Lecture 4 of 41

Lab 1a:
OpenGL Basics

William H. Hsu
Department of Computing and Information Sciences, KSU

KSOL course pages: http://snipurl.com/1y5gc
Course web site: http://www.kddresearch.org/Courses/CIS636
Instructor home page: http://www.cis.ksu.edu/~bhsu

Readings:
SIGGRAPH 2000 OpenGL tutorial (Shreiner, Angel, Shreiner): http://bit.ly/fVBjk8
Today: Chapter 2 (review), Chapter 16, Eberly *2e* – see http://snurl.com/1ye72
Next class: Section 2.3 (esp. 2.3.7), 2.6, 2.7, Eberly 2e
Angel, *OpenGL: A Primer*, 3e
This week: FVFH slides on Viewing

Lecture Outline

- **Reading for Last Class: §2.3 (esp. 2.3.4), Eberly 2e; Foley *et al.* Slides**
- **Reading for Today: Chapters 2, 16, Eberly 2e; Foley *et al.* Slides**
- **Reading for Next Class: §2.3 (esp. 2.3.7), 2.6, 2.7, Eberly 2e**
- **Last Time: Matrix Stack for 3-D Viewing Transformation**
  - $N = D_{Persp}\ S_{Far}\ S_{xy}\ M_{Rot}\ T_{Trans}$
  - **Perspective: optical principles, terminology**
- **Today: Highlights from First of Three Tutorials on OpenGL (Three Parts)**
  - **1. OpenGL and GL Utility Toolkit (GLUT) – V. Shreiner**
  - **2. Basic rendering – V. Shreiner**
  - **3. 3-D viewing setup – E. Angel**
- **Next Class: Scan Conversion (Rasterization) of Lines, Polygons**

Where We Are

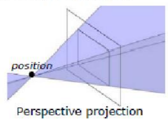
Lecture	Topic	Primary Source(s)
0	Course Overview	Chapter 1, Eberly 2e
1	**CG Basics: Transformation Matrices; Lab 0**	**Sections (§) 2.1, 2.2**
2	Viewing 1: Overview, Projections	§ 2.2.3 – 2.2.4, 2.8
3	Viewing 2: Viewing Transformation	§ 2.3 esp. 2.3.4; FVFH slides
4	**Lab 1a: Flash & OpenGL Basics**	**Ch. 2, 16[1], Angel *Primer***
5	Viewing 3: Graphics Pipeline	§ 2.3 esp. 2.3.7; 2.6, 2.7
6	Scan Conversion 1: Lines, Midpoint Algorithm	§ 2.5.1, 3.1; FVFH slides
7	**Viewing 4: Clipping & Culling; Lab 1b**	**§ 2.3.5, 2.4, 3.1.3**
8	Scan Conversion 2: Polygons, Clipping Intro	§ 2.4, 2.5 esp. 2.5.4, 3.1.6
9	Surface Detail 1: Illumination & Shading	§ 2.5, 2.6.1 – 2.6.2, 4.3.2, 20.2
10	**Lab 2a: Direct3D / DirectX Intro**	**§ 2.7, Direct3D handout**
11	Surface Detail 2: Textures; OpenGL Shading	§ 2.6.3, 20.3 – 20.4, *Primer*
12	Surface Detail 3: Mappings; OpenGL Textures	§ 20.5 – 20.13
13	**Surface Detail 4: Pixel/Vertex Shad.; Lab 2b**	**§ 3.1**
14	Surface Detail 5: Direct3D Shading; OGLSL	§ 3.2 – 3.4, Direct3D handout
15	Demos 1: CGA, Fun; Scene Graphs: State	§ 4.1 – 4.3, **CGA handout**
16	**Lab 3a: Shading & Transparency**	**§ 2.6, 20.1, *Primer***
17	**Animation 1: Basics, Keyframes; HW/Exam**	**§ 5.1 – 5.2**
	Exam 1 review; Hour Exam 1 (evening)	**Chapters 1 – 4, 20**
18	**Scene Graphs: Rendering; Lab 3b: Shader**	**§ 4.4 – 4.7**
19	**Demos 2: SFX; Skinning, Morphing**	**§ 5.3 – 5.5, CGA handout**
20	Demos 3: Surfaces; B-reps/Volume Graphics	§ 10.4, 12.7, **Mesh handout**

Lightly-shaded entries denote the due date of a written problem set; heavily-shaded entries, that of a machine problem (programming assignment); blue-shaded entries, that of a paper review; and the green-shaded entry, that of the term project.

