Exposure metering (AE)

CS 178, Spring 2010

I added two recap slides after the lecture. You are responsible for metering on the midterm, but not HDR imaging.

I also adjusted the midterm review slides to reduce coverage of gamma correction, since I didn't fully cover it during this lecture.

Good luck on your midterm!

Marc Levoy
Computer Science Department
Stanford University

Outline: metering

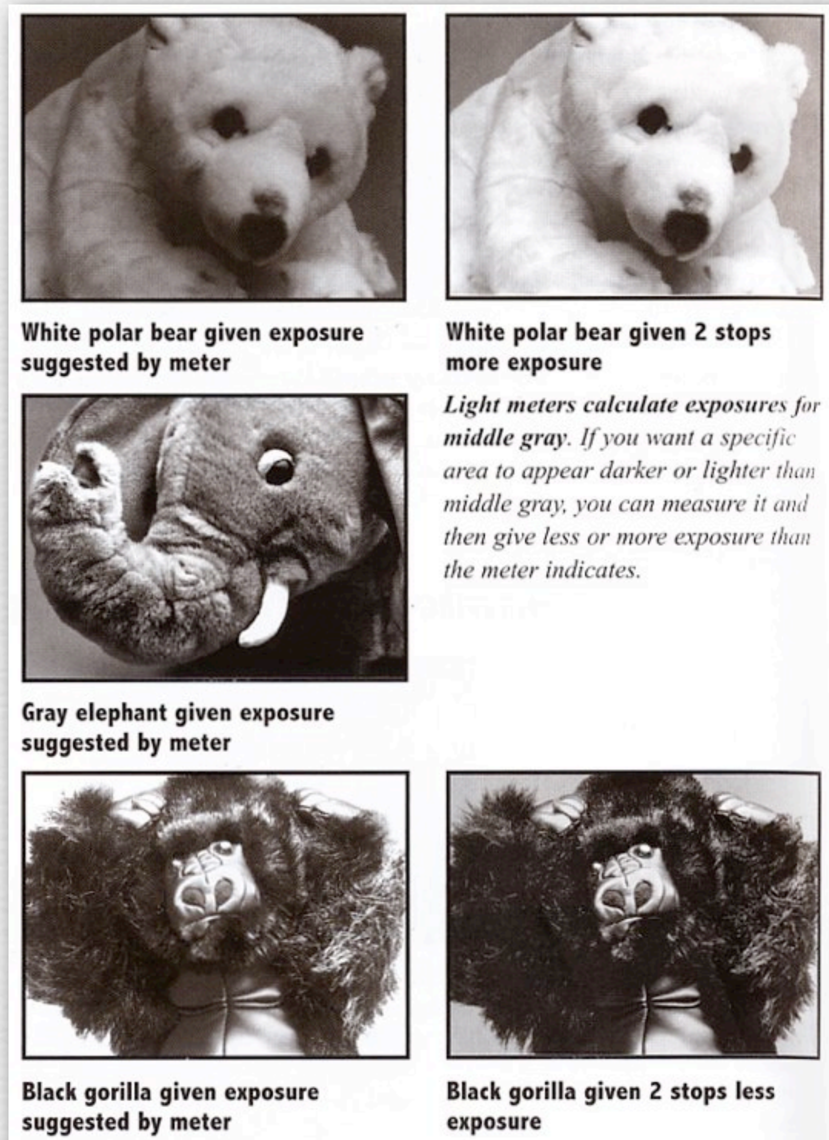
- What makes metering hard?
  - the meter doesn't know what you're looking at
  - the dynamic range problem
- background topics
  - Ansel Adams' zone system
  - gamma and gamma correction
- metering technologies
- metering modes (center, evaluative,...)
- shooting modes (Av, Tv, P, M)
- exposure compensation, etc.
- high dynamic range (HDR) imaging

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...


White polar bear given exposure suggested by meter

White polar bear given 2 stops more exposure

Light meters calculate exposures for middle gray. If you want a specific area to appear darker or lighter than middle gray, you can measure it and then give less or more exposure than the meter indicates.

Gray elephant given exposure suggested by meter

Black gorilla given exposure suggested by meter

Black gorilla given 2 stops less exposure

(http://fotocommunity.de)

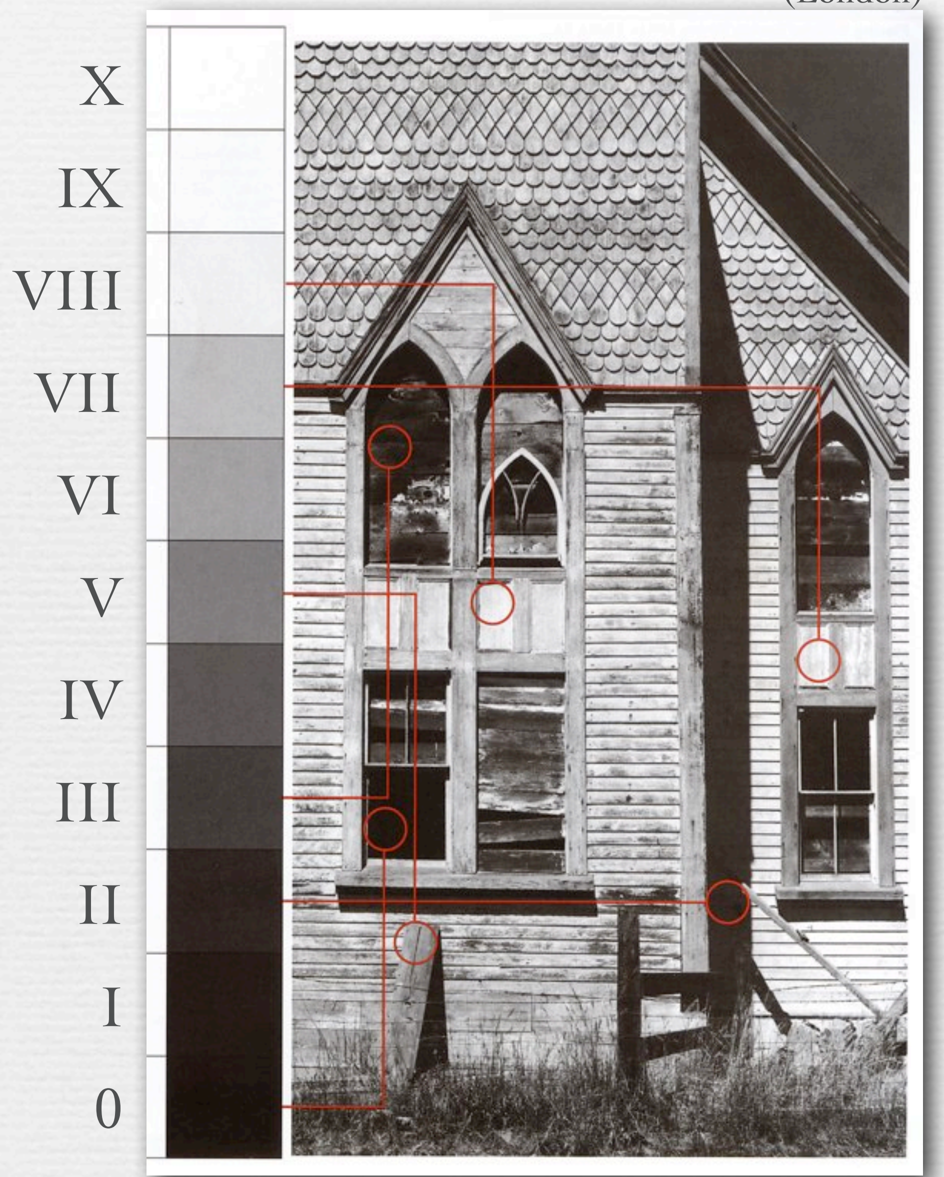
Ansel Adams's zone system

(London)

