Interactive Computer Graphics

Objectives

- Introduction to Interactive Computer Graphics
  - Software
  - Hardware
  - Applications
- Top-down approach
- Shader-Based OpenGL compatible with
  - OpenGL 3.1 (and later)
  - Open GL ES 2.0
  - webGL

Credits

- Course structure based on Ed Angel and Dave Shreiner, *Interactive Computer Graphics, A Top-down Approach with OpenGL (Sixth Edition)*, Addison-Wesley, 2012
- Slides based on lectures for CS/EECE 412 Computer Graphics at the University of New Mexico by Prof. Edward Angel

Prerequisites

- Good programming skills
- Linux-based software development
- Basic Data Structures
  - Linked lists
  - Arrays
- Geometry
- Linear Algebra
  - Vectors & matrices

Requirements

- Weekly Programming Projects
- Optional Term Project
  - Defined by each student
- Grad Students Only
  - Summarize 2 research papers
- Go to class web site

Resources

- Can run OpenGL on any system
  - Windows: check graphics card properties for level of OpenGL supported
  - Linux
  - Mac: need extensions for 3.1 equivalence
- Get GLUT from web if needed
  - Provided on Macs
  - freeglut available on web
- Get GLEW from web

References

- www.opengl.org
  - Standards documents
  - Sample code
- The OpenGL Programmer's Guide (the Redbook) 8th Edition
  - The definitive reference
  - OpenGL 4.1
- OpenGL Shading Language, 3rd Edition
- All Addison-Wesley Professional

Image Formation

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

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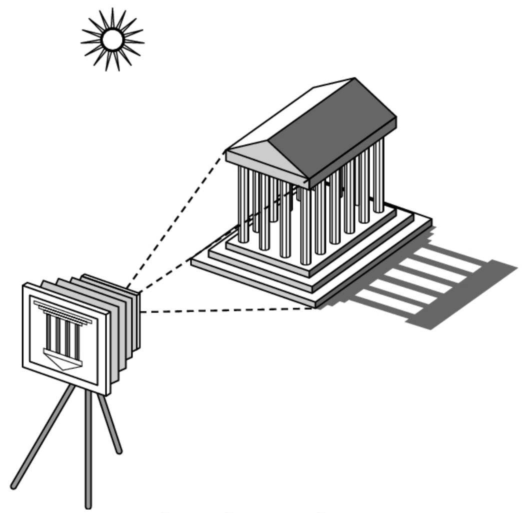
Elements of Image Formation

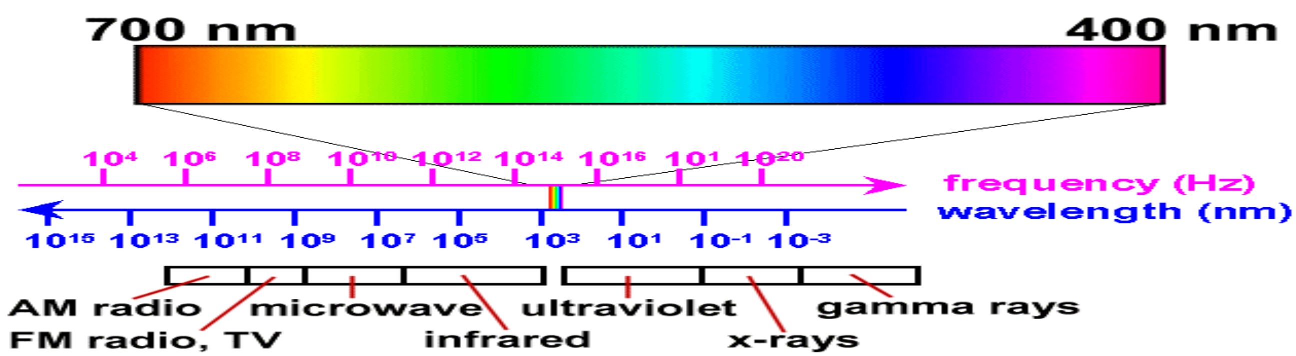
- Objects
- Viewer
- Light source(s)



- 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)

