Display and Color

Reading

- Foley van Dam. 4.1-3, 13.3-4.
- Hearn Baker (3/E). 2.1-2, 12-2.7

Further reading:

- I.E. Sutherland. Sketchpad: a man-machine graphics communication system. Proceedings of the Spring Joint Computer Conference, p. 329-346, 1963.
- T.H. Myer & I.E. Sutherland. On the design of display processors. Communications of the ACM 11(6): 410-414, 1968.
- Brian Wandell. Foundations of Vision. Chapter 4. Sinauer Associates, Sunderland, MA, 1995.
- Gerald S. Wasserman. Color Vision: An Historical Introduction. John Wiley & Sons, New York, 1978

Lecture outline:

1. Display devices (CRT, LCD, and FED)
2. Frame Buffer (Memory to Display)
3. Color Lookup Table
4. Gamma Correction
5. Color Spaces: RGB, CMY, HSV, YIQ, CIE XYZ
6. Alpha Channel and Double Buffering

DISPLAY DEVICES

(1) CRT-CATHODE RAY TUBE

Mechanism: Shoot electrons with varying energy through vertical & horizontal deflectors to hit spot on screen

Phosphors on screen jump to excited state when hit by electrons, emit **monochromatic** light when they drop to rest state.

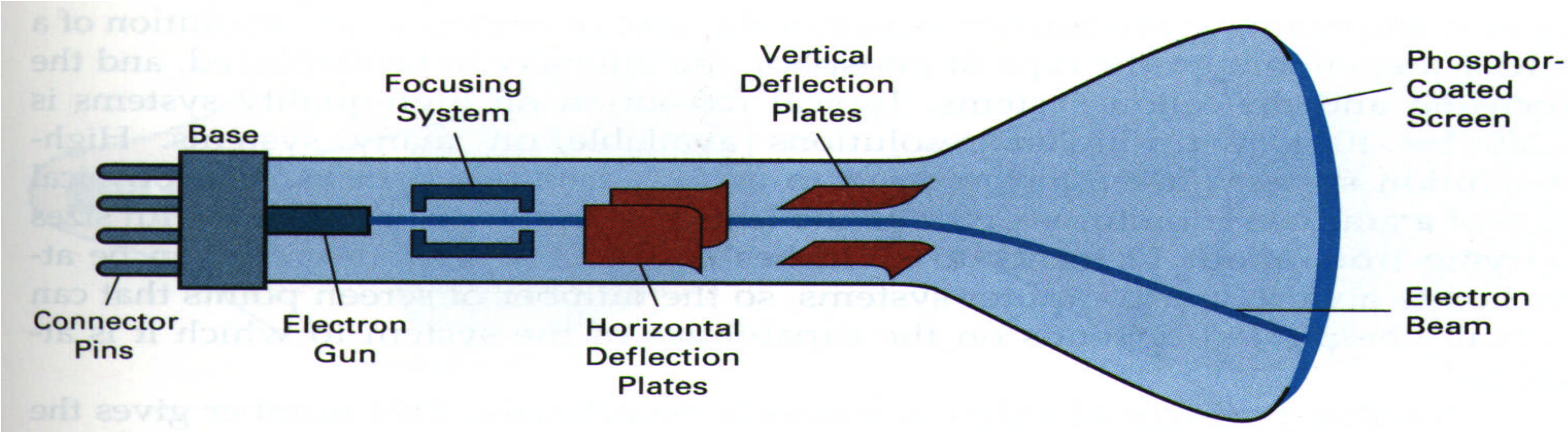
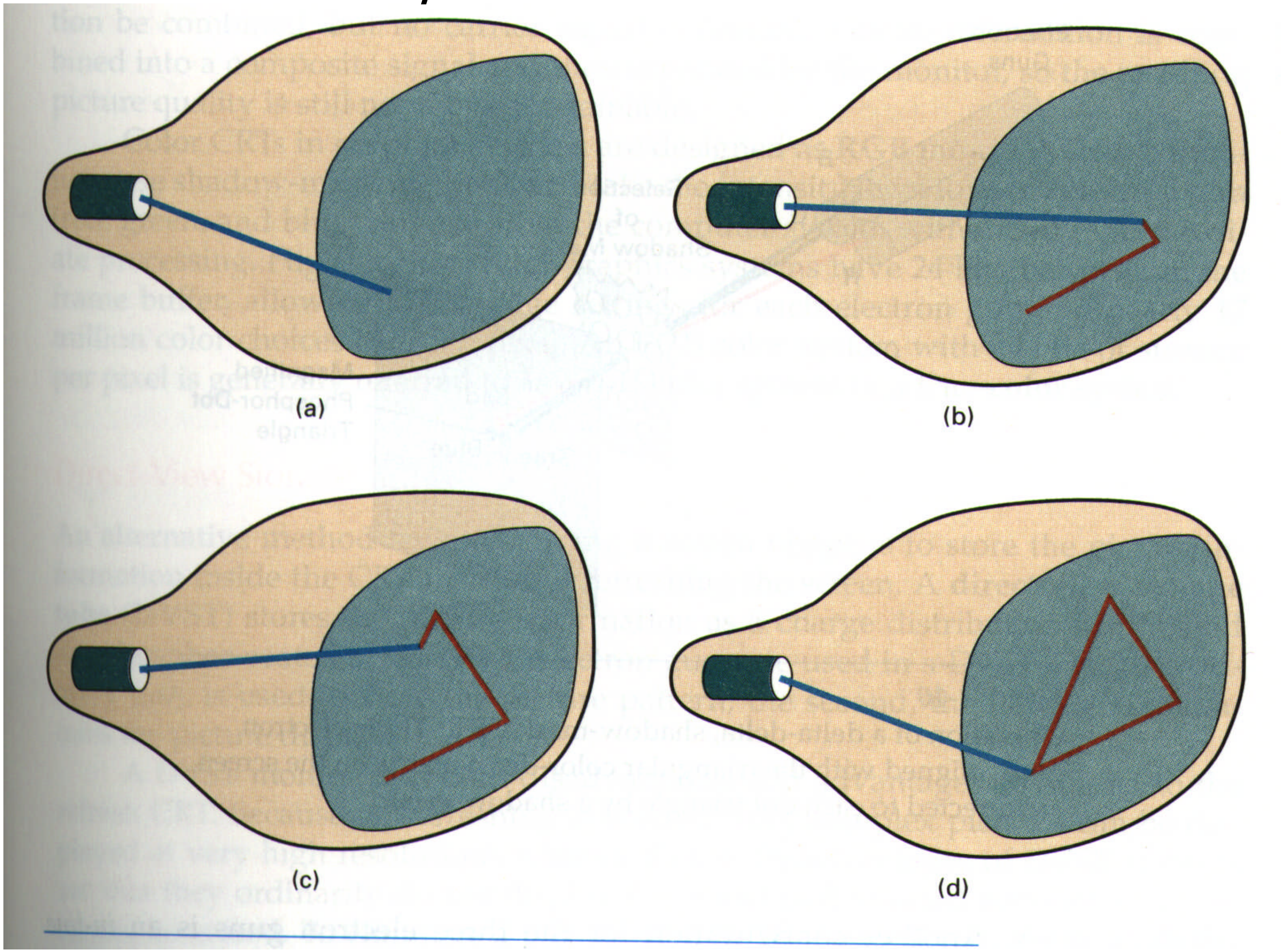
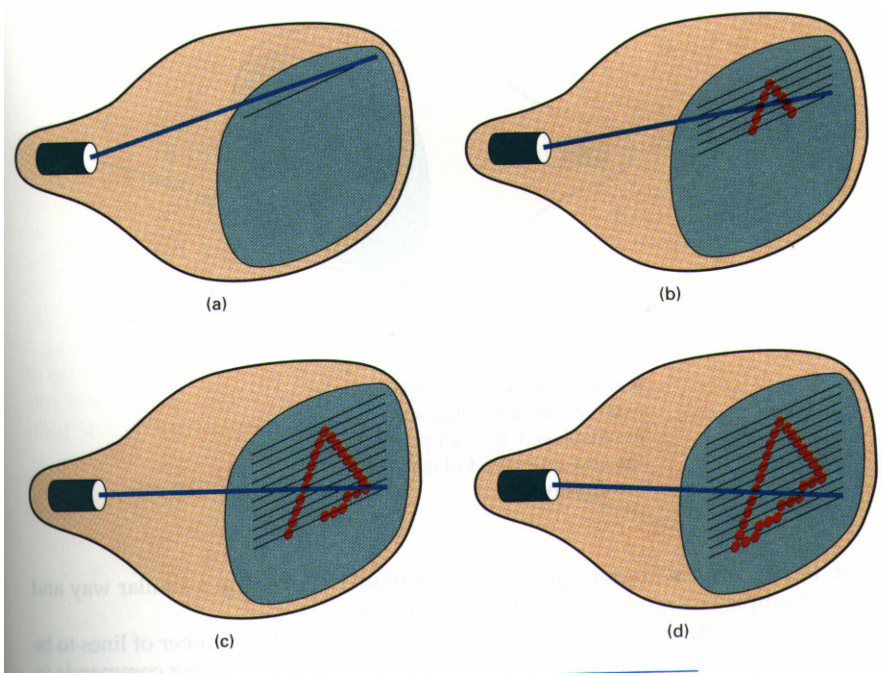


Figure 2-4
Electrostatic deflection of the electron beam in a CRT.

Random Scan / Vector Scan



Raster Scan



- Electron beam traces over screen in **raster scan order**.
  - Each left-to-right trace is called a **scan line.**
  - Each spot on the screen is a **pixel**.
  - When the beam is turned off to sweep back, that is a **retrace**, or a **blanking interval.**

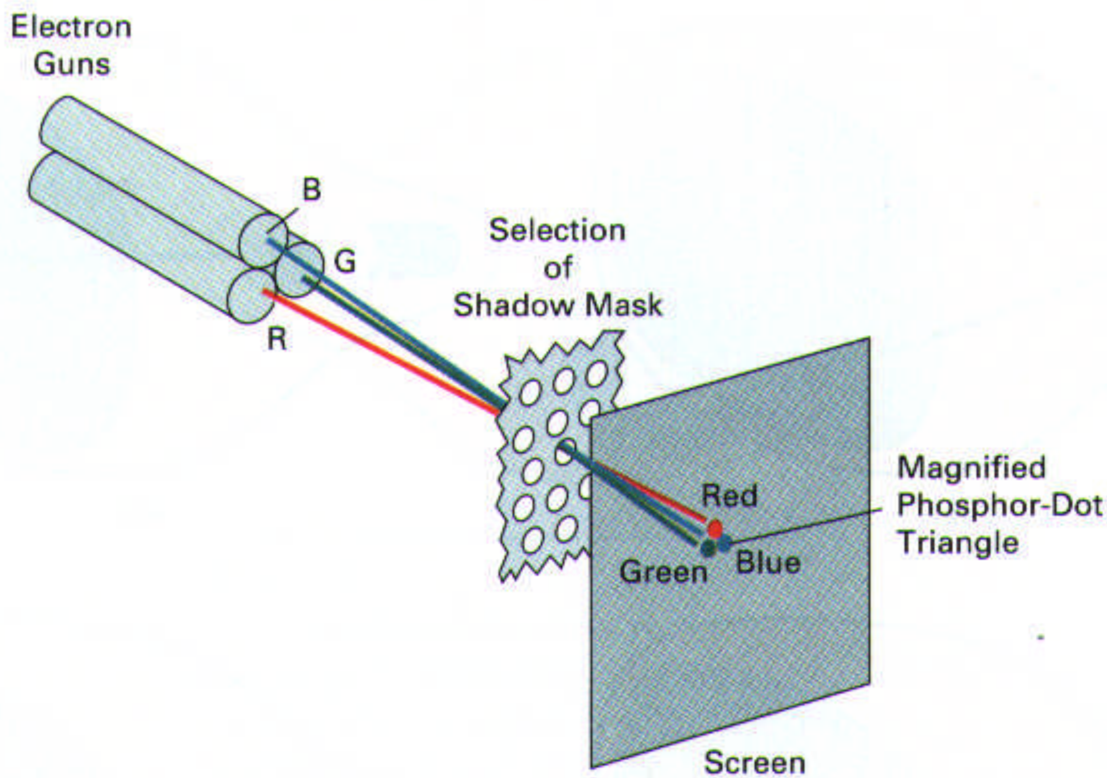
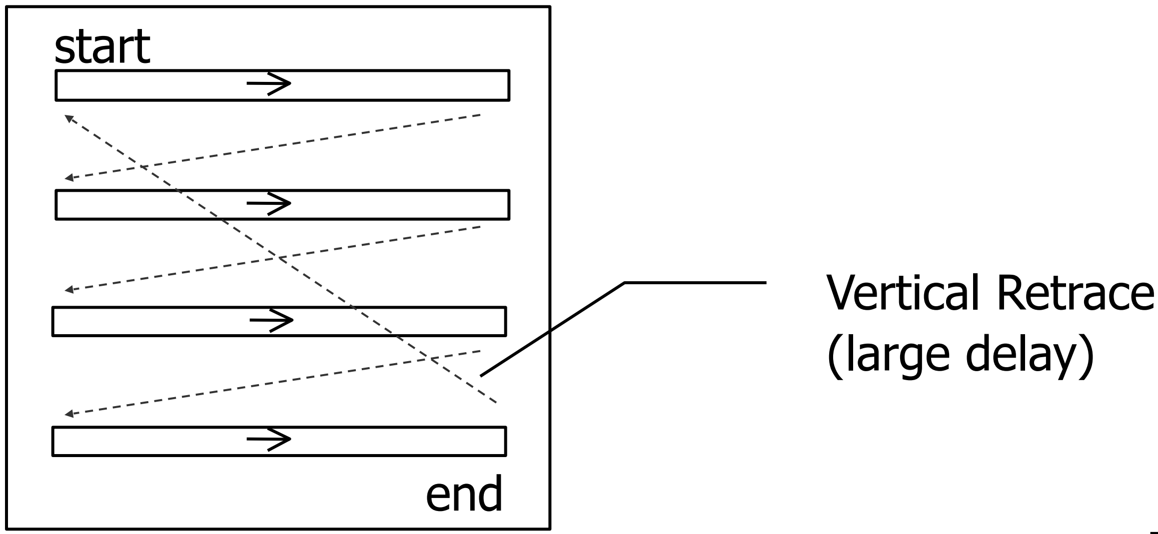


