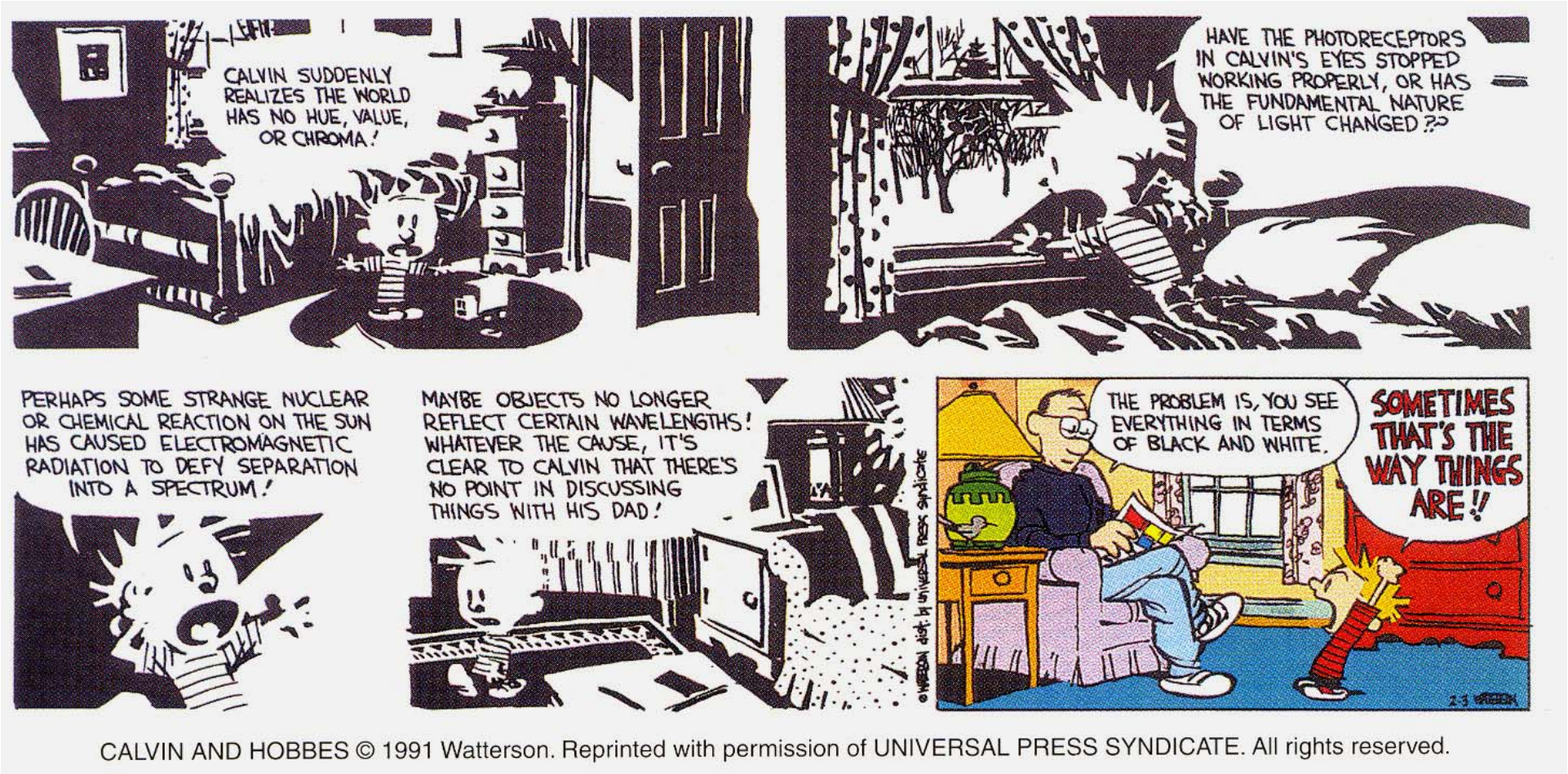
Dynamic Range and Contrast



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6.098 Digital and Computational Photography
6.882 Advanced Computational Photography

Dynamic Range and Contrast

Bill Freeman

Frédo Durand

MIT - EECS

- **Bill is traveling and won't have office hours today.**
- **You can email Ce or Frédo if you have questions or want a meeting.**

Light, exposure and dynamic range

- **Exposure: how bright is the scene overall**
- **Dynamic range: contrast in the scene**

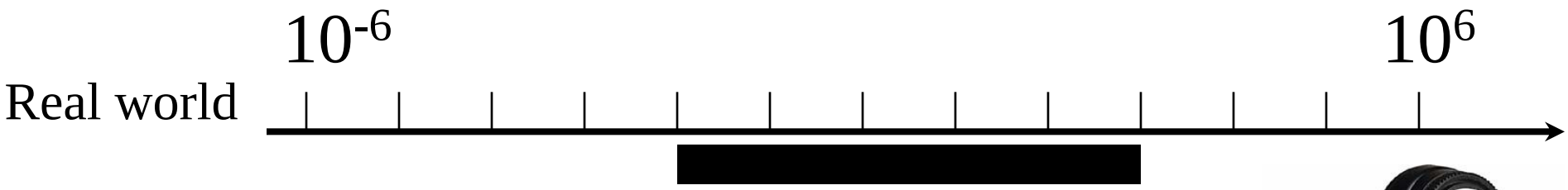
- **Bottom-line problem: illumination level and contrast are not the same for a photo and for the real scene.**

Example:

- **Photo with a Canon G3**
- **Jovan is too dark**
- **Sky is too bright**

Real world dynamic range

- **Eye can adapt from ~ 10^{-6} to 10^{6} cd/m^2**
- **Often 1 : 100,000 in a scene**

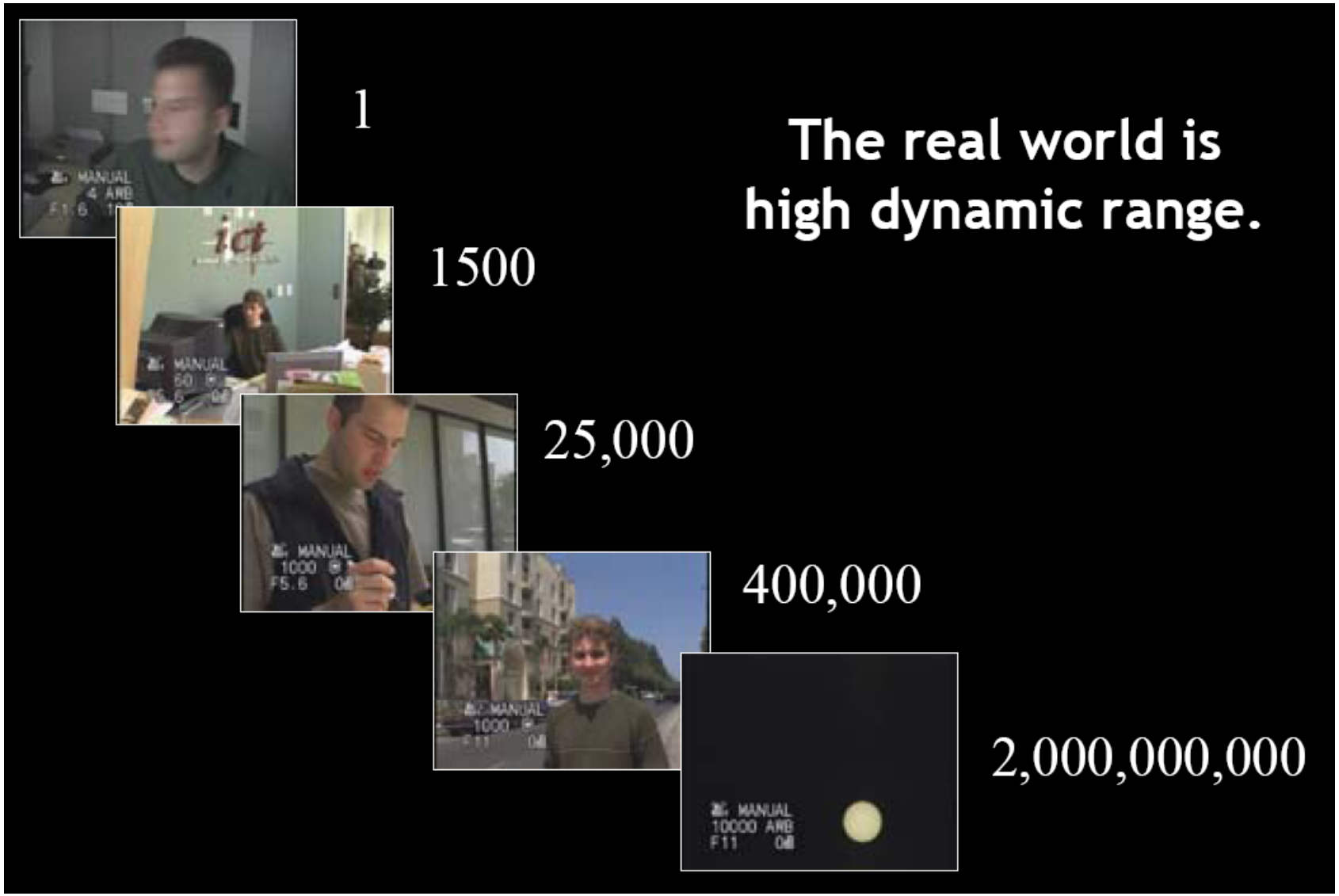


High dynamic range

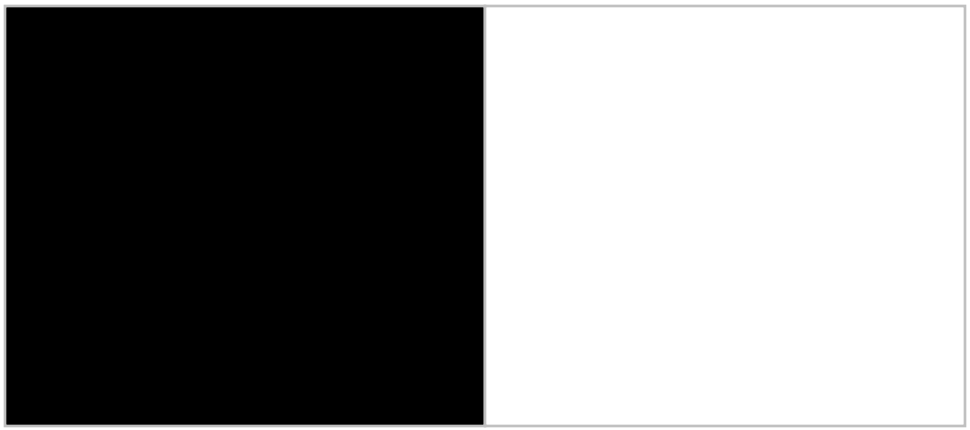
spotmeter

The world is high dynamic range

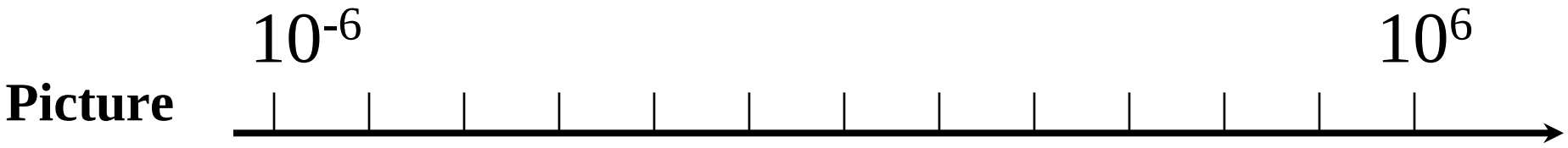
- **Slide from Paul Debevec**



Picture dynamic range: Guess!

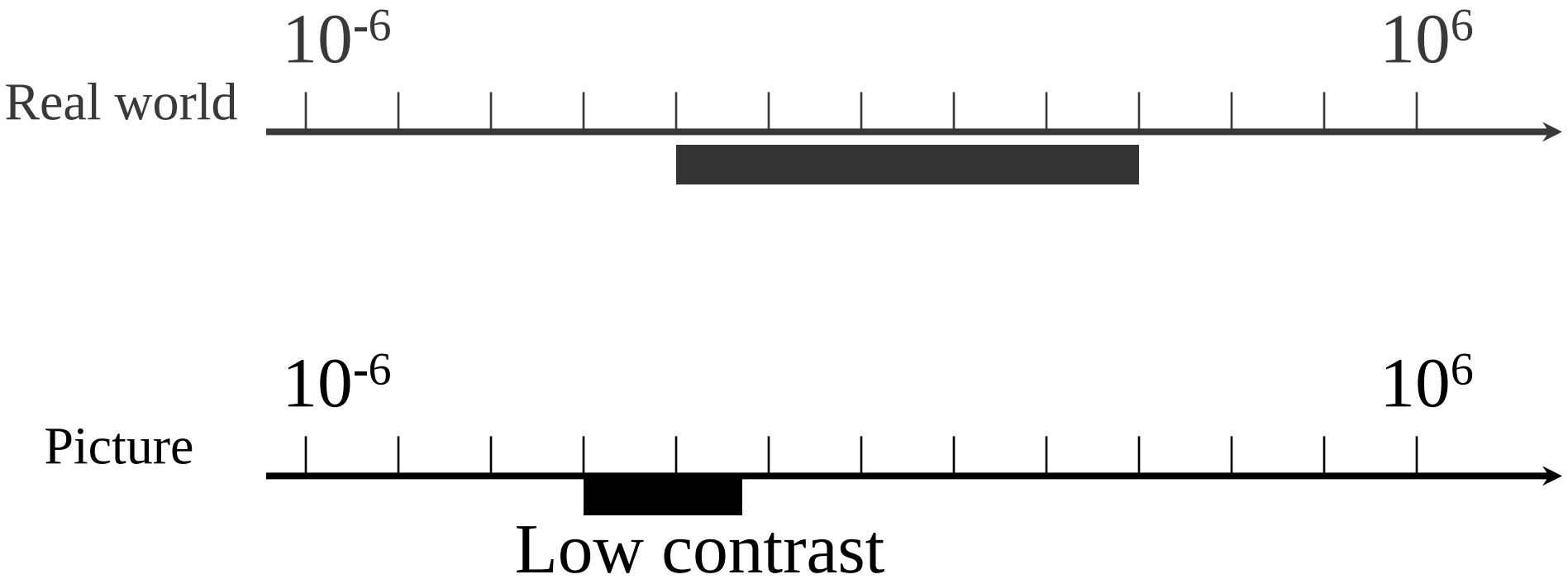


pure black pure white



Problem 2: Picture dynamic range

- **Typically 1: 20 or 1:50**
  - Black  is ~ 50x darker than white 
- **Max 1:500**

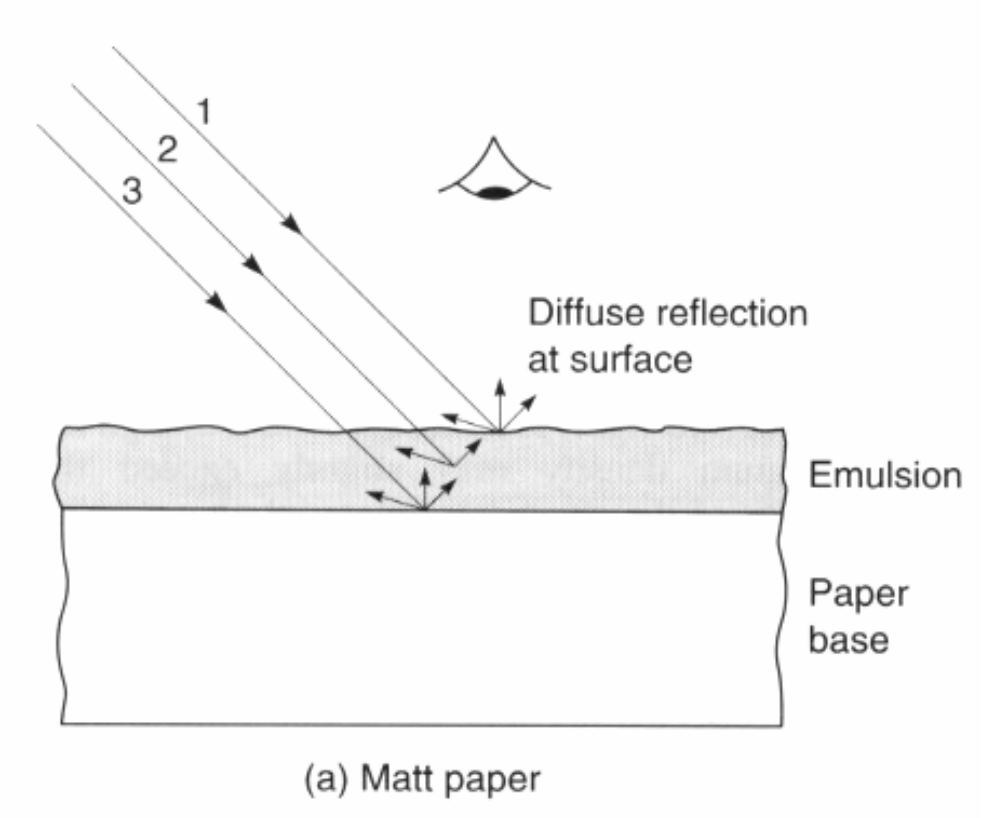


Why is it difficult ?

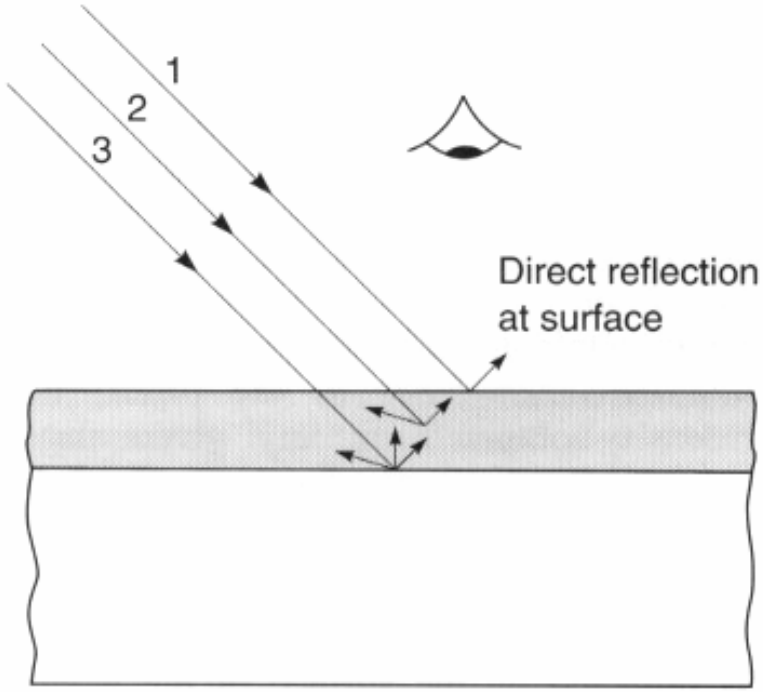
- **Is it harder to obtain good blacks, or good whites?**
- **Black is harder. It's hard to absorb all the light.**
  - See the history of painting: good blacks appeared late
- **We can achieve excellent white**
  - Albedo >100%
  - How is this possible?
  - Use fluorescence
  - Most white materials (paper, paint, fabric) are fluorescent

Photo paper dynamic range

- **Matte vs. glossy: who has the highest dynamic range?**
- **Glossy because for some directions, it does not reflect light at all, while matte reflects equally in all directions**



(a) Matt paper



(b) Glossy paper

From The Manual of Photography, Jacobson et al.

