CS-423: Computer Graphics

Computer Graphics

- *Computer graphics* deals with all aspects of creating images with a computer
  - Hardware
  - Software
  - Applications

Example

- Where did this image come from?

- What hardware/software did we need to produce it?

3

What is this course about?

- To learn essential computer graphics concepts
- To learn how to write computer graphics applications in OpenGL.

Learning Goals and Objectives

- What do we expect to gain from this course?
  1. To learn the state of the art computer graphics techniques
  2. Development and implementation of graphics algorithms
  3. Necessary mathematics
  4. Graphics programming skills for 2D and 3D
  5. Learning at least one standard graphics library and its use (OpenGL)

Pre-requisites

- Linear Algebra
- Data Structures
- Algorithms
- The course requires:
  1. Substantial programming effort.
  2. Frequent use of concepts from algebra, geometry, trigonometry and calculus.

Course Contents

1. Introduction to Computer Graphics
2. Mathematical Preliminaries
3. Introduction to OpenGL
4. Drawing Figures (clipping, transformations)
5. Vector Tools for Graphics
6. Transformation of Objects
7. Modeling Shapes with Polygonal Meshes
8. Three Dimensional Viewing
9. Rendering
10. Ray Tracing
11. Texture Mapping

Recommended Texts

1. Computer Graphics using OpenGL by F.S. Hill Jr., Stephen M. Kelley, 3rd Edition, 2009.

2. Computer Graphics using OpenGL by Donald Hearn, M. Pauline Baker, 3rd Edition, 2003.

Why Study Computer Graphics?

- Some people want a better set of tools for plotting curves and presenting the data they encounter in their other studies or work.
- Some want to write computer-animated games, while others are looking for a new medium for artistic expression.
- Most people want to be more productive, and to communicate ideas better, and computer graphics can be a great help.

What is Computer Graphics?

- The **computer graphics** is one of the most effective and commonly used way to information in form of graphics object such as pictures, charts, graphs and diagram instead of simple text.

- **Computer graphics** is a process of generating, manipulating, storing and displaying graphics object.

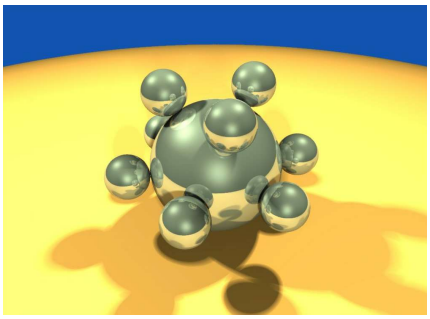
  Ex: Such as pictures, charts, graphs, diagrams.

What is Computer Graphics?

- Different people have different meanings:
  - Computer graphics are the **pictures** generated by a computer.
  - Computer graphics refers to the **tools** that are used to make/process pictures.
- In general when we say computer graphics, we mean a **field of study** involving various tools and the pictures produced by them

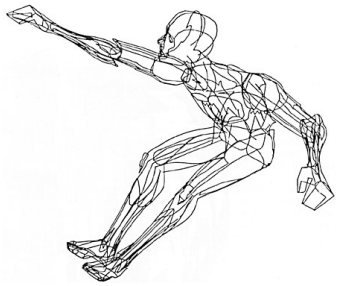
What is Computer Graphics?

- Pictures generated by a computer
  - Example: a ray-traced picture with shadows.



History

- William Fetter while working at Boeing in 1960 used the term "computer graphics" for the first time to describe his models.
- He was working on making 3D model of human body to explore various cockpit designs. For this purpose he used pen plotter to produce a number of wireframe models of the human body.

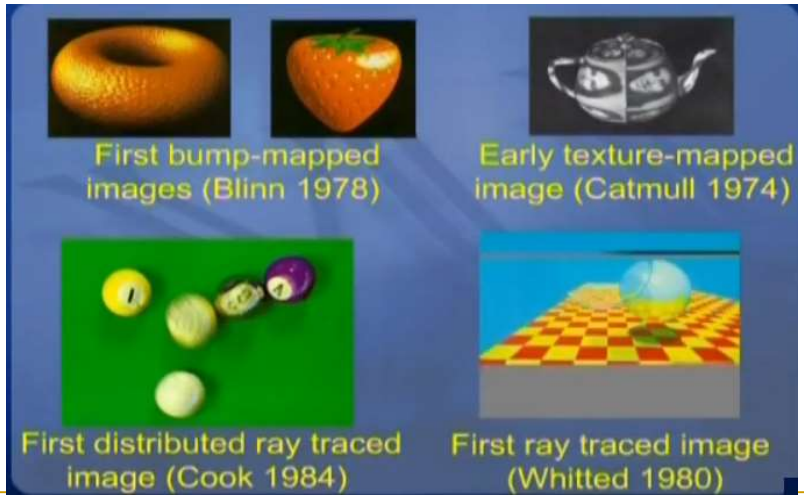


History

- The field of computer graphics is acknowledged by many to have started with the pioneering PhD thesis at MIT in 1963 of Ivan Sutherland.
- He developed the first interactive graphics system "Sketchpad", based on the use of a light-pen, CRT display and function-key panel.

History

History



Basics of Computer Graphics

- Thus we can say that computer graphics makes it possible to express data in pictorial form.
- In computer graphics objects are presented as a collection of discrete picture elements.
- **Picture Element = Pixel**
- The **pixel** is the smallest screen elements.

Basics of Computer Graphics

- **What you can do with graphics before displaying it on screen?**

✓ Graphics allows rotation, translation, scaling and performing various projections before displaying it.

✓ It also allows to add effects such as hidden surface removal, shading and transparency to the picture.

Basics of Computer Graphics

- User can edit (modify content, structure or appearance) graphics object with using keyboard, mouse or touch sensitive panel on the screen.
- There is close relationship between input devices and display devices.
- **Graphics Devices = Input Devices + Display Devices**

Advantages of Computer Graphics

- High quality graphics displays on PC
- It provides tools for producing pictures
- Produce animation using static image with computer graphics
- Produce 1-D image in 2-D or 3-D using different simulators.
- Using motion dynamics tool, user can make object stationary and the viewer moving around them.
- Using update dynamics, it is possible to change the shape, colour or other properties of object.

Applications of Computer Graphics

- Presentation Graphics
- Graphics User Interface
- Computer Art
- Telemedicine
- Education
- Entertainment
- Auto CAD
- Virtual Reality
- Image Processing

Presentation Graphics

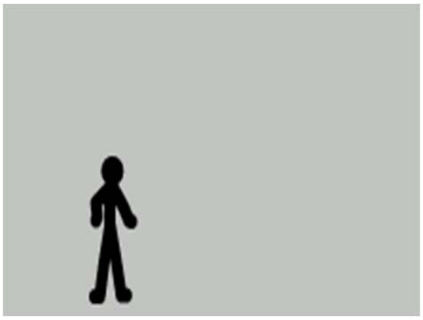
- In this application reports are generated on slides or transparencies.
- It is normally used to summarize financial, statistical, mathematical, scientific, and economics data for research.
- Graphs and charts can be in 3-D formats to make the presentation.