- 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



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**

Illuminated by sun versus by moon

1/500s, f/6.3, ISO 100

8s, f/1.7, ISO 400

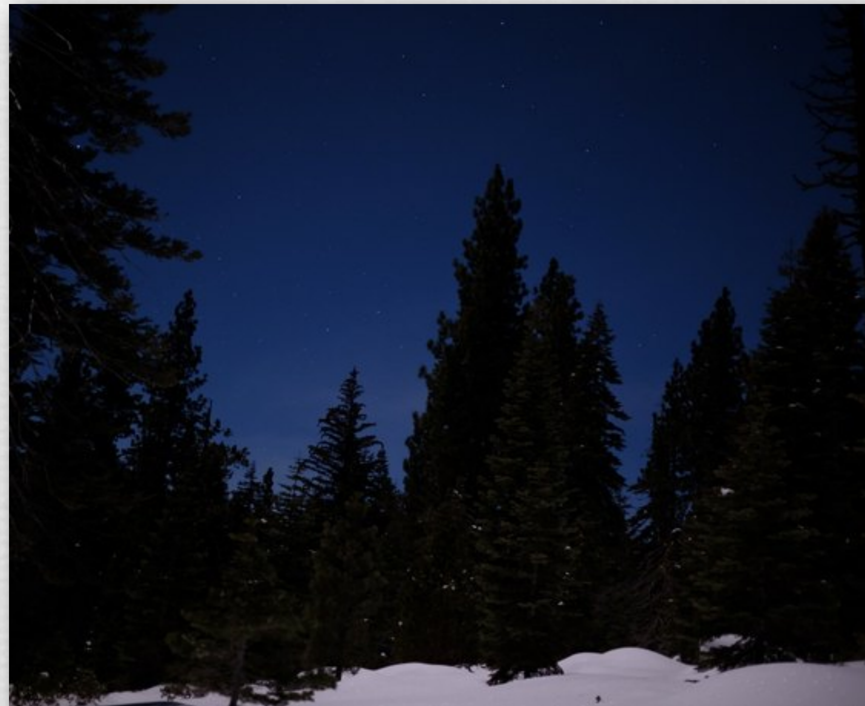
- total difference in shooting settings = 256,000:1
- luminance of snow pixels (in RAW file) differ by another ~2×

Illuminated by sun versus by moon

RAW file

1/500s, f/6.3, ISO 100

RAW file



8s, f/1.7, ISO 400

- total difference in shooting settings = 256,000:1
- luminance of snow pixels (in RAW file) differ by another ~2×
- JPEG value = $(\text{RAW value} / 65536)^{1/\gamma} \times 255$, where $\gamma = 2.2$

Illuminated by sun versus by moon

JPEG file

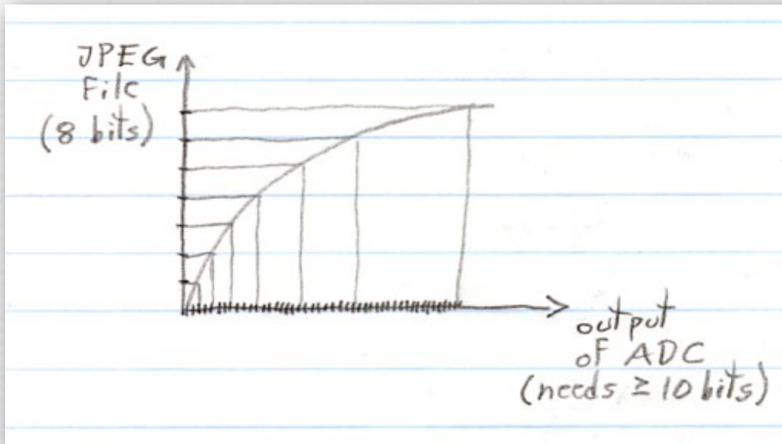
1/500s, f/6.3, ISO 100

JPEG file

8s, f/1.7, ISO 400

- total difference in shooting settings = 256,000:1
- luminance of snow pixels (in RAW file) differ by another ~2×
- JPEG value = (RAW value / 65536)$^{1/\gamma}$ × 255, where γ = 2.2

ADC must output more bits than JPEG stores (contents of whiteboard)



- converting from ADC values (as stored in a RAW file) to the values stored in a JPEG file includes a tone mapping transformation
- this transformation is typically non-linear and includes a step called *gamma mapping*, which has the form $output = input^{\gamma}$ $(0.0 \leq input \leq 1.0)$
- since JPEG files only store 8 bits/pixel for each color component, for a scene consisting of a smooth gray ramp to fill each of these 256 buckets, the camera's ADC needs to output ≥ ~10 bits
- otherwise, dark parts of the ramp will exhibit banding after applying gamma mapping and requantizing (integerizing)

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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)

20:1	photographic print (higher for glossy paper)
50:1	artist's paints
200:1	slide film
256:1	JPEG file (8 bits for each of Y'UV)
500:1	negative film
1000:1	LCD display
4000:1	digital SLR (~12 bits)

- challenges
  - choosing which 12 bits of the world to capture on your sensor
  - metering the world to help you make this decision, since the world has more dynamic range than the sensor can see at once
  - compressing 12 bits into 5 bits for print, or 8 for JPEG
    - this is the *tone mapping* problem

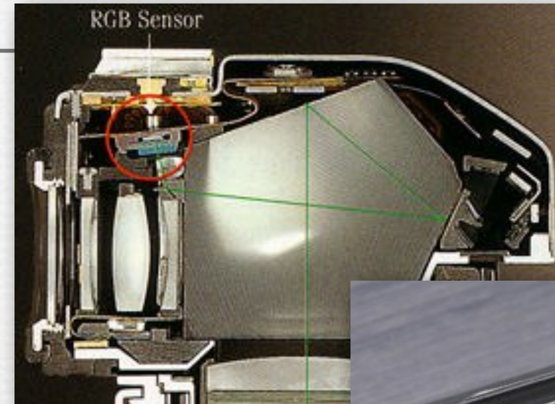
Recap

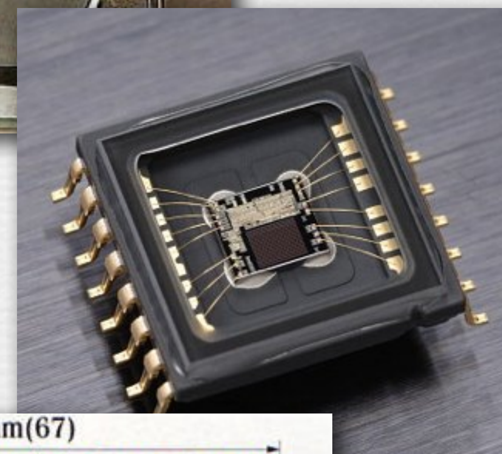
- automatic metering is hard
  - the camera doesn't know how bright objects really are, hence where in the image intensity range to place them
  - the camera's main sensor can't see the world's dynamic range at once
- the dynamic range problem
  - the dynamic range of the real world is large (80M:1)
  - the dynamic range humans can see is also large (100M:1)
  - the dynamic range of reproduction media is small (100's:1)
  - the range of cameras is somewhere in the middle (1000's:1)
  - so cameras can't see the whole world's range at once, and they must compress the range they do see for reproduction
- you can use image intensities to compare scene brightnesses, but only before the non-linear RAW → JPEG gamma mapping

