
Synthetic Aperture Confocal Imaging Coded Aperture

Computational Photography

Hendrik Lensch, Summer 2007

Projects

List available now

Project proposal (2 pages): 1st of June

- LaTeX Template will be made available

Project idea presentation: 8th of June

Final Project presentation: 20th of July

Project report: 1st of August

(8 pages – research paper)

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Tasks for You

Prüfungsanmeldung / registration for exam
(as soon as possible!)

<http://frweb.cs.uno-sb.de/03.Studium/011.HISPOS/>

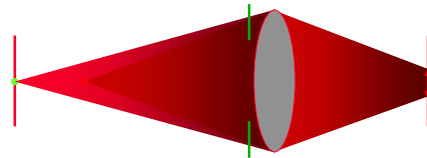
Evaluation

<http://frweb.cs.uni-sb.de/03.Studium/08.Eva/>

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Synthetic aperture photography

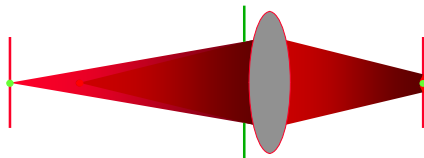


[following slides by Marc Levoy]

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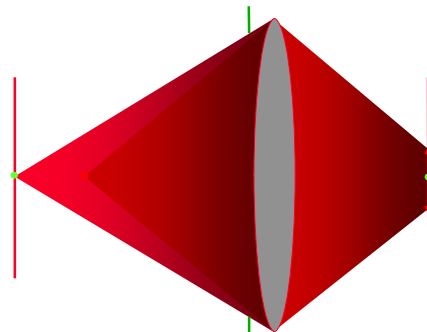
Synthetic aperture photography



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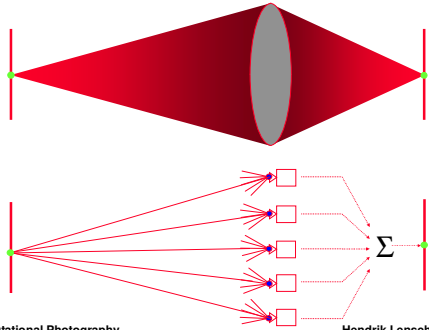
Synthetic aperture photography



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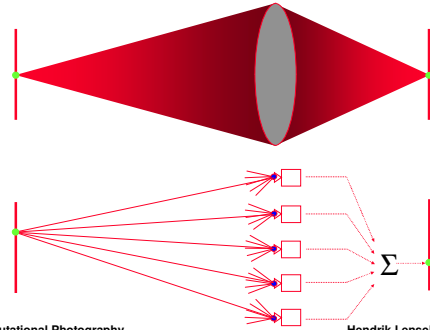
Synthetic aperture photography



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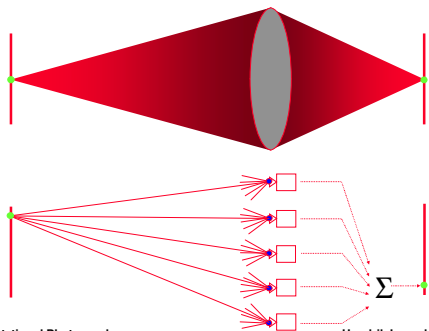
Synthetic aperture photography



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Synthetic aperture photography



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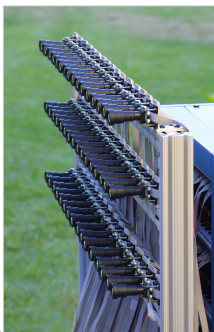
Related work

not like synthetic aperture radar (SAR)
more like X-ray tomosynthesis
[Levoy and Hanrahan, 1996]
[Isaksen, McMillan, Gortler, 2000]