Presentation Graphics

Charts/Graphs

Entertainment

- It is used in making motion pictures, music, videos and television shows.

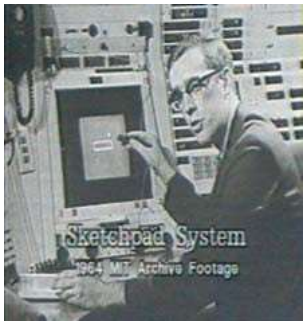


Graphical User Interface

- Major component of GUI interface is a window manager that allows a user to display multimedia window areas.
- Interface generally comes with a menu and icons for fast selection of processing options.
- Icon is a graphics symbol designed to look like a processing options.

Graphical User Interface

User Interfaces



Ivan Sutherland, Sketchpad, Light-pen, vector display

Apple iPad

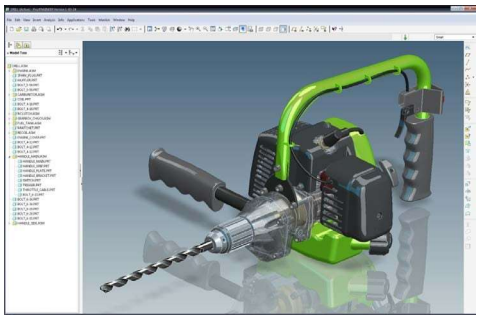
Console Controller

Computer-aided Design

- E.g., drills, or houses. The computer version is easy to alter if necessary.
  - Analysis and simulation can be used also. The shape of the drill might look nice, but the casing might be too weak or too heavy, or might be uncomfortable to grip.
  - Algorithms can be applied to the model of the drill to analyze its weight and heft, and to test whether the inner workings of the drill will fit properly inside the casing.

Computer-Aided Design

Sketchup

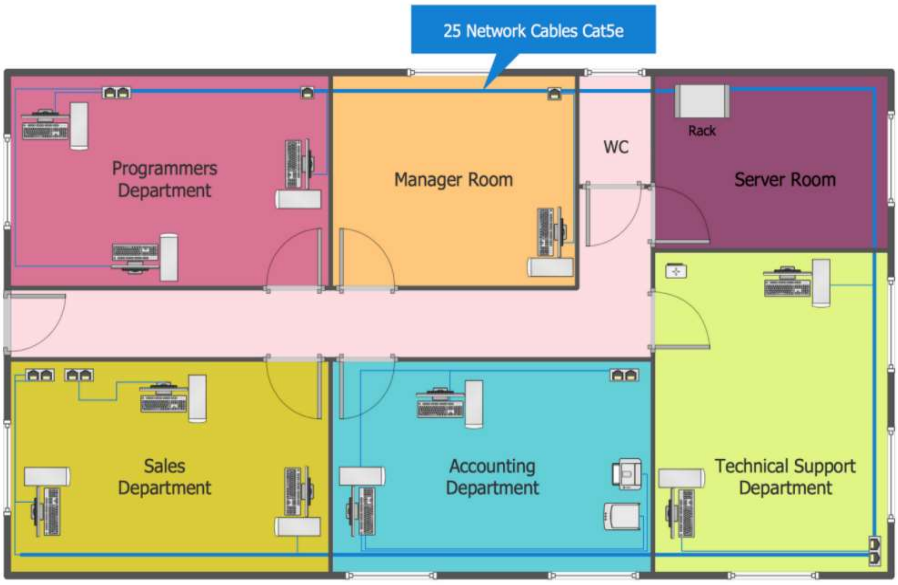


ProEngineer

Auto CAD

- Use of computer graphics is in design process of engineering and architecture system.
- Auto cad applications are design to create building, automobiles, aircraft, spacecraft, textiles and more models.

Auto CAD



31

Computer Art

- Computer graphics widely used in fine arts and commercial applications.
- Artist use a variety of applications like paint packages, mathematics packages, desktop publishing software and animation program.

32

Art, Entertainment and Publishing

- Computer graphics are widely used in the production of movies, television programs, books, games, and magazines.

Art, Entertainment and Publishing

- **Browsing on the World Wide Web:** the browser must rapidly interpret the data on a page and draw it on the screen as high quality text and graphics.
- **Slide, Book, and Magazine Design:** Computer graphics are used in **page layout** programs to design the final look of each page of a book or magazine. The user can interactively move text and graphics around to find the most pleasing arrangement.

Art, Entertainment and Publishing

- A **paint system** generates images. A common example of a paint system and photo manipulation system is *Adobe Photoshop®*.

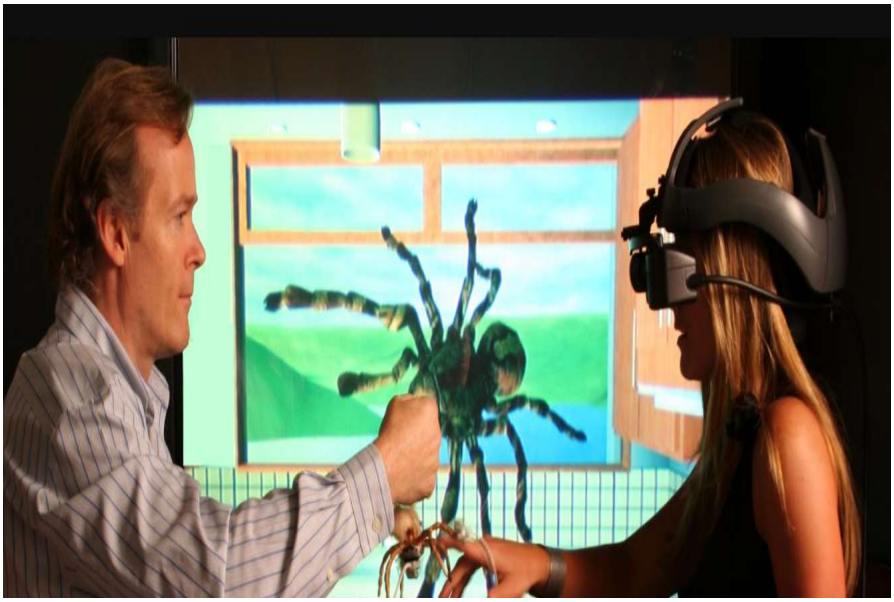
Computer Art

Virtual Reality

- Virtual reality provides a very realistic effect using sight and sound, while allowing the user to interact with the virtual world.

37

Virtual Reality



38

Virtual (and Augmented) Reality

Ivan Sutherland: Head-mounted displays, with mechanical tracker

Oculus Rift

Telemedicine

- In this application physician can consult with one another using video conferencing capabilities, where all can see the data and images, it brings together experts from a number of places in order to provide better care.
- Also used in bio-medical instrument like cardiogram, CT-Scan reports, X-ray.