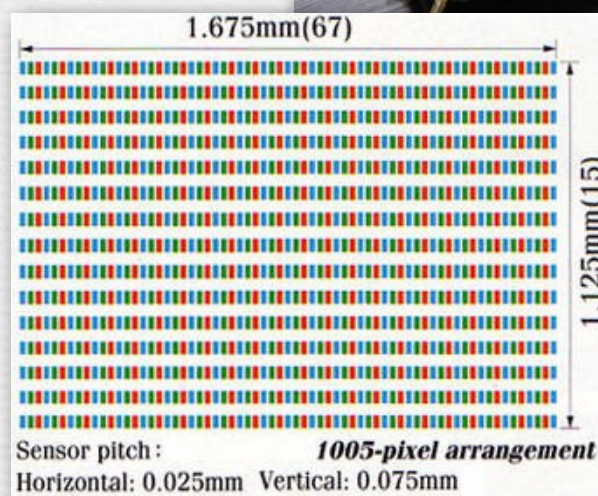
Questions?

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?

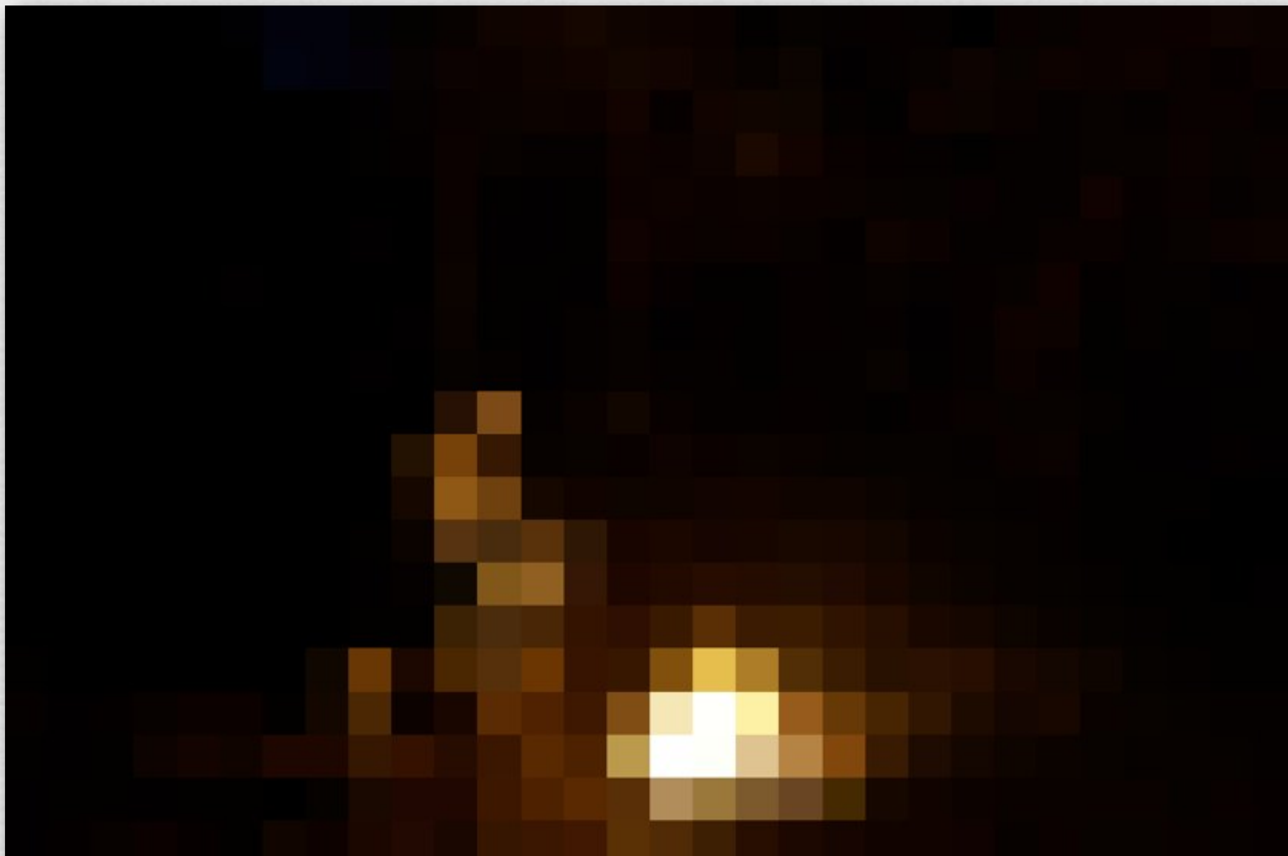
Low resolution makes metering hard

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

(Marc Levoy)

Low resolution makes metering hard

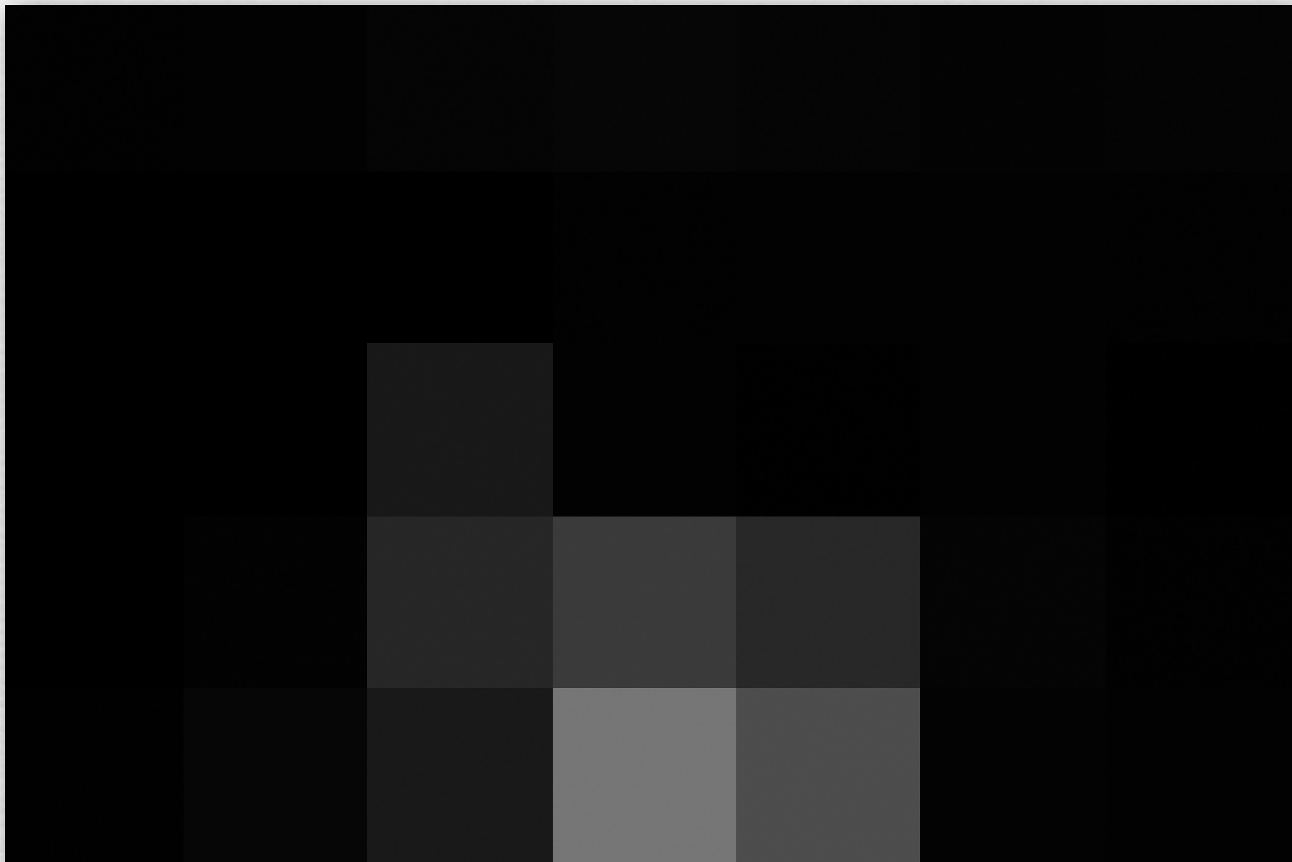
- How about this scene?
  Should the bright pixels be allowed to saturate?



