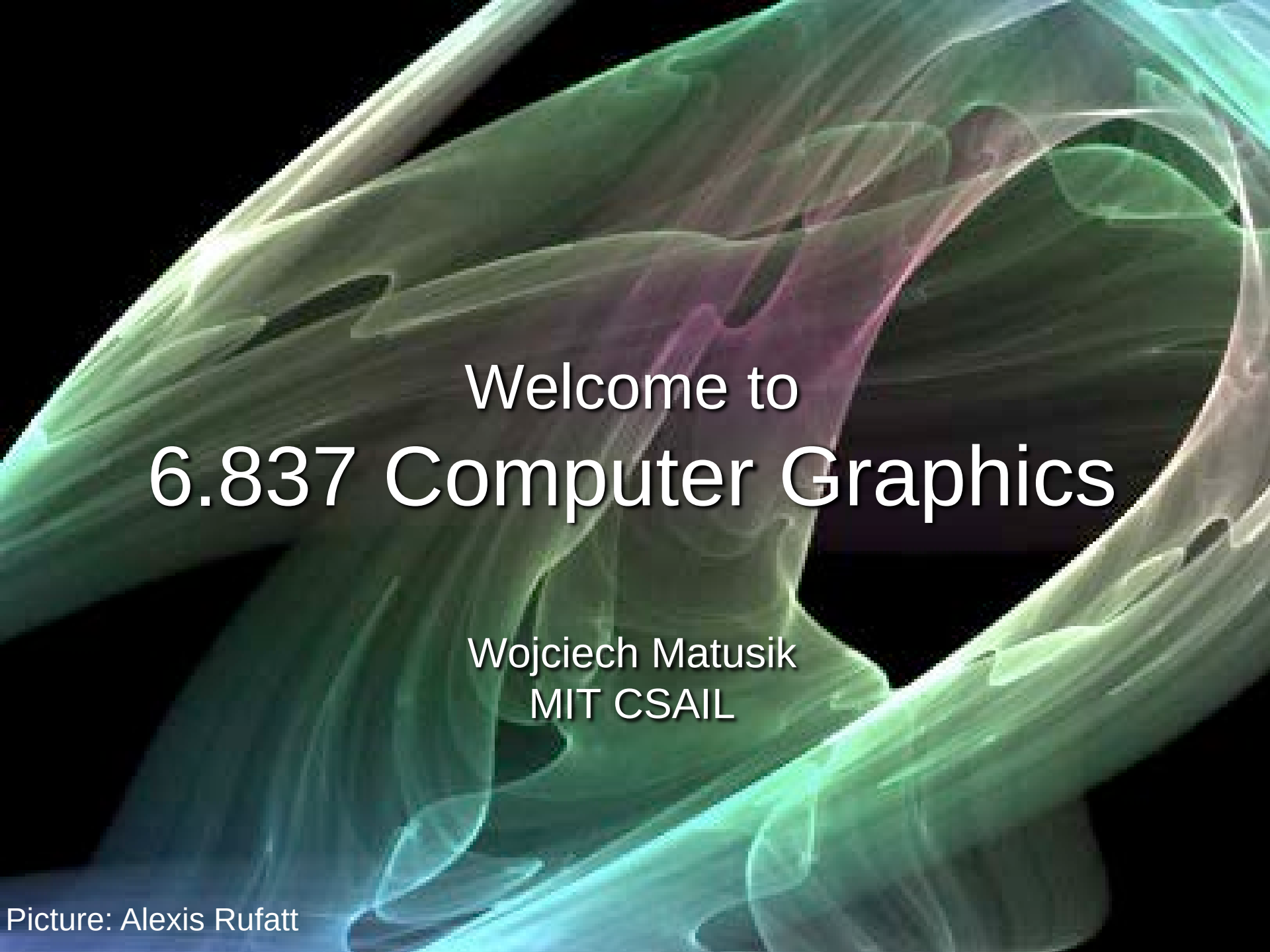


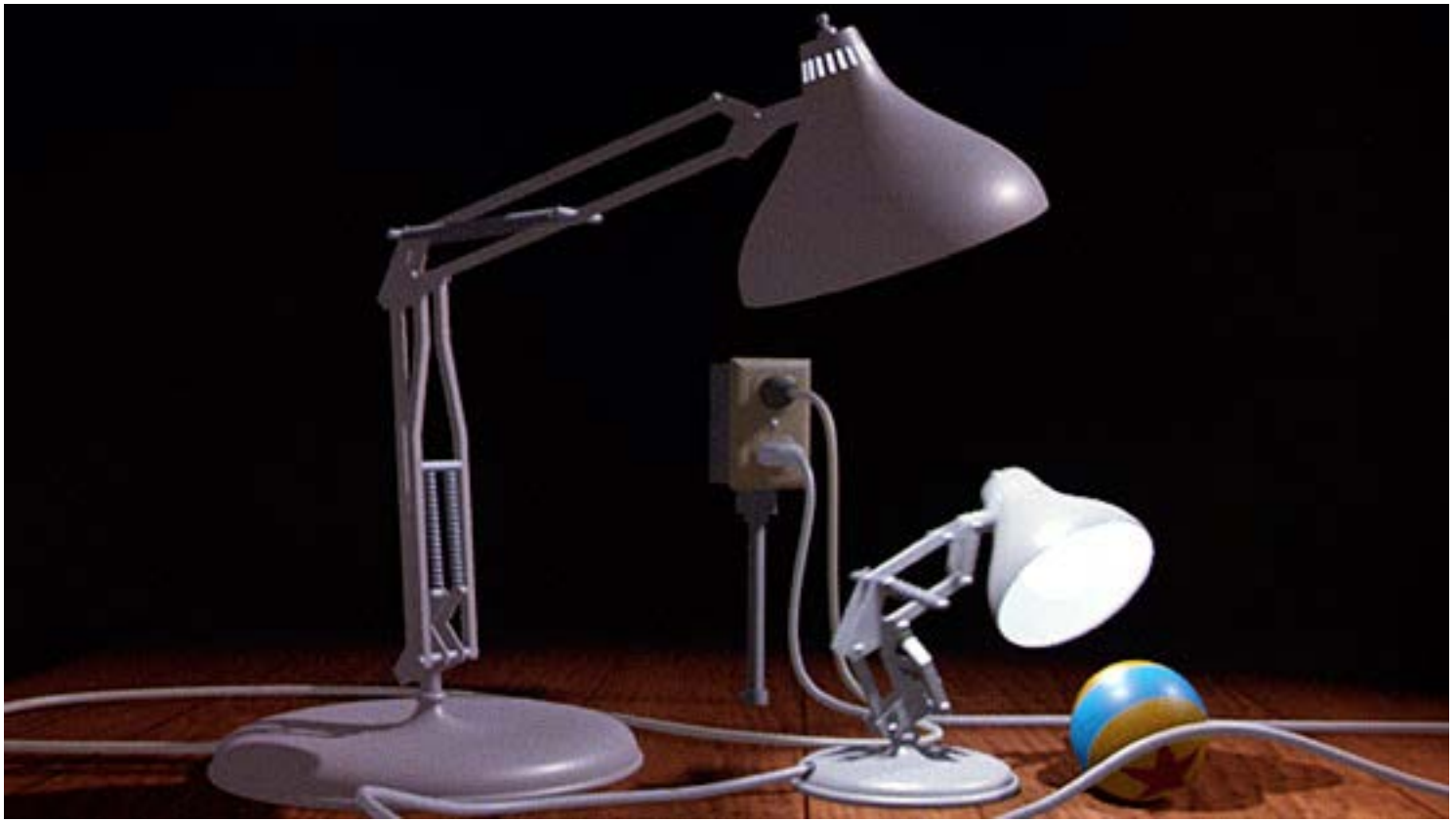
Welcome to
6.837 Computer Graphics

Wojciech Matusik
MIT CSAIL

Picture: Alexis Rufatt

Luxo Jr.

- Pixar Animation Studios, 1986
- Director: John Lasseter



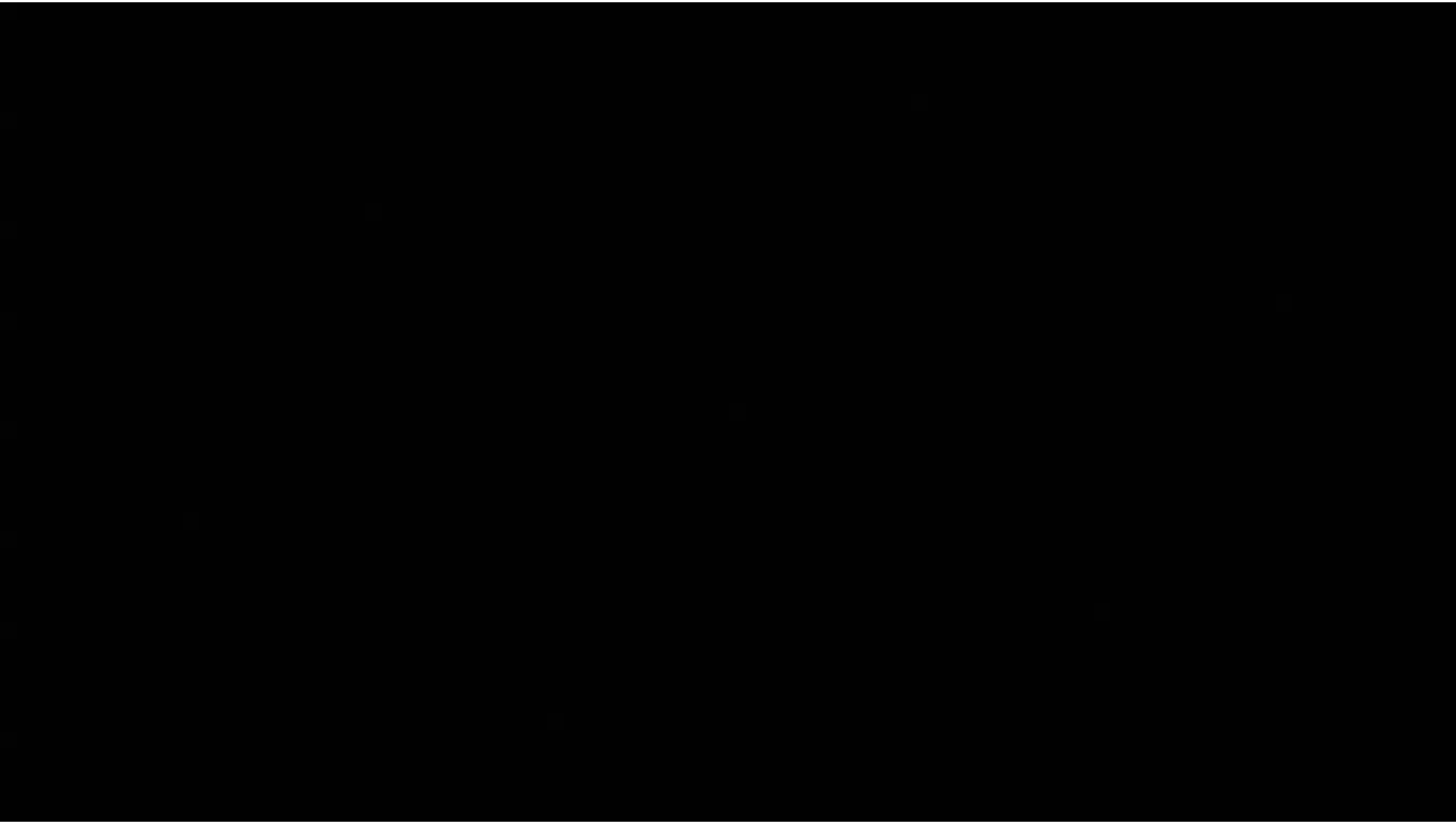
Plan

- Overview of computer graphics
- Administrivia
- Overview of the semester
- Overview of assignments
- Intro to OpenGL & assignment 0

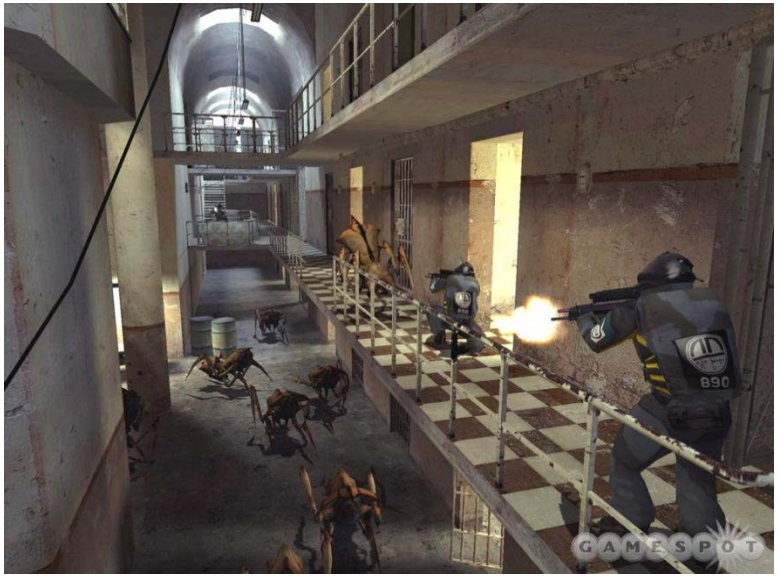
What are the applications of graphics?