Green, **blue** and **red** letters denote **exam review**, **exam**, and **exam solution review** dates.

Review: Viewing Transformation

- **Placement** of view volume (visible part of world) specified by camera's position and orientation
  - *Position* (a point)
  - *Look* and *Up* vectors
- **Shape** of view volume specified by
  - *horizontal* and *vertical view angles*
  - *front and back clipping planes*
- Perspective projection: projectors intersect at *Position*
- Parallel projection: projectors parallel to *Look vector*, but never intersect (or intersect at infinity)



Perspective projection

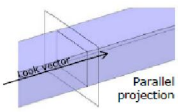
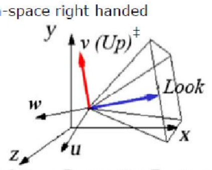


Image Source: Steve Marschner, Cornell

- Coordinate Systems
  - **world coordinates** – standard right-handed *xyz* 3-space
  - **camera coordinates** – camera-space right handed coordinate system (*u, v, w*); origin at *Position* and axes rotated by orientation; used for transforming arbitrary view into canonical view



Arbitrary Perspective Frustum

‡ v isn't strictly the *Up vector* but the projection of *Up*

Adapted from slides © 1997 – 2010 van Dam *et al.*, Brown University
http://bit.ly/hiSt0f Reused with permission.

Review: CTM for "Polygons-to-Pixels" Pipeline

- Entire problem can be reduced to a composite matrix multiplication of vertices, clipping, and a final matrix multiplication to produce screen coordinates.
- Final composite matrix (*CTM*) is composite of all modeling (instance) transformations (*CMTM*) accumulated during scene graph traversal from root to leaf, composited with the final composite normalizing transformation *N* applied to the root/world coordinate system:

1) $N = D_{persp} S_{far} S_{xy} M_{rot} T_{trans}$

2) $CTM = N \cdot CMTM$

3) $P' = CTM \cdot P$ for every vertex P defined in its own coordinate system

4) $P_{screen} = 512 \cdot P' + 1$ for all **clipped** P'

Adapted from slides © 1997 – 2010 van Dam *et al.*, Brown University
http://bit.ly/hiSt0f Reused with permission.

Lab 1 of 7, Part A [1]: Setup, OpenGL/Mesa, & XWindows

CIS 636 Interactive Computer Graphics
CIS 736 Computer Graphics

Lab 1a of 7
OpenGL Setup and Basics

The purpose of this lab exercise is to help you get up and running with Mesa (Linux OpenGL) in the CIS Department's Linux environment and over XWindows, and to show you some basic rendering.

This lab assignment is worth a total of 10 points (1%).

Upload an electronic copy of the assignment in PDF form (converted from your word processor, or scanned) to your K-State Online (KSOL) drop box before the due date and time.

References

NeonHelium tutorials: http://nehe.gamedev.net
Mesa home page: http://www.mesa3d.org
OpenGL FAQ: http://www.opengl.org/resources/faq/
OpenGL viewing docs: http://www.opengl.org/resources/faq/technical/viewing.htm

Problems 4-7 of this lab are adapted from:

Dunham, D. (2008). Lab 5, *CS 5721 (Computer Graphics)*, fall, 2008. Duluth, USA: University of Minnesota. Retrieved from: http://bit.ly/9dLERE

1. **(20%) Modelview transformation: 3-D Rotation of 2-D objects.** Follow Lesson 03 to rotate the flat polygons and then render them. Turn in `lab1_1.c` and `lab1_1.jpg`.
2. **(20%) Modelview transformation: 3-D Rotation of 3-D objects.** Follow Lesson 04 to draw 3-D polyhedra and rotate them. Turn in `lab1_2.c` and `lab1_2.jpg`.
3. **(20%) XWindows.** Repeat Lesson 04 from a notebook computer or PC running Mac OS X, Windows XP, Windows Vista, or Windows 7. Turn in `lab1_3.jpg`.