Nikon: 1005 color pixels

Low resolution makes metering hard

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



Canon: 35
B&W zones

Low resolution makes metering hard

- How about this scene?
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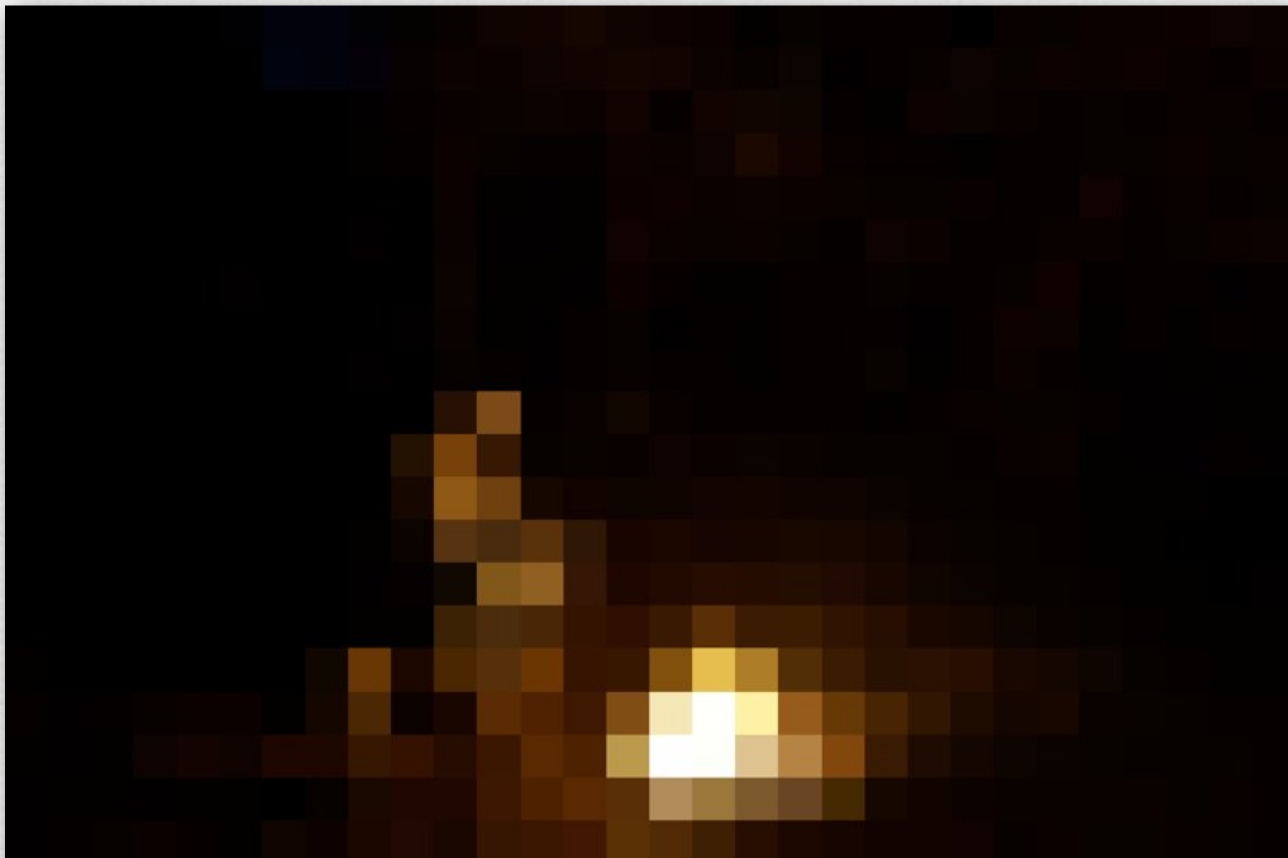


Nikon: 1005 color pixels

Low resolution makes metering hard

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

(Andrew Adams)

