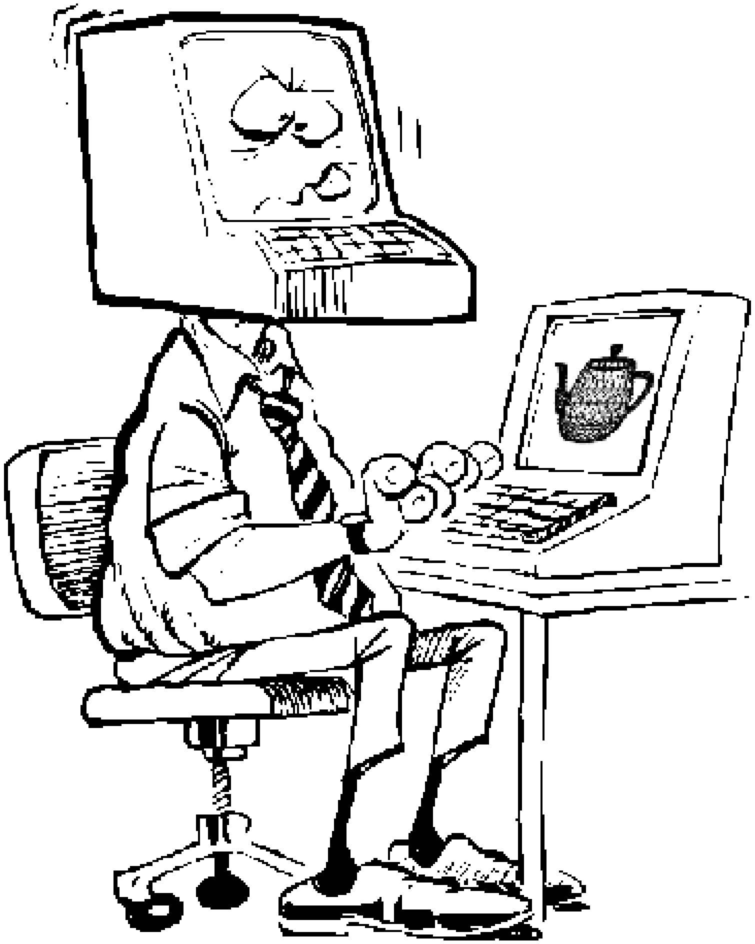
6.837 Lecture 1

6.837 - Principles of Computer Graphics



Introductions

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About this Course

www.graphics.lcs.mit.edu/classes/6.837/F01

Computer Graphics?

Display Technologies

More notes on the course's organization can be found on the course web page. In addition, all of the slides used in the class lectures, will be available there.

Computer Graphics

What computers do....

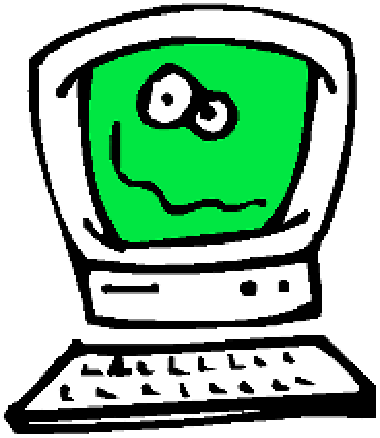
*process, transform,*and ***communicate*** information

Aspects of communication

- Origin (where does information come from?)
- Throughput (how frequent?)
- Latency (how long do I have to wait)?
- Presentation (what does it look like?)

Computer Graphics is...

the technology for presenting information



Computer graphics has become the predominant form of computer output. Even the text on most computer screens are "rendered" using computer graphics methods, as opposed to being mechanically transferred onto paper by an inked metal stamp.

Okay, but...
what is this course really about?

Not!

Paint and Imaging packages
(Adobe Photoshop)
CAD packages (AutoCAD)
Rendering packages (Lightscape)
Modeling packages (3D Studio MAX)
Animation packages (Digimation)
Graphics APIs (OpenGL)
Graphics Modeling and Languages
(RenderMan)

We will cover...

Graphics programming algorithms
Graphics data structures
Color and human vision
Graphical interface design and programming
Applied geometry and modeling
Applied numerical computing

Ugh... sounds like Computer Science

Computer Graphics is about **Movies**!

If you can imagine it, it can be done with computer graphics.

Obviously, Hollywood has caught on to this. Each summer, we are amazed by state-of-the-art special effects. More and more of these images exist only within the memory of a computer. There seems to be no end in sight for this trend. But we're not just talking about big budget mega-productions. There are music videos, and spinning logos on the 6 o'clock news. Computer graphics is now as much a part of the entertainment industry as stunt men and makeup.

The entertainment industry plays many other important roles in the field of computer graphics.

1. Leaders in quality and artistry
2. Not slaves to conceptual purity
3. Big budgets and tight schedules
4. Constant reminder that there is more to CG than technology.
5. How did they do that?
6. They define our expectations.

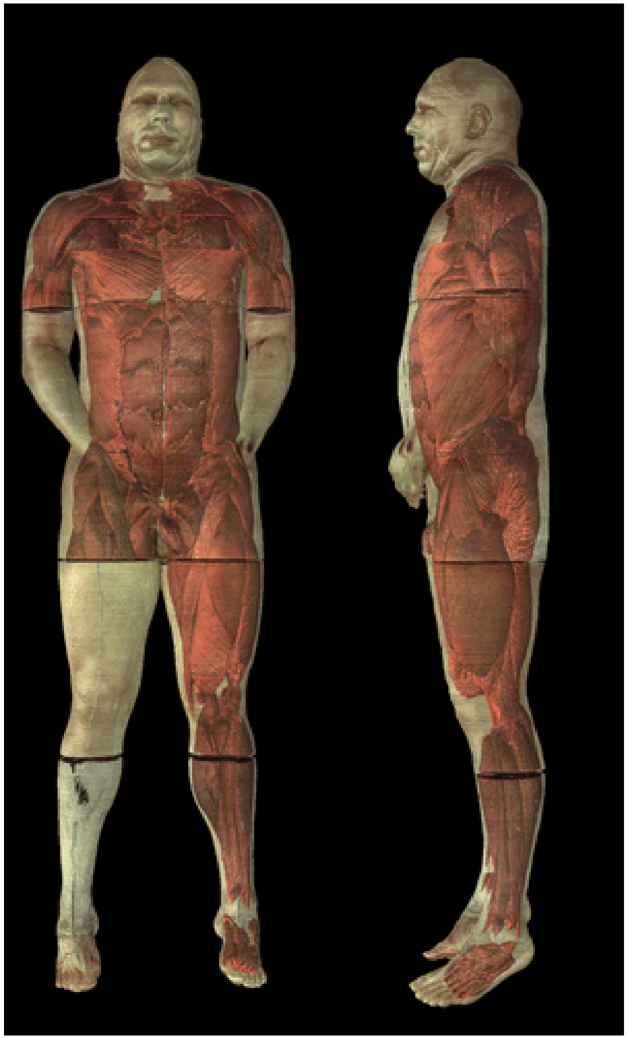
Games are okay here!

Games are an important driving force in computer graphics. In this class we are going to talk about games. We'll discuss on how they work. We'll also question how they get so much done with so little to work with. If you have time to play computer games between now and the end of the semester ask yourselves, how do they do that? Study the screen. How does the screen look when things are moving? What about when things are still. Why do they always go into those low resolution display modes that everyone else considers worthless. Let yourself get blown up. If anyone asks, tell them you're doing science.

How the game's industry impacts computer graphics

1. Focus on interactivity
2. Cost-effective solutions
3. Avoiding computation and other tricks
4. Games drive the baseline

Medical Imaging

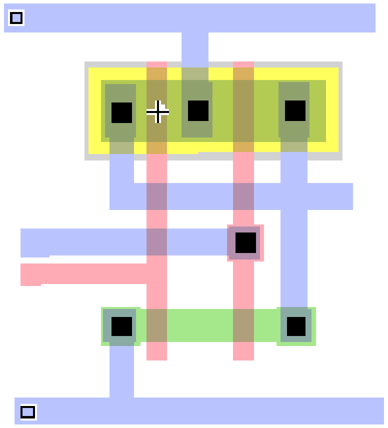


There are few endeavors more noble than the preservation of life. Today, it can honestly be said that computer graphics plays an significant role in saving lives. The range of application spans from tools for teaching and diagnosis, all the way to treatment. Computer graphics is *tool* in medical applications rather than an a mere artifact. No cheating or tricks allowed.

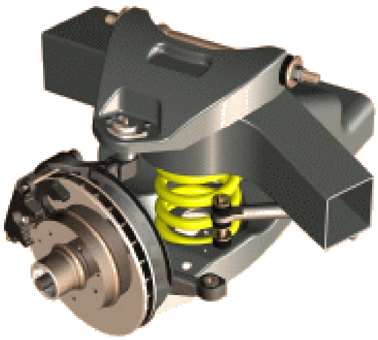
How medical applications influence computer graphics technology

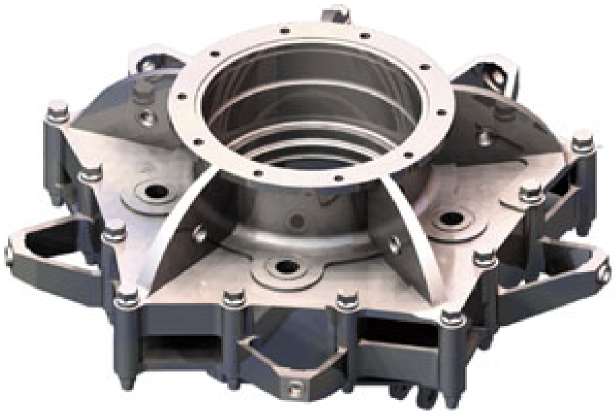
1. New data representations and modalities
2. Drive issues of precision and correctness
3. Focus on presentation and interpretation of data
4. Construction of models from acquired data

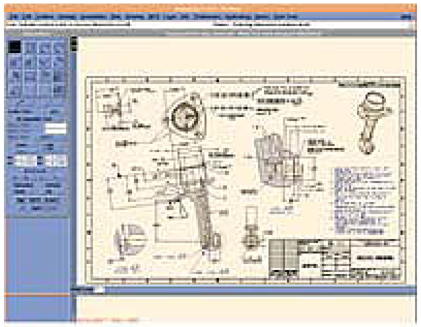
Computer Aided Design



Computer graphics has had a dramatic impact on the design process. Today, most mechanical and electronic designs are executed entirely on computer. Increasingly, architectural and product designs are also migrating to the computer. Automated tools are also available that verify tolerances and design constraints directly from CAD designs. CAD designs also play a key role in a wide range of processes from the design of tooling fixtures to manufacturing.