Figure 2-10
Operation of a delta-delta, shadow-mask CRT. Three electron guns, aligned with the triangular color-dot patterns on the screen, are directed to each dot triangle by a shadow mask.

<u>How do you make a picture?</u>

Raster scan: Sweep screen with electron beam.

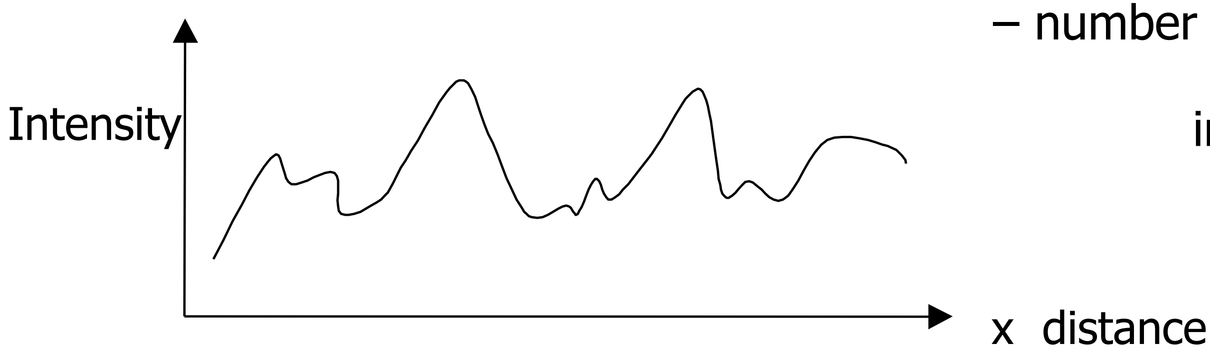


Intensity on <u>one line</u> is like a graph

Refresh rate

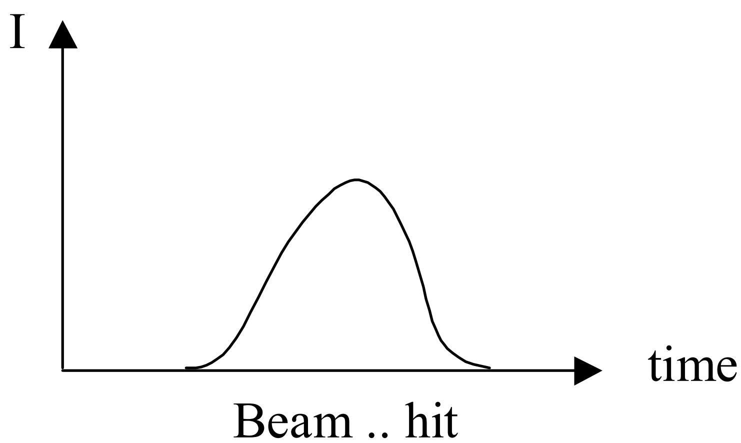
– number of pictures drawable

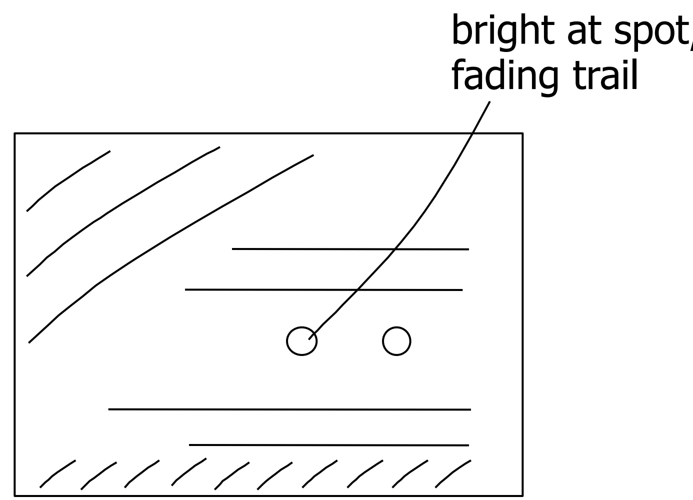
in one second



How do you see a whole image ?

Phosphor light emission decays with time.

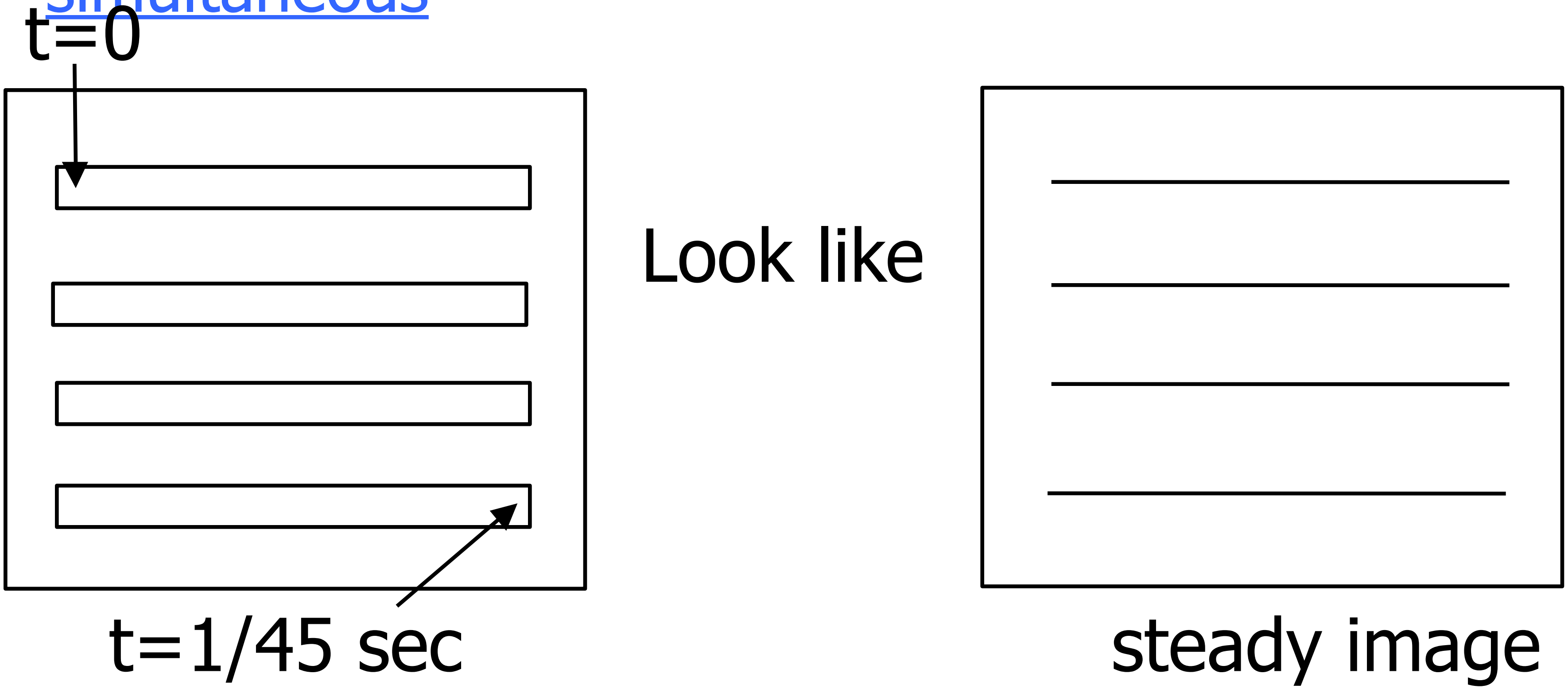




So screen is only **partially lit** at any time

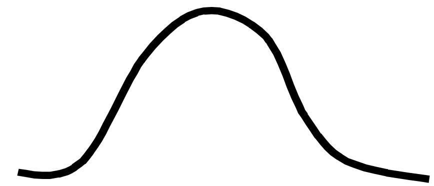
Photo of screen will show **partial** picture

You see whole picture because your eyes see all light flashes within **~ 1/45 sec** of each other as simultaneous



<u>Matching Phosphors & scan rate to human eye</u>

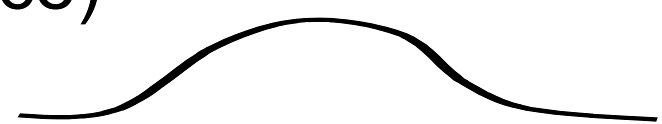
Fast-Decay Phosphor (short persistence)



Slow Refresh 1/30sec flicker in single lines, OK in blurry TV images if interlaced

Fast Refresh ~1/60-1/70 sec No flicker

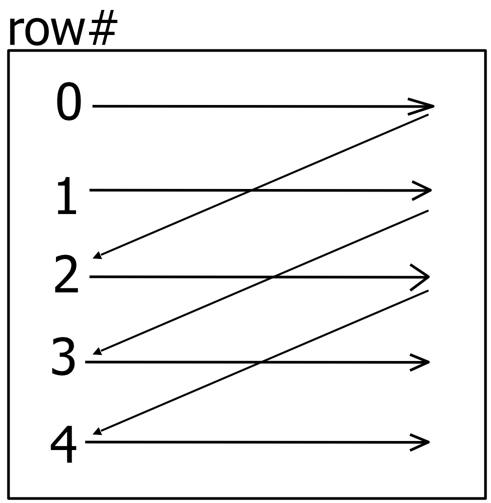
Slow Decay Phosphor (long Persistence)



Problems: - no good long-persistence blue

- need a solution when we need to use short-persistence phosphor (see next slide)

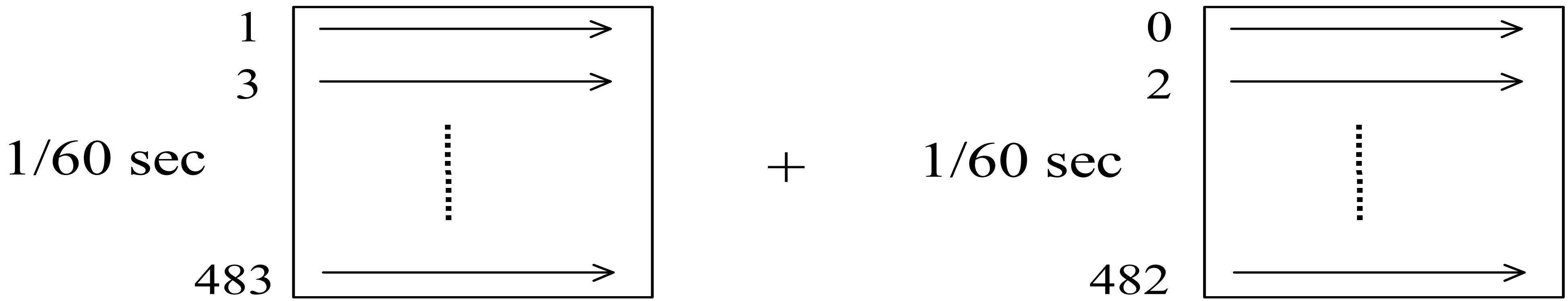
INTERLACING: trick to get less flicker out of fixed signal bandwidth



similar trick in movies:
24 frames/sec doubled to
48 by repeating each frame!