Paper dynamic range

- **Can be altered by adding toning chemicals**
  - Darken the blacks

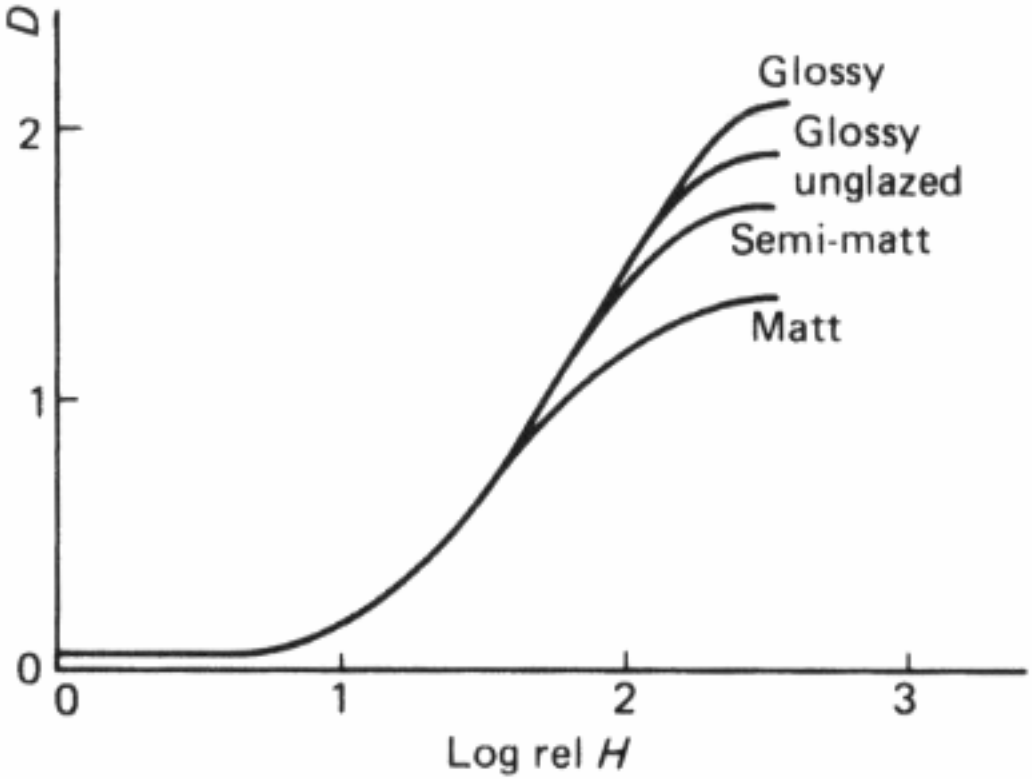
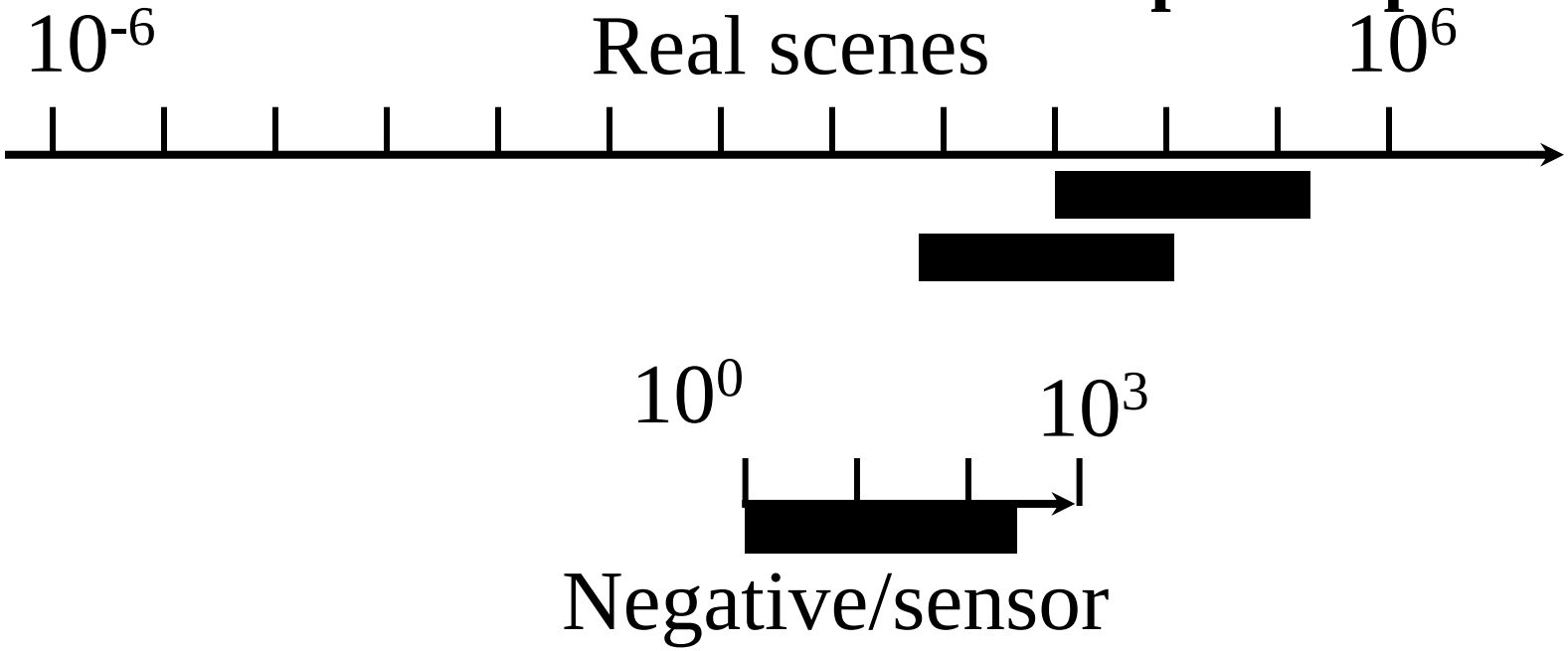


Figure 15.24 Characteristics of papers of different surfaces

From The Manual of Photography, Jacobson et al.

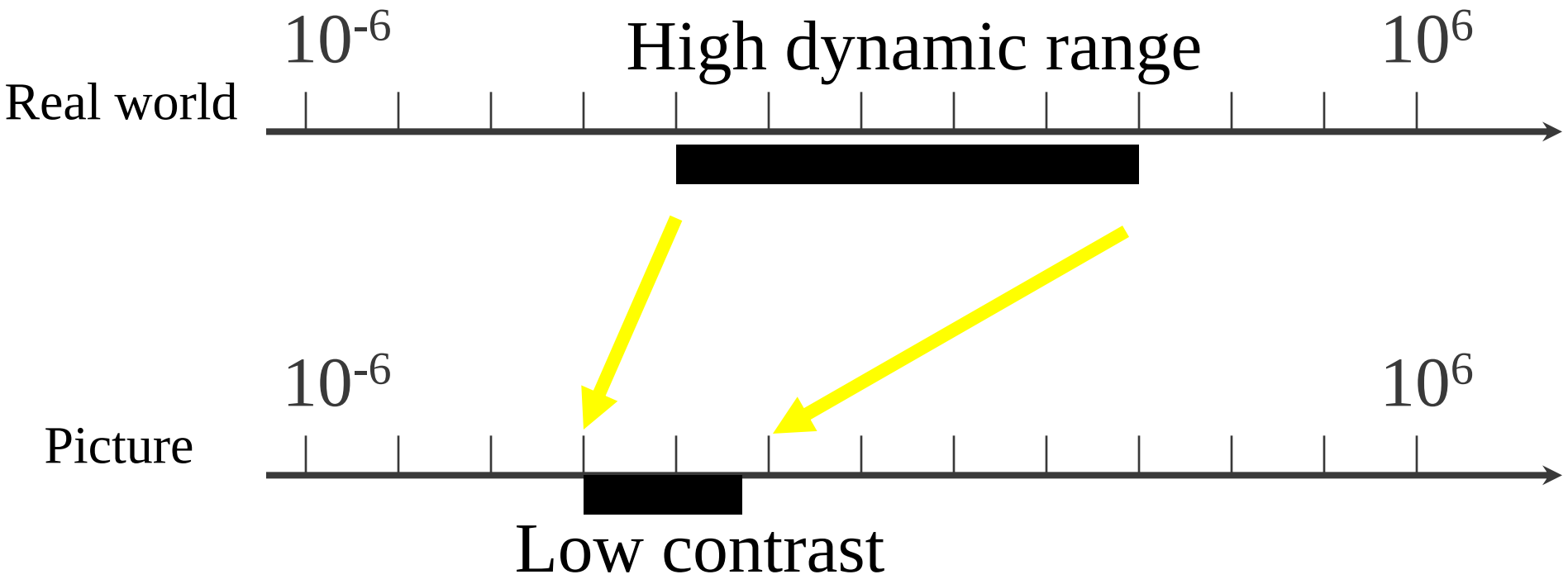
Problem 1

- **The range of illumination levels that we encounter is 10 to 12 orders of magnitudes**
- **Negatives/sensors can record 2 to 3 orders of magnitude**
- **How do we center this window? Exposure problem.**



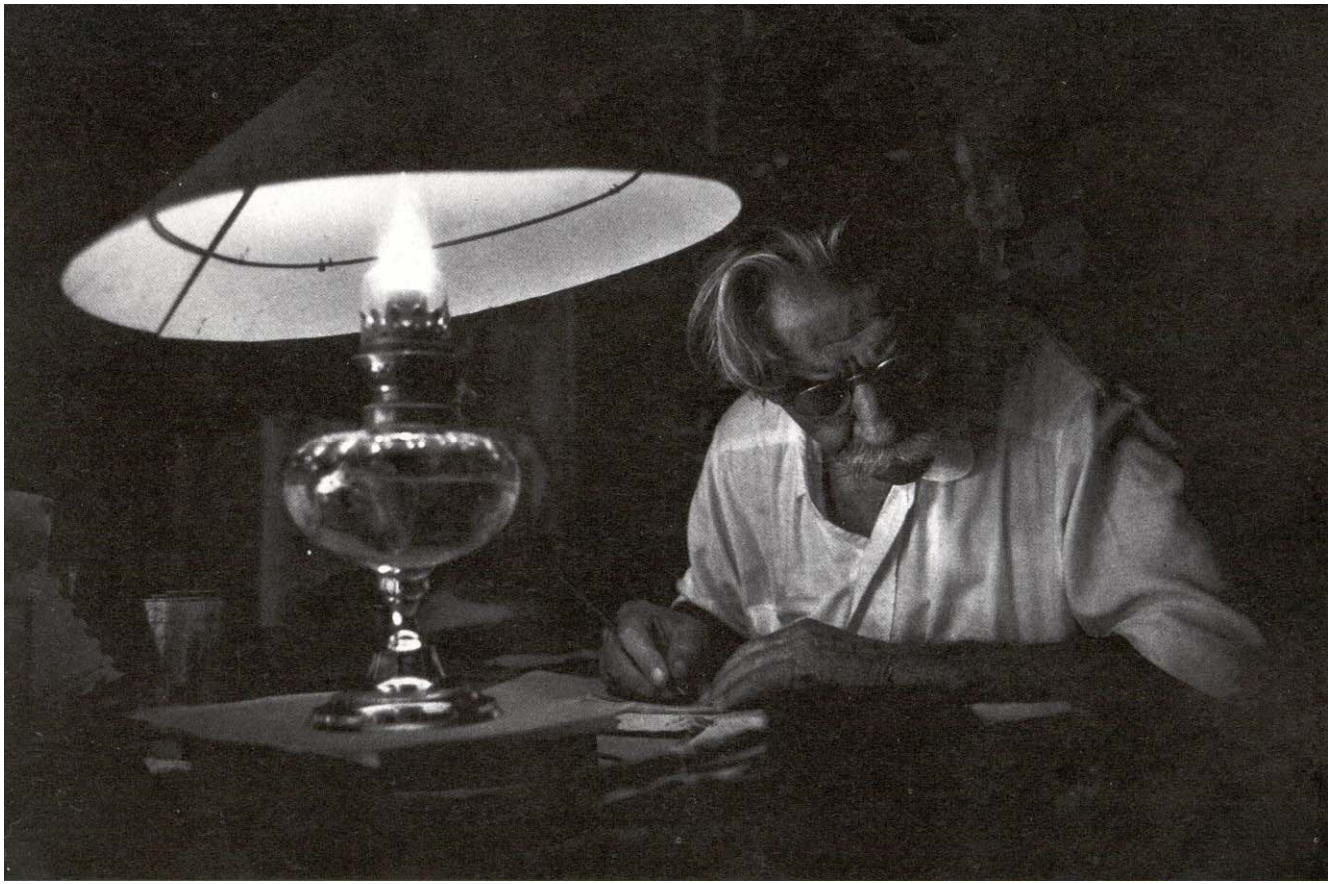
Contrast reduction

- **Match limited contrast of the medium**
- **Preserve details**



Limited dynamic range can be good!

- **W. Eugene Smith photo of Albert Schweitzer**
- **5 days to print!**
- **Things can be related because the intensity is more similar**
- **Balance, composition**

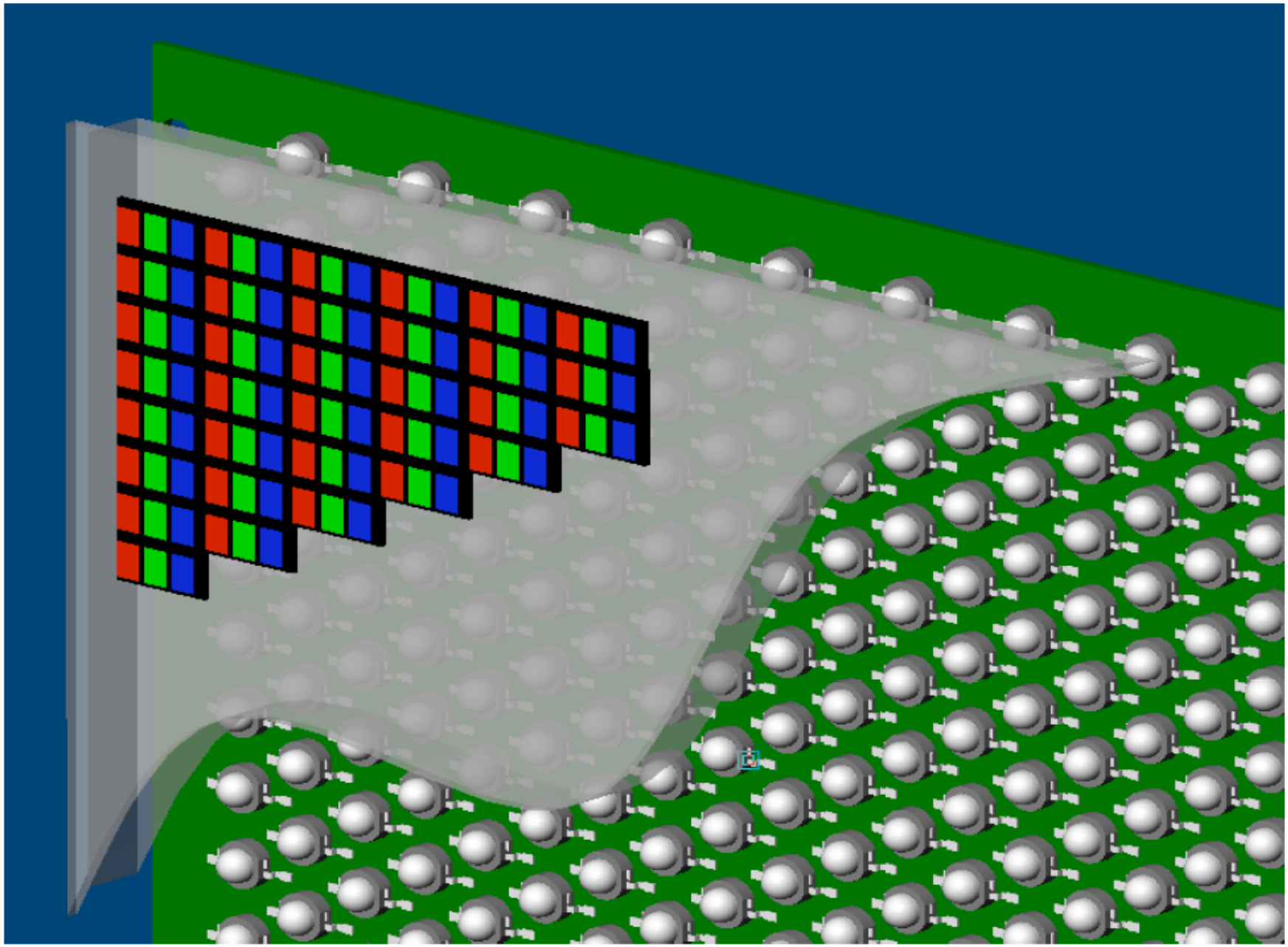


Questions?

Sunnybrook HDR display

- Use Bright Source + Two 8-bit Modulators
  - Transmission multiplies together
  - Over 10,000:1 dynamic range possible

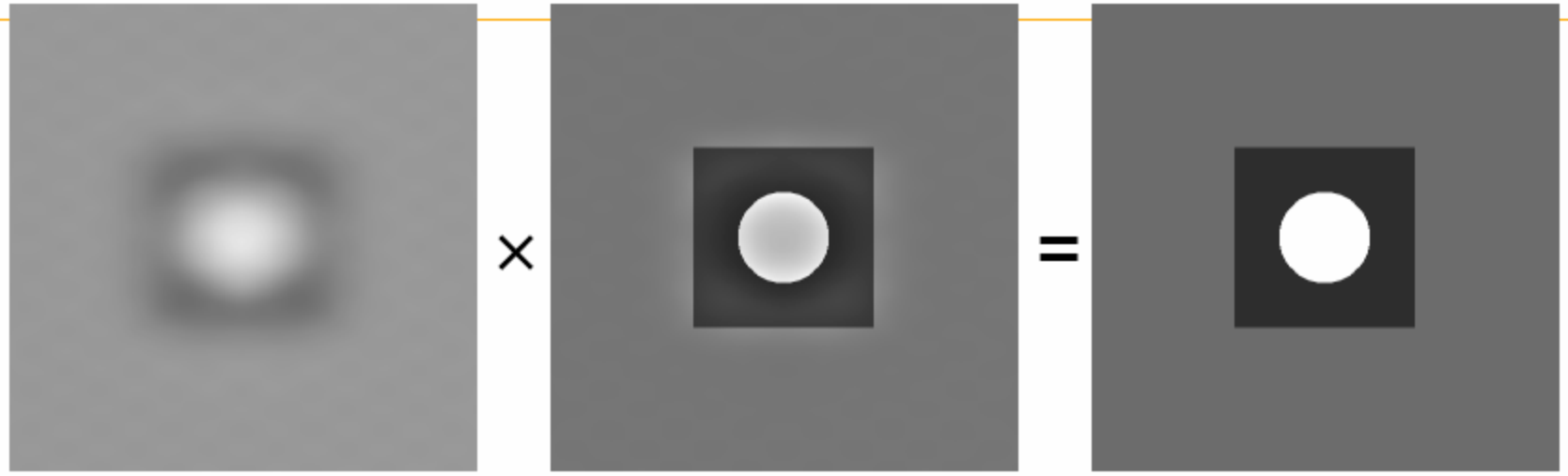
Slide from the 2005 Siggraph course on HDR



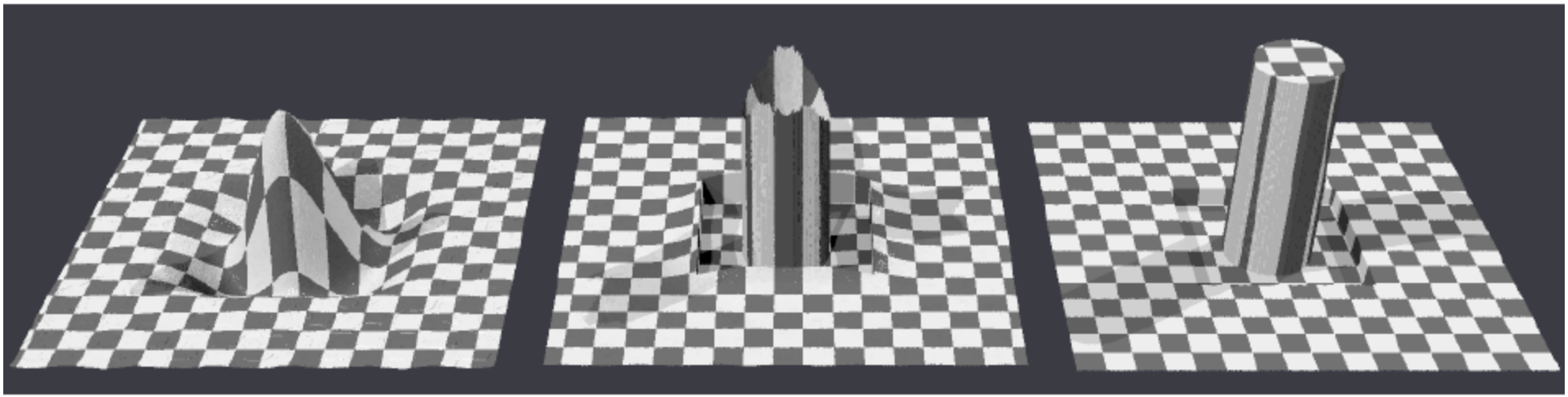
Slide from the 2005 Siggraph course on HDR

How It Works

SIGGRAPH2005



LED Backlight | LCD Screen | Combined Result

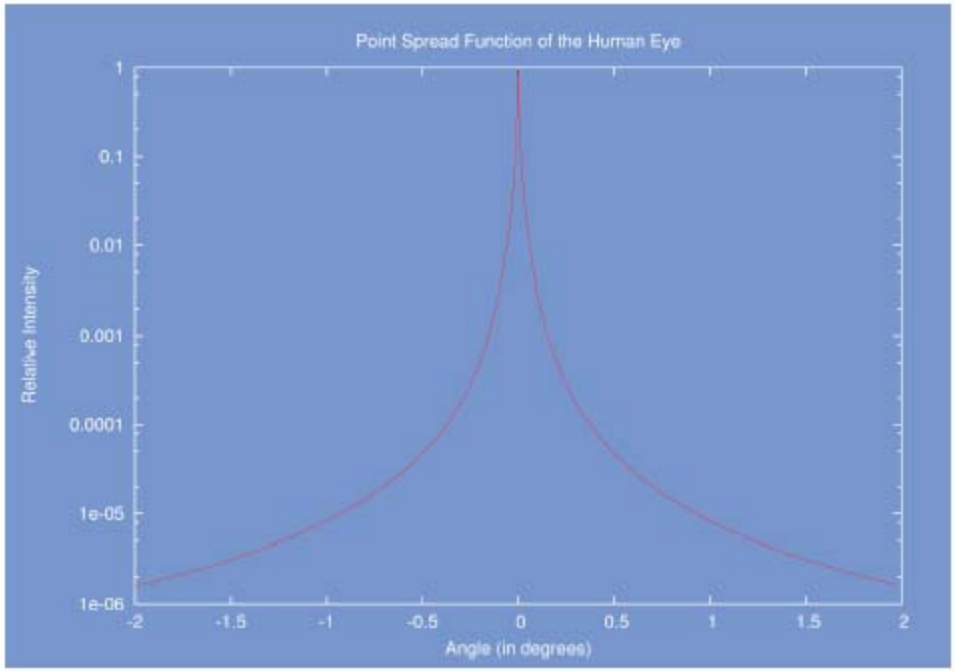


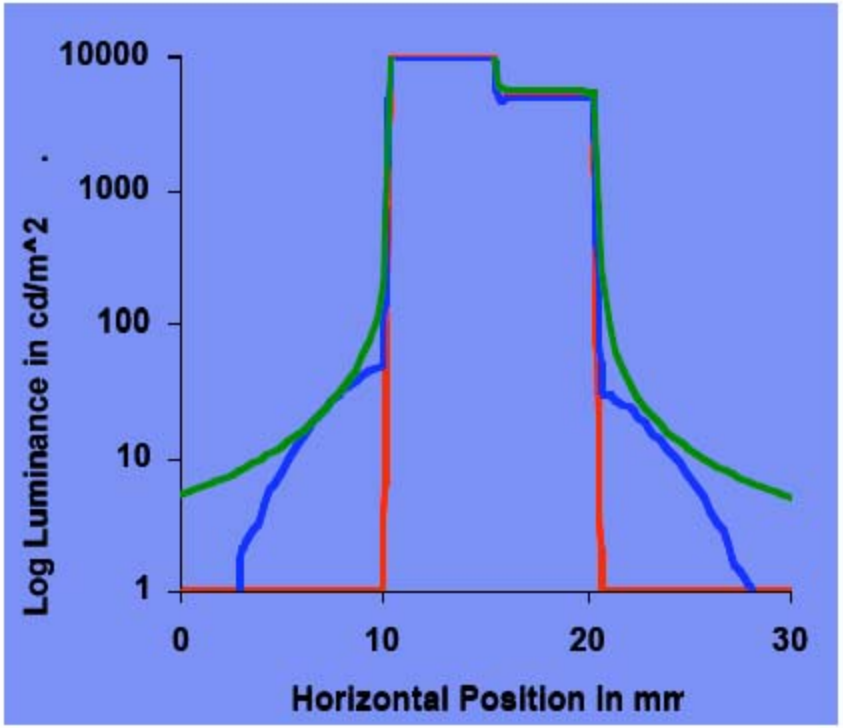
Slide from the 2005 Siggraph course on HDR

What If Edge Contrast Exceeds LCD Range?