Lab 1 of 7, Part A [2]: Perspective View Volume Specification

4. (10%) Step 1. Perspective Viewing with OpenGL

```
glMatrixMode( GL_MODELVIEW );
glLoadIdentity();
```

5. (10%) Step 2: Making things move in Perspective

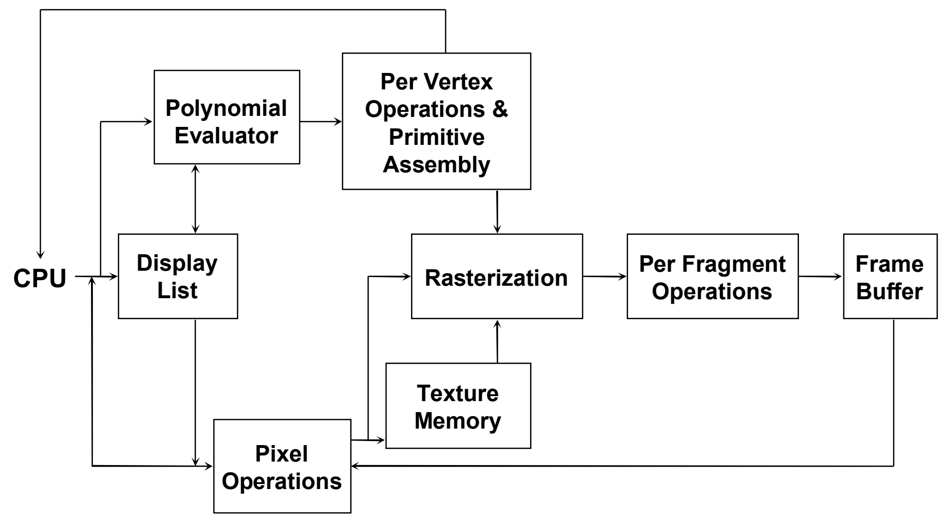
```
glFrustum( -width/2.0, width/2.0, -height/2.0, height/2.0, -1.0,
-20.0 );
gluPerspective( field_of_view, aspect, near, far );
```

6. (10%) Step 3: Specifying the Viewing matrix

```
gluLookAt(  eyeX, eyeY, eyeZ,
            centerX, centerY, centerZ,
            upX, upY, upZ                  );
```

7. (10%) Step 4: Instancing Objects

OpenGL Architecture

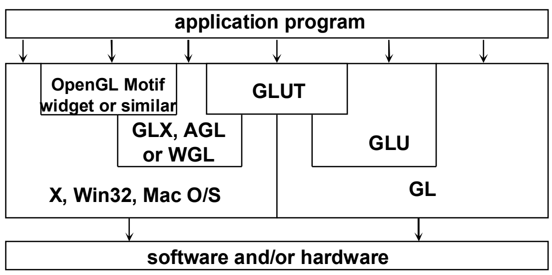


OpenGL Rendering Application Programmer Interface

- Geometric primitives
  - points, lines and polygons
- Image Primitives
  - images and bitmaps
  - separate pipeline for images and geometry
    - linked through texture mapping
- Rendering depends on state
  - colors, materials, light sources, etc.

