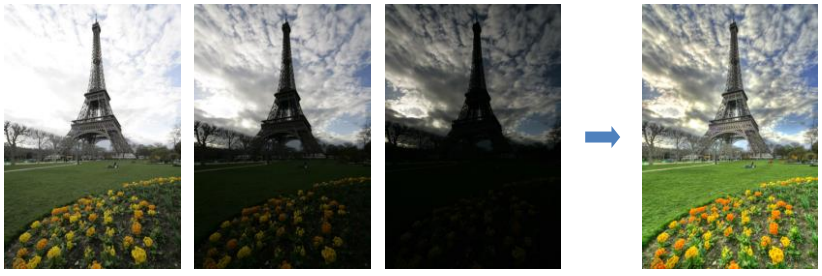
CS4670: Computer Vision

Noah Snavely

Computational photography



The ultimate camera

What does it do?

The ultimate camera

Infinite resolution

Infinite zoom control

Desired object(s) are in focus

No noise

No motion blur

Infinite dynamic range (can see dark and bright things)

...

Creating the ultimate camera

The “analog” camera has changed very little in >100 yrs

- we’re unlikely to get there following this path

More promising is to combine “analog” optics with computational techniques

- “Computational cameras” or “Computational photography”

This lecture will survey techniques for producing higher quality images by combining optics and computation

Common themes:

- take multiple photos
- modify the camera

Noise reduction

Take several images and average them

Why does this work?

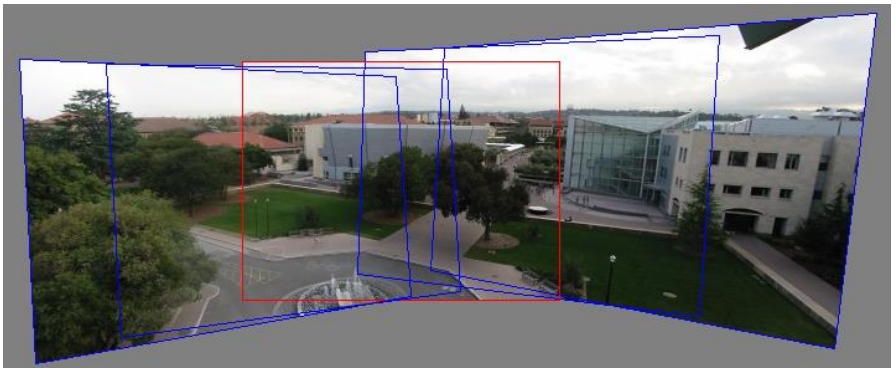
Basic statistics:

- variance of the mean decreases with n:

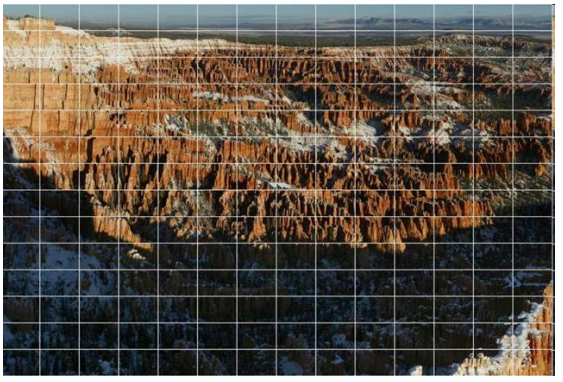
$$Var(\overline{X}) = \frac{\sigma^2}{n}$$

Field of view

We can artificially increase the field of view by compositing several photos together (project 2).



Improving resolution: Gigapixel images



Max Lyons, 2003
fused 196 telephoto shots

A few other notable examples:

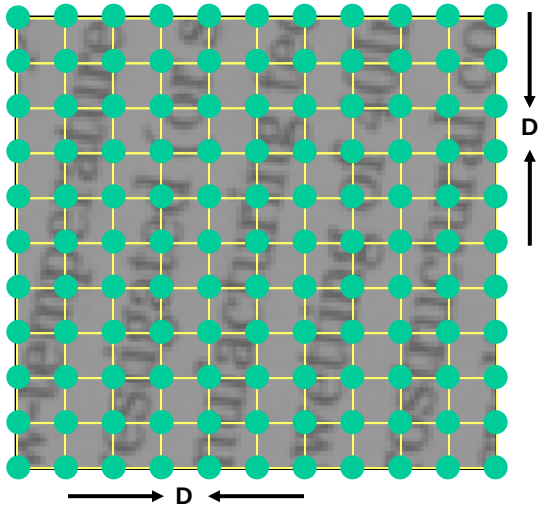
- Obama inauguration (gigapan.org)
- HDView (Microsoft Research)

Improving resolution: super resolution

What if you don't have a zoom lens?