SIGGRAPH2005

Observers cannot tell when this happens because the eye has limited local contrast capacity due to scattering





See Seetzen et al., SIGGRAPH 2004

Slide from the 2005 Siggraph course on HDR

Production 37” HDR Display

SIGGRAPH2005

Slide from the 2005 Siggraph course on HDR

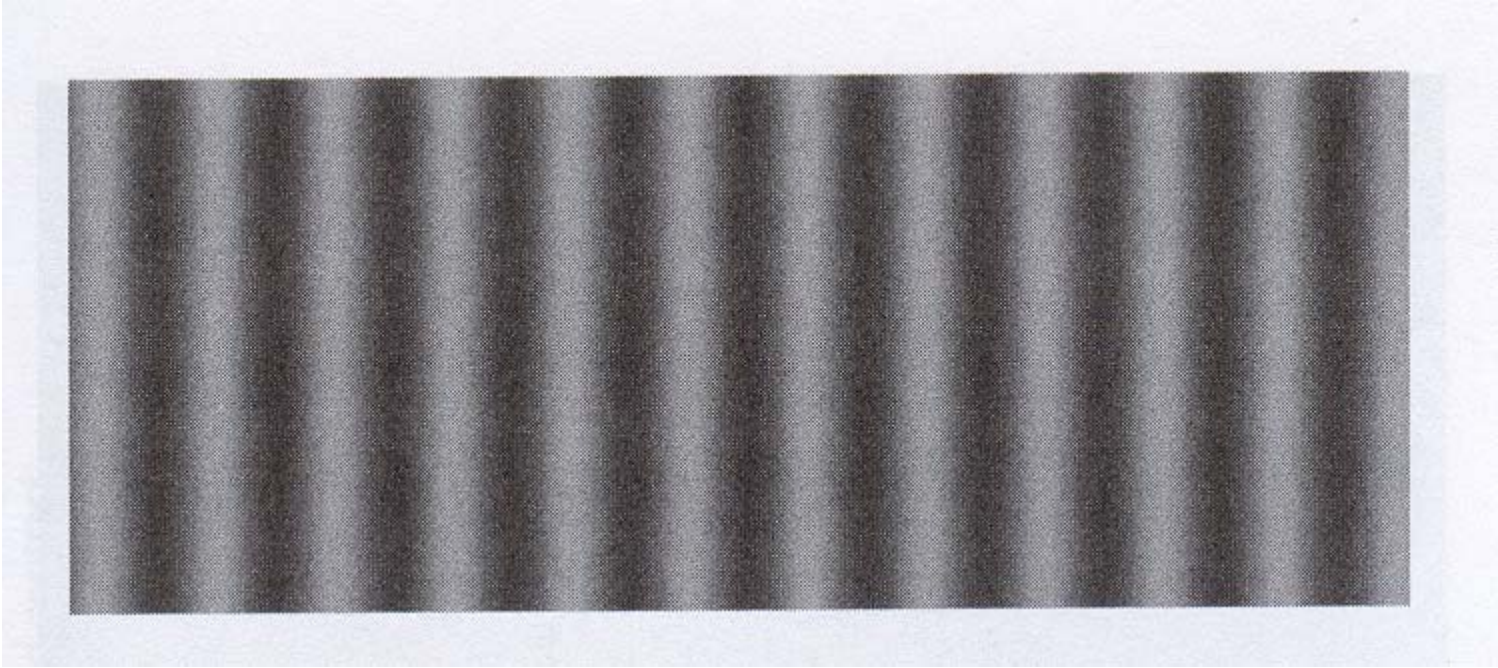
Questions?

How humans deal with dynamic range

- **We're sensitive to contrast (multiplicative)**
  - A ratio of 1:2 is perceived as the same contrast as a ratio of
    100 to 200
  - Makes sense because illumination has a multiplicative effect
  - Use the log domain as much as possible
- **Dynamic adaptation (very local in retina)**
  - Pupil (not so important)
  - Neural
  - Chemical
- **Different sensitivity to spatial frequencies**

Contrast Sensitivity

- **Sine Wave grating**
- **What contrast is necessary to make the grating visible?**



Contrast Sensitivity Function (CSF)

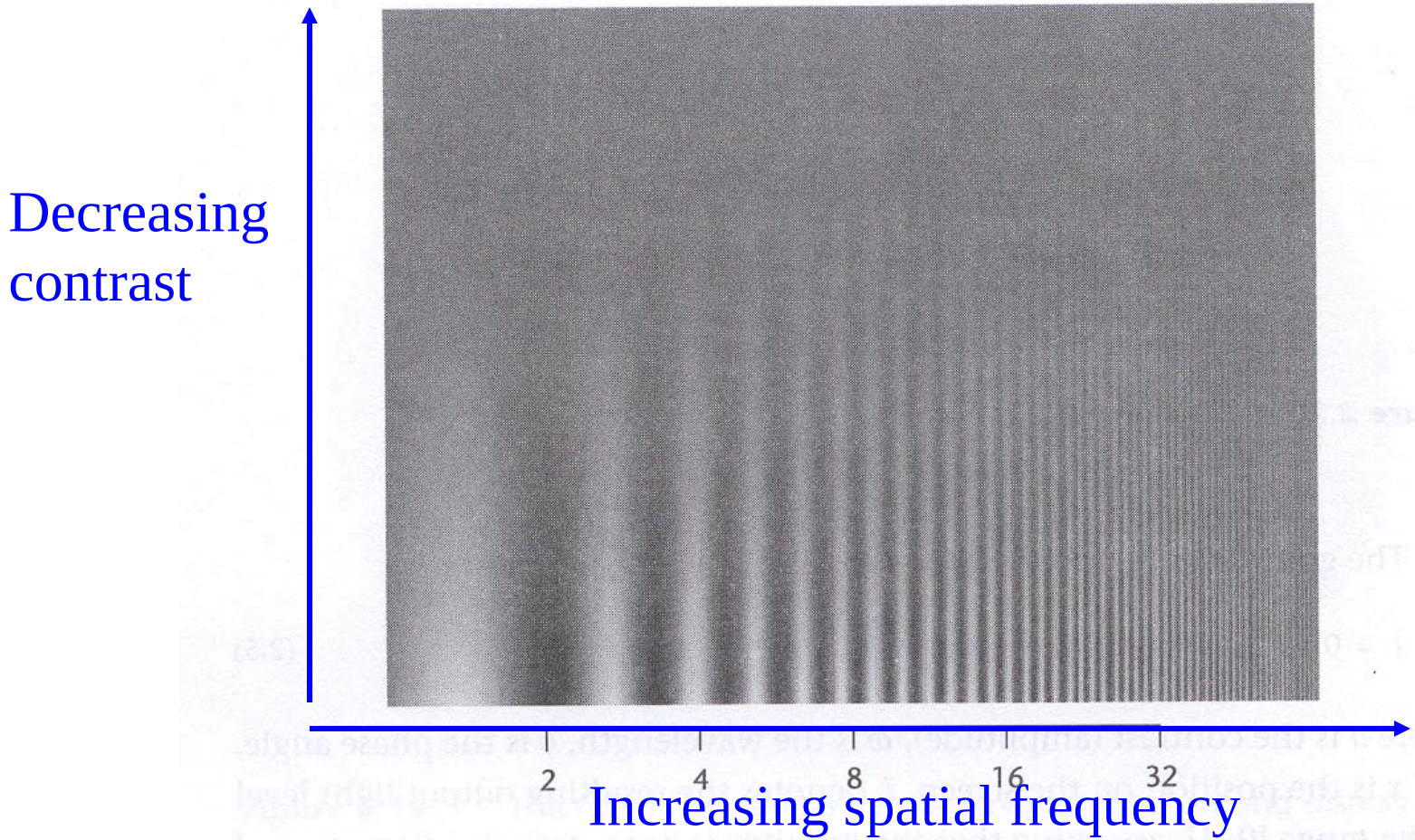


Figure 2.21 This grating pattern changes frequency exponentially from left to right and varies in contrast in a vertical direction. The highest frequency you can resolve depends on the distance from which you view the pattern. The scale gives the spatial frequency if it is viewed from 2.3 m.

Contrast Sensitivity Function (CSF)

- **Low sensitivity to low frequencies**
- **Importance of medium to high frequencies**
- **Most methods to deal with dynamic range reduce the contrast of low frequencies**
- **But keep the color**

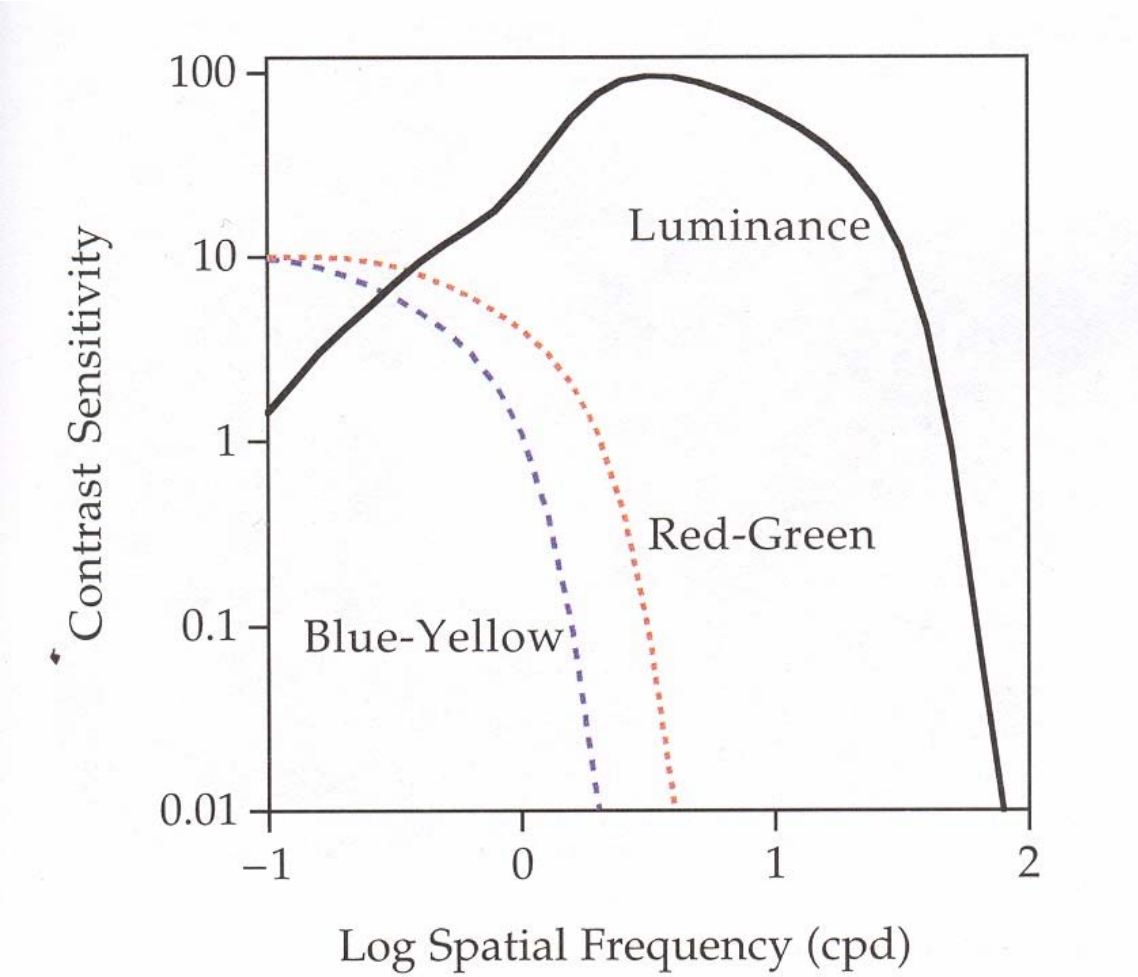


Figure 1-18. Spatial contrast sensitivity functions for luminance and chromatic contrast.

Important

- **Multiply image by constant:**

  make it brighter
- **Contrast = ratio**
- **How do we change contrast then?**

  Exponent, e.g. square root reduces contrast

DENSITY

Too light. *Increase exposure time.*

Too dark. *Decrease exposure time.*

CONTRAST

Too flat. *Use higher contrast paper grade or higher print filter.*

Too contrasty. *Use lower contrast paper grade or higher print filter.*

BLACK-AND-WHITE TEST PATCHES

Black-and-white test patches are an aid in judging a print. To evaluate the density and contrast of a print, you need standards against which to compare the tones in your print, since the eye can be fooled into accepting a very dark gray as black or a very light gray as white, enough to make the difference between a flat, dull print and a rich, brilliant one. Two small pieces of printing paper will help, one developed to the darkest black and the other to the brightest white that the paper can produce. By placing a black or white patch next to an area, you can accurately judge how light or dark the tone actually is.

As a bonus, the black patch indicates developer exhaustion; the developer should be replaced when you are no longer able to produce a black tone in a print as dark as the black patch no matter how much exposure you give the paper. The white patch will help you check for the overall gray tinge caused by safelight fogging.

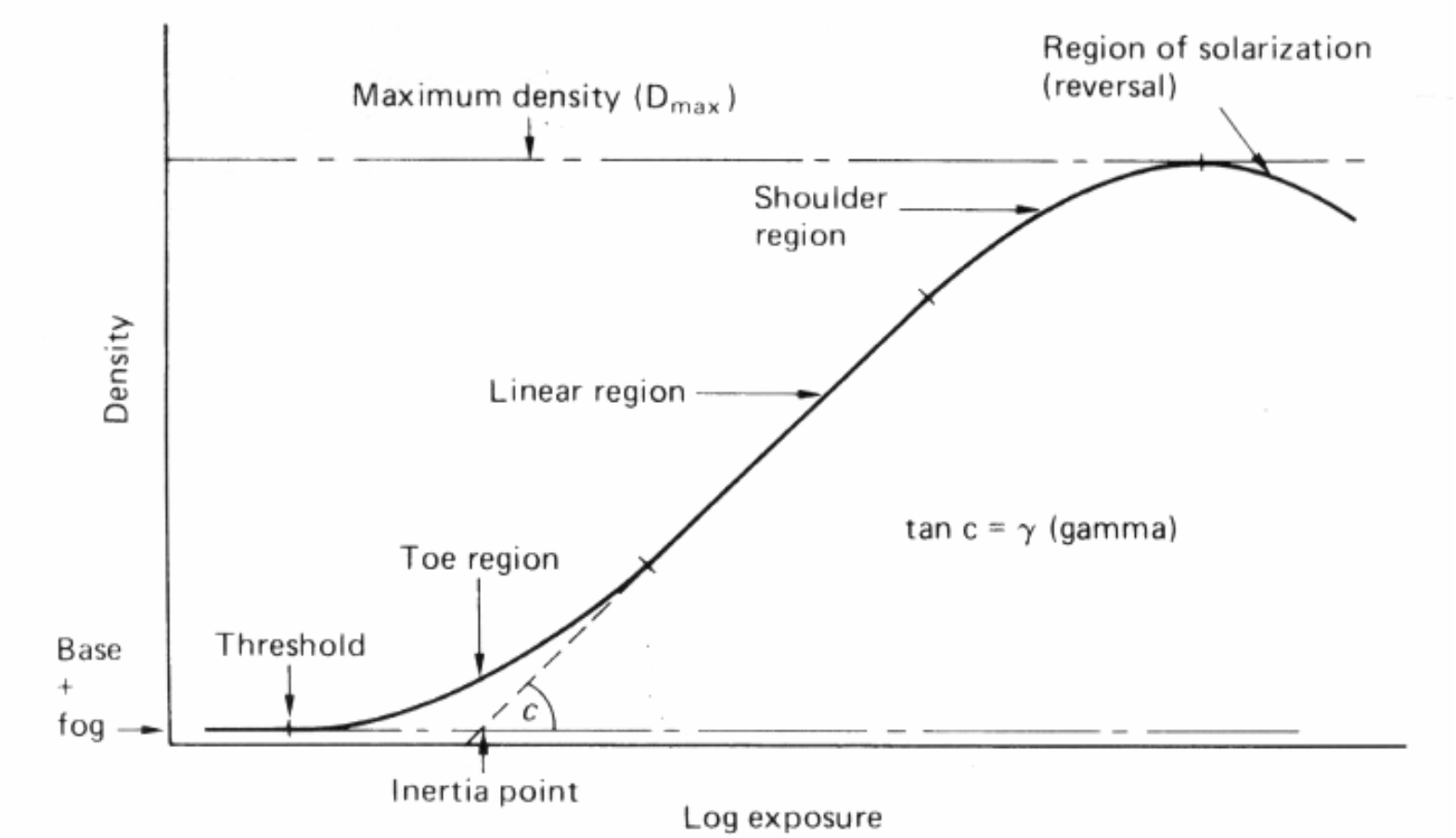
Make the patches at the beginning of a printing session when developer and fixer are fresh. Cut two 2-inch-square pieces from your printing paper. Use the enlarger as the light source to make the black patch. Set the enlarger head about a foot and a half above the baseboard. The patch should be borderless, so do not use an easel. Expose one patch for 30 seconds at f/5.6; do not expose the other. Develop both patches with constant agitation for the time recommended by the manufacturer. Process as usual with stop bath and fixer. Remove promptly from fixer after the recommended time, then store in fresh water. To avoid any possible fogging of the white patch, cut and process the paper in a minimum amount of safelight.

From Photography by London et al.

Questions?

Negative and response curve

- **Negatives typically afford 3 orders of magnitude**
- **More than printing paper**



The 'geography' of the characteristic curve of a negative material

Jacobson et al.

Questions?

Digital pipeline

- **Photosites transform photons into charge (electrons)**
  - The sensor itself is linear
- **Then goes through analog to digital converter**
  - up to 12 bits/channel
- **Stop here when shooting RAW**
- **Then image processing and a response curve are applied**
- **Quantized and recorded as 8-bit JPEG**

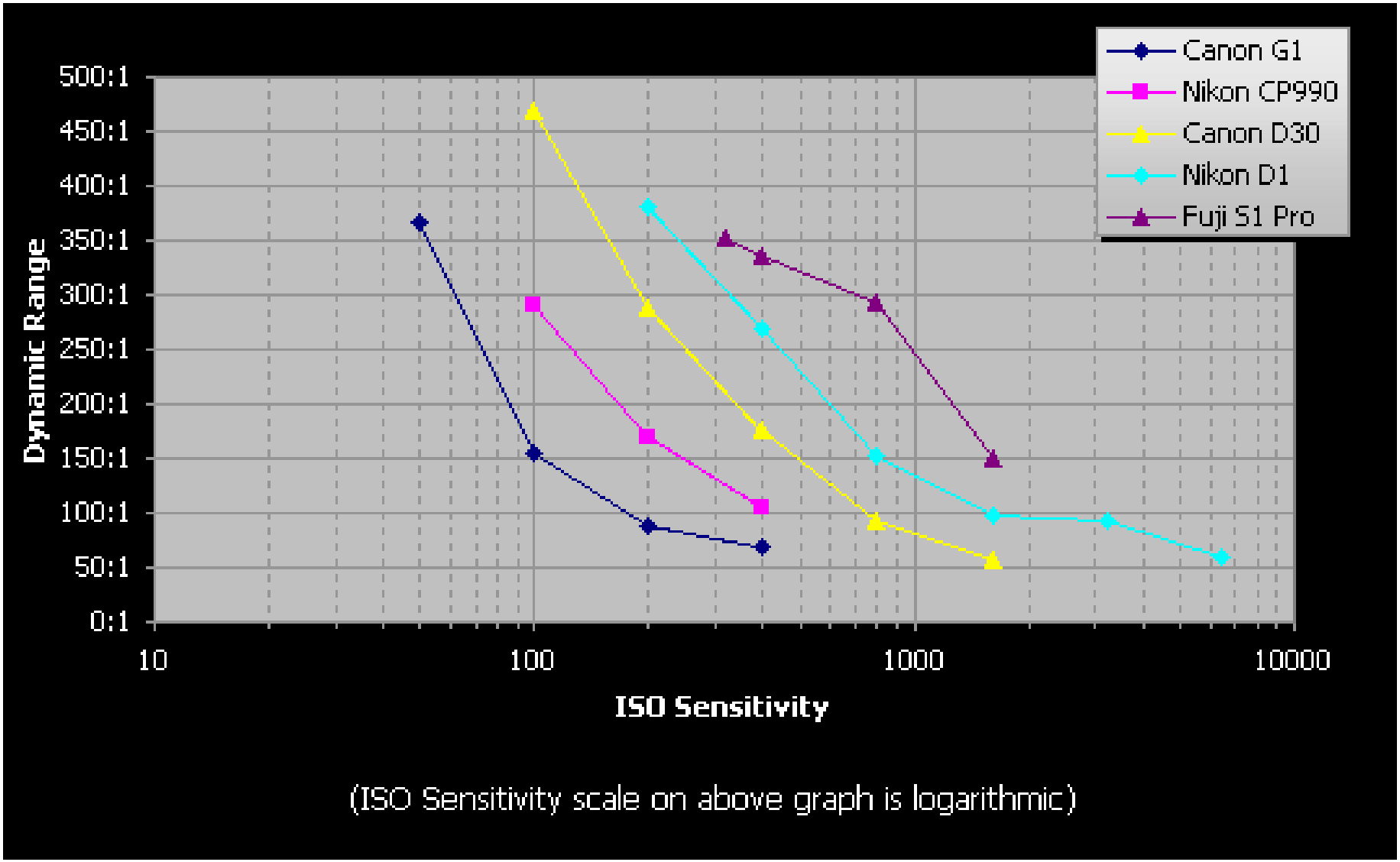
Sensors and dynamic range

- **Photosites transform photons into charge (electrons)**
- **The sensor itself is linear**
- **Each photosite has a given well capacity (number of photons it can record)**
- **Once this capacity is exceeded, it saturates**
- **Noise is sqrt(capacity)**

