Foundations of Computer Graphics (Fall 2012)

CS 184, Lecture 12: Raster Graphics and Pipeline

http://inst.eecs.berkeley.edu/~cs184

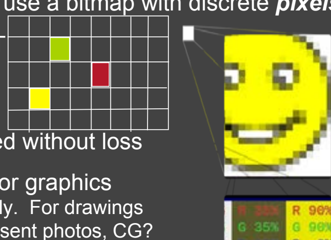
Lecture Overview

- Many basic things tying together course
  - Is part of the material, will be covered on midterm
- *Raster graphics*
- Gamma Correction
- Color
- Hardware pipeline and rasterization
- Displaying Images: Ray Tracing and Rasterization
  - Essentially what this course is about (HW 2 and HW 5)
- Introduced now so could cover basics for HW 1,2,3
  - Course will now "breathe" to review some topics

Some images from wikipedia

Images and Raster Graphics

- Real world is continuous (almost)
- How to represent images on a display?
- Raster graphics: use a bitmap with discrete ***pixels***
- Raster scan CRT (paints image line by line)
- Cannot be resized without loss
- Compare to vector graphics
  - Resized arbitrarily. For drawings
  - But how to represent photos, CG?

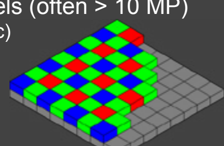


Displays and Raster Devices

- CRT, flat panel, television (rect array of pixels)
- Printers (scanning: no physical grid but print ink)
- Digital cameras (grid light-sensitive pixels)
- Scanner (linear array of pixels swept across)
- Store image as 2D array (of RGB [sub-pixel] values)
  - In practice, there may be resolution mismatch, resize
  - Resize across platforms (phone, screen, large TV)
- Vector image: description of shapes (line, circle, …)
  - E.g., line art such as in Adobe Illustrator
  - Resolution-Independent but must *rasterize* to display
  - Doesn't work well for photographs, complex images

Resolutions

- Size of grid (1920x1200 = 2,304,000 pixels)
  - 32 bit of memory for RGBA framebuffer 8+ MB
- For printers, pixel density (300 dpi or ppi)
  - Printers often binary or CMYK, require finer grid
  - iPhone "retina display" > 300 dpi. At 12 inches, pixels closer than retina's ability to distinguish angles
- Digital cameras in Mega-Pixels (often > 10 MP)
  - Color filter array (Bayer Mosaic)
  - Pixels really small (micron)



Monitor Intensities

- Intensity usually stored with 8 bits [0…255]
- HDR can be 16 bits or more [0…65535]
- Resolution-independent use [0…1] intermediate
- Monitor takes input value [0…1] outputs intensity
  - Non-zero intensity for 0, black level even when off
  - 1.0 is maximum intensity (output 1.0/0.0 is contrast)
  - Non-linear response (as is human perception)
  - 0.5 may map to 0.25 times the response of 1.0
  - Gamma characterization and gamma correction
  - Some history from CRT physics and exponential forms

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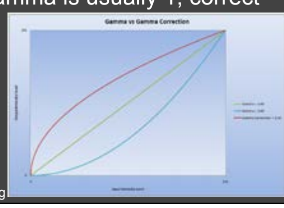
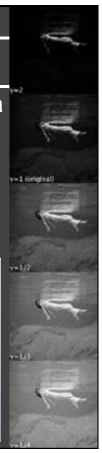
Nonlinearity and Gamma

- Exponential function $I = a^{\gamma}$
- I is displayed intensity, a is pixel value
- For many monitors γ is between 1.8 and 2.2
- In computer graphics, most images are linear
  - Lighting and material interact linearly
- Gamma correction $a' = a^{\frac{1}{\gamma}}$
- Examples with γ = 2
  - Input a = 0 leads to final intensity I = 0, no correction
  - Input a = 1 leads to final intensity I = 1, no correction
  - Input a = 0.5 final intensity 0.25. Correct to 0.707107
  - Makes image "brighter" [brightens mid-tones]

Gamma Correction

- Can be messy for images. Usually gamma on one monitor, but viewed on others…
- For television, encode with gamma (often 0.45, decode with gamma 2.2)
- CG, encode gamma is usually 1, correct