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Example using 45 cameras



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Synthetic pull-focus

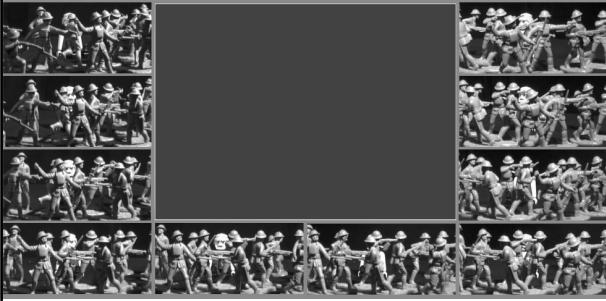


[video]

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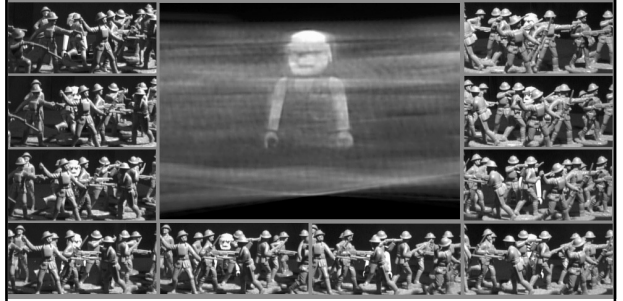
Crowd scene



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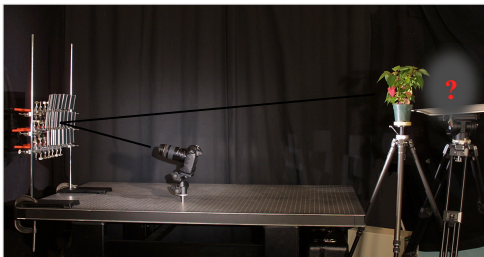
Crowd scene



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Synthetic aperture photography using an array of mirrors



11-megapixel camera
22 planar mirrors

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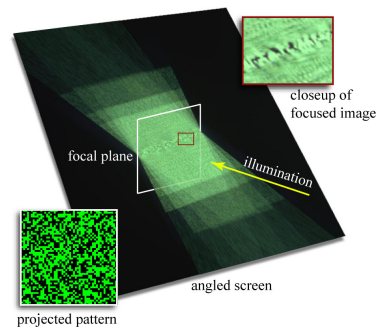
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Computational Photography

Synthetic aperture illumination



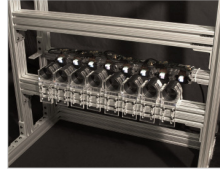
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Synthetic aperture illumination

technologies

- array of projectors
- array of microprojectors
- single projector + array of mirrors



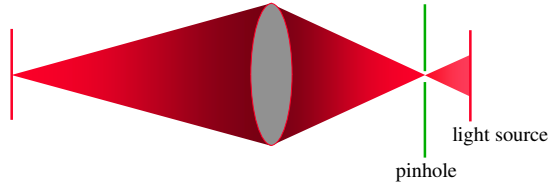
applications

- bright display
- autostereoscopic display [Matusik 2004]
- confocal imaging [this paper]

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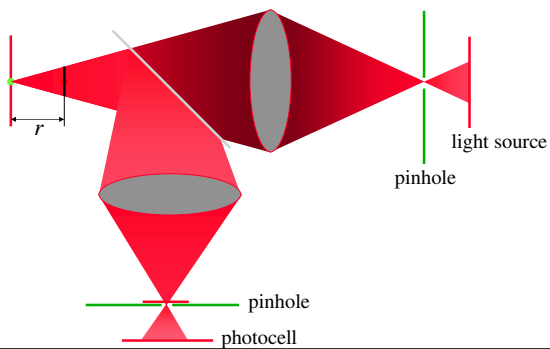
Confocal scanning microscopy



