

Photographic Tone Reproduction

Tone Reproduction

Definition: Compressing the dynamic range of a scene's luminances/radiances so that it can be displayed on a given device in such a way that minimizes the perceptual difference between viewing the scene and viewing the rendering of the scene.

Photographic Response

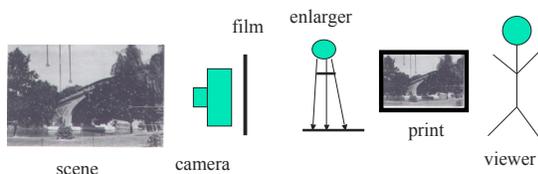
- An alternative to modeling visual response directly.
- Instead, models response to photographic materials (film/paper).

Photographic Response

- Why bother with photographic model?
 - Far better understood than human visual system.
 - Optimized for human viewing
 - Artistic photography
 - Composition of CG elements with scenes captured on film.

Photographic Pipeline

- Follow the path of light from scene to photo to viewer!



Lighting Units

- Units:
 - Radiance – light hitting a surface from a given direction (light traveling along a ray)
 - Luminance – photometric equivalent of radiance (radiance scaled by luminous efficiency curve)
 - Irradiance – light hitting a surface from all directions
 - Illuminance – photometric equivalent of irradiance (irradiance scaled by luminous efficiency curve)

Photographic Units

exposure

$$E = It$$

I = Illuminance (lux)
 t = time (sec)
 E = exposure (lux-sec)

density

$$D = \log(O)$$

O = opacity = $1/T$
 T = transmission
 $= I_t/I_o$

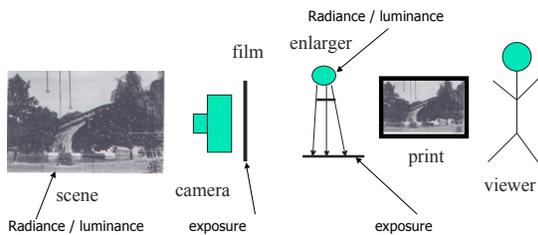
I_t = transmitted light
 I_o = incident light

Photographic Units

- Exposure
 - Essentially defines the amount of light hitting the photographic material at each point
- Density
 - A logarithmic means for describing transparency once the material is developed

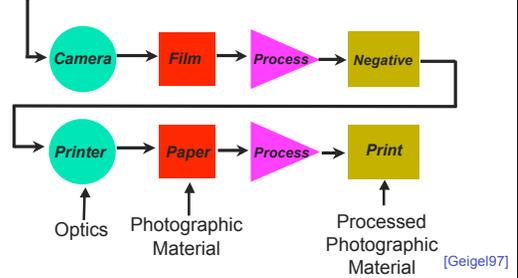
Step 1: Calculate exposure

- Follow the path of light from scene to photo to viewer!



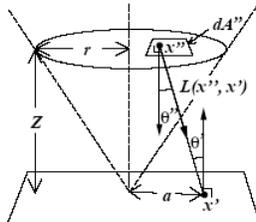
Photographic Response

- Print photography process



Luminance to exposure

- To get irradiance at a given point on the film plane, we must integrate radiance values over a circle representing the exit pupil.



Luminance to exposure

- Things to consider when figuring out exposure.
 - Irradiance from scene radiance
 - Vignetting
 - Transmittance (formerly called transmission)
 - Flare
 - Shutter efficiency
- A bit more than the basic pinhole camera!

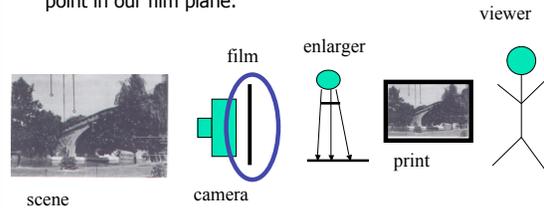
Luminance to exposure

Final model

$$Exposure(x') = (L\tau \frac{\pi}{4f^2} \cos^4 \theta + I_f) \eta t$$

Step 2: Simulate film response

- We now know how much exposure is present on each point in our film plane:



Photographic Materials

- Comprised of microscopic grains of silver halide in a gelatin (emulsion)
- Latent image formed when exposed to light
- Silver halide converted to metallic silver during processing.
- Converted silver results in opacity

Photographic Response

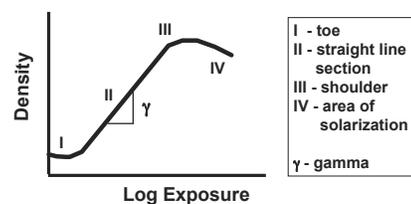
- Brightness Response** - high level response of an emulsion to light
- Spectral Sensitivity** - Response of a material to different wavelengths of light
- Acuity** - Level at which material can reproduce spatial details
- Graininess** - Observed variation due to grain distribution

