CS230 : Computer Graphics
Winter 2012

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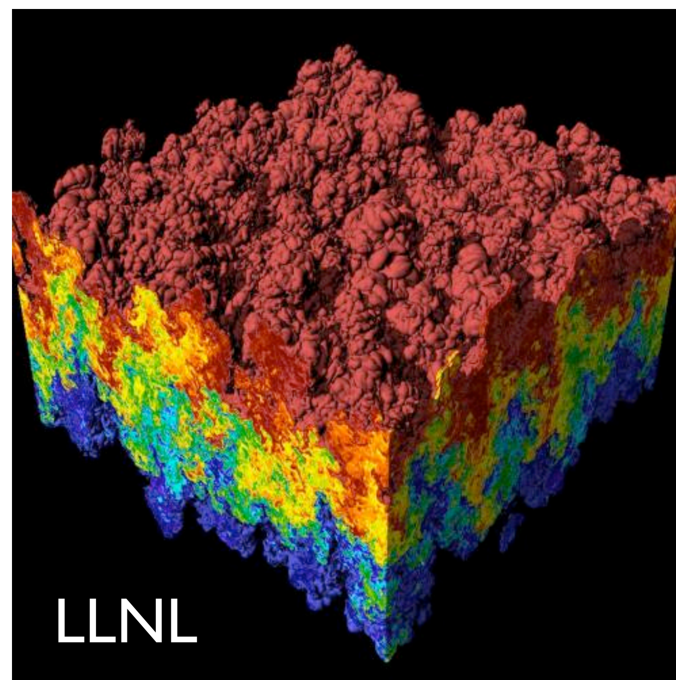
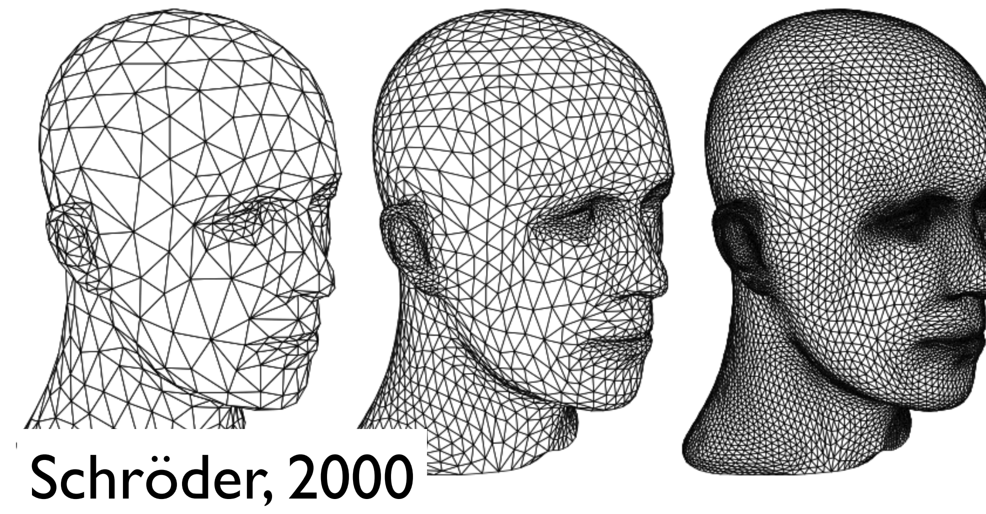
Computer Science & Engineering
UC Riverside

Welcome to CS230!

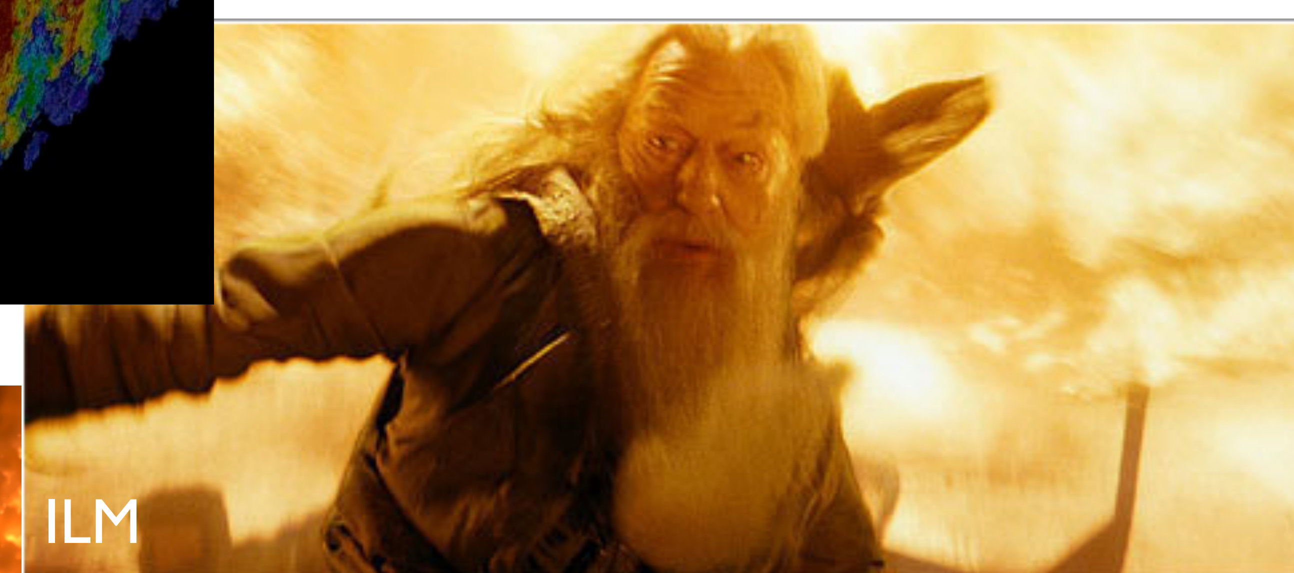
Talton et al., 2011



LLNL



Schröder, 2000



ILM

Henrik Wann Jensen

Hong et al. 2007

Pixar

Today's agenda

- Course Logistics
- Introduction: graphics areas and applications
- Course schedule
- Introduction to the graphics pipeline and OpenGL
- Math review

Course Logistics

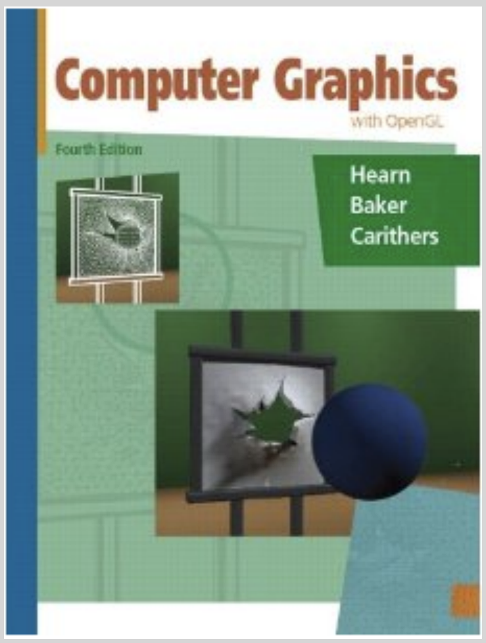
- Instructor: Tamar Shinar
- No TA
- Website: http://www.cs.ucr.edu/~shinar/courses/cs230
- Lectures: MW, 3:40-5pm
- Office hours: after class, and Wed1-2pm, WCH 419
- announcements (assignments, etc.) made in class and on course website

Course Logistics

- Grading
  - 10% class participation
  - 60% assignments (3 assignments, each ~2 weeks)
  - 30% final project
  - No exams
- Total of 3 late days (72 hours) for the quarter for the assignments only
- final must be submitted on time
- assignments individual; project individual or group of 2

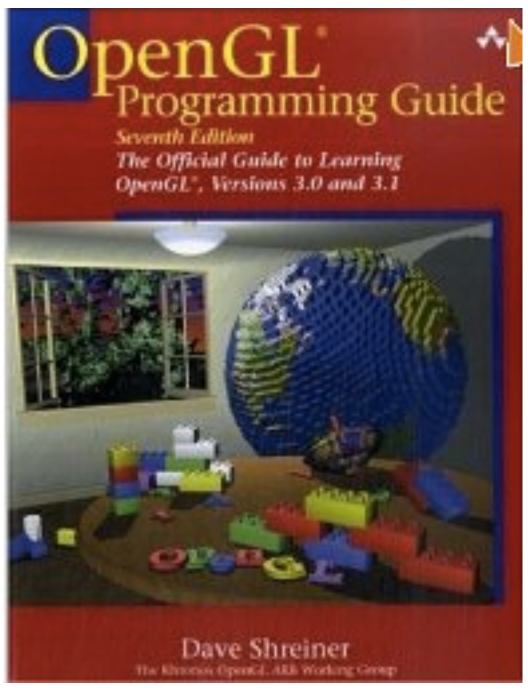
- In-class participation
  - some in class problems - only graded for correctness if we've already covered it
    - otherwise only graded for presence and effort
  - may ask someone to work a problem
- quiz will normally be in the first 5-10 minutes of class -- today we'll have a short one at the end that you will get full credit on -- check your own math skills and give me a sense of class's math skill
- Q. how many people have taken graphics before? MS students? PhD students? Want to go on to work in graphics?
- final project:
  - there will be a proposal due

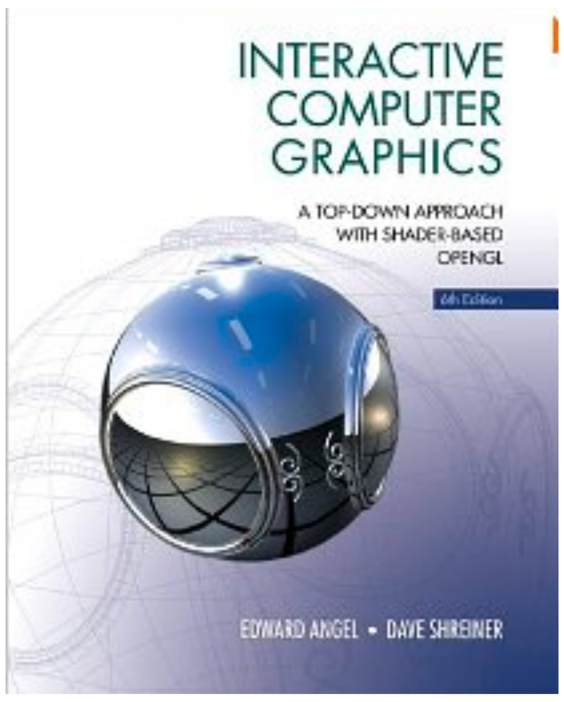
Textbook

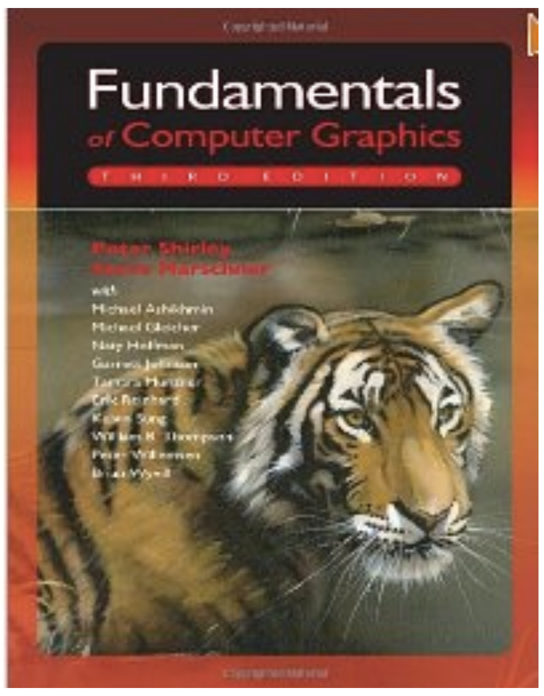


Computer Graphics with OpenGL
Hearn Baker, Carithers

Additional books







if you like using a book
- red book older version online:http://fly.cc.fer.hr/~unreal/theredbook/
And if you prefer -- all material is online in one form or another -- you don't have to buy a book but it can be useful for a coherent presentation