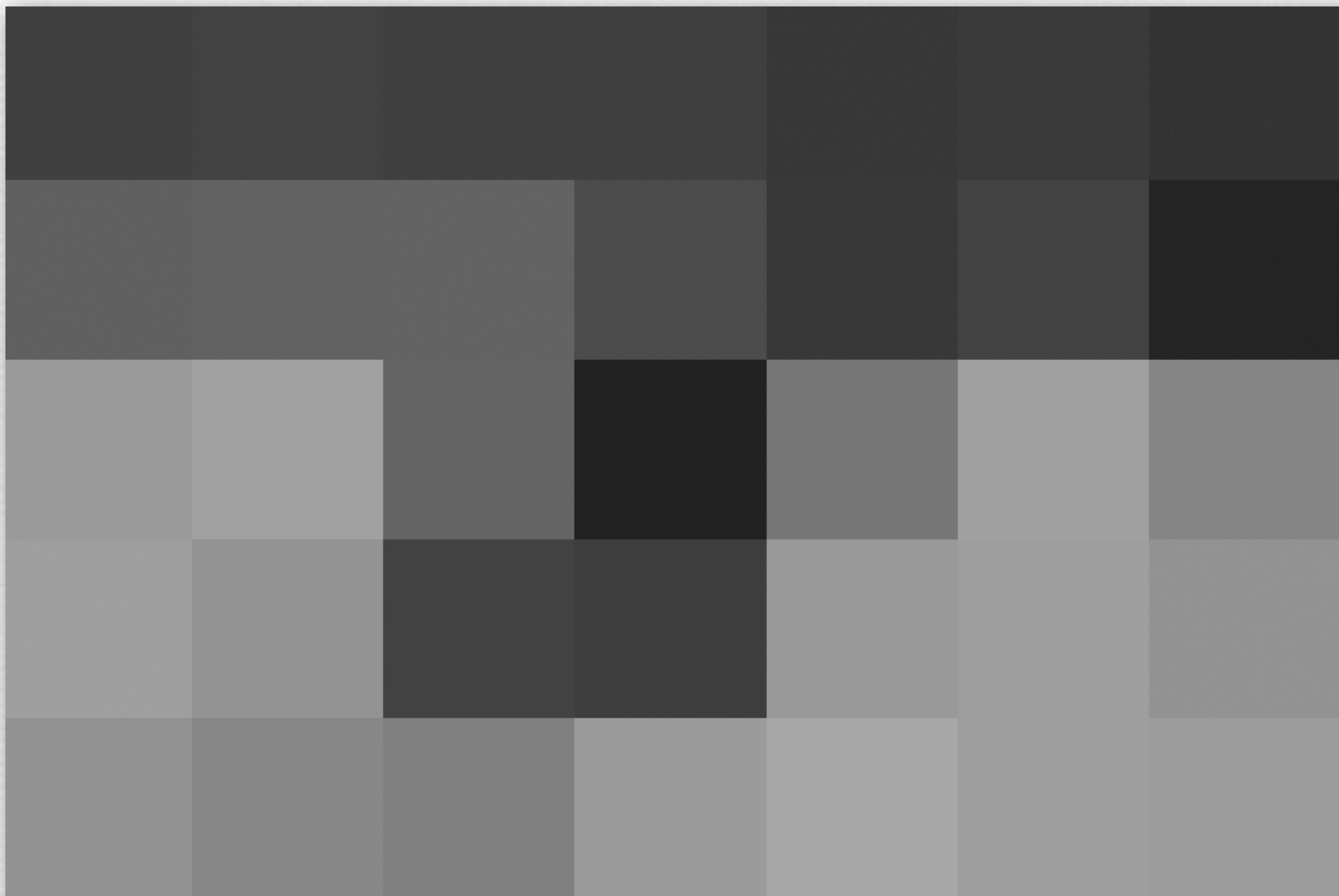
Low resolution makes metering hard

- 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?



Canon: 35 B&W zones

Low resolution makes metering hard

- What about the bright pixel in this scene?

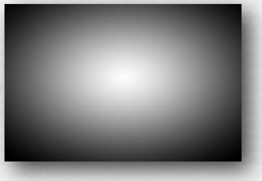
Nikon: 1005
color pixels

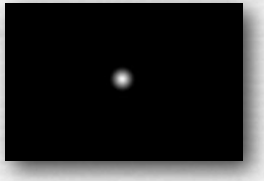
Low resolution makes metering hard

- What about the bright pixel in this scene?

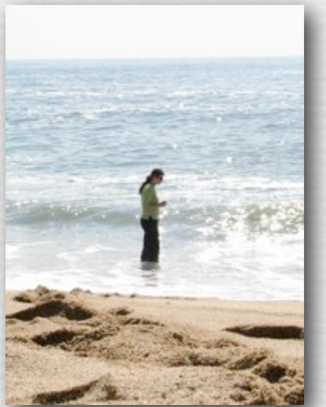
(Marc Levoy)

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, local contrast, spatial arrangement of zones, focus 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 or viewfinder)
- 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
  - use to ensure correct appearance of dark or light subjects
  - 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

Recap

- metering in SLRs is done by a special sensor with big pixels
  - big pixels provide high dynamic range, to allow a one-shot decision
- metering in point-and-shoots is done by the main sensor
  - if the scene is too bright, it must reduce exposure and try again
- metering systems try to “understand” the scene
  - including analyzing focus, placement of objects, camera mode, etc.
  - but their low resolution makes this hard
- cameras offer a range of automatic to manual shooting modes
  - they also allow you to compensate if your object of interest is unusually light (polar bear) or dark (gorilla)

Questions?

High dynamic range (HDR) imaging

- step 1: capturing HDR images
- step 2a: direct display of HDR images, or

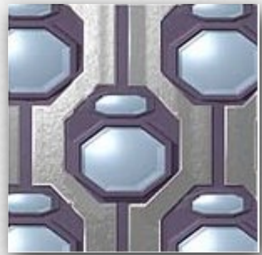
- step 2b: tone mapping to create an LDR image for display

- goals of tone mapping
  - squeeze 12 bits of sensor into 8 bits of JPEG
  - or squeeze >12 of HDR image into 8 bits of JPEG
  - apply gamma mapping (for reasons we'll discuss later)
  - apply mapping for human adaption if scene was very dark
  - or bright...

you're not responsible for HDR imaging on your midterm

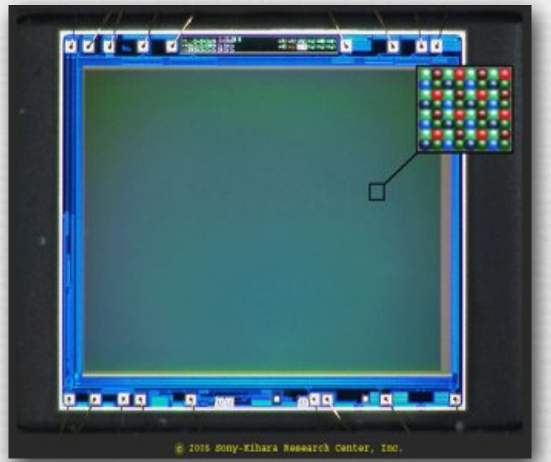
Capturing HDR images

- assorted pixels

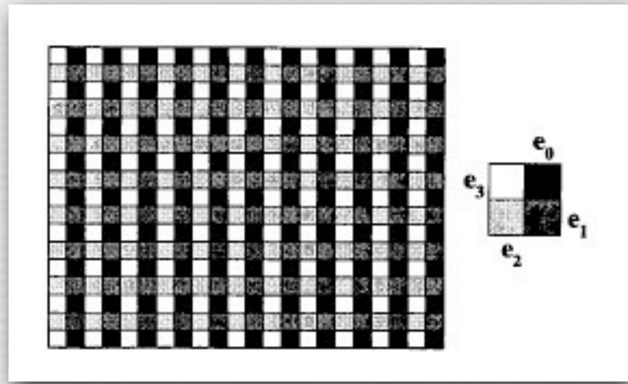


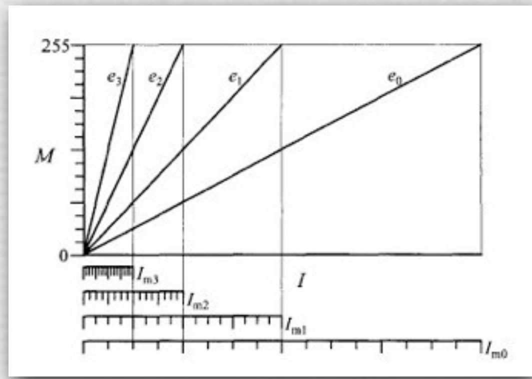
Fuji SuperCCD

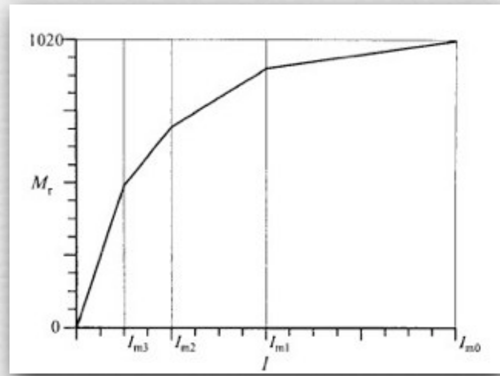
- per-pixel neutral density filters
  [Nayar CPVR 2000]
  - throws away photons
  - trades spatial resolution for dynamic range