Movies/special effects

More than you would expect



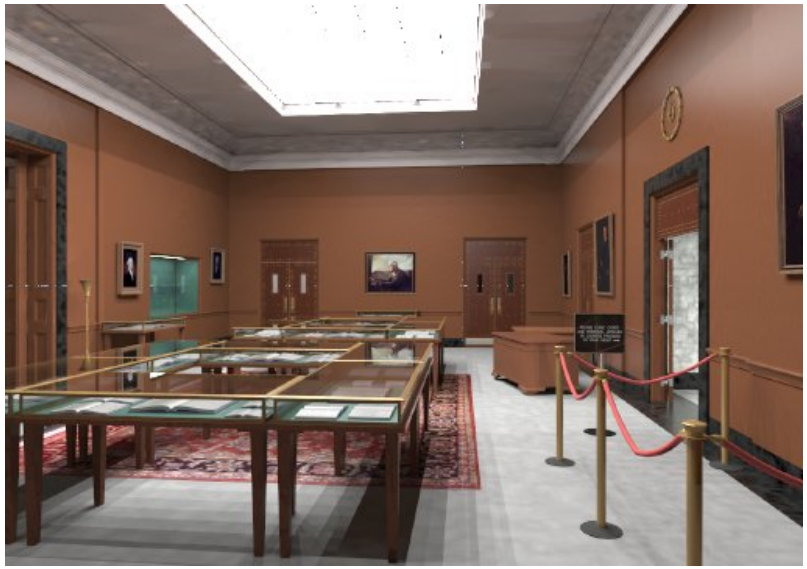
Video Games

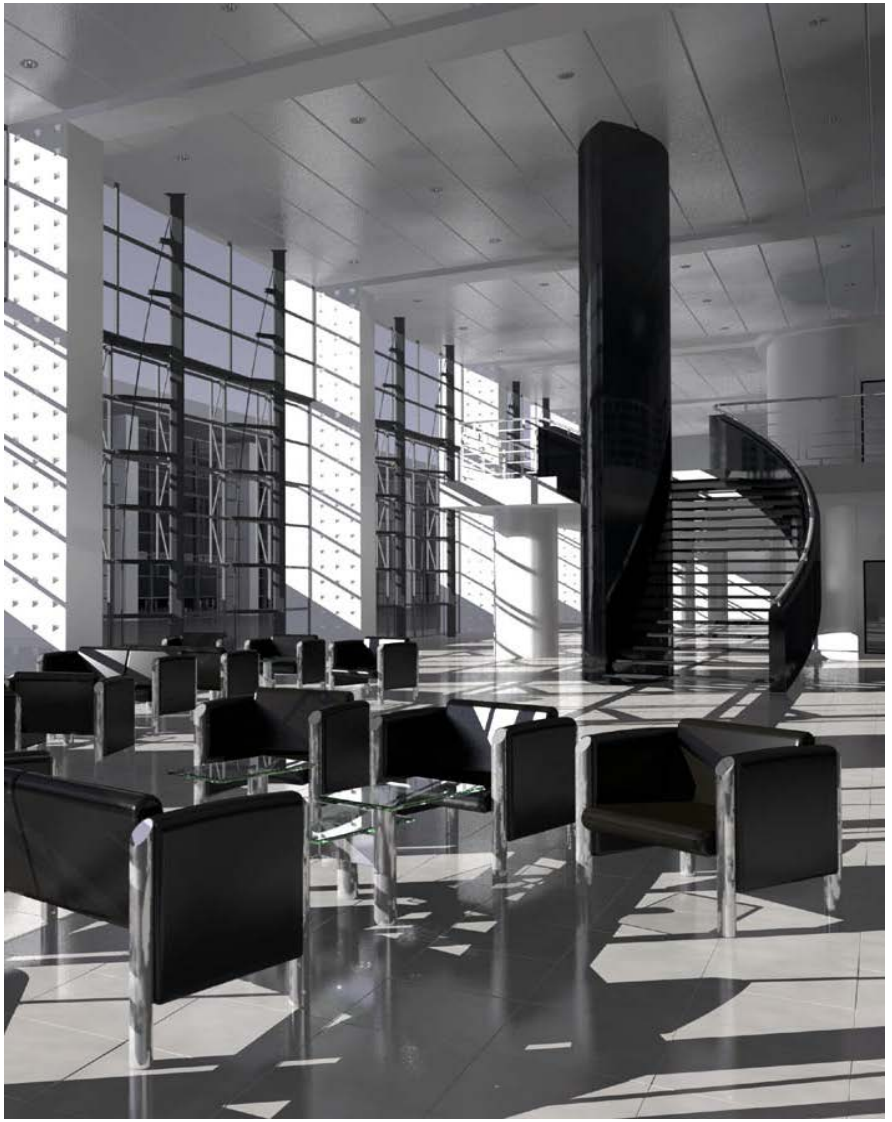


Simulation

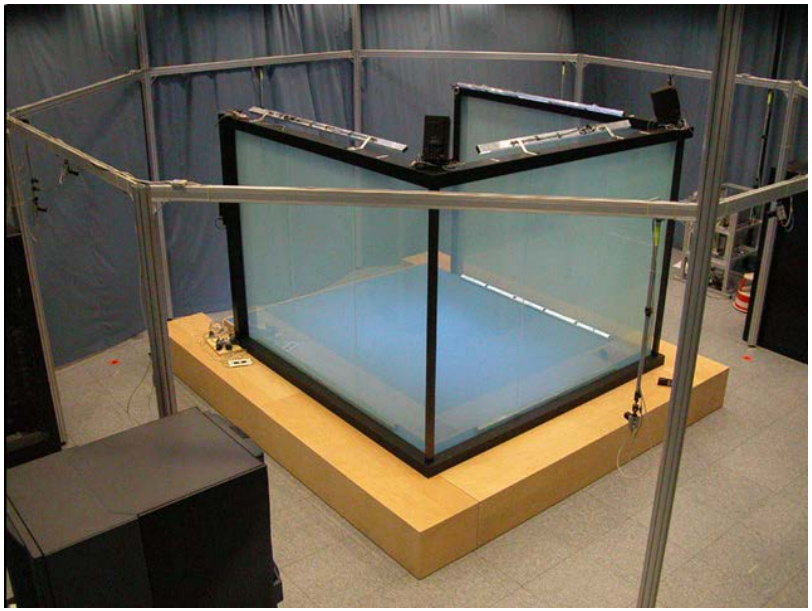
CAD-CAM & Design

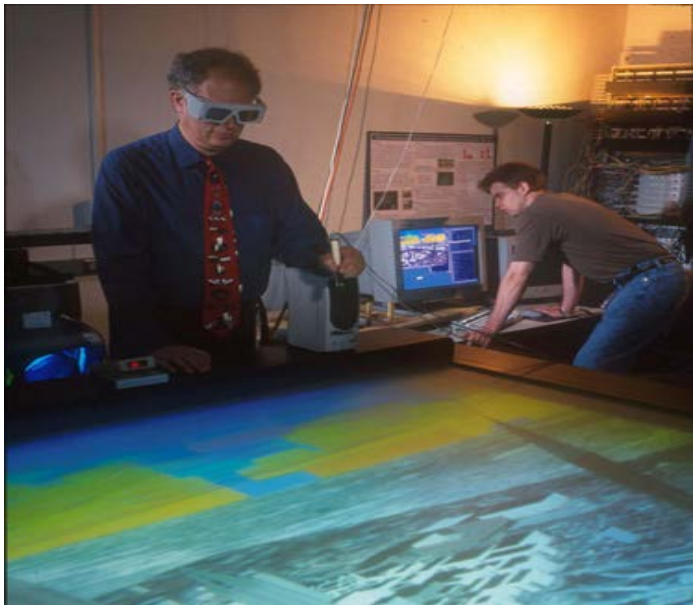
Architecture



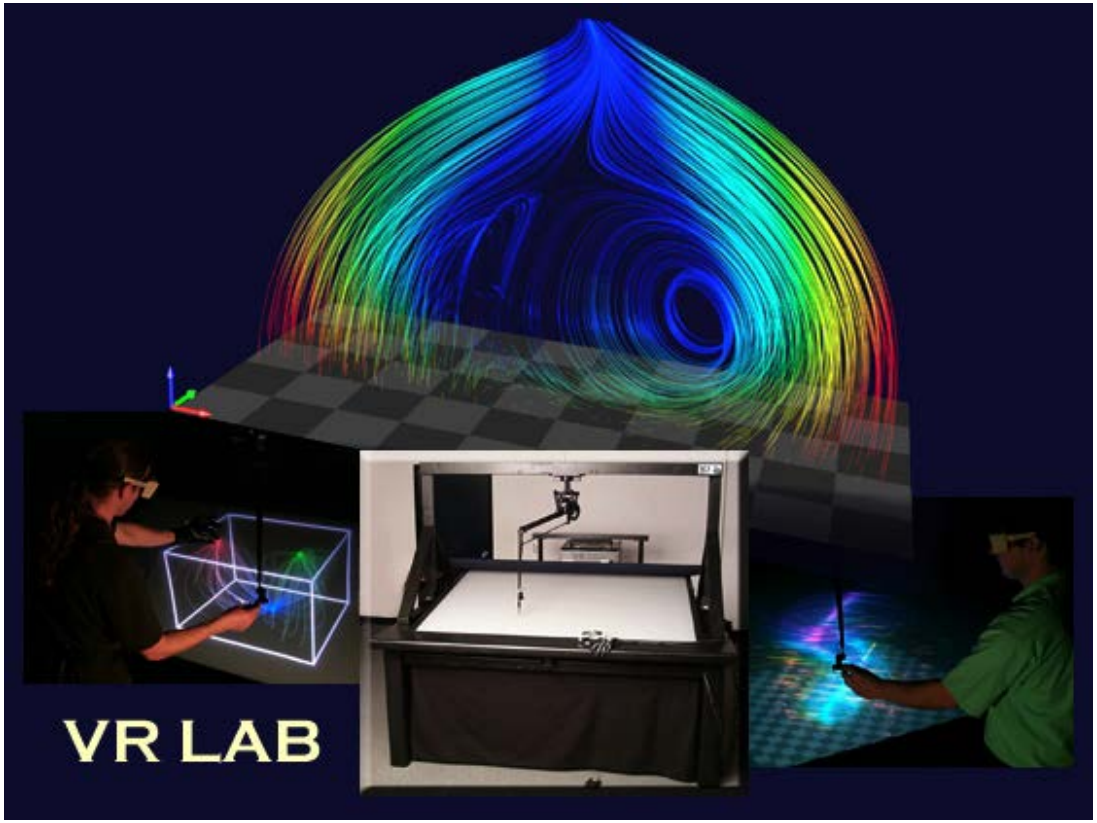


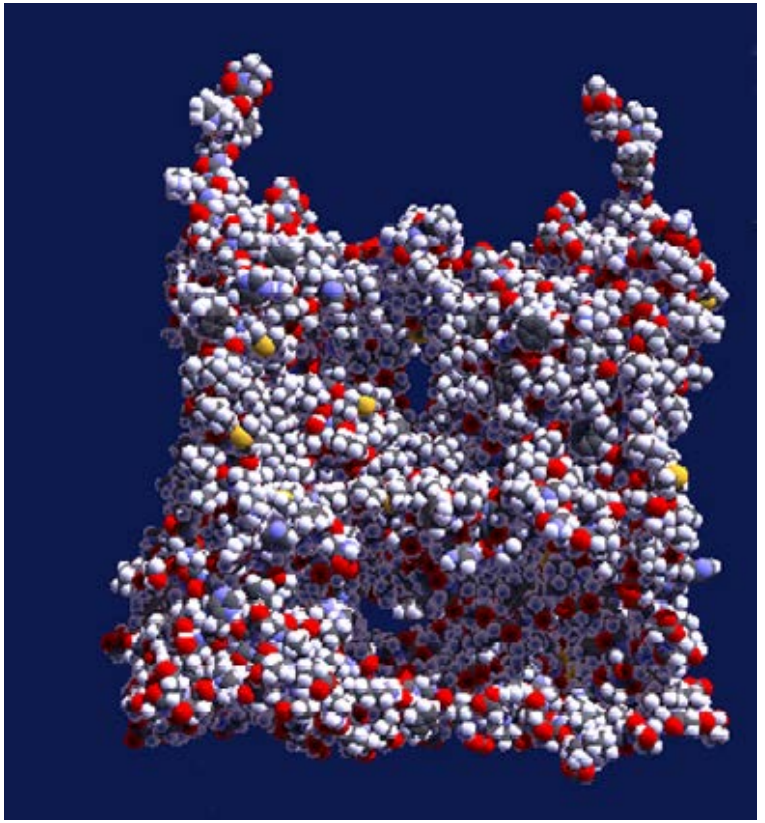
Virtual Reality



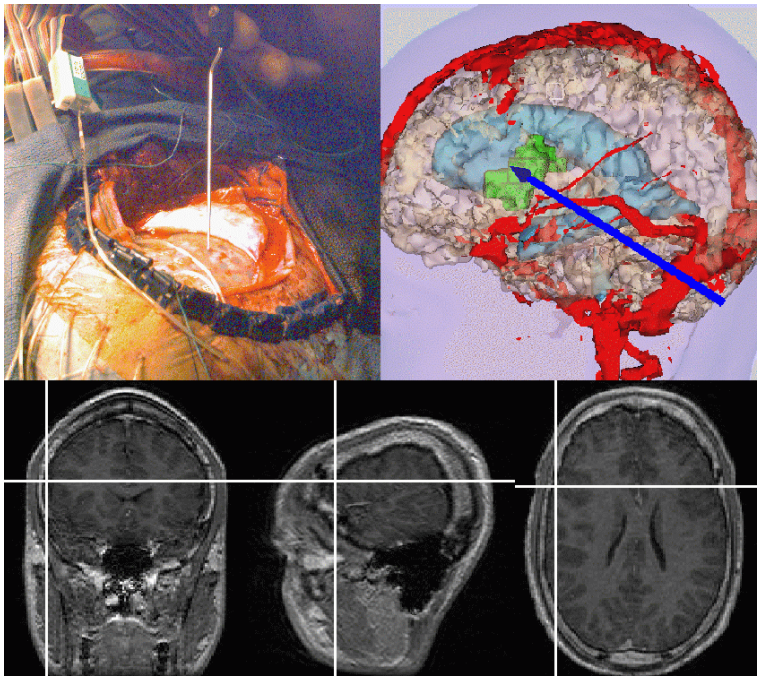


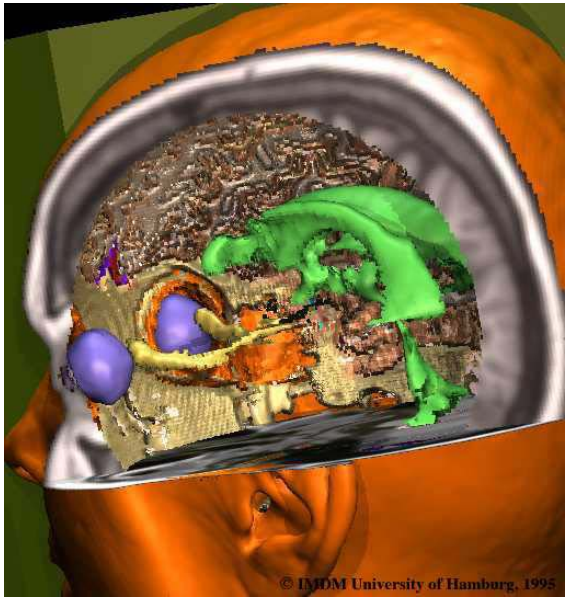
Visualization

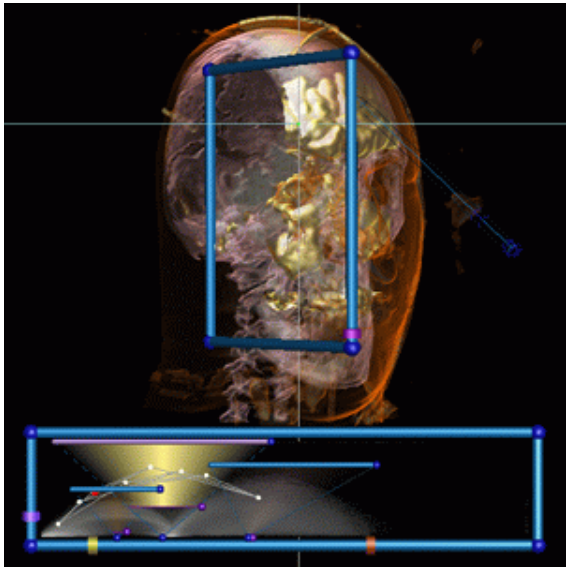




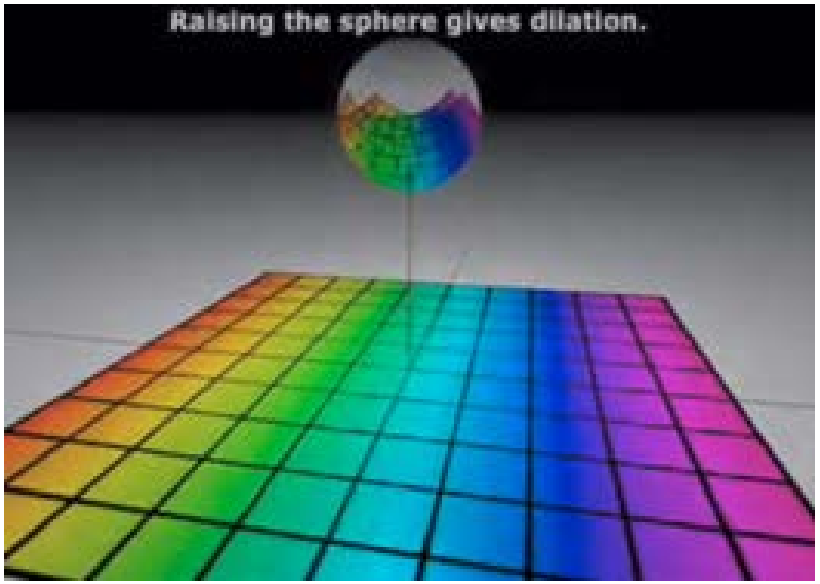
Medical Imaging

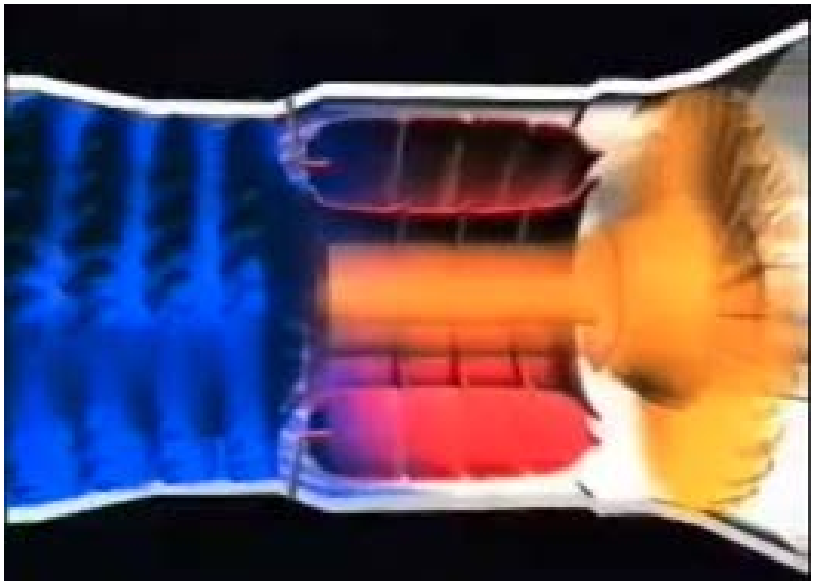




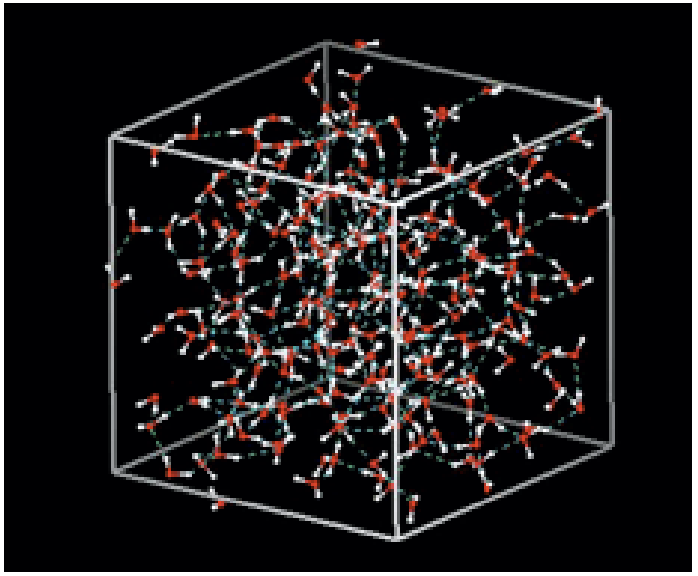


Education

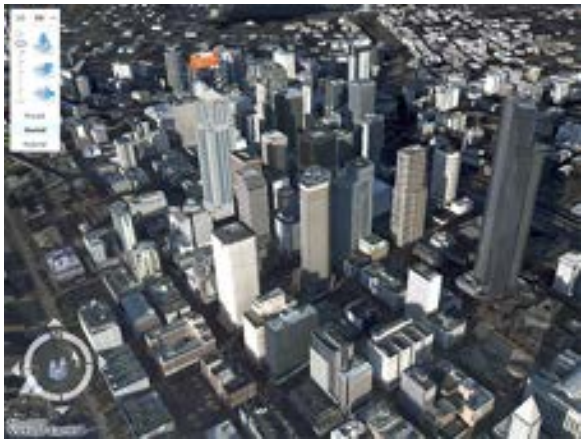

Raising the sphere gives dilation.

