
# Computer Graphics

Spring 2017

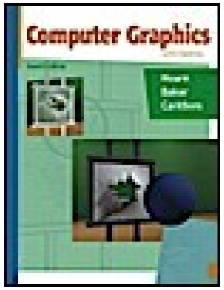
PRINCETON UNIVERSITY

# Overview

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

# Administrative Matters

- Instructors
  - Szymon Rusinkiewicz
  - Amit Bermano
- TAs
  - Andy Zeng
  - Riley Simmons-Edler
- Book
  - *Computer Graphics with OpenGL, 4th Ed,* Hearn, Baker, and Carithers




- Web page
  - http://www.cs.princeton.edu/~cos426/
- Questions / Discussion
  - http://www.piazza.com/

# Coursework

- Programming Assignments (40%)
  - Assignment #1: Image Processing
  - Assignment #2: Modeling
  - Assignment #3: Rendering
  - Assignment #4: Animation
- Exams (20% each)
  - In class (Mar 16 and May 4)
- Final Project (20%)
  - Your choice!
  - Completed in groups of 2-4
  - Due on Dean's date

# Programming Assignments

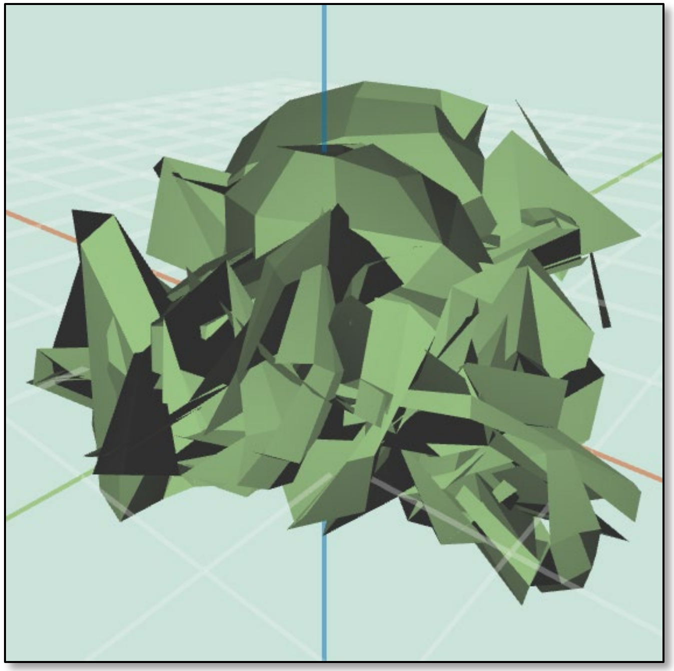
- Who?
  - Pair programming, at most twice with same partner
- When?
  - Roughly every 2-3 weeks
- Where?
  - Anywhere you want, e.g. home or clusters
- How?
  - Javascript (Precept this week), some OpenGL / GLSL
- What?
  - Menu of features, some required, some optional
  - Submit to art gallery!

# Art Gallery

- Everybody should submit entries!
  - +1 point for submitting

Cool Images/Videos

*(Jimmy Zuber, CS 426, Spring 2014)*



Bloopers

*(Reed Tantiviramanond, CS 426, Spr15)*

Characters for web banner

# Collaboration Policy

- Overview:
  - You must write your own code (no credit for other code)
  - You must cite the sources of any ideas/code
- It’s OK to …
  - Work closely with your partner
  - Talk with other students about ideas, approaches, etc.
  - Get ideas from information in books, web sites, etc.
  - Get “support” code from example programs
- It’s NOT OK to …
  - Share code with another student
  - Use ideas or code acquired from other sources without attribution

# Precepts

- When and Where?
  - Wednesday and Thursday 7:30-8:20
  - Friend 004
  - Attend either one – same content
- Content
  - Additional material (e.g., Javascript intro)
  - Discussion of assignments
  - Review for exams

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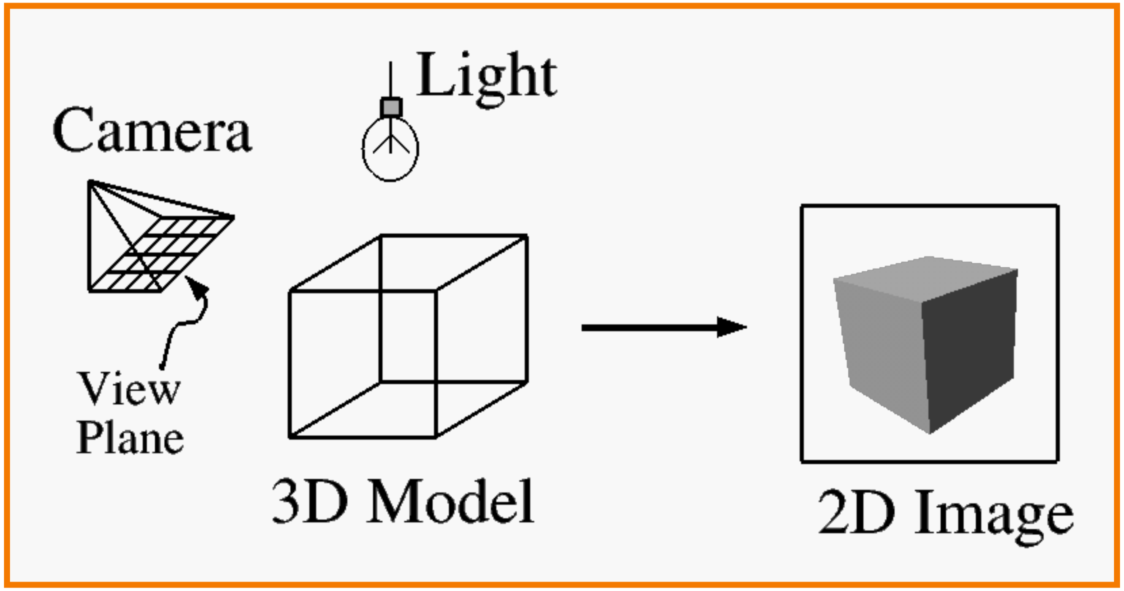
# What Is Computer Graphics?

Imaging: *representing 2D images*

Modeling: *representing 3D objects*

Rendering: *creating 2D images from 3D*

Animation: *simulating changes over time*



# What Is Computer Graphics?

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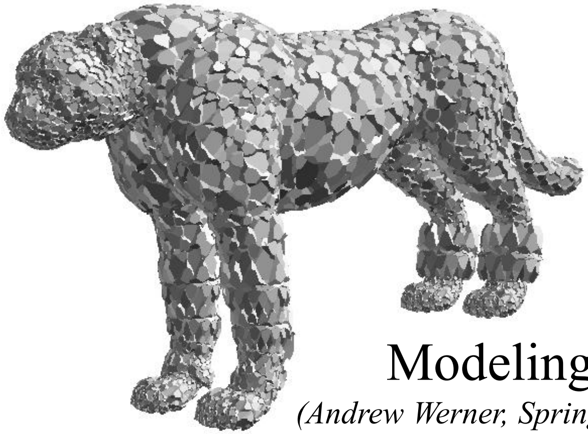
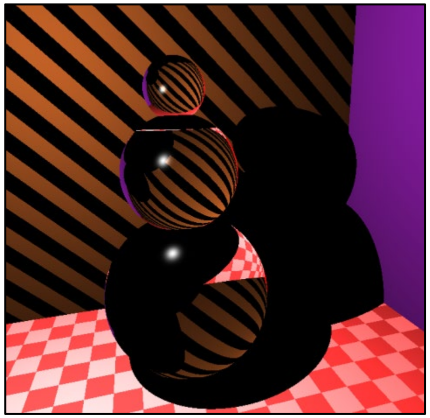
Image Processing

*(Rusty Coleman, CS426, Fall99)*



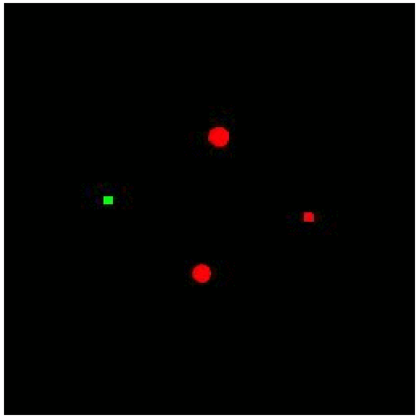
Modeling

*(Andrew Werner, Spring 2014)*



Rendering

*(David Paulk, CS426, Spr2015)*



Animation

*(*Riley Thomasson, Spring 2014*)*

# Part I: Imaging

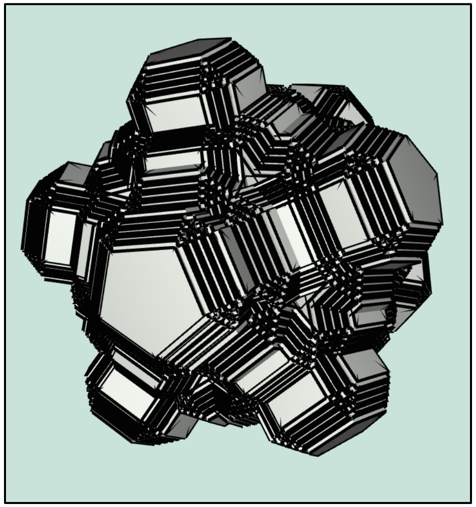
- Image Basics
  - Definition
  - Color models
- Image Representation
  - Sampling
  - Reconstruction
  - Quantization & Aliasing
- Image Processing
  - Filtering
  - Warping
  - Composition
  - Morphing