- **The bigger the photosite, the higher the range**

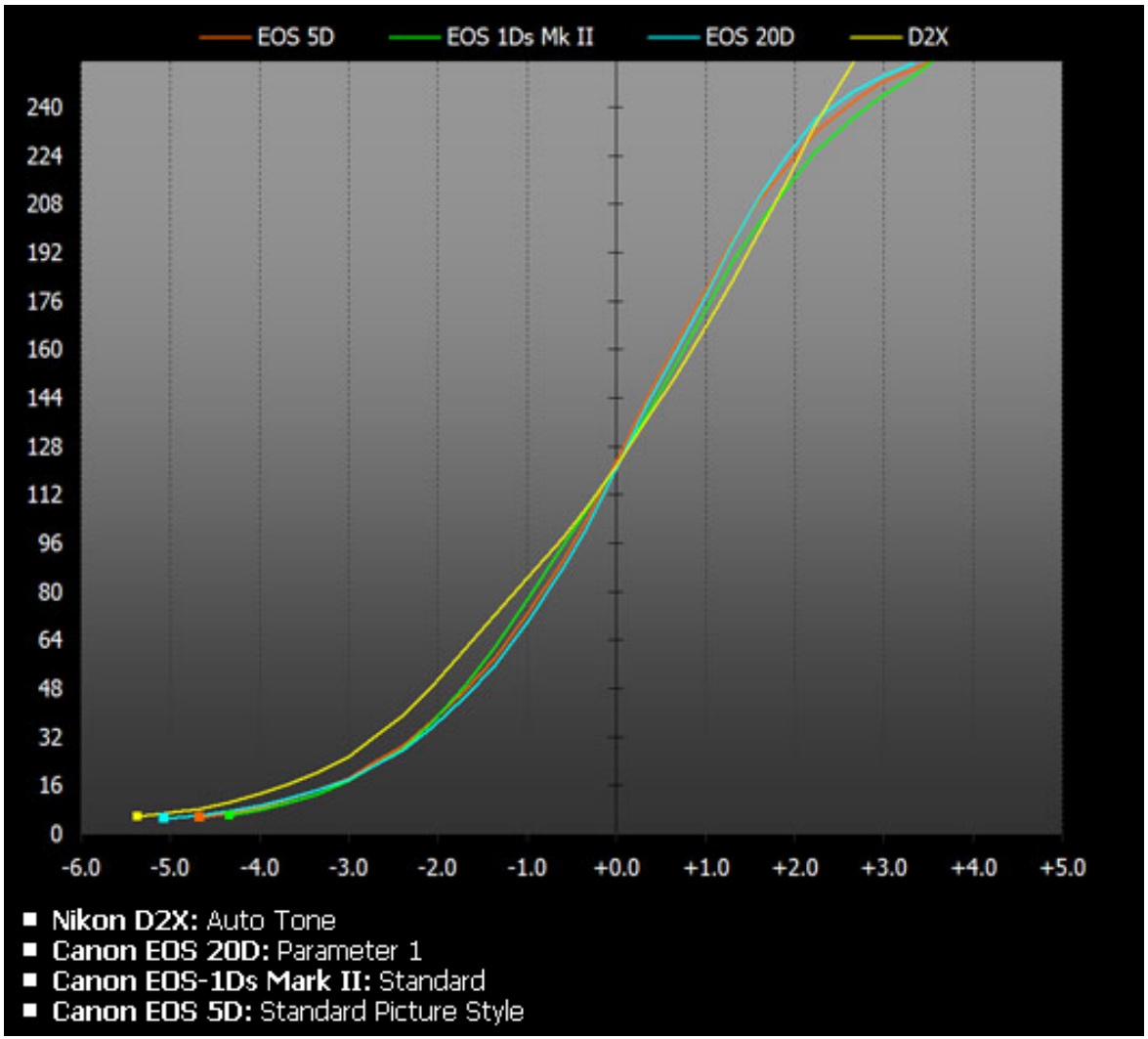
Dynamic range and sensor size

- **http://www.dpreview.com/news/0011/00111608dyna**



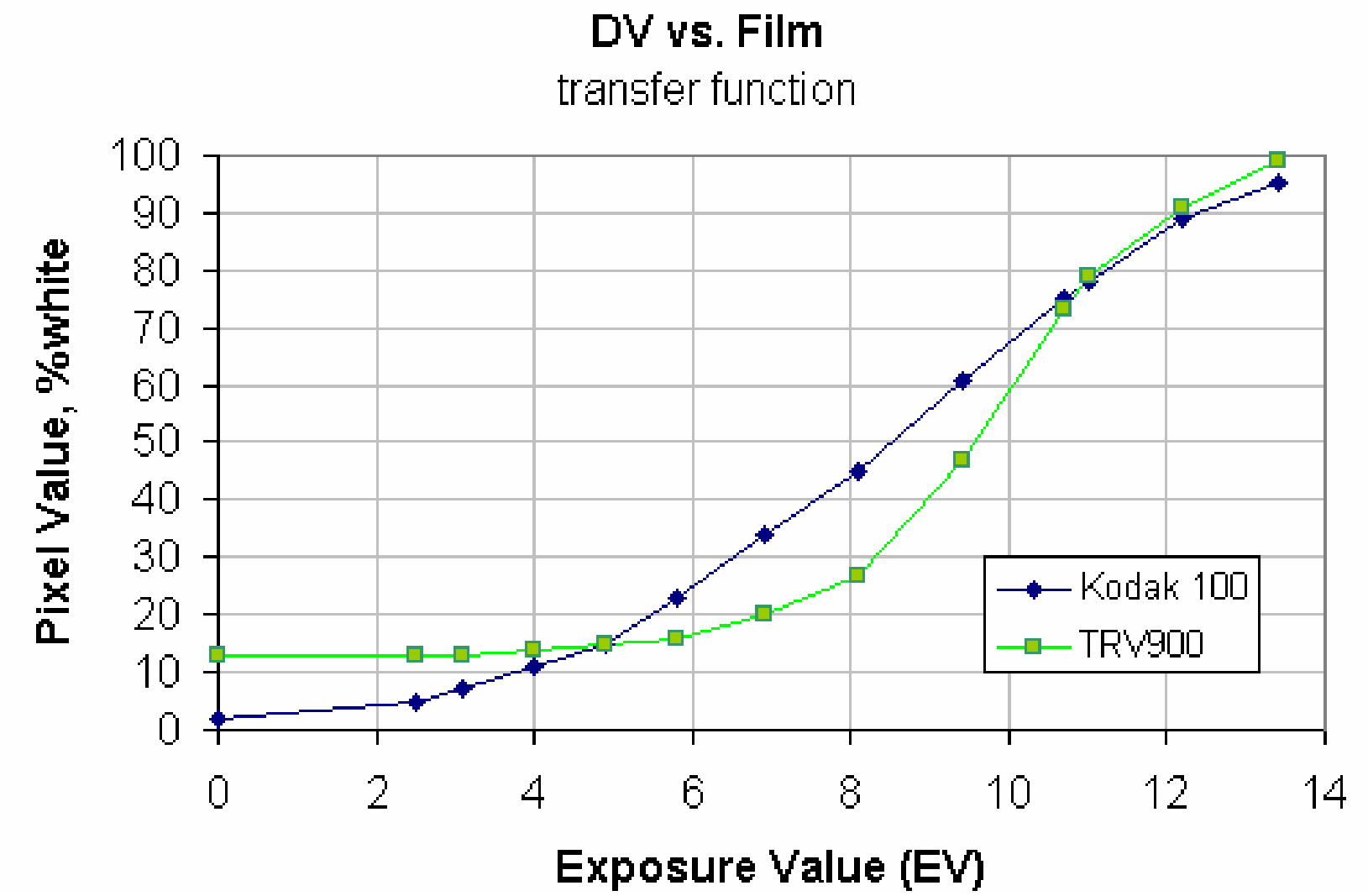
Response curve of current D-SLR

- **http://www.dpreview.com/reviews/canoneos5d/page22.asp**

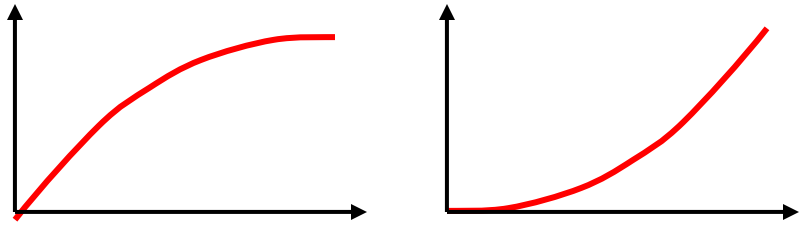


Response curve, dynamic range

- **Video sensors have poor dynamic range**



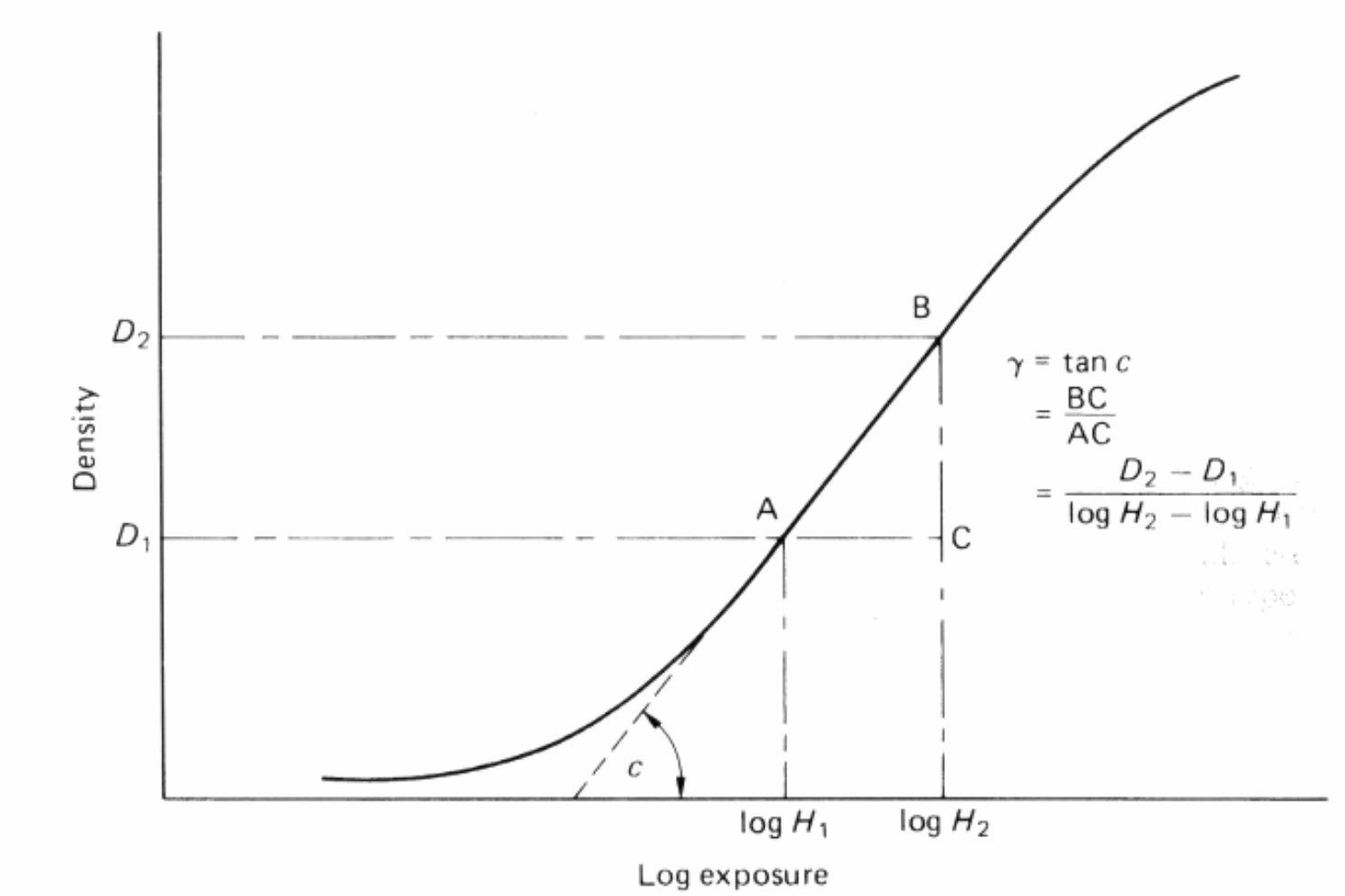
The infamous gamma curve



- **A gamma curve x->x^{γ} is used for many reasons:**
  - CRT response
  - Color quantization
  - Perceptual effect
- **Sometimes with $\gamma > 1$, sometimes $\gamma < 1$**
- **These issues are often oversimplified/confused, including in prominent textbooks**
  - i.e. they are explained wrong

Film gamma

- **Control dynamic range, contrast mapping**

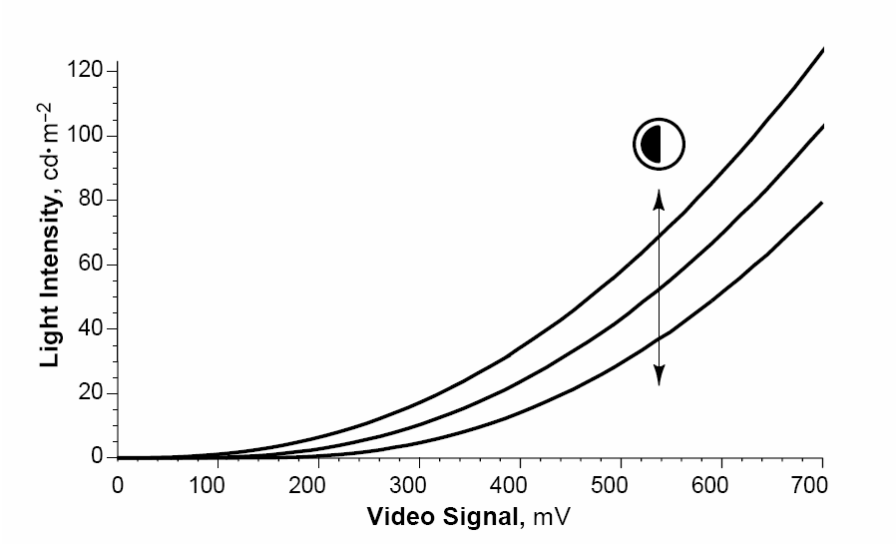


Gamma in terms of density and log exposure

From The Manual of Photography, Jacobson et al.

Cathode Ray Tube gamma

- **The relationship between voltage and light intensity is non linear**
- **Can be approximated by an exponent 2.5**
- **Must be inverted to get linear response**



From Ponton's FAQ
http://www.poynton.com/

Color quantization gamma

- **The human visual system is more sensitive to ratios: is a grey twice as bright as another one?**
- **If we use linear encoding, we have tons of information between 128 and 255, but very little between 1 and 2!**
- **Ideal encoding?**

  Log
- **Problems with log?**

  Gets crazy around zero

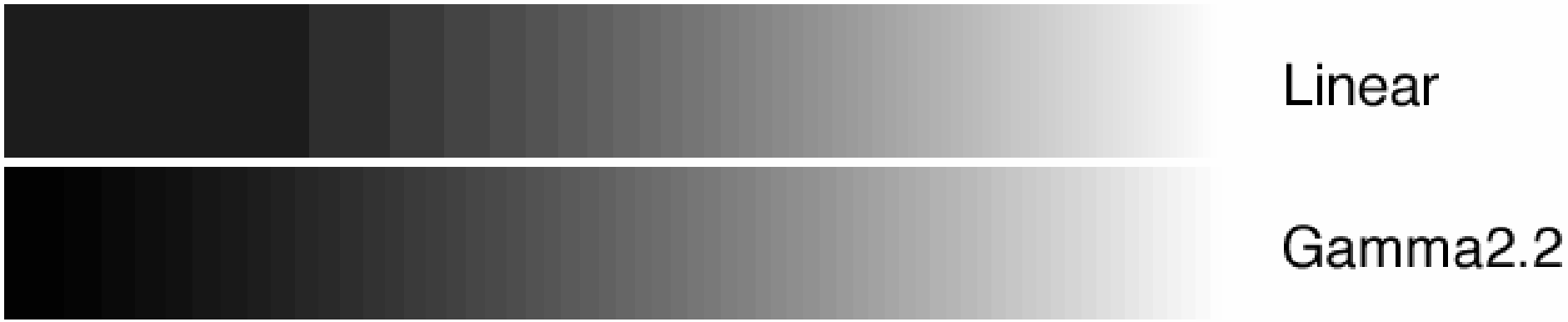
Solution: gamma

Color quantization gamma

- **The human visual system is more sensitive to ratios: is a grey twice as bright as another one?**
- **If we use linear encoding, we have tons of information between 128 and 255, but very little between 1 and 2!**
- **This is why a non-linear gamma remapping of about 2.0 is applied before encoding**
- **True also of analog signal to optimize signal-noise ratio**
- **It is a nice coincidence that this is exactly the inverse of the CRT gamma**

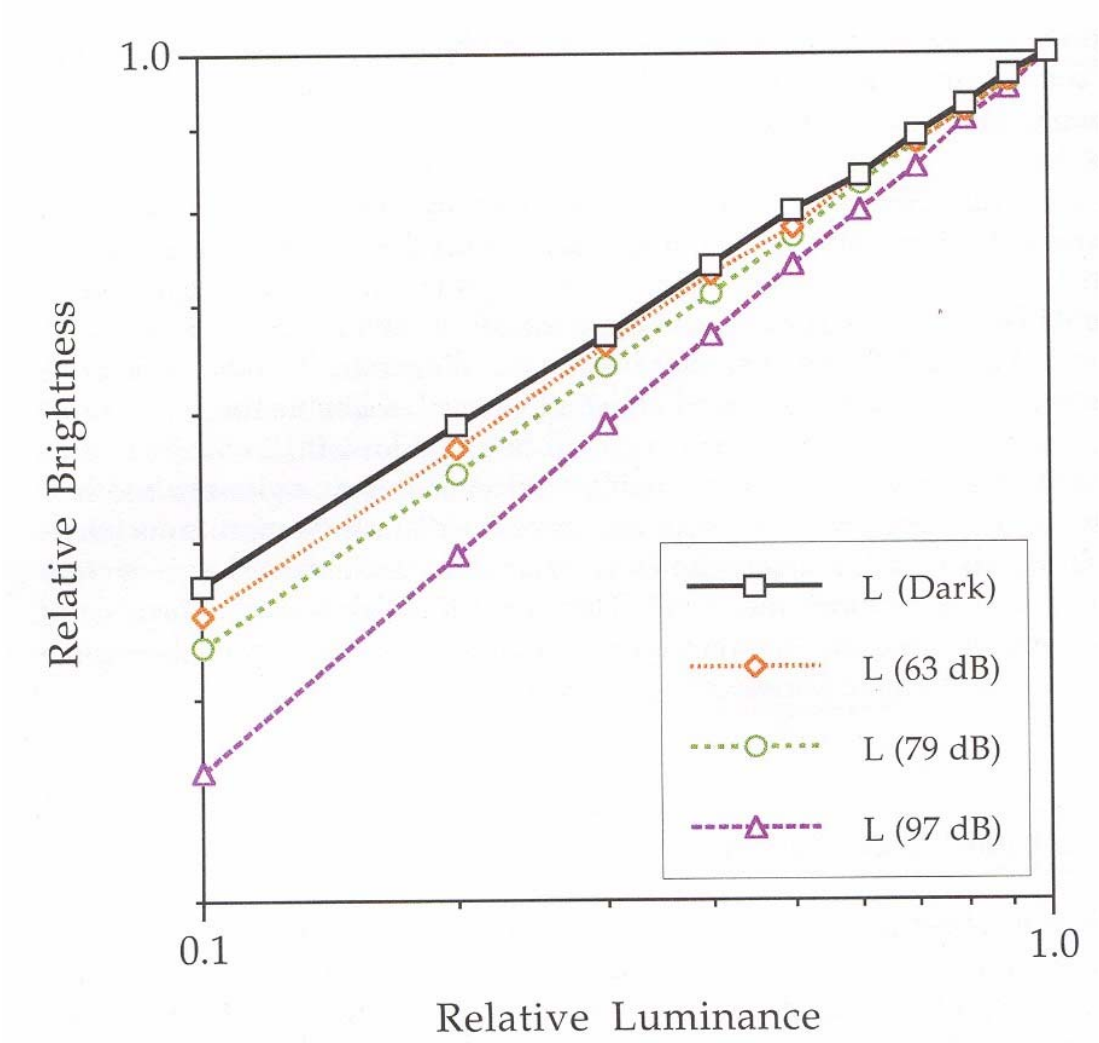
Gamma encoding

- **From Greg Ward**
- **only 6 bits for emphasis**



Stevens effect

- **Perceived contrast increases with luminance**



Perceptual effect

- **We perceive colors in darker environment less vivid**
- **Must be compensated by boosting colors**

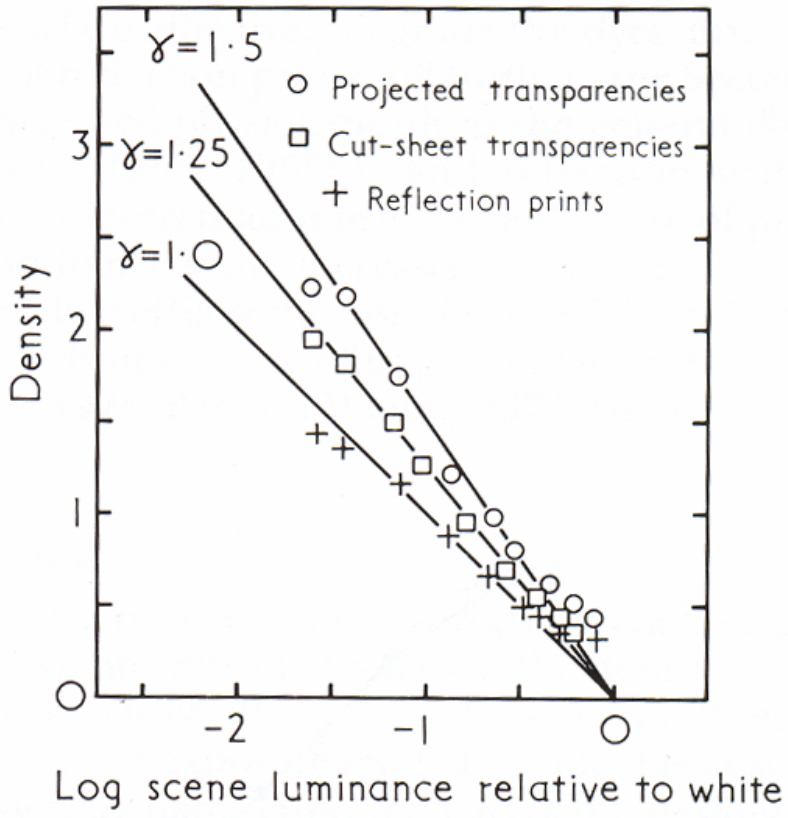


Fig. 6.13. The displayed density of the nine-step grey scale plotted against the log luminances of its steps relative to white. Reflection print systems have a displayed gamma of 1.0, cut-sheet transparency systems a displayed gamma of 1.25, and projected transparency systems a displayed gamma of 1.5.

