Dynamic Range and Contrast

6.098 Digital and Computational Photography
6.882 Advanced Computational Photography

Dynamic Range and Contrast

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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

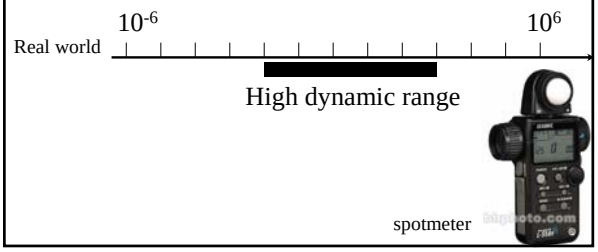
- **Exposure: how bright is the scene overall**
- **Dynamic range: contrast in the scene**
- **Bottom-line problem: illumination level and contrast are not the same for a photo and for the real scene.**

Example:

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

Real world dynamic range

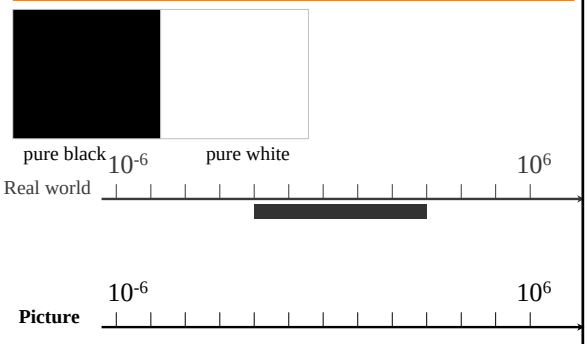
- **Eye can adapt from ~ 10^{-6} to 10^{6} cd/m^2**
- **Often 1 : 100,000 in a scene**

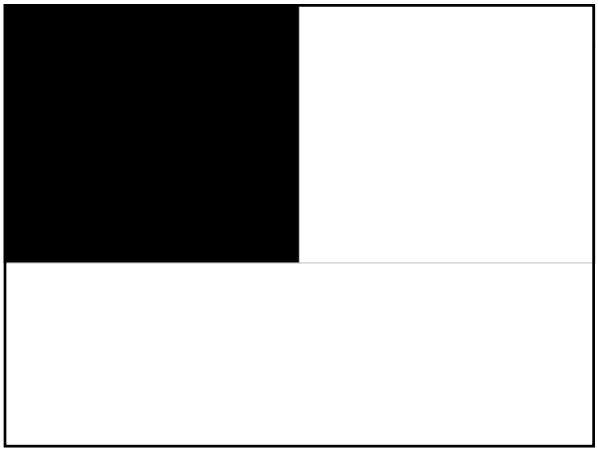


The world is high dynamic range

- **Slide from Paul Debevec**

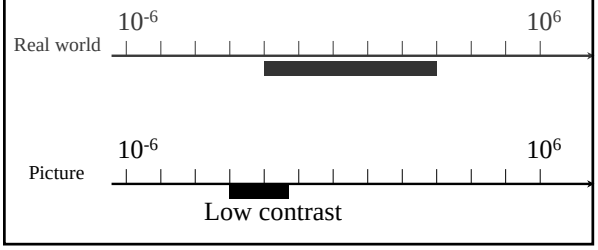
Picture dynamic range: Guess!





Problem 2: Picture dynamic range

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



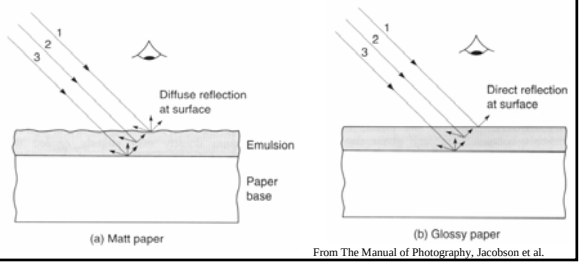
Low contrast

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**



From The Manual of Photography, Jacobson et al.

Paper dynamic range

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

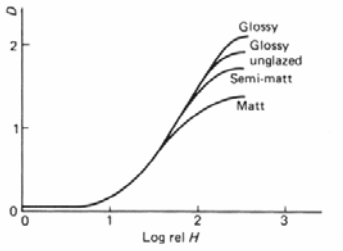
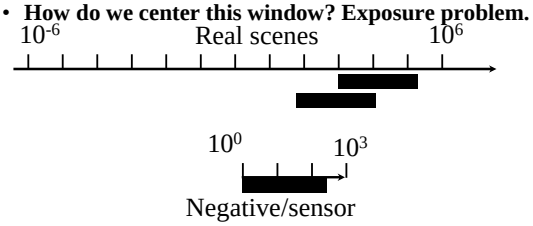


Figure 15.24 Characteristics of papers of different surfaces

From The Manual of Photography, Jacobson et al.

