Displays and Framebuffers

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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 Join 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"
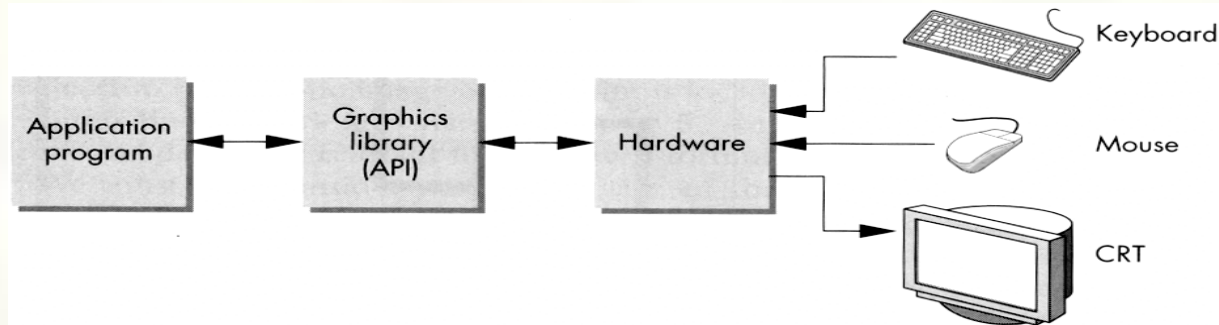 - light pens
  - Long-lived (1958 – 1983!)

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
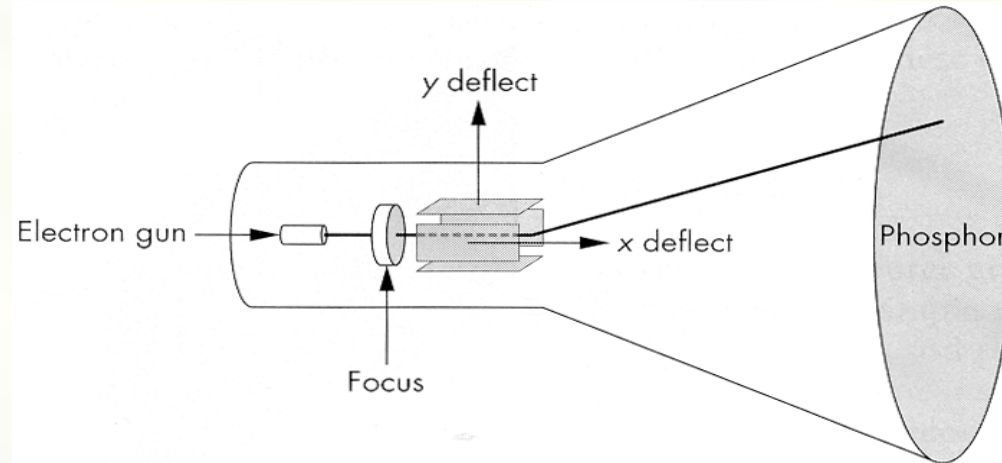
Modern graphics systems

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
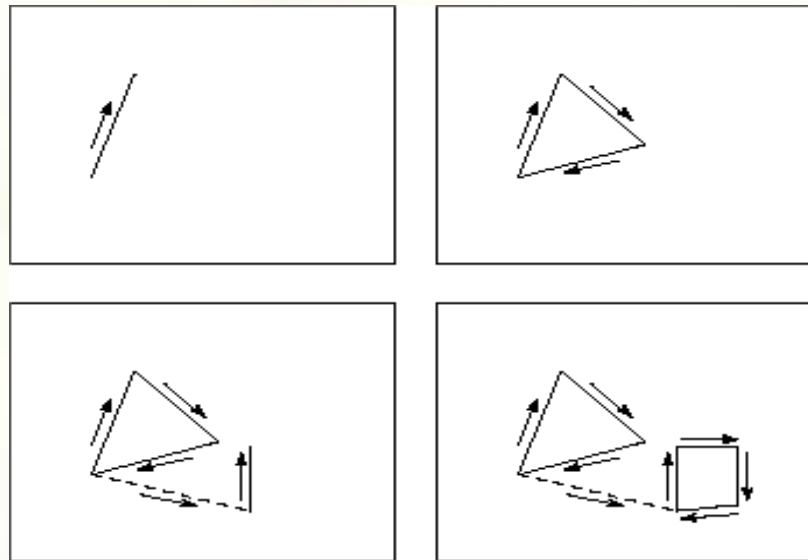 - electron beam
  - anode with phosphor coating

