# CS155b – Computer Graphics

**Instructor**: Giovanni Motta (gim@ieee.org)
Volen, Room #255. Phone: x62718

**Class**:

Mon. and Wed. from 5 to 6:30pm
Abelson #131

**Teaching Assistants**:

Anthony Bucci (abucci@cs)
John Langton (psyc@cs)
Anurag Maskey (anurag@cs)

# Books

**Textbook:**
***Computer Graphics: Principles and Practice in C,*** by J. D. Foley, A. Van Dam, S. K. Feiner, J. F. Hughes. Addison-Wesley, 2nd ed..

**OpenGL:**
***OpenGL Programming Guide: The Official Guide to Learning OpenGL, Version 1.2,*** by M. Woo, J. Neider, T. Davis, D. Shreiner, OpenGL Architecture Review Board. Addison-Wesley, 3rd ed..

**Suggested:**
***Mathematics for 3D Game Programming & Computer Graphics,*** by Eric Lengyel. Charles River Media.

# Additional References

**Web Page:**
http://www.cs.brandeis.edu/~cs155

**Lectures:**
Published on the web page in Adobe pdf format.

**Demo, Sample Programs, Useful Links:**
Web page.

**Essential Math Reference Book:**
***Essential Mathematics for* Computer *Graphics, fast,***
by John Vince. Springer.

# Homework

**Programming:**
With OpenGL library called from C/C++.

**Theory:**
Will cover the topics discussed in class.

In general, two weeks due date.
Solution will be given in class on due date.
No late homework accepted.

**Exams:**
Midterm and Final. In class, closed book.

# Goals

Learning the principles of Computer Graphics

Understanding graphical models, fundamental techniques, algorithms and implementation issues

Practicing some applied mathematics

Getting acquainted with a Graphical Library (OpenGL)

# Syllabus

Introduction
Overview, Applications, Examples.

2D Drawing
Scan Conversion of Lines and Circles, Polygon Clipping, Polygon Filling.

2D Viewing and Geometrical Transformations
Rotation, Reflection, Shear, Scale and Translation. World to Viewport Coordinate Transformation.

3D Solid Modeling
3D Models and Representations, Curves and Surfaces.

3D Viewing and Geometrical Transformations
Geometrical Transformations, Projections and Viewing in 3D, Visible Surface Algorithms.

**Color**
Color Spaces, Metrics, Transformations.

**Illumination and Shading**
Light Models, Shading Models, Transparency, Shadows.

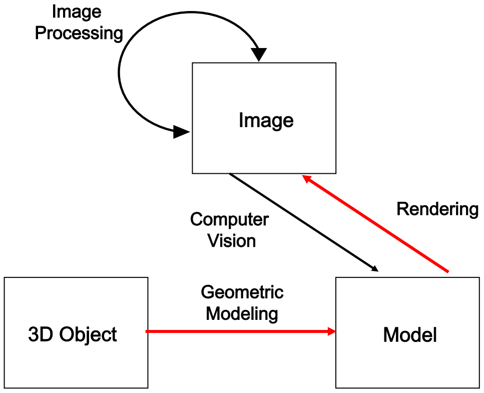
**Free Form Modeling**
Interpolation and Approximation, Curve and Surface Splines.

**Advanced Topics**
Ray Tracing, Texture Mapping, Animation, Morphing, Physics Based Models.

## Applications

- •CAD - Computer Aided Design (Mechanical, Architectural)
- •Simulators (Flight, Driving, Sports)
- •Advertising
- •Virtual Reality
- •Architectural Visualization
- •Art and Entertainment
- •Games
- •Special effects
- •Education
- •Scientific visualization

## The Visual Sciences



## The Visual Sciences

**Image Processing:**

From Images to Images

**Computer Vision:**

From Images to Models

**Computer Graphics:**

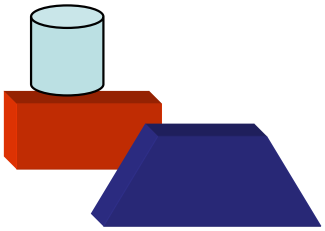
From Objects to Models (Geometric Modeling).

From 2D/3D Models to Images (Rendering).

From 4D Models to Images (Animation).

