3. Graphics Hardware

Reading

- Angel, sections 1.2, 1.7
- Hearn & Baker, sections 2.1-2.2, 4.3
- 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

Graphics dates from the early days of computing.

- Line printer art.

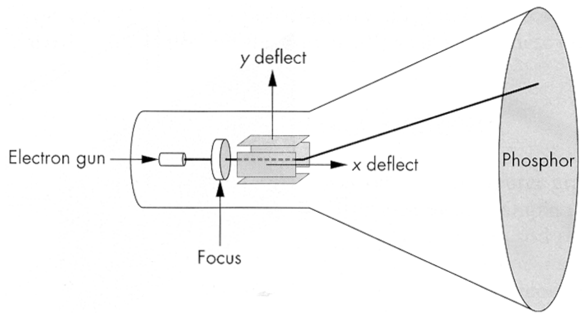
History, cont.

- Whirlwind Computer - MIT, 1950
  - CRT display

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

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

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)

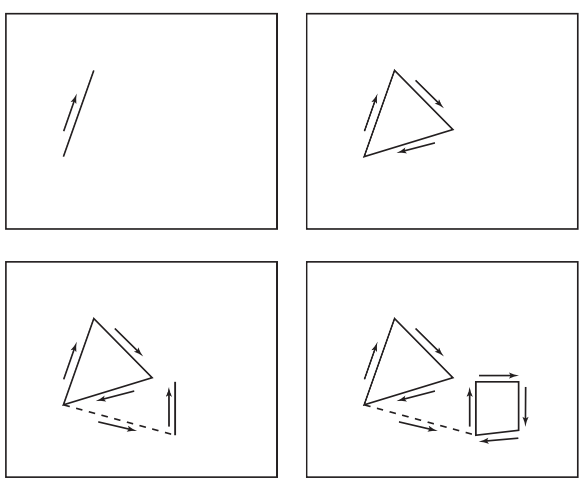
Different phosphors have different:

- 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 need at least 60 Hz (why 60 Hz?)
- exact frequency depends on:
  - persistence
  - image intensity
  - ambient lighting
  - wavelength
  - observer

Calligraphic displays



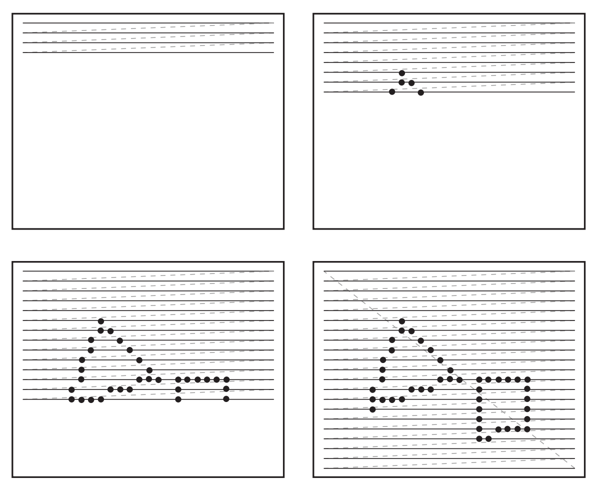
Also called **vector displays**, **stroke displays**, or **random-scan displays**.

Used by:

- Sutherland's Sketchpad
- Asteroids video game
- Oscilloscopes

Raster displays

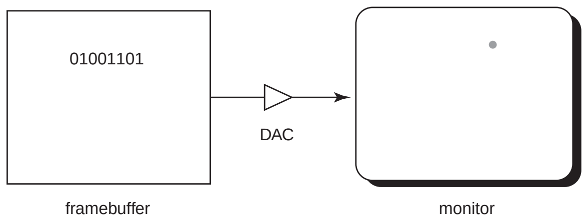
ras.ter, from radere, "to scrape"



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



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.

Resolution

The display's **resolution** is determined by:

- number of scan lines
- number of pixels per scan line
- number of bits per pixel

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

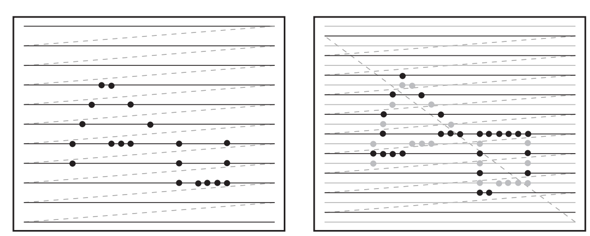
Frame aspect ratio = horizontal / vertical size

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 always 1.

Interlacing



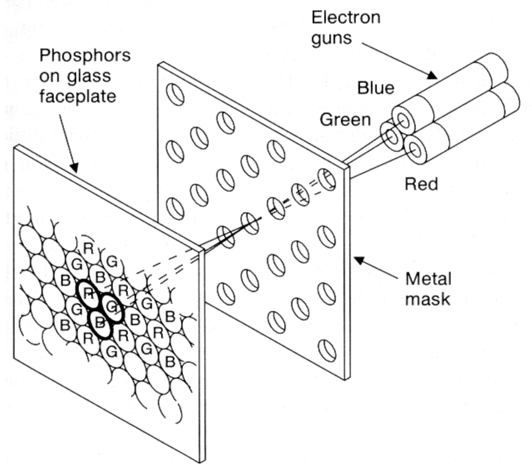
To reduce bandwidth in broadcast television, the refresh cycle is broken into two **fields**:

- odd and even
- each lasting 1/30th second

Q: when does this work well?