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
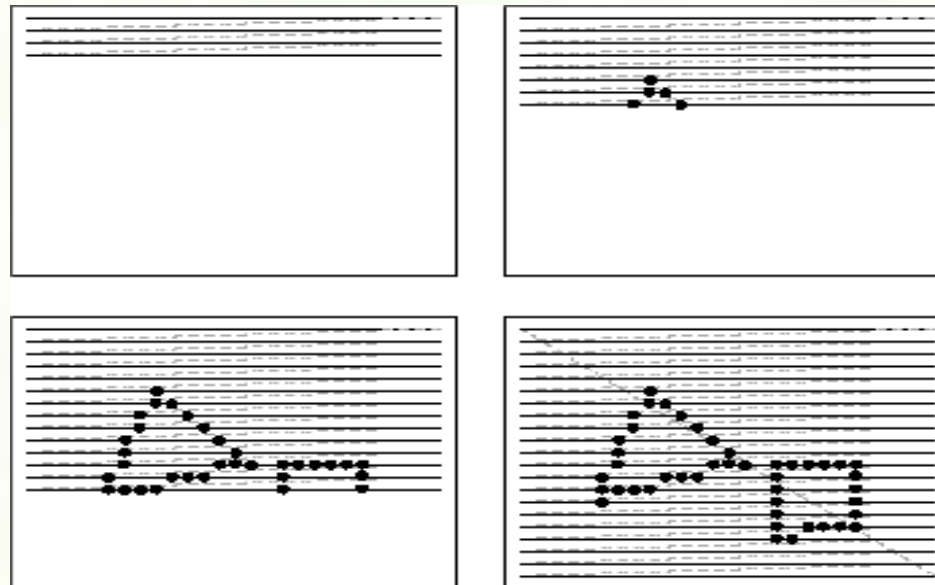 - Asteroids video game
  - Oscilloscopes

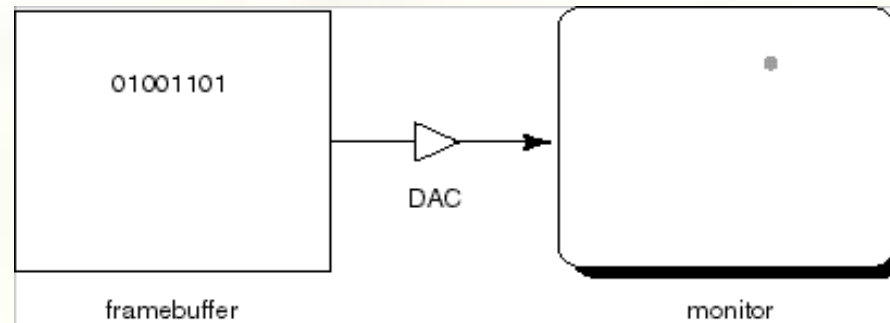# Modern use – Laser light shows

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
Laser printed page		
300 dpi	8.5 x 11 x 300^2 1b	1 MB
1200 dpi	8.5 x 11 x 1200^2 1b	17 MB
Film	4500 x 3000 x 30b	50 MB

Aspect ratio

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

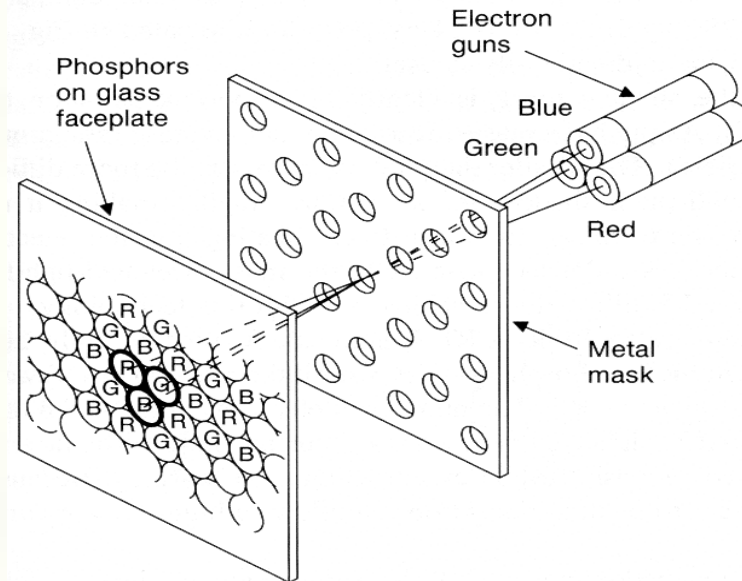|	
TV	4 : 3
HDTV	16 : 9
Letter-size paper	8.5 : 11 (about 3 :
35mm film	3 : 2
Panavision	2.35 : 1