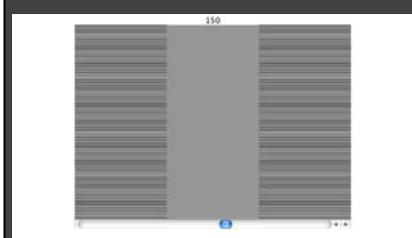


www.dfstudios.co.uk/wp-content/uploads/2010/12/graph_gamcor.png

Finding Monitor Gamma

- Adjust grey until match 0-1 checkerboard to find mid-point a value i.e., a for I = 0.5 $I = a^{\gamma}$

$$\gamma = \frac{\log 0.5}{\log a}$$



http://www.cs.cornell.edu/Courses/cs4620/2008fa/homeworks/gamma.htm

Human Perception

- Why not just make everything linear, avoid gamma
- Ideally, 256 intensity values look linear
- But human perception itself non-linear
  - Gamma between 1.5 and 3 depending on conditions
  - Gamma is (sometimes) a feature
  - Equally spaced input values are perceived roughly equal

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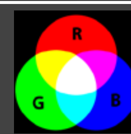
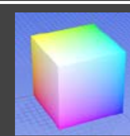
Color

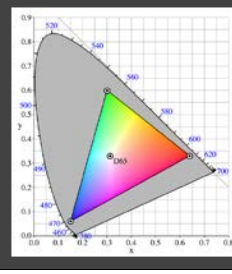
- Huge topic (can read textbooks)
  - Schrodinger much more work on this than quantum
- For this course, RGB (red green blue), 3 primaries
- Additive (not subtractive) mixing for arbitrary colors
- Grayscale: 0.3 R + 0.6 G + 0.1 B
- Secondary Colors (additive, not paints etc.)
  - Red + Green = Yellow, Red + Blue = Magenta, Blue + Green = Cyan, R+G+B = White
- Many other color spaces
  - HSV, CIE etc.

RGB Color

- Venn, color cube
- Not all colors possible







Images from wikipedia

Eyes as Sensors

The human eye contains cells that sense light

- Rods
  - No color (sort of)
  - Spread over the retina
  - More sensitive
- Cones
  - Three types of cones
  - Each sensitive to different frequency distribution
  - Concentrated in fovea (center of the retina)
  - Less sensitive

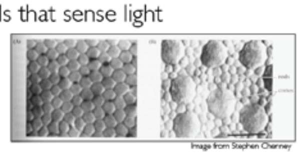


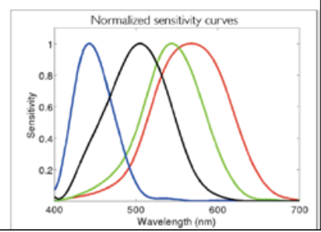
Image from Stephen Chenney

Slides courtesy Prof. O'Brien

Cones (Trichromatic)

- Each type of cone responds to different range of frequencies/wavelengths
  - Long, medium, short
- Also called by color
  - Red, green, blue
  - Misleading

"Red" does not mean your red cones are firing...



Cone Response

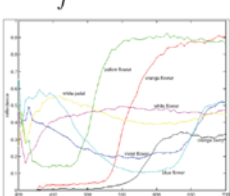
Response of a cone is given by a convolution integral :

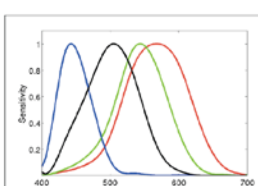
$$L = \int \Phi(\lambda) L(\lambda) \mathrm{d}\lambda$$