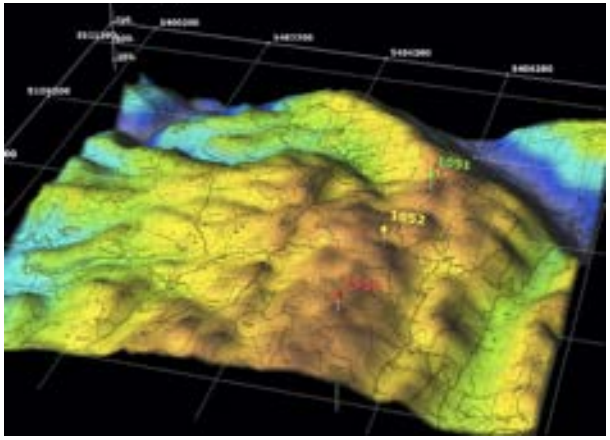


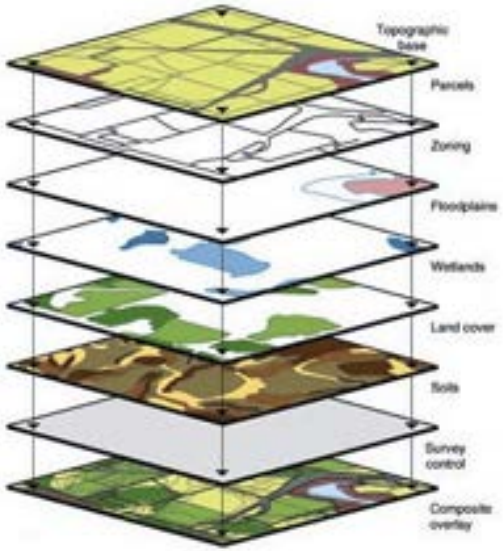

VISIBLE BODY
Hide, show, or fade the anatomy and access definitions.



Geographic Info Systems & GPS

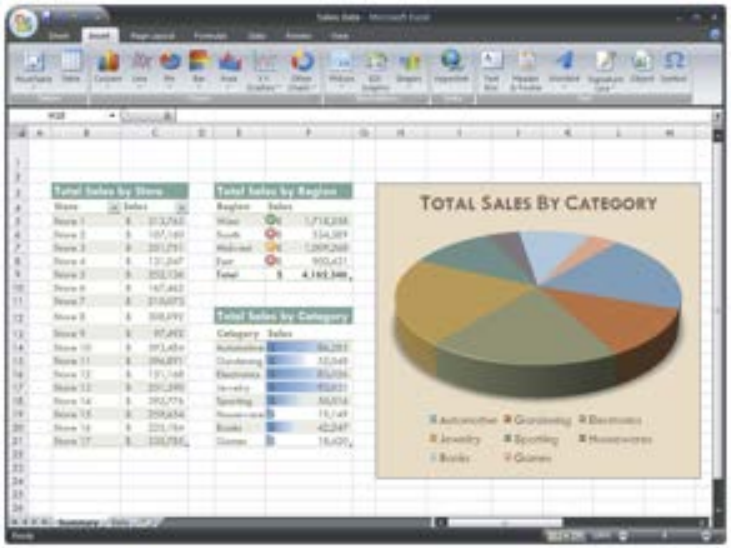






Any display

- Computers go through OpenGL and DirectX to display anything
- 2D graphics, Illustrator, Flash, Fonts



What do you expect to learn?

- And why?

What you will learn in 6.837

- Fundamentals of computer graphics algorithms
  - Will give a pretty good idea of how to implement lots of the things just shown
- We will concentrate on 3D, not 2D illustration or image processing
- Basics of real-time rendering and graphics hardware
- Basic OpenGL
  - Not the focus, though: Means, not the end.
- You will get C++ programming experience

What you will NOT learn in 6.837

- OpenGL and DirectX hacks
  - Most become obsolete every 18 months anyway!
  - Does not really matter either: Graphics is becoming all software again (OpenCL, Larrabee, etc.)
- Software packages
  - CAD-CAM, 3D Studio MAX, Maya
  - Photoshop and other painting tools
- Artistic skills
- Game design

How much Math?

- Lots of simple linear algebra
  - Get it right, it will help you a lot!
- Some more advanced concepts
  - Homogeneous coordinates
  - Ordinary differential equations (ODEs) and their numerical solution
  - Sampling, antialiasing (some gentle Fourier analysis)
  - Monte-Carlo integration
- Always in a concrete and visual context

Beyond computer graphics

- Many of the mathematical and algorithmic tools are useful in other engineering and scientific context
- Linear algebra
- Splines
- Differential equations
- Monte-Carlo integration
- …

Questions?

Plan

- Overview of computer graphics
- **Administrivia**
- Overview of the semester
- Overview of assignments
- Intro to OpenGL & assignment 0

Team

- Instructor
  - Wojciech Matusik
- TAs
  - Desai Chen
  - Ye Wang
  - Ray Gonzalez

Administrivia: Website, Staff Email

- Course website at Stellar
  - https://stellar.mit.edu/S/course/6/fa12/6.837/
  - Announcements
  - Slides (posted soon after each lecture)
  - Assignments, both instructions and turn-in
  - **You need a MIT certificate!**
- Message Board
  - https://piazza.com/mit/fall2012/6837/home
- **6837-staff@csail.mit.edu**
  - Reaches all of us, preferred method of communication

Administrivia: Grading Policy

- Assignments: 75%
  - Two-week programming assignments
  - Must be completed individually
  - *No final project*
- Quiz: 10%
  - Tuesday, Oct 16 (in class)
- Final Exam: 10%
  - TBA during finals week
- Participation: 5%

Administrivia: Prerequisites

- Not strictly enforced
- All assignments are in C++
  - *Optional review/introductory session*
    Monday Sept 10, 7pm-9pm (Room 4-237)
- Calculus, Linear Algebra
  - Solving equations, derivatives, integral
  - vectors, matrices, basis, solving systems of equations
  - *Optional review/introductory session*
    Monday Sept 17, 7pm-9pm (Room 4-237)

Administrivia: Assignments

- Turn in code and executable (Athena Linux)
- Always turn in a README file
  - Describe problems, explain partially-working code
    Say how long the assignment took
- Coding style important
  - Some assignments are cumulative
- Collaboration policy:
  - You can chat, but code on your own
  - Acknowledge your collaboration! (in readme file)
- Late policy:
  - **The deadline is absolute: 0 if not on time**
  - Due Wednesday @ 8pm
  - Extensions only considered if requested 1 week before due date
  - Medical problems must be documented

The deadline is absolute

- I mean it.
- I do regularly give 0 for,
  - an assignment turned in half an hour late
  - turning in the wrong file
- Submit early, even before you might be fully done

Collaboration policy

- You can chat, but code on your own (we use automated plagiarism detection software!)
- Use Piazza message board
- Help others on Piazza message board (will help your grade!)
- Acknowledge your collaboration (in README)
- Talk to each other, get a community going
  - Graphics is fun!

Administrivia: Assignments

- **The assignments are a lot of work. Really.**
  - Start early!

Assignments

0: Warm up (mesh display with OpenGL)

1: Curves & surfaces

2: Hierarchical modeling, skinning

3: Physically-based simulation

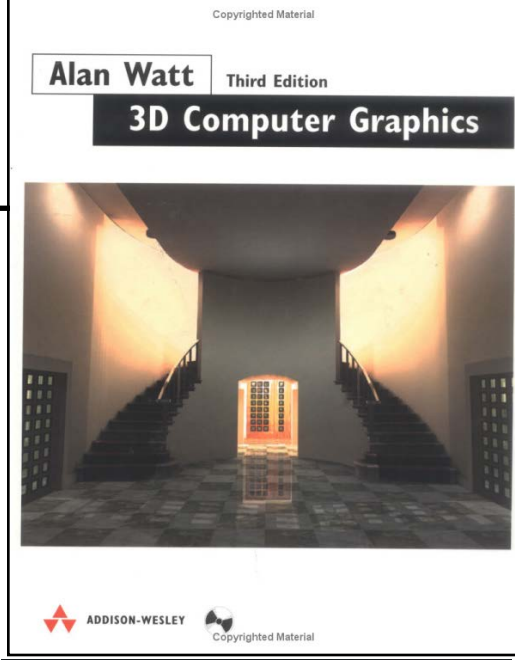
4: Ray casting

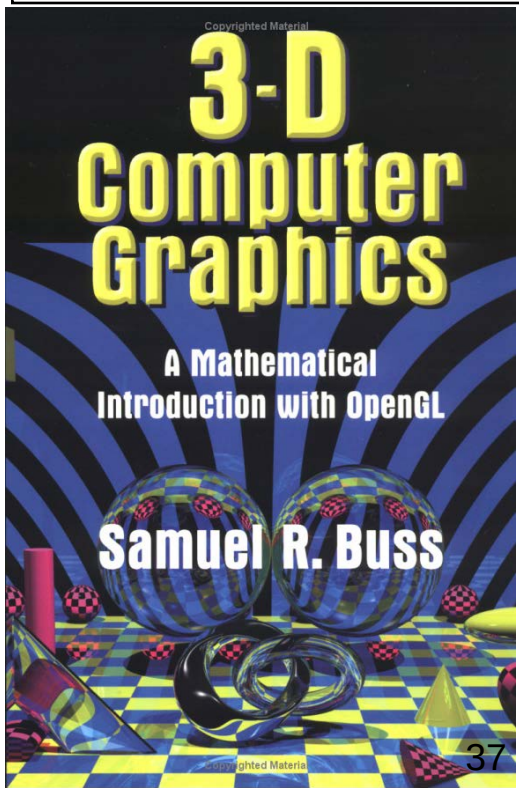
5: Ray tracing

(more in later slides)

Textbooks

- No textbook is required
- Recommendations
  - 3D Computer Graphics (Watt)
  - 3D Computer Graphics: A Mathematical Introduction with OpenGL (Buss)
    - **There is a free online version** available from Books24x7 (http://libraries.mit.edu/get/books24x7, requires MIT Certificate)
  - Real-Time Rendering, 3rd ed. (Akenine-Möller, Haines, Hoffman)
  - Fundamentals of Computer Graphics, 3rd ed. (Shirley, Marschner)





Questions?

Plan

- Overview of computer graphics
- Administrivia
- **Overview of the semester**
- Overview of assignments
- Intro to OpenGL & assignment 0

How do you make this picture?

Remedy Entertainment / Microsoft Games Studios

How do you make this picture?

How do you make this picture?

How do you make this picture?

- Modeling
  - Geometry
  - Materials
  - Lights
- Animation
  - Make it move
- Rendering
  - I.e., draw the picture!
  - Lighting, shadows, textures...

How do you make this picture?

- Modeling
  - Geometry
  - Materials
  - Lights
- Animation
  - Make it move
- Rendering
  - I.e., draw the picture!
  - Lighting, shadows, textures...

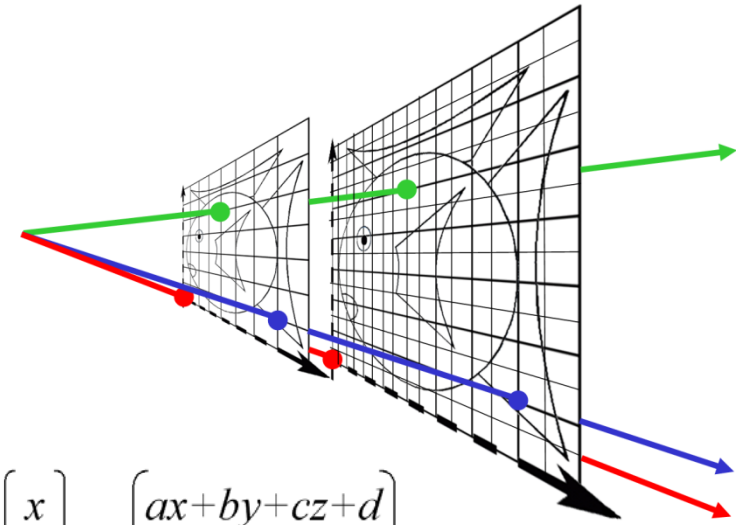
Questions?

Overview of the Semester

- Modeling, Transformations
- Animation, Color
- Ray Casting / Ray Tracing
- The Graphics Pipeline
- Textures, Shadows
- Sampling, Global Illumination

Transformations

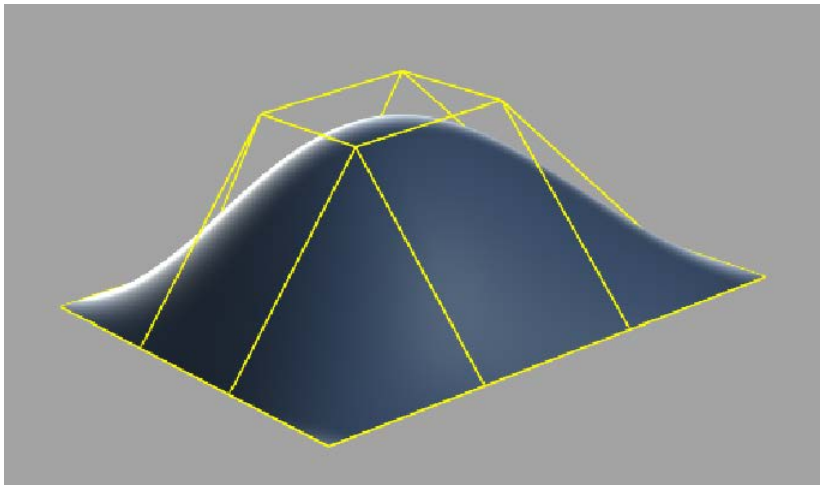
- Yep, good old linear algebra
- Homogeneous coordinates
  - (Adding dimensions to make life harder)
- Perspective

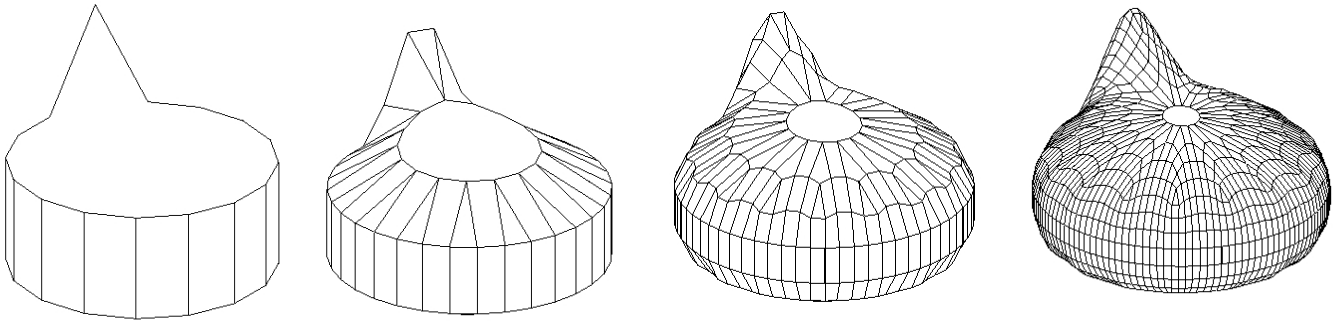


$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} a & b & c & d \\ e & f & g & h \\ i & j & k & l \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} ax+by+cz+d \\ ex+fy+gz+h \\ ix+jy+kz+l \\ 1 \end{bmatrix}$$

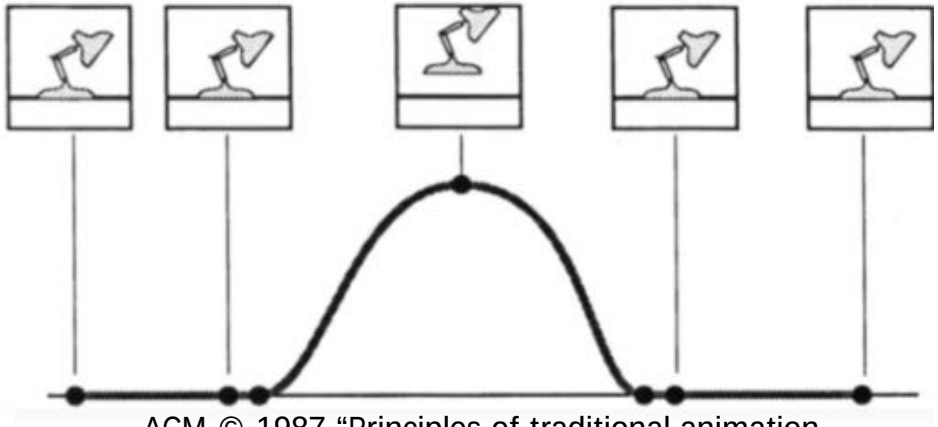
Modeling

- Curves and surfaces
- Subdivision surfaces





Animation: Keyframing



ACM © 1987 “Principles of traditional animation applied to 3D computer animation”