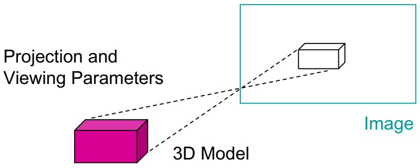
## Geometric Modeling

- •From a concept (or a real object) to a geometric representation on a computer
- •Example: a sphere can be described as (*x*,*y*,*z*,*r*)
- •Complex objects can be constructed from simpler ones



## Rendering

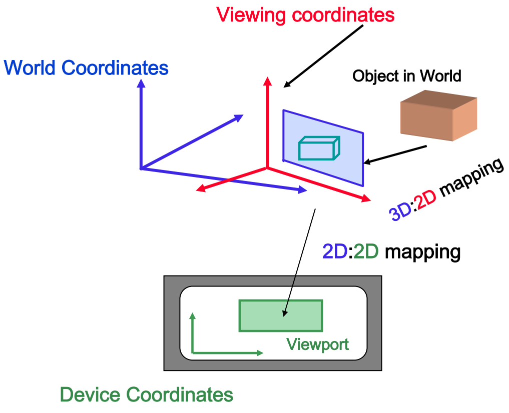
- •Given a scene and viewing parameters, produce an image
- •Images are a 2D array of pixels
- •Important sub problems:
  - –Which pixels are covered by each object ? (Scan Conversion)
  - –What is visible at each pixel ? (Visible Surface Algorithm)
  - –What color should a pixel be ? (Illumination, Shading Algorithms).



## Animation

- •Definition of complex time-dependent behavior of objects
- •Issues with rigid and elastic joints
- •Realistic rendering of collective behaviors
- •Examples:
  - –Automatic interpolation between key-frames
  - –Physics based simulation

## Viewing Transformation Pipeline



Viewing coordinates

World Coordinates

Object in World

3D:2D mapping

2D:2D mapping

Viewport

Device Coordinates

## Rendered Image

## Viewing Factors

- **Objects:**
  - –Geometrical Properties of an Object (Solid Modeling)
  - –Physical Properties of Object's Surfaces (Illumination Models, Color Models)
- **Camera:**
  - –Projections
- **Light Source:**
  - –Color Theory
- **Spatial set-up:**
  - –3D Transformations, Coordinate Systems

## 2D Drawing

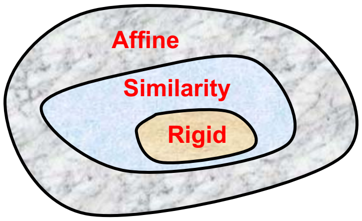
**Goal: Getting Acquainted with Images**

- Displays (Raster vs. Vector)
- Basic Definitions: Pixel, Resolution, Dynamic Range…
- Line Drawing (Incremental and Mid-Point Algorithms)
- Techniques for Drawing Circles
- Filling Polygons

## 2D Transformations

**Goal: Introduction to 3D, Review Linear Algebra**

- Basic 2D Transformations: Translation, Scaling, Rotation, Shear.
- Composition of Transformations and Transformation Groups:



Affine

Similarity

Rigid

## 2D Transformations

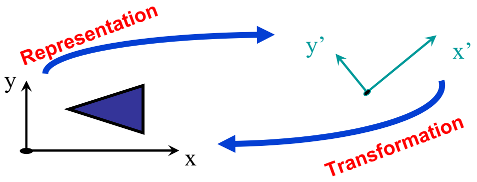
- Transformations in Matrix notation:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

- Composition of transformations in matrix notation
- The homogeneous coordinates in 2D:

$$(x, y) \rightarrow (X, Y, W) = (tx, ty, t)$$

- Change of coordinates:



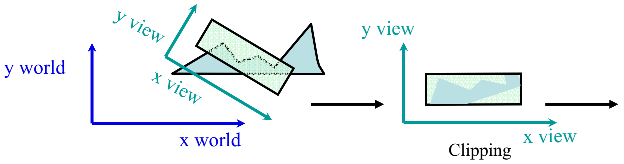
Representation

Transformation

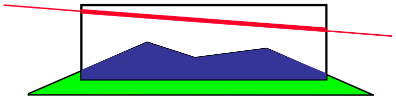
## 2D Viewing

**Goal: Introduction to 3D and some Rendering Concepts**

Viewing Transformation pipe-line:



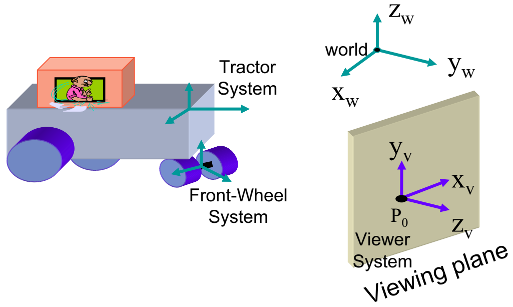
Line and Polygon Clipping:



## 3D Viewing

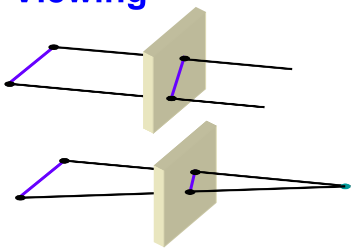
**Goal: Geometrical Transformations in Viewing Pipe-iine**

From Model Coordinates to Viewer Coordinates:

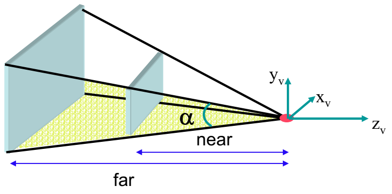


## 3D Viewing

- Projections:
  - Orthographic
  - Oblique
  - Perspective



- The Viewing Volume:

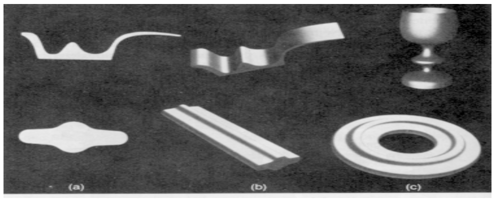


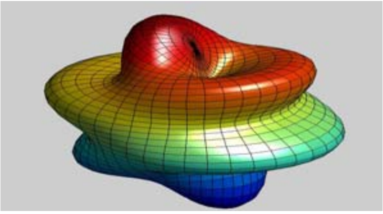
## Solid Modeling

**Goal: Learn how to Define Solid Objects**

- **1D Curves in 3D**
  - Primitive based: line segments.
  - Free form:
    - Implicit, Explicit, Parametric (Polynomials, Splines)
- **2D Surfaces in 3D**
  - Primitive Based: Polygon Mesh
  - Free Form: As Above
- **3D volumes in 3D**
  - Volume Rep.
    - Sweep Volumes
    - Spatial Occupancy (Voxels, Octree, …)
    - Constructive Solid Geometry
  - Boundary Rep.
    - Polyhedra
    - Free Form: As Above

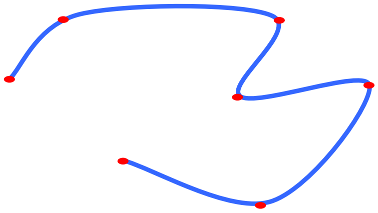
## Solid Modeling





## Parametric Surfaces

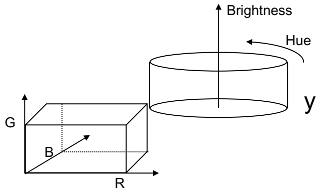
- **Bilinear Interpolation**
- **Splines:**
  - Cardinal Spline
  - Hermite Spline
  - Bezier Spline
  - B Spline

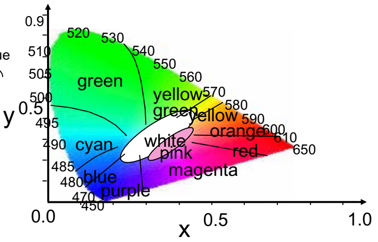


# Color Theory

**Goal: Understanding what a color is**

- •The Trichromatic Color Theory
- •Linear Color Space and Color Representations: RGB, CMY,HSB
- •Perceptual Color Spaces: LAB,YIQ
- •The CIE Chromaticity Diagram

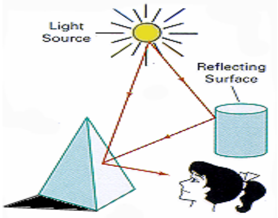




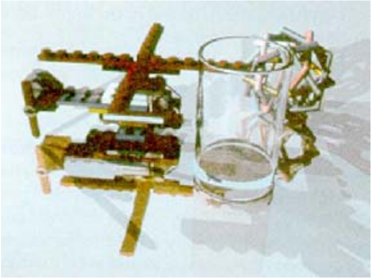
# Illumination Models and Shading

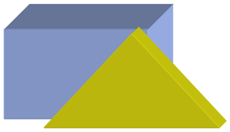
**Goal: Understanding the  physical properties of an object**

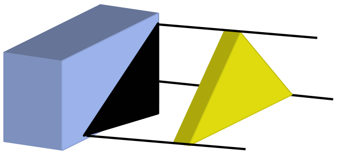
- •Light Source Parameters (Shape, Position, Color, Intensity)
- •Surface Parameters: Ambient, Diffuse, Specular
- •Polygon Rendering Methods
- •Transparency
- •Shadow



