Computer Graphics

Szymon Rusinkiewicz

Princeton University

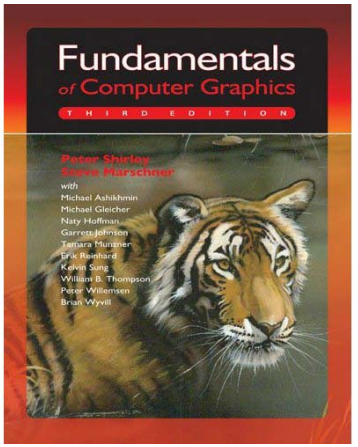
COS 426, Spring 2012

Overview

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

Administrative Matters

- Instructors
  - Szymon Rusinkiewicz
  - TA #1: Tianqiang Liu
  - TA #2: Jingwan (Cynthia) Lu
- Book
  - *Fundamentals of Computer Graphics*
    Peter Shirley and Steve Marschner,
    Third Edition, A.K. Peters, July 2009,
    ISBN: 978-1568814698



- Web page
  - http://www.cs.princeton.edu/cos426

Questions / Discussion

- We will use Piazza (www.piazza.com) to handle question/answer and general help
- Use this instead of email to instructors/TAs
- Will set it up for everyone enrolled as of today

Coursework

- Programming Assignments (50%)
  - Assignment #0: C++ programming / HTML / dropbox
  - Assignment #1: Image Processing
  - Assignment #2: Mesh Processing
  - Assignment #3: Ray Tracing
  - Assignment #4: Particle System Animation
- Exams (25%)
  - In class (Mar 15 and May 3)
- Final Project (25%)
  - Video game!
  - Completed in groups of 2-4

Programming Assignments

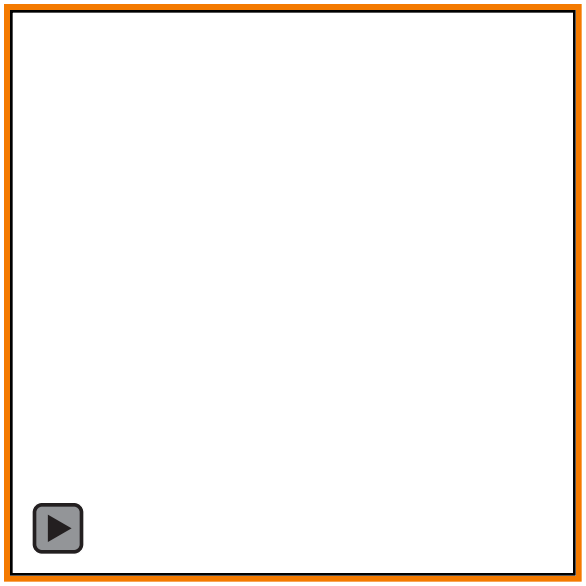
- When?
  - Roughly every 2-3 weeks
- Where?
  - Anywhere you want, e.g. home or Friend 017 lab
- How?
  - C++ (Precept this week; install compiler now!)
  - Interactive rendering APIs: OpenGL, GLUT
- What?
  - Basic feature lists
  - Optional features
  - Art contest

Art Contest

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

Cool Images

(James Percy, CS 426, Fall99)



Videos

(Phil Wei, 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 other sources without attribution

Precepts

- Schedule?
  - Friday 1:30 – 2:30
  - Friday 3:00 – 4:00
  - Other?
- Place?
  - TBA

Overview

- Administrivia
  - People, times, places, etc.
- Syllabus
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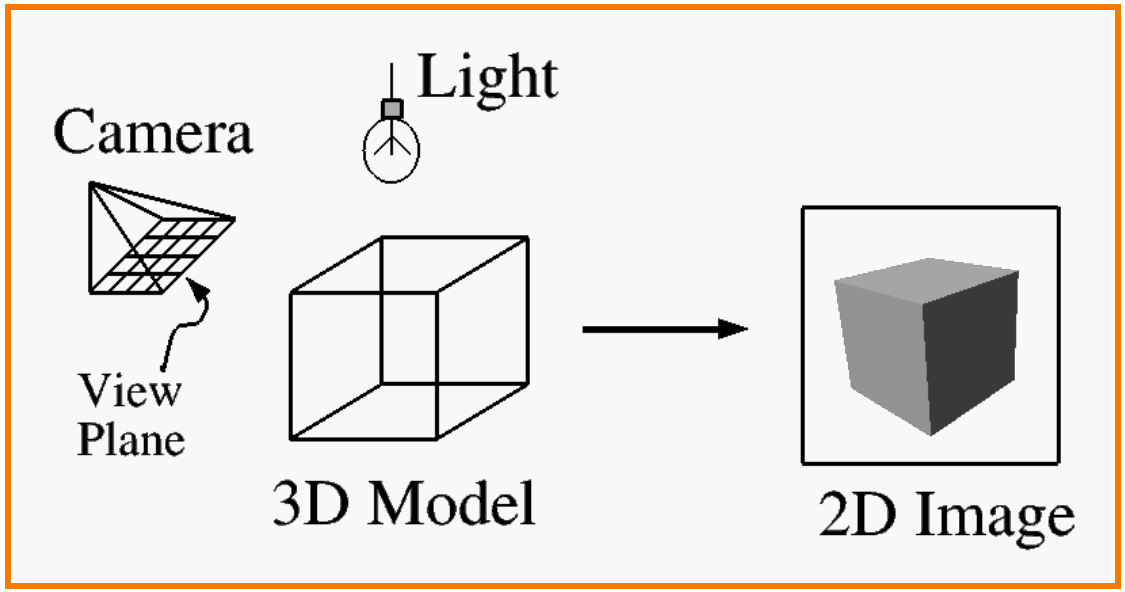
- Raster Graphics
  - Getting started …

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*



Syllabus

I. Image processing

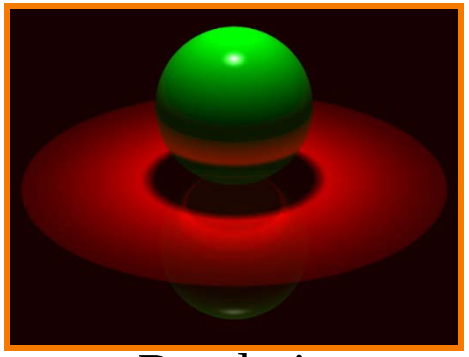
II. Modeling

III. Rendering

IV. Animation

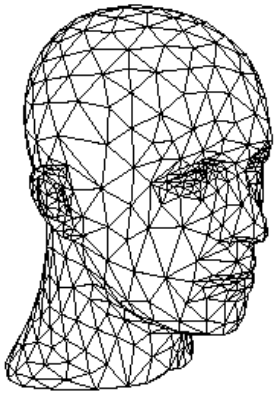
Image Processing

(Rusty Coleman, CS426, Fall99)



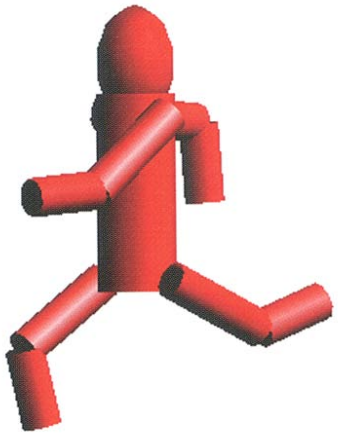
Rendering

(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)

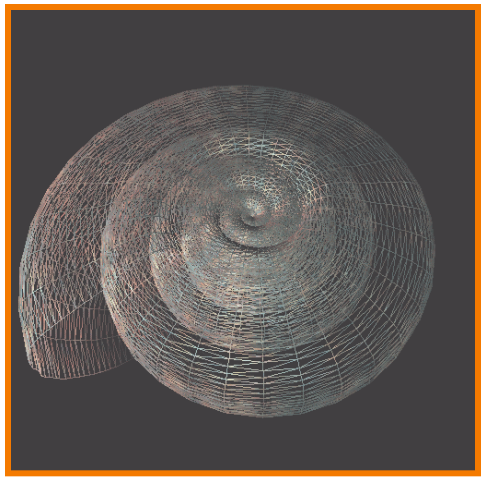
Image Morphing

(All students in CS 426, Fall98)

Part II: Modeling

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

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

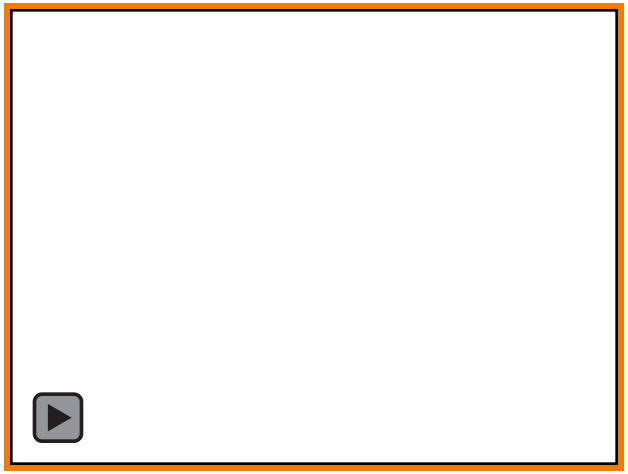


Shell
(Douglas Turnbull, CS 426, Fall99)

Part III: Rendering

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

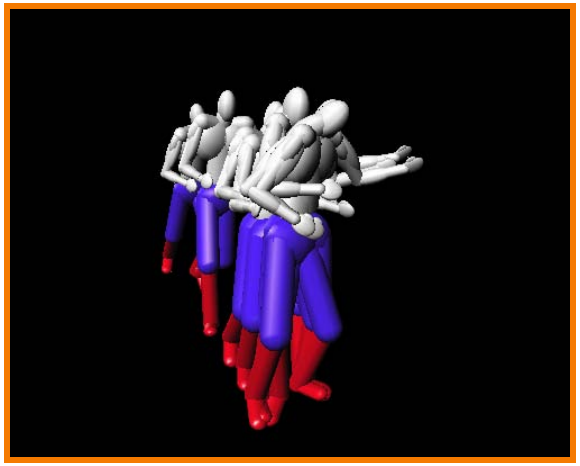
Pixel Shading
(Final Fantasy, Square Pictures)



Ray Tracing
(Sid Kapur, CS 426, Spr04)

