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

Display Technologies
- Front projection
- Back projection
- Direct view
- Backlit

Display Technologies
- CRT
- LED
- LCD
- Plasma Panels
- DLP
- OLED
- Etc.

Trade-offs
- Cost, Weight, Size
- Power consumption
- Spatial & Color resolution
- Peak brightness, Black, contrast
- Etc.
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

- Direct view
- Backlight source
**LCD:** backlit

**Plasma Panels:** emit light; soon extinct?

**DLP:** http://www.dlp.com/includes/video_demo.aspx

For digital projection

Digital Micromirror Device

**Trade-offs**

- Peak brightness
- Black level
- Contrast
- Screen brightness
- Motion artifacts
- Aging
- Maximum resolution
- Thickness
- Weight
- Power consumption

http://www.displaymate.com/ShootOut_Comparison.htm
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

Vector graphics

- Display list:
  - Move (100,200)
  - Draw (200,200)
  - Draw (200,100)
  - Draw (100,100)

Raster Display graphics

- Digital Display:
  - Based on (analog) raster-scan TV technology
  - The screen (and a picture) consists of discrete pixels

How CRT draws a picture

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

- **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?)

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

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: e.g. 720p, 60Hz, 16:9
- Blu-ray: 1080p
- Other standards?

**Raster Scan Control**

- Scan Controller (video adaptor) and frame buffer
**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 many bytes in the frame buffer?
  \[1024 \times 1280 \times 24 / 8 = 4M \text{ Byte}\]
  \[@30fps = 120MB/sec\]

**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)

![Color Look Up Table Diagram]

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

![Simple Graphics System Diagram]

**Dedicated memory**

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

![Dedicated Memory Diagram]
A dedicated processor for graphics processing

Graphics Accelerator

Graphics Memory/Frame buffer
Graphics Processor
Scan Controller

CPU
Main Memory
System bus

Graphics Accelerator

NVIDIA GPUs

Quadro FX 5600
Memory Size 1.5GB GDDR3
Memory Interface 384-bit
Memory Bandwidth 76.8 GB/sec.
Max Power Consumption 171W
Number of Slots 2
Display Connectors DVI-I DVI-I Stereo
Dual-Link DVI 2
Price $2,999.00

Quadro FX 4600
Memory Size 768MB GDDR3
Memory Interface 384-bit
Memory Bandwidth 67.2 GB/sec.
Max Power Consumption 134W
Number of Slots 2
Display Connectors DVI-I DVI-I Stereo
Dual-Link DVI 2
Price $1,999.00
**AMD GPUs**

### Desktop vs Mobility Radeon Graphics

<table>
<thead>
<tr>
<th></th>
<th>Desktop Radeon HD 6990</th>
<th>Desktop Radeon HD 6870</th>
<th>Radeon HD 6990M</th>
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<tr>
<td>Transistors</td>
<td>5.28 billion</td>
<td>1.7 billion</td>
<td>1.7 billion</td>
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<tr>
<td>Engine Clock</td>
<td>850 MHz</td>
<td>900 MHz</td>
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<td>3072</td>
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<td>Texture Units</td>
<td>192</td>
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<td>32</td>
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<td>3.1 TFLOPS</td>
<td>2.0 TFLOPS</td>
<td>1.60 TFLOPS</td>
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<td>GDDR5-4200</td>
<td>GDDR5-3600</td>
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<td>DRAM Interface</td>
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<tr>
<td>Memory Bandwidth</td>
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<td>134 GB/s</td>
<td>115.2 GB/s</td>
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<td>375 W</td>
<td>151 W</td>
<td>100 W</td>
</tr>
</tbody>
</table>

### Evolution of Performance

![Evolution of Performance Chart](image)

**The Evolution of GPUs**


**The GPU Computing Era**


**The Graphics Pipeline**

![The Graphics Pipeline Diagram](image)
**Graphics Bus Interface**

PCI based technology

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

**Graphics Bus Interface (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)

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**Accelerated Graphics Port (AGP)**

A dedicated bus that allows direct access of main memory

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

**AGP**

- 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?

![Diagram showing bandwidth between GPU and Core Logic]

Reading and Lab1

- Textbook Chapter 1, 2

Lab 1: Compile and run the sample OpenGL program posted on the class web site