CS4670: Computer Vision

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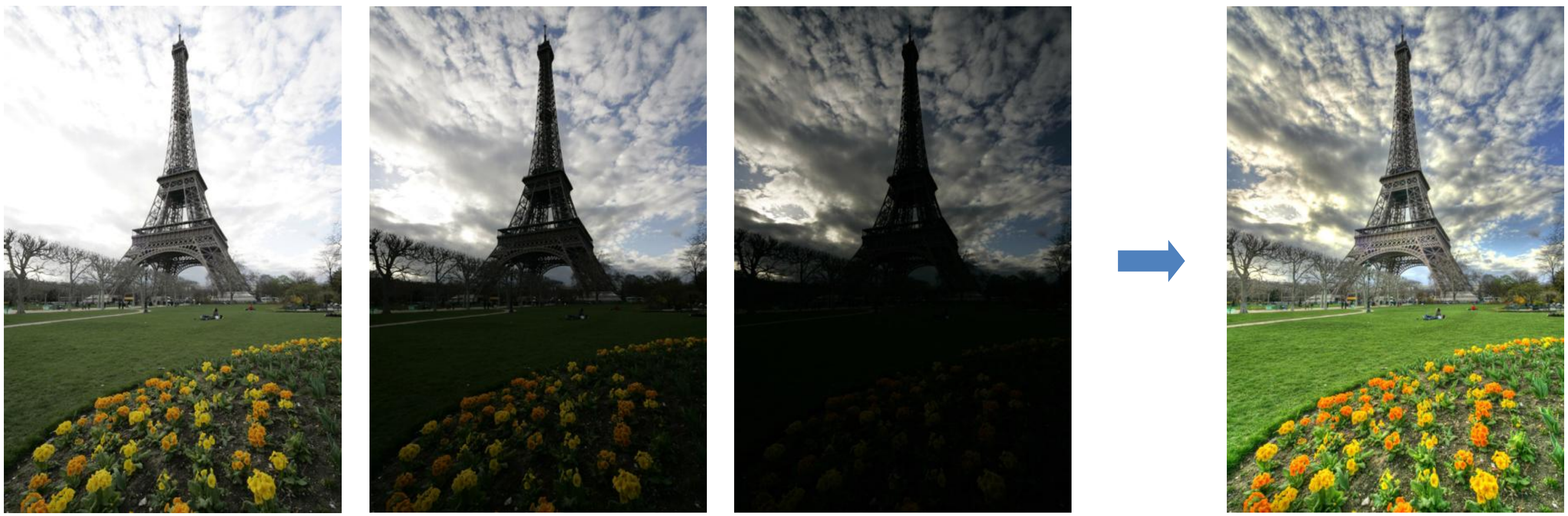
Lecture 33: Computational photography



Photometric stereo

Limitations

Big problems

- doesn't work for shiny things, semi-translucent things
- shadows, inter-reflections

Smaller problems

- camera and lights have to be distant
- calibration requirements
  - measure light source directions, intensities
  - camera response function

Newer work addresses some of these issues

Some pointers for further reading:

- Zickler, Belhumeur, and Kriegman, *"Helmholtz Stereopsis: Exploiting Reciprocity for Surface Reconstruction."* IJCV, Vol. 49 No. 2/3, pp 215-227.
- Hertzmann & Seitz, "*Example-Based Photometric Stereo: Shape Reconstruction with General, Varying BRDFs*." IEEE Trans. PAMI 2005

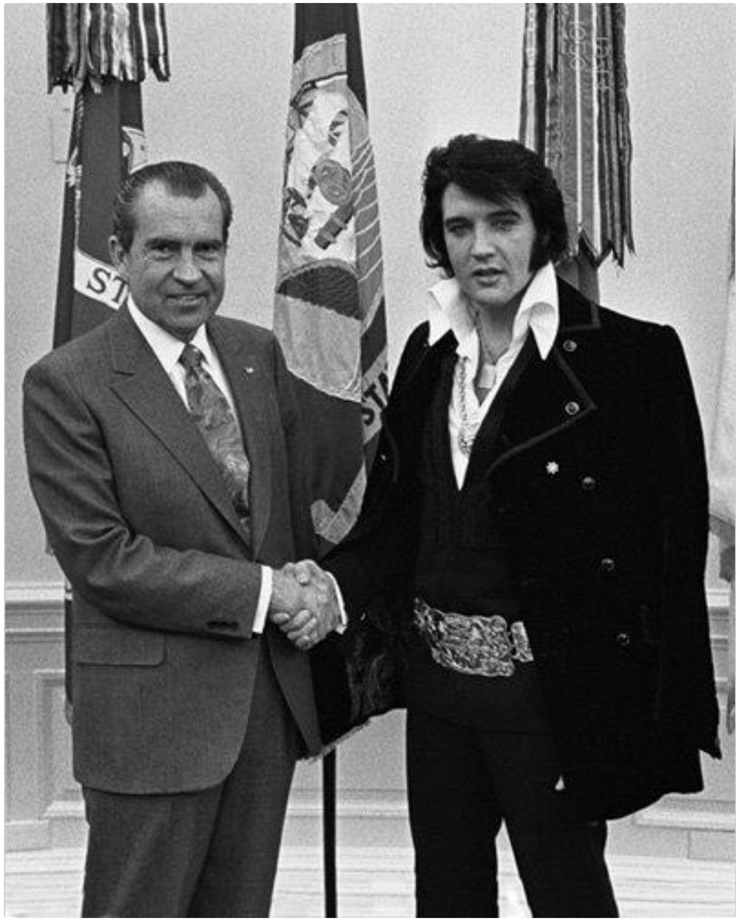
Finding the direction of the light source

P. Nillius and J.-O. Eklundh, "Automatic estimation of the projected light source direction," CVPR 2001

Application: Detecting composite photos

Which is the real photo?

Fake photo



Real photo

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?

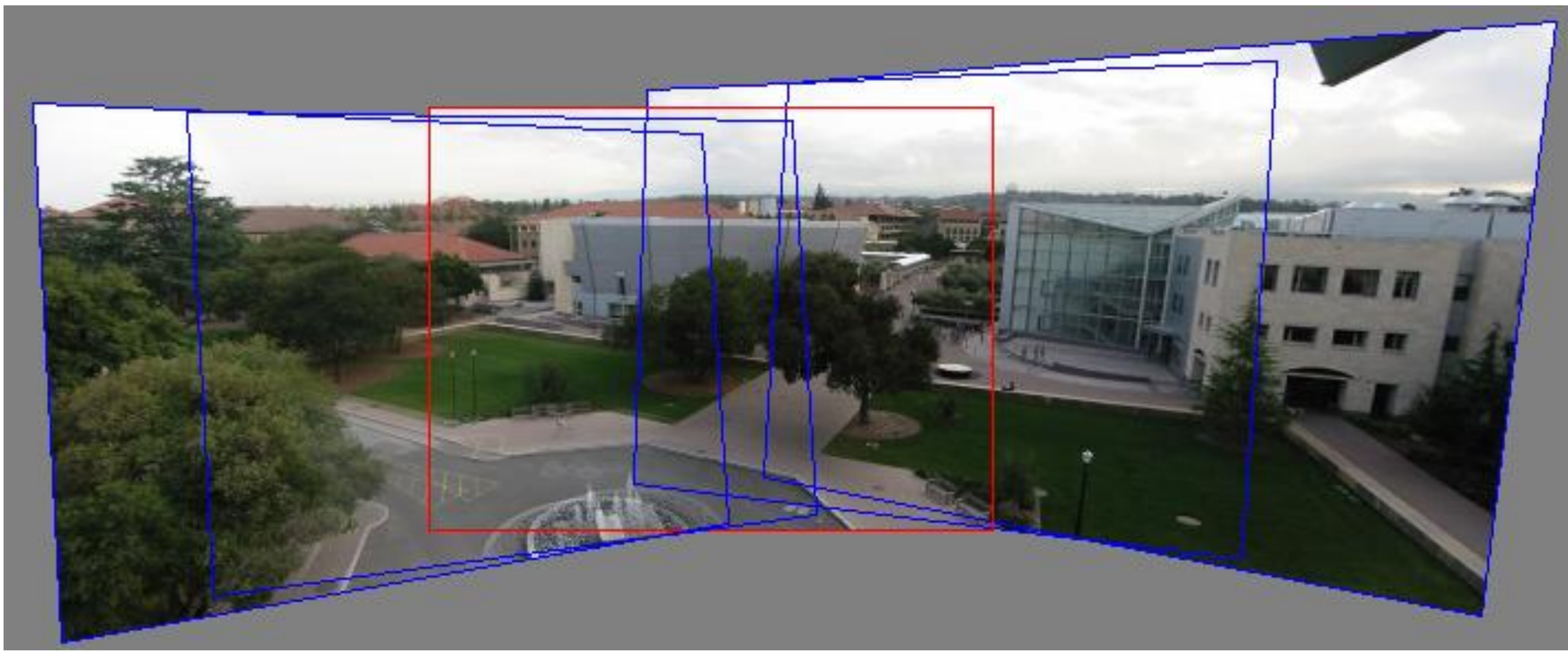
Basic statistics:

- variance of the mean decreases with n:

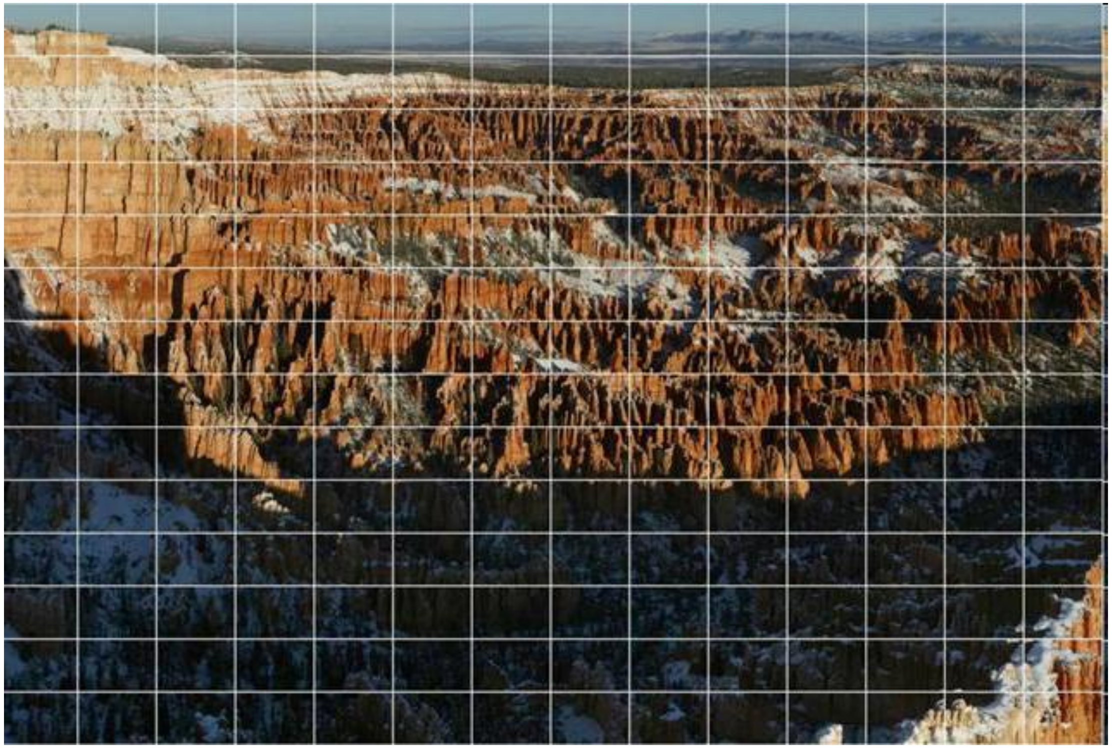
$$Var(\overline{X}) = \frac{\sigma^2}{n}$$

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:

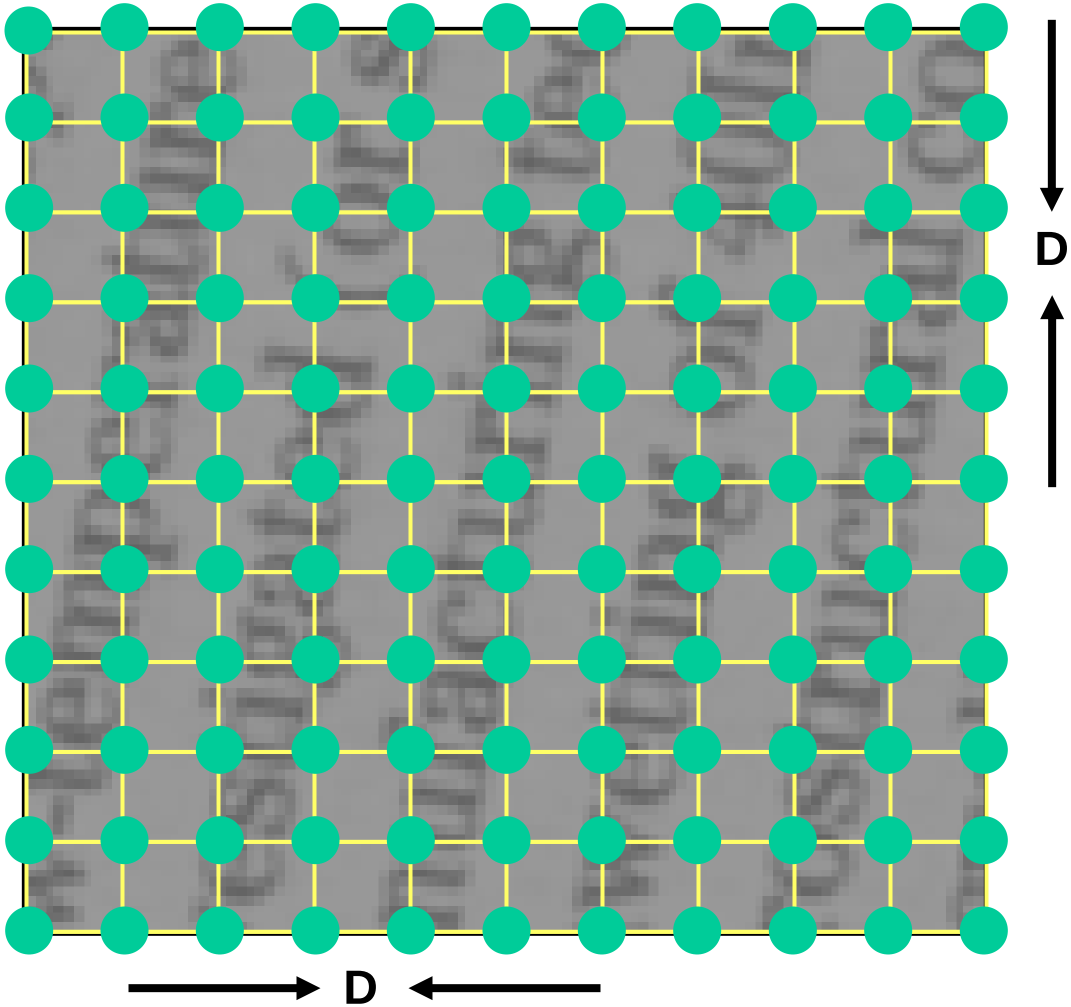
- Obama inauguration (gigapan.org)
- HDView (Microsoft Research)

Improving resolution: super resolution

What if you don’t have a zoom lens?

