1. Graphics Hardware

Reading

Required:

- Hearn and Baker, Sections 2.1–2.2, 4.3

Recommended:

- 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*, 329–346, 1963.
- T. H. Myer and I. E. Sutherland. On the design of display processors. *Communications of the ACM* 11(6): 410–414, 1968.

History

Crude graphics dates from early days of computing:

- Plotting on line printers
- Whirlwind Computer — 1950, MIT
  - CRT displays
- SAGE air-defense system — middle 1950's
  - "Command and control system"
  - Light pens
- Sketchpad — 1963, Ivan Sutherland
  - Constraint-based
  - Interaction techniques for choosing, pointing, drawing
  - Data structures for replicating components
  - Beginning of modern interactive graphics

Cathode ray tubes (CRTs)

Cathode ray tube (Angel, fig 1.3)

Consists of:

- Electron gun
- Electron focusing lens
- Horizontal and vertical deflection plates or coils
- Electron beam
- Anode (phosphor coating)

CRTs, cont.

Electrons hit the phosphors which then emit light through:

- Flourescence (fraction of μsec)
- Phosphorescence (10 to 60 μsec)

Different phosphors have different:

- colors
- persistence

Image needs to be *refreshed* to avoid *flicker*:

- Typically, need at least 60Hz
- Exact number depends on:
  - · Persistence
  - · Image intensity
  - · Ambient lighting
  - · Wavelength
  - · Observer

Calligraphic displays

Calligraphic display (H&B, fig 2-9)

“Calligraphic display” ≡ “Vector display”
≡ “Stroke display”
≡ “Random scan display”

Calligraphic displays, cont.

Used, for example, by:

- Sutherland’s Sketchpad
- Asteroids video game
- Oscilloscopes

Raster displays

ras.ter, from radere, to scrape

History:

- Developed by Dick Shoup — early 70’s, Xerox PARC
- Based on TV technology
- Has had huge impact on computer graphics

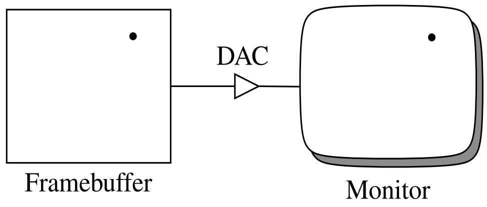
Raster displays, cont.

Raster display (H&B, fig 2-7)

Description:

- Electron beam traced in "raster scan order"
- Each left-to-right trace called a "scan line"
- Each spot on the screen called a "pixel"

Framebuffer



Framebuffer and display

Description:

- Intensity of beam modulated according to "framebuffer" contents
- Each element of framebuffer associated with a "pixel" on the screen

Resolution

Resolution is determined by:

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

Examples:

Bitmapped display	$960 \times 1152 \times 1$b	1/8 MB
NTSC TV	$640 \times 480 \times 16$b	1/2 MB
Color workstation	$1280 \times 1024 \times 24$b	4 MB
Laser-printed page		
300dpi	$8.5 \times 11 \times 300^2 \times 1$b	1 MB
1200dpi	$8.5 \times 11 \times 1200^2 \times 1$b	17 MB
Film	$4500 \times 3000 \times 30$b	50 MB
Hologram (4 in)	$300,000 \times 300,000 \times 16$b	180 GB

Aspect ratio

"Frame aspect ratio" = horizontal / vertical size

TV	4 : 3
HDTV	16 : 9
Standard paper	$8.5 : 11 \approx 3 : 4$
35mm film	3 : 2
Panavision	2.35 : 1

"Pixel aspect ratio" = pixel width / pixel height
(Hopefully always 1!)

Interlacing

Raster scan (Foley, fig 1.3)

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

The shadow mask CRT (Foley, fig 4.14)

Most color monitors employ “shadow mask” technology:

- Uses “triads” of red, green, and blue phosphors at each pixel
- Uses three electron guns, one for each color
- Uses “shadow mask”

Such CRTs are also known as “RGB monitors.”

