



Displays and Framebuffers





Reading

■ Required

- Angel, pp.19-34 [reader 153-168].
- Hearn & Baker, pp. 35-49 [reader 83-90].
- OpenGL Programming Guide (available online):
 - First four sections of chapter 2
 - First section of chapter 6

■ Optional

- Foley et al., sections 1.5, 4.2-4.5
- 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.



History

- Whirlwind Computer - MIT, 1950
 - CRT display
 - First real-time graphics



- SAGE air-defense system - middle 1950's
 - “Whirlwind II”
 - light pens
 - Long-lived (1958 – 1983!)



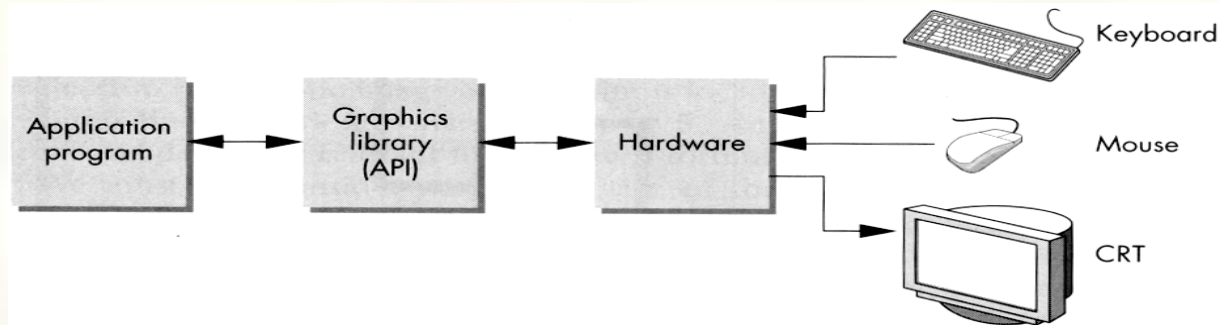
History

- Sketchpad - 1963, Ivan Sutherland
 - first interactive graphics system
 - constraint-based
 - interaction techniques for choosing, pointing, drawing
 - Lightpen, buttons, knobs
 - data structures for replicating components
 - hierarchical modeling





Modern graphics systems



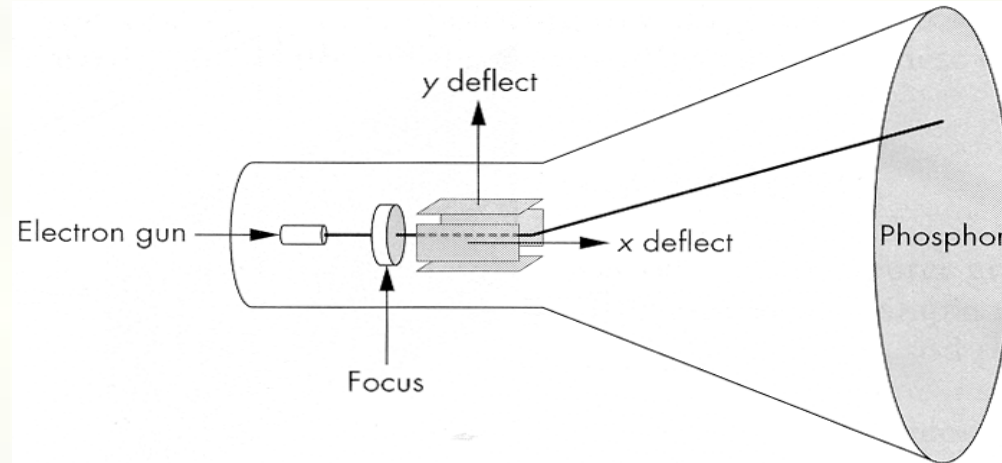
Current graphics systems consist of:

- An application, which talks to a...
- Graphics library (e.g., OpenGL or Direct3D), which talks to the...
- Graphics hardware

The graphics hardware can do a lot of fancy work these days. At a minimum, it contains a framebuffer to drive a display...



