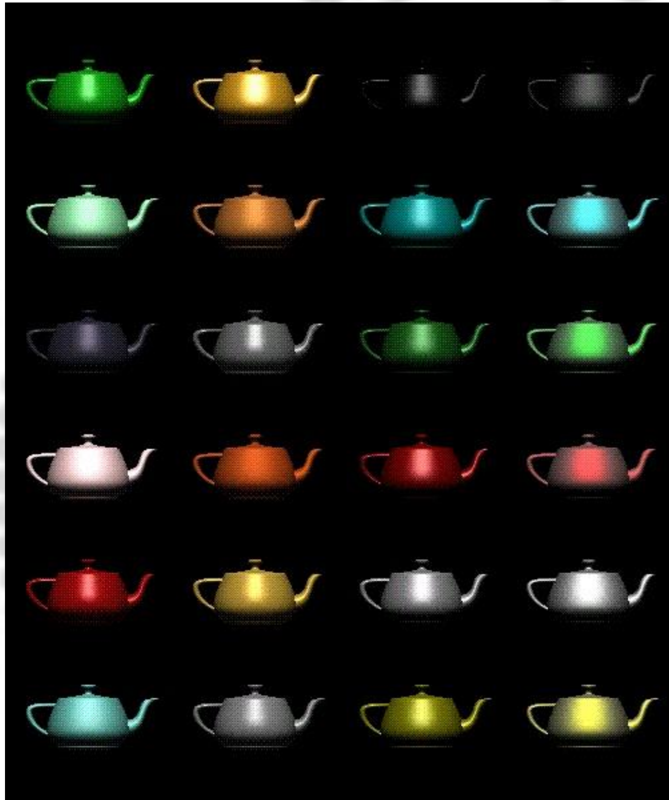
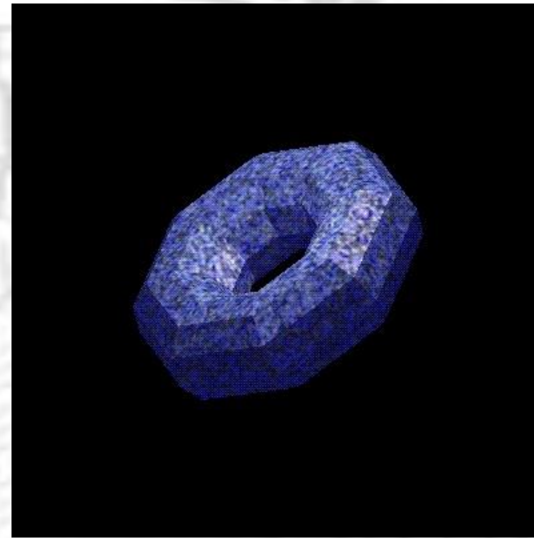
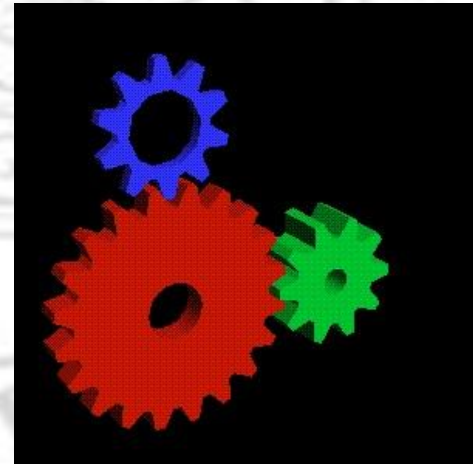
OpenGL







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OpenGL

- What it is:
  - Software interface to graphics hardware
  - ~ 120 C-callable routines for 3D graphics
  - Hardware independent
  - When running with X (with GLX extension)
    - Client-server model
    - Network transparent

OpenGL

- What it is not:
  - *Not* a windowing system (no window creation)
  - *Not* a UI system (no keyboard and mouse routines)
  - *Not* a 3D modeling system (Open Inventor, VRML, Java3D, 3DMax, Blender, etc.)

OpenGL Functionality

- Simple geometric objects (e.g. lines, polygons, rectangles, etc.)
- Transformations, viewing, clipping
- Hidden line & hidden surface removal
- Color, lighting, texture
- Bitmaps, fonts, and images
- Immediate- & retained- mode graphics
- Etc.
- But no shadow, raytracing, radiosity

OpenGL Convention

- Functions:
  - prefix gl + capital first letter (e.g. glClearColor)
- Constants:
  - prefix GL + all capitals (e.g. GL_COLOR_BUFER_BIT)

OpenGL Convention (cont.)

- Many variations of the same functions
  - void glClearColor[2,3,4][b,s,i,f,d,ub,us,ui](v)
    - [2,3,4]: dimension
    - [b,s,i,f,d,ub,us,ui]: data type
    - (v): optional pointer (vector) representation

OpenGL Basic Concepts

- OpenGL as a state machine
  - Graphics primitives going through a “pipeline” of rendering operations
  - OpenGL controls the state of the pipeline w. many state variables (fg & bg colors, line thickness, texture pattern, eyes, lights, surface material, etc.)
  - Binary state: glEnable & glDisable
  - query: glGet[Boolean,Integer,Float,Double]v

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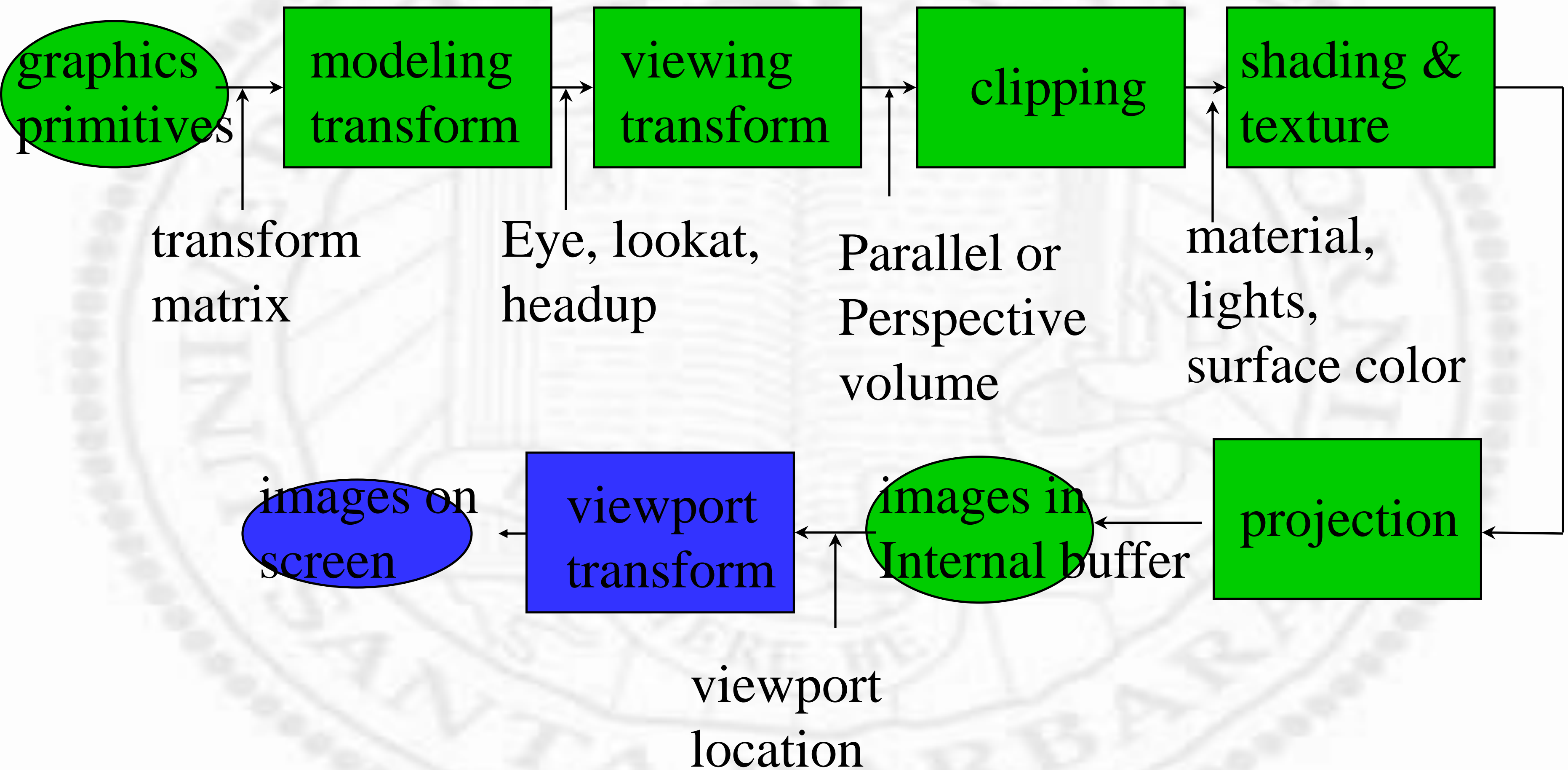
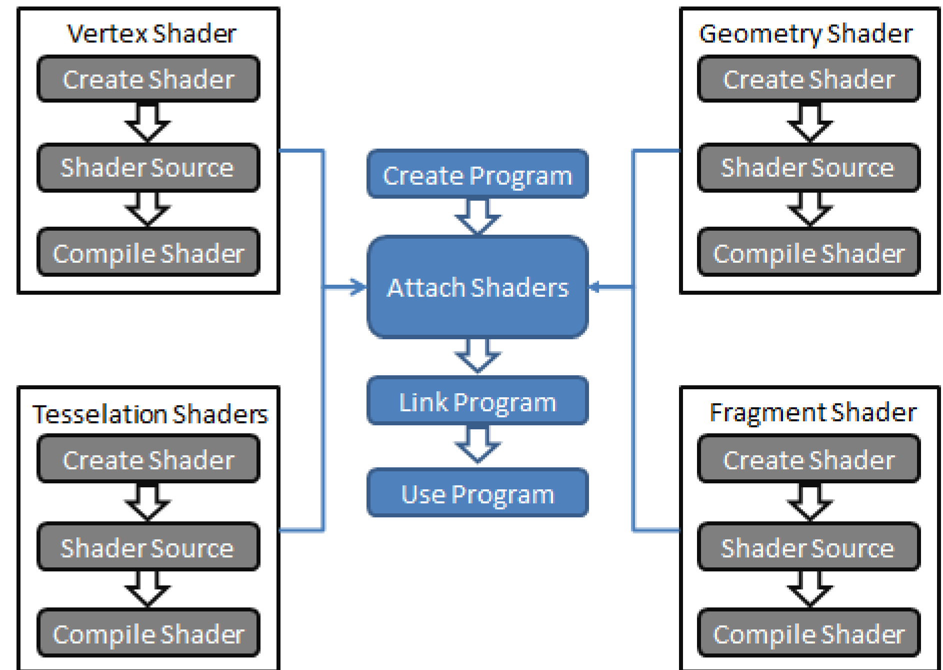
Rendering Pipeline



GL Shaders

- With the advance of GPU
  - Vertices (primitives) can be handled in parallel
  - Geometry transformation, tessellation, coloring are done with different "shaders" in GLSL (shading language)
  - These shaders are assembled into a program and executed on GPU



Type of Shaders

- GL_VERTEX_SHADER
- GL_GEOMETRY_SHADER
- GL_TESS_CONTROL_SHADER
- Gl_TESS_EVALUATION_SHADER
- GL_FRAGMENT_SHADER

Type of Shaders

- GL_VERTEX_SHADER
  - Operate on 3D position, normal and texture coors of a vertex
- GL_TESS_CONTROL_SHADER
  - Compute per-patch attributes and sub-division levels
- GL_TESS_EVALUATION_SHADER
- GL_GEOMETRY_SHADER
- GL_FRAGMENT_SHADER
  - Rasterization and interpolation

Create Shaders

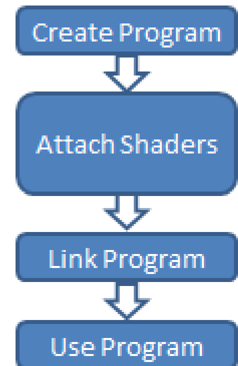
- Shaders themselves are snippets of OpenGL programs to accomplish different graphic tasks in a (customizable) pipeline
- Easiest way: store codes in a file, read the file, set the codes, and compile

```
1   char *vs;
2   GLuint v;
3
4   // get a shader handler
5   v = glCreateShader(GL_VERTEX_SHADER);
6   // read the shader source from a file
7   vs = textFileRead(vertexFileName);
8   // conversions to fit the next function
9   const char *vv = vs;
10  // pass the source text to GL
11  glShaderSource(v, 1, &vv,NULL);
12  // free the memory from the source text
13  free(vs);
14  // finally compile the shader
15  glCompileShader(v);
```

Programs

- A sequence of shaders to be executed by GPU
- Multiple programs (for rendering, say, glossy objects and matte objects)
- Multiple shaders in each program
- A shader in multiple programs

```
1   GLuint p;
2
3   p = glCreateProgram();
4
5   glAttachShader(p,s1);
6   glAttachShader(p,s2);
7
8   glLinkProgram(p);
9   ...
10  // and later on
11  glUseProgram(p);
```



ing it All Together

```
void setShaders() {

    GLuint v, g, f;
    char *vs,*gs, *fs;

    // Create shader handlers
    v = glCreateShader(GL_VERTEX_SHADER);
    g = glCreateShader(GL_GEOMETRY_SHADER);
    f = glCreateShader(GL_FRAGMENT_SHADER);

    // Read source code from files
    vs = textFileRead("example.vert");
    gs = textFileRead("example.geom");
    fs = textFileRead("example.frag");

    const char * vv = vs;
    const char * gg = gs;
    const char * ff = fs;

    // Set shader source
    glShaderSource(v, 1, &vv,NULL);
    glShaderSource(g, 1, &gg,NULL);
    glShaderSource(f, 1, &ff,NULL);

    free(vs);free(gs);free(fs);

    // Compile all shaders
    glCompileShader(v);
    glCompileShader(g);
    glCompileShader(f);

    // Create the program
    p = glCreateProgram();

    // Attach shaders to program
    glAttachShader(p,v);
    glAttachShader(p,g);
    glAttachShader(p,f);

    // Link and set program to use
    glLinkProgram(p);
    glUseProgram(p);
```

Programmable vs. Fixed Pipeline

- We will talk about fixed OpenGL pipeline
- OpenGL 4.0 and ES (mobile) move toward programmable (shader-based) pipeline
- Allow customized per-fragment and per-pixel processing (e.g., bump mapping) on GPU for significant speed up

Points, Lines, Polygons

- Specified by a set of vertices
  - void glVertex[2,3,4][s,i,f,d](v) (TYPE coords)
- Polygons:
  - simple, convex, no holes
- Grouped together by glBegin() & glEnd()

```
glBegin(GL_POLYGON)
    glVertex3f( …)
    glVertex3f( …)
glEnd
```

Points, Lines, Polygons Details

- Points:
  - size: void glPointSize(GLfloat size)
- Lines:
  - width: void glLineWidth(GLfloat width)
  - stippled lines:

    glLineStipple()

    glEnable(GL_LINE_STIPPLE)

Points, Lines, Polygons Details (cont.)

- void glPolygonMode(face, mode)
  - face: GL_FRONT, GL_BACK, GL_FRONT_AND_BACK
  - mode: GL_POINT, GL_LINE, GL_FILL
  - default: both front and back as filled

Points, Lines, Polygons Details (cont.)

- face culling
  - void glEnable(GL_CULL_FACE)
  - void glCullFace(mode)
    - mode: GL_FRONT, GL_BACK, GL_FRONT_AND_BACK
    - outside: back-facing polygon not visible
    - inside: front-facing polygon not visible

Other Primitives

- Many
  - GL_TRIANGLES
  - GL_TRIANGLE_STRIP
  - GL_QUADS
  - GL_QUAD_STRIP
  - Etc.

