Computer Graphics

Adam Finkelstein
Princeton University
COS 426, Spring 2005

Overview

- Administrivia
  - People, times, places, etc.
- Syllabus
  - What will I learn in this course?
- Raster Graphics
  - Getting started …

Administrative Matters

- Instructors
  - Adam Finkelstein - *CS 424, stop in any time, or email*
  - Jason Lawrence (TA) - *CS 415, office Thur 4:30-5:30*
- Book
  - *Computer Graphics with OpenGL, Third Edition,*
    Donald Hearn and M. Pauline Baker,
    Prentice Hall, 2004 ISBN: 0-13-015390-7
- Web page
  - http://www.cs.princeton.edu/courses/cos426

Coursework

- Exams (30%)
  - In class (Mar 10 and Apr 26)
- Programming Assignments (40%)
  - Assignment #1: Image Processing (due Feb 20)
  - Assignment #2: Ray Tracing (due Mar 20)
  - Assignment #3: Modeling (due Apr 3)
  - Assignment #4: Animation (due Apr 17)
- Final Project (20%)
  - Do something cool! (due at end of semester)
- Class Participation (10%)

Programming Assignments

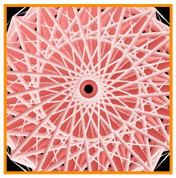
- When?
  - Roughly every two weeks
- Where?
  - Anywhere you want, e.g. home or Friend 017 lab
- How?
  - Windows (017), Unix/Linux ("hats"), or MacOSX
  - C and C++, OpenGL, GLUT
- What?
  - Basic feature lists
  - Extra credit lists
  - Art contest

Art Contest

- Everybody should submit entries!
  - 1 point for submitting
  - 2 points for winning

Cool Images
(Brian Beck, CS 426, Sprint04)

Videos
(Jon Beyer, CS 426, Spring04)



Bloopers
(Kathleen Mulcahey, CS 426, Fall99)

Collaboration Policy

- Overview:
  - o You must write your own code (no credit for other code)
  - o You must reference your sources of any ideas/code
- It's OK to …
  - o Talk with other students about ideas, approaches, etc.
  - o Get ideas from information in books, web sites, etc.
  - o Get "support" code from example programs
    - » But, you must reference your sources
- It's NOT OK to …
  - o Share code with another student
  - o Use ideas or code acquired from another sources without attribution

Precepts

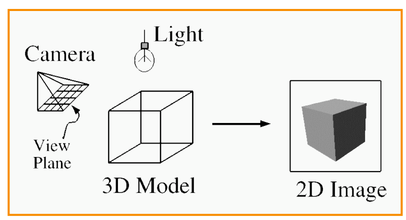
- Schedule?
  - o Wednesday, 7-8PM
- Place?
  - o TBA

Overview

- Administrivia
  - o People, times, places, etc.
- ➢ Syllabus
  - o What will I learn in this course?
- Raster Graphics
  - o Getting started …

Introduction

- What is computer graphics?
  - o Imaging = *representing 2D images*
  - o Modeling = *representing 3D objects*
  - o Rendering = *constructing 2D images from 3D models*
  - o Animation = *simulating changes over time*



Applications

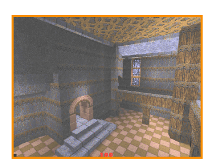
- Entertainment
- Computer-aided design
- Scientific visualization
- Training
- Education
- E-commerce
- Computer art

Applications

- ➔ **Entertainment**
- Computer-aided design
- Scientific visualization
- Training
- Education
- E-commerce
- Computer art

Jurasic Park
(Industrial, Light, & Magic)

Geri's Game
(Pixar Animation Studios)

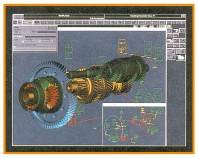


Quake
(Id Software)

Applications

- Entertainment
- ➔ **Computer-aided design**
- Scientific visualization
- Training
- Education
- E-commerce
- Computer art