OpenGL & Related APIs

- AGL, GLX, WGL
  - glue between OpenGL and windowing systems
- GLU (OpenGL Utility Library)
  - part of OpenGL
  - NURBS, tessellators, quadric shapes, etc.
- GLUT (OpenGL Utility Toolkit)
  - portable windowing API
  - not officially part of OpenGL



Preliminaries

- Headers Files
  - ⇨ #include <GL/gl.h>
  - ⇨ #include <GL/glu.h>
  - ⇨ #include <GL/glut.h>
- Libraries
- Enumerated Types
  - ✸ OpenGL defines numerous types for compatibility
    - ⇨ GLfloat
    - ⇨ GLint
    - ⇨ Glenum
    - ⇨ *etc.*

GLUT Callback Functions

- Application Structure
  - ✸ Configure and open window
  - ✸ Initialize OpenGL state
  - ✸ Register input callback functions
    - ⇨ render
    - ⇨ resize
    - ⇨ input: keyboard, mouse, etc.
  - ✸ Enter event processing loop

Sample Program

```
void main( int argc, char** argv )
{
  int mode = GLUT_RGB|GLUT_DOUBLE;
  glutInitDisplayMode( mode );
  glutCreateWindow( argv[0] );
  init();
  glutDisplayFunc( display );
  glutReshapeFunc( resize );
  glutKeyboardFunc( key );
  glutIdleFunc( idle );
  glutMainLoop();
}
```


OpenGL Initialization

- Set up whatever state you're going to use

```
void init( void )
{
  glClearColor( 0.0, 0.0, 0.0, 1.0 );
  glClearDepth( 1.0 );

  glEnable( GL_LIGHT0 );
  glEnable( GL_LIGHTING );
  glEnable( GL_DEPTH_TEST );
}
```

GLUT Callback Functions

- Routine to call when something happens
  - window resize or redraw
  - user input
  - animation
- “Register” callbacks with GLUT

```
glutDisplayFunc( display );
glutIdleFunc( idle );
glutKeyboardFunc( keyboard );
```


Rendering Callback

- Do all of your drawing here

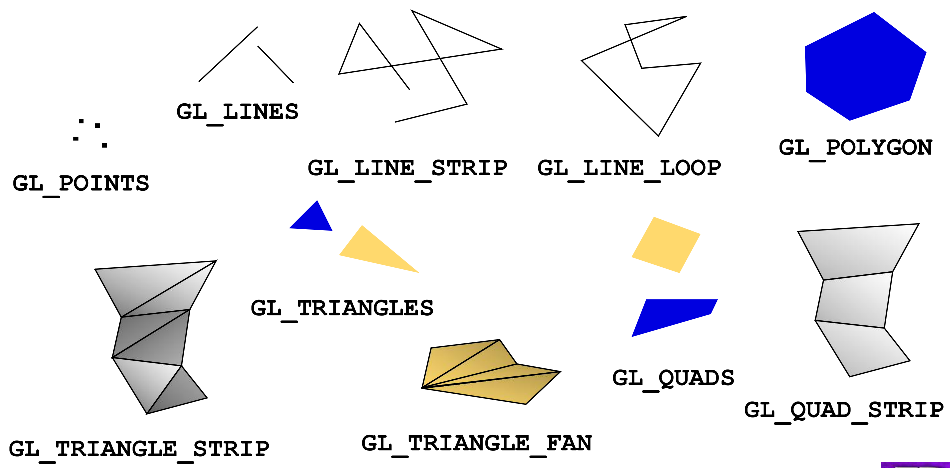
```
glutDisplayFunc( display );

void display( void )
{
  glClear( GL_COLOR_BUFFER_BIT );
  glBegin( GL_TRIANGLE_STRIP );
    glVertex3fv( v[0] );
    glVertex3fv( v[1] );
    glVertex3fv( v[2] );
    glVertex3fv( v[3] );
  glEnd();
  glutSwapBuffers();
}
```