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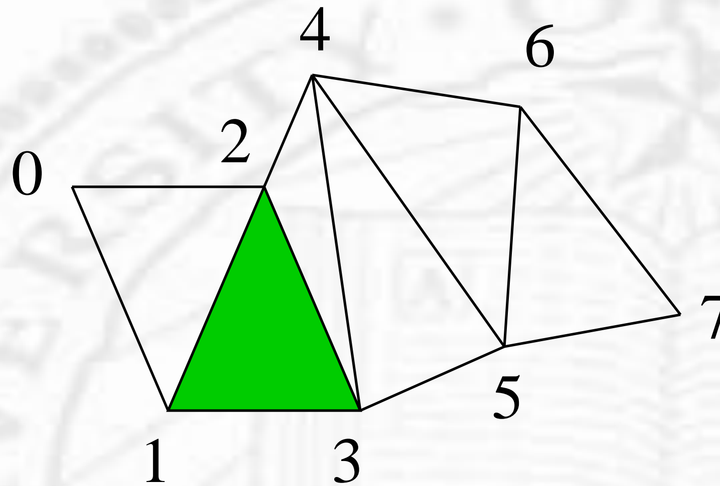
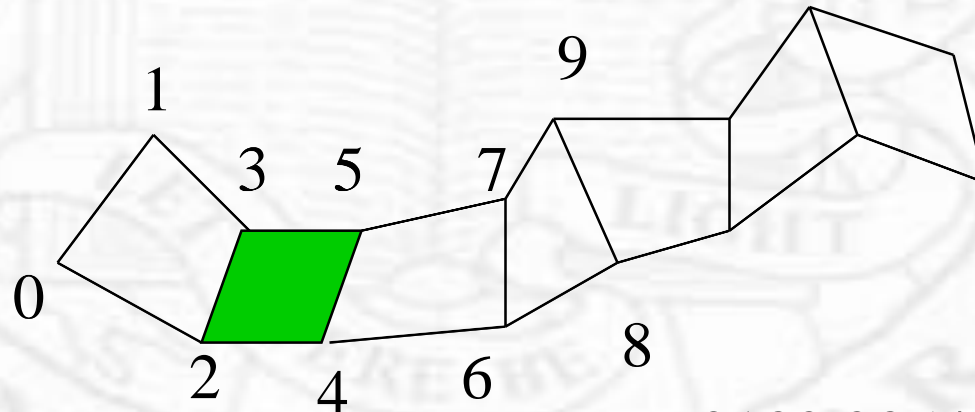
Other Primitives



GL_TRIANGLE_STRIP

012,213,234,435

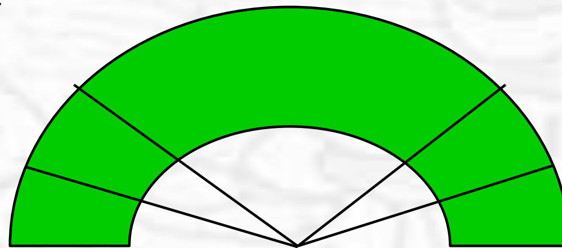
GL_QUAD_STRIP



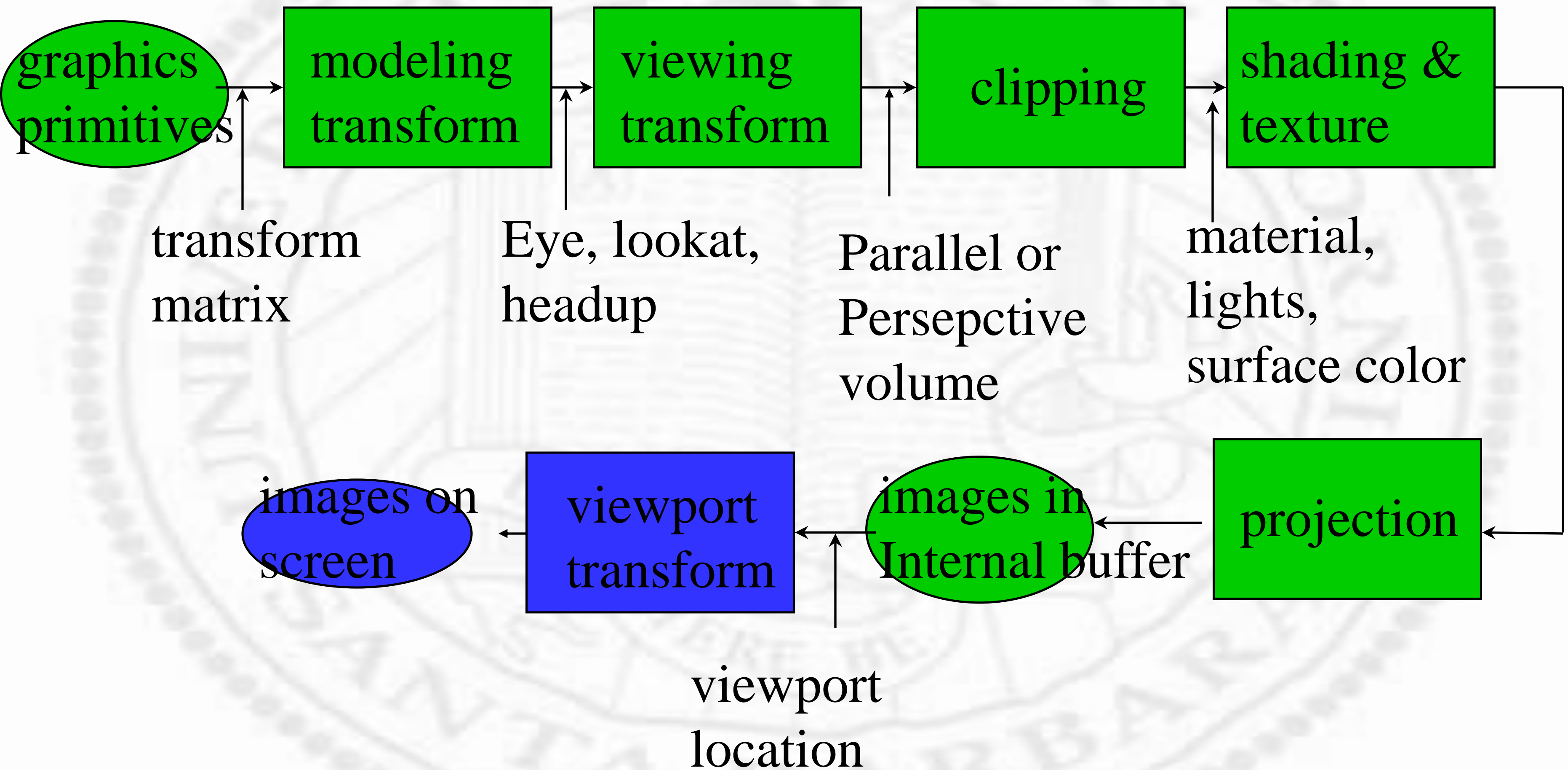
0132,2354,4576

Hint on Homework

- Only two primitives are needed
  - A cube (with GL_POLYGON) for modeling "straight" pieces
  - A flexible quad or triangular strip, allowing:
    - Any angular extent
    - Different width
    - Sampling rate
    - Etc.

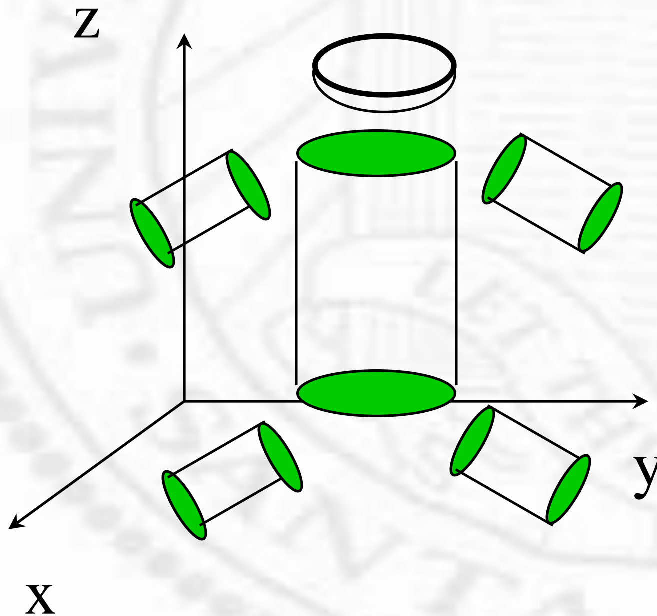


Rendering Pipeline



Geometric Transform

- Step 1: Modeling transform
  - A global "world" coordinate system where one constructs and manipulates models



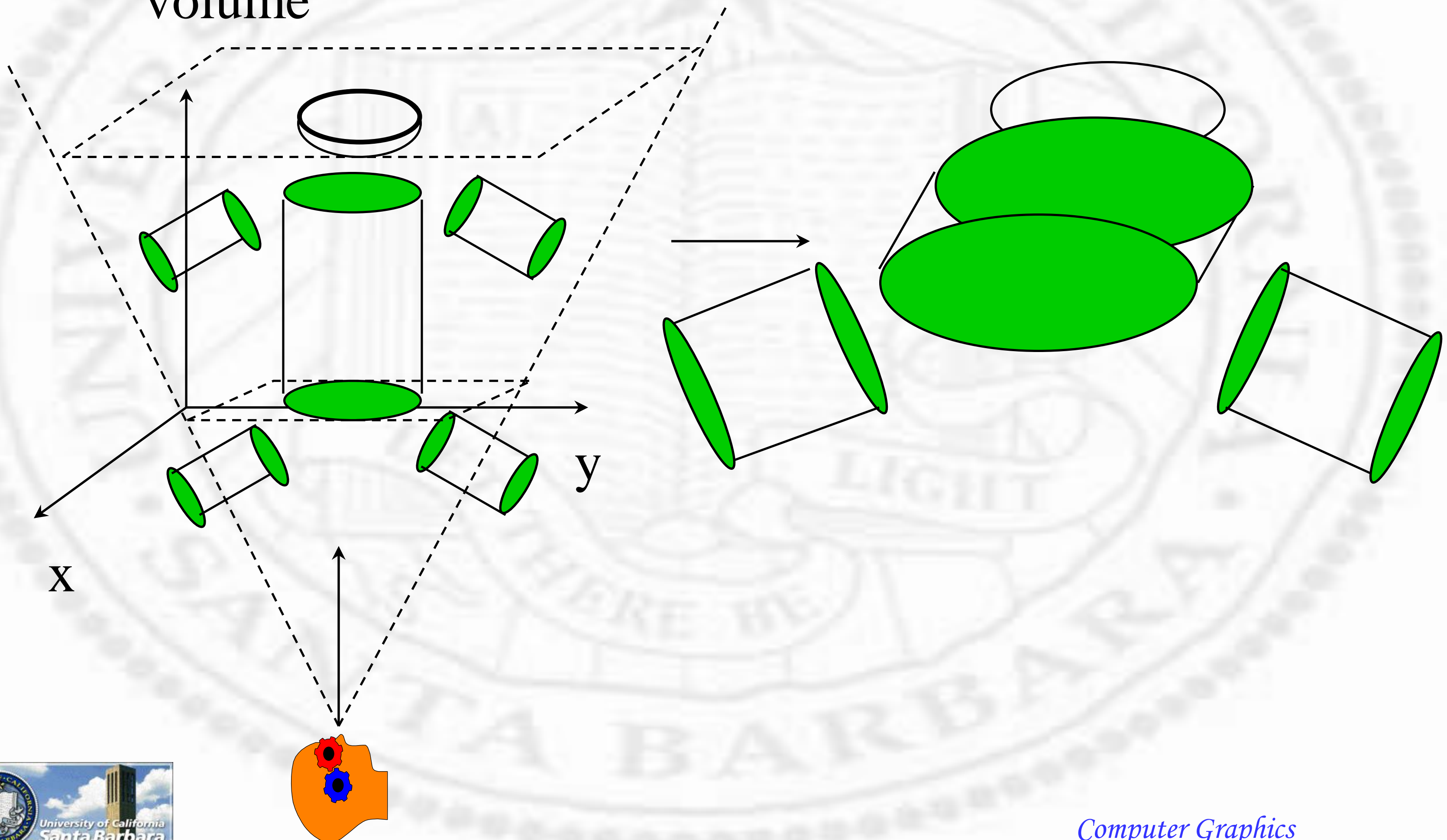
glTranslate[f,d](x,y,z)

glRotate[f,d](x,y,z)

glScale[f,d](x,y,z)

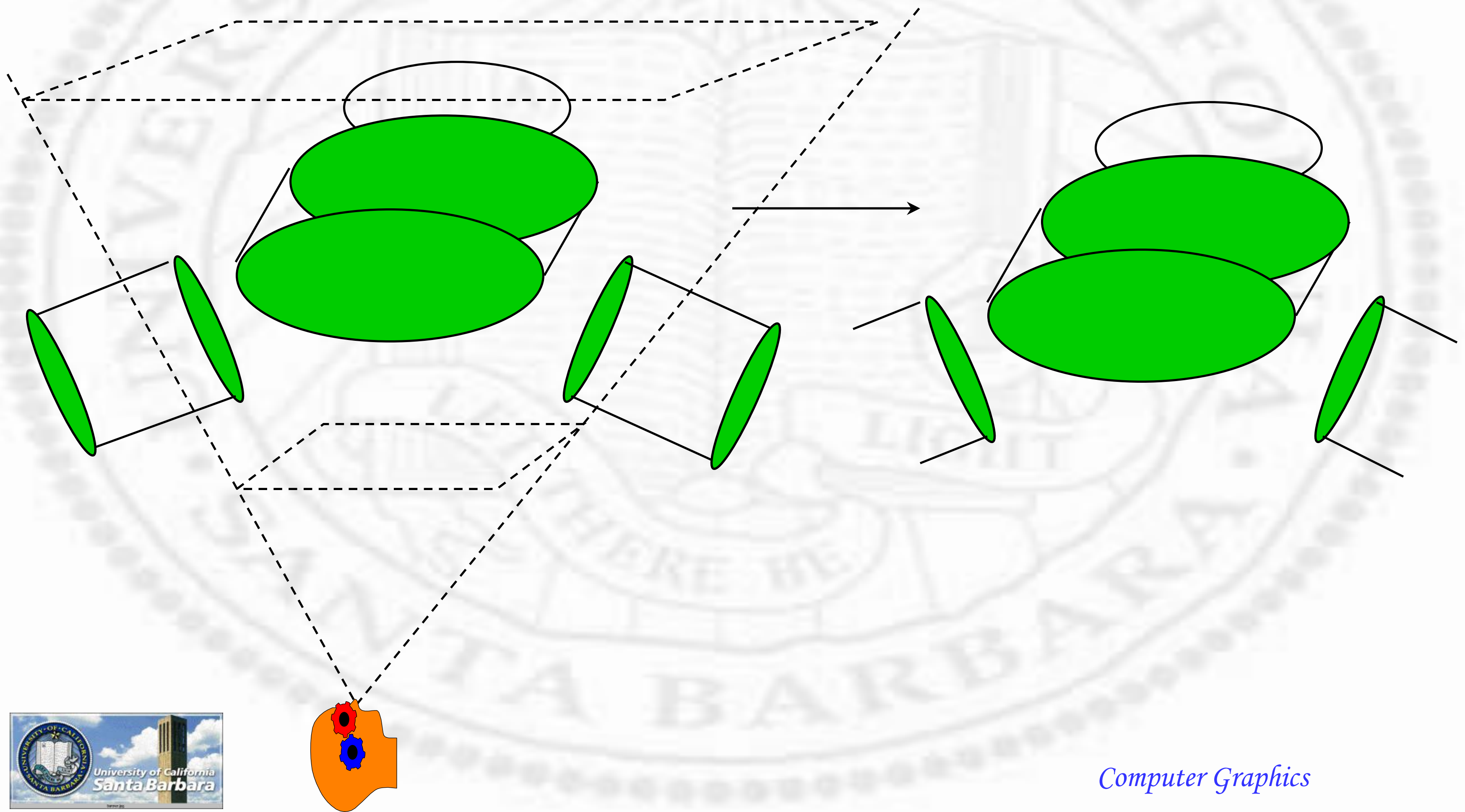
Geometric Transform

- Step 2: Viewing transform
  - Select the eye pos, look-at dir, head-up dir, and view volume