Los Angeles Airport
(Bill Jepson, UCLA)

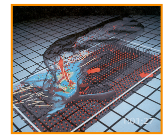


Gear Shaft Design
(Intergraph Corporation)

Boeing 777 Airplane
(Boeing Corporation)

Applications

- Entertainment
- Computer-aided design
- ➔ **Scientific visualization**
- Training
- Education
- E-commerce
- Computer art



Airflow Inside a Thunderstorm
(Bob Wilhelmson, University of Illinois at Urbana-Champaign)

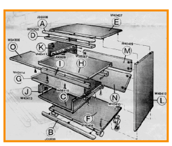
Apo A-1
(Theoretical Biophysics Group, University of Illinois at Urbana-Champaign)

Visible Human
(National Library of Medicine)

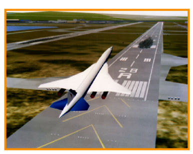
Applications

- Entertainment
- Computer-aided design
- Scientific visualization
- ➔ **Training**
- Education
- E-commerce
- Computer art

Driving Simulation
(Evans & Sutherland)



Desk Assembly
(Silicon Graphics, Inc.)

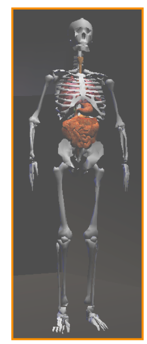


Flight Simulation
(NASA)

Applications

- Entertainment
- Computer-aided design
- Scientific visualization
- Training
- ➔ **Education**
- E-commerce
- Computer art

Forum of Trajan
(Bill Jepson, UCLA)



Human Skeleton
(SGI)

Applications

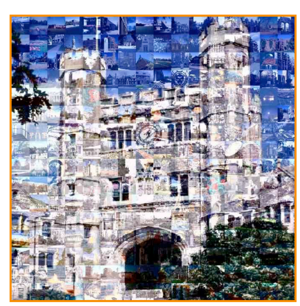
- Entertainment
- Computer-aided design
- Scientific visualization
- Training
- Education
- ➔ **E-commerce**
- Computer art

Interactive Kitchen Planner
(Matsushita)

Virtual Phone Store
(Lucent Technologies)

Applications

- Entertainment
- Computer-aided design
- Scientific visualization
- Training
- Education
- E-commerce
- ➔ **Computer art**



Blair Arch
(Marissa Range '98)

Syllabus

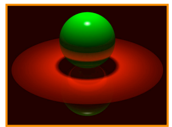
I. Image processing

II. Rendering

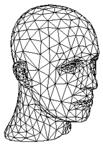
III. Modeling

IV. Animation

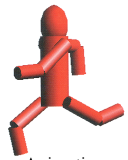
Image Processing
(Rusty Coleman, CS426, Fall99)



Rendering
(Michael Bostock, CS426, Fall99)



Modeling
(Dennis Zorin, CalTech)



Animation
(Angel, Plate 1)

Part I: Image Processing

- Raster Graphics
  - Display devices
  - Color models
- Image Representation
  - Sampling
  - Reconstruction
  - Quantization & Aliasing
- Image Processing
  - Filtering
  - Warping
  - Composition
  - Morphing

Image Composition
(Michael Bostock, CS426, Fall99)

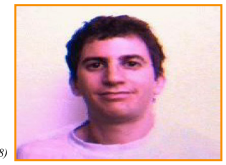
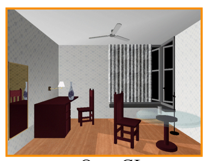


Image Morphing
(All students in CS 426, Fall98)

Part II: Rendering

- 3D Rendering Pipeline
  - Modeling transformations
  - Viewing transformations
  - Hidden surface removal
  - Illumination, shading, and textures
  - Scan conversion, clipping
  - Hierarchical scene graphics
  - OpenGL
- Global illumination
  - Ray tracing
  - Radiosity



