Computer Graphics

Tom Funkhouser

Princeton University

COS 426, Spring 2014

Overview

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

Administrative Matters

- Instructors
  - Tom Funkhouser
  - Sid Chaudhuri and Ohad Fried
- Book
  - *Computer Graphics with OpenGL, 4th Ed,* Hearn, Baker, and Carithers, Prentice Hall, 2010. ISBN: 978-0136053583
- Web page
  - http://www.cs.princeton.edu/courses/archive/spring14/cos426

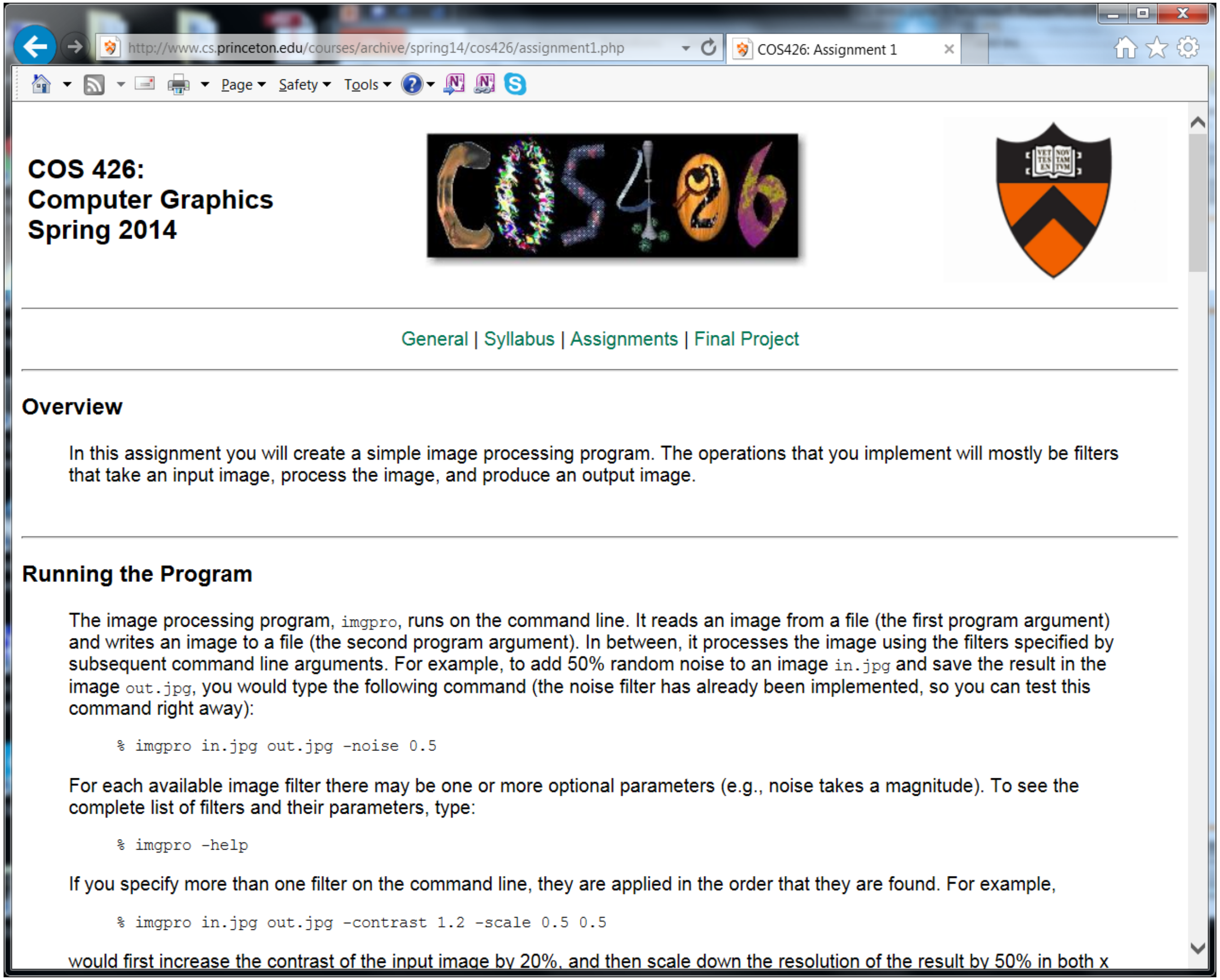
Coursework

- Exams (25%)
  - In class (3/13 and 5/1)
- Programming Assignments (50%)
  - Assignment #1: Image Processing (due 2/23)
  - Assignment #2: Modeling (due 3/9)
  - Assignment #3: Ray Tracing (due 4/6 and 4/13)
  - Assignment #4: Animation (due 4/27)
- Final Project (25%)
  - Game! (due at end of semester)

Programming Assignments

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

Programming Assignments



http://www.cs.princeton.edu/courses/archive/spring14/cos426/assignment1.php

COS426: Assignment 1

COS 426:
Computer Graphics
Spring 2014

General | Syllabus | Assignments | Final Project

Overview

In this assignment you will create a simple image processing program. The operations that you implement will mostly be filters that take an input image, process the image, and produce an output image.

Running the Program

The image processing program, `imgpro`, runs on the command line. It reads an image from a file (the first program argument) and writes an image to a file (the second program argument). In between, it processes the image using the filters specified by subsequent command line arguments. For example, to add 50% random noise to an image `in.jpg` and save the result in the image `out.jpg`, you would type the following command (the noise filter has already been implemented, so you can test this command right away):

```
% imgpro in.jpg out.jpg -noise 0.5
```

For each available image filter there may be one or more optional parameters (e.g., noise takes a magnitude). To see the complete list of filters and their parameters, type:

```
% imgpro -help
```

If you specify more than one filter on the command line, they are applied in the order that they are found. For example,

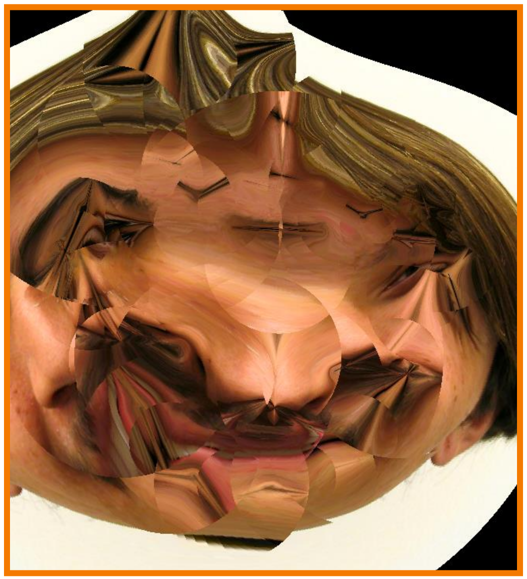
```
% imgpro in.jpg out.jpg -contrast 1.2 -scale 0.5 0.5
```

would first increase the contrast of the input image by 20%, and then scale down the resolution of the result by 50% in both x

Art Contest

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

Cool Images/Videos
(James Percy, CS 426, Fall99)



Bloopers
(Alex Combs, CS 426, Spr05)

Characters for web banner

Collaboration Policy

- Overview:
  - You must write your own code
  - You must not leverage code written by others
  - You must reference your resources
- It's OK to …
  - Talk with other students about ideas, approaches, etc.
  - Get ideas from information in books, wikipedia, etc.
  - Use "support" code provided with our assignments
- It's NOT OK to …
  - Show your code to another student
  - Look at code written by another student
  - Leverage code acquired from other sources

Questions / Discussion

- Piazza (www.piazza.com)
  - View announcements
  - Post questions to the class
  - Answer other students questions
  - Set up for everyone enrolled as of today
  - Use this instead of email to instructors/Tas (can send private messages)

Precepts

- Schedule
  - Wed 3:30-4:30 (Friend 108)

    and/or
  - Wed 7:30-8:30 (CS 102)

Overview

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- ➢ Syllabus
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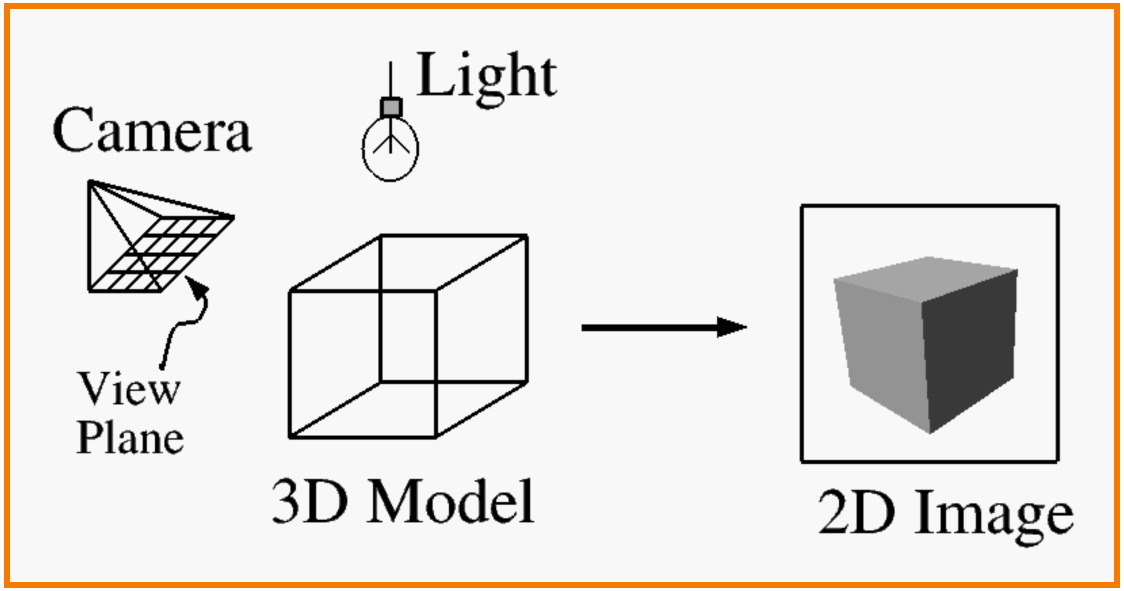
Introduction

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



Syllabus

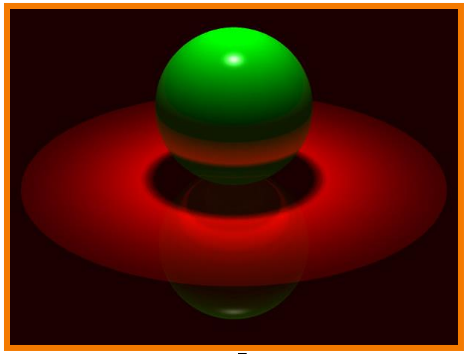
I. Imaging

II. Modeling

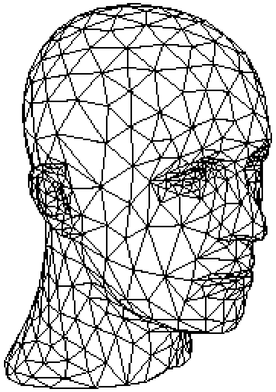
III. Rendering

IV. Animation

Image Processing
(Rusty Coleman, CS426, Fall99)



Rendering
(Michael Bostock, CS426, Fall99)



Modeling
(Dennis Zorin, CalTech)

Animation
(Pixar)

Part I: Imaging

- Image Basics
  - Definition
  - 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, 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 III: Rendering

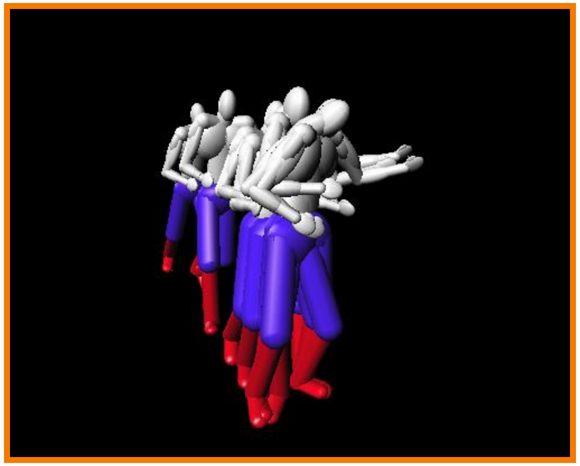
- 3D Rendering Pipeline
  - Modeling transformations
  - Viewing transformations
  - Hidden surface removal
  - Illumination, shading, and textures
  - Scan conversion, clipping
  - Hierarchical scene graphics
  - OpenGL
- Global illumination
  - Ray tracing
  - Radiosity

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

Geri's Game

(Pixar Animation Studios)

Jurasic Park

(Industrial, Light, & Magic)