Photographic Response

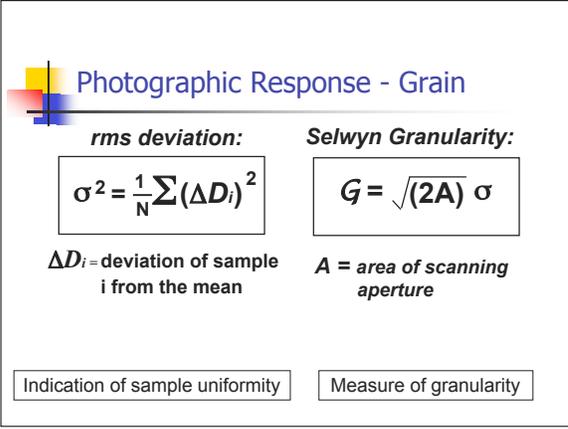
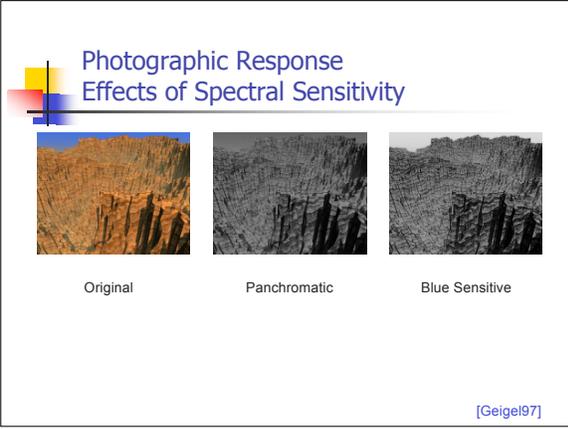
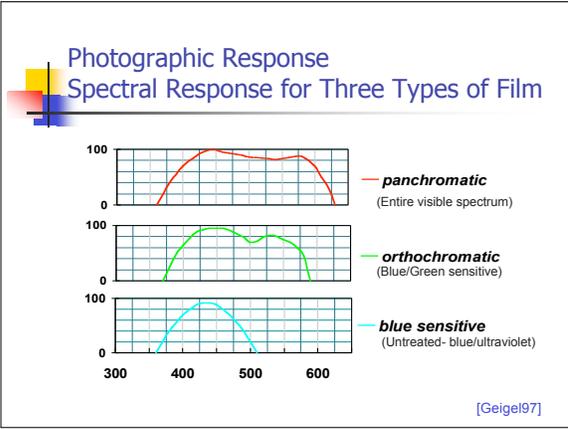
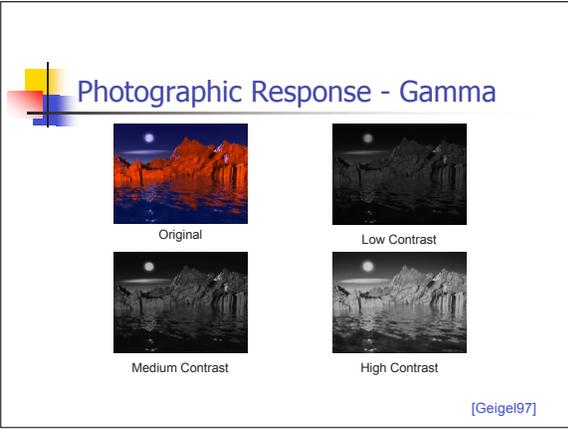
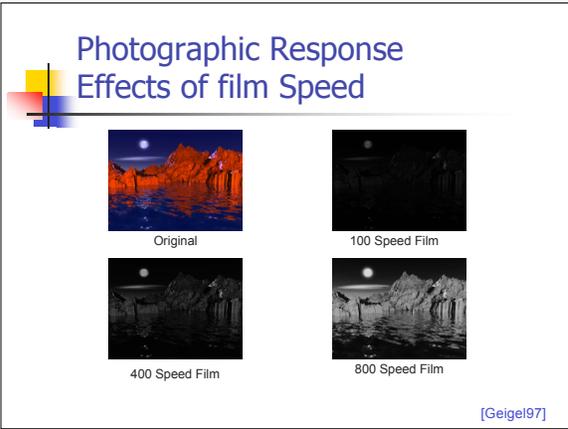
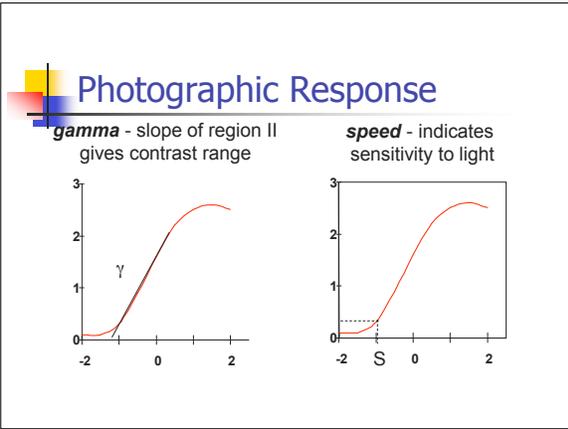
- Sensitometry**
 - The science of measuring the sensitivity of photographic materials
 - Each characteristic has its own unique sensitometric measure.

