Exposure metering

CS 178, Spring 2009

Begun 4/30/09, will be finished later (maybe next week). Note added to slide 8 on 5/4/09.

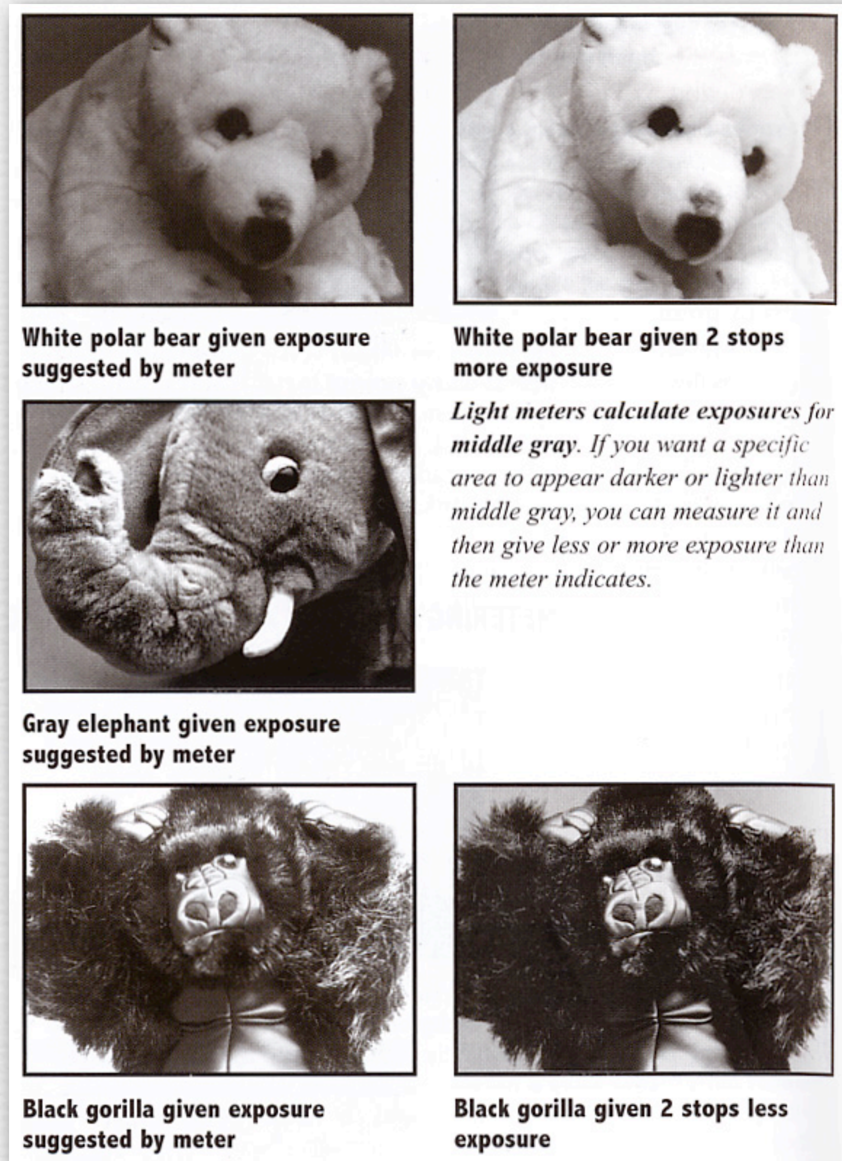
Marc Levoy
Computer Science Department
Stanford University

Outline

- What makes metering hard?
  - the meter doesn't know what you're looking at
  - the dynamic range problem
- background topics
  - Ansel Adams' zone system
  - gamma and gamma correction
  - sampling versus quantization
- metering on modern digital cameras
- high dynamic range (HDR) imaging
  - capture
  - display
  - tone mapping

What makes metering hard?

(London)



- light meters don't know what you're looking at
  - so they assume the scene is mid-gray (18% reflective)
- the world is full of hard metering problems...

(http://fotocommunity.de)

The dynamic range problem

- even if meters were omniscient, the dynamic range of the world is higher than the dynamic range of a camera

- the real world

800,000:1	surface illuminated by sun vrs by moon, (20 f/stops, or 1/1000 sec vrs 13 minutes)
100:1	diffuse white surface versus black surface
80,000,000:1	**total dynamic range**

- human vision

100:1	photoreceptors (including bleaching)
10:1	variation in pupil size
100,000:1	neural adaptation
100,000,000:1	**total dynamic range**

The dynamic range problem

- media (approximate and debatable)

10:1	photographic print (higher for glossy paper)
20:1	artist's paints
200:1	slide film
500:1	negative film
1000:1	LCD display
2000:1	digital SLR (11 f/stops, so 11 bits)

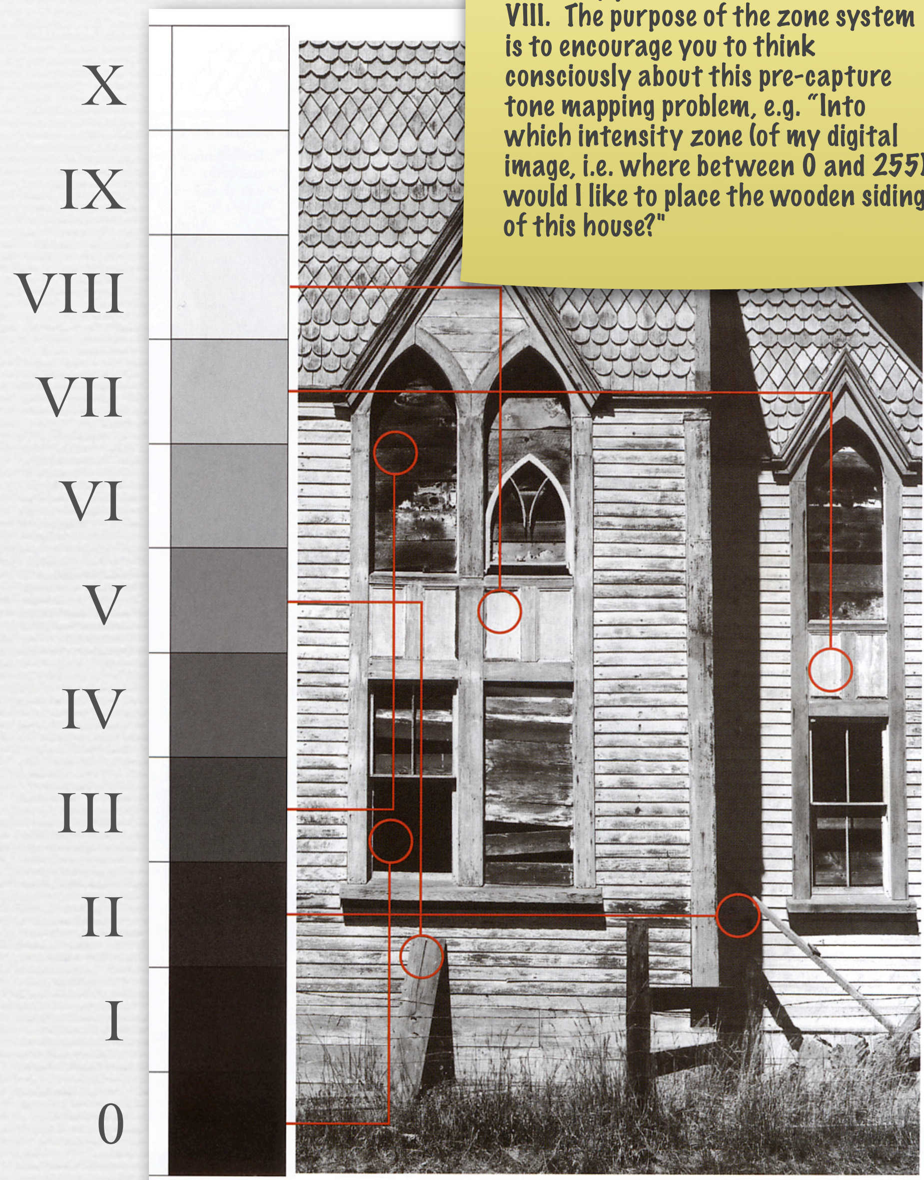
- challenges
  - choosing which 6-12 f/stops of the world to include in your photograph (cell phone to professional SLR, respectively)
  - metering the world to help you make this decision, since the world has more dynamic range than any light meter
  - compressing 12 f/stops into 4 bits for print, or 10 for LCD
    - this is the *tone mapping* problem

Ansel Adams's zone system

- roughly 1 f/stop per zone
  - X = "maximum white of the paper base"
  - IX = "slight tonality, but no texture: flat snow in sunlight"
  - VIII = "textured snow, lightest wood at right"