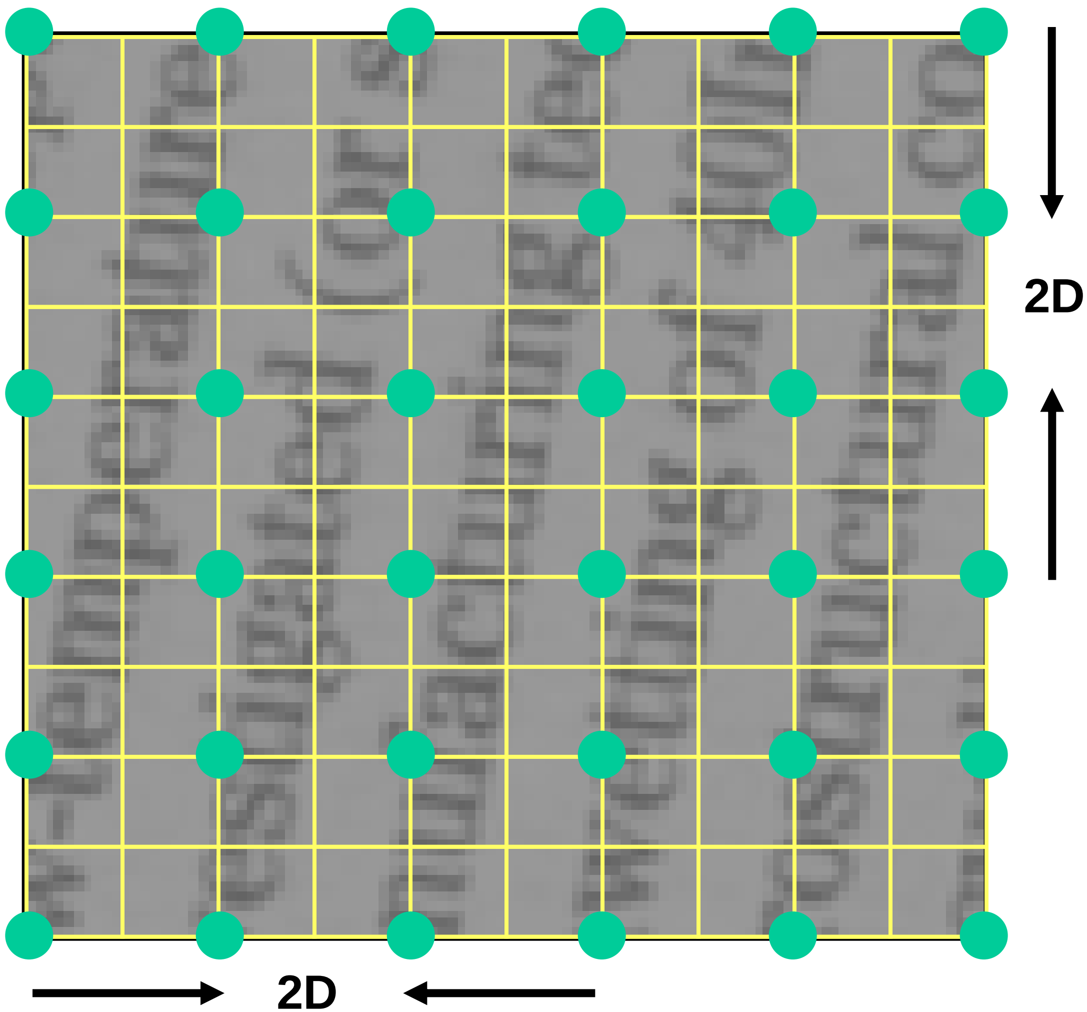
Intuition (slides from Yossi Rubner & Miki Elad)

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



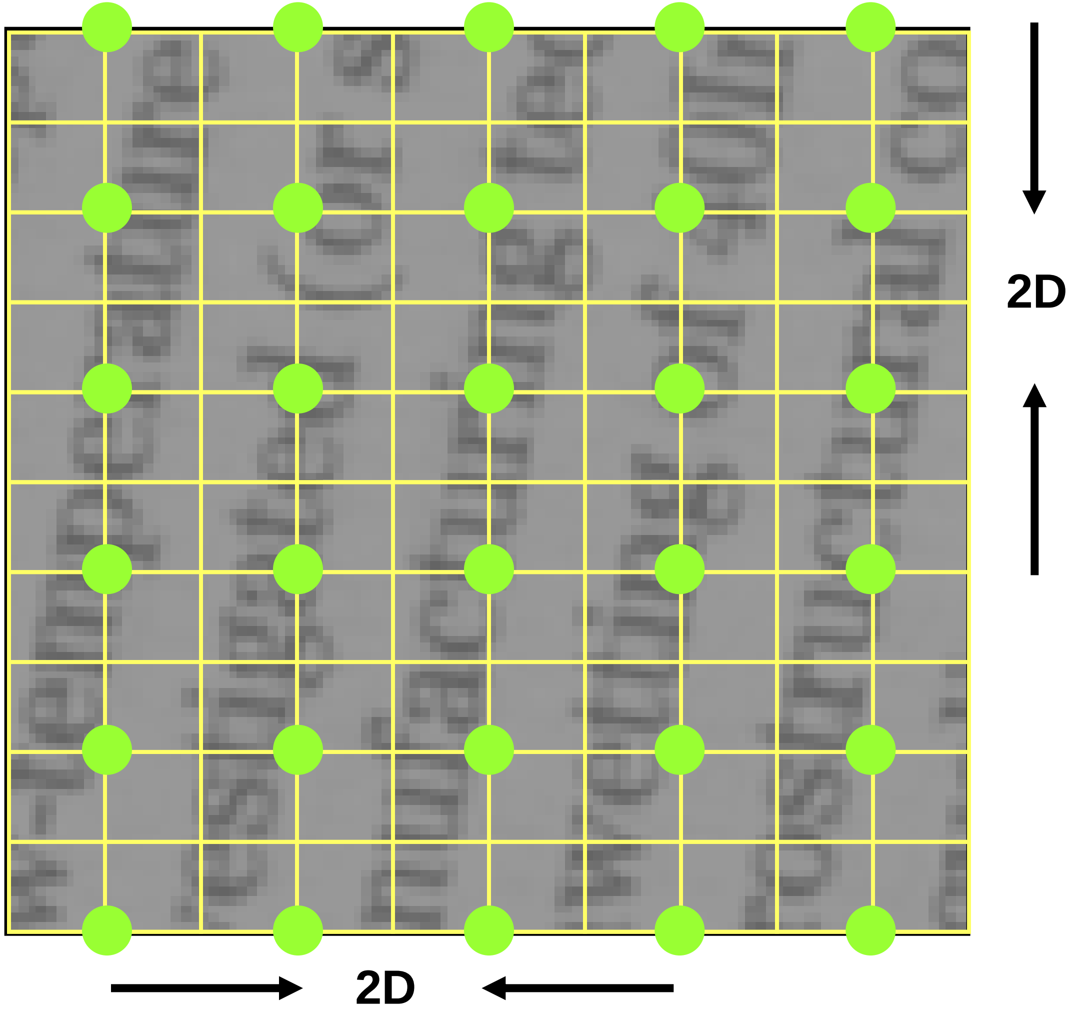
Intuition (slides from Yossi Rubner & Miki Elad)

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



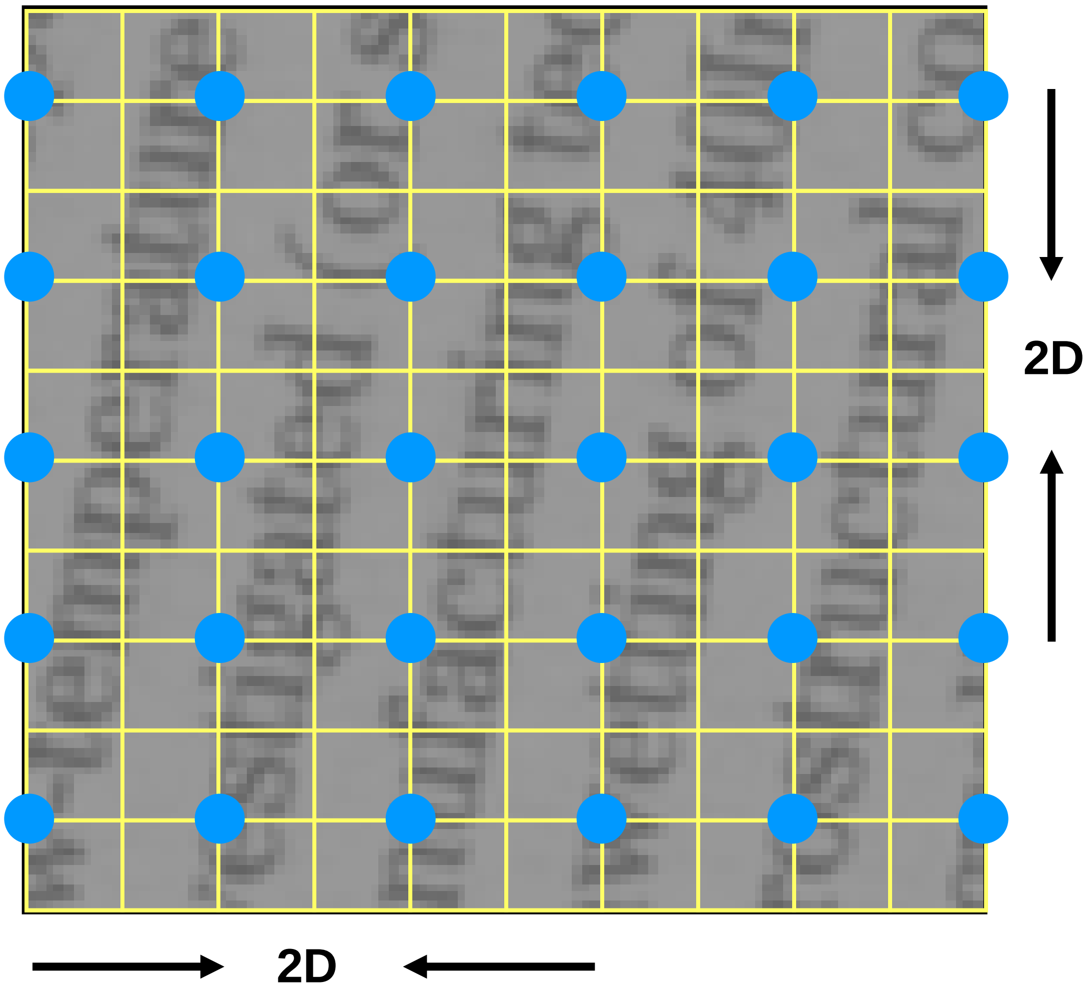
Intuition (slides from Yossi Rubner & Miki Elad)