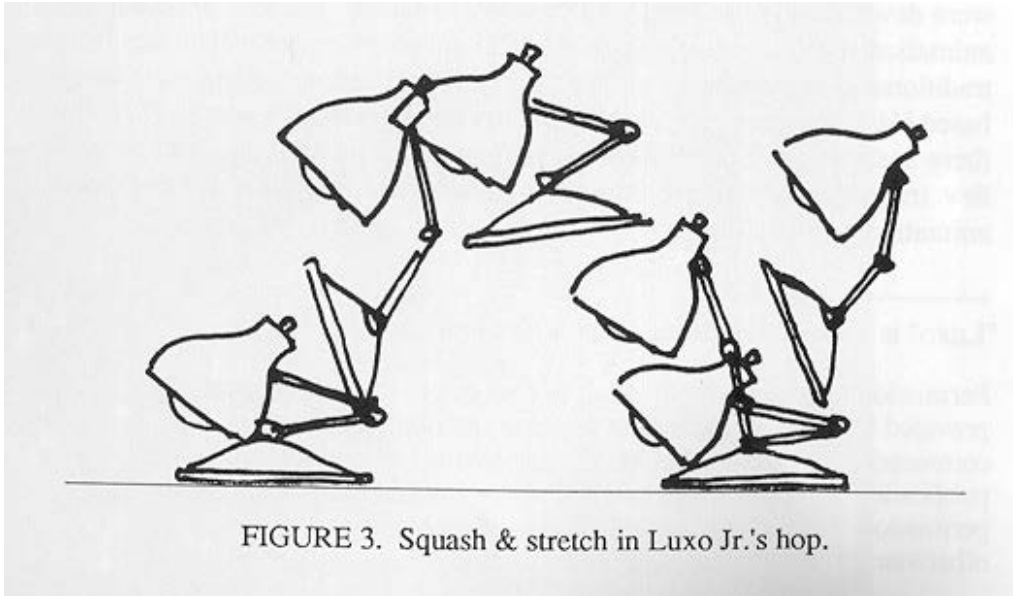
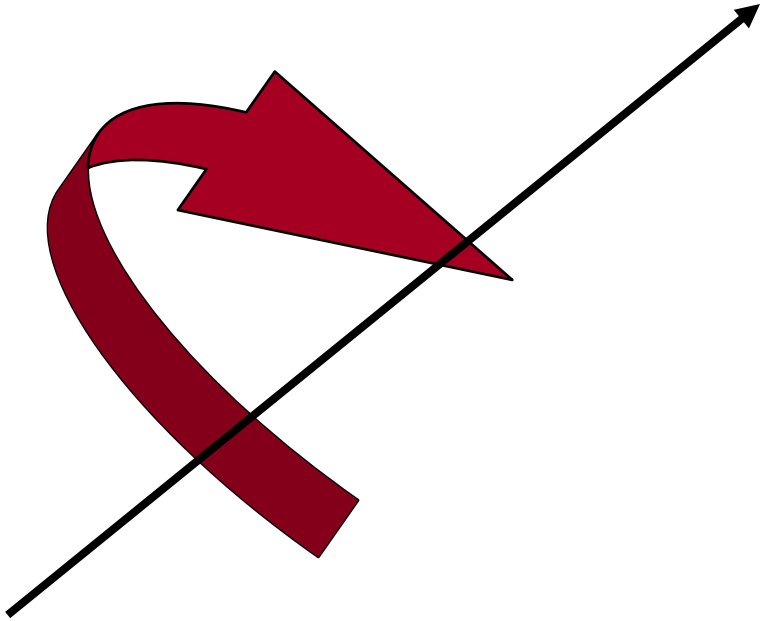
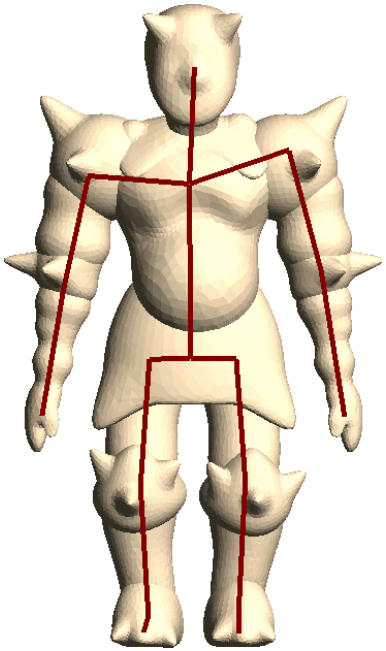


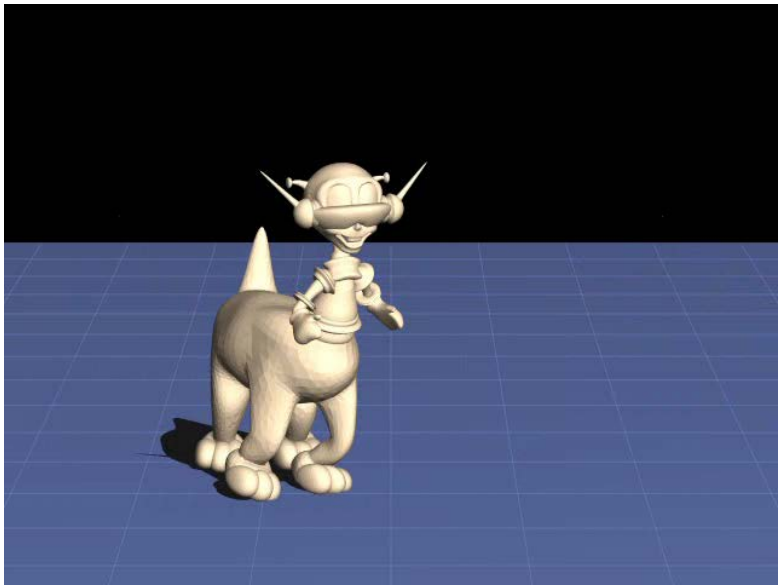
FIGURE 3. Squash & stretch in Luxo Jr.'s hop.



Character Animation: Skinning

- Animate simple “skeleton”
- Attach “skin” to skeleton
  - Skin deforms smoothly with skeleton
- Used everywhere (games, movies)



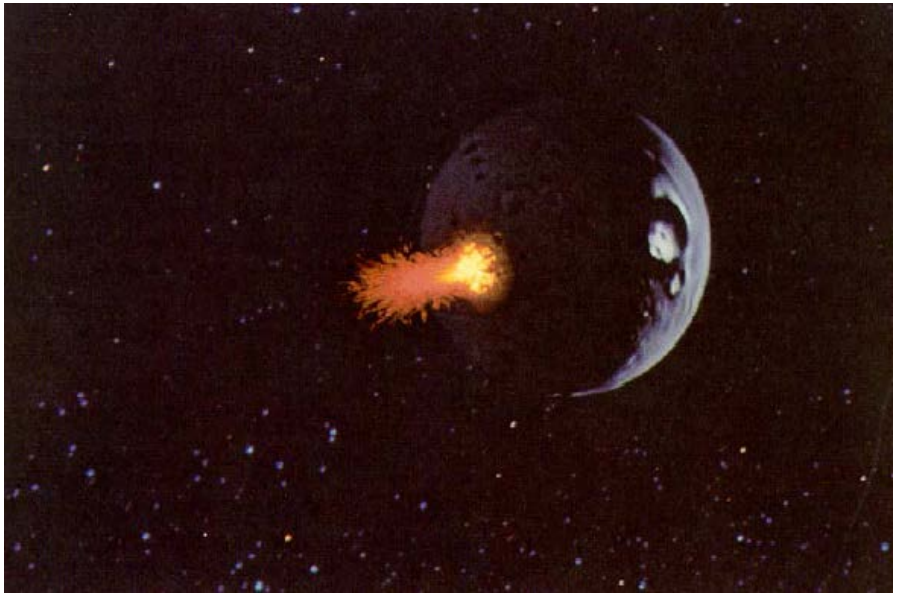


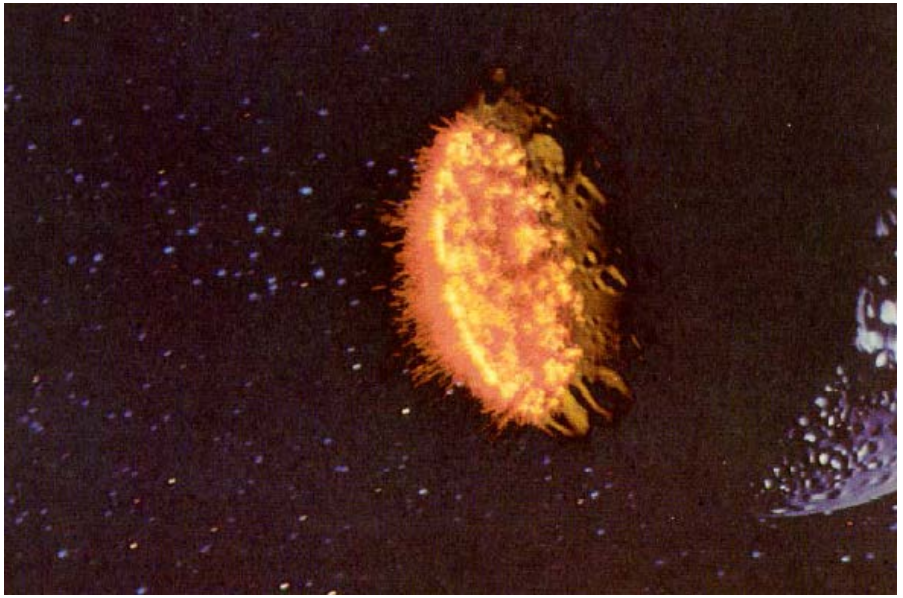
Ilya Baran

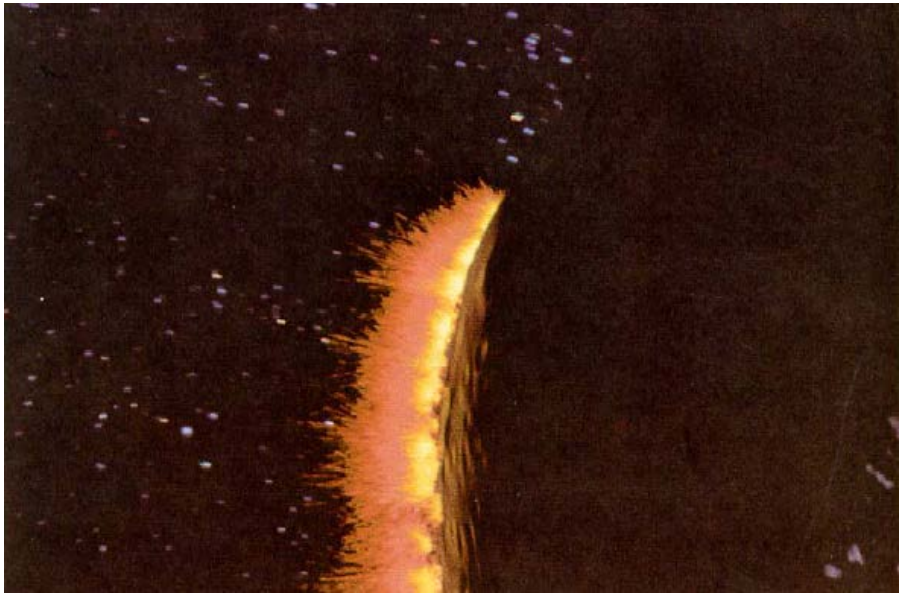
Epic Games

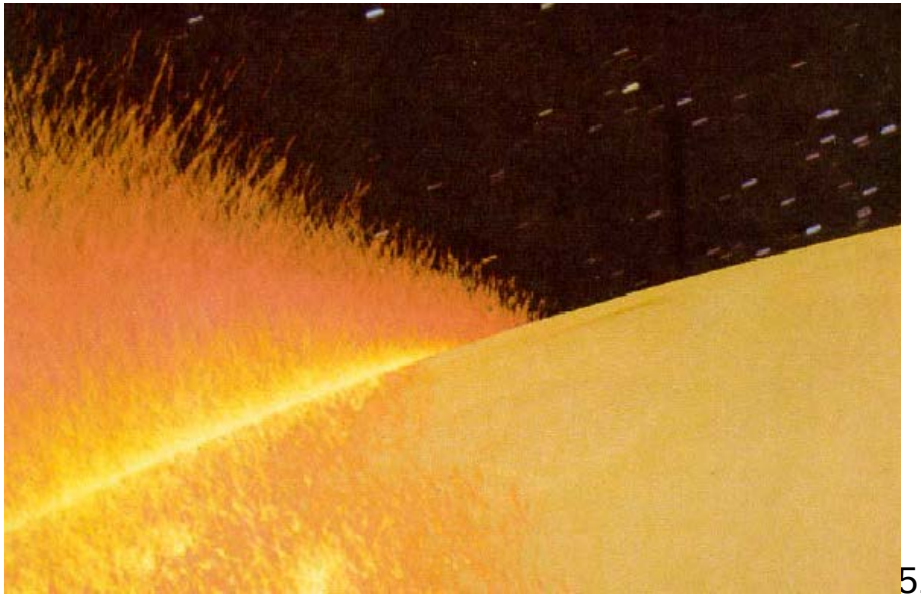
50

Particle system (PDE)





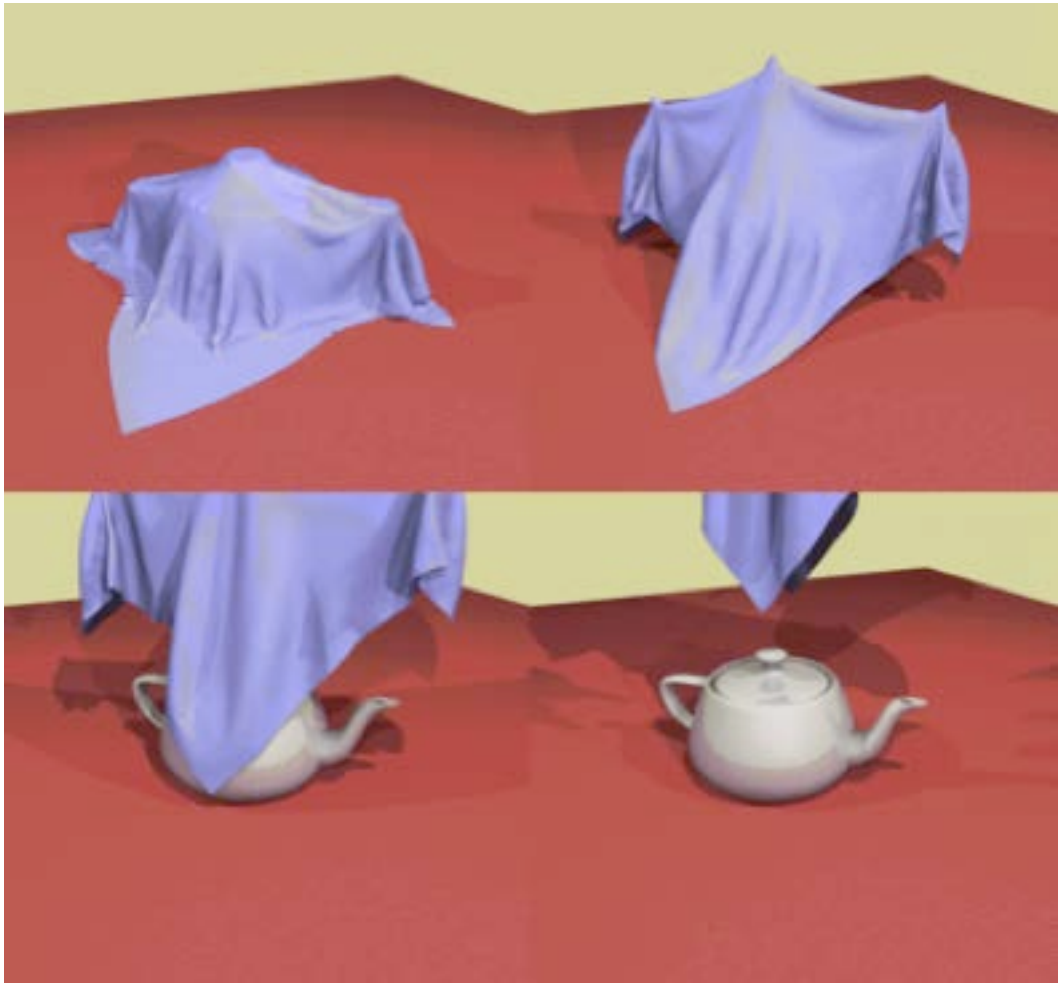




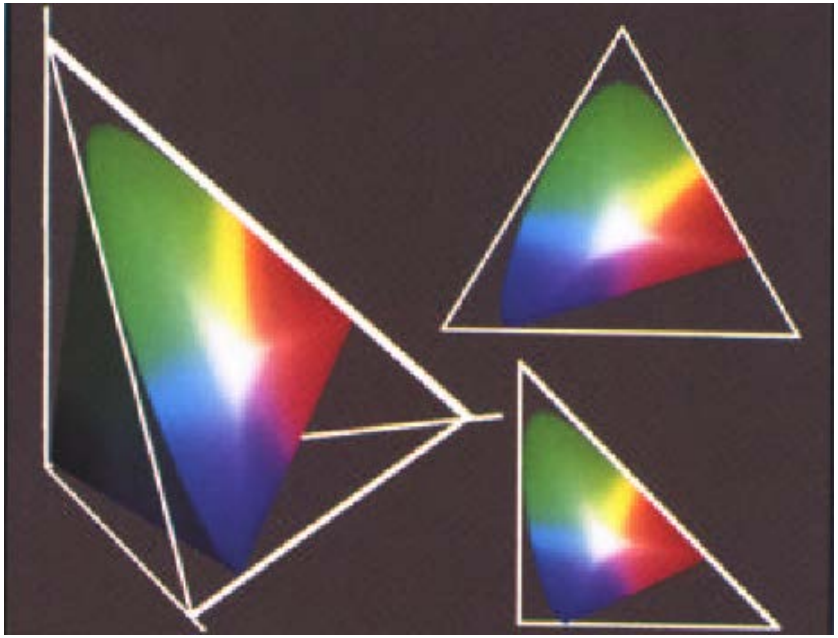
“Physics” (ODEs)