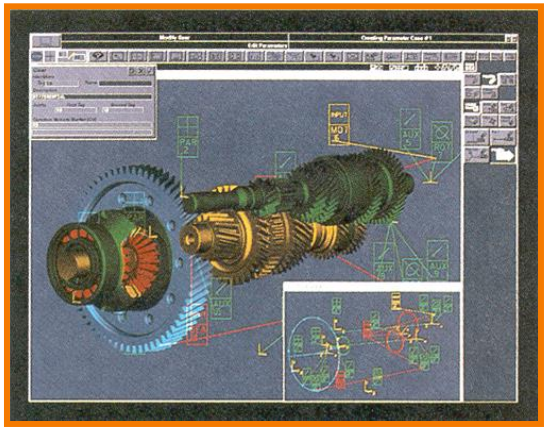
Quake

(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

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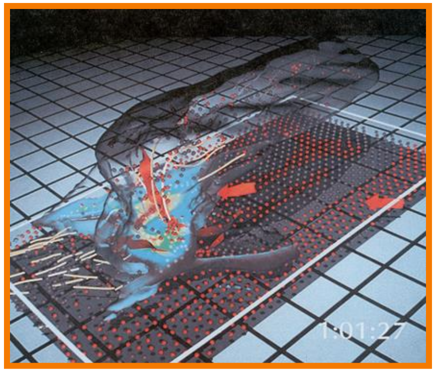
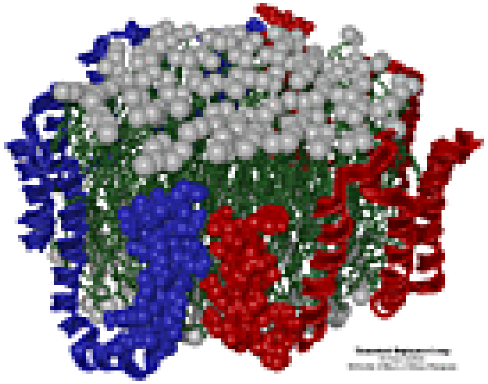
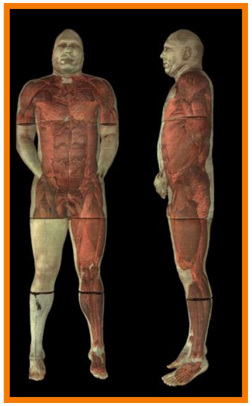
- Computer art



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



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

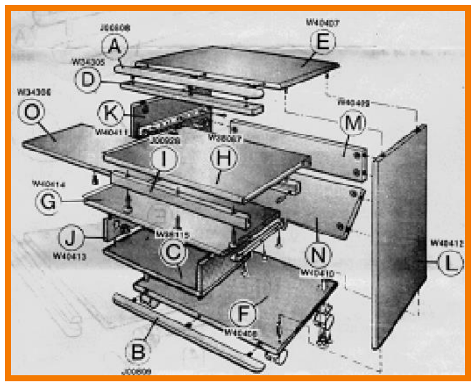


Visible Human
(National Library of Medicine)

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

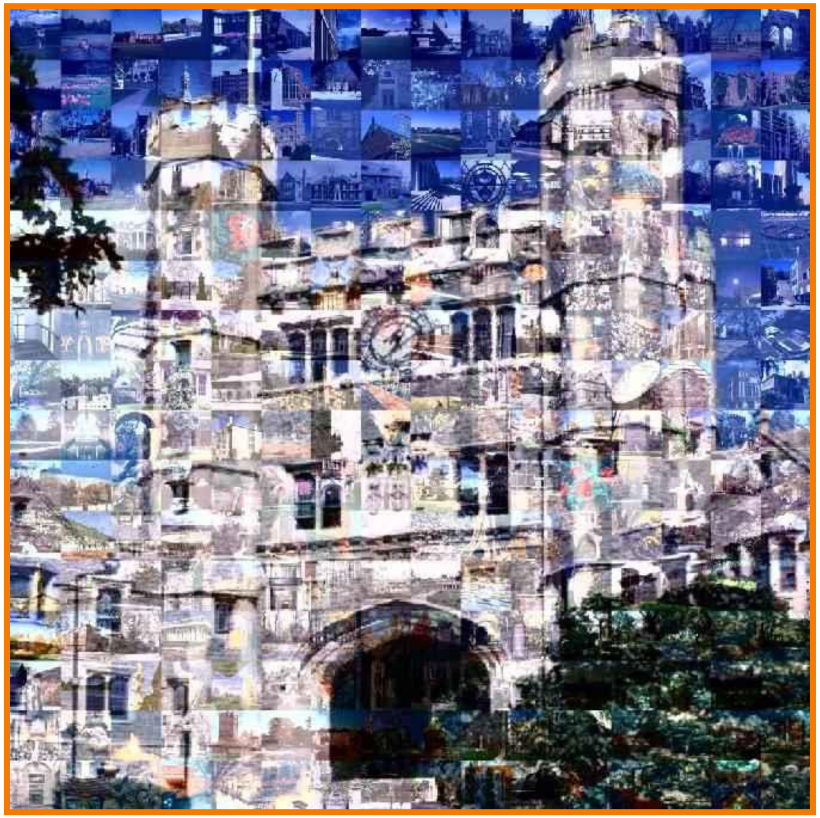
- Entertainment
- Computer-aided design
- Scientific visualization
- Training
- Education
- ➜ **E-commerce**
- Computer art

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)

Overview

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

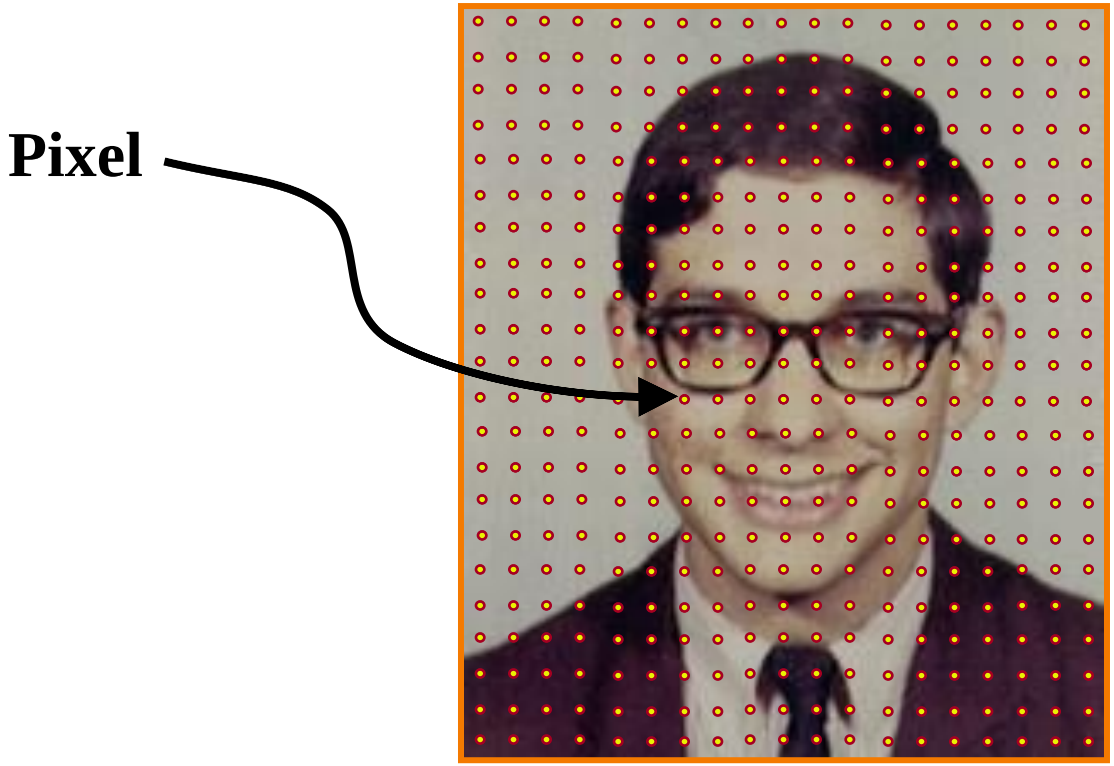
What is an Image?

What is an Image?

An image is a 2D rectilinear array of pixels

Digital image

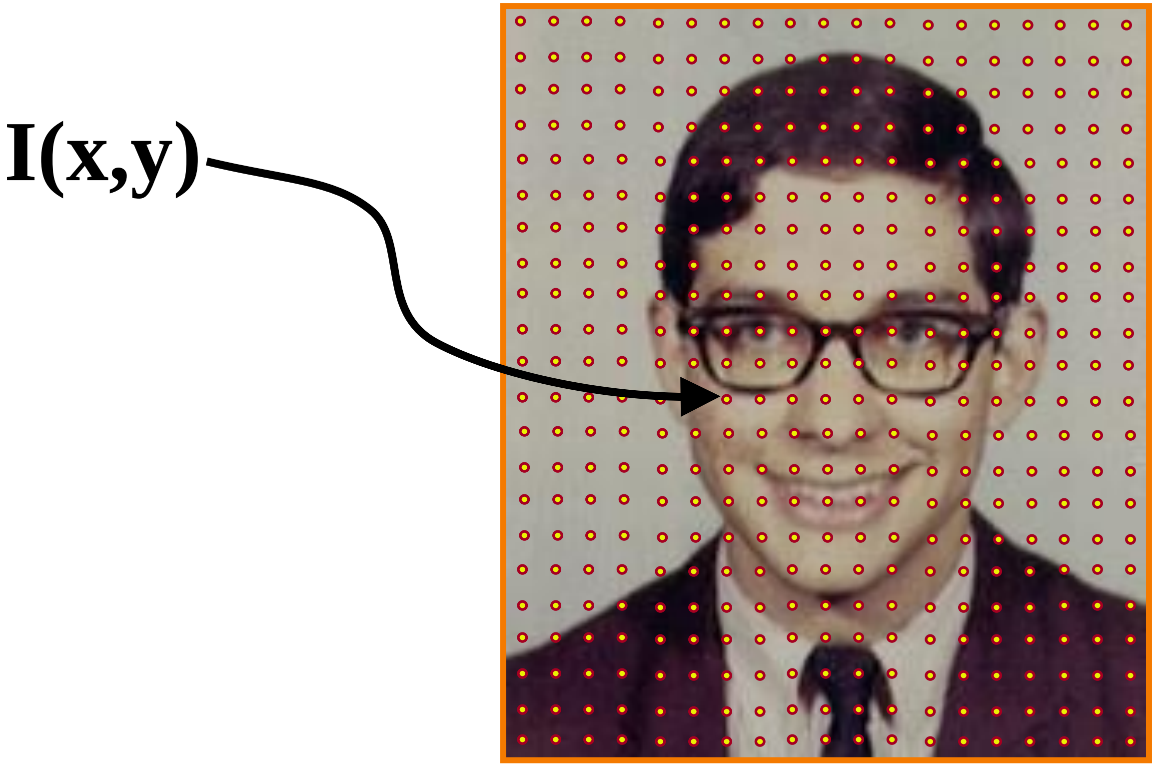
What is a Pixel?



Digital image

What is a Pixel?

Sample of a function at a position

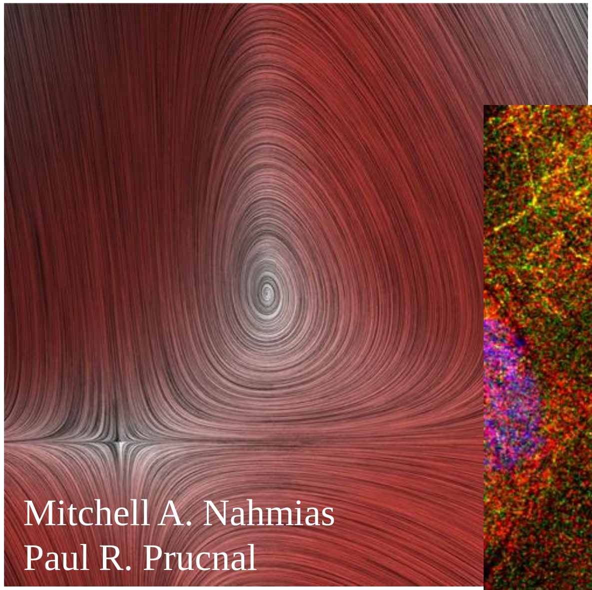


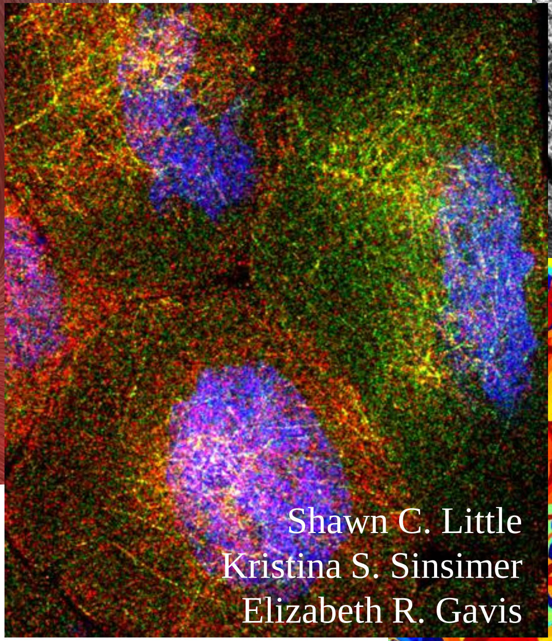
Digital image

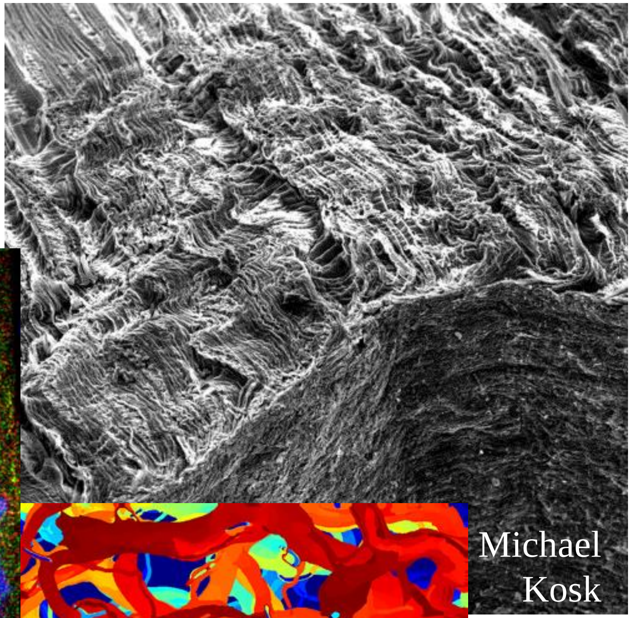
What Function?