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



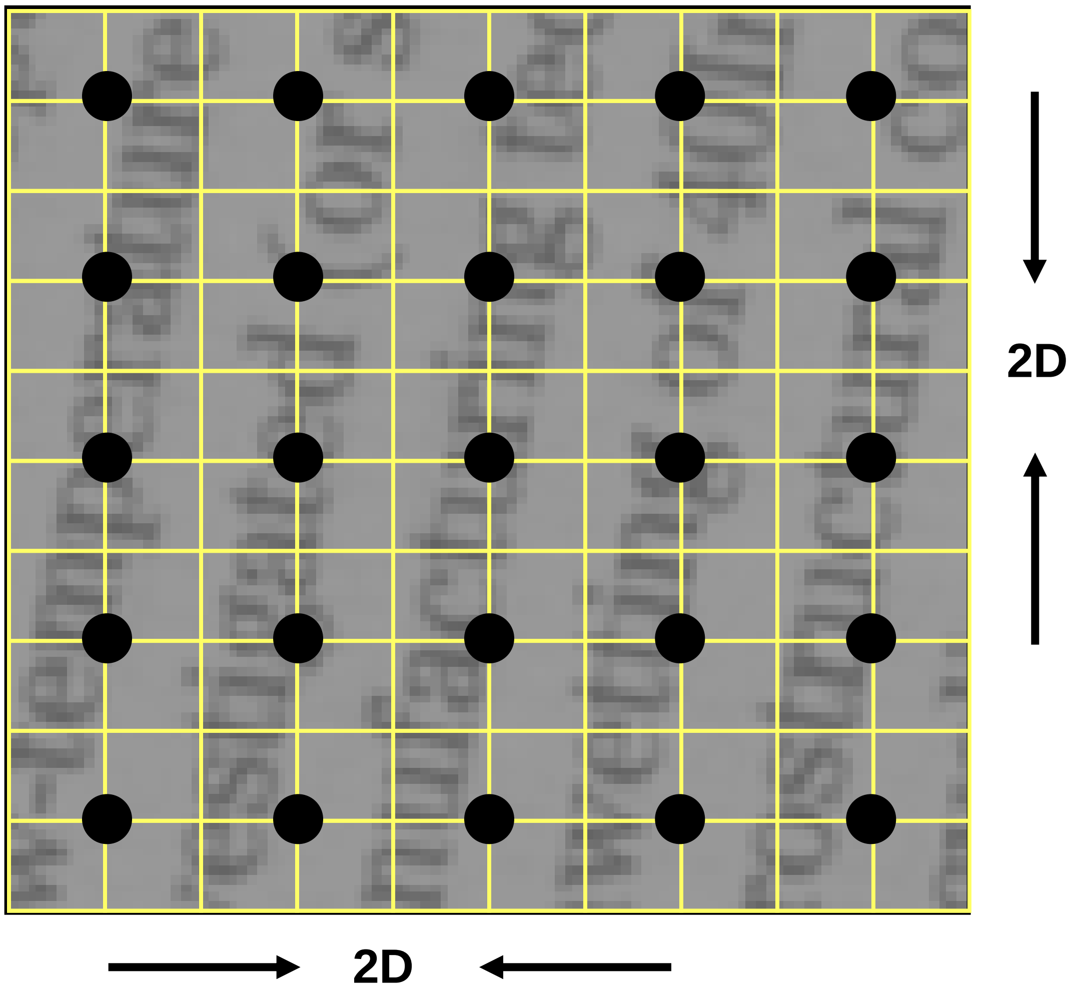
Intuition (slides from Yossi Rubner & Miki Elad)

Similarly, by shifting down we get a third image:



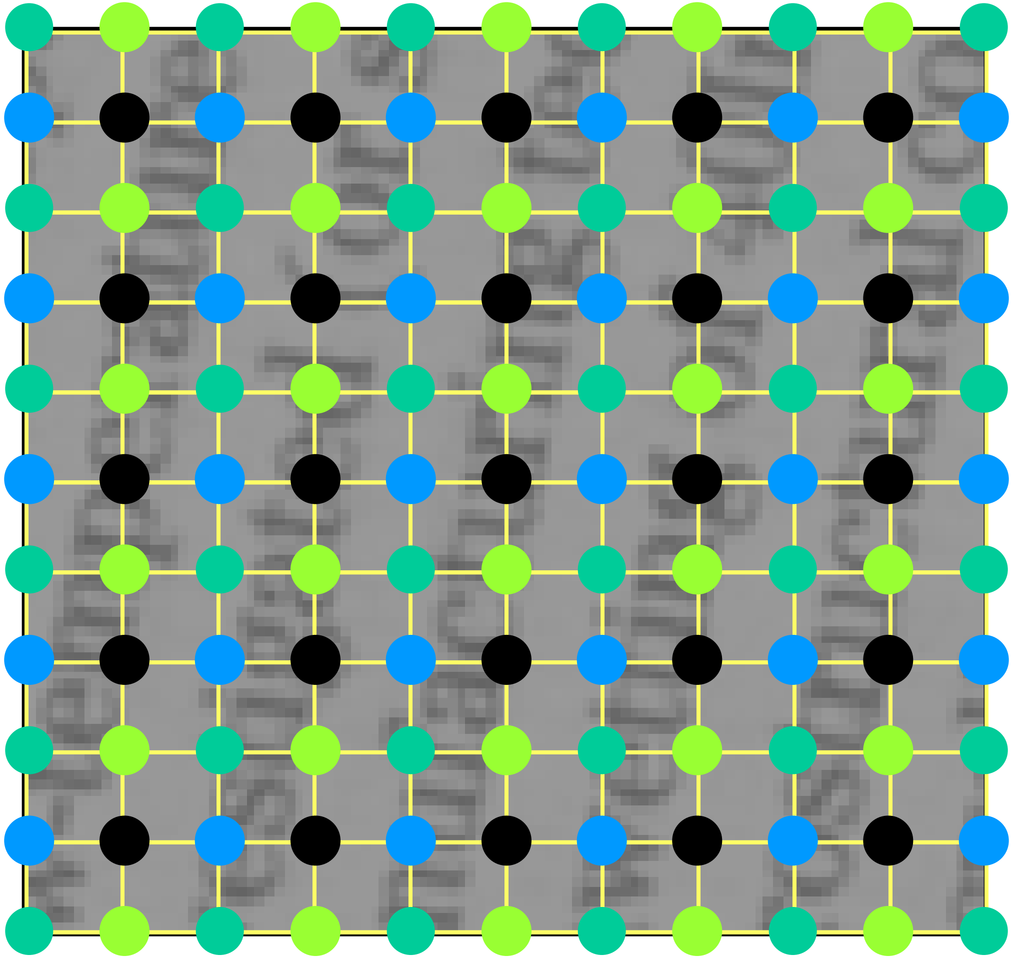
Intuition (slides from Yossi Rubner & Miki Elad)