About me

- B.S., University of Illinois in Urbana-Champaign, Mathematics, Computer Science, art
- Ph.D., 2008, Stanford University on simulation methods for computer graphics
- Started at UCR in the fall
- Work in graphics simulation and biological simulation

http://www.cs.ucr.edu/~shinar

Graphics applications

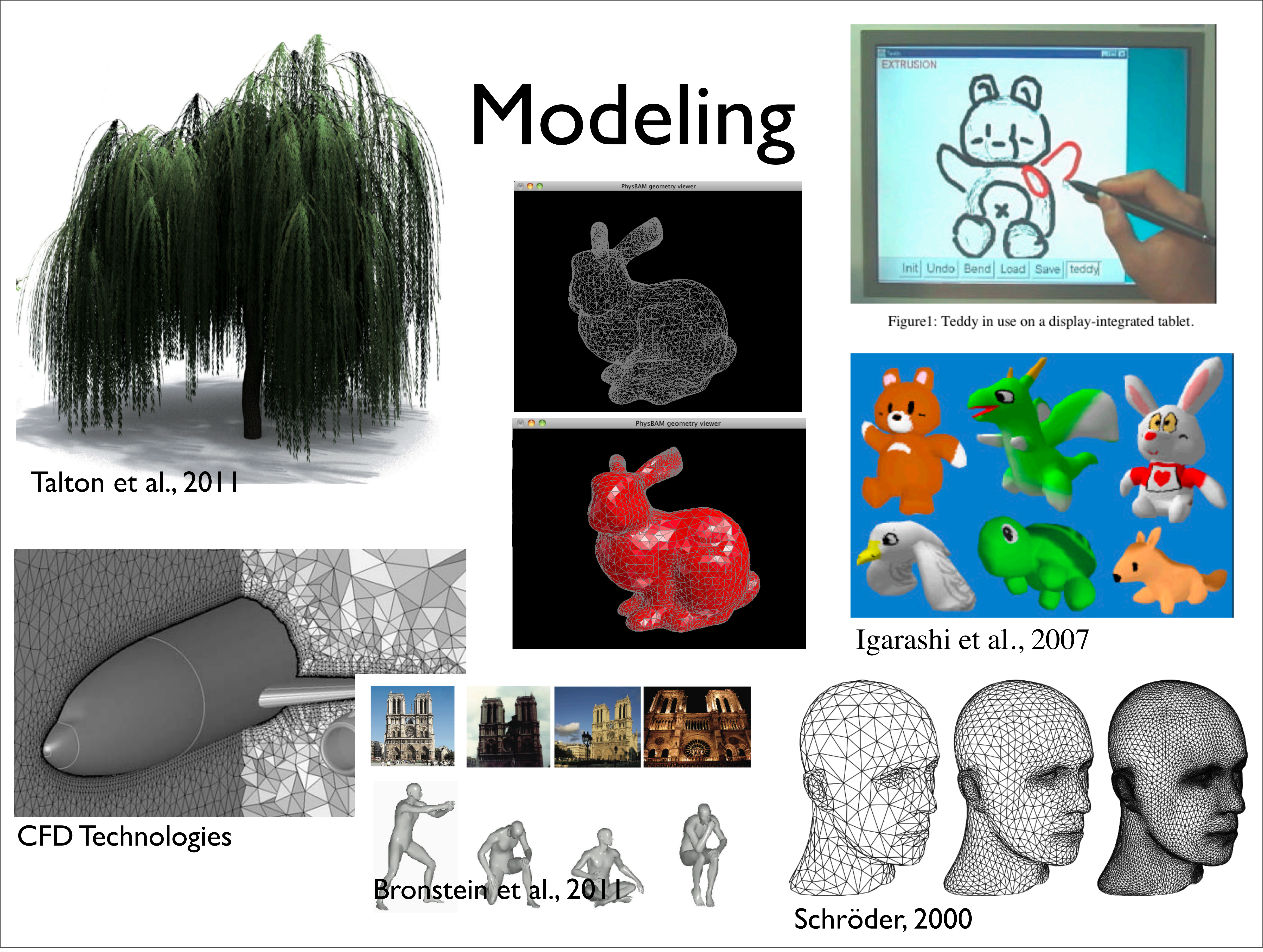
- 2D drawing
- Drafting, CAD
- Geometric modeling
- Special effects
- Animation
- Virtual Reality
- Games
- Educational tools
- Surgical simulation
- Scientific and information visualization
- Fine art

Graphics areas

- **Modeling** - mathematical *representations* of physical objects and phenomena
- **Rendering** - creating a *shaded image* from 3D models
- **Animation** - creating motion through a sequence of images
- **Simulation** - physics-based models for modeling dynamic environments

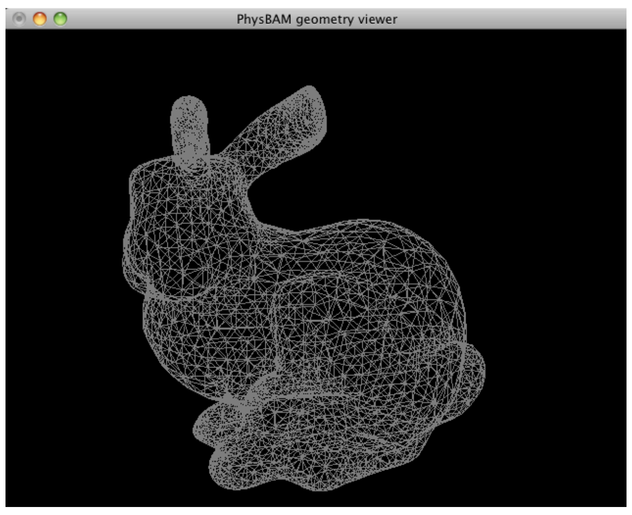
Which area would you like your final project to be in?

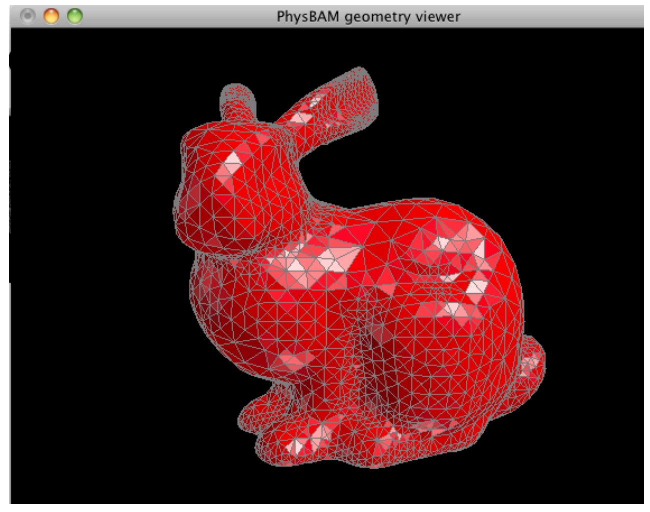
Think about which area interests you, dovetails with your present or future research, or that you want to learn more about
Modeling and **rendering** are separate stage
- first design and position objects -- **modeling**
- then add lights, materials properties, effects -- **rendering**



- subdivision surface - Siggraph course notes 2000
- Teddy : sketch based interface for 3D modeling
- Talton et al. -- procedural modeling - for games, virtual worlds, design, etc.
  - combine machine learning and graphics
- Bronstein - reasoning about geometric models for search