Additive color mixing

The RGB cube (Angel, fig 2.27)

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, B is known as a “full-color system.”

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

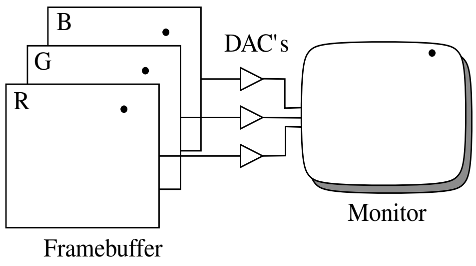
Specifying color

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?

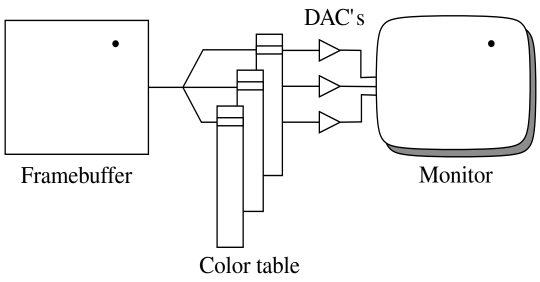
RGB Framebuffer



RGB framebuffer and display

Color tables

"Color tables" allow more color versatility when you only have a few bits per pixel.



Using a color table

Idea:

- Each framebuffer element stores an *index* into a color table, where the actual color is stored.
- Color table entries can be changed in software.

Color tables, cont.

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

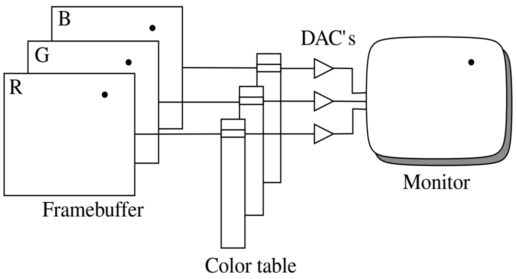
Color tables, cont.

Example: What would be a "good" choice of colors for displaying a greyscale image on "color-mapped" hardware with 8-bit indices?

Color tables on 24-bit systems

Even "full color" systems with 24 bits per pixel often use color tables.

In this case, there is a separate color table for each 8-bit channel:



Using color tables for each channel

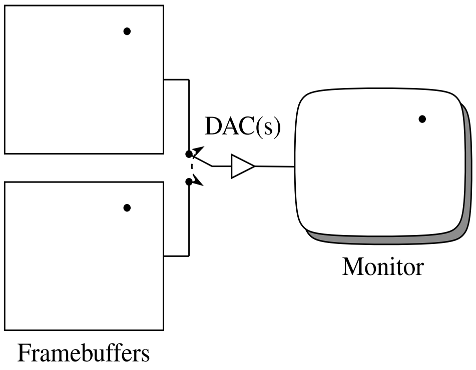
Full-color SGI's are like this.

Q: Why would you want this capability?

Double-buffering

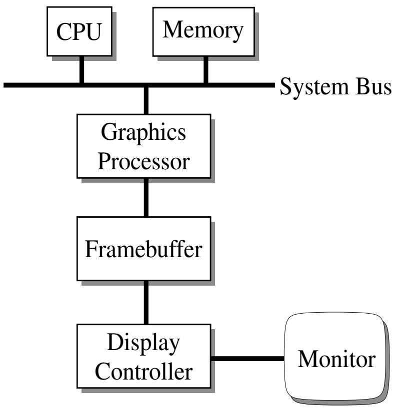
Q: What happens when you write to the framebuffer while it is being displayed on the monitor?

Solution: double-buffering.



Double-buffered display system

Raster graphics system architecture



Summary

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

1. Sketchpad (1963) was the first interactive graphics system.
2. The basic components of a B&W or color CRT.
3. All of the terms in quotation marks.
4. The difference between raster and calligraphic displays.
5. How to compute screen resolution.
6. The one-to-one correspondence between elements of framebuffer memory and pixels on the screen.
7. How red, green, and blue are mixed to form different colors.
8. How color tables work.
9. How double-buffering works.