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

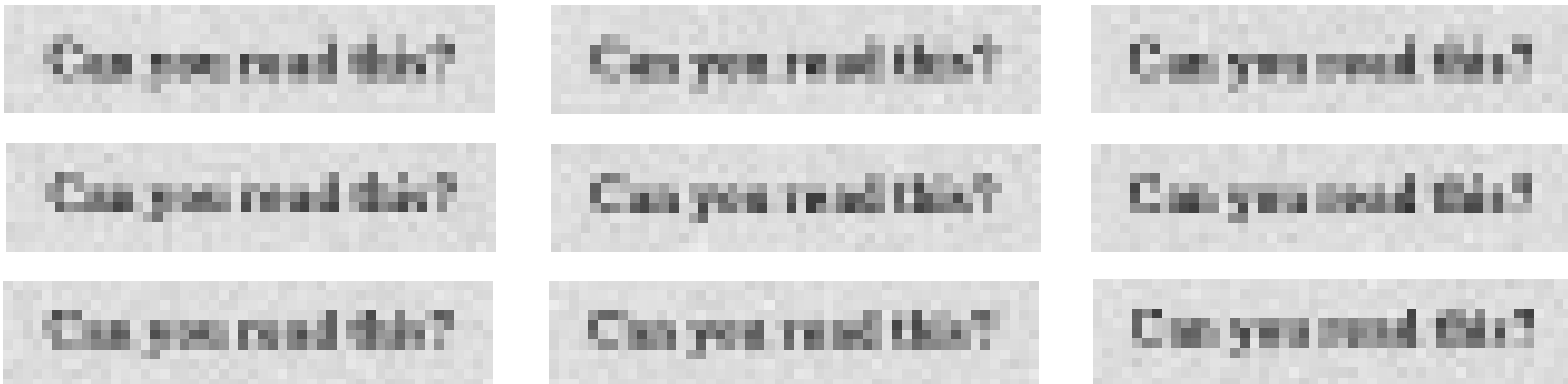


Intuition

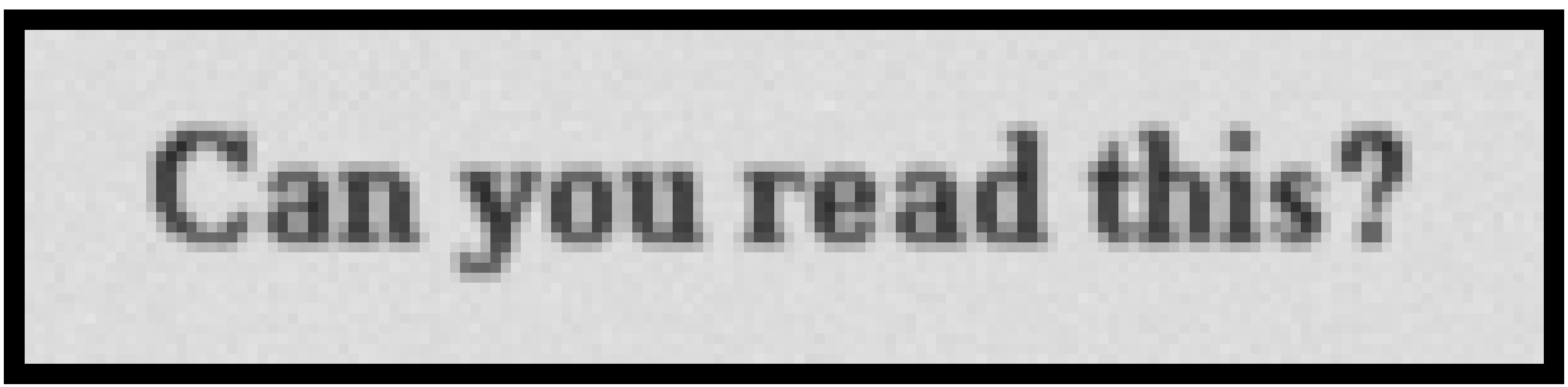
By combining all four images the desired resolution is obtained, and thus perfect reconstruction is guaranteed.



Example

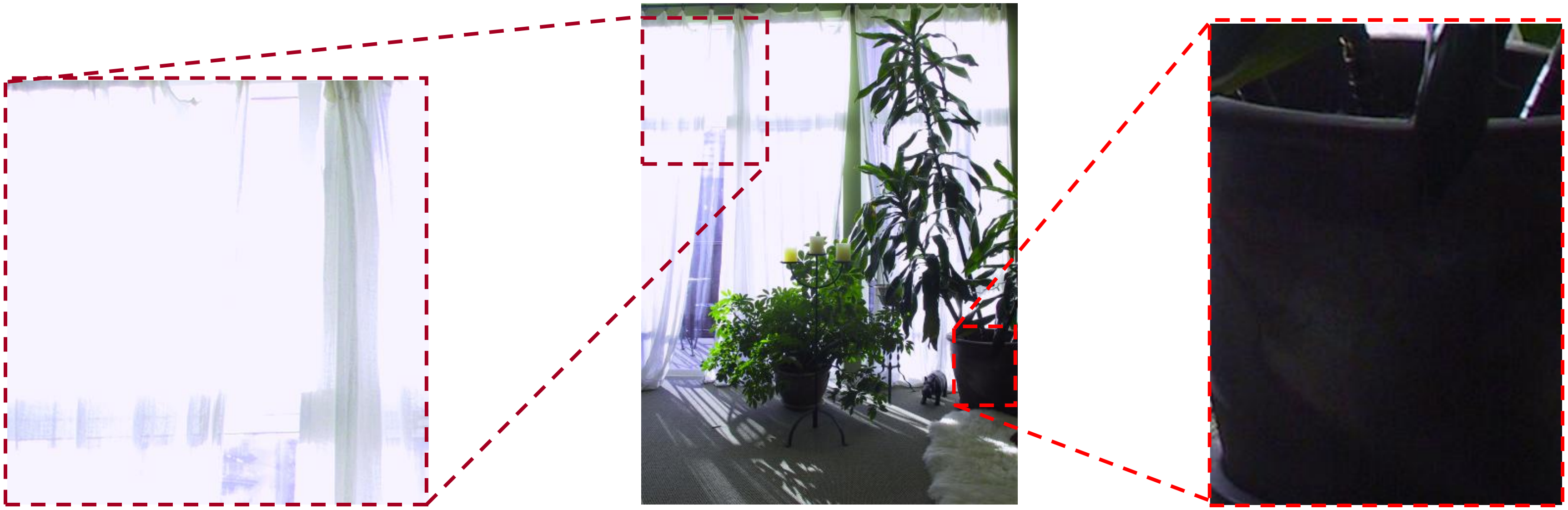


3:1 scale-up in each axis using 9 images, with pure global translation between them