Rendering



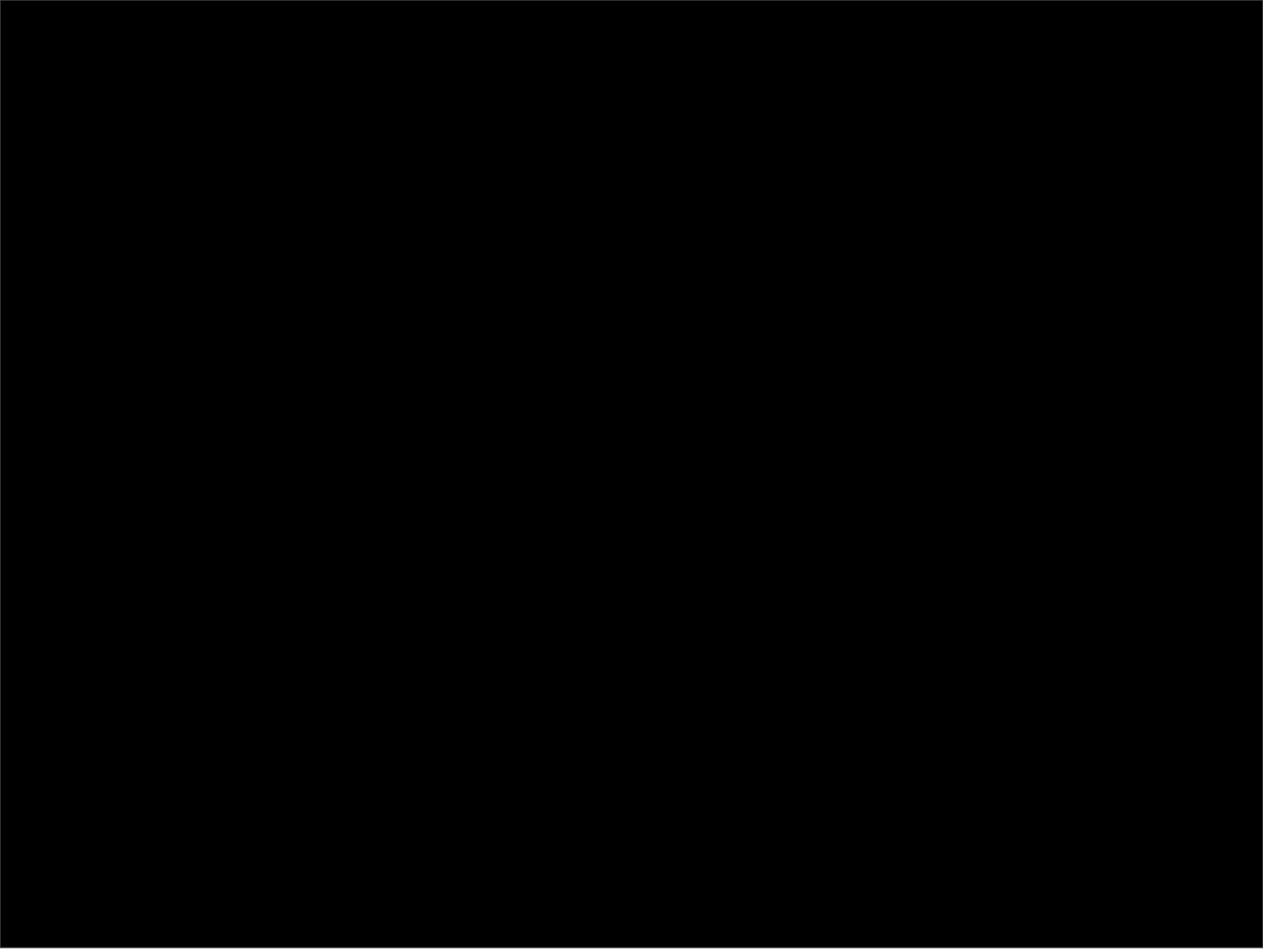


Hong et al. 2007

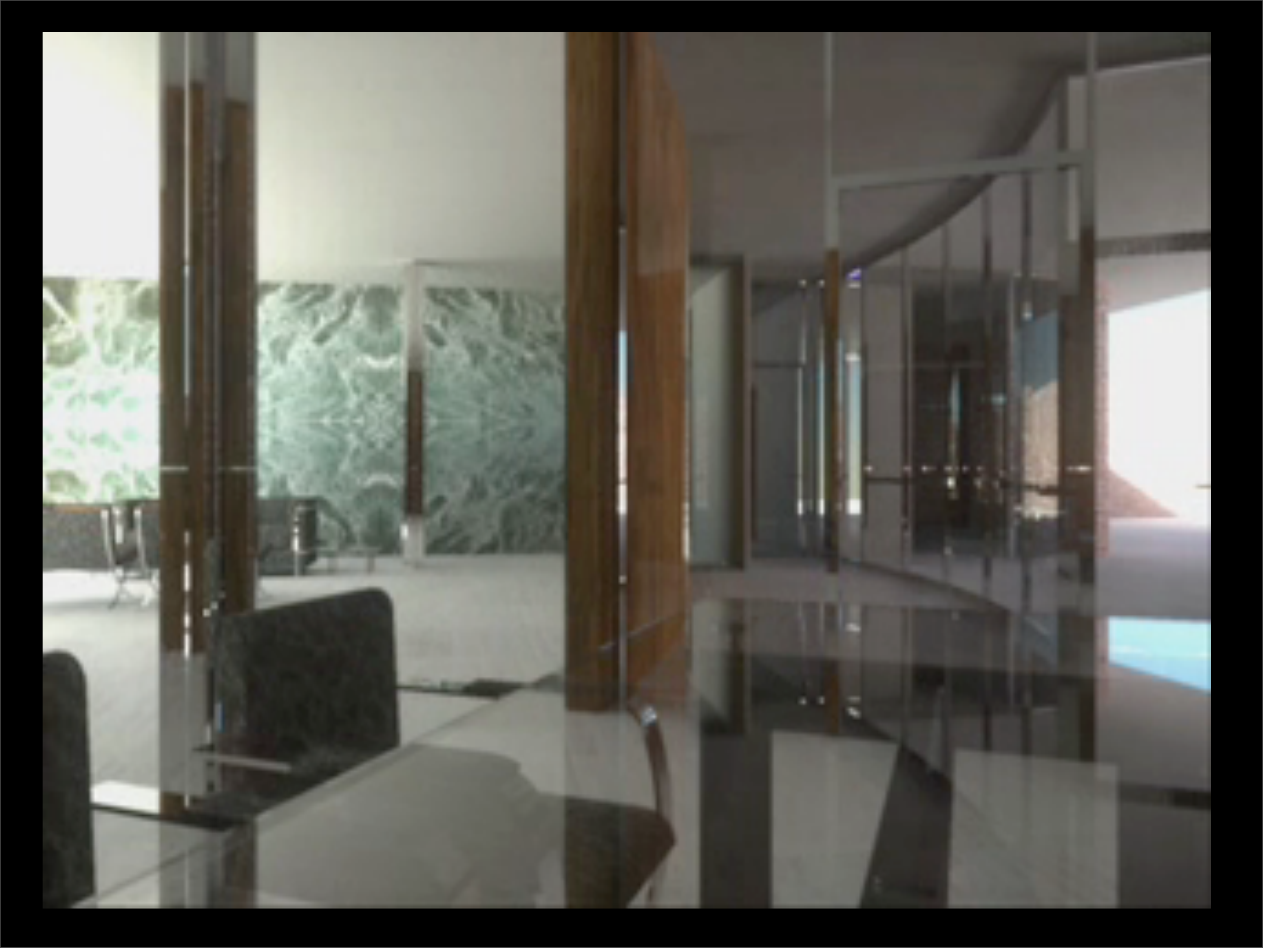
Henrik Wann Jensen

d'Eon and Irving, 2011

- opengl - 3D graphics (z-buffer) rendering
- **teapot - image-based lighting** - illuminated by a high dynamic range environment - metal, glass, diffuse, and glossy
- **subsurface scattering** - to capture translucent materials such as skin and marble
- rendering a emissive material such as fire - **participating medium** - scattering, absorption
- **local** vs **global** illumination



- direct vs. global illumination



– direct vs. global illumination

Animation

Sleeping Beauty, Disney, 1959

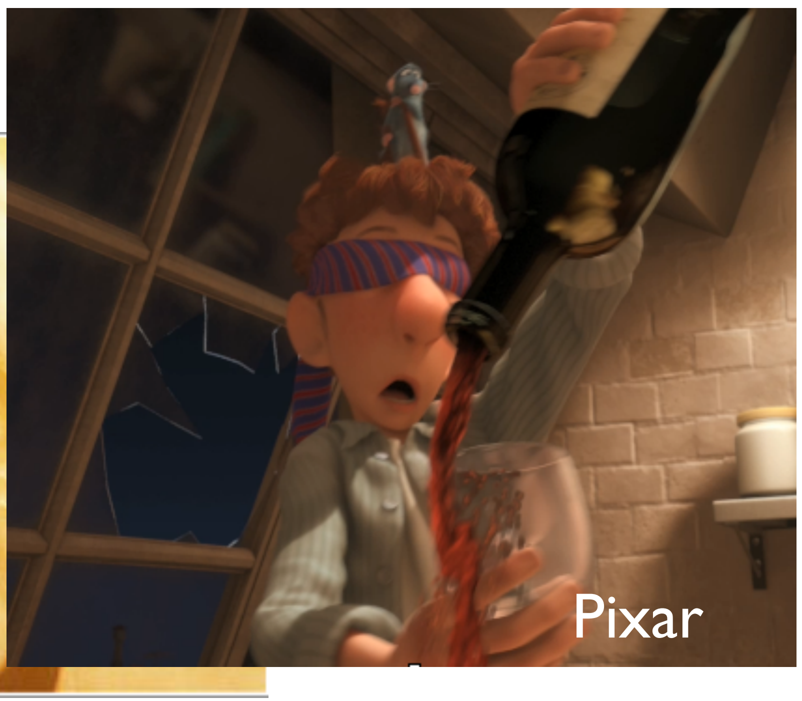
Adventures of Tintin, Weta 2011

Animation

Sleeping Beauty, Disney, 1959

Adventures of Tintin, Weta 2011

Simulation



Firestorm
Harry Potter and the Half Blood Prince
Industrial Light + Magic

Firestorm
Harry Potter and the Half Blood Prince
Industrial Light + Magic

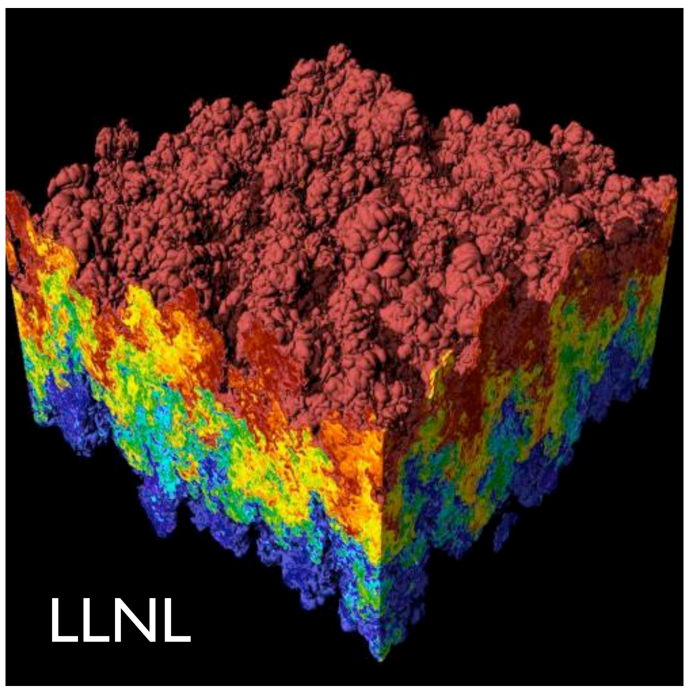
fluid simulation in Pixar's *Ratatouille*

fluid simulation in Pixar's *Ratatouille*

Other areas...

- Interactivity (HCI)
- Image processing
- Visualization
- Computational photography


L-1 Identity Solns


LLNL


Lytro

Microsoft Kinect

- Lytro demo: http://www.lytro.com/living-pictures/2325

Course overview

- Learn fundamental 3D graphics concepts
- Implement graphics algorithms
  - make the concepts concrete
  - expand your abilities and confidence for future work

Course schedule

tentative; see course website for up-to-date schedule

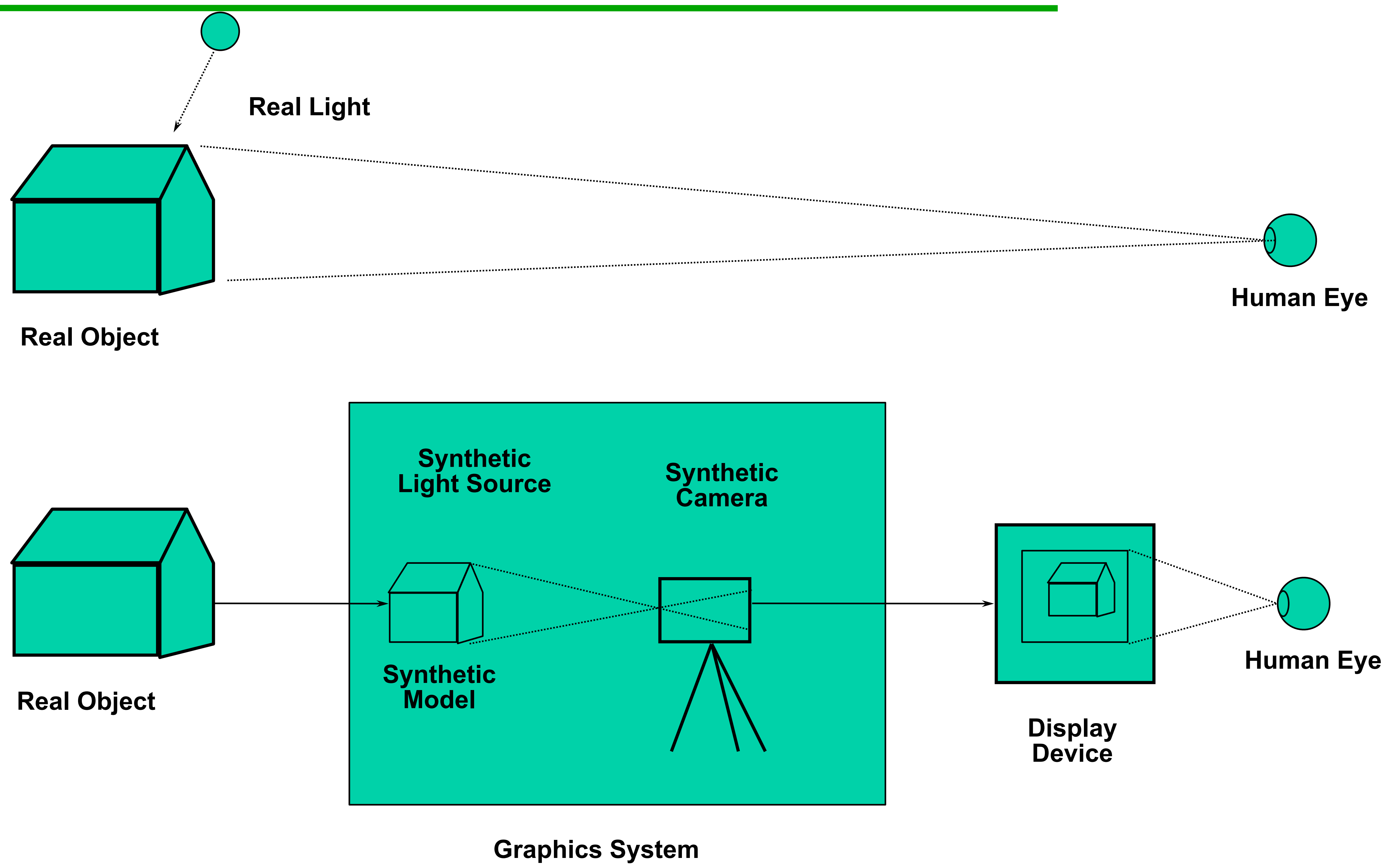
Lecture	Date	Topic	Reading	Assigned	Due
1	Jan 9	Introduction	HBC, Ch. 3		
2	Jan 11	Modeling, graphics primitives	HBC, Ch. 4, 5		
-	Jan 16	HOLIDAY			
3	Jan 18	Rasterization	HBC, Ch. 6	Assignment 1	
4	Jan 23	3D transforms and viewing	HBC, Ch. 9, 10		
5	Jan 25	3D Modeling	HBC, Ch. 13, 14, 15		
6	Jan 30	3D Modeling, cont.	HBC, Ch. 13, 14, 15	Assignment 2	Assignment 1
7	Feb 1	Visible surface detection	HBC, Ch. 16		
7	Feb 6	Lighting and surface shading	HBC, Ch. 17		
8	Feb 8	Texture mapping	HBC, Ch. 18		
9	Feb 13	Global Illumination	HBC, Ch. 21	Assignment 3	Assignment 2
10	Feb 15	Programmable Shaders	HBC, Ch. 22		
-	Feb 20	HOLIDAY			Project Proposal
12	Feb 22	Animation	HBC, Ch. 12		
13	Feb 27	Graphics hardware			Assignment 3
14	Feb 29	Particle systems			
15	Mar 5	Rigid body simulation			
16	Mar 7	Deformable body simulation			
17	Mar 12	Character animation			
18	Mar 14	Fluid simulation			
-	Finals week (TBA)	Project presentations			Final Project