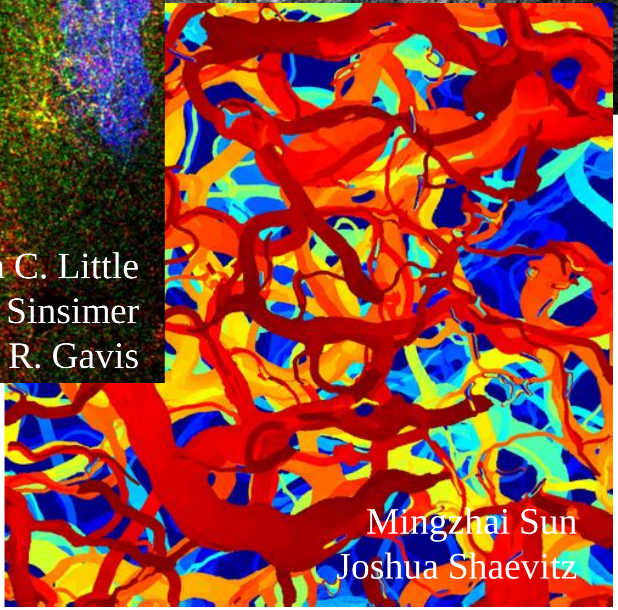
What Function?

Could be any function …







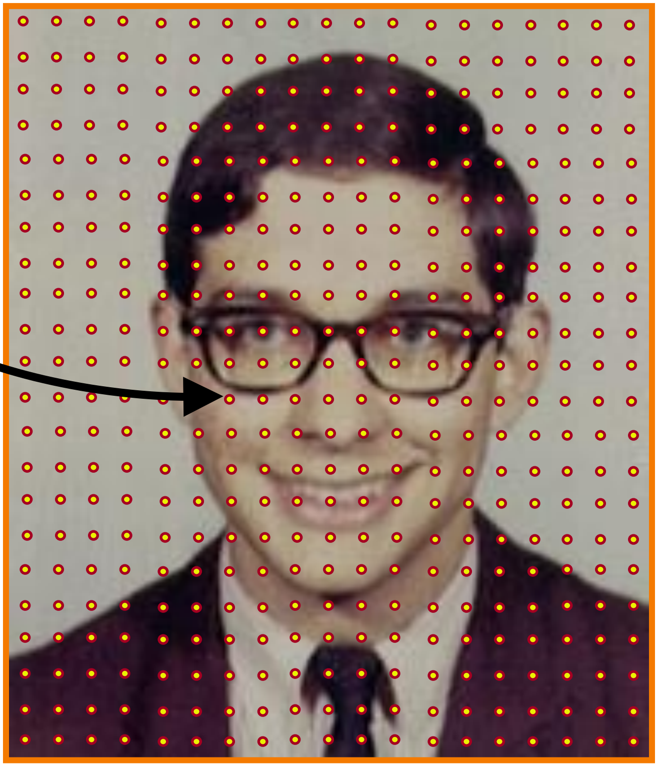


Art of Science
(Friend Center hallway)

What Function?

What about photographic images?

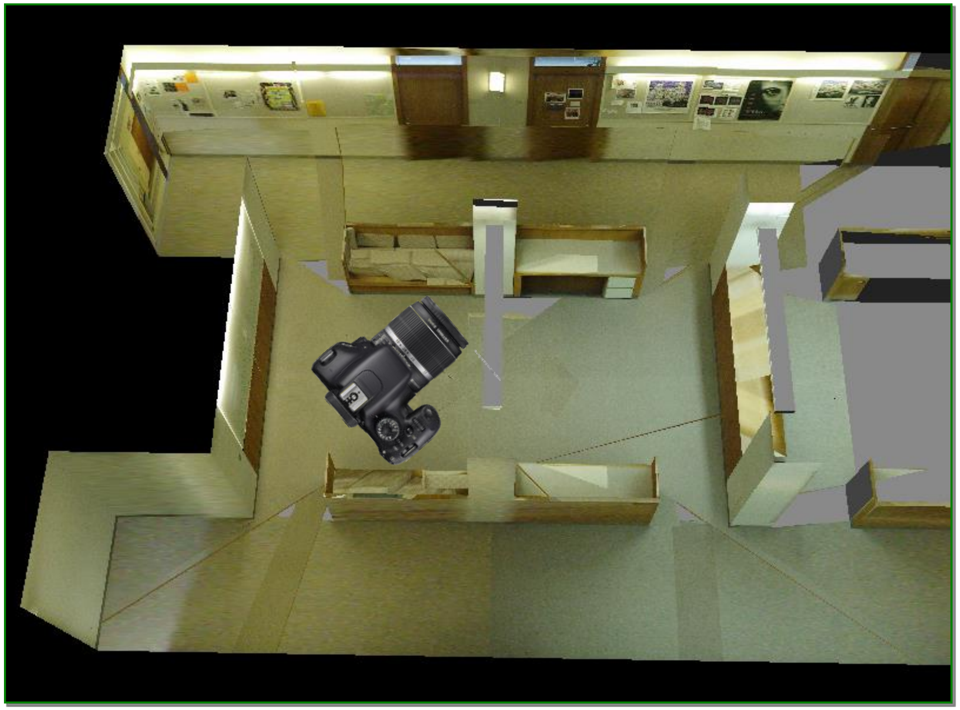
I(x,y)?



Digital photograph

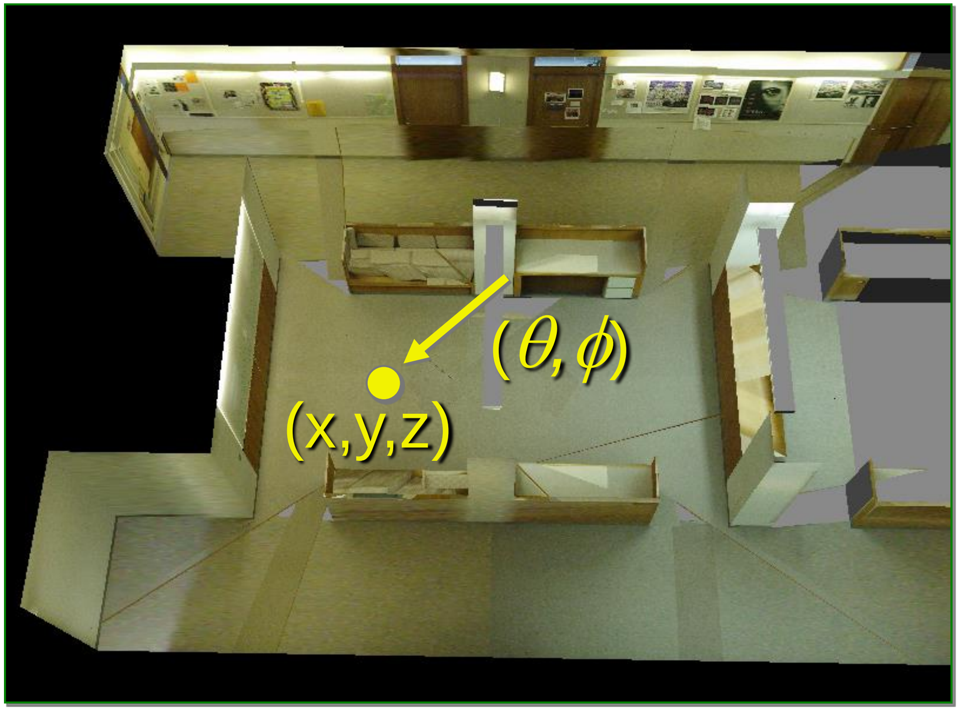
Plenoptic Function

- Each pixel of a photographic image is a function of radiance arriving at a sensor



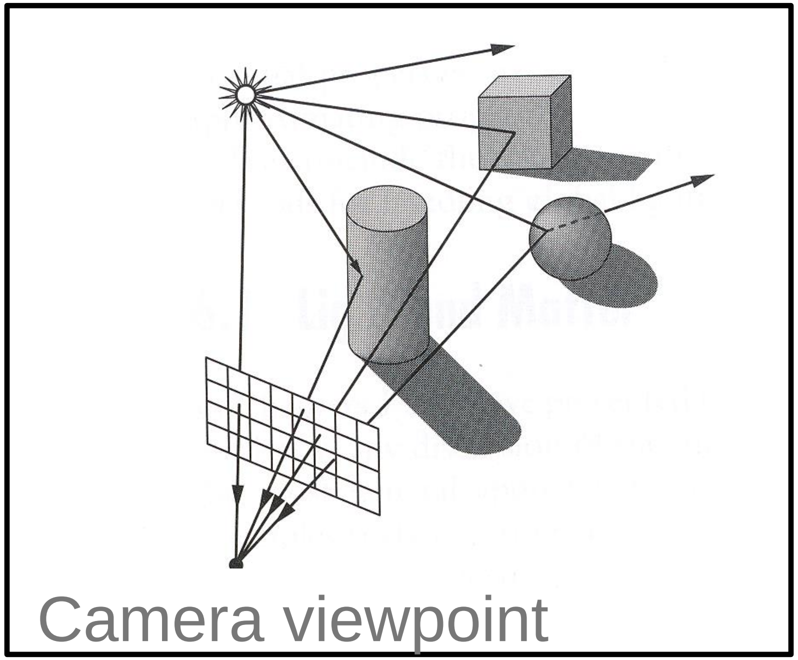
Plenoptic Function

- The 7D plenoptic function $L(x,y,z,\theta,\phi,t,\lambda)$ describes the radiance arriving …
    - at any position (x,y,z),
    - in any direction (θ,ϕ),
    - at any time (t),
    - at any frequency (λ)



Photographic Images

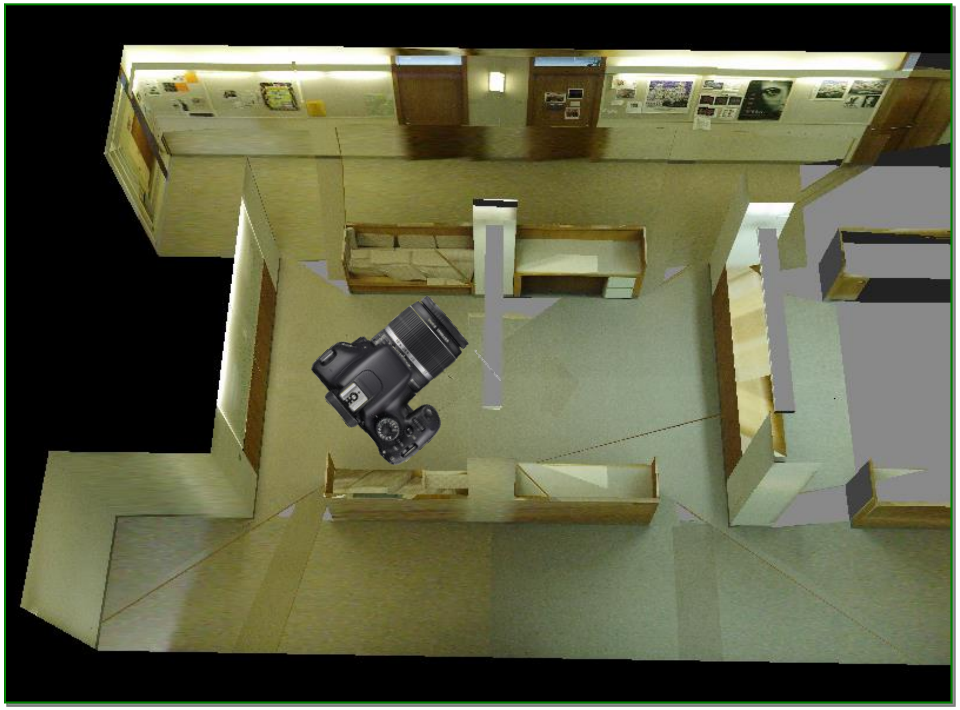
- An idealized photographic image contains a 2D array of samples of the 7D plenoptic function
  - at a particular camera viewpoint,
  - for 2D array of directions,
  - at a certain time,
  - at certain frequencies



Photographic Images

In practice, can't measure plenoptic function directly

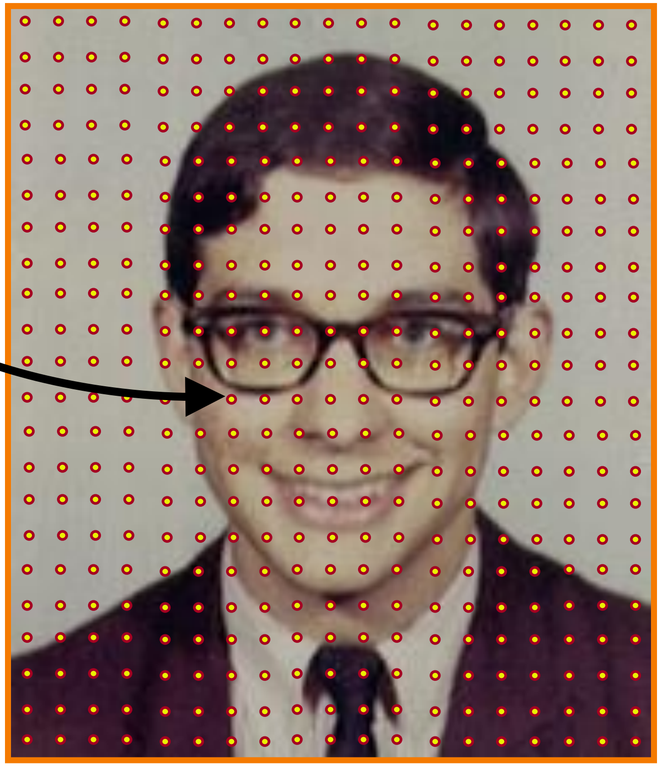
- Photoreceptors in eye
- Film in a traditional camera
- CCD cells in digital camera