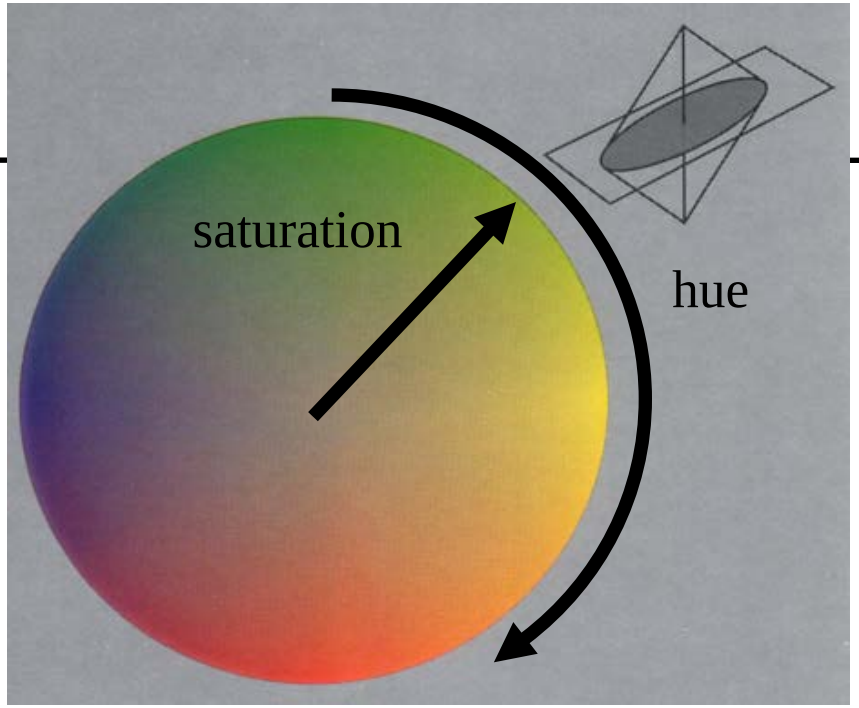
- Fire, smoke
- Cloth

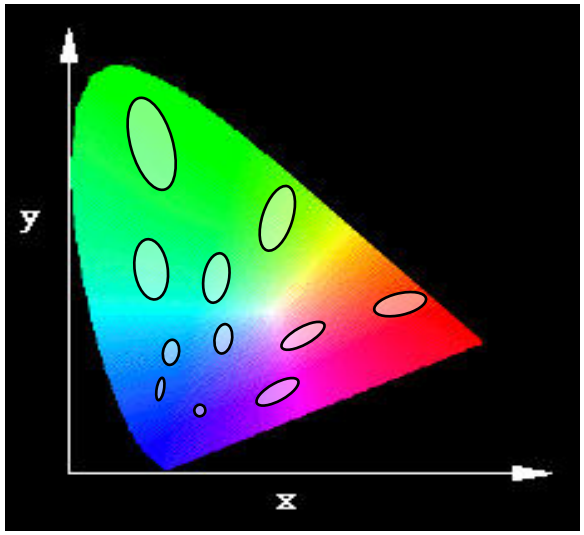
- Quotes because we do “visual simulation”

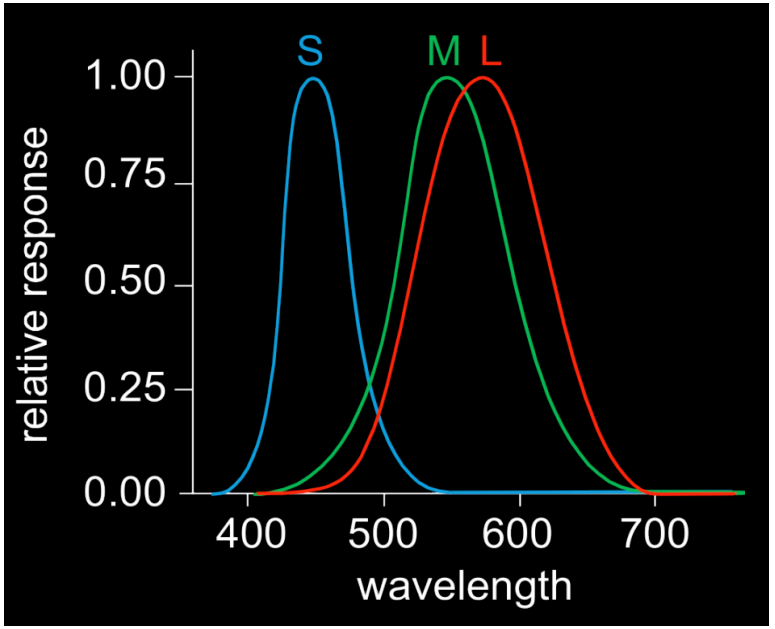


Color



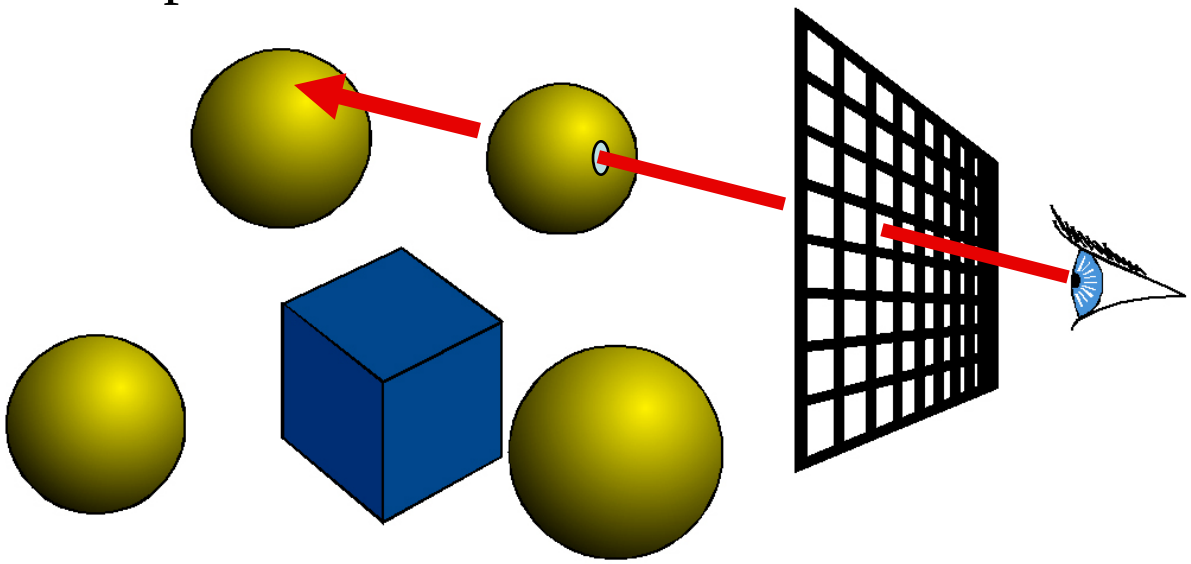

saturation
hue


y
x


S
M
L
1.00
0.75
0.50
0.25
0.00
relative response
400
500
600
700
wavelength

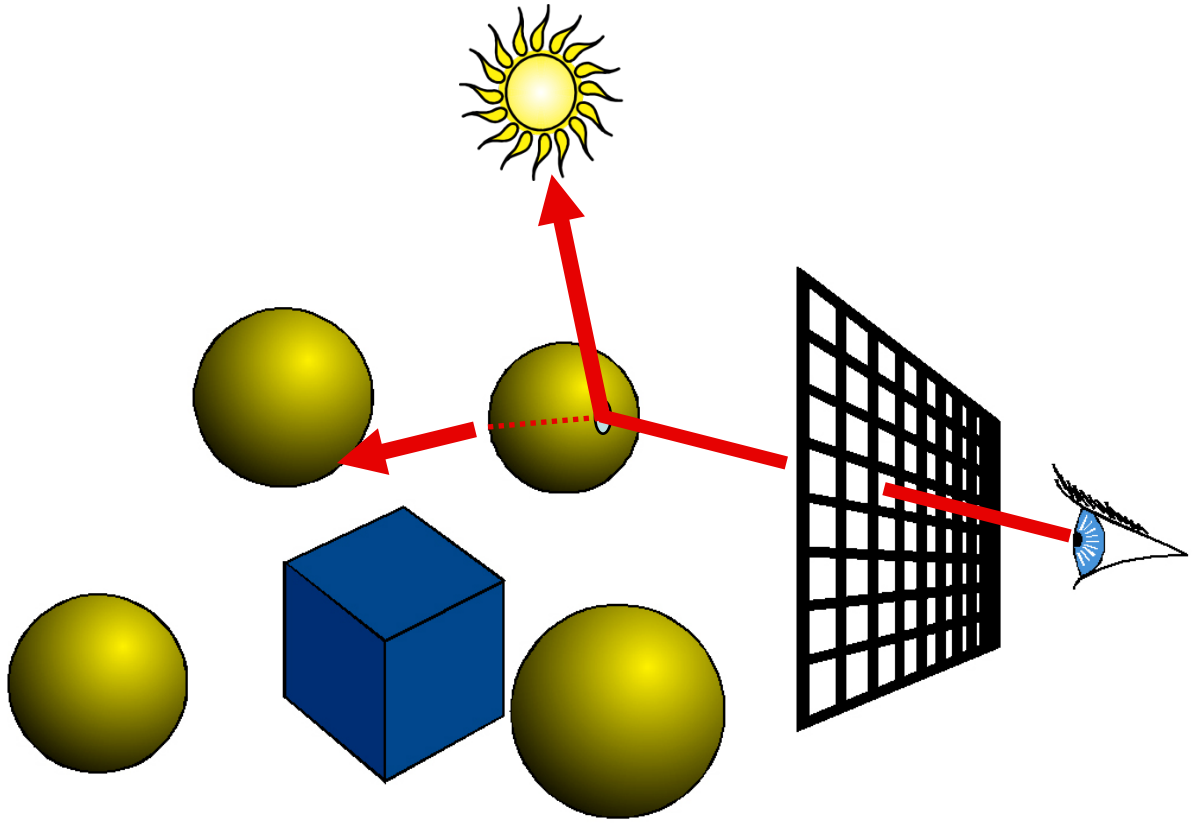
Ray Casting

- For every pixel
  construct a ray from the eye
  - For every object in the scene
    - Find intersection with the ray
    - Keep if closest



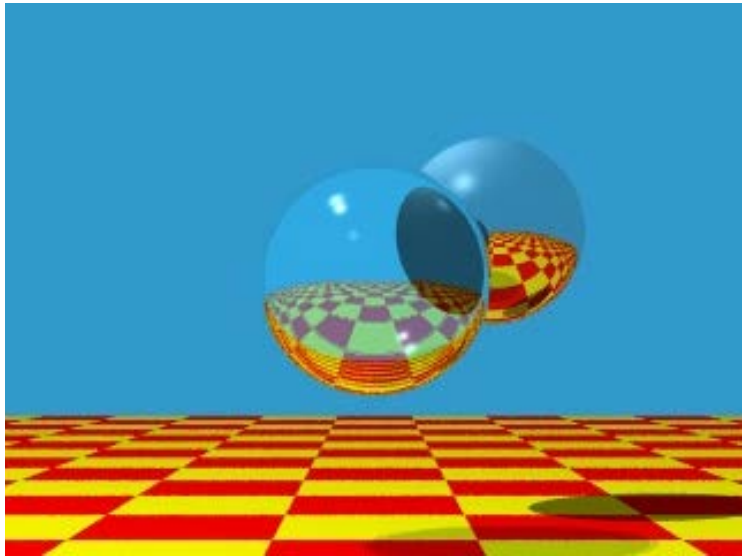
Ray Tracing

- Shade (interaction of light and material)
- Secondary rays (shadows, reflection, refraction)



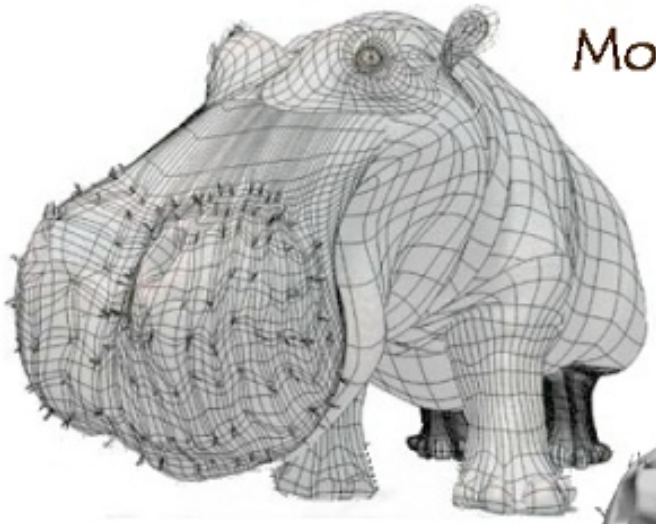
Ray Tracing

- Original Ray-traced image by Whitted



- Image computed using the Dali ray tracer by Henrik Wann Jensen
- Environment map by Paul Debevec

Textures and Shading



Model

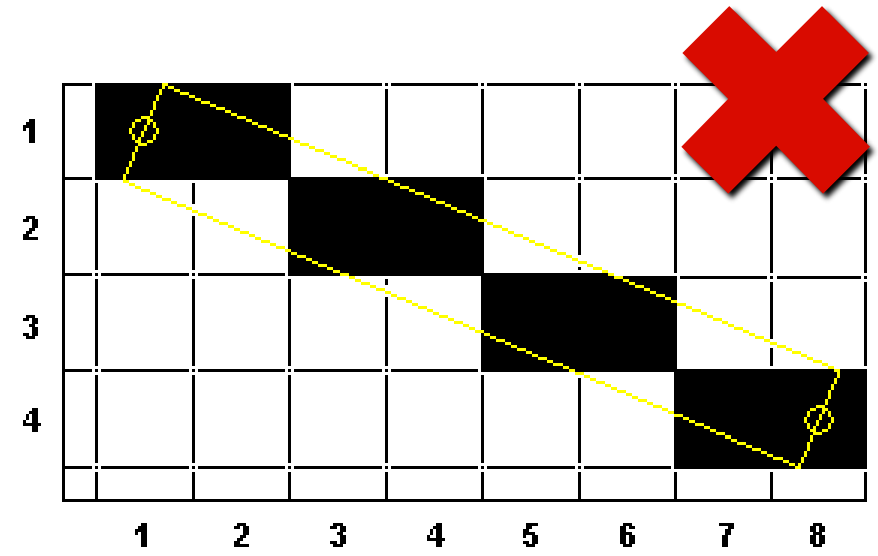
Model + Shading

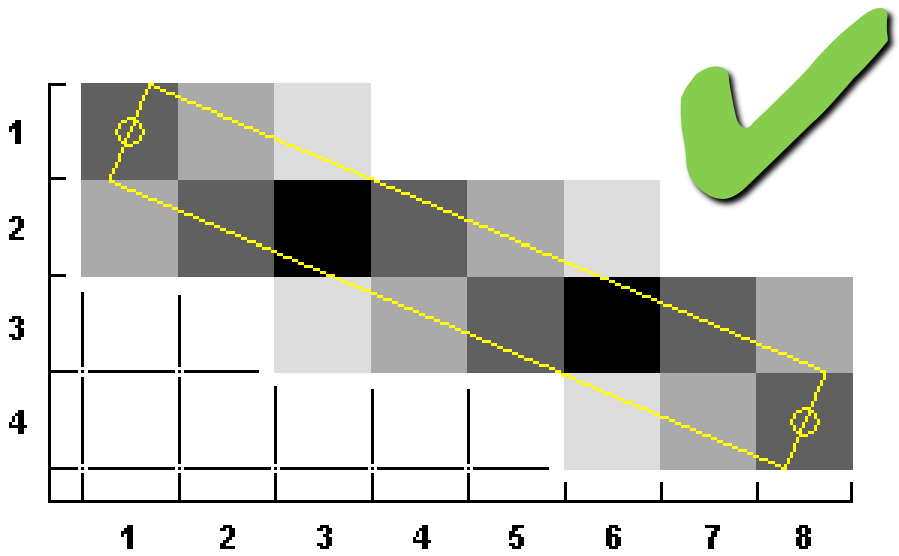
Model + Shading
+ Textures

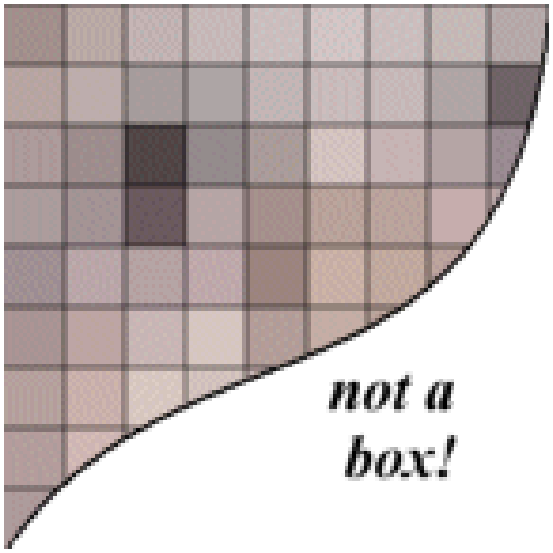
At what point
do things start
looking real?