CS230
Intro to OPEN GL

(with some slides courtesy of V. Zordan)

OpenGL: Conceptual Model

OpenGL: Conceptual Model



Introduction to OpenGL

- **Open G**raphics **L**ibrary, managed by Khronos Group
- A software interface to graphics hardware
- Standard API with support for multiple languages and platforms, open source
- ~250 distinct commands
- Main competitor: Microsoft's Direct3D
- **http://www.opengl.org/wiki/Main_Page**

- used to produce interactive 3D graphics
- sits between programmer and 3D accelerators and hardware
- **standard** requires support for feature set for all implementations
- Both OpenGL and Direct3D support feature sets -- they take advantage of hardware acceleration or use software emulation when a feature is unavailable in hardware
- Direct3D is proprietary
- OpenGl and Direct3D both implemented in the display driver

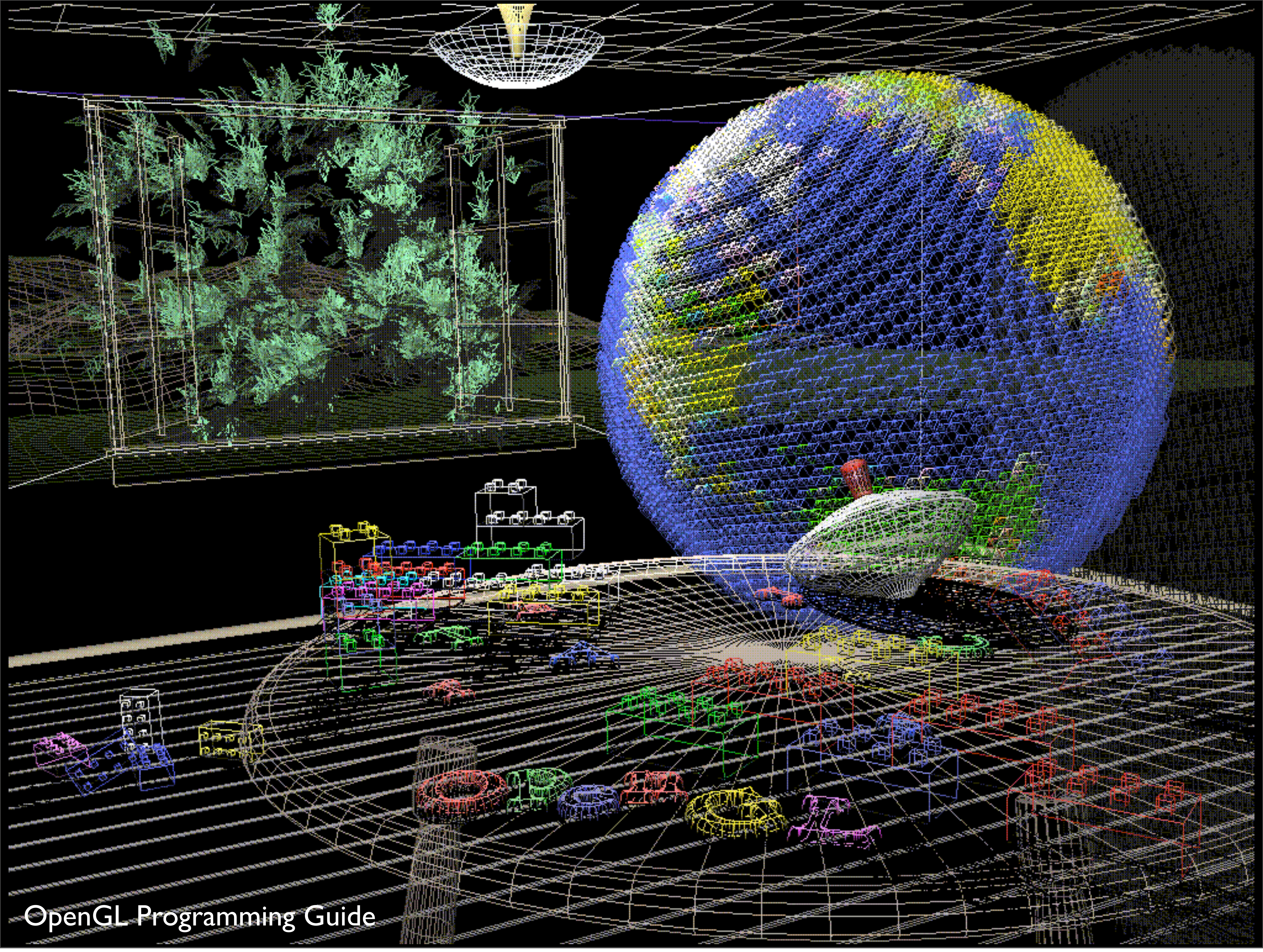
OpenGL - Software to Hardware

- Silicon Graphics (SGI) revolutionized the graphics workstation by putting graphics pipeline in hardware (1982)
- To use the system, application programmers used a library called GL
- With GL, it was relatively simple to program three dimensional interactive applications

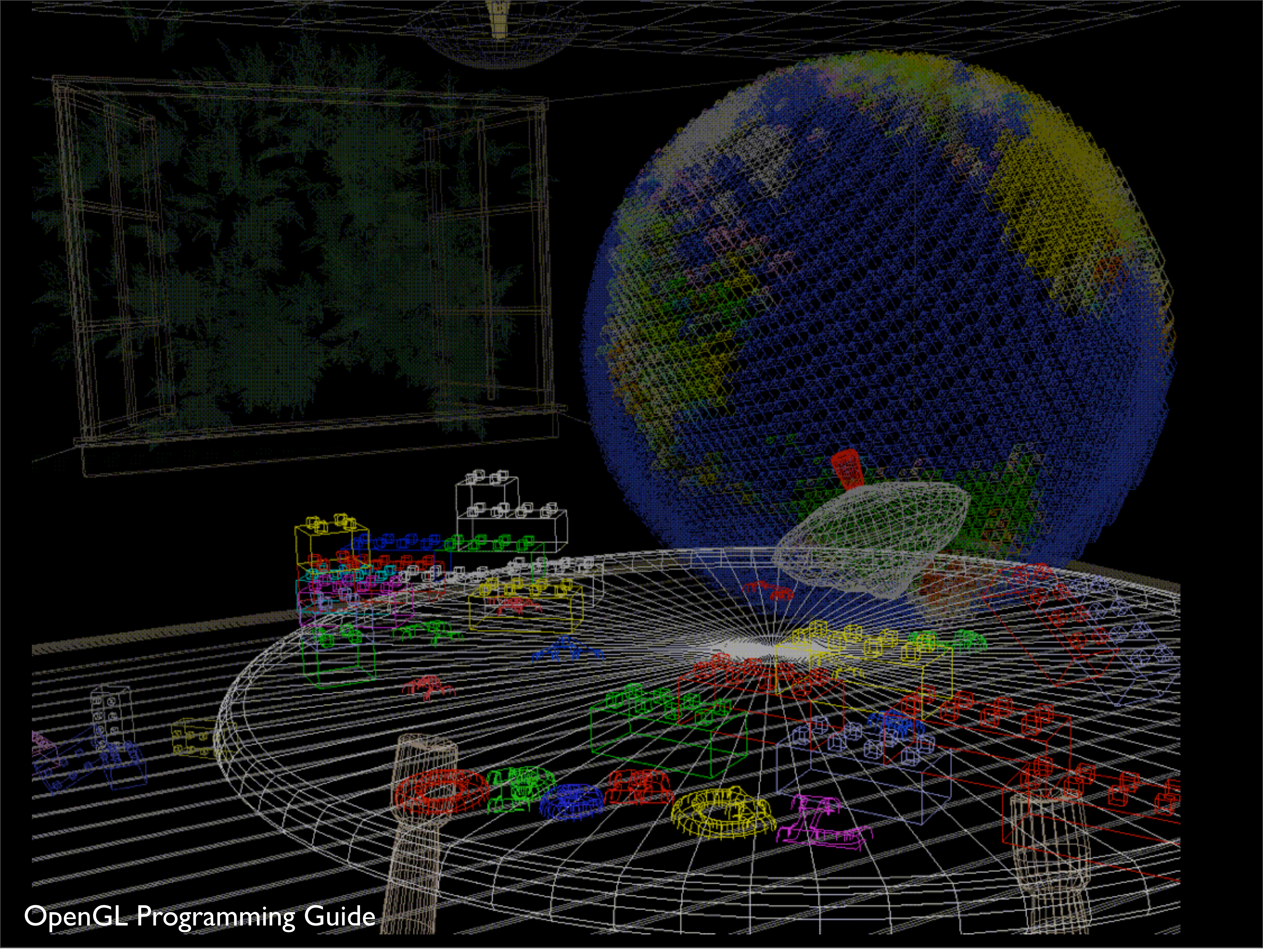
OpenGL

- The success of GL lead to OpenGL (1992), a platform-independent API that was
  - Easy to use
  - Close to the hardware - excellent performance
  - Focus on rendering
  - Omitted windowing and input to avoid window system dependencies

What can OpenGL do?
Examples from the
OpenGL Programming Guide (“red book”)



- **Wireframe** models
  - shows each object up of polygons
- the **lines are are the edges** and the **faces of the polygons make up the object surface**



supports the atmospheric effect “fog”

Plate 2. The same scene using fog for depth-cueing (lines further from the eye are dimmer). See Chapter 7 .