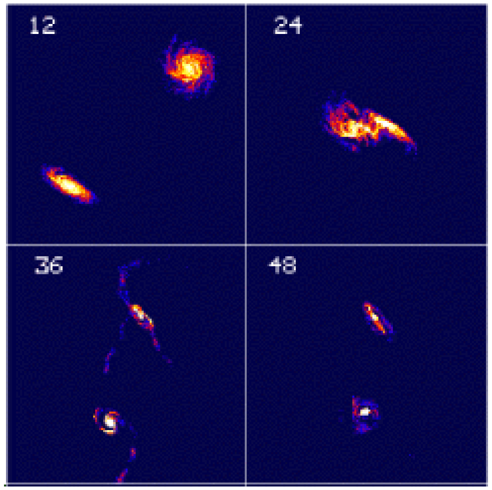




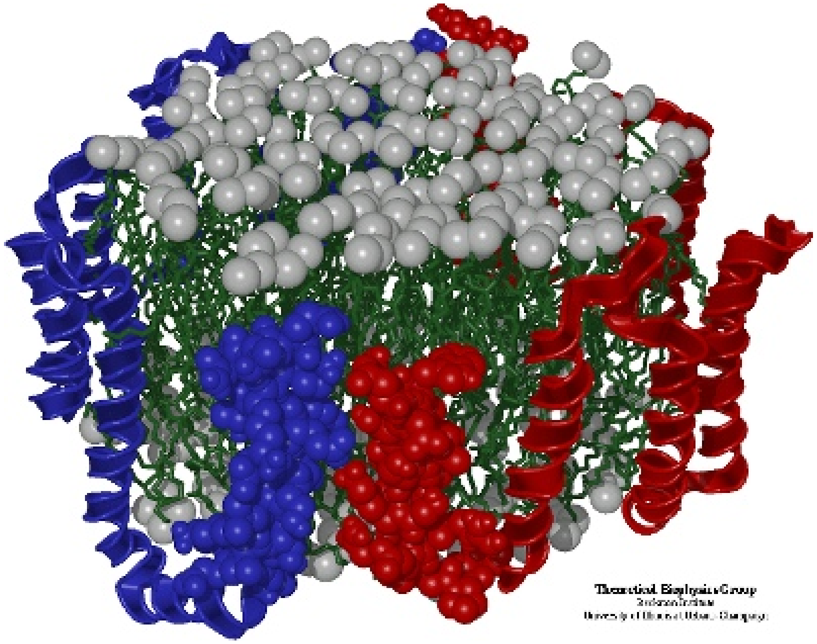
CAD has had the follow impact on computer graphics.

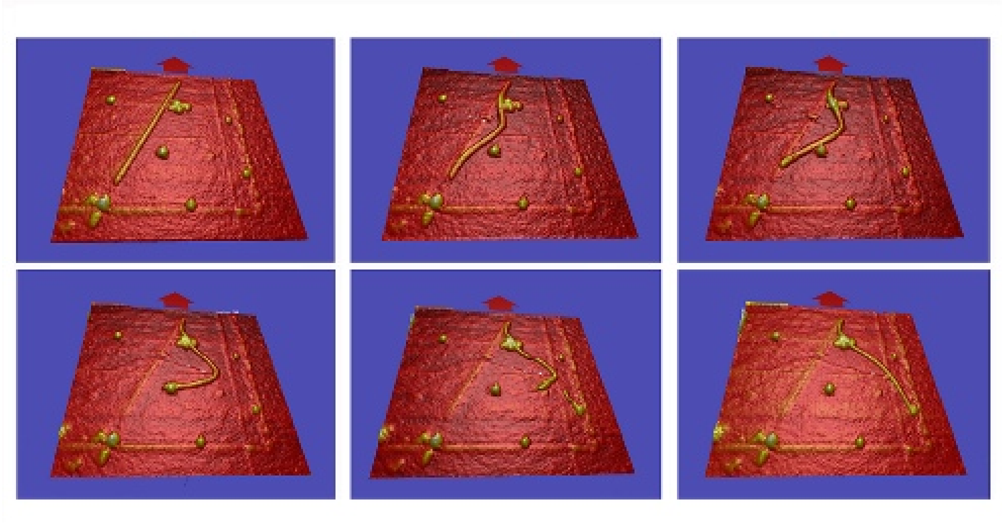
1. Drives the high-end of the HW market
2. Integration of computing and display resources
3. Reduced design cycles (faster systems sooner)

Scientific Visualization

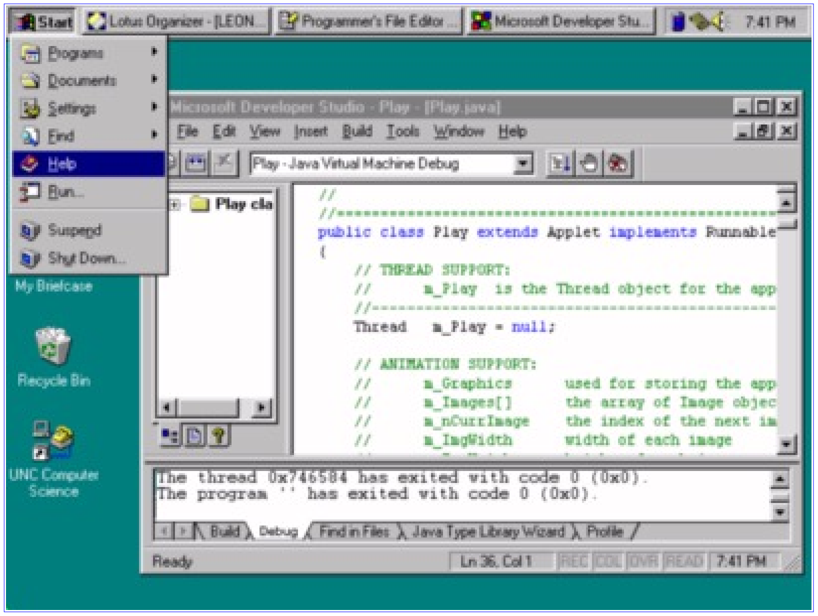


Computer graphics makes vast quantities of data accessible. Numerical simulations frequently produce millions of data values. Similarly, satellite-based sensors amass data at rates beyond our abilities to interpret them by any other means than visually. Mathematicians use computer graphics to explore abstract and high-dimensional functions and spaces. Physicists can use computer graphics to transcend the limits of scale. With it they can explore both microscopic and macroscopic worlds.

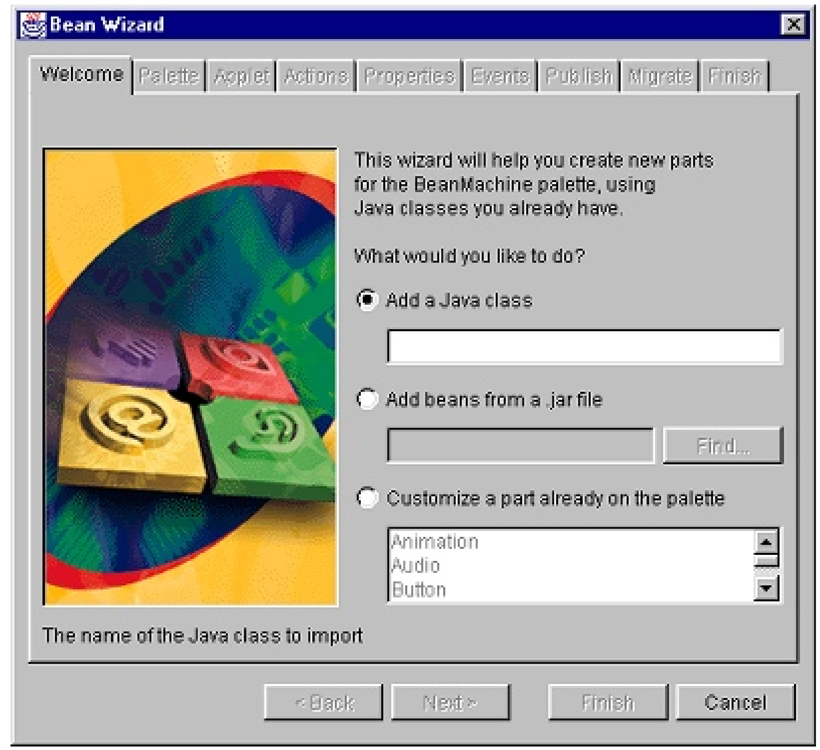


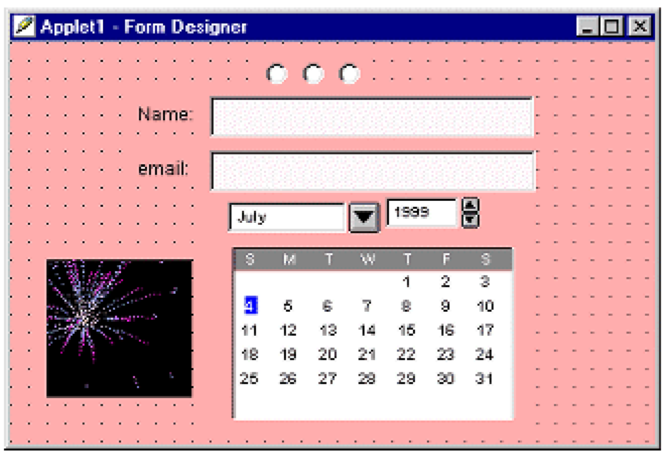


Graphical User Interfaces (GUIs)