    .....
  - V = 18% gray card

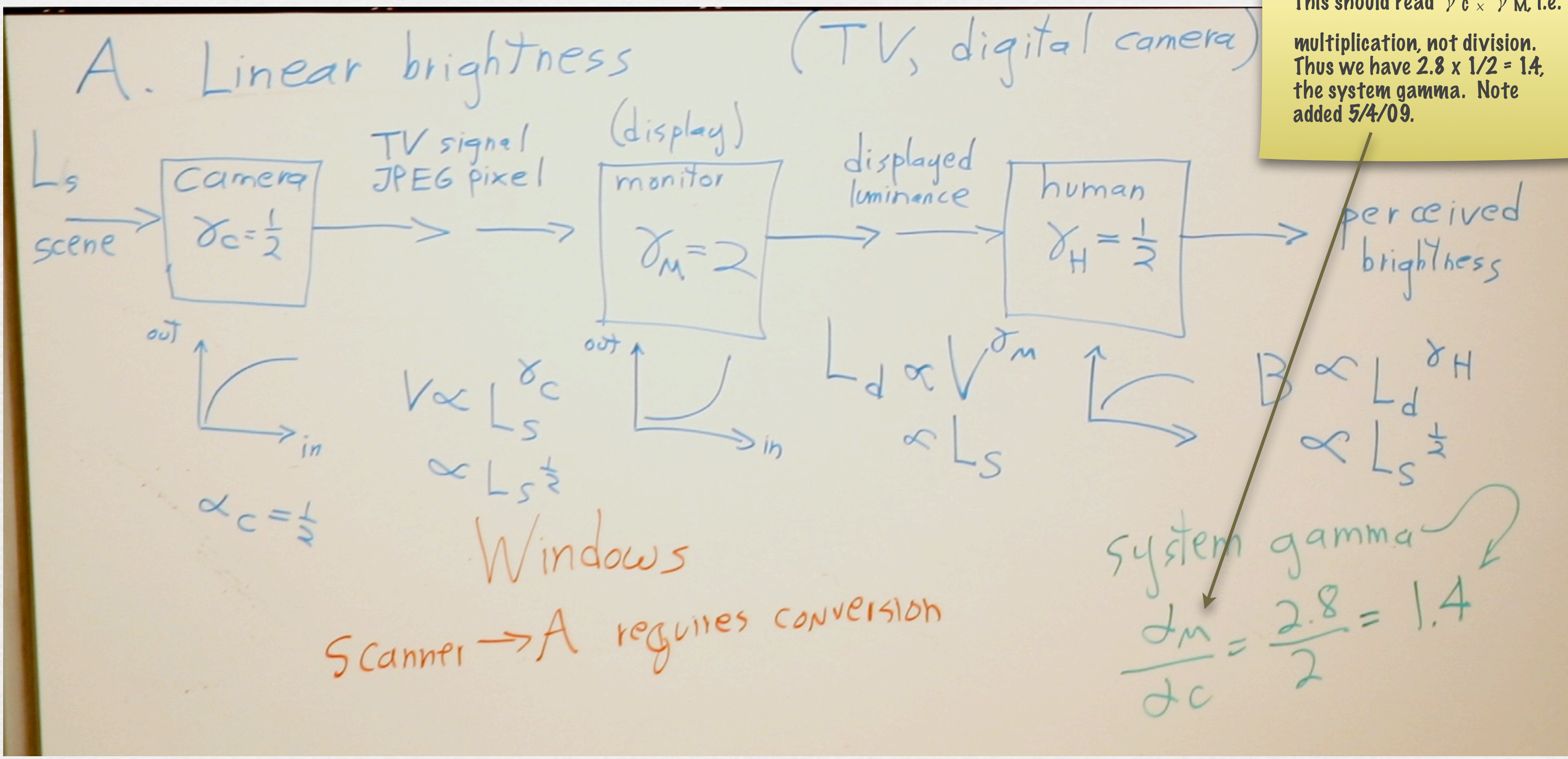
    .....
  - 0 = "maximum black that photographic paper can produce"
- lesson for the digital age
  - plan the tones you want in your image for each part of the scene



In class I didn't do a great job of explaining whether these zones are in the scene or on the photographic paper. They are on the paper. The text accompanying each zone refers to examples of real-world objects that would *normally* be mapped to those tones on the paper, e.g. one would normally place textured snow in zone VIII. The purpose of the zone system is to encourage you to think consciously about this pre-capture tone mapping problem, e.g. "Into which intensity zone (of my digital image, i.e. where between 0 and 255) would I like to place the wooden siding of this house?"

Gamma and gamma correction

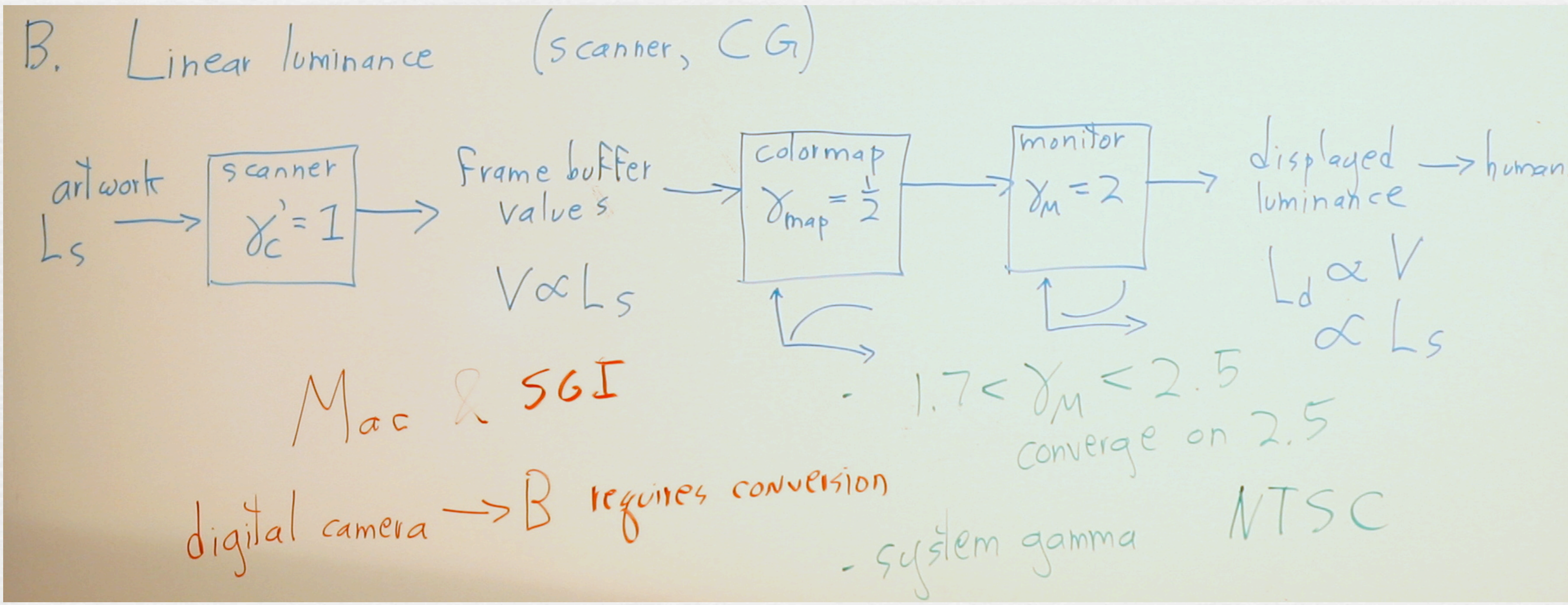
- systems in which the transmitted signal (or stored pixel) is proportional to (i.e. linear with) perceived brightness



This should read $\gamma_C \times \gamma_M$, i.e. multiplication, not division. Thus we have 2.8 x 1/2 = 1.4, the system gamma. Note added 5/4/09.

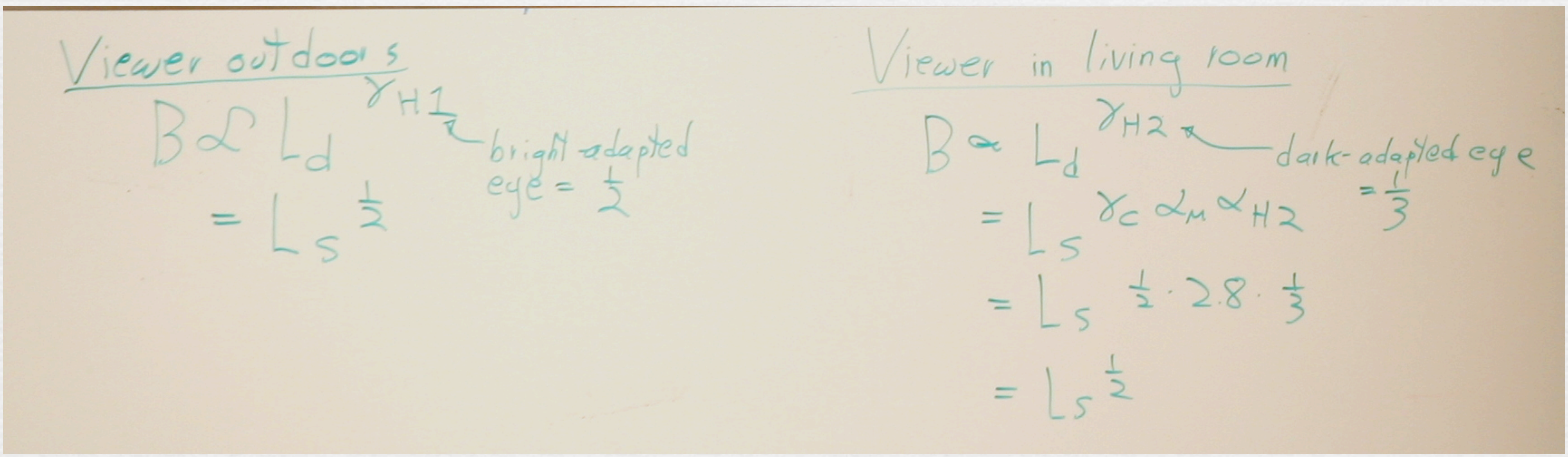
Gamma and gamma correction

- systems in which the stored pixel is proportional to scene luminance



System gamma

- why the gamma of NTSC television monitors (2.8) is higher than the inverse of the gamma of cameras (0.5)