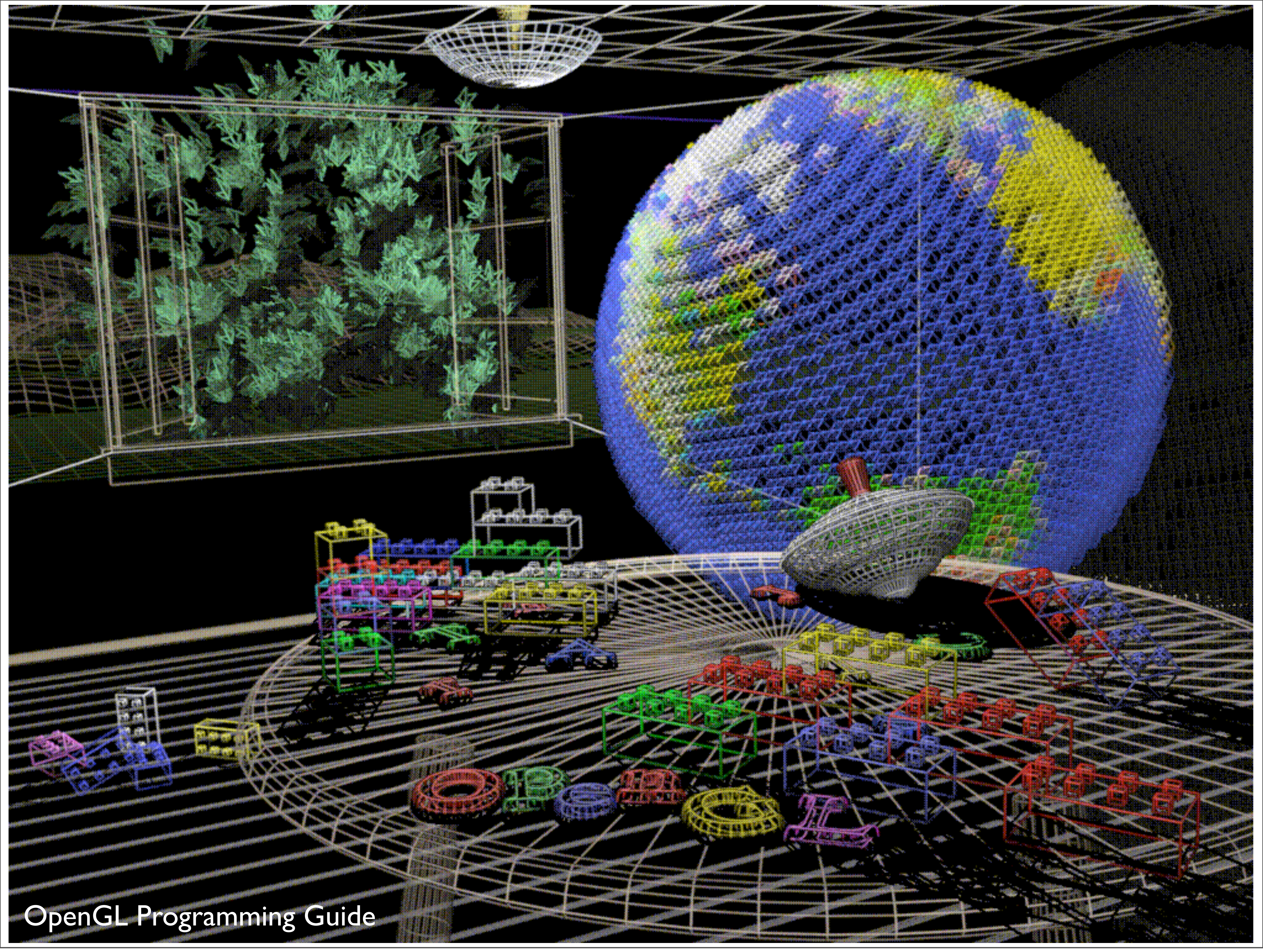


Plate 3. The same scene with **antialiased lines** that **smooth the jagged edge**s. See Chapter 7 .

when you approximate smooth edges using pixels, this leads to jagged lines
especially with near vertical and near horizontal lines

Plate 4. The scene drawn with **flat-shaded polygons** (a **single color for each filled polygon**). See Chapter 5 .

“unlit scene”

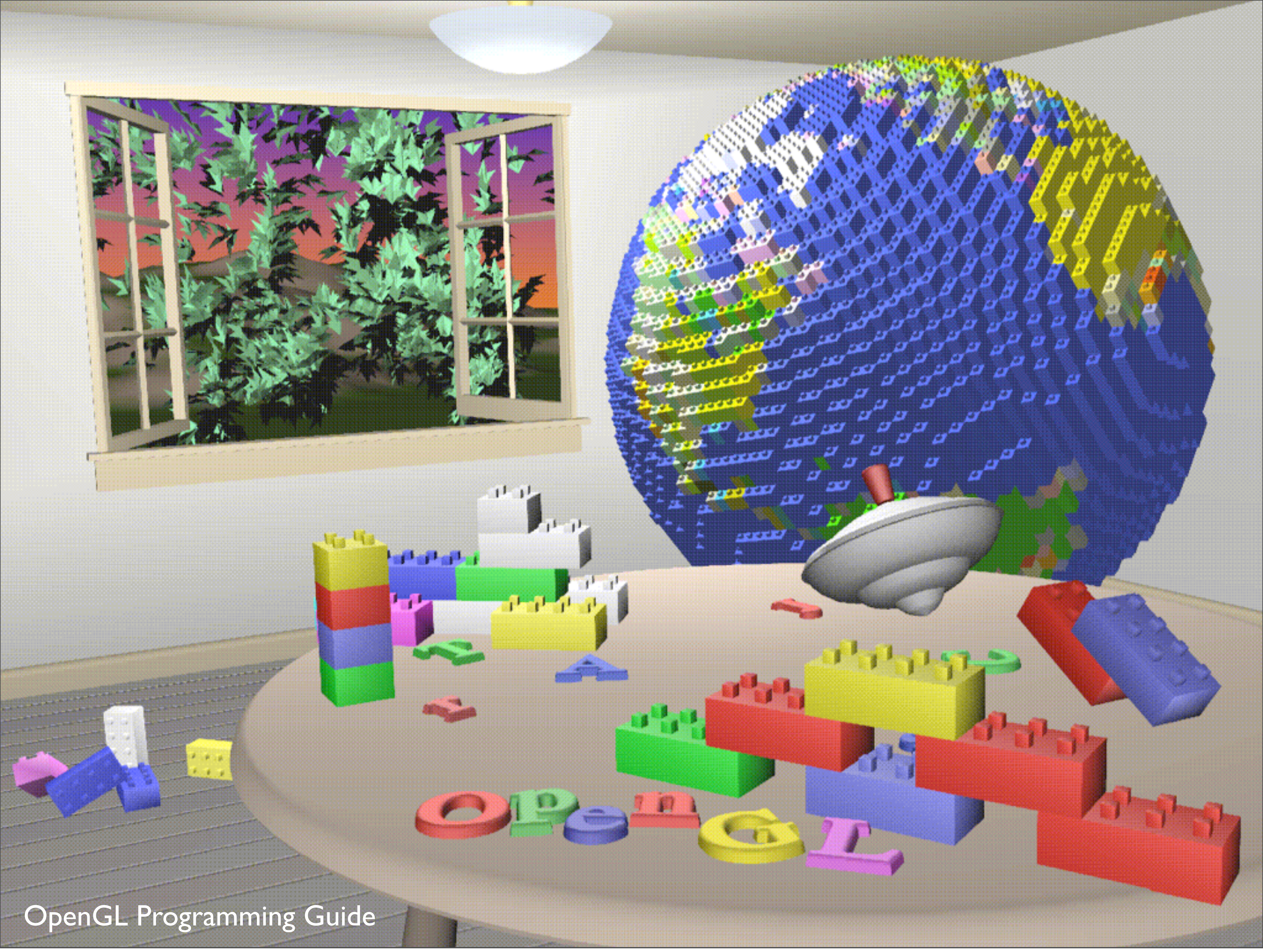


Plate 5. The scene rendered with **lighting** and **smooth-shaded polygons.** See Chapter 5 and Chapter 6 .

Plate 6. The scene with **texture maps and shadows added.** See Chapter 9 and Chapter 13 .

Plate 7. The scene drawn with one of the objects **motion-blurred**. The **accumulation buffer** is used **to compose the sequence of images** needed to blur the moving object. See Chapter 10 .

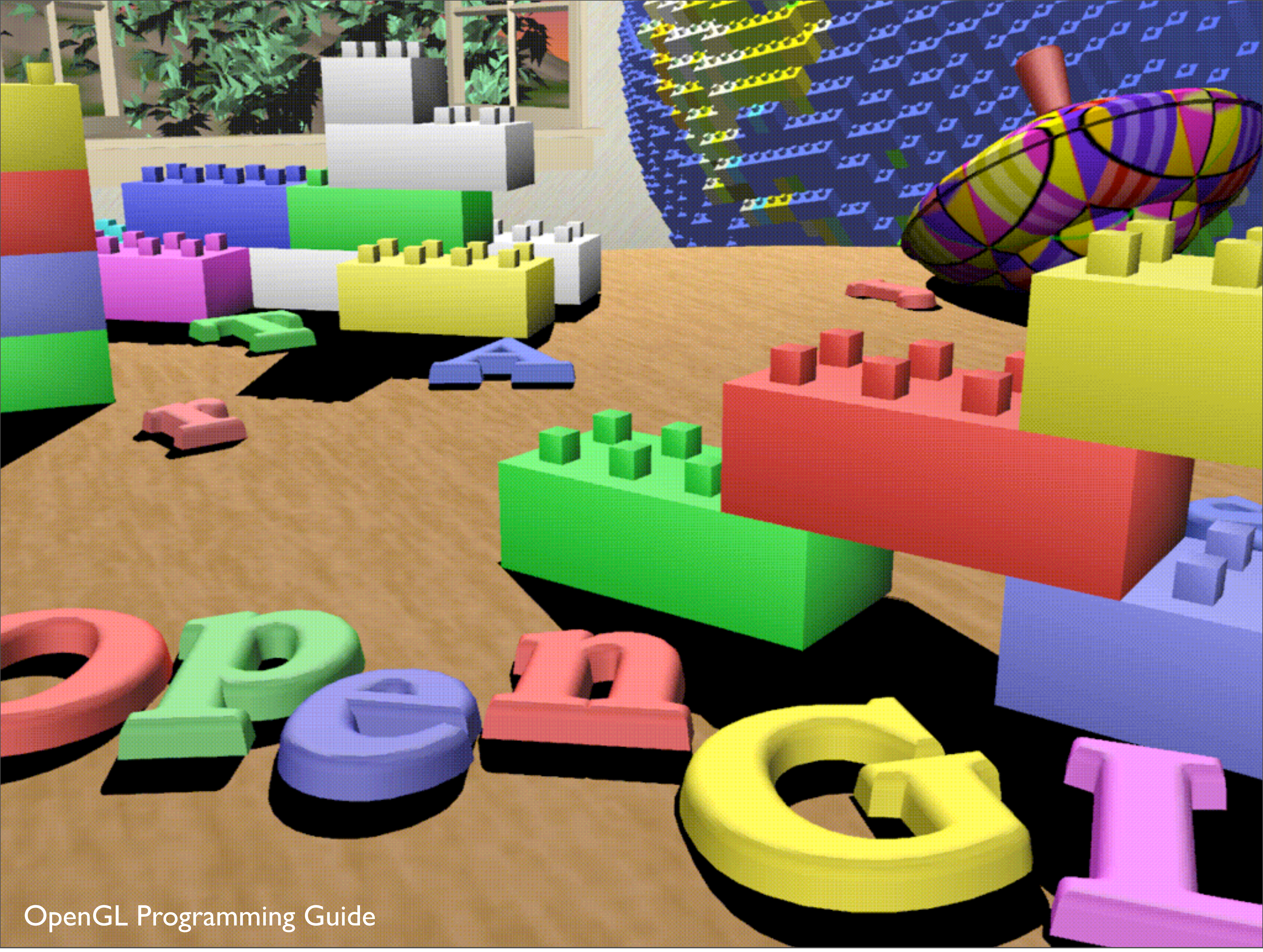


Plate 8. A close-up shot - the scene is **rendered from a new viewpoint.** See Chapter 3 .

Plate 9. The scene drawn using **atmospheric effects (fog)** to simulate a smoke-filled room. See Chapter 7 .