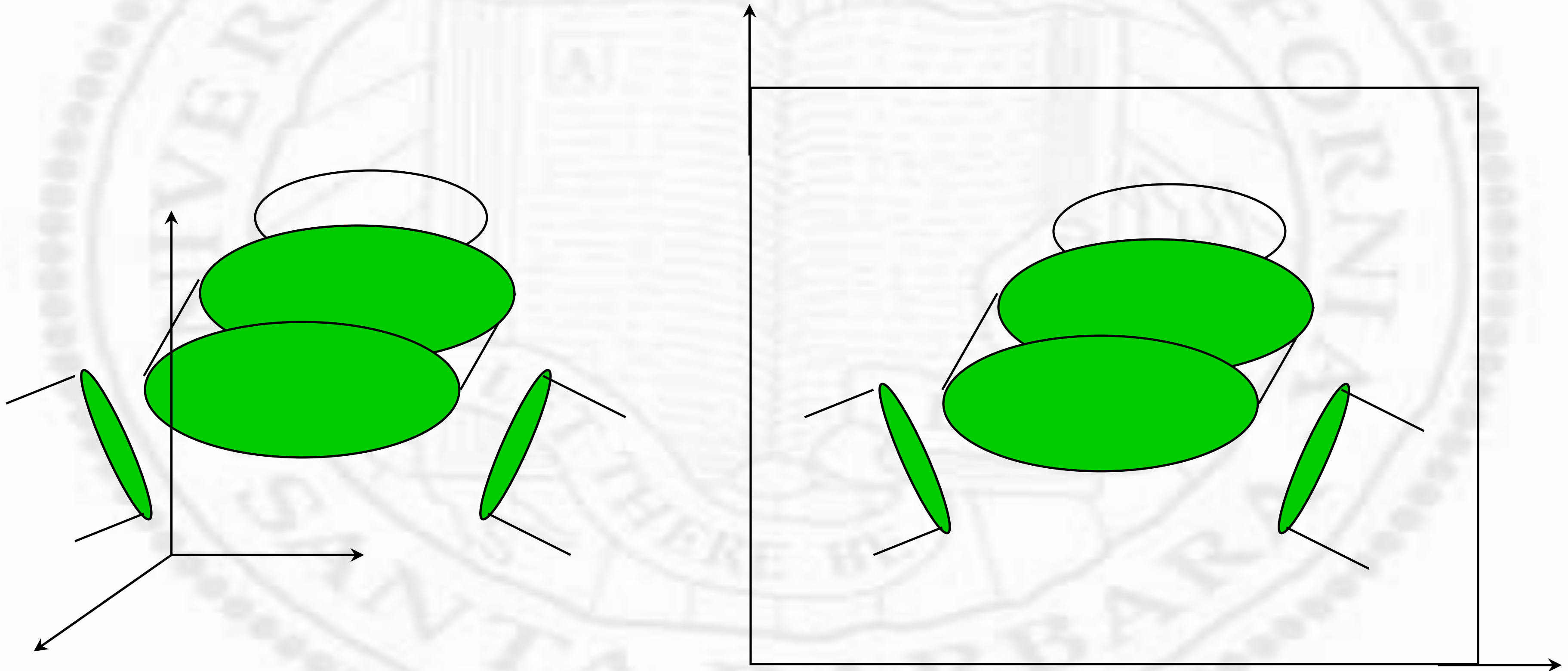
Geometric Transform

- Step 3: Clipping
  - Remove primitives that are not in the view volume



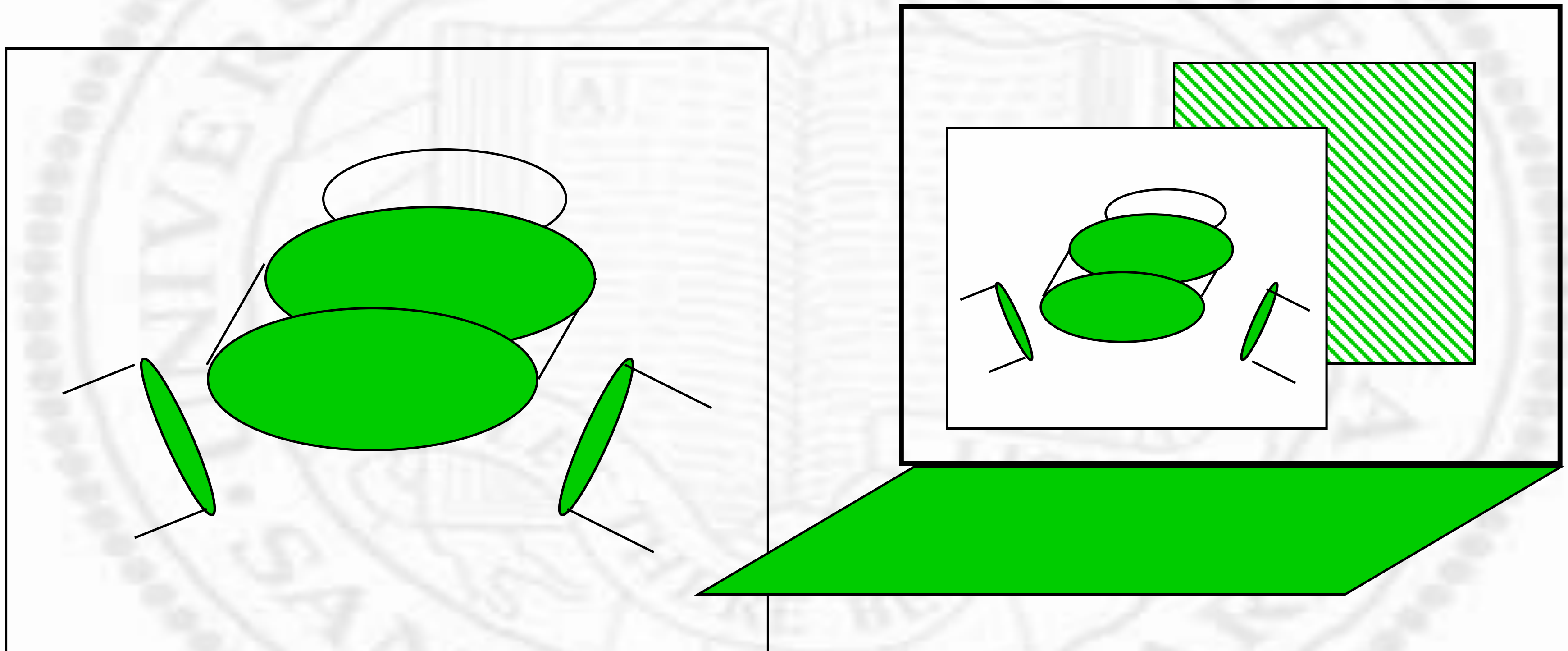
Geometric Transform

- Step 4: Projection
  - Map from 3D into 2D



Geometric Transform

- Step 5: Viewport transform
  - Map 2D images onto screen



Transform in OpenGL

- OpenGL uses stacks to maintain transformation matrices (MODELVIEW stack is the most important)
- You can load, push and pop the stack
- The current transform is applied to all graphics primitive until it is changed

General Transform Commands

- Specify current matrix
  - void glMatrixMode(GLenum mode)
    - GL_MODELVIEW, GL_PROJECTION, GL_TEXTURE
- Initialize current matrix
  - void glLoadIdentity(void)
  - void glLoadMatrix[f,d](const TYPE *m)

General Transform Commands (cont.)

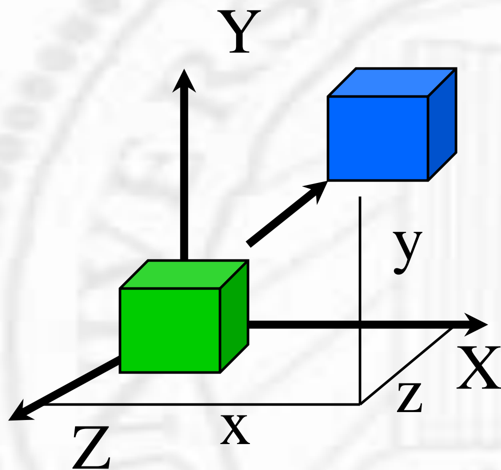
- Concatenate current matrix
  - void glMultMatrix(const TYPE *m)
    - C = CMv (remember: GL uses a stack)
- Caveat: OpenGL matrices are stored in column major (this is different from C convention)

$$M = \begin{bmatrix} m_1 & m_5 & m_9 & m_{13} \\ m_2 & m_6 & m_{10} & m_{14} \\ m_3 & m_7 & m_{11} & m_{15} \\ m_4 & m_8 & m_{12} & m_{16} \end{bmatrix}$$

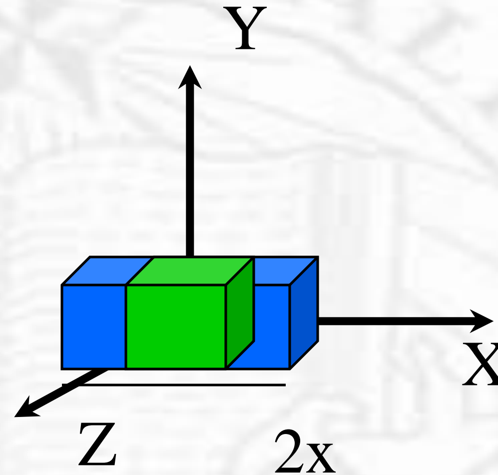
Best use utility functions glTranslate, glRotate, glScale

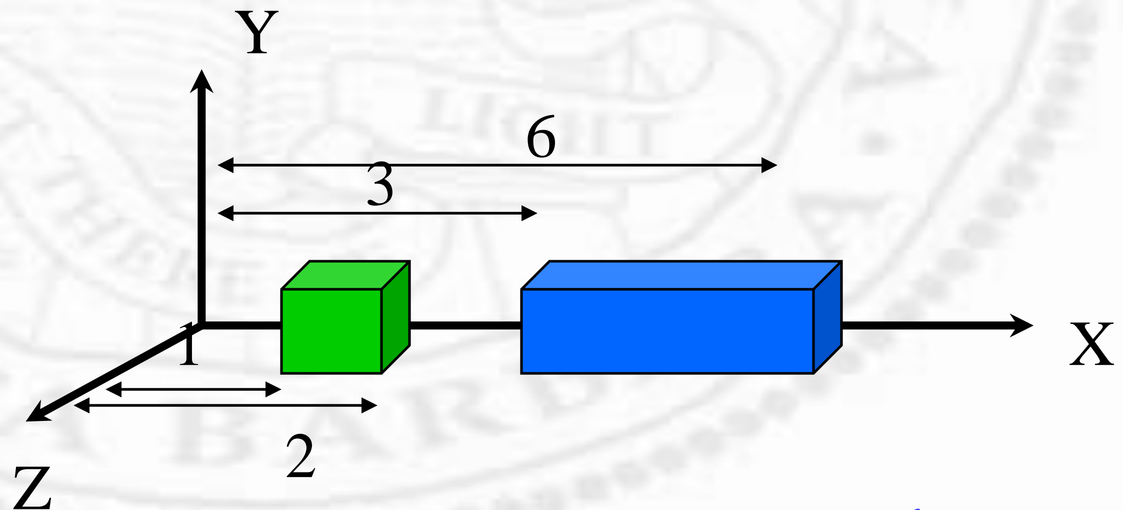
Transformations

- Translation



- Scaling

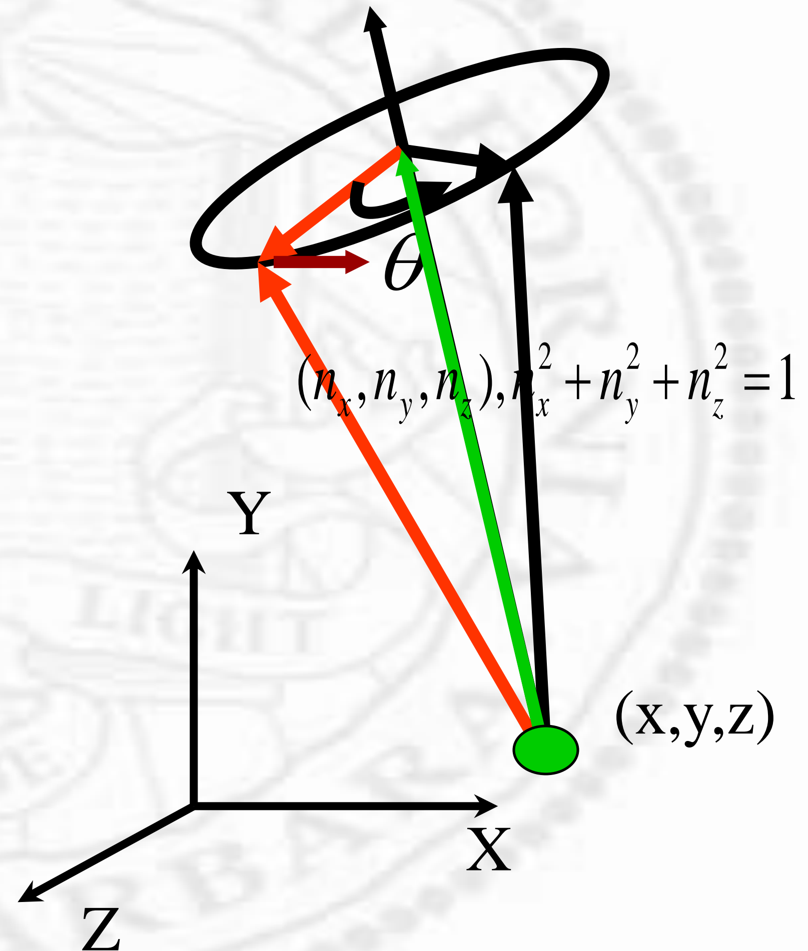




•Scaling is w.r.t the origin
•Apparent movement if object is not zero centered

Rotation

- Six DOFs (things you can specify)
  - Axis Location (3)
  - Axis Orientation (2)
  - Angle (1)



Rotation in OpenGL

- Axis location
  - Always go through the origin
- Axis orientation
  - Any (x,y,z) axes
- Angle of rotation
- Again, rotation is w.r.t the origin
- Apparent movement occurs if the object is not zero-centered

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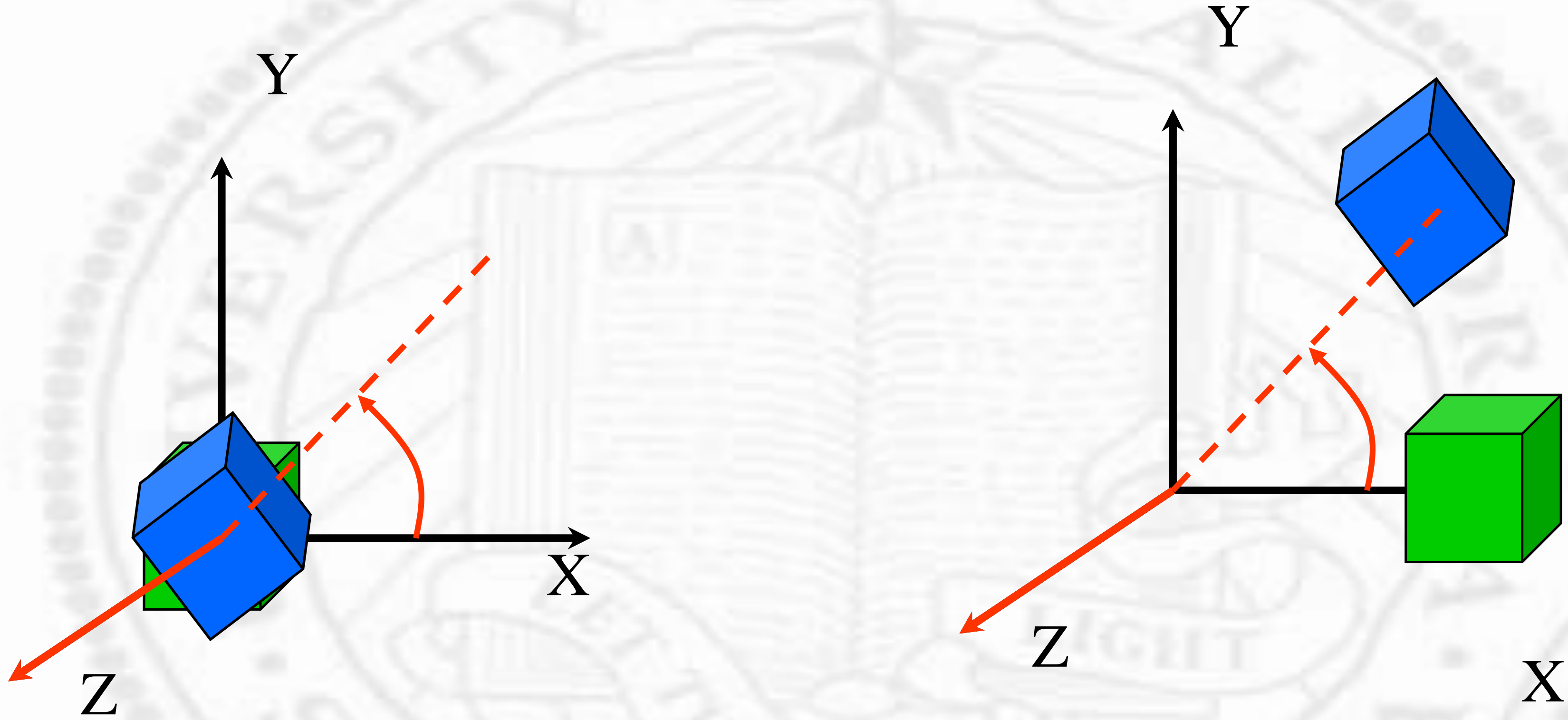
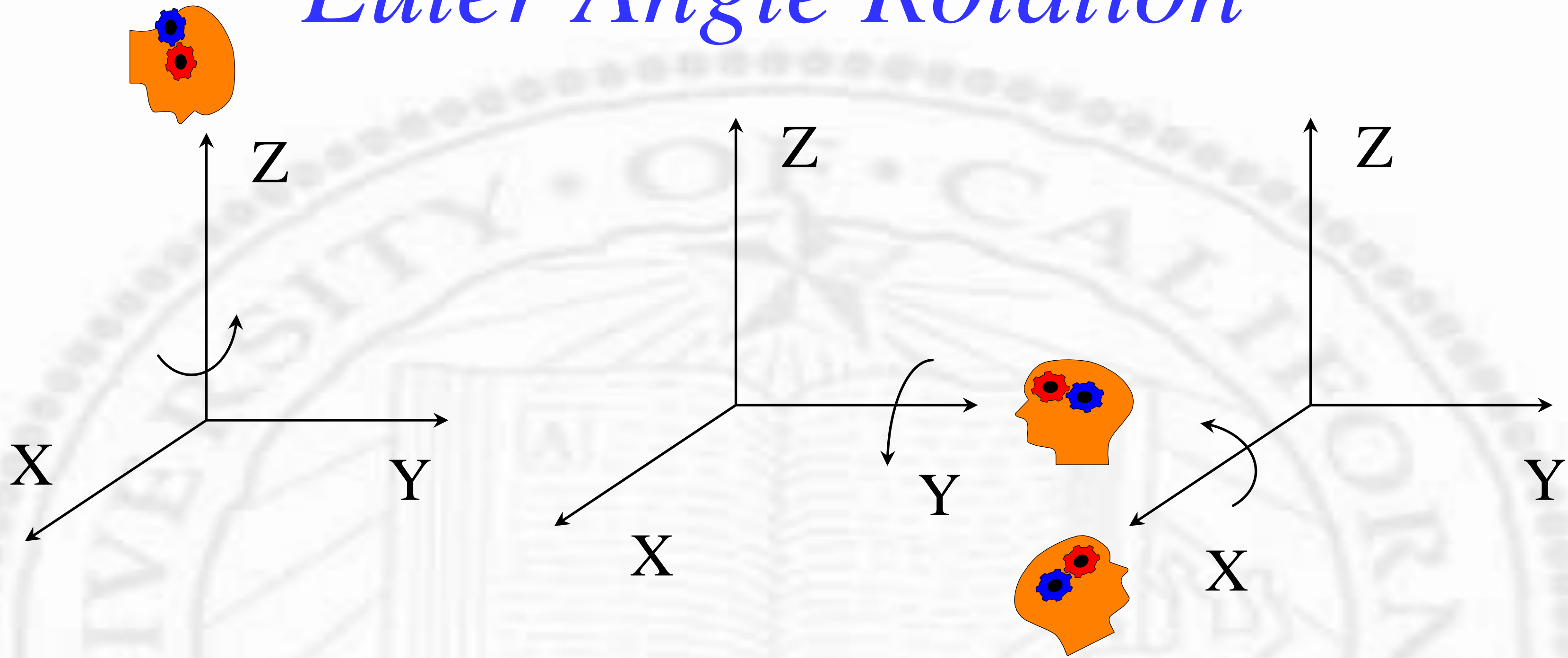
Rotation