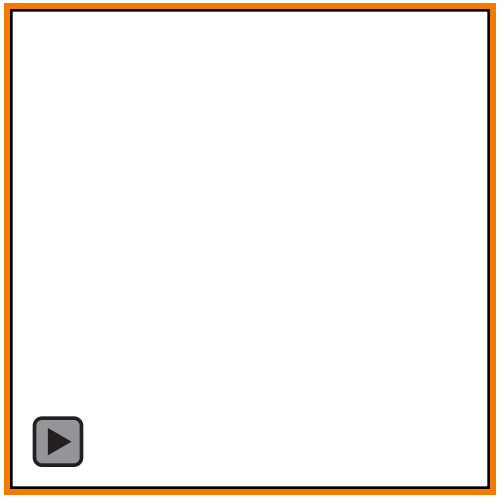
Part IV: Animation

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



Dancing Guy

(Jon Beyer, CS426, Spr05)



Ice Queen

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

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

Up
(Pixar Animation Studios)

Jurassic Park
(Industrial, Light, & Magic)

Halo
(Bungie)

Applications

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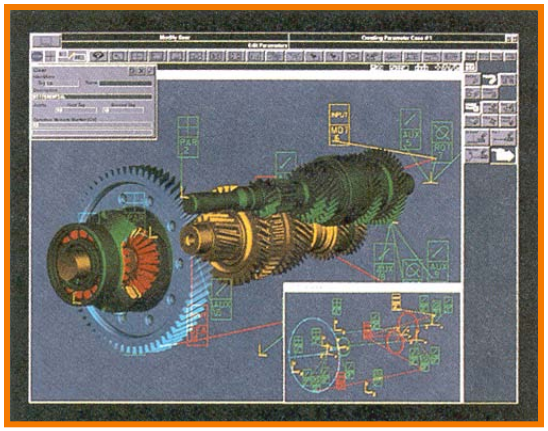
- Computer art

Los Angeles Airport
(Bill Jepson, UCLA)

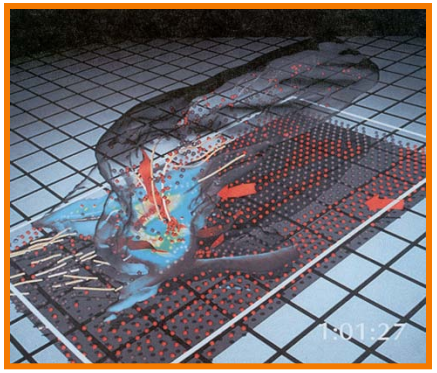


Gear Shaft Design
(Intergraph Corporation)

Boeing 777 Airplane
(Boeing Corporation)

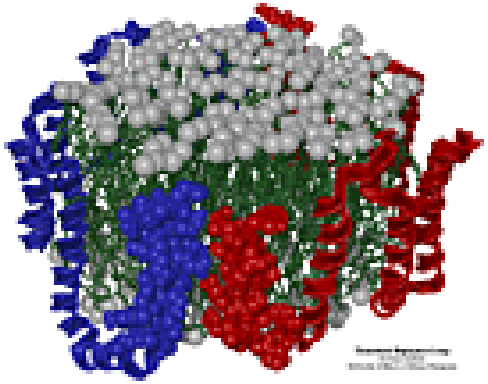
Applications

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



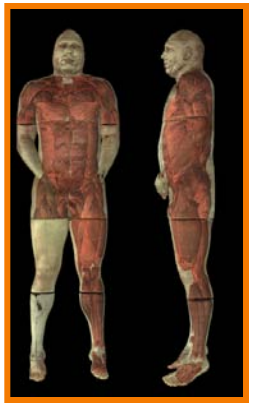
Airflow Inside a Thunderstorm

(Bob Wilhelmson,
University of Illinois at Urbana-Champaign)



Apo A-1

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

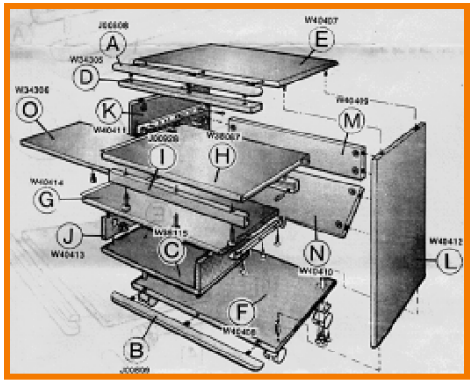


Visible Human

(National Library of Medicine)

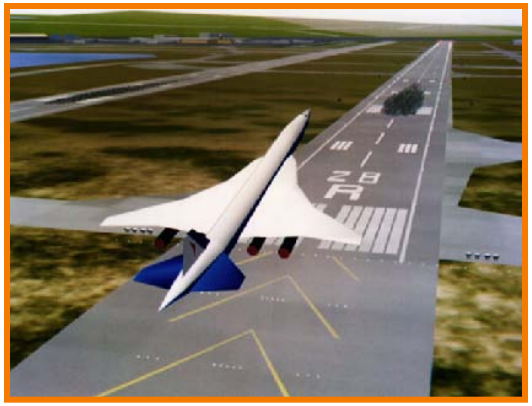
Applications

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



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 Jepson, UCLA)

Human Skeleton

(SGI)

Applications

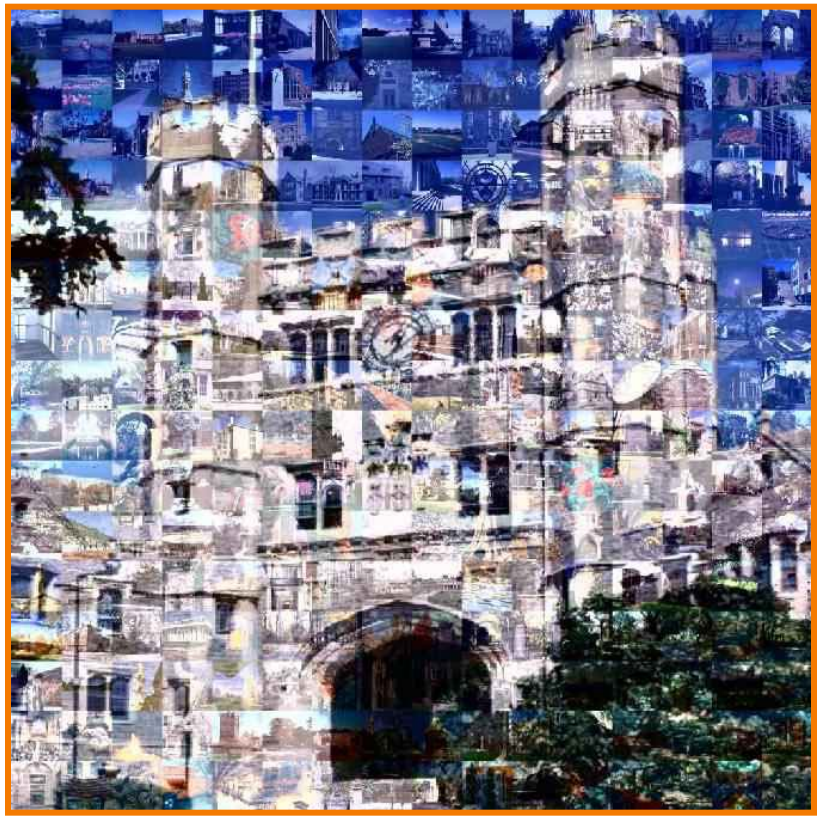
- Entertainment
- Computer-aided design
- Scientific visualization
- Training
- Education
- **E-commerce**
- Computer art

Virtual Footwear Wall

(Intel)

Applications

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



Blair Arch

(Marissa Range '98)

Overview

- Administrivia
  - People, times, places, etc.
- Syllabus
  - What will I learn in this course?

➢ Raster Graphics
  - Let's get started … (Yes, this WILL be on the exam!)

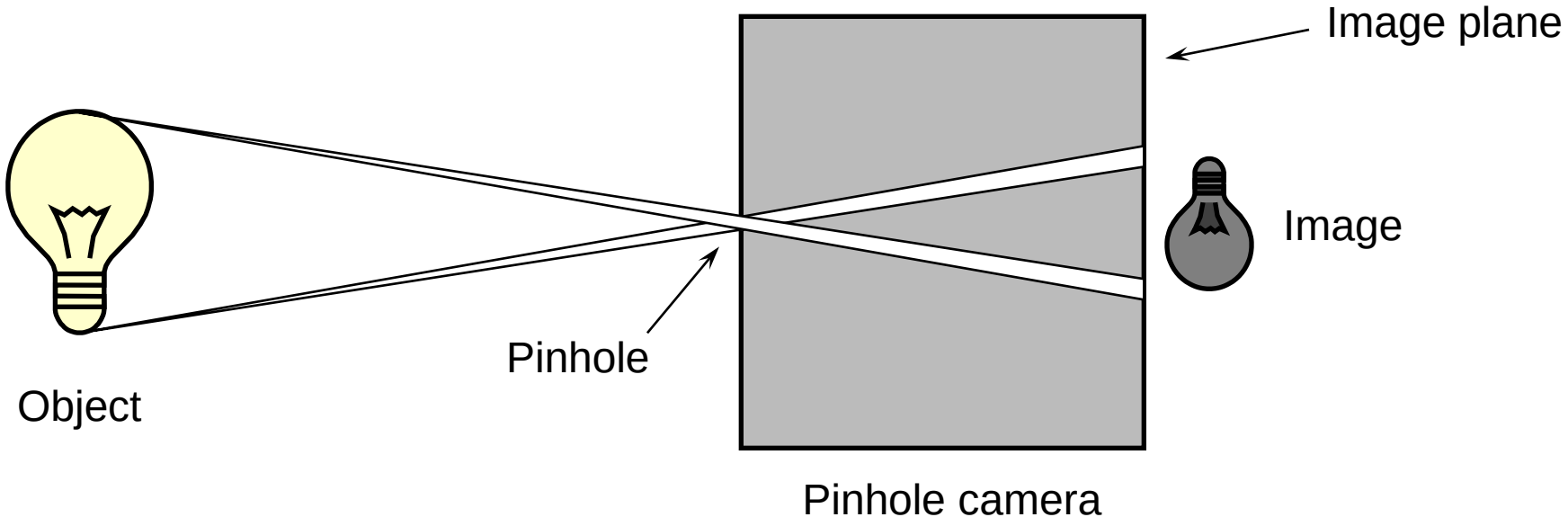
Raster Graphics

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

What is an Image?

What is an Image?

- Amount of light as a function of direction, flowing through an ideal camera



Points on image plane
↔ directions of light

What is a Digital Image?

What is a Digital Image?

- Sampled representation of a continuous image…
- Stored as a 2D rectilinear array of ***pixels***

Continuous image

Digital image

What is a Digital Image?

A Pixel is a Sample, not a Little Square!