OpenGL state machine

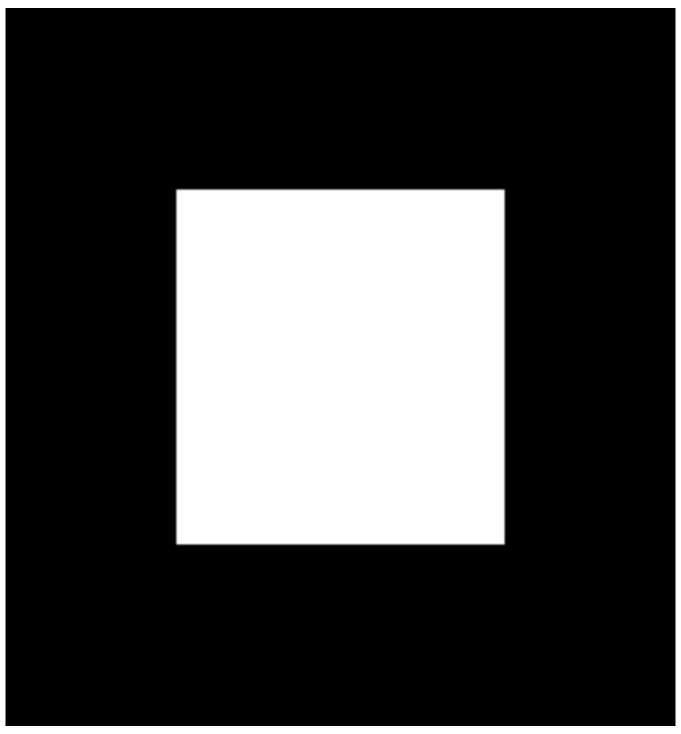
- put OpenGL into various states
  - e.g., current color, current viewing transformation
  - these remain in effect until changed
  - glEnable(), glDisable(), glGet(), glIsEnabled()
  - glPushAttrib(), glPopAttrib() to temporarily modify some state

OpenGL command syntax

- commands: **gl**ClearColor();
  - glVertex**3f**()
- constants: **GL**_COLOR_BUFFER_BIT
- types: GLfloat, GLdouble, GLshort, GLint,

Simple OpenGL program

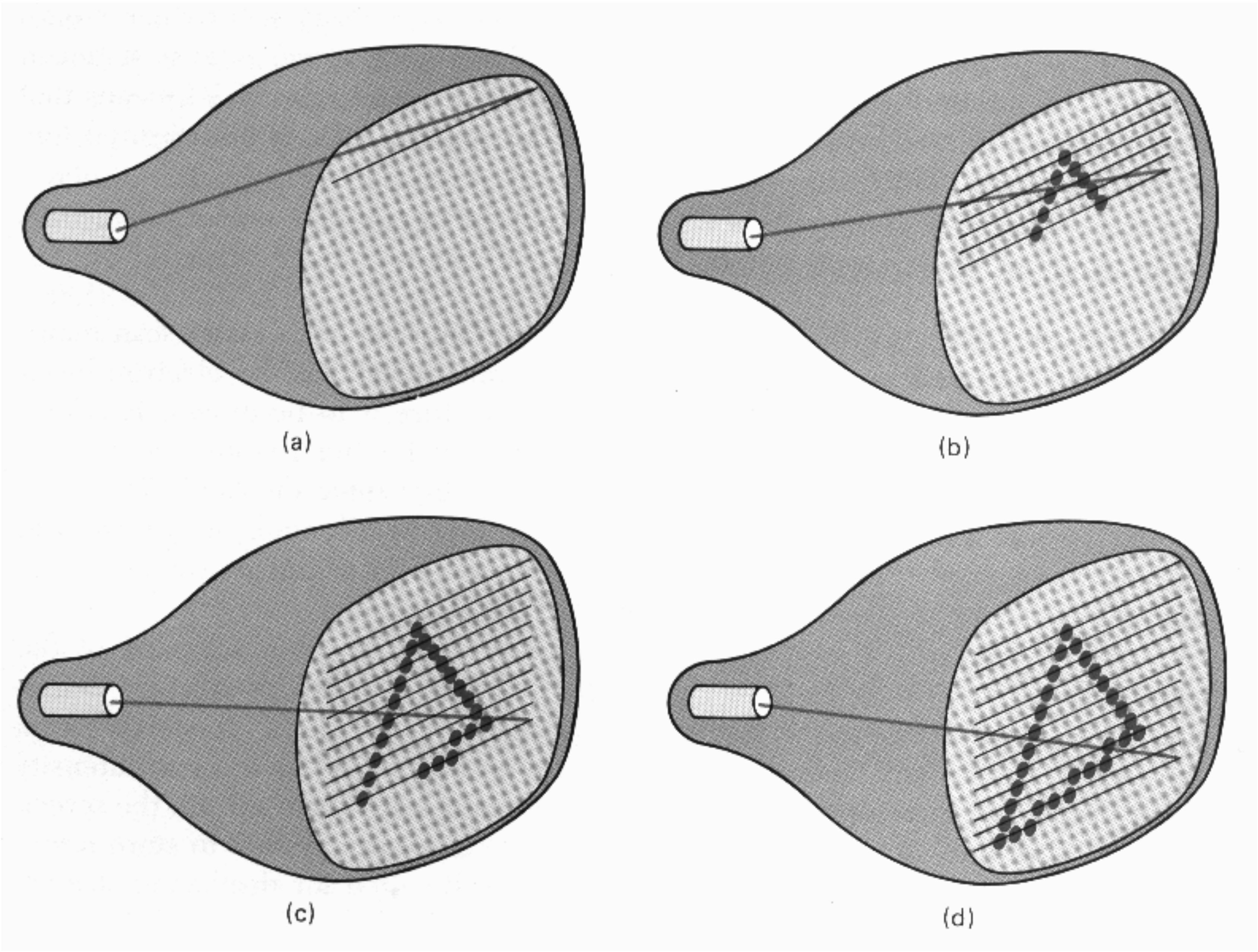
```
#include <whateverYouNeed.h>

main() {

   InitializeAWindowPlease();

   glClearColor(0.0, 0.0, 0.0, 0.0);
   glClear(GL_COLOR_BUFFER_BIT);
   glColor3f(1.0, 1.0, 1.0);
   glOrtho(0.0, 1.0, 0.0, 1.0, -1.0, 1.0);
   glBegin(GL_POLYGON);
      glVertex3f(0.25, 0.25, 0.0);
      glVertex3f(0.75, 0.25, 0.0);
      glVertex3f(0.75, 0.75, 0.0);
      glVertex3f(0.25, 0.75, 0.0);
   glEnd();
   glFlush();

   UpdateTheWindowAndCheckForEvents();
}
```



OpenGL Programming Guide, 7th Ed.

- blue are placeholders for windowing system commands
- clear color, actual clear
- Ortho - the coordinate system
- flush executes the commands

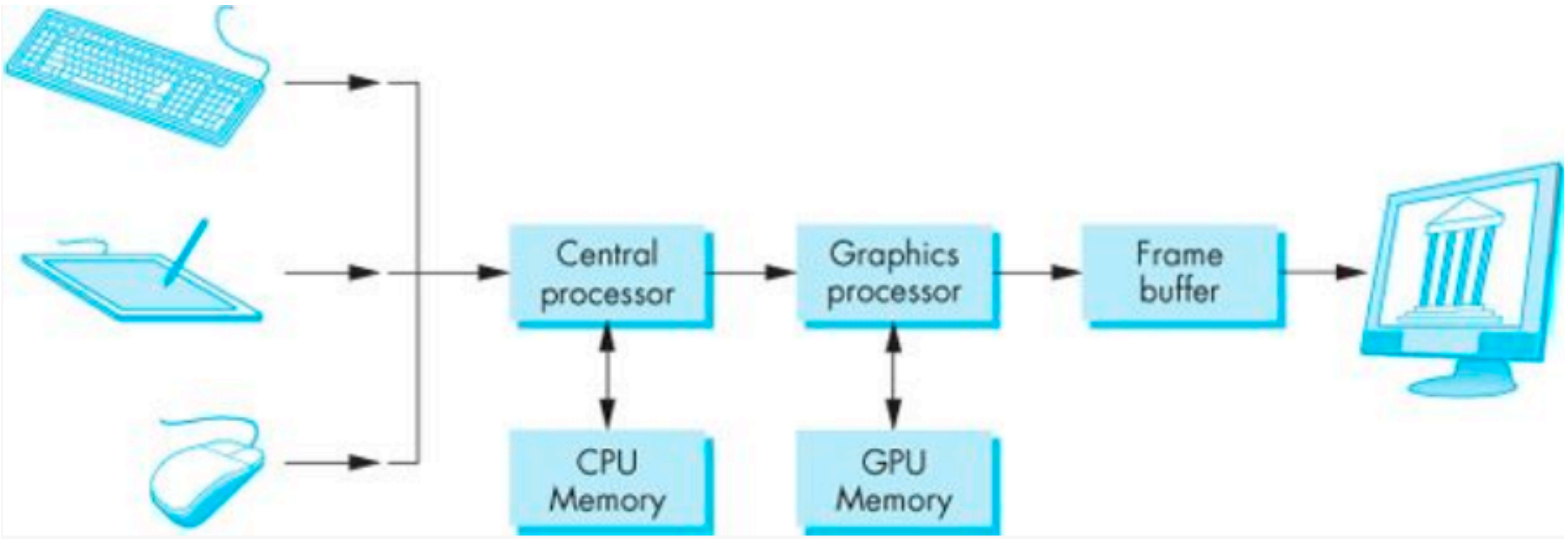
Raster images



Hearn, Baker, Carithers

virtually all graphics system are **raster based,** meaning the image we see is a **raster of pixels**
Here a raster scan device display an image as a set of discrete points across each scanline

Modern graphics system



Input devices

Output devices

Interactive Computer Graphics, Angel and Shreiner

the pixels are stored in a location in memory call the **frame buffer**
frame buffer resolution determines the details in the image
- e.g., 24 bit color "full color"
- high dynamic range or HDR use 12 or more bits for each color

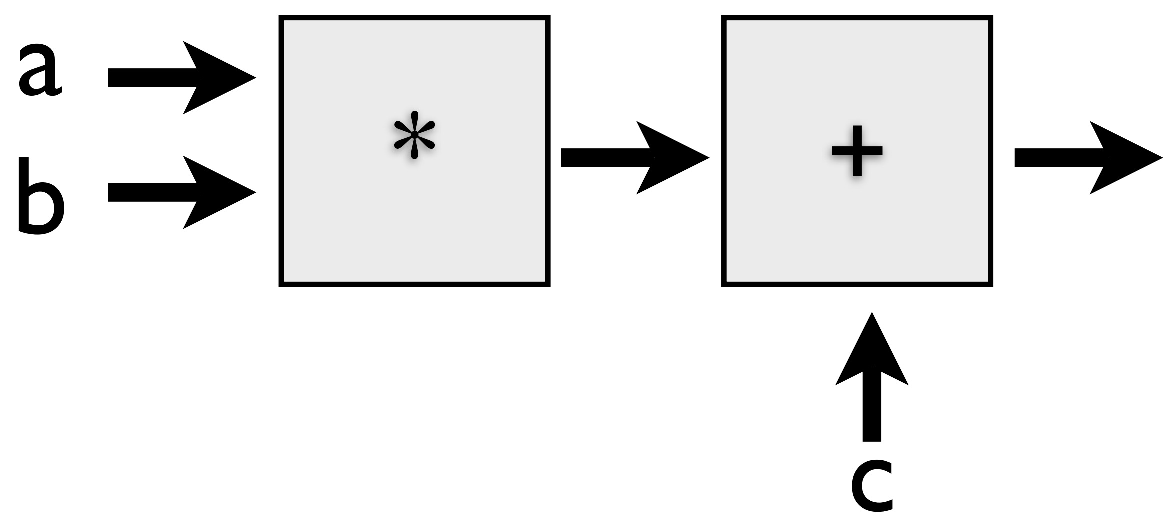
frame buffer = color buffers + other buffer