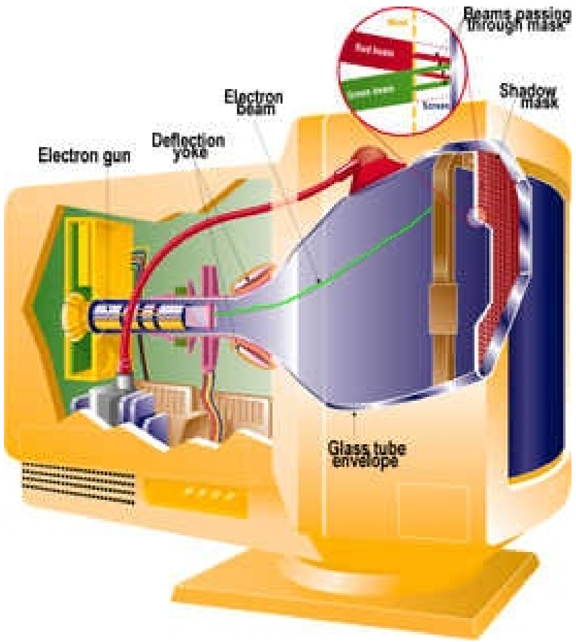


Computer graphics is an integral part of every day computing. Nowhere is this fact more evident than the modern computer interface design. Graphical elements such as windows, cursors, menus, and icons are so common place it is difficult to imagine computing without them. Once graphics programming was considered a speciality. Today, nearly all professional programmers must have an understanding of graphics in order to accept input and present output to users.





Display Technologies



Cathode Ray Tubes (CRTs)

- Most common display device today
- Evacuated glass bottle
  (last remaining vacuum tube)
- Heating element (filament)
- Electrons attracted to focusing anode cylinder
- Vertical and Horizontal deflection plates
- Beam strikes phosphor coating on front of tube

CRTs, or video monitors, are the most common output device on computers today. The figure below illustrates the basic structure of a CRT. A CRT is an evacuated glass bottle, with a heating element on one end and a phosphor coated screen on the other. When a current flows through this heating element, called a filament, the conductivity of the metal filament is reduced due to the high temperature. This cause electrons to pile up on the filament, because they can not move as fast as they would like to (Notice I'm wearing my "electrons-are-particles" hat). Some of these electrons actually *boil off* of the filament.

These free electrons are attracted to a strong positive charge from the outer surface of the focusing anode cylinder (sometimes called an electrostatic lens). However, the inside of the cylinder has a weaker negative charge. Thus when the electrons head toward the anode they are forced into a beam and accelerated by the repulsion of the inner cylinder walls in just the way that water is speeds up when its flow though a smaller diameter pipe. By the time the electrons get out they're going so fast that they fly past the cathode they were heading for.

The next thing that the electrons run into are two sets of weakly charged deflection plates. These plates have opposite charges, one positive the other negative. While their charge is not strong enough to capture the fast moving electrons they do influence the path of the beam. The first set displaces the beam up and down, and the second displaces the beam left and right. The electrons are sent flying out of the neck of the bottle, called a *yolk*, until they smash into the phosphor coating on the other end of the bottle. The impact of this collision on the out valence bands of the phosphor compounds knocks some of the electrons to jump into the another band. This causes a few photons to be generated, and results in our seeing a spot on the CRT's face.

Vector Displays

- Oscilloscopes were some of the 1st computer displays
- Used by both analog and digital computers
- Computation results used to drive the vertical and horizontal axis (X-Y)
- Intensity could also be controlled (Z-axis)
- Used mostly for line drawings
- Called *vector*, *calligraphic* or affectionately *stroker* displays
- Display list had to be constantly updated
  (except for storage tubes)

CRTs were embraced as output devices very early in the development of digital computers. There close cousins, vacuum tubes, were some of the first switching elements used to build computers. Today, the CRT is a the last remaining vacuum tube in most systems (Even the flashing lights are solid-state LEDs).

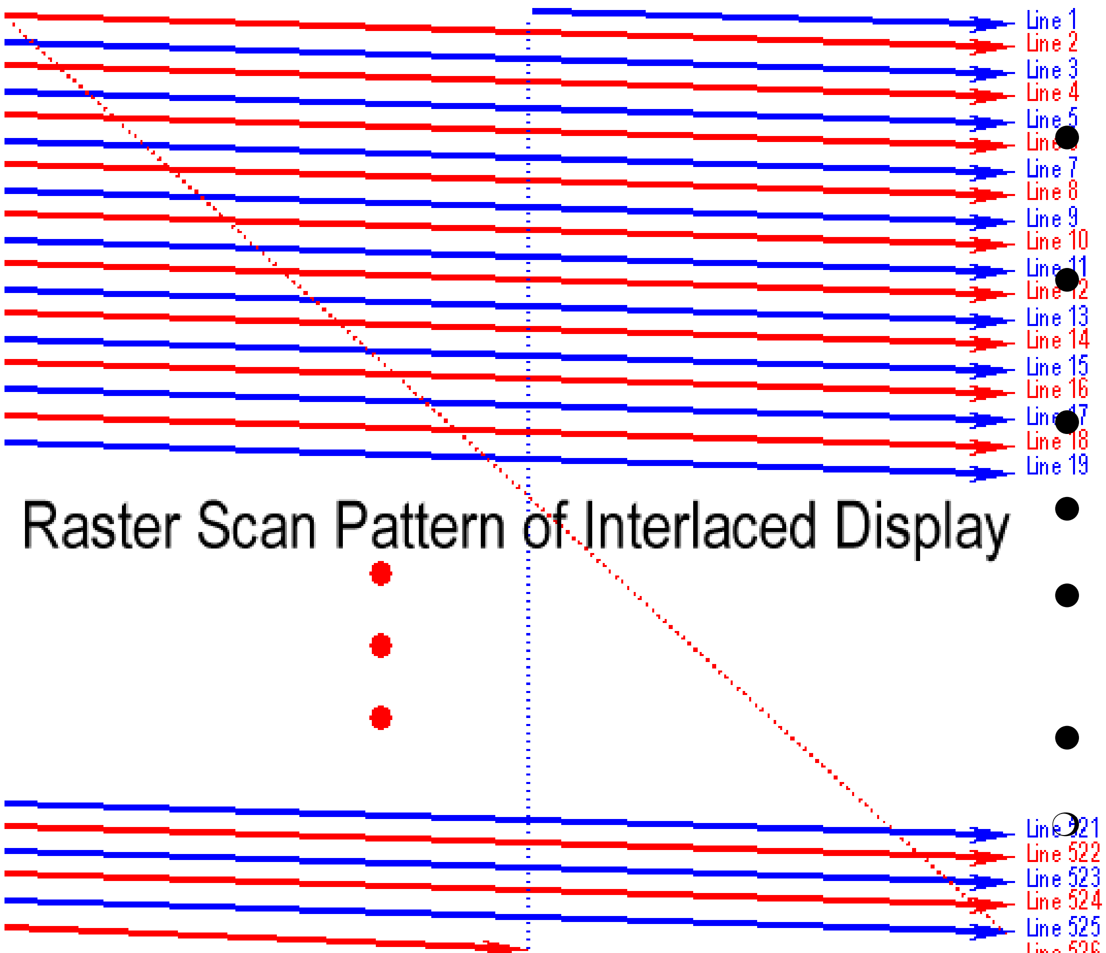
Most likely, oscilloscopes were some of the first computer graphics displays. The results of computations could be used to directly drive the vertical and horizontal displacement plates in order to draw lines on the CRT's face. By varying the current to the heating filament the output of the electron beam could also be controlled. This allowed the intensity of the lines to vary from bright to completely dark.

These early CRT displays were called *vector*, *calligraphic* or affectionately *stroker* displays. The demonstration above gives some feel for how they worked.

By the way, this demo is an active Java applet. You can click and drag your mouse inside of the image to reorient the CRT for a better view. Notice the *wireframe* nature of the displayed image. This demo is complicated by the fact that it's a wireframe simulation of a wireframe display system. Notice how the color of the gray lines of the CRT vary from dark to light indicating which parts of the model that are closer to the viewer. This technique is called *depth-cueing*, and it was used frequently on vector displays. The intensity variations seen on the teapot, however, are for a different reason. Eventually, the phosphors recover from their excited state and the displaced electrons return back to their original bands. The glow of the phosphor fades. Thus, the image on the CRT's face must be constantly redrawn, refreshed, or updated.

The two primary problems with vector displays are that they required constant updates to avoid fading, thus limiting the drawn scene's complexity, and they only drew wireframes.