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

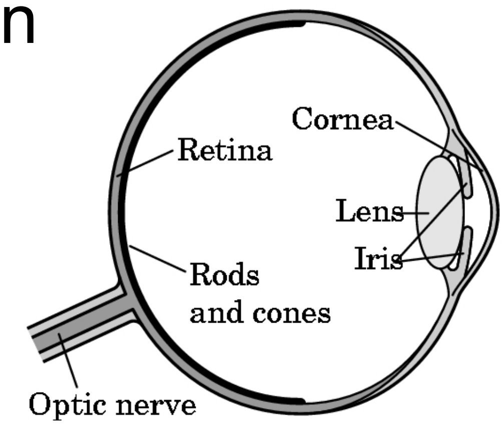


Luminance and Color Images

- 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

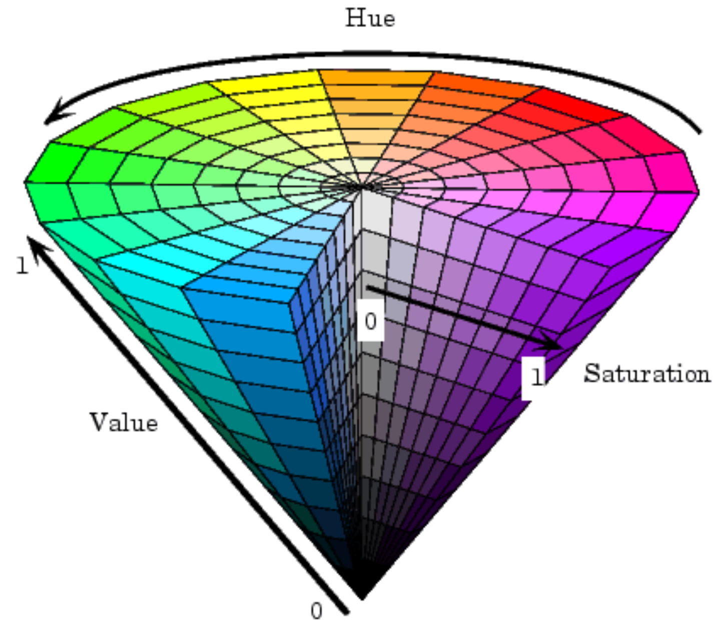
- Human visual system has two types of sensors
  - Rods: monochromatic, night vision
  - Cones
    - Color sensitive
    - Three types of cones
    - Only three values (the *tristimulus* values) are sent to the brain



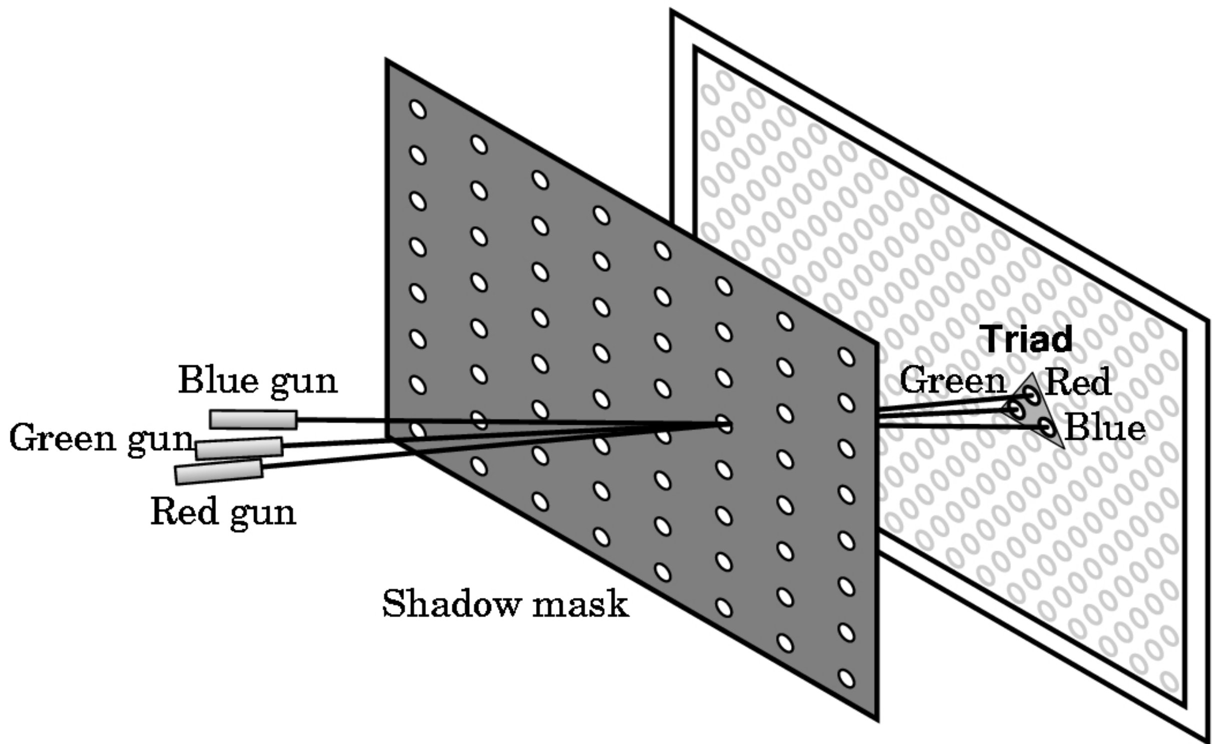
- Need only match these three values
  - Need only three *primary* colors

