Introduction to Computer Graphics with WebGL

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Overview

- These lectures are for a senior/graduate elective for computer science and engineering majors(and others with good programming skills)
- The course is based on a modern approach using programmable shaders in the new textbook: Ed Angel and Dave Shreiner, Interactive Computer Graphics, A Top-down Approach with WebGL(Seventh Edition), Addison-Wesley
- These lectures cover Chapters 1-7 in detail and survey Chapters 8-12

Week 1

- Video 1.1: Introduction
- Video 1.2: Detailed Outline and Examples
- Video 1.3: Example Code in JS
- Video 1.4: What is Computer Graphics?
- Video 1.5: Image Formation

- Reading: Chapter 1
- Exercises: Run some examples on your browser

Video 1.1

- Course Overview
- Required Background
- References

Contact Information

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Objectives

- Broad introduction to Computer Graphics
  - Software
  - Hardware
  - Applications
- Top-down approach
- Shader-Based WebGL
  - Integrates with HTML5
  - Code runs in latest browsers

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Prerequisites

- Good programming skills in C (or C++)
- Basic Data Structures
  - Linked lists
  - Arrays
- Geometry
- Simple Linear Algebra
- Note: CS/ECE 412 is neither a pre- or corequisite
  - Considerable overlap
  - Should not take both for credit

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Requirements

- 3 Assigned Projects
  - Simple
  - Interactive
  - 3D
- Term Project
  - You pick
- See

www.cs.unm.edu/~angel/ONLINE_GRAPHICS

for assignments, projects and other info

Why is this course different?

- Shader-based
  - Most computer graphics use OpenGL but still use fixed-function pipeline
  - does not require shaders
  - Does not make use of the full capabilities of the graphics processing unit (GPU)
- Web
  - With HTML5, WebGL runs in the latest browsers
  - makes use of local hardware
  - no system dependencies

References

- Interactive Computer Graphics (7th Edition)
- The OpenGL Programmer's Guide (the Redbook) 8th Edition
- OpenGL ES 2.0 Programming Guide
- WebGL Programming Guide
- WebGL Beginner's Guide
- WebGL: Up and Running
- JavaScript: The Definitive Guide

Web Resources

- www.cs.unm.edu/~angel/
- www.cs.unm.edu/~angel/WebGL/7E
- www.opengl.org
- get.webgl.org
- www.kronos.org/webgl
- www.chromeexperiments.com/webgl
- learningwebgl.com

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Video 1.2

- Course Outline
- Examples at

  www.cs.unm.edu/~angel/WebGL/7E

Outline: Part 1

- Introduction
- Text: Chapter 1
- Week 1
    - What is Computer Graphics?
    - Applications Areas
    - History
    - Image formation
    - Basic Architecture

Outline: Part 2

- Basic WebGL Graphics
- Text: Chapter 2
- Weeks 2-4
  - Architecture
  - JavaScript
  - Web execution
  - Simple programs in two and three dimensions
  - Basic shaders and GLSL

Outline: Part 3

- Interaction
- Text: Chapter 3
- Week 5
    - Client-Server Model
    - Event-driven programs
    - Event Listeners
    - Menus, Buttons, Sliders
    - Position input

Outline: Part 4

- Three-Dimensional Graphics
- Text: Chapters 4-6
- Weeks 6-9
    - Geometry
    - Transformations
    - Homogeneous Coordinates
    - Viewing
    - Lighting and Shading

Outline: Part 5

- Discrete Methods
- Text: Chapter 7
- Weeks 10-12
  - Buffers
  - Pixel Maps
  - Texture Mapping
  - Compositing and Transparency
  - Off-Screen Rendering

Outline: Part 6

- Hierarchy and Procedural Methods
- Text: Chapters 9-10
- Weeks 13-14
- Tree Structured Models
  - Traversal Methods
  - Scene Graphs
  - Particle Systems
  - Agent Based Models

Outline: Part 7

- Advanced Rendering
- Text: Chapter 12
- Week 15

Examples

Book website:

www.cs.unm.edu/~angel/WebGL/7E

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Video 1.3

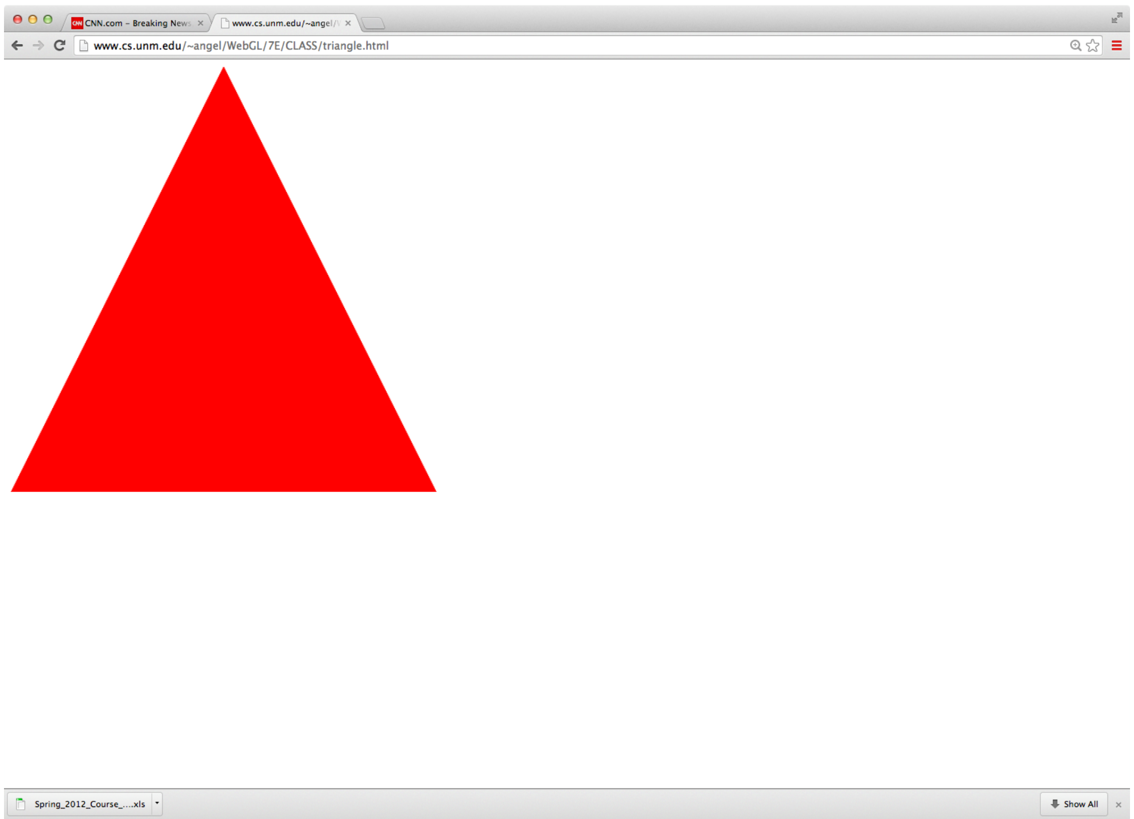
- Example: Draw a triangle
  - Each application consists of (at least) two files
  - HTML file and a JavaScript file
- HTML
  - describes page
  - includes utilities
  - includes shaders
- JavaScript
  - contains the graphics