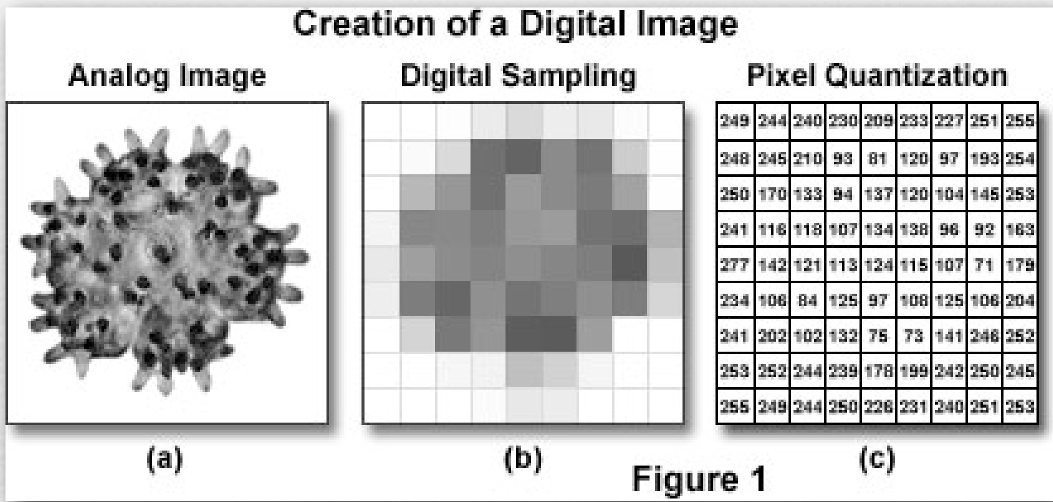


JPEG file: pixel value ∝ ~perceived brightness

(Marc Levoy)

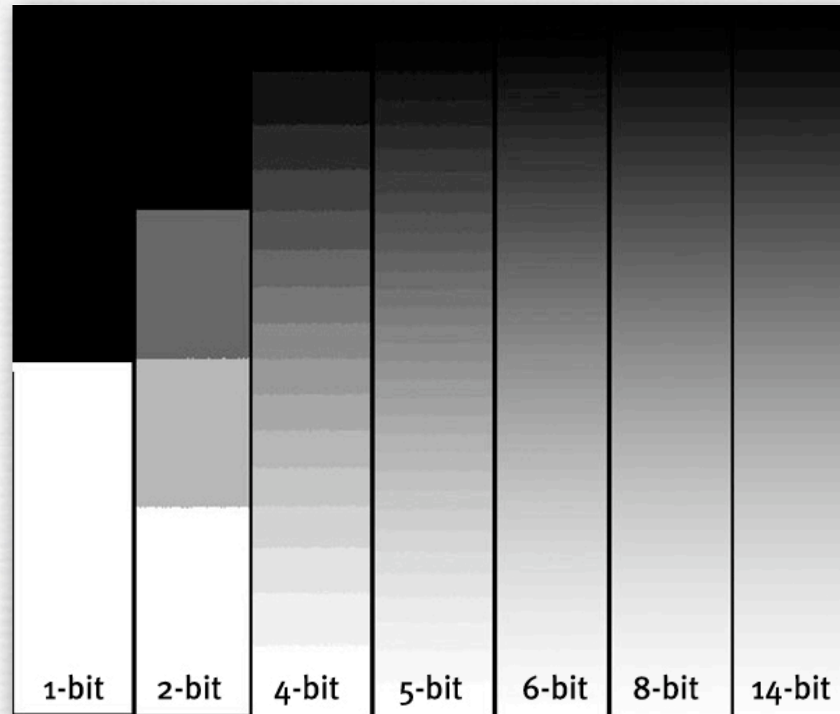
RAW file, "linear" option: pixel value ∝ scene luminance (Marc Levoy)

Sampling versus quantization



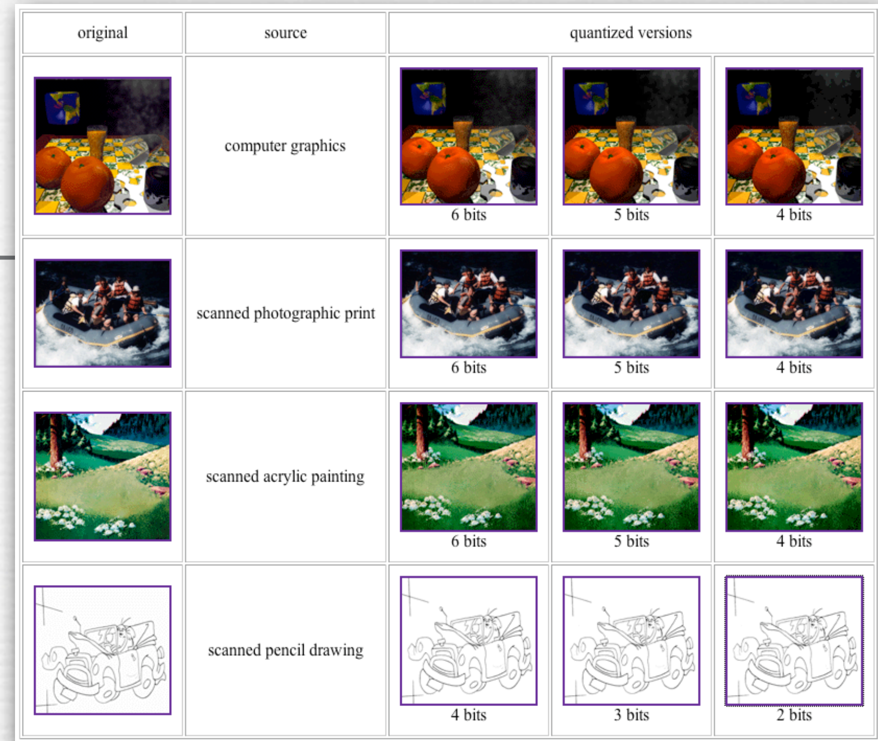
(http://learn.hamamatsu.com/articles/digitalimagebasics.html)

(Canon)



- an image is a function $\vec{f}(\vec{x})$
  - typically $(\vec{x}) = (x, y)$ and $\vec{f} = (R, G, B)$
- we sample the domain $(\vec{x})$ of this function as pixels
- we quantize the range $\vec{f}$ of this function as intensity levels

Examples



original	source	quantized versions		
	computer graphics	6 bits	5 bits	4 bits
	scanned photographic print	6 bits	5 bits	4 bits
	scanned acrylic painting	6 bits	5 bits	4 bits
	scanned pencil drawing	4 bits	3 bits	2 bits

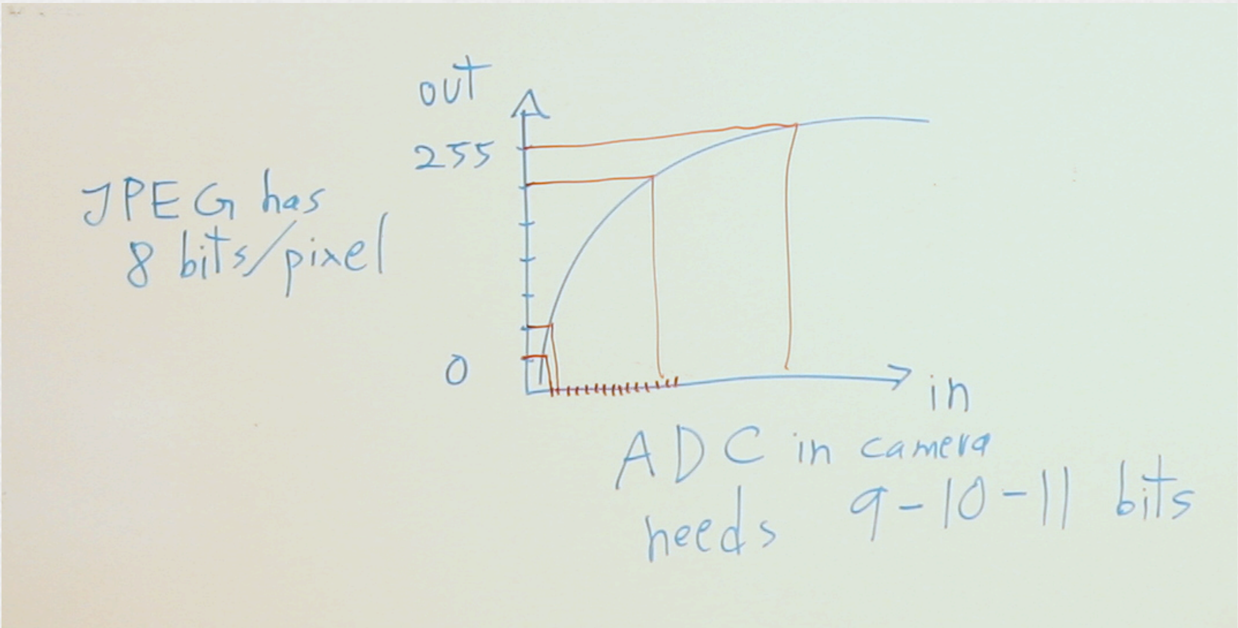
(HTML DEMO)

http://graphics.stanford.edu/courses/cs178-09/demos/demoquant/simplequant.html

- some scenes may require 7-8 bits
  - if they contain smooth gradations of lighting
- displays typically require 8-10 bits
  - to allow non-linear mapping (gamma correction) before display
- good cameras typically offer 10-14 bits
  - to capture high dynamic range (HDR) scenes
  - to provide latitude for metering errors by photographer
  - to allow non-linear tone mapping (including gamma) before storing