Euler Angle Rotation



$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

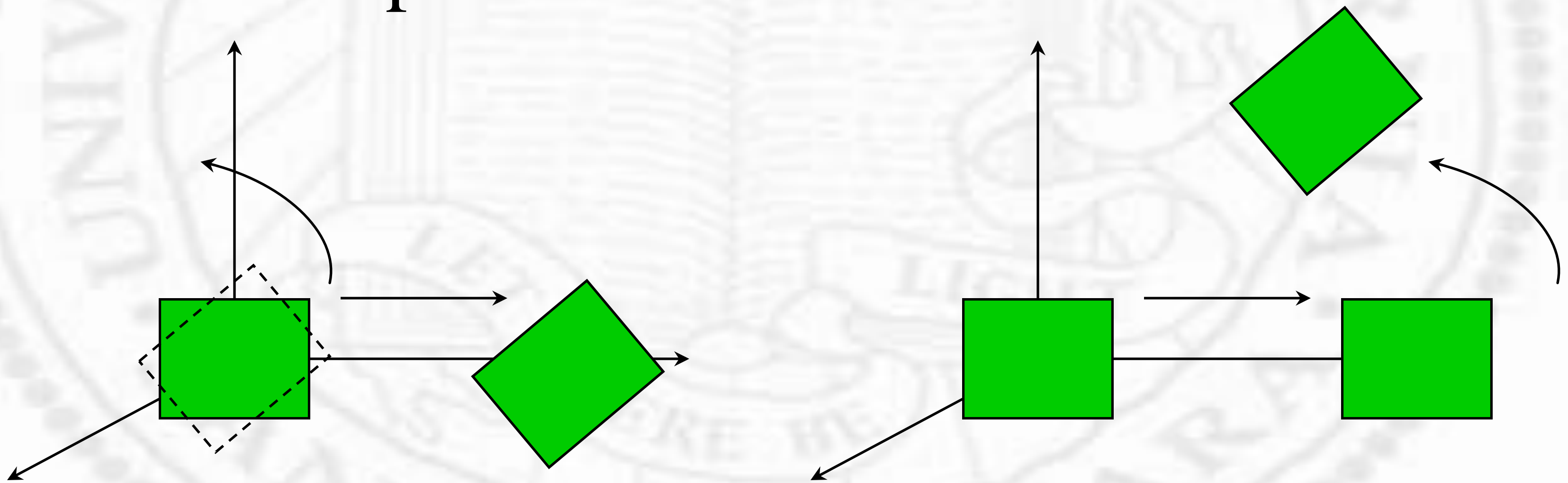
$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Step 1: Modeling Transform

glTranslate[f,d](x,y,z)
glRotate[f,d](angle,x,y,z)
glScale[f,d](x,y,z)

- Order is important



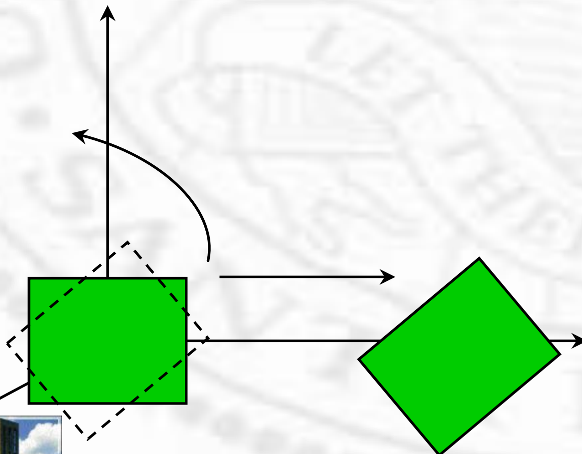
Rotate *then* Translate

Translate *then* Rotate

Step 1: Modeling Transform *(cont.)*

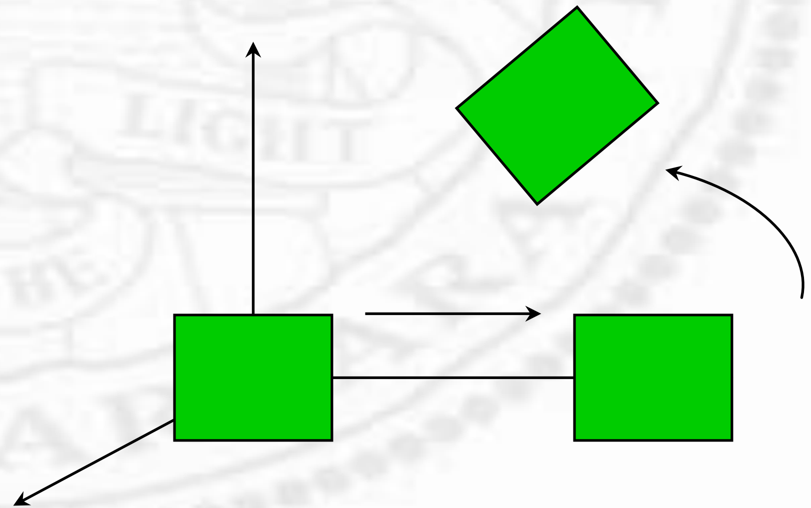
```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
glMultiMatrixf(T);
glMultiMatrixf(R);
draw_the_object(v);
```

v' = ITRv



```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
glMultiMatrixf(R);
glMultiMatrixf(T);
draw_the_object(v);
```

v' = IRTv



Modeling Transform

- Usually, think there is a global "world" coordinate system where
  - all objects are defined
  - rotation, translation, scaling of *objects* in the world system
  - order is *reverse* (backward)
- Can also be thought in a "local" (camera) coordinate system where
  - x, y, z are fixed w.r.t the reviewer (camera)
  - Coordinate system moves with the viewer
  - Order is forward

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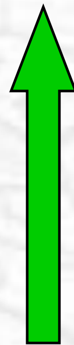
Two Different Views

- As a global system
  - object moves but coordinates stay the same
  - apply in the *reverse* order
- As a local system
  - object moves and coordinates move with it
  - applied in the *forward* order

- ***The code and OpenGL operation are identical!!!***
- ***The difference is in how you (human) interpret what happens!!!***

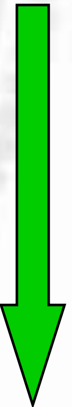
```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity(T1);
glMultiMatrixf(T2);
…
glMultiMatrixf(Tn);
draw_the_object(v);
```

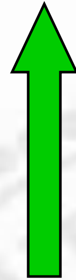
$\mathbf{v' = IT_1T_2T_nv}$



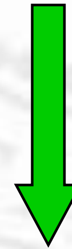
```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity(T1);
glMultiMatrixf(T2);
…
glMultiMatrixf(Tn);
draw_the_object(v);
```

$\mathbf{v' = IT_1T_2T_nv}$

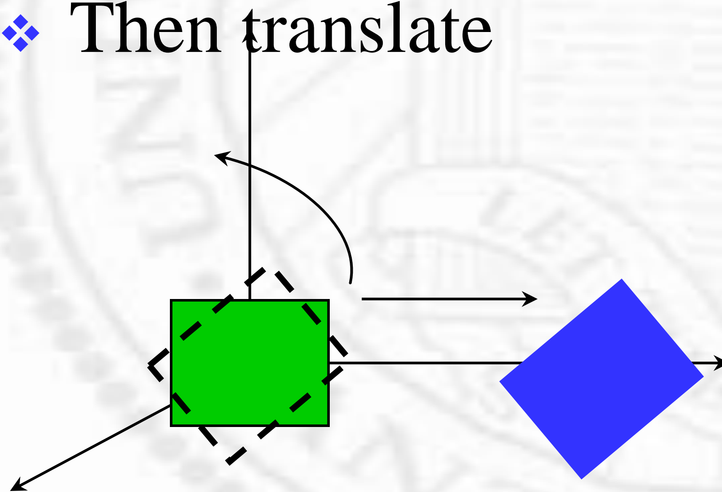




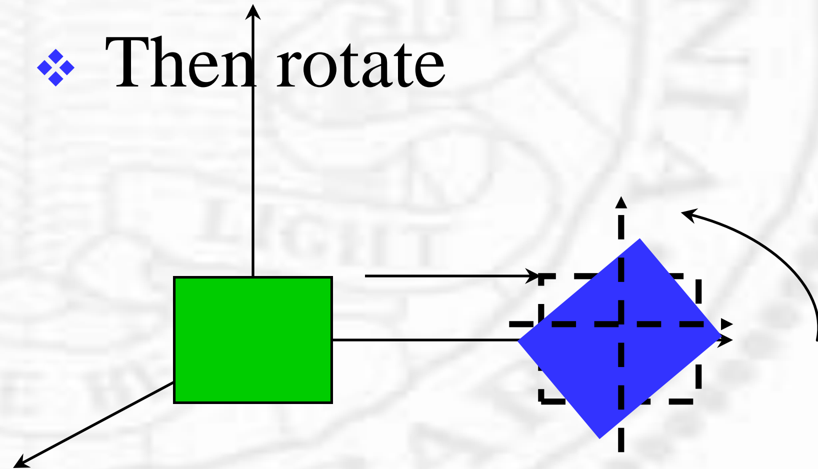
```
glLoadIdentity();
glMultiMatrixf(T);
glMultiMatrixf(R);
draw_the_object(v);
```

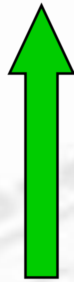


- Global view
- Roate object
- Then translate



- Local view
- Translate object (*and coordinate*)
- Then rotate

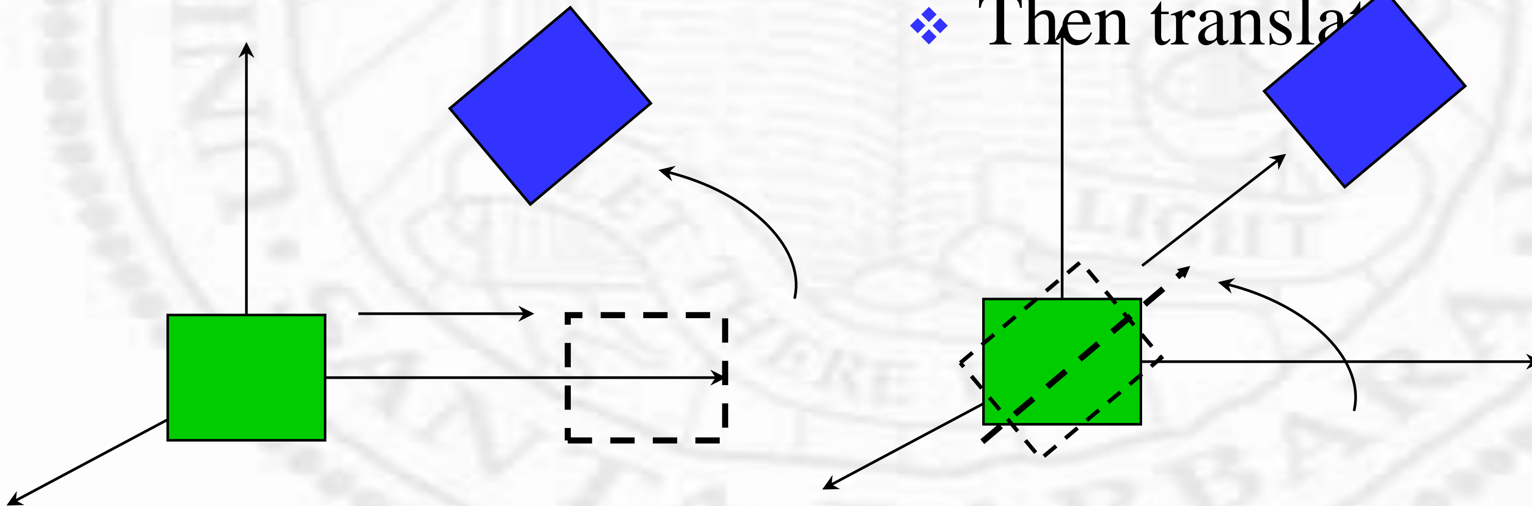


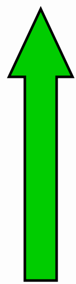


```
glLoadIdentity();
glMultiMatrixf(R);
glMultiMatrixf(T);
draw_the_object(v);
```

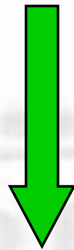
- Global view
- Translate object
- Then rotate

- Local view
- Rotate object (*and coordinate*)
- Then translate





```
glLoadIdentity();
glRotate(0,0,90);
glTranslate(1,0,0);
glRotate(0,0,45);
glTranslate(1,0,0);
draw_the_object(v);
```



```
glLoadIdentity();
glRotate(0,0,90);
glTranslate(1,0,0);
glRotate(0,0,45);
glTranslate(1,0,0);
draw_the_object(v);
```

$(-\frac{1}{\sqrt{2}}, 1+\frac{1}{\sqrt{2}})$

$(-\frac{1}{\sqrt{2}}, 1+\frac{1}{\sqrt{2}})$

y

$(\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}})$

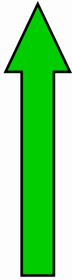
(0,1)

$(1+\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}})$

(0,0) (1,0) x

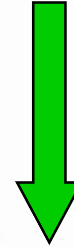
(0,0)

z



```
glLoadIdentity();
glRotate(0,0,90);
glTranslate(0,1,0);
glScale(2,0.5,1);
glTranslate(1,0,0);
draw_the_object(v);
```

```
glLoadIdentity();
glRotate(0,0,90);
glTranslate(0,1,0);
glScale(2,0.5,1);
glTranslate(1,0,0);
draw_the_object(v);
```



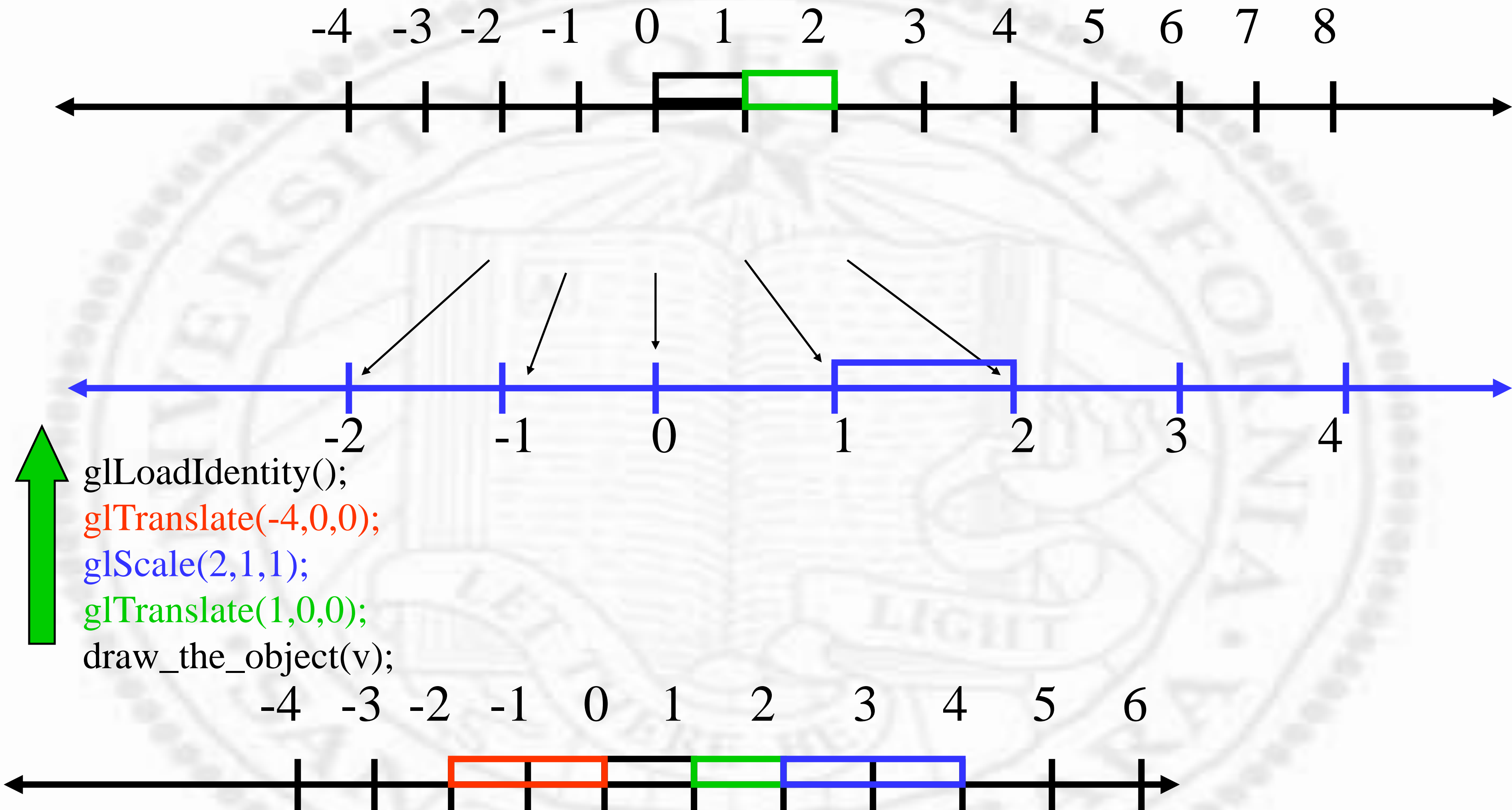
Caveats: scale in local view may distort coordinate systems!!