Image Composition
*(Michael Bostock, CS426, Fall99)*

Image Morphing
*(Ianf, Wikipedia)*

# Part II: Modeling

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



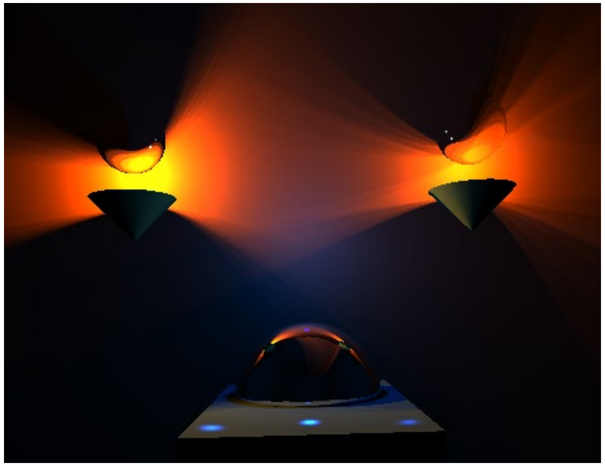
(John Whelchel, CS 426, Spr2015)

(Brendan Chou, Spring 2014)

# 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

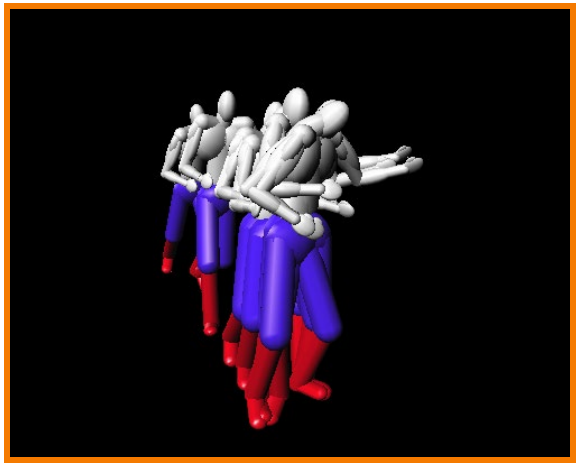
Pixel Shading
*(Final Fantasy, Square Pictures)*



Global Illumination
*(Diana Liao, CS 426, Spr15)*

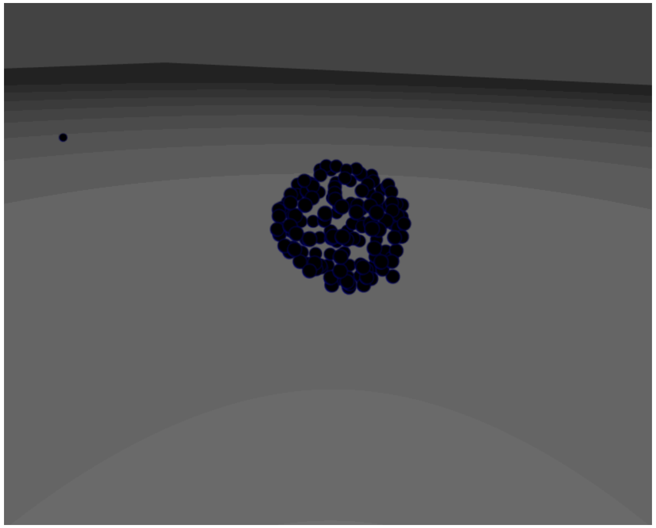
# Part IV: Animation

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



Dancing Guy
*(Jon Beyer, CS426, Spr05)*

Particle system
(Drew Wallac, Spring 2015)



# Applications

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


Geri's Game

*(Pixar Animation Studios)*

# Applications

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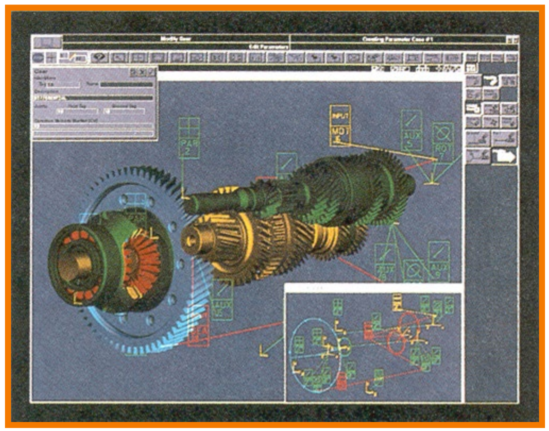
Los Angeles Airport
*(Bill Jepson, UCLA)*



Gear Shaft Design
*(Intergraph Corporation)*

Boeing 777 Airplane
*(Boeing Corporation)*

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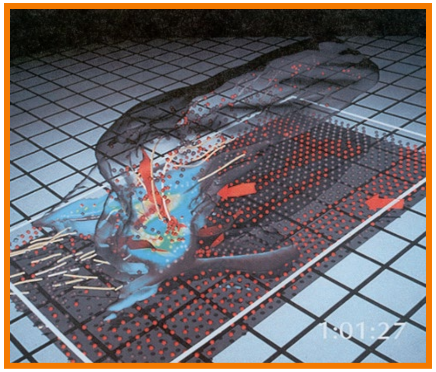
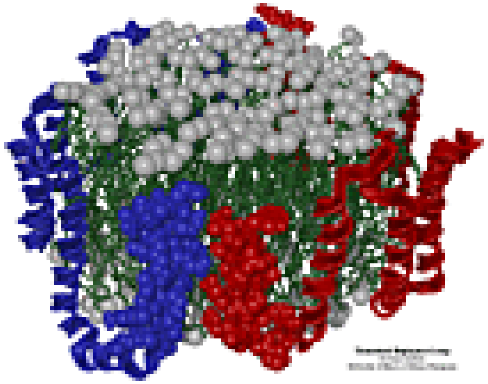



Airflow Inside a Thunderstorm
*(Bob Wilhelmson, University of Illinois at Urbana-Champaign)*



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

Visible Human
*(National Library of Medicine)*

# Applications

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- **Training**
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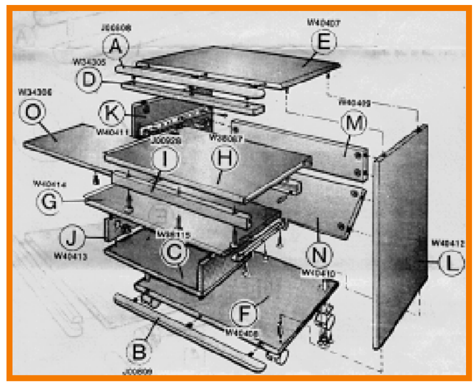
Driving Simulation
*(Evans & Sutherland)*




Desk Assembly
*(Silicon Graphics, Inc.)*

Flight Simulation
*(NASA)*

# Applications

- Entertainment
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- ➜ **Education**
- E-commerce
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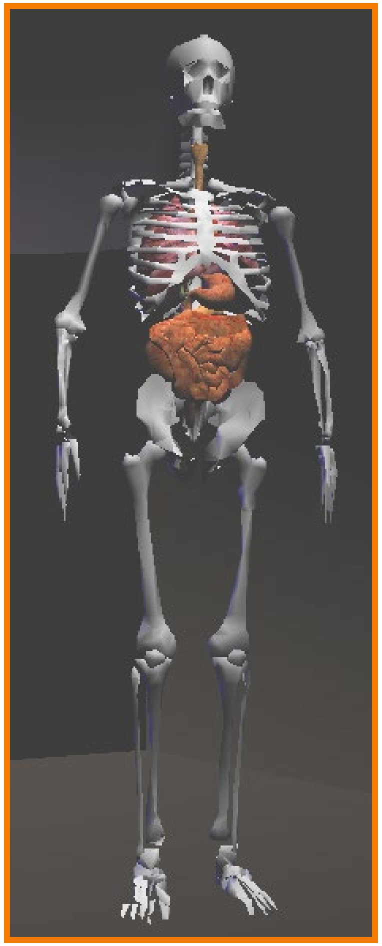
Forum of Trajan
*(Bill Jepson, UCLA)*



