Graphics Hardware

- Monitor (CRT, LCD,...)
- Graphics accelerator
  - Scan controller
  - Video Memory (frame buffer)
  - Display/Graphics Processor
- CPU/Memory/Disk ...

Cathode Ray Tube (CRT)

1. Filament (generate heat)
2. Cathode (emit electrons)
3. Control grid (control intensity)
4. Focus
5. Deflector
6. Phosphor coating

Color CRT

3 electron guns, 3 color phosphor dots at each pixel

Color = {red, green, blue}
Red = 0 to 100%
Green = 0 to 100%
Blue = 0 to 100%

Black = (0,0,0)
White = (1,1,1)
Red = (1,0,0)
Green = (0,1,0)
Blue = (0,0,1)
...

LED
LCD

Plasma Panels

Raster Display graphics

Digital Display
- Based on (analog) raster-scan TV technology
- The screen (and a picture) consists of discrete pixels, and each pixel has one or multiple phosphor dots

How to draw a picture?
- We have only one electron gun but many pixels in a picture need to be lit simultaneously...
Refresh

- **Refresh** - the electron gun needs to come back to hit the pixel again before it fades out
- An appropriate fresh rate depends on the property of phosphor coating
  - **Phosphor persistence**: the time it takes for the emitted light to decay to 1/10 of the original intensity
- Typical **refresh rate**: 60 – 80 times per second (Hz)
  (What will happen if refreshing is too slow or too fast?)

Random Scan Order

- Old way: No pixels - The electron gun draws straight lines from location to location on the screen (vector graphics)
  - a.k.a. calligraphic display, Random scan device, vector drawing display
  - Use either display list or storage tube technology

Raster Scan Order

- What we do now: the electron gun will scan through the pixels from left to right, top to bottom (**scanline by scanline**)

Raster Scan Order

- The electron gun will scan through the pixels from left to right, top to bottom (**scanline by scanline**)
  - Horizontal retrace
Raster Scan Order
- The electron gun will scan through the pixels from left to right, top to bottom (scanline by scanline)

Progressive vs. Interlace
- Progressive: Scan every scan line
- Interlace: Scan only every other scan line (even -> odd -> even -> odd ...)
  - so the refresh rate becomes twice as fast

Standards
- NTSC: Interlaced, 525 line, 59.94Hz, 4:3
- DTV: Digital version of NTSC, 480i, 4:3
- HDTV: commonly 720p, 60Hz, 16:9
- Blu-ray: 1080p
- Other standards?

Raster Scan Control
- Scan Controller (video adaptor) and frame buffer
Frame Buffer

- Frame buffer: the memory to hold the pixel intensity values
- Properties of a frame buffer that affect the graphics performance:
  - Size: screen resolution
  - Depth: color level
    - 1 bit/pixel: black and white
    - 8 bits/pixel: 256 levels of gray
    - 24 bits/pixel: 16 million colors
  - Speed: refresh speed
- Color is expensive ...
  - At least used to be
  - The more color you want, the more bits you will need for each pixel
  - Exercise: 1024 x 1280 screen with 24 bits per pixel, how large is the frame buffer?
    \[1024 \times 1280 \times 24 / 8 = 4M \text{ Byte}\]
    \[@30\text{fps} = 120\text{MB/sec}\]
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- Color Lookup Table
  - Say I am a poor man ... I only have 3 bits per pixel
  - But I insist on having high quality pictures ...
  - Use Color Look Up Table (LUT)
  - 3 bits/pixel frame buffer
    - You can still have 24 bits in each of the color table entries

A simple graphics system

- Frame buffer can be part of the main memory
- Problem?
Dedicated memory

Video memory: On-board frame buffer: much faster to access

Graphics Accelerator

A dedicated processor for graphics processing

CPUs vs. GPUs

<table>
<thead>
<tr>
<th>Pentium Extreme Edition 840</th>
<th>GeForce 7800 GTX</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2 GHz Dual Core</td>
<td>430 MHz</td>
</tr>
<tr>
<td>230M Transistors</td>
<td>362M Transistors</td>
</tr>
<tr>
<td>90nm process</td>
<td>110nm process</td>
</tr>
<tr>
<td>206 mm²</td>
<td>250 mm²</td>
</tr>
<tr>
<td>2x 1MB Cache</td>
<td>315 GFlops (shader)</td>
</tr>
<tr>
<td>25.6 GFlops</td>
<td>1.3 TFlops (total)</td>
</tr>
</tbody>
</table>
The Graphics Pipeline

Evolution of Performance

Graphics Bus Interface

PCI based technology

- Graphics Memory/Frame buffer
- Graphics Processor
- Scan Controller
- Other Peripherals
- System Bus - 800MB/s
- CPU
- Main Memory
- PCI Bus - 132 MB/s

The Graphics Pipeline (2)

- PCI Bus becomes the bottleneck!
  - Many devices are using it
  - There is a lot of stuff needs to be transmitted from main memory to graphics memory (geometry, textures, etc)
  - Example: 2M triangle, 90 Bytes each - 180MB > 132 MB (PCI bandwidth)
Accelerated Graphics Port (AGP)

A dedicated bus that allows direct access of main memory

- AGP 1x is four times as fast compared to PCI! (now we have AGP 8x)
- No more local bus congestion!
- More geometry can be processed!
- Direct execution of many graphics operations from main memory

 PCI Express

- Bandwidth?

Reading and Lab0

- Textbook Chapter 1, 2

Lab 0: Compile and run the sample OpenGL program posted on the class web site