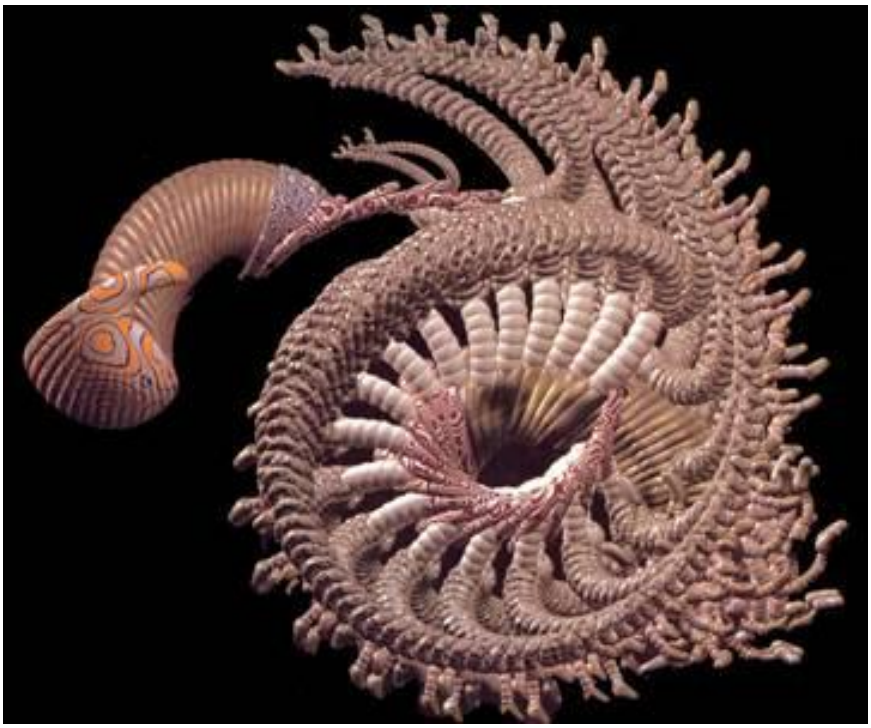
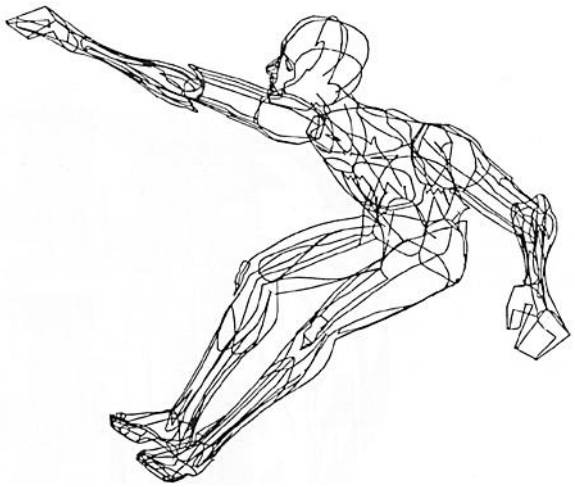
Introduction



Geometric model based on rules that govern patterns of natural forms (William Latham, SIGGRAPH 1992).

What is Computer Graphics?

- Computer graphics generally means creation, storage manipulation, and simulation of **models** and images
- Such models come from diverse and expanding set of fields including physical, mathematical, artistic, biological domains, and even the humanities



William Fetter coined the term "computer graphics" in 1960 to describe new design methods he was pursuing at Boeing; He used a 3D model of human body to create a series of widely-reproduced images on pen-plotter exploring cockpit design.

