



Computer Graphics

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Princeton University
COS 426, Spring 2007



Overview

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



Administrative Matters

- Instructors
 - Tom Funkhouser - CS 422, *stop in anytime*
 - Chris DeCoro (TA)
- 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 15 and May 3)
- Programming Assignments (40%)
 - Assignment #1: Image Processing (due Feb 20)
 - Assignment #2: Modeling (due Mar 11)
 - Assignment #3: Ray Tracing (due Apr 15)
 - Assignment #4: Animation (due Apr 29)
- Final Project (20%)
 - Do something cool! (due at end of semester)
- Class Participation (10%)



Programming Assignments

- When?
 - Roughly every 2-3 weeks
- Where?
 - Anywhere you want, e.g. home or Friend 017 lab
- How?
 - C and C++
 - OpenGL, GLUT
- What?
 - Basic feature lists
 - Extra credit lists
 - Art contest

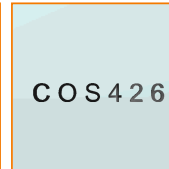


Art Contest

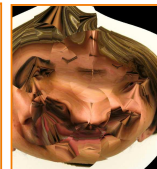
- Everybody should submit entries!
 - 1 point for submitting
 - 2 points for winning



Cool Images
(James Percy, CS 426, Fall99)



Videos
(Phil Wit, CS 426, Spr04)



Bloopers
(Alex Combs, CS 426, Spr05)

Collaboration Policy



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

Precepts



- Schedule?
 - Wednesday
- Place?
 - TBA

Overview

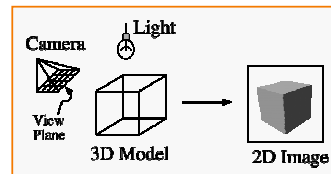


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Introduction



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



Applications



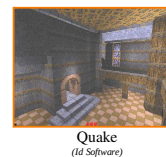
- Entertainment
- Computer-aided design
- Scientific visualization
- Training
- Education
- E-commerce
- Computer art

Applications



→ Entertainment

- Computer-aided design
- Scientific visualization
- Training
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Applications



- Entertainment
- ➔ **Computer-aided design**
- Scientific visualization
- Training
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- Computer art



Gear Shaft Design
(Intergraph Corporation)



Los Angeles Airport
(Bill Jepsen, UCLA)

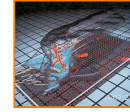


Boeing 777 Airplane
(Boeing Corporation)

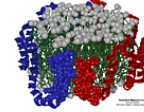
Applications



- Entertainment
- Computer-aided design
- ➔ **Scientific visualization**
- Training
- Education
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Airflow Inside a Thunderstorm
(Bob Wilhelmson,
University of Illinois at Urbana-Champaign)



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

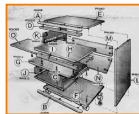


Visible Human
(National Library of Medicine)

Applications



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



Desk Assembly
(Silicon Graphics, Inc.)



Driving Simulation
(Evans & Sutherland)



Flight Simulation
(NASA)

Applications



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



Forum of Trajan
(Bill Jepsen, UCLA)



Human Skeleton
(SGI)

Applications



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



Interactive Kitchen Planner
(Matsushita)

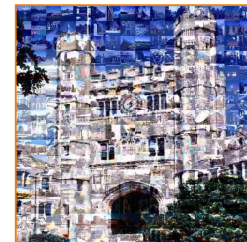


Virtual Phone Store
(Lucern Technologies)

Applications



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



Blair Arch
(Marissa Range '98)

Syllabus



I. Image processing

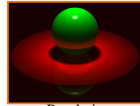
II. Modeling

III. Rendering

IV. Animation



Image Processing
(Rusty Coleman, CS426, Fall99)



Rendering
(Michael Bostock, CS426, Fall99)



Modeling
(Dennis Zarin, CalTech)



Animation
(Angel, Plate 1)

Part I: Image Processing



• Raster Graphics

- Display devices
- Color models



Image Composition
(Michael Bostock, CS426, Fall99)

• Image Representation

- Sampling
- Reconstruction
- Quantization & Aliasing

• Image Processing

- Filtering
- Warping
- Composition
- Morphing



Image Morphing
(All students in CS 426, Fall98)

Part II: Modeling



• Representations of geometry

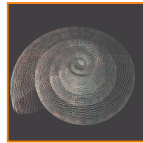
- Curves: splines
- Surfaces: meshes, splines, subdivision
- Solids: voxels, CSG, BSP

• Procedural modeling

- Sweeps
- Fractals
- Grammars



Scenery Designer
(Dirk Balfanz, Igor Guskov,
Sangeev Kumar, & Ruidro Samanta,
CS426, Fall95)



Shell
(Douglas Turnbull,
CS 426, Fall99)