Coding in WebGL

- Can run WebGL on any recent browser
  - Chrome
  - Firefox
  - Safari
  - IE
- Code written in JavaScript
- JS runs within browser
  - Use local resources

Example: triangle.html

Code in Examples/triangle.html



Example Code

```
<!DOCTYPE html>
<html>
<head>
<script id="vertex-shader" type="x-shader/x-vertex">
#version 300 es
in vec4 vPosition;
void main(){ gl_Position = vPosition;}
</script>
<script id="fragment-shader" type="x-shader/x-fragment">
#version 300 es
precision mediump float;
out vec4 fColor;
void main(){ fColor = vec4( 1.0, 0.0, 0.0, 1.0 );}
</script>
```

HTML File (cont)

```
<script type="text/javascript" src="../Common/initShaders.js"></script>
<script type="text/javascript" src="../Common/MVnew.js"></script>
<script type="text/javascript" src="triangle.js"></script>
</head>
<body>
<canvas id="gl-canvas" width="512" height="512">
Oops ... your browser doesn't support the HTML5 canvas element
</canvas>
</body>
</html>
```

JS File

```
var gl;
var points;

window.onload = function init(){
    canvas = document.getElementById( "gl-canvas" );
    gl = canvas.getContext('webgl2');
    if (!gl) { alert( "WebGL 2.0 isn't available" ); }

// Three Vertices
   var vertices = [
        vec2( -1, -1 ),
        vec2(  0,  1 ),
        vec2(  1, -1 )
   ];
```

JS File (cont)

```
//  Configure WebGL
//
    gl.viewport( 0, 0, canvas.width, canvas.height );
    gl.clearColor( 1.0, 1.0, 1.0, 1.0 );

//  Load shaders and initialize attribute buffers

    var program = initShaders( gl, "vertex-shader", "fragment-shader" );
    gl.useProgram( program );

// Load the data into the GPU

    var bufferId = gl.createBuffer();
    gl.bindBuffer( gl.ARRAY_BUFFER, bufferId );
    gl.bufferData( gl.ARRAY_BUFFER, flatten(vertices), gl.STATIC_DRAW );
```

JS File (cont)

```
// Associate out shader variables with our data buffer

      var vPosition = gl.getAttribLocation( program, "vPosition" );
      gl.vertexAttribPointer( vPosition, 2, gl.FLOAT, false, 0, 0 );
      gl.enableVertexAttribArray( vPosition );
      render();
};

function render() {
    gl.clear( gl.COLOR_BUFFER_BIT );
   gl.drawArrays( gl.TRIANGLES, 0, 3 );
}
```

Exercise

- Download the code from the class website
- Load the triangle.html and triangle.js to your computer and run them from there
- Edit the two files to change the color and display more than one triangle

JavaScript Notes

- JavaScript (JS) is the language of the Web
  - All browsers will execute JS code
  - JavaScript is an interpreted object-oriented language
- References
  - Flanagan, JavaScript: The Definitive Guide, O'Reilly
  - Crockford, JavaScript, The Good Parts, O'Reilly
  - Many Web tutorials

JS Notes

- Is JS slow?
  - JS engines in browsers are getting much faster
  - Not a key issues for graphics since once we get the data to the GPU it doesn't matter how we got the data there
- JS is a (too) big language
  - We don't need to use it all
  - Choose parts we want to use
  - Don't try to make your code look like C or Java

JS Notes

- Very few native types:
  - numbers
  - strings
  - booleans
- Only one numerical type: 32 bit float
  - var x = 1;
  - var x = 1.0; // same
  - potential issue in loops
  - two operators for equality == and ===
- Dynamic typing

Scoping

- Different from other languages
- Function scope
- variables are *hoisted* within a function
  - can use a variable before it is declared
- Note functions are first class objects in JS

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JS Arrays

- JS arrays are objects
  - inherit methods
  - var a = [1, 2, 3];
    is not the same as in C++ or Java
  - a.length   // 3
  - a.push(4); // length now 4
  - a.pop();   // 4
  - avoids use of many loops and indexing
  - Problem for WebGL which expects C-style arrays

Typed Arrays

JS has typed arrays that are like C arrays

```
var a = new Float32Array(3)
var b = new Uint8Array(3)
```

Generally, we prefer to work with standard JS arrays and convert to typed arrays only when we need to send data to the GPU with the flatten function in MV.js

A Minimalist Approach

- We will use only core JS and HTML
  - no extras or variants
- No additional packages
  - CSS
  - JQuery
- Focus on graphics
  - examples may lack beauty
- You are welcome to use other variants as long as I can run them from your URL

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What is Computer Graphics?