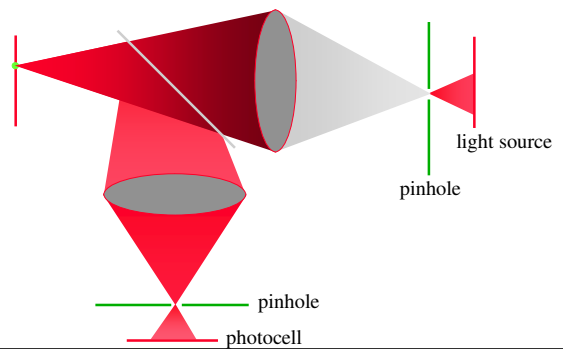
Computational Photography

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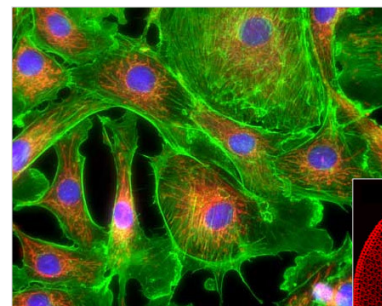
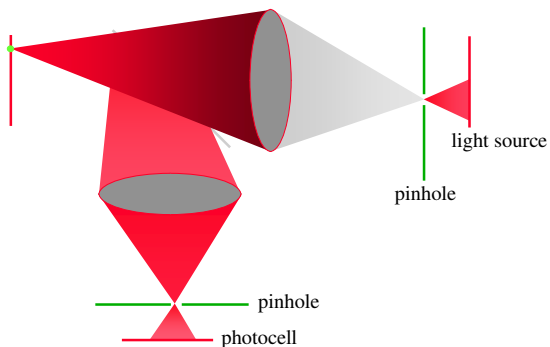
Confocal scanning microscopy