Elementary Rendering

- Geometric Primitives
- Managing OpenGL State
- OpenGL Buffers

OpenGL Geometric Primitives

- All geometric primitives are specified by vertices



Simple Example

```
void drawRhombus( GLfloat color[] )
{
     glBegin( GL_QUADS );
     glColor3fv( color );
     glVertex2f( 0.0, 0.0 );
     glVertex2f( 1.0, 0.0 );
     glVertex2f( 1.5, 1.118 );
     glVertex2f( 0.5, 1.118 );
     glEnd();
}
```


OpenGL Command Formats

glVertex3fv(v)

Number of components

```
2 - (x,y)
3 - (x,y,z)
4 - (x,y,z,w)
```

Data Type

```
b  - byte
ub - unsigned byte
s  - short
us - unsigned short
i  - int
ui - unsigned int
f  - float
d  - double
```

Vector

omit "v" for scalar form

`glVertex2f( x, y )`

Specifying Geometric Primitives

- **Primitives are specified using**

```
glBegin( primType );
glEnd();
```

  - *primType* determines how vertices are combined

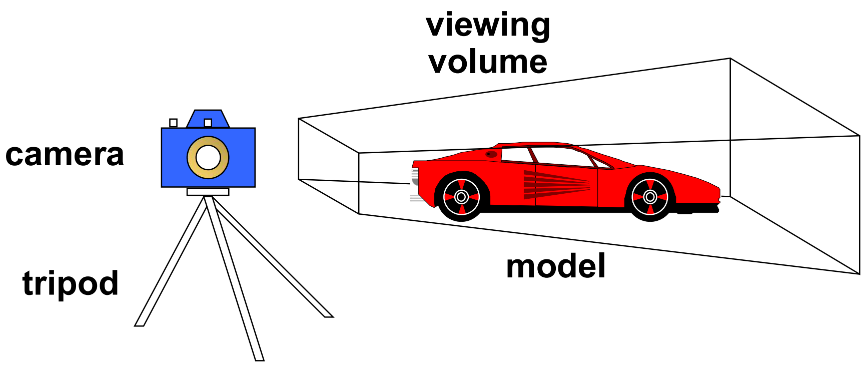
```
GLfloat red, green, blue;
Glfloat coords[3];
glBegin( primType );
for ( i = 0; i < nVerts; ++i ) {
  glColor3f( red, green, blue );
  glVertex3fv( coords );
}
glEnd();
```


Transformations in OpenGL

- **Modeling**
- **Viewing**
  - orient camera
  - projection
- **Animation**
- **Map to screen**

Camera Analogy

- 3D is just like taking a photograph (lots of photographs!)



Camera Analogy & Transformations

- Projection transformations
  - adjust the lens of the camera
- Viewing transformations
  - tripod–define position and orientation of the viewing volume in the world
- Modeling transformations
  - moving the model
- Viewport transformations
  - enlarge or reduce the physical photograph

25

Coordinate Systems & Transformation Steps

- **Steps in Forming an Image**
  - **specify geometry (world coordinates)**
  - **specify camera (camera coordinates)**
  - **project (window coordinates)**
  - **map to viewport (screen coordinates)**
- **Each step uses transformations**
- **Every transformation is equivalent to a change in coordinate systems (frames)**

26

Preview: Fixed Function Pipeline, Spaces & Matrices

(See Eberly 2e § 2.3.2 – 2.3.7, pp. 48-66, especially p. 58)

1. model coordinates / object coordinates	X_{model} → (H_{world})
2. world coordinates / scene coordinates	X_{world} → (H_{view})
3. camera coordinates / eye coordinates	X_{view} → (H_{proj})
4. (optional) view coordinates / clip coordinates	X_{clip} → (perspective division)
5. normalized device coordinates (NDC)	X_{ndc} → (H_{window})
6. screen coordinates	X_{window}

H_{world}: modelview transformation

Normalizing transformation: $X_{world} \rightarrow X_{ndc}$ {
- H_{view}: "view matrix" **(really NT!)**
- H_{proj}: projection matrix
- /w: perspective division

H_{window}: window matrix
(*aka* viewport transformation)

