

# Computer Graphics using OpenGL

## Chapter 1

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## What is Computer Graphics?

Computers...  
accept, process, transform and present  
information.

Computer Graphics...  
involves technology to accept, process, transform  
and present information in a visual form.

## Ok but... what is the course really about?

Graphics algorithms  
Graphics data structures  
Color and human vision  
Graphical interface design and programming  
Modeling, Animation, Rendering

### What its not about?

Photoshop, AutoCAD, Maya, Renderman, Graphics  
APIs.

...**WOW**, programming in OpenGL and computer  
science!!

## CG is Movies

To Reality and beyond!!

- Define directions of CG
- Set quality standards



## Games are allowed

- Focus on interactivity
- Push current hardware to its li
- Games drive the baseline



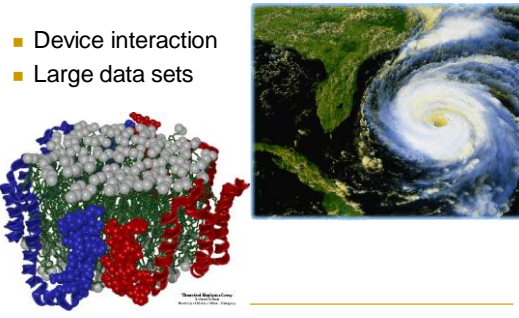
## Industrial Design

- Precision modeling
- Engineering Visualization



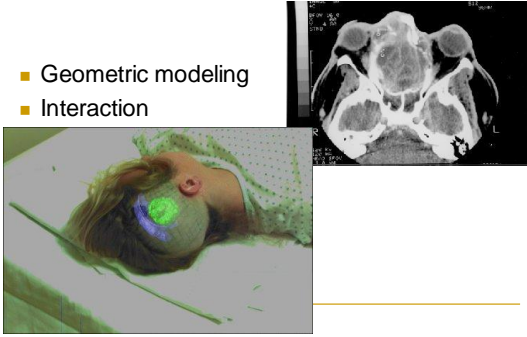
### Scientific Visualization

- Device interaction
- Large data sets



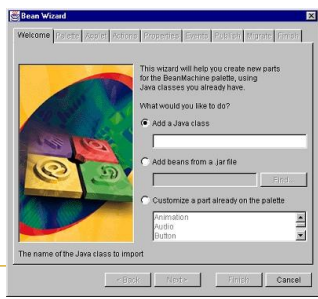
### Medical Imaging

- Geometric modeling
- Interaction



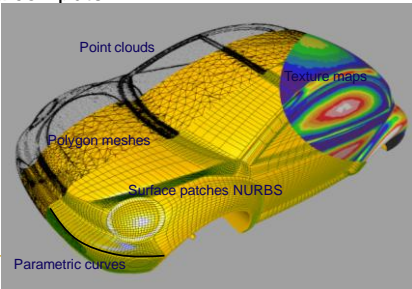
### Graphical User Interfaces

- Interaction with software and hardware



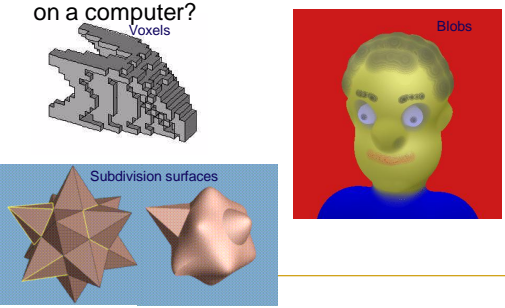
### Elements of CG (modeling)

How do we represent an object geometrically on a computer?



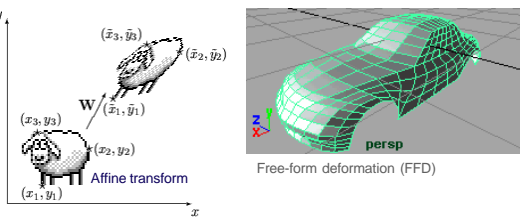
### Elements of CG (modeling) II

How do we represent an object geometrically on a computer?



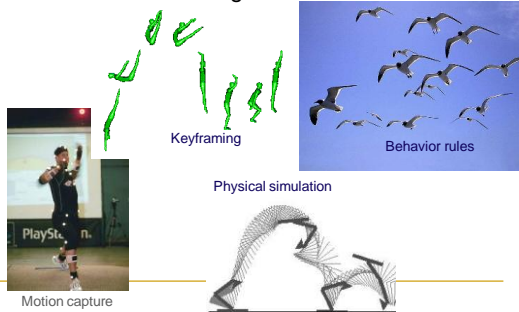
### Elements of CG (modeling) III

How can one change a digital model?



## Elements of CG (animation)

How does one make digital models move?



## Elements of CG (animation) II

How does one make digital models move?