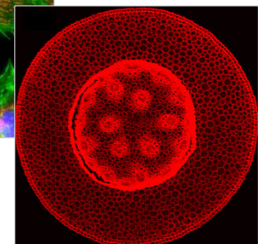
Confocal scanning microscopy



Confocal scanning microscopy

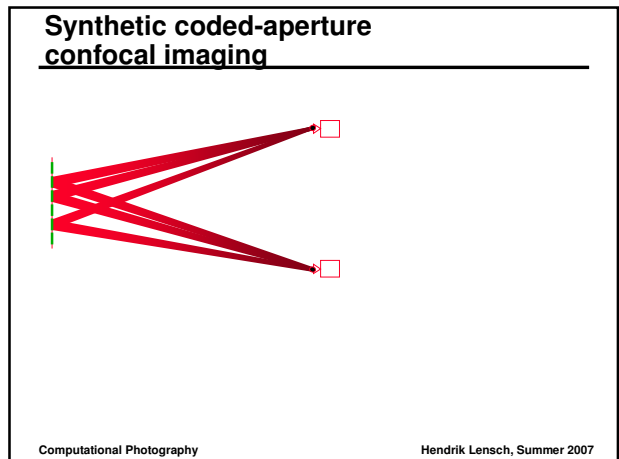
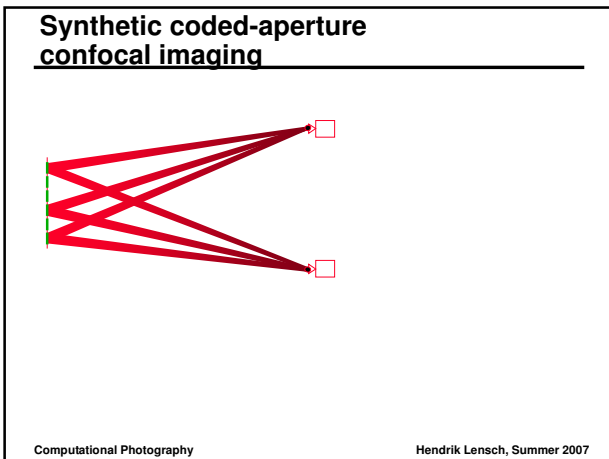
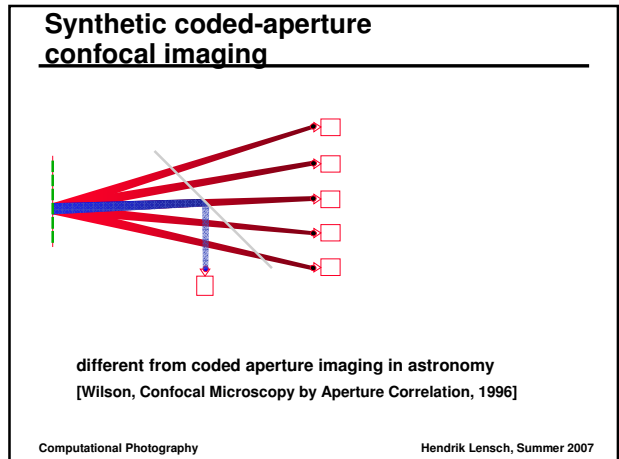
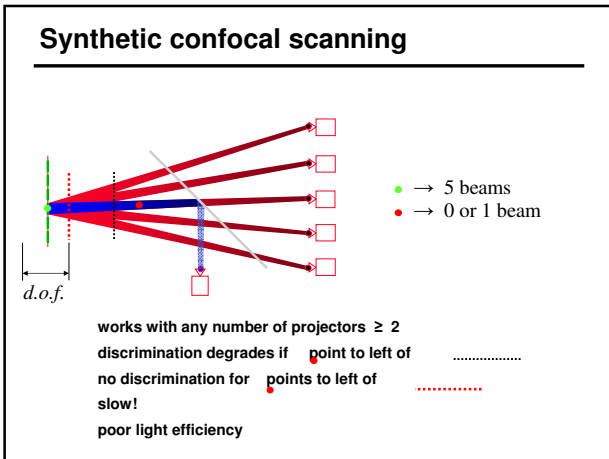
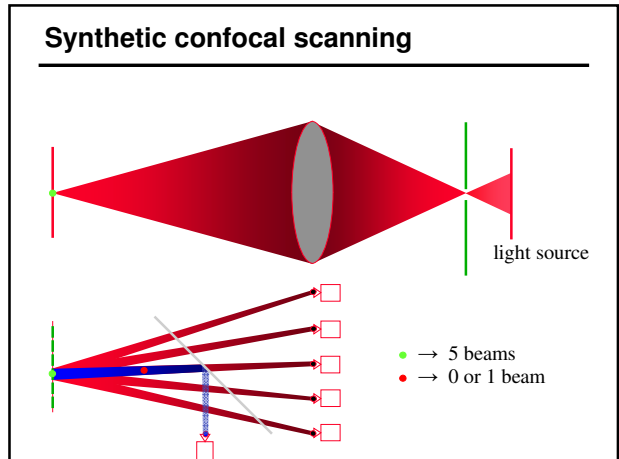
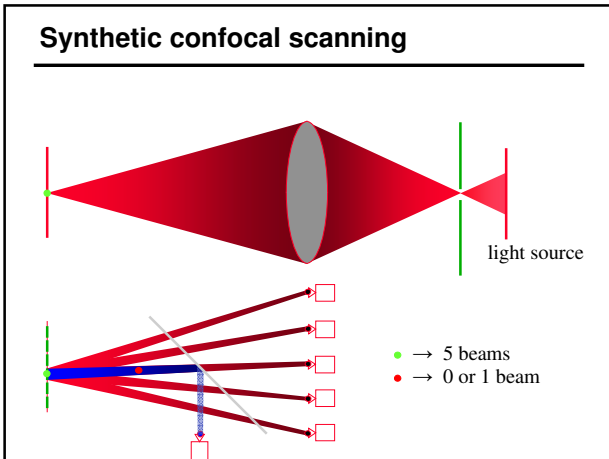


[UMIC SUNY/Stonybrook]

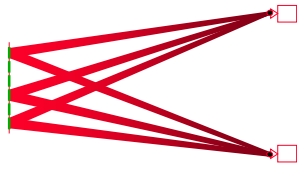


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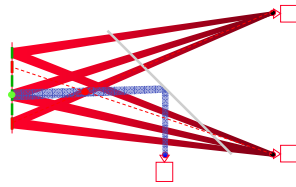
Synthetic coded-aperture confocal imaging