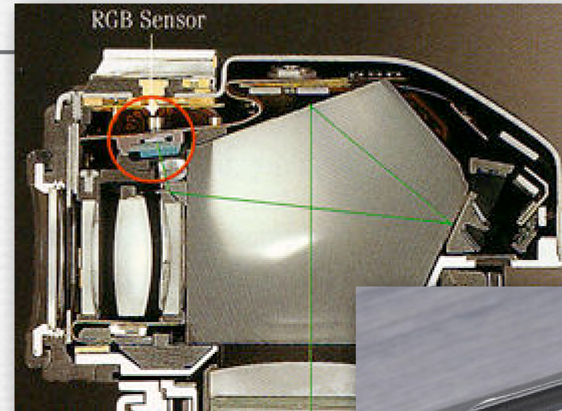
Input needs more bits than output

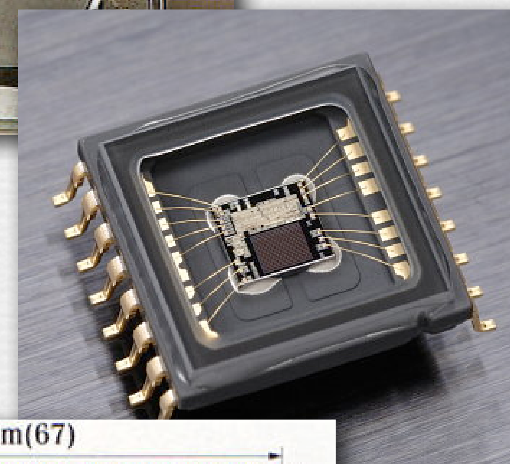
- input needs more bits than output if you plan to apply a non-linear transformation
- example: since JPEG files only store 8 bits/pixel, the camera should output ~10 bits; otherwise, dark regions will exhibit banding after applying output = input$^{1/2}$ and requantizing (integerizing) in the camera's processor

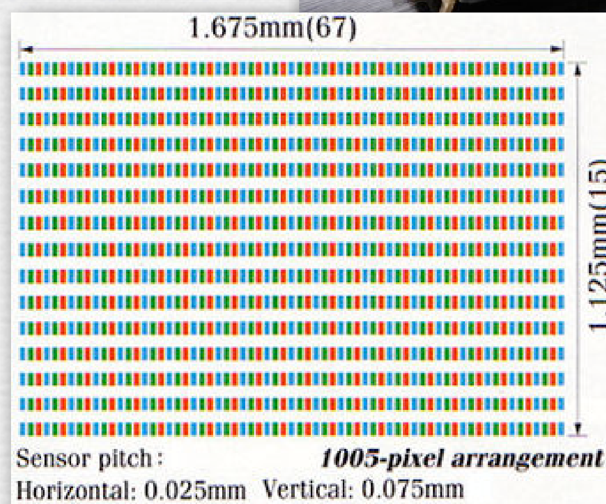


Metering technologies

- SLRs use a low-res sensor looking at the focusing screen
  - Nikon: 1005-pixel RGB sensor
  - Canon: silicon photocell (SPC) with 35 B&W zones
  - big pixels, so low res, but wide dynamic range (Canon=20 bits)
- point-and-shoots use the main image sensor
  - small pixels, so easily saturated
  - if saturated, reduce exposure time and try again
- both are through the lens (TTL)







(http://steves-digicams.com & http://mir.com.my)

Low resolution makes metering hard

- What's this scene? What should the exposure be?

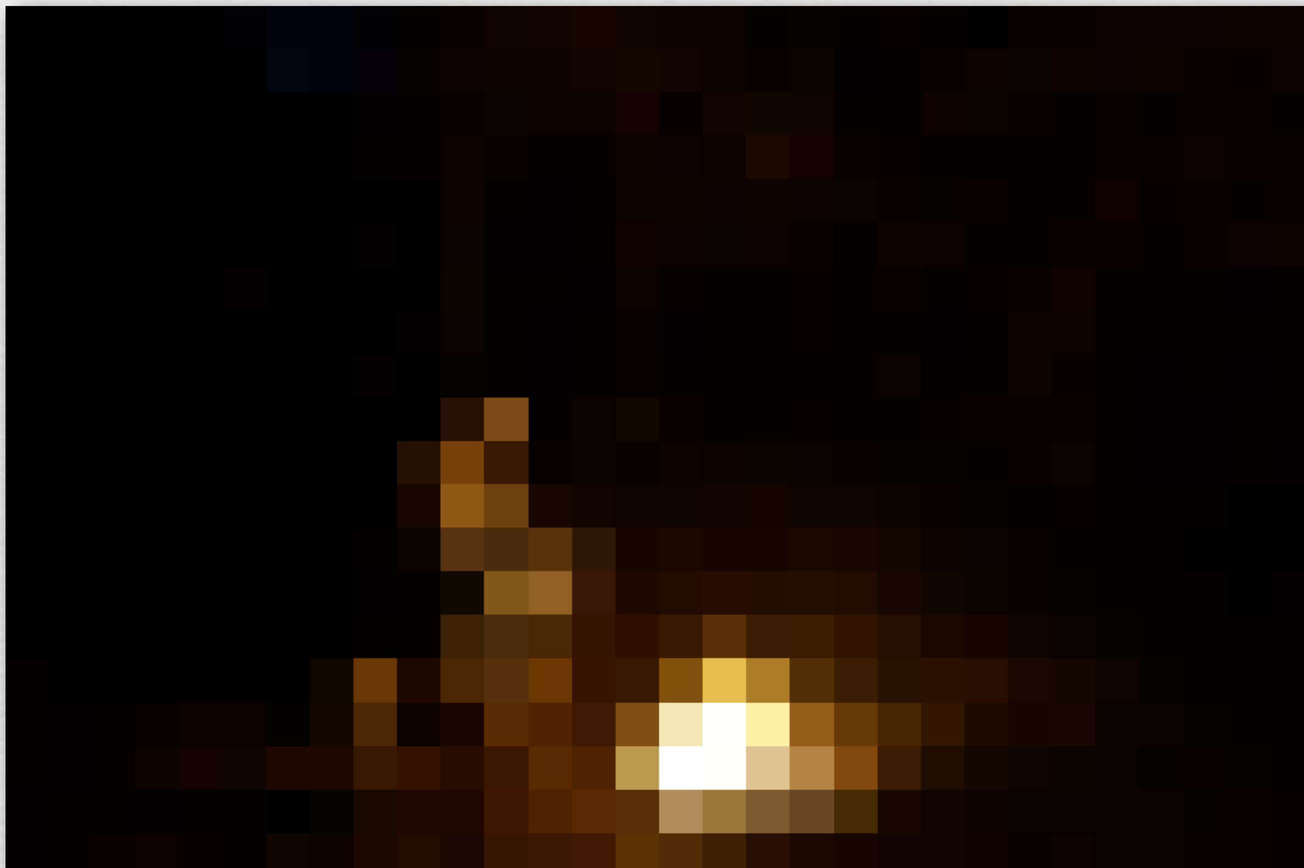
Low resolution makes metering hard

- What's this scene? What should the exposure be?

(Marc Levoy)

Low resolution makes metering hard

- How about this scene?
  Should the bright pixels be allowed to saturate?