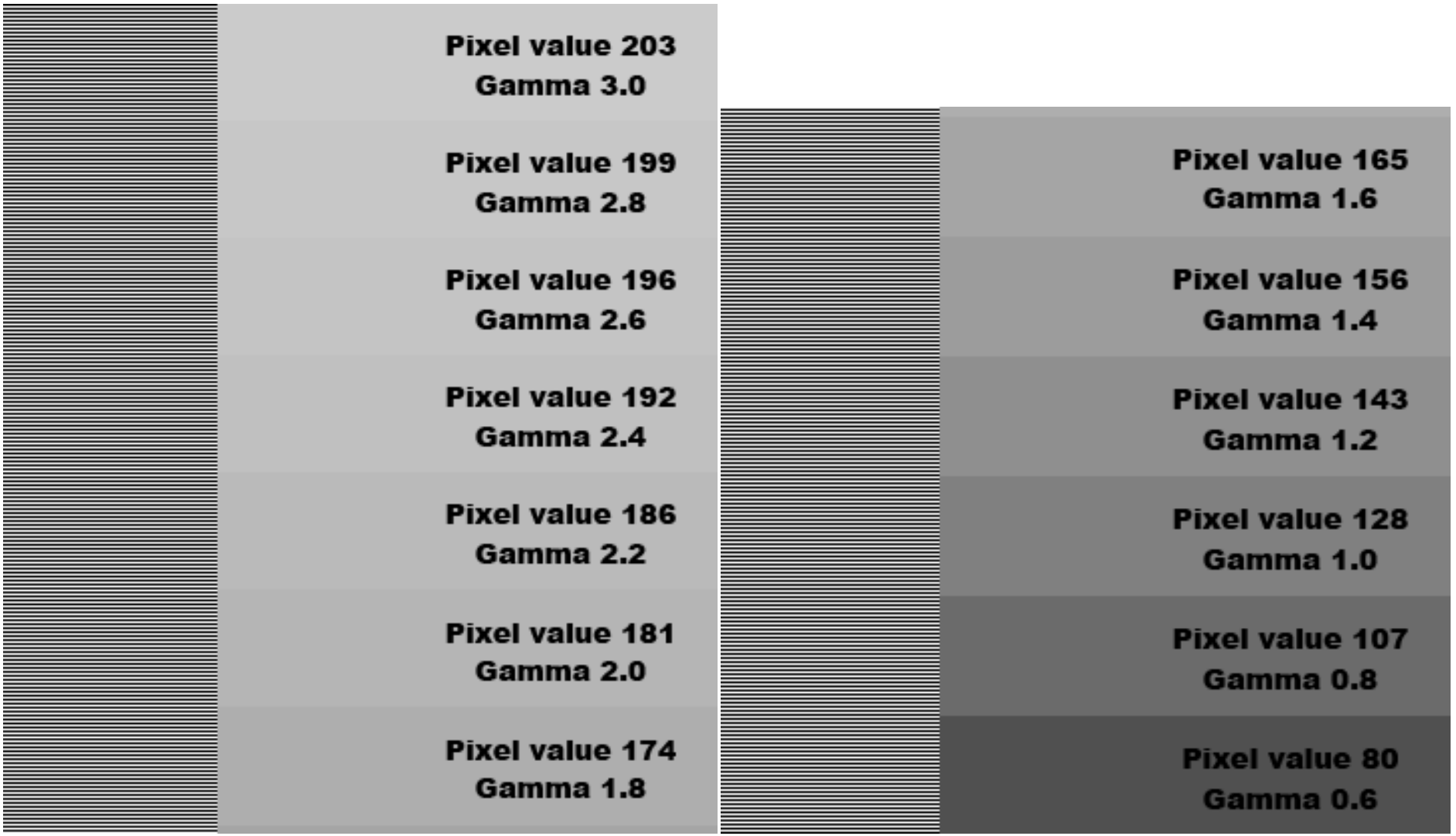
At the end of the day

- **At the camera or encoding level, apply a gamma of around 1/2.2**
- **The CRT applies a gamma of 2.5**
- **The residual exponent 2.2/2.5 boosts the colors to compensate for the dark environment**

- **See**
  http://www.poynton.com/GammaFAQ.html
  http://www.poynton.com/notes/color/GammaFQA.html
  http://www.poynton.com/PDFs/Rehabilitation_of_gamma.pdf

Gamma calibration

- **Exploit linear fusion in the eye**



Gamma is messy

- **Because it's poorly understood**
- **Because it's poorly standardized**
  - Half of the images on the net are linear, half are gamma-compressed
- **Because it might make your image processing non-linear**
  - A weighted average of pixel values is not a linear convolution! Bad for antialiasing
  - But it is often desirable for other image processing, because then it corresponds more to human perception of brightness

Questions?

Response curve manipulation

- **Traditional photography**
  - Chemicals and duration of development
  - Paper grade (~γ)
  - Flashing the paper before printing
  - Various chemicals on paper
- **Digital**
  - Curve tool

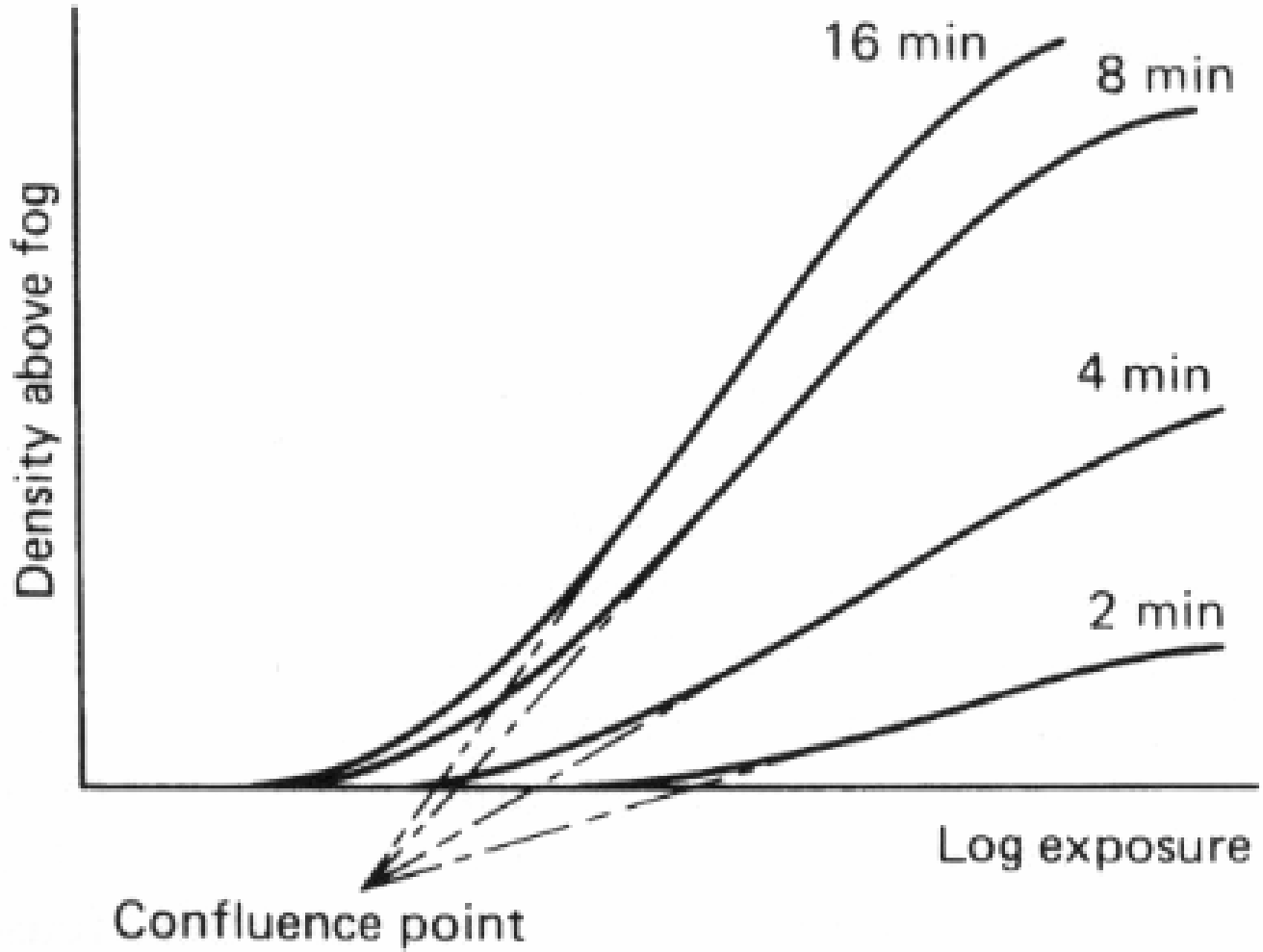
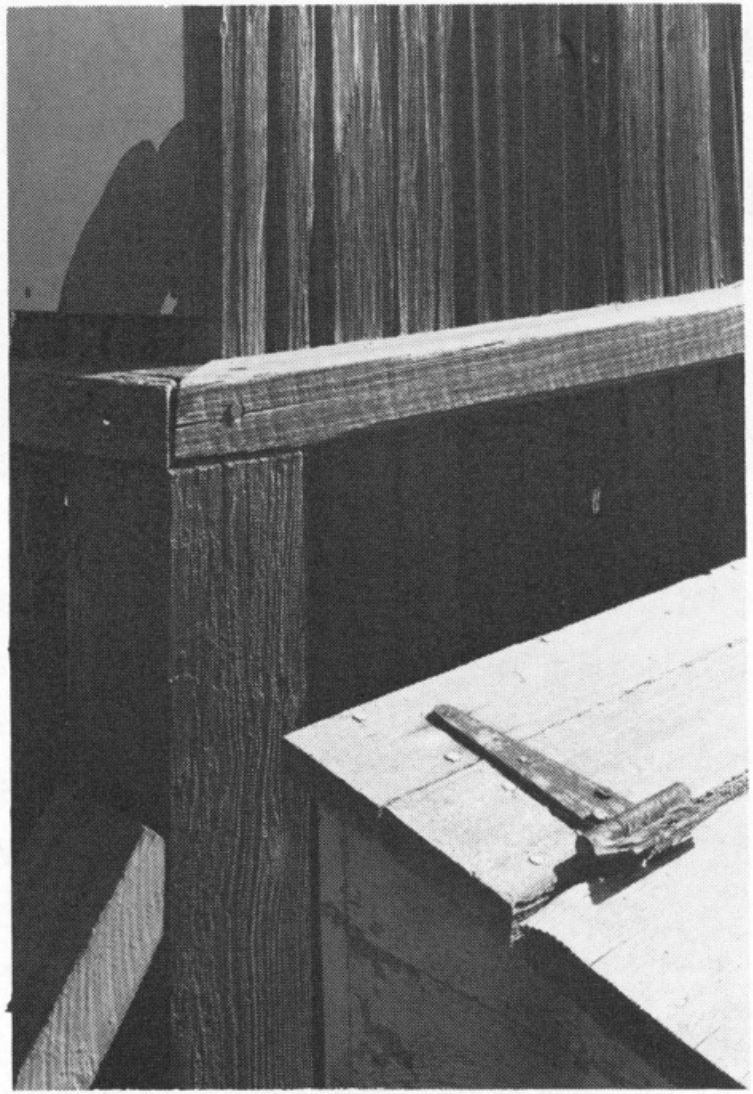


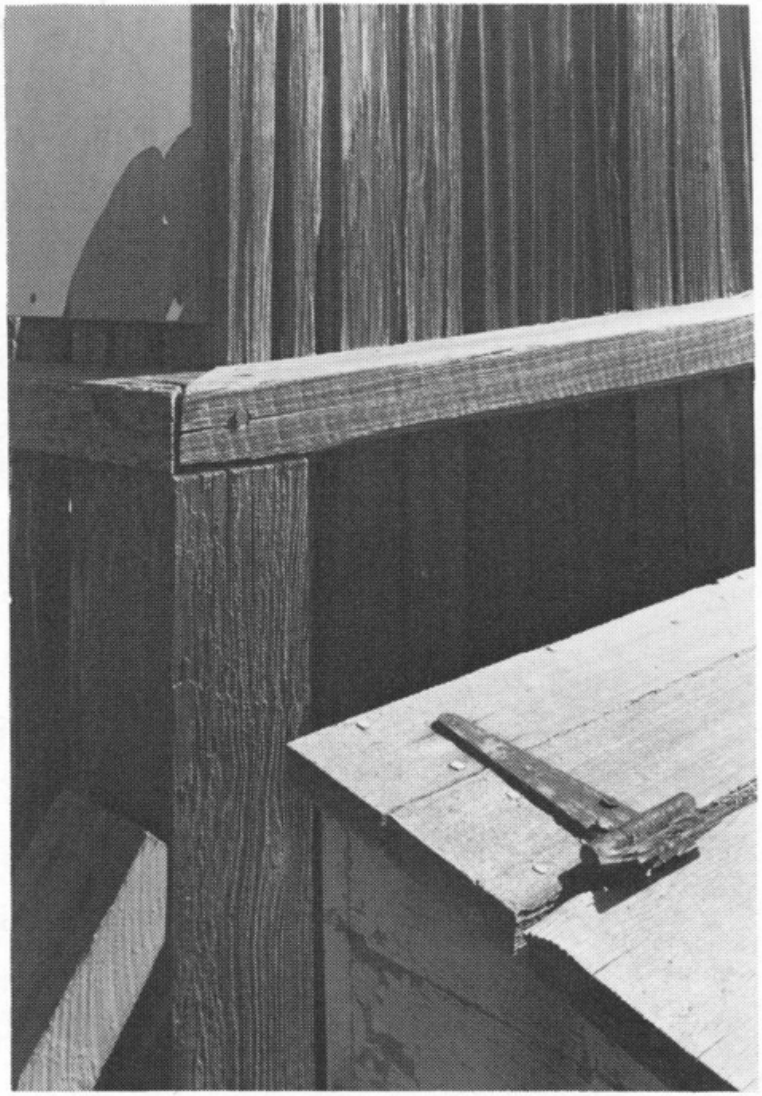
Figure 15.8 Effect of development time on characteristic curve of current sensitive materials

From The Manual of Photography, Jacobson et al.

Reduced development



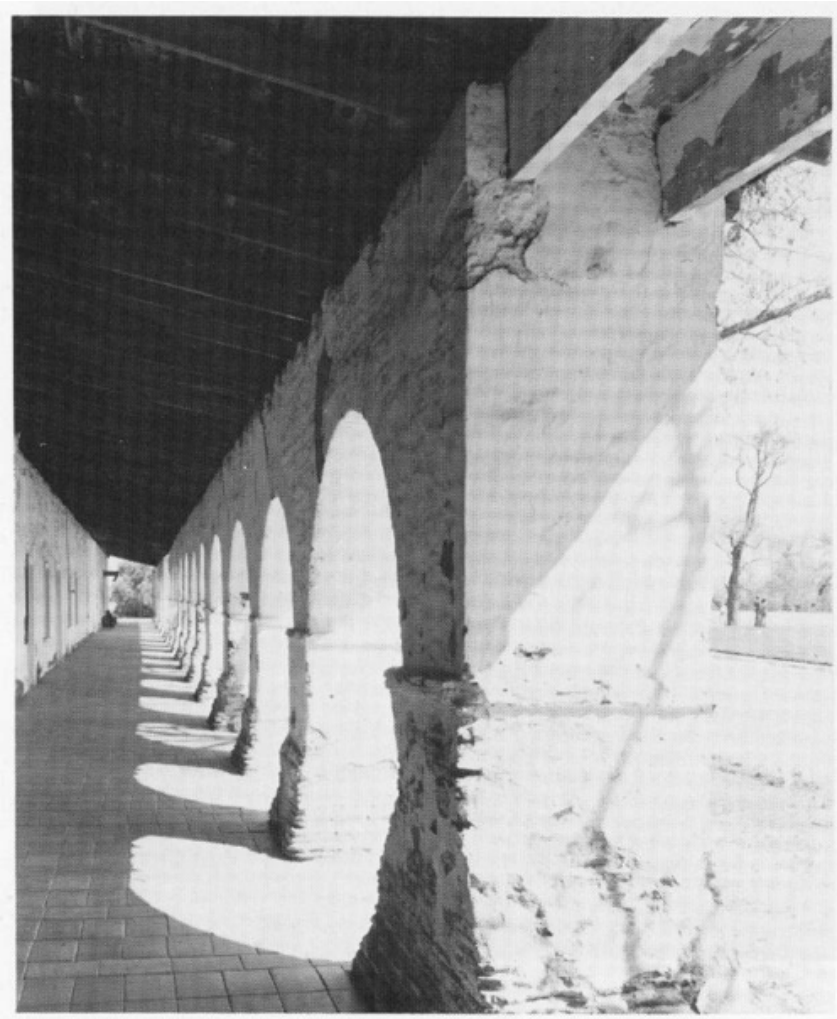
Normal development



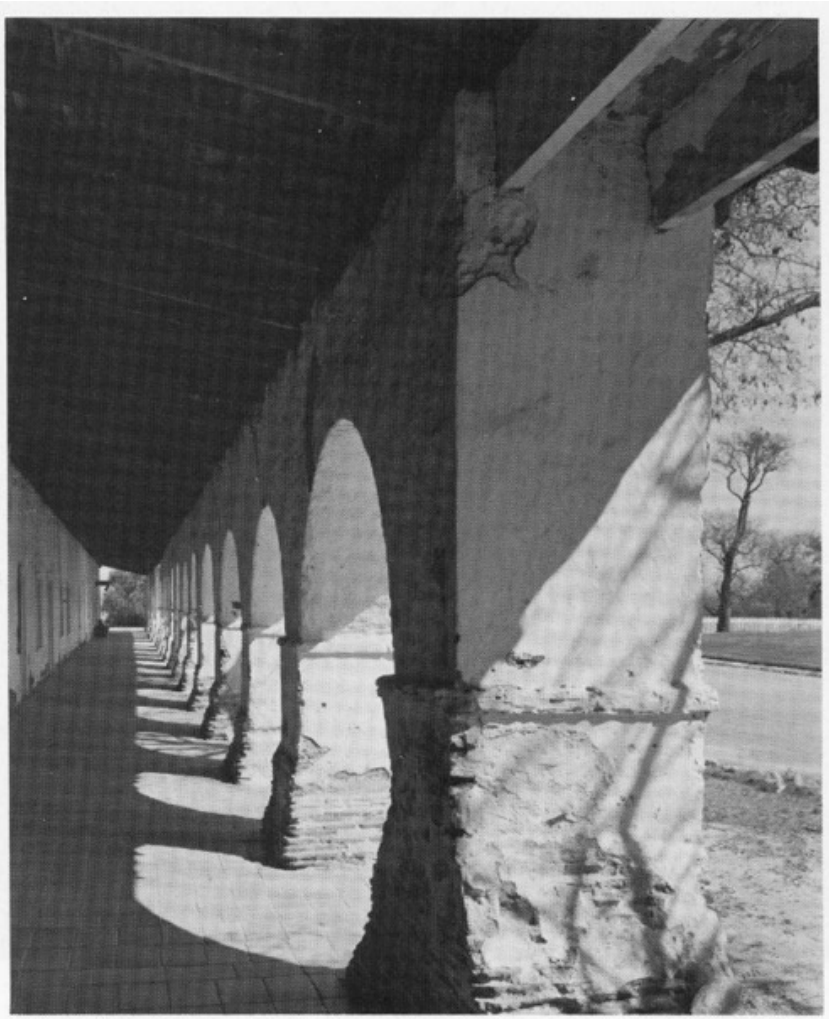
Contraction (short development)

Source: Ansel Adams

Two solutions



One development solution



Two development solution:
the dark areas are the same,
but bright areas are different

Source: Ansel Adams

Pre-exposure

- **Briefly expose negative to a uniform light**
- **Raises the values of everything (in particular puts dark values above the low-contrast toe of response curve)**

Without pre-exposure

With pre-exposure

Source: Ansel Adams

Paper

- **Paper grade = contrast (think γ)**
- **Multigrade paper**
  - For black and white
  - grade depends on wavelength
  - Use filters to choose grade

Questions?