HSB: hue, saturation, and brightness

- Also called HSV (hue saturation value)
- Hue is the actual color. Measured in degrees around the cone (red = 0 or 360 yellow = 60, green = 120, etc.).
- Saturation is the purity of the color, measured in percent from the center of the cone (0) to the surface (100). At 0% saturation, hue is meaningless.
- Brightness is measured in percent from black (0) to white (100). At 0% brightness, both hue and saturation are meaningless.



Shadow Mask CRT



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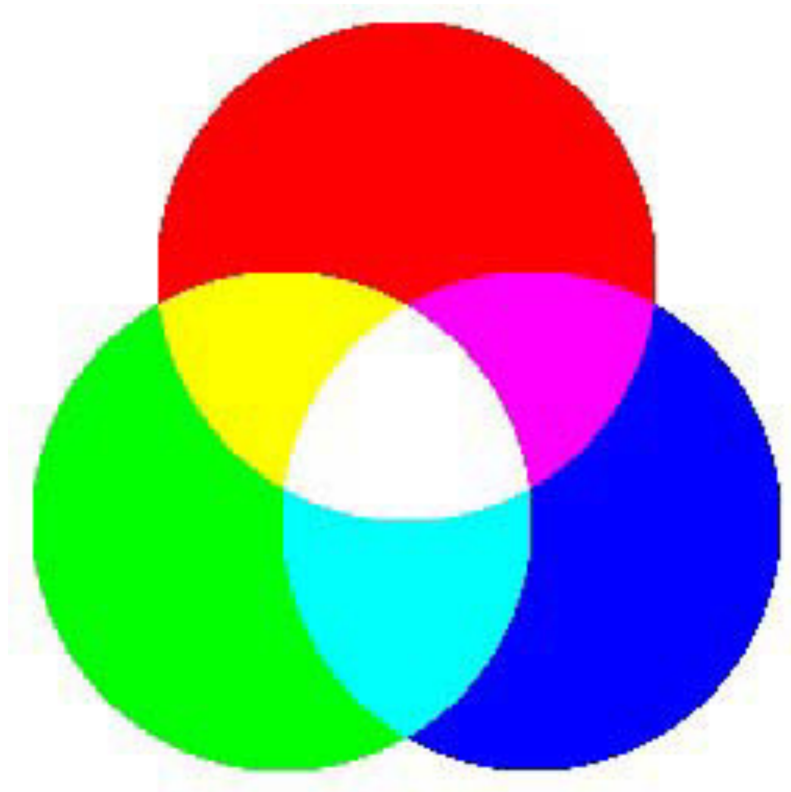
Additive and Subtractive Color

- Additive color
  - Form a color by adding amounts of three primaries
    - CRTs, projection systems, positive film
  - Primaries are Red (R), Green (G), Blue (B)