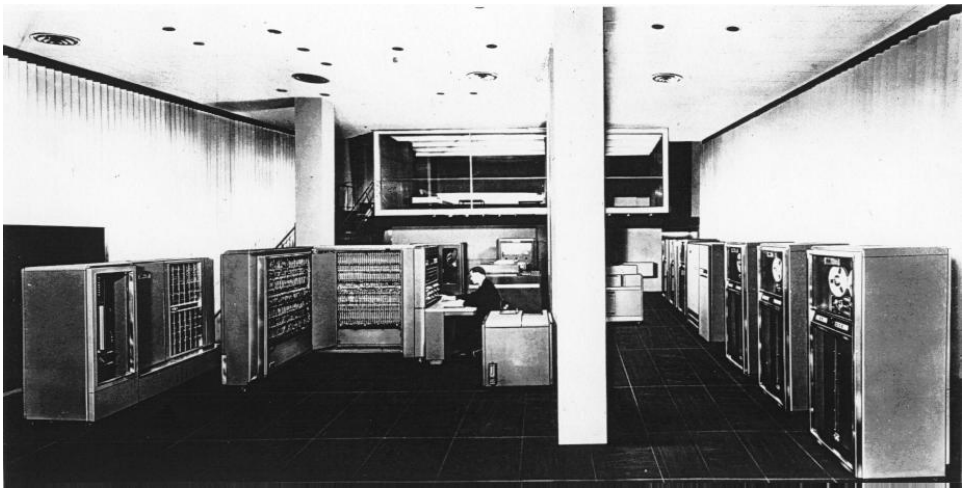
What is Interactive Computer Graphics?

- User controls contents, structure, and appearance of models and their displayed images via rapid visual feedback
- Basic components of an interactive graphics system
  - input (e.g., mouse, tablet and stylus, force feedback device, scanner, live video streams…)
  - processing (and storage)
  - display/output (e.g., screen, paper-based printer, video recorder, non-linear editor…)
- First truly interactive graphics system, Sketchpad, pioneered by Ivan Sutherland for his 1963 Ph.D. thesis (MIT)

Sketchpad in 1963. Note use of a CRT monitor, light pen and function-key panel.

NON-Interactive Computer Graphics?

- Before Sketchpad, output via plotters/printers, input via keypunch, both in batch (1950-now)



Card punching (left). IBM 704 (right) took up a whole room and was capable of about 4,000 arithmetic operations/second.

- Today, still use batch mode for final production-quality video and film (special effects – fx), where one frame of a 24 fps movie may take 8-24 hours to render on fastest PC!

Render farm

Modern Computer Graphics

Enabled by hardware revolution

- **Moore's Law**: every 12-18 months, computer power improves by factor of 2 in price / performance as feature size shrinks
- Graphics chips are on even faster exponentials: major improvements every six to nine months
  - NVIDIA GTX 480… 1344.96 gigaflops

nVidia GoForce™ chip
(cellphones and PDAs)

- Newest processors are 64-bit, 2, 4, 6, 8, or 12 core
  - Intel Core i7 – consumer, 4 cores hyperthreaded to provide 8 threads
  - Intel Westmere EX – industrial, 12 cores HT, 24 threads

Modern Computer Graphics

Hardware revolution (cont'd)

- Graphic subsystems
  - Offloads graphics processing from CPU
  - nVidia GeForce™, ATI Radeon™
- GPU has led to development of other dedicated subsystems
  - Physics: nVidia PhysX PPU (Physics Processing Unit), standard on many NVIDIA GPUs
  - Artificial Intelligence: IBM Watson
- Novel Input Devices

Modern Computer Graphics

Software Evolution

- Models, algorithms and data structures
  - Modeling of materials
  - Rendering of natural phenomena
  - "Acceleration data structures" for ray tracing
- Parallelization
  - Most operations are embarrassingly parallel: changing value of one pixel is often independent of other pixels
- Distributed and Cloud computing
  - Send operations into 'cloud', get back results, don't care how
  - Rendering even available as internet service!