(−1,3)
(−1,1)
y
(1,1)
(3,1)
(0.5,0)
(1.5,0)
(−0.5,0)
(1,0)
(3,0)
x
z

A movement of 2 instead of 1!

(−1,3)
(−1,1)
(0,0.5)
(−1,0.5)
(−0.5,0)
(0.5,0)
(−1,−0.5)
(0,−0.5)
(−1,−1)

More on Scaling



Hierarchical Transform

- Used very frequently for building complex objects in a modular manner
- Cf. subroutine calls
- Be able to push and pop transform matrices as needed
- OpenGL provides two stacks
  - at least 32 4x4 model view matrices
  - at least 2 4x4 projection matrices
- glLoadMatrix(), glMultMatrix(), glTrans(rotate, scale, etc.) ***affect top-most (current) one*** (*the others are not affected*!)

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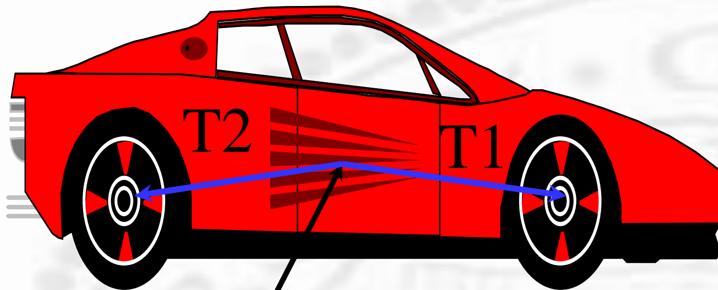
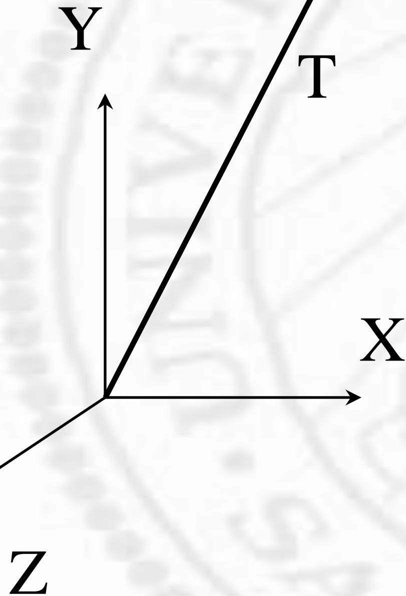
Hierarchical Transform (cont.)

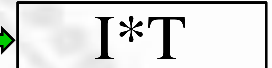
- void glPushMatrix(void)
  - topmost matrix is ***copied*** (top and second-from-top)
- void glPopMatrix(void)
  - topmost is ***gone*** (second-from-top becomes top)
- *Very* important
  - For OpenGL beginner
    - Transformation ordering
    - Transformation grouping

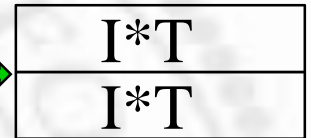
Hierarchical Transform (cont.)

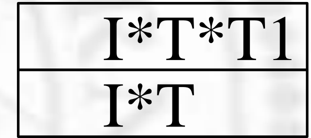


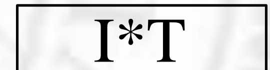


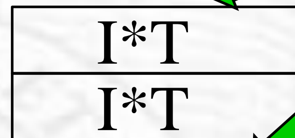

```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
glTranslatef(T);
draw_ car_body();
glPushMatrix();
    glTranslatef(T1);
    draw_wheel();
glPopMatrix();
glPushMatrix();
    glTranslatef(T2);
    draw_wheel();
glPopMatrix();
glPushMatrix();
...
```

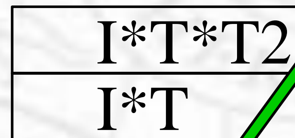






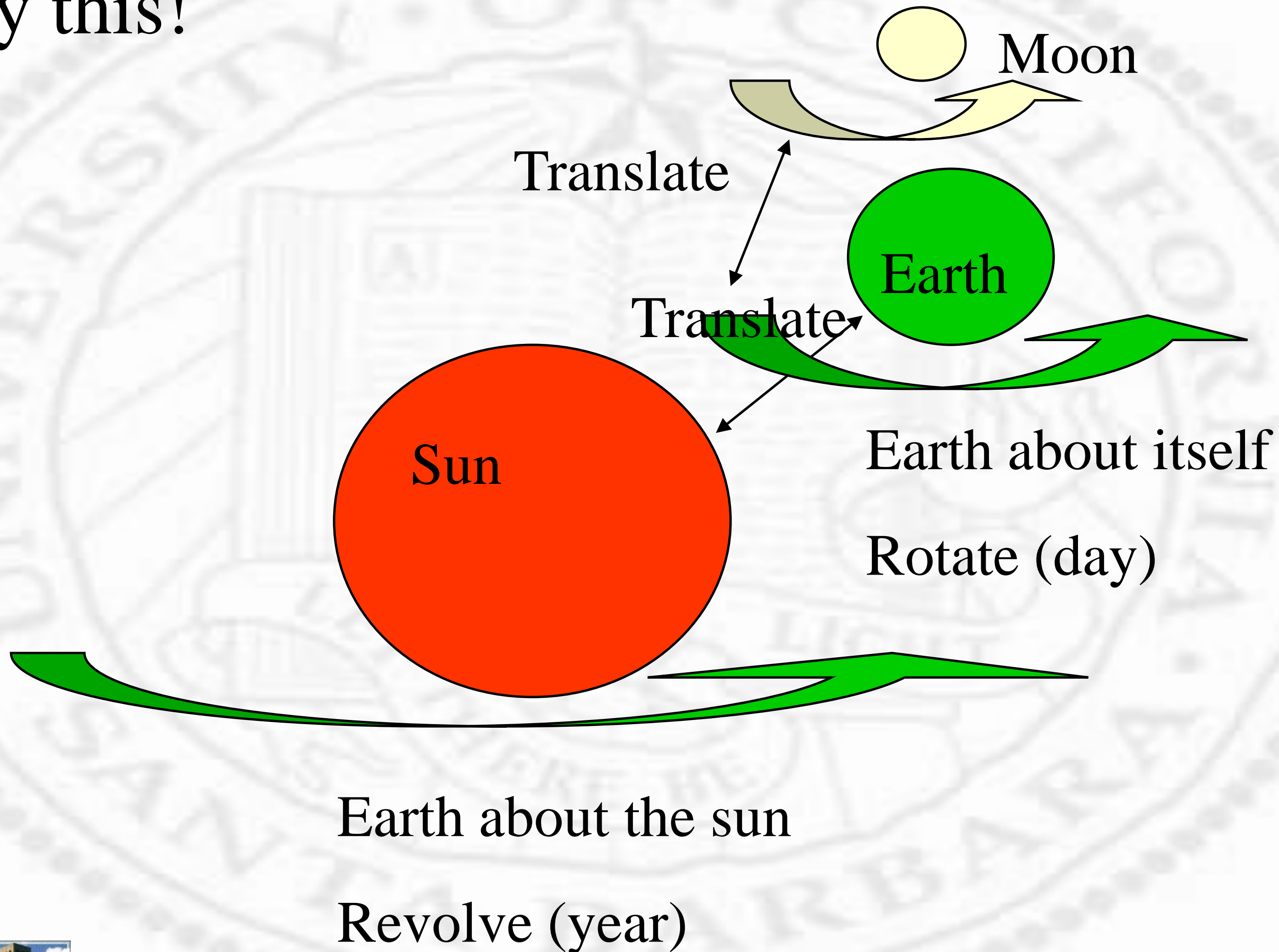






Hierarchical Transform

- Try this!



The Sun

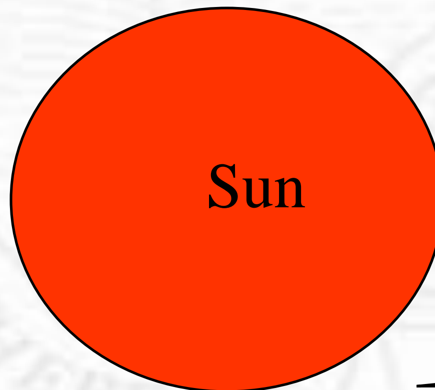
- Suppose the Sun is the center of the universe
  - No translation
  - Turn about itself

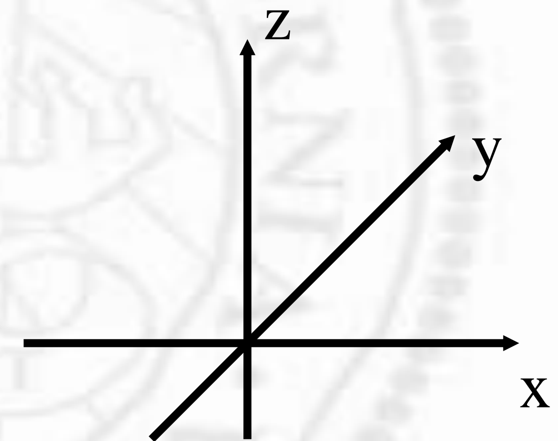
```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
glPushmatrix();
    glRotate(Rs);
    draw_sun();
glPopMatrix();
```

I

I
I

I*Rs
I

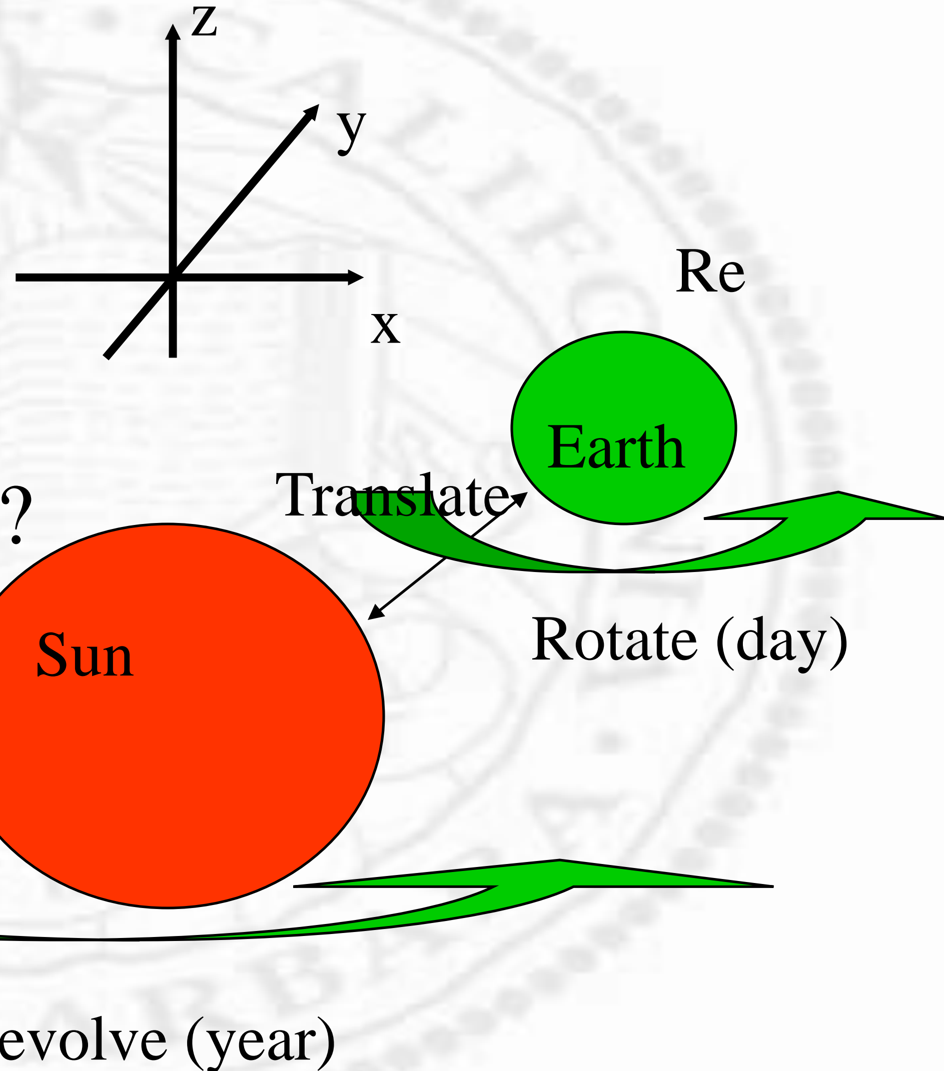




I

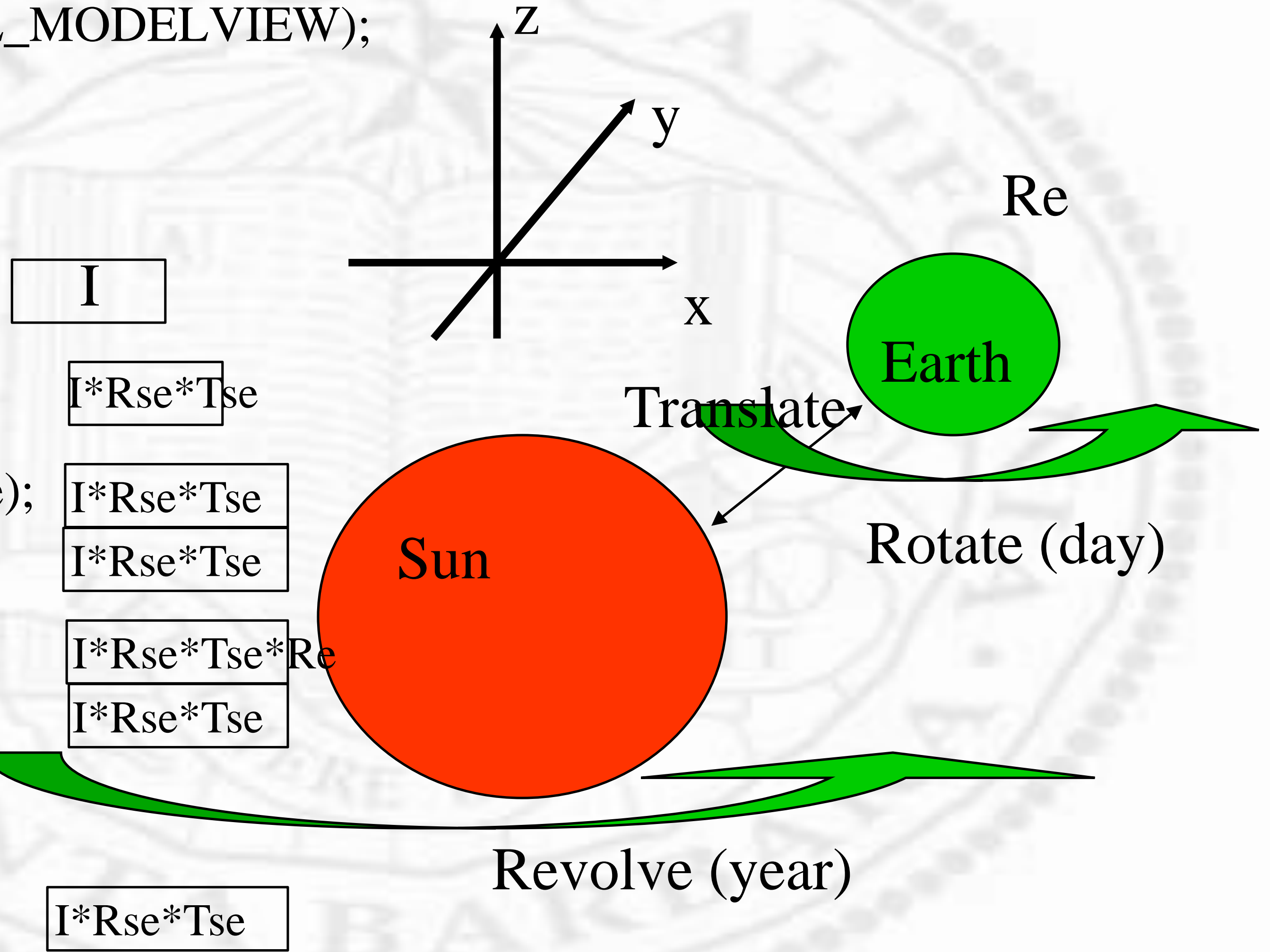
The Earth

- DOFs
  - Translation away from the sun
  - Rotate about the sun
  - Rotate about itself
- Which DOFs to isolate?
- Viewer centered or global view?