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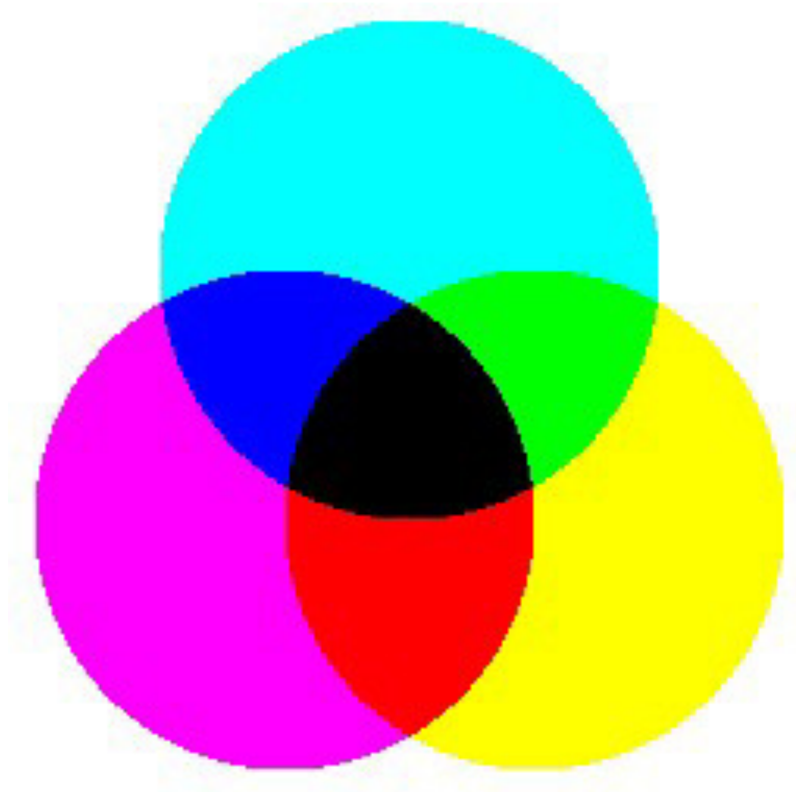
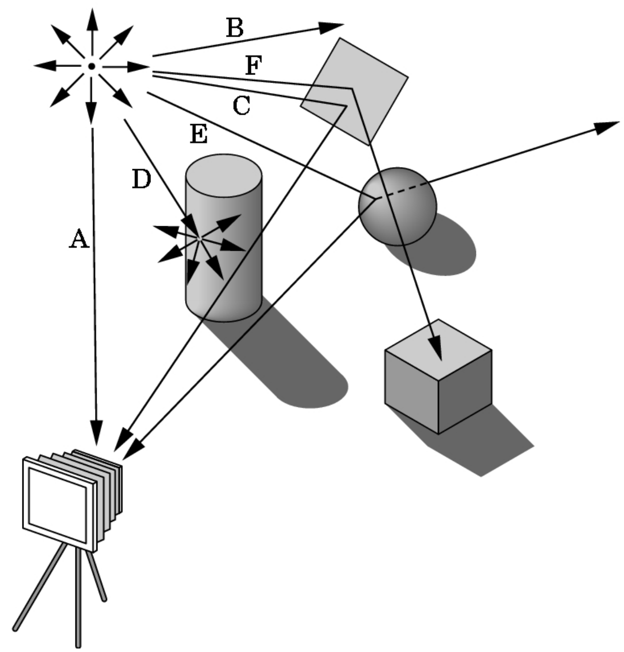
Additive and Subtractive Color

- Subtractive color
  - Form a color by filtering white light with cyan (C), Magenta (M), and Yellow (Y) filters
    - Light-material interactions
    - Printing
    - Negative film



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.