Reference: www.taudio.com/tripod_pages/tech_DTV.html

RS170 Video - 30Hz interlaced



Video Terminology Summary

1. Refresh Rate : 30Hz, 60Hz = # times full image is redrawn each second

2. Interlaced, Non-Interlaced :

   Image drawn twice (even lines then odd lines) in one, refresh time OR, Image drawn once in one refresh time

3. Persistence :

   Short phosphor : disappears quickly allows quick moving images

   Long phosphor : disappears slowly prevents flicker on 30 Hz refresh systems

(2) LCD (Liquid Crystal Display)

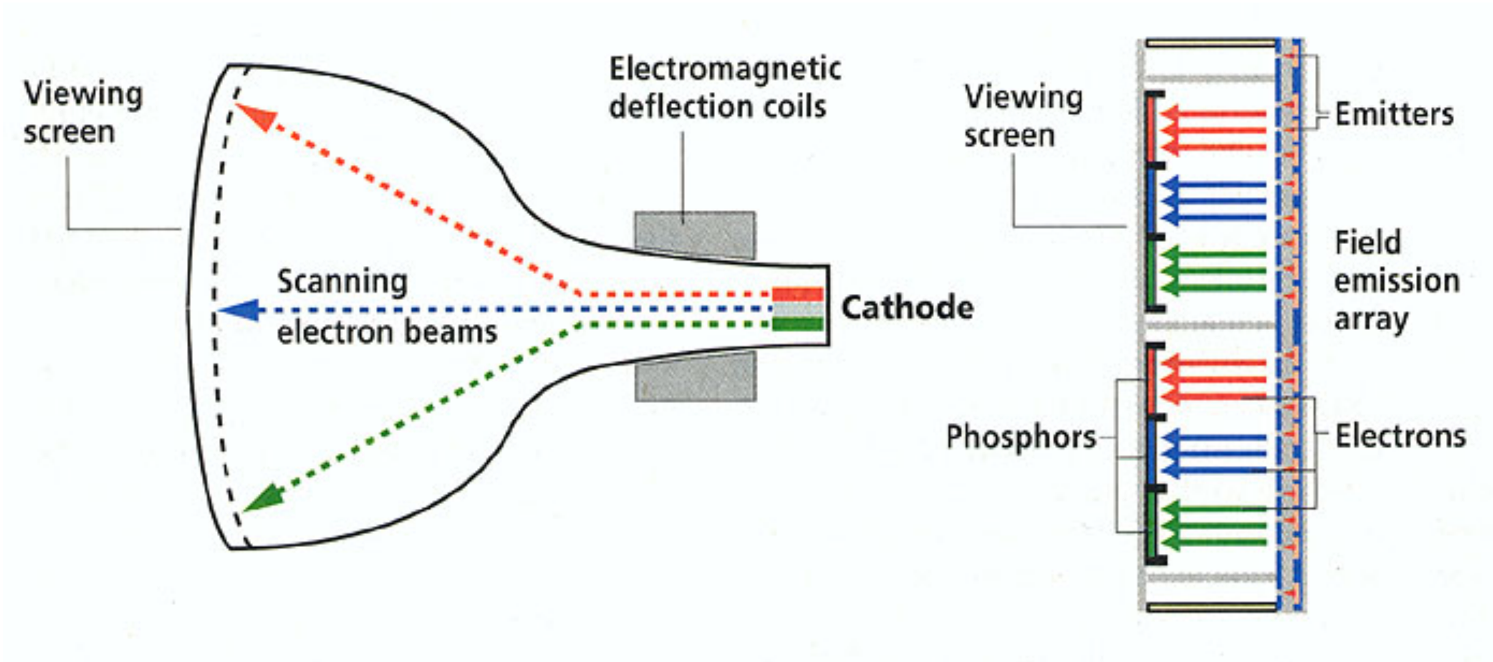
- Thinner than CRT
- Consumes less power
- Concept: It blocks light rather than emits light
- Passive matrix
  - Grid of conductors
  - Pixels located at the intersection of the grid
  - Light is controlled by sending current
- Active matrix (TFT, thin film transistor)
  - One transistor at one pixel location
  - Require less current
  - Faster refresh time
- Viewing angle is much smaller than CRT

(3) FED (Field Emission Display)

- A better technology
- Flat display
- Same viewing angle as CRT
- As bright as CRT
- Actually it is a flat CRT

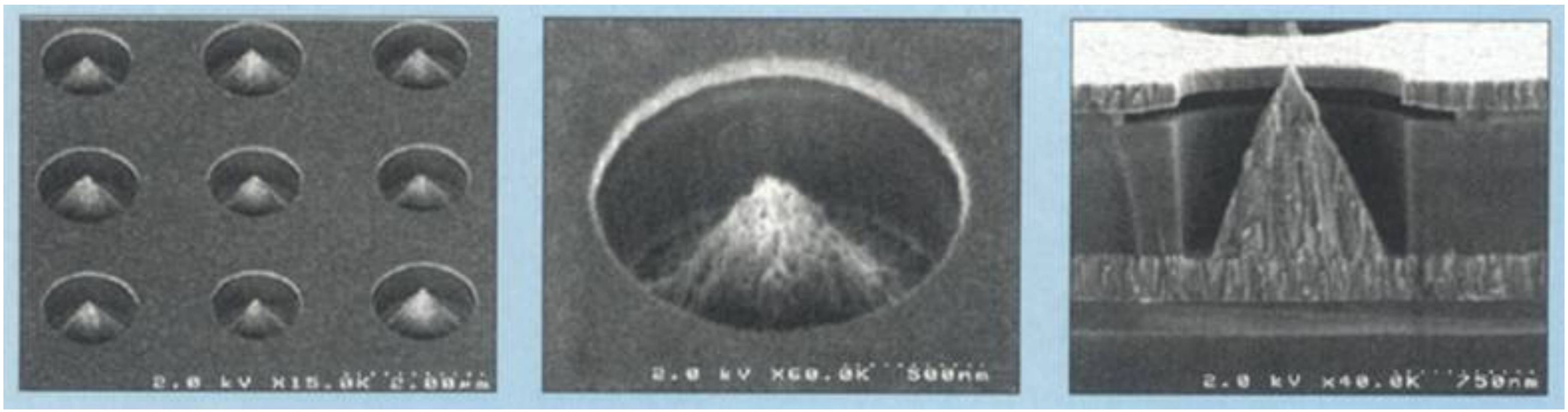
FED (Field Emission Display)

- Instead of one electron gun as in the case of CRT
- there are thousands of micro-electron guns
- Phosphors are used to give same brightness and viewing angle



FED (Field Emission Display)

- Electrons tend to be emitted at <u>sharp points</u>

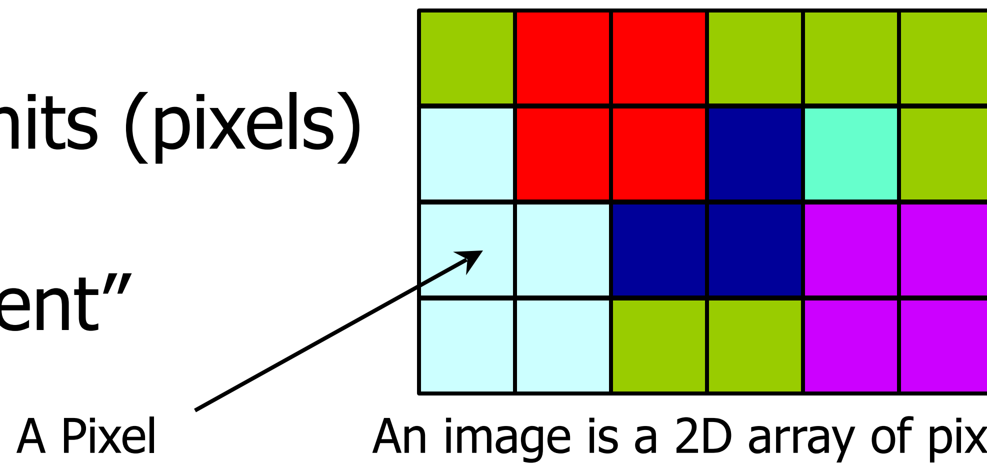


Frame Buffer

Graphical Storage (Memory) & Transformation hardware for digital images

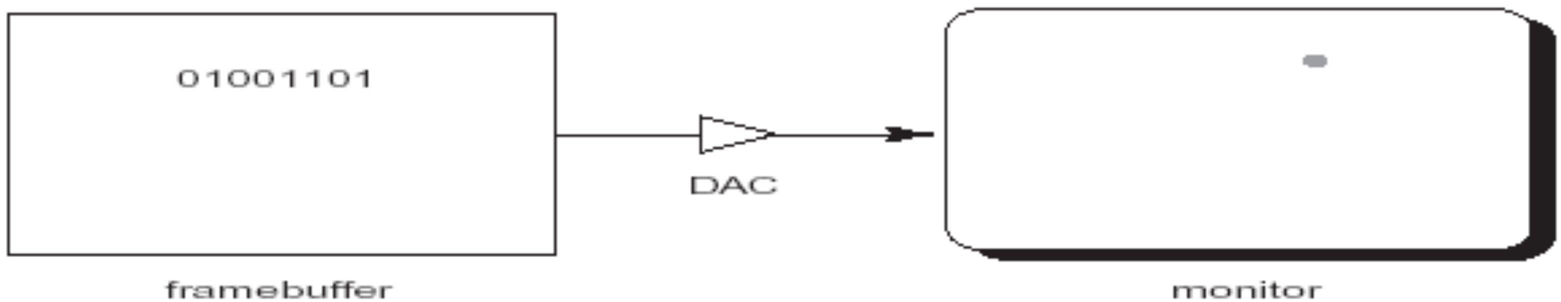
Computer images are digital

Quantize space into units (pixels) stored as numbers in pixels = “picture element”



An image is a 2D array of pixels

(1) Greyscale/Monochrome Frame Buffer



- Intensity of the raster scan beam is modulated according to the contents of a **frame buffer**.
- Each element of the frame buffer is associated with a single **pixel** on the screen.