Raster Displays

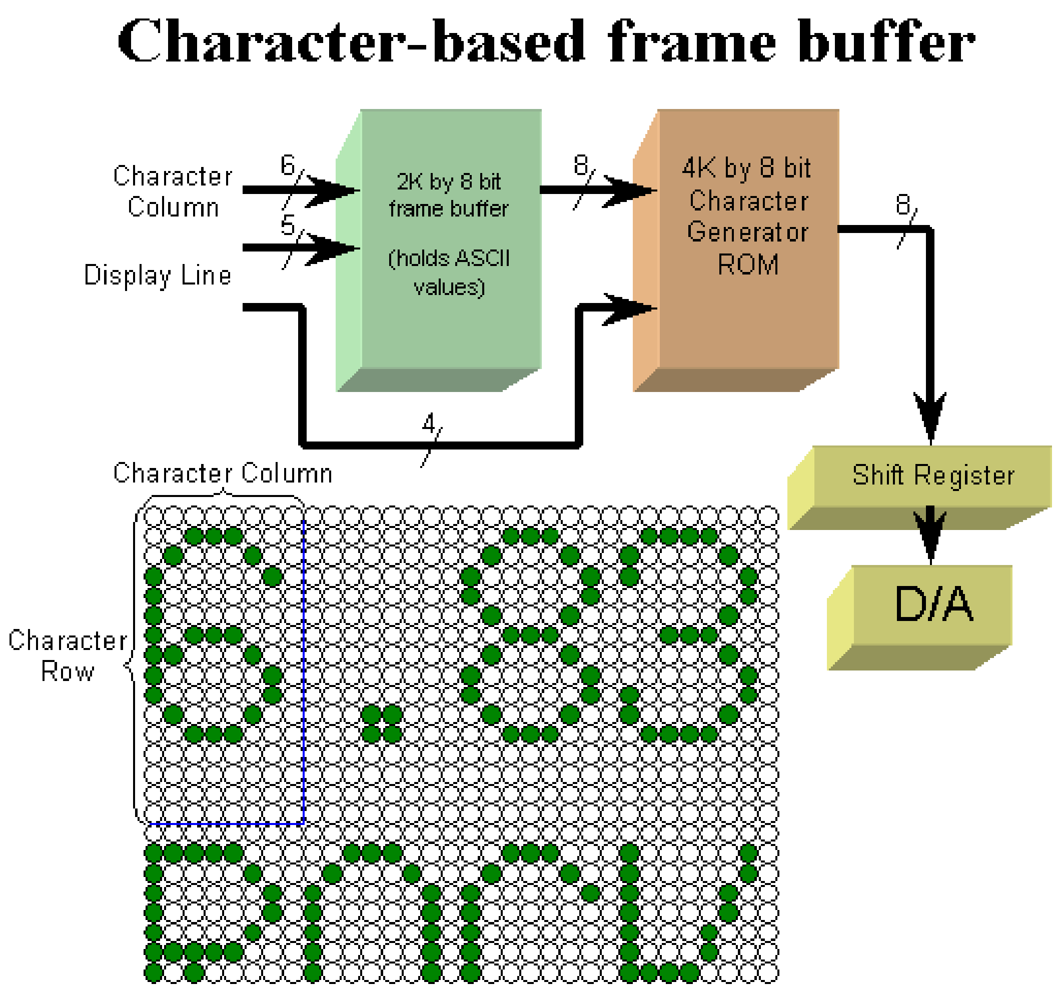


- TV boomed in the 50s and early 60s (they got cheap)
- B/W TVs are basically oscilloscopes (with a hardwired scan pattern)
- Entire screen painted 30 times/sec
- Screen is traversed 60 times/sec
- Even/Odd lines on alternate scans (called fields)
- Interlace - a *hack* to give
  - Smooth motion on dynamic scenes
  - High Resolution on static scenes
  - Optimize bandwidth

During the late 50s and early 60s, broadcast television, really began to take off. It had been around for a while, but it didn't become a commodity item until about this time. Televisions are basically just oscilloscopes. The main difference is that instead of having complete control over the vertical and horizontal deflection, a television sweeps its trace across the entire face in a regular fixed pattern (the actual details are slightly more complicated, but that's the jist of it). This scanning pattern proceeds from the top-left of the screen to the bottom-right as shown in the diagram. The final result is that the entire screen is painted once every 1/30th of a second (33 mS).

Televisions were mass produced and inexpensive. For a computer to paint the entire screen it needs only to synchronize its painting with the constant scanning pattern of the raster. The solution to this problem was to add a special memory that operated synchronous to the raster scanning of the TV, called a *frame buffer*. While televisions were cheap, memory wasn't. So there was a long period where the patterns were scanned out of a cheap high-density read-only memories, called *character generators*. The trick was to use a single 8 bit code to specify an 8 by 12 character pattern from the ROM, and with a few addressing tricks one could build a nice display (80 by 25 character) with only 2 kilobytes of memory. Thus the era of the CRT-terminal was born.

Raster Display Simulation



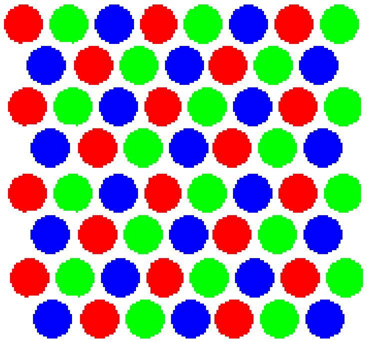
In a raster display the path of the electron beam is hardwired. The computer must synchronize its "painting" of the screen with the scanning of the display. The computer only controls the intensity of the color at each point on the screen. Usually a dedicated section of memory, called the *frame buffer*, is used to store these intensity variations.

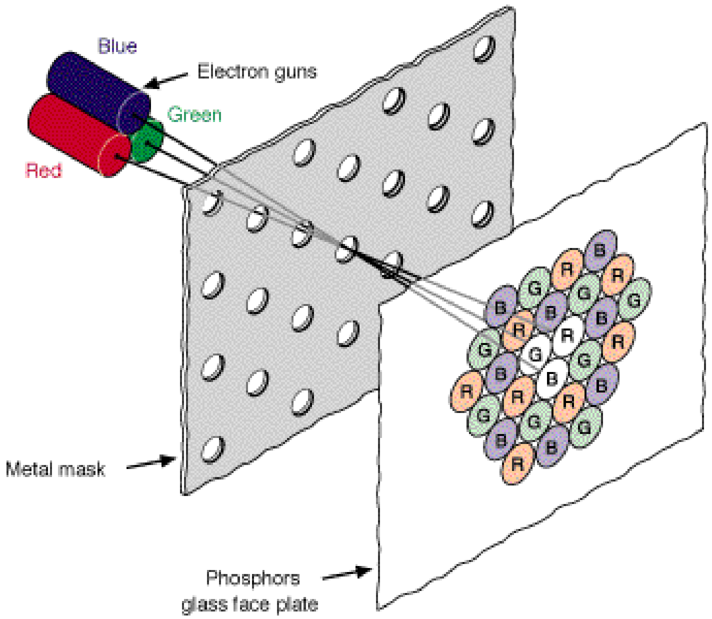
The simulation above is a Java applet that simulates the scanning of a raster display. Move the CRT wireframe (by clicking and dragging) in order to get a better feel.

There were a few attempts at building systems with downloadable or programmable character generators. And a few systems added an extra byte to specify the foreground and background colors of the character cell. Lots of tank/maze arcade games in the 70's worked this way. But by the late 70's and early 80's the price of memory started a free-fall and the graphics terminal was born. In a later lecture we'll go into a lot more detail about the notion of a framebuffer an how it is fundamental to modern computer graphics.

Color Video

Delta Electron Gun Arrangement

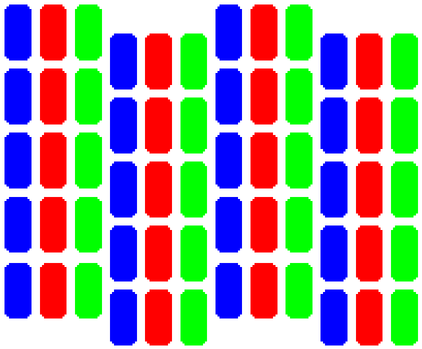


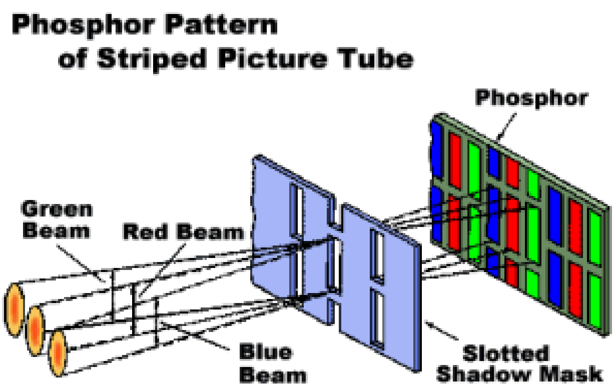


Color CRTs are *much* more complicated

- Requires precision geometry
- Patterned phosphors on CRT face
- Aligned metal *shadow mask*
- Three electron guns
- Less bright than monochrome CRTs

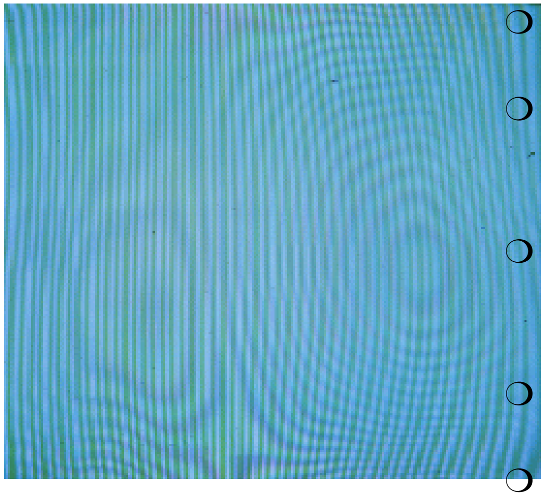
In-line Electron Gun Arrangement





Raster Display

- Disadvantages
  - Requires screen-sized memory array
  - Discrete spatial sampling (pixels)
  - Moire patterns result when shadow-mask and dot-pitch frequencies are mismatched
  - Convergence (varying angles of approach distance of e-beam across CRT face)
  - Limit on practical size (< 40 inches)
  - Spurious X-ray radiation
  - Occupies a large volume



- Advantages
  - Allows solids to be displayed
  - Leverages low-cost CRT H/W (TVs)
  - Whole Screen is constantly updated

❍ Bright light-emitting display technology

Color CRT's are more complicated than the simple monochrome models summarized before. The phosphors on the face of a color CRT are laid out in a precise geometric pattern. There are two primary variations, the *stripe* pattern of in-line tubes shown on the left, and the *delta* pattern of delta tubes as shown on the right.