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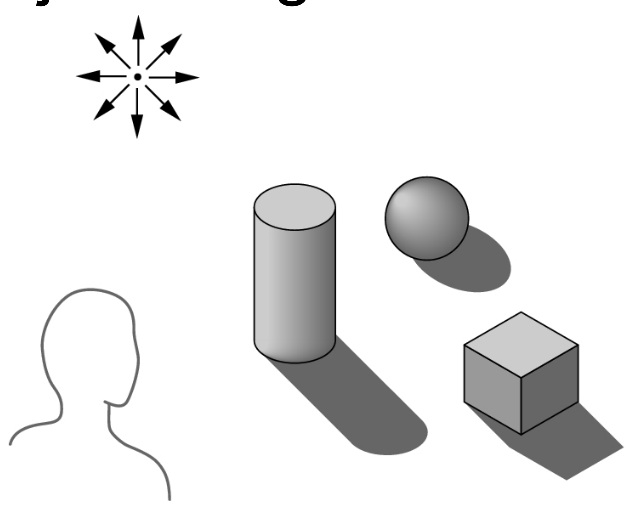
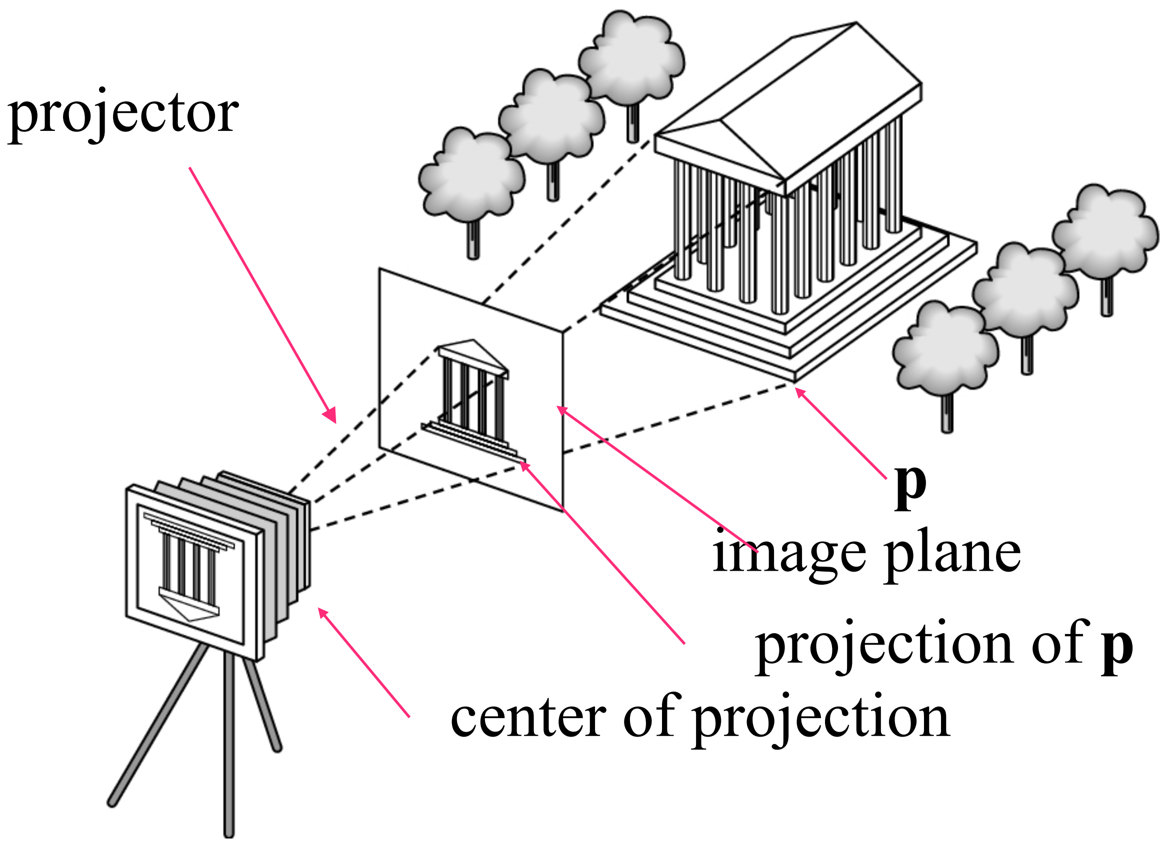
Global vs Local Lighting

- 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



Synthetic Camera Model

- Local lighting
- Projects geometry onto image plane.
- Use local info to shade point



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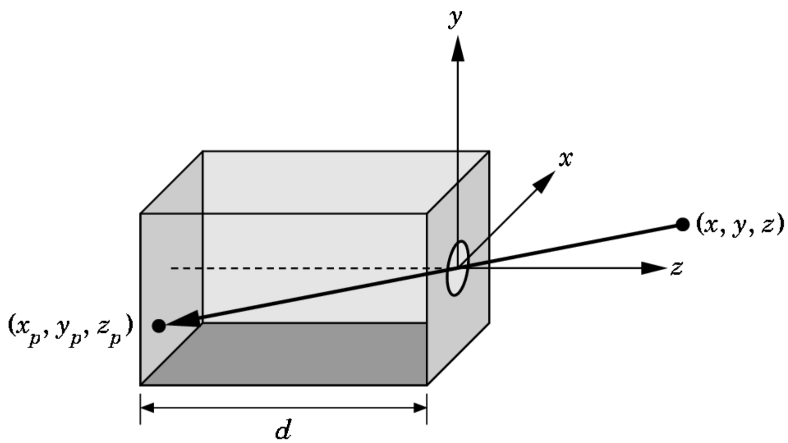
Pinhole Camera



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

$x_p = -x/(z/d)$ $y_p = -y/(z/d)$ $z_p = d$

These are equations of simple perspective

Advantages – Local Lighting

- 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

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

Models and Architectures

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Objectives

- Learn the basic design of a graphics system
- Introduce pipeline architecture
- Examine software components for an interactive graphics system

Image Formation Revisited

- Can we mimic the synthetic camera model to design graphics hardware & software?
- Application Programmer Interface (API)
  - Need only specify
    - Objects
    - Materials
    - Viewer
    - Lights
- But how is the API implemented?

