1. Displays and framebuffers

Reading

Required

- Angel, pp.19-31.
- Hearn & Baker, pp. 36-38, 154-157.
- 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.
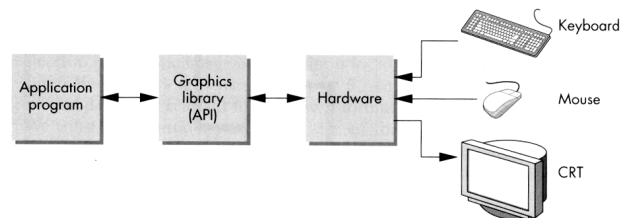
History

- Whirlwind Computer - MIT, 1950
  - CRT display

- SAGE air-defense system - middle 1950's
  - "Whirlwind II"
  - light pens

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

Modern graphics systems
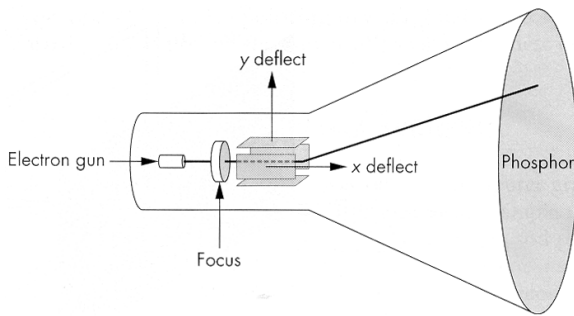

Current graphics systems consist of:

- 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:

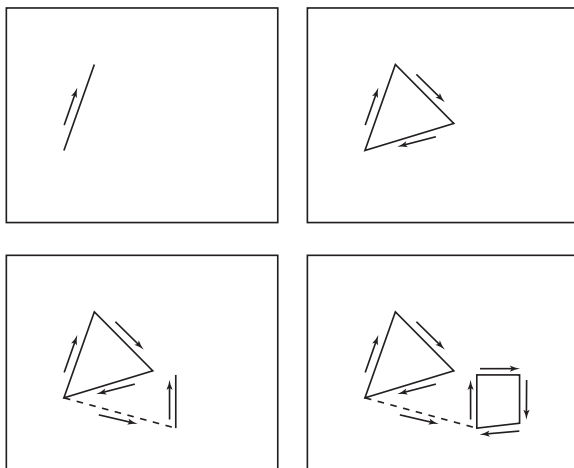- fluorescence (fraction of usec)
- phosphorescence (10 to 60 usec)

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

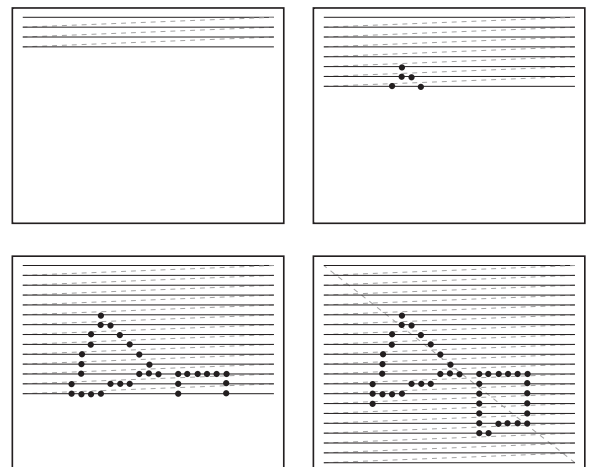Also called **vector displays**, **stroke displays**, or **random-scan displays**.

Used by:

- Sutherland's Sketchpad
- Asteroids video game
- Oscilloscopes
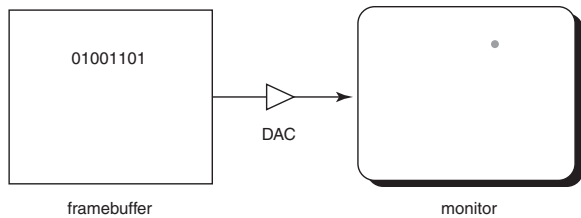
Raster displays

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

framebuffer — 01001101 — DAC — monitor

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:

$$I \sim V^{\gamma}$$

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

Aspect ratio

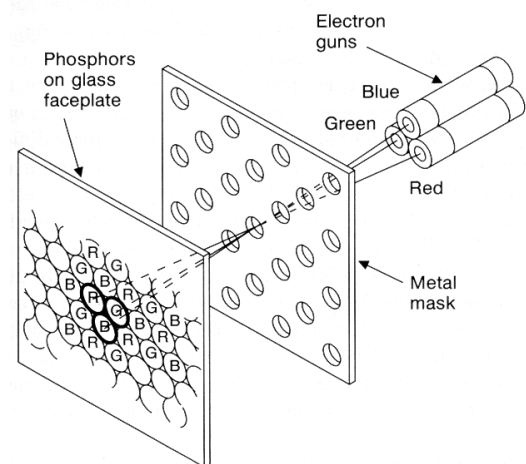**Frame aspect ratio** = horizontal / vertical size

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

Pixel aspect ratio = pixel width / pixel height

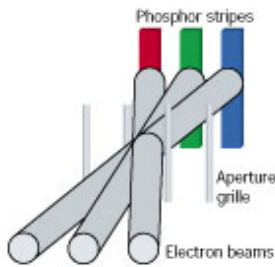- nowadays, this is <u>almost</u> always 1.

