So You Want to Write a Ray Tracer

Checkpoint 7 – Tone Reproduction

Ray Tracing Assignment

• Goal is to reproduce the following

Whitted, 1980

Ray Tracing Assignment

• Seven checkpoints
  1. Setting the Scene
  2. Camera Modeling
  3. Basic Shading
  4. Procedural Shading
  5. Recursive Ray Tracing – Reflection
  6. Recursive Ray Tracing – Transmission
  7. Tone Reproduction

Check 7

• Goal is to take this from CG units to real units!

Checkpoint 7 – Tone Reproduction

Tone Reproduction

• Change your ray tracer so that it:
  1. Maps lighting units (0-1) to real lighting units
  2. Applies a tone reproduction operator to compress these simulated radiances to display radiances
Tone Reproduction

• The $L_{\text{max}}$ argument
  – Will be used as the maximum luminance in the scene.
  – In other words, all lighting units are multiplied by $L_{\text{max}}$
    • A CG lighting value of 1 will be mapped to this maximum physical
      lighting value (unit is nits).
    • Other lighting values will be scaled linearly.
    • Note: You will now have illumination values that exceed 1.

• The $L_{\text{dmax}}$ argument
  – Maximum luminance of the display device.
  – Use value of 100 nits.

So, instead of converting 0-1 to 0 – 255 for java or using 0-1 directly for openGL, you will
  – Multiply illumination color values by $L_{\text{max}}$ to get illuminances $->[0, L_{\text{max}}]$.
  – Then, apply a tone reproduction operator to get pixel values.

I.e., we are post-processing the results of the rendering pipeline.

Two Tone Reproduction Operators

• You will implement two different tone reproduction operators:
  – Perceptual: Ward’s from Graphics Gems IV
  – Photographic: Reinhard, et al. in 2002

Ward Tone Reproduction

$$sf = \frac{1}{L_{\text{dmax}}} \left[ \frac{1.219 + \left( \frac{L_{\text{dmax}}}{2} \right)^{0.4}}{1.219 + L_{\text{wa}}} \right]^{2.5}$$

• Ward’s TR Operator defines a scale factor:
  – $L_{\text{wa}} = sf \cdot L_{\text{wa}}$

• Where
  – $L_{\text{wa}}$ = adaptation luminance
  – Average luminance in scene.

Applying to RGB

• One problem with tone reproduction is that it is tone reproduction and not color reproduction
  – Thus, we will apply the same operator to each of the $R$, $G$, $B$ components, while in reality we should do a separate calculation for each component.
  – Related to this tone reproduction operator, you will
    • Calculate $sf$ using a calculated luminance based on a combination of $R$, $G$, $B$ components at each pixel
    • Then, we will apply $sf$ to each $R,G,B$ component.

Luminance

• Like in photography, the operators deal in luminances and not radiances.
Luminance

- quick and dirty approximation to pixel luminance given $R$, $G$, $B$:

$$L_w(x,y) = 0.27R(x,y)+0.67G(x,y)+0.06B(x,y)$$

- Note: $L_w$ is in the range $[0, L_{max}]$

Log Average Luminance

- To find the log-average luminance of scene

$$\overline{L_w} = \exp\left(\frac{1}{N} \sum_{x,y} \log (\delta + L_w(x,y))\right)$$

- where
  - $L_w(x,y)$ = luminance at pixel $x,y$
  - $N$ = number of pixels
  - $\delta$ = some small number (to prevent log going to infinity)

Ward Tone Reproduction

$$sf = \frac{1}{L_{max}} \left[ \frac{1.219 + (L_{max}/0.04)^{2.25}}{1.219 + L_{max}^{2.25}} \right]$$

1. Scale $R$, $G$, $B$ values by $L_{max}$ for each pixel
2. Calculate log-avg luminance ($L_w$)
3. Calculate $sf$ by setting $L_{wa} = L_w$
4. Final display colors ($L_d$) are the results of applying the $sf$ calculated in step 2 to the $R$, $G$, $B$ values from step 1.

Reinhard Tone Reproduction

- Basic idea:
  - Map the average scene luminance to Zone 5.
  - Map remaining luminances based on "photographic-like" response.

Reinhard Tone Reproduction

- Step 1
  - Obtain luminance values
  - Scale $R$, $G$, $B$ values by $L_{max}$ for each pixel
- Step 2
  - Calculate log-avg luminance ($L_w$)

- Hey, you already did this for Ward.

Reinhard Tone Reproduction

- Mimics Ansel Adam’s Zone System
  - http://photography.cicada.com/zs/emulator/
Reinhard Tone Reproduction

• Step 3
  – scale the luminance values $R_s$, $G_s$, $B_s$ by mapping the key value to Zone V (18% gray)

$$L_s(x,y) = \frac{a}{T_k} L(x,y)$$

where
  - $T_k$ = the key value
  - $L(x,y)$ = scene luminance at pixel $x,y$, i.e., your calculated $R,G,B$ values scaled by $L_{max}$
  - $a =$ % gray for zone V; use $a = 0.18$
  - $L_s(x,y)$ = scaled luminance, i.e., $R_s, G_s, B_s$

• Step 4
  – Find the display luminances for $R_d$, $G_d$, and $B_d$ based on film-like response

$$L_d(x,y) = \frac{L_s(x,y) * L_{dmax}}{1 + L_s(x,y)}$$

where
  - $L_s(x,y)$ = scaled luminance, i.e., $R_s, G_s, B_s$
  - $L_d$ = display luminances, $R_d, G_d, B_d$
  - $L_d$ is in the range $[0, L_{dmax}]$

• Step 5
  – Final pixel colors are determined by scaling $L_d$ found in step 3 by $L_{dmax}$

Tone Reproduction

• Gamma

$$L_d = (L_{dmax} V)^{\gamma}$$

• In final step, for this assignment, we are assuming a gamma of 1.

Reinhard’s Results

[Reinhard, 2002]

Linear scaling
Loss of detail

Using TR Operator
[Reinhard, 2002]
Checkpoint 7

- To be posted to Web site
  - Six images produced by running your raytracer with three different values of \( L_{\text{max}} \) for EACH tone reproduction operator:
    - Lo-Range Lighting: \( L_{\text{max}} = 1 \) nit
    - Mid-Range Lighting: \( L_{\text{max}} = 100 \) nits
    - Hi-Range Lighting: \( L_{\text{max}} = 1000 \) nits
  - Tone Reproduction:
    - Ward’s Model
    - Reinhard’s Model
- Please label which is which.

Extra Extra

- For 5 points
  - Modify the Reinhard operator so that you can specify what luminance is to be used as the key value.
    - Constant value
    - Value at a pixel

Checkpoint 7

- Due dates:
  - Images to be posted to Web site
    - Midnight Nov 3rd.
  - Final raytracer code to be posted on mycourse
    - Midnight Nov 3rd
    - Code must be submitted to receive credit!
    - Include README with details to build
- Questions?