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Synthetic coded-aperture confocal imaging



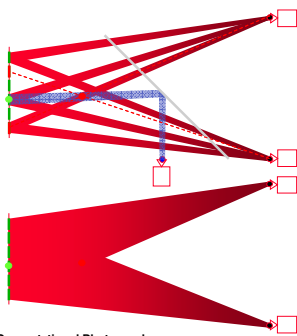
100 trials

- → 2 beams × ~50/100 trials ≈ 1
- → ~1 beam × ~50/100 trials ≈ 0.5

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Synthetic coded-aperture confocal imaging



100 trials

- → 2 beams × ~50/100 trials ≈ 1
- → ~1 beam × ~50/100 trials ≈ 0.5

floodlit

- → 2 beams
- → 2 beams

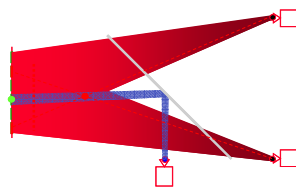
trials = 1/4 × floodlit

- → 1 - 1/4 (2) ≈ 0.5
- → 0.5 - 1/4 (2) ≈ 0

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Synthetic coded-aperture confocal imaging



100 trials

- → 2 beams × ~50/100 trials ≈ 1
- → ~1 beam × ~50/100 trials ≈ 0.5

floodlit

- → 2 beams
- → 2 beams

trials = 1/4 × floodlit

- → 1 - 1/4 (2) ≈ 0.5
- → 0.5 - 1/4 (2) ≈ 0

50% light efficiency

any number of projectors ≥ 2

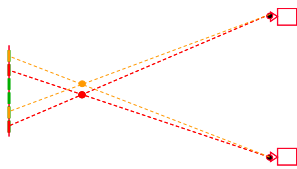
no discrimination to left of

works with relatively few trials (~16)

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Synthetic coded-aperture confocal imaging



100 trials

- → 2 beams × ~50/100 trials ≈ 1
- → ~1 beam × ~50/100 trials ≈ 0.5

floodlit

- → 2 beams
- → 2 beams

trials = 1/4 × floodlit

- → 1 - 1/4 (2) ≈ 0.5
- → 0.5 - 1/4 (2) ≈ 0

50% light efficiency

any number of projectors ≥ 2

no discrimination to left of

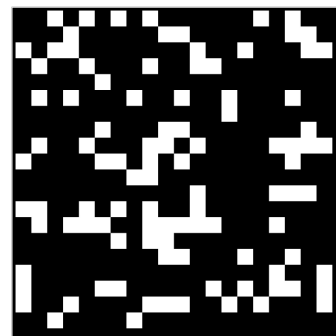
works with relatively few trials (~16)

needs patterns in which illumination of tiles are uncorrelated

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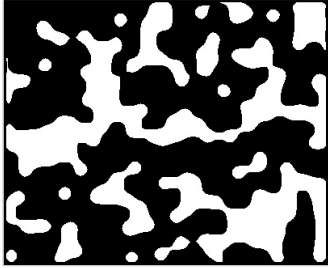
Example pattern



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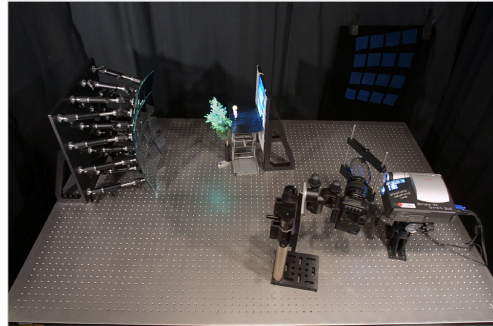
Patterns with less aliasing