Within the neck of the CRT there are three electron guns, one each for red, green, and blue (the actual beams are all the same color-- *invisible*). There is also a special metal plate just behind the phosphor cover front face, called a *shadow mask*. This mask is aligned so that it simultaneously allows each electron beam to see only the phosphors of its assigned color and blocks the phosphor of the remaining two colors.

The figure shown above shows the configuration of an example in-line tube. On page 44 of **Hearn & Baker** you'll see a similar diagram for a delta electron gun configuration

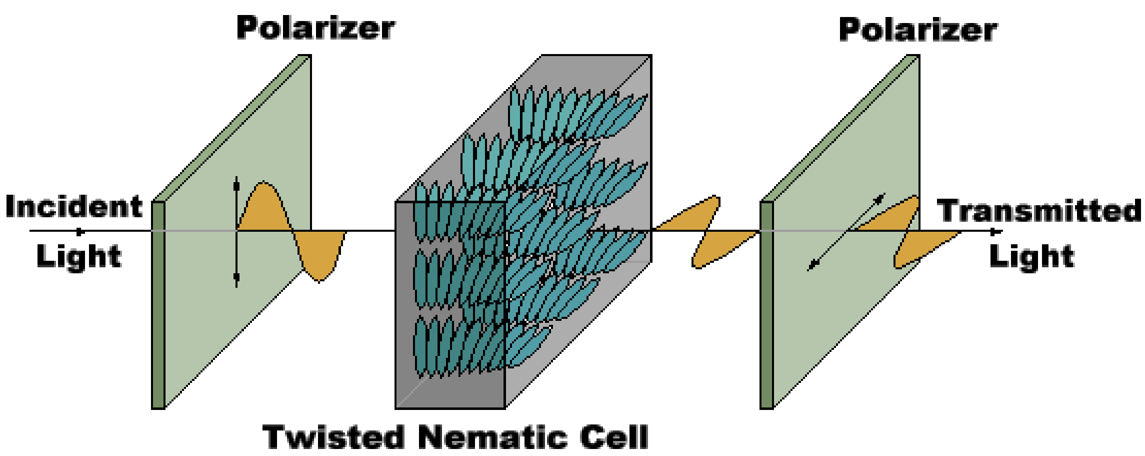
A significant portion of the electron beam's energy strikes the mask rather than the phosphors. This has two side effects. The shadow mask has to be extremely rigid to stay aligned with the phosphor patterns on the CRT face. The collision of electrons with metal mask causes the mask to emit some of it absorbed energy as electromagnetic radiation. Most of this energy is in the form of heat, but some fraction is emitted as x-rays. X-rays can present a health hazard. This wasn't a large problem for television because the intensity of the x-ray radiation falls off quickly as you move away from the screen. However, computer monitors are supposed to be viewed from a short distance. This health concern along with the high voltages and power dissipations of CRTs has motivated the development of new display technologies.

For more information on CRTs check out the following links:

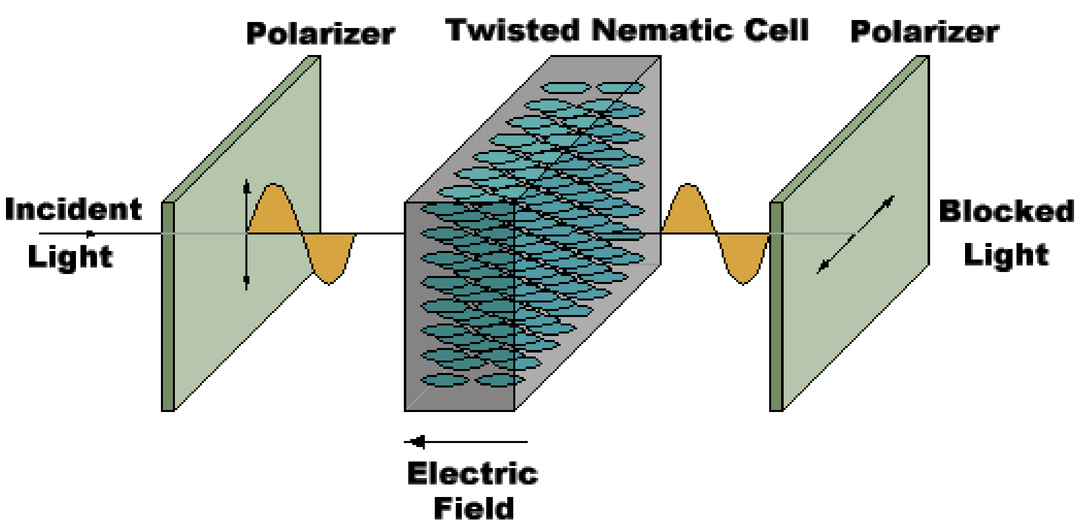
The Scoop on CRTs
History

Liquid Crystal Displays (LCDs)

Currently, the most popular alternative to the CRT is the Liquid Crystal Display (LCD). LCDs are organic molecules that, in the absence of external forces, tend to align themselves in crystalline structures. But, when an external force is applied they will rearrange themselves as if they were a liquid. Some liquid crystals respond to heat (i.e. *mood rings*), others respond to electromagnetic forces.



When used as optical (light) modulators LCDs change polarization rather than transparency (at least this is true for the most popular type of LCD called *Super-twisted Nematic Liquid crystals*). In their unexcited or crystalline state the LCDs rotate the polarization of light by 90 degrees. In the presence of an electric field, LCDs the small electrostatic charges of the molecules align with the impinging E field.

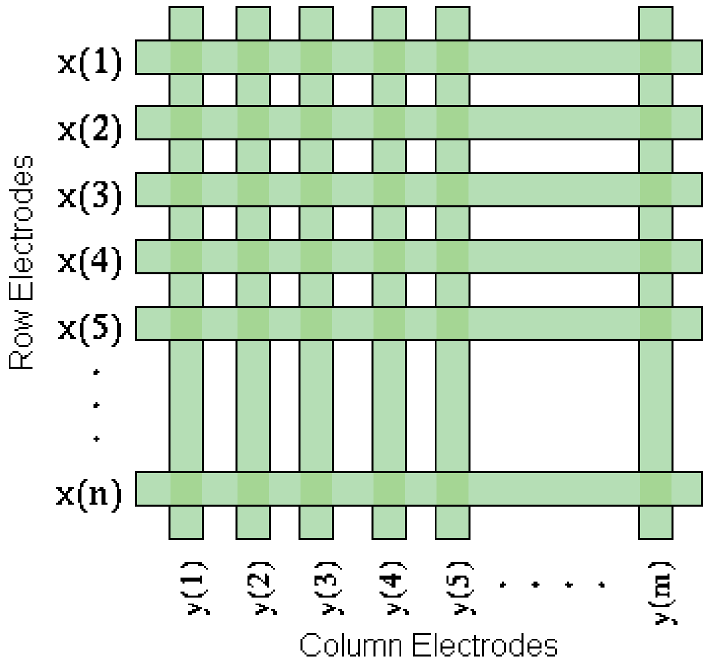


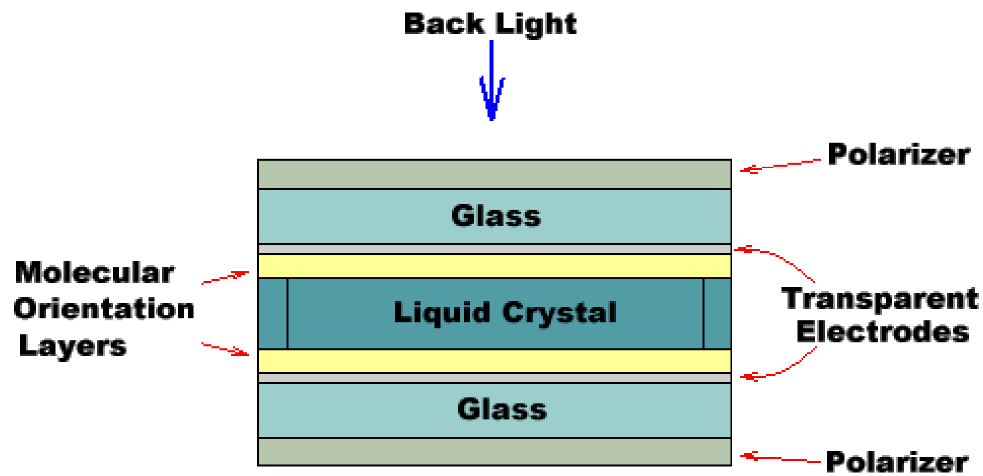
The LCD's transition between crystalline and liquid states is a slow process. This has both good and bad side effects. LCDs, like phosphors, remain "on" for some time after the E field is applied. Thus the image is *persistent* like a CRT's, but this lasts just until the crystals can realign themselves, thus they must be constantly refreshed, again, like a CRT.

The book **Hearns & Baker** is a little confusing in describing how LCDs work (pp. 47-48). They call the relaxed state the "On State" and the excited state the "Off State".