Cathode ray tubes (CRTs)



- Consists of:
 - electron gun
 - electron focusing lens
 - deflection plates/coils
 - electron beam
 - anode with phosphor coating

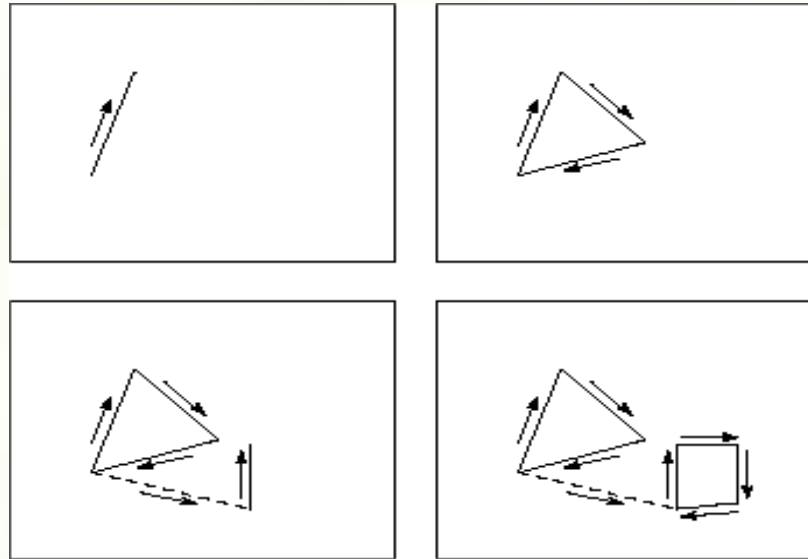


CRTs, cont.

- Electrons “boil off” the heated cathode and shoot towards the anode. Electrons striking the phosphors create light through:
 - fluorescence (fraction of usec)
 - phosphorescence (10 to 60 usec)
- Different phosphors have different:
 - color
 - red: europium yttrium vanadate
 - green: zinc cadmium sulfide
 - blue: zinc sulfide
 - persistence (as long as a few seconds)
- The image must be **refreshed** to avoid **flicker**, typically at least 60 Hz, though 72 Hz is easier on the eyes.



Calligraphic displays



- Also called **vector displays**, **stroke displays**, or **random-scan displays**.
- Used by:
 - Sutherland's Sketchpad
 - Asteroids video game
 - Oscilloscopes