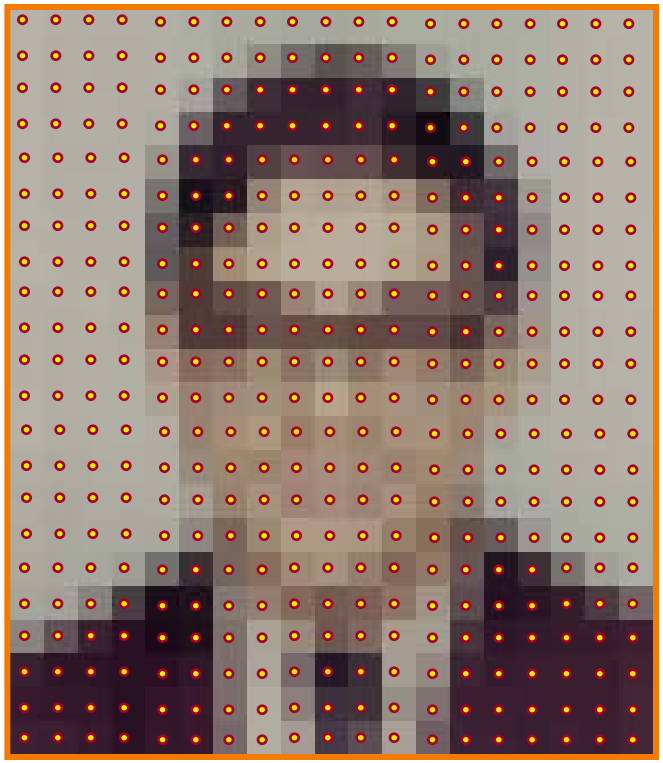
Continuous image

Digital image

What is a Digital Image?

A Pixel is a Sample, not a Little Square!

Continuous image



Digital image

What is a Digital Image?

A Pixel is a Sample, not a Little Square!

Continuous image

Digital image

Image Acquisition

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

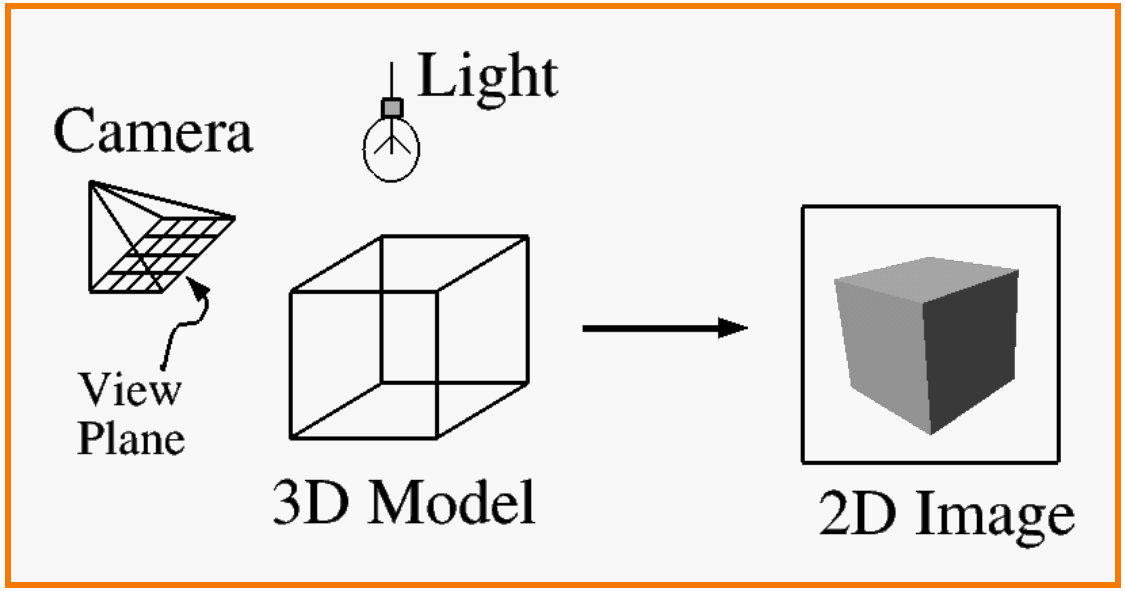


Image Display

- Re-create continuous function from samples
  - Example: LCD display

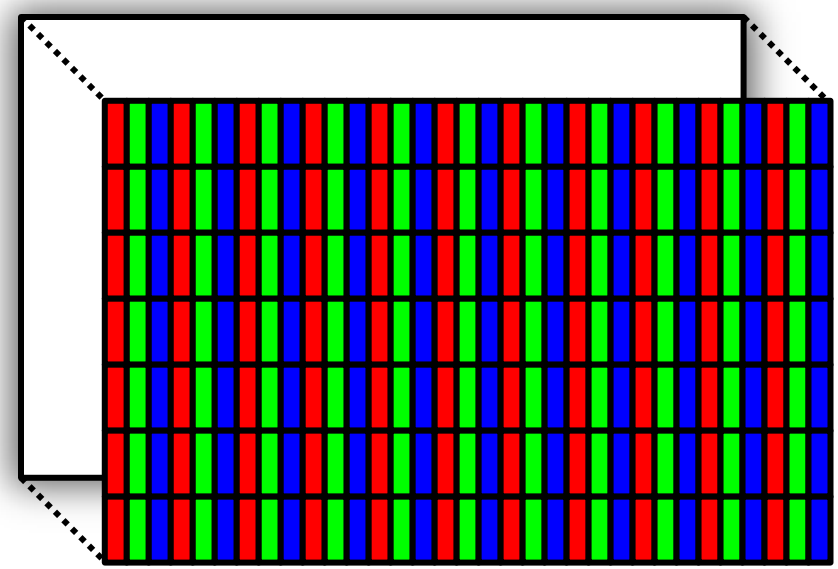


Image is reconstructed by displaying pixels with finite area (rectangles)

Image Resolution

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

Typical Resolutions

	Width x Height	Depth	Rate
Computer	1280 x 800	24	60
NTSC TV	640 x 480	16-ish	30
Film	3000 x 2000	36	24
Laser Printer	6600 x 5100	1	-

Frame Buffer

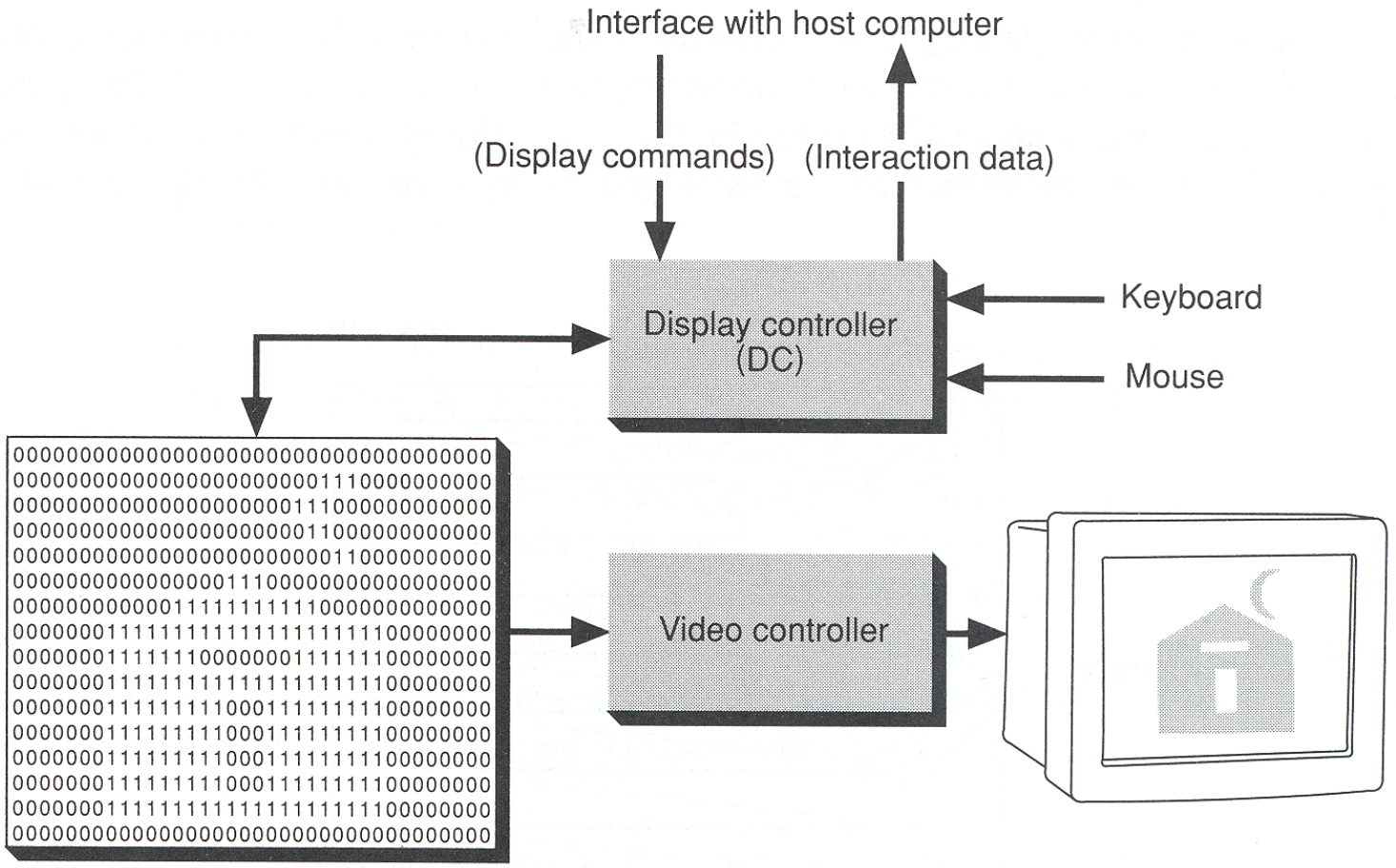
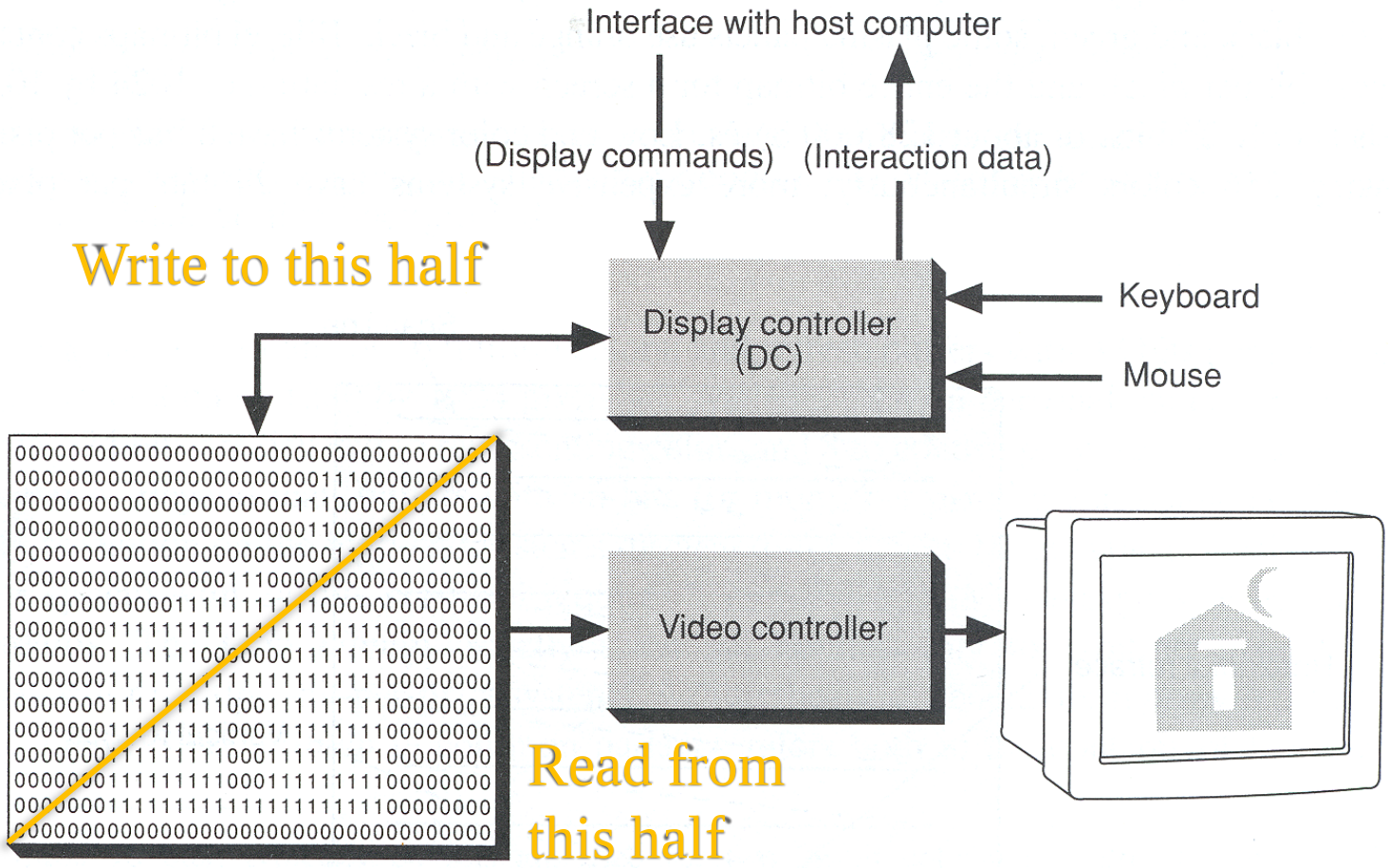