Photographic Images

Photographic pixels as finite samples of the plenoptic function

$f(x,y,z,\theta,\phi,t,\lambda)$



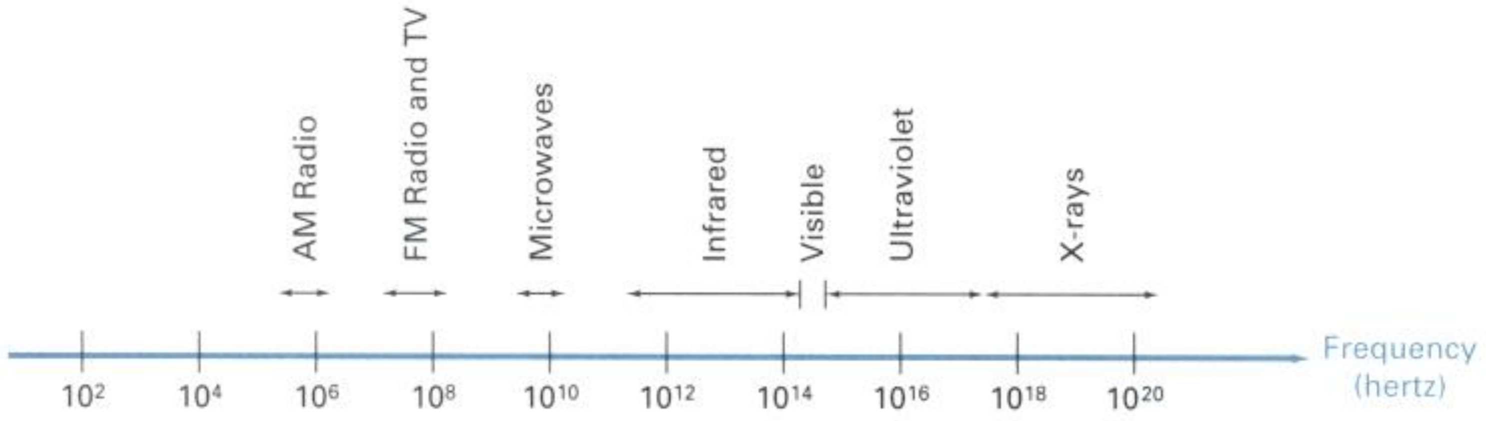
Digital photograph

What Frequencies?

$$f(x,y,z,\theta,\phi,t,\lambda)$$

Electromagnetic Spectrum

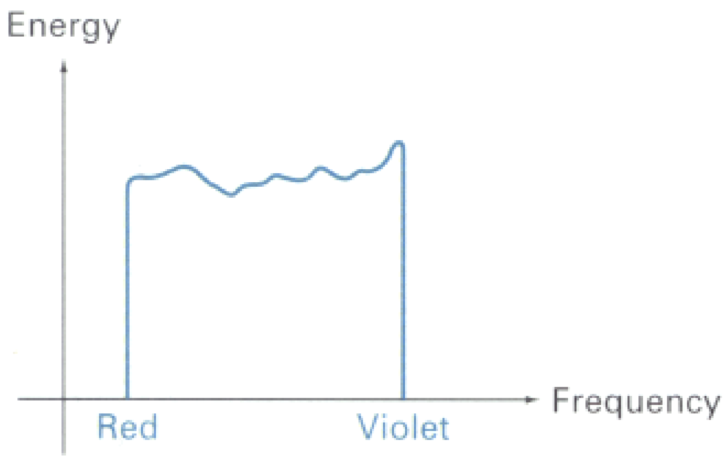
- Visible light frequencies range between ...
  - Red = 4.3 x 10^{14} hertz (700nm)
  - Violet = 7.5 x 10^{14} hertz (400nm)



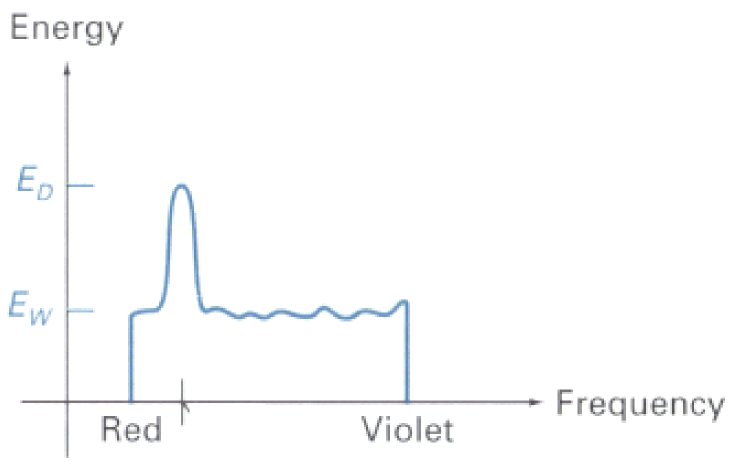
Figures 15.1 from H&B

Color

- The color of light is characterized by its spectrum
  - Magnitude of wave at every visible frequency



White Light



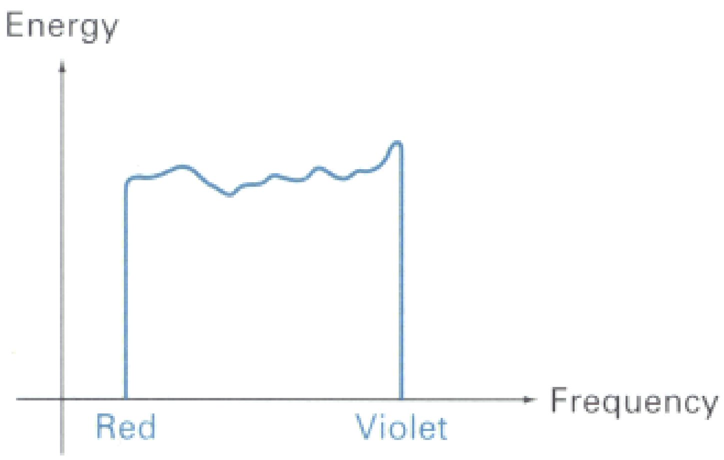
Orange Light

Figures 15.3-4 from H&B

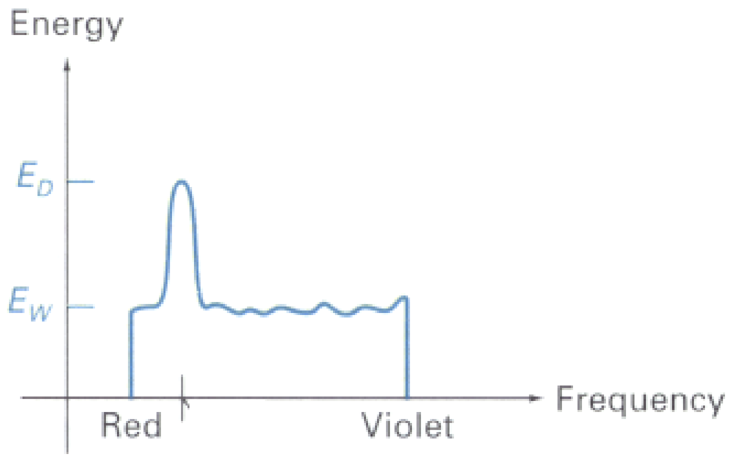
Color

How do we represent a color in a computer?

- Must store a finite amount of data to represent magnitudes for infinite number of frequencies