Their statement is only true from the point of view of the pixels when the LCDs are used in a *transmissive mode* (like on most laptops). The opposite is true when the LCDs are used in a *reflective mode* (like on watches).

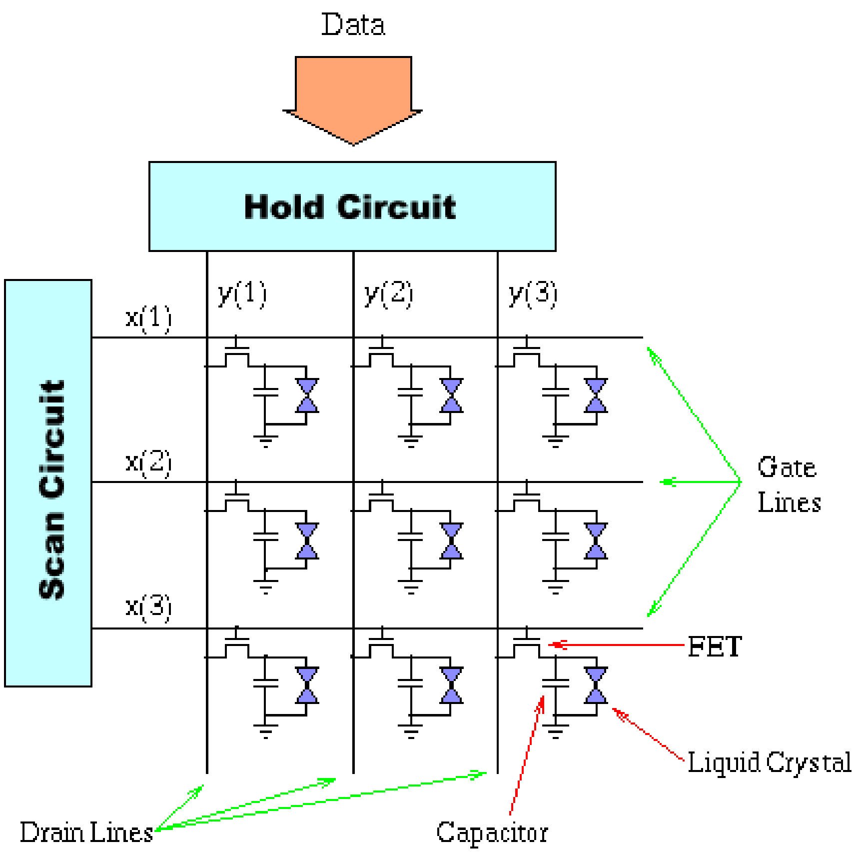
Reflective and Backlit LCDs





Rather than generating light like a CRTs, LCDs act as light values. Therefore, they are dependent on some external light source. In the case of a transmissive display, usually some sort of *back light* is used. Reflective displays take advantage of the ambient light. Thus, transmissive displays are difficult to see when they are overwhelmed by external light sources, whereas reflective displays can't be seen in the dark. You should also note that at least half of the light is lost in most LCD configurations. Can you see why?

Active Matrix LCDs



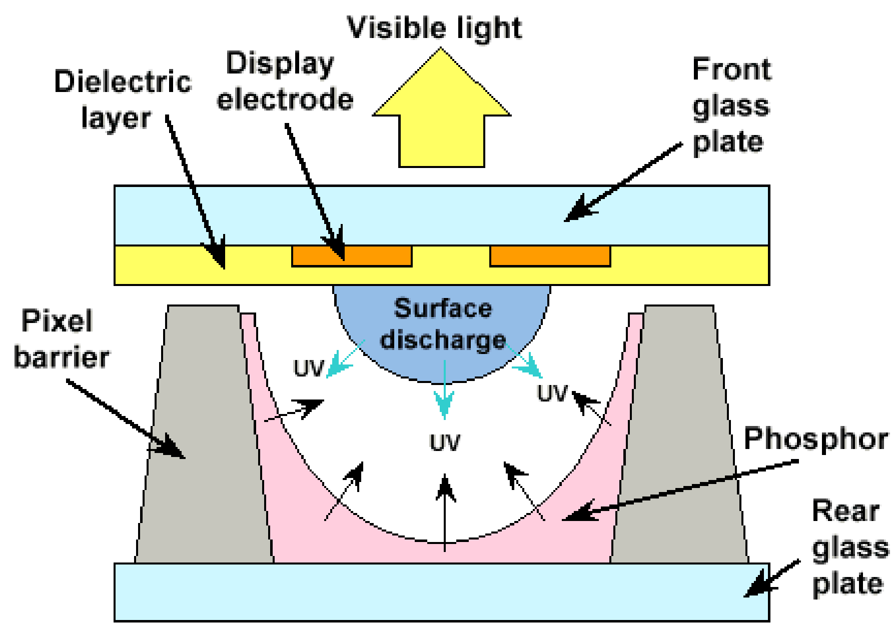
The LCD's themselves have extremely low power requirements. A very small electric field is required to excite the crystals into their liquid state. Most of the energy used by an LCD display system is due to the back lighting.

I mentioned earlier that LCD's slowly transition back to their crystalline state when the E field is removed. In scanned displays, with a large number of pixels, the percentage of the time that LCDs are excited is very small. Thus the crystals spend most of their time in intermediate states, being neither "On" or "Off". This behavior is indicative of *passive displays*. You might notice that these displays are not very sharp and are prone to ghosting. Another way to building LCD displays uses an *active matrix*. The individual cells are very similar to those described above. The main difference is that the electric field is retained by a capacitor so that the crystal remains in a constant state. Transistor switches are used to transfer charge into the capacitors during the scanning process. The capacitors can hold the charge for significantly longer than the refresh period yielding a crisp display with no shadows. Active displays, require a working capacitor and transistor for each LCD or pixel element, and thus, they are more expensive to produce.

- An overview of display technologies and the source of some of my figures.
- A nice discussion of the history and technical details of LCDs
- More discussion of LCDs and the source of some of my figures.

Plasma Display Panels

- Promising for large format displays
- Basically fluorescent tubes
- High-voltage discharge excites gas mixture (He, Xe)
- Upon relaxation UV light is emitted
- UV light excites phosphors
- Large viewing angle

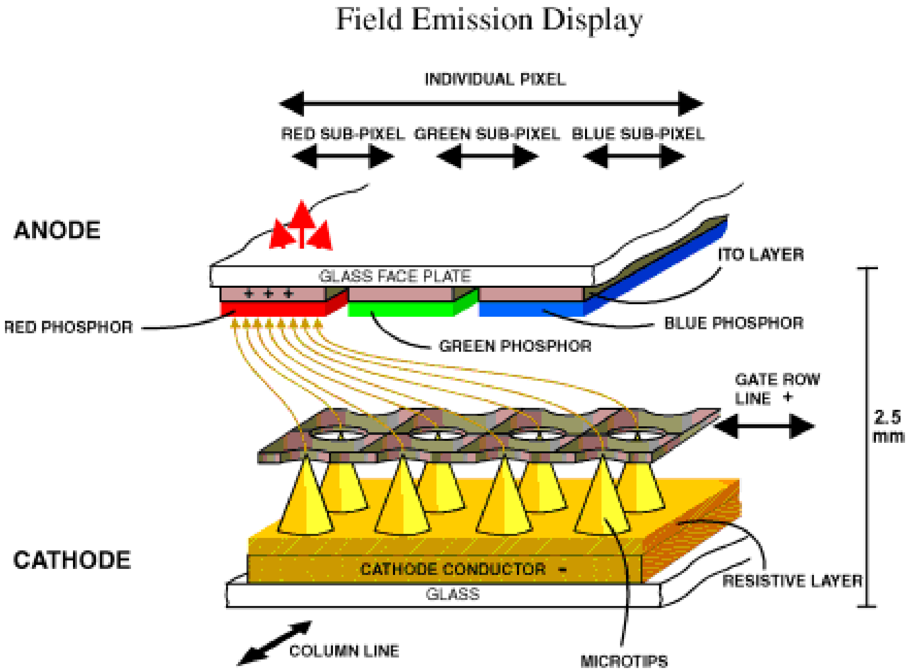


- Less efficient than CRTs
  - Not as bright
  - More power
- Large pixels (~1mm compared to 0.2mm for CRT)
- Ion bombardment depletes phosphors

Plasma display panels (PDPs) are essentially a matrix of very small fluorescent tubes with red, green, and blue phosphors. As in ordinary tubes, a discharge is initiated by a high voltage which excites a mixture of inert-gases such as He and Xe. Upon relaxation, ultra-violet (UV) radiation is generated which excites the phosphors.

