Advanced Computer Graphics
CSE 163 [Spring 2017], Lecture 2
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Course Outline

- 3D Graphics Pipeline
  - Modeling (Creating 3D Geometry)
  - Rendering (Creating, shading images from geometry, lighting, materials)

Unit 1: Foundations of Signal and Image Processing
Understanding the way 2D images are formed and displayed, the important concepts and algorithms, and to build an image processing utility like Photoshop
Weeks 1 – 3.

Assignment 1, Due Apr 28.
Anyone need help finding partners?
Should already have downloaded code, skimmed assn
After today, enough to finish 3.2, 3.3 (first half)
Should START EARLY (this week) on assn
Second half next week.
Class participation, discussion important
If you have to miss a class, see podcast if available
Please sign up for Piazza

Outline

- Intensity and Color (briefly)
  - Basic operations (3.2 in assignment [10 points])
- Quantization, Halftoning and Dithering
  - (3.3 in assignment [10 points])
- Next week: Sampling and Reconstruction
  - Including signal processing and fourier analysis
  - Implementation of simple digital filters, resizing
  - Second half of assignment
- Lectures main source; will also try handout

Intensities: Human Perception

- Human eye can perceive wide range of intensities
  - Dimly lit darkened room to bright sunlight
  - Radiance ratio in these cases is a million to one or more
- How does it work? [image only 256 gray levels]
  - Nonlinear human response
  - Care about ratio of intensities (log scale). So jump from 0.1 to 0.11 as important as 0.50 to 0.55 (not .5 to .51)
  - E.g.: cycle through 50W,100W,150W (step from 50 to 100 much greater than from 100 to 150)
- Technically, equispaced intensities multiplicative
  - 0.02, 0.0203, 0.0206, … 0.9848, 1.00 [for 100 values]
- Area of CG known as tonemapping (we ignore)
Gamma Correction

- Website: http://graphics.stanford.edu/gamma.html
- Practical problem: Images look too dark/bright...

Monitors were CRT displays with nonlinear resp.

\[ I = a V^\gamma \]
\[ V = \left( \frac{I}{a} \right)^{\frac{1}{\gamma}} \]

\( \gamma \approx 2.5 \)  

NTSC, use 2.2 (camera pre-corrected)

Rendering linear (physical space) **Gamma Correct**

Example

- Say RGB is something like (1, 0.5, 0)
- Values of 1 and 0 don’t change (black, white, primary colors unaffected by gamma correction)
- Value of .5 becomes .707 (power of \( \frac{1}{2} \), gamma = 2)
- Final color is (1, 0.707, 0) [brighter, less saturated]

Color

- Already seen: RGB model (color cube)
- Today: A very brief overview of real story
- Intuitive specify: Hue, Saturation, Lightness
  - Hexacone
  - Can convert HSV to RGB
  - Many other fancy, perceptual spaces

Color: Tristimulus Theory

- Perception: Tri-stimulus theory
  - 3 types of cones: basis for RGB
  - Cone response functions
  - Luminous efficiency (G>R>B)
  - Color matching: Note "negative colors"
  - CIE overview

Basic Image Processing (HW 1: 3.2)

- Brightness: Simply scale pixel RGB values (1 leaves image intact, 0 makes it black)
- Gamma Correction
- Crop (integer coords) to focus on important aspects
Basic Image Processing (HW 1: 3.2)

- Contrast [0 is constant grey image, 1 is original]
  - Find constant grey image by averaging
  - Interpolate between this and original

```
-2.5  0  0.5  1.0  2.0
```

Basic Image Processing (HW 1: 3.2)

- Saturation [0 is greyscale, 1 is original colors]
  - Interpolate between grayscale (but not const) and orig.
  - Negative values correspond to inverting hues [negative]

```
-1.0  0.0  0.5  1.0  2.0
```

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  - Second half of assignment (and written part)

Images and Resolution

- Image is a 2D rectilinear discrete array of samples
- There are resolution issues:
  - Intensity resolution: Each pixel has only Depth bits
  - Spatial resolution: Image is only width*height pixels
  - Temporal resolution: Monitor refreshes only at some rate

<table>
<thead>
<tr>
<th></th>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTSC</td>
<td>640x480</td>
<td>8 bits</td>
<td>30 Hz</td>
<td></td>
</tr>
<tr>
<td>PC</td>
<td>1280x1024</td>
<td>24 bits RGB</td>
<td>75 Hz</td>
<td></td>
</tr>
<tr>
<td>Film</td>
<td>3000x2000</td>
<td>12 bits</td>
<td>24 Hz</td>
<td></td>
</tr>
<tr>
<td>Laser Printer</td>
<td>7000x2000</td>
<td>1 (on or off)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Some material for slides courtesy Greg Humphreys and Tom Funkhouser

Sources of Error or Artifacts

- Quantization: Not enough intensity resolution (bits)
  - Halftoning/dithering: Reduce visual artifacts due to quantization
- Spatial and Temporal Aliasing: not enough resolution
  - Sampling and reconstruction to reduce visual artifacts due to aliasing (next week)

Uniform Quantization

```
1 bit
2 bits: NOTE CONTOURS
8 bits
4 bits
```
**Uniform Quantization**

2 bits: NOTE CONTOURS

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**Reducing Quantization**

- Halftoning
- Dithering
  - Random Dither
  - Error Diffusion (Floyd-Steinberg)

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**Halftoning**

- Motivation: bilevel printing. Trade off spatial resolution for more intensity levels
- Dots of appropriate size to simulate grey levels
- Area of dots proportional intensity

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**Halftone Patterns**

- Cluster of dots (pixels) to represent intensity (trading spatial resolution for increased intensity resolution)
- Exploits spatial integration in eye

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**Reducing Quantization**

- Halftoning
- Dithering (distribute errors among pixels)
  - Random Dither
  - Error Diffusion (Floyd-Steinberg)

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**Dithering**

8 bits original

2 bits quantize: Note Contours

2 bits FLOYD STEINBERG

2 bits random dither: noise not contours
Random Dither

- Randomize quantization errors [see assignment for exact details on adding random noise]
- Seems silly (add random noise), but eye more tolerant of high-frequency noise than contours or aliasing
- More complex algorithms (not considered here) are ordered dither with patterns of thresholds rather than completely random noise

Error Diffusion

- Spread quantization error to neighboring pixels to the right and below (later in the process)
- Reduces net error, gives best results

$$\text{Error} = \text{pixel}(x,y) - \text{quantize}(x,y);$$
$$\text{pixel}(x+1,y) = \alpha \cdot \text{Error};$$
$$\text{pixel}(x-1,y+1) = \beta \cdot \text{Error};$$
$$\text{pixel}(x+1,y+1) = \delta \cdot \text{Error};$$

Quantization (Sec 3.3 Ass 1)

- Simple quantization (should be straightforward)
- Random Dither (just add noise, pretty simple)
- Floyd-Steinberg (trickiest)
  - Must implement a diffusion of error to other pixels (simply add in appropriate error to them)
  - Uses fractions, so must use floating point
  - And possibly negative numbers since error can be minus
  - Boundary conditions (what if no right etc.) toroidal [may not be relevant in this case] or change weights appropriately, but don’t darken boundaries