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Computer Graphics

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

Example

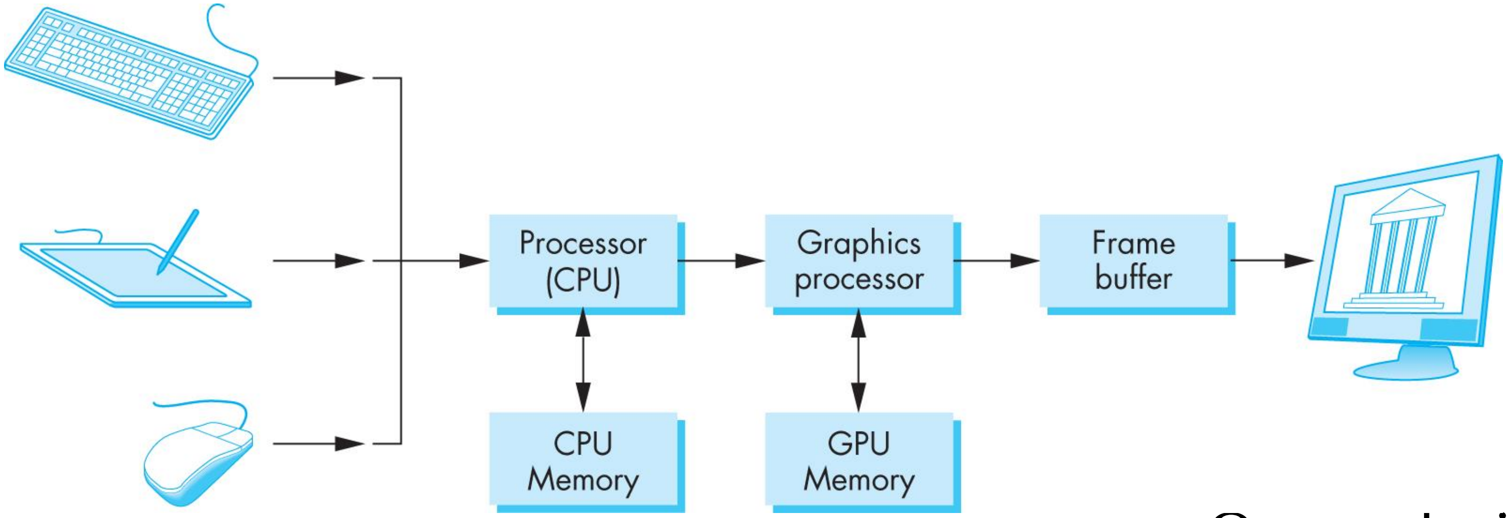
- Where did this image come from?

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

Preliminary Answer

- **Application**: The object is an artist's rendition of the sun for an animation to be shown in a domed environment (planetarium)
- **Software**: Maya for modeling and rendering but Maya is built on top of OpenGL
- **Hardware**: PC with graphics card for modeling and rendering