OpenGL
(Chi Zhang, CS 426, Fall99)

Ray Tracing
(James Percy, CS 426, Fall99)

Part III: Modeling

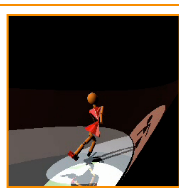
- Representations of geometry
  - Curves: splines
  - Surfaces: meshes, splines, subdivision
  - Solids: voxels, CSG, BSP
- Procedural modeling
  - Sweeps
  - Fractals
  - Grammars

Shell
(Douglas Turnbull, CS 426, Fall99)

Scenery Designer
(Dirk Balfanz, Igor Guskov, Sanjeev Kumar, & Rudro Samanta, CS426, Fall95)

Part IV: Animation

- Keyframing
  - Kinematics
  - Articulated figures
- Motion capture
  - Capture
  - Warping
- Dynamics
  - Physically-based simulations
  - Particle systems
- Behaviors
  - Planning, learning, etc.



Ice Queen
(Mao Chen et al CS426, Fall98)

Animation
(Jon Beyer, CS426, Spring04)

Overview

- Administrivia
  - People, times, places, etc.
- Syllabus
  - What will I learn in this course?
- ➢ Raster Graphics
  - Let's get started …

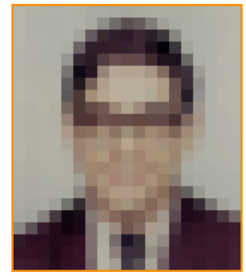
Raster Graphics

- Images
  - o What is an image?
  - o How are images displayed?
- Colors
  - o How do we perceive colors?
  - o How do we represent colors in a computer?

What is an Image?

- An image is a 2D rectilinear array of pixels

Continuous image

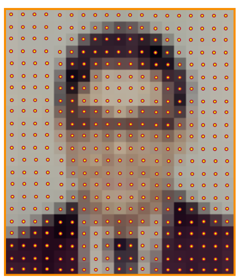


Digital image

What is an Image?

- An image is a 2D rectilinear array of pixels

Continuous image



Digital image

A pixel is a sample, not a little square!

What is an Image?

- An image is a 2D rectilinear array of pixels

Continuous image

Digital image

A pixel is a sample, not a little square!

Image Acquisition

- Pixels are samples from continuous function
  - o Photoreceptors in eye
  - o CCD cells in digital camera
  - o Rays in virtual camera

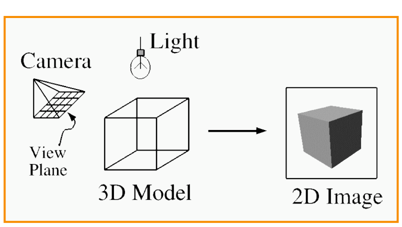
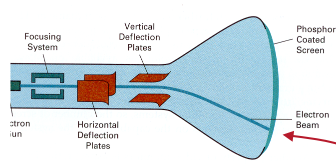


Image Display

- Re-create continuous function from samples
  - o Example: cathode ray tube



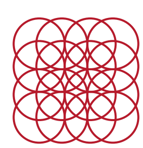


Image is reconstructed by displaying pixels with finite area (Gaussian)

Liquid Crystal Display (LCD)

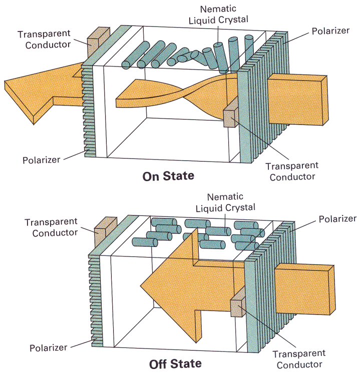


Figure 2.16 from H&B

Display Hardware

- Video display devices
  - » Cathode Ray Tube (CRT)
  - » Liquid Crystal Display (LCD)
  - o Plasma panels
  - o Thin-film electroluminescent displays
  - o Light-emitting diodes (LED)
- Hard-copy devices
  - o Ink-jet printer
  - o Laser printer
  - o Film recorder
  - o Electrostatic printer
  - o Pen plotter