Sony







Games with ND filters

1/500s, f/5.6, ISO 800

Games with ND filters

1/125s

Games with ND filters

1/30s

Games with ND filters

1/8s

Games with ND filters

1/2s

Games with ND filters

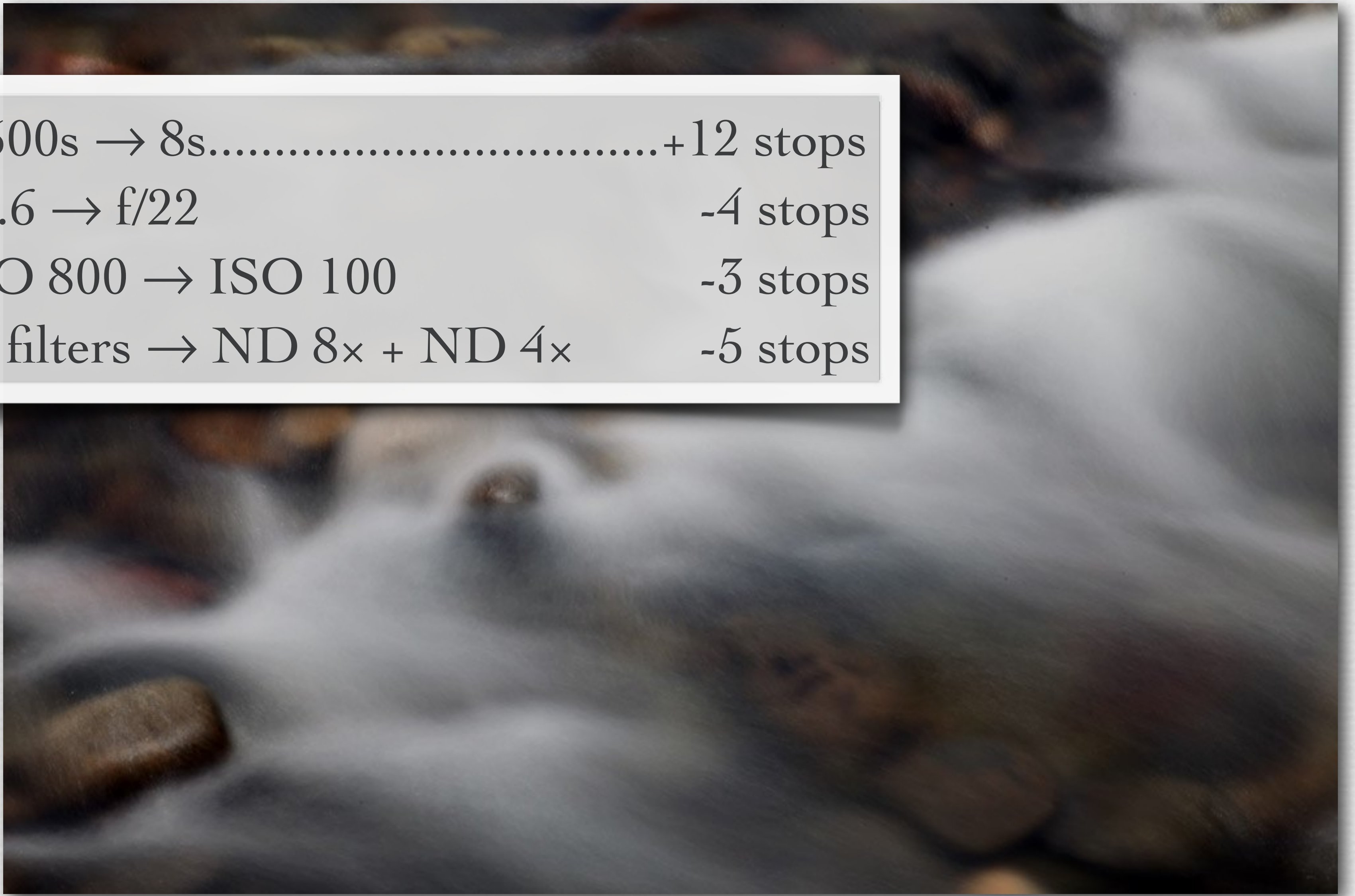
2s

Games with ND filters

8s

Games with ND filters

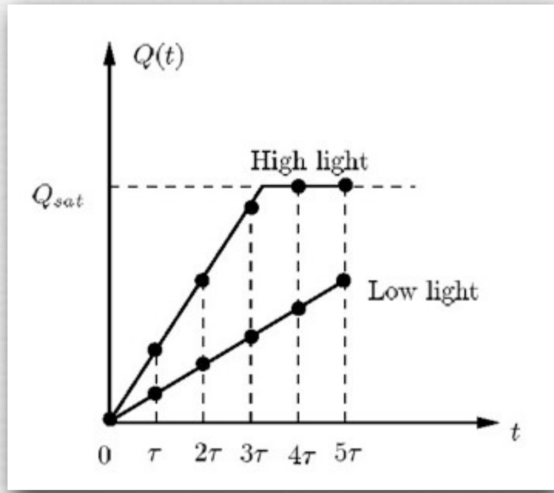
1/500s → 8s	+12 stops
f/5.6 → f/22	-4 stops
ISO 800 → ISO 100	-3 stops
no filters → ND 8× + ND 4×	-5 stops