Basic Graphics System



Output device

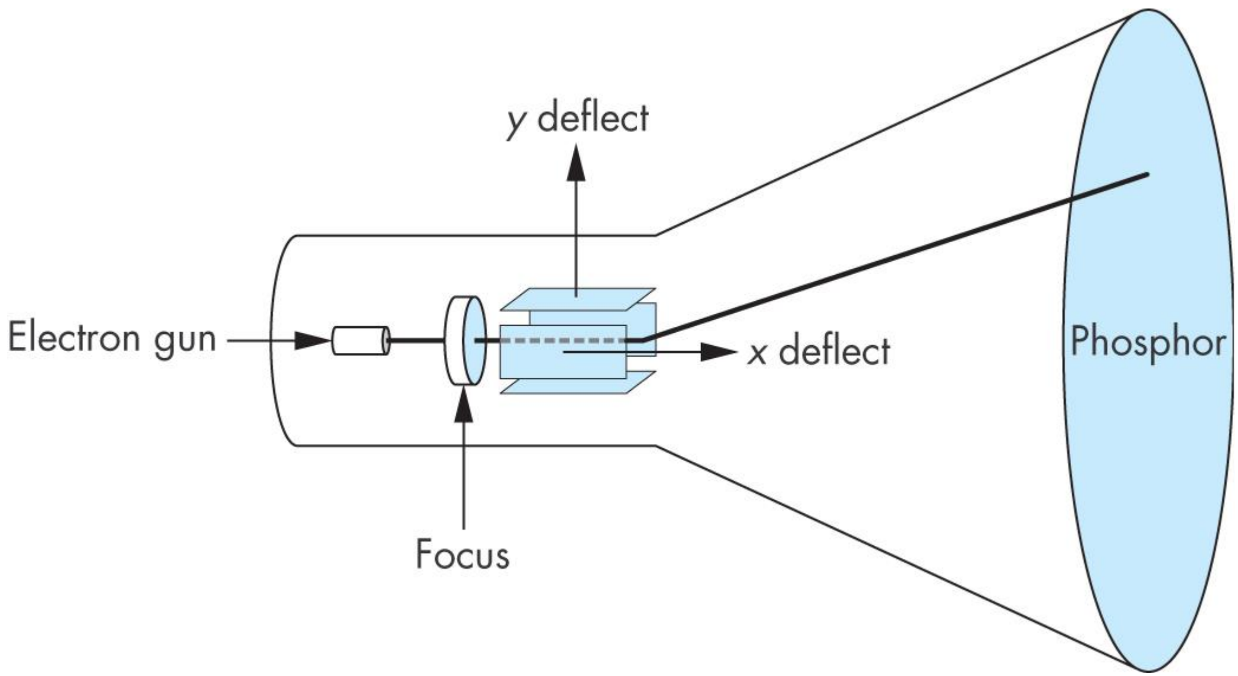
Input devices

Image formed in frame buffer

Computer Graphics: 1950-1960

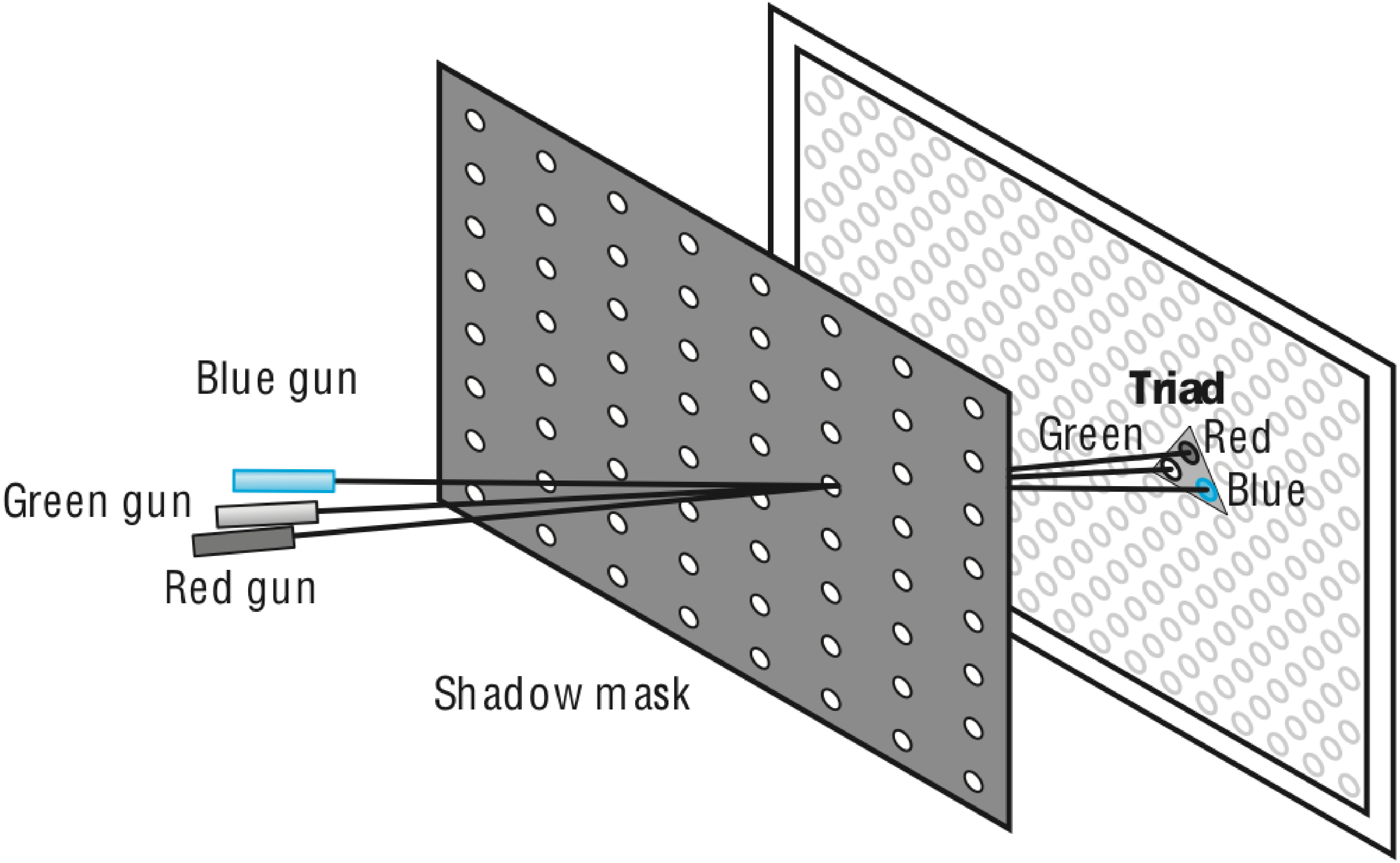
- Computer graphics goes back to the earliest days of computing
  - Strip charts
  - Pen plotters
  - Simple displays using A/D converters to go from computer to calligraphic CRT
- Cost of refresh for CRT too high
  - Computers slow, expensive, unreliable

Cathode Ray Tube (CRT)



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

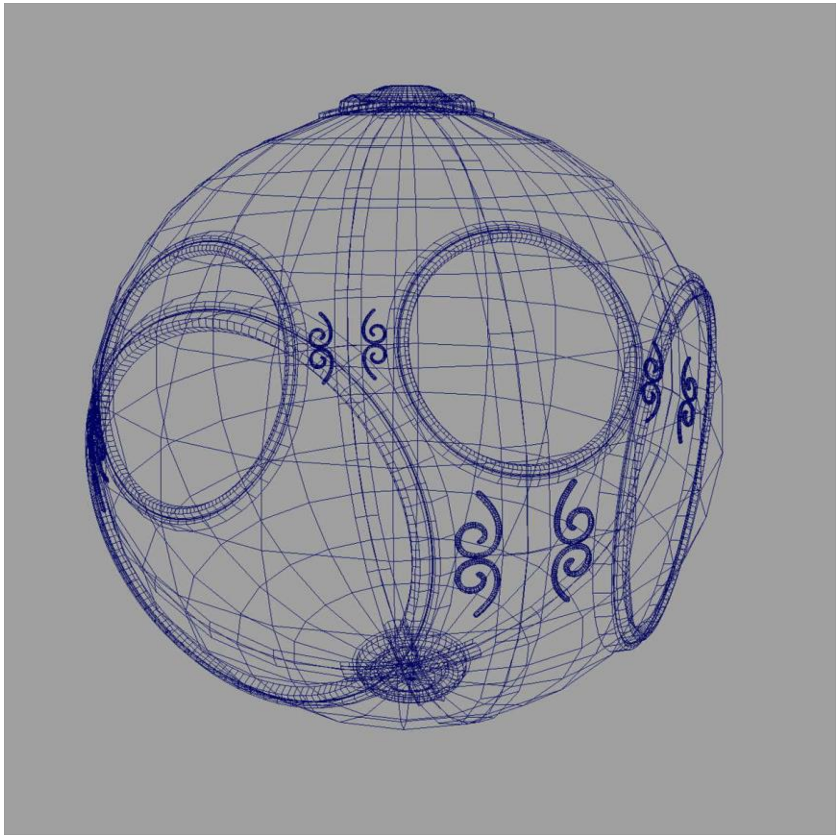
Shadow Mask CRT



Computer Graphics: 1960-1970

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

wireframe representation of sun object

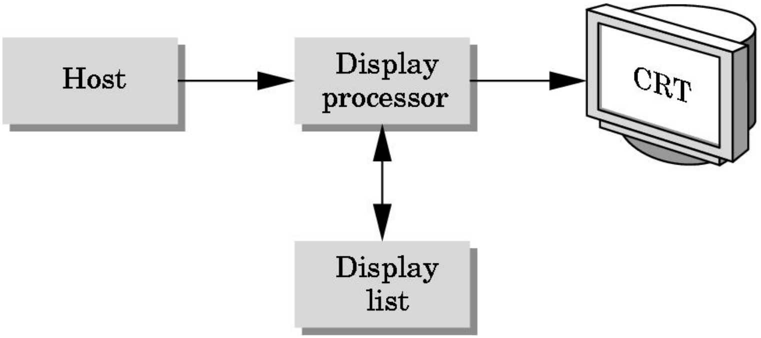


Sketchpad

- 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)