Image Resolution

- Intensity resolution
  - o Each pixel has only "Depth" bits for colors/intensities
- Spatial resolution
  - o Image has only "Width" x "Height" pixels
- Temporal resolution
  - o Monitor refreshes images at only "Rate" Hz

Typical Resolutions

	Width x Height	Depth	Rate
NTSC	640 x 480	8	30
Workstation	1280 x 1024	24	75
Film	3000 x 2000	12	24
Laser Printer	6600 x 5100	1	-

Frame Buffer

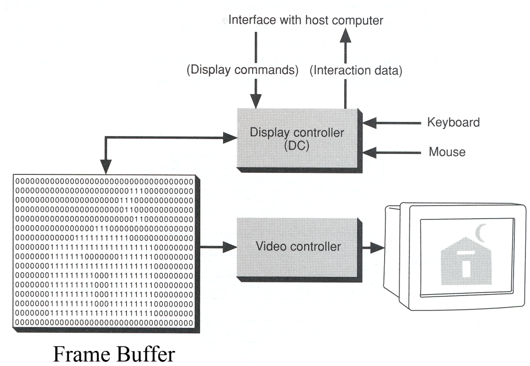
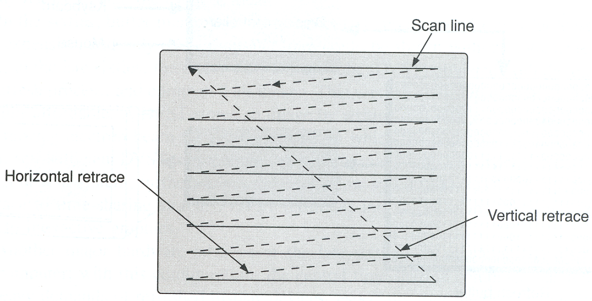


Figure 1.2 from FvDFH

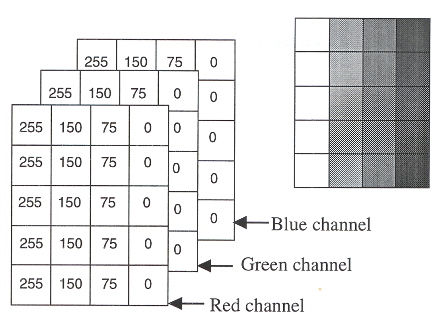
Frame Buffer Refresh



Refresh rate is usually 60-75Hz

Figure 1.3 from FvDFH

Color Frame Buffer



Color CRT

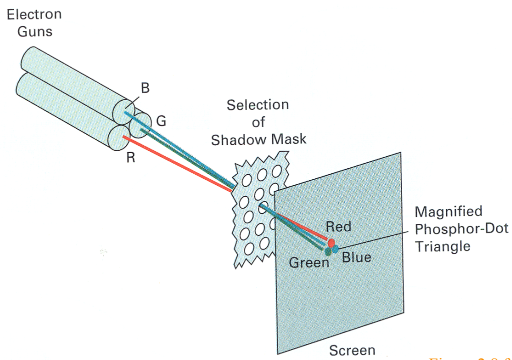


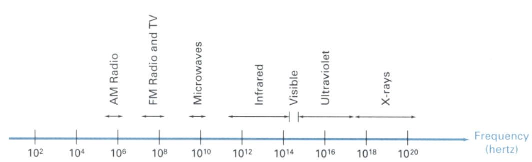
Figure 2.8 from H&B

Raster Graphics

- Images
  - What is an image?
  - How are images displayed?
- Colors
  - How do we perceive colors?
  - How do we represent colors in a computer?