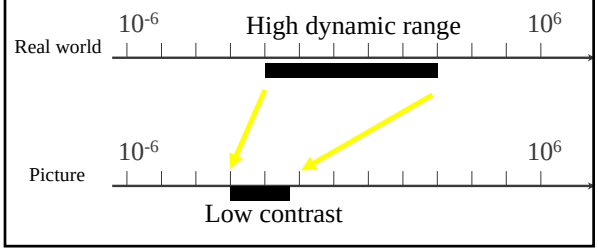
Problem 1

- **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.**



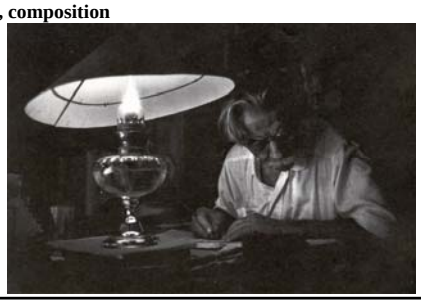
Contrast reduction

- **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**

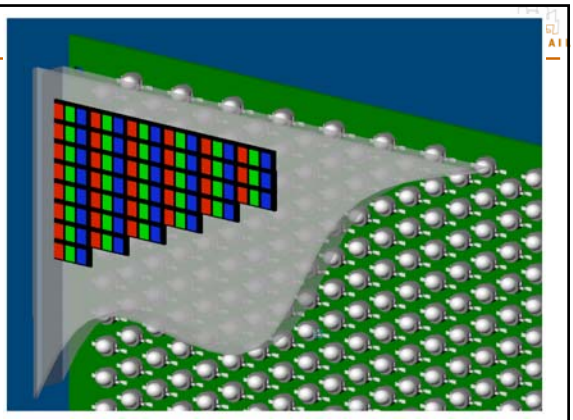


Questions?

Sunnybrook HDR display

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

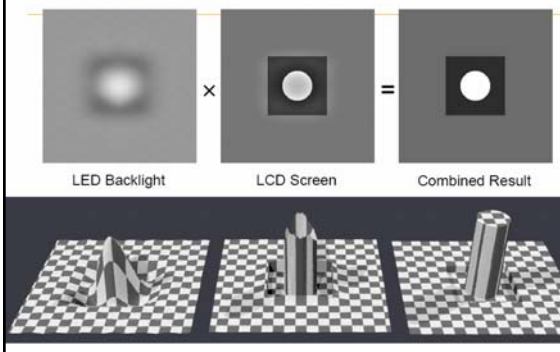
Slide from the 2005 Siggraph course on HDR



Slide from the 2005 Siggraph course on HDR

How It Works

SIGGRAPH2005

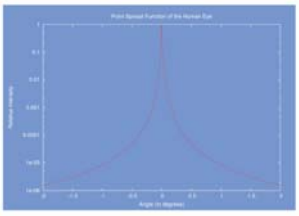


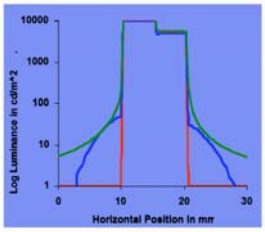
Slide from the 2005 Siggraph course on HDR

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)

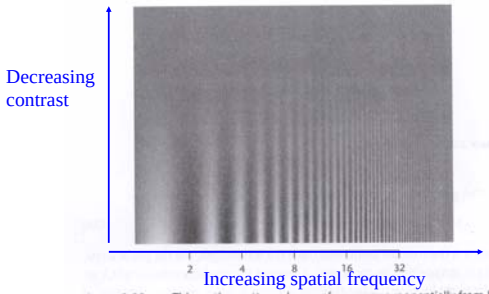


Figure 2.21 This grating pattern changes frequency exponentially from left to right and varies in contrast in a vertical direction. The highest frequency you can resolve depends on the distance from which you view the pattern. The scale gives the spatial frequency if it is viewed from 2.3 m.