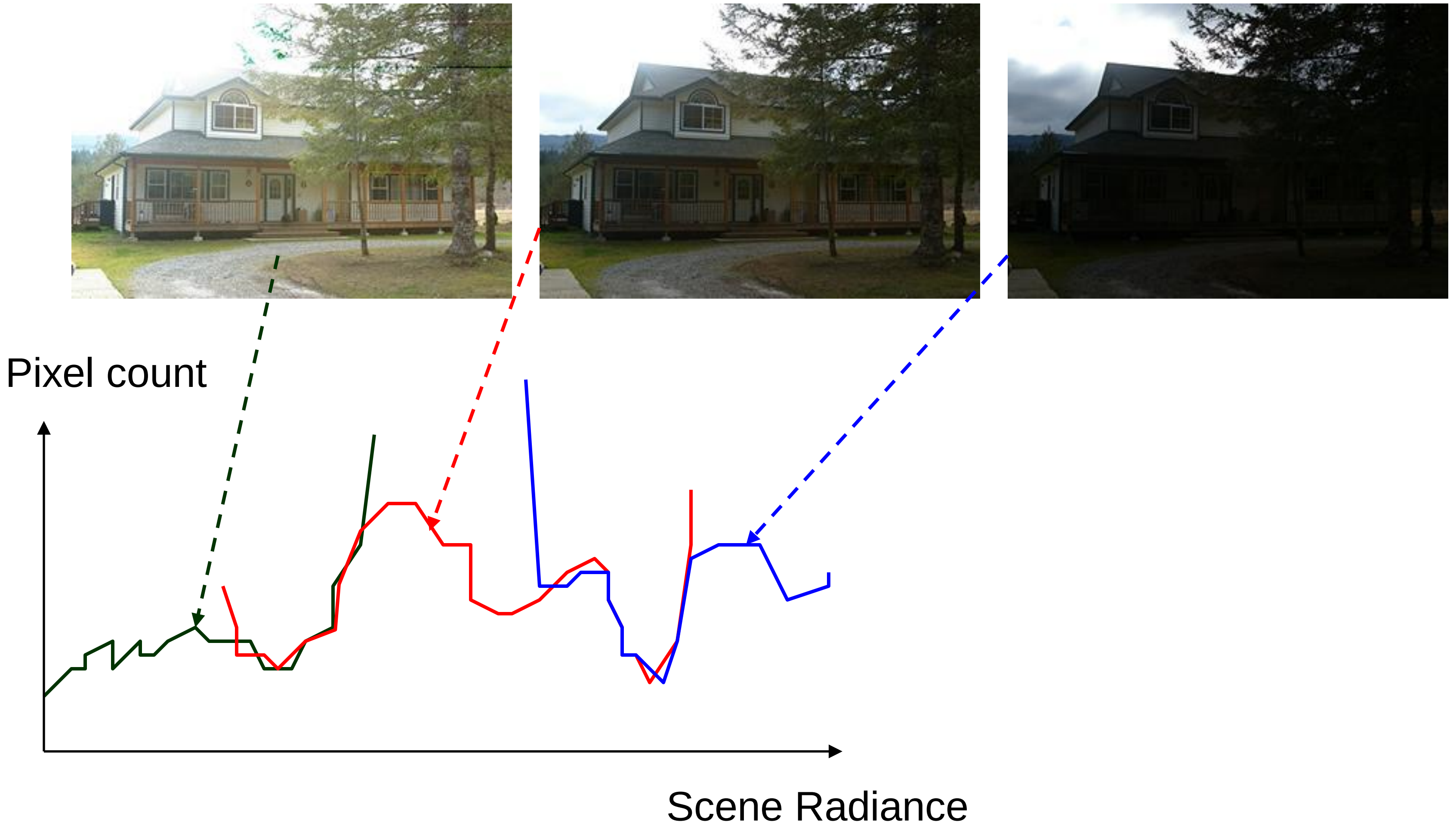


Dynamic Range

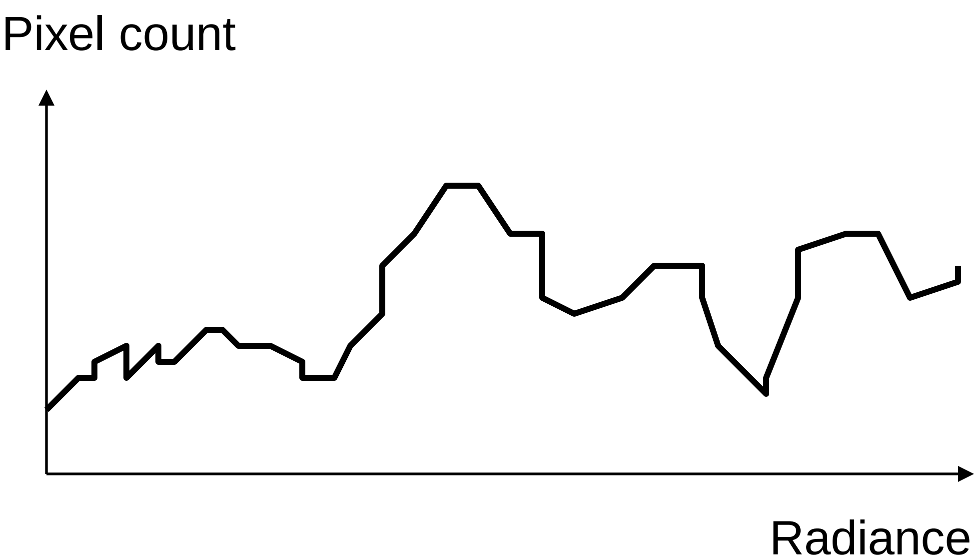
Typical cameras have limited dynamic range



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

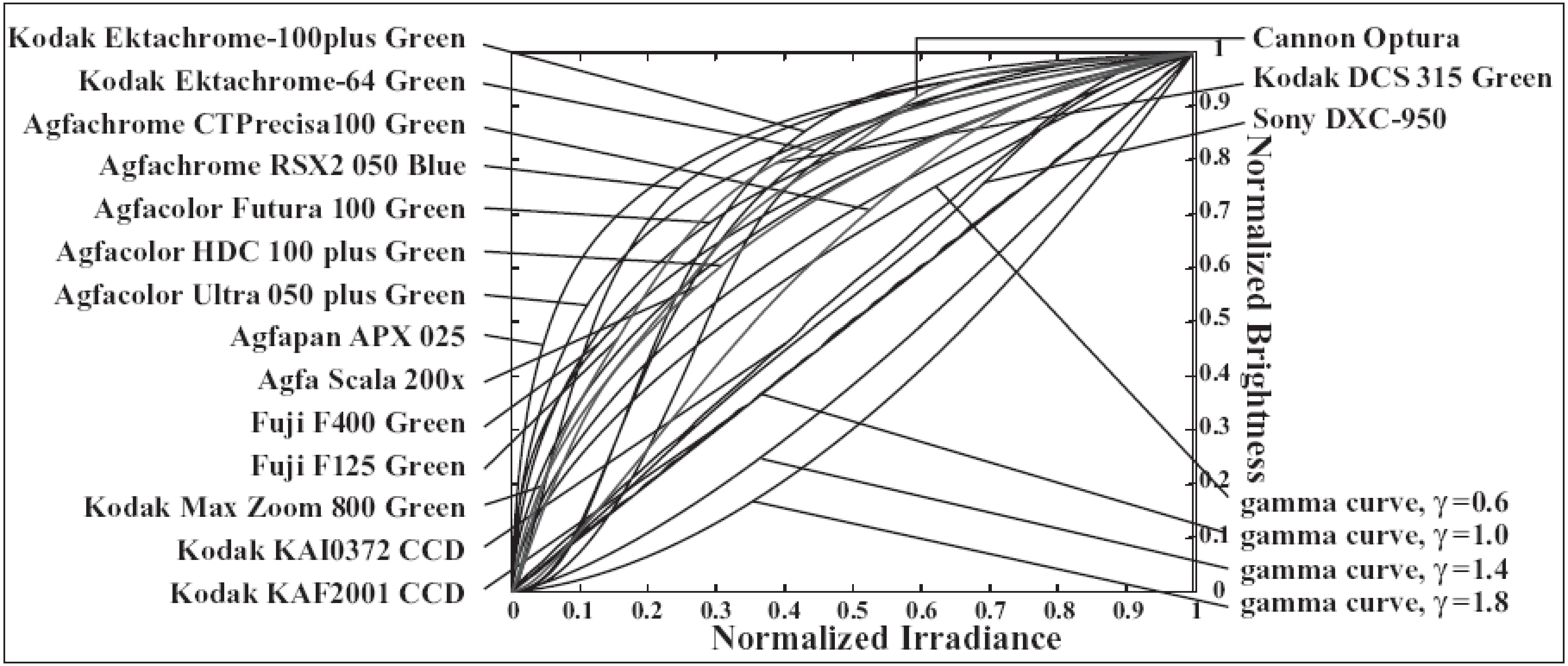
Unknown, nonlinear response

- pixel intensity $\neq$ 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
- Focus

But sometimes you can do better by modifying the camera…

Focus

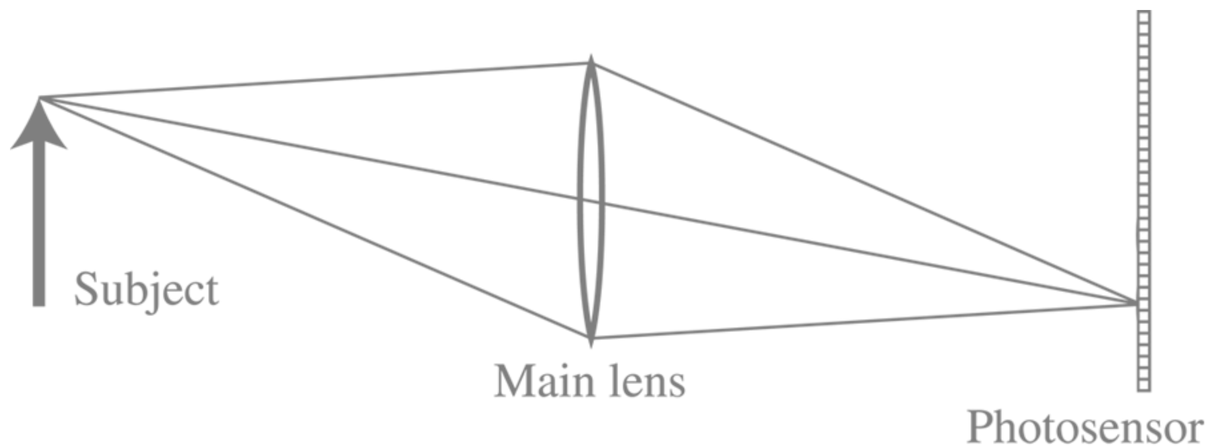
Suppose we want to produce images where the desired object is ***guaranteed*** to be in focus?