Electromagnetic Spectrum

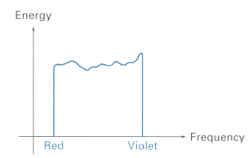
- Visible light frequencies range between ...
  - Red = 4.3 x 10^{14} hertz (700nm)
  - Violet = 7.5 x 10^{14} hertz (400nm)



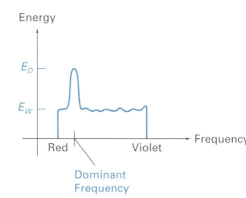
Figures 15.1 from H&B

Visible Light

- The color of light is characterized by …
  - Hue = dominant frequency (highest peak)
  - Saturation = excitation purity (ratio of highest to rest)
  - Lightness = luminance (area under curve)



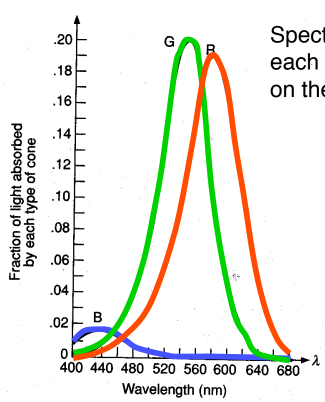
White Light



Orange Light

Figures 15.3-4 from H&B

Color Perception



Spectral-response functions of each of the three types of cones on the human retina.

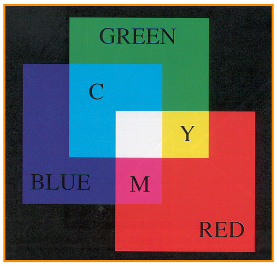
Tristimulus theory of color

Figure 13.18 from FvDFH

Color Models

- RGB
- XYZ
- CMY
- HSV
- Others

RGB Color Model

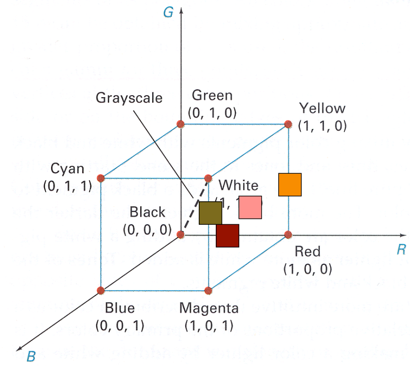


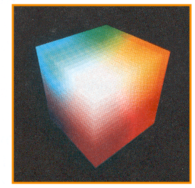
Colors are additive

R	G	B	Color
0.0	0.0	0.0	Black
1.0	0.0	0.0	Red
0.0	1.0	0.0	Green
0.0	0.0	1.0	Blue
1.0	1.0	0.0	Yellow
1.0	0.0	1.0	Magenta
0.0	1.0	1.0	Cyan
1.0	1.0	1.0	White
0.5	0.0	0.0	?
1.0	0.5	0.5	?
1.0	0.5	0.0	?
0.5	0.3	0.1	?

Plate II.3 from FvDFH

RGB Color Cube





Figures 15.11&15.12 from H&B

RGB Spectral Colors

Amounts of RGB primaries needed to display spectral colors

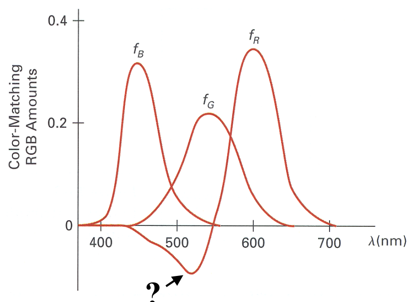


Figure 15.5 from H&B

XYZ Color Model (CIE)