Nikon: 1005 color pixels

Low resolution makes metering hard

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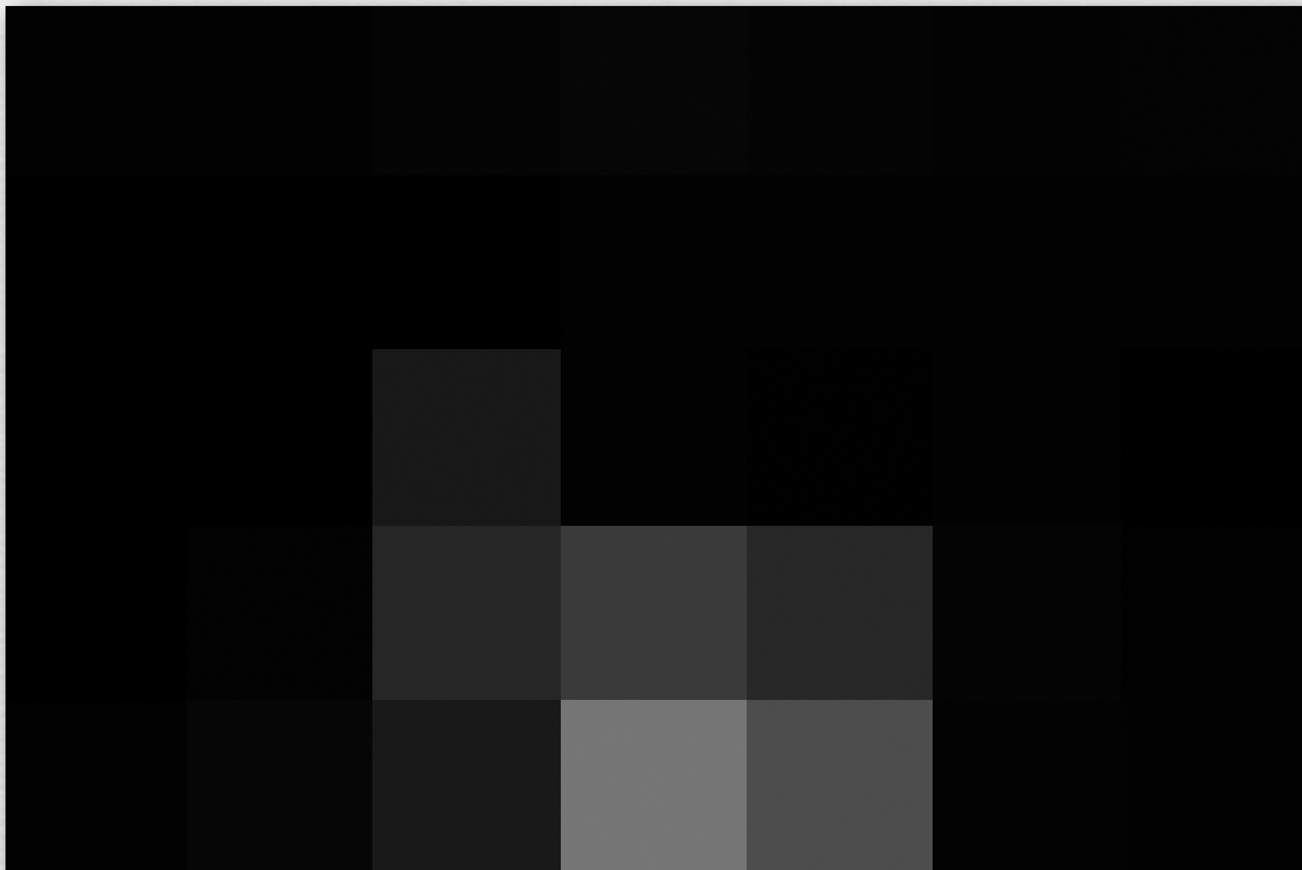

Canon: 35
B&W zones

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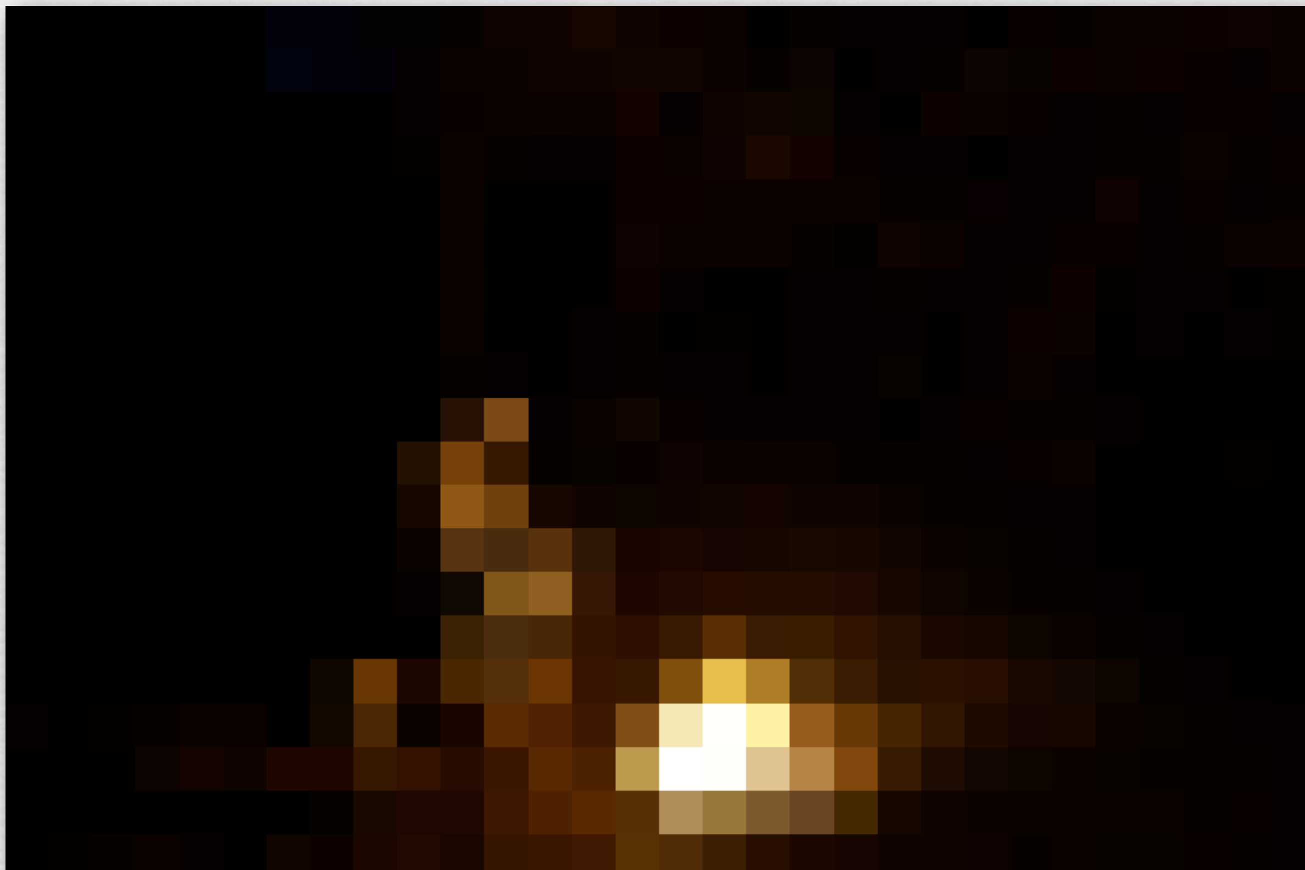


Nikon: 1005 color pixels

Low resolution makes metering hard

- How about this scene?
  Should the bright pixels be allowed to saturate?

(Andrew Adams)

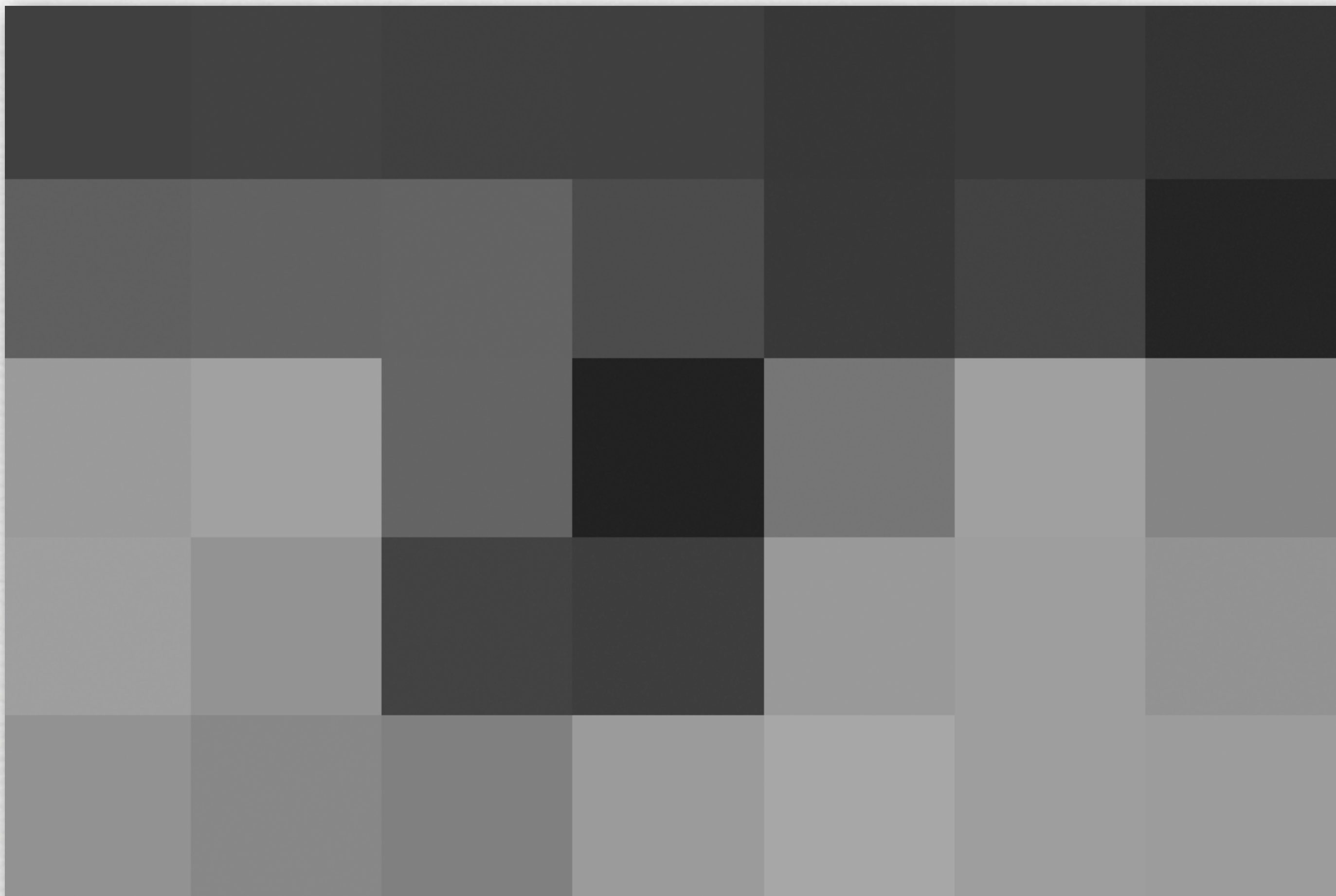
Low resolution makes metering hard

- What about the bright pixel in this scene?