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

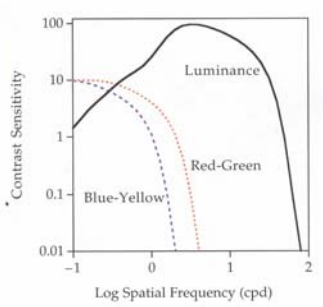


Figure 1-18. Spatial contrast sensitivity functions for luminance and chromatic contrast.

Important

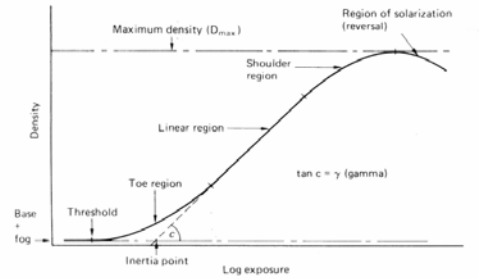
- Multiply image by constant: make it brighter
- Contrast = ratio
- How do we change contrast then? Exponent, e.g. square root reduces contrast

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**

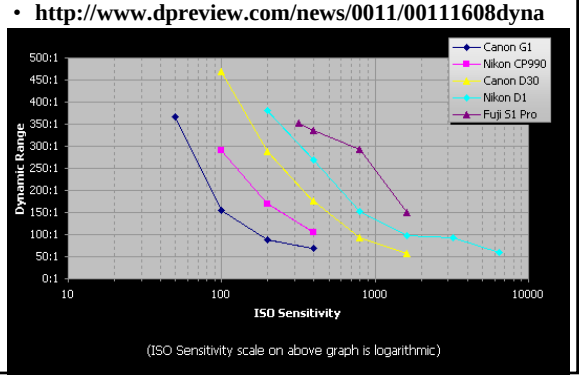
Sensors and dynamic range

- **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

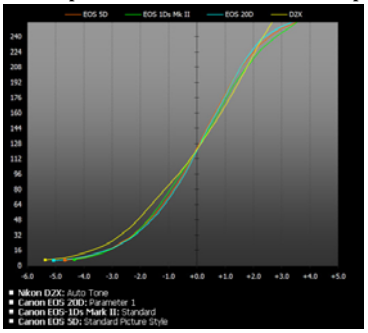
- **http://www.dpreview.com/news/0011/00111608dyna**



(ISO Sensitivity scale on above graph is logarithmic)

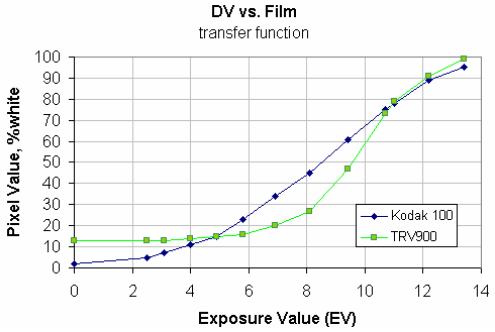
Response curve of current D-SLR

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



Response curve, dynamic range

- **Video sensors have poor dynamic range**

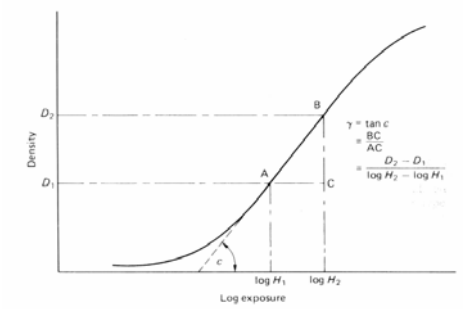


The infamous gamma curve

- **A gamma curve $x \rightarrow x^{\gamma}$ 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**