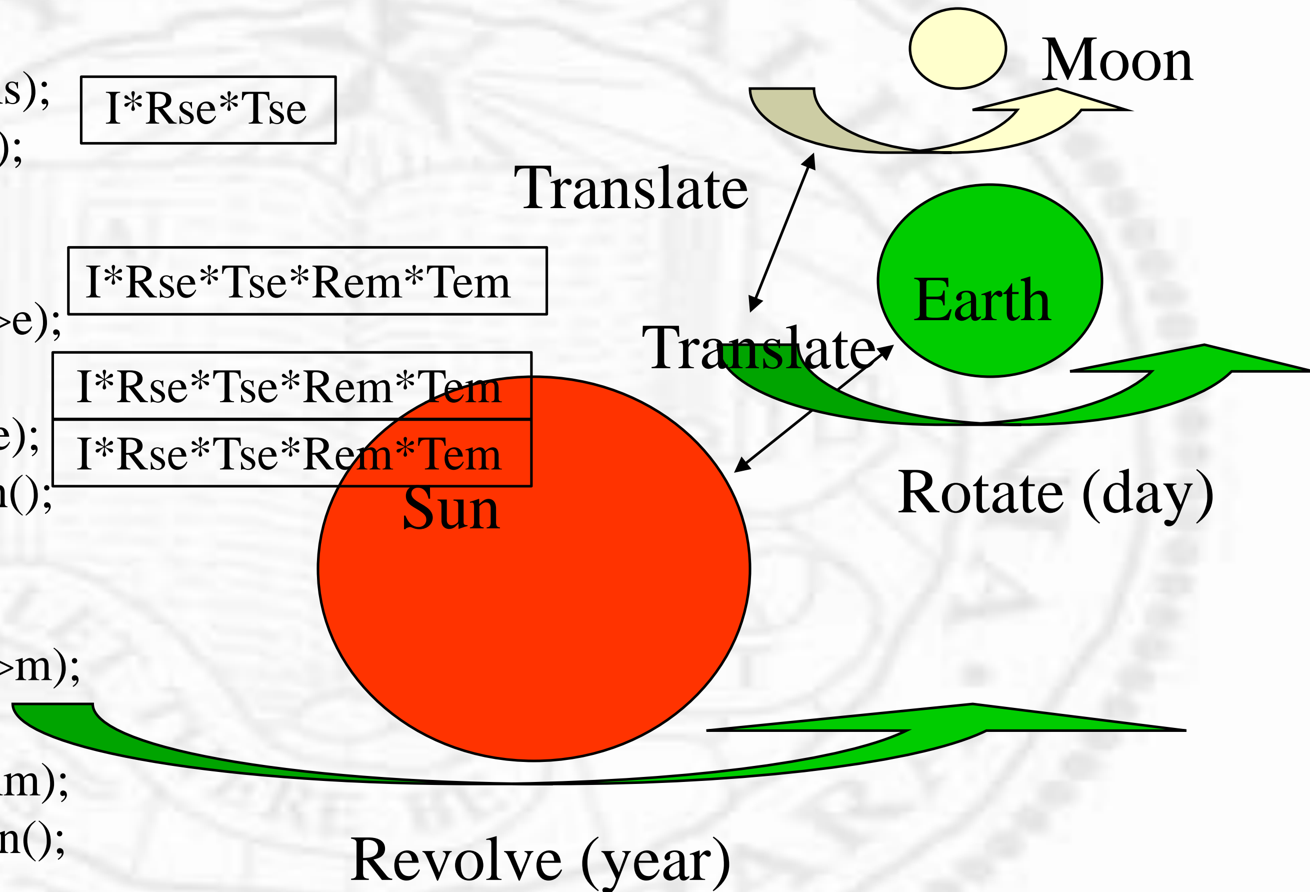
The Earth

```
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
glPushmatrix();
    glRotate(Rs);
    draw_sun();
glPopMatrix();
glRotate(Rs->e);
glTranslatef(Ts->e);
glPushMatrix();
    glRoate(Re);
    draw_earth();
glPopMatrix();
```



The Moon

- glMatrixMode(GL_MODELVIEW);
- glLoadIdentity();
- glPushmatrix();
- glRotate(Rs);
  draw_sun();
- glPopMatrix();
- glRotate(Rs->e);
- glTranslatef(Ts->e);
- glPushMatrix();
- glRoate(Re);
- draw_earth();
- glPopMatrix();
- glRotate(Re->m)
- glTranslatef(Te->m);
- glPushMatrix();
- glRotate(Rm);
- draw_moon();
- glPopMatrix();



Rules of thumb

- Go down
  - Push
- Go up
  - Pop
- Remember transform at a level to be reused by siblings
- Even with a singe branch (sun -> earth -> moon)
- Push and pop for transform applying only at a particular level

HomeWork

- Scene
  - Cube
    - Face
      - Polygon
      - Eaves
        - Face
        - …
        - Face
      - …
      - Eaves
    - …
    - Face
  - …
  - Cube

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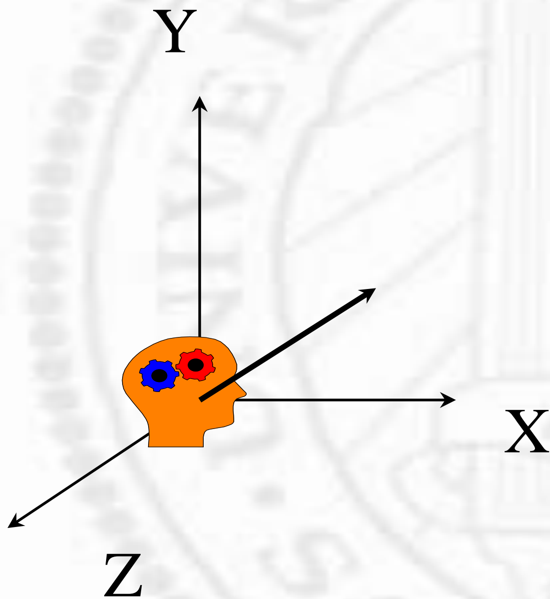
Viewing Transform (Extrinsic)

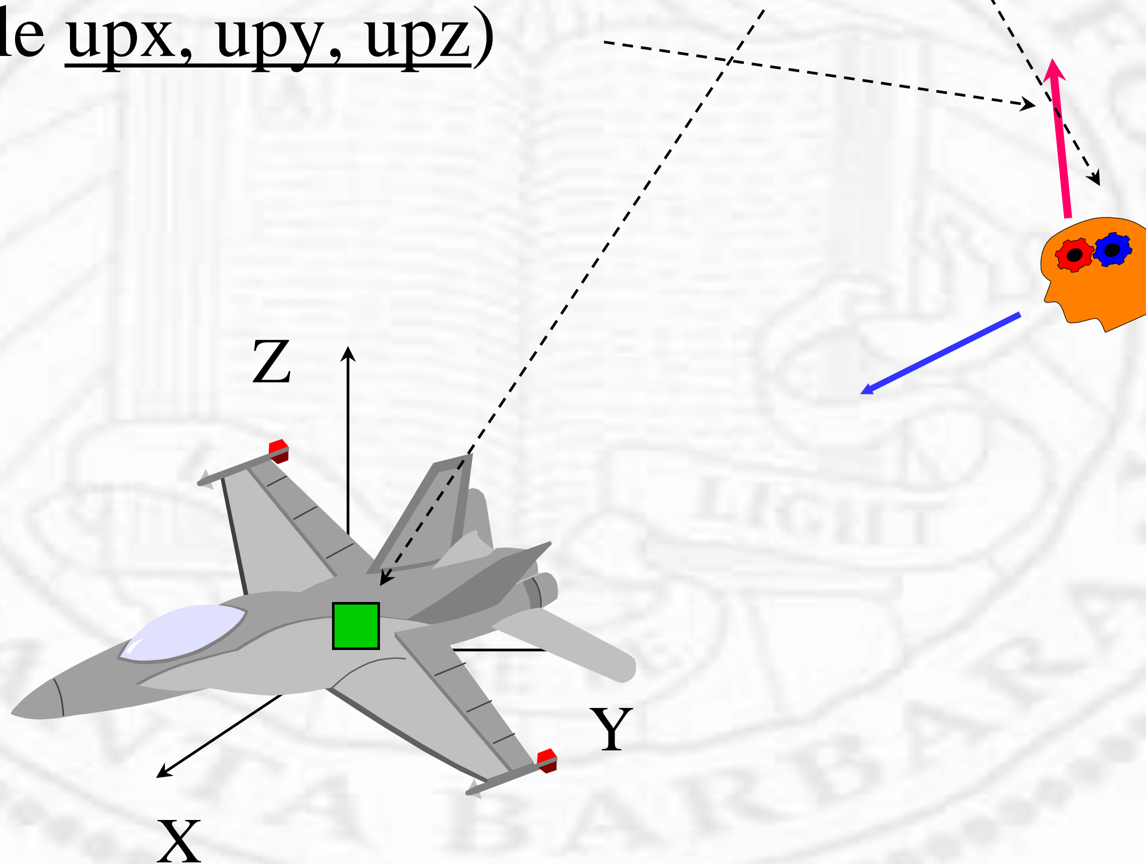
- Default: eyes at origin, looking along -Z



- Important parameters:
  - where is the observer (camera)?
    - *origin of the viewing system*
  - What is the look-at direction?
    - *-z direction*
  - What is the head-up direction?
    - *y direction*

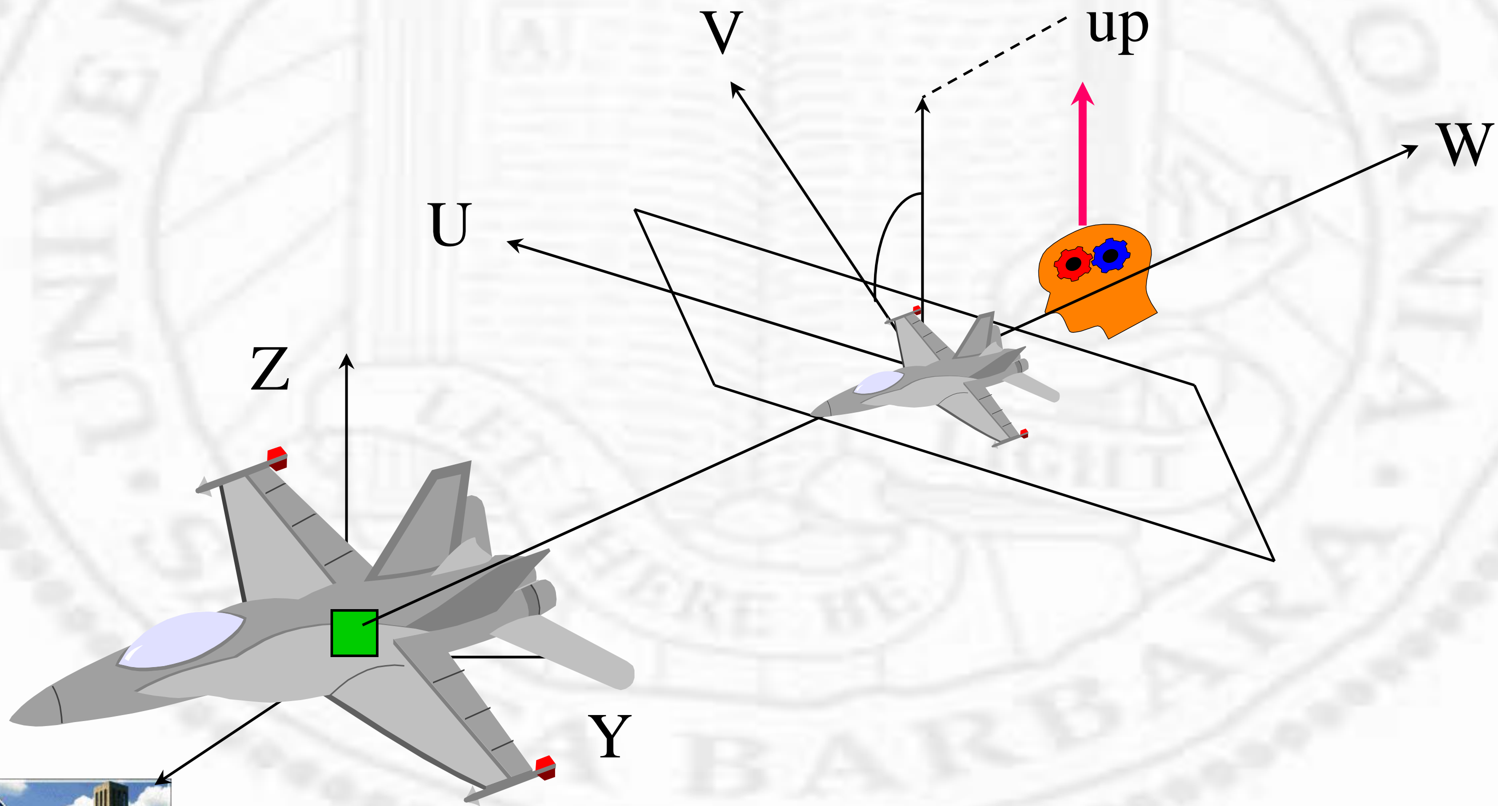
Viewing Transform (cont.)

void gluLookAt (GLdouble eyex, eyey, eyez,
GLdouble centerx, centery, centerz,
GLdouble upx, upy, upz)



Viewing Transform (cont.)

- **eye** and **center: local** w(z) direction
- **up** and **local w(z):** local v(y) direction
- **local v(y)** and **w(z)** directions: local u(x) direction

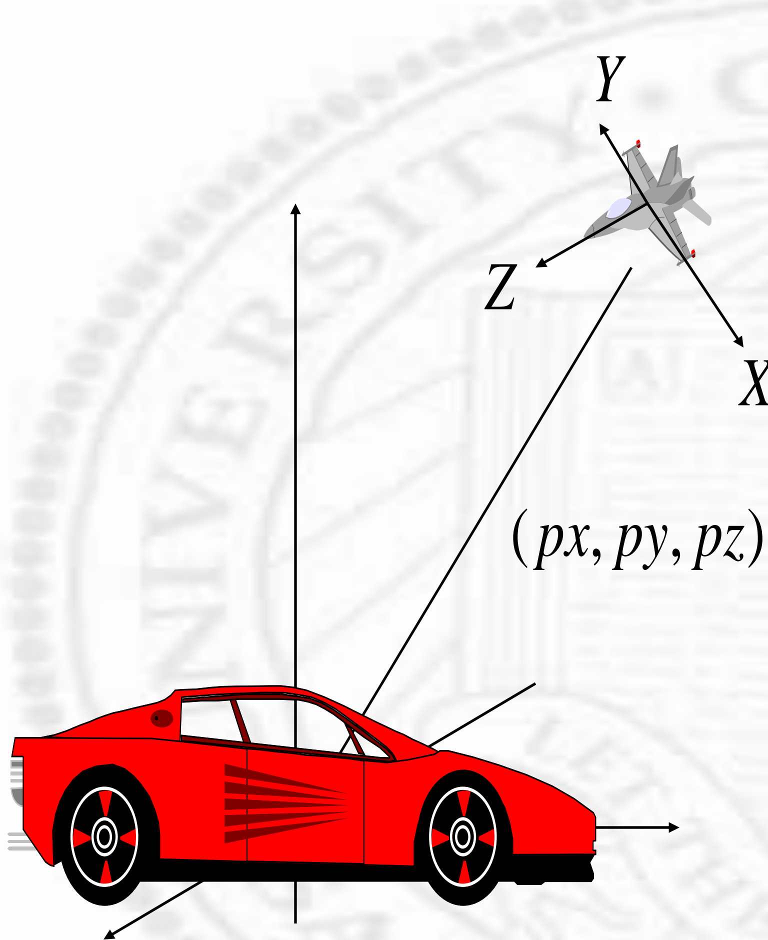


Viewing Transform

- Occur after modeling transform
- Usually involves only translation + rotation (no scaling)
- Best done by gluLookAt function
- Can also be done using glTranslate + glRotate (need to think about moving the camera instead of object in opposite way)

Viewing Transform - the hard way

- Use gluLookAt if possible
- Think in an object-centered way (forward)
- Camera is at the origin pointing along -z
- Rotate and translate objects to expose the right view



- glMatrixMode
- glLoadIdentity
- glRotateZ(roll)
- glRotateY(pitch)
- glRotateX(heading)
- glTranslate(-px,-py,-pz)
- Other modeling transform
- glBegin … glEnd