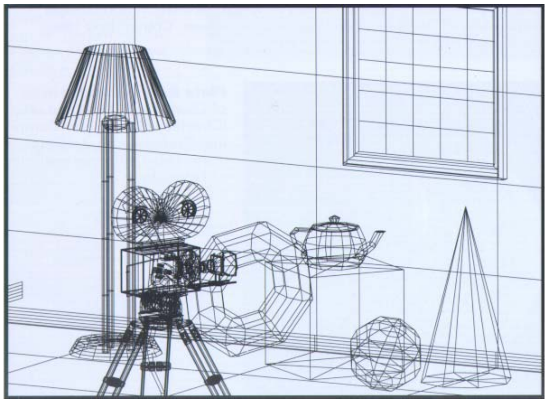
# Illumination Models and Shading





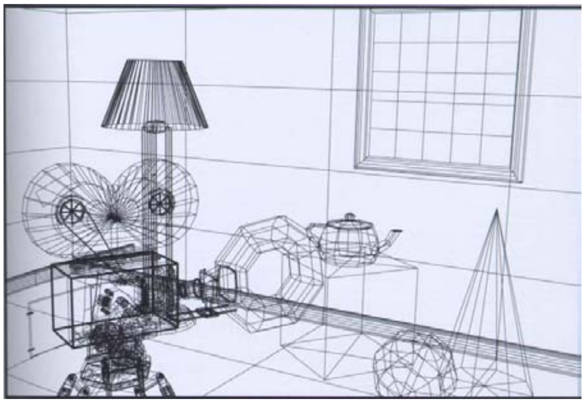


## Example: Creating an Image from a Model



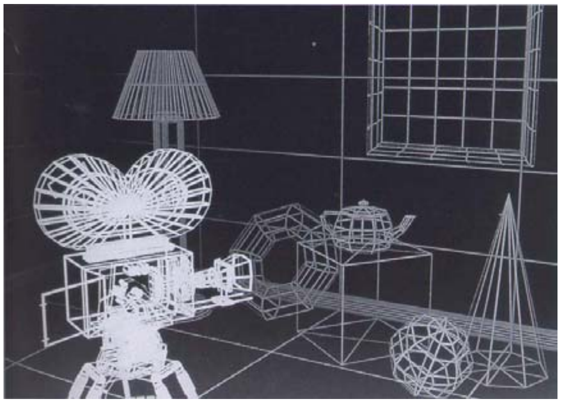
Polygonal Model Generated from Spline Patches. Orthographic Projection

## Example: Creating an Image from a Model



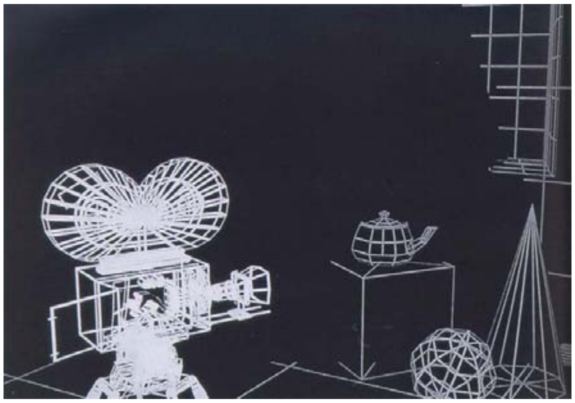
Polygonal Model Generated from Spline Patches. Perspective Projection

