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

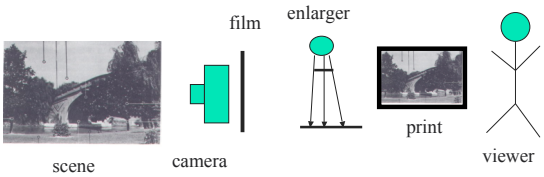
- An alternative to modeling visual response directly.
- Instead, models response to photographic materials (film/paper).

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
$= I_t / I_o$

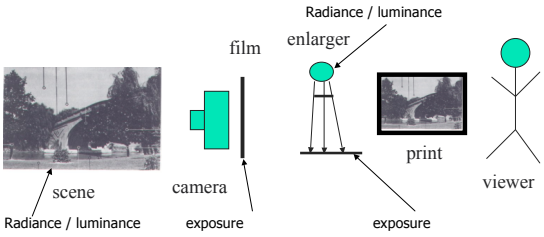
I_t = transmitted light
I_o = incident light

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

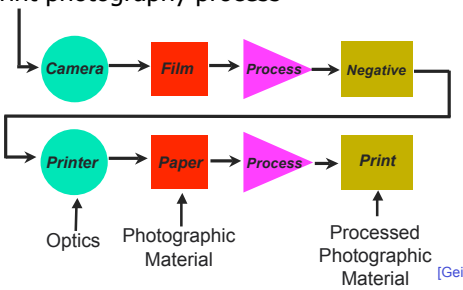
Step 1: Calculate exposure

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



Photographic Response

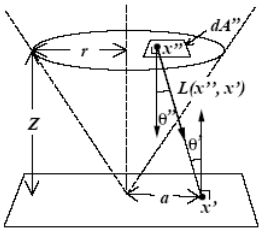
- Print photography process



[Geigel97]

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

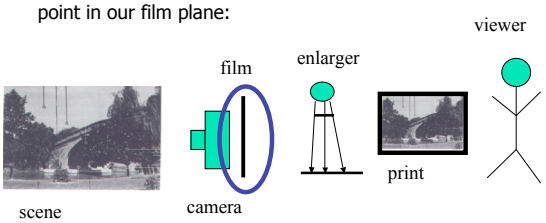
$$Exposure(x') = (L\tau \frac{\pi}{4n^2}\cos^4\theta + I_f)\ \eta\ t$$

illuminance from scene — flare — shutter eff. — time

set by photographer

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

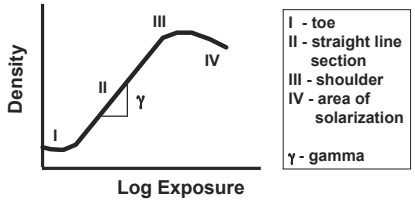
- Brightness Response - high level response of an emulsion to light
- Spectral Sensitivity - Response of a material to different wavelengths of light
- Acuity - Level at which material can reproduce spatial details
- Graininess - Observed variation due to grain distribution

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



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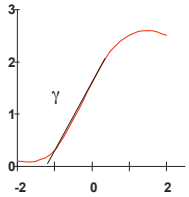
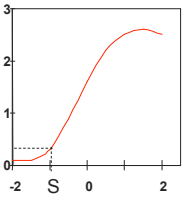
Photographic Response

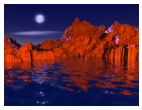
gamma - slope of region II gives contrast range



speed - indicates sensitivity to light



Photographic Response
Effects of film Speed


Original

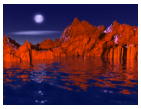

100 Speed Film


400 Speed Film


800 Speed Film

[Geigel97]

Photographic Response - Gamma


Original

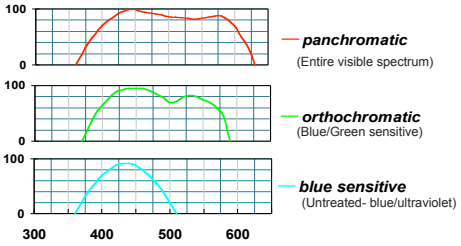

Low Contrast


Medium Contrast


High Contrast

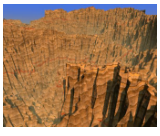
[Geigel97]

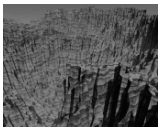
Photographic Response
Spectral Response for Three Types of Film

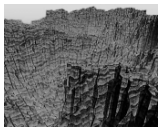


[Geigel97]

Photographic Response
Effects of Spectral Sensitivity


Original


Panchromatic


Blue Sensitive

[Geigel97]

Photographic Response - Grain

rms deviation:

$$\sigma^2 = \frac{1}{N}\sum(\Delta D_i)^2$$

ΔD_i = **deviation of sample i from the mean**

Selwyn Granularity:

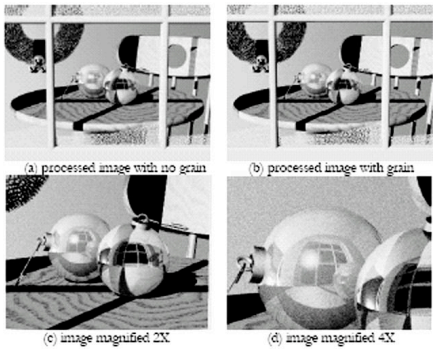
$$G = \sqrt{(2A)}\,\sigma$$

A = area of scanning aperture

Indication of sample uniformity

Measure of granularity

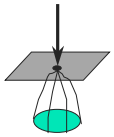
Photographic Response - Grain



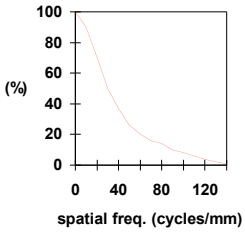
[Geigel97]

Photographic Response – Acuity (Resolution)

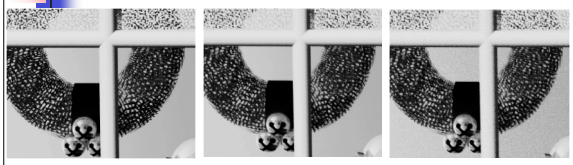
point spread function



modulation transfer function



Photographic Response - Acuity



Without MTF | With MTF | With MTF & Grain

[Geigel97]

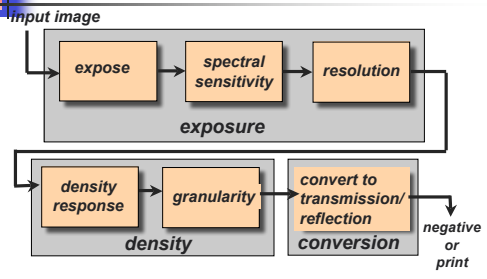
Photographic Response

- High level description of photographic response
  - Model can process at grain level, but impractical to do so.
  - All sensiometic 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.

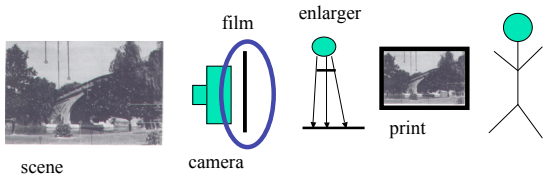
Modeling Photographic Response



[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

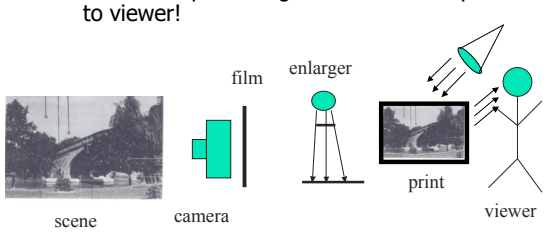
- Exposure
  - Essentially defines the amount of light hitting the photographic material at each point
- Density
  - A logarithmic means for describing reflection once the material is developed
    - For photographic paper, reflective density is calculated.
    - Reflective density = fraction of light 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 luminaces produces a decent picture

Modeling Photographic Response

- Virtual Darkroom Applet

http://www.jogle.com/Research/vdr/java/vdr.html

Issues with Tone Reproduction

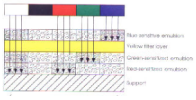
- Tone, not color
- Viewing /display conditions generally not considered
- Real time tone reproduction

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.

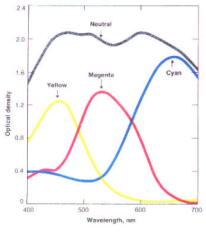
Photographic Response

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



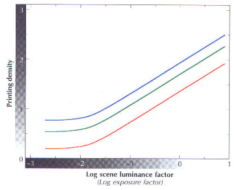
Photographic Response

- Color Materials
  - Each layer has it's own spectral sensitivity



Photographic Response

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

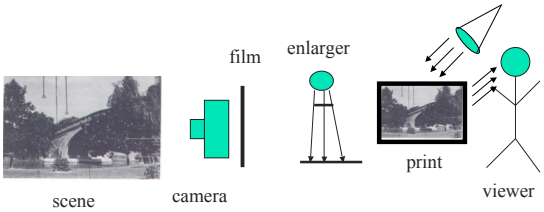


Photographic Response

- Color Grain and Acutity
  - 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!

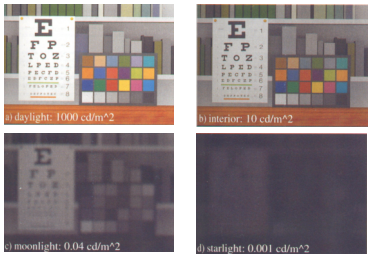


Issues with Tone Reproduction

- 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



[Ferwerda96]

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]
  - Tumbin (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

- High Dynamic Range Images
- A Unifying framework for tone reproduction
- The last of the checkpoints