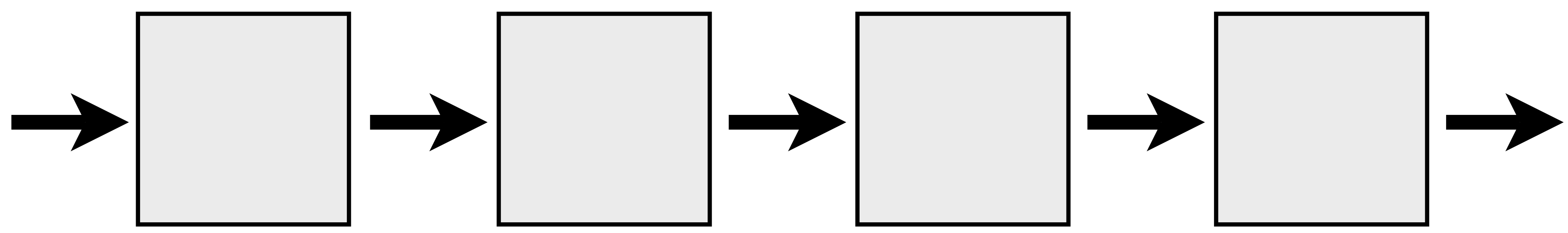
Z-buffer Rendering

- Z-buffering is very common approach, also often accelerated with hardware
- OpenGL is based on this approach

Pipelining operations

An arithmetic pipeline that computes c+(a*b)



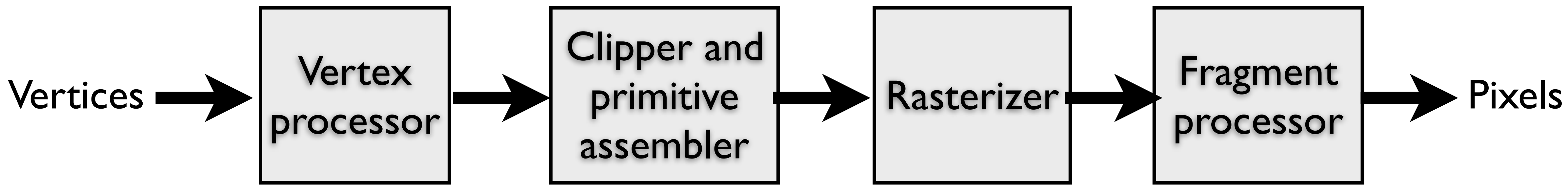


By pipelining the arithmetic operation, the **throughput**, or rate at which data flows through the system, has been **doubled**

If the pipeline had more boxes, the **latency, or time it takes one datum to pass through the system**, would be higher

throughput and latency must be balanced

3D graphics pipeline



Geometry: objects – made of primitives – made of vertices
Vertex processing: coordinate transformations and color
Clipping and primitive assembly: output is a set of primitives
Rasterization: output is a set of fragments for each primitive
Fragment processing: update pixels in the frame buffer

the pipeline is best when we are doing the same operations on many data sets
-- good for computer graphics!! where we process larges sets of vertices and pixels in the same manner

1. **Geometry**: objects – made of primitives – made of vertices
2. **Vertex processing:** coordinate transformations and color
3. **Clipping and primitive assembly:** use clipping volume. must be primitive by primitive rather than vertex by vertex. therefore vertices must be assembled into primitives before clipping can take place. Output is a set of primitives.
4. **Rasterization:** primitives are still in terms of vertices -- must be converted to pixels. E.g., for a triangle specificied by 3 vertices, the rasterizer must figure out which pixels in the frame buffer fill the triangle. Output is a set of **fragments for each primitive**. A fragment is like a **potential pixel.** Fragments can carry depth information used to figure out if they lie behind other fragments for a given pixel.
5. **Fragment processing:** update pixels in the frame buffer. some fragments may not be visible. texture mapping and bump mapping. blending.

Other rendering approaches include

Other rendering approaches

- Ray tracing, radiosity, and photon mapping
- more physical but don't achieve real-time performance

ray-tracing comes close to real time
none come close to to the performance of pipeline architectures
GPUs implement this graphics pipeline
- for many years, these pipeline architectures had fixed functionality
- recently, **the vertex processor and the fragment processor are now programmable this opens the door for many features that were not part of the pipeline to become part of the pipeline and hence become realtime - e.g., bump mapping**

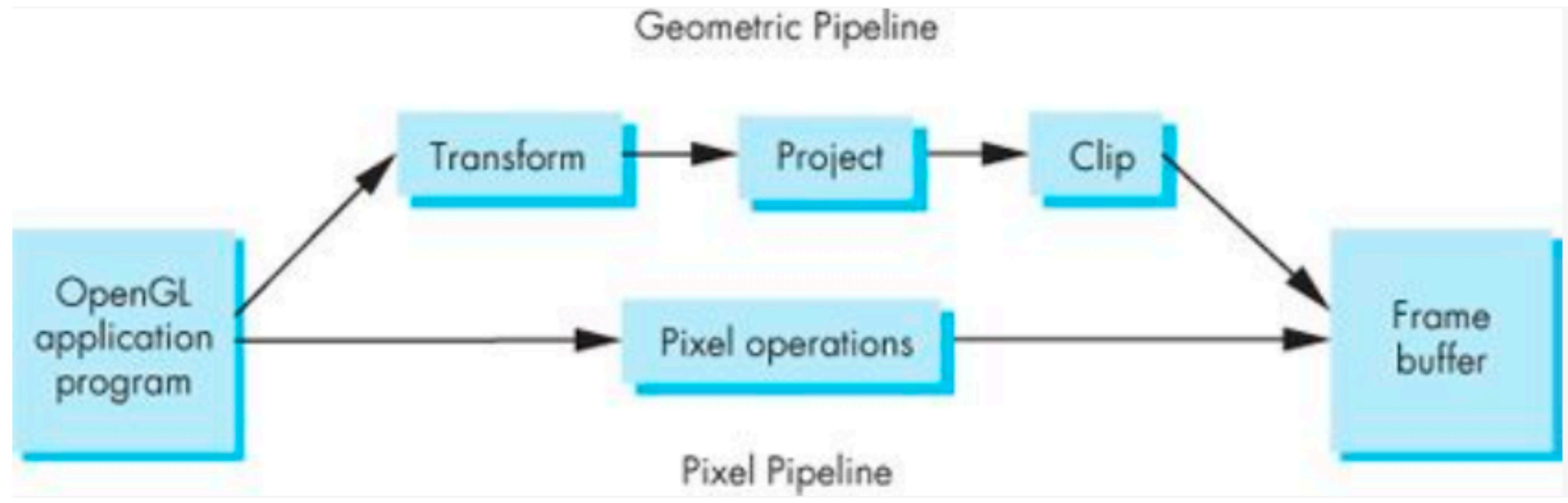
GPUs are also now being used for high performance computing that does not involve graphics

3D graphics pipeline

- optimized for drawing 3D triangles with shared vertices
- map 3D vertex locations to 2D screen locations
- shade triangles and draw them in back to front order using a z-buffer
- speed depends on # of triangles
- most operations on vertices can be represented using a 4D coordinate space - 3D position + homogeneous coordinate for perspective viewing
    - 4x4 matrices and 4-vectors

- use varying level of detail - fewer triangles for distant objects
1. construct shapes from primitives - points, lines, polygons, images, bitmaps, (mathematical descriptions of objects) - specify the **model**

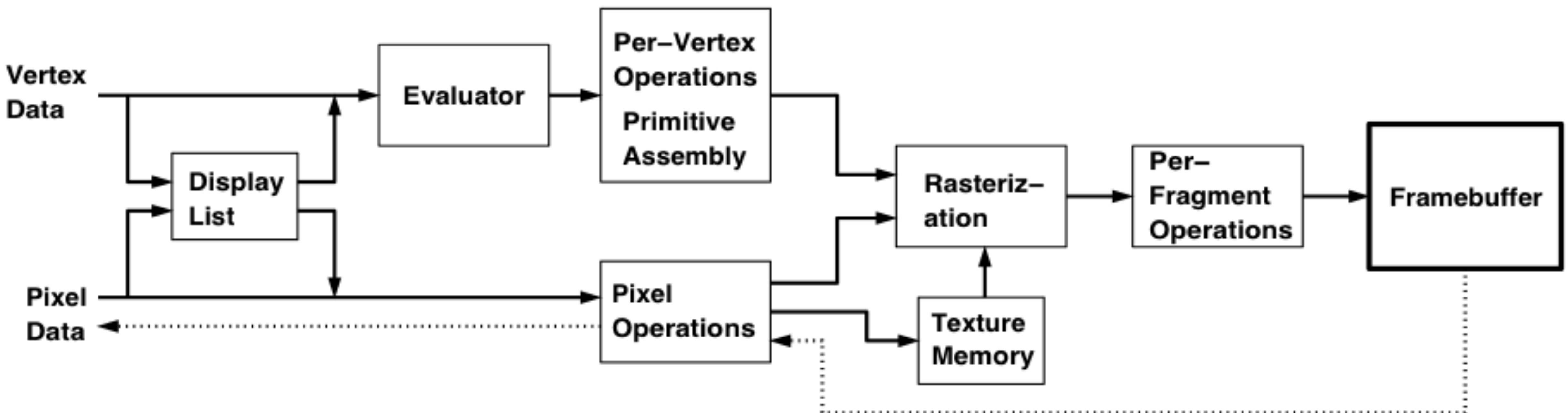
OpenGL Rendering Pipeline



Simplified

Interactive Computer Graphics, Angel and Shreiner

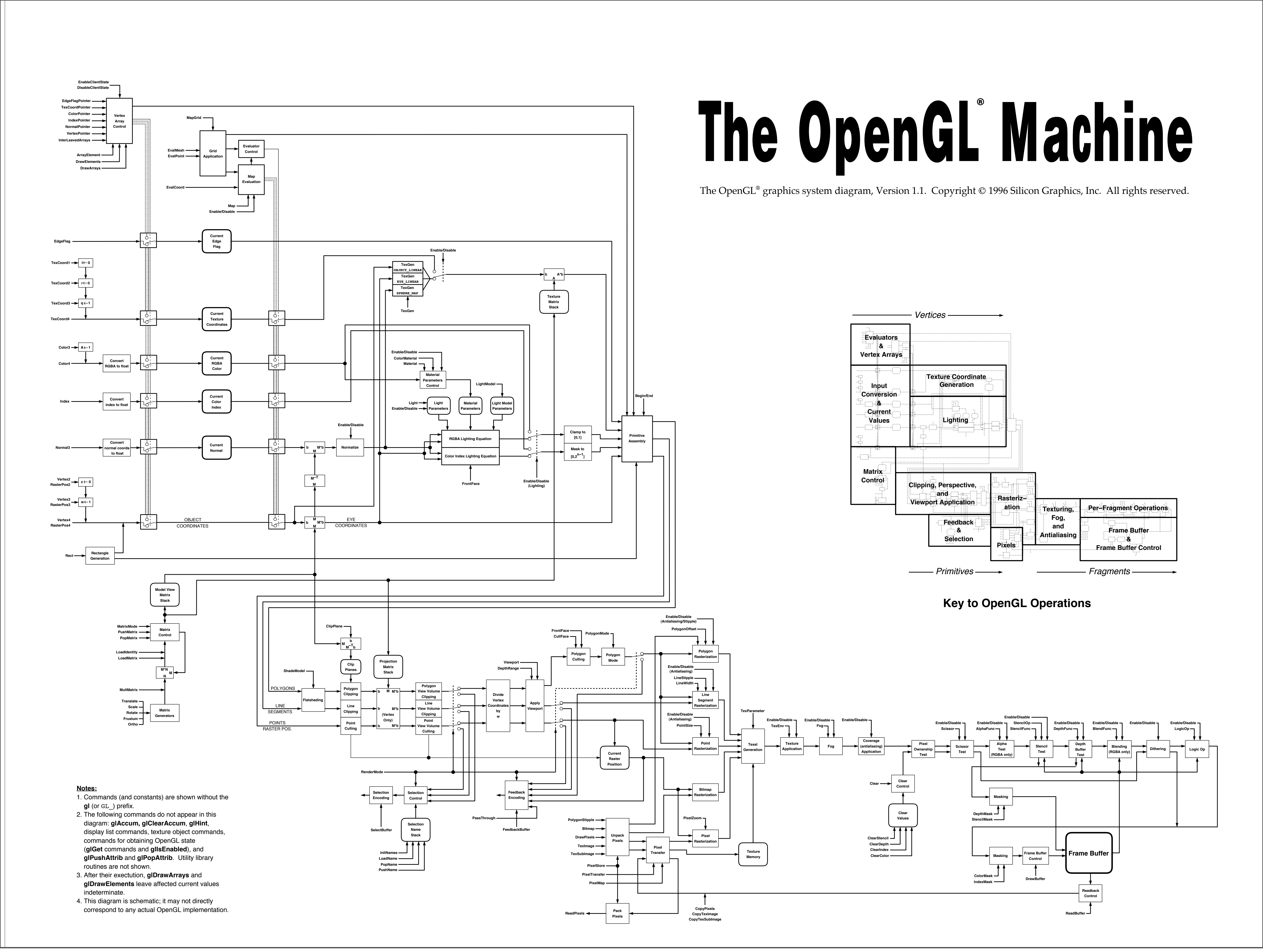
Text



Segal and Akeley, 1994

Figure 1. Block diagram of OpenGL.