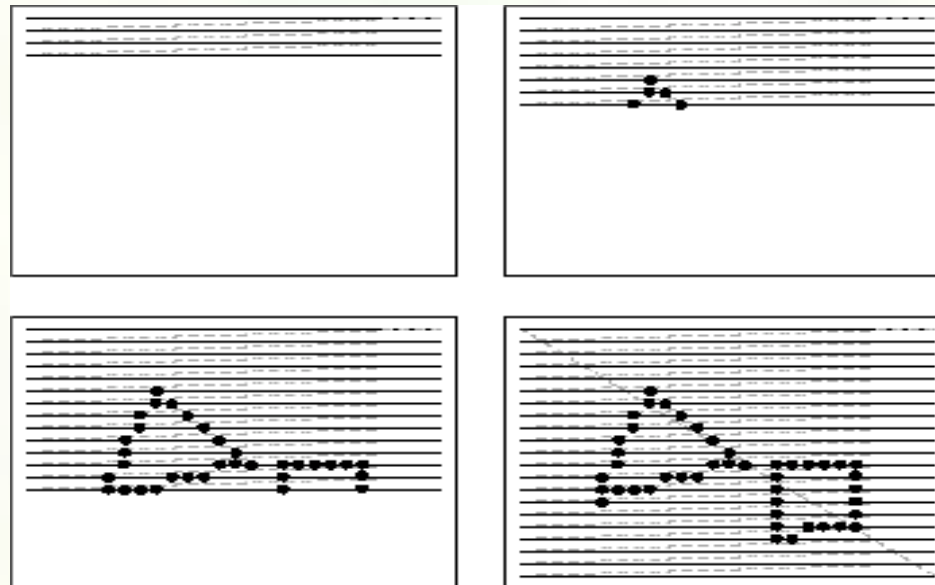
Modern use – Laser light shows





Raster displays

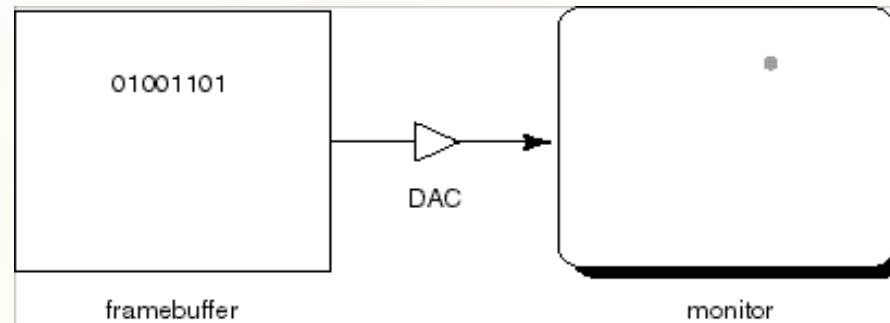
- **ras.ter**, from radere, “to scrape”



- 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**.



Framebuffers



- Intensity of the raster scan beam is modulated according to the contents of a **framebuffer**.
- Each element of the framebuffer is associated with a single **pixel** on the screen.
- *Note:* the brightness of a pixel is controlled by the voltage coming from the DAC, but the CRT has a non-linear response:

$$I = V^\gamma$$

- Monitor gammas are typically around 1.7-2.5.



Resolution

- The display's "**resolution**" is determined by:
 - number of scan lines
 - number of pixels per scan line
 - number of bits per pixel
- Resolution is used here to mean total number of bits in a display. It should really refer to the resolvable dots per unit length...

■ 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
	Laserprinted page		
	300 dpi	8.5 x 11 x 300b	1 MB
	1200 dpi	8.5 x 11 x 1200b	17 MB
	Film	4500 x 3000 x 30b	50 MB



Aspect ratio

- **Frame aspect ratio** = horizontal / vertical size

TV 4 : 3

HDTV 16 : 9

Letter-size paper 8.5 : 11 (about 3 :

35mm film 3 : 2

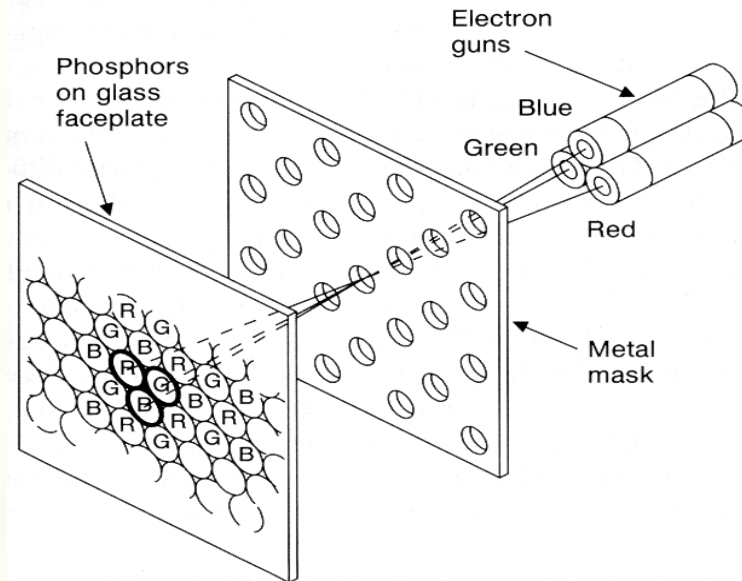
Panavision 2.35 : 1

- **Pixel aspect ratio** = pixel width / pixel height

- nowadays, this is almost always 1.