Amounts of CIE primaries needed to display spectral colors

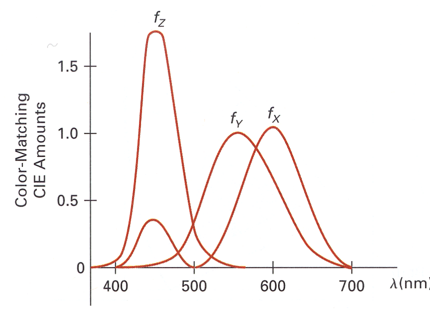


Figure 15.6 from H&B

CIE Chromaticity Diagram

Normalized amounts of X and Y for colors in visible spectrum

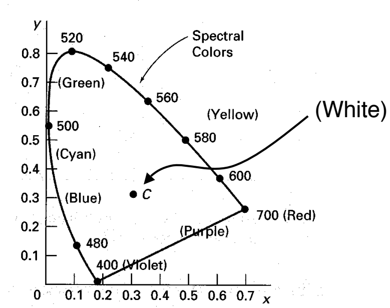
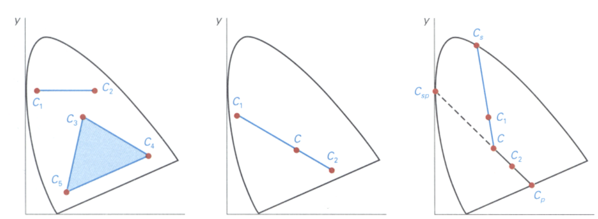


Figure 15.7 from H&B

CIE Chromaticity Diagram



Compare Color Gamuts

Identify Complementary Colors

Determine Dominant Wavelength and Purity

Figures 15.8-10 from H&B

RGB Color Gamut

Color gamut for a typical RGB computer monitor

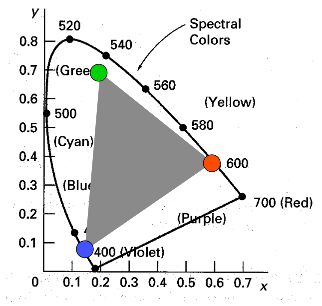
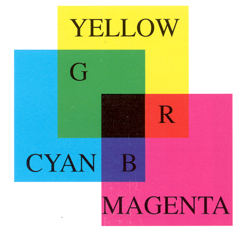


Figure 15.13 from H&B

CMY Color Model



Colors are subtractive

C	M	Y	Color
0.0	0.0	0.0	White
1.0	0.0	0.0	Cyan
0.0	1.0	0.0	Magenta
0.0	0.0	1.0	Yellow
1.0	1.0	0.0	Blue
1.0	0.0	1.0	Green
0.0	1.0	1.0	Red
1.0	1.0	1.0	Black
0.5	0.0	0.0	
1.0	0.5	0.5	
1.0	0.5	0.0	

Plate II.7 from FvDFH

CMY Color Cube

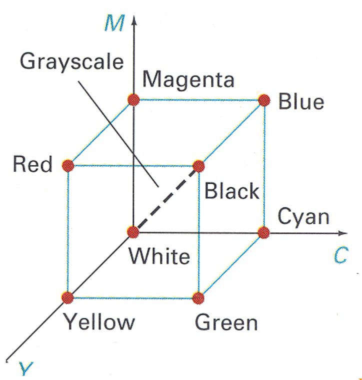
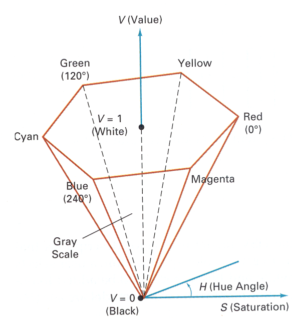


Figure 15.14 from H&B

HSV Color Model



H	S	V	Color
0	1.0	1.0	Red
120	1.0	1.0	Green
240	1.0	1.0	Blue
*	0.0	1.0	White
*	0.0	0.5	Gray
*	*	0.0	Black
60	1.0	1.0	
270	0.5	1.0	
270	0.0	0.7	

Figure 15.16&15.17 from H&B

Summary

- Images
  - Pixels are samples
  - Frame buffers
  - Display hardware (CRTs, LCDs, printers, etc.)
  - Devices have limited resolution
- Colors
  - Tristimulus theory of color
  - CIE Chromaticity Diagram
  - Different color models for different devices, uses, etc.