Dynamic Range and Contrast

Calvin suddenly realizes the world has no hue, value, or chroma.

Perhaps some strange nuclear or chemical reaction on the sun has caused electromagnetic radiation to defy separation into a spectrum.

Maybe objects no longer reflect certain wavelengths! Whatever the cause, it’s clear to Calvin that there’s no point in discussing things with his dad!

Have the photoreceptors in Calvin’s eyes stopped working properly, or has the fundamental nature of light changed?

The problem is, you see everything in terms of black and white.

Sometimes that’s the way things are!

CALVIN AND HOBBES © 1991 Watterson. Reprinted with permission of UNIVERSAL PRESS SYNDICATE. All rights reserved.
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 $\sim 10^{-6}$ to $10^6$ cd/m²
- Often 1 : 100,000 in a scene

High dynamic range

Real world $10^{-6}$ $10^6$

Spotmeter
The world is high dynamic range

- Slide from Paul Debevec

The real world is high dynamic range.
Picture dynamic range: Guess!

Real world

pure black

10^{-6}

pure white

10^{-6}

Picture

10^{-6}

10^{6}
Problem 2: Picture dynamic range

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

Real world

Picture

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.

\[10^{-6} \quad \text{Real scenes} \quad 10^6\]

\[10^0 \quad 10^3\]

Negative/sensor
Contrast reduction

- Match limited contrast of the medium
- Preserve details

Real world

<table>
<thead>
<tr>
<th>10^{-6}</th>
<th>High dynamic range</th>
<th>10^{6}</th>
</tr>
</thead>
</table>

Low contrast

<table>
<thead>
<tr>
<th>10^{-6}</th>
<th>10^{6}</th>
</tr>
</thead>
</table>
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

Low-res B&W backlight  |  High-res color foreground

Slide from the 2005 Siggraph course on HDR
Slide from the 2005 Siggraph course on HDR
How It Works

LED Backlight × LCD Screen = Combined Result

Slide from the 2005 Siggraph course on HDR
What If Edge Contrast Exceeds LCD Range?

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
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)

Decreasing contrast

Increasing spatial frequency

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
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 fix.

Remove promptly from fixer after the recommended time, then store in fresh water. To avoid any possible tinging 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
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 $\sqrt{\text{capacity}}$
• The bigger the photosite, the higher the range
Dynamic range and sensor size

Response curve of current D-SLR

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

\[ \gamma = \frac{D_2 - D_1}{\log H_2 - \log H_1} = \frac{BC}{AC} = \tan c \]

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
## Gamma calibration

- Exploit linear fusion in the eye

<table>
<thead>
<tr>
<th>Pixel value</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>203</td>
<td>3.0</td>
</tr>
<tr>
<td>199</td>
<td>2.8</td>
</tr>
<tr>
<td>196</td>
<td>2.6</td>
</tr>
<tr>
<td>192</td>
<td>2.4</td>
</tr>
<tr>
<td>186</td>
<td>2.2</td>
</tr>
<tr>
<td>181</td>
<td>2.0</td>
</tr>
<tr>
<td>174</td>
<td>1.8</td>
</tr>
<tr>
<td>165</td>
<td>1.6</td>
</tr>
<tr>
<td>156</td>
<td>1.4</td>
</tr>
<tr>
<td>143</td>
<td>1.2</td>
</tr>
<tr>
<td>128</td>
<td>1.0</td>
</tr>
<tr>
<td>107</td>
<td>0.8</td>
</tr>
<tr>
<td>80</td>
<td>0.6</td>
</tr>
</tbody>
</table>
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 (\(\sim \gamma\))
  – 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 $\gamma$)
• 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

<table>
<thead>
<tr>
<th>Zone</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0</strong></td>
<td>Solid black; the same as the film rebate</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td>Nearly black; just different from Zone 0</td>
</tr>
<tr>
<td><strong>II</strong></td>
<td>The first hint of texture</td>
</tr>
<tr>
<td><strong>III</strong></td>
<td>Textured shadow; the first recognizable shadow detail</td>
</tr>
<tr>
<td><strong>IV</strong></td>
<td>Average shadow value on Caucasian skin, foliage and buildings</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>Middle grey: the pivot value; light foliage, dark skin</td>
</tr>
<tr>
<td><strong>VI</strong></td>
<td>Caucasian skin, textured light grey; shadow on snow</td>
</tr>
<tr>
<td><strong>VII</strong></td>
<td>Light skin; bright areas with texture, such as snow in low sunlight</td>
</tr>
<tr>
<td><strong>VIII</strong></td>
<td>Highest zone with any texture</td>
</tr>
<tr>
<td><strong>IX</strong></td>
<td>Pure untextured white</td>
</tr>
</tbody>
</table>
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!

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

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

Main light

Fill-in light

Accent light

Background light
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 twig, 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
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.

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.

http://www.artwolfe.com/
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.

GERALD RUSSELL
Reno 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 on 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.
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

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
Refs

http://www.hdrsoft.com/resources/dri.html
http://www.clarkvision.com/imagedetail/dynamicrange2/
http://www.debevec.org/HDRI2004/
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