- **Pixel aspect ratio** = pixel width / pixel height
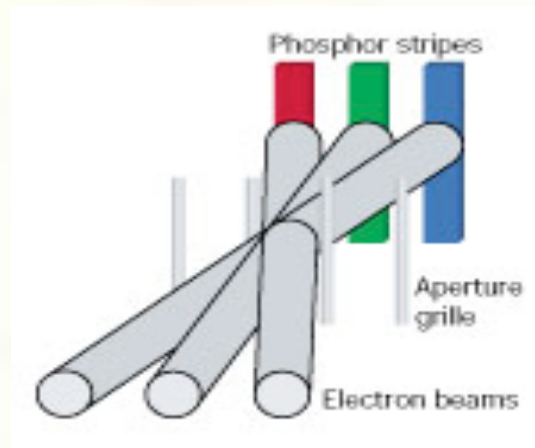 - nowadays, this is <u>almost</u> always 1.

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 ¼ and ¾ of the way up the screen on Trinitron displays. Why?

Liquid Crystal Displays
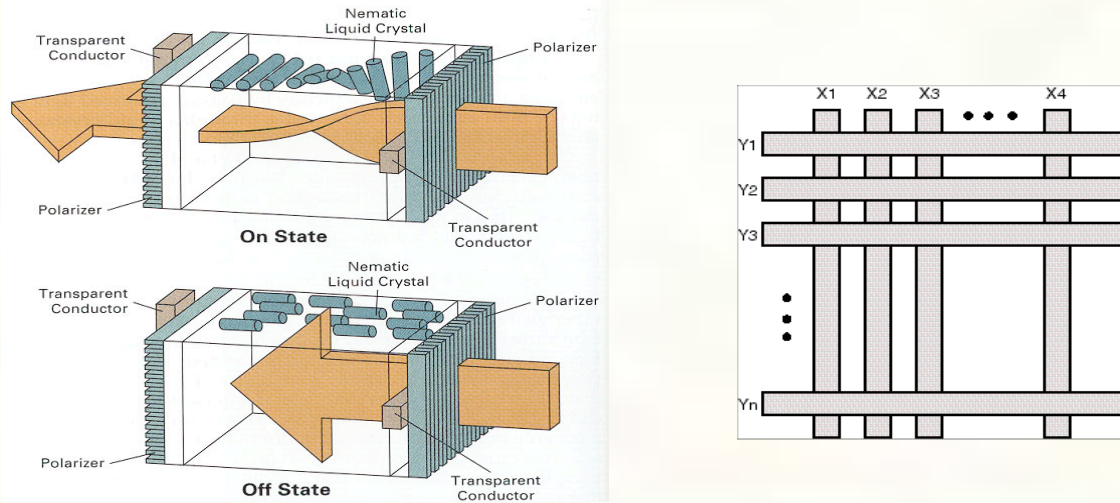
- CRTs are rapidly being displaced by **liquid crystal displays** (**LCD's**).
    - Light enters a **vertical polarizer**
    - **Nematic crystal** twists light based on applied voltage (more voltage, less twisting)
    - Light passes through **horizontal polarizer**
- Passive matrix displays use a 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
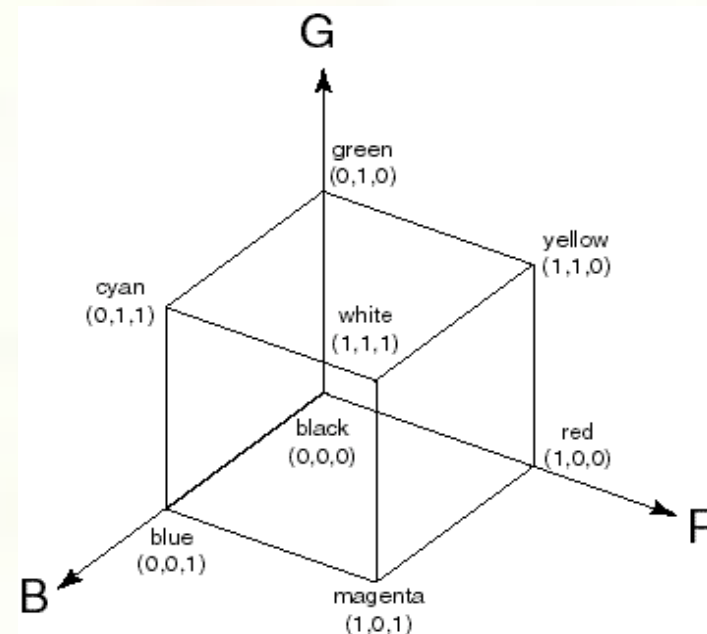
- All colors on a monitor or LCD are produced using combinations of red, green, and blue.
- A display that allows 256 voltage settings for each of R, G, and B is known as a **full-color system**.
- The description of each color in framebuffer memory is known as a **channel**.
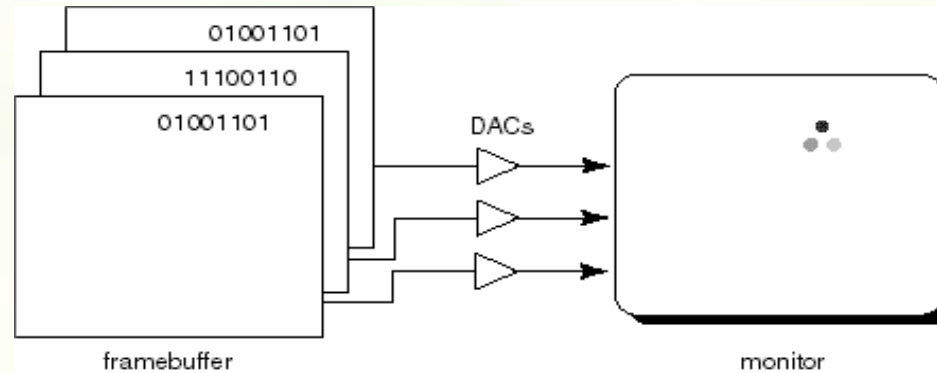
Color tables