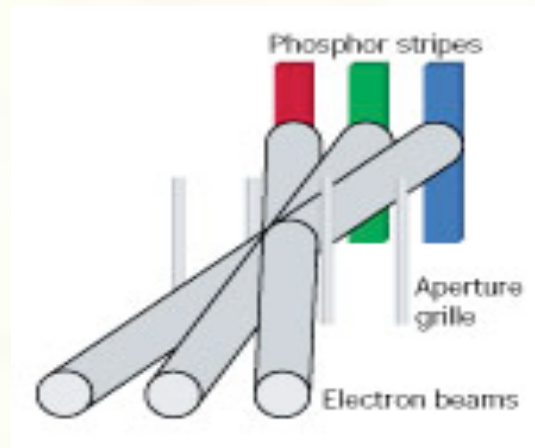
Color CRT monitors



- Many color monitors employ **shadow mask** technology. The variety depicted above:
 - uses **triads** of red, green, and blue phosphors at each pixel
 - uses three electron guns, one per color
 - **shadow mask** used to make each kind of phosphor only “visible” from one gun
- These are also known as **RGB monitors**.



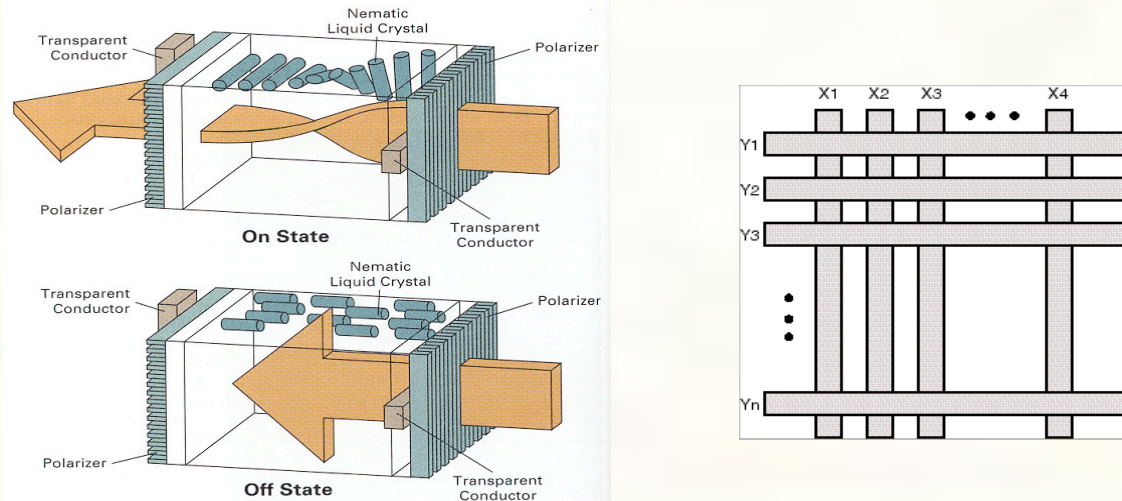
Color Trinitron CRT's



- A competing technology is called Trinitron (by Sony):
 - uses vertical stripes of red, green, and blue phosphors at each pixel
 - uses three electron guns, one per color
 - uses an **aperture grille** to make each kind of phosphor only “visible” from one gun
- You can see two horizontal lines at about $\frac{1}{4}$ and $\frac{3}{4}$ of the way up the screen on Trinitron displays. Why?