Resolution

- The display's **resolution** (or frame buffer size) is determined by:
  - number of scan lines
  - number of pixels per scan line
  - number of bits per pixel (lowercase b is **bit**)
- Examples:

– Bitmapped display	960 x 1152 x 1b	1/8 MB
– NTSC TV	640 x 480 x 16b	1/2 MB
– Color workstation	1280 x 1024 x 24b	4 MB
– Laser-printed page		
• 300 dpi	8.5 x 11 x 3002 x 1b	1 MB
• 1200 dpi	8.5 x 11 x 12002 x 1b	17 MB
– Film	4500 x 3000 x 30b	50 MB

Examples:

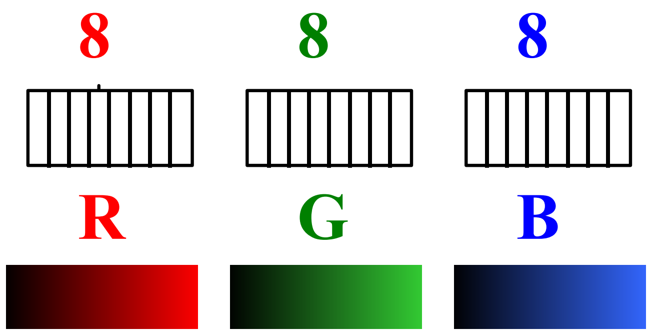
1 bit : B or W (binary image)

8 bit : 0-255 gray intensities (greyscale image)

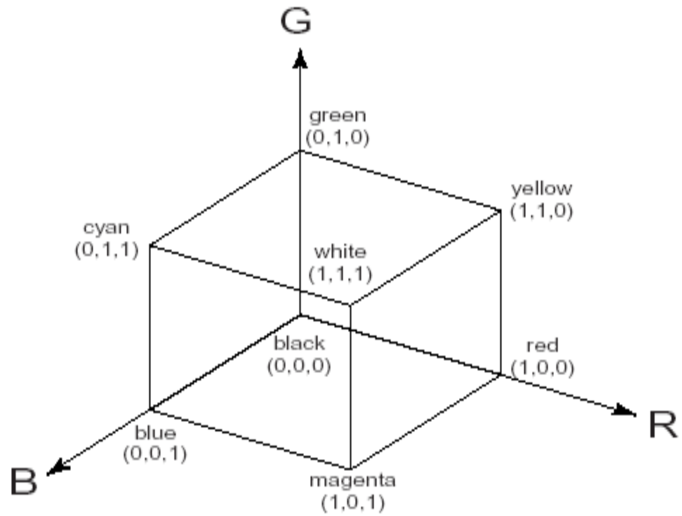
0-black 255

gray

True Color : 8 bit per RGB

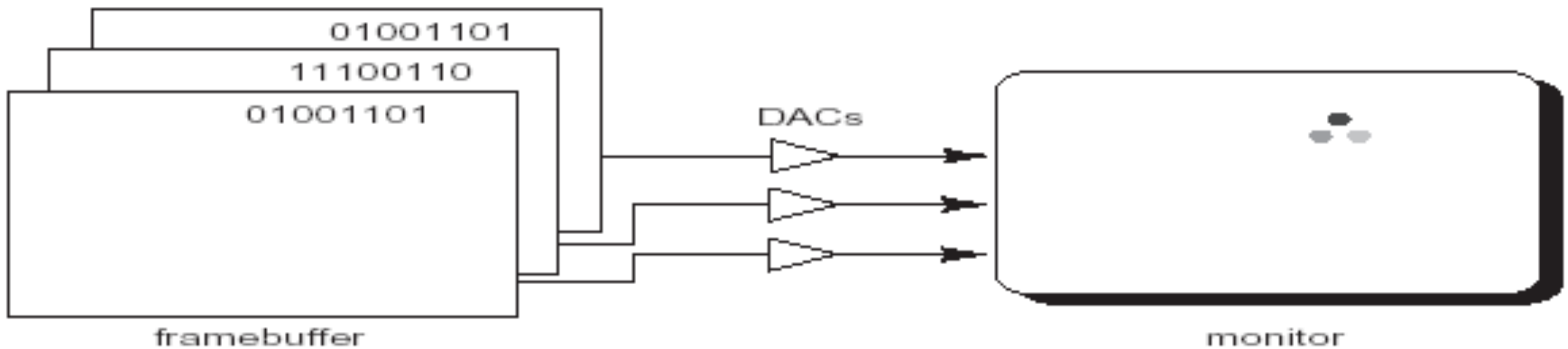


Additive Color Mixing



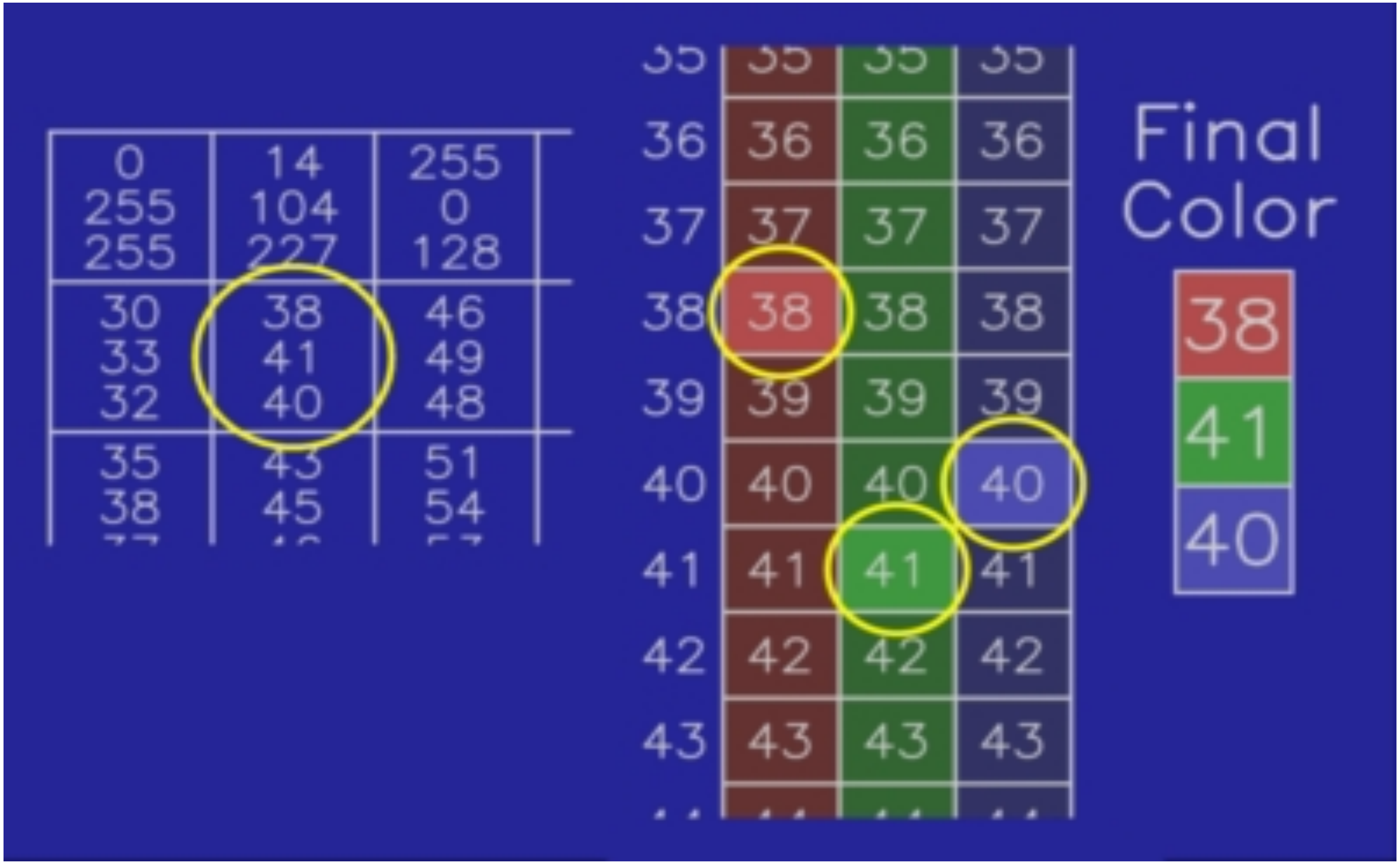
- All colors on a monitor are produced using combinations of red, green, and blue.
- A monitor that allows 256 voltage settings for each of R, G, and B is known as a **full-color system**.
- The description of each color in frame buffer memory is known as a **channel**.

(2) RGB Framebuffer

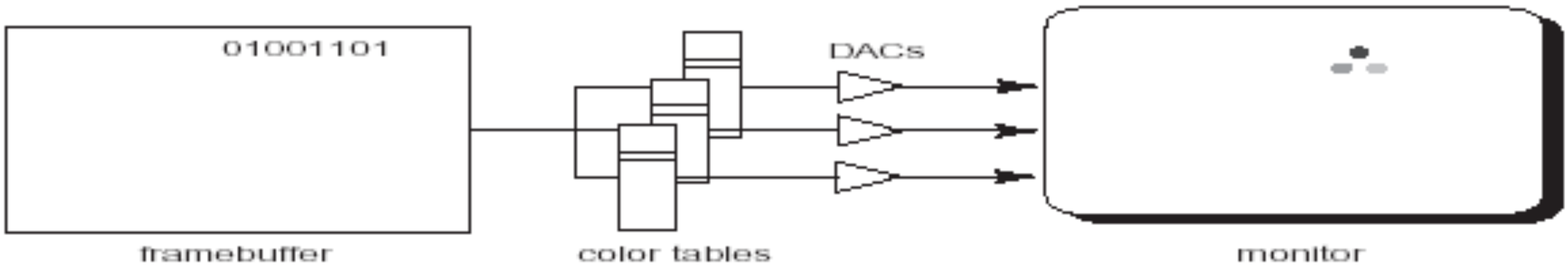


- The term **true-color** is sometimes used to refer to systems which the frame buffer directly stores the values of each channel.

RGB values in Frame Buffer

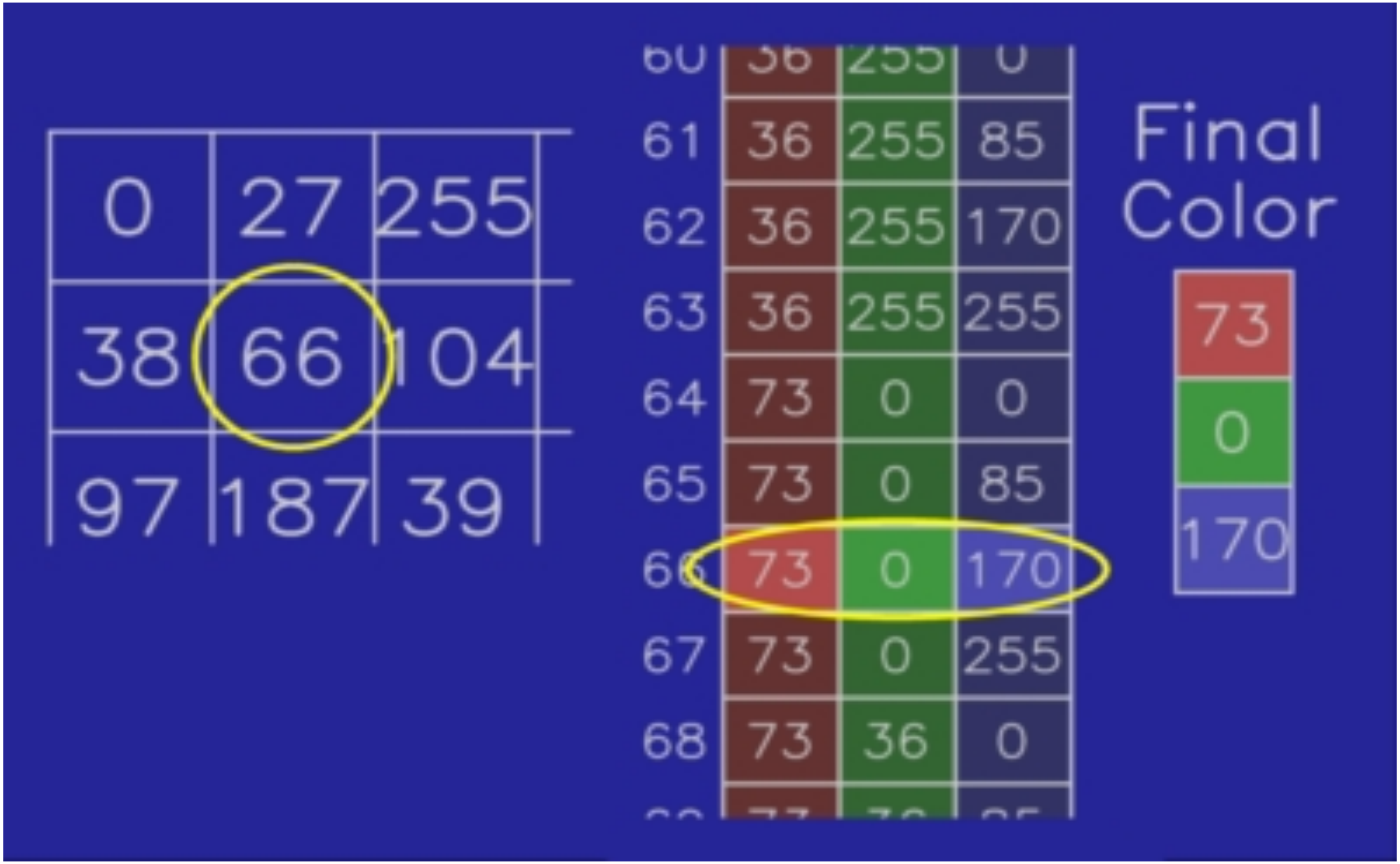


(3) Color Tables (Indices in Frame buffer)