The Zone system

- **Formalism to talk about exposure, density**
- **Zone = intensity range, in powers of two**
- **In the scene, on the negative, on the print**

Source: Ansel Adams

The Zones

The Zones

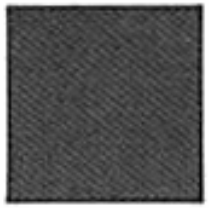
0 Solid black; the same as the film rebate

I Nearly black; just different from Zone 0

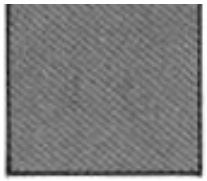
II The first hint of texture

III Textured shadow; the first recognizable shadow detail

IV Average shadow value on Caucasian skin, foliage and buildings



V Middle grey: the pivot value; light foliage, dark skin



VI Caucasian skin, textured light grey; shadow on snow

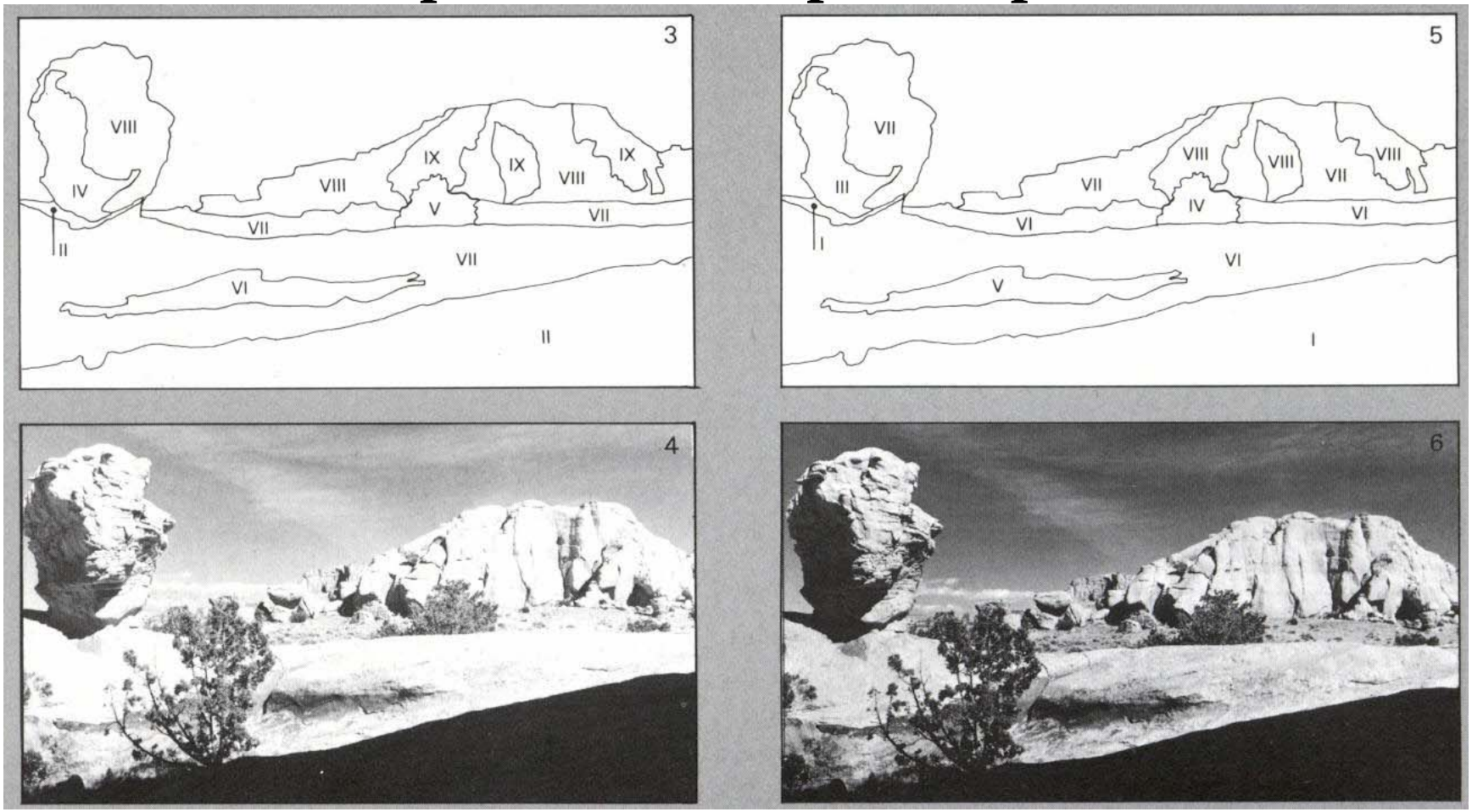
VII Light skin; bright areas with texture, such as snow in low sunlight

VIII Highest zone with any texture

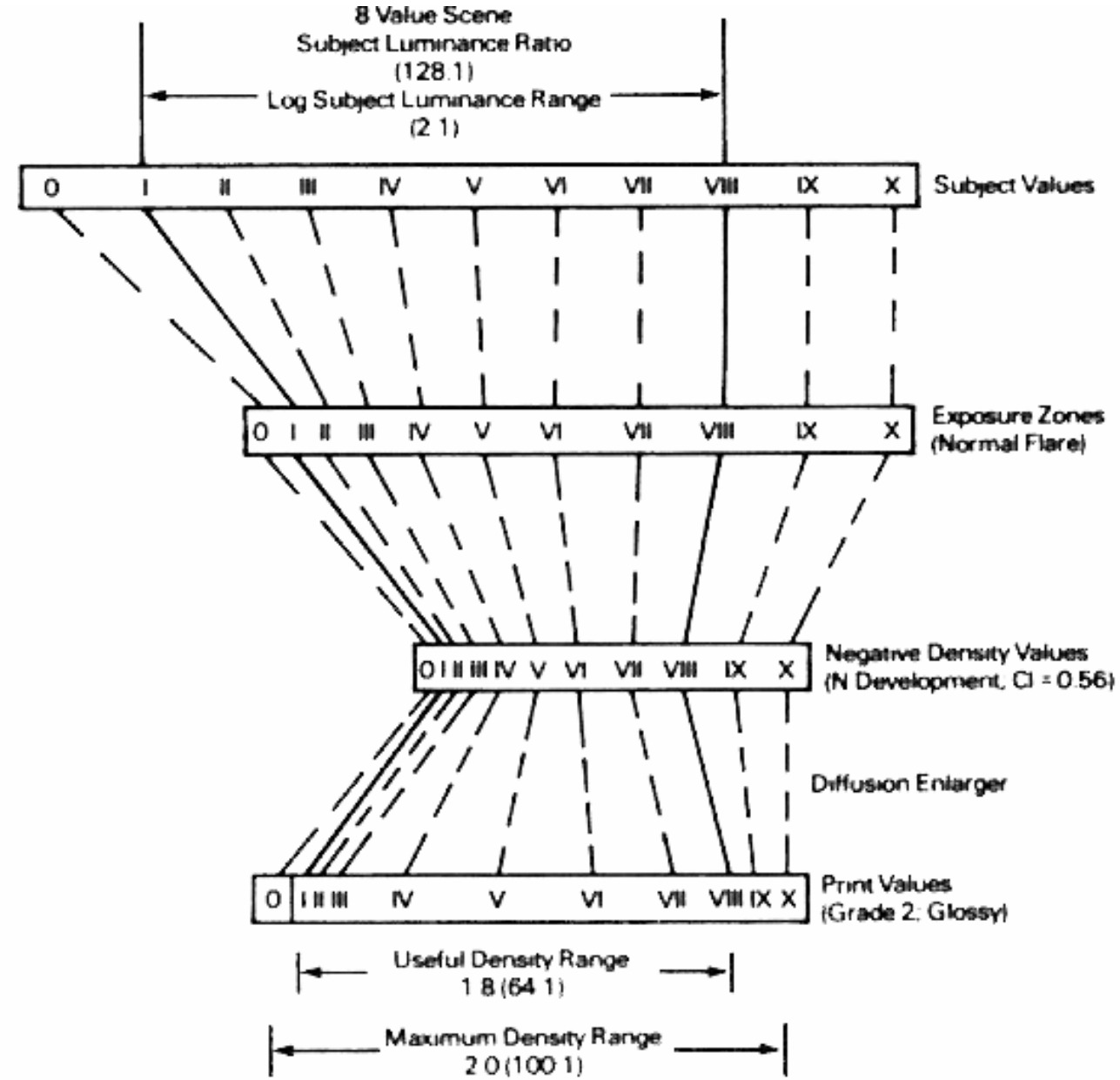
IX Pure untextured white

The Zone system

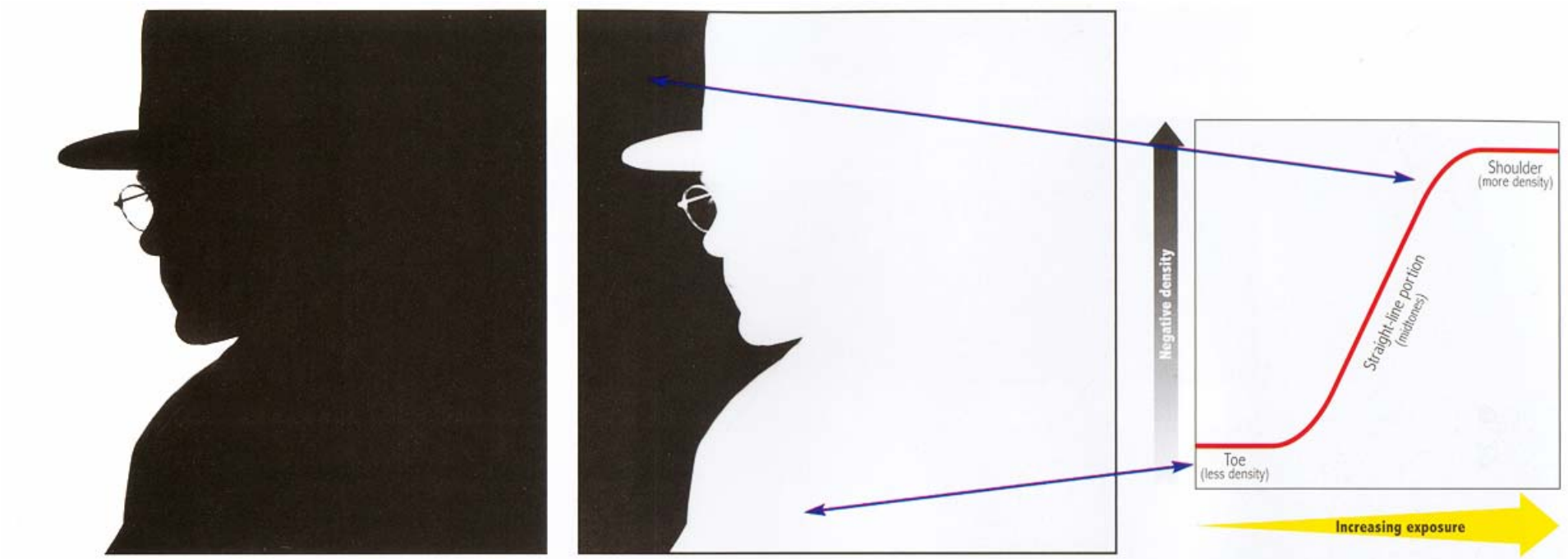
- **You decide to put part of the system in a given zone**
- **Decision: exposure, development, print**



Recap for film



Limited dynamic range can be good!



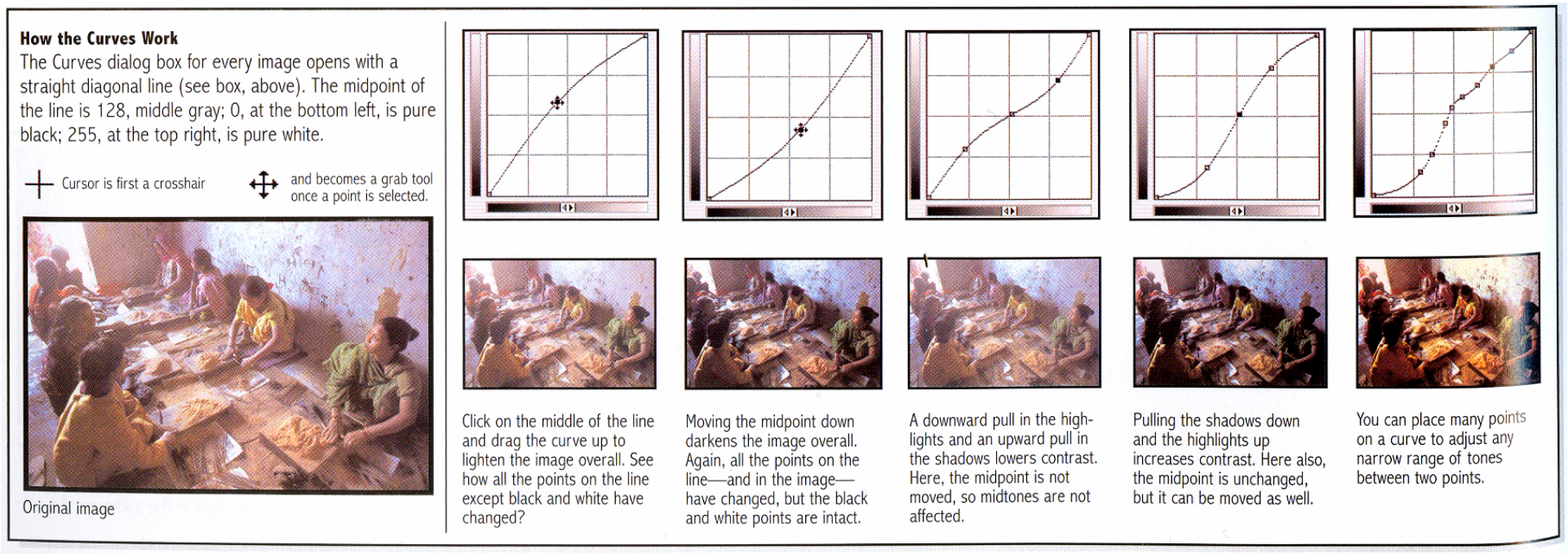
JEFF SEDLICK Man in Hat, 1998

In this high-contrast scene, the silhouetted man is at the toe of the curve. *The white wall is at the shoulder of the curve. The picture has few grays, and the curve rises steeply in the middle straight-line portion of the curve.*

From Photography by London et al.

Photoshop curves

- **Specify an arbitrary remapping curve**
- **Especially useful for black and white**



How the Curves Work

The Curves dialog box for every image opens with a straight diagonal line (see box, above). The midpoint of the line is 128, middle gray; 0, at the bottom left, is pure black; 255, at the top right, is pure white.

Cursor is first a crosshair

and becomes a grab tool once a point is selected.

Original image

Click on the middle of the line and drag the curve up to lighten the image overall. See how all the points on the line except black and white have changed?

Moving the midpoint down darkens the image overall. Again, all the points on the line—and in the image—have changed, but the black and white points are intact.

A downward pull in the highlights and an upward pull in the shadows lowers contrast. Here, the midpoint is not moved, so midtones are not affected.

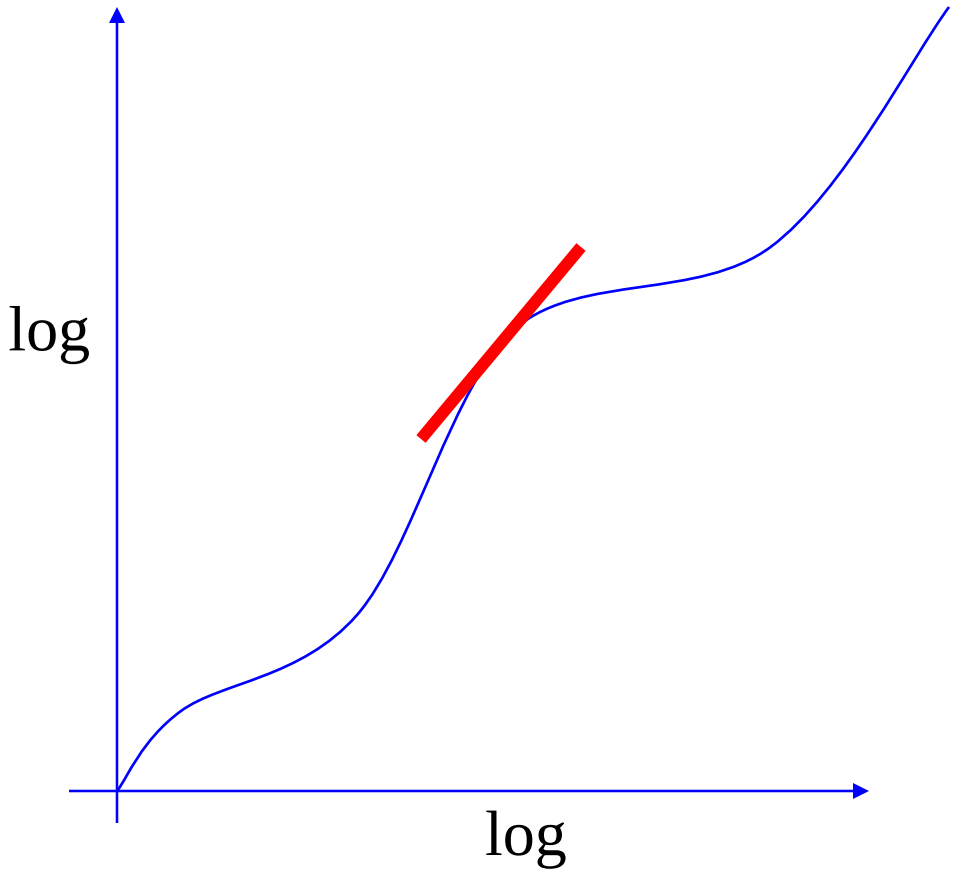
Pulling the shadows down and the highlights up increases contrast. Here also, the midpoint is unchanged, but it can be moved as well.

You can place many points on a curve to adjust any narrow range of tones between two points.

From Photography by London et al.

Contrast modification by the curve?

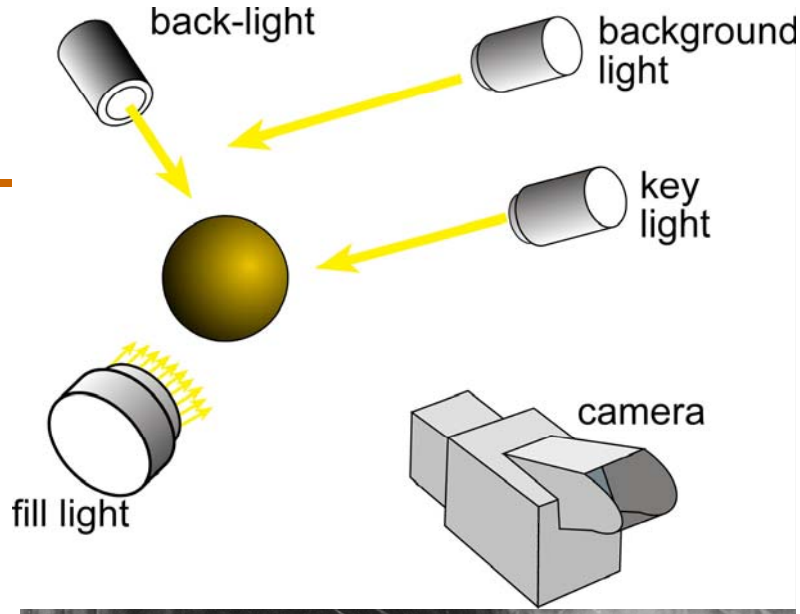
- **Look at the remapping in log-log**
- **Slope = local exponent=contrast modification**



Questions?