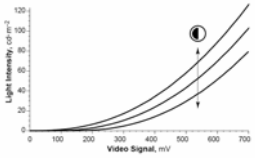


Gamma in terms of density and log exposure

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

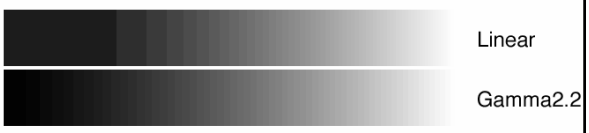
Solution: gamma

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**

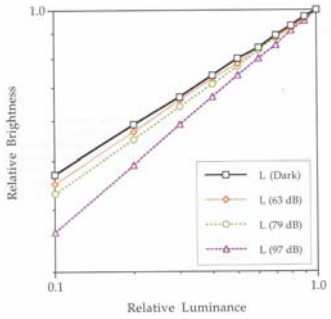
Gamma encoding

- 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

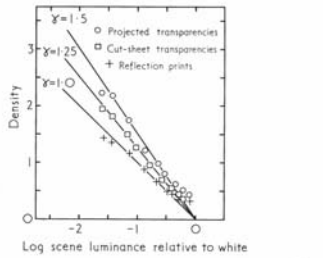


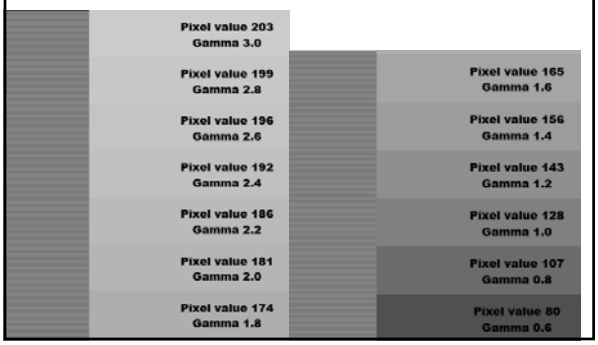
Fig. 6.13. The displayed density of the nine-step grey scale plotted against the log luminances of its steps relative to white. Reflection print systems have a displayed gamma of 1.0, cut-sheet transparency systems a displayed gamma of 1.25, and projected transparency systems a displayed gamma of 1.5.

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

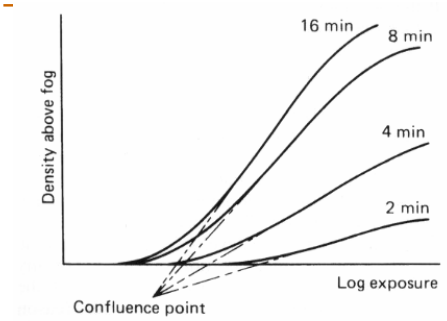
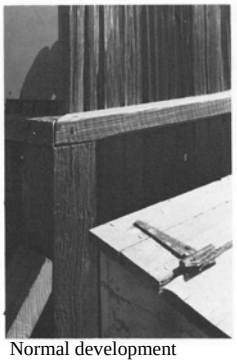


Figure 15.8 Effect of development time on characteristic curve of current sensitive materials

From The Manual of Photography, Jacobson et al.

Reduced development



Normal development

Contraction (short development)

Source: Ansel Adams

Two solutions

One development solution

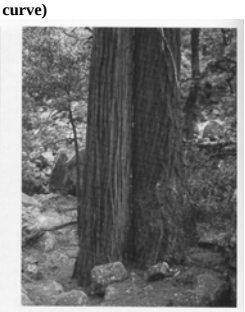
Two development solution: the dark areas are the same, but bright areas are different

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

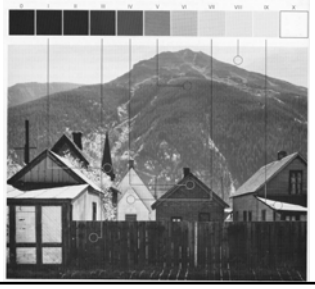
Paper

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

Questions?