- **Color tables** allow more color versatility when you only have a few bits per pixel. You get to select a small **palette** from a large number of available colors.
- Each frame buffer element is now an index into the color table, where the actual values of each channel are stored.
  - Color table entries can be changed in software.
- Back to the old days when memory is limited (see color index mode in OGL: glIndexi and glutSetColor)

8-bit Indices in Color Table

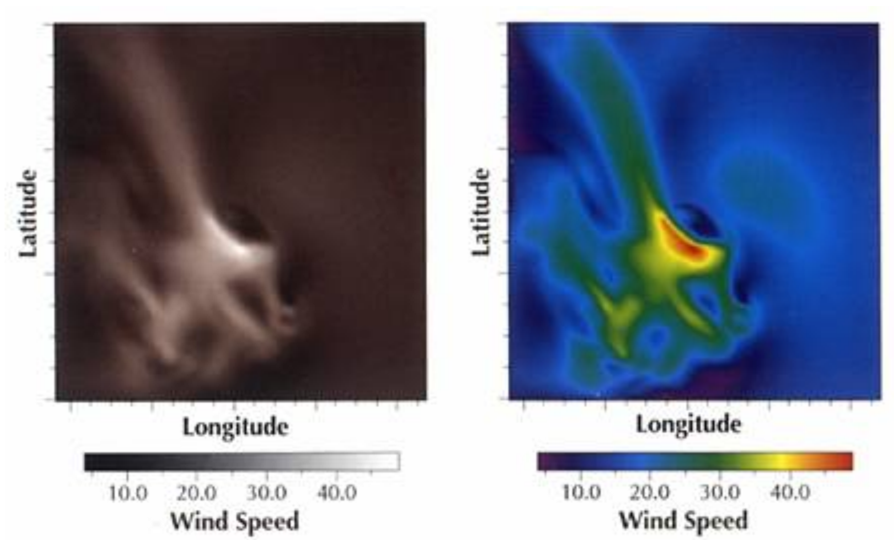


Uses of Look Up Tables (LUT)

1. <u>Pseudo Color:</u>

   Assign computed values systematically to a gray or color spectrum to emphasize important differences

   Examples:
   1. Bone in X-ray negative has pixel value > 100, change from gray to blue above 100.
   2. Coloring wind speed



Note: Pseudo color can be implemented without color LUT

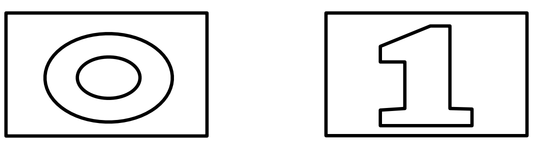
Uses of Look Up Tables (LUT)

2. <u>Special Effects:</u>

Alter visibility without changing frame buffer (no need to render the scene again).
Alter shape of color spectrum in real time to alter pseudocolors emphasis

Example: Cross fade (old DOS games)

(in frame buffer)

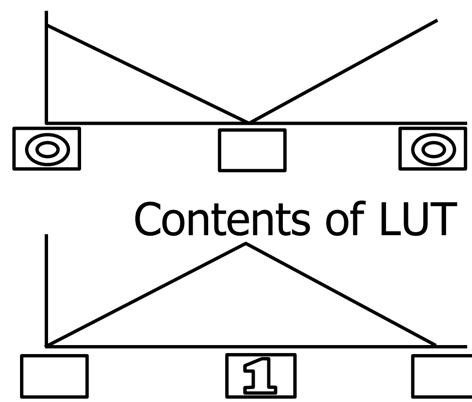


Bitplane 0   Bitplane 1

LUT

01	…
10	…
11	…

Contents of LUT address 0



time

Contents of LUT address 1

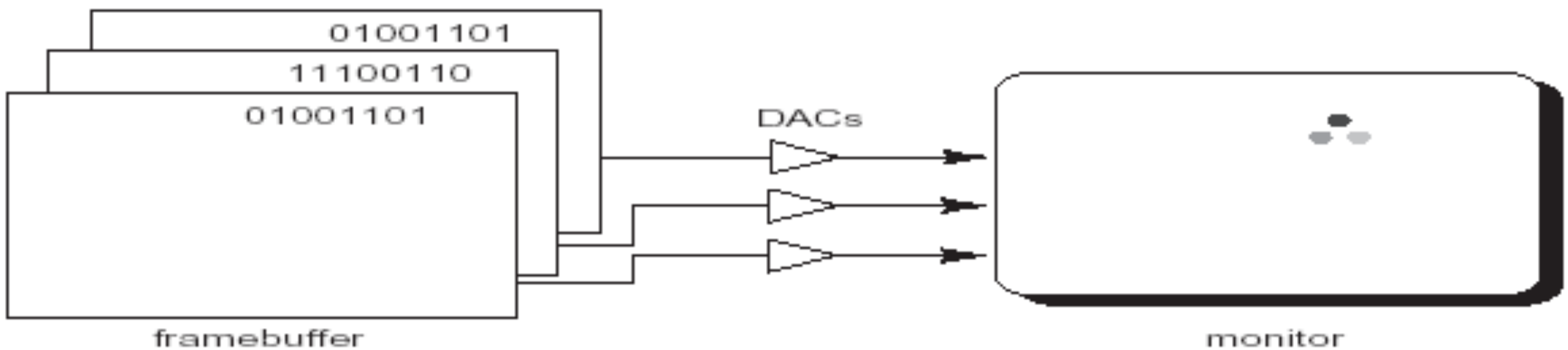
time

* No need to redraw the scene

Gamma(γ) Correction

DAC's convert memory value to voltage LINEARLY

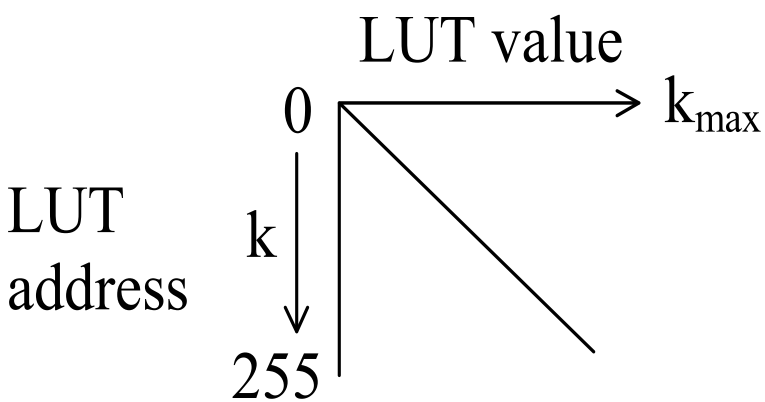
CRT's convert voltage to intensity NON-LINEARLY

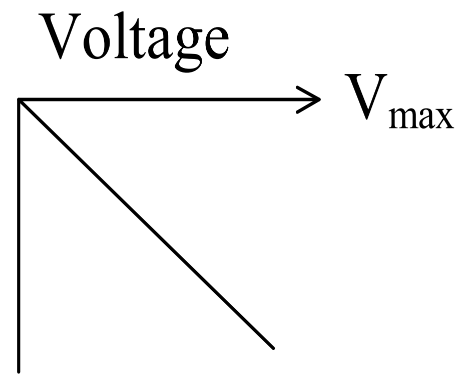


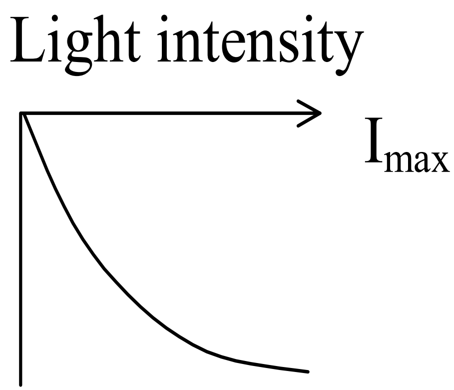
Goal: Mapping value to intensity linearly

CRTs convert intensity to voltage NON-LINEARLY

Exception: Mac monitor







Phosphor responds nonlinearly to voltage

Issue #1: Selecting Intensity (About Human Perception)

- Let intensity levels be distributed between 0 and 1.
- Observation:
  The **perceived** difference between 0.1 to 0.2 is not equal to the difference between 0.2 to 0.3
- Our eyes response non-linearly to intensity.
- To display n+1 successive intensity levels with equal perceived brightness, the intensity levels of the monitor should be spaced so that the ratio of successive intensities is constant. (relative light intensities are perceived by human on a logarithmic scale)

$$\frac{I_1}{I_0} = \frac{I_2}{I_1} = \frac{I_3}{I_2} = \boxed{?} = \frac{I_{255}}{I_{254}} = r > 1.0 \quad \text{Note: r is the ratio}$$

- I_0 = smallest intensity > 0 , depends on CRT
  I_{255} = intensity 1

Selecting Intensity

- Multiply everything,

$$r = \left(\frac{1}{I_0}\right)^{1/n}$$

$I_{255} = 1$ and $n = 255$

- For a level j

$$I_j = r^j I_0 = \left(\frac{1}{I_0}\right)^{\frac{j}{n}} I_0 = I_0^{\frac{n-j}{n}}$$

For n+1 intensity levels

For example, if $I_o = 1/8$ for a system with $n = 3$, we have $r = 2$, and the 4 (i.e., n+1) intensity values are 1/8, 1/4, 1/2, 1.