Human Skeleton
*(SGI)*

# Applications

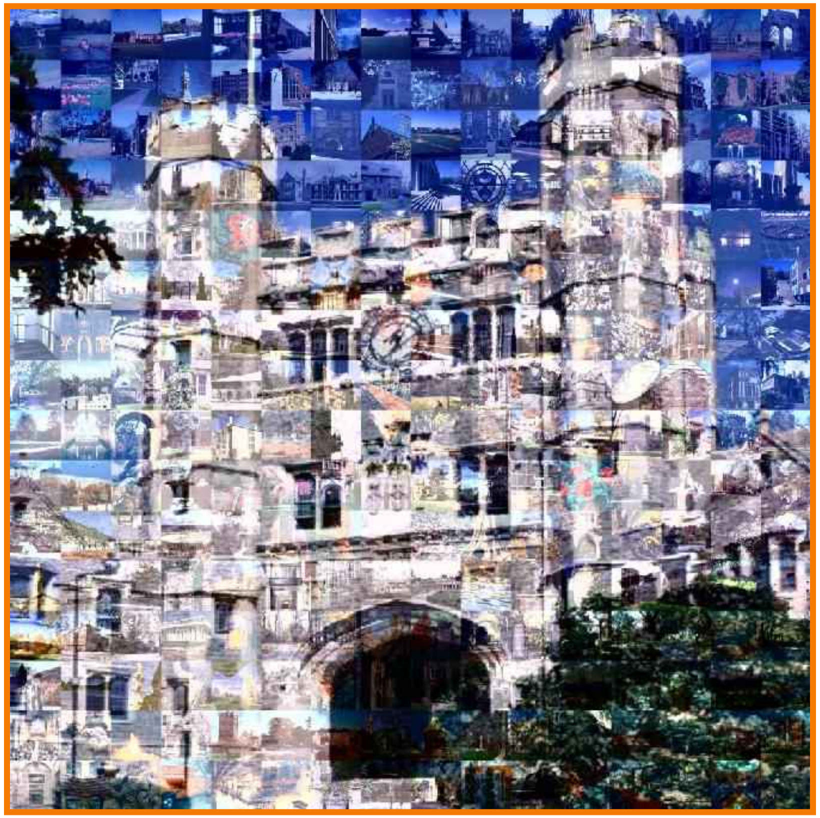
- Entertainment
- Computer-aided design
- Scientific visualization
- Training
- Education
- → **E-commerce**
- Computer art

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
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- Syllabus
  - What will I learn in this course?
- ➢ Raster Graphics
  - Let’s get started … (Yes, this WILL be on the exam!)

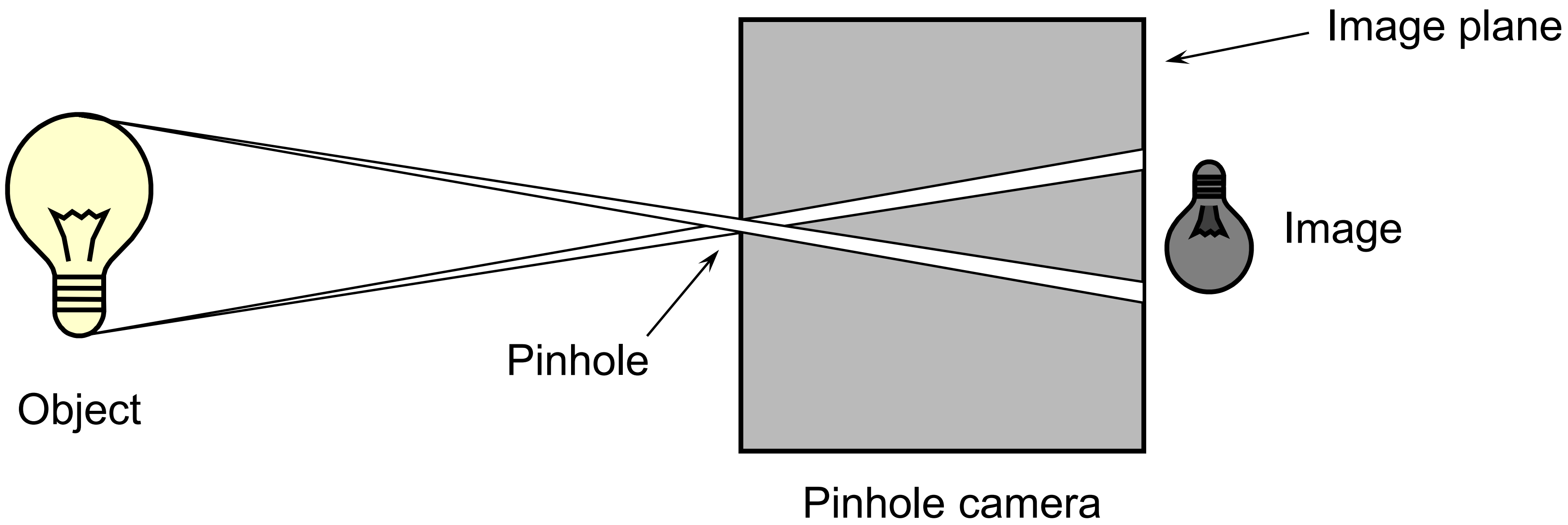
# Raster Graphics

- 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

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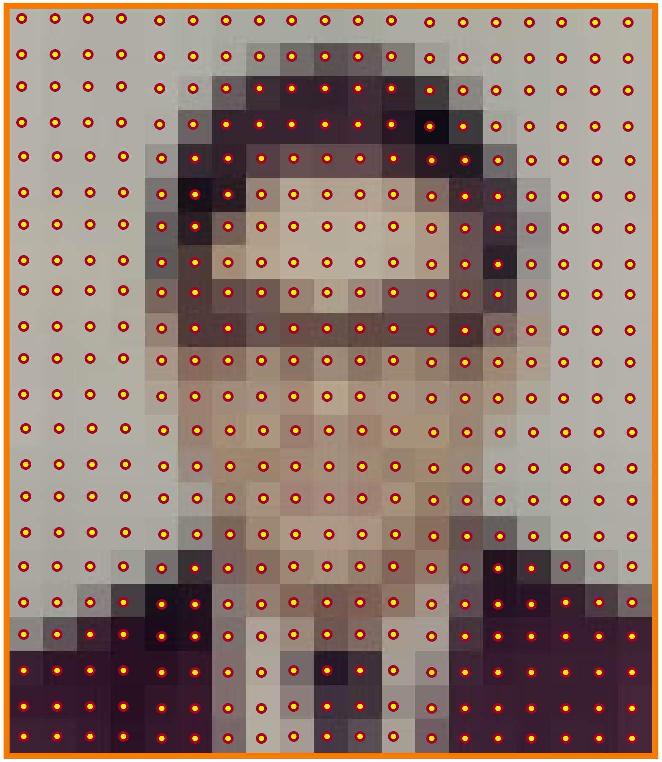
A Pixel is a Sample, not a Little Square!

Continuous image



Digital image

# What is a Digital Image?

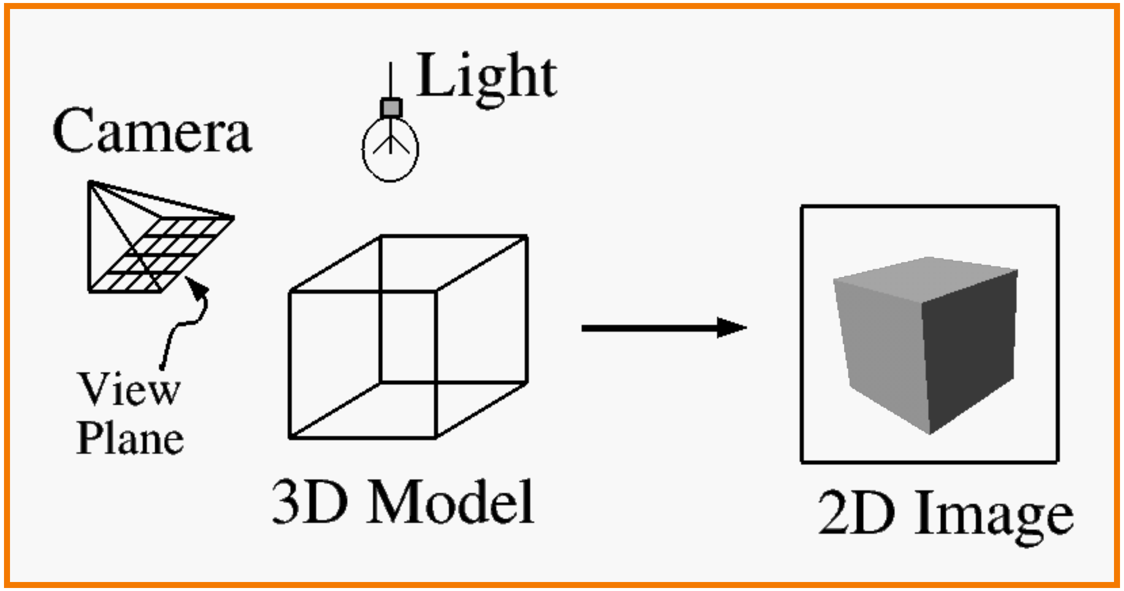
A Pixel is a Sample, not a Little Square!