Photographic Response

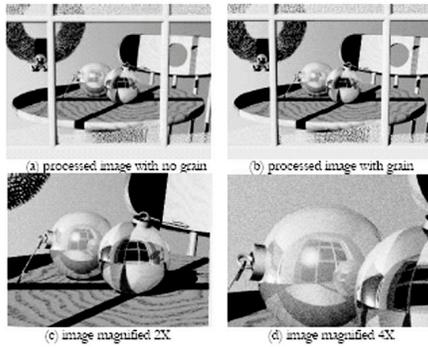
- A typical brightness response / characteristic curve



[Geigel97]



Photographic Response - Grain

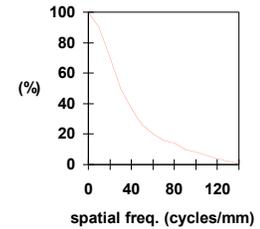


[Geigel97]

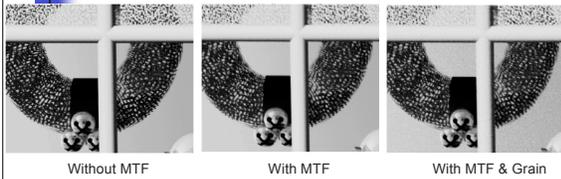
Photographic Response – Acuity (Resolution)

point spread function

modulation transfer function



Photographic Response - Acuity



[Geigel97]

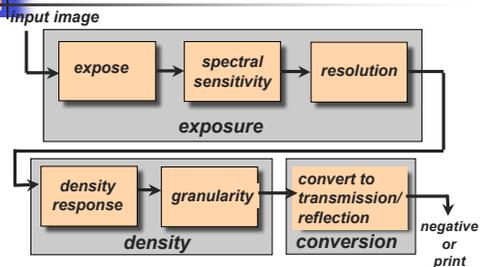
Photographic Response

- High level description of photographic response
 - Model can process at grain level, but impractical to do so.
 - All sensimetric measurements are available for photo materials from the manufacturer.

Modeling Photographic Response

- Uses sensitometric measures to model characteristics of photo materials
- Physically based
- Built using an imaging pipeline where each module in the pipe represents an image processing operation.

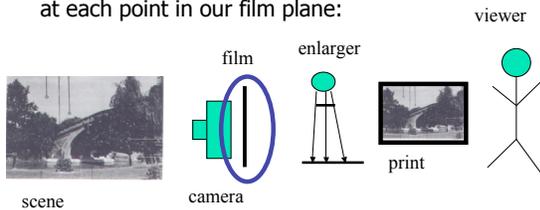
Modeling Photographic Response



[Geigel97]

Okay, where are we?

- We now know how transparent our negative is at each point in our film plane:



Step 3: Create the print

- To create the print:
 - Negative is placed in an enlarger
 - Light is shown through the negative onto photographic paper (which contains an emulsion)
 - Paper is exposed and then developed
- Note that the enlarger has its own lens system.

Photographic Units

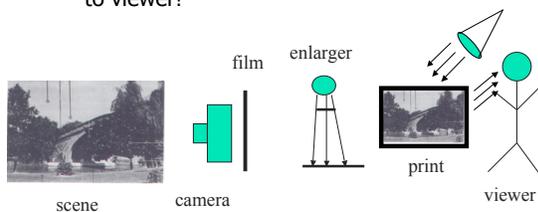
- Exposure
 - Essentially defines the amount of light hitting the photographic material at each point
- Density
 - A logarithmic means for describing reflection once the material is developed
 - For photographic paper, reflective density is calculated.
 - Reflective density = fraction of light that goes through the emulsion on the paper, hits the paper base and reflects back to the viewer.

Modeling Photographic Response

- Must run thru pipeline twice, once for capture on film and once for printing
- Result of model
 - Image of floats $[0, 1]$
 - Represents transmission or reflection values

Step 4: View the print

- Follow the path of light from scene to photo to viewer!



