Today’s Topics

• Review the syllabus
• Review course policies
• Color
• CIE system
• chromaticity diagram
• color gamut, complementary colors, dominant wavelength
• Students will fill out a questionnaire
Who is your instructor?

- I'm Mike Eckmann, an Assistant Professor in the Mathematics and Computer Science Dept., Skidmore College. This is my eighth year of teaching at Skidmore. Before coming to Skidmore I was at Lehigh University in PA.

- I studied Mathematics and Computer Engineering and Computer Science all at Lehigh University.

- I was employed as a programmer (systems analyst) for eight years.
General comments

• I’m really looking forward to teaching this course again. I have taught this course several times and it has gone pretty well.

• Partly because of student feedback, a lab hour was added. This lab hour will allow you to have time to work on programming in class (in addition to outside of class) so that I will be there to help out if you need it.
Syllabus

• Office hours
• Text book
• Class room
• Assignments
  – Mostly programming
• Collaboration policy
• Grading scheme
• Attendance
• Readings

http://www.skidmore.edu/~meckmann/2012Spring/cs325/index.html

The most up-to-date syllabus will be found on the course web page.
Suggestions on how to succeed in this (or any? CS) course

• Keep up on the reading before the class period that we cover it.

• Participate in class -- ask questions in class (best), via email or in my office.

• Start the programs as soon as they are assigned. You will run into snags. Debugging can take a long long long time. Lab periods will help.

• These are based on my observations of successful students in past classes.
CG Definition and Application Areas

- Computer Graphics is using computer hardware and software to assist in creating images.

- Application areas of computer graphics are many
  - Entertainment: Film, art, games
  - Scientific Visualization (large, multidimensional data sets) examples: http://accad.osu.edu/~waynec/history/lesson18.html
  - Systems used for various types of training
  - Usability of computers (Human Computer Interaction)
  - And more...
Some of the concepts we’ll cover

• In this course we will be learning about the following Computer Graphics concepts.
  – Color
  – Algorithms for drawing lines, circles, etc. in 2d.
  – Learning how to transform a 3d description of a scene into 2d for display on a screen, based on viewing angle, etc.
  – How to model lighting in scenes.
  – Some of the concepts behind making realistic looking models of objects.
  – And more...
Programming Oriented

• I feel that writing programs using the concepts learned in class is one of the best ways to really understand those concepts. Writing programs that produce graphics requires the programmer to have a deep understanding of the topics involved.

• I’ll assume you know how to program well in Java.

• I will review the Linear Algebra material necessary for the course.

• I will cover the basics of the OpenGL/Jogl graphics library (soon).
Programming Oriented

• OpenGL is a graphics library that has functionality to draw pixels, lines, polygons, etc. It also contains ways for us to control the appearance of what is drawn: e.g. Color, surface properties, lighting in the scene, textures etc.

• We will be using OpenGL to aid us in our graphics programming. However, this course is not a course in learning all the cool stuff you can do with OpenGL, instead we will use some of the basic functions available in the OpenGL library to draw pixels etc. which will allow us to implement (and learn about) some important algorithms in Computer Graphics.

• Think about the data structures you coded from scratch in cs206 --- same idea here.
Some Examples of Computer Graphics in Films

• 1982: Star Trek: The Wrath of Khan
  – First all digital computer graphics sequence in a film
• 1985: Young Sherlock Holmes
  – First fully computer graphics created character in a film
• 1993: Jurassic Park
  – First computer graphically created live animals in a film
• 1995: Toy Story
  – First feature length CG film.
• 1997: Titanic
  – http://www.pbs.org/wgbh/nova/specialfx2/real.html
Examples of Computer Graphics in Films

• 2001: Final Fantasy: The Spirits Within
• Stats for this film:
  – Poly counts for main characters = ~ 300,000
  – Number of Frames in the Movie = 149,246
    • (at 24 frames/sec. for over 100 minutes)
  – 934,162 days of render time on one processor
  – Used ~ 1200 processors
  – Storage ~ 4 TB
Examples of Computer Graphics in Films

• 2009: Avatar
• Stats for this film:
  – Poly counts for plants = ~ 100,000 – 1 million
  – Number of full CG frames in the movie = 158,400
    • (at 24 frames/sec. for 110 minutes)
  – Number of partial CG frames in the movie = 28,800
    • (at 24 frames/sec. for 20 minutes)
  – Multiply those by 2 (because of 3D)
  – Each frame 30-50 (60-100) hours of render time
  – Used ~ 40,000 processors w/ 104 TB RAM
Color

- Ok, enough introduction, let’s start our discussion of color. Color is covered in Chapter 19 of our textbook.
- Physically, color is electromagnetic radiation in the visible light frequency range.
- Psychologically, how humans perceive color is more than just the frequency. Hue, brightness and purity are what characterize what color is seen. These terms will be defined shortly.
**Color**

- Frequency range of visible light is approx. from:
  - $3.8 \times 10^{14}$ Hz up to $7.9 \times 10^{14}$ Hz


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Color Terms

• White light contains approx. equal amounts of all frequencies of the visible range and when light hits an opaque object, some frequencies are absorbed and others are reflected. The ones that are reflected are the colors that we see.

• Hue, Brightness and Purity are the three perceived characteristics of light.