Figure 1.2 from FvDFH

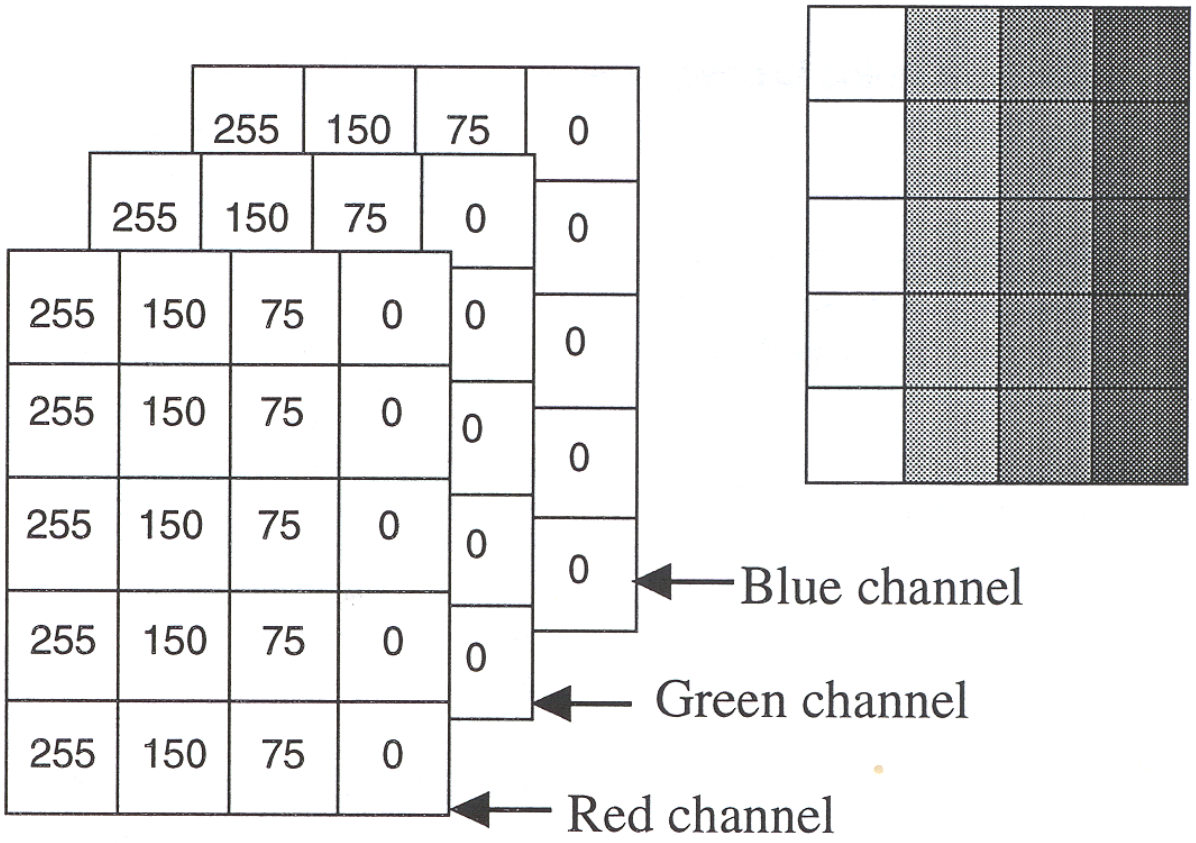
Frame Buffer: Double Buffering



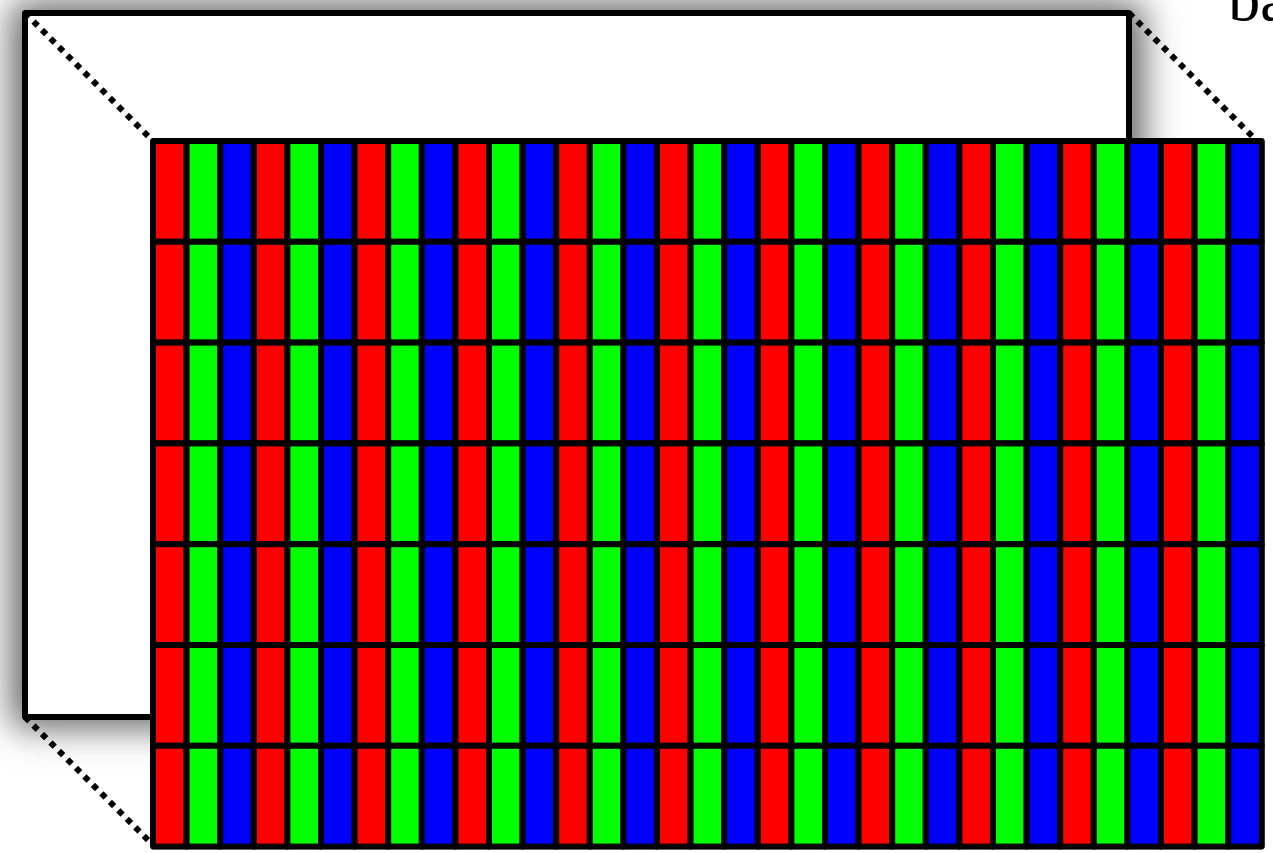
Swap after every frame

Figure 1.2 from FvDFH

Color Frame Buffer



Color LCD



backlight

liquid crystal mask: one per pixel per color

Color CRT

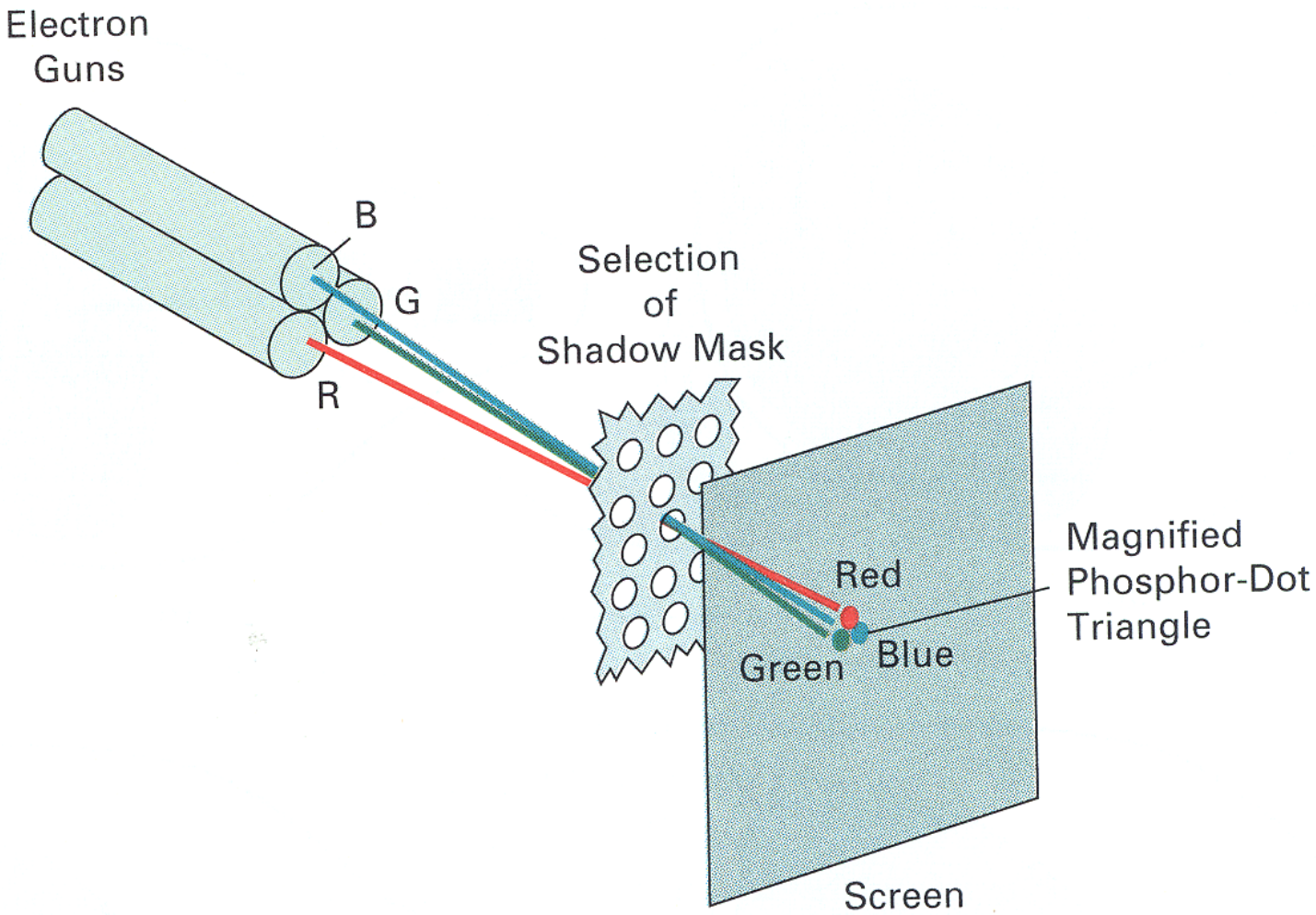


Figure 2.8 from H&B

Raster Graphics

- Images
  - What is an image?
  - How are images displayed?

➢ Colors
  - What is a color?
  - How do we perceive colors?
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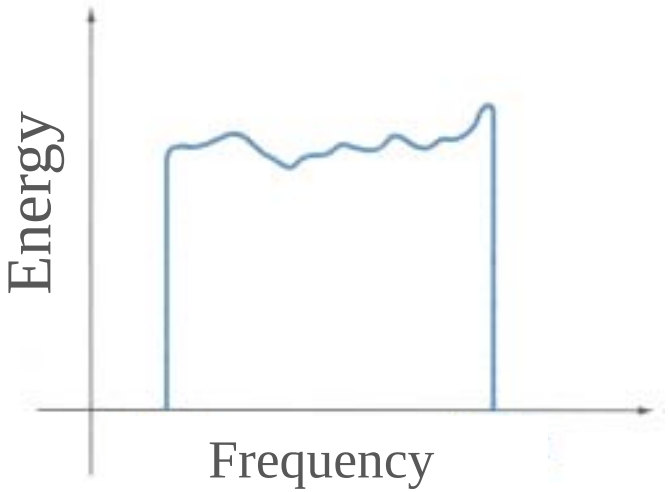