8s

Capturing HDR images

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



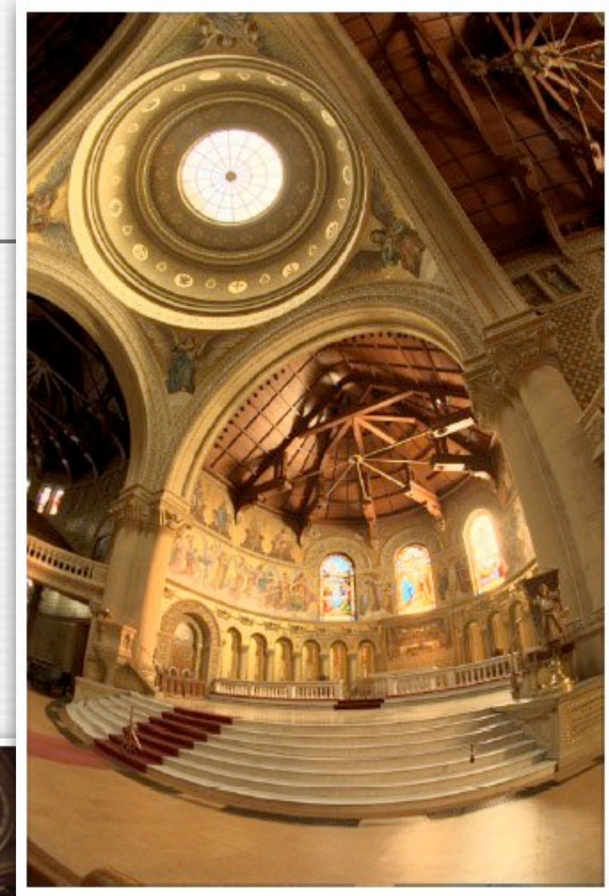
normal

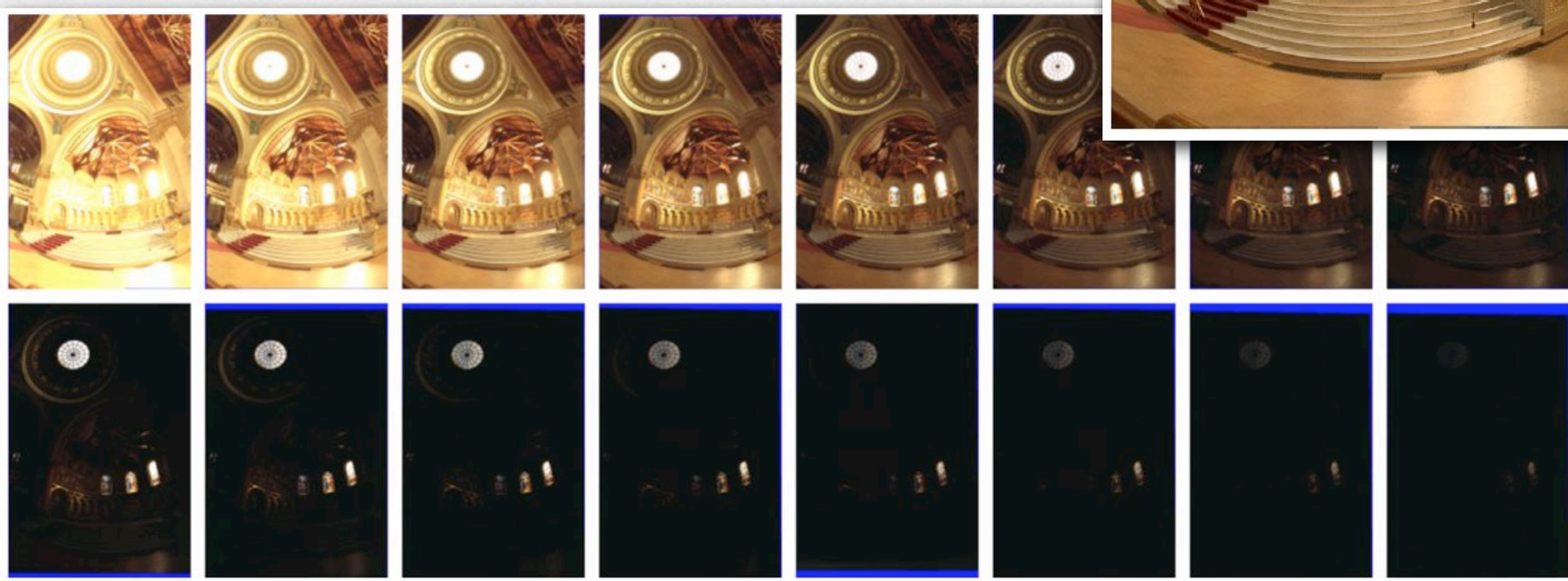
Pixim

Capturing HDR images

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

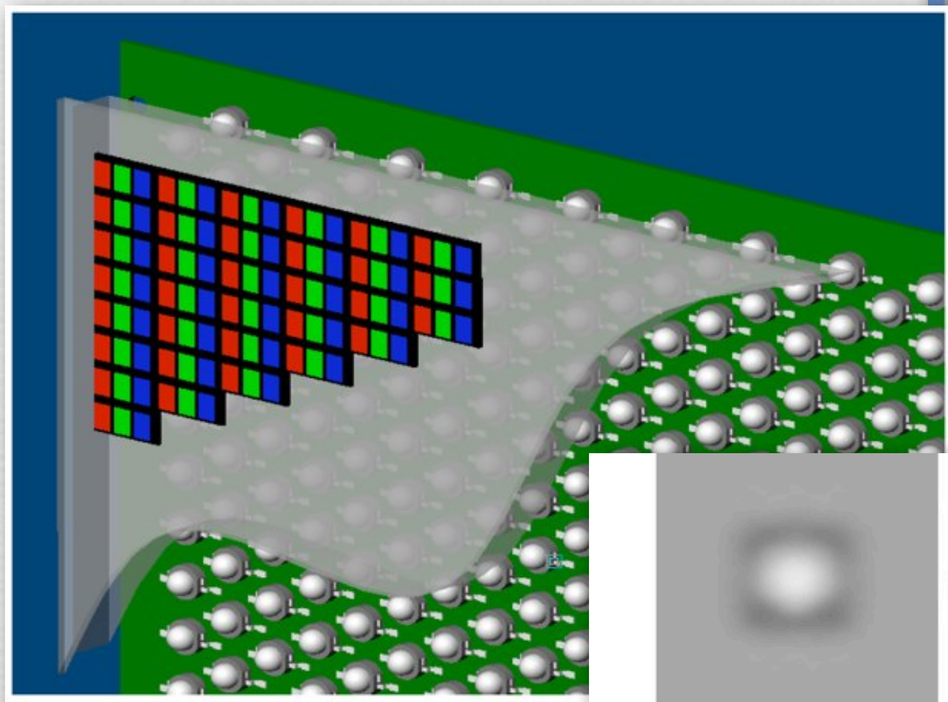
Q. How about changing the ISO?

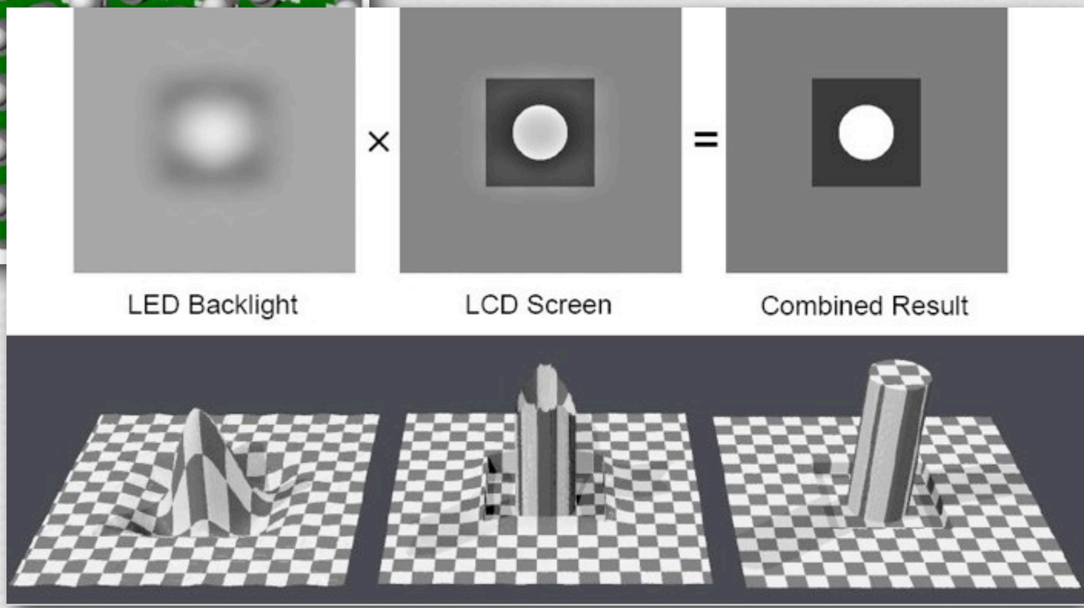




Direct display of HDR images

- Sunnybrook HDR display





In the figure at upper right, note the decomposition into a low-res image that conveys the broad changes in brightness and a high-res image that conveys local details. This kind of two-image decomposition is central to HDR tone mapping algorithms, as we'll see later in the course.