Intuition (slides from Yossi Rubner & Miki Elad)

For a given band-limited image, the Nyquist sampling theorem states that if a uniform sampling is fine enough (≥**D**), perfect reconstruction is possible.



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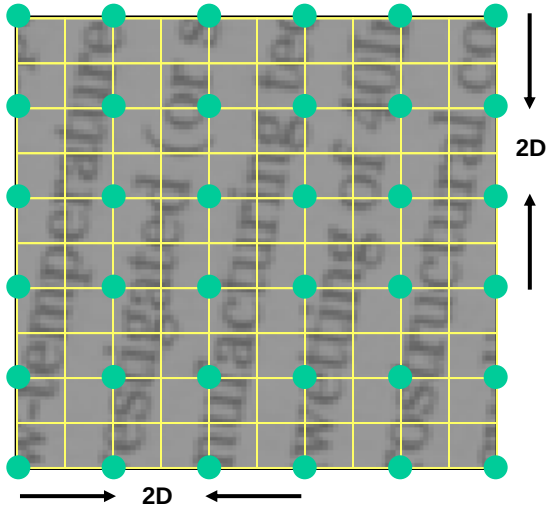
Intuition (slides from Yossi Rubner & Miki Elad)

Due to our limited camera resolution, we sample using an insufficient 2D grid



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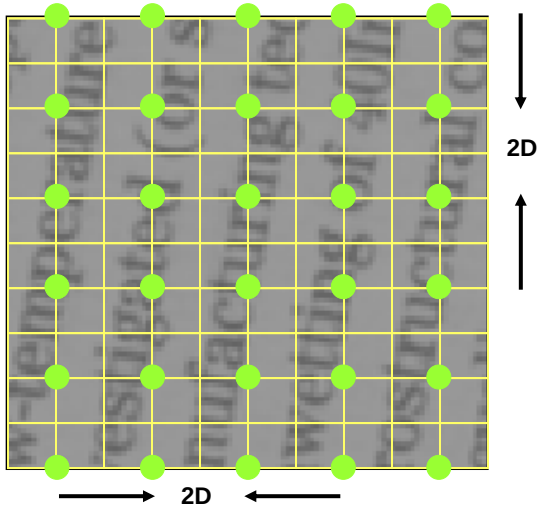
Intuition (slides from Yossi Rubner & Miki Elad)

However, if we take a second picture, shifting the camera 'slightly to the right' we obtain:



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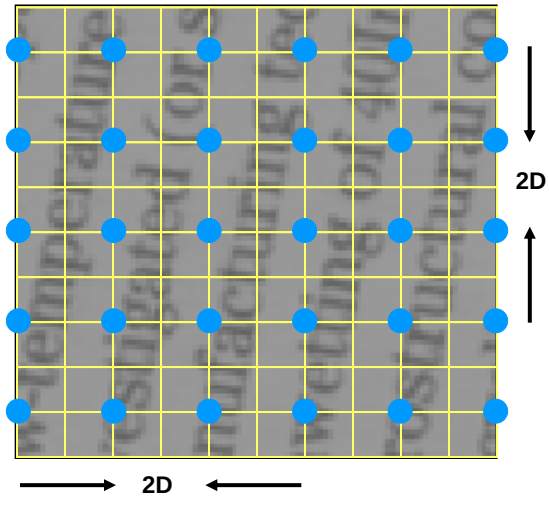
Intuition (slides from Yossi Rubner & Miki Elad)

Similarly, by shifting down we get a third image:



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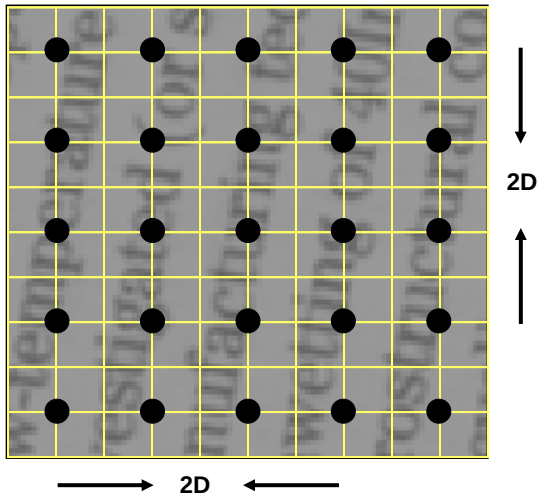
Intuition (slides from Yossi Rubner & Miki Elad)