What is a Color?

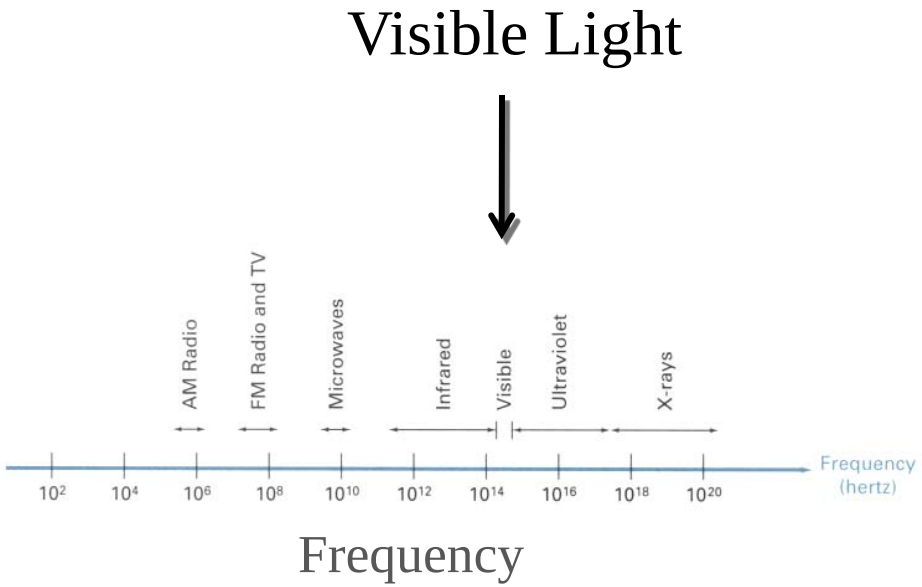
What is a Color?

- One definition is a distribution of energies amongst frequencies in the visible light range



Red
4.3×10^{14} Hz
(700nm)

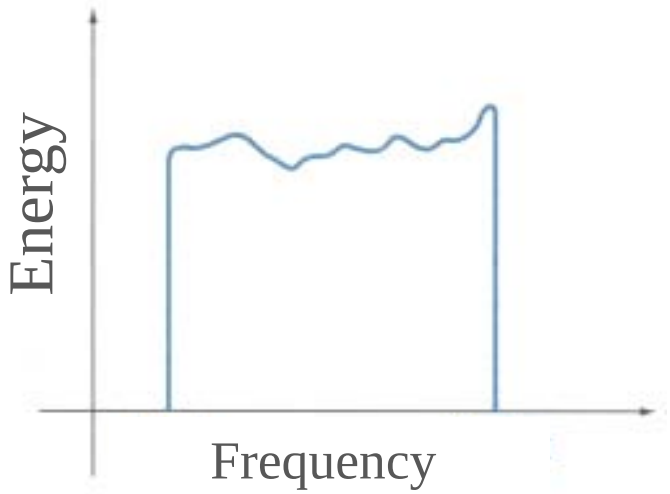
Violet
7.5×10^{14} Hz
(400nm)



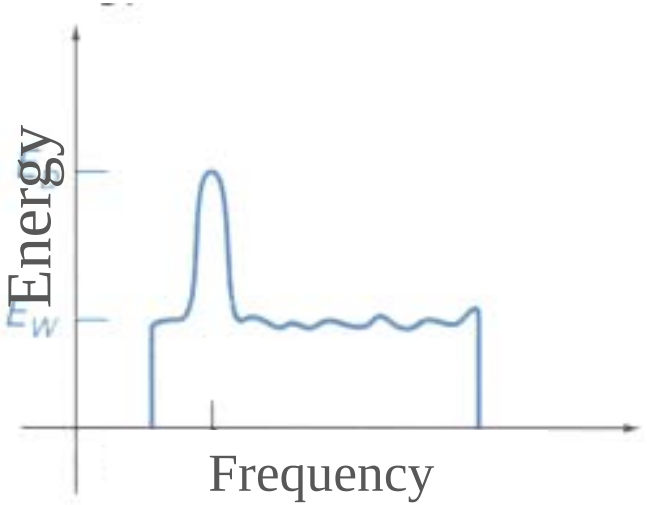
Figures 15.1,3 from H&B

Visible Light

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



White Light



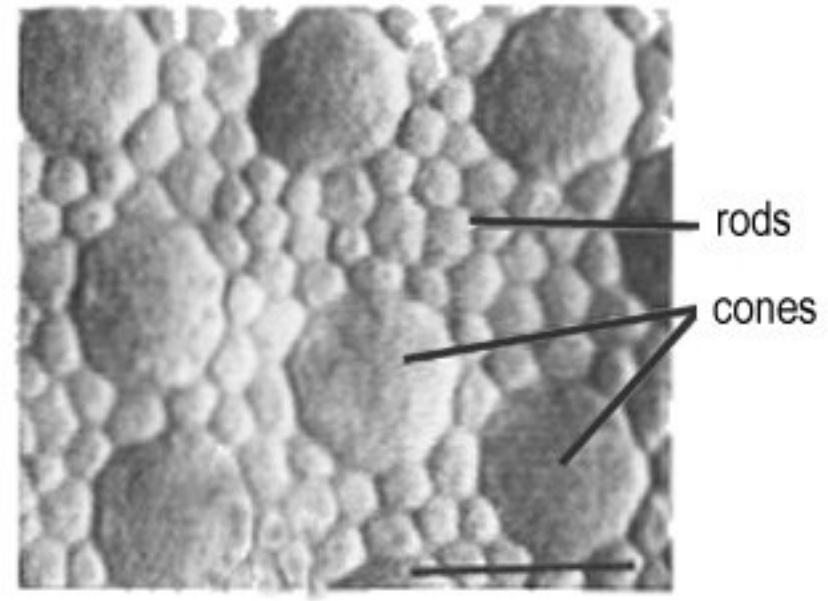
Orange Light

Figures 15.3-4 from H&B

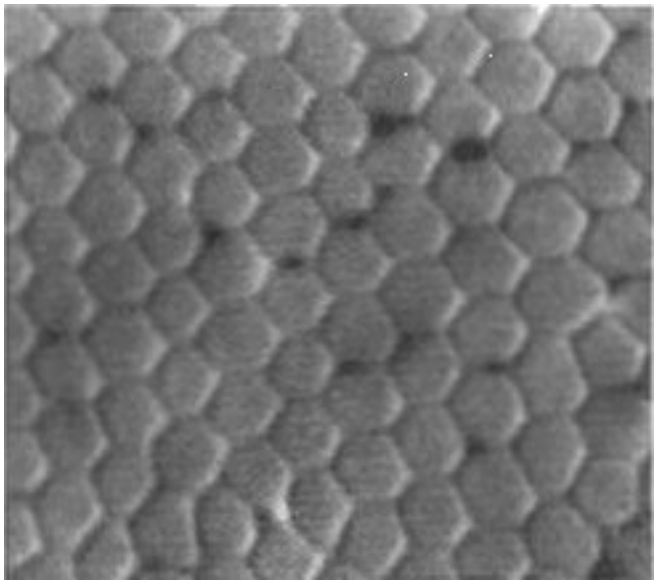
How Do We Perceive Color?