Issue #2: Gamma Correction (About Phosphor)

- After we have the intensity levels……
- Another problem:
  Value 0.5 $\rightarrow$ Voltage $0.5V_{max}$ $\nrightarrow$ Half gray
- Gamma correction corrects this part of non-linearity.
- In fact,

$$I = kV^{\gamma} \quad \text{or} \quad V = \left(\frac{I}{k}\right)^{1/\gamma}$$

- k and γ depends on the CRT properties
- Usually gamma γ within 2.2 - 2.5

Question

- Given a value I, what is the desired V (voltage)?
- Step 1: Find which level (index to the LUT), i.e. find j,

$$j = ROUND(\log_r \left(\frac{I}{I_0} \right))$$

- Step 2: Find I_j by $I_j = r^j I_0$
- Step 3: Find V by $V = \left(\frac{I_j}{k} \right)^{1/\gamma}$

A Good Practice

- Adjust your monitor (gamma/brightness/contrast) until you can <u>distinguish full range of grays</u>

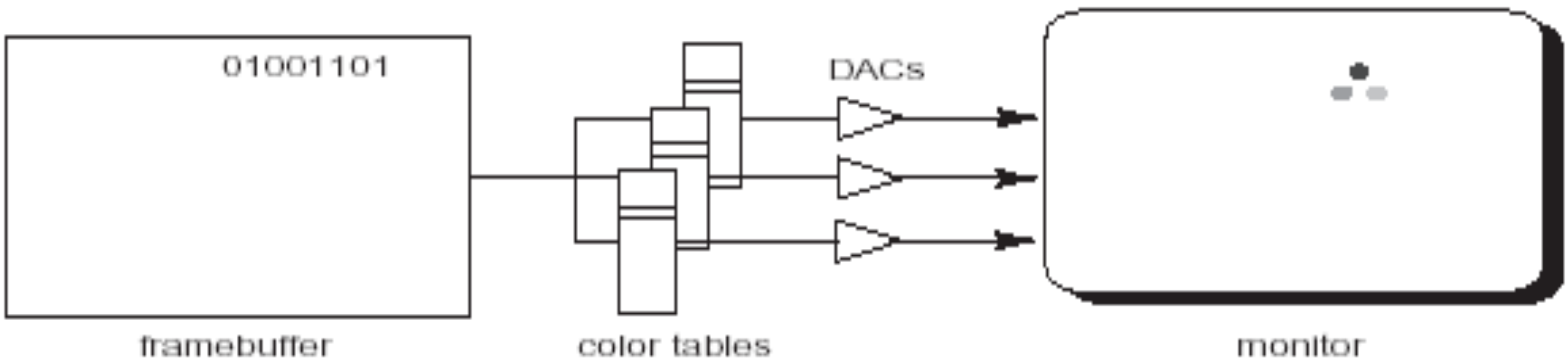
From the book

[Digital Lighting

and Rendering]

Now you should know…

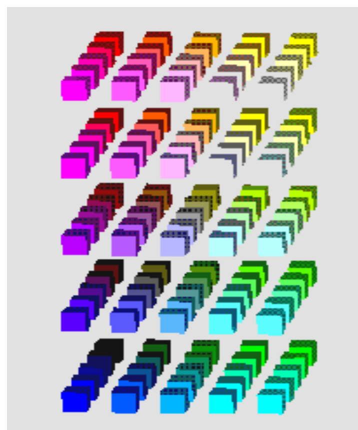
It’s all about this picture:

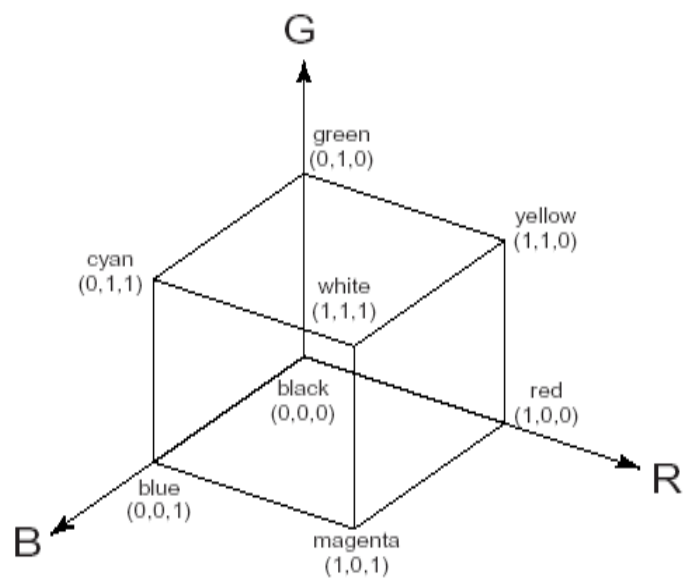


What’s next? Color…

Color space: RGB

- Perhaps the most familiar color space, and the most convenient for display on a CRT.
- **Additive** color space

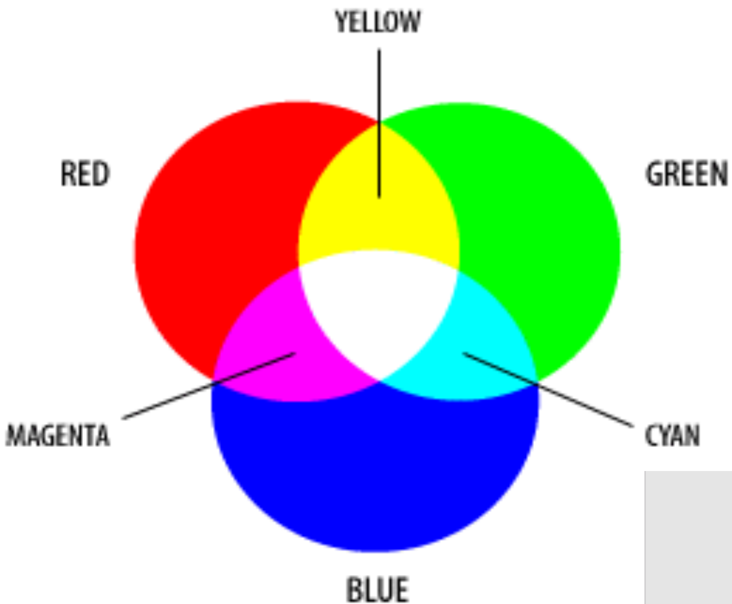


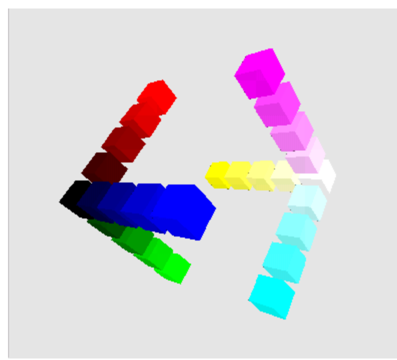


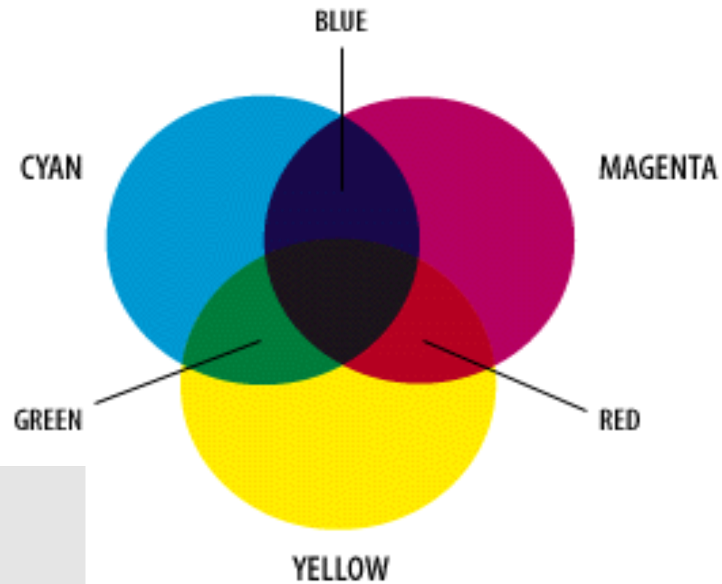
Color space: CMY

- A **subtractive** color space used for printing.
- Involves three subtractive primaries:
  - **Cyan - subtracts red**
  - **Magenta - subtracts green**
  - **Yellow - subtracts blue**
- Mixing two pigments subtracts their opposites from white.
- CMYK adds black ink rather than using equal amounts of all three (more economic).

RGB vs. CMY

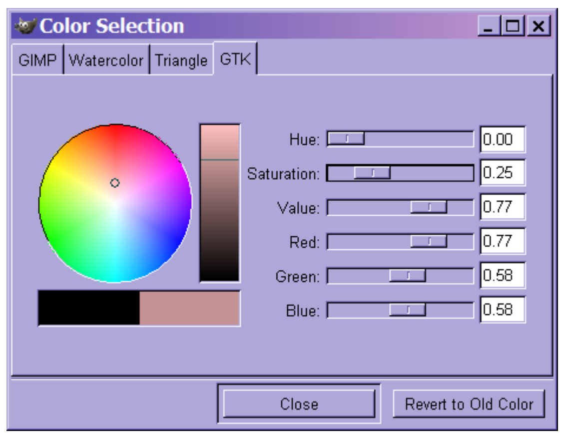

YELLOW
RED
GREEN
MAGENTA
CYAN
BLUE



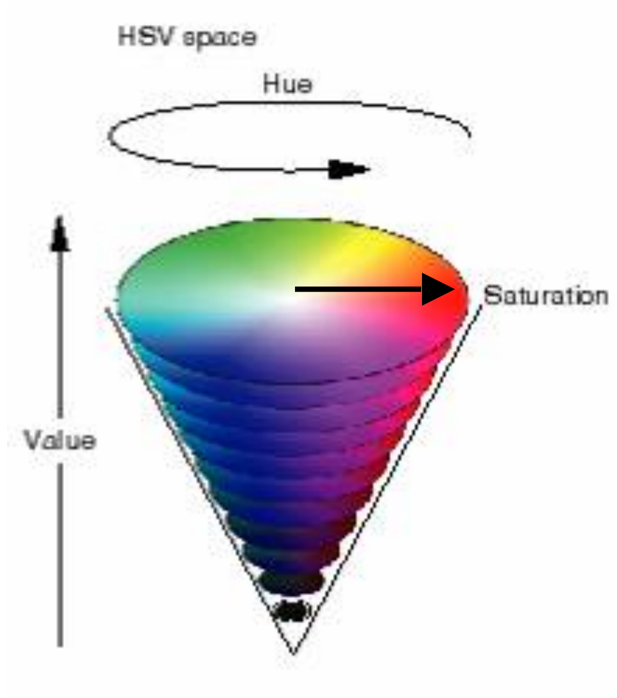

BLUE
CYAN
MAGENTA
GREEN
RED
YELLOW

Color space: HSV

- More natural for user interaction, corresponds to the **artistic concepts** of tint, shade and tone.
- The HSV space looks like a cone:
  - H ~ circular (color)
  - S ~ distance from axis
  - V ~ brightness



[from GIMP]



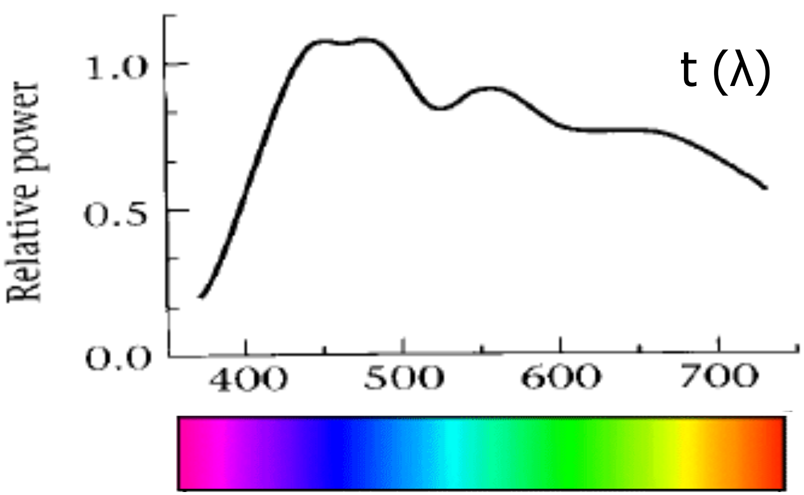
Color space: YIQ

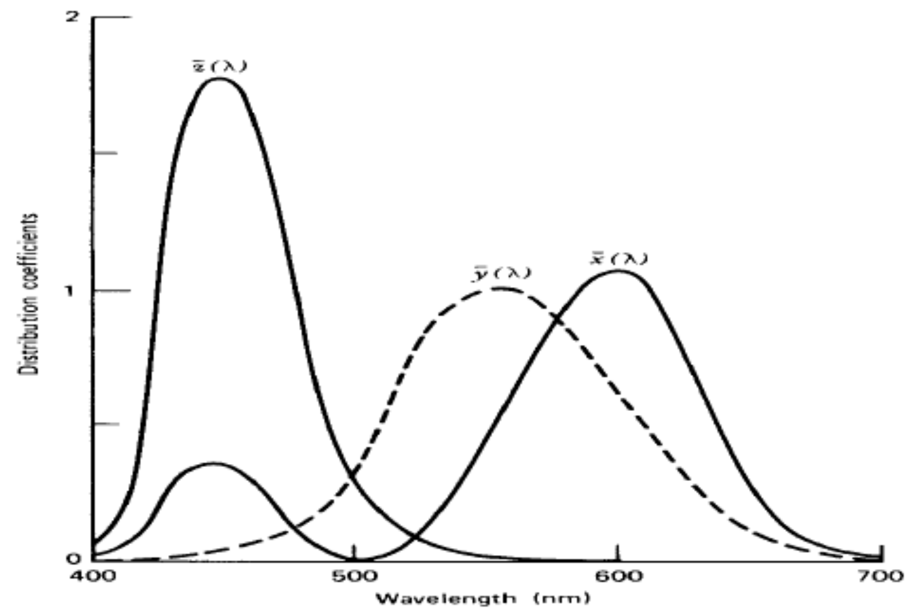
- Used in **TV broadcasting (NTSC)**, YIQ exploits useful properties of the visual system.
  - Y - luminance (taken from CIE)
  - I - orange-cyan hue (for flesh-tone shading)
  - Q - green-magenta hue
- YIQ is broadcast with relative bandwidth ratios 8:3:1
  - We’re best as distinguishing changes in luminance.
  - B/W TV uses the Y channel only

More Fundamental: CIE XYZ System

- A standard created in 1931 by CIE, defined in terms of three color matching functions.

