3. Graphics Hardware

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

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


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**.

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**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**.

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**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?

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**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.

![Diagram of framebuffer, color table, and monitor]

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.

![Diagram of framebuffer, color tables, and monitor]

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.

![Diagram of double-buffering technique]
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.