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
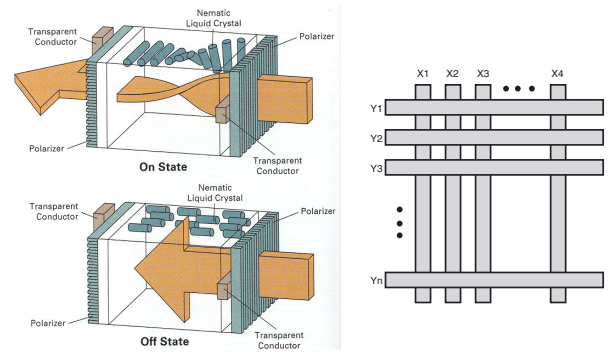

A competing technology is called Trinitron (by Sony):

- 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

Laptops typically use **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.

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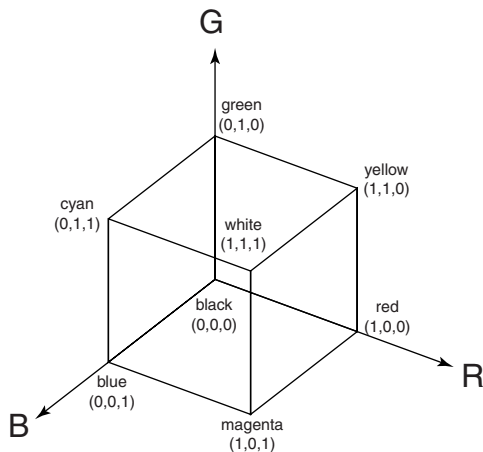
All colors on a monitor or LCD are produced using combinations of red, green, and blue.
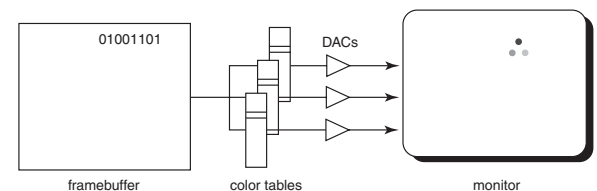
A display that allows 256 voltage settings for each of R, G, and B is known as a **full-color system**.

The description of each color in framebuffer memory is known as a **channel**.

Color tables

Color tables 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.
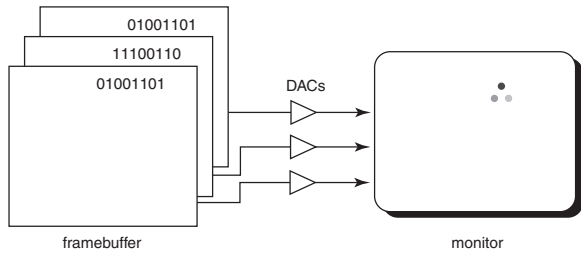

Each framebuffer element is now an index into the color table, where the actual values of each channel are stored.

- Color table entries can be changed in software.
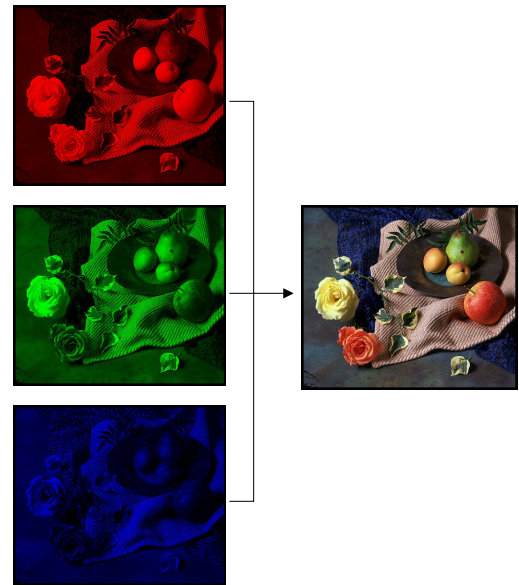
RGB framebuffer

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

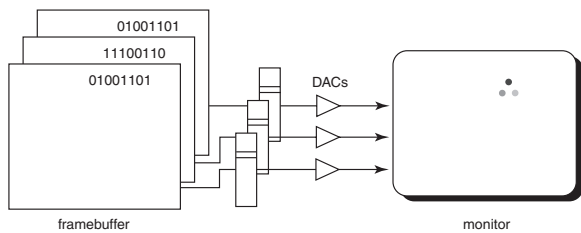As memory prices have fallen, true-color has become fairly standard.

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.
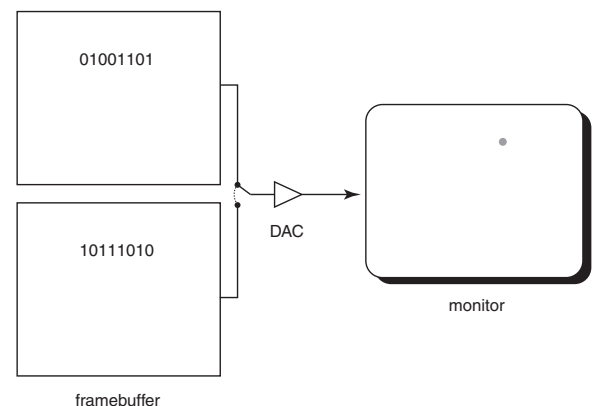

Q: Why would you want this capability?

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.