• Hue: the Dominant Frequency of perceived light

• Brightness (aka Luminance of the light): the total light energy

• Purity (aka Saturation): a measure of how much white light is entering the eye (e.g. Red is more pure than pink)

• Chromaticity refers collectively to hue and purity (everything except brightness)
Color

- Frequency is measured in Hertz (Hz) which is 1 / seconds
- Wavelength is often used to describe colors where the wavelength = speed of light / frequency
- Speed of light is approx. $3 \times 10^8$ m / s
- Visible light’s wavelength range is approximately:
  - wavelength of the low frequency end $3.8 \times 10^{14}$ Hz is: $3 \times 10^8$ m/s / $3.8 \times 10^{14}$ Hz = 789 nm (Red end)
  - wavelength of the high frequency end of $7.9 \times 10^{14}$ Hz is: $3 \times 10^8$ m/s / $7.9 \times 10^{14}$ Hz = 379 nm (Violet end)
Color

Figure 12-4
Energy distribution for a light source with a dominant frequency near the red end of the frequency range.


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Color

• The last slide shows a color that is reddish and fairly pure due to the fact that $E_D$ is $>> E_W$.

• If the graph contained approximately the same amount of energy of each frequency then it would represent white.
Color

• If we combine light with different dominant frequencies, we can create other colors. We combine primary colors in various proportions to make up a wide range of colors known as the color gamut.

• Complementary colors are two colors that combine to produce white.

• No finite set of light sources can produce all colors. The color gamut of three primary colors is typically sufficient for most purposes.
Color

• The **tristimulus theory** of color perception states that the retina in the human eye has three kinds of color sensors (cones) with peak sensitivities to red, blue and green light.
  
  - Cones (6-8 million in retina, concentrated in fovea) for color / bright light vision
  
  - Rods (over 100 million in retina, none in fovea) for achromatic brightness levels / night vision
  
  - fovea is in center of retina --- that's where most of the cones are
  
  - Let's look here for the rod & cone distribution throughout the retina:
    
    
    • [http://dragon.uml.edu/psych/rodconedistribution.html](http://dragon.uml.edu/psych/rodconedistribution.html)
Color

• The **tristimulus theory** of color perception (continued)
  – Experiments have shown that based on this theory that blue's peak is 440 nm, green's is 545 nm, and red's is 580 nm.
  – Also, experiments have shown that the eye's response to blue light is much less strong than to red and green.
  – Given 3 primary colors, we can combine them with various proportions to produce new colors. Defining colors by mixtures of three primaries is an extremely useful approach.
Color

• Experiments were done on humans to determine what proportions of three primaries would produce certain test colors.

• The experiments were like this:
  – A test color was shown.
  – An adjustable color was also shown that contained a mixture of three primaries 700 nm (red), 546.1 nm (green) and 435.8 nm (blue).
  – The observer adjusted the amount of each of the three primaries until the observer determined that it matched the test color.

• Some test colors were not matchable. In these cases, a primary was added to the test color and then attempted to be matched. This resulted in the original test color being represented by a certain mixture of the three primaries (one with a negative contribution.)
Public domain image – This shows how much of each of the three primaries are needed to generate each monochromatic color (the wavelength on the x-axis.)
Color

- This is a chromaticity diagram (shows colors at a single (highest) brightness). Only hue and saturation are represented.

- The bottom left circle is the blue primary, the top circle is the green primary and the bottom right circle is the red primary. These are the three primaries from the last slide.

- The triangle contains the color gamut of those primaries.
Color

• The next slide shows color matching functions $f_Z$, $f_Y$ and $f_X$ for a standard set (CIE 1931) of primaries $Z$, $Y$ and $X$. These three colors were defined so that there is no need for a negative contribution of one of them and so that the entire range of visible colors is producible.

• These three colors $X$, $Y$ and $Z$ correspond roughly to red, green, and blue respectively.
Color

Figure 12-6
The three color-matching functions for the CIE primaries.


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Color

• Data files exist with the amounts of each of the color matching functions needed to produce colors at all the wavelengths between 360 nm and 830 nm.

• The values in the charts correspond to the graph on the last slide. The values are used as weights thusly:

\[ \text{Color} = xX + yY + zZ, \]

where \( x \), \( y \) and \( z \) are the weights applied to the primaries \( X \), \( Y \) and \( Z \).

• \( x+y+z \) is the total light energy. We can normalize with respect to this amount.
Color

- **Color** = \( xX + yY + zZ \)
- \( x' = \frac{x}{x+y+z} \)
- \( y' = \frac{y}{x+y+z} \)
- \( z' = \frac{z}{x+y+z} \)
- Since \( x' + y' + z' = 1 \), any color can be represented by just two of the \( x' \), \( y' \) and \( z' \).
- By normalizing based on the total light energy (brightness) we are only now dealing with hue and purity (collectively known as Chromaticity)
- The graph on the next slide is in 2d and it's x axis corresponds to \( x' \) here, and y axis to \( y' \) here.
Figure 12-7
CIE chromaticity diagram for the spectral colors from 400 nm to 700 nm.
Questionnaire & Homework

• Please fill out the questionnaire and give it to me before you leave today.

• READING:
  – Color Models & Color Applications:
    • Read Chapter 19 (entire chapter) (it’s only 18 pages – best if you read before Wednesday’s class)
  – Introduction:
    • Skim Chapter 1
    • Read Chapter 3