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: liquid crystal display (LCD)

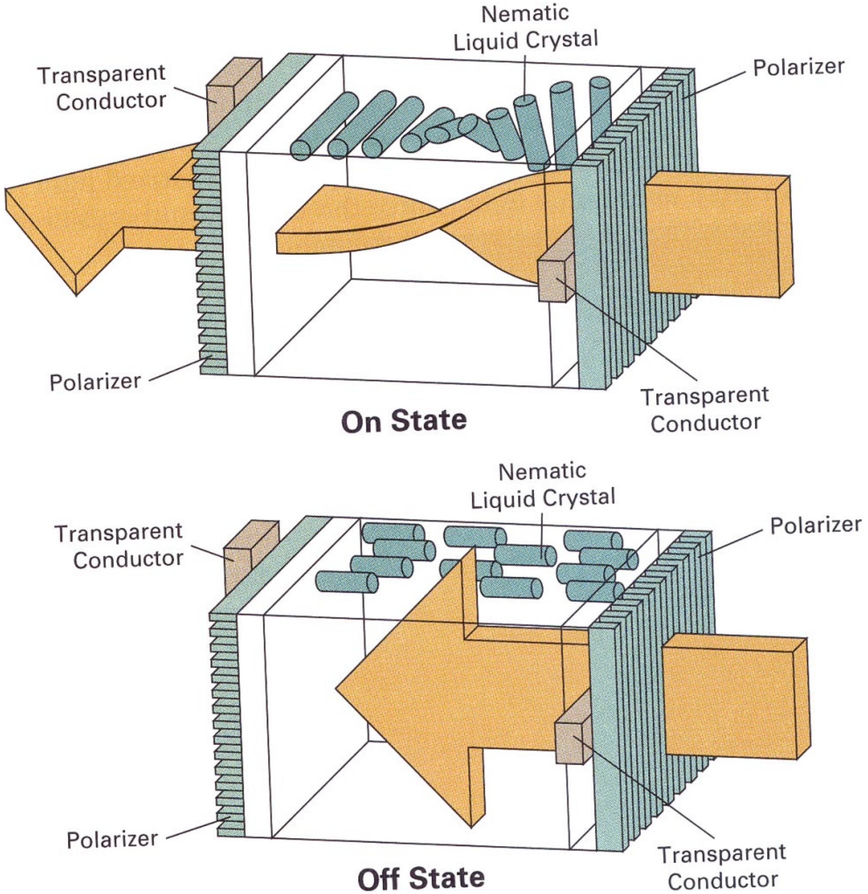
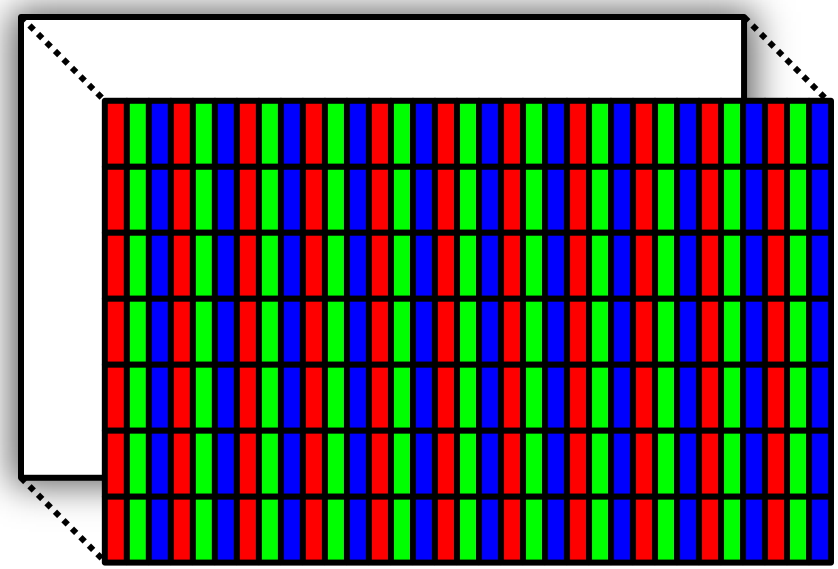


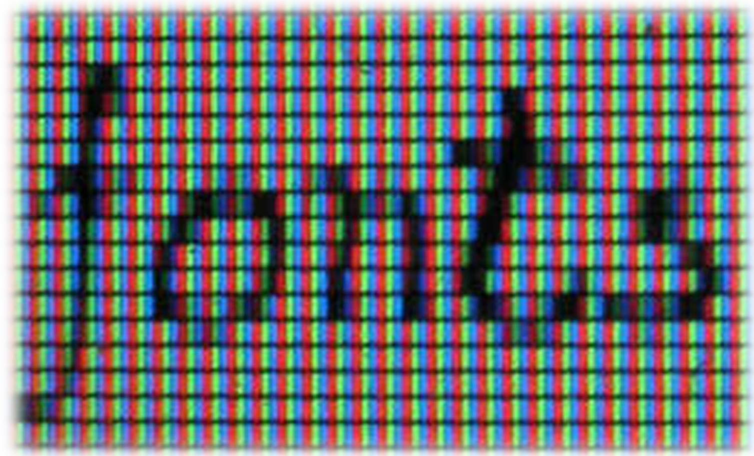

Figure 2.16 from H&B

# Image Display

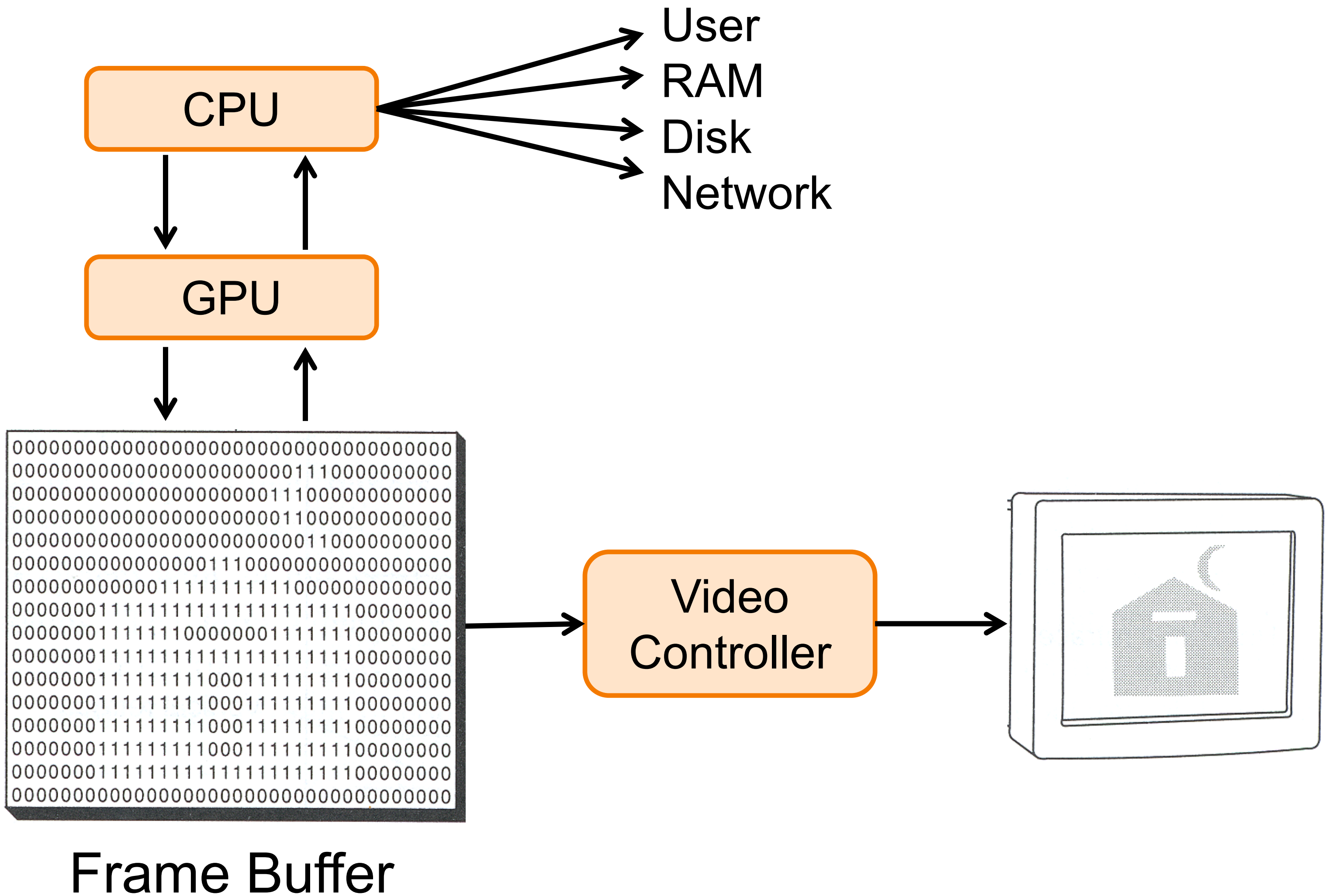
## LCD up close



- Pixels with finite area (rectangles)
- Colors are interleaved



# How Are Digital Images Stored?




Based on Figure 1.2 from FvDFH

# Frame Buffer Limits: Resolution

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

Typical Resolutions

| | Width x Height | Depth | Rate |
|---|---|---|---|
| Cheap laptop | 1366 x 768 | 24 | 60 |
| High-end laptop | 2560 x 1600 | 24 | 60 |
| TV | 1920 x 1080 | 16-ish | 60 (interleaved) |
| Film | 3000 x 2000 | 36 | 24 |
| Printer | 5100 x 6600 | 1-4 | - |