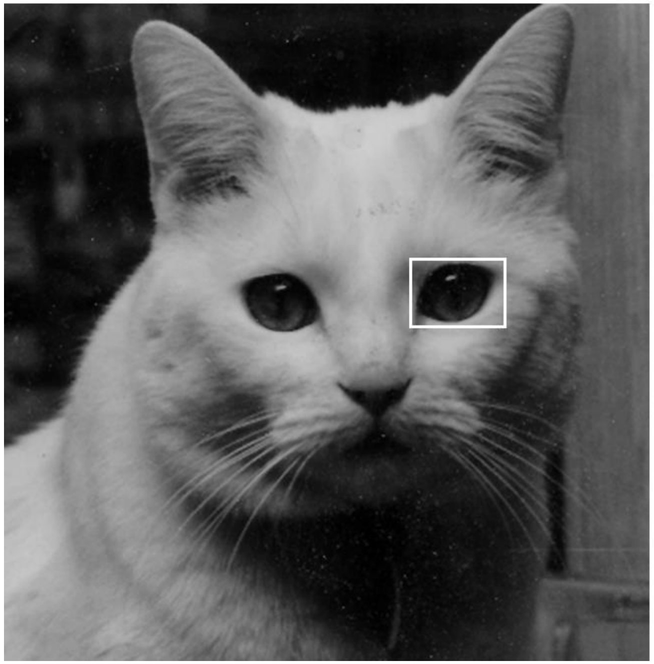
- Graphics stored in display list (display file) on display processor
- Host *compiles* display list and sends to DPU

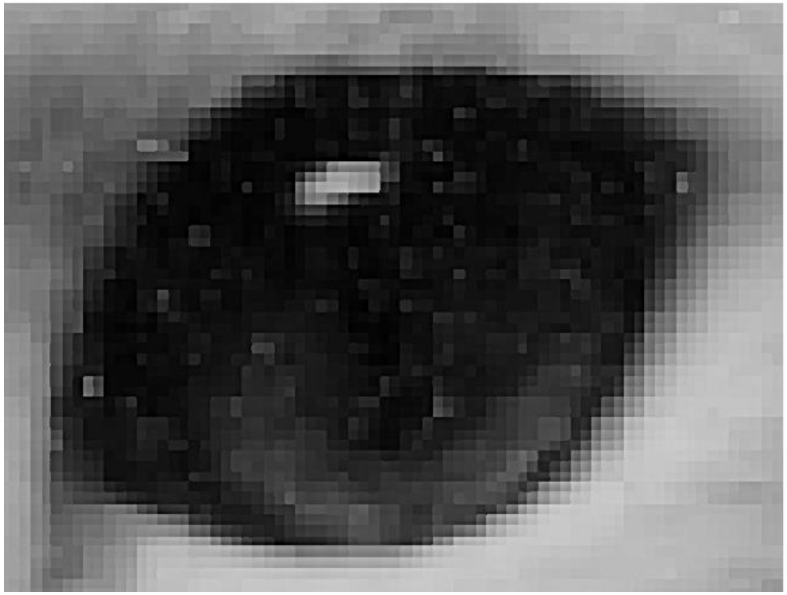
Computer Graphics: 1970-1980

- 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*





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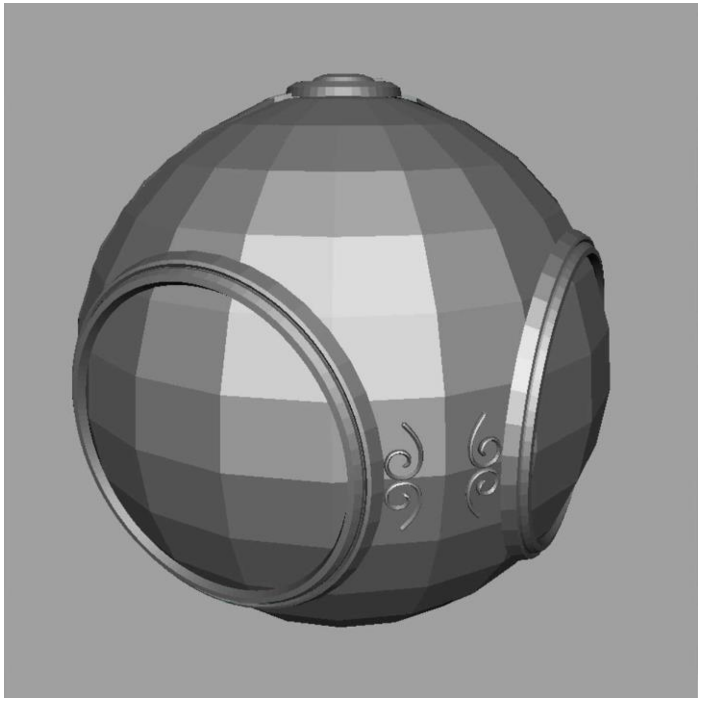
Raster Graphics