Q: what's a worst-case example?

Color CRT monitors

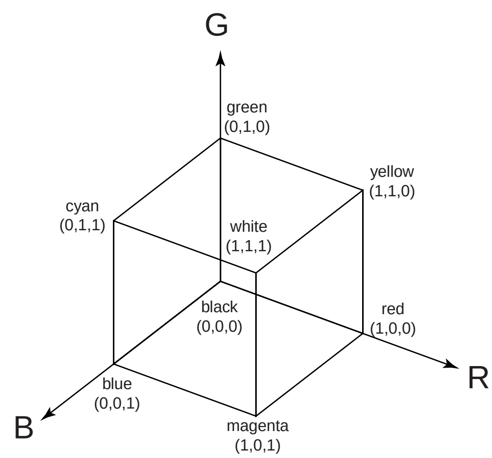


Most color monitors employ **shadow mask** technology:

- 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**.

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 framebuffer memory is known as a **channel**.

Specifying colors

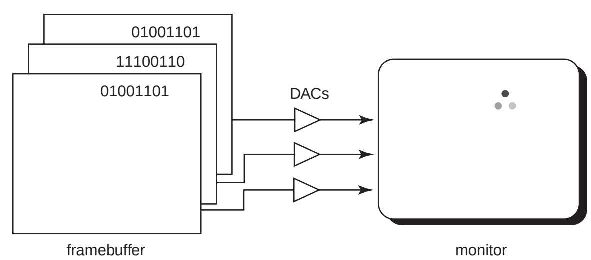
The number of color choices depends on the amount of framebuffer storage allocated per pixel.

Q: How many colors can be displayed with:

- 3 bits per pixel?
- 8 bits per pixel?
- 24 bits per pixel?

16 bpp systems often allocate 5 bits to red, 6 to green, and 5 to blue. Why does green get the extra bit?

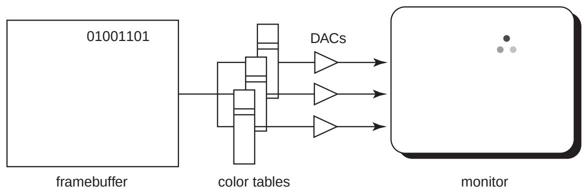
RGB framebuffer



The term **true-color** is sometimes used to refer to systems which the framebuffer directly stores the values of each 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** of from a large number of available colors.

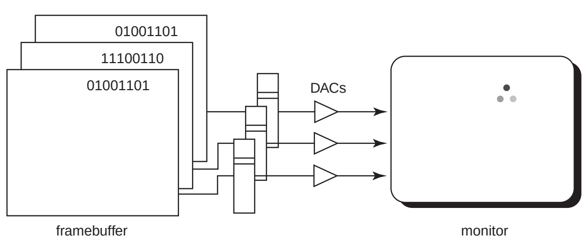


Each framebuffer element is now an index into the color table, where the actual values of each channel are stored.

- Color table entries can be changed in software.

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.



Most SGI workstations are like this.

Q: Why would you want this capability?

Color table examples

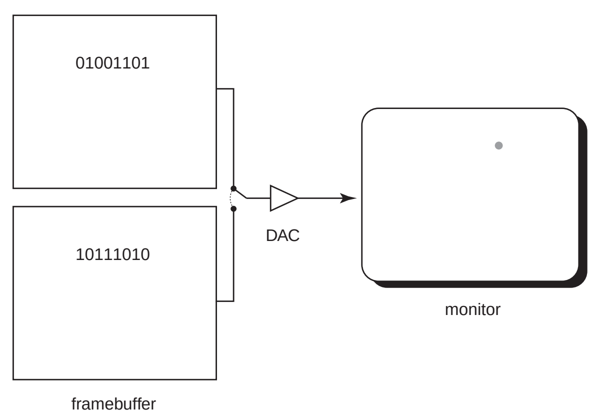
What would be a "good" choice of colors to put into the color table if the hardware has 3-bit indices?

What would be a "good" choice of table entries for displaying a grayscale image on color-mapped hardware with 8-bit indices?

Double-buffering

Q: What happens when you write to the framebuffer while it is being displayed on the monitor?

Double-buffering provides a solution.



Summary

Here's what you should take home from this lecture:

- Sketchpad (1963) was the first interactive graphics system.
- The basic components of black-and-white and color CRTs.
- All of the **boldfaced terms**.
- Raster vs. calligraphic displays.
- Computing screen resolution & framebuffer size.
- The correspondence between elements of framebuffer memory and pixels on-screen.
- How color tables work.
- How double-buffering works.