Telemedicine

41

Image Processing

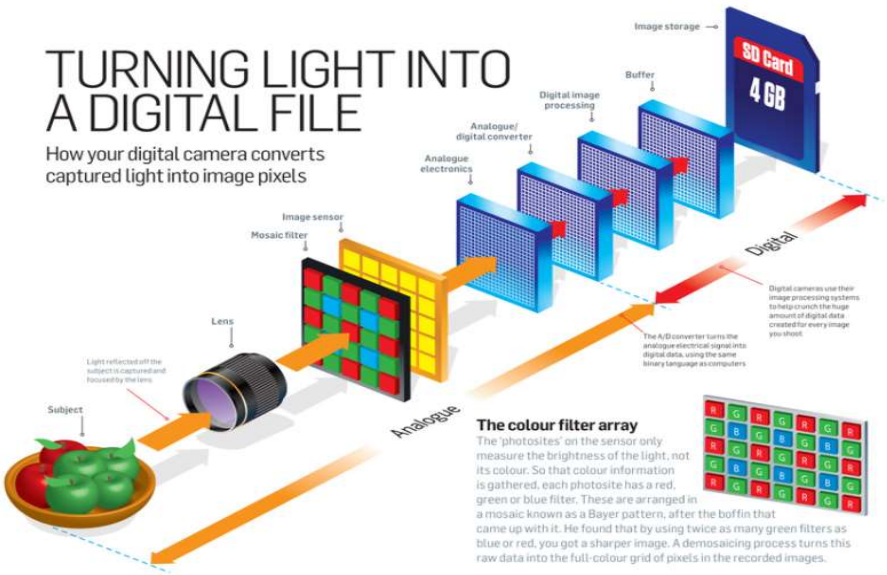
- Image processing, converts an existing image into digitized form by converting the image file format.
- Image processing technique is mostly used in commercial application that can rearrange/modify image in different format.

42

Image Processing

- Computer graphics create pictures and images based on some description, or model, in a computer.
- Image processing improves or alters images that were created elsewhere.
  - Processing can remove noise from an image, enhance its contrast, sharpen its edges, and fix its colors.
  - Software routines can search for certain features in an image, and highlight them to make them more noticeable or understandable.

Image Processing



2D Image Processing

45

Education

- A wide range of individual education software with multimedia.
- It is also used in classroom to enhance the educational experience and simplify teacher's work.
- In distance learning, where all students may not be at same place during a class.

46

Displaying Simulations

- **Flight simulator**: the system is a plane with a shape and flying characteristics, along with a world consisting of a landing field, mountains, other planes, and air, all modeled appropriately.

Visual Simulation and Training

- Apollo spacecraft
- Flight simulators
- Driving simulators
- Surgical simulation

Davinci surgical robot
Intuitive Surgical

Driving simulator
Toyota Higashifuji Technical Center

Digital Media Technologies

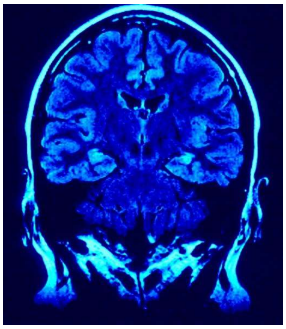
- Digital photography
- Inkjet and laser printers
- Digital video and HDTV
  - Electronic books
  - Graphics on the web:
    - Photos (flickr)
    - Videos (youtube)

Sony Video Camera

Apple Laserwriter

Volume Visualization

- Areas of different colors immediately inform a physician about the health of each part of the brain.



Scientific Visualization

The Virtual Human
Karl-Heinz Hoehne

Outside-In
The Geometry Center

51

Video Games

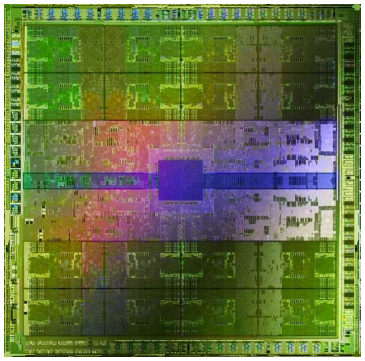
Spore

Crysis

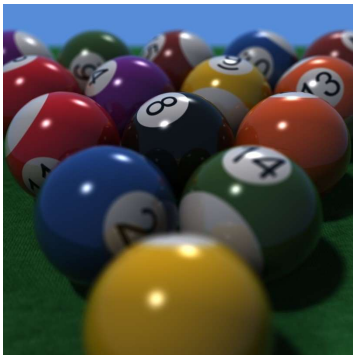
Braid

52

Graphics Hardware

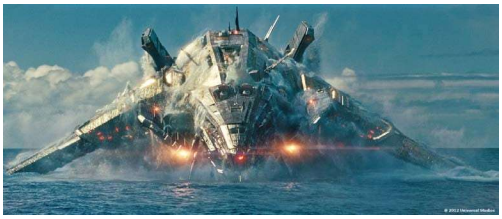


NVIDIA Fermi



NVIDIA OptiX

Visual Effects (VFX): Liquids



Battleship

The Day After Tomorrow

Terminator 2

VFX: Gases

Harry Potter and the Order of the Phoenix

Terminator 3

Star Wars Episode III

VFX: Solids

- Destruction: fracture, explosions, etc.

Super 8

2012

VFX: CG Creatures

Yoda, Star Wars Episode II

Sméagol/Gollum, The Lord of the Rings

57

VFX: Digital Doubles

The Curious Case of Benjamin Button

58

Motion Capture Technology

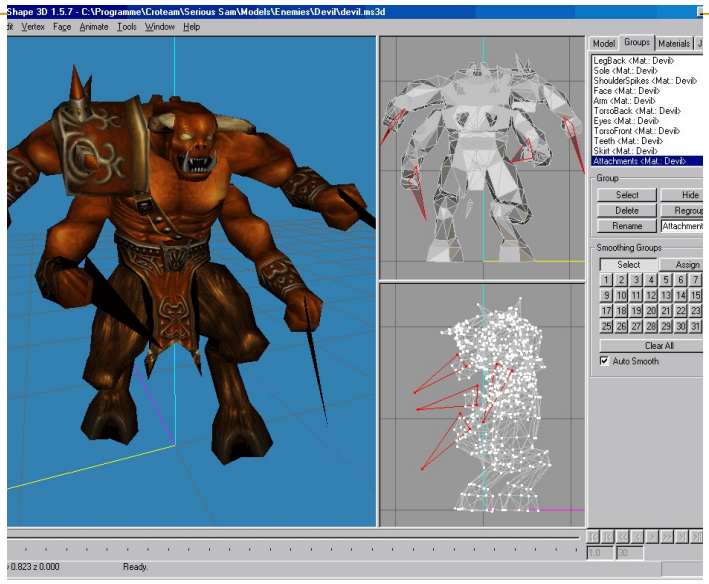
Facial capture in Avatar

Motion capture of Olympic swimmer Dana Vollmer by Manhattan Mocap
(technology transition)