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

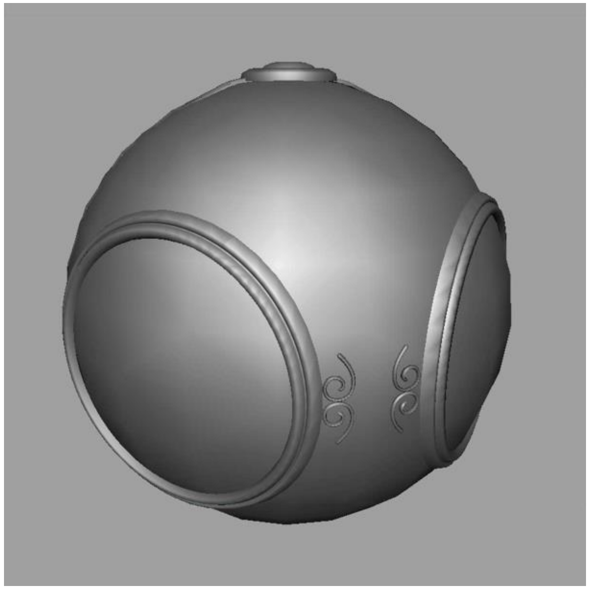


PCs and Workstations

- 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

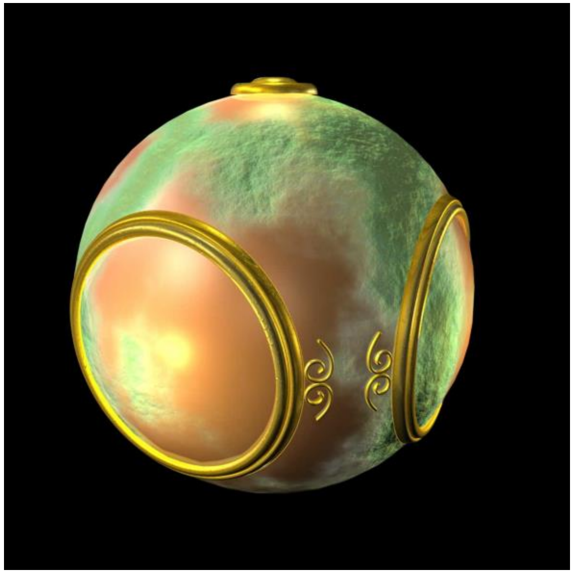
Computer Graphics: 1980-1990

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)

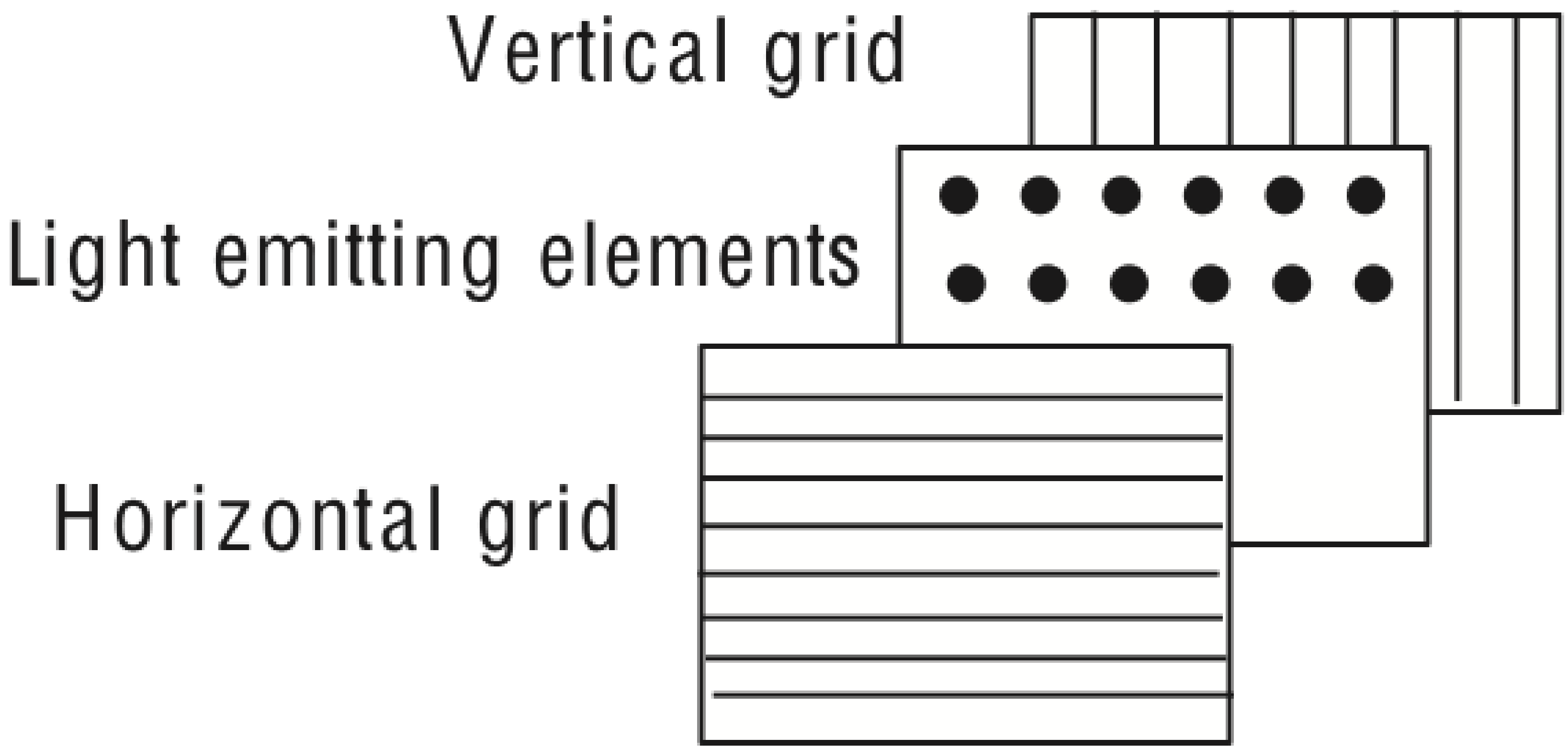
Computer Graphics: 1990-2000

- 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 for PCs dominate market
  - Nvidia, ATI
- Game boxes and game players determine direction of market
- Computer graphics routine in movie industry: Maya, Lightwave
- Programmable pipelines
- New display technologies

Generic Flat Panel Display



Computer Graphics 2011-

- Graphics is now ubiquitous
  - Cell phones
  - Embedded
- OpenGL ES and WebGL
- Alternate and Enhanced Reality
- 3D Movies and TV

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Image Formation

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Objectives

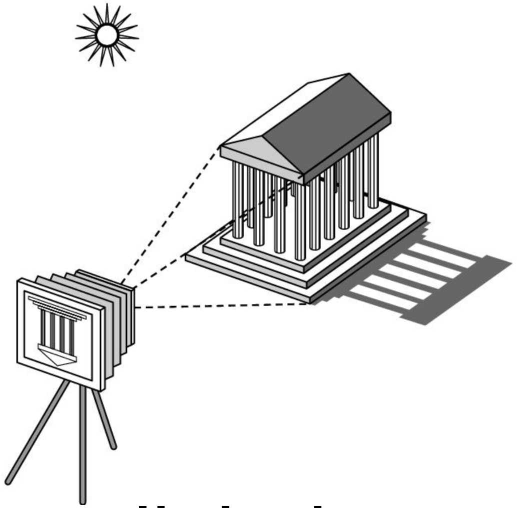
- Fundamental imaging notions
- Physical basis for image formation
  - Light
  - Color
  - Perception
- Synthetic camera model
- Other models