Nikon: 1005 color pixels

Low resolution makes metering hard

- What about the bright pixel in this scene?



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Low resolution makes metering hard

- What about the bright pixel in this scene?

Nikon: 1005 color pixels

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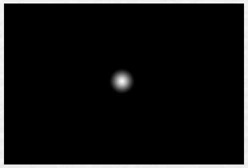
(Marc Levoy)

Metering modes

- center-weighted average

- spot (3.5% of area on Canon)



- evaluative
  - learn from database of images
  - decision may depend on brightness from each zone, color (Nikon), local contrast, spatial arrangement of zones, focusing distance
  - decision affected by camera mode (Portrait, Landscape,...)

- face detection
- future?
  - object recognition, personalization based on my shooting history or online image collections, collaborative metering

Shooting modes

- Aperture priority (Av)
  - photographer sets aperture (hence depth of field)
  - camera sets shutter speed
- Shutter priority (Tv)
  - photographer sets shutter speed (hence motion blur)
  - camera sets aperture
- Program (P)
  - camera decides both
  - photographer can trade off aperture against shutter speed with a dial
- Manual (M)
  - photographer decides both (with feedback from meter)
- Auto
  - camera decides both
  - photographer can't make stupid mistakes

Other modes

- exposure compensation
  - tells camera to under/over-expose by specified # of f/stops
  - don't forget to reset it to zero when you're done!
- exposure lock (a.k.a. AE lock)
  - freezes exposure
  - pressing shutter button halfway only focuses
- exposure bracketing
  - takes several pictures a specified number of f/stops apart

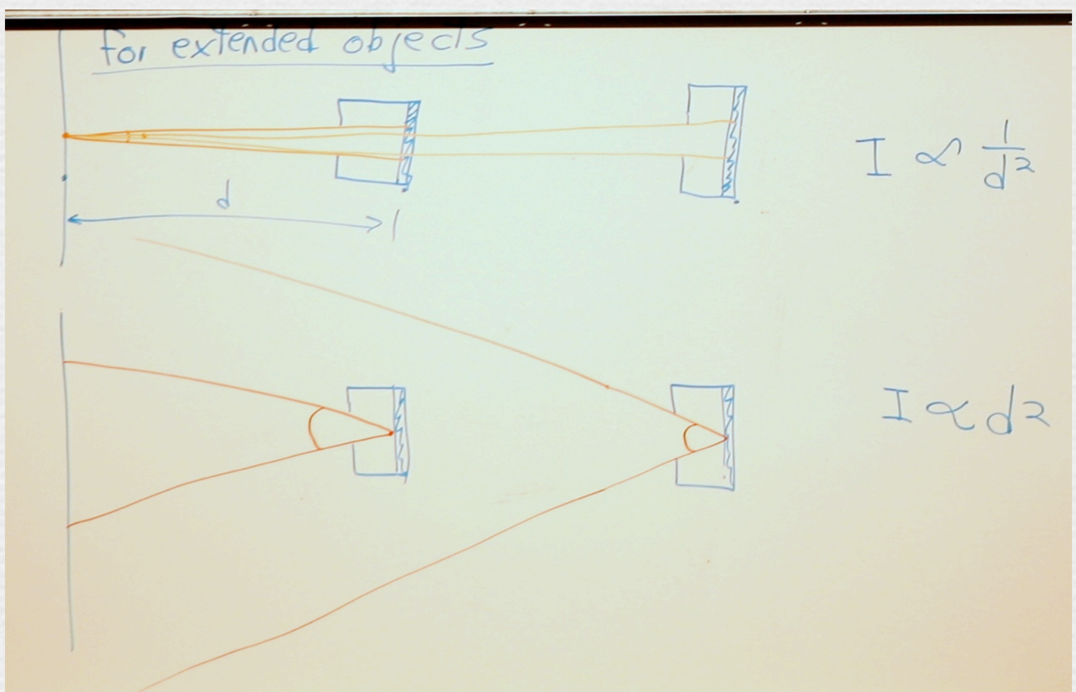
Handheld light meters

- less important in digital photography, because we can review photographs, adjust the exposure, and reshoot

Q. What happens to the reading on a light meter as you walk towards the subject?

Handheld light meters

- for tiny objects (i.e. objects that don't fill a pixel), intensity in that pixel falls off as the square of the light meter's (or camera's) distance from the object
- for large ("extended") objects, meaning objects that cover a pixel even when viewed from afar, the area of that object seen by the pixel grows as the square of distance; this exactly offsets the previous falloff, so the meter reading (and the intensity of that pixel in any photograph you take of the extended object) is independent of distance; otherwise, light meters would be useless



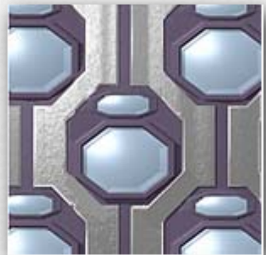
High dynamic range (HDR) imaging

- step 1: capturing HDR images
- step 2a: direct display of HDR images, or
- step 2b: tone mapping to create an LDR image for display

Capturing HDR images

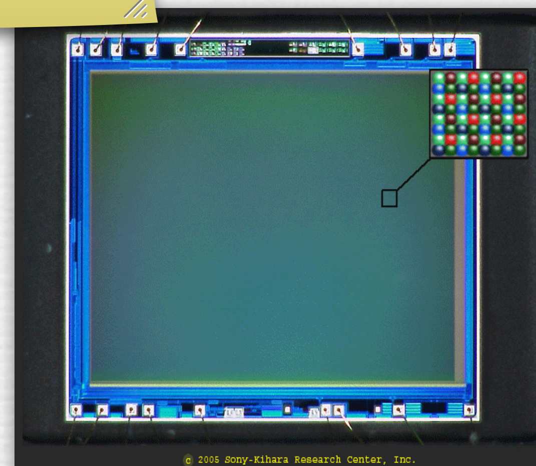
I don't have an answer yet about how Fuji's pixels of different sizes can have different sensitivies to the same photon flux. If anybody knows, please email me.

- assorted pixels

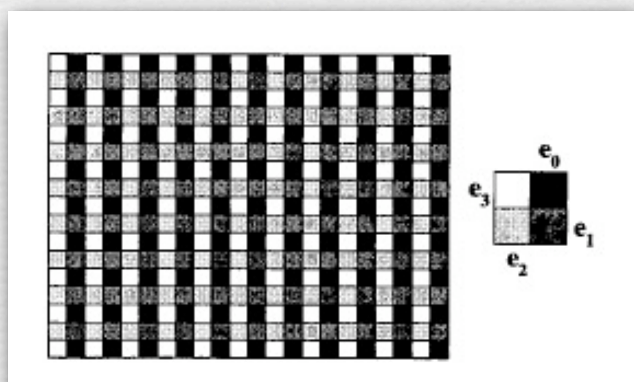


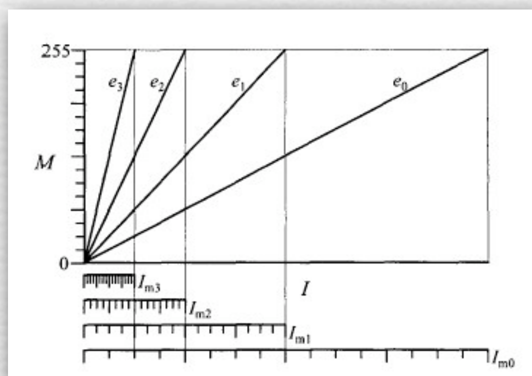
Fuji SuperCCD

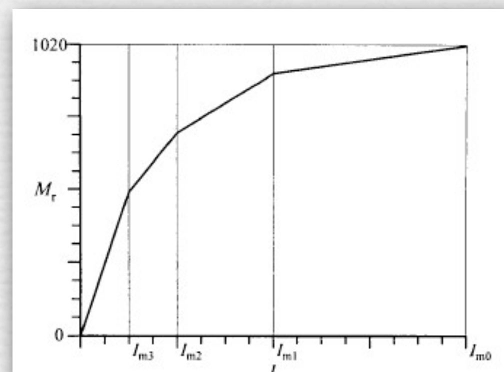
- per-pixel neutral density filters
  [Nayar CPVR 2000]
  - throws away photons
  - trades spatial resolution for dynamic range



Sony

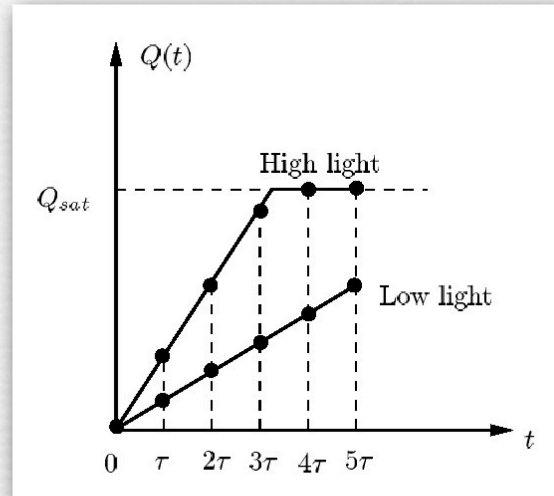






Capturing HDR images

- non-destructive readout of pixels
  [Gamal 1999]
  - measures light by counting time to saturation
  - improves dynamic range,
    but not sensitivity at low end