## Example: Creating an Image from a Model



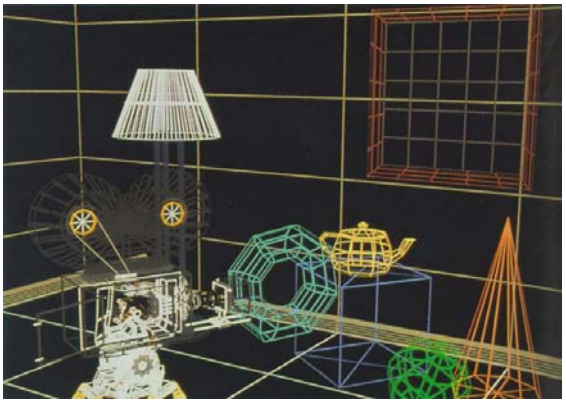
Depth Cueing

## Example: Creating an Image from a Model



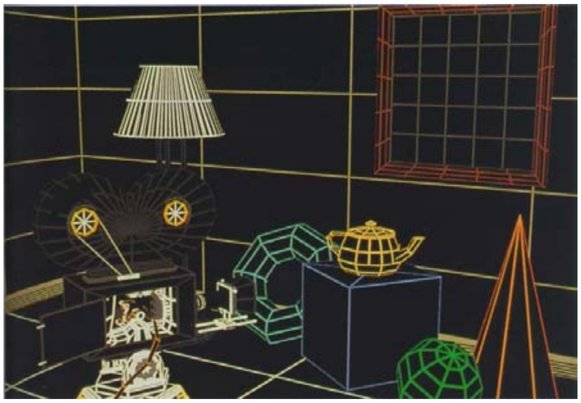
Depth Clipping

## Example: Creating an Image from a Model



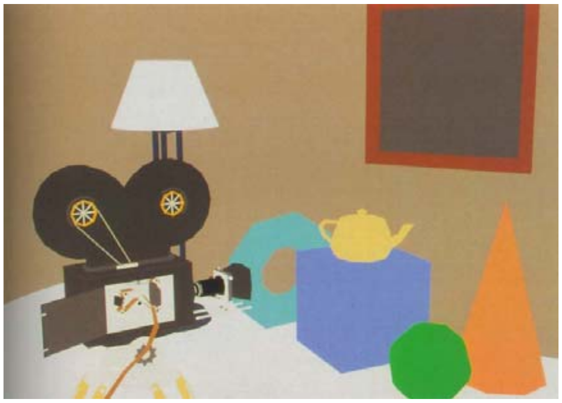
Colored Vectors

## Example: Creating an Image from a Model



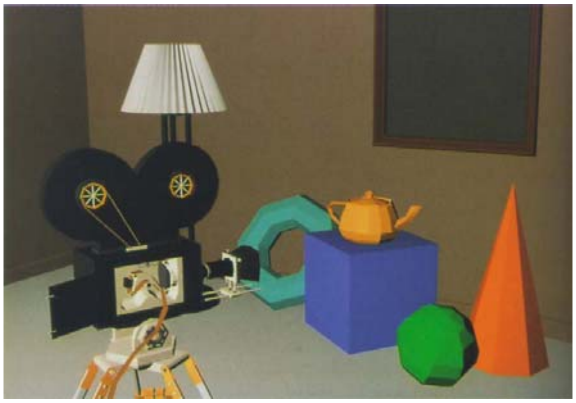
Visible Line Determination

## Example: Creating an Image from a Model



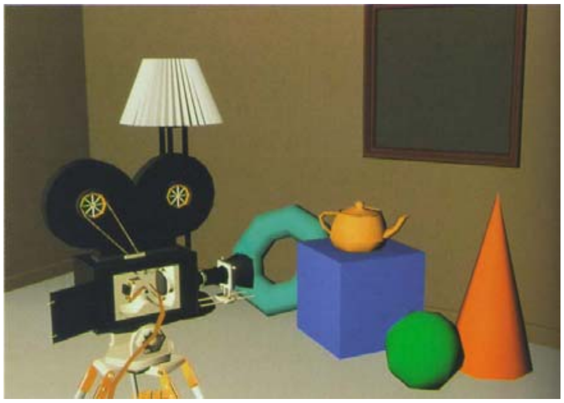
Visible Surface Determination with Ambient Illumination

## Example: Creating an Image from a Model



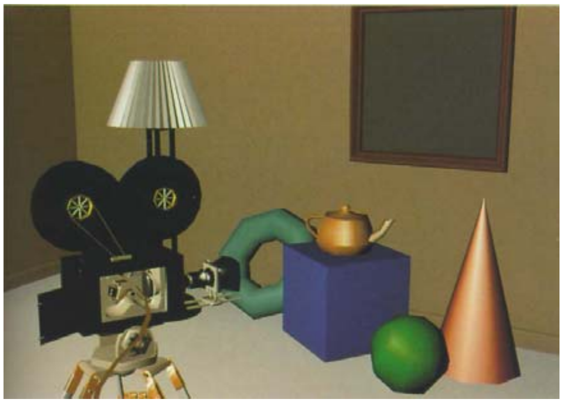
Individually Shaded Polygon with Diffuse Reflection