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

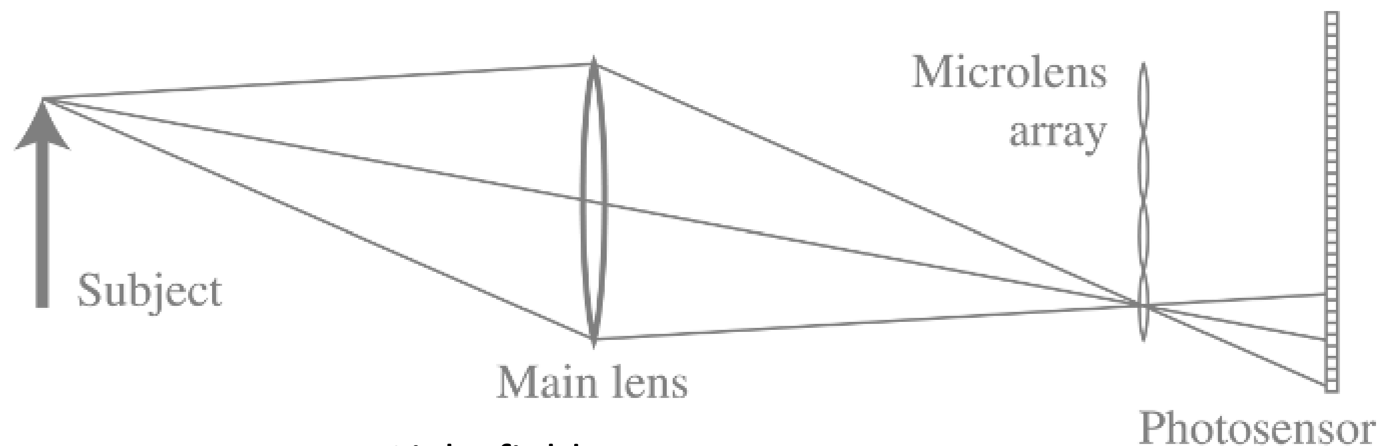
Light field camera [Ng et al., 2005]

http://www.refocusimaging.com/gallery/

Conventional vs. light field camera

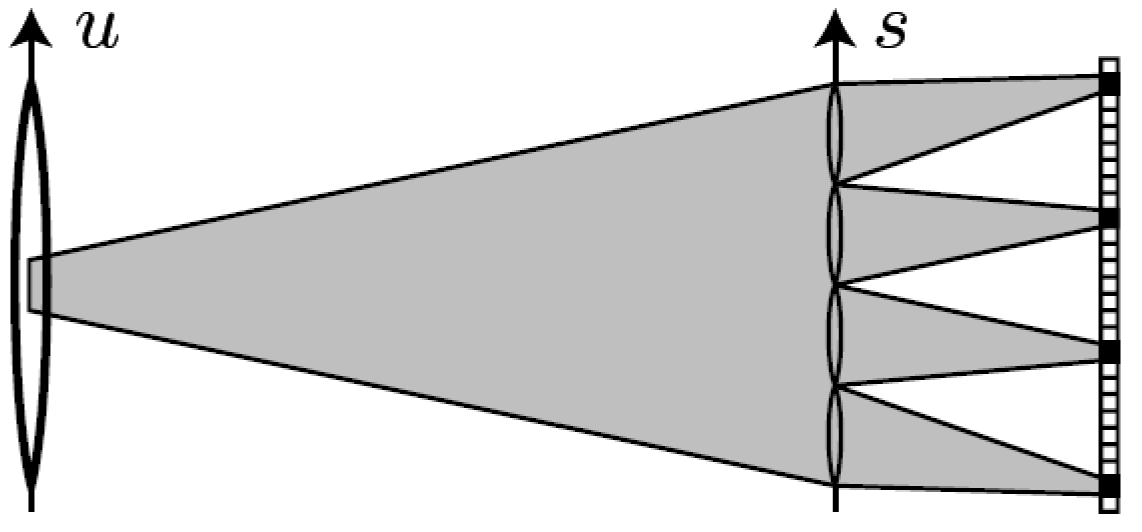


Conventional camera



Light field camera

Light field camera

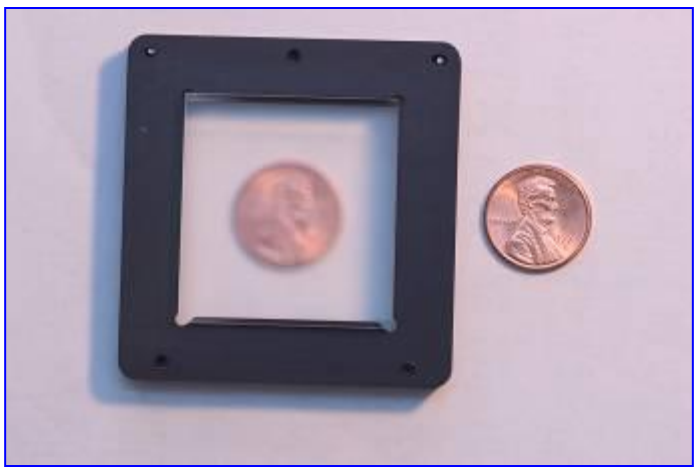


Rays are reorganized into many smaller images corresponding to subapertures of the main lens

