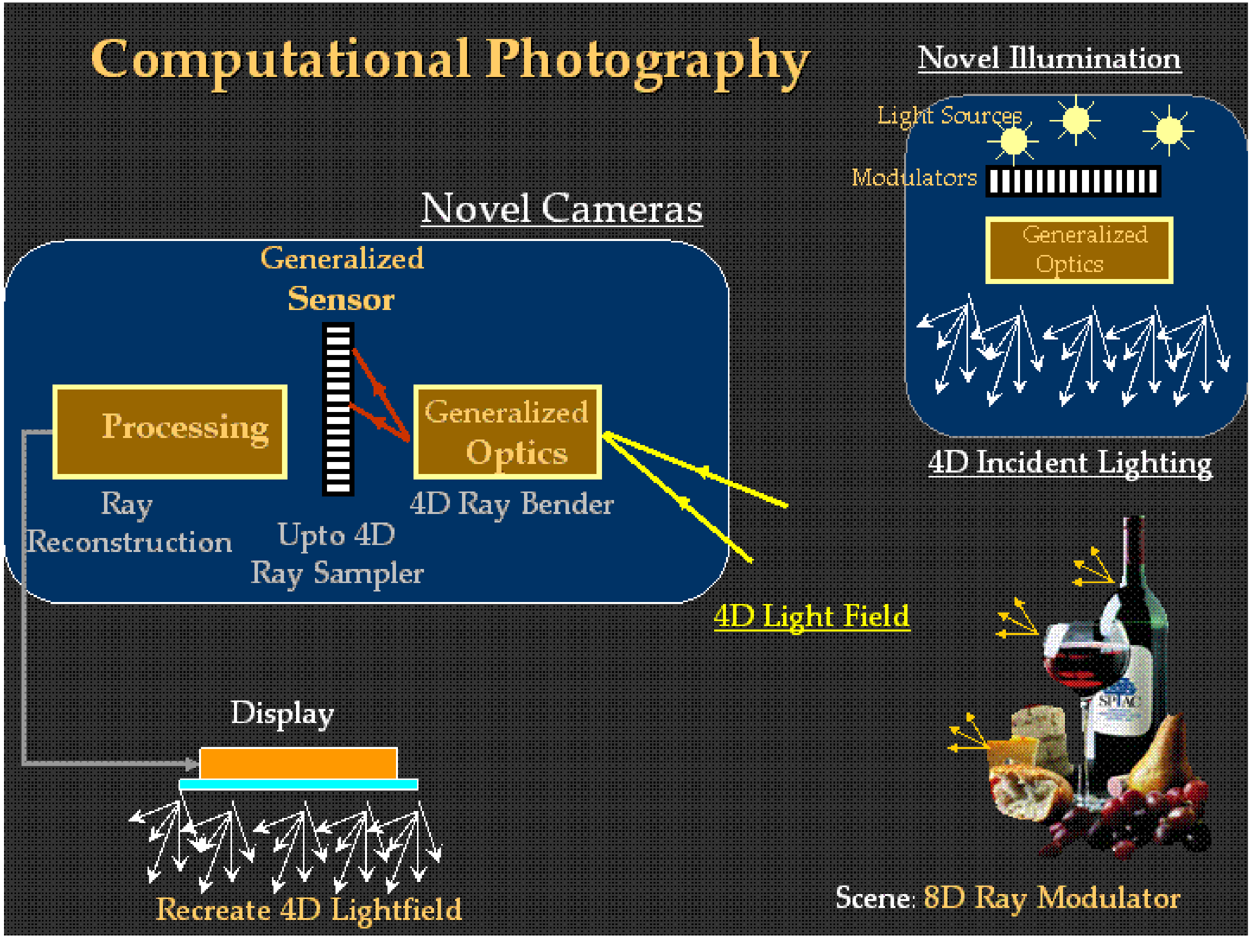
Frankencamera

- 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



Images from “*The Frankencamera: An Experimental Platform for Computational Photography*” Adams et al.

The Future



Images from "*Computational Photography: Epsilon to Coded Imaging*" Ramesh Raskar.
Emerging Trends in Visual Computing 2008 http://videolectures.net/etvc08_raskar_cpetci/