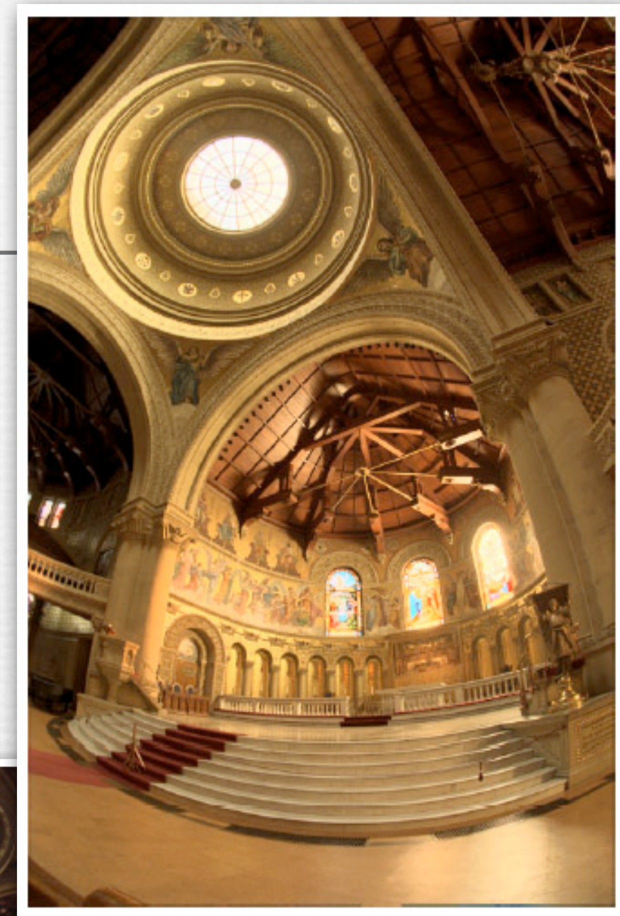
normal

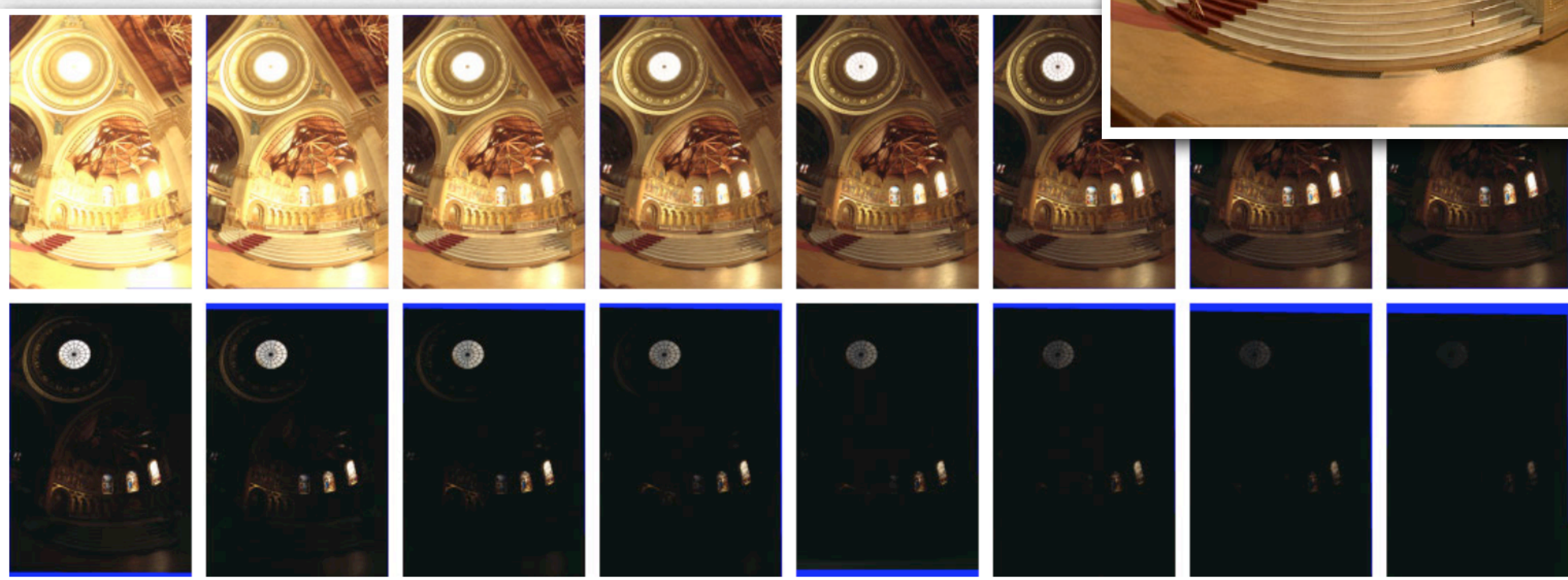
Pixim

Capturing HDR images

- multiple bracketed exposures
  [Debevec SIGGRAPH 1997]
- changing the exposure time is usually better than changing the aperture

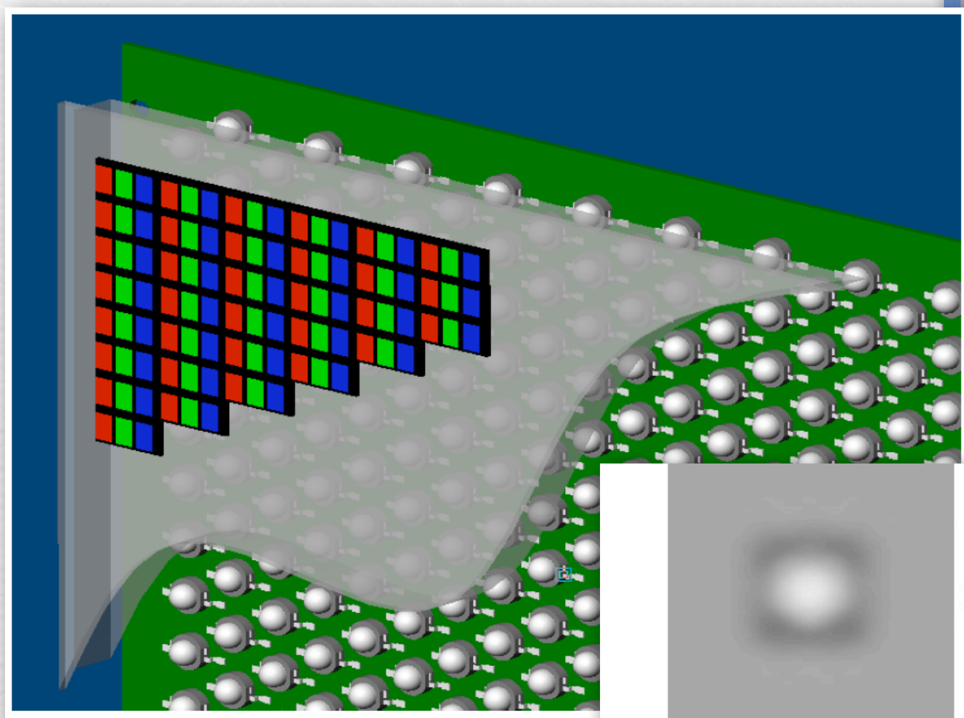
Q. How about changing the ISO?