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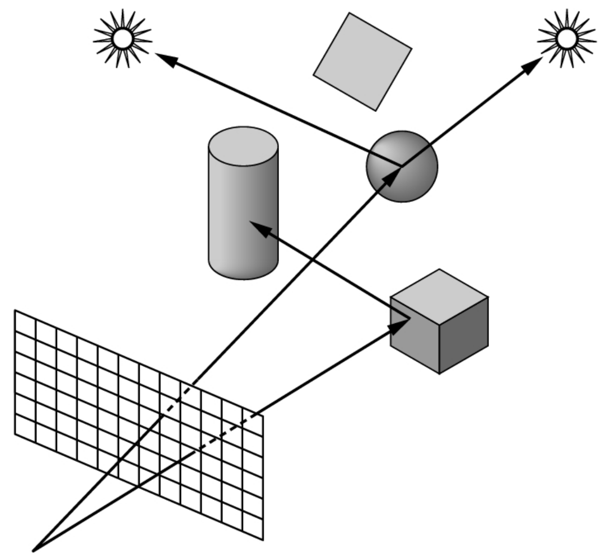
Physical Approaches

- **Ray tracing**: follow rays of light from center of projection until they either are absorbed by objects or go off to infinity
  - Can handle some global effects
    - Multiple reflections
    - Translucent objects
  - Slow
  - Must have whole data base available at all times



- **Radiosity**: Energy-transfer-based approach
  - Very slow

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Practical Approach

- Process objects one at a time in the order they are generated by the application
  - Can consider only local lighting
- Pipeline architecture

application program

display

- All steps can be implemented in hardware on the graphics card

Vertex Processing

- Much of the work in the pipeline is in converting object representations from one coordinate system to another
  - Object coordinates
  - Camera (eye) coordinates
  - Screen coordinates
- Every change of coordinates is equivalent to a matrix transformation
- Vertex processor also computes vertex colors

Projection

- *Projection* is the process that combines the 3D view with the 3D objects to produce the 2D image
  - Perspective projections: all projectors meet at the center of projection
  - Parallel projection: projectors are parallel, center of projection is replaced by a direction of projection

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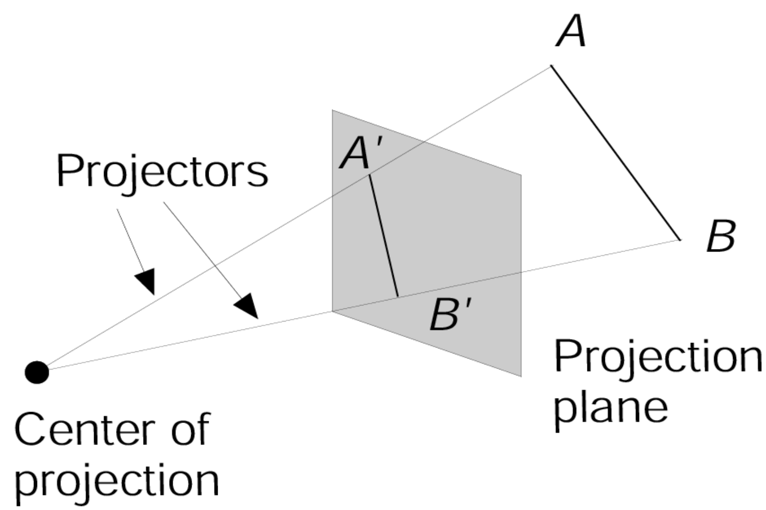
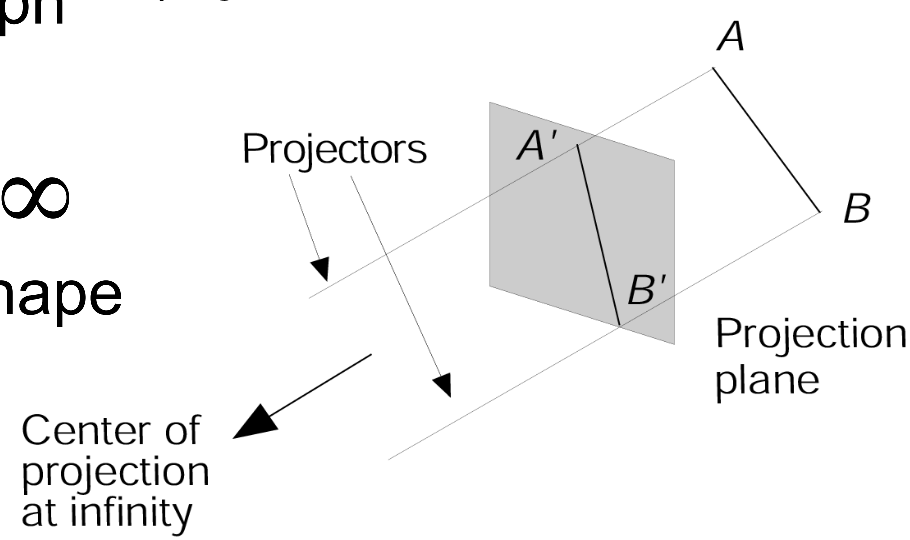
31