# Raster Graphics

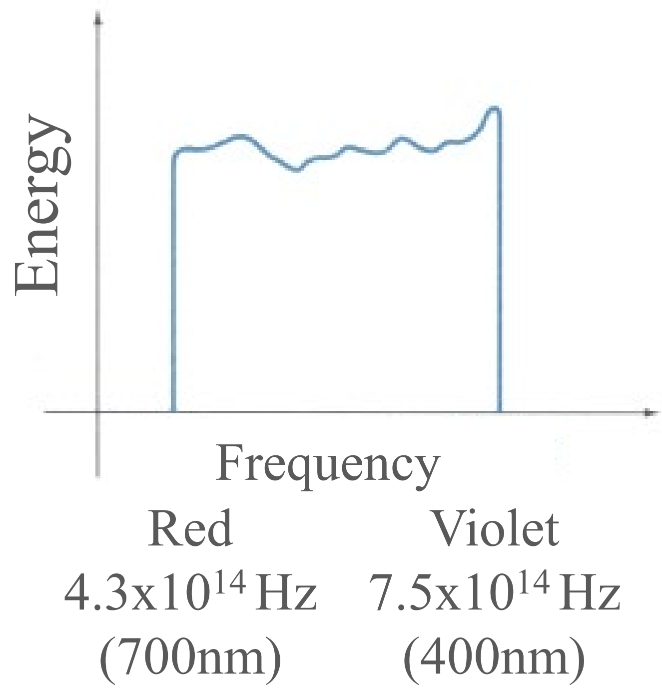
- Images
  - What is an image?
  - How are images displayed?

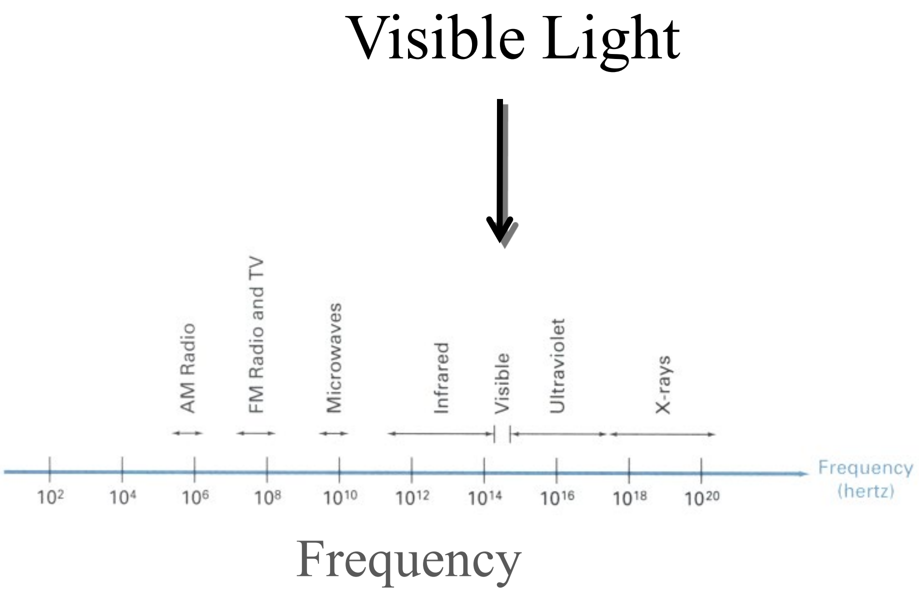
- Colors
  - What is a color?
  - How do we perceive colors?
  - How do we represent colors in a computer?

# What is a Color?

# What is a Color?

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



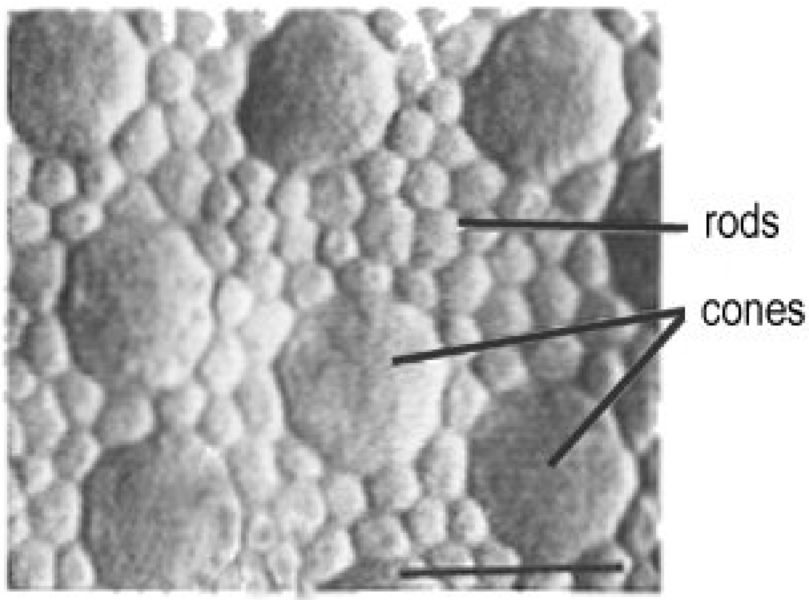




Figures 15.1,3 from H&B

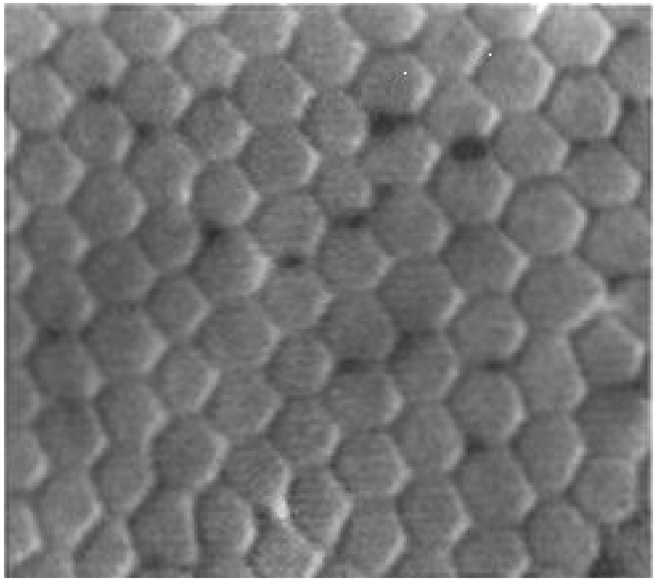
# How Do We Perceive Color?

# Modern Understanding of Color

- Two types of receptors: rods and cones

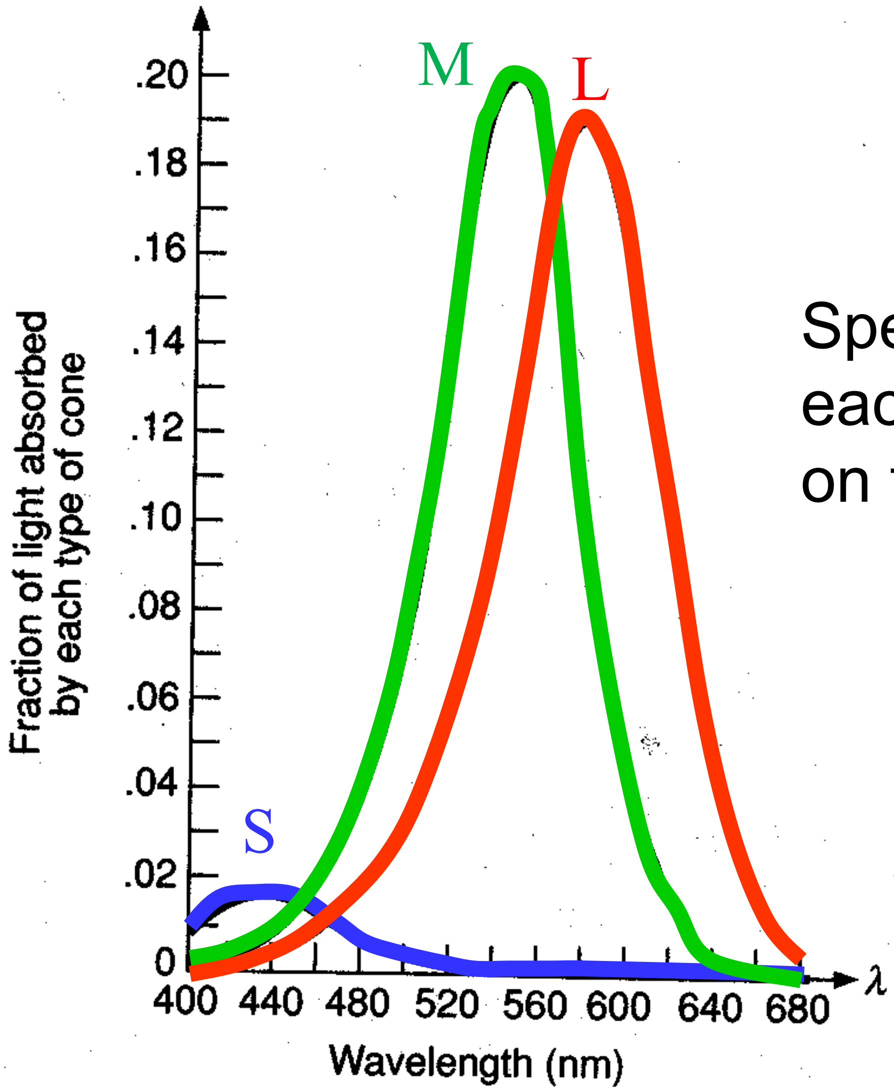



Rods and cones



Cones in *fovea*
(central part of retina)