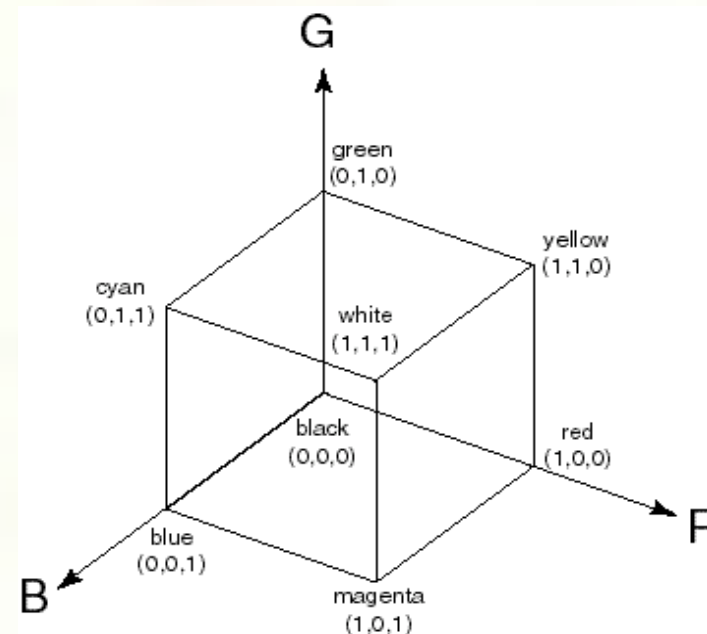
Liquid Crystal Displays



- CRTs are rapidly being displaced by **liquid crystal displays (LCD's)**.
 - Light enters a **vertical polarizer**
 - **Nematic crystal** twists light based on applied voltage (more voltage, less twisting)
 - Light passes through **horizontal polarizer**
- Passive matrix displays use a matrix of electrodes to control the voltages. Problem: slow to switch, overflows.
- Most modern LCD displays are active matrix displays. They have a transistor at each cell. They use a faster switching crystal and transistors that hold charge and prevent overflow.
- Color filters are used to get color display.



Additive color mixing

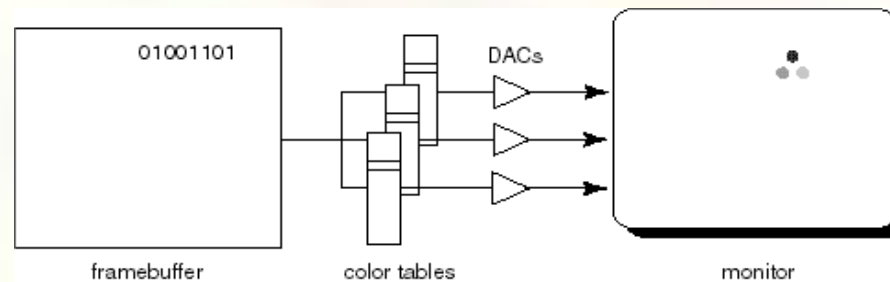


- All colors on a monitor or LCD are produced using combinations of red, green, and blue.
- A display that allows 256 voltage settings for each of R, G, and B is known as a **full-color system**.
- The description of each color in framebuffer memory is known as a **channel**.



Color tables

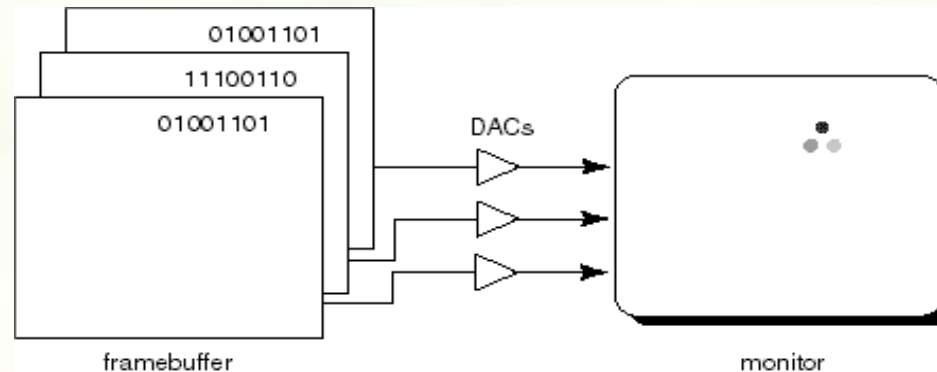
- **Color tables** (video lookup tables) allow more color versatility when you only have a few bits per pixel. You get to select a small **palette** from a large number of available colors.