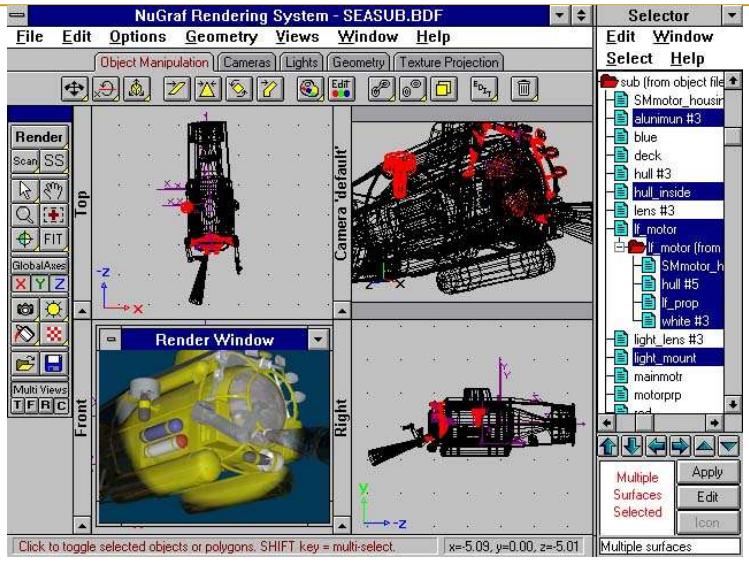
Animated Films

Toy Story 3

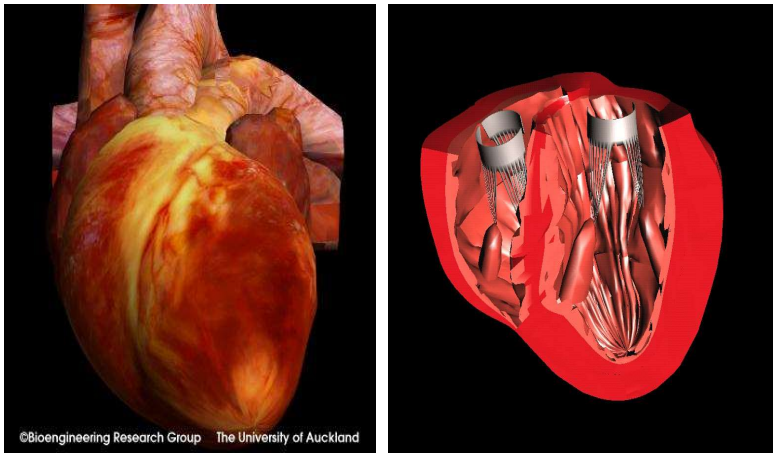
Monsters, Inc.



Game Character building using 3d Studio Max

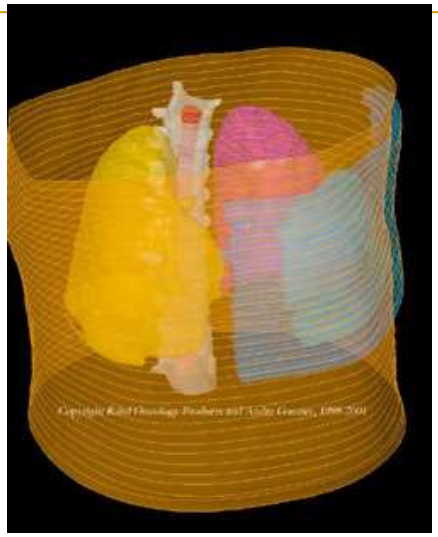


Wire frame models and rendering in Maya



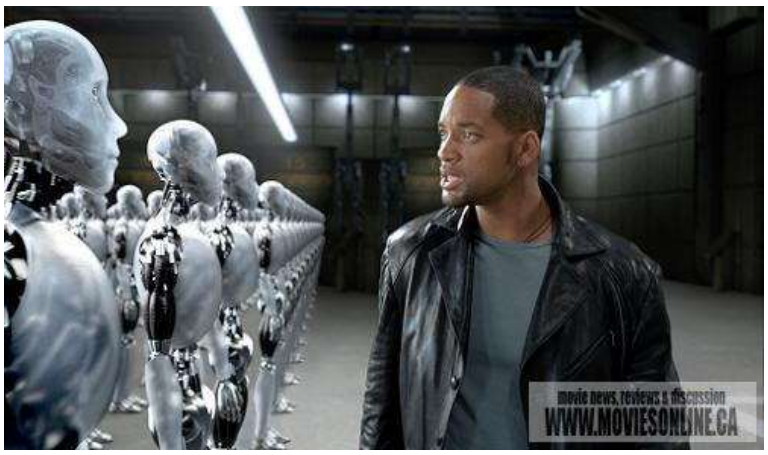
A virtually realistic model of the heart using computer graphics

63



A virtually realistic model of the lungs using computer graphics

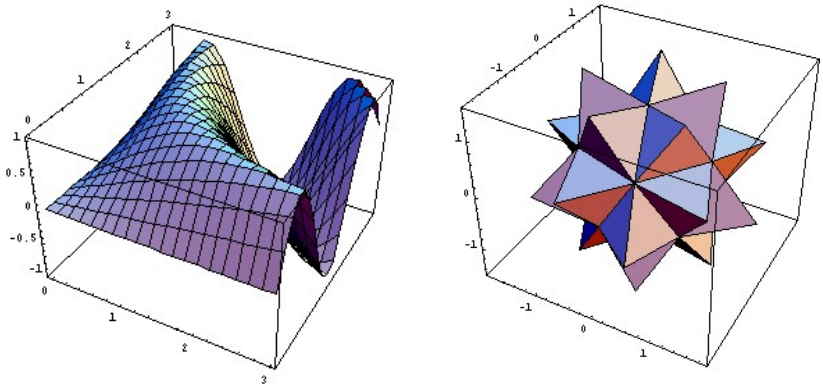
64



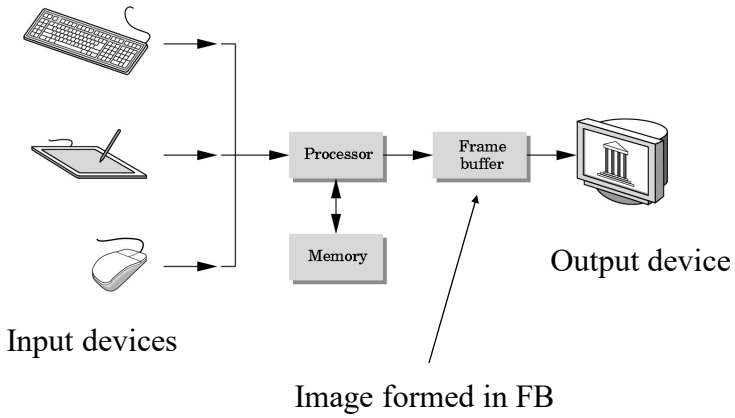
A scene from the movie I-Robot

Displaying Mathematical Functions

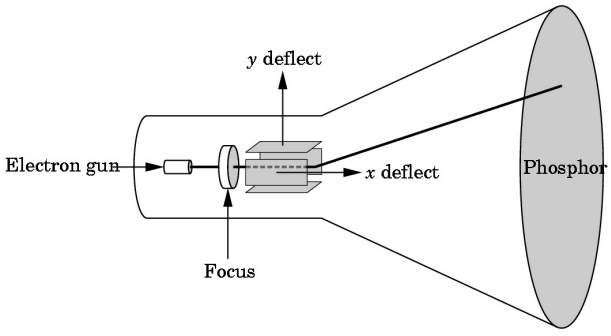
- E.g., Mathematica®



Basic Graphics System



CRT



Can be used either as a line-drawing device (calligraphic) or to display contents of frame buffer (raster mode)