$$M = \int \Phi(\lambda) M(\lambda) \mathrm{d}\lambda$$

$$S = \int \Phi(\lambda) S(\lambda) \mathrm{d}\lambda$$

continuous version of a dot product





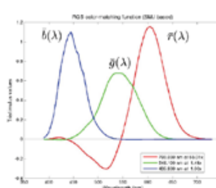
Color Matching Functions

Using Color Matching Functions

Given color matching functions in matrix form and new light

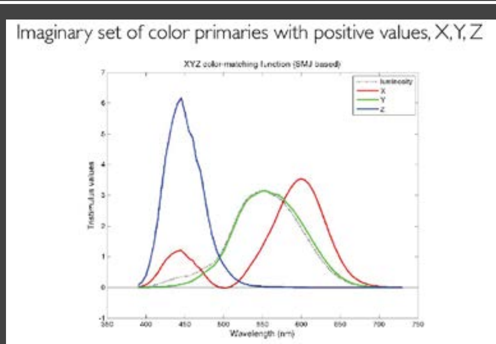
$$C = \begin{pmatrix} \bar{r}(\lambda_1) & \dots & \bar{r}(\lambda_N) \\ \bar{g}(\lambda_1) & \dots & \bar{g}(\lambda_N) \\ \bar{b}(\lambda_1) & \dots & \bar{b}(\lambda_N) \end{pmatrix}$$

$$\Phi = \begin{pmatrix} \phi(\lambda_1) \\ \vdots \\ \phi(\lambda_N) \end{pmatrix}$$



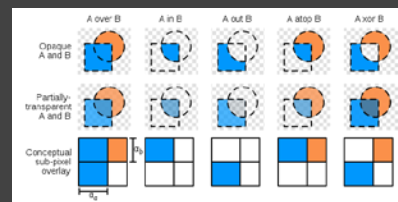
amount of each primary necessary to match is given by $C\Phi$

CIE XYZ



Alpha Compositing

- RGBA (32 bits including alpha transparency)
  - You mostly use 1 (opaque)
  - Can simulate sub-pixel coverage and effects
- Compositing algebra



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Read chapter 8 more details

Hardware Pipeline

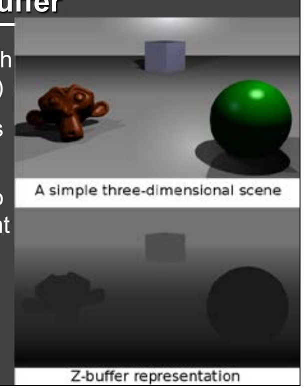
- Application generates stream of vertices
- Vertex shader called for each vertex
  - Output is transformed geometry
- OpenGL rasterizes transformed vertices
  - Output are fragments
- Fragment shader for each fragment
  - Output is Framebuffer image

Rasterization

- In modern OpenGL, really only OpenGL function
  - Almost everything is user-specified, programmable
  - Basically, how to draw (2D) primitive on screen
- Long history
  - Bresenham line drawing
  - Polygon clipping
  - Antialiasing
- What we care about
  - OpenGL generates a fragment for each pixel in triangle
  - Colors, values interpolated from vertices (Gouraud)

Z-Buffer

- Sort fragments by depth (only draw closest one)
- New fragment replaces old if depth test works
- OpenGL does this auto can override if you want
- Must store z memory
- Simple, easy to use



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What is the core of 3D pipeline?

- For each object (triangle), for each pixel, compute shading (do fragment program)
- Rasterization (OpenGL) in HW 2
  - For each object (triangle)
    - For each pixel spanned by that triangle
      - Call fragment program
- Ray Tracing in HW 5: flip loops
  - For each pixel
    - For each triangle
      - Compute shading (rough equivalent of fragment program)
- HW 2, 5 take almost same input. Core of class

Ray Tracing vs Rasterization

- Rasterization complexity is N * d
  - (N = objs, p = pix, d = pix/object)
  - Must touch each object (but culling possible)
- Ray tracing naïve complexity is p * N
  - Much higher since p >> d
  - But acceleration structures allow p * log (N)
  - Must touch each pixel
  - Ray tracing can win if geometry very complex
- Historically, OpenGL real-time, ray tracing slow
  - Now, real-time ray tracers, OpenRT, NVIDIA Optix
  - Ray tracing has advantage for shadows, interreflections
  - Hybrid solutions now common

Course Goals and Overview

- Generate images from 3D graphics
- Using both rasterization (OpenGL) and Raytracing
  - HW 2 (OpenGL), HW 5 (Ray Tracing)
- Both require knowledge of transforms, viewing
  - HW 1
- Need geometric model for rendering
  - Splines for modeling (HW 3)
- Having fun and writing "real" 3D graphics programs
  - HW 4 (real-time scene in OpenGL)
  - HW 6 (final project)