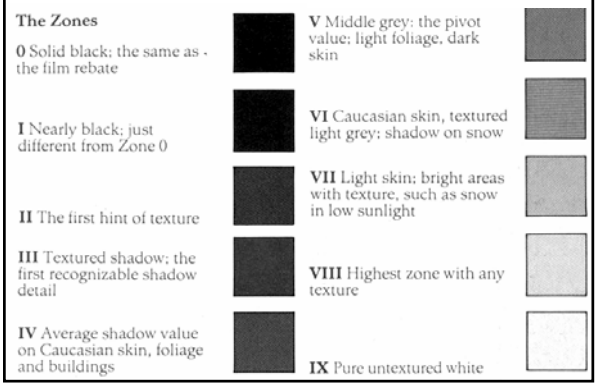
The Zone system

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



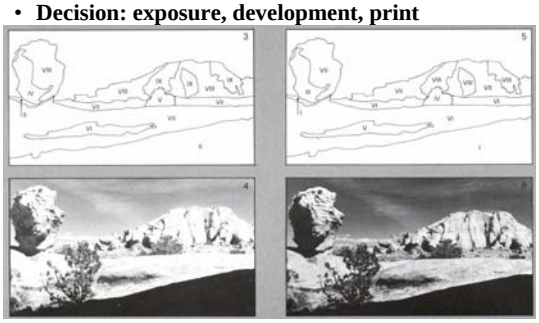
Source: Ansel Adams

The Zones

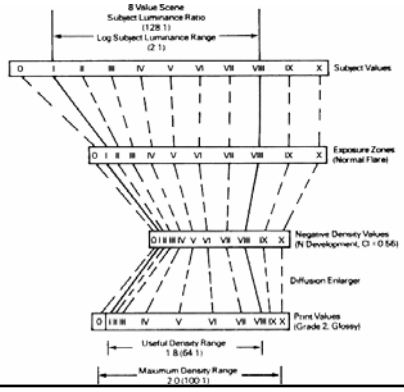


The Zone system

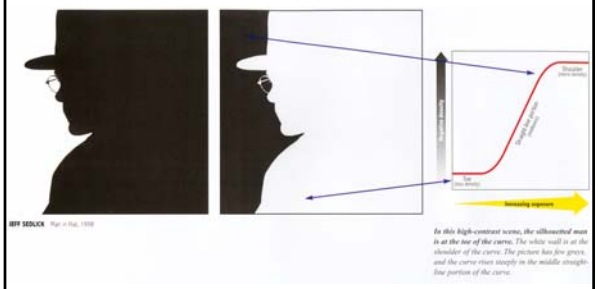
- **You decide to put part of the system in a given zone**
- **Decision: exposure, development, print**



Recap for film



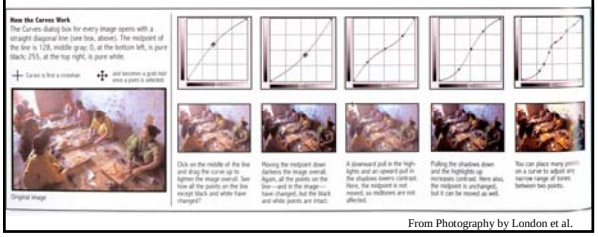
Limited dynamic range can be good!



From Photography by London et al.

Photoshop curves

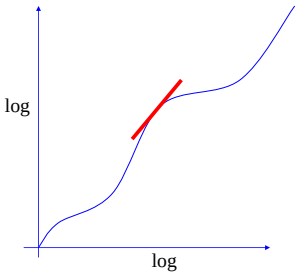
- **Specify an arbitrary remapping curve**
- **Especially useful for black and white**



From Photography by London et al.

Contrast modification by the curve?

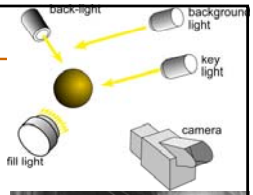
- **Look at the remapping in log-log**
- **Slope = local exponent=contrast modification**



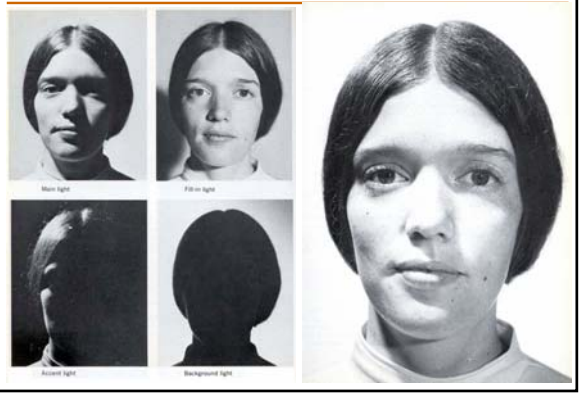
Questions?

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



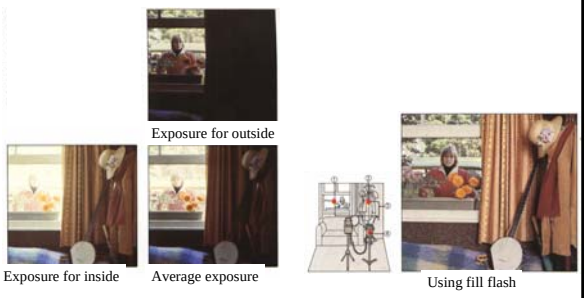
Portrait lighting



Fill-in flash

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

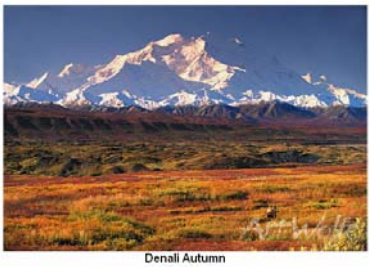
- **Art Wolfe: In the late evening light, I composed this image using a graduated neutral-density filter to bring the overall exposure into alignment, thus preserving the detail in the clouds in the sky and the reflections on the water.**