## Elements of CG (rendering)

How does one present a digital scene?



## Elements of CG (rendering) II

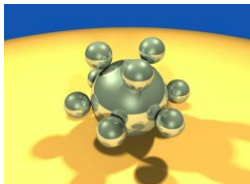
How does one present a digital scene?

- **Scene Graph:** Hierarchical description of objects and parts of objects relative to each other.
- **Lighting:** Where are the lights in the scene?
- **Cameras:** Where is the scene viewed from (pin-hole model)?
- **Projection:** How is the scene projected onto an image (parallel vs. perspective)?
- **Visibility**
- **Clipping**
- **Scan Conversion**
- **Illumination**
- **Textures**
- **Special Effects**



## What Are Computer Graphics?

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



## 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 book. The OpenGL way of creating graphics is used widely in both academia and industry.

## Field of Computer Graphics

- Computer graphics also often means the whole **field of study** that involves these tools and the pictures they produce.
- The special interest group in graphics, SIGGRAPH, was formed in 1969. (The must-not-miss annual SIGGRAPH meeting now attracts 30,000 participants a year.)
  - SIGGRAPH is a Special Interest Group in the ACM: the Association for Computing Machinery.

## 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.

## 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!*)

## Where Are Computer Graphics Used?

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

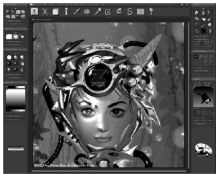


## Where Are Computer Graphics Used? (2)

- 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.

## Where Are Computer Graphics Used? (3)

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



## Computer Graphics and 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.

## 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.

## 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.

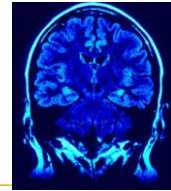


## Computer-aided Design

- 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.

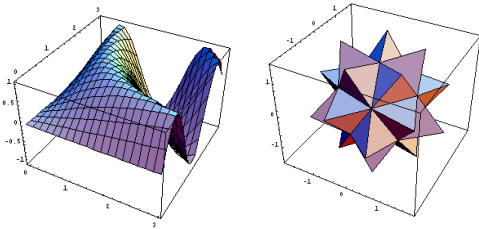
## Volume Visualization

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



## Displaying Mathematical Functions

- E.g., Mathematica®

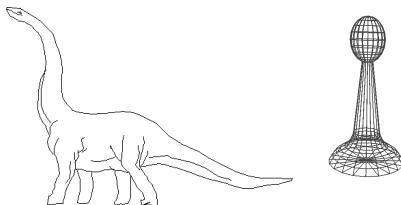


## Elements of Pictures

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

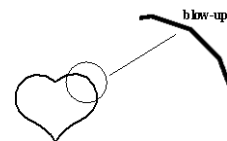
## Polylines

- 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)

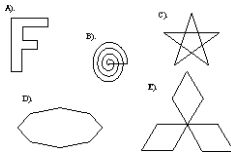
- Simplest polyline: a single straight line segment.
  - A line segment is specified by its two endpoints, say  $(x_1, y_1)$  and  $(x_2, y_2)$ . A drawing routine for a line might look like `drawLine(x1, y1, x2, y2);`
- Dot: `drawDot(x1, y1);`

### 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:
  - $(x_0, y_0), (x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)$ .

### 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.



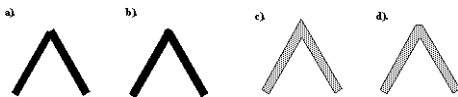
### Polyline Attributes

- 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.



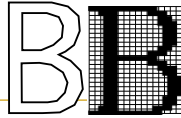
### Text

- 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  
 Underlined text  
 Rotated Text Outlined text  
 SMALLCAPS

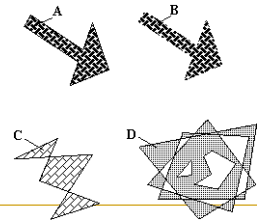
## Text Attributes

- 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.



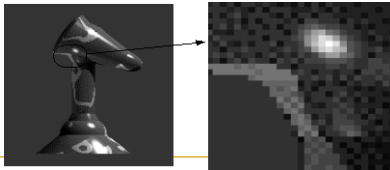
## Filled Regions

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



## 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.)

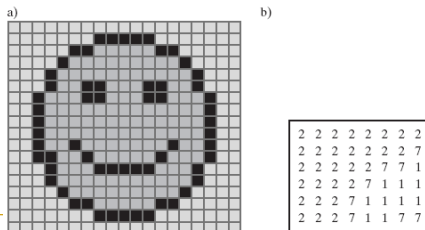


## Pixmaps and Bitmaps

- 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.



## Creating Pixmaps and Bitmaps

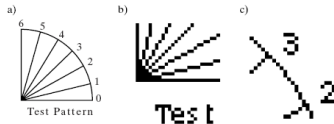
- Hand designed images, created by person.
- Computed images, using an algorithm.
- Scanned images.





