3. Displays and framebuffers

**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

**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 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

**Raster**, 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

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:

<table>
<thead>
<tr>
<th>Display</th>
<th>Resolution</th>
<th>Size</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitmapped display</td>
<td>960 x 1152 x 1b</td>
<td>1/8 MB</td>
<td></td>
</tr>
<tr>
<td>NTSC TV</td>
<td>640 x 480 x 1b</td>
<td>1/2 MB</td>
<td></td>
</tr>
<tr>
<td>Color workstation</td>
<td>1280 x 1024 x 24b</td>
<td>4 MB</td>
<td></td>
</tr>
<tr>
<td>Laser-printed page</td>
<td>300 dpi</td>
<td>8.5 x 11 x 300 x 1b</td>
<td>1 MB</td>
</tr>
<tr>
<td></td>
<td>1200 dpi</td>
<td>8.5 x 11 x 1200 x 1b</td>
<td>17 MB</td>
</tr>
<tr>
<td>Film</td>
<td>4500 x 3000 x 30b</td>
<td>50 MB</td>
<td></td>
</tr>
</tbody>
</table>

Aspect ratio

Frame aspect ratio = horizontal / vertical size

<table>
<thead>
<tr>
<th>Display</th>
<th>Aspect Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV</td>
<td>4 : 3</td>
</tr>
<tr>
<td>HDTV</td>
<td>16 : 9</td>
</tr>
<tr>
<td>Letter-size paper</td>
<td>8.5 : 11 (about 3 : 4)</td>
</tr>
<tr>
<td>35mm film</td>
<td>3 : 2</td>
</tr>
<tr>
<td>Panavision</td>
<td>2.35 : 1</td>
</tr>
</tbody>
</table>

Pixel aspect ratio = pixel width / pixel height

- nowadays, this is almost 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 CRT monitors, cont’d

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?
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.

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**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**.

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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.

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**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 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?

**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?

**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.