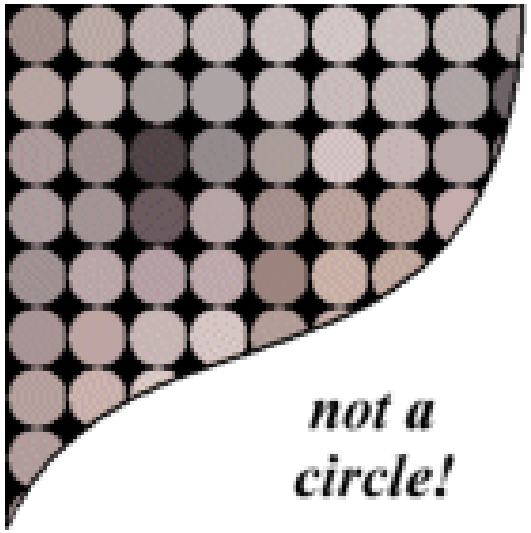
For more info on the computer artwork of Jeremy Birn
see http://www.3drender.com/jbirn/productions.html

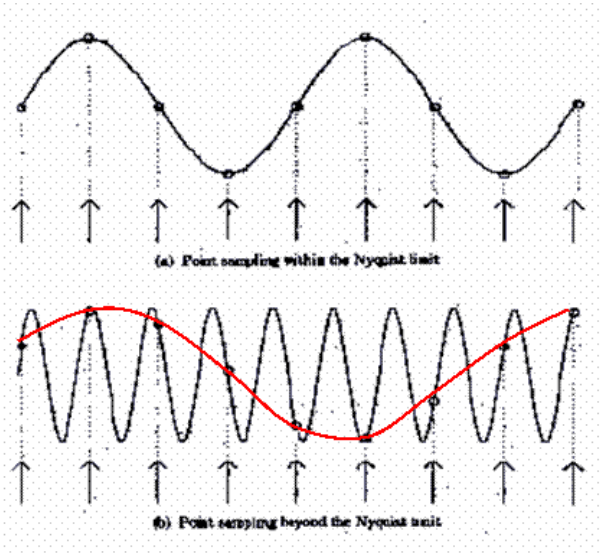
Sampling & Antialiasing











Shadows

Figure 12. Frame from *Luxo Jr.*

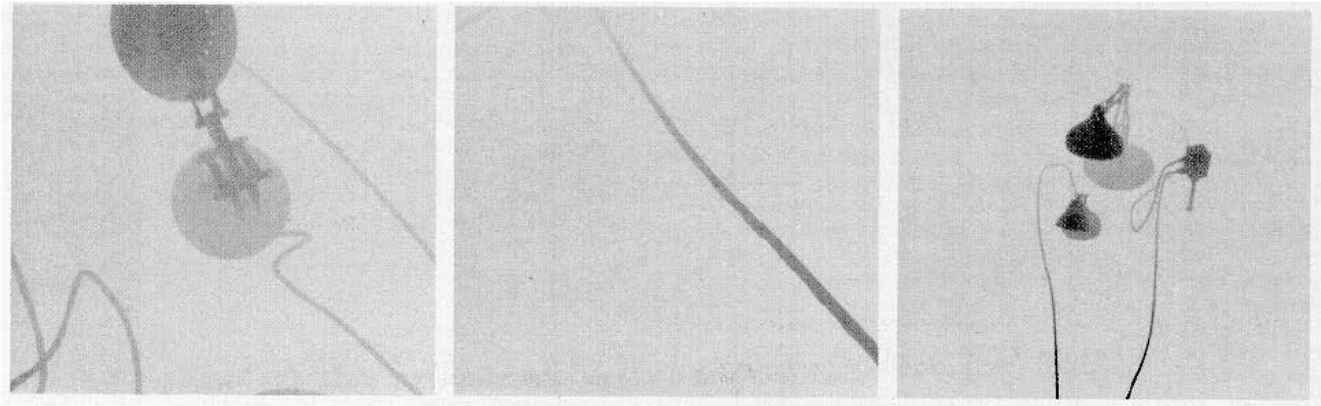
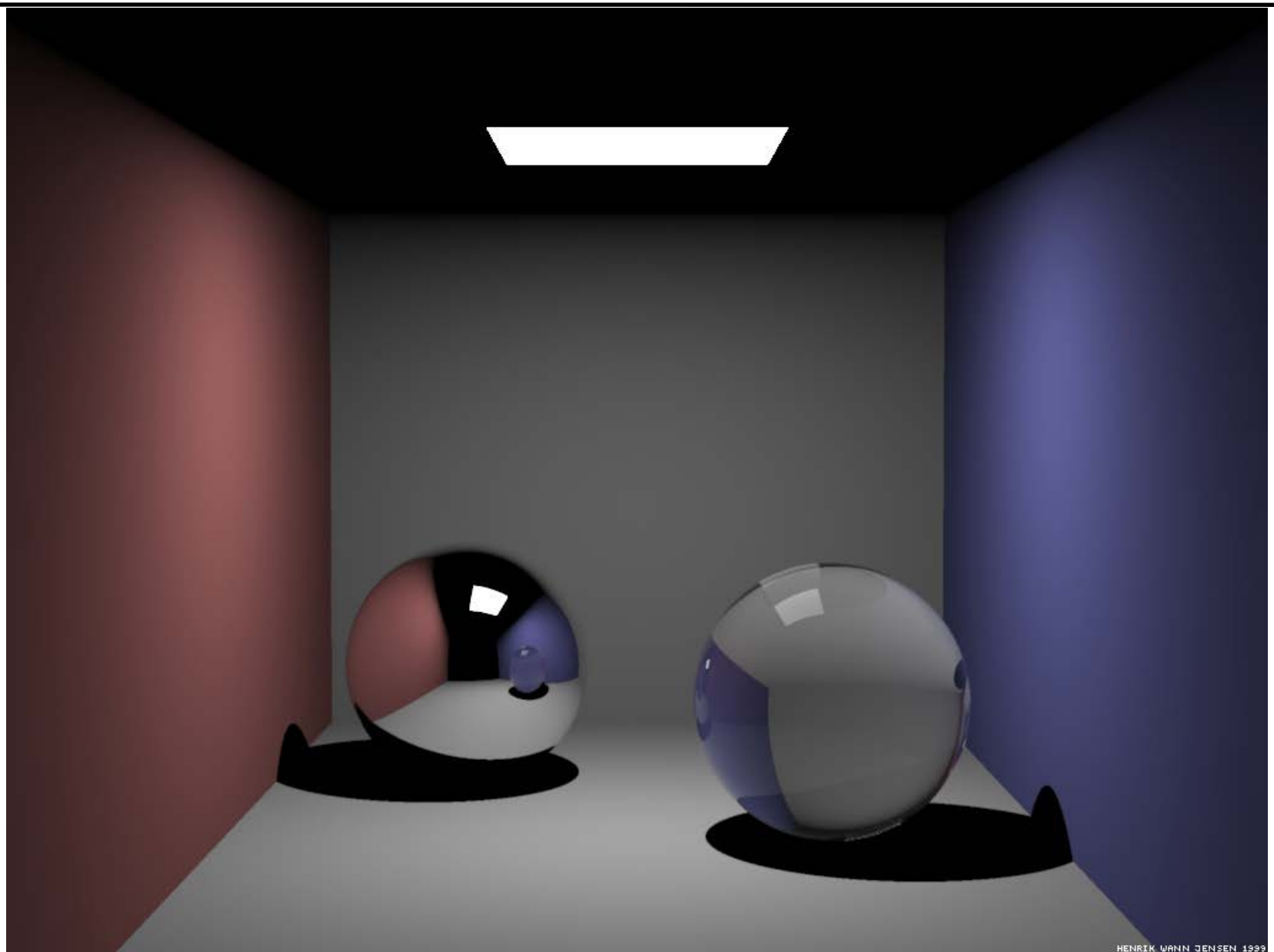
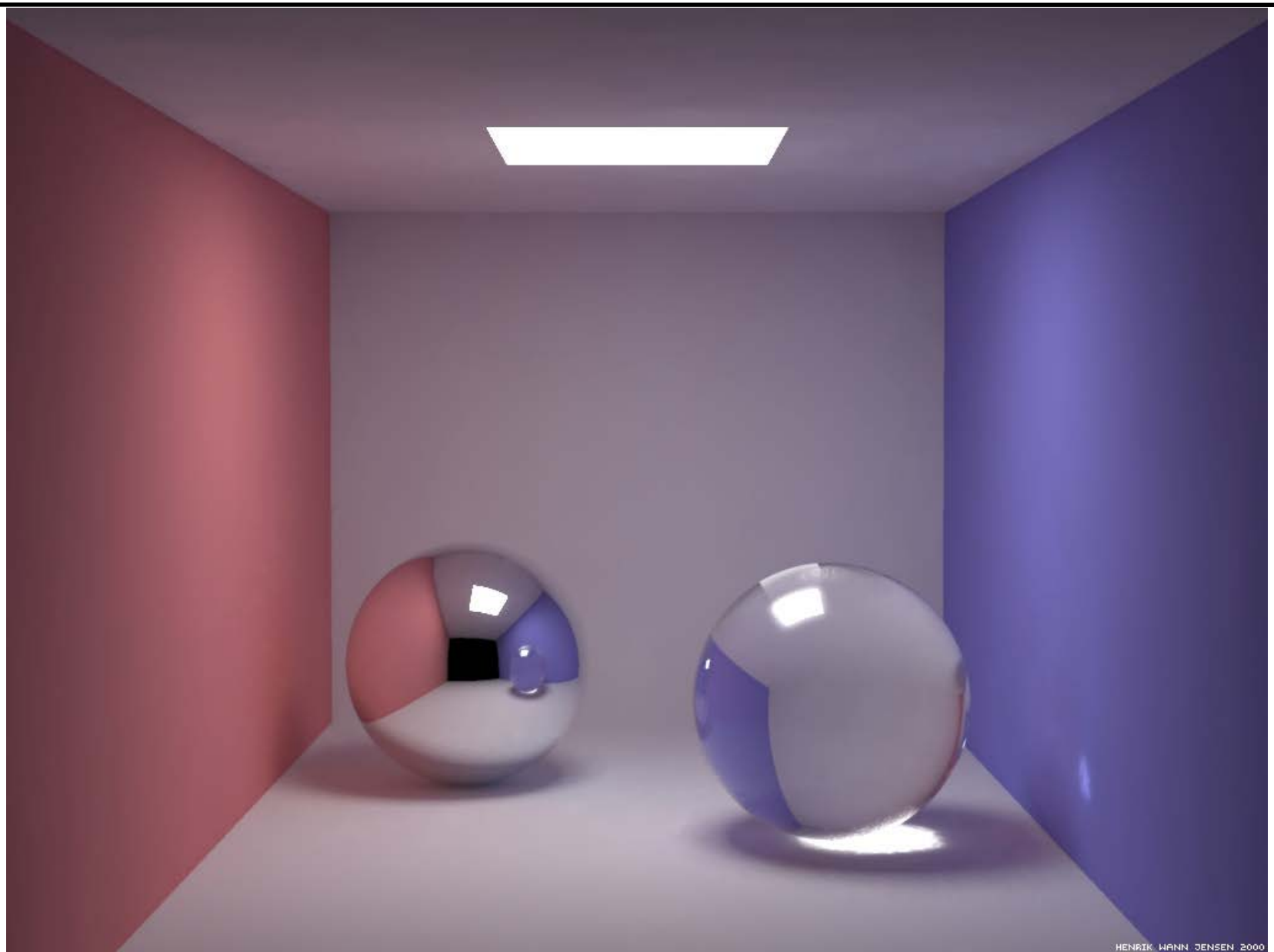


Figure 13. Shadow maps from *Luxo Jr.*

Traditional Ray Tracing



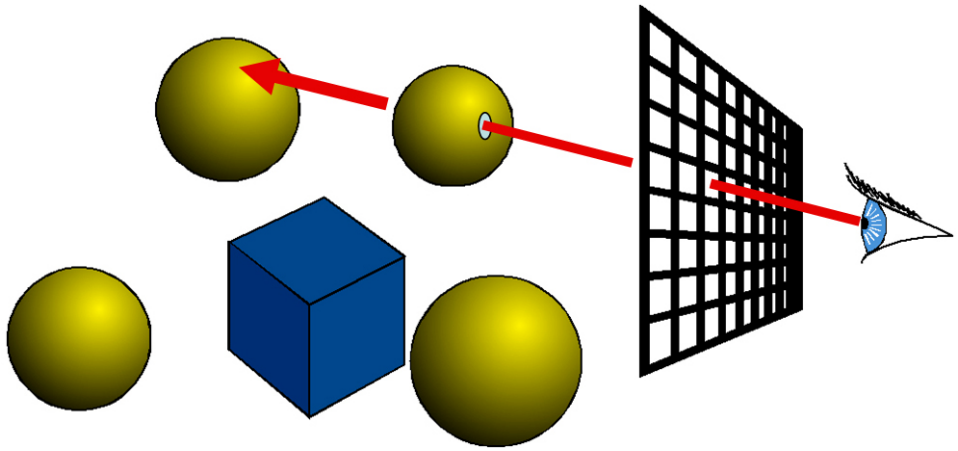
Global Illumination



The Graphics Pipeline

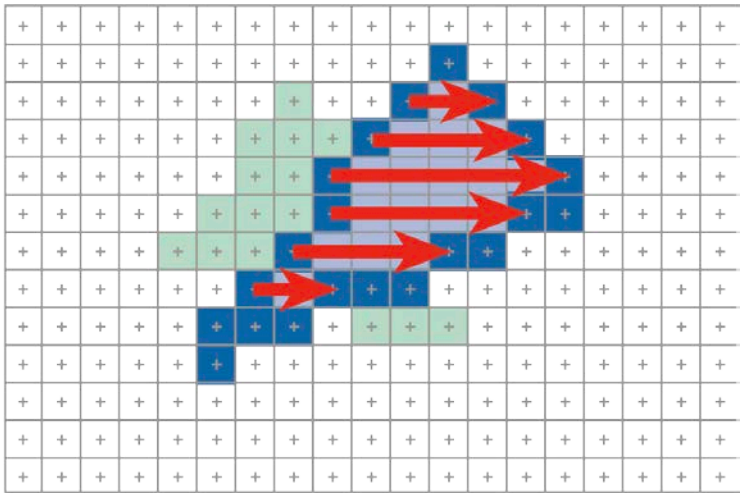
Ray Casting

```
For each pixel
    For each object
        Send pixels to scene
```



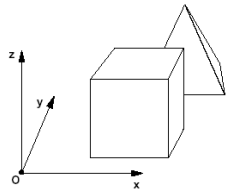
Rendering Pipeline

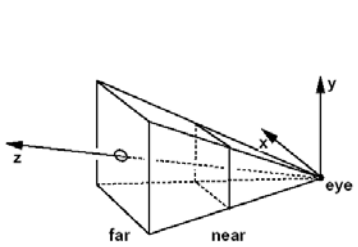
```
For each triangle
    For each projected pixel
        Project scene to pixels
```

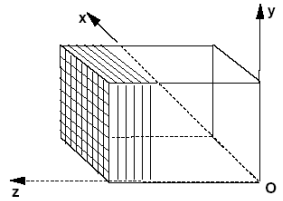


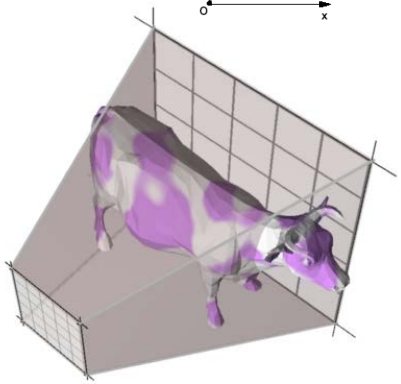
The Graphics Pipeline

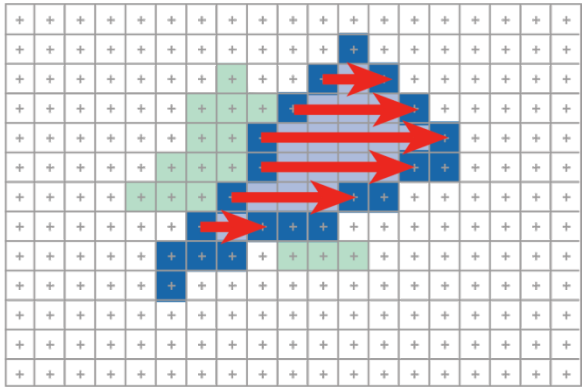
- Transformations
- Clipping
- Rasterization
- Visibility

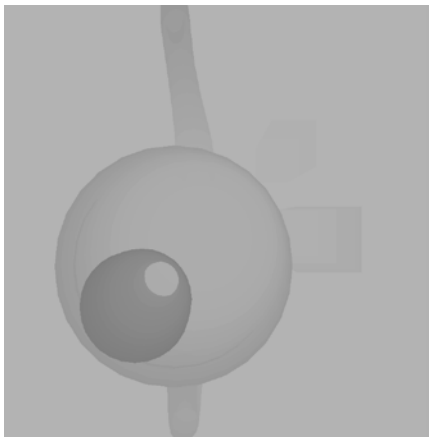










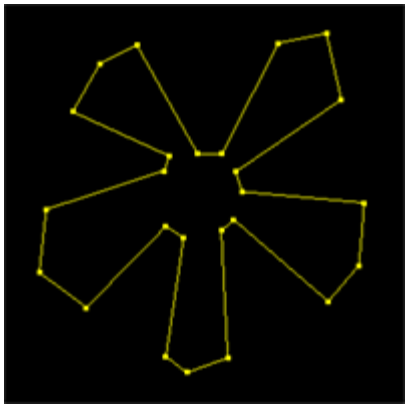


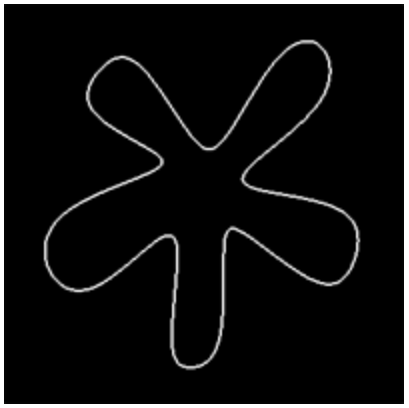
Questions?