Part III: Rendering



• 3D Rendering Pipeline

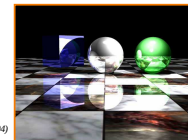
- Modeling transformations
- Viewing transformations
- Hidden surface removal
- Illumination, shading, and textures
- Scan conversion, clipping
- Hierarchical scene graphics
- OpenGL



Pixel Shading
(Final Fantasy, Square Pictures)

• Global illumination

- Ray tracing
- Radiosity



Ray Tracing
(Sid Kaper, CS 426, Spr04)

Part IV: Animation



• Keyframing

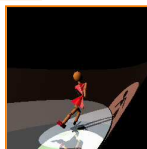
- Kinematics
- Articulated figures



Dancing Guy
(Jon Beyer, CS426, Spr05)

• Motion capture

- Capture
- Warping



Ice Queen
(Mao Chen, Zaijin Guan, Zhiyan Liu, & Xiaohu Qie,
CS426, Fall98)

• Dynamics

- Physically-based simulations
- Particle systems

• Behaviors

- Planning, learning, etc.

Overview



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• Syllabus

- What will I learn in this course?

Ø Raster Graphics

- Let's get started ...

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?

What is an Image?



- An image is a 2D rectilinear array of pixels



Continuous image



Digital image

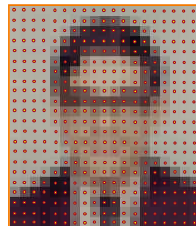
What is an Image?



- 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
 - Photoreceptors in eye
 - CCD cells in digital camera
 - Rays in virtual camera

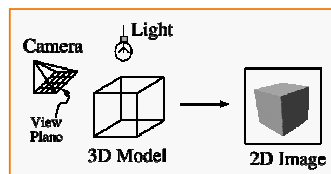
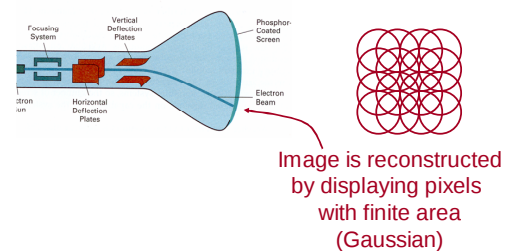


Image Display



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



Liquid Crystal Display (LCD)

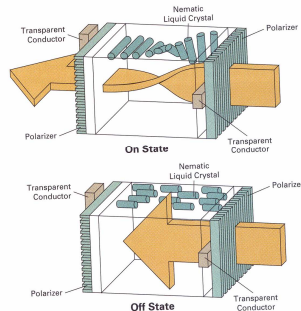


Figure 2.16 from H&B

Display Hardware



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

Image Resolution



- Intensity resolution
 - Each pixel has only "Depth" bits for colors/intensities
- Spatial resolution
 - Image has only "Width" x "Height" pixels
- Temporal resolution
 - 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

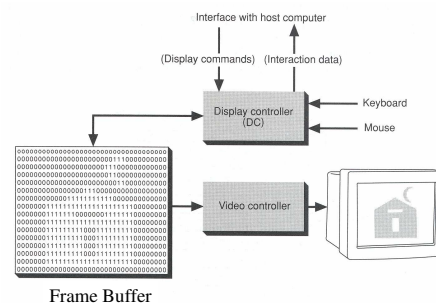
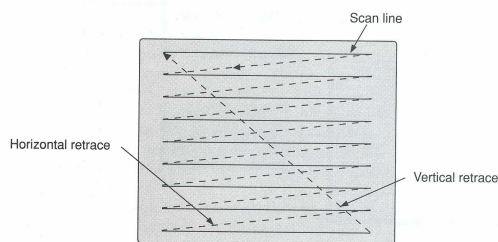


Figure 1.2 from FvDFH

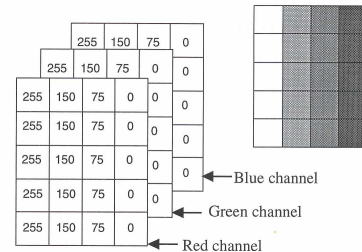
Frame Buffer Refresh



Refresh rate is usually 60-75Hz

Figure 1.3 from FvDFH

Color Frame Buffer



Color CRT

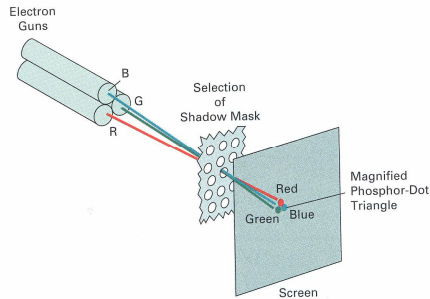


Figure 2.8 from H&B

Raster Graphics

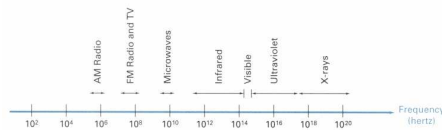


- Images
 - What is an image?
 - How are images displayed?
- Colors
 - How do we perceive colors?
 - How do we represent colors in a computer?