- **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.
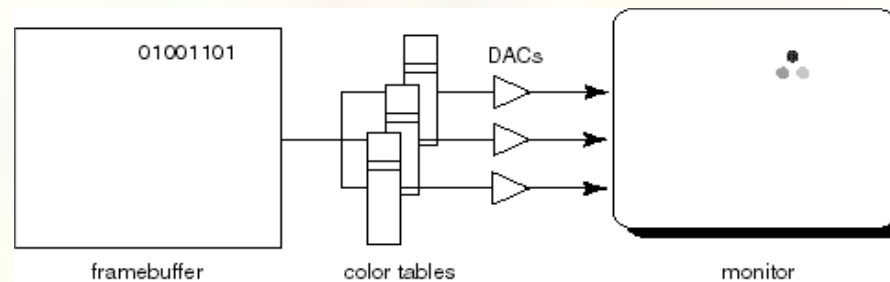
- Each framebuffer element is now an index into the color table, where the actual values of each channel are stored.
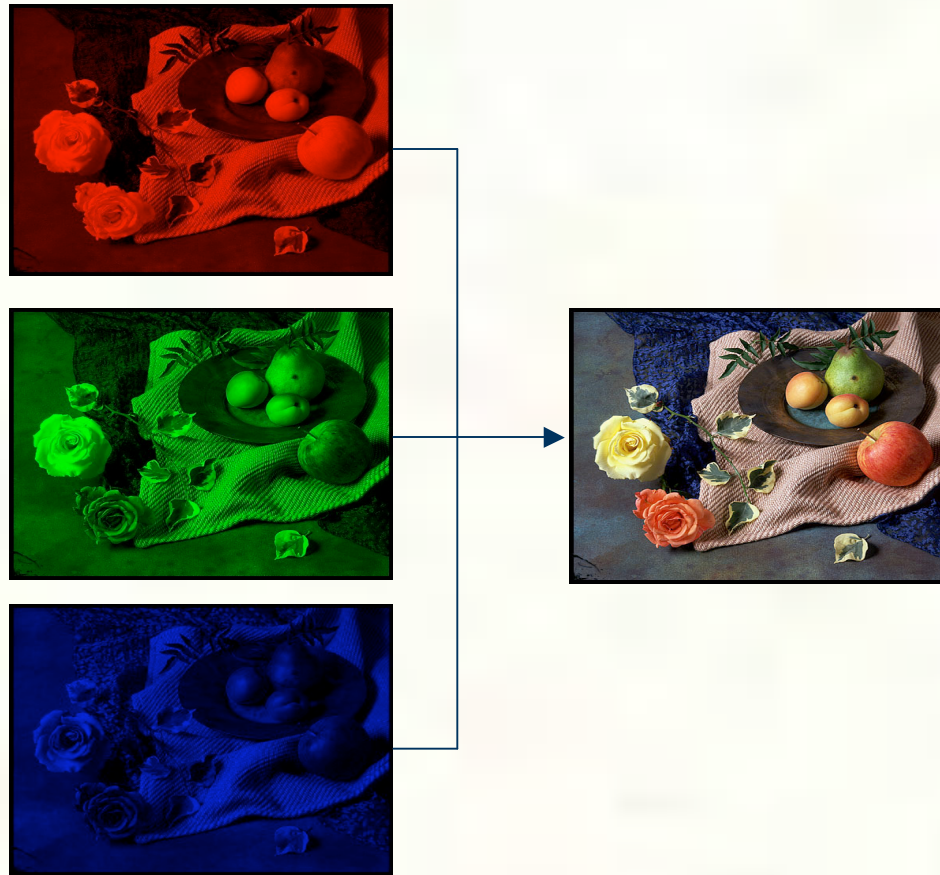 - Color table entries can be changed in software.