Modern Understanding of Color

- Two types of receptors: rods and cones

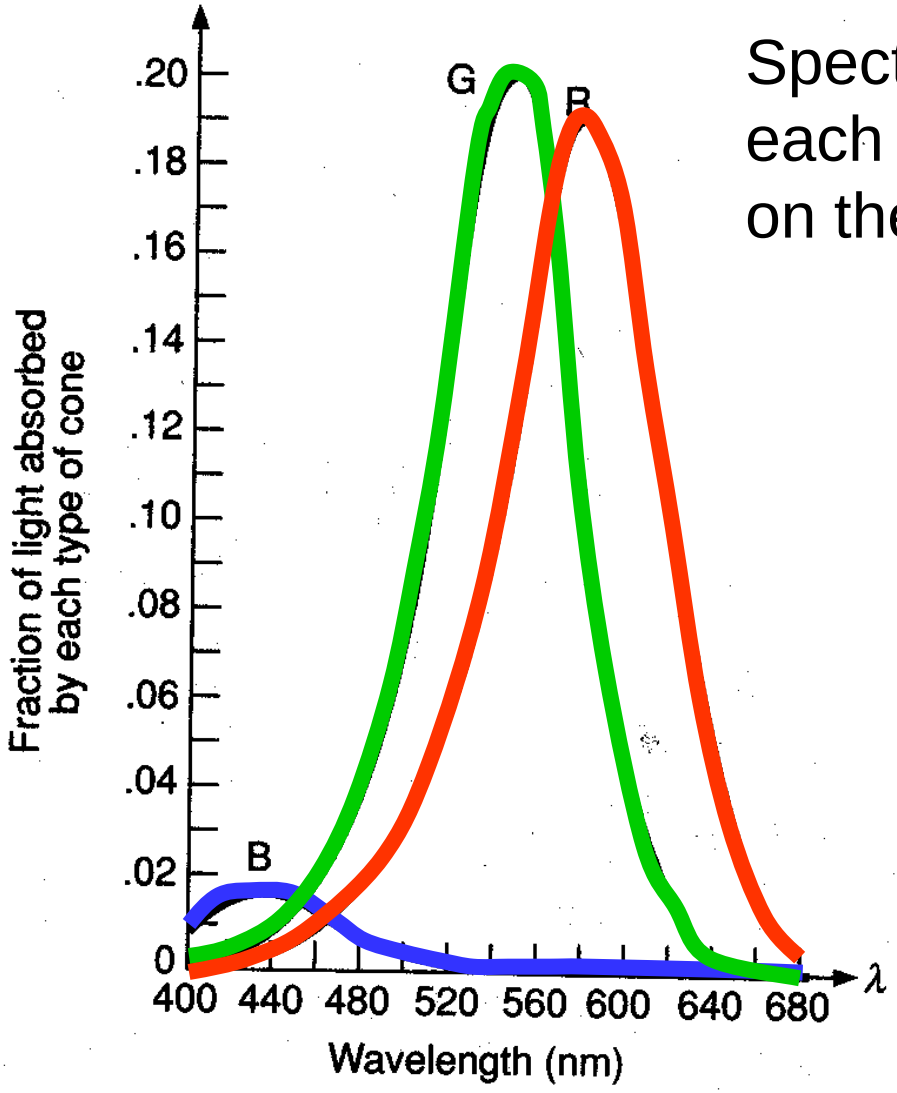


Rods and cones



Cones in *fovea*
(central part of retina)