## Example: Creating an Image from a Model



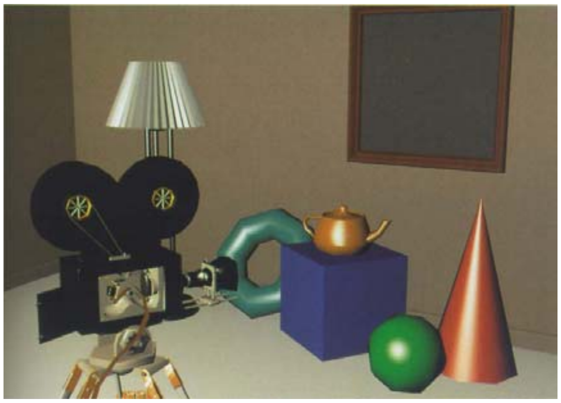
Gouraud Shaded Polygon with Diffuse Reflection

## Example: Creating an Image from a Model



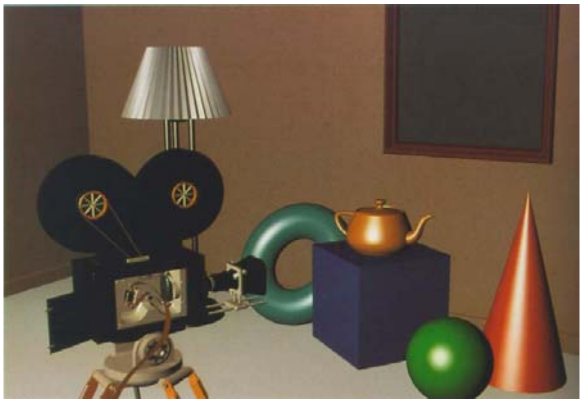
Gouraud Shaded Polygon with Specular Reflection

## Example: Creating an Image from a Model



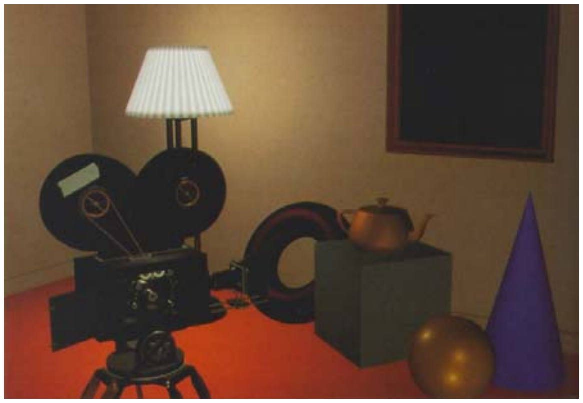
Phong Shaded Polygon with Specular Reflection

## Example: Creating an Image from a Model



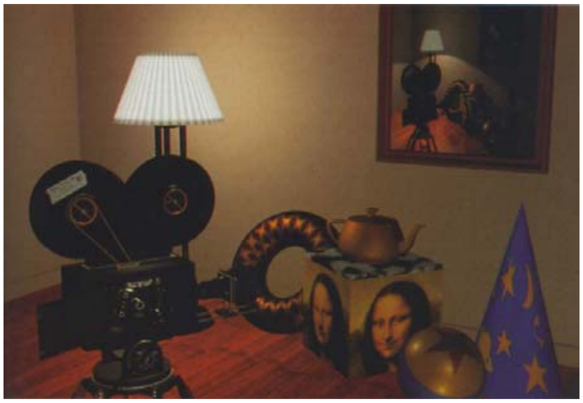
Curved Surfaces with Specular Reflection

## Example: Creating an Image from a Model



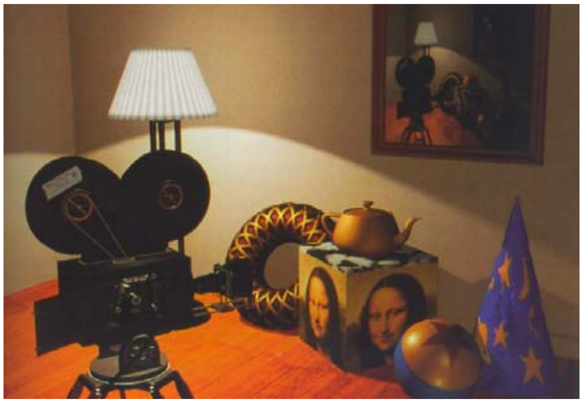
Multiple Lights

## Example: Creating an Image from a Model



Texture Mapping

## Example: Creating an Image from a Model



Shadows

## Example: Creating an Image from a Model

Reflection Mapping

## Example: Polynomial Texture Maps

From:

http://www.hpl.hp.com/research/ptm/

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From:

http://www.hpl.hp.com/research/ptm/