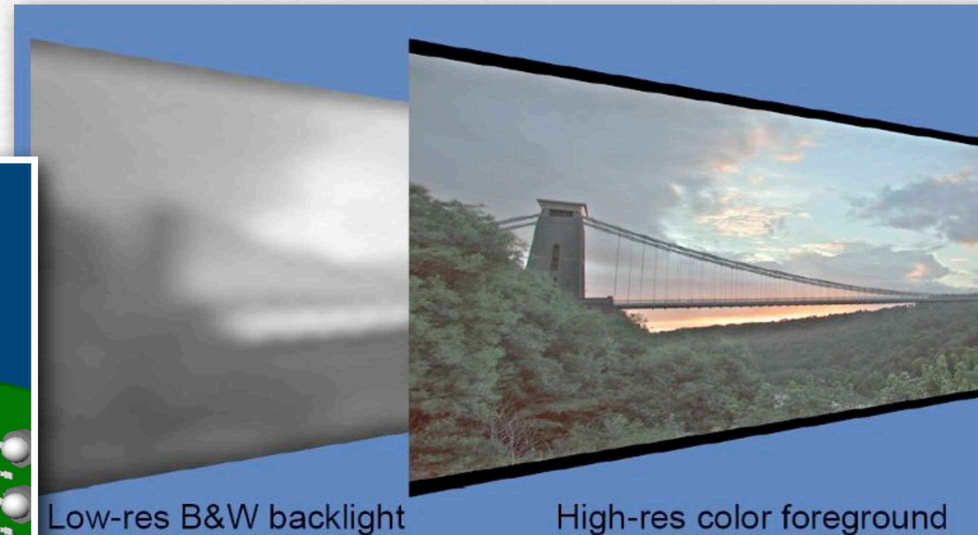


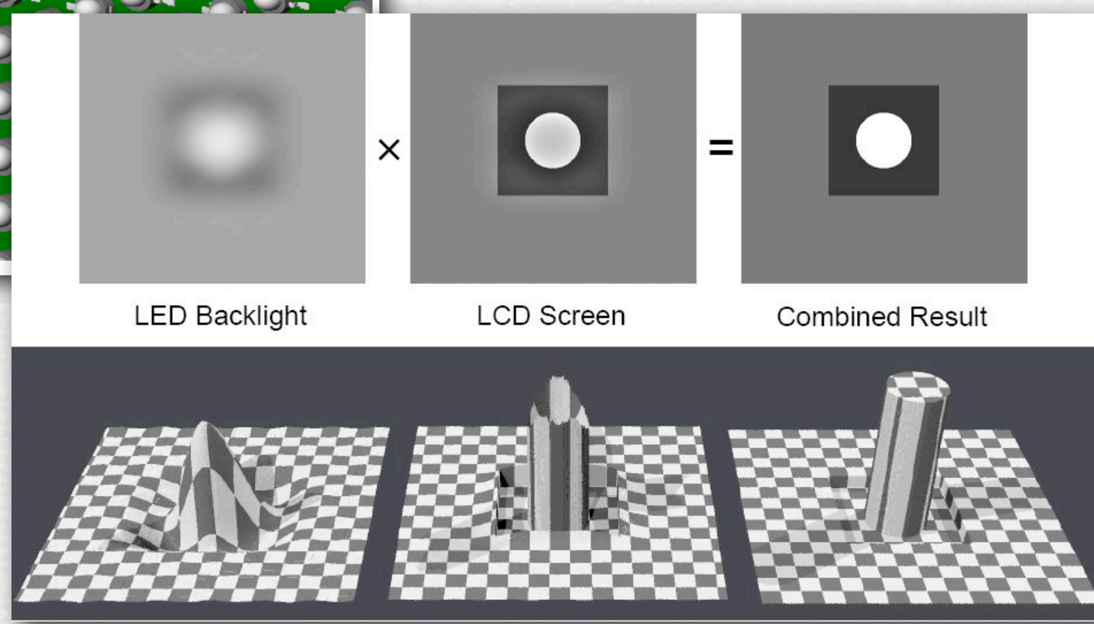


Direct display of HDR images

- Sunnybrook HDR display







Tone mapping to convert HDR to LDR

- sometimes it works, and sometimes it doesn't...

(Marc Levoy)

(Marc Levoy)

(Marc Levoy)

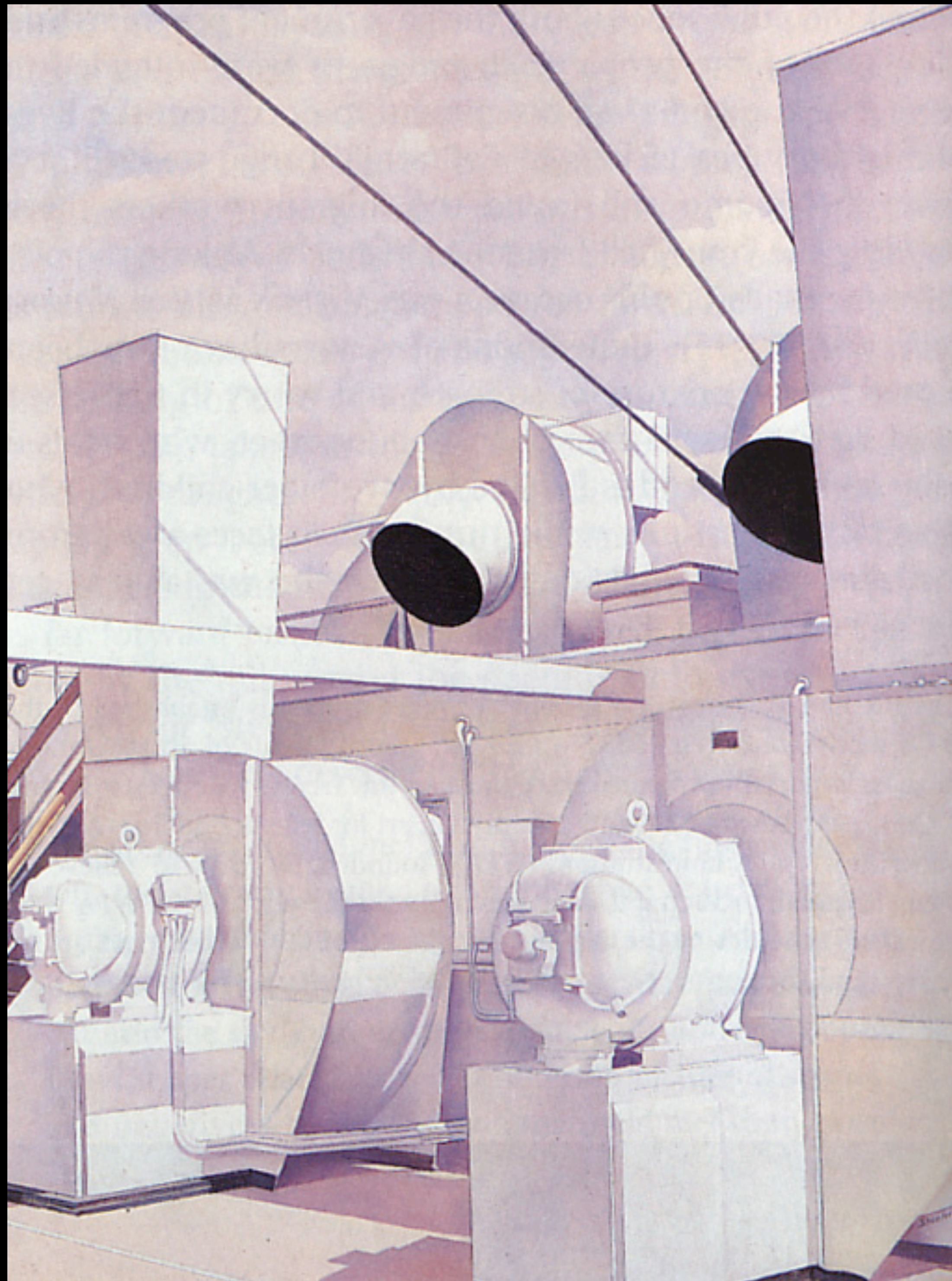
Cathedral,
Valencia

(Marc Levoy)

Cathedral,
Valencia

(Marc Levoy)

How do artists solve the tone mapping problem?



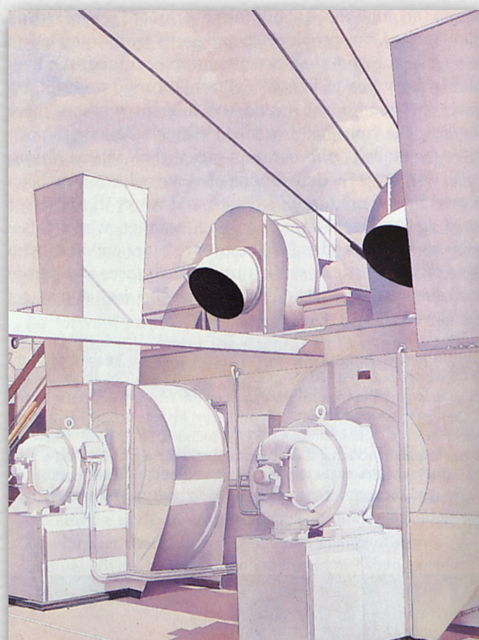
Charles Sheeler,
The Upper Deck
(1929)

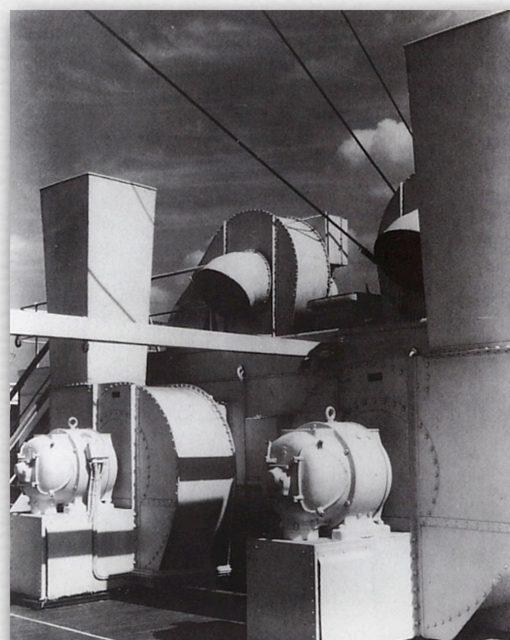
Joseph Wright, The Orrery (1765)

How do artists solve the tone mapping problem?

- for bright scenes
  - human vision is dazzled, compressing brightnesses
- for dark scenes
  - shadows are below threshold, so completely black

Hermann von Helmholtz
(1821-1894)
"The relation of optics to painting"





(Gardner)

To be continued...

Slide credits

- Andrew Adams
- Fredo Durand

- London, Stone, and Upton, *Photography* (ninth edition), Prentice Hall, 2008.
- Tanser and Kleiner, *Gardner's Art Through the Ages* (10th ed.), Harcourt Brace, 1996.
- Rudman, T., *Photographer's Master Printing Course*, Focal Press, 1998.
- Adams, A., *The Print*, Little, Brown and Co., 1980.