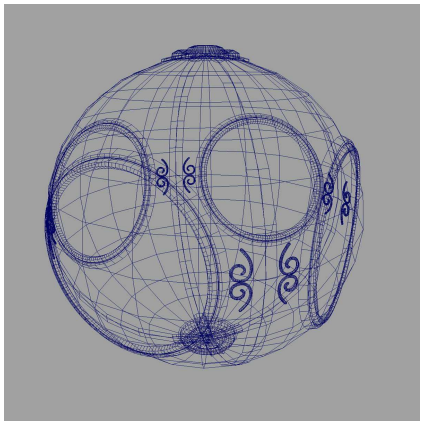
Computer Graphics: 1950-1960

- Computer graphics goes back to the earliest days of computing
  - Strip charts
  - Pen plotters
  - Simple displays using A/D converters to go from computer to calligraphic CRT
- Cost of refresh for CRT too high
  - Computers slow, expensive, unreliable

Computer Graphics: 1960-1970

- *Wireframe* graphics
  - Draw only lines
- Sketchpad
- Display Processors
- Storage tube

wireframe representation of sun object

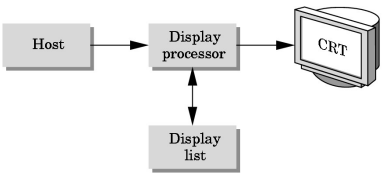


Sketchpad

- Ivan Sutherland's PhD thesis at MIT
  - Recognized the potential of man-machine interaction
  - Loop
    - Display something
    - User moves light pen
    - Computer generates new display
  - Sutherland also created many of the now common algorithms for computer graphics

Display Processor

- Rather than have the host computer try to refresh display use a special purpose computer called a *display processor* (DPU)



- Graphics stored in display list (display file) on display processor
- Host *compiles* display list and sends to DPU

Direct View Storage Tube

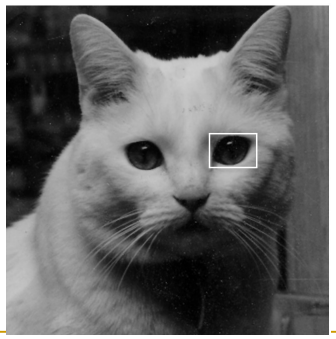
- Created by Tektronix
  - Did not require constant refresh
  - Standard interface to computers
    - Allowed for standard software
    - Plot3D in Fortran
  - Relatively inexpensive
    - Opened door to use of computer graphics for CAD community

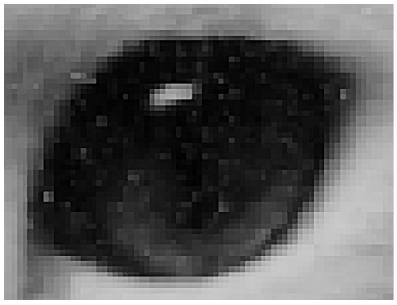
Computer Graphics: 1970-1980

- Raster Graphics
- Beginning of graphics standards
  - IFIPS
    - GKS: European effort
      - Becomes ISO 2D standard
    - Core: North American effort
      - 3D but fails to become ISO standard
- Workstations and PCs

Raster Graphics

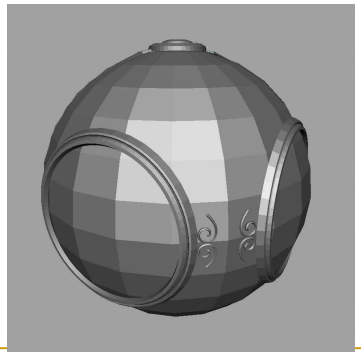
- Image produced as an array (the *raster*) of picture elements (*pixels*) in the *frame buffer*





Raster Graphics

- Allows us to go from lines and wire frame images to filled polygons

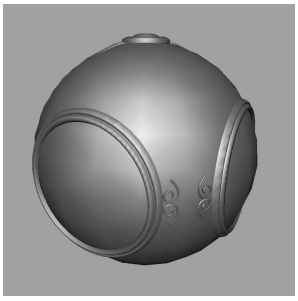


PCs and Workstations

- Although we no longer make the distinction between workstations and PCs, historically they evolved from different roots
  - Early workstations characterized by
    - Networked connection: client-server model
    - High-level of interactivity
  - Early PCs included frame buffer as part of user memory
    - Easy to change contents and create images

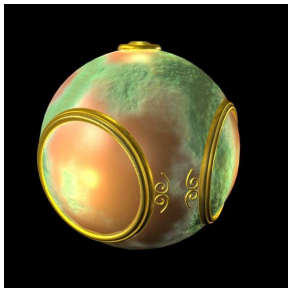
Computer Graphics: 1980-1990

Realism comes to computer graphics



smooth shading

environment mapping



bump mapping

Computer Graphics: 1980-1990

- Special purpose hardware
  - Silicon Graphics geometry engine
    - VLSI implementation of graphics pipeline
- Industry-based standards
  - PHIGS
  - RenderMan
- Networked graphics: X Window System
- Human-Computer Interface (HCI)

Computer Graphics: 1990-2000

- OpenGL API
- Completely computer-generated feature-length movies (Toy Story) are successful
- New hardware capabilities
  - Texture mapping
  - Blending
  - Accumulation, stencil buffers

Computer Graphics: 2000-2010

- Photorealism
- Graphics cards (GPU) for PCs dominate market
  - Nvidia, ATI
- Game boxes and game players determine direction of market (Wii, Kinect, etc)
- Computer graphics routine in movie industry: Maya, Lightwave
- Programmable pipelines

Computer Graphics: 2010-

- Mobile Computing
  - iPhone
- Cloud Computing
  - Amazon Web Services (AWS)
- Virtual Reality
  - Oculus Rift
- Artificial Intelligence
  - Big Data/Deep Learning
  - Google Car

Computer Graphics Tools

- Tools are both software and hardware.
  - Hardware tools include video monitors, graphics cards, and printers that display graphics.
  - They also include input devices such as a mouse, data glove, or trackball that let users point to items and draw figures.

Computer Graphics Tools (2)

- Software tools: the operating system, editor, compiler, and debugger you commonly use.
  - Graphics routines: e.g., functions to draw a simple line or circle (or characters such as **G**).
  - Functions to manage windows with pull-down menus, input, and dialog boxes.
  - Functions to allow the programmer to set up a camera in 3D coordinate system and take snapshots of objects.

Device Independent Graphics

- *Device independent graphics* libraries that allow the programmer to use a common set of functions within an application, and to run the *same* application on a variety of systems and displays are available.
- OpenGL is such a library, and is the tool we shall use in this course. The OpenGL way of creating graphics is used widely in both academia and industry.

Presentation Options

- **Frame-by-frame:** A single frame can be drawn while the user waits. (very boring)
- **Frame-by-frame under control of the user:** A sequence of frames can be drawn, as in a PowerPoint® presentation; the user presses a key to move onto the next slide, but otherwise has no way of interacting with the slides. (much less boring)

Presentation Options

- **Animation:** A sequence of frames proceeds at a particular rate while the user watches with delight; (exciting, as in such animated movies as The Incredibles® and Shrek®)
- **Interactive Program:** In an interactive graphics experience, the user controls the flow from one frame to another using an input device such as a mouse or keyboard in a manner that was unpredictable at the time the program was written. This can delight the eye. A computer game is a familiar case of an interactive graphics presentation. (delightful!)