# Color Perception




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

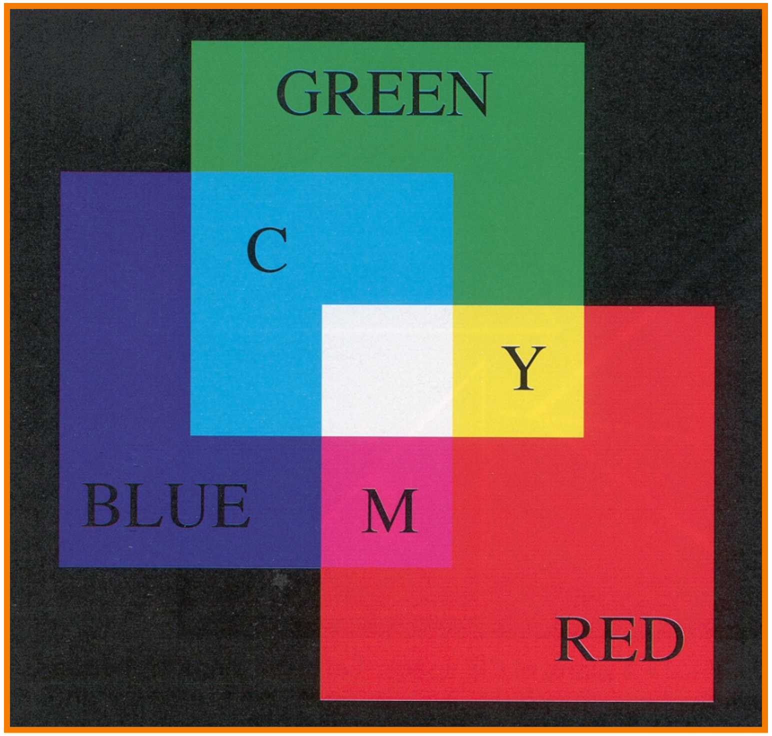
Figure 13.18 from FvDFH

# Representing Colors in a Computer

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

Tristimulus theory of color

# RGB Color Model

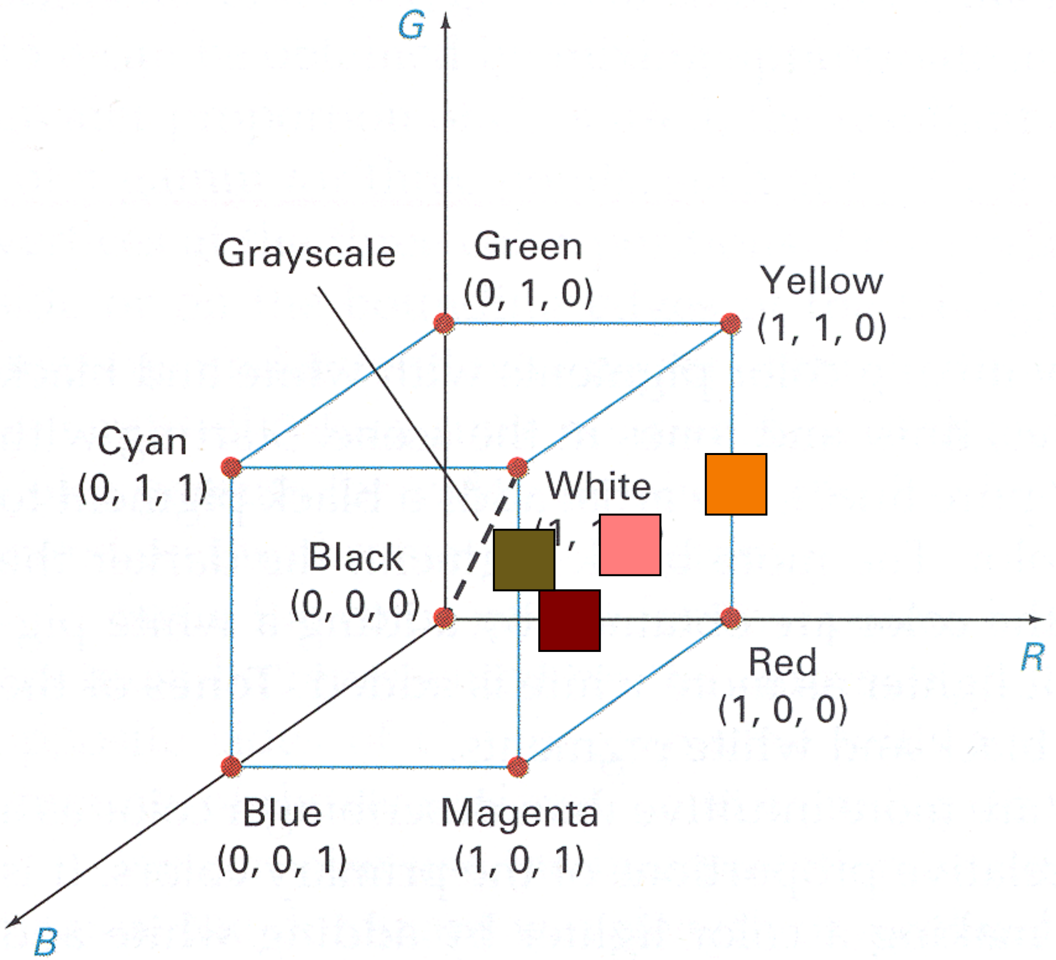


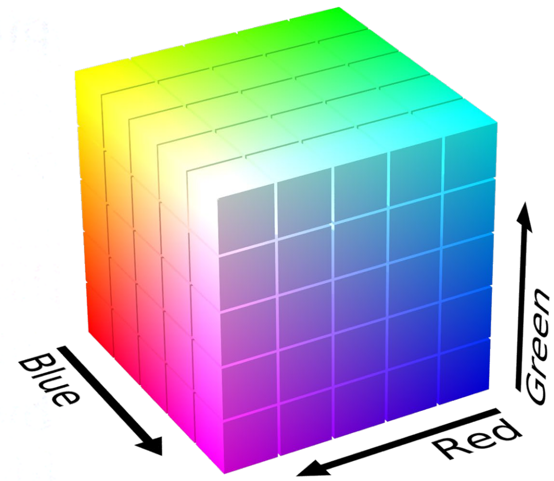

Colors are additive

| 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




H&B

# RGB Spectral Colors

Amounts of RGB primaries needed to display spectral colors

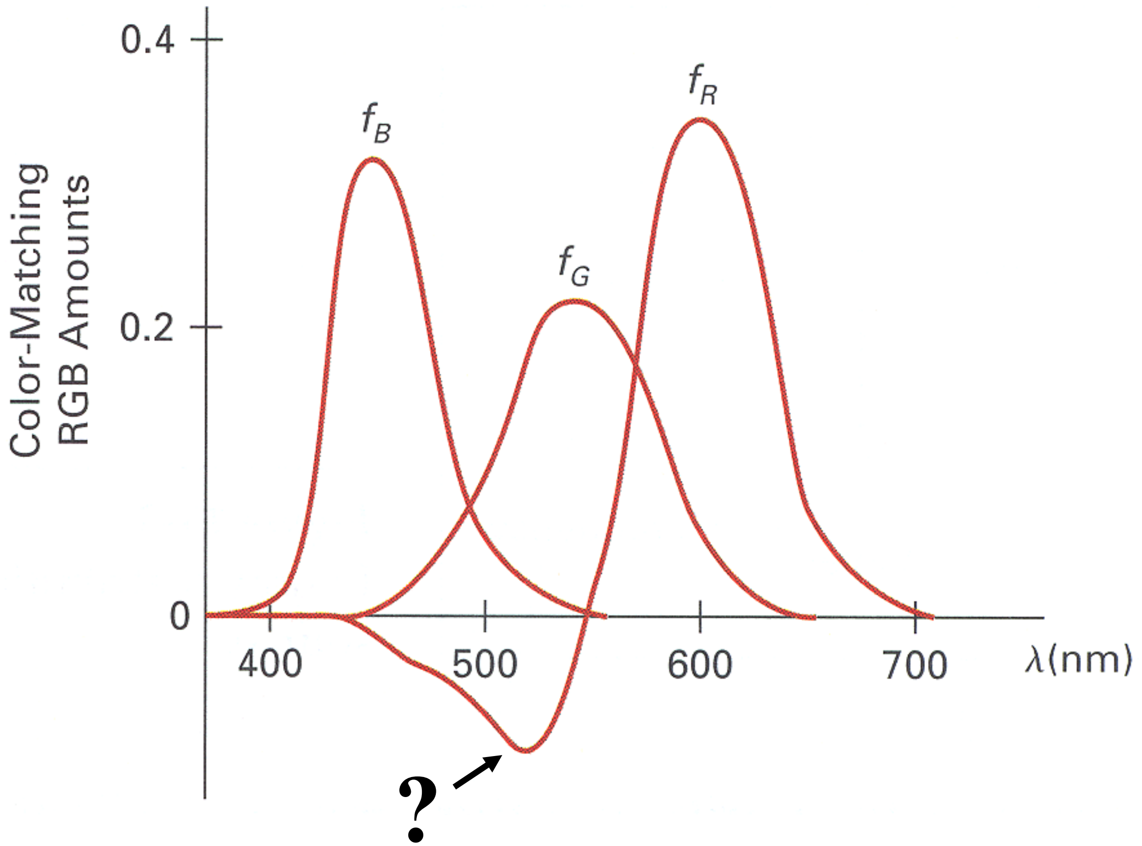



Figure 15.5 from H&B

# XYZ Color Model (CIE)

Linear transform of RGB

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.412452 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