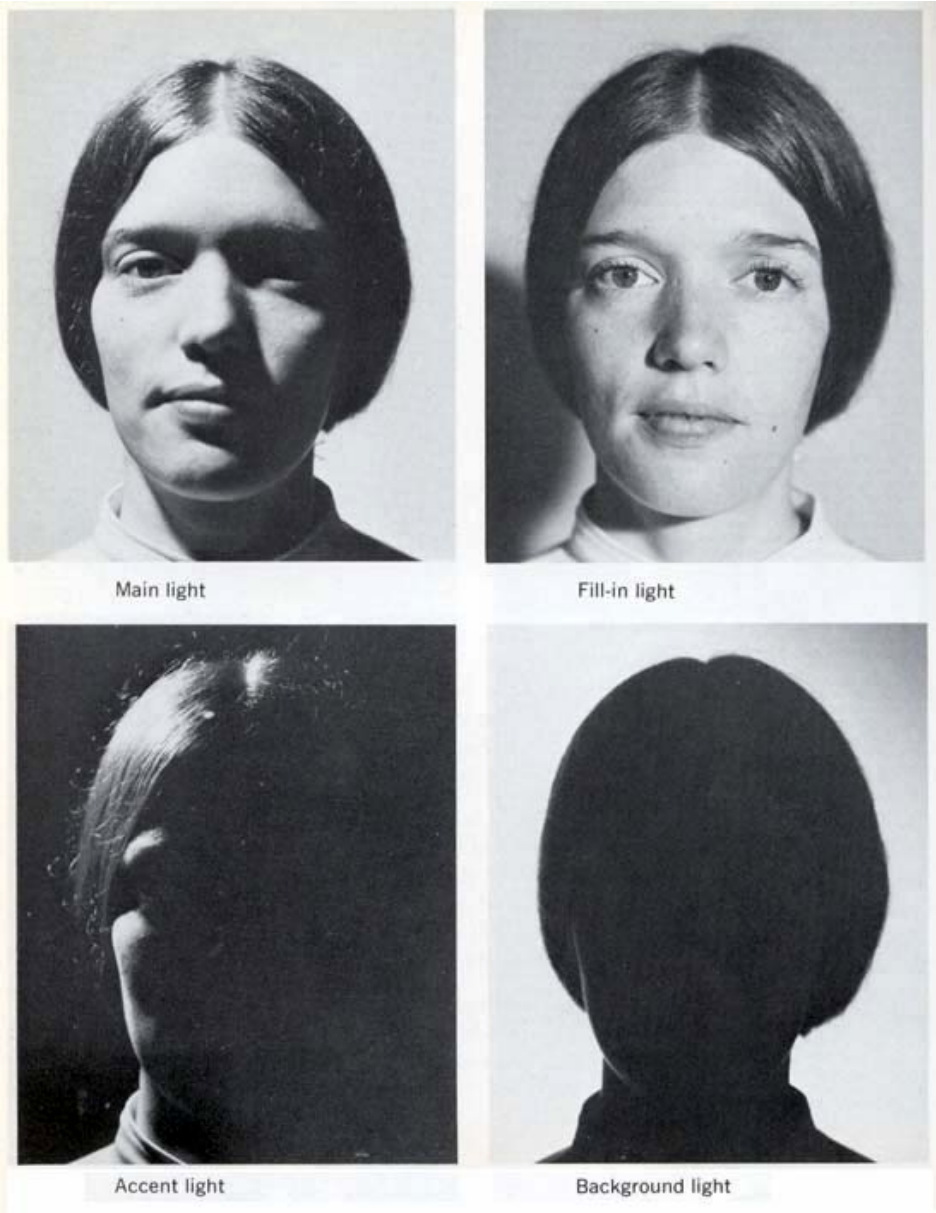
Lighting

- **E.g. 3-point lighting**
  - Reduce dynamic range
  - Emphasize silhouettes → 3D cues

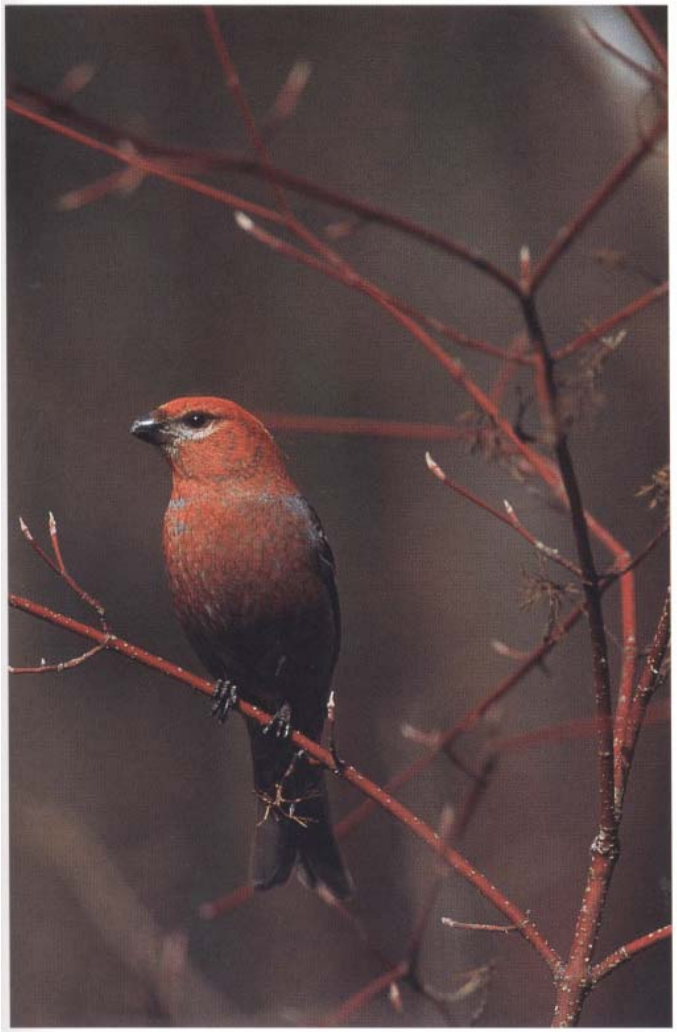


- **Goals of lighting:**
  - Manage dynamic range
  - Reveal shape, layout, material
  - Tell story

Portrait lighting

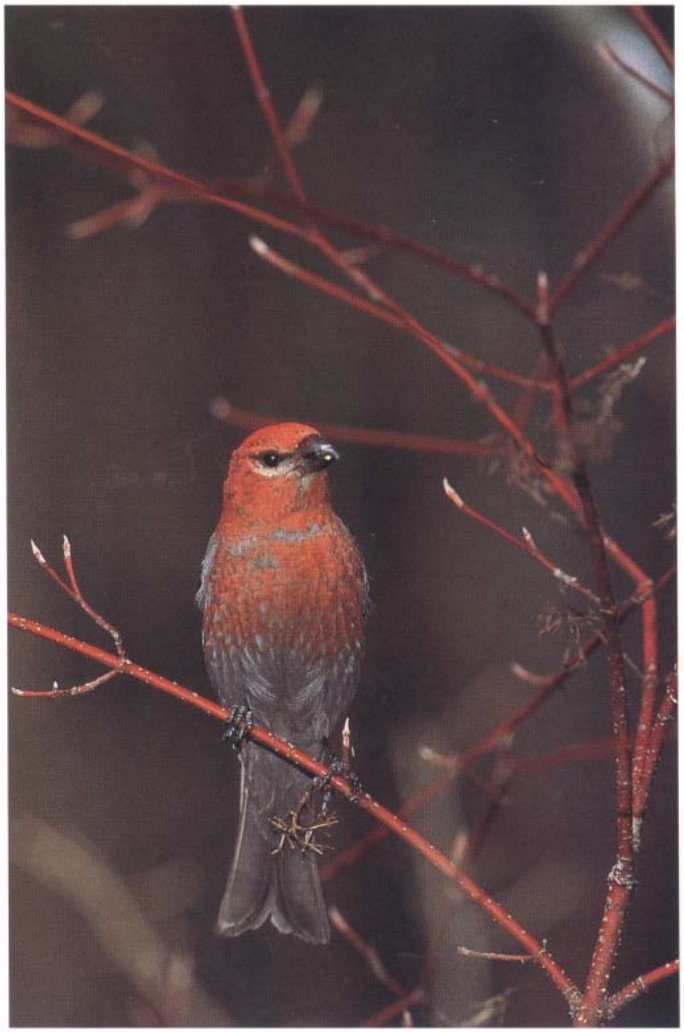


Fill-in flash



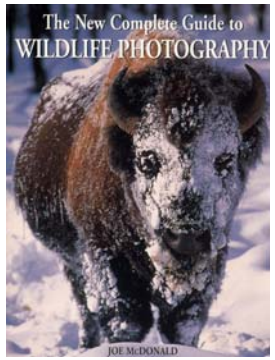
PINE GROSBEAK, Wild Eyes, Montana. 500mm F4 lens, 1/250 sec. at *f*/4.5, Fujichrome 100

This image and the one at right were made within seconds of each other. This one was made without flash, and the lower half of the bird lies in shade.

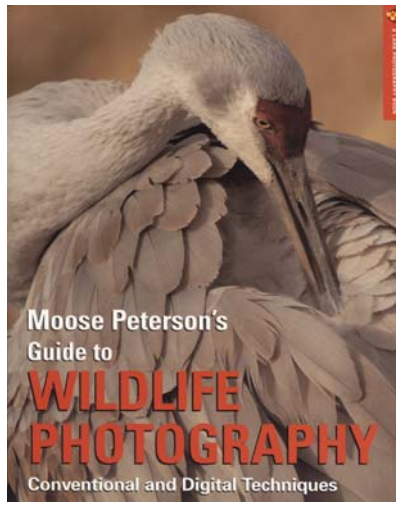


PINE GROSBEAK, Wild Eyes, Montana. 500mm F4 lens, 1/250 sec. at *f*/4.5. TTL teleflash at -1.0, Fujichrome 100

Using flash, the previously dark areas are filled in with visible detail, and the entire scene looks a little brighter due to the brightened red twigs, as well. Note that the flash casts a telltale shadow off the bird's perch, visible as a dark line directly below the twig. Which image is the best? It is up to the viewer to decide.



Mountain Bluebird.
Captured By D1H,
600mm f/4D ED-IF AF-S,
on Lexar digital film.
The top photo was
exposed with existing light;
photo on left was captured
using flash fill.



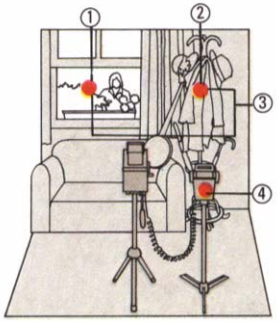
Fill-in flash

- **Use flash to reduce contrast**

Exposure for outside

Exposure for inside

Average exposure



Using fill flash

From Le Livre de la Photo Couleur (Larousse)

Interior photography

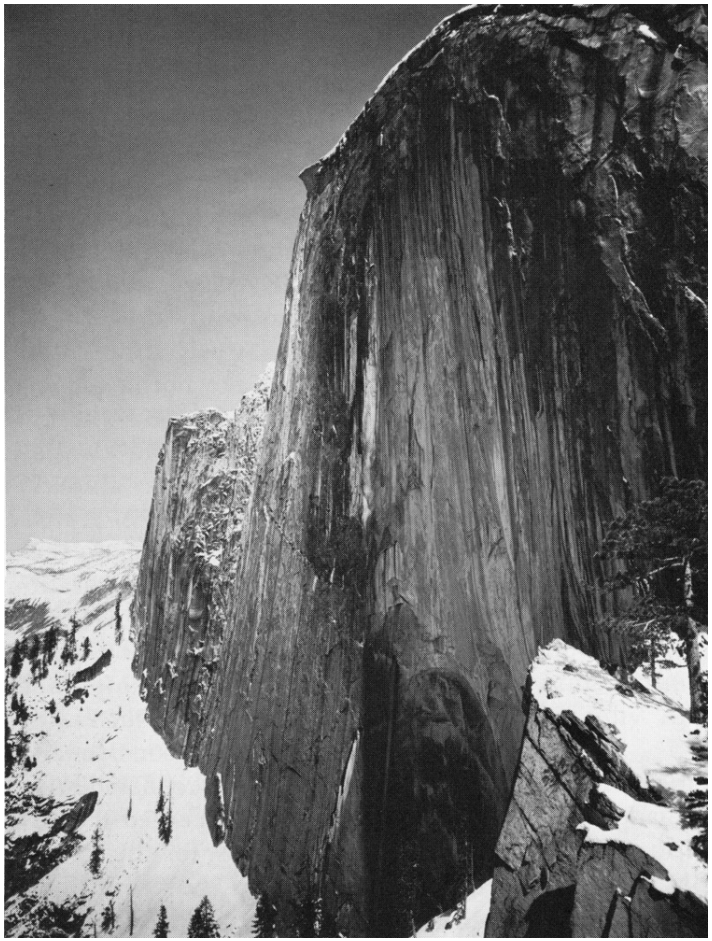
- **Balancing exterior and interior is challenging!**

Let’s try it!

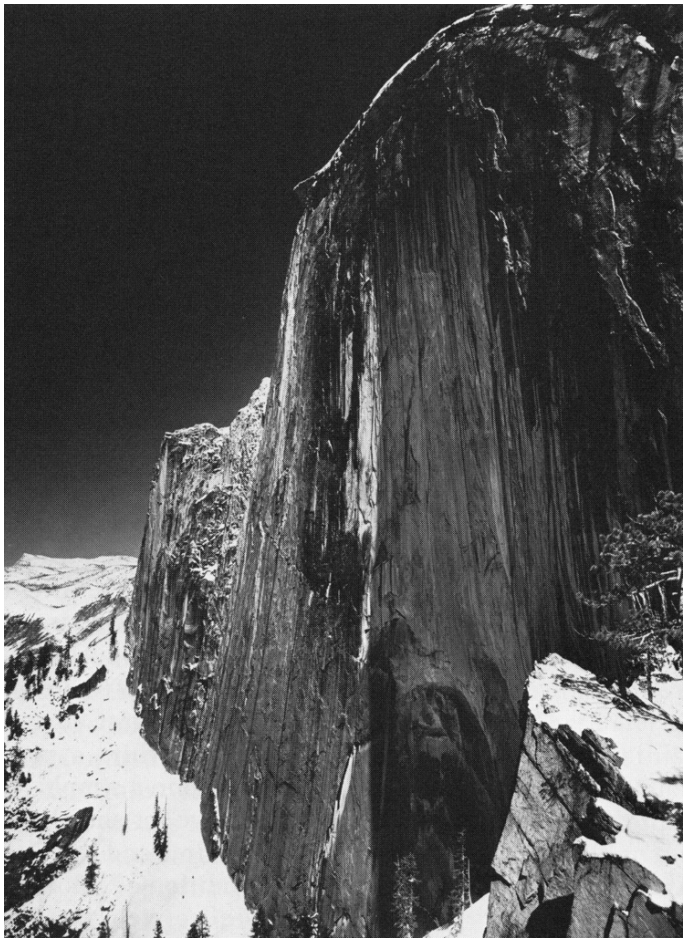
Questions?

Filtering: black and white

- **Red/orange/yellow filters darken the sky**



No filter



With red filter

Source: Ansel Adams

Graduated neutral density

No filter: sky is too bright

Vertical neutral density gradient

Graduated ND & landscape

- **Art Wolfe: In the late evening light, I composed this image using a graduated neutral-density filter to bring the overall exposure into alignment, thus preserving the detail in the clouds in the sky and the reflections on the water.**

Portage Lake, Horizontal

http://www.artwolfe.com/

Graduated ND & landscape

- **Art Wolfe: Here I had to use a combination of filters and settings that greatly reduced my chance of success. I used my zoom to bring in Denali and the moose. A polarizing filter brought out the rich colors of the tundra and darkening the sky and a graduated, neutral-density filter to bring the entire scene into the same exposure.**

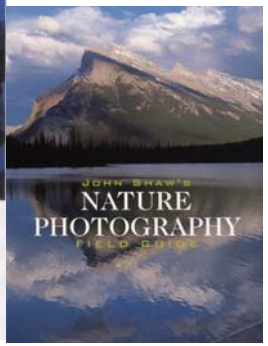
Denali Autumn

http://www.artwolfe.com/

Graduated ND & landscape

HOWSE PEAK AND REFLECTIONS IN
LOWER WATERFOWL LAKE, BANFF
NATIONAL PARK, CANADA.
Nikon F4, Nikon 28–70mm lens, Fuji Velvia.

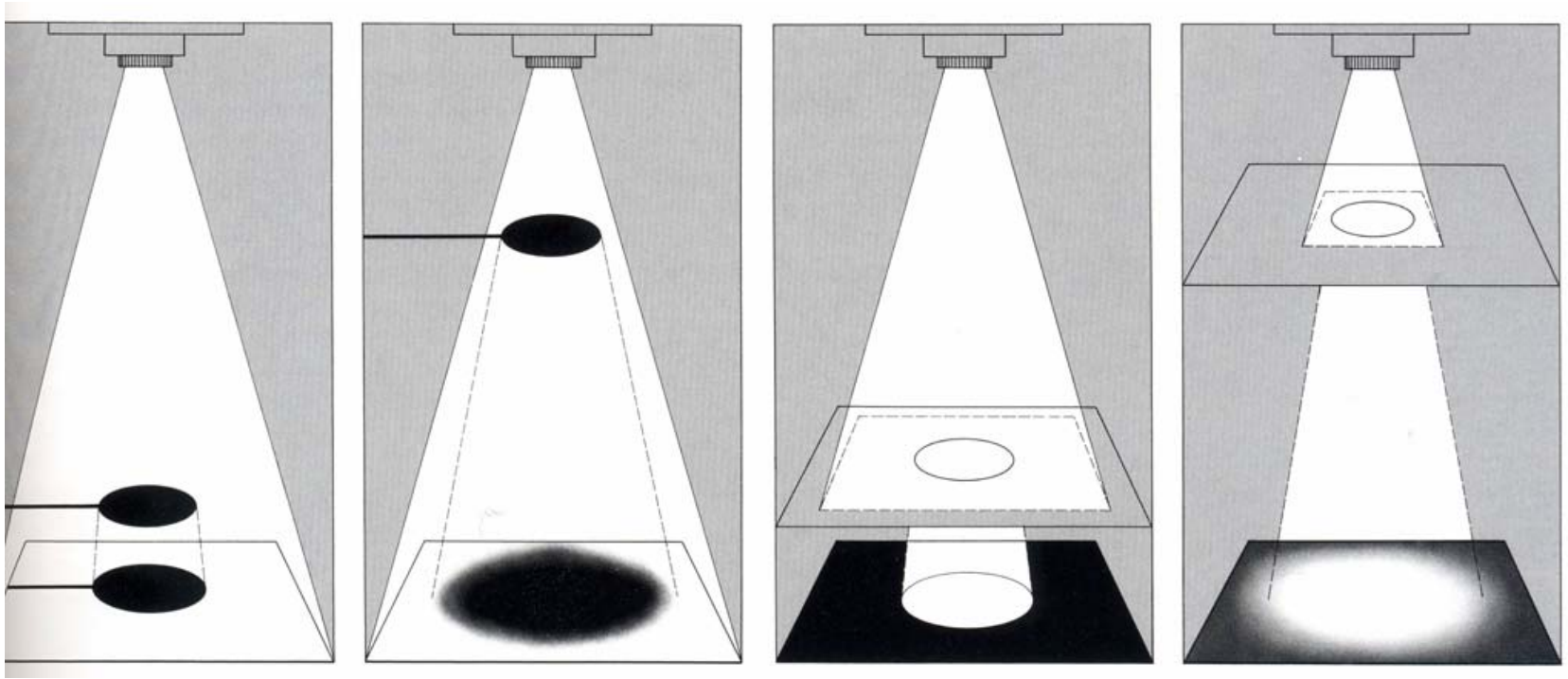
This photo is over-filtered. I used a 2-stop graduated ND where I should have used a 1-stop. Notice that the reflection of the mountain is slightly lighter than the mountain itself, a physical impossibility.



Questions?

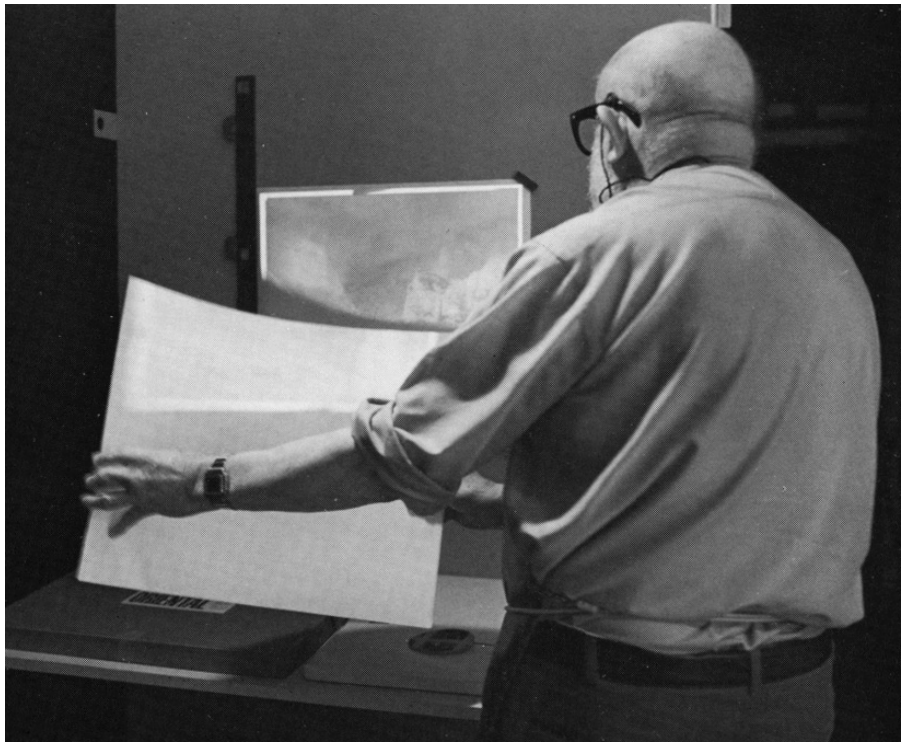
Dodging and burning

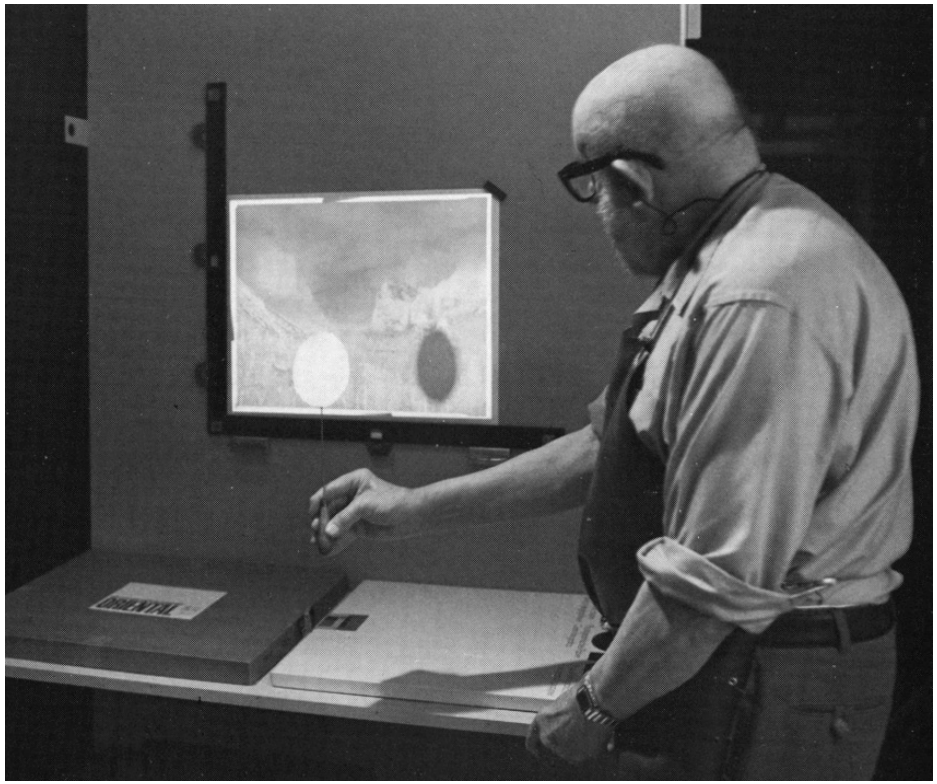
- **During the print**
- **Hide part of the print during exposure**
  - Makes it brighter