Modeling Photographic Response

- Prints are reflective media
- Are not visible unless illuminated
- Values from model must be modified to account for the luminance / color characteristic of the assumed print illumination

Modeling Photographic Response

- Some nice factoids
 - Photographic engineers have spent an awful lot of time and energy in designing films and papers to assure, to the best of their power:
 - A photo viewed using "normal" or "typical" lighting will be a nice perceptual match with the scene photographed.
 - The luminance range of CRTs approximates normal interior viewing conditions fairly well.
 - Scaling reflectances to CRT luminances produces a decent picture

Modeling Photographic Response

- Virtual Darkroom Applet
 - <http://www.jogle.com/Research/vdr/java/vdr.html>



Issues with Tone Reproduction

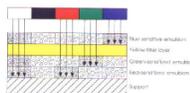
- Tone, not color
- Viewing /display conditions generally not considered
- Real time tone reproduction

Issues with Tone Reproduction

- Tone, not color
 - Most tone reproduction operators are applied equally to RGB.
 - Not necessarily the way to gain best results.
 - As an example, look at color film.

Photographic Response

- So what about color?
 - Color Materials have multiple emulsion layers, each sensitive to a certain range (red, green, blue) of wavelength.



Photographic Response

- Additive Color (light)
 - Primaries (red, green, blue)



Photographic Response

- Subtractive color (dyes)
 - primaries (magenta, cyan, yellow)

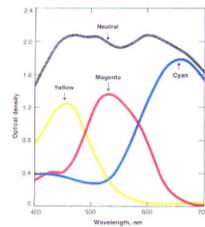


Photographic Response

- Note that in additive system:
 - White - Red = Cyan
 - White - Green = Magenta
 - White - Blue = Yellow
- In subtractive system
 - Cyan dye absorbs red light
 - Magenta dye absorbs green light
 - Yellow dye absorbs blue light

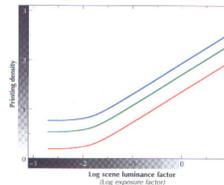
Photographic Response

- Color Materials
 - Each layer has its own spectral sensitivity



Photographic Response

- Color Brightness Response
 - Each emulsion layer will have its own characteristic curve

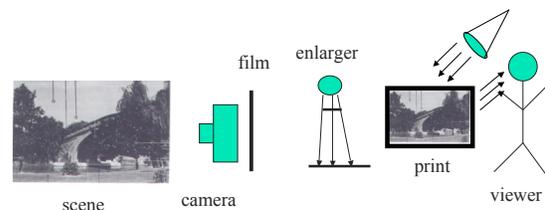


Photographic Response

- Color Grain and Acuity
 - Each layer will have its own MTF and grain characteristics.
- Applying same TR to each color channel may not be the best approach.
- Questions.

Photographic Pipeline (back in the day)

- Follow the path of light from scene to photo to viewer!

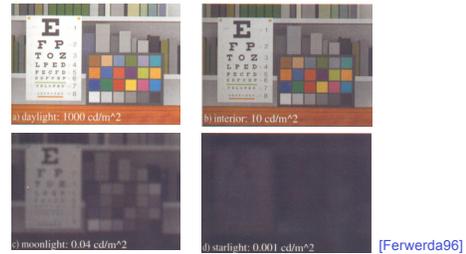


Issues with Tone Reproduction

- Viewing conditions
 - Viewing conditions can affect perception
- Adaptation
 - The process by which the visual mechanism adjusts to the conditions under which the eyes are exposed to radiant energy.
- Considered by Ferwerda in his TR Operator
- Should also be considered in viewing conditions.

General Brightness Adaptation

- Note also...differences in acuity



Adaptation

- General brightness adaptation
 - Adjustments in response to the overall level of stimulus exposed
- Lateral brightness adaptation
 - Adjustments in response due to stimulus in adjacent areas of the retina
- Chromatic adaptation
 - Adjustments in response to the average chromaticity in the stimulus.

So what's the point

- If the viewing conditions of the "virtual scene" does not match those of the viewing of the rendered image of the virtual screen.
 - Perceptual match will not occur.

Characteristics of a observer

- Brightness response
- Spectral response
- Acuity
- Noise (Grain)

- For a human observer, all are variable based on viewing conditions.

Tone Reproduction in real time

- With advances in graphics hardware, some Tone Reproduction algorithms have been programmed on GPUs
 - Ferwerda [Durand, Dorsey 2001]
 - Reinhard [Goodnight, et al, 2003]
 - Tumblin (and others) [Artusi, et. Al, 2003]



Human Visual System

- A good overview of CG tone reproduction operators is available from
 - "Tone Reproduction and Physically Based Spectral Rendering" by Devlin et al., *State of the Art Report*, EUROGRAPHICS 2002.
- Questions?



Tone Reproduction

- Summary
 - Means of compressing dynamic range of scene to fit that of display
 - Observer / Response Model
 - Human Visual System
 - Photographic Systems
 - Map to Device Model



Next time

- Unifying framework
- The last of the checkpoints