Planar Geometric Projections

- Projections onto Planes
  - Consider the line *AB*
- Perspective Projection
  - a single viewing location
  - similar to a photograph
- Parallel Projection
  - viewing location at ∞
  - good for capturing shape and dimensions





1994 Foley/VanDam/Finer/Huges/Phillips ICG

Primitive Assembly

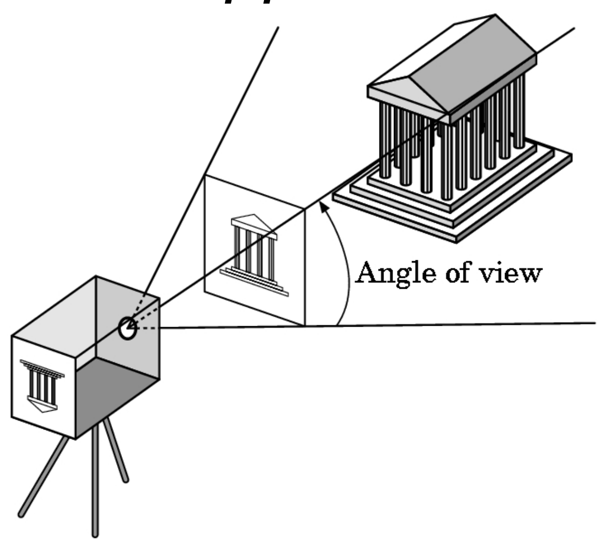
Vertices must be collected into geometric objects before clipping and rasterization can take place

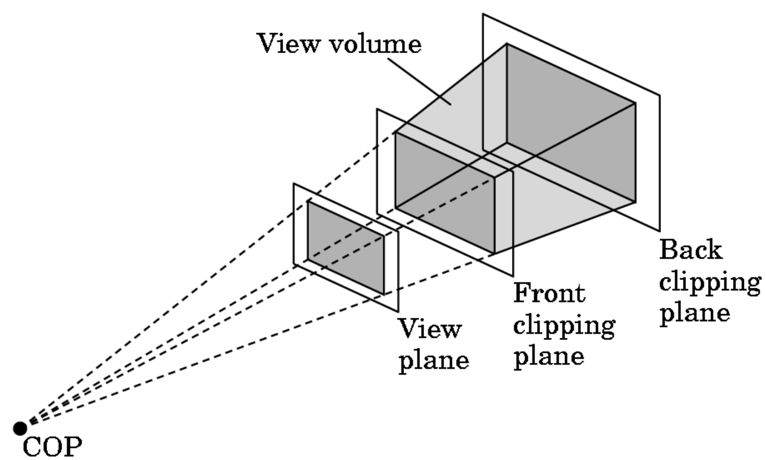
- Line segments
- Polygons
- Curves and surfaces

Clipping

Just as a real camera cannot "see" the whole world, the virtual camera can only see part of the world or object space

- Objects that are not within this volume are said to be *clipped* out of the scene





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Rasterization

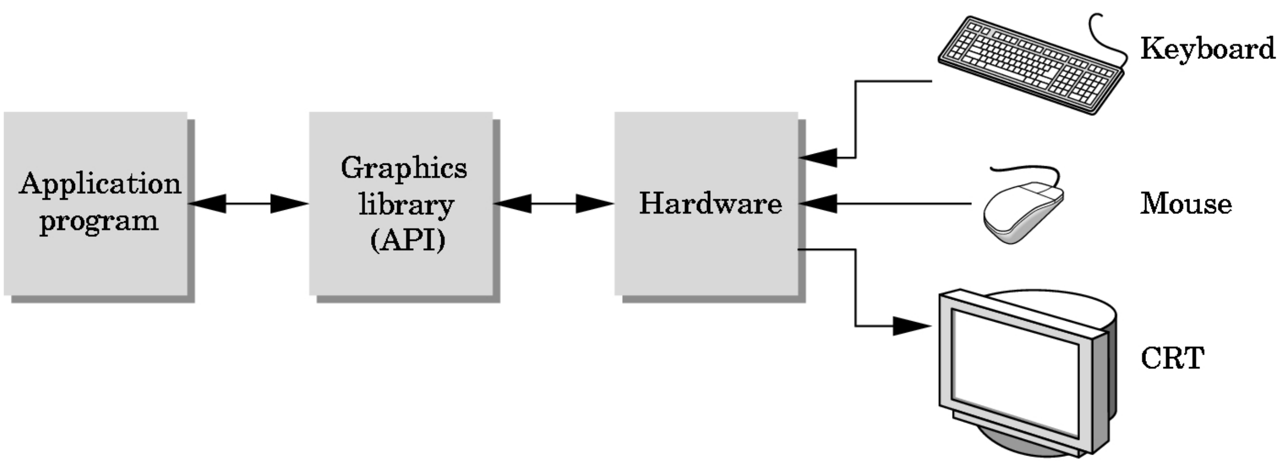
- If an object is not clipped out, the appropriate pixels in the frame buffer must be assigned colors
- Rasterizer produces a set of fragments for each object
- Fragments are "potential pixels"
  - Have a location in frame bufffer
  - Color and depth attributes
- Vertex attributes are interpolated over objects by the rasterizer