## 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).

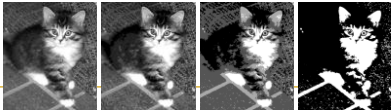


## Color and Grayscale

- 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)

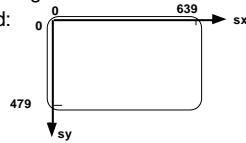
- Commonly the 8-bit depth is used as an index into a table of colors (a “color look-up table, or color LUT”.)
- True color** images have a color depth of 24 or 32 bits.
  - The color representation is excellent, but such images require huge amounts of memory to store.

## Graphics Display Devices

- 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:



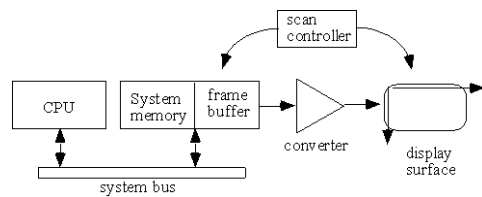
## Graphics Display Devices (3)

- 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.

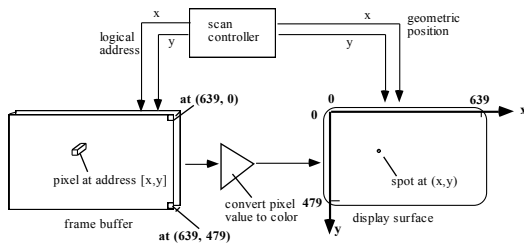
## Graphics Display Devices (4)

- 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

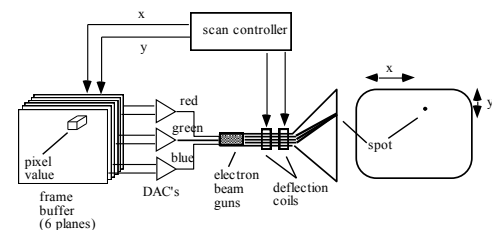


## Graphics Display Device Operation



## 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.

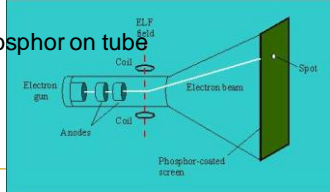
## Data Transfer Accelerators

- 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).

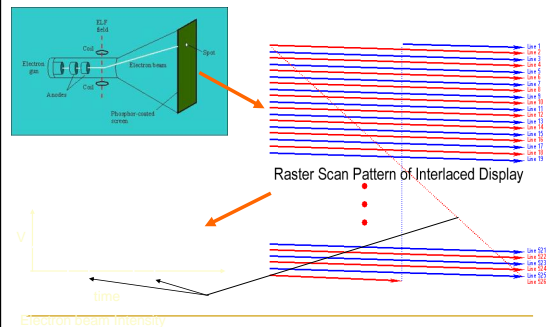
## Display Technology

### Raster Displays (CRT)

- Common display device today
- Evacuated glass bottle
- Electrons attracted to anode
- Deflection plates
- Beam strikes phosphor on tube

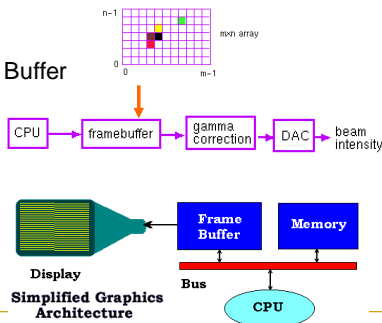


## Raster Displays I



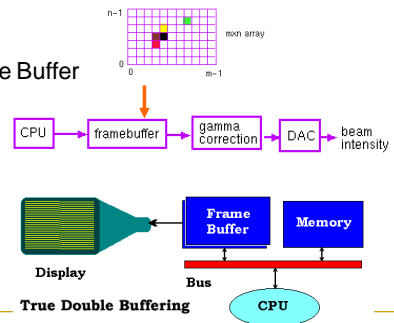
## Display Architecture

### Frame Buffer



## Display Architecture

### Double Buffer



### Display Architecture II

True Color Frame Buffer : 8 bits per pixel RGB

### Display Architecture II

Indexed Color Frame Buffer : 8 bit index to color map

### Display Devices II

Plasma      Holographic

Immersive      Head-mounted      Volumetric

### 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.

### Types of input Graphics primitives

primitives	Relationship with Device
String	Keyboard
Choice	Mouse, buttons,
Valuator	Mouse, Knobs
Locator	Mouse,
Pick	Mouse,

## 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 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.



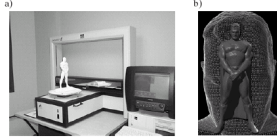
## Graphics Input Devices (4)

- **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.



### 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.

