Dynamic Range and Contrast

CALVIN SUDDENLY REALIZES THE WORLD HAS NO HUE, VALUE, OR CHROMA.

HAVE THE PHOTORECEPTORS IN CALVIN'S EYES STOPPED WORKING PROPERLY, OR HAS THE FUNDAMENTAL NATURE OF LIGHT CHANGED?

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!

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

Frédo Durand
MIT - EECS
Light, exposure and dynamic range

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

- Bottom-line problem:
- display/print have limited contrast
Plan

• The dynamic range problem
• Human vision
• Traditional Photography
• Digital photography

• Next time: computational solutions
  – multiple-exposure merging
  – tone mapping
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 $10^6 \text{ cd/m}^2$
- Often 1 : 100,000 in a scene
The world is high dynamic range

- Slide from Paul Debevec
Picture dynamic range: Guess!

Real world

<table>
<thead>
<tr>
<th>pure black</th>
<th>pure white</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-6}$</td>
<td>$10^{6}$</td>
</tr>
</tbody>
</table>

Picture

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-6}$</td>
<td>$10^{6}$</td>
</tr>
</tbody>
</table>
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

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.

$10^{-6}$  $10^0$  $10^3$  $10^6$

Real scenes

Negative/sensor
Problem 2: Contrast reduction

- Match limited contrast of the medium
- Preserve details
Important

• Multiply image by constant: make it brighter (aka. change density)
• Contrast = ratio
• How do we change contrast then? Exponent, e.g. square root reduces contrast
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, even though the tone actually is 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 impression you give the paper. The white patch will help you check for the overall gray tinge caused by safelighting 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 1/30s, 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. Avoid any possible fogging of the white patch, cut and process the paper in a minimum amount of safelight.
Limitations of the medium

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

Notion pioneered by H. von Helmholtz
Questions?
Exception: 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
How It Works

LED Backlight × LCD Screen = Combined Result

Slide from the 2005 Siggraph course on HDR
Production 37” HDR Display

Slide from the 2005 Siggraph course on HDR
Questions?
Plan

• The dynamic range problem
• Human vision
• Traditional Photography
• Digital photography

• Next time: computational solutions
  – multiple-exposure merging
  – tone mapping
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.
Questions?
Plan

• The dynamic range problem
• Human vision
• Traditional Photography
• Digital photography

• Next time: computational solutions
  – multiple-exposure merging
  – tone mapping
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
Negative and response curve

- Negatives typically afford 3 orders of magnitude
- More than printing paper
- Shoulder region provides a little more dynamic range (but less precision there)
Questions?
Response curve manipulation

• Traditional photography
  – Chemicals and duration of development
  – Paper grade (\(\sim \gamma\))
  – Flashing the paper before printing
  – Various chemicals on paper
  – Note: you have one curve for negative, one for paper
    Usually they have inverse gamma (but not strictly, enables contrast control)

• Digital
  – Curve tool
Figure 15.8  Effect of development time on characteristic curve of current sensitive materials
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)

Source: Ansel Adams

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

Take picture

Develop negative

Print
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
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

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.
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.

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/
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

**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
Dodging and burning

Source: Ansel Adams
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
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?
Plan

• The dynamic range problem
• Human vision
• Traditional Photography
• Digital photography

• Next time: computational solutions
  – multiple-exposure merging
  – tone mapping
Digital pipeline

• Photosites transform photons into charge (electrons)
  – The sensor itself is linear
• Then goes through analog to digital converter
  – up to 14 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
Response curve, dynamic range

- Video sensors have poor dynamic range
Questions?
Response curve of current D-SLR

Question?
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/
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
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
Questions?
Histogram

- See http://www.luminous-landscape.com/tutorials/understanding-series/understanding-histograms.shtml
  http://www.luminous-landscape.com/tutorials/expose-right.shtml

- Horizontal axis is pixel value
- Vertical axis is number of pixels
• Clipped pixels (value $>255$)
• Pro and semi-pro digital cameras allow you to make them blink.
HDR Cameras

- HDR sensors using CMOS
  - Use a log response curve
    - e.g. SMaL,
- Assorted pixels
  - Fuji
    - Nayar et al.
- Per-pixel exposure
  - Filter
    - Integration time
- Multiple cameras using beam splitters
- Other computational photography tricks
HDR cameras

- http://www.hdrc.com/home.htm
- http://www.smalcamera.com/technology.html
- http://www.pixim.com/
- http://www.ptgrey.com/
- http://www.siliconimaging.com/
Questions?
Back to 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.
Opponents and image compression

- JPG, MPG, television
- Color opponents instead of RGB
- Compress color more than luminance
  - downsample by factor of two for jpeg
  - less bandwidth for TV
JPEG Compression

- YCbCr
  - half the resolution for Cr &Cb

- Perform DCT to work in frequency space
  - Local DCT, 8x8 blocks

- Use CSF for quantization (more bits for sensitivity with more contrast)

- Other usual coding tricks
References
Refs

http://www.hdrsoft.com/resources/dri.html
http://www.clarkvision.com/imagedetail/dynamicrange2/
http://www.debevec.org/HDRI2004/
http://www.luminous-landscape.com/tutorials/hdr.shtml
http://www.anyhere.com/gward/hdrenc/
http://www.openexr.com/
http://gl.ict.usc.edu/HDRShop/
http://www.anyhere.com/