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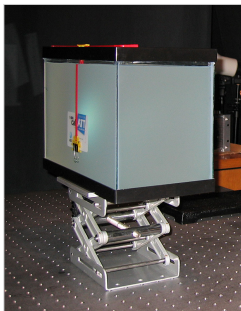
Implementation using an array of mirrors



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Confocal imaging in scattering media



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small tank

- too short for attenuation
- lit by internal reflections

Experiments in a large water tank

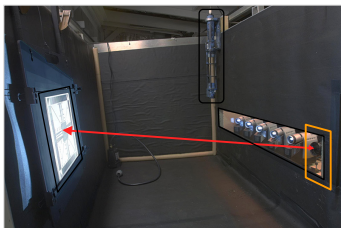


50-foot flume at Wood's Hole Oceanographic Institution (WHOI)

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Experiments in a large water tank



4-foot viewing distance to target
surfaces blackened to kill reflections
titanium dioxide in filtered water
transmissometer to measure turbidity

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Experiments in a large water tank



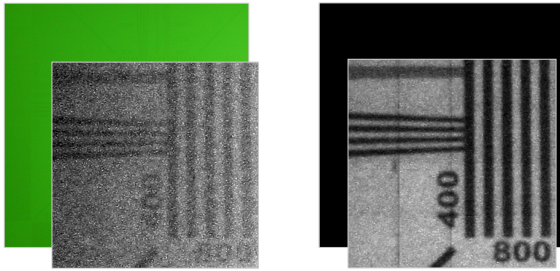
stray light limits performance
one projector suffices if no occluders



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Seeing through turbid water



floodlit

scanned tile

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Coded Aperture

Motivation

- building a camera without a lens
- hard to bend high energy rays
 - astronomy, x-rays
- high energy rays can be blocked -> pinhole?
- pinhole has too much light loss
- use multiple pinholes at the same time
- how to reconstruct the desired signal?

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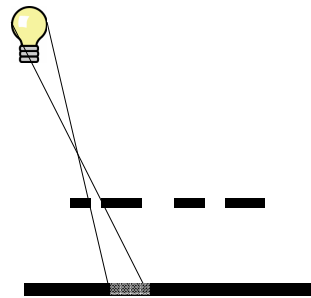
Coded Aperture Imaging



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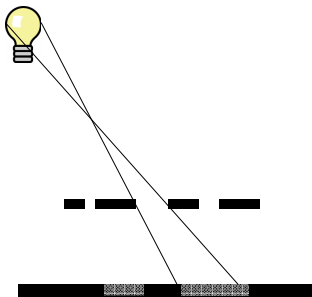
Coded Aperture Imaging



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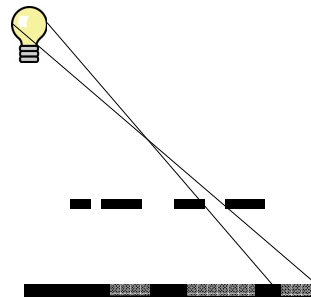
Coded Aperture Imaging



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Coded Aperture Imaging



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Coded Aperture Imaging

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Coded Aperture Imaging

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Reconstruction by Back Projection

project each photon back through the mask
similar to back projection in CT

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Reconstruction by Back Projection

etc.

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Reconstruction by Back Projection

etc.

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Reconstruction by Inversion

C – camera image, M – mask, I – sky image, N - noise

acquisition: $C = M I + N$

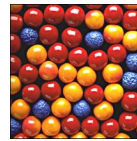
inversion: $I = M^{-1}C - M^{-1}N$

- the mask needs to be invertible
- even if it is there might be some numerical problems

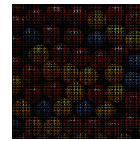
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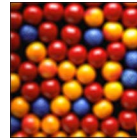
An Example



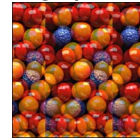
original image



single pinhole



larger aperture



multiple pinholes

[<http://www.paulcarlisle.net/old/codedaperture.html>]