From The Master Printing Course, Rudman

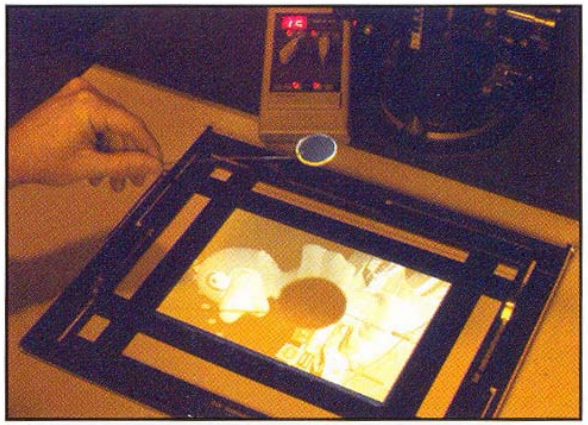
Dodging and burning

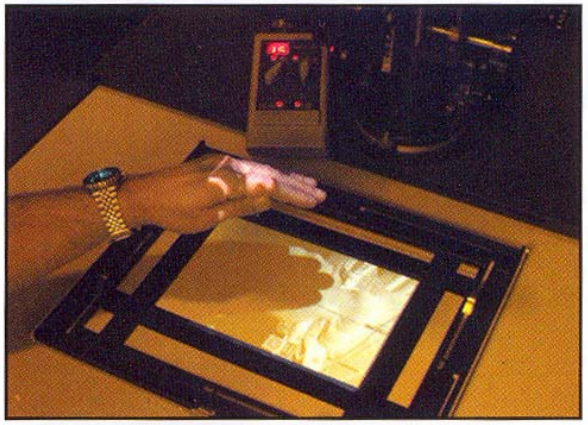




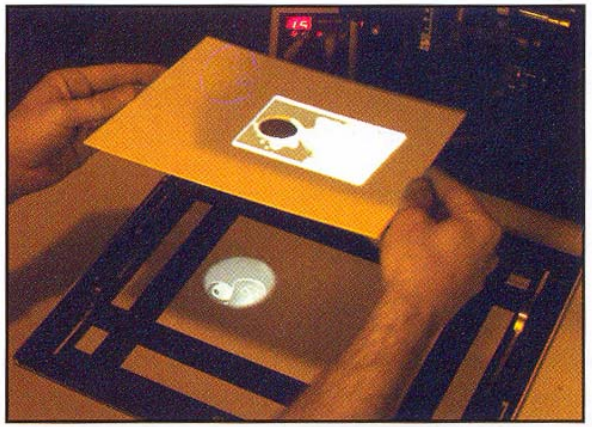
Source: Ansel Adams

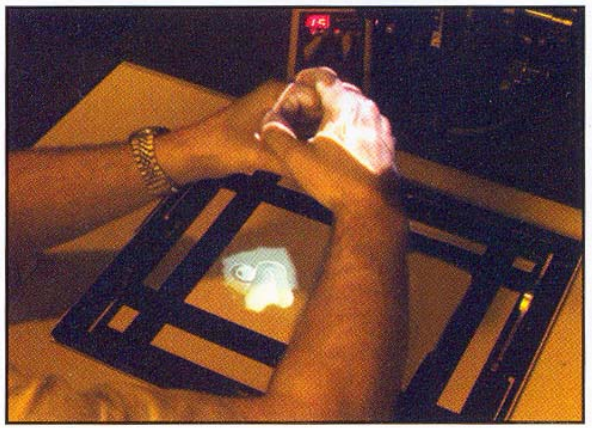
Dodging and burning





Dodging *holds back light during the basic printing exposure to lighten an area.*



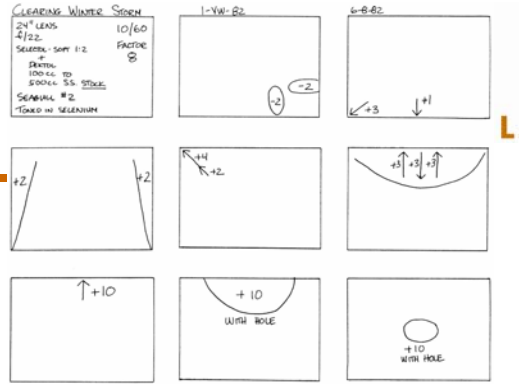


Burning *adds light after the basic exposure to darken an area.*

From Photography by London et al.

Dodging and burning

- **Must be done for every single print!**

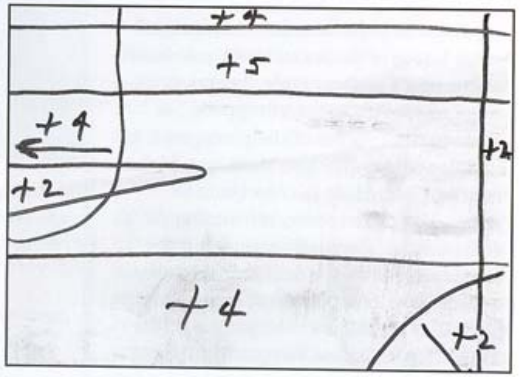


Straight print

After dodging and burning

Above, the original, straight print was exposed for 10 seconds without any manipulation. *Below, each band of a test strip became darker as the photographer added light. Test strips not only help determine the best overall exposure, but also guide decisions about how much more time to expose certain areas (burn) or how much time to subtract from the basic exposure (dodge) in parts of the print.*

5 sec 10 sec 15 sec 20 sec
Additional exposure



GERRY RUSSELL Mono Lake

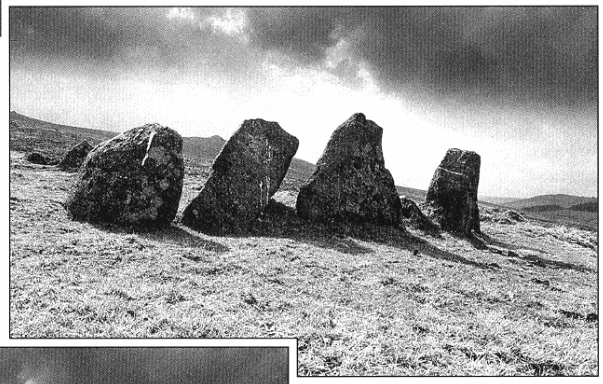
Dodging, burning, and the exposure in general give you choices. *You can make a relatively realistic rendition of a scene or choose to emphasize and dramatize parts of it, as in sky above.*

Reprints will be easier if you make notes of what you did. *A very light print (left) or a sketch of the print records how much to burn or dodge each part of the image.*

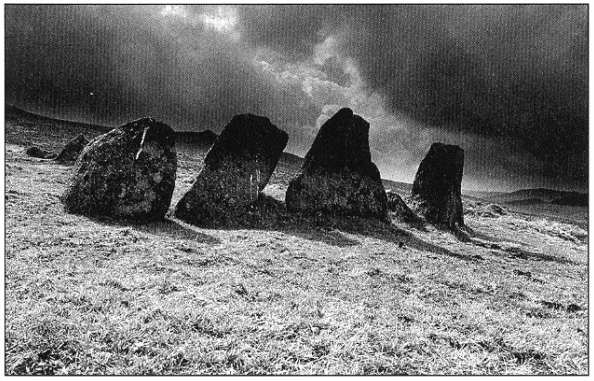
From Photography by London et al.

Dodging & burning is difficult!

A *The straight work print without additional burning-in.*

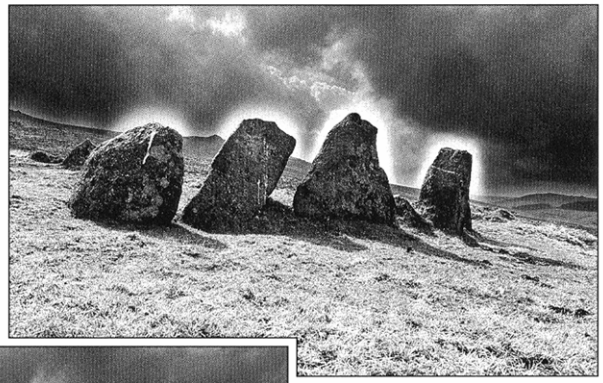


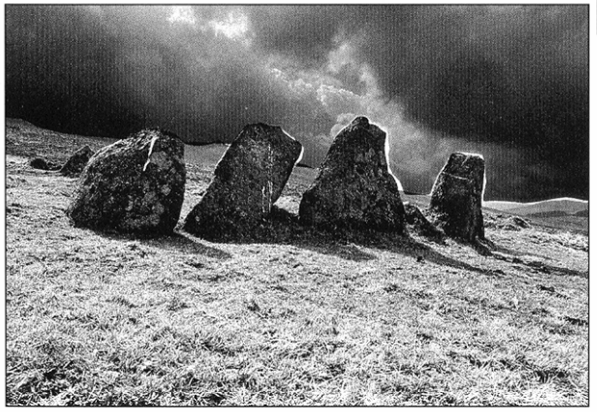
B *This print shows the result of trying to mask off the foreground by using a moving card. An even more obvious light band will appear in the sky if the card is not kept moving.*



C *In order to remove the light band in fig B, the mask has been lowered. This, however, has caused parts of the horizon to become black.*

D *The halo effect, here deliberately exaggerated, resulted from dodging the stones during the second exposure while burning-in the sky.*





E *It is very difficult to cut a dodging card with precision, especially for a relatively small print like this. As a result, parts of the sky at the horizon are white, although careful spotting can disguise this problem when it is small. But parts of the mid-grey hill tops have gone jet black, which is less easy to rectify.*

Source: Rudman

Advanced versions

- **Dodging card**
  - Precisely cut out shapes in the image
- **Multigrade paper**
  - Dodge/burn with different filter/grade
  - Vary local contrast (not only brightness)
- **Focus**
  - Change focus of enlarger and doge and burn
  - Local control of sharpness
- **Locally paint chemical on print**
  - Can have a multiplicative, additive or exponential effect depending on chemical

Questions?

- **Gordon Parks**

Digital dodge-burn and graduated ND

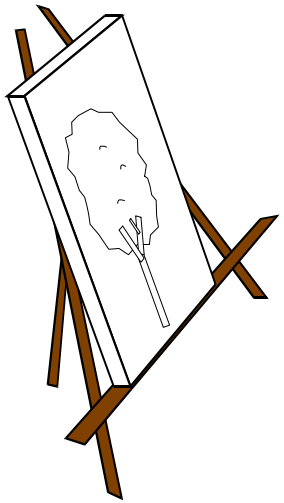
- **Use adjustment layer and gradient tool**
  - Use curve adjustment layer
  - Modulate its effect using the layer mask
- **Just paint in black**
  - On a separate layer
  - With a low opacity
- **Multiple exposure photography**
  - Use a tripod
  - “Bracket” your exposure
  - Stack exposures as layers in photoshop
  - Use layer masks to select which region comes from which exposure

Questions?

Limitations of the medium

- **Flatness**
- **Finite size, frame**
- **Unique viewpoint**
- **Static**
- **Contrast and gamut**

Limited medium



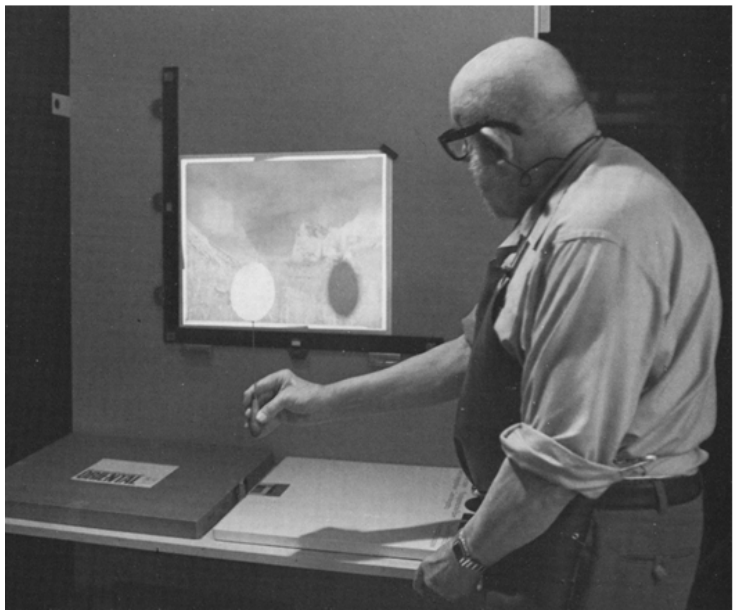
Notion pioneered by H. von Helmholtz

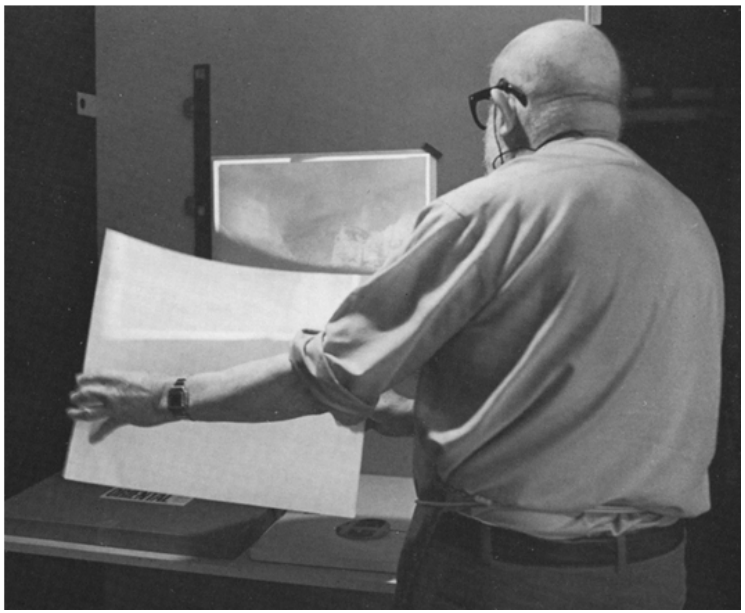
Accentuation: watercolor

- **Turner, Joseph Mallord William, S. Giorgio Maggiore: Early Morning, 1819, Watercolor, 22.4 x 28.7 cm, Tate Gallery, London**

Compensation: tone mapping, dodge

- **Get the advantage of limitation without defect**

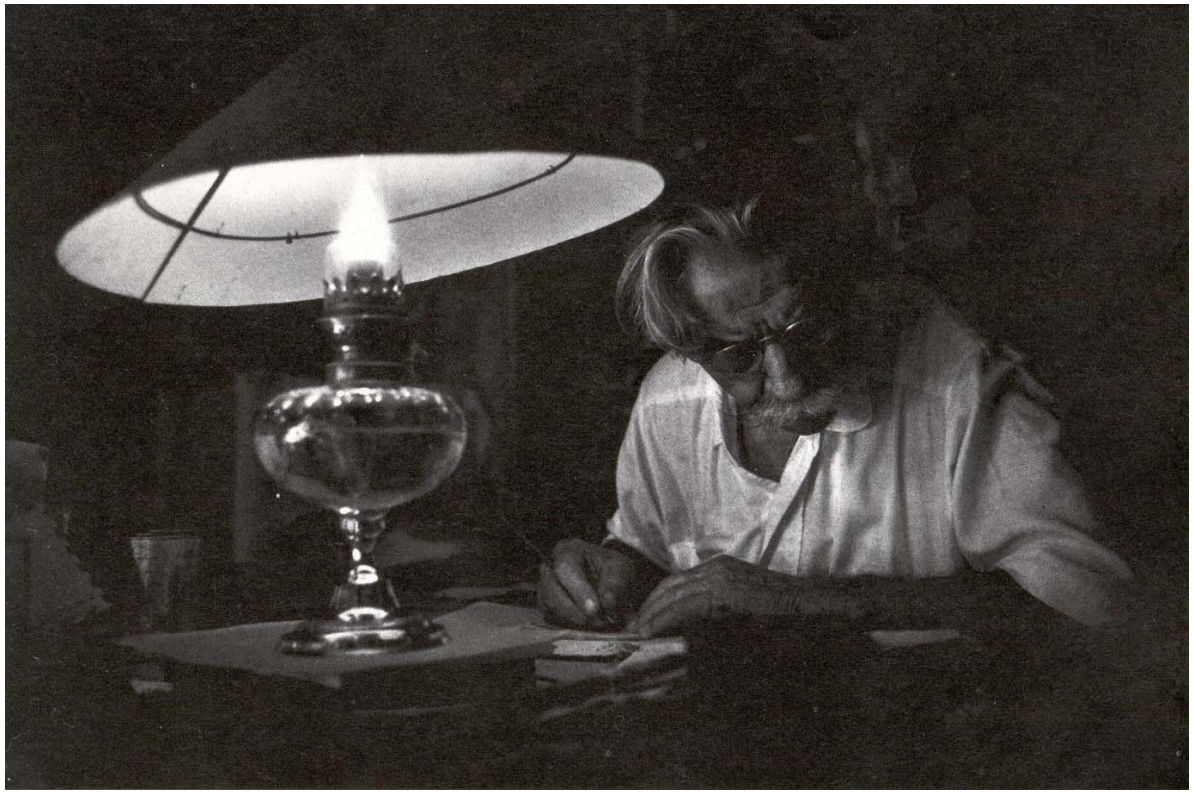




Limitations of the medium

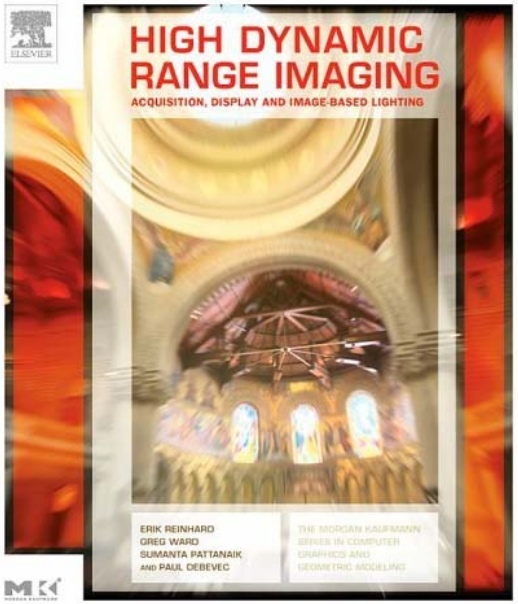
- **Can be eliminated**
- **Can be compensated**
- **Can be accentuated**

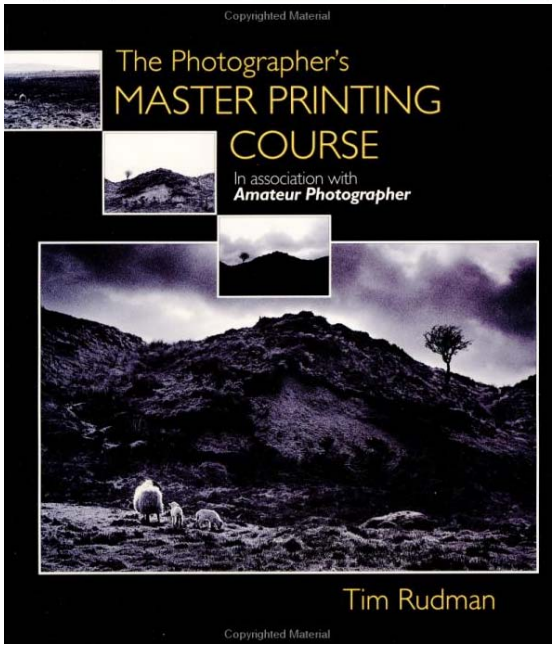
Are often an advantage as well



Questions?

References


HIGH DYNAMIC RANGE IMAGING
ACQUISITION, DISPLAY AND IMAGE-BASED LIGHTING
ERIK REINHARD
GREG WARD
SUMANTA PATTANAIK
AND PAUL DEBEVEC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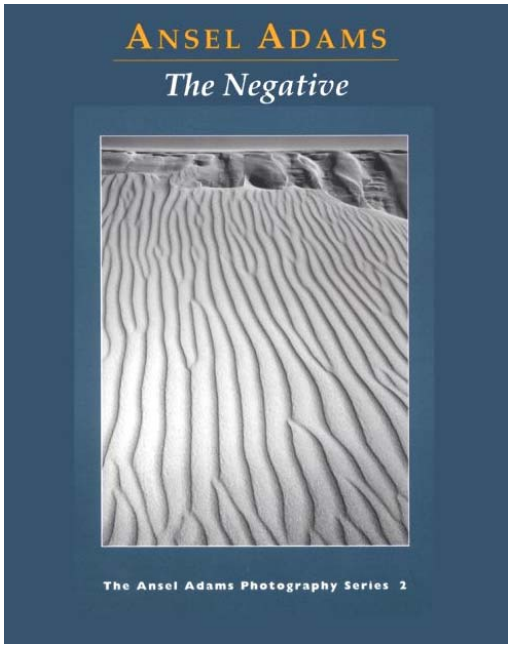
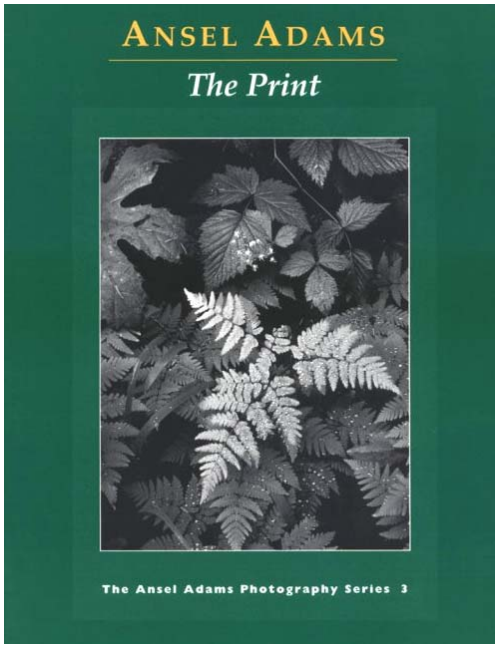

ANSEL ADAMS
The Negative
The Ansel Adams Photography Series 2


ANSEL ADAMS
The Print
The Ansel Adams Photography Series 3

Refs

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http://www.clarkvision.com/imagedetail/dynamicrange2/

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