And finally, by shifting down and to the right we get the fourth image:



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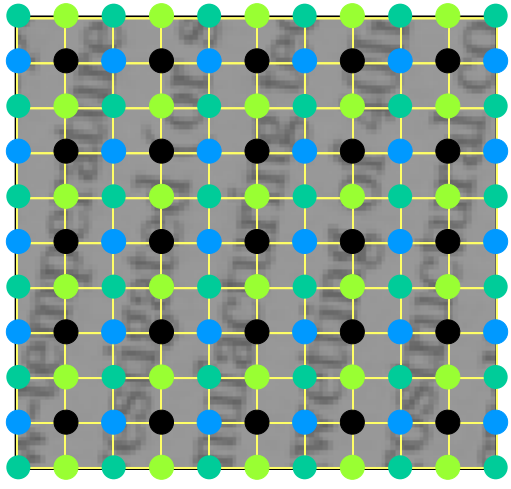
Intuition

By combining all four images the desired resolution is obtained, and thus perfect reconstruction is guaranteed.



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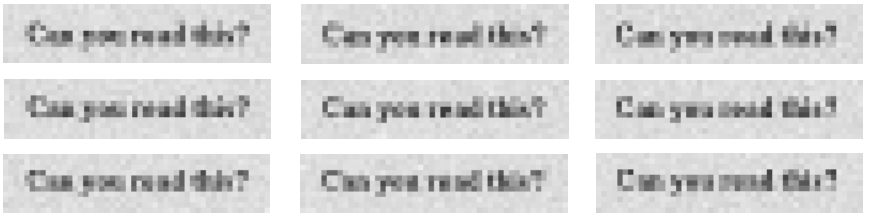
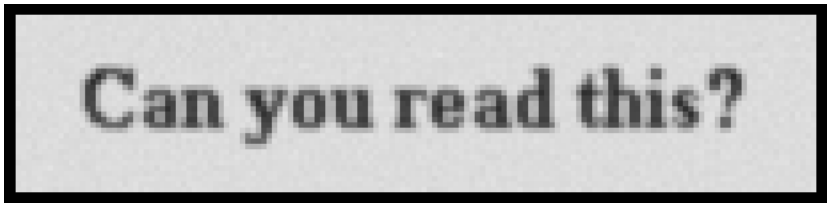
Example



3:1 scale-up in each axis using 9 images, with pure global translation between them



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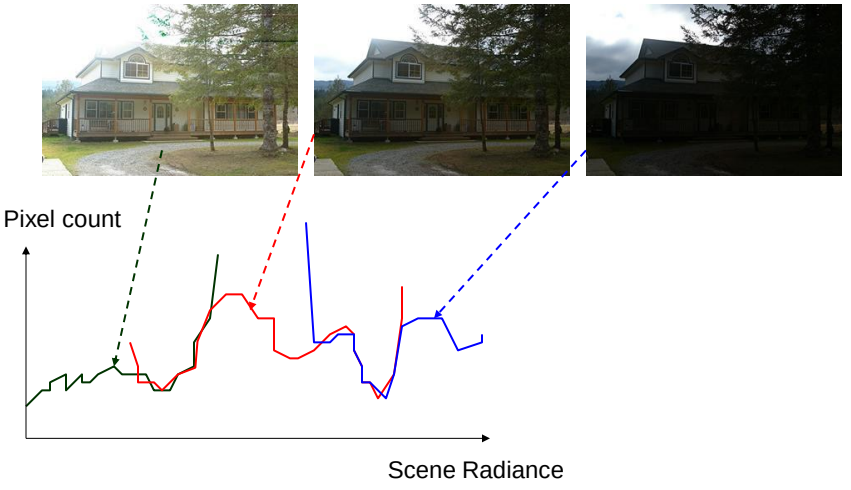
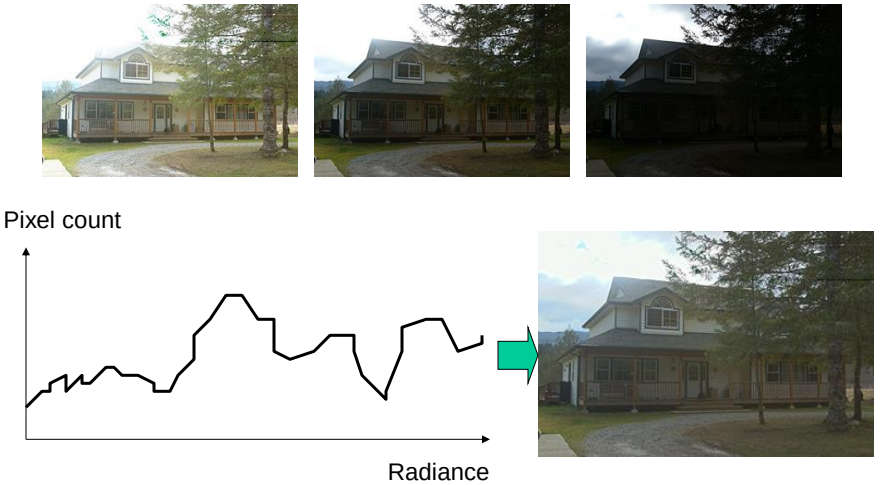
Dynamic Range