Tone mapping to convert HDR to LDR

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


(Marc Levoy)

(Marc Levoy)

(Marc Levoy)

(Marc Levoy)

(Marc Levoy)

(Marc Levoy)


(Marc Levoy)

Cathedral, Valencia

(Marc Levoy)

Cathedral,
Valencia

(Marc Levoy)

Cathedral,
Valencia

(Marc Levoy)

tone mapping in Photoshop CS4 by exposure and gamma

Cathedral, Valencia

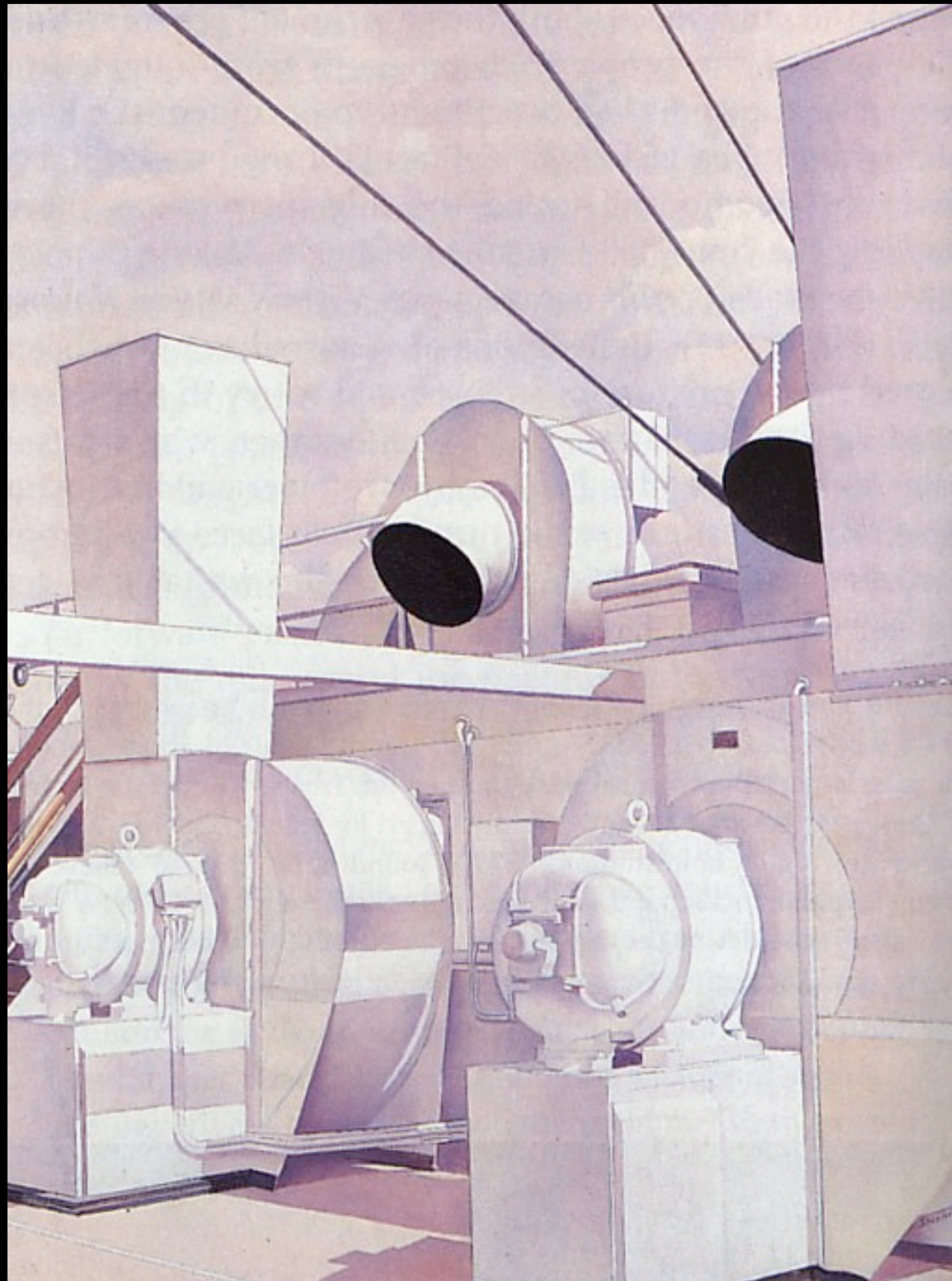
(Marc Levoy)

tone mapping in
Photoshop CS4
by histogram
equalization

Cathedral,
Valencia

(Marc Levoy)

How do artists solve the tone mapping problem?



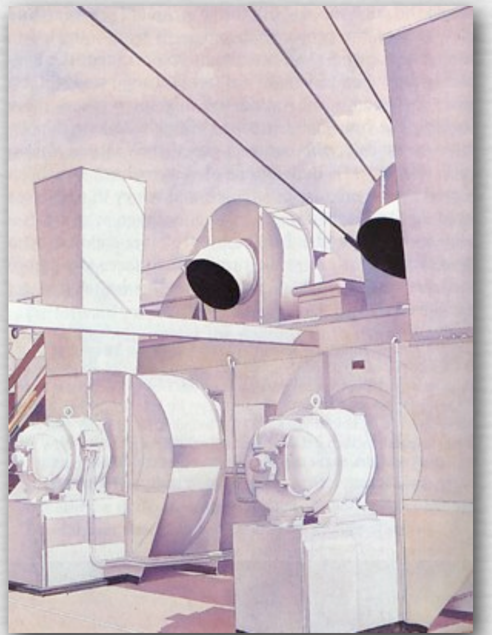
Charles Sheeler,
The Upper Deck
(1929)

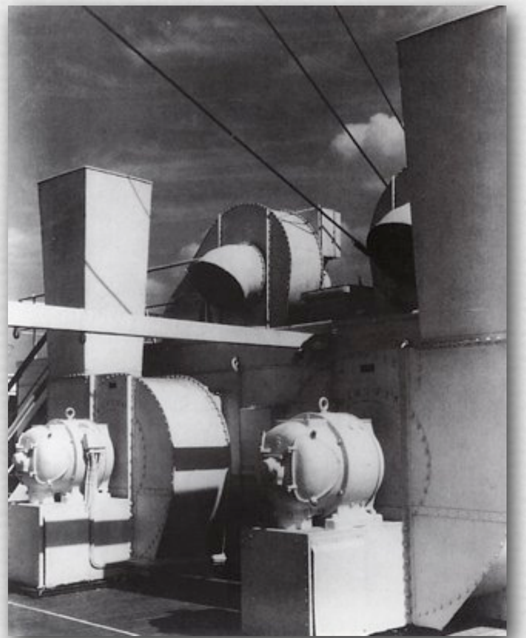
Joseph Wright, The Orrery (1765)

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)

(borrowed from lecture on noise)

Slide credits

We'll continue our discussion of tone mapping, including HDR tone mapping, later in the course.

- Andrew Adams
- Fredo Durand

- London, Stone, and Upton, *Photography* (ninth edition), Prentice Hall, 2008.
- Canon, *EF Lens Work III: The Eyes of EOS*, Canon Inc., 2004.
- Adams, A., *The Print*, Little, Brown and Co., 1980.
- Tanser and Kleiner, *Gardner's Art Through the Ages* (10th ed.), Harcourt Brace, 1996.