Plan

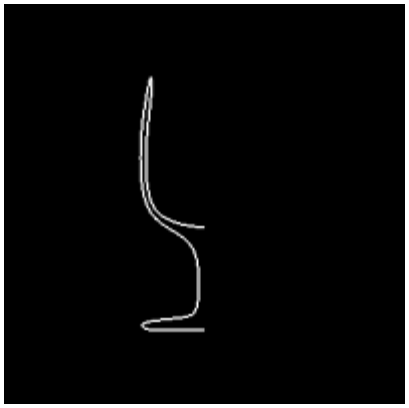
- Overview of computer graphics
- Administrivia
- Overview of the semester
- **Overview of assignments**
- Intro to OpenGL & assignment 0

Assignment 1: curves & surfaces

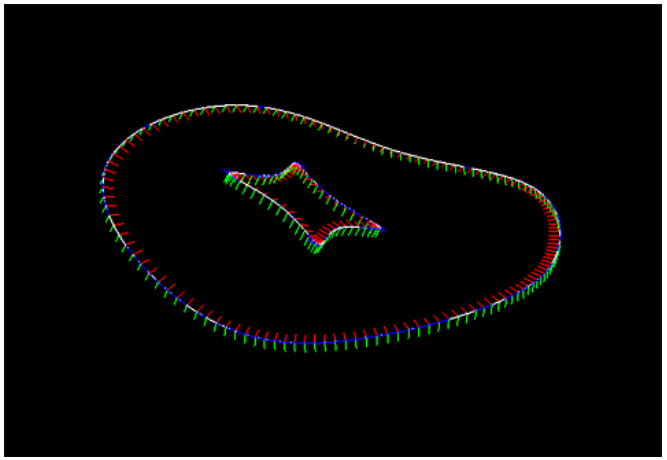


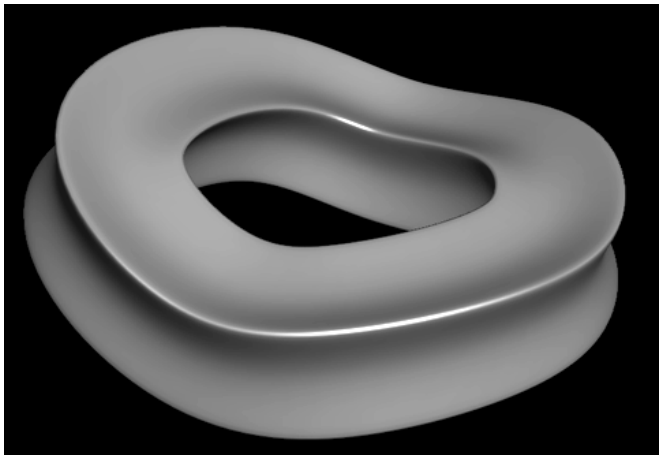


Bezier curves



Surfaces of revolution

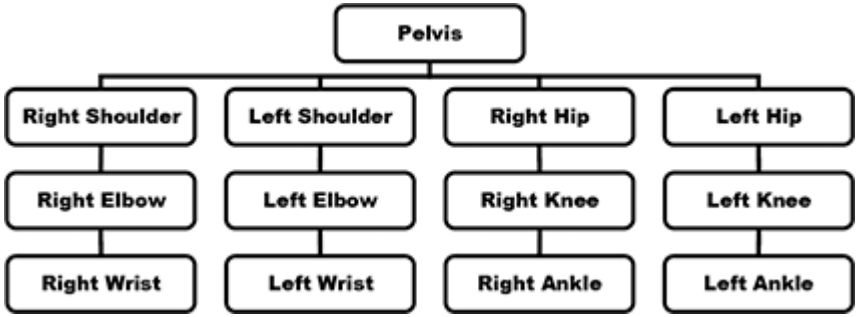


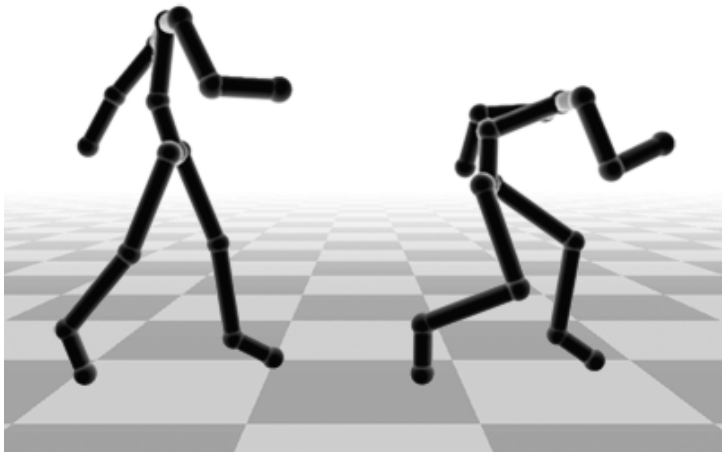


Sweep surfaces

Assignment 2: hierarchical modeling

- Animate character skeleton as tree of transformations

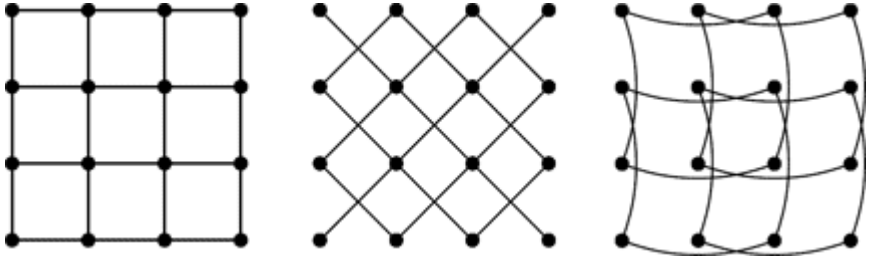


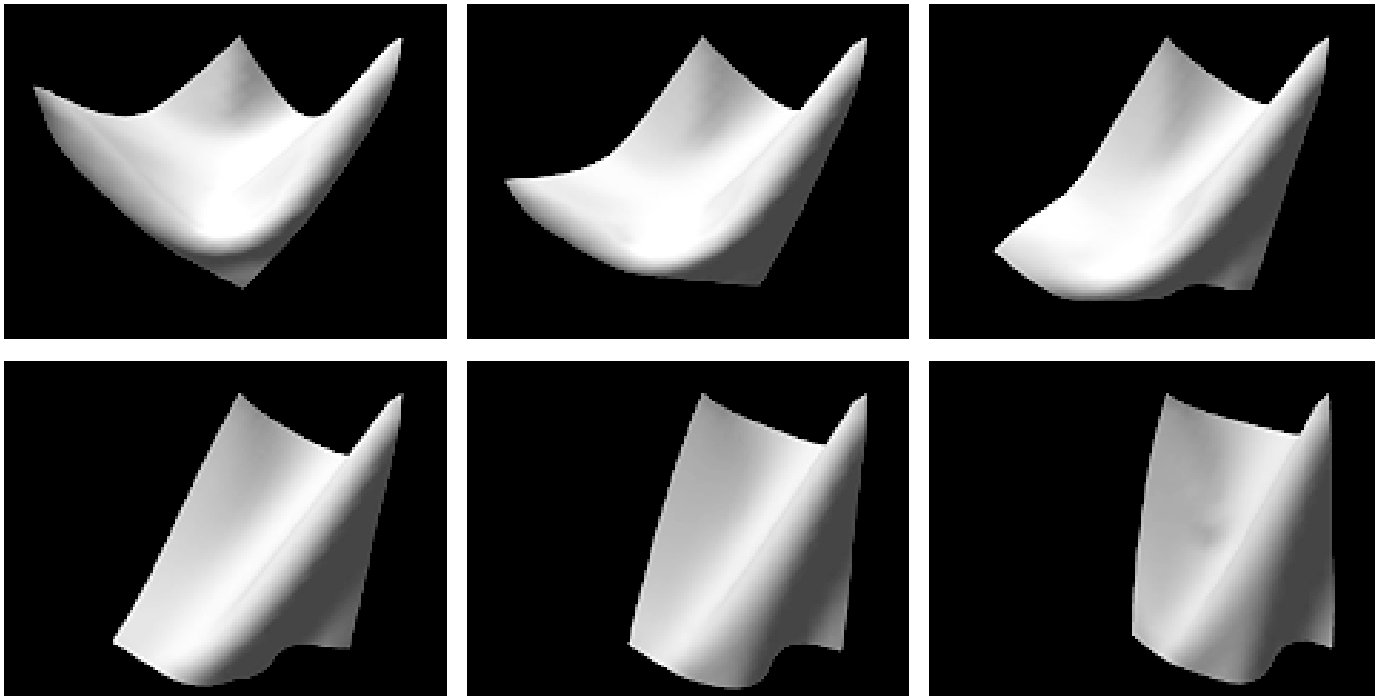


- Skinning: smooth surface deformation

Assignment 3: physics

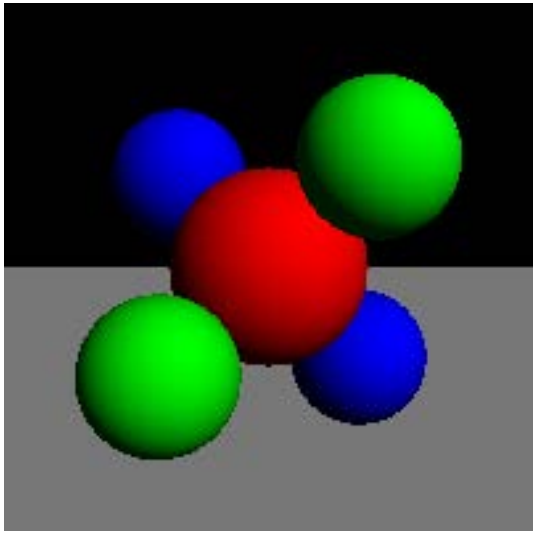
- Simulate cloth as a mass-spring network
  - ODE integration

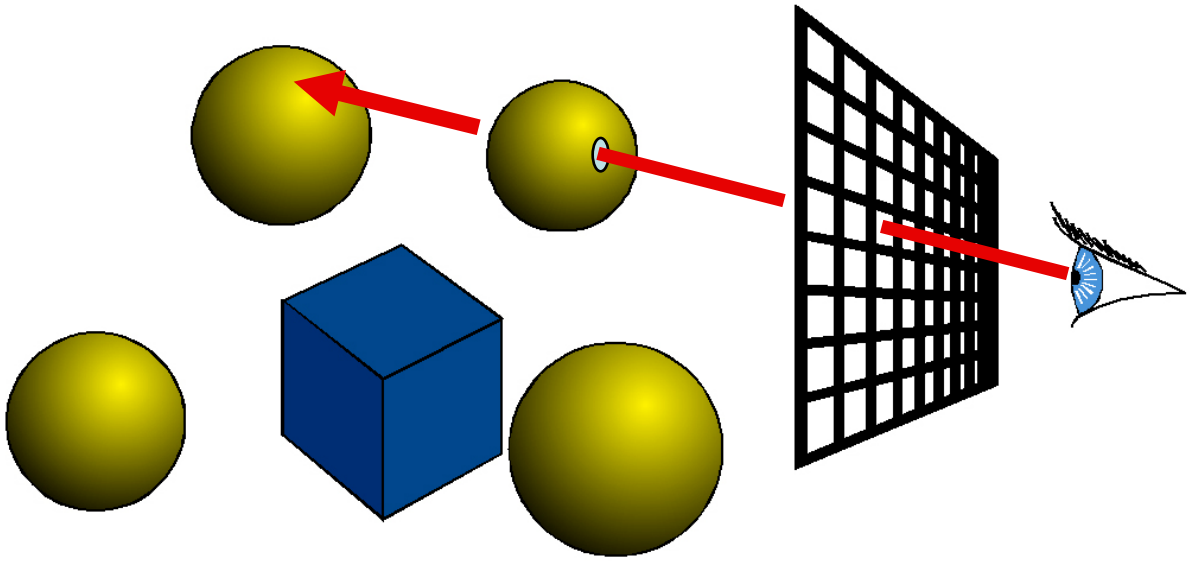




Assignment 4: ray casting

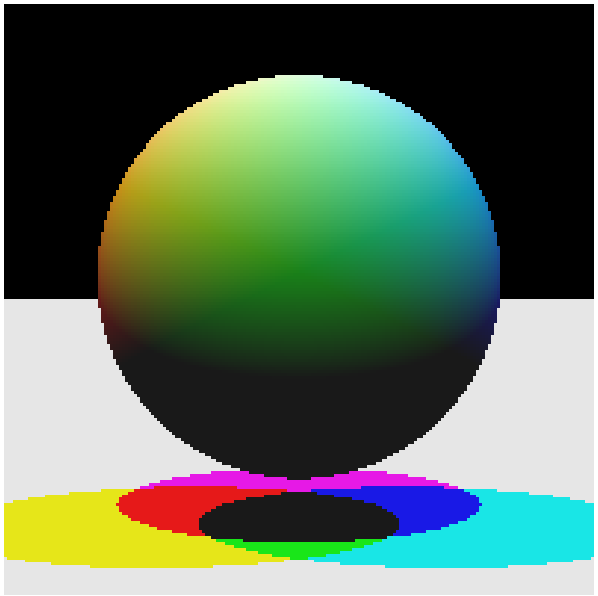
- Cast rays from the viewpoint
- Intersect with scene primitives

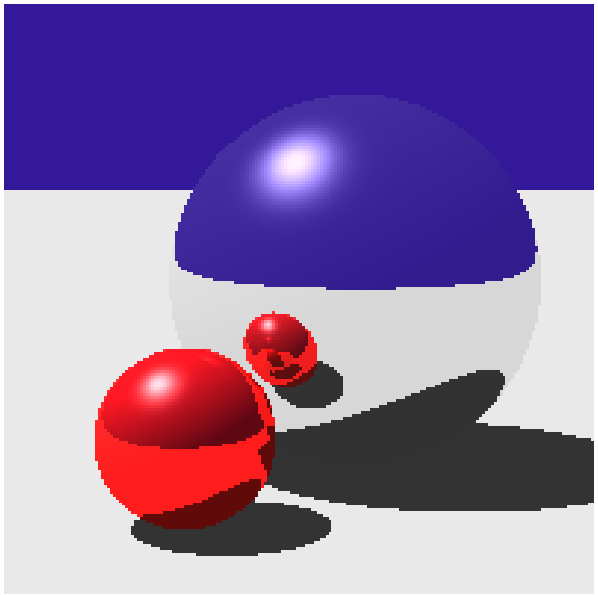


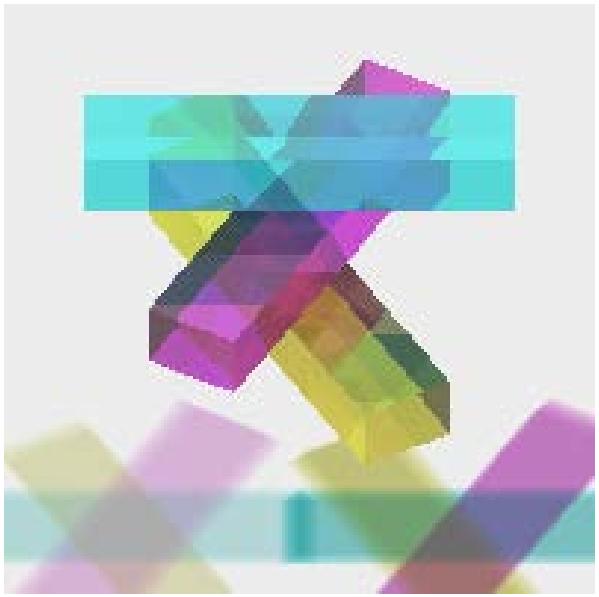


Assignment 5: ray tracing

- Shadows, reflection, refraction
- + flexible extension







Questions?