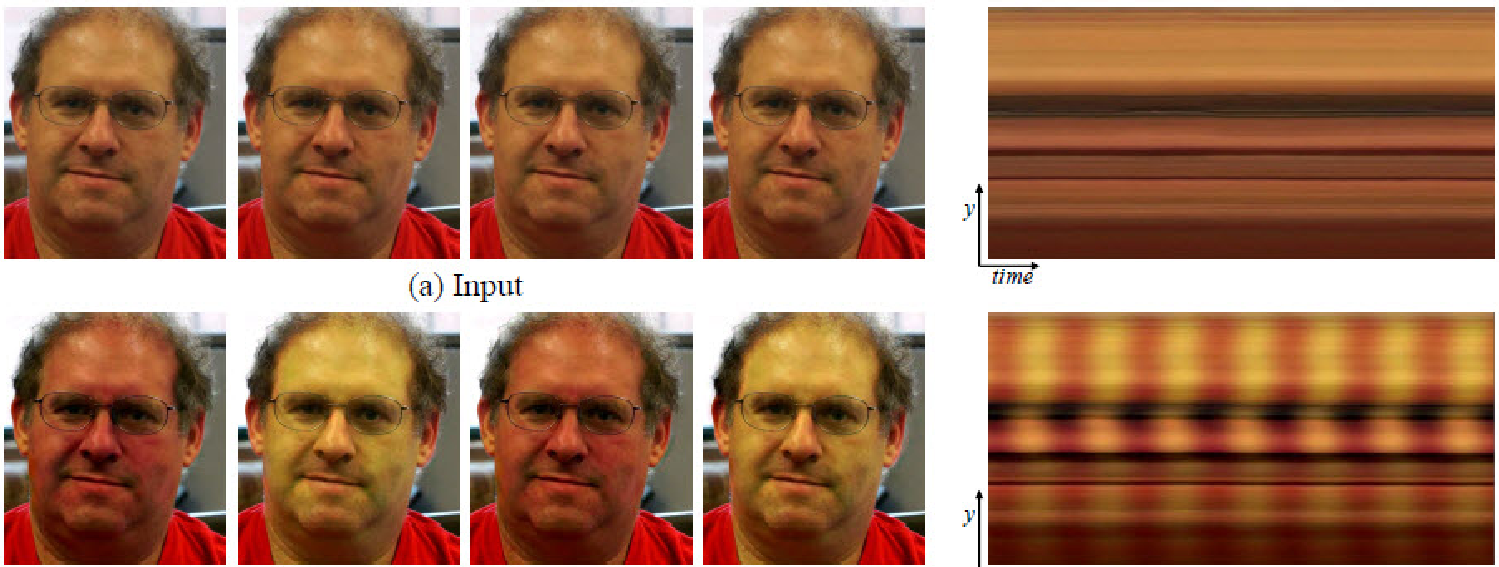
The Future – Research

SIGGRAPH2013

- 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.



(a) Input

(b) Magnified

(c) Spatiotemporal *YT* slices

VIDEOS

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Researchers in the CP field

- Marc Levoy (Stanford)
  http://graphics.stanford.edu/~levoy/

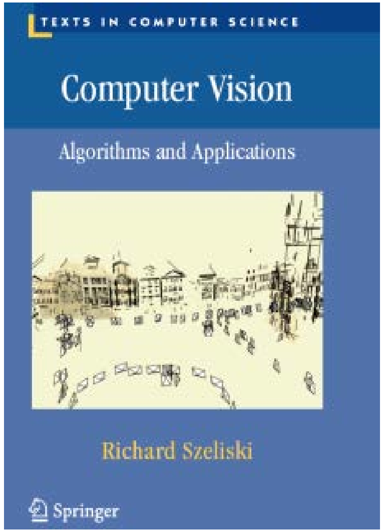
- Shree K. Nayar (Columbia University)
  http://www.cs.columbia.edu/~nayar/

- Ramesh Raskar (MIT Media Lab)
  http://web.media.mit.edu/~raskar/

- William T. Freeman (MIT Computer Science and Artificial Intelligence Laboratory) http://people.csail.mit.edu/billf/

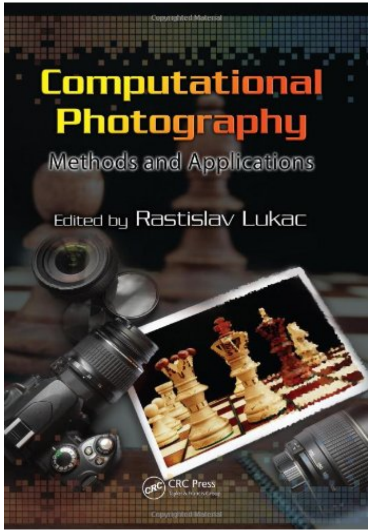
Resources for Further Inquiries

Books:

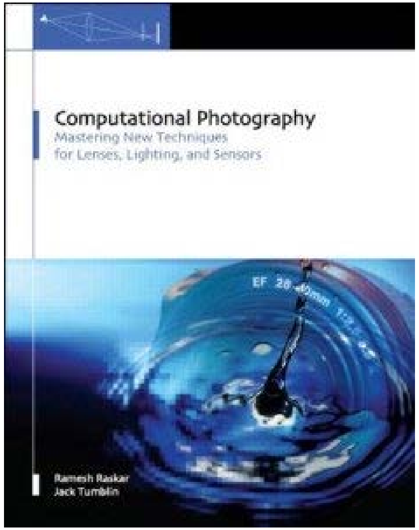


2010
Richard Szeliski, Microsoft Research

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)
- IEEE *Computer* , vol.39, no.8, pp.18,21, Aug. 2006

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, debluring, 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:

- Changyin Zhou and Shree Nayar "Computational Cameras: Convergence of Optics and Processing," IEEE Transactions on Image Processing, Vol.20, No.12, pp.3322-3340, Dec, 2011.
- B. Hayes “Computational Photography”, American Scientist March-April 2008, Volume 96, Number 2
- SIGGRAPH 2008 Tutorial: “Advanced Computational Photography”, lecture notes and video, R. Raskar et al.
- Richard Szeliski “Computer Vision”, Springer 2010
- Wikipedia

THANK YOU FOR YOUR ATTENTION

Questions?