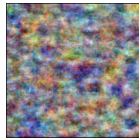
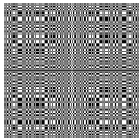
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MURA Code

coding pattern:

$$A_{i,j} = \begin{cases} 0 & \text{if } i = 0, \\ 1 & \text{if } j = 0, i \neq 0, \\ 1 & \text{if } C(i)C(j) = +1, \\ 0 & \text{otherwise,} \end{cases} \quad C(\text{periodic function})$$



Computational Photography

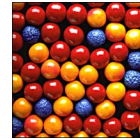
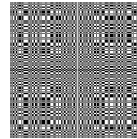
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Rconstruction by Cross Correlation

decoding pattern:

$$D_{i,j} = \begin{cases} +1 & \text{if } i + j = 0, \\ +1 & \text{if } A_{i,j} = 1 (i + j \neq 0), \\ -1 & \text{if } A_{i,j} = 0 (i + j \neq 0) \end{cases}$$

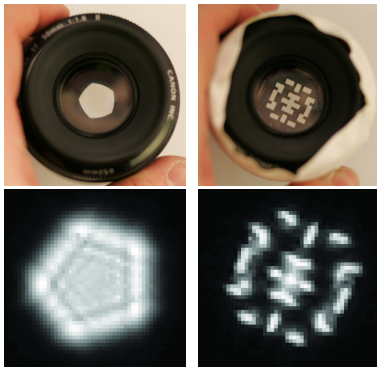
compute cross correlation between captured image and D



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Masks in Conventional Photography

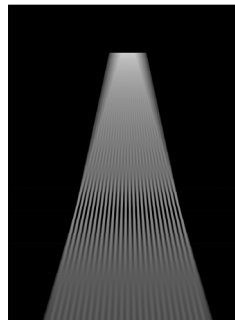


[Levin 2007]

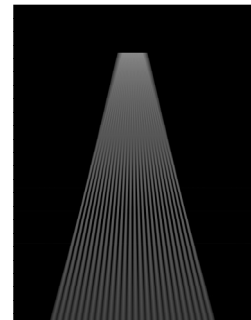
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Depth-related PSF



wide aperture



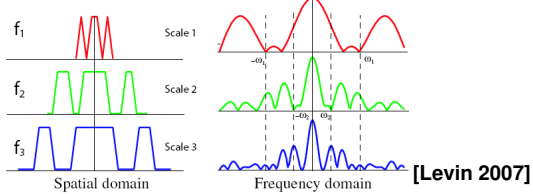
stopped down

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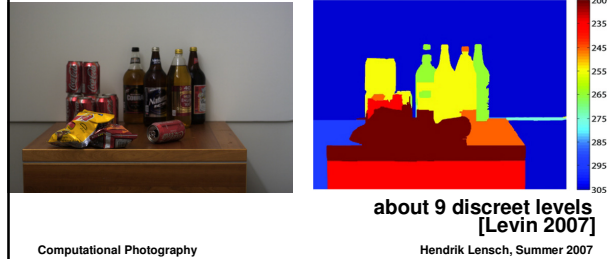
Depth Recovered from a single image

- improved depth-from-defocus by special mask design by brute-force optimization of the mask
- objective function: location of zeros in the frequency domain at different magnifications (depth)
- consider frequency distribution in natural images



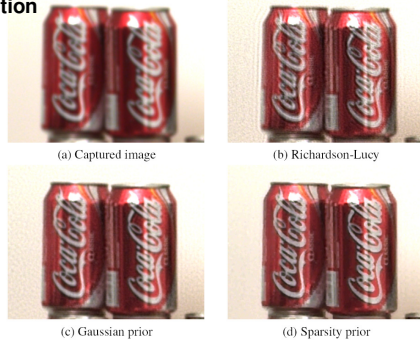
Depth Recovered from a single image

- for each image region find the filter size that best matches the observed image given natural image statistics
- combine with graph cut



Application: Refocusing

after depth is known apply a spatially varying deconvolution



[Levin 2007]