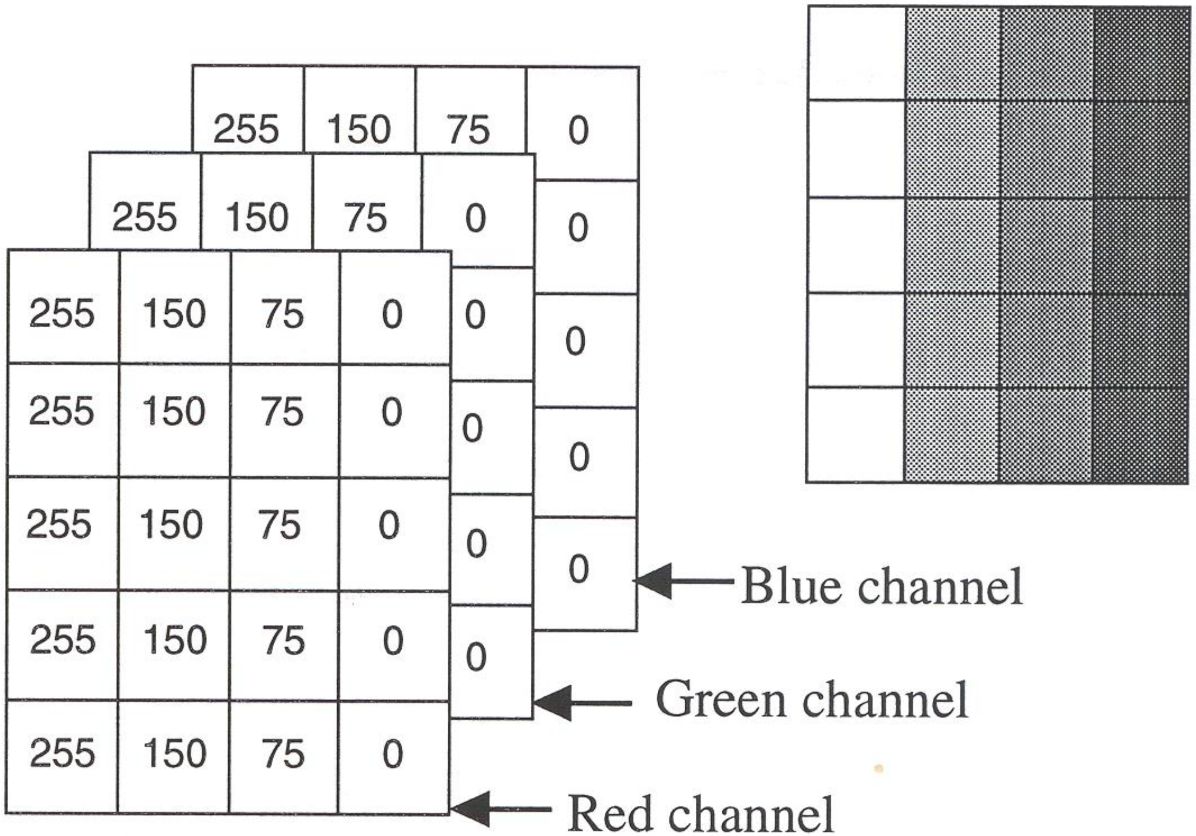
White Light



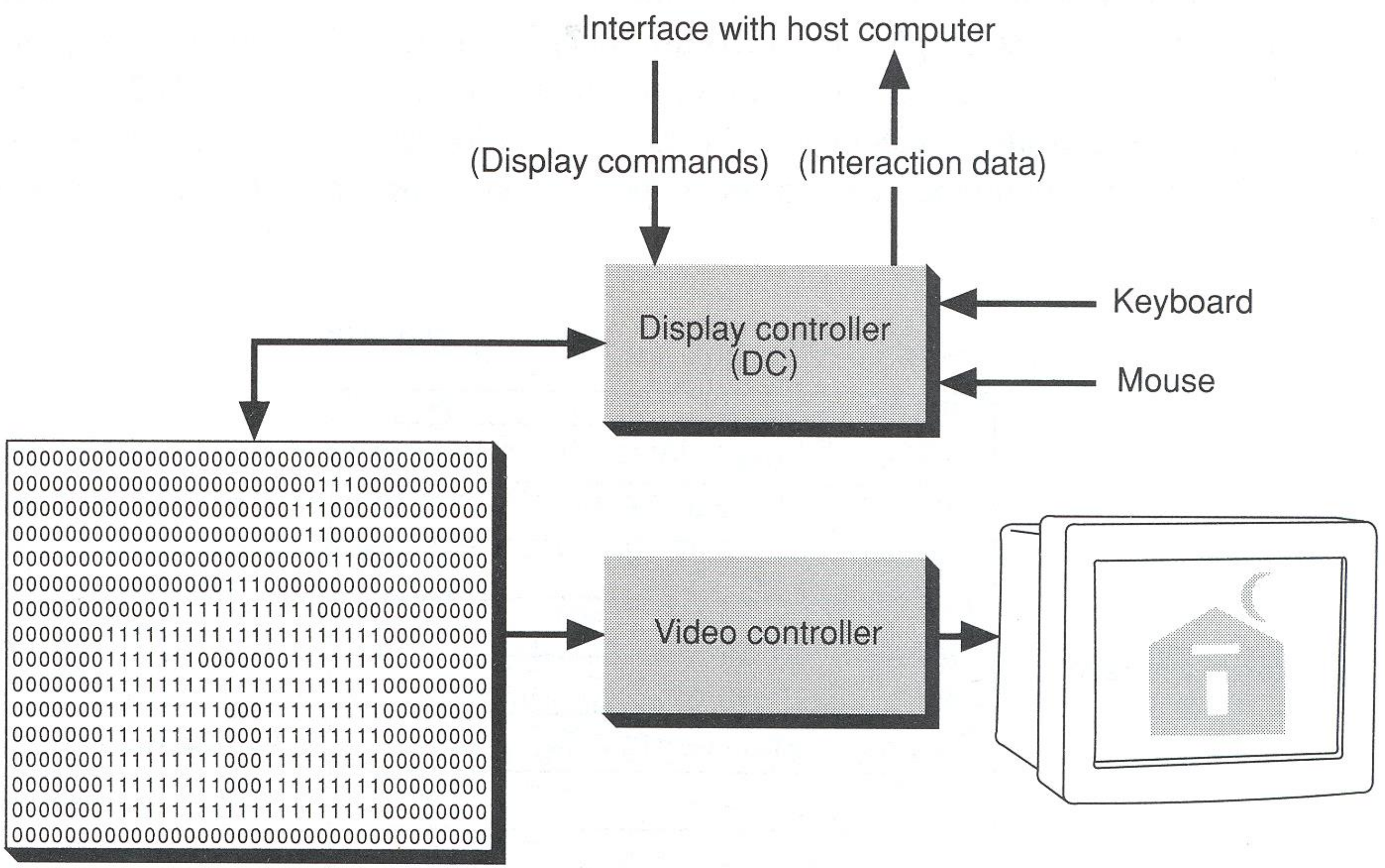
Orange Light

Figures 15.3-4 from H&B

Color Frame Buffer



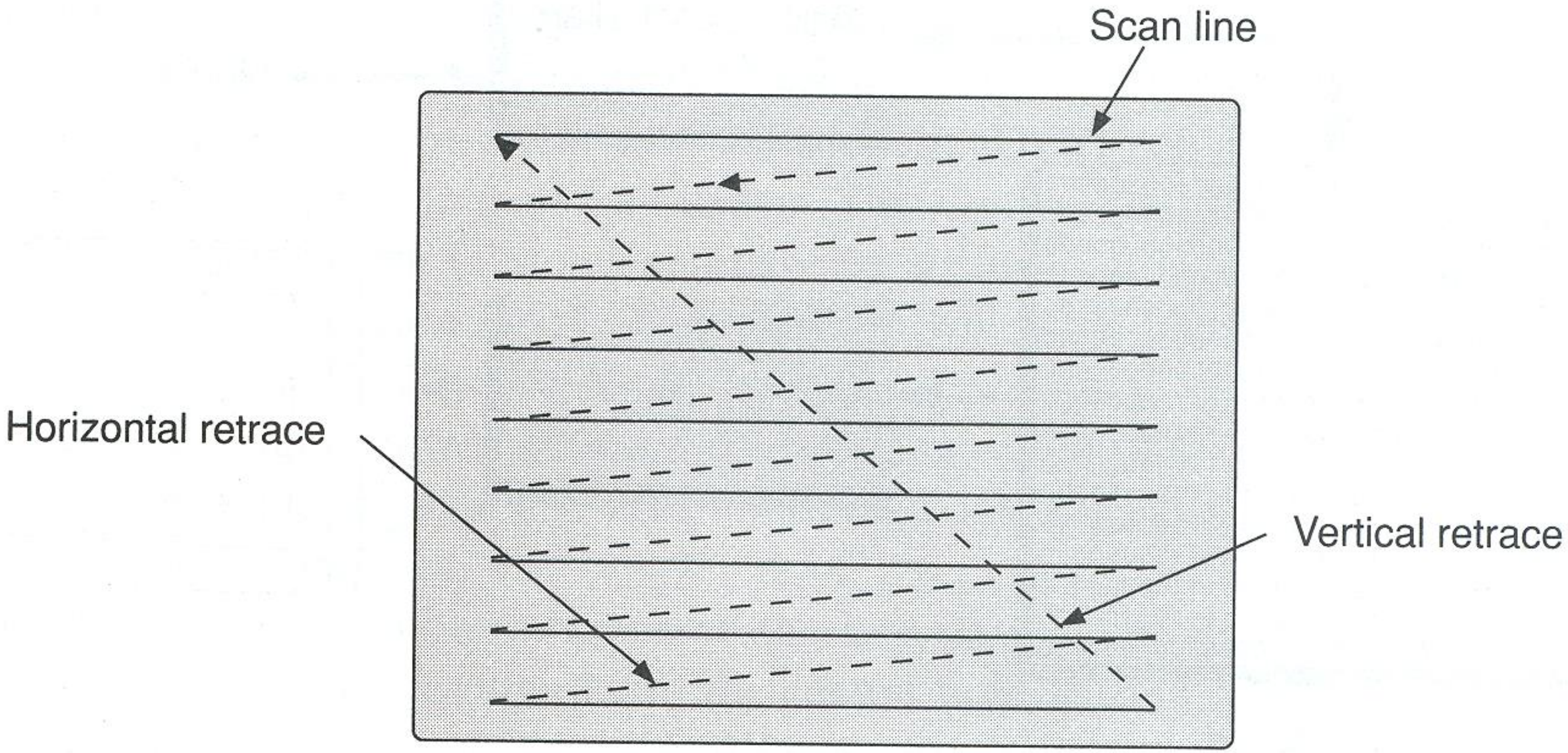
Frame Buffer Display



Frame Buffer

Figure 1.2 from FvDFH

Frame Buffer Display



Refresh rate is usually 60-75Hz

Figure 1.3 from FvDFH

Frame Buffer Display

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

Frame Buffer Display

Example: liquid crystal display (LCD)

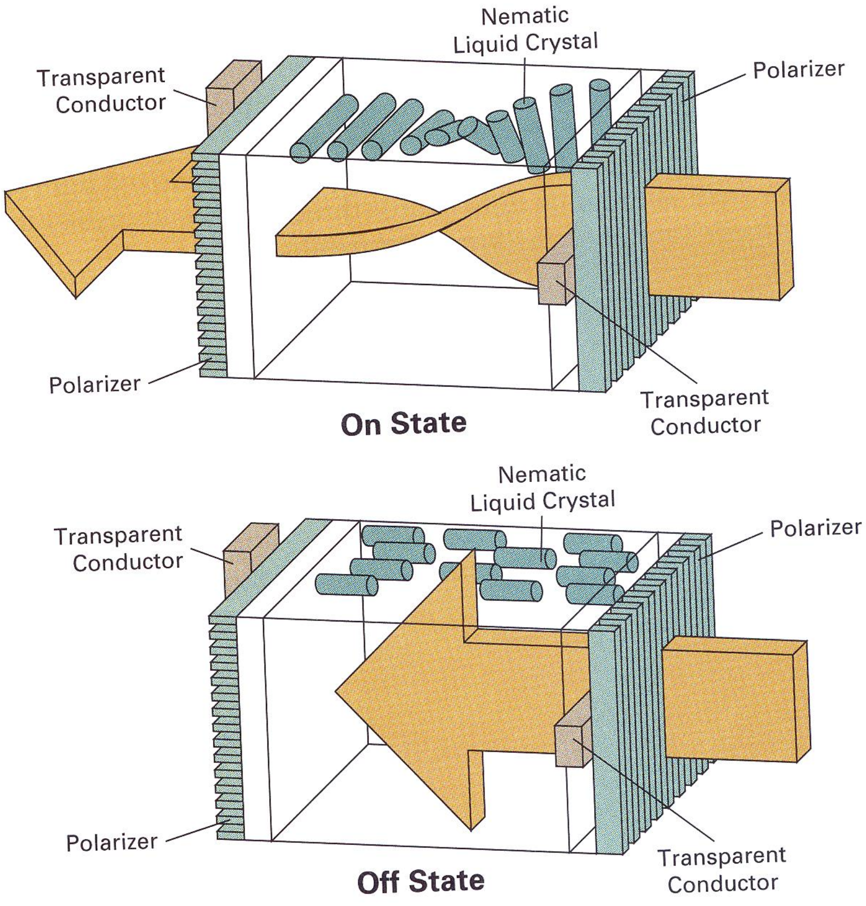
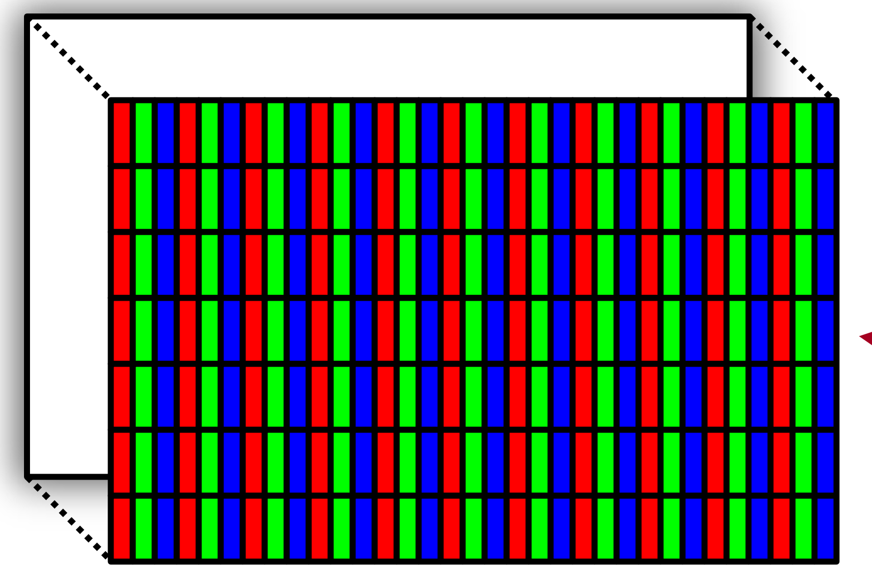


Figure 2.16 from H&B

Frame Buffer Display

Example: liquid crystal display (LCD)



Colors are interleaved

Frame Buffer Display

- Example: cathode ray tube (CRT)

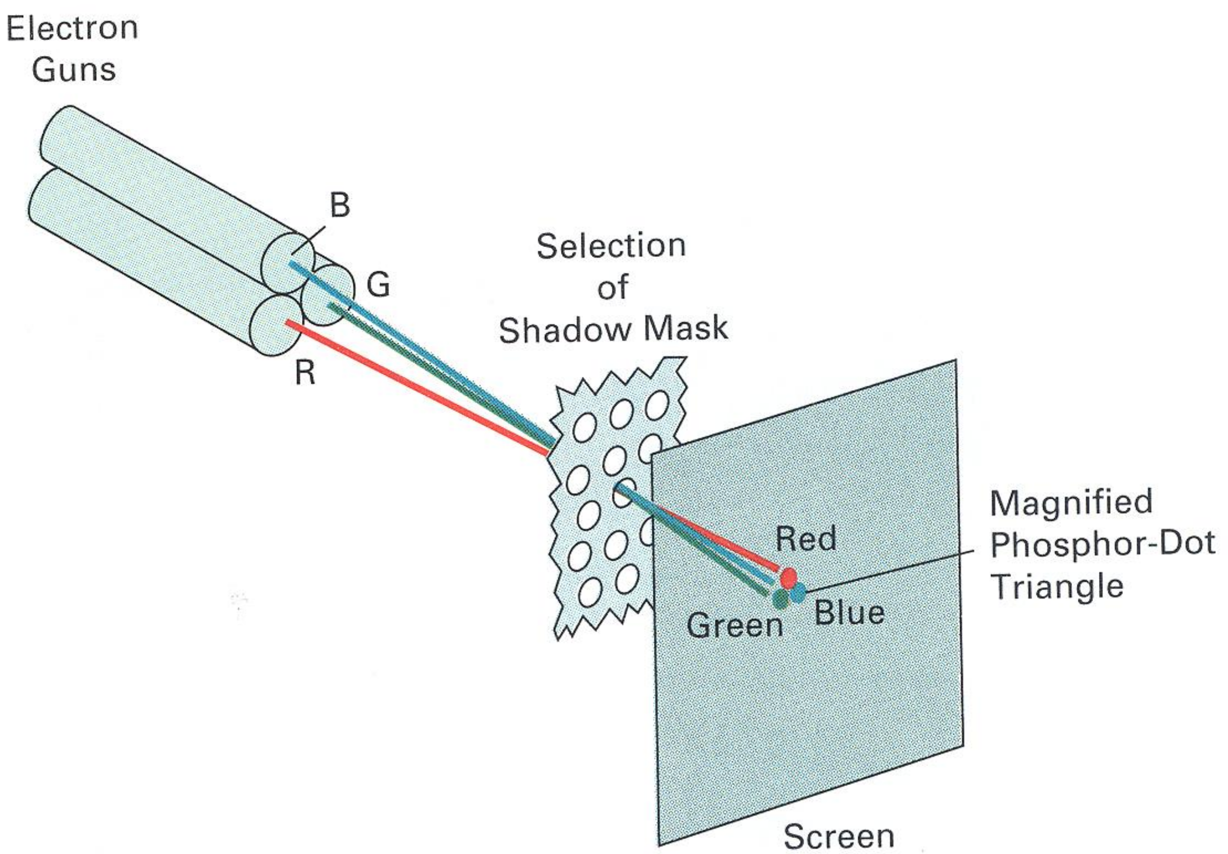
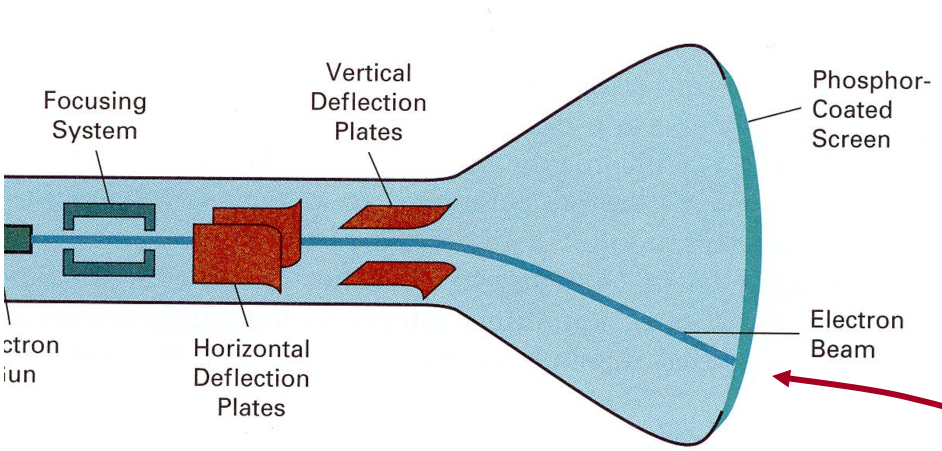