All colors can be composed of non-negative amounts of XYZ

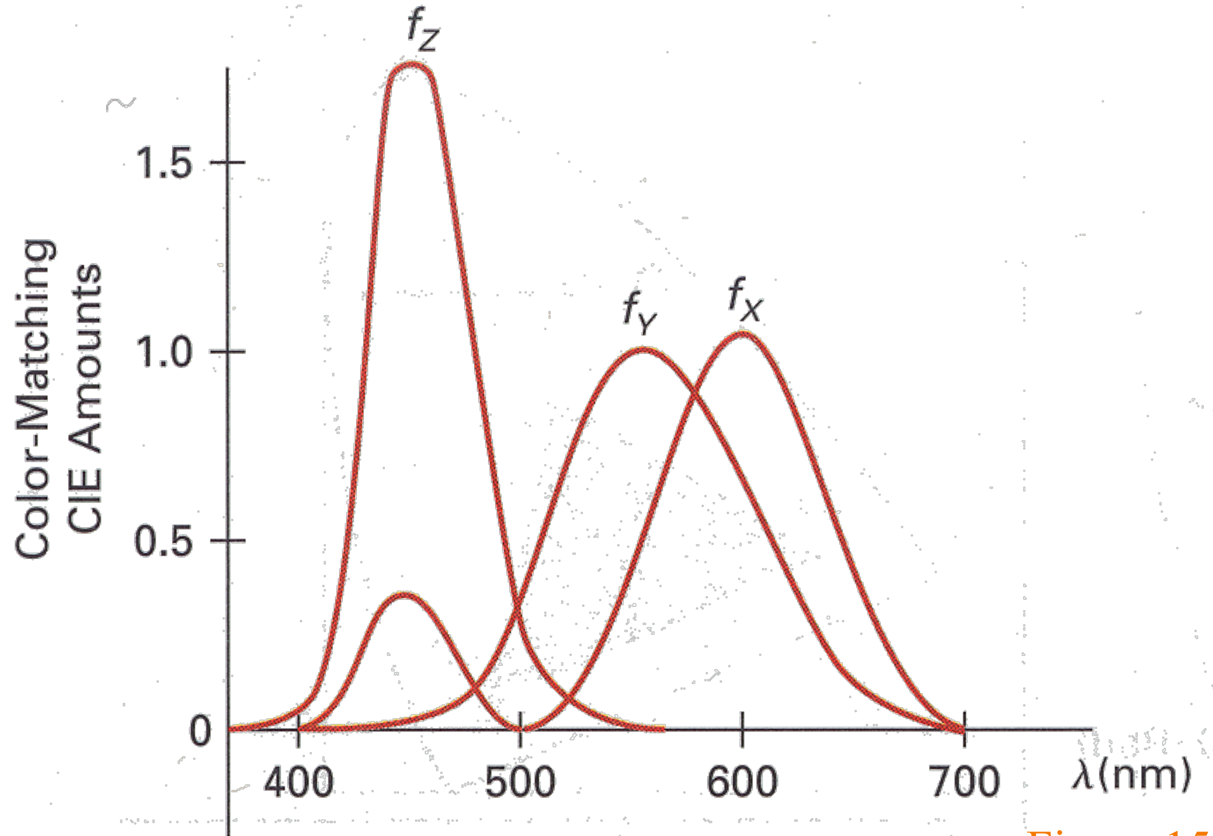
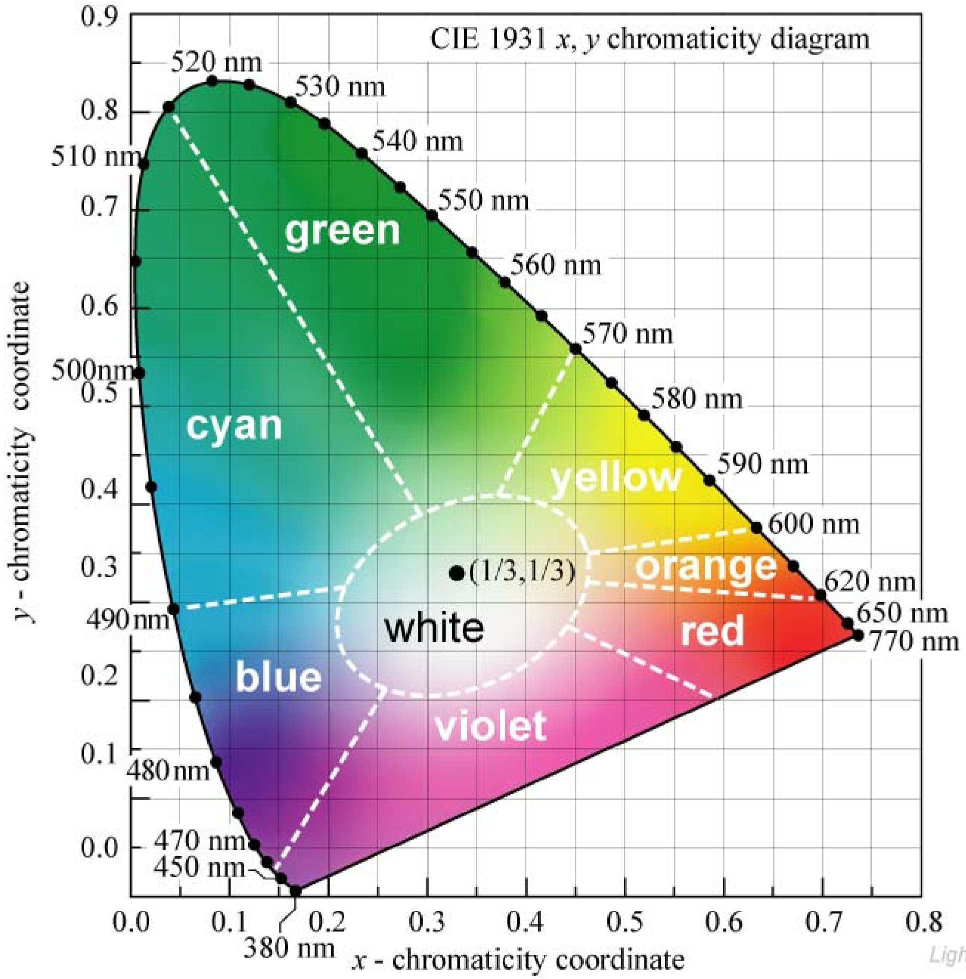