- Each framebuffer 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.



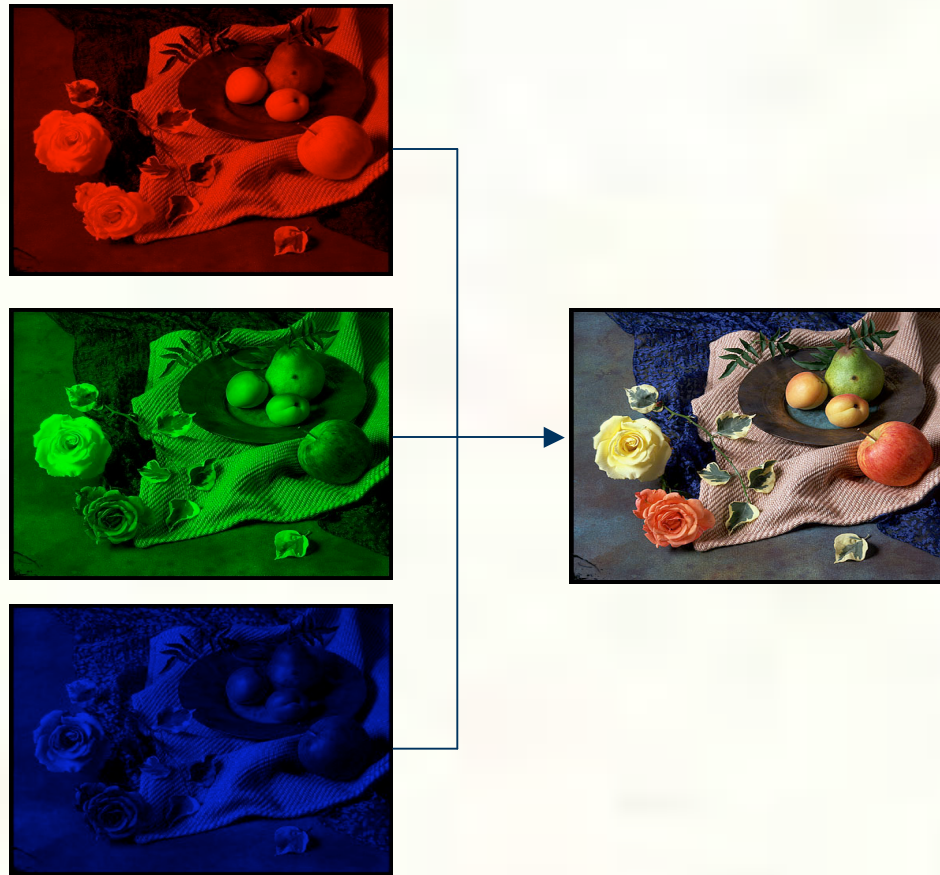
RGB framebuffer



- The term **true-color** is sometimes used to refer to systems which the framebuffer directly stores the values of each channel.
- As memory prices have fallen, true-color has become standard.



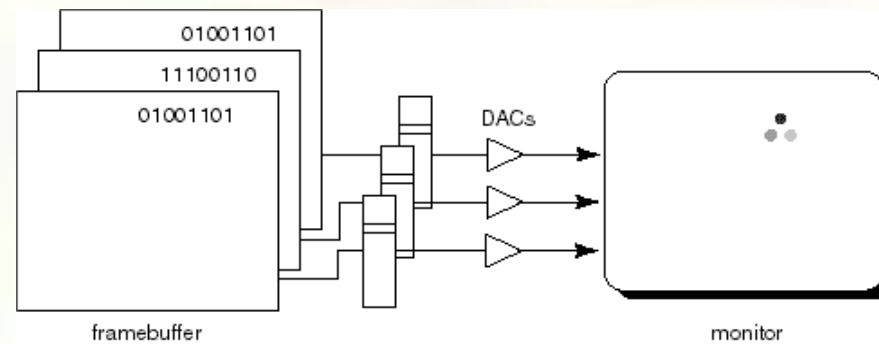
Anatomy of an RGB image





Color tables on 24-bit systems

- Even full-color systems often use color tables. In this case, there is a separate color table for each 8 bit channel.