Figure 2.8 from H&B

Frame Buffer Display

Note: image is an array of samples –
continuous function is “reconstructed” during display



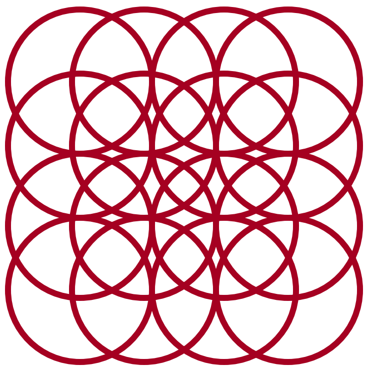
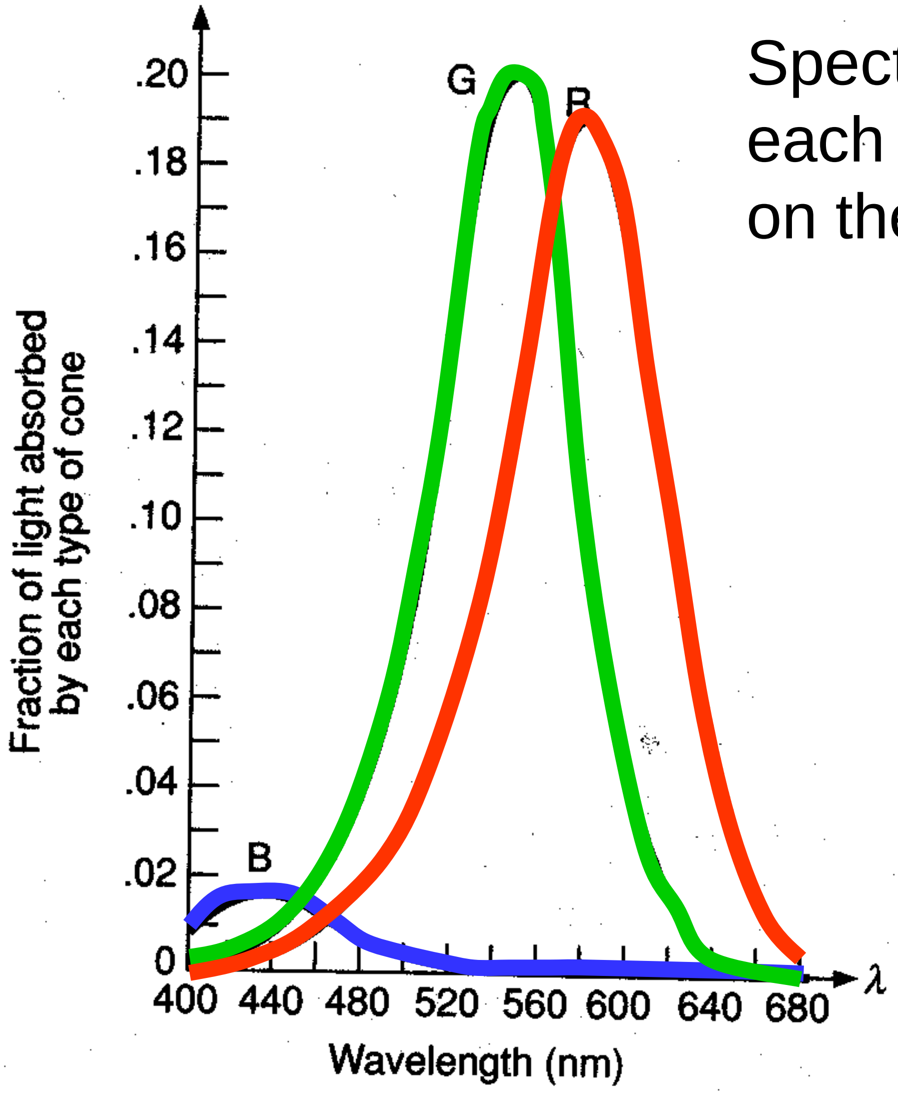


Image is reconstructed
by displaying pixels
with finite area
(Gaussian)

Color

Why red, green, and blue (RGB)?

Human Color Perception

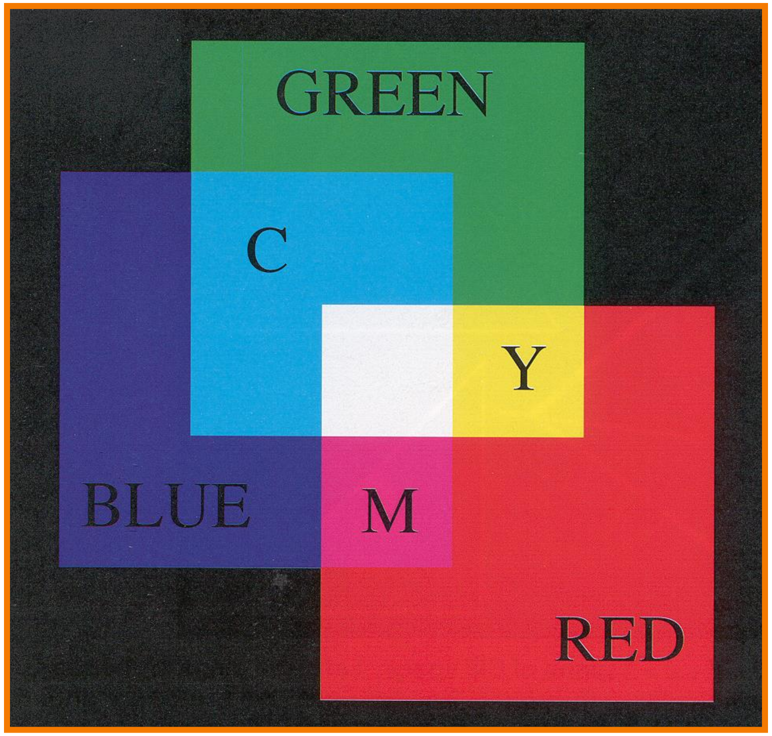


Spectral-response functions of each of the three types of cones on the human retina.