Plan

- Overview of computer graphics
- Administrivia
- Overview of the semester
- Overview of assignments
- **Intro to OpenGL & assignment 0**

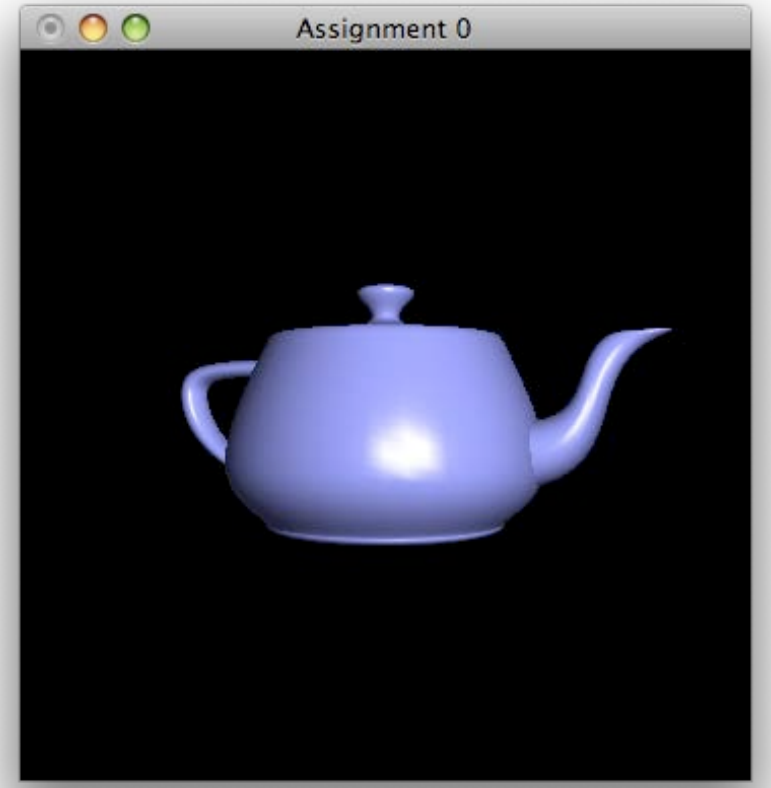
Simple 3D with OpenGL

- OpenGL is an API that allows you to send commands to the graphics card to draw 2D or 3D scenes
- At the beginning of the semester, we will use OpenGL as a black box to display 3D content
- Later, we will see what is under the hood

Assignment 0

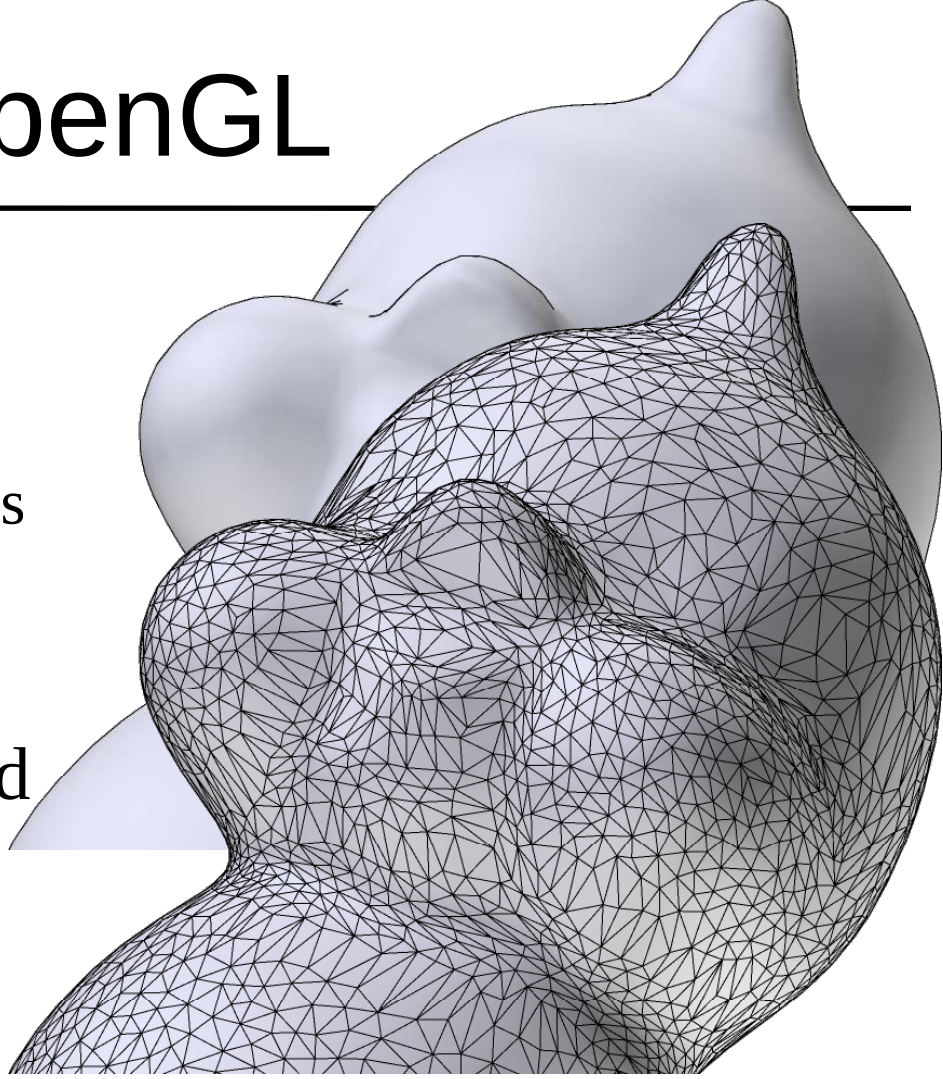
- Read a file with triangle mesh data
  - Including mesh normals
- Display it using OpenGL
  - Colors, simple movement

- Due next Wednesday!

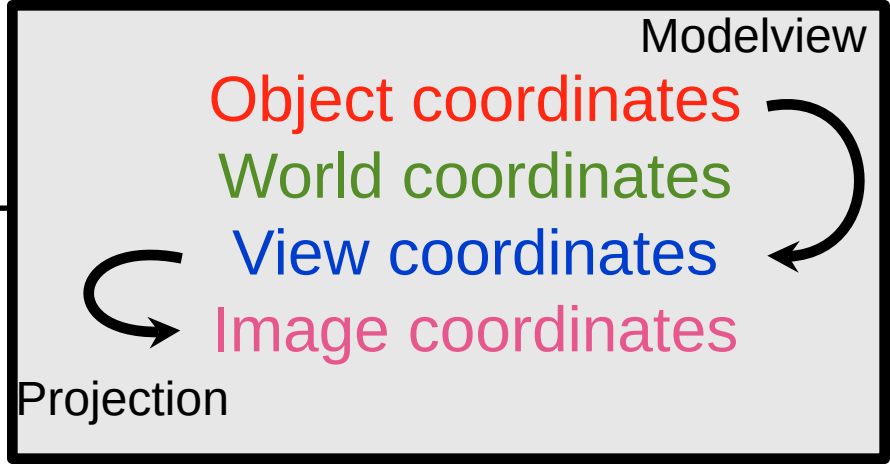


Simple 3D with OpenGL

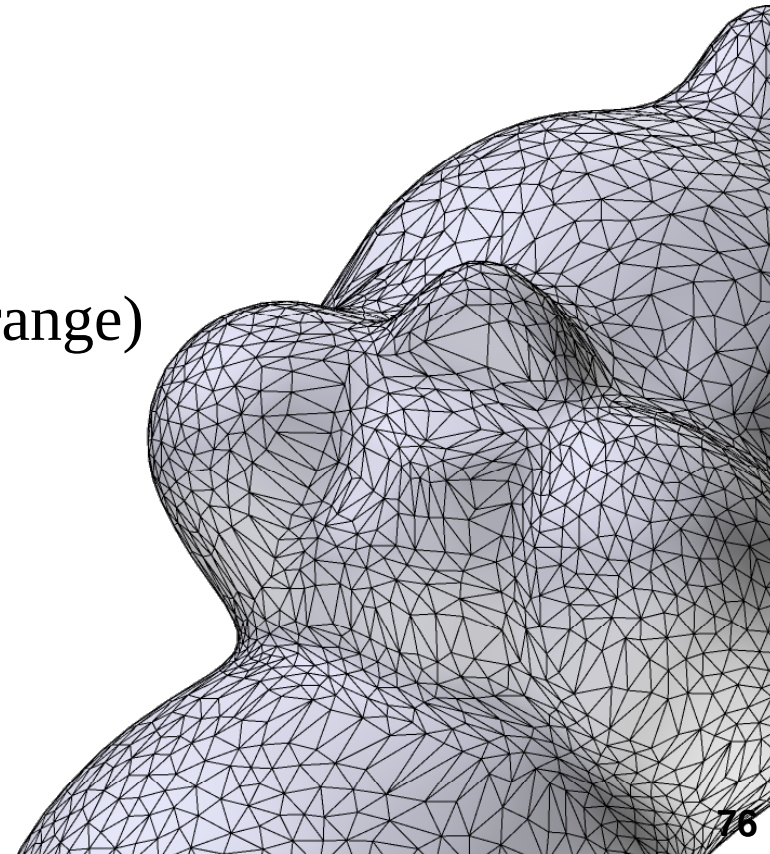
- Scene represented as triangles
  - A triangle is a set of 3 vertices
  - A vertex is a set of 3 floating point numbers (x, y, z)
- We will use OpenGL to send this to the graphics card (GPU)
  - The GPU will do its magic to display the scene from the current viewpoint (Later, we will get to see how this happens)



How to Draw?



- You need to tell OpenGL
  - The geometry of the object
    - Vertex positions
    - Vertex normals
    - 3 x vertex makes a triangle!
  - Camera parameters
    - Field of view, aspect ratio, (depth range)
    - The “projection matrix”



Questions?

OpenGL high-level pseudocode

- Initialize
  - (get graphics context, etc.)
- For each frame
  - Manage UI
  - Set appropriate viewpoint
  - Set light source directions
  - For each triangle

```
For i=0 to 2
   Send vertex data
```

OpenGL Example: Viewing

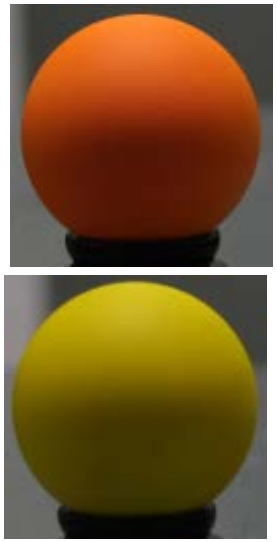
```
// Current matrix affects objects positions
glMatrixMode( GL_MODELVIEW );
// Initialize to the identity
glLoadIdentity();
// Position the camera at [0,0,5], looking at
// [0,0,0], with [0,1,0] as the up direction.
gluLookAt(0.0, 0.0, 5.0,
          0.0, 0.0, 0.0,
          0.0, 1.0, 0.0);
// Rotate by -20 degrees about [0,1,0]
glRotated(-20.0, 0.0, 1.0, 0.0);

// Draw a teapot.
glutSolidTeapot(1.0);
```

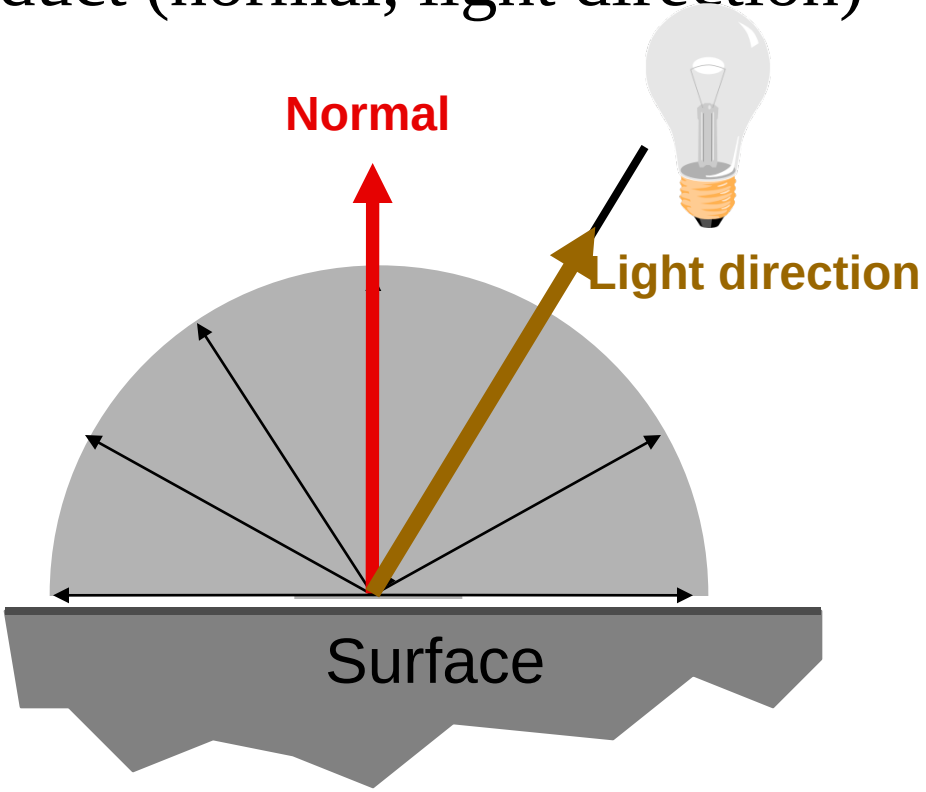
Vertex data

- What information do we need at each vertex?
  - Coordinates (3 floats)
  - Color (optional, 3 floats)
  - Normal information (optional, 3 floats)
  - Transparency (optional, 1 float)
  - More to come (texture information, shininess)

Why normals?

- To compute color as a function of light direction
- Simplest: Diffuse or Lambert model
  - Intensity = dot product (normal, light direction)





OpenGL Code

```
glBegin(GL_TRIANGLES); //what follows describes triangles
glColor3d (1,1,0); //red, green and blue components=>(yellow)
glNormal3d (0, 0, 1); //normal pointing up
glVertex3d (2,3,3); //3D position x, y, z
glColor3d (1,0,0);
glNormal3d (0, 0, 1);
glVertex3d (5,3,3);
glColor3d (1,0,1);
glNormal3d (0, 0, 1);
glVertex3d (3,6,3);
glEnd();
```

OpenGL high-level pseudocode

- Initialize
  - (get graphics context, etc.)
- For each frame
  - Manage UI
  - Set appropriate viewpoint
  - Set light source directions
  - For each triangle

```
For i=0 to 2
   Send vertex data
```

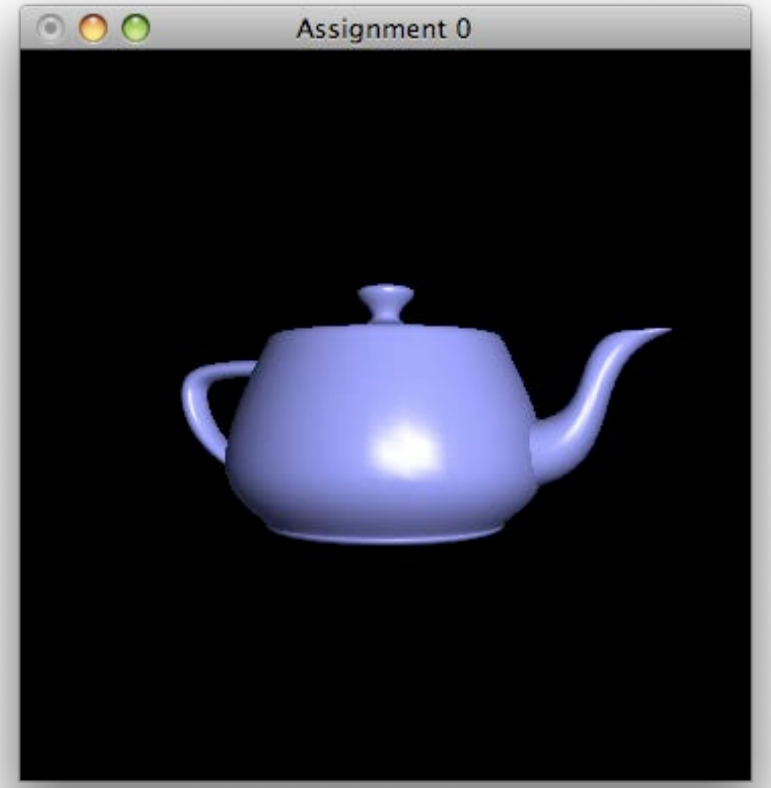
OpenGL is a state machine

- Each command changes the state
  - But `glVertex` also “pushes” data
- For example, glColor3f changes the current color.
  - The color remains valid until we call glColor*xx* again
  - Use it before each vertex to get per-vertex color.
- Other state to manage lighting and other rendering aspects
- Can make it hard to debug
- *(Note: This is conceptually simple, but not quite how you write efficient code these days.)*

Assignment 0

- Read a file with triangle mesh data
  - Including mesh normals
- Display it using OpenGL
  - Colors, simple movement

- Due next Wednesday!



What is missing?

- Shadows
- Shininess
- Texture
- Etc.

- Be patient, you will have plenty enough

Linear Algebra is Everywhere

- Vertices are 3-vectors
- Normals are 3-vectors
  - Orthogonal to surface tangent plane
  - Cross product
- Colors are 3-vectors
- Diffuse shading is a dot product
- A non-bending object moving in a scene undergoes a rigid transformation
- Changing the viewpoint is a linear transformation of the scene coordinate
- Brush up in the review session!

What Makes Graphics Fun?

- Very interdisciplinary
  - Within CS: systems, compilers, languages, computer architecture, algorithms, numerical techniques
  - Math, physics, art, perception, architecture, manufacturing
- Helps you understand why the world looks the way it does
- You can “see” the result