More Applications

1. Art, Entertainment and Publishing
    1. Movie Production, Animation & Special Effects
    2. Computer Games
    3. Browsing on the World Wide Web
    4. Slides, Books and Magazine Design
2. Computer Graphics and Image Processing
3. Monitoring a Process
4. Displaying Simulations
5. Computer Aided Design
    1. Computer-aided Architectural Design
    2. Electrical Circuit Design
6. Scientific Analysis and Visualization

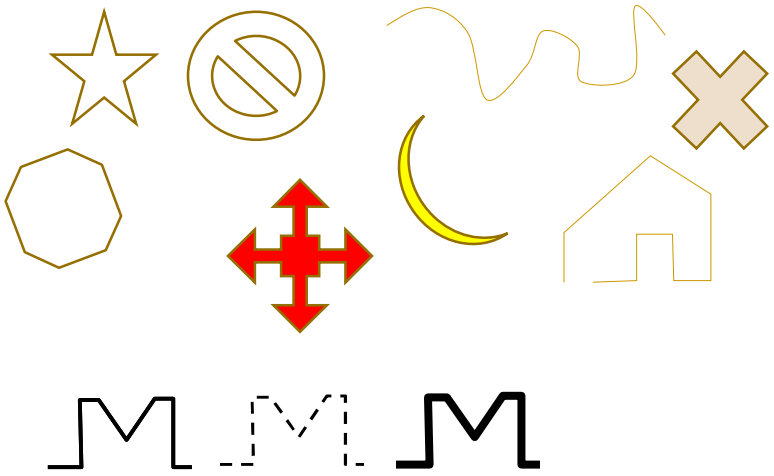
Process Monitoring

- Highly complex systems such as air traffic control systems must be monitored by a human to watch for impending trouble.
- An air traffic control system consists of monitors that display where nearby planes are situated.
  - The user sees a schematic representation for the process, giving the whole picture at a glance.
  - Various icons can flash or change color to alert the user to changes that need attention.

Elements of Pictures

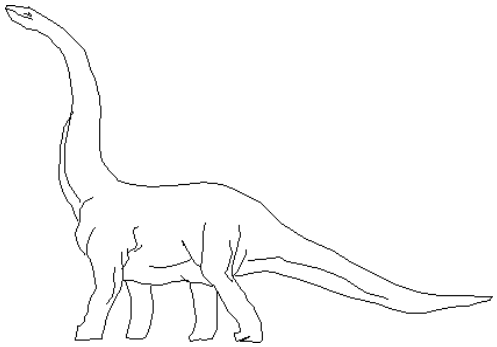
- **Output primitives**:
  - **points**
  - **lines**
  - **polylines**
  - **text**
  - **filled regions**
  - **raster images**
- **Attributes:** how an output primitive appears; e.g., color and thickness.

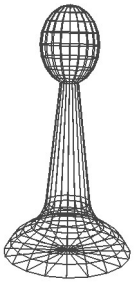
Polylines



Polylines

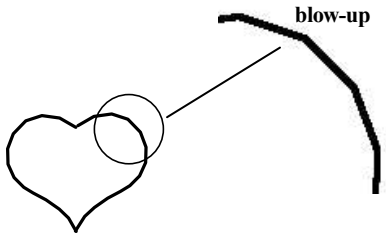
- A polyline is a connected sequence of straight lines.





Polylines (2)

- A polyline can appear to the eye as a smooth curve. This figure shows a magnification of a curve revealing its underlying short line segments.



Polylines (3)

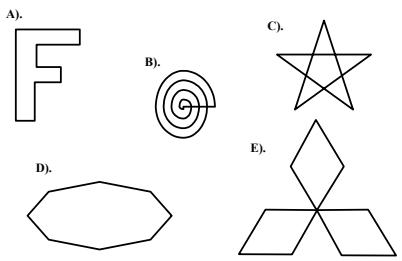
- Simplest polyline: a single straight line segment.
  - A line segment is specified by its two endpoints, say (x_1, y_1) and (x_2, y_2). A drawing routine for a line might look like drawLine(x1, y1, x2, y2);
- Dot: drawDot(x1, y1);

Polylines (4)

- When there are several lines in a polyline, each one is called an **edge**, and two adjacent lines meet at a **vertex**.
- The edges of a polyline can cross one another**.** A polyline does not have to be closed.
- Polylines are specified as a list of vertices, each given by a coordinate pair: (x_0, y_0), (x_1, y_1), (x_2, y_2), ..., (x_n, y_n).

Polylines (5)

- A **polygon** has its first and last points connected by an edge.
- If no two edges cross, the polygon is called **simple.** Only A) and D) are simple.

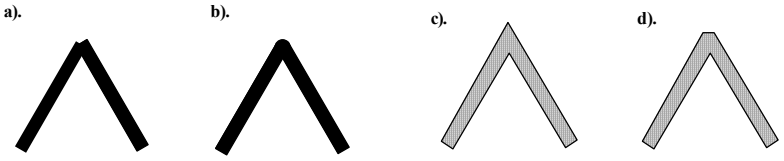


Polyline Attributes

- Color, thickness and stippling of edges, and the manner in which thick edges blend together at their endpoints.
- Typically all the edges of a polyline are given the same attributes.

Polyline Attributes (2)

- Joining ends: “butt-end”, rounded ends, mitered joint, and trimmed mitered joint.



Text

- Some graphics devices have both a **text mode** and a **graphics mode**.
- Text in text mode uses a built-in character generator.
- Text in graphics mode is drawn.

Big Text

Little Text

Shadow Text

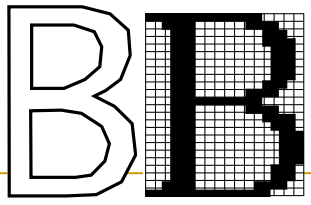
Distorted text

Rotated Text **Outlined text**

SMALLCAPS

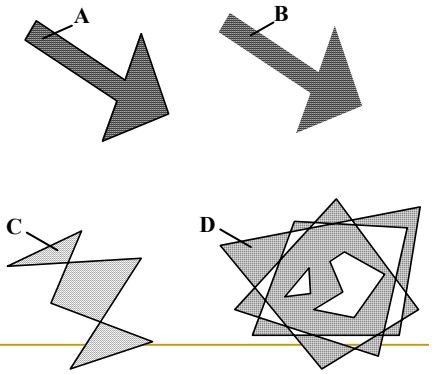
Text Attributes

- Font, color, size, spacing, and orientation.
- Font: Allegro or **English Script**
- Orientation: Characters/strings may be drawn tilted (e.g., vertically).
- Characters are defined by a set of polylines or by dots.