Tristimulus theory of color

Figure 13.18 from FvDFH

RGB Color Model

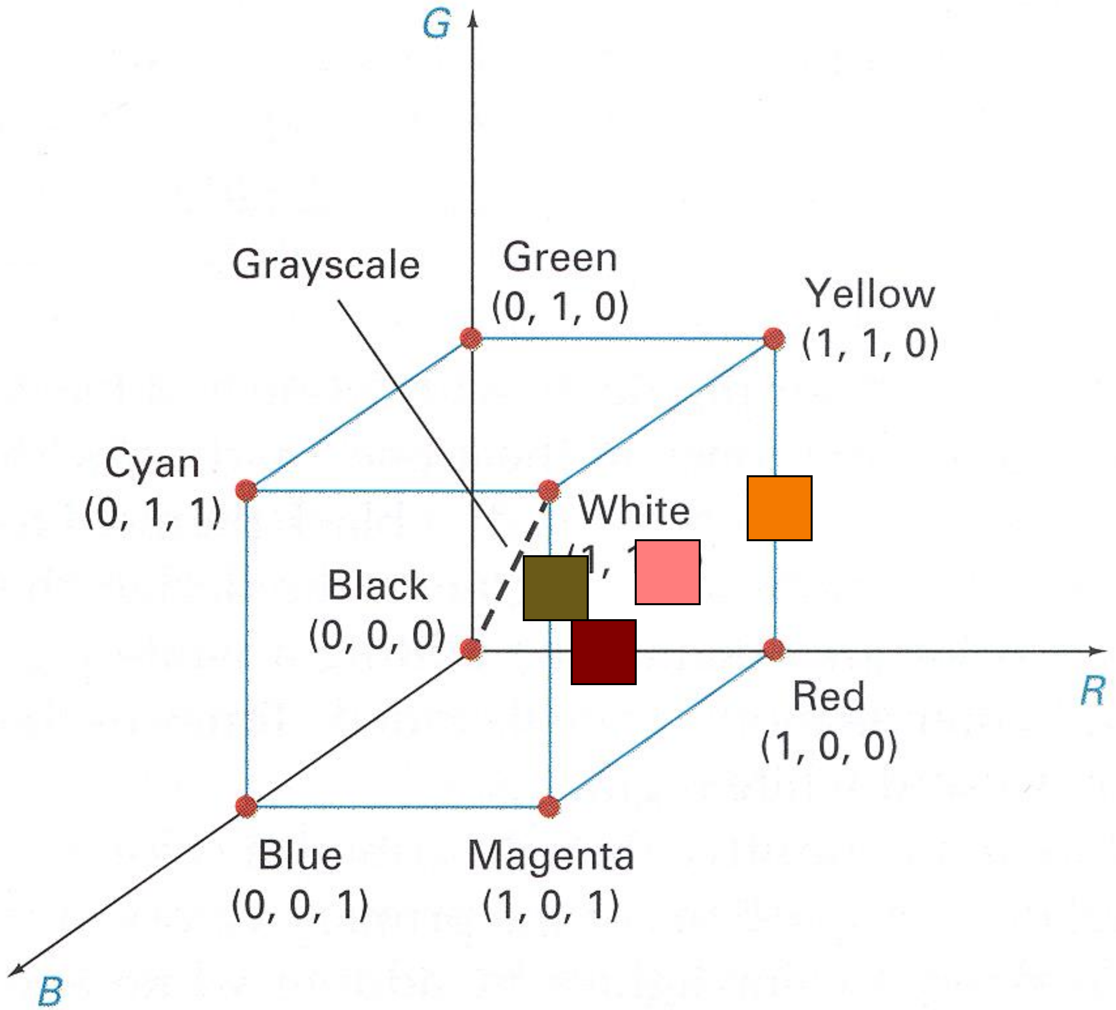


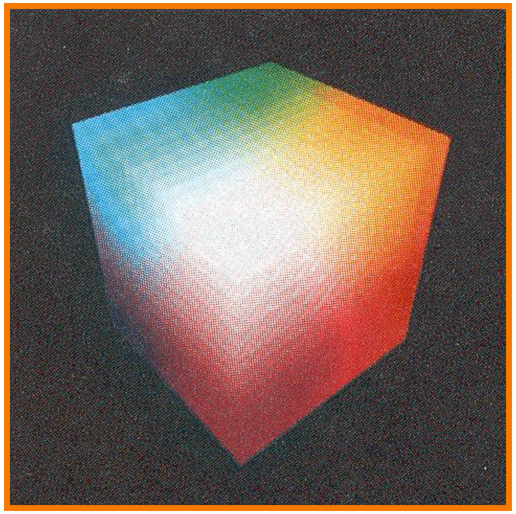
Colors are additive

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





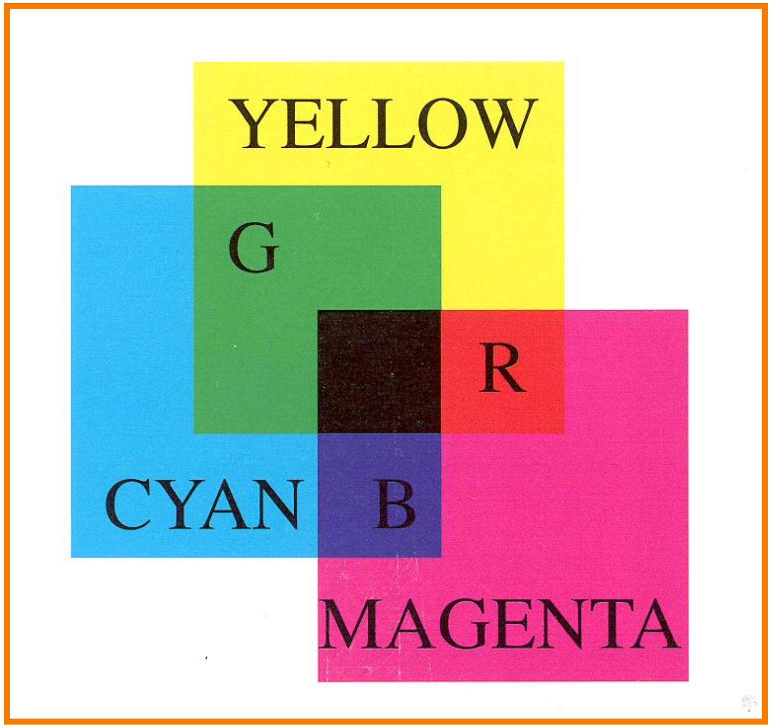
Figures 15.11&15.12 from H&B

Other Color Models

- CMY
- HSV
- XYZ
- La*b*
- Others

Different color models are useful for different purposes

CMY Color Model



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	

Useful for printers
because colors are subtractive

Plate II.7 from FvDFH

CMY Color Model

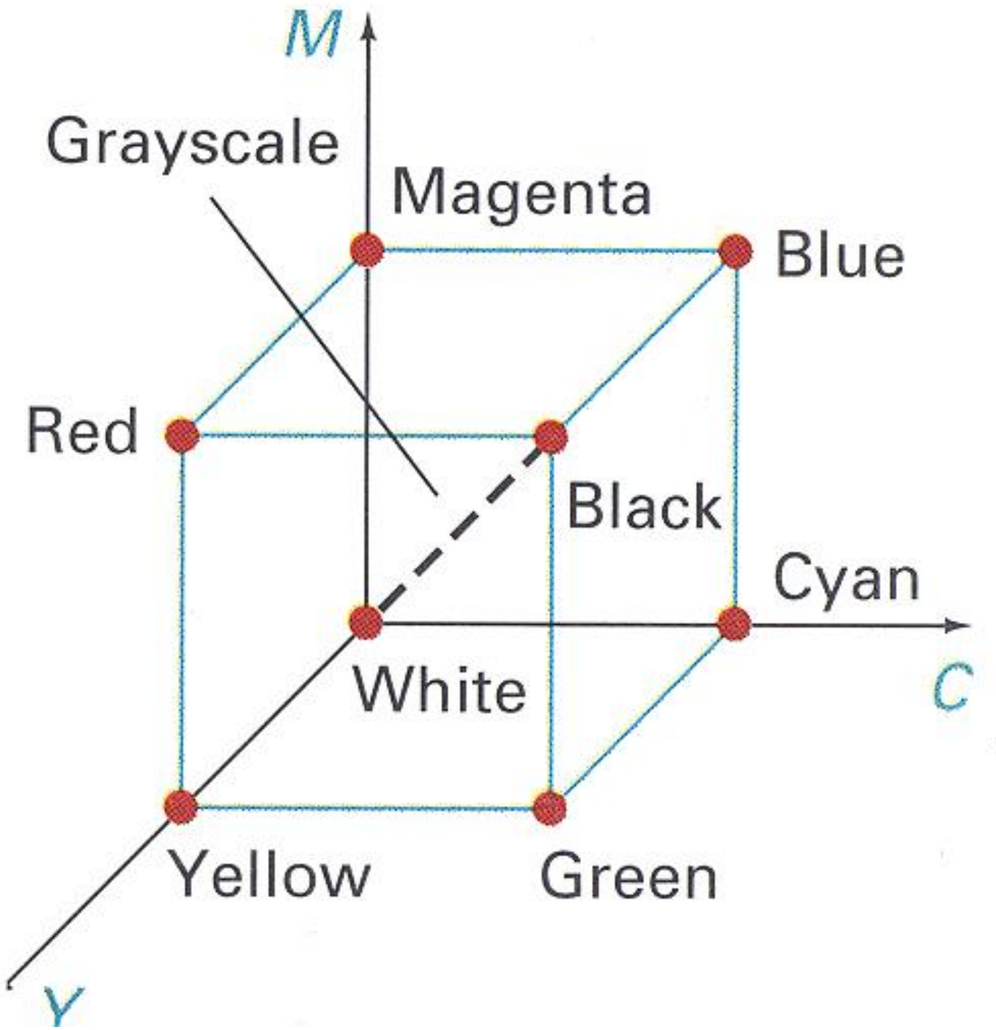
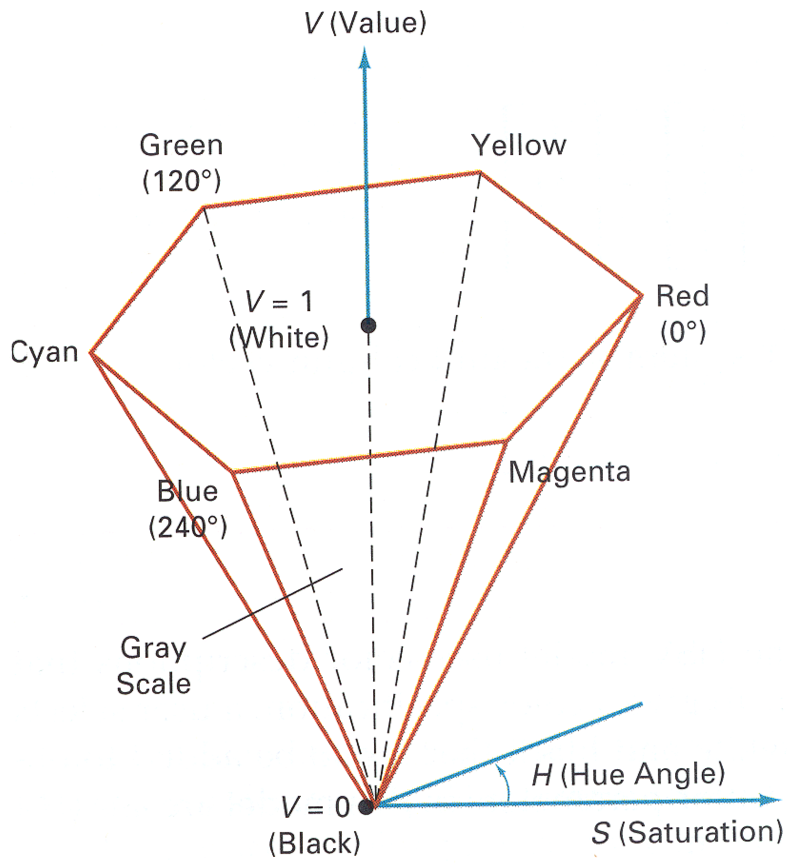


Figure 15.14 from H&B

HSV Color Model

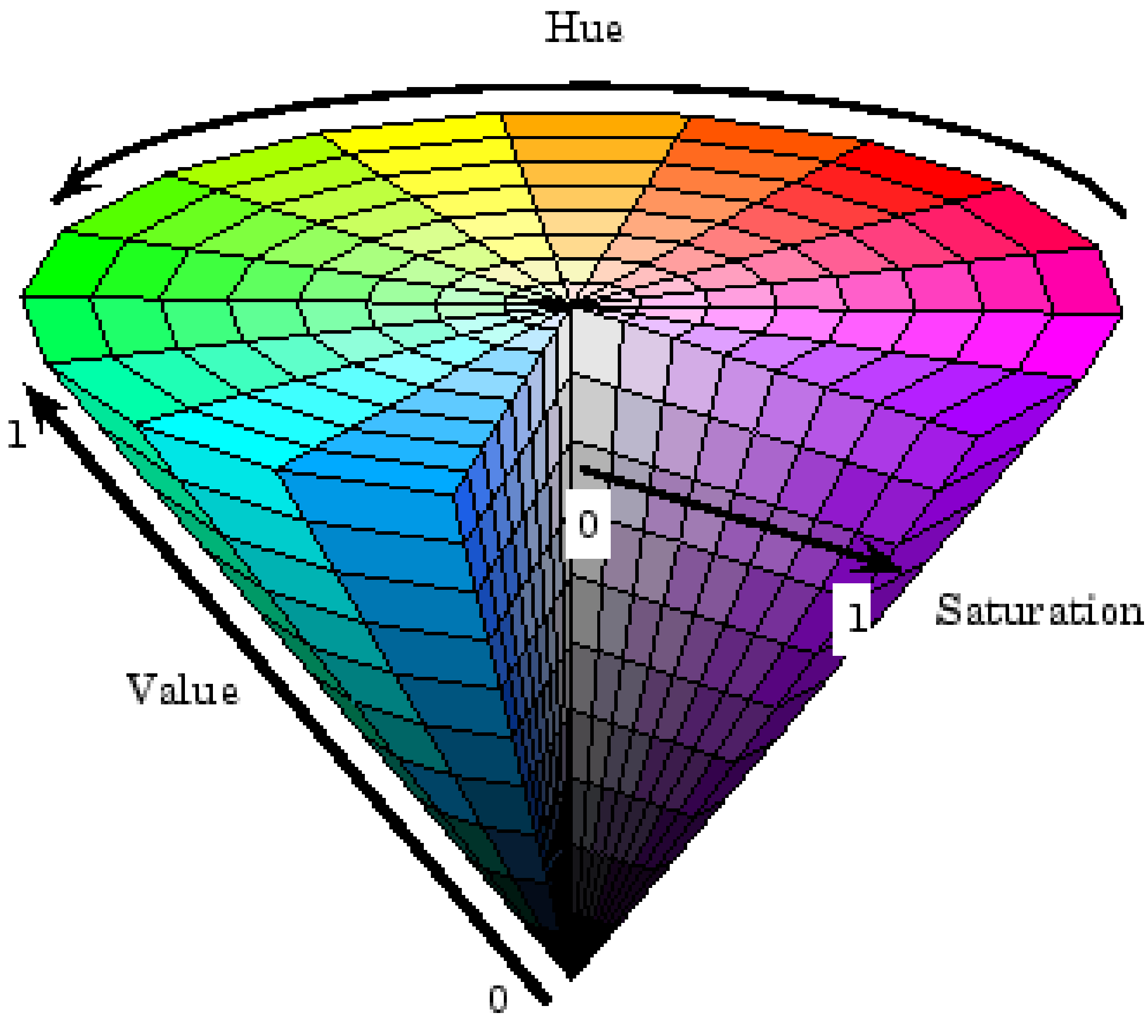


H	S	V	Color
0	1.0	1.0	Red
120	1.0	1.0	Green
240	1.0	1.0	Blue
*	0.0	1.0	White
*	0.0	0.5	Gray
*	*	0.0	Black
60	1.0	1.0	
270	0.5	1.0	
270	0.0	0.7	

Useful for user interfaces because dimensions are intuitive

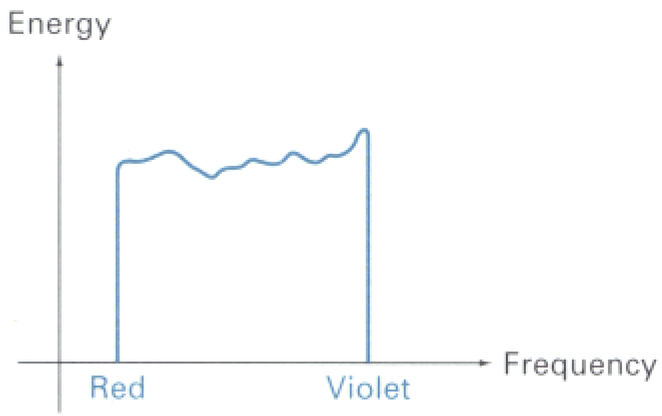
Figure 15.16&15.17 from H&B

HSV Color Model

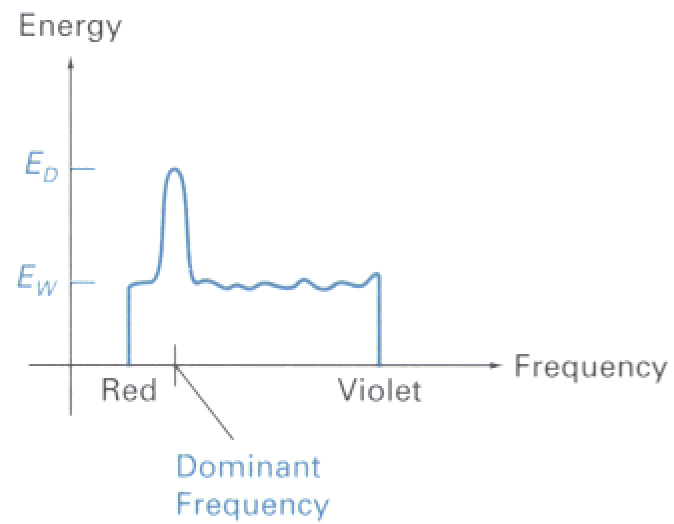


HSV Color Model

- HSV interpretation in terms of color spectrum
  - Hue = dominant frequency (highest peak)
  - Saturation = excitation purity (ratio of highest to rest)
  - Value = luminance (area under curve)



White Light

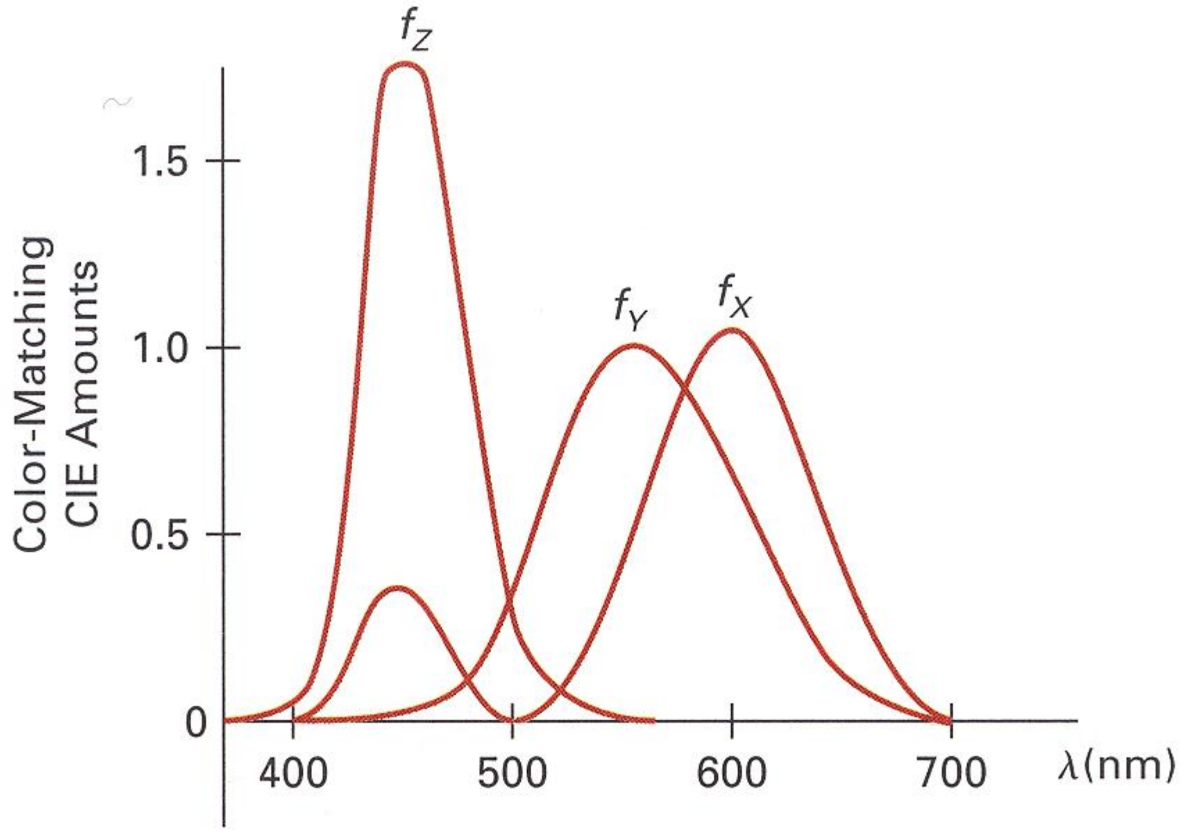


Orange Light

Figures 15.3-4 from H&B

XYZ Color Model (CIE)