Typical cameras have limited dynamic range

HDR images — merge multiple inputs



HDR images — merged



Camera is not a photometer!

Limited dynamic range

- 8 bits captures only 2 orders of magnitude of light intensity
- We can see ~10 orders of magnitude of light intensity

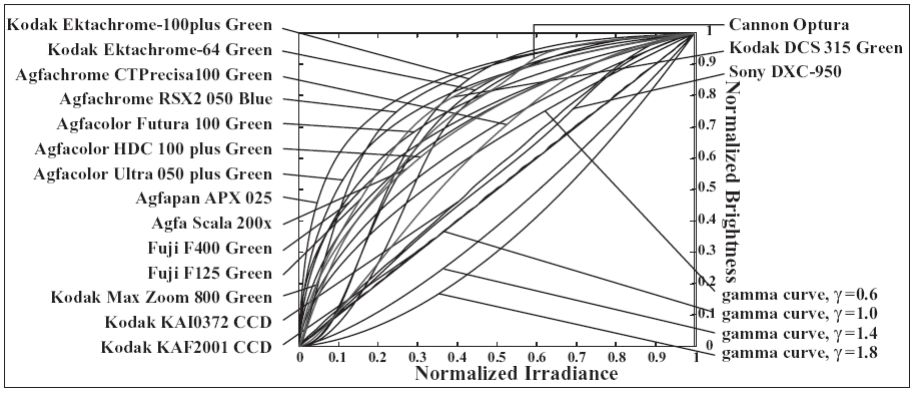
Unknown, nonlinear response

- pixel intensity ≠ amount of light (# photons, or "radiance")

Solution:

- Recover response curve from multiple exposures, then reconstruct the ***radiance map***

Camera response function



Capture and composite several photos

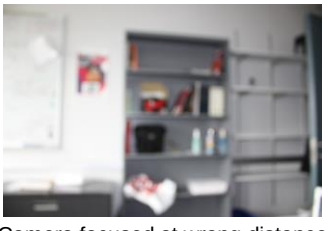
Works for

- field of view
- resolution
- signal to noise
- dynamic range

But sometimes you can do better by modifying the camera…

Why are images blurry?

Depth of field



Camera focused at wrong distance

Motion blur

How can we remove the blur?

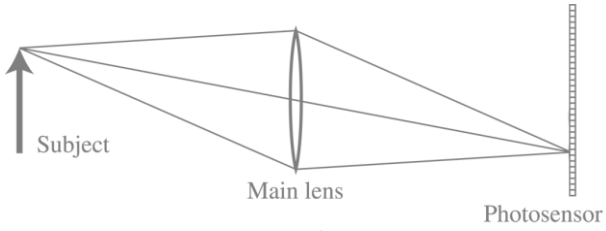
Focus

Suppose we want to produce images where we can ***change the focus*** after the fact?

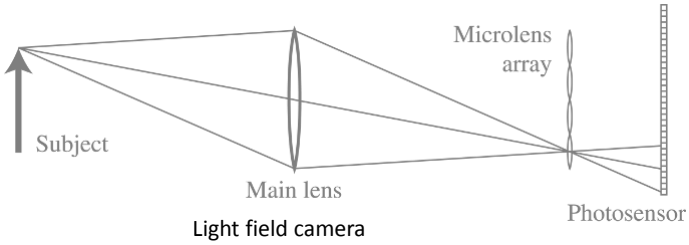
Or suppose we want ***everything*** to be in focus?