Image Formation

- In computer graphics, we form images which are generally two dimensional using a process analogous to how images are formed by physical imaging systems
  - Cameras
  - Microscopes
  - Telescopes
  - Human visual system

Elements of Image Formation

- Objects
- Viewer
- Light source(s)



- Attributes that govern how light interacts with the materials in the scene
- Note the independence of the objects, the viewer, and the light source(s)

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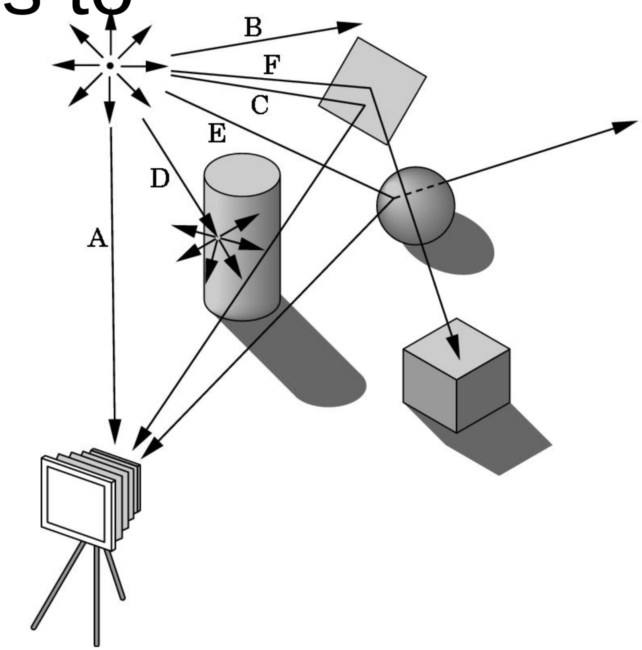
Light

- *Light* is the part of the electromagnetic spectrum that causes a reaction in our visual systems
- Generally these are wavelengths in the range of about 350-750 nm (nanometers)
- Long wavelengths appear as reds and short wavelengths as blues

Ray Tracing and Geometric Optics

One way to form an image is to follow rays of light from a point source finding which rays enter the lens of the camera. However, each ray of light may have multiple interactions with objects before being absorbed or going to infinity.

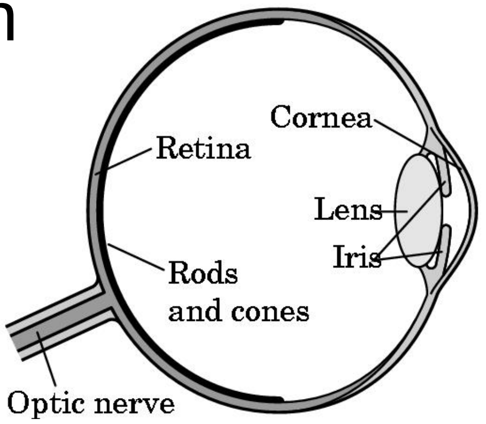


Luminance and Color Images

- Luminance Image
  - Monochromatic
  - Values are gray levels
  - Analogous to working with black and white film or television
- Color Image
  - Has perceptional attributes of hue, saturation, and lightness
  - Do we have to match every frequency in visible spectrum? No!

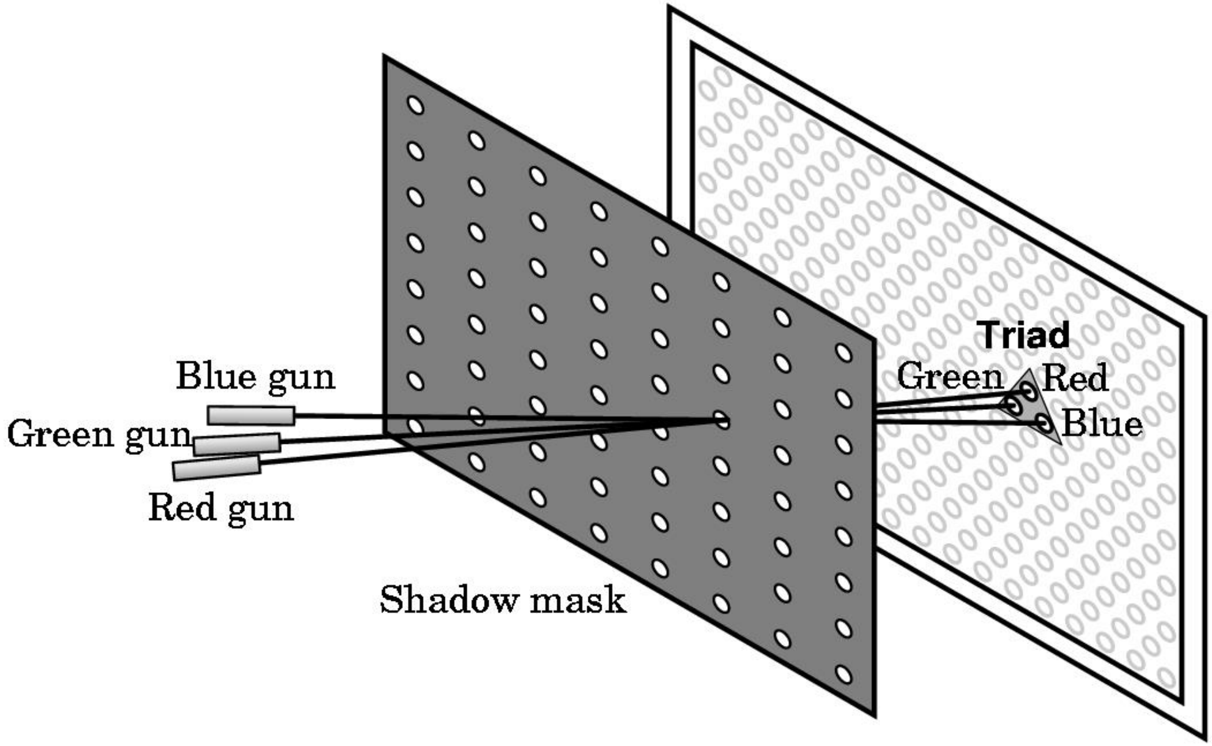
Three-Color Theory

- Human visual system has two types of sensors
  - Rods: monochromatic, night vision
  - Cones
    - Color sensitive
    - Three types of cones
    - Only three values (the *tristimulus* values) are sent to the brain