Figure 15.6 from H&B

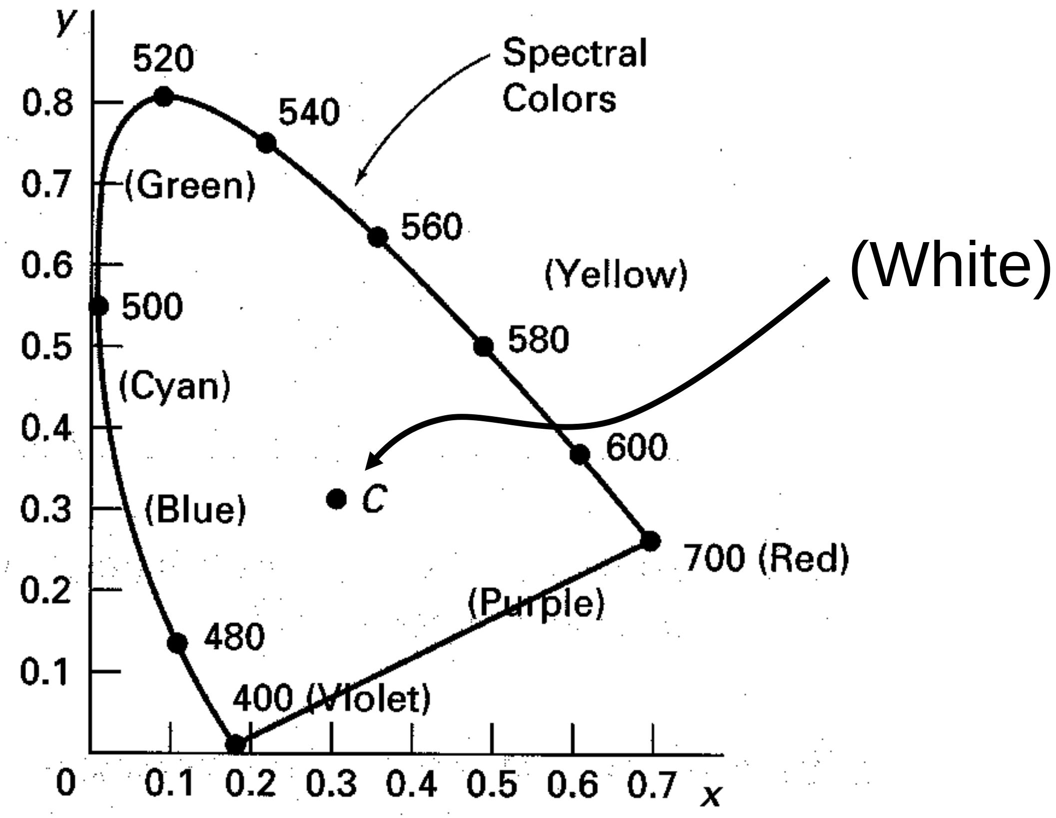


Derived from perceptual experiments

All spectra that map to same XYZ give same visual sensation

XYZ Color Model (CIE)

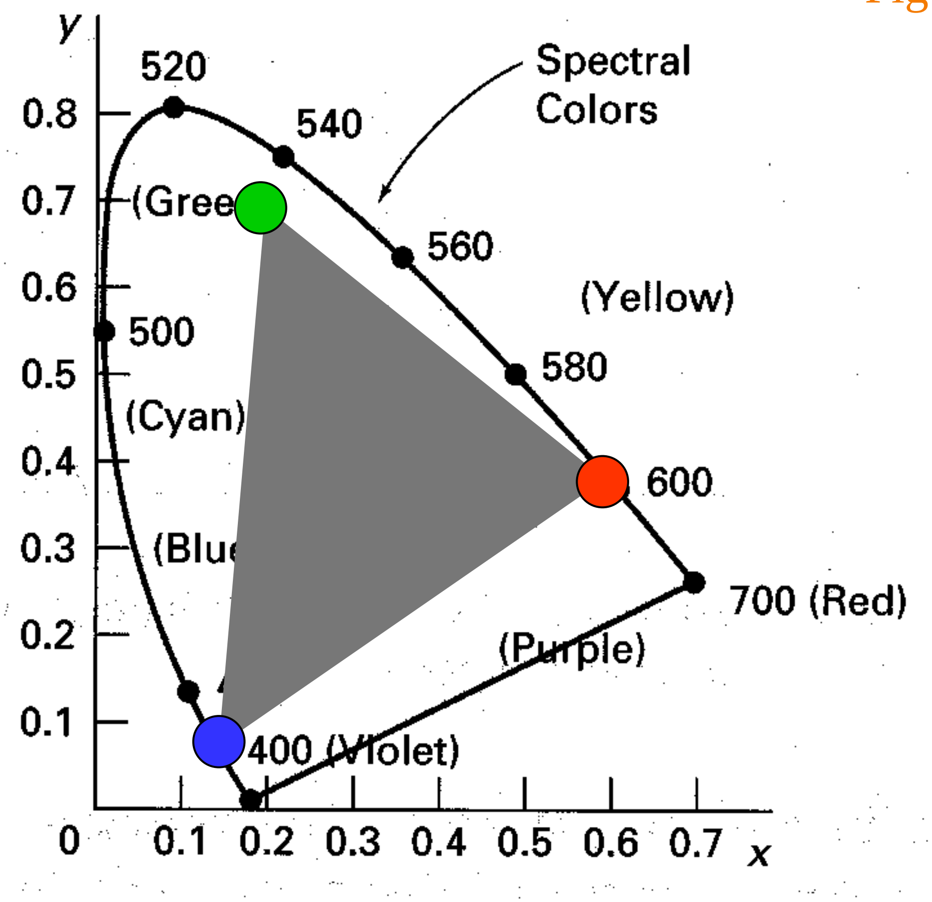
Figure 15.7 from H&B



Normalized amounts of X and Y for colors in visible spectrum

XYZ Color Model (CIE)

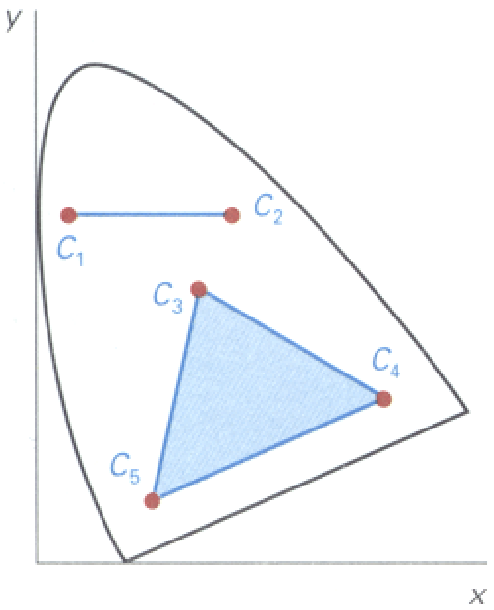
Figure 15.13 from H&B



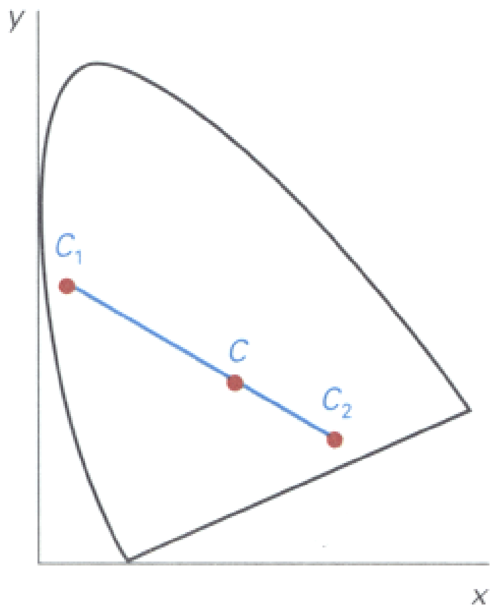
Useful for reasoning about coverage of color gamuts

XYZ Color Model (CIE)

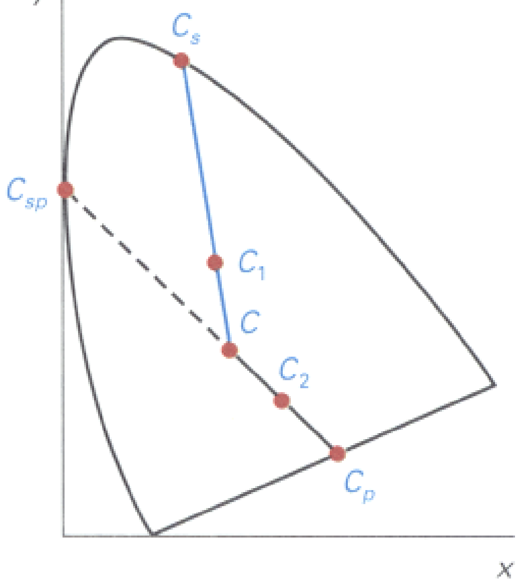
Figures 15.8-10 from H&B



Compare
Color
Gamuts



Identify
Complementary
Colors

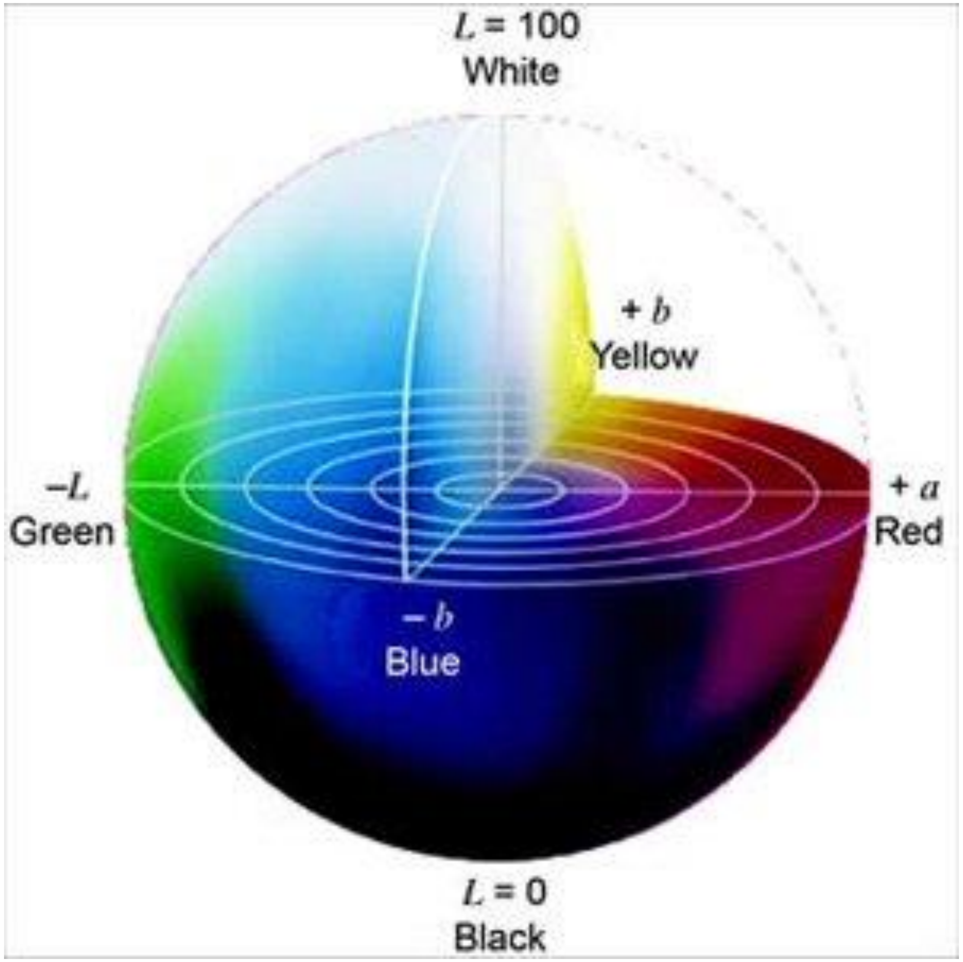


Determine
Dominant Wavelength
and Purity

Useful for characterizing perceptual qualities of colors

La*b* Color Model

Non-linear compression of XYZ color space based on perception



Useful for measuring perceptual differences between colors

Summary

- Images
  - Pixels are samples
  - Photographs sample plenoptic function
- Colors
  - Tristimulus theory of color
  - Different color models for different devices, uses, etc.
  - RGB model is common due to human perception
  - CIE Chromaticity Diagram
- Next time
  - Image processing!