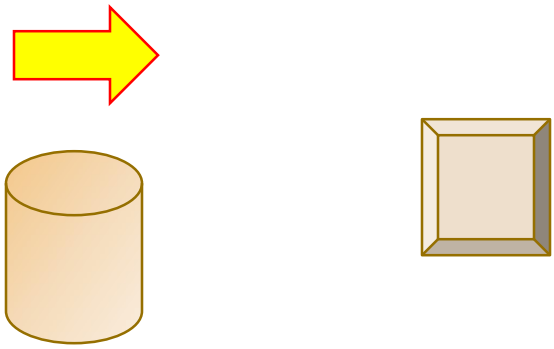


Filled Regions

- The **filled region** (sometimes called *fill area*) primitive is a shape filled with some color or pattern.
- Example: polygons



Filled Regions

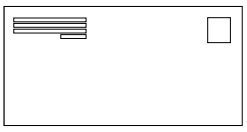


Raster Images



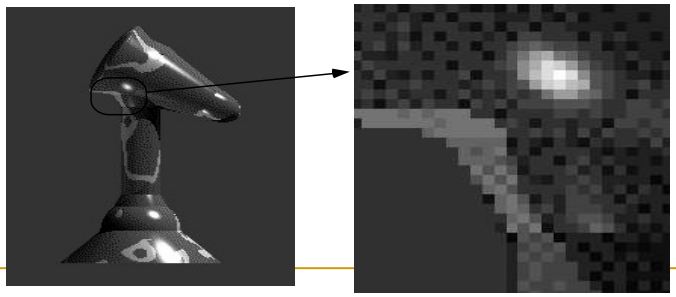







Raster Images

- A raster image is made up of many small cells (pixels, for “picture elements”), in different shades of gray. (Right: magnified image showing pixels.)



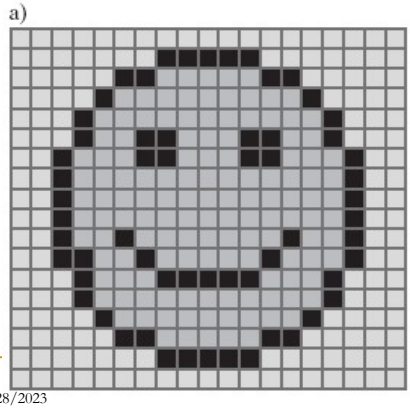
Pixmaps and Bitmaps

- A raster image is stored in a computer as a rectangular array of numerical values.
- The array has a certain number of rows and a certain number of columns.
- Each numerical value represents the value of the pixel stored there.
- The array as a whole is often called a **pixel map** or **bitmap.**

Pixmaps and Bitmaps Example

- The numbers show the values in the upper left 6 rows x 8 columns of the image.

a)



b)

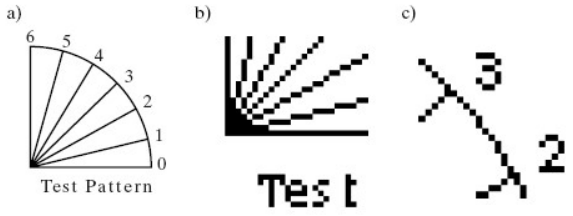
2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	7
2	2	2	2	2	7	7	1
2	2	2	2	7	1	1	1
2	2	2	7	1	1	1	1
2	2	2	7	1	1	7	7

Creating Pixmaps and Bitmaps

- Hand designed images**,** created by person.
- Computed images, using an algorithm.
- Scanned images.

The "Jaggies"

- Any close-up version of a pixmap will show that the image is composed of pixels rather than lines. Thus the lines also appear jagged (the Jaggies).

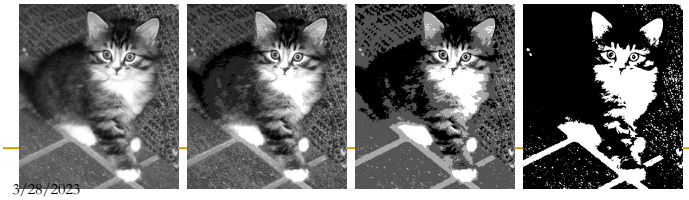


Color and Grayscale

- Two pixel values in an image is called **bi-level,** or a **1 bit per pixel** image. Colors are black and white.
- 2^n pixel values in an image requires n bits per pixel and gives 2^n shades of gray.
  - Most commonly, n is 2, 4, or 8, producing 4, 16, or 256 shades of gray.

Color and Grayscale (2)

- An image with 8 bits per pixel may be reduced to fewer bits per pixel by truncating values.
- Gradations of gray may change to a uniform shade of gray.
- Below: 6, 3, 2, and 1 bit per pixel.



Color and Grayscale (3)

- Color is usually described as a combination of red, green, and blue light.
- Each pixel is a 3-tuple: e.g., (23, 14, 51), for red (R), green (G), and blue (B).
- The total number of bits allowed for R, G, and B values is the **color depth**.
  - A color depth of 8 is often used: 3 bits each for R and G. and 2 bits for B.

Color and Grayscale (4)

  - Commonly the 8-bit depth is used as an index into a table of colors (a “color look-up table, or color LUT”.)
- **True color** images have a color depth of 24 or 32 bits.
  - The color representation is excellent, but such images require huge amounts of memory to store.

Graphics Display Devices

- Line-Drawing Devices
  - Pen plotters
  - Flatbed plotters
  - Drum Plotters
- Raster Displays
  - Video monitor
  - Flat Panel Displays (laptops)
  - Laser printers, dot-matrix printers, ink-jet plotters

Graphics Display Devices

- Graphics displays are either line-drawing devices or raster displays.
- Line-drawing devices:
  - Pen plotter, which moves an ink pen across a (large) sheet of paper. (E.g., seismic wave plotters.)
  - Vector video device, which moves a beam of electrons across the screen from any one point to any other point, leaving a glowing trail.

Graphics Display Devices (2)

- Raster displays:
  - Computer monitor: moves a beam of electrons across the screen from left to right and top to bottom.
  - Printer: does the same thing with ink or toner.
  - Coordinate system used:

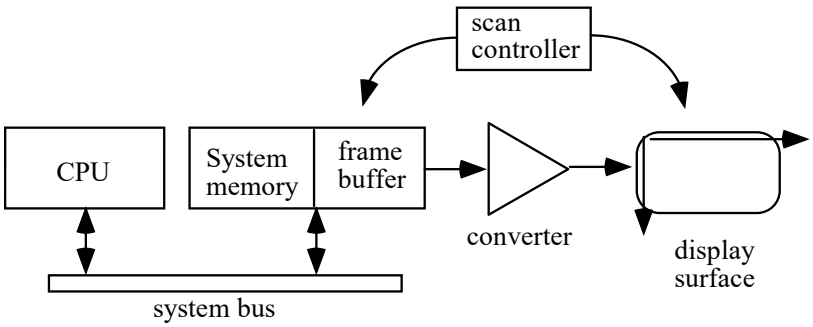
Graphics Display Devices (3)

- Raster displays are always connected to a **frame buffer**, a region of memory sufficiently large to hold all the pixel values for the display.
  - The frame buffer may be physical memory on-board the display or in the host computer**.**
  - Alternatively, a graphics card installed in a personal computer might house the frame buffer.