Wavelength (intensity profile)





CIE Coordinates

- Given an emission spectrum, we can use the CIE matching functions to obtain the *X*, *Y* and *Z* coordinates.

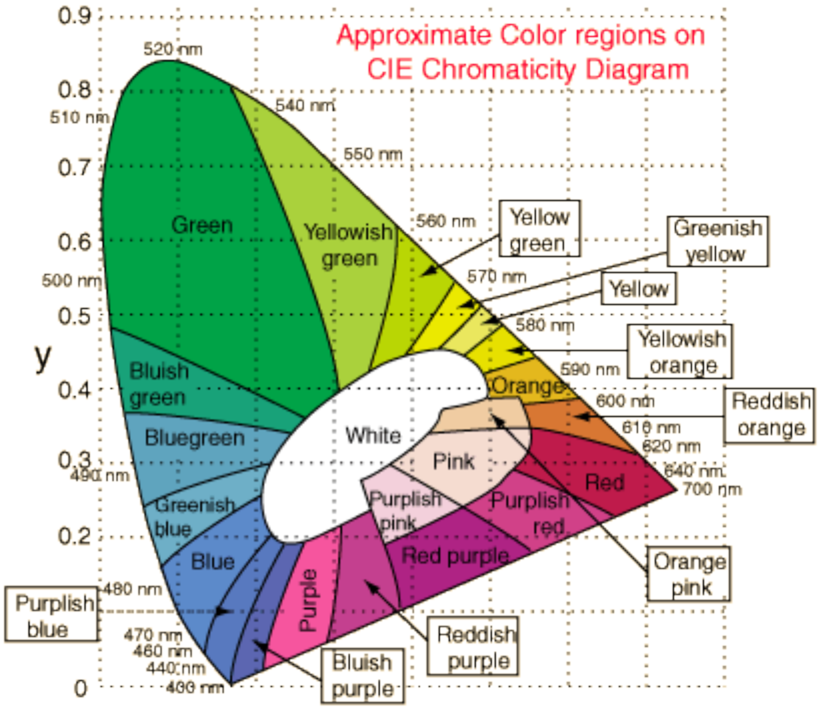
$$X = \int \bar{x}(\lambda) t(\lambda) d\lambda \qquad x = \frac{X}{X+Y+Z}$$

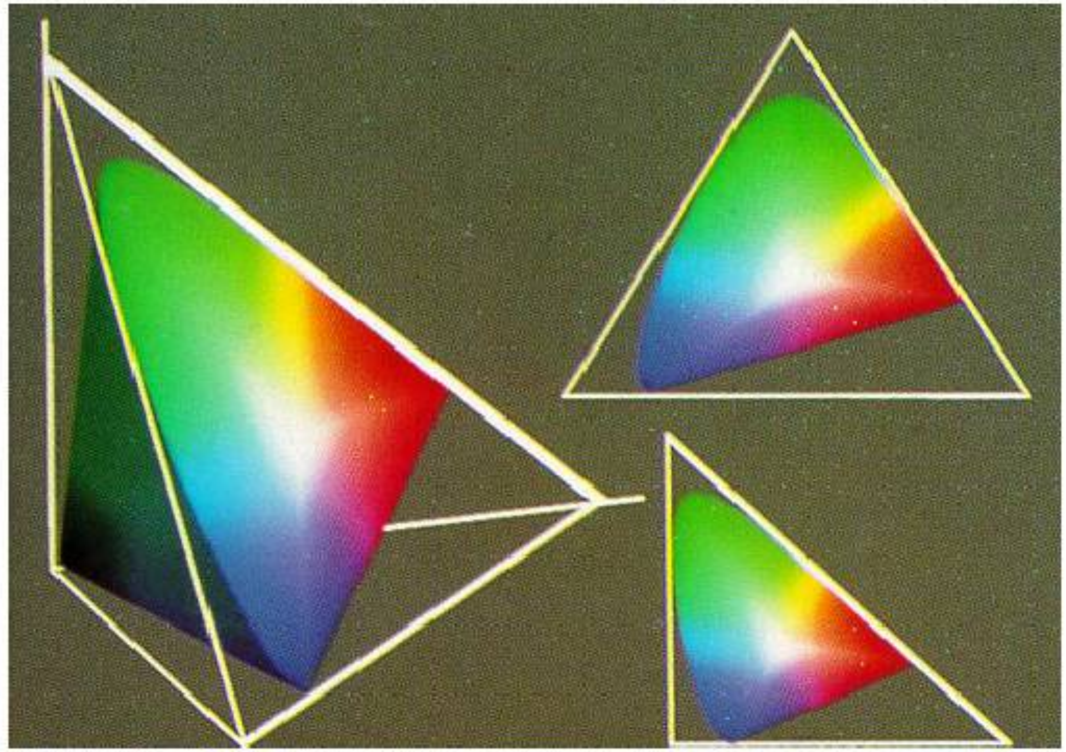
$$Y = \int \bar{y}(\lambda) t(\lambda) d\lambda \qquad y = \frac{Y}{X+Y+Z}$$

$$Z = \int \bar{z}(\lambda) t(\lambda) d\lambda \qquad z = \frac{Z}{X+Y+Z}$$

- Then we can compute chromaticity coordinates. This gives a brightness independent notion of color.

The CIE Color Blob

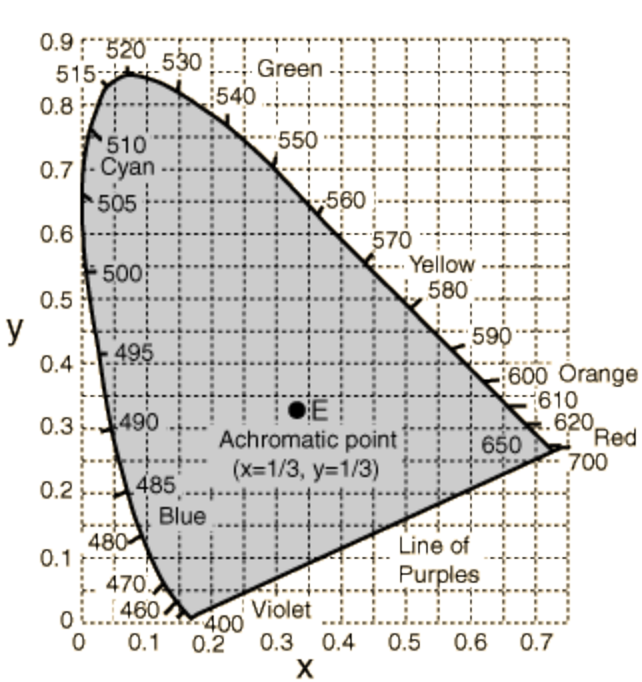


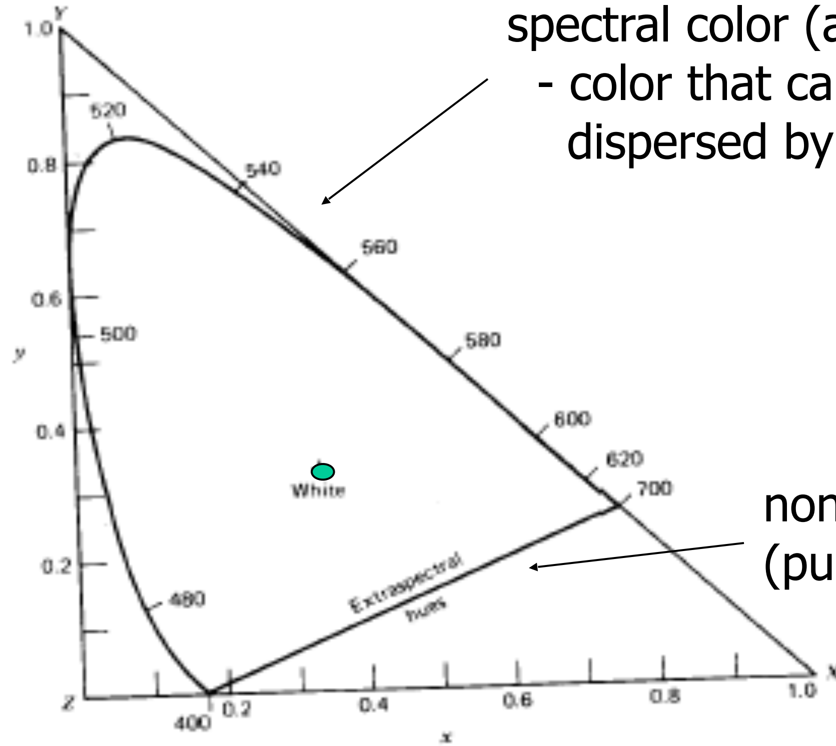


Note: x + y + z is always 1 after normalization

The CIE Chromaticity Diagram

- A projection of the plane x+y+z=1.
- Each point is a chromaticity value, which depends on **dominant wavelength**, or **hue**, and **excitation purity**, or **saturation**.





spectral color (along the curve)
- color that cannot be further dispersed by a prism

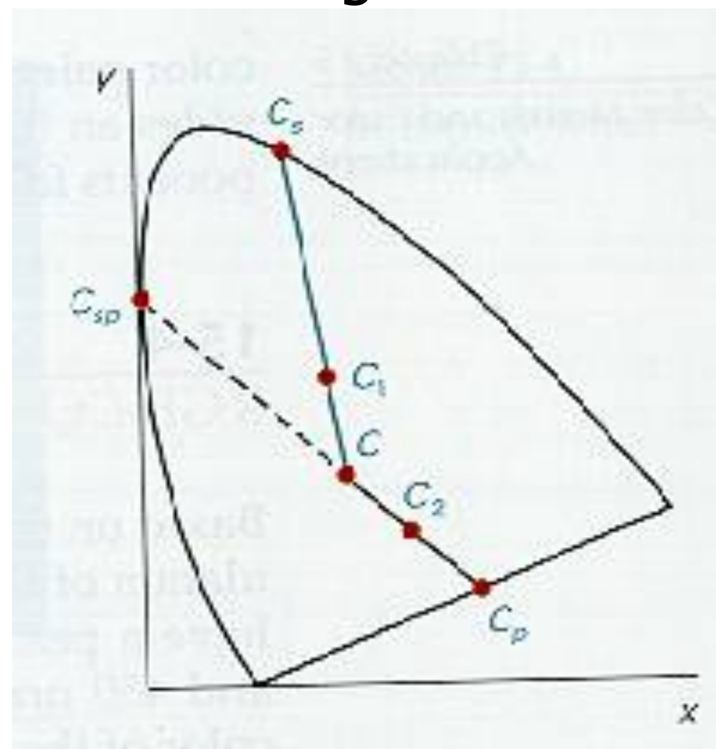
nonspectral color (purple line)

More about Chromaticity

- **Dominant wavelengths** go around the perimeter of the chromaticity blob.
  - A color's dominant wavelength (let the color be C_1) is where a line from white through C_1 intersects the perimeter
  - Some colors, called nonspectral colors, don't have a dominant wavelength (e.g. C_2). Its **complementary** dominant wavelength is taken.
- Excitation purity is measured in terms of a color's position on the line to its dominant wavelength.