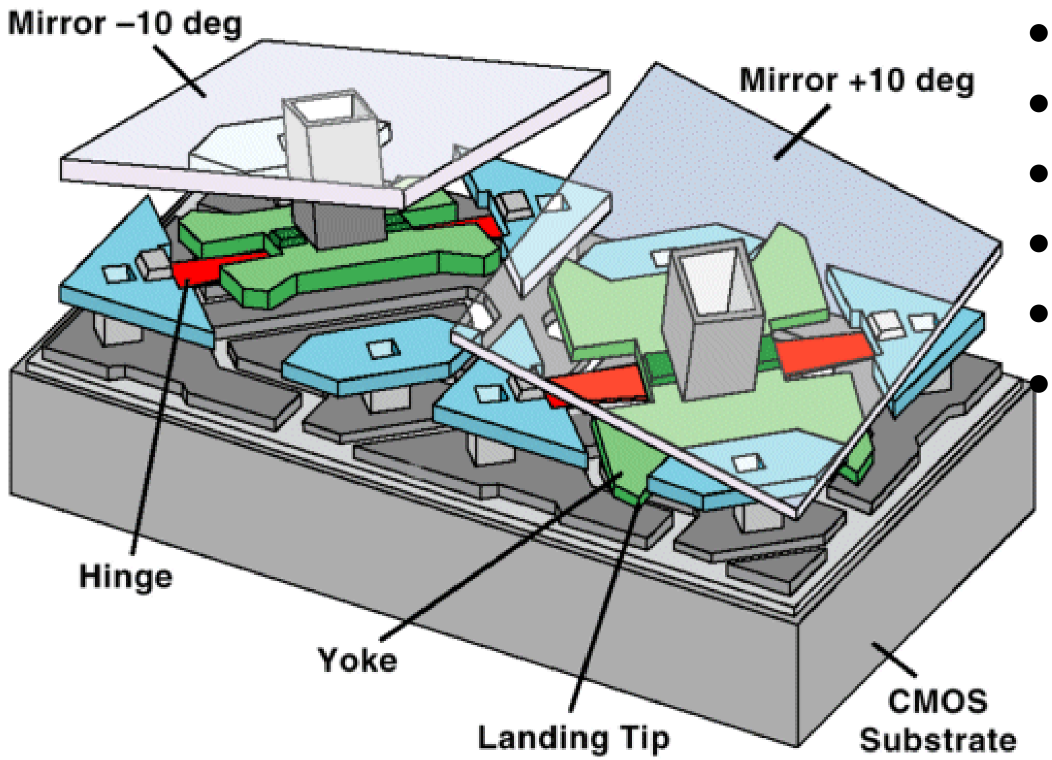
PDPs provide a large viewing angle since the phosphors emit light uniformly. A 40-inch PDP typically consumes about 300 W whereas the peak brightness is only 1/3 of that of a CRT consuming about half the power. Sealing and vacuum pressure support problems apply to PDPs as well, requiring thicker glass as the screen is enlarged. In addition, the discharge chambers have pixel pitches of more than 1 mm which makes it difficult to construct high-definition television (HDTV) and work-station monitors. By contrast, TFTLCDs, CRTs and FEDs may have pixel pitches as small as 0.2 mm.

Field Emission Devices (FEDs)

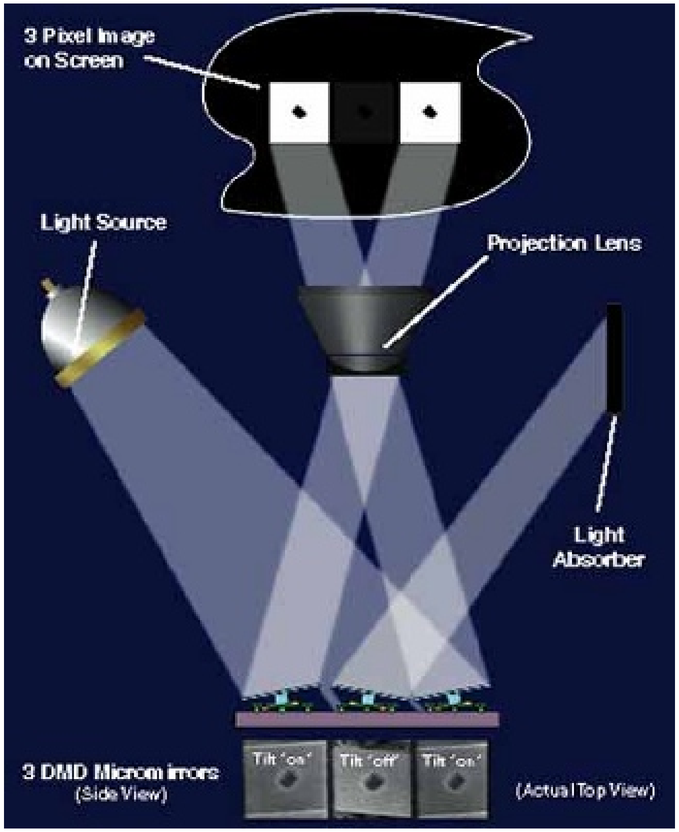


- Works like a CRT with multiple electron guns at each pixel
- Uses modest voltages applied to sharp points to produce strong E fields
- Reliable electrodes proven difficult to produce
- Limited in size
- Thin, and requires a vacuum

Digital Micromirror Devices (DMDs)

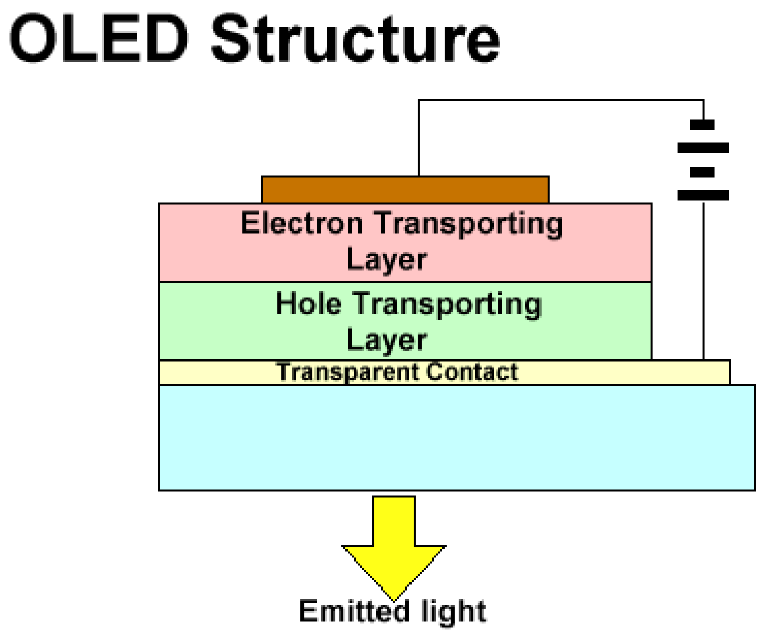


- Microelectromechanical (MEMs) devices
- Fabricated using VLSI processing techniques
- 2-D array of mirrors
- Tilts +/- 10 degrees
- Electrostatically controlled
- Truly digital pixels

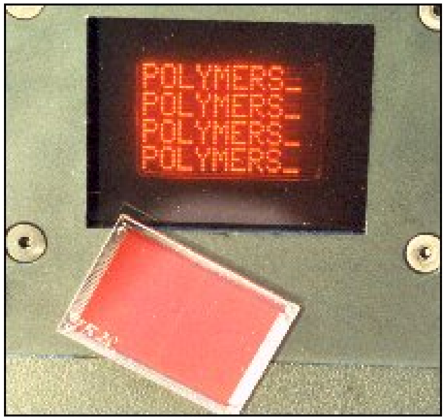


- Suitable only for projection displays
- Gray levels via Pulse-Width Modulation (PWM)
- Color via multiple chips or a color-wheel
- Excellent resolution and *fill-factor*
- Light efficient
- Problems with stray light and flicker

Light Emitting Diode (LED) Arrays



- Organic Light Emitting Diodes (OLEDSs)
- Function is similar to a semiconductor LED
- Thin-film polymer construction
- Potentially simpler processing
  - Transparent
  - Flexible
  - Can be vertically stacked
  - Excellent brightness
  - Large viewing angle
  - Efficient (low power/low voltage)
  - Fast (< 1 microsec)
  - Can be made large or small
  - Tend to breakdown



The operation of organic LEDs is similar to inorganic semiconductor LEDs. When two materials, one with an excess of mobile electrons the other with a deficiency, are place in close contact a junction region is formed. When a small potential is applied the resistance of this junction to the transport of electrons can be overcome. The motion of the electrons in an LED causes excites the electron on lower valance bands causing them to move up or down into other bands. This configuration is unstable and the electrons quickly return to their previous state. This change in energy (induced by the electrons returning to their proper valence bands) causes a photon to be emitted. Unlike crystalline semiconductors, though, these organic devices are made by depositing a thin-film layer from a solution or by a vacuum deposition process. They are not grown like a crystal, and they do no require a high-temperature process to dope them. This allows large areas to be processed, unlike typical semiconductor fabrication.

Several recent developments have stimulated significant interest in OLEDs. These include new materials and new processes. The performance of prototype systems has been very promising. It appears likely that commercial display products will appear in the near future.

OLEDs have many advantages. They are light-emitting, low-voltage, full-color, and have an easily produced electronic structure. All other light-emitting, flat panel technologies employ high voltages. The simple structure is clearly not a characteristic of other popular flat panel display types.

OLED development has progressed rapidly, but there is still much work to be done. Display lifetime remains a key issue with OLEDs. Many of the researchers already feel confident that these problems can be overcome.

The Ultimate Display!

There's 3D and then there is 3D 3D 3D 3D

Most often we present 3-dimensional graphics on 2-dimensional displays.

What is the potential for presenting 3D information in a way that it can be percieved as 3D?

Yes, we are talking about holodecks!

Can we build one? How?

Head-Mounted Displays

Consider carrying two displays around on your head.