- Assembly-line approach to processing data
- Vertex data: data that is or will be converted to vertices: points, lines, polygons, surfaces
- Pixel data: images, bitmaps, pixels
- vertex data and pixel data follow different paths, but both eventually undergo rasterization and per-fragment operations
- Display lists:
  - data can be save in display lists or processed in immediate mode
  - from display list it can be processed same as in immediate mode
- Evaluators:
  - all geometric data eventually reduced to vertices (evaluators for parametrized curves and surfaces)
- Per-vertex operations: converts the vertices into primitives
  - 3D spatial coordinate transformed to screen coordinate + depth value
  - texture coordinates generated and transformed here
  - lighting calculations using material properties, light information, normals,
  - in newer versions of OpenGL, using a “vertex shader” is mandatory
    - GLSL
    - this replaces all the per-vertex operations
- Primitive assembly:
  - clipping is a major part
    - eliminate parts of geometry outside a half-space
    - remove points or for lines and polygons it can add points
  - results: complete geometric primitives: transformed and clipped vertices with color, depth, and texture-coordinate values
- Pixel operations:
  - pixels take a different route through the OpenGL rendering pipeline
- Texture assembly:
  - apply textures to objects (Ch. 9)
- Rasterization:



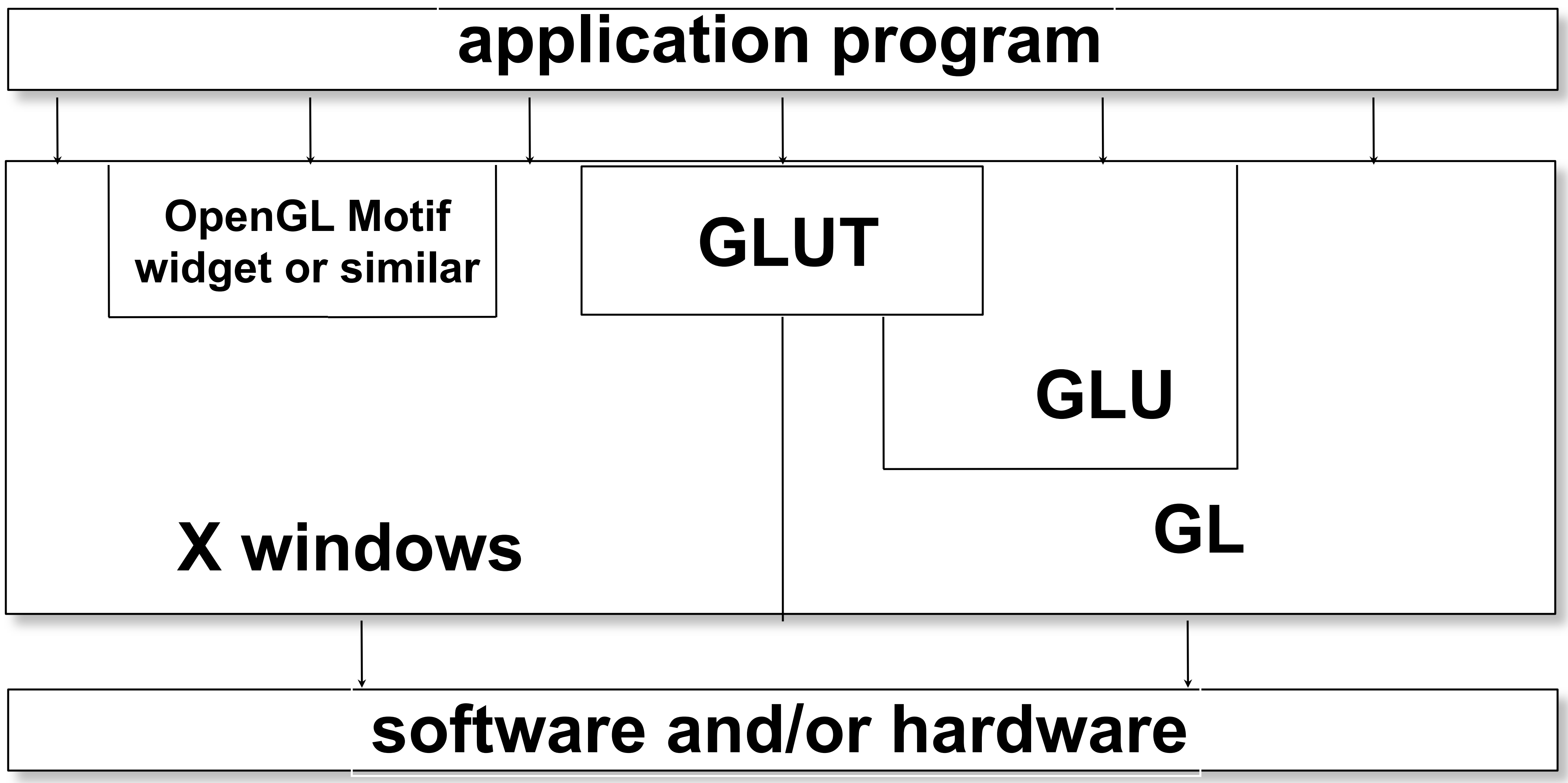
– open up file to look at this more closely

OpenGL Libraries

- OpenGL core library (gl.h)
  - OpenGL32 on Windows
  - GL on most unix/linux systems
- OpenGL Utility Library -GLU (glu.h)
  - avoids having to rewrite code
- OpenGL Utility Library -GLUT (glut.h)
  - Provides functionality such as:
    - Open a window
    - Get input from mouse and keyboard
    - Menus

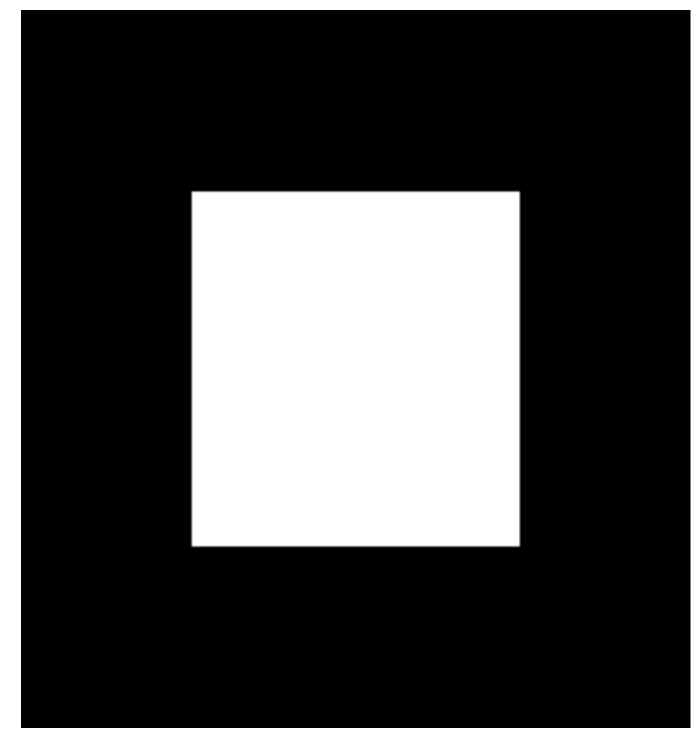
- GL
  - no windowing commands
  - no commands for higher-level geometry - you build these using primitives (points, lines, polygons)
- GLU - standard in every implementation
- OpenGL Utility library provides modeling support
  - quadratic surfaces, NURBS curves and surfaces

Software Organization



Simple OpenGL program

```
#include <whateverYouNeed.h>

main() {

   InitializeAWindowPlease();

   glClearColor(0.0, 0.0, 0.0, 0.0);
   glClear(GL_COLOR_BUFFER_BIT);
   glColor3f(1.0, 1.0, 1.0);
   glOrtho(0.0, 1.0, 0.0, 1.0, -1.0, 1.0);
   glBegin(GL_POLYGON);
      glVertex3f(0.25, 0.25, 0.0);
      glVertex3f(0.75, 0.25, 0.0);
      glVertex3f(0.75, 0.75, 0.0);
      glVertex3f(0.25, 0.75, 0.0);
   glEnd();
   glFlush();

   UpdateTheWindowAndCheckForEvents();
}
```

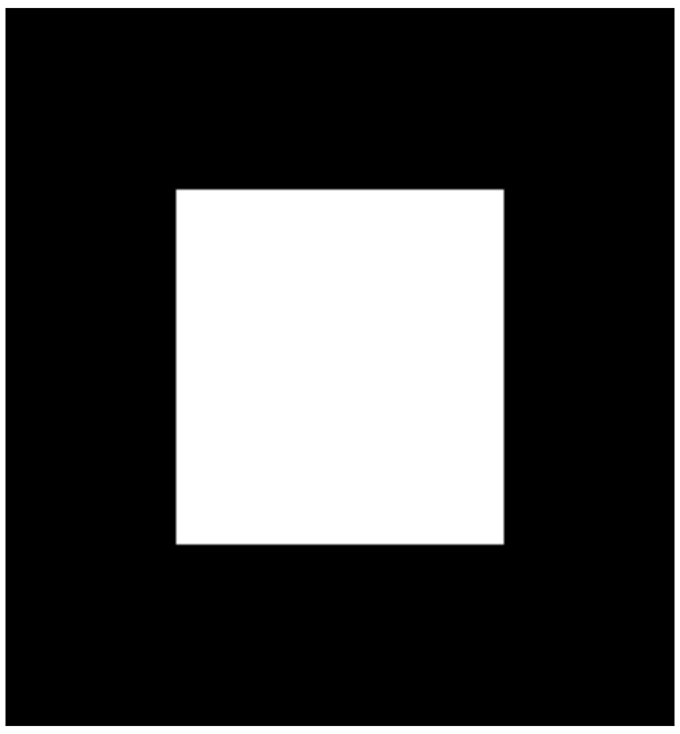


OpenGL Programming Guide, 7th Ed.

- blue are placeholders for windowing system commands
-can replace blue code with calls to **glut**

Simple OpenGL program

```
#include<GL/glut.h>

void init() {
   glClearColor(0.0, 0.0, 0.0, 0.0);
}

void display() {
   glClear(GL_COLOR_BUFFER_BIT);
   glColor3f(1.0, 1.0, 1.0);
   glOrtho(0.0, 1.0, 0.0, 1.0, -1.0, 1.0);
   glBegin(GL_POLYGON);
      glVertex3f(0.25, 0.25, 0.0);
      glVertex3f(0.75, 0.25, 0.0);
      glVertex3f(0.75, 0.75, 0.0);
      glVertex3f(0.25, 0.75, 0.0);
   glEnd();
   glFlush();
}
main() {
    glutInit(&argc, argv);
    glutInitDisplayMode (GLUT_SINGLE | GLUT_RGB);
    glutInitWindowSize (FB_WIDTH, FB_HEIGHT);
    glutCreateWindow ("Test OpenGL Program");
    init();
    glutDisplayFunc(display);
    glutMainLoop();
}
```



- blue are placeholders for windowing system commands
-can replace blue code with calls to **glut**

END