Electromagnetic Spectrum



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

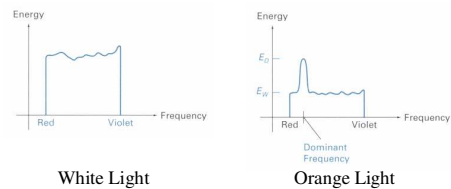


Figures 15.1 from H&B

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)



Figures 15.3-4 from H&B

Color Perception

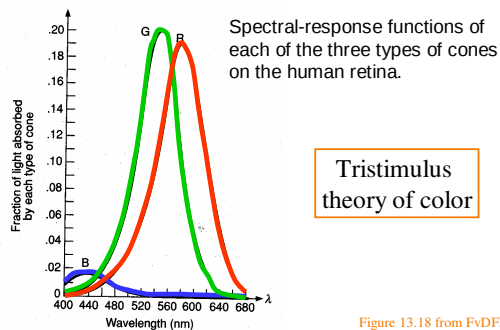


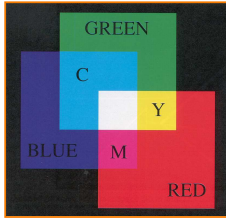
Figure 13.18 from FvDFH

Color Models



- RGB
- XYZ
- CMY
- HSV
- Others

RGB Color Model

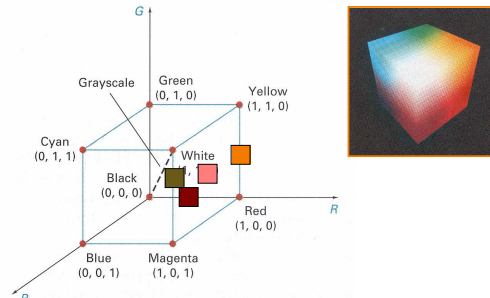


Colors are additive

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

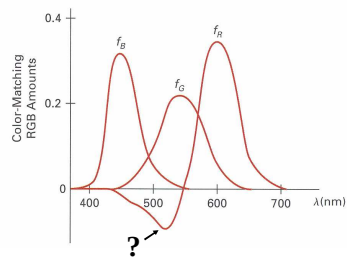


Figure 15.5 from H&B

XYZ Color Model (CIE)



Amounts of CIE primaries needed to display spectral colors

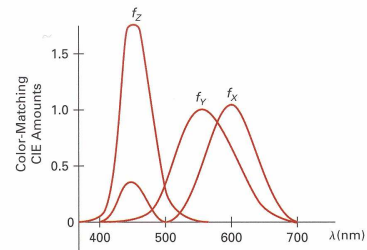


Figure 15.6 from H&B

CIE Chromaticity Diagram



Normalized amounts of X and Y for colors in visible spectrum

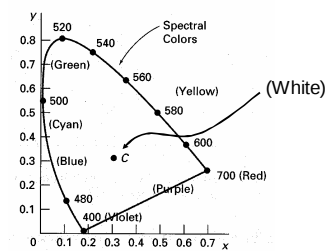
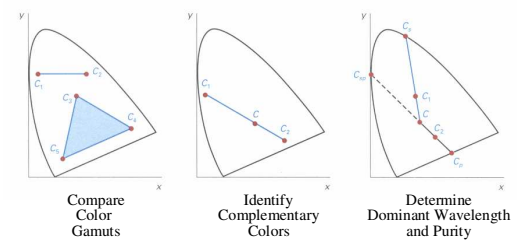


Figure 15.7 from H&B

CIE Chromaticity Diagram



Figures 15.8-10 from H&B

RGB Color Gamut



Color gamut for a typical RGB computer monitor

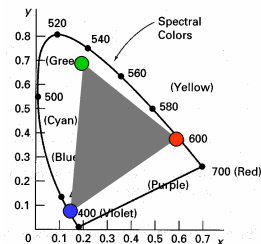
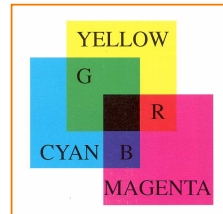


Figure 15.13 from H&B

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

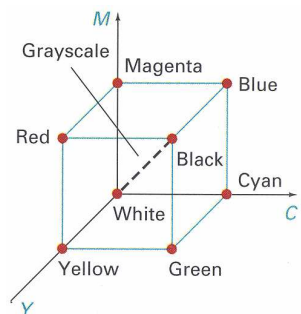
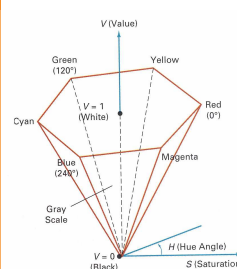


Figure 15.14 from H&B

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.