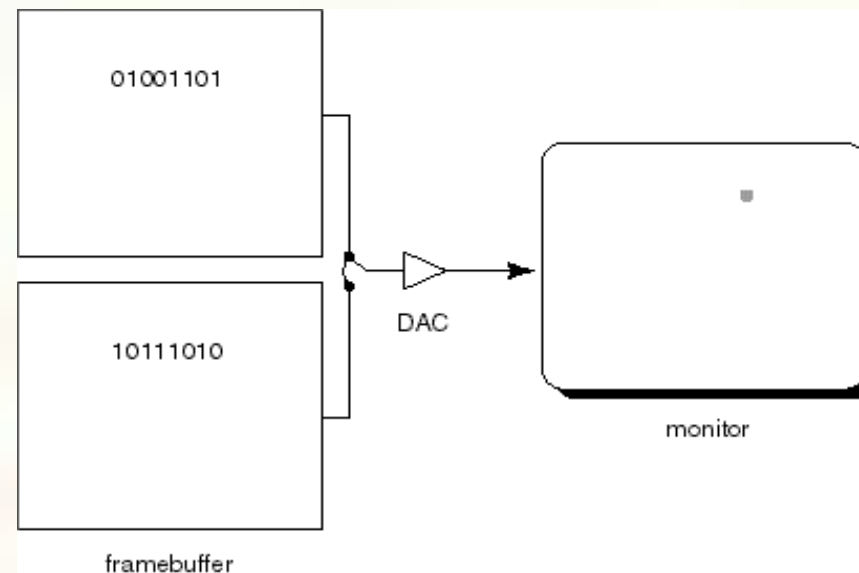


- **Q:** Why would you want this capability?



Double-buffering

- **Q:** What happens when you write to the framebuffer while it is being displayed on the monitor?
- **Double-buffering** provides a solution.





OpenGL

- The API we'll be using for drawing to the framebuffer is OpenGL.
- For 2D graphics, OpenGL lets you specify colors of primitives and then draw them to the screen. Typical primitives include:
 - Points
 - Lines
 - Unfilled polygons
 - Filled polygons
- You just name a color, declare the primitive type, and specify the vertices, and OpenGL does the rest.
- OpenGL also supports “alpha” blending. A typical operation is a linear mixture that blends a new color into the framebuffer: $F_{new} = \alpha C + (1 - \alpha) F_{old}$



Summary

- Here's what you should take home from this lecture:
 - All of the **boldfaced terms**.
 - Sketchpad (1963) was the first interactive graphics system.
 - The basic components of black-and-white and color CRTs.
 - Raster vs. calligraphic displays.
 - The principle operation for an LCD display.
 - Computing screen resolution & framebuffer size.
 - The correspondence between elements of framebuffer memory and pixels on-screen.
 - How color tables and double-buffering work.



Next lecture – Fourier Theory

- Topic:

- Fourier Analysis and Sampling Theory

- How do we know when we have enough samples? What kinds of errors can we expect when we don't have enough samples?

- Required readings:

- Watt, Section 14.1

- Recommended readings/references:

- Ron Bracewell, *The Fourier Transform and Its Applications*, McGraw-Hill.

- (This is an entire book)

- Don P. Mitchell and Arun N. Netravali, “Reconstruction Filters in Computer Computer Graphics ,” *Computer Graphics*, (Proceedings of SIGGRAPH 88). 22 (4), pp. 221-228, 1988.