Color Perception



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

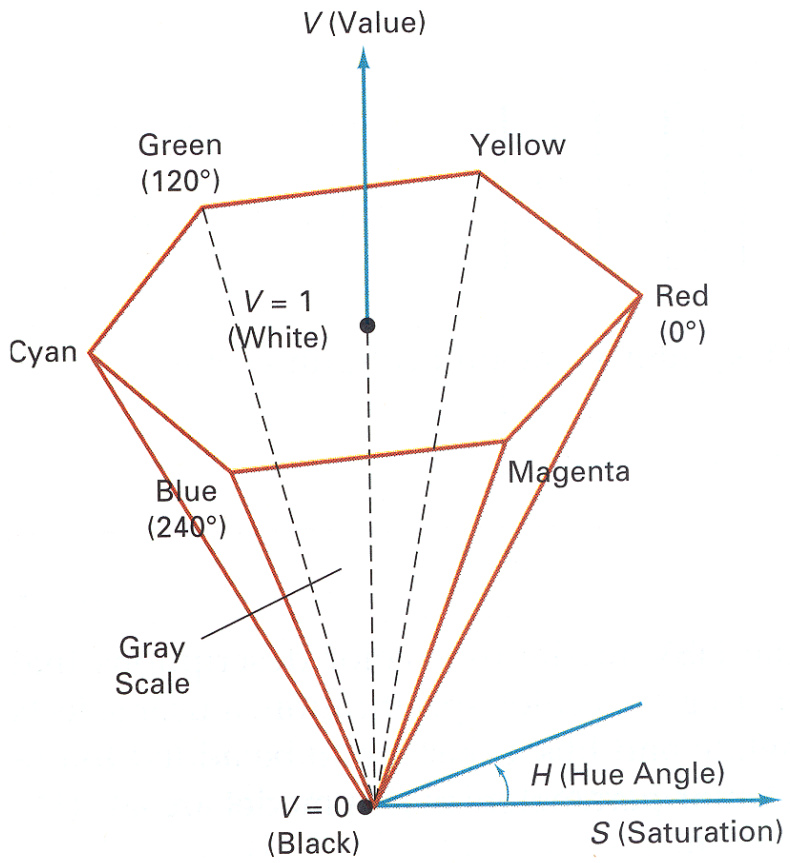
Figure 13.18 from FvDFH

Representing Colors in a Computer

- Common color models
  - HLS
  - HSV
  - RGB
  - XYZ
  - CMY
  - Others

Tristimulus theory of color

HLS & HSV Color Models

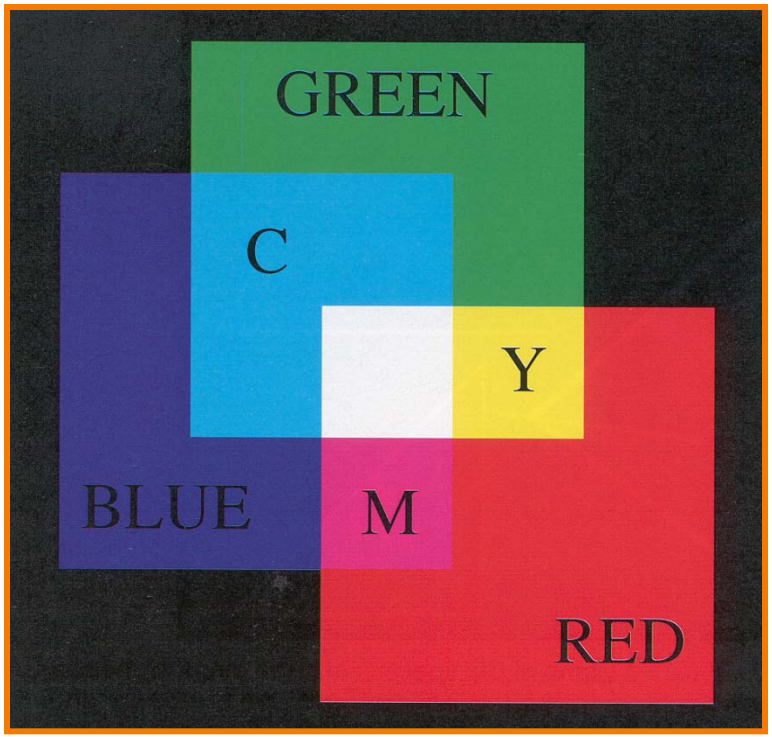


HSV Color Cone

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

RGB Color Model

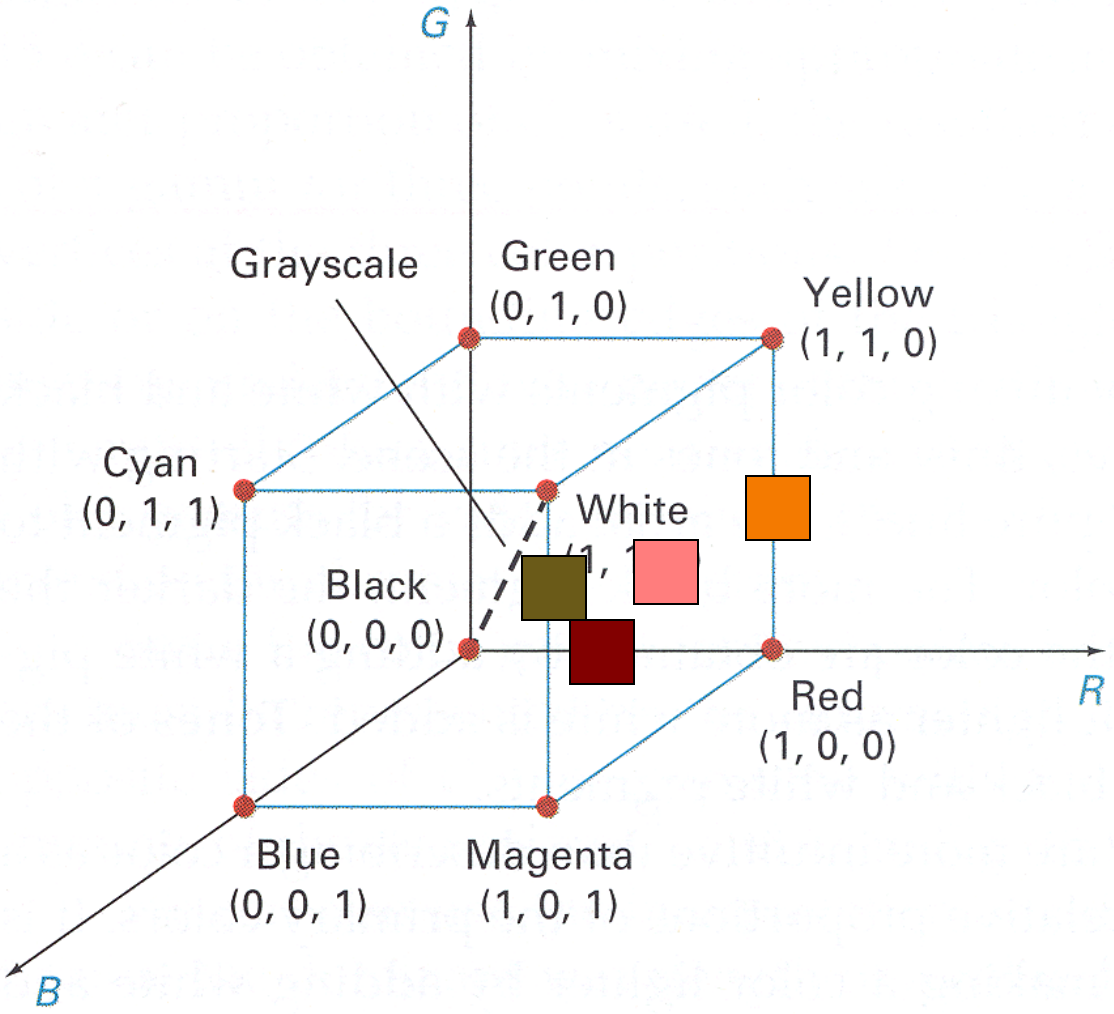


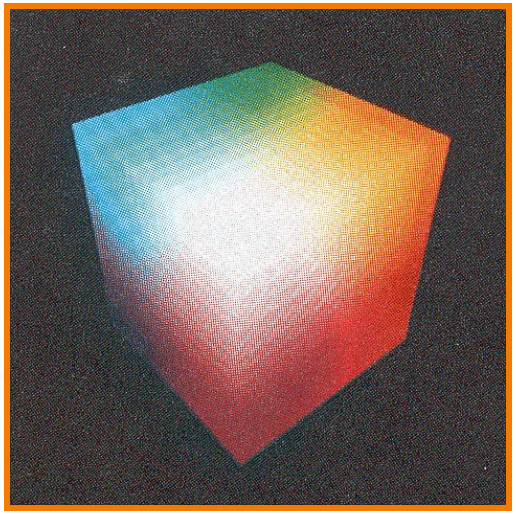
Colors are additive

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

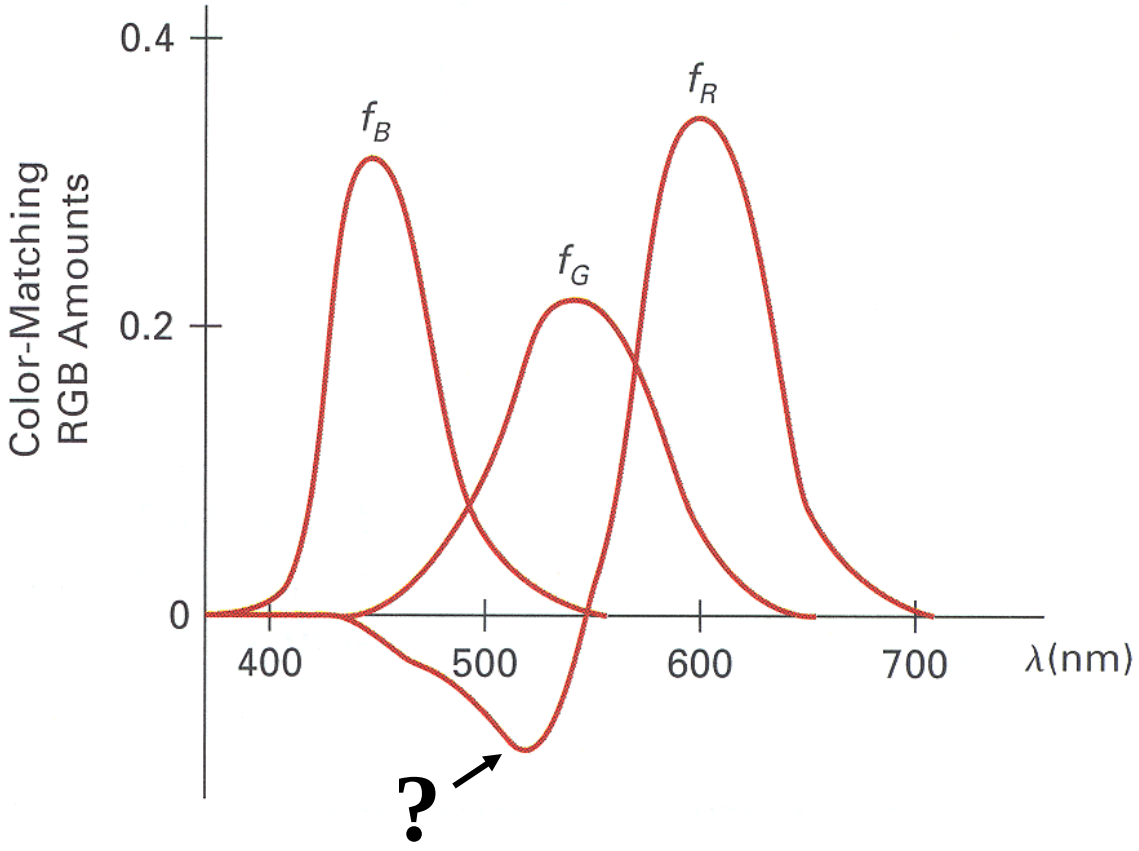


Figure 15.5 from H&B

XYZ Color Model (CIE)