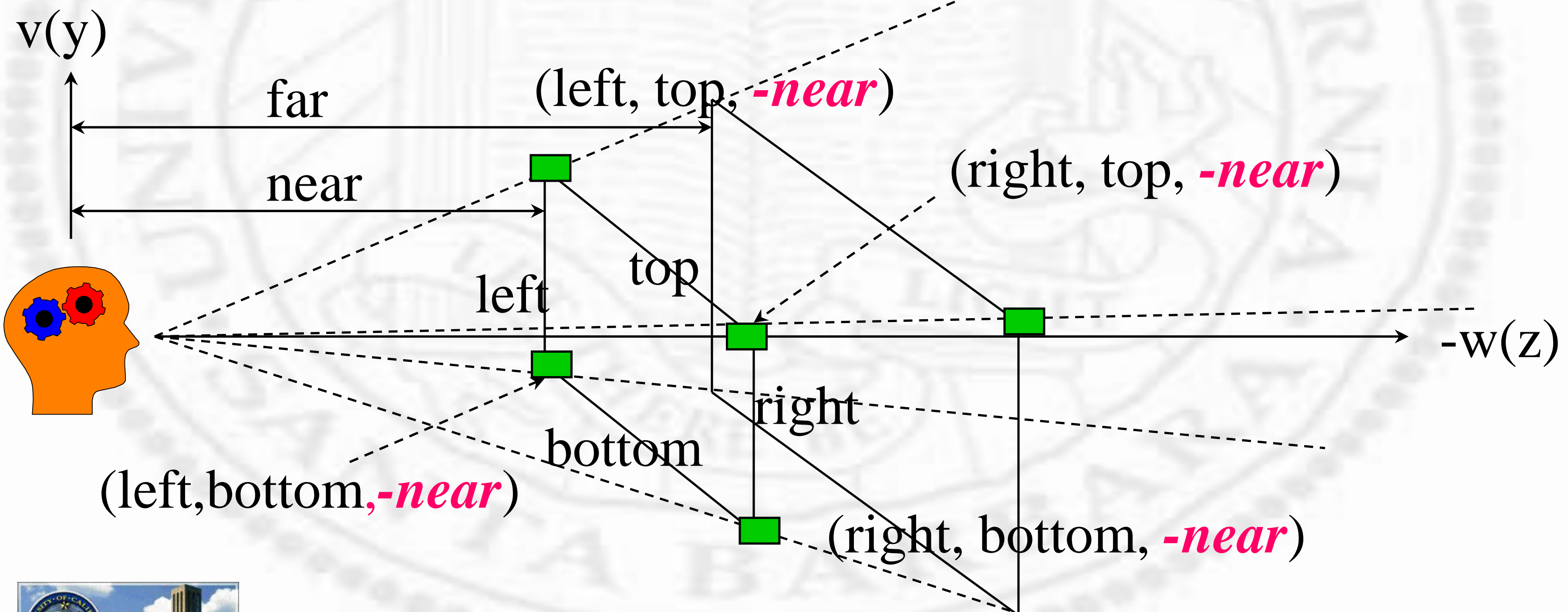
Shading and Texturing

- A BIG topic in graphics
- For photo realistic rendering
- Two aspects: *geometry* (location and orientation) and *appearance* (color, shading, texture)
- Here we concentrate on *geometry* only

Perspective Projection (Intrinsic)

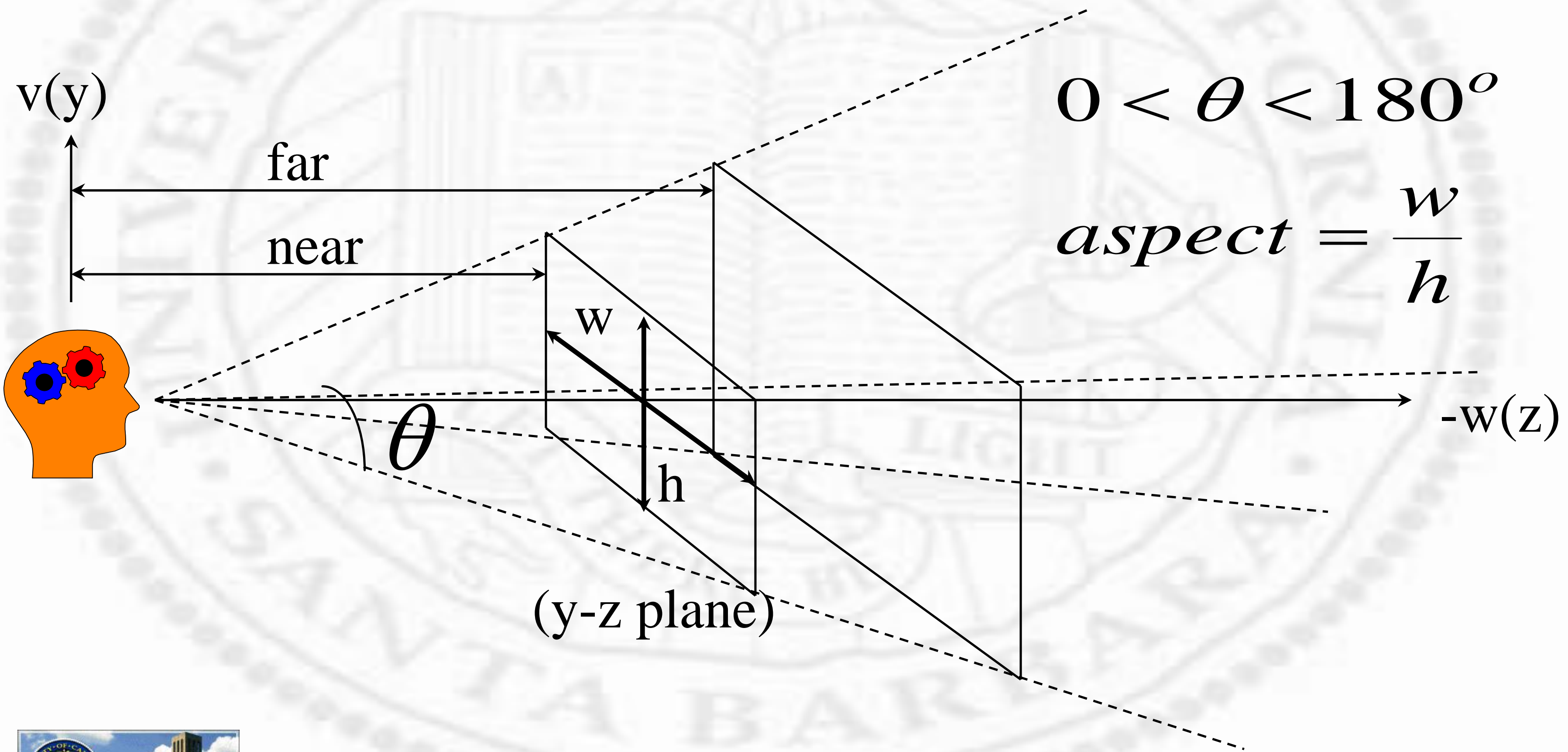
- glMatrixMode(GL_PROJECTION);
- glLoadIdentity();
- void glFustrum(GLDouble

  left, right, bottom, top, near, far);

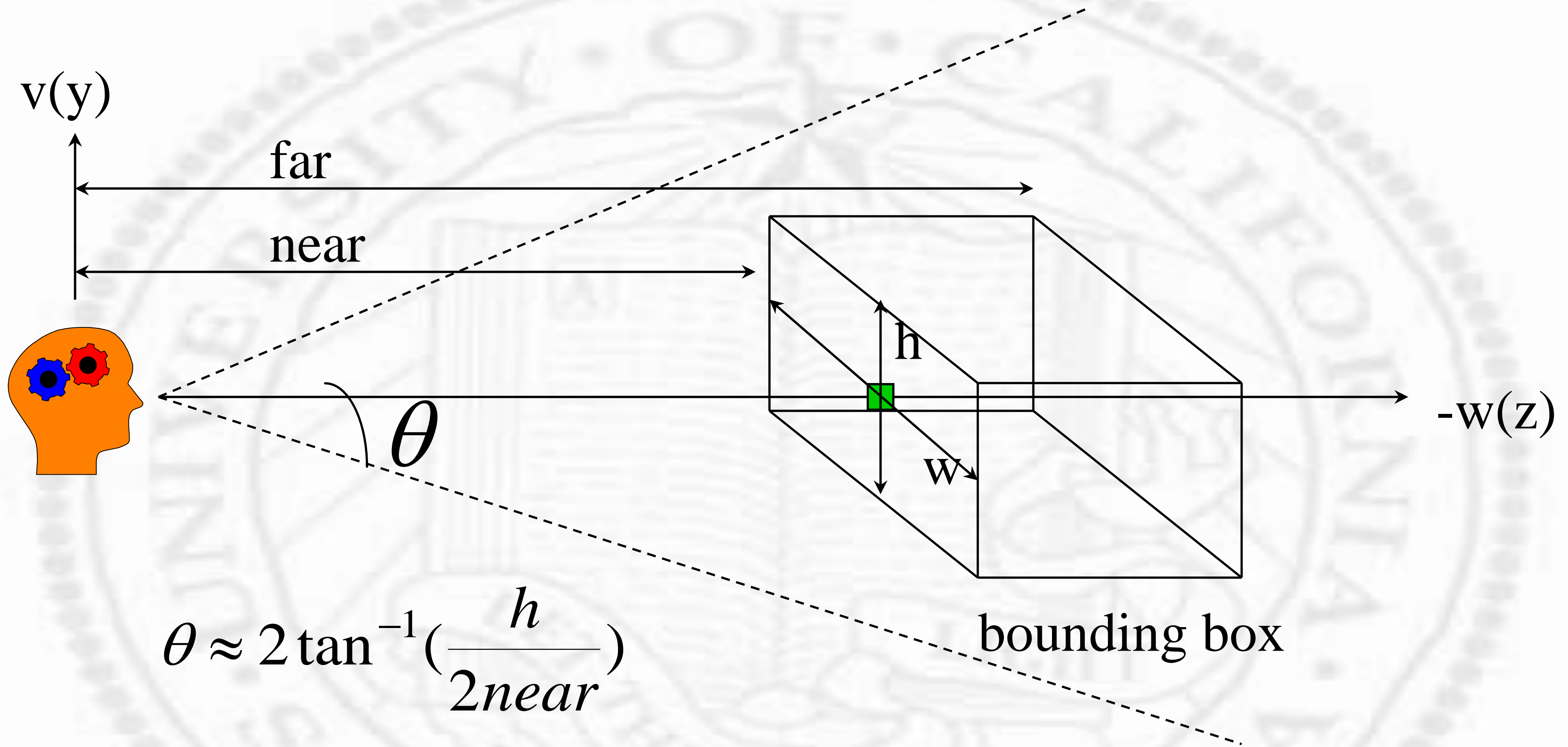


Perspective Projection (cont.)

- void gluPerspective(GLdouble fovy, aspect, near, far)-- for **symmetric** view volume



Perspective Projection (cont.)



$$\theta \approx 2\tan^{-1}\left(\frac{h}{2near}\right)$$

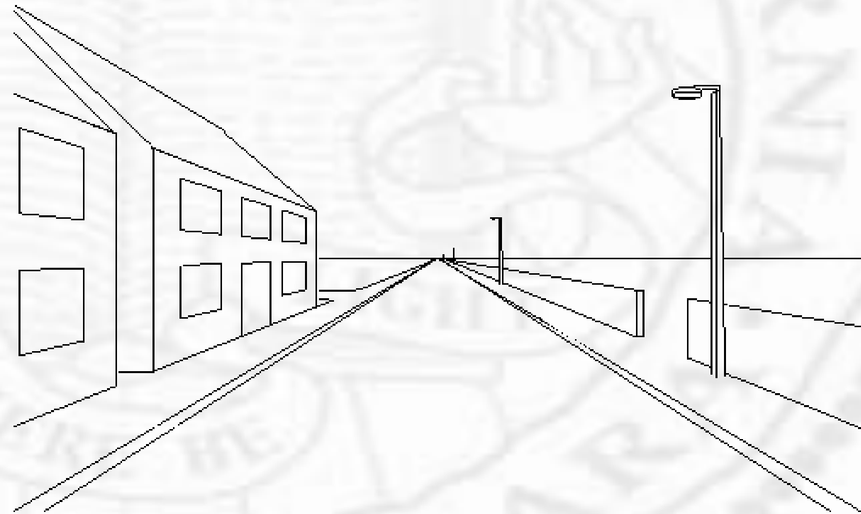
$$aspect \approx \frac{w}{h}$$

Example

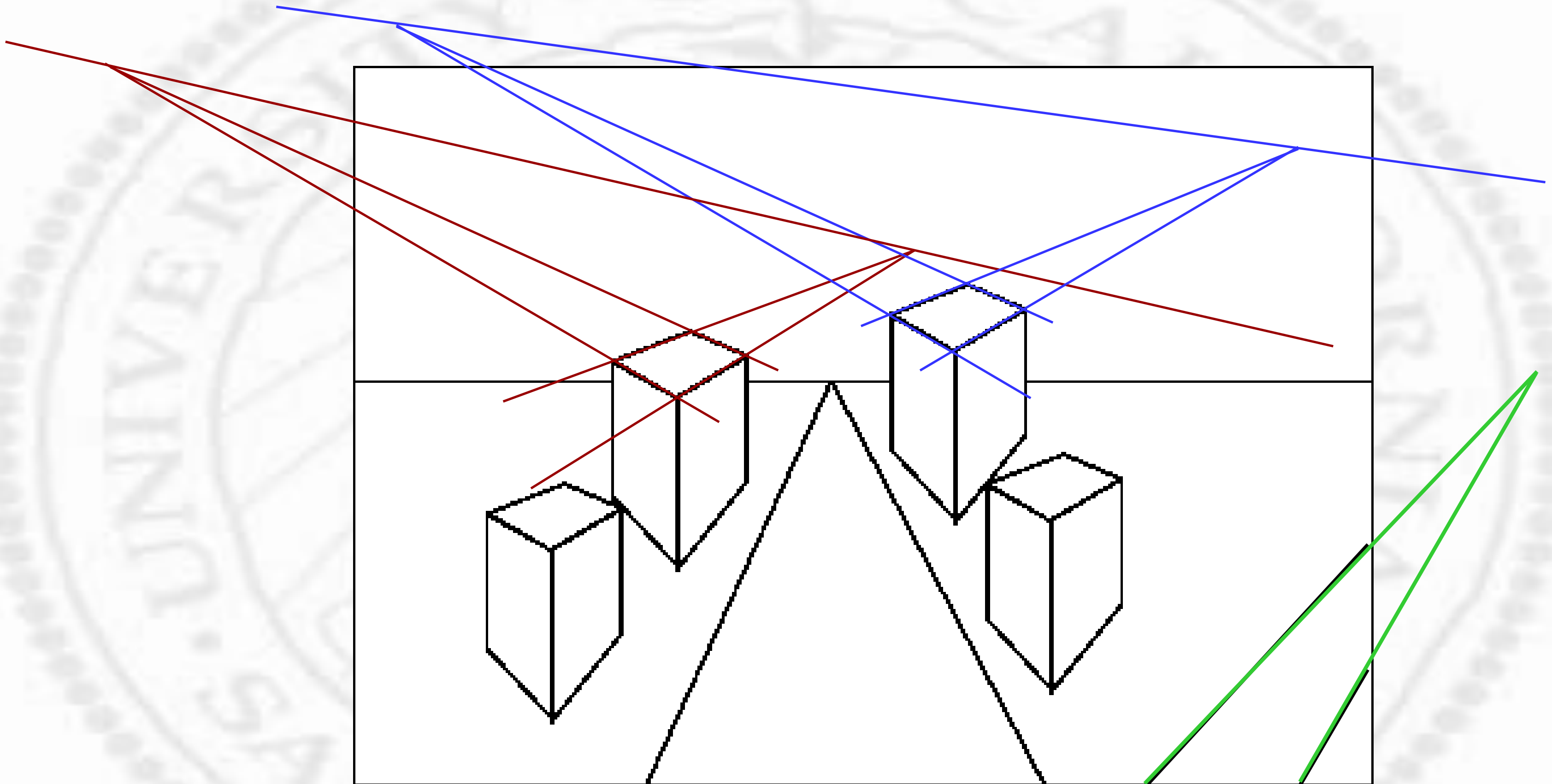
Example

Vanishing points, horizon lines

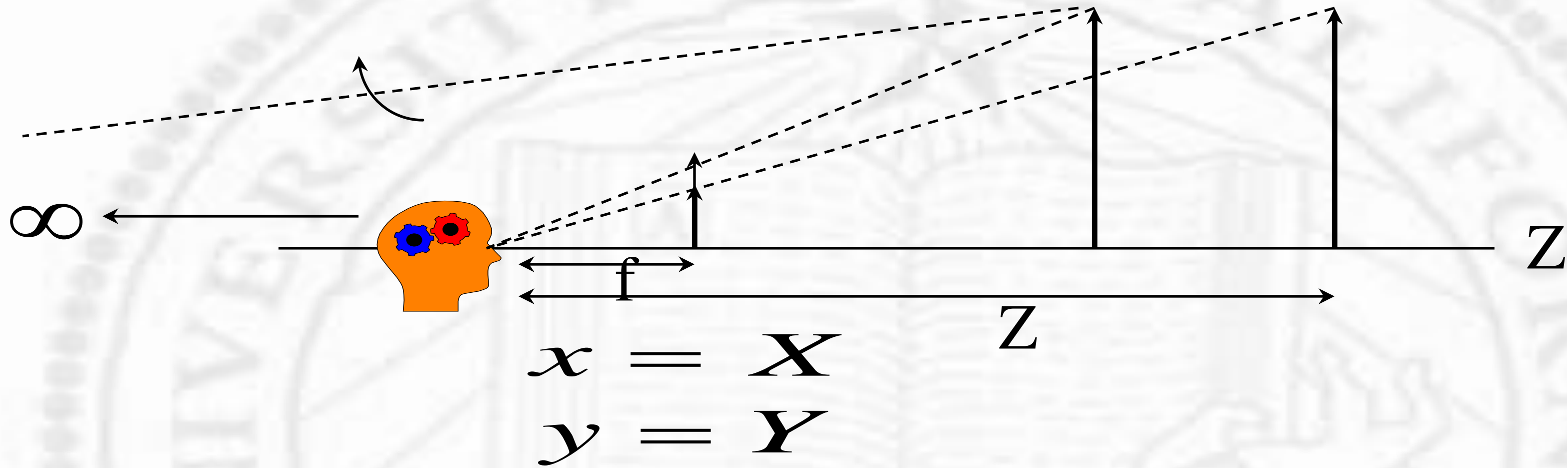
- Parallel lines in the scene intersect at the *horizon line*
  - Each pair of parallel lines meet at a *vanishing point*
  - The collection of vanishing points for all sets of parallel lines *in a given plane* is collinear, called the *horizon line* for that plane