Matrix Operations

- Specify Current Matrix Stack

  `glMatrixMode( GL_MODELVIEW or GL_PROJECTION )`
- Other Matrix or Stack Operations

  `glLoadIdentity()` `glPushMatrix()`

  `glPopMatrix()`
- Viewport
  - usually same as window size
  - viewport aspect ratio should be same as projection transformation or resulting image may be distorted

  `glViewport( x, y, width, height )`

Projection Transformation

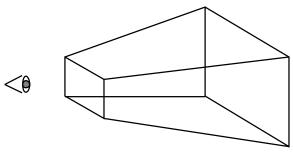
- Shape of viewing frustum
- Perspective projection

  `gluPerspective( fovy, aspect, zNear, zFar )`

  `glFrustum( left, right, bottom, top, zNear, zFar )`
- Orthographic parallel projection

  `glOrtho( left, right, bottom, top, zNear, zFar )`

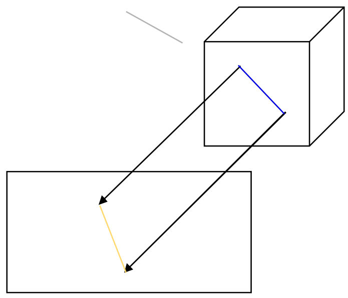
  `gluOrtho2D( left, right, bottom, top )`
  - ⇨ calls `glOrtho` with z values near zero



Applying Projection Transformations

- Typical use (orthographic projection)

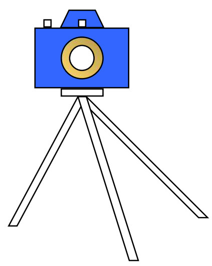
```
glMatrixMode( GL_PROJECTION );
glLoadIdentity();
glOrtho( left, right, bottom, top, zNear, zFar );
```



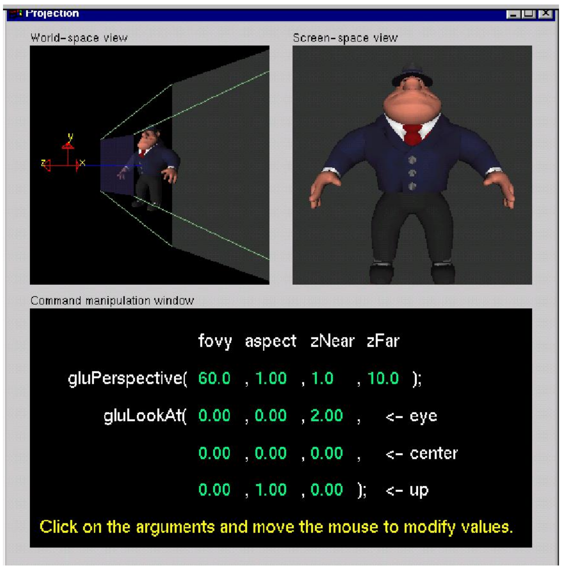
Viewing Transformations

- Position the camera/eye in the scene
  - place the tripod down; aim camera
- To “fly through” a scene
  - change viewing transformation and redraw scene
- gluLookAt(eye_x, eye_y, eye_z, aim_x, aim_y, aim_z, up_x, up_y, up_z)
  - up vector determines unique orientation
  - careful of degenerate positions