Amounts of CIE primaries needed to display spectral colors

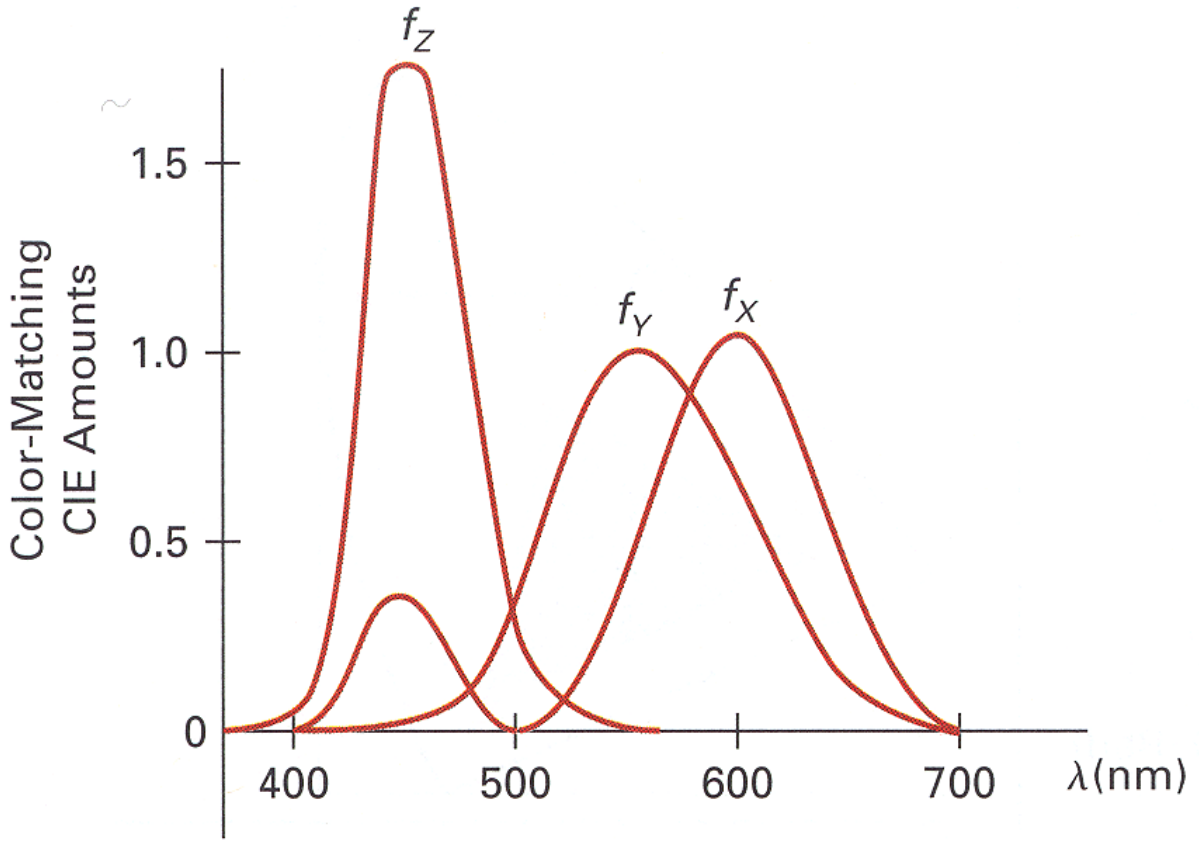


Figure 15.6 from H&B

CIE Chromaticity Diagram

Normalized amounts of X and Y for colors in visible spectrum

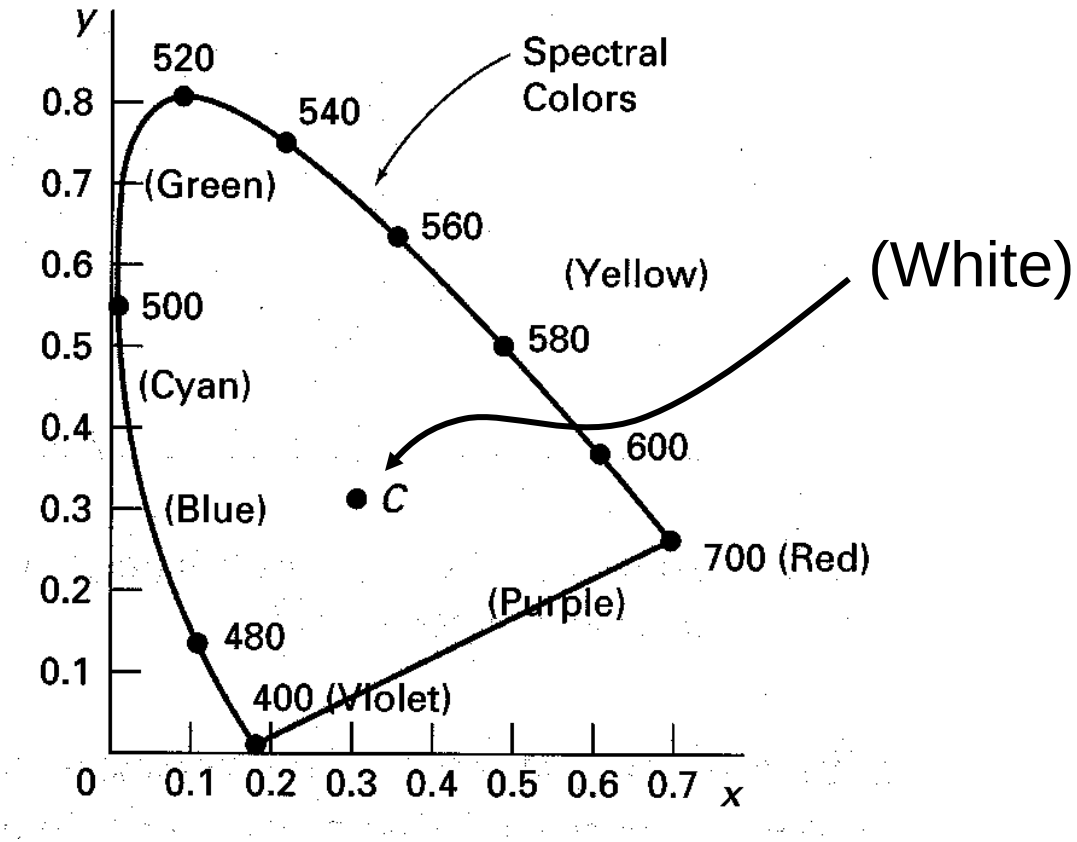
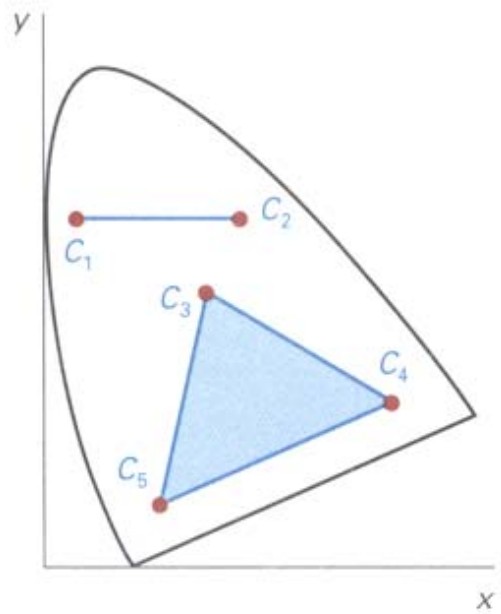
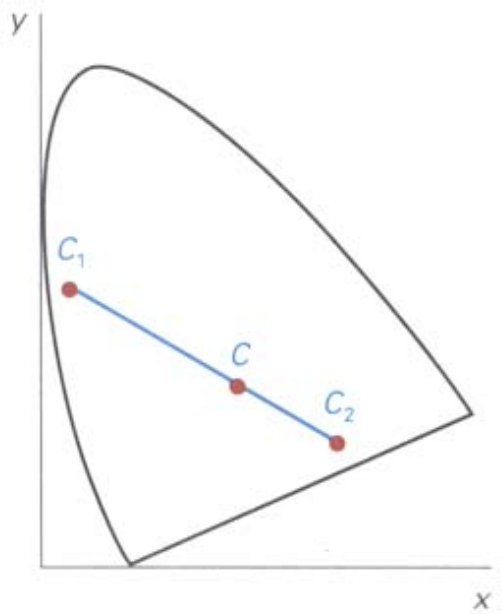


Figure 15.7 from H&B

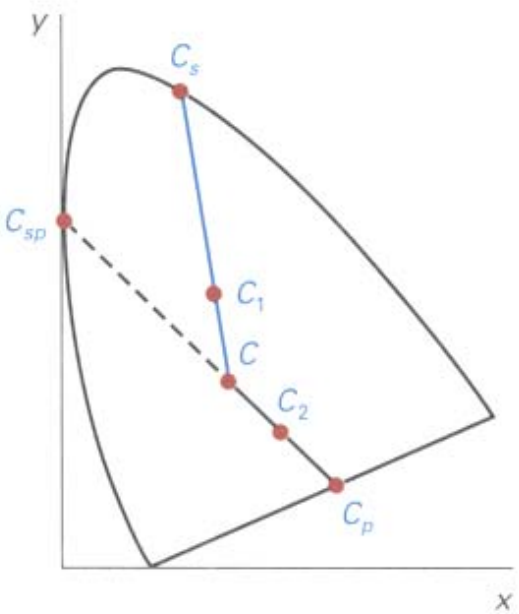
CIE Chromaticity Diagram



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 display

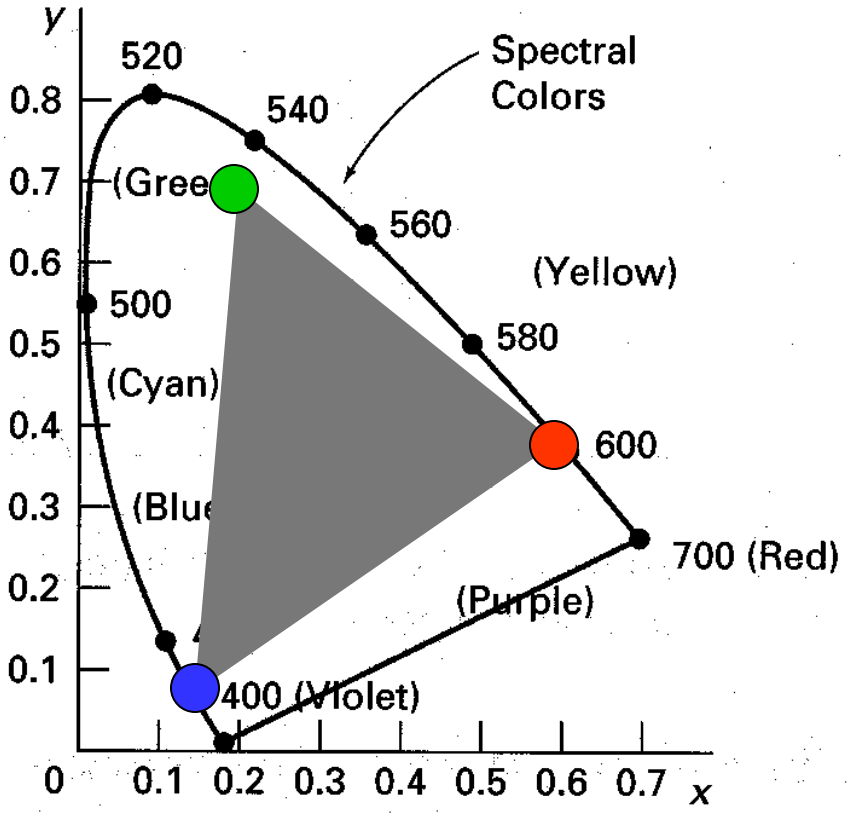


Figure 15.13 from H&B

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

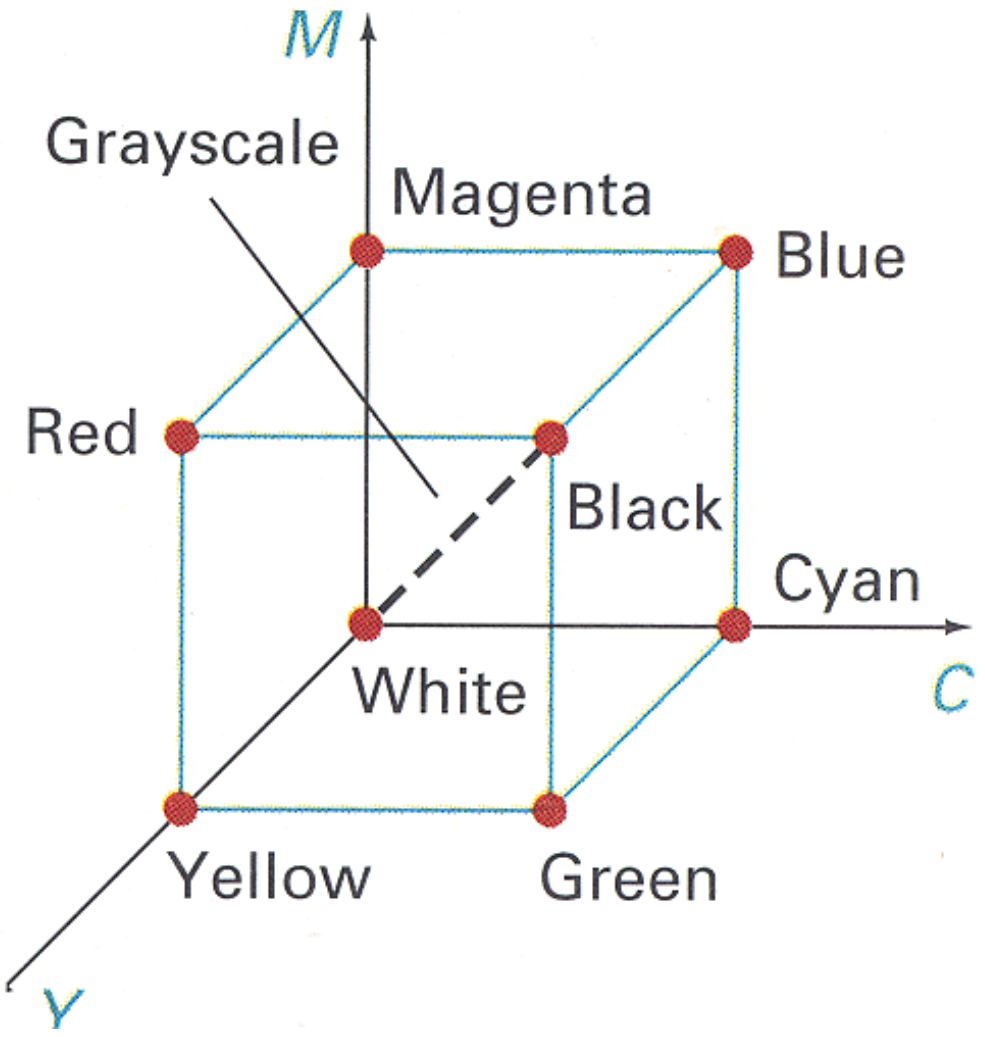


Figure 15.14 from H&B

Summary

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