Vanishing points, horizon lines



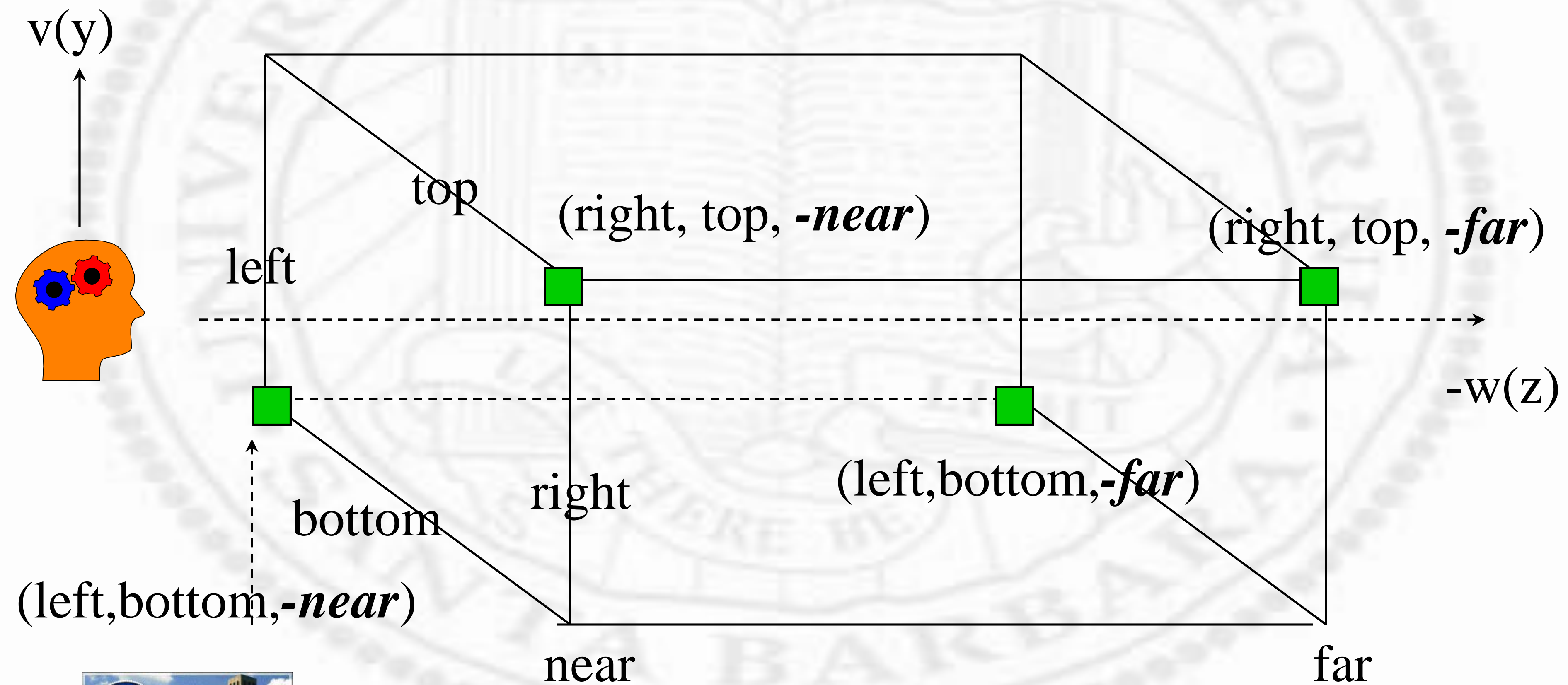
Parallel (Orthographical) Projection



- No perspective foreshortening
  - sizes and angles can be measured and compared
- Useful for engineering drawing
  - top, front, side views

Parallel (Othographic) Projection

- void glOrtho(GLdouble left, right, bottom, top, near, far)

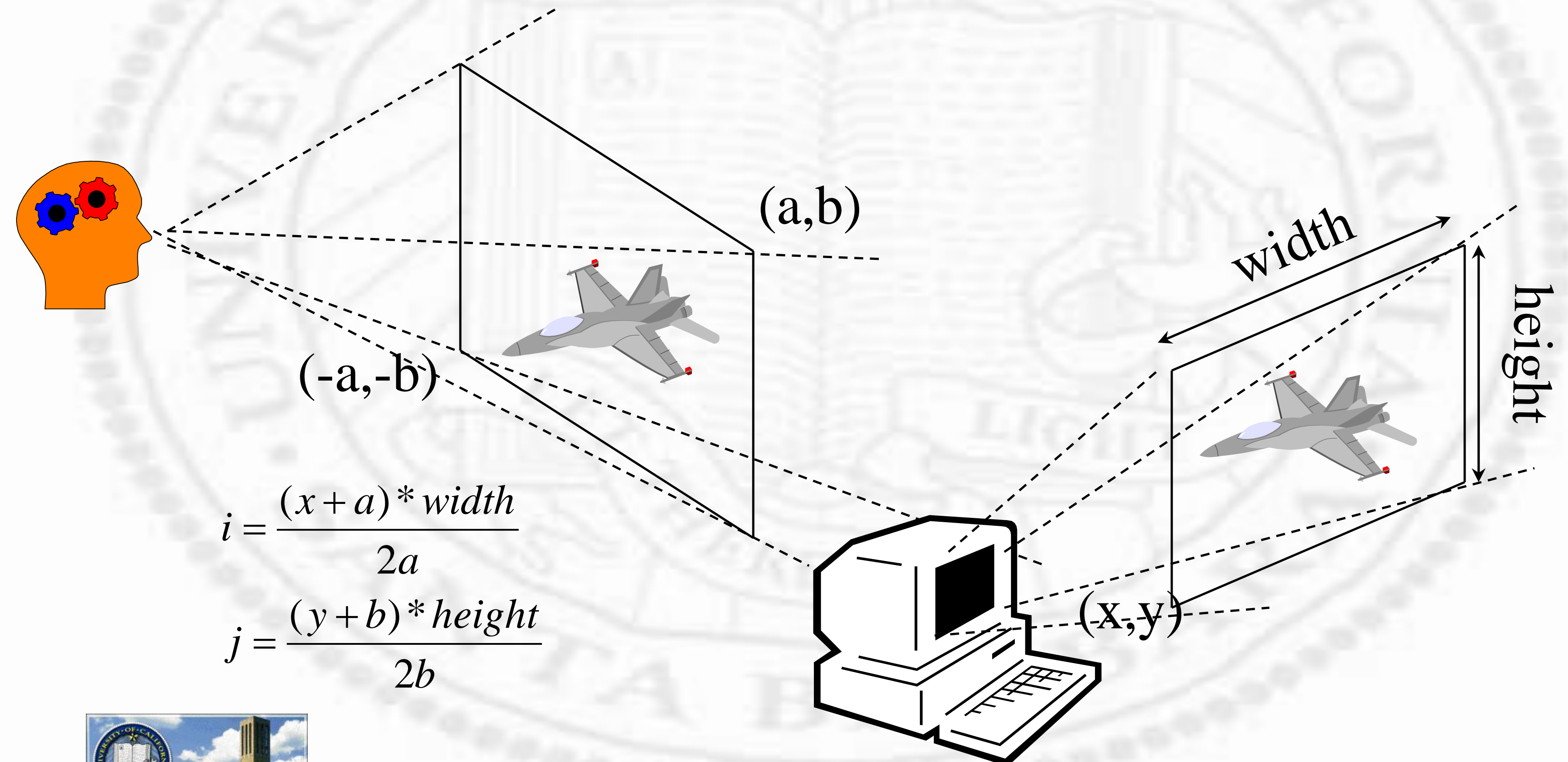


Clipping

- Get rid of the things that are not seen
- To do things efficiently require some mathematical twiddling (details later)

Viewport Transform

- void glViewport(GLint x, y, GLsizei width, height);
- The internal buffer is mapped to the rectangle specified by (x,y) lower left corner of size width and height



$$i = \frac{(x+a)*width}{2a}$$

$$j = \frac{(y+b)*height}{2b}$$

Viewport Transform

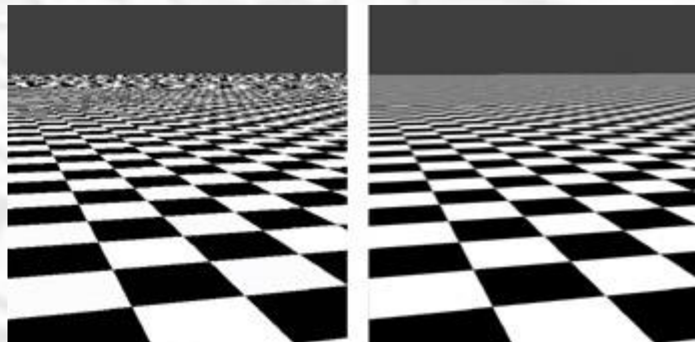
- Multiple buffers can be mapped to a single window (if they have different viewports)
- Distortion may occur if viewport does not have the right aspect ratio

gluPerspective(fovy, 1.0, near, far)
glViewport(0,0,400,400)

gluPerspective(fovy, 1.0, near, far)
glViewport(0,0,400,200)

Image Plane?

- Q: Where it is?
- A: It doesn't really matter (conveniently set at z=-1)
- Q: What is the film resolution?
- A: Depend on the real window resolution
  - In reality, to get smooth (anti-aliased) display, rendering is done at sub-pixel accuracy (A-buffer)



OpenGL-Related Libraries

- GLU (prefix glu-)
  - utility library
- GLX (prefix glX-)
  - OpenGL extension to X
- Programming Guide aux library (prefix aux-)
  - windowing, input, simple objects (also try ToGL)
- GLUT (prefix glut-)
  - windowing, input, simple objects (OpenGL1.1 and later, replacing aux-)

OpenGL-Related Libraries

- Open Inventor
  - objects + methods of interaction
  - creating + editing 3D scenes
  - data format exchange

(Most) Basic OpenGL

- Create a drawing buffer (*not* a screen window)
- Clear buffer
- Draw to buffer
- Link buffer to screen window display
- Interaction (expose, resize, mouse, keyboard input, etc).

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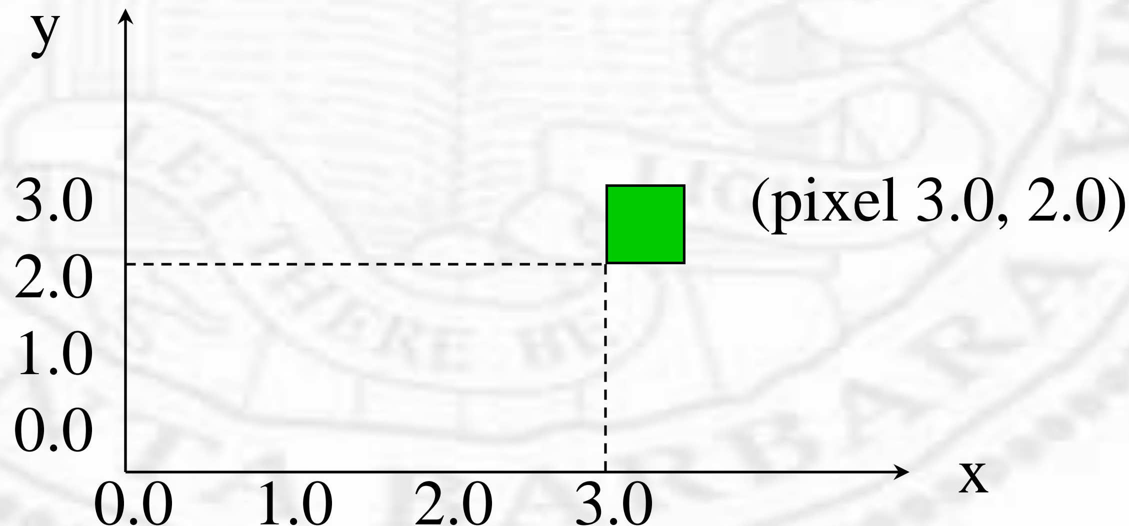
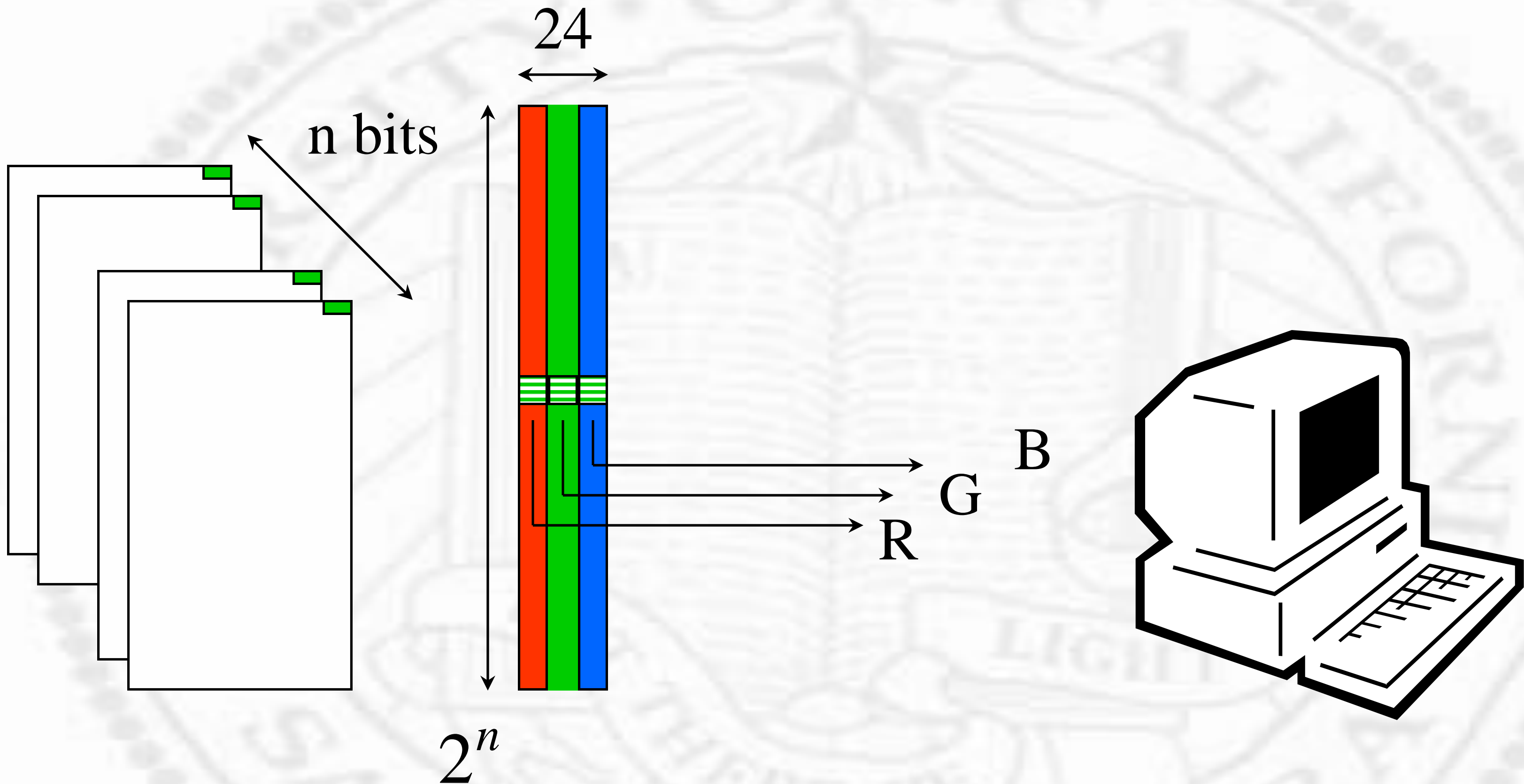
OpenGL Buffers

- Rectangular arrays of pixels
- Color buffers: front-left, front-right, back-left, back-right
  - At least one, color indexed or RGBA
  - Stereoscopic systems have left and right
  - Doubled buffered systems have front and back