Light field camera [Ng et al., 2005]

Conventional vs. light field camera

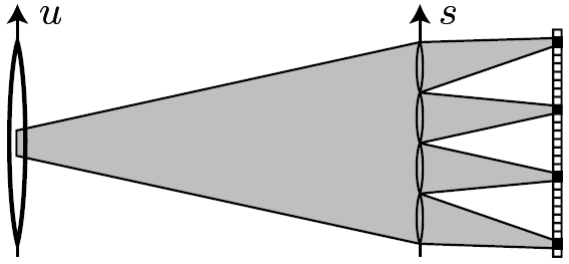


Conventional camera



Light field camera

Light field camera

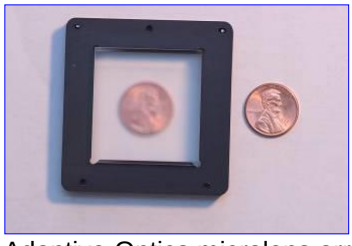


Rays are reorganized into many smaller images corresponding to subapertures of the main lens

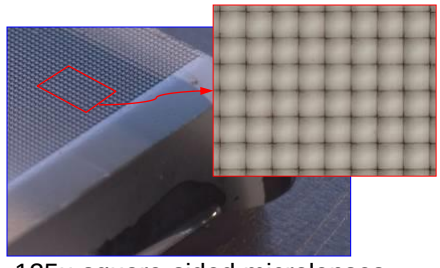
Prototype camera

Contax medium format camera

Kodak 16-megapixel sensor



Adaptive Optics microlens array

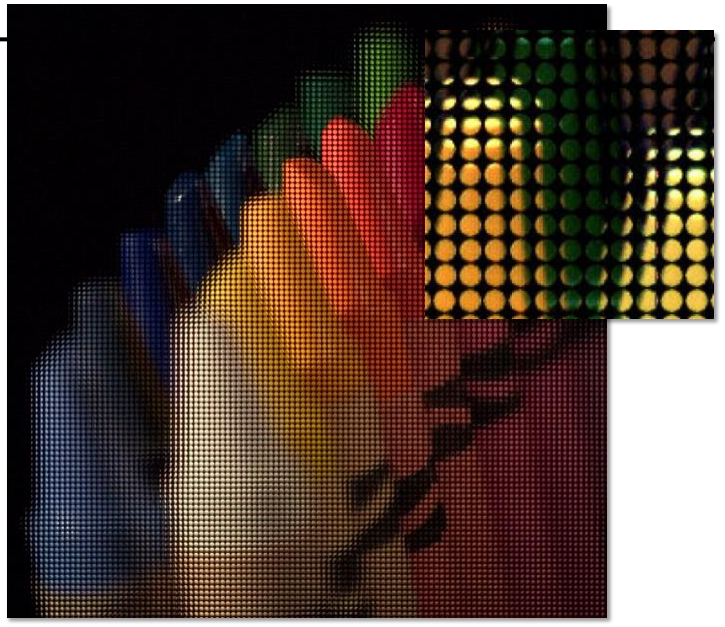


125μ square-sided microlenses

4000 × 4000 pixels ÷ 292 × 292 lenses = 14 × 14 pixels per lens

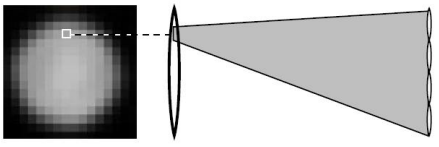
Lytro camera

https://www.lytro.com/camera/



What can we do with the captured rays?

Change viewpoint



Example of digital refocusing

All-in-focus images

Combines sharpest parts of all of the individual refocused images

Using single pixel from each subimage

All-in-focus

If you only want to produce an all-focus image, there are simpler alternatives

E.g.,

- Wavefront coding [Dowsky 1995]
- Coded aperture [Levin SIGGRAPH 2007], [Raskar SIGGRAPH 2007]
  - can also produce change in focus (ala Ng's light field camera)

Many more possibilities

Seeing through/behind objects

- Using a camera array (“synthetic aperture”)
- Levoy et al., SIGGRAPH 2004

Removing interreflections

- Nayar et al., SIGGRAPH 2006

Family portraits where everyone’s smiling

- Photomontage (Agarwala at al., SIGGRAPH 2004)

…

More on computational photography

SIGGRAPH course notes and video

Other courses

- MIT course
- CMU course
- Stanford course
- Columbia course

Wikipedia page

Symposium on Computational Photography

ICCP 2009 (conference)