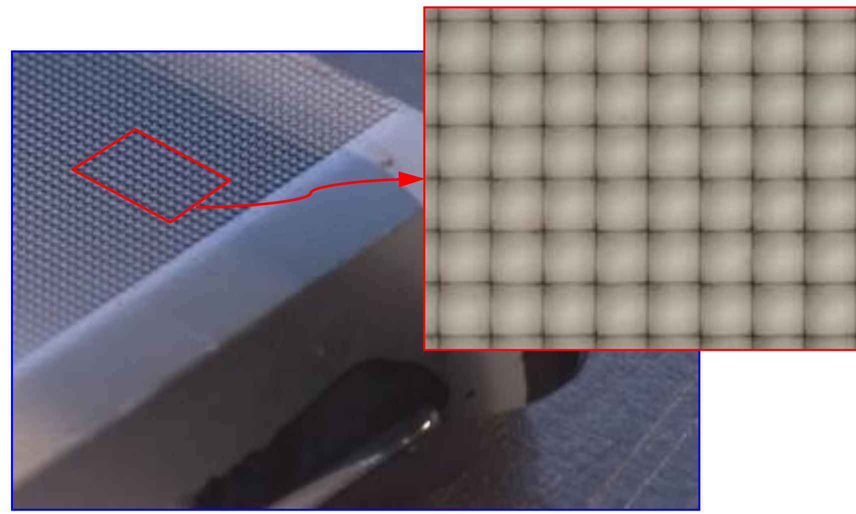
Prototype camera

Contax medium format camera

Kodak 16-megapixel sensor

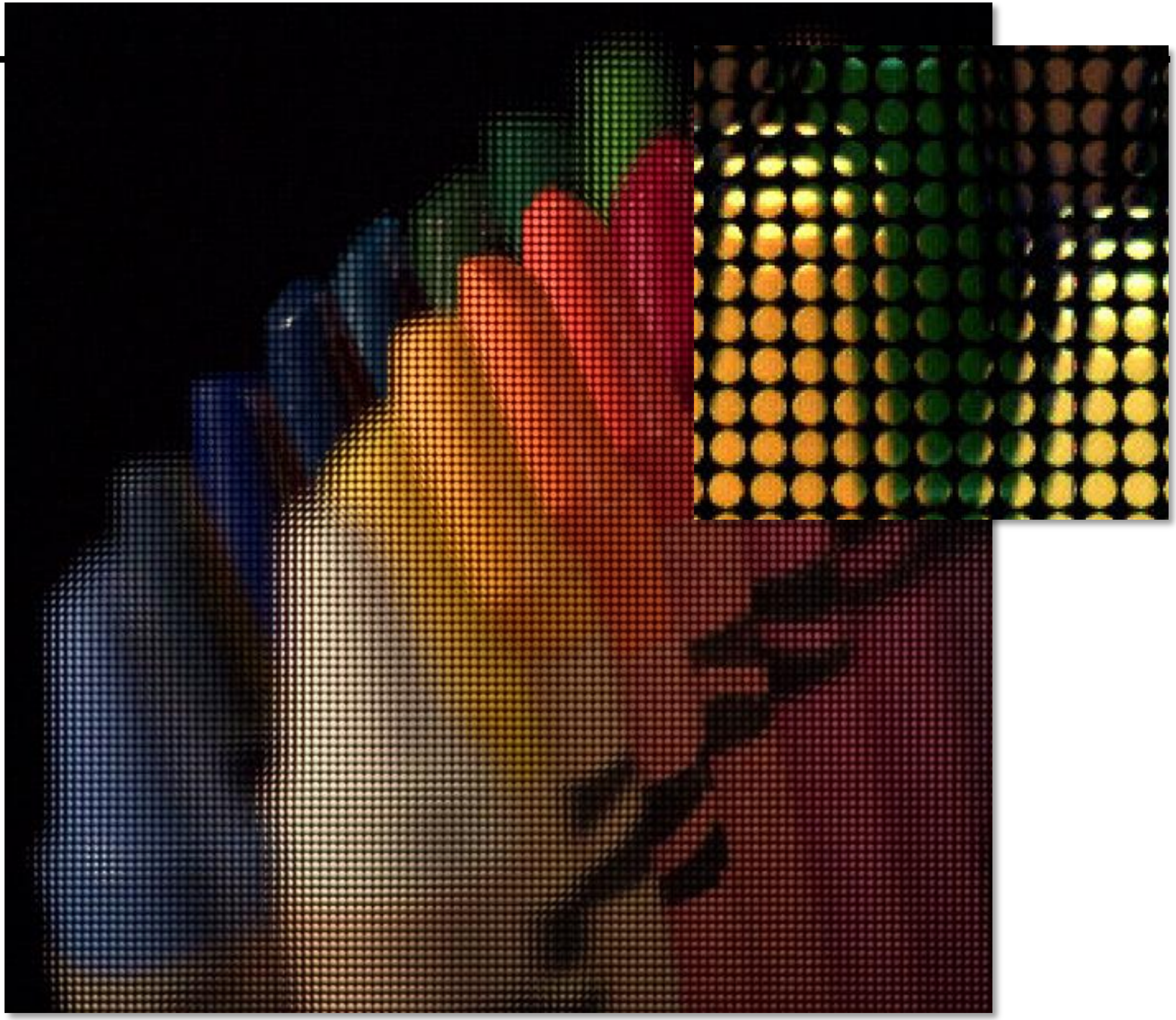


Adaptive Optics microlens array



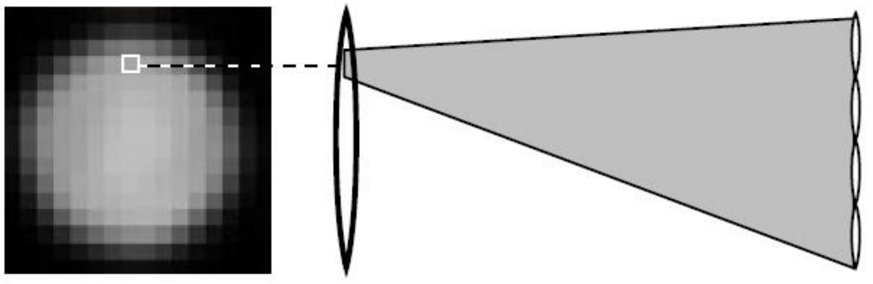
125μ square-sided microlenses

4000×4000 pixels $\div$ 292×292 lenses $=$ 14×14 pixels per lens



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)

Why are images blurry?

Depth of field

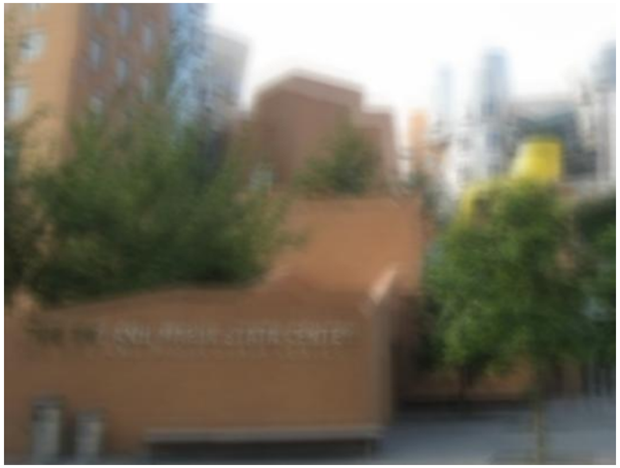
Camera focused at wrong distance

Motion blur

How can we remove the blur?

Motion blur

Especially difficult to remove, because the blur kernel is unknown



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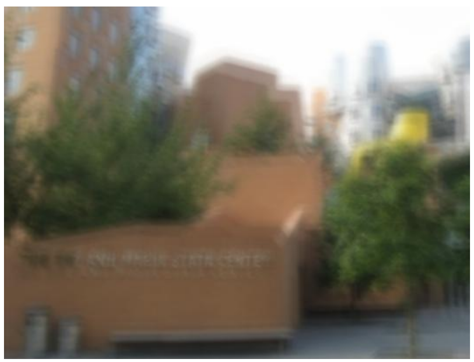
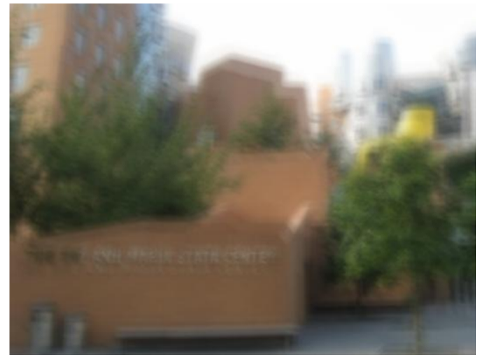
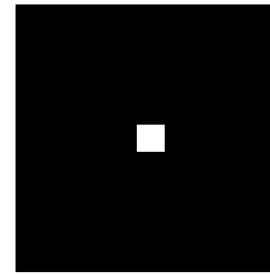
both unknown

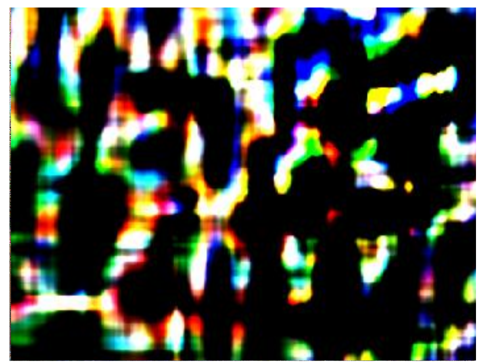
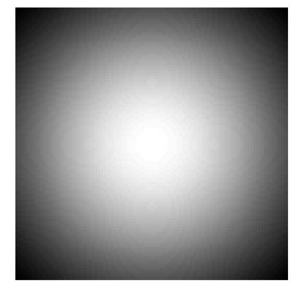
Multiple possible solutions



Blurry image

Sharp image | Blur kernel

=  $\otimes$ 

=  $\otimes$ 

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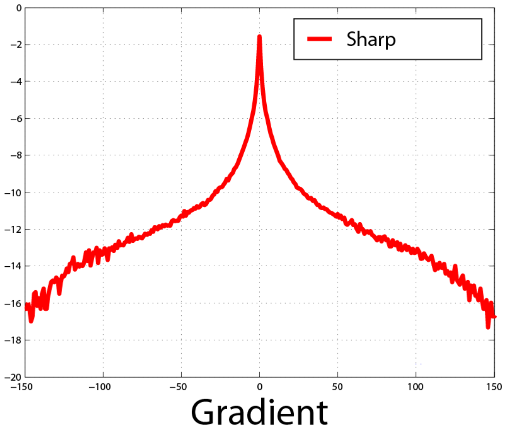
Slide courtesy Rob Fergus

Priors can help

Priors on natural images

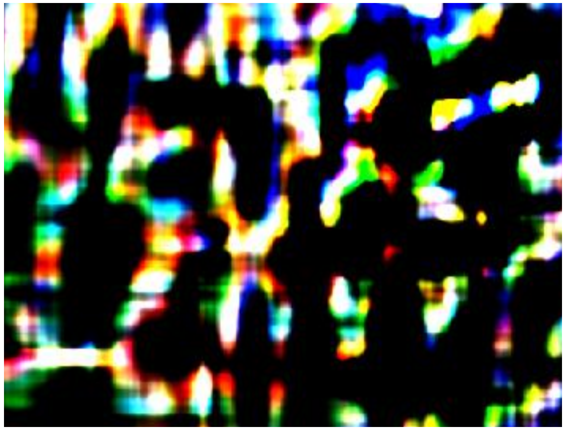
 

Image A is more “natural” than image B

Natural image statistics

Characteristic distribution with heavy tails

Histogram of image gradients