Portage Lake, Horizontal

http://www.artwolfe.com/

Graduated ND & landscape

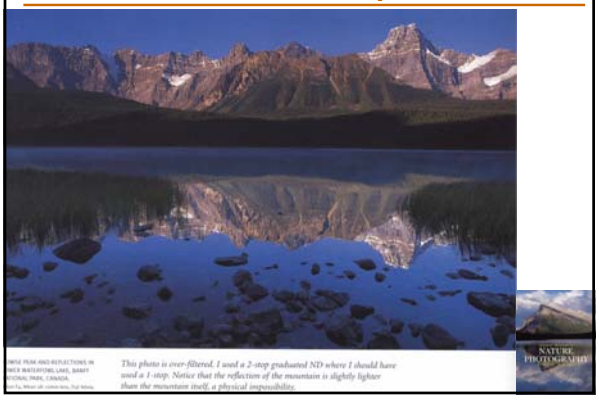
- **Art Wolfe: Here I had to use a combination of filters and settings that greatly reduced my chance of success. I used my zoom to bring in Denali and the moose. A polarizing filter brought out the rich colors of the tundra and darkening the sky and a graduated, neutral-density filter to bring the entire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



Denali Autumn

http://www.artwolfe.com/

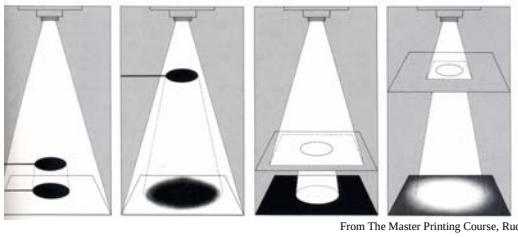
Graduated ND & landscape



Questions?

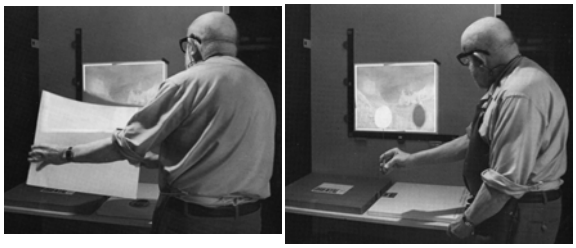
Dodging and burning

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



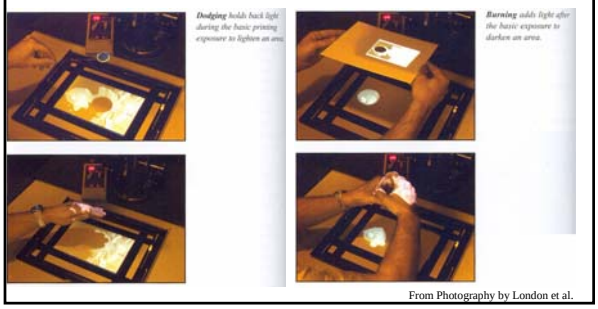
From The Master Printing Course, Rudman

Dodging and burning



Source: Ansel Adams

Dodging and burning



From Photography by London et al.

Dodging and burning

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

Straight print | After dodging and burning

Dodging & burning is difficult!

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**

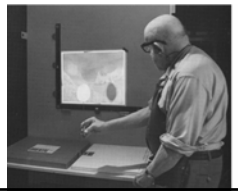
Notion pioneered by H. von Helmholtz

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



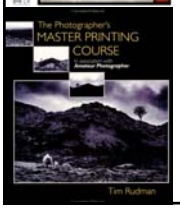
Limitations of the medium

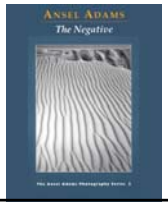
- Can be eliminated
- Can be compensated
- Can be accentuated

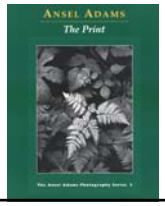
Are often an advantage as well

Questions?

References







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