tripod



Projection Tutorial



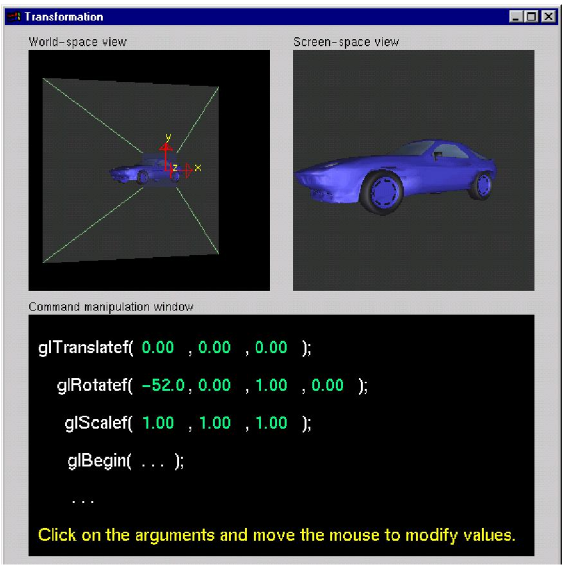
Modeling Transformations

- **Move object**
  `glTranslate{fd}( x, y, z )`
- **Rotate object around arbitrary axis**
  `glRotate{fd}( angle, x, y, z )`
  - **angle is in degrees**
- **Dilate (stretch or shrink) or mirror object**
  `glScale{fd}( x, y, z )`

$$\begin{pmatrix} x & y & z \end{pmatrix}$$

33

Transformation Tutorial



34

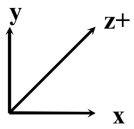
Connection: Viewing and Modeling

- Moving camera is equivalent to moving every object in the world towards a stationary camera
- Viewing transformations are equivalent to several modeling transformations
  - `gluLookAt()` has its own command
  - can make your own *polar view* or *pilot view*

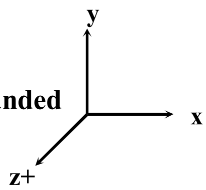
Projection is Left-Handed

- Projection transformations (`gluPerspective, glOrtho`) are left handed
  - think of *zNear* and *zFar* as distance from view point
- Everything else is right handed, including the vertices to be rendered

left handed



right handed



resize(): Perspective & LookAt

```
void resize( int w, int h )
{
    glViewport( 0, 0, (GLsizei) w, (GLsizei) h );
    glMatrixMode( GL_PROJECTION );
    glLoadIdentity();
    gluPerspective( 65.0, (GLfloat) w / h,
                    1.0, 100.0 );
    glMatrixMode( GL_MODELVIEW );
    glLoadIdentity();
    gluLookAt( 0.0, 0.0, 5.0,
               0.0, 0.0, 0.0,
               0.0, 1.0, 0.0 );
}
```

resize(): *Ortho (part 1)*

```
void resize( int width, int height )
{
   GLdouble aspect = (GLdouble) width / height;
   GLdouble left = -2.5, right = 2.5;
   GLdouble bottom = -2.5, top = 2.5;
   glViewport( 0, 0, (GLsizei) w, (GLsizei) h );
   glMatrixMode( GL_PROJECTION );
   glLoadIdentity();
```

… continued …

resize(): *Ortho (part 2)*

```
   if ( aspect < 1.0 ) {
      left /= aspect;
      right /= aspect;
   } else {
      bottom *= aspect;
      top *= aspect;
   }
   glOrtho( left, right, bottom, top, near, far );
   glMatrixMode( GL_MODELVIEW );
   glLoadIdentity();
}
```

Summary

- Three Tutorials from SIGGRAPH 2000
- Today (Part 1): OpenGL and GL Utility Toolkit (GLUT) – Vicki Shreiner
  - Overall architecture
  - Initialization
  - Viewport management
- Part 2: Basic Rendering – Vicki Shreiner
- Part 3: 3-D Viewing – Edward Angel
  - Math background (see CG Basics 1)
  - Viewing and normalization transformations (see CG Basics 4)
  - More on viewing in CG Basics 4
  - View volume specification
  - Automated part: clipping

Terminology

- OpenGL and GL Utility Toolkit (GLUT)
  - State machine
  - Using GLUT
  - Specifying perspective, parallel projections
- Transformations
  - Fixed function pipeline: modelview, normalizing, viewing
  - Rigid body: preserves distance (*e.g.*, translation, rotation)
  - Linear
    - Preserves vector addition, scalar multiplication
    - *e.g.*, rotation, scaling
  - Affine: linear transformation followed by translation
  - Non-affine: all others (*e.g.*, perspective-to-parallel transformation)