RGB framebuffer

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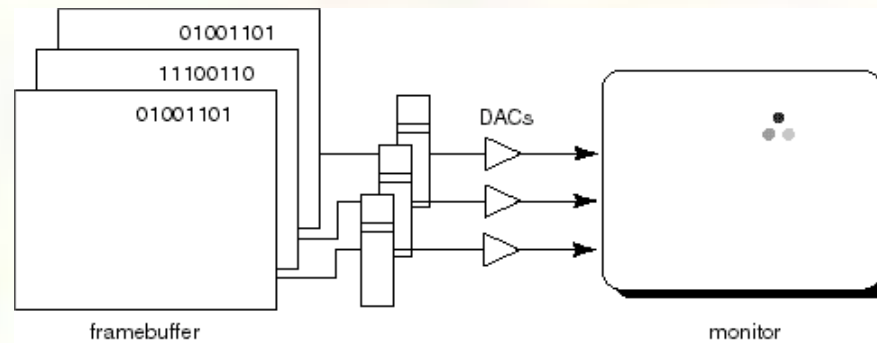- As memory prices have fallen, true-color has become standard.

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.
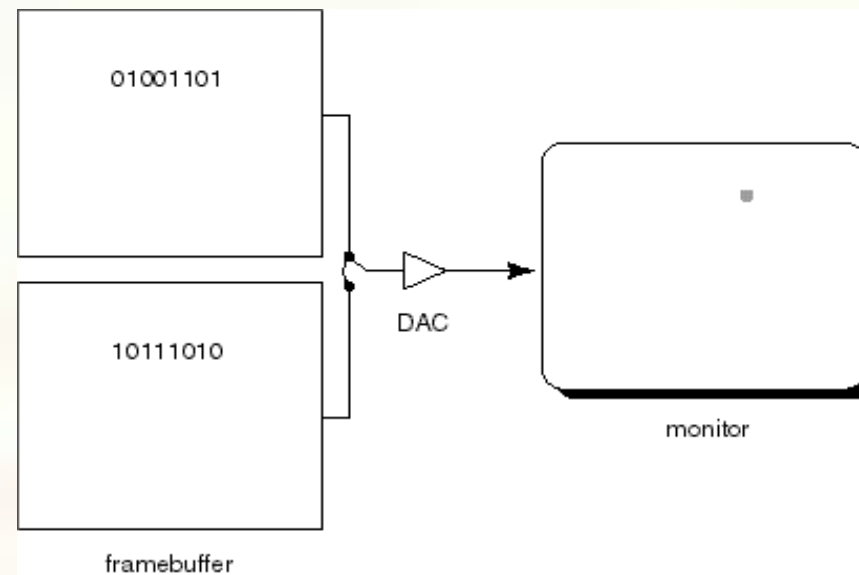

■ **Q:** Why would you want this capability?

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.