Figure 15.6 from H&B

# CIE Chromaticity Diagram

Normalized amounts of X and Y for colors in visible spectrum



# RGB Color Gamut

Color *gamut* for a typical RGB computer display

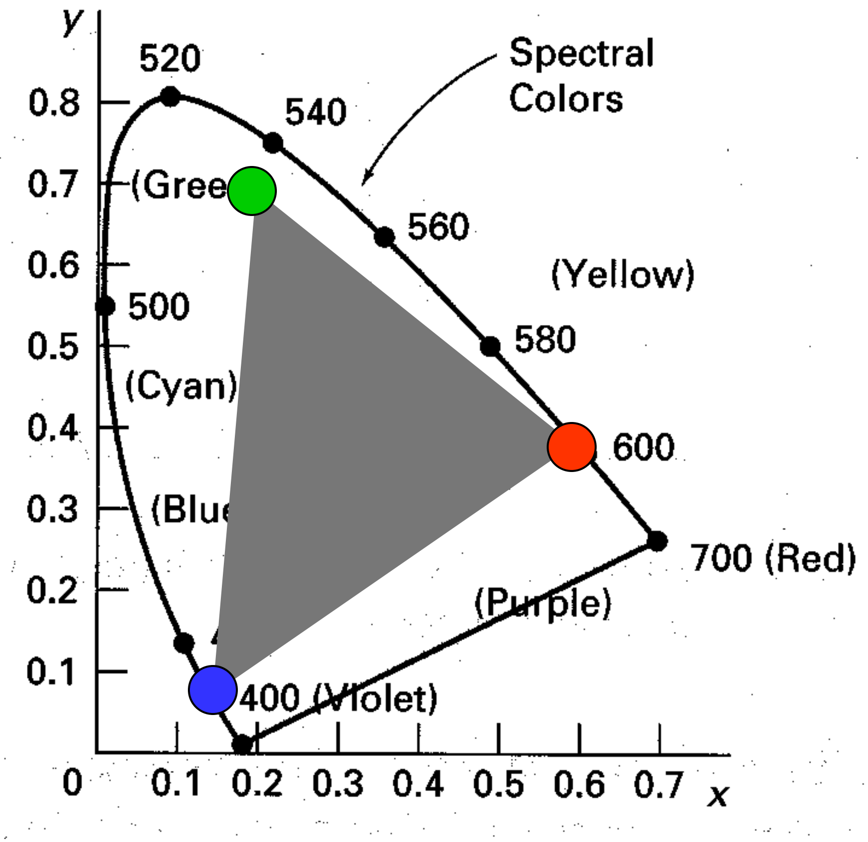



Figure 15.13 from H&B

# Other Color Models

- CMY
- HSV
- CIELAB
- Others

Different color models are useful for different purposes

# CMY Color Model

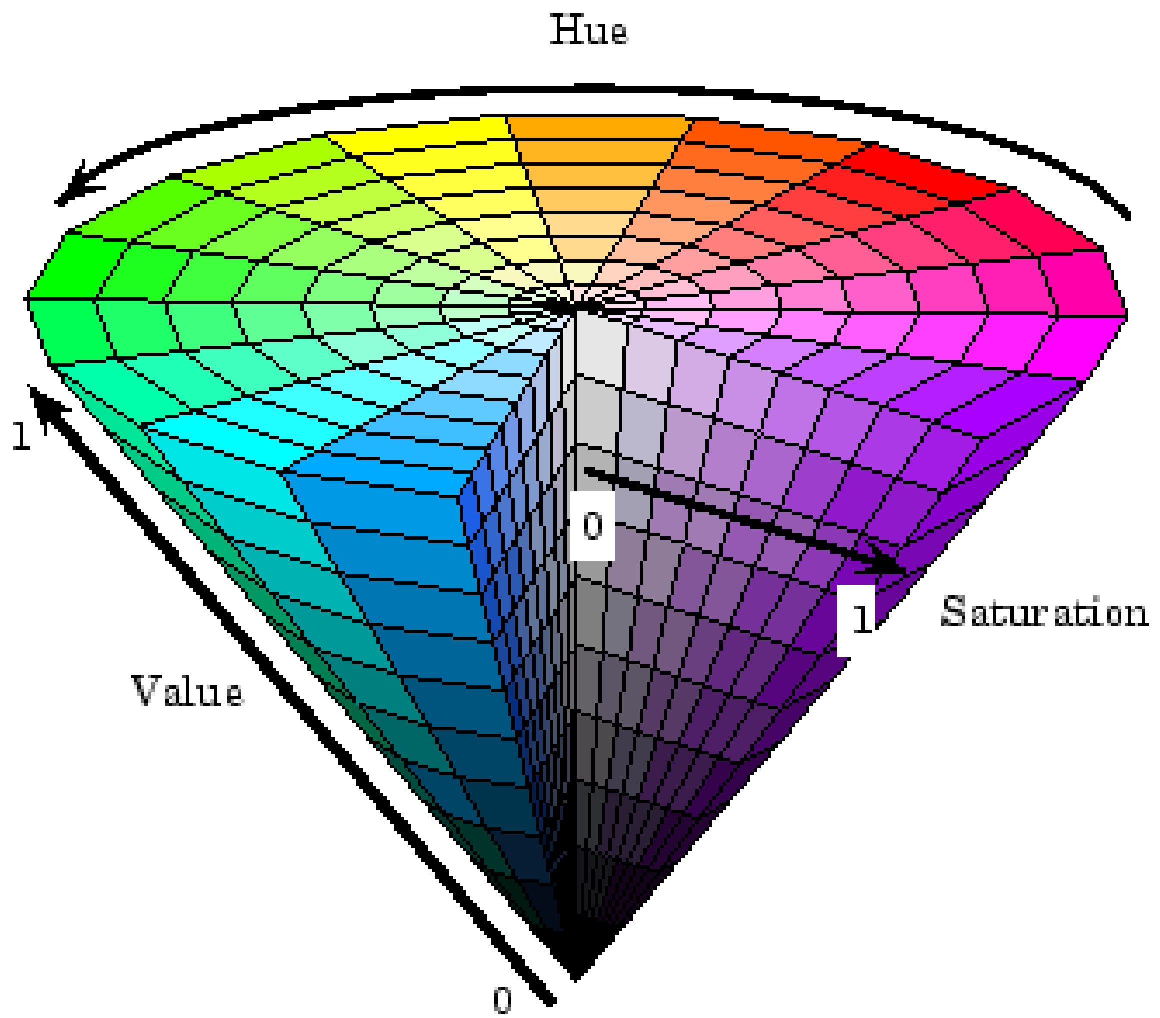

| C | M | Y | Color |
|---|---|---|---|
| 0.0 | 0.0 | 0.0 | White |
| 1.0 | 0.0 | 0.0 | Cyan |
| 0.0 | 1.0 | 0.0 | Magenta |
| 0.0 | 0.0 | 1.0 | Yellow |
| 1.0 | 1.0 | 0.0 | Blue |
| 1.0 | 0.0 | 1.0 | Green |
| 0.0 | 1.0 | 1.0 | Red |
| 1.0 | 1.0 | 1.0 | Black |
| 0.5 | 0.0 | 0.0 | |
| 1.0 | 0.5 | 0.5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

- Useful for printers because colors are subtractive
- Add blac**K** ink – CMYK

Plate II.7 from FvDFH

# HSV Color Model

Intended for ease of color picking

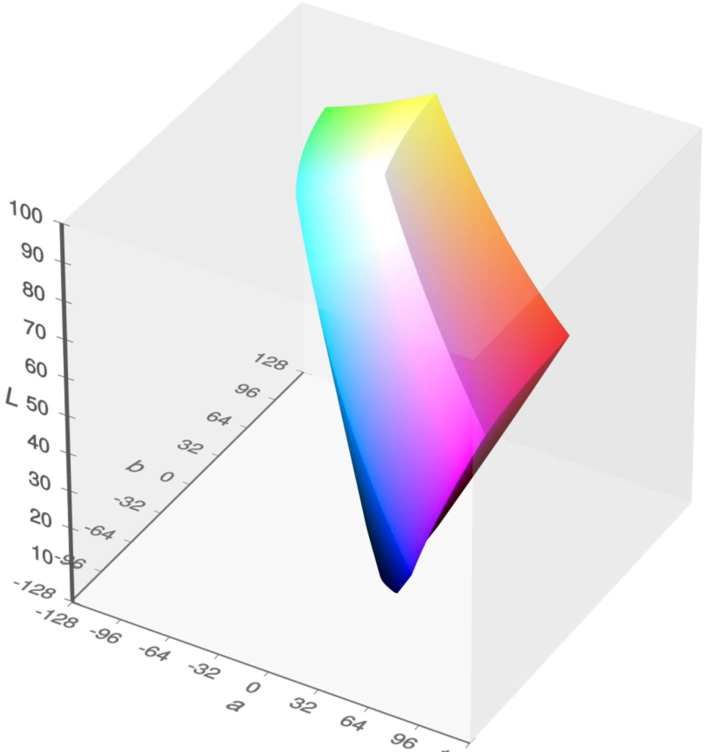


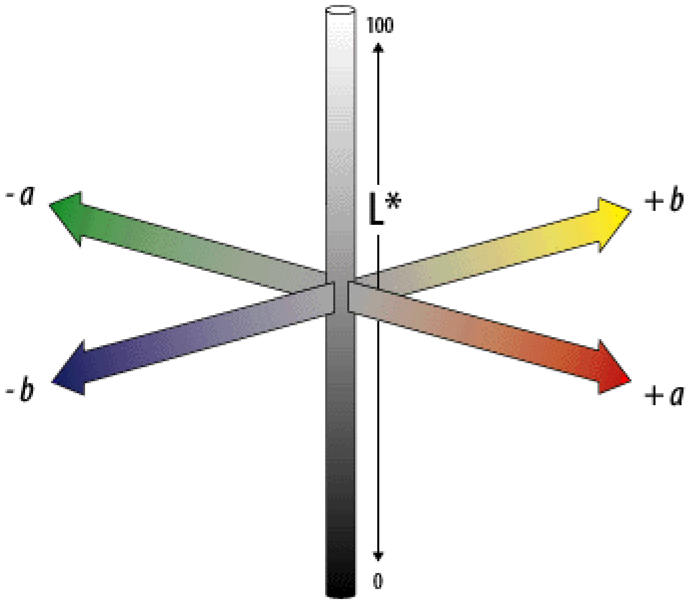
# CIELAB Color Model

Non-linear transform of XYZ based on human perception

$$L^\star = 116 f\left(\frac{Y}{Y_n}\right) - 16$$
$$a^\star = 500\left(f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right)$$
$$b^\star = 200\left(f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right)$$

$$f(t) = \begin{cases} \sqrt[3]{t} & \text{if } t > \delta^3 \\ \frac{t}{3\delta^2} + \frac{4}{29} & \text{otherwise} \end{cases}$$
$$\delta = \frac{6}{29}$$
$$X_n = 95.047,\quad Y_n = 100.000,\quad Z_n = 108.883$$




Useful for measuring *perceptual differences* between colors

# Summary

- Images
  - Pixels are samples
  - Frame buffers
  - Display hardware (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.