Fragment Processing

- Fragments are processed to determine the color of the corresponding pixel in the frame buffer
- Colors can be determined by texture mapping or interpolation of vertex colors
- Fragments may be blocked by other fragments closer to the camera
  - Hidden-surface removal

The Programmer’s Interface

- Programmer sees the graphics system through a software interface: the Application Programmer Interface (API)



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API Contents

- Functions that specify what we need to form an image
  - Objects
  - Viewer
  - Light Source(s)
  - Materials
- Other information
  - Input from devices such as mouse and keyboard
  - Capabilities of system

Object Specification

- Most APIs support a limited set of primitives including
  - Points (0D object)
  - Line segments (1D objects)
  - Polygons (2D objects)
  - Some curves and surfaces
    - Quadrics
    - Parametric polynomials
- All are defined through locations in space or *vertices*

Example (old style)

type of object

location of vertex

```
glBegin(GL_POLYGON)
 glVertex3f(0.0, 0.0, 0.0);
 glVertex3f(0.0, 1.0, 0.0);
 glVertex3f(0.0, 0.0, 1.0);
glEnd( );
```

end of object definition

Example (GPU based)

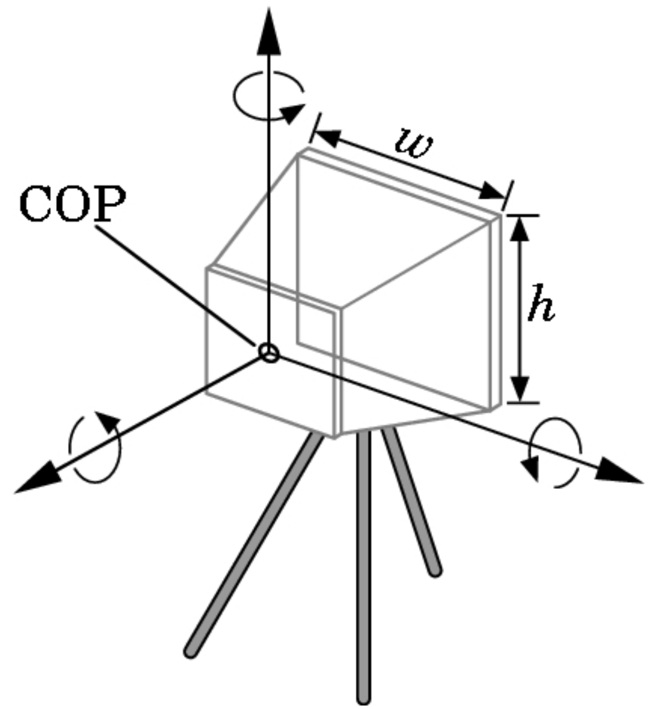
- Put geometric data in an array

```
vec3 points[3];
points[0] = vec3(0.0, 0.0, 0.0);
points[1] = vec3(0.0, 1.0, 0.0);
points[2] = vec3(0.0, 0.0, 1.0);
```

- Send array to GPU
- Tell GPU to render as triangle

Camera Specification

- Six degrees of freedom
  - Position of center of lens
  - Orientation
- Lens
- Film size
- Orientation of film plane



Lights and Materials

- Types of lights
  - Point sources vs. distributed sources
  - Spot lights
  - Near and far sources
  - Color properties
- Material properties
  - Absorption: color properties
  - Scattering
    - Diffuse
    - Specular