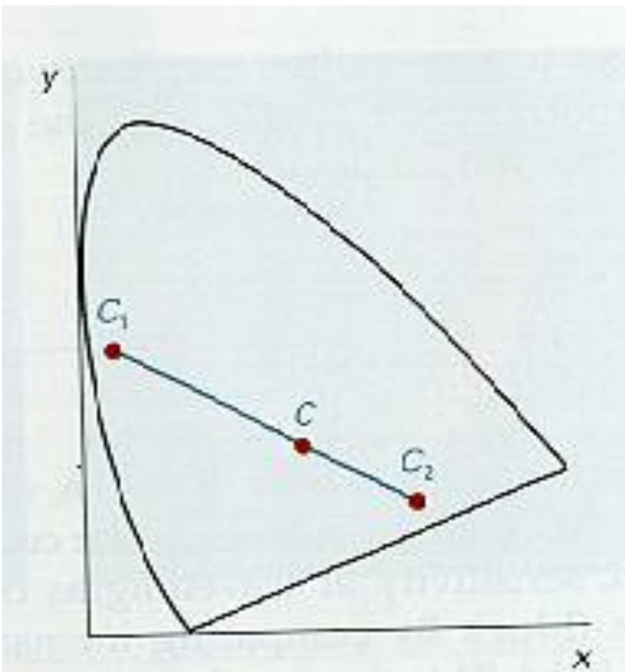
Dominant Wavelength & Excitation Purity

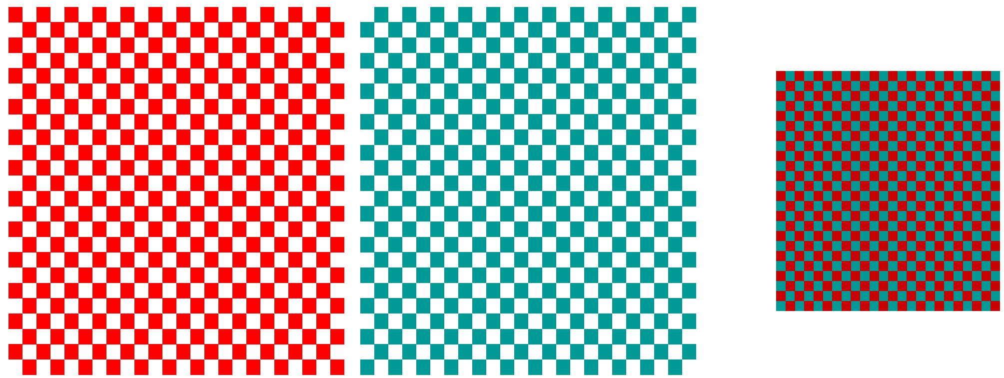
- Point C in the diagram corresponds to white light.
- From any color point, such as C_1, excitation purity is defined as the relative distance of C_1 from C along the line joining C and C_s, I.e., CC_1/CC_s
- The dominant wavelength of C_1 is C_s.



Complementary Colors

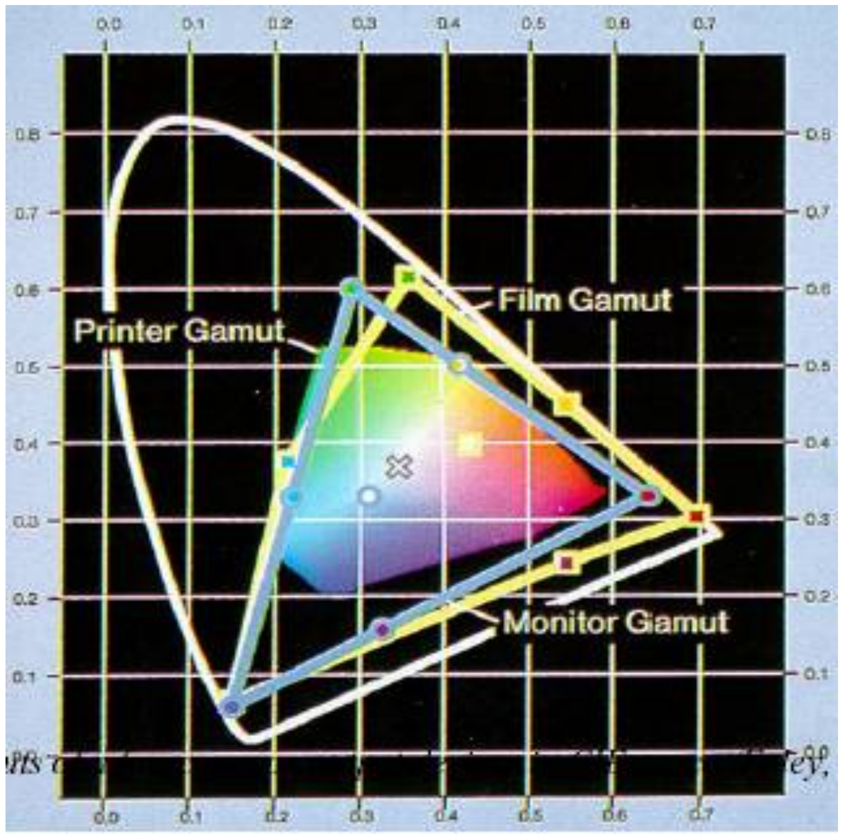
- Complementary colors lie on opposite sides of white, and can be mixed to get grays.





Gamuts

- Not every output device can reproduce every color. A device's range of reproducible colors is called its **gamut**.



Alpha Channel

- We only store one color in one pixel location.
- But compositing images will give unpleasant "hard edges"
- How can I reduce the unpleasant effect?
- Channel in addition to R, G, and B
- Blend with the lower layer will give you smoother visual effect.
- Can be regarded as "1 - transparency" or "opacity"
- Can be regarded as "proportion of occupied area"

Example: Blending

Source

$R_1G_1B_1$

+

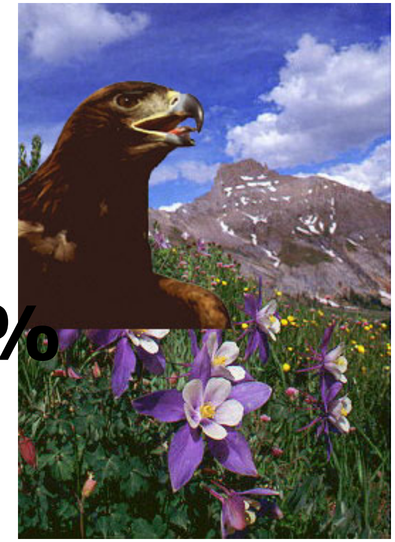
Destination

$R_2G_2B_2$

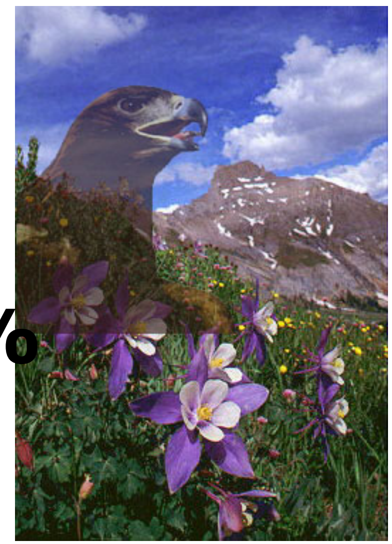
A_2 = Alpha Mask

[0,1]

α=100%



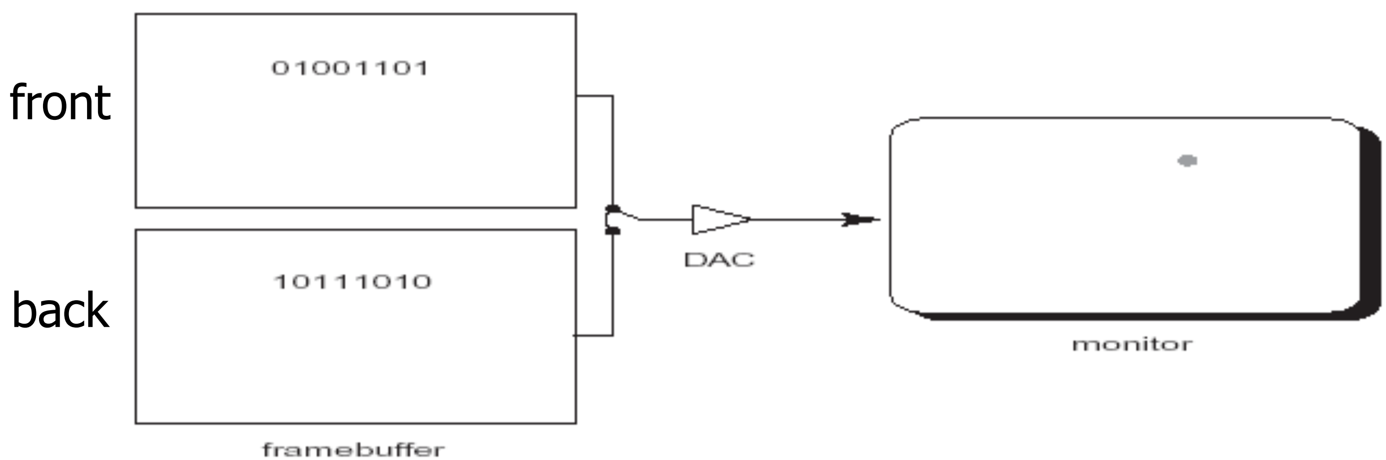
α=50%



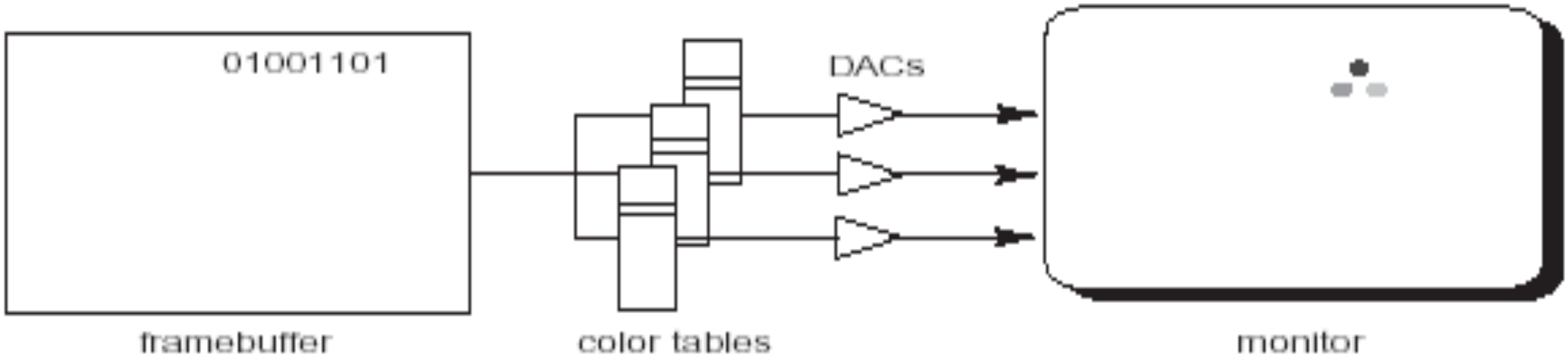
Resultant R = R1 * (1 – **α** * A2) + R2 * **α** * A2

Double Buffering

- **Q:** What happens when you write to the frame buffer while it is being displayed on the monitor?
- **Double-buffering** provides a solution
  - Render to the back buffer and swap when rendering is done
  - Double the memory



Summary:



1. Display devices (CRT, LCD, and FED)
2. Frame Buffer (Memory to Display)
3. Color Lookup Table (it is indexing)
4. Gamma Correction (To make it linear!)
5. Color Spaces: RGB, CMY, HSV, YIQ, CIE XYZ
6. Alpha Channel and Double Buffering