+ Stereopsis is a strong 3D queue
+ Existing Technology
+ Personal Display
- Obtrusive
- Narrow FOV (Tunnel Vision)
- Low Resolution
- Tracking

Currently the most popular 3-Dimensional (VR) display

Caves and Fish Bowls

Alternate left and right eye images on a single display

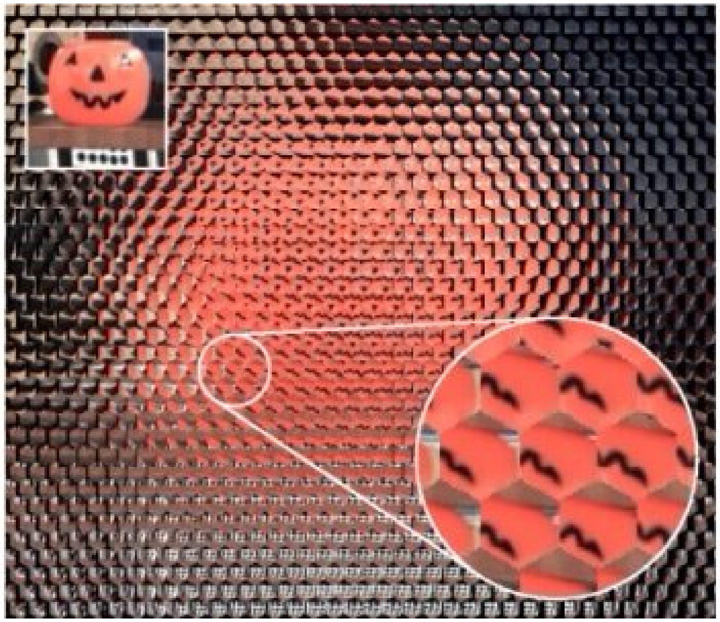
- Electronic shutters
- Polarization
- Red/Green
- Barriers

+Lighter or no headware
+High resolution
-Significant infrastructure
 (5-wall caves have been built)
-Personal
-Still needs tracking

Autostereo Displays

HoloVideo Display

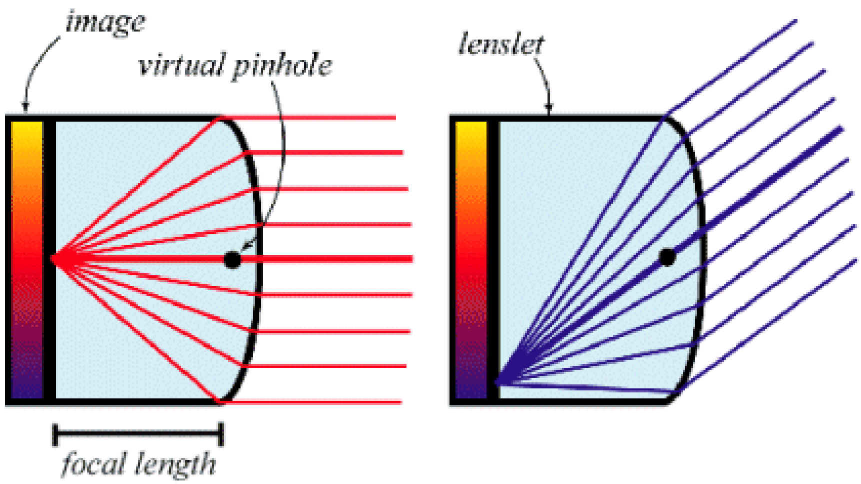
+Multi-viewer
+No Encumberances
-Requires an *extremely* high-resolution display element
-Narrow-band illumination



Integral Display

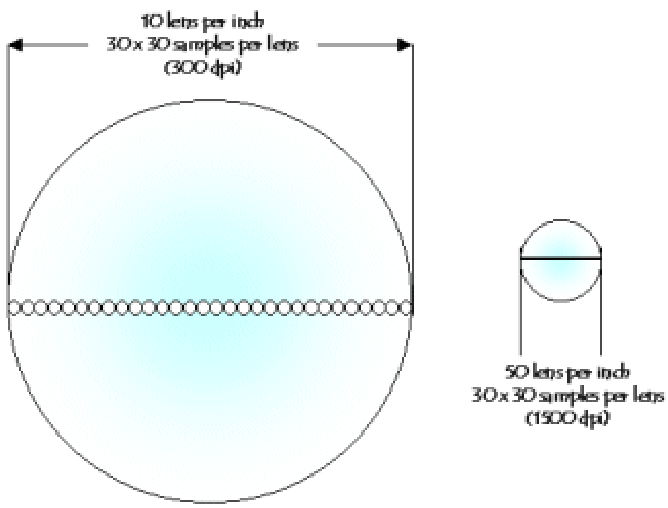
+Multi-viewer
+No Encumberances
+Requires a *moderately* high-resolution display
-Requires a dense array of lenses

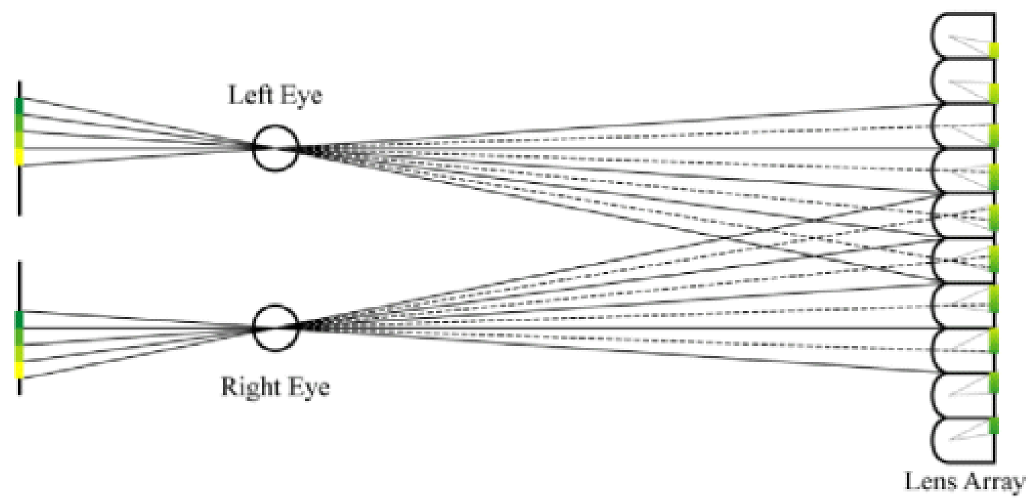
How it Works



Lens Properties

- Plastic hexangonal lens array
- Each lens is a "view dependent" pixel
- Currently 10 lens/inch

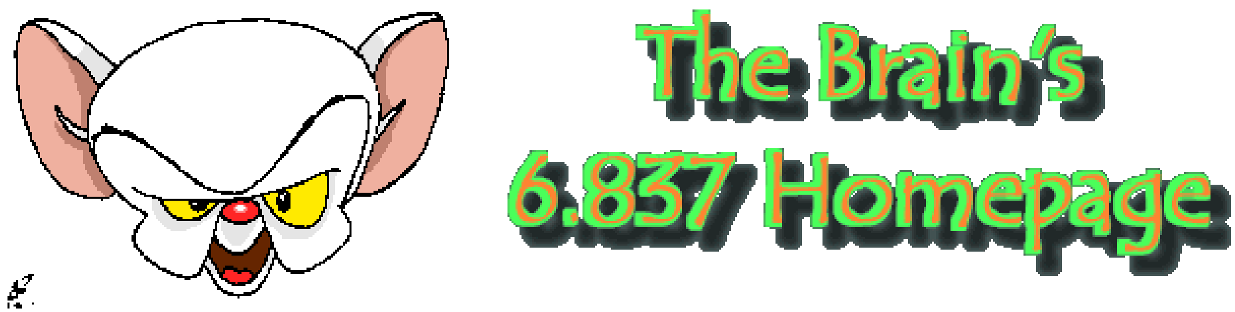




More information at: www.graphics.lcs.mit.edu/~aisaksen/projects/autostereoscopic
Paper at: www.graphics.lcs.mit.edu/~aisaksen/projects/drlf

Exercise #1

Set up your course homepage by next Tuesday 9/11



MIT's Graphics Group
My *REAL* homepage
6.837's homepage

Narf!

Homepage Requirements:

- REGISTER TODAY (on course Webpage)
- Locate on imagery in `/mit/imagery2/6.837/F01/username` (you must execute "**add imagery2**" first)
- Something about you
- Links to Exercise 1 and to the 5 projects
- Area for links to computer graphics sites that you find interesting
- A link back to the 6.837 homepage

A First Java Program

We start by writing what is called a Java *applet*. This is a form of a Java program that can be embedded in a HTML document and accessed from the web. An example HTML document that calls our example applet is shown below:

```
<HTML>
<HEAD>
<TITLE>Demo Applet</TITLE>
</HEAD>
<BODY>

<H1>Demo Applet</H1>
<P>My favorite class is 6.837</P>
<HR>
<CENTER>

<APPLET code="Demo.class" width=200 height=200>
</APPLET>

</CENTER>
<HR>
</BODY>
</HTML>
```

The italicized lines add the Java applet to our document. Notice the *.class* extension. All Java source code files should end with a *.java* extension. The source is here.

Java Example

Next, the source of the *demo.java* file is shown.

```
import java.applet.*;
import java.awt.*;

public class Demo extends Applet {
        Image image;
        int count;

        public void init() {
            image = getImage(getDocumentBase(), "world.jpg");
            count = 1;
        }

        public void paint(Graphics g) {
            g.drawImage(image, 0, 0, this);
            g.setColor(Color.red);
            for (int y = 15; y < size().height; y += 15) {
                int x = (int) (size().width/2 + 30*Math.cos(Math.PI*y/75));
                g.drawString("Hello", x, y);
            }
            showStatus("Paint called "+count+" time"+((count > 1)?"s":""));
            count += 1;
        }
}
```

You can get the source here and the world.jpg image here.

The Applet in Action

Demo Applet

My favorite class is 6.837

This is all of the Java programming language that we will specifically cover in class.

If you have never used Java before, you might want to consider buying one of the books discussed on the course's home page.

6.837 Topics

- Pixels, Rasters and Sprites
- Filling, Colors and Grayscale
- Line Drawing
- Aliasing and Resampling
- Scan Conversion
- Transformations: 2D and 3D (x3)
- Viewing and Projection
- Clipping and Culling
- 3D Modeling
- Visible Surface Algorithms (x2)
- Illumination and Shading (x2)
- Ray Tracing
- Texture Mapping (x2)
- Radiosity
- Animation (x2)
- Special Topics


Java
Roasters