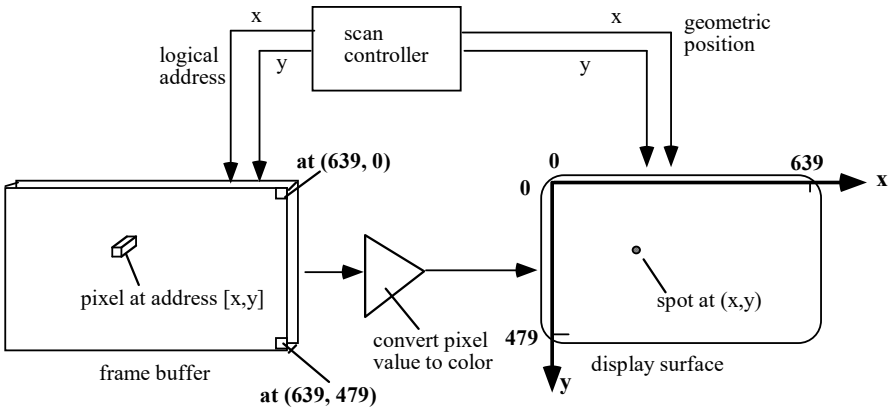
Graphics Display Devices (4)

- Each instruction of the graphics program (stored in system memory) is executed by the central processing unit (CPU), storing an appropriate value for each pixel into the frame buffer.
- A **scan controller** (not under program control) causes the frame buffer to send each pixel through a converter to the appropriate physical location on the display surface.
- The converter takes a pixel value such as 01001011 and converts it to the corresponding color value quantity that produces a spot of color on the display.

Function of Scan Controller

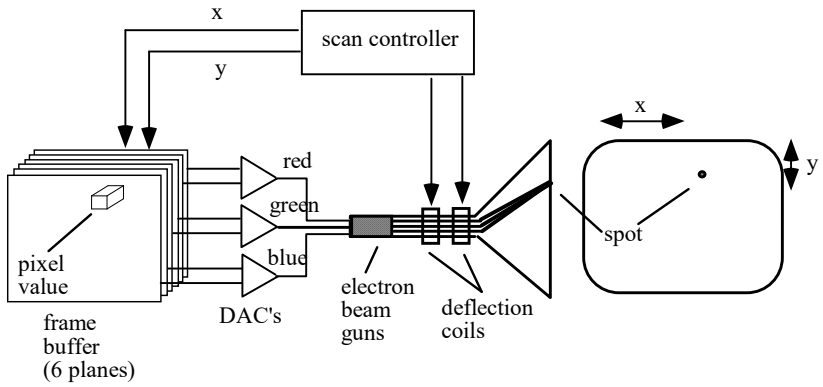


Graphics Display Device Operation



Video Monitor Operation

- Based on cathode ray tube (CRT).



Video Monitor Operation (2)

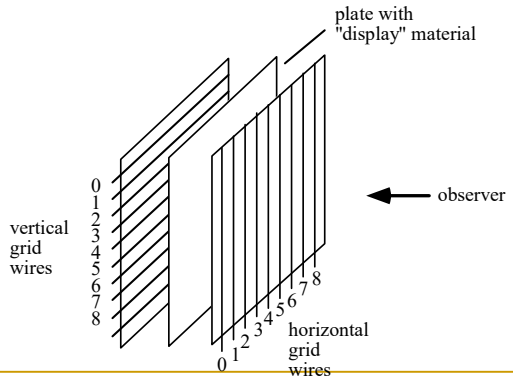
- The digital frame buffer value is converted to an analog voltage for each of R, G, and B by the DAC. Electron guns for each color are deflected to the appropriate screen location.
- The process is repeated 60 times each second to prevent flicker.

Data Transfer Accelerators

- Using 24- or 32-bit color requires that large amounts of data be transferred very fast between computer and display.
- Fast buses and graphics cards can improve the transfer speed.
- The cards implement the **graphics pipeline**: the nature of the processing steps to display the image and the order in which they must occur (specified by the graphics language, e.g., OpenGL).

Flat Panel Displays

- Flat panel displays: use a mesh of wires to set color of a pixel.



Hard Copy Raster Devices

- In graphics, to reproduce a scene with colors we want a color laser or inkjet printer.
- Printers equipped to use PostScript (a page description language) can generate high quality text and graphics on a printed page.
- A **film recorder** uses a strip of photographic film, exposed by the electron beam as it sweeps over it (once) in a raster pattern. Film recorders are frequently used to make high-quality 35-mm slides, or movies.

Graphics Input Types

- **String:** a **string of characters** followed by a termination character typed in by the user and stored in memory.
- **Valuator:** a real value between 0.0 and 1.0, which can be used to fix the length of a line, the speed of an action, or perhaps the size of a picture.

Graphics Input Types (2)

- **Locator:** a **coordinate pair** (*x*, *y*) which enables the user to point to a position on the display.
- **Pick:** identifies a portion of a picture for further processing (e.g., touchscreen).
  - Some graphics packages allow a picture to be defined in terms of **segments**, which are groups of related graphics primitives.

Graphics input primitives

- String – keyboard device
- Choice – a set of buttons on a mouse
- Valuator – knob or joystick
- Locator – mouse pointer
- Pick – Mouse or some other input device

Graphics input devices

- Keyboard
- Mouse
- Tablet with a pen
- Joystick and traceball
- Data Glove
- 3D Digitizers

Graphics Input Devices

- **Keyboard:** strings of characters;
  - Some keyboards have cursor keys or function keys, which can be used to produce pick input primitives.
- **Buttons.** Sometimes a separate bank of buttons is installed on a workstation. The user presses one of the buttons to perform a pick input function.

Graphics Input Devices (2)

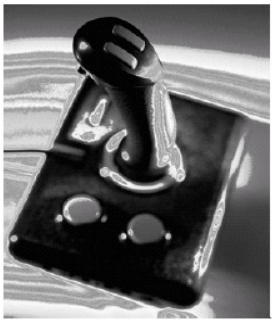
- **Mouse:** changes in position.
  - Software keeps track of the mouse's position and moves a **graphics cursor** — a small dot or cross — on the screen accordingly.
  - The mouse is most often used to perform a locate function. There are usually buttons on the mouse that the user can press to trigger the action.

Graphics Input Devices (3)

- **Tablet:** locate input primitives. A **tablet** provides an area on which the user can slide a stylus. The tip of the stylus contains a micro switch. By pressing down on the stylus the user can trigger the locate.

Graphics Input Devices (4)

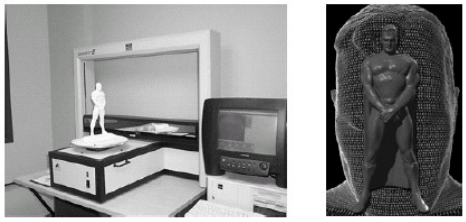
- **Joystick and Trackball:** locate and valuator devices.



3-D Graphics Input Devices

- A laser beam scans over the solid object in an *x*, *y* raster pattern, measuring the distance between the image capture device and the object.

a) b)



3-D Graphics Input Devices (2)

- Capturing motion: a device that can track the position of many points on a moving body in real-time, saving the motion for animation or data analysis.