Environmental Evolution (1/5)

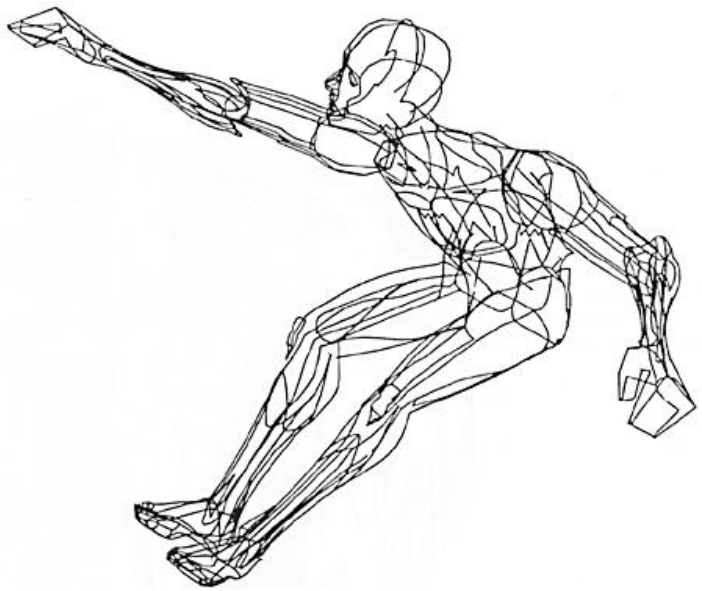
Character Displays (1960s – now)

- **Display:** text plus pseudo-graphics
- **Object and command specification:** command-line typing
- **Control over appearance:** coding for text formatting (.p = paragraph, .i 5 = indent 5)

Environmental Evolution (2/5)

Vector (Calligraphic) Displays (1963 – 1980s)

- **Display:** line drawings and stroke text; 2D and 3D transformation hardware
- **Object and command specification:** command-line typing, function keys, menus
- **Control over appearance:** pseudo-WYSIWYG



- Term "vector" graphics survives as "scalable vector graphics" library from Adobe – shapes as transformable objects rather than just bitmaps

Environmental Evolution (3/5)

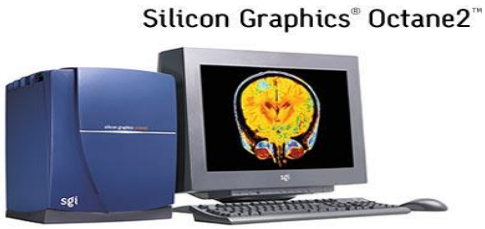
Raster displays for PCs and workstations
(1972 at Xerox PARC - now)

- **Display:** windows, icons, legible text, "flat" graphics
  Note: late 60's saw first use of raster graphics, especially for flight simulators
- **Object and command specification:** minimal typing via WIMP (Windows, Icons, Menus, Pointer) GUI: point-and-click selection of menu items and objects, widgets and direct manipulation (e.g., drag and drop), "messy desktop" metaphor
- **Control over appearance:** WYSIWYG (which is really WYSIAYG, What You See Is **All** You Get)

Environmental Evolution (4/5)

3D graphics workstations (1984 at SGI – now)

- Display: real-time, pseudo-realistic images of 3D scenes
- Object and command specification: 2D, 3D and nD input devices (controlling 3+ degrees of freedom) and force feedback haptic devices for point-and-click, widgets, and direct manipulation
- Control over appearance: WYSIWYG
- Application control: multi-tasking, networked (client/server) computation and window management



Graphics workstations such as these have been replaced with commodity hardware (GPUs)