- Need only match these three values
  - Need only three *primary* colors

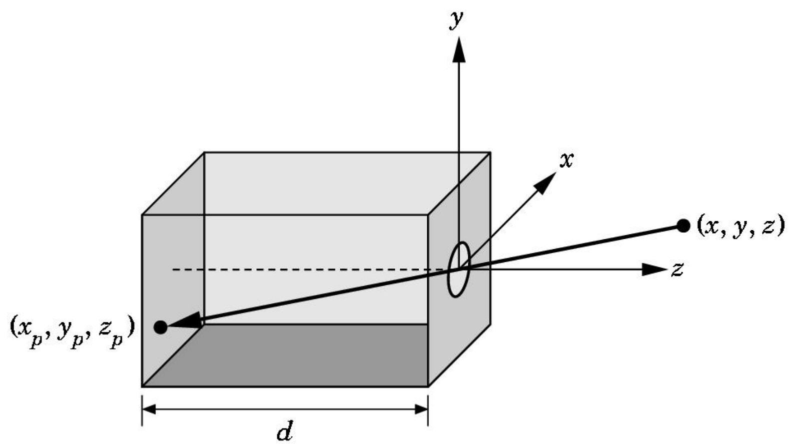
Shadow Mask CRT



Additive and Subtractive Color

- Additive color
  - Form a color by adding amounts of three primaries
    - CRTs, projection systems, positive film
  - Primaries are Red (R), Green (G), Blue (B)
- Subtractive color
  - Form a color by filtering white light with cyan (C), Magenta (M), and Yellow (Y) filters
    - Light-material interactions
    - Printing
    - Negative film

Pinhole Camera

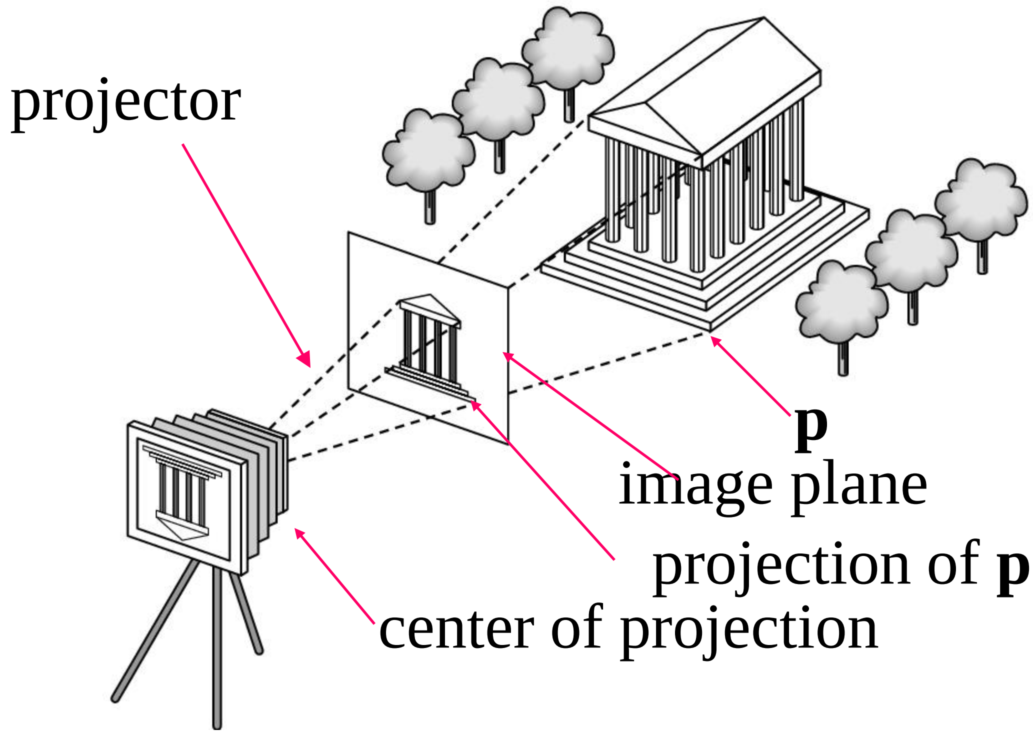


Use trigonometry to find projection of point at (x,y,z)

$$x_p = -x/z/d \qquad y_p = -y/z/d \qquad z_p = d$$

These are equations of simple perspective

Synthetic Camera Model

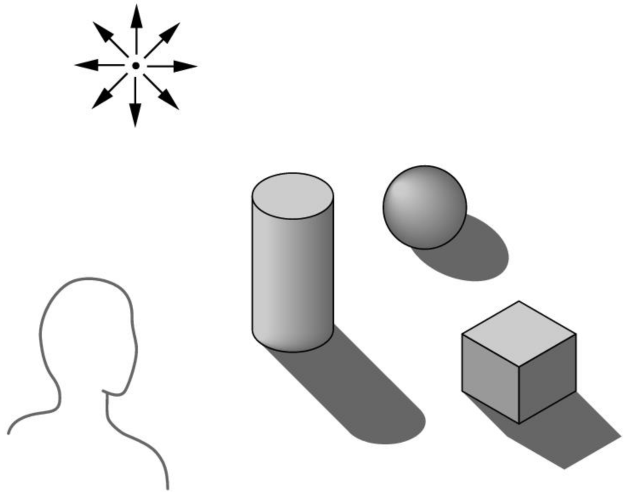


Advantages

- Separation of objects, viewer, light sources
- Two-dimensional graphics is a special case of three-dimensional graphics
- Leads to simple software API
  - Specify objects, lights, camera, attributes
  - Let implementation determine image
- Leads to fast hardware implementation

Global vs Local Lighting

- Cannot compute color or shade of each object independently
  - Some objects are blocked from light
  - Light can reflect from object to object
  - Some objects might be translucent



Why not ray tracing?

- Ray tracing seems more physically based so why don't we use it to design a graphics system?
- Possible and is actually simple for simple objects such as polygons and quadrics with simple point sources
- In principle, can produce global lighting effects such as shadows and multiple reflections but ray tracing is slow and not well-suited for interactive applications
- Ray tracing with GPUs is close to real time