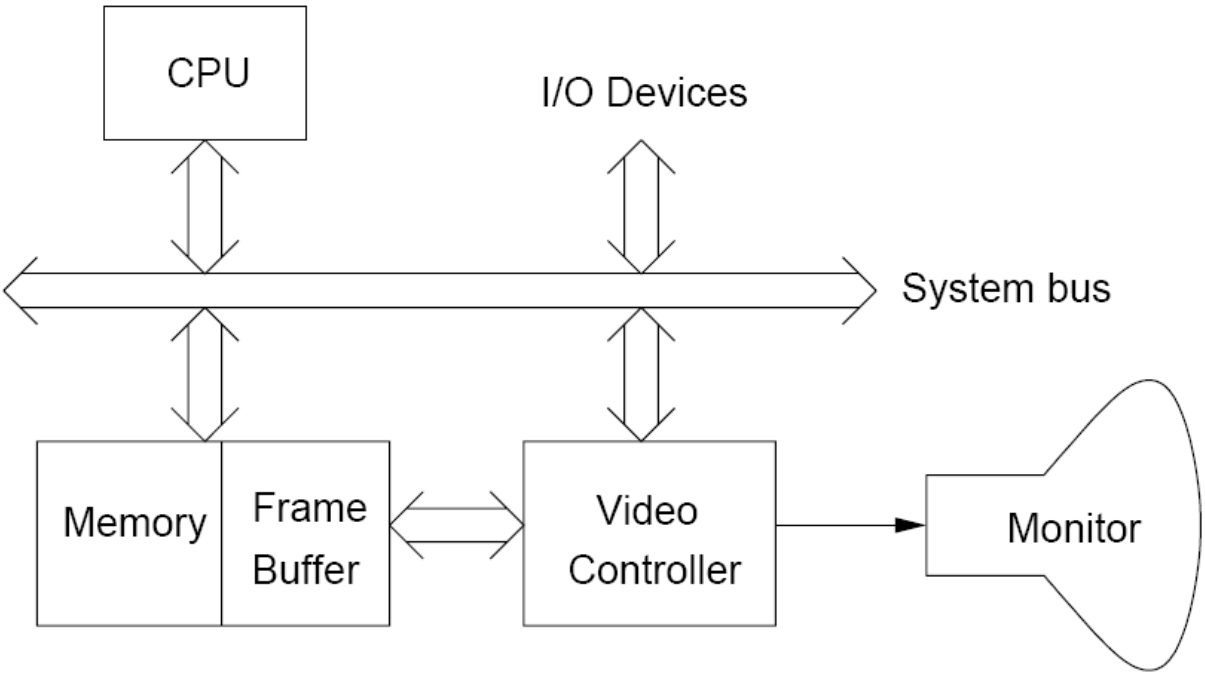
Environmental Evolution (5/5)

High-end PCs with graphics cards (nVidia GeForce™, ATI Radeon™)

- Have supplanted graphics workstations
- Such PCs are clustered together over high speed buses or LANs to provide "scalable graphics" to drive tiled PowerWalls, Caves, etc.
  - Now accessible to consumers via new technologies

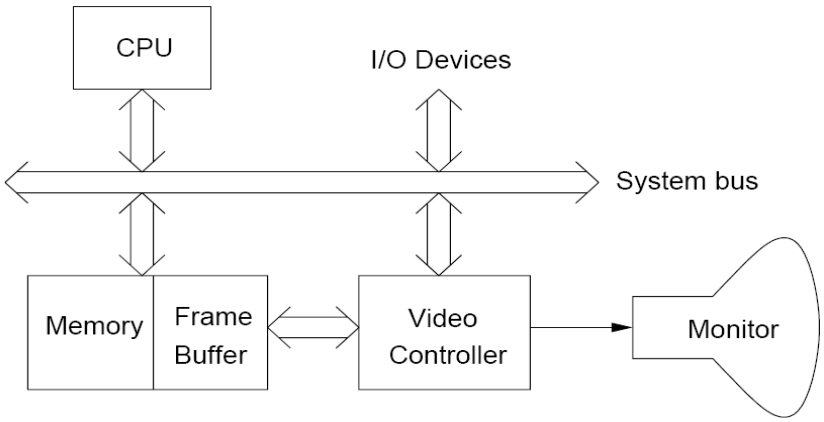
Can put multiple GPUs together in a computer using NVIDIA's SLI bridge.

The Graphics Card (1/3)

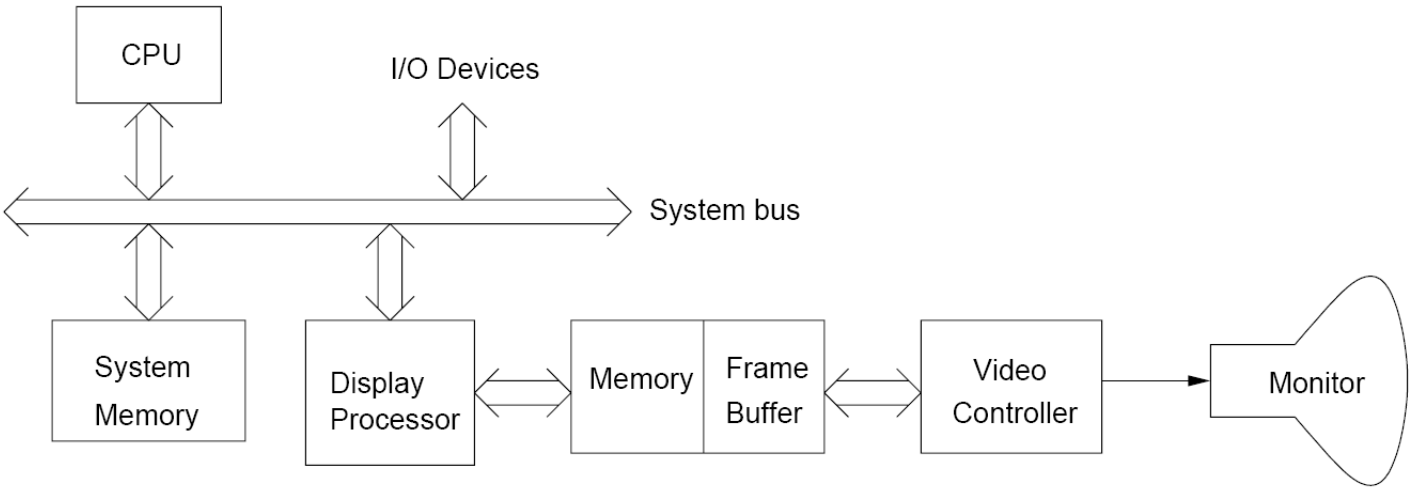


Simple Raster Graphics System

The Graphics Card (2/3)



Simple Raster Graphics System



Raster Graphics with Display Processor

(i.e., graphics card or video card)

The Graphics Card (3/3)

- relieves the computer's main processor from much of the mundane repetitive effort involved in maintaining the frame buffer

- typically, it provides assistance for a number of operations including the following:

  - **Transformations:** Rotations and scalings used for moving objects and the viewer's location.

  - **Clipping:** Removing elements that lie outside the viewing window.

  - **Projection:** Applying the appropriate perspective transformations.

  - **Shading and Coloring:** The color of a pixel may be altered by increasing its brightness. Simple shading involves smooth blending between some given values. Modern graphics cards support more complex procedural shading.

  - **Texturing:** Coloring objects by "painting" textures onto their surface. Textures may be generated by images or by procedures.

  - **Hidden-surface elimination:** Determines which of the various objects that project to the same pixel is closest to the viewer and hence is displayed.

Recap

- CG = creation (i.e., modeling), storage and manipulation (i.e., simulation, animation, interaction) of objects and images

- Interactive CG = control via rapid visual feedback; Sketchpad!

- CG evolution: enabled by hw&sw evolution; stages:
  - character displays (1960 -)
  - vector displays (1963 – 1980)
  - raster displays (1972 – now)
  - 3D gfx workstations (1984 – now)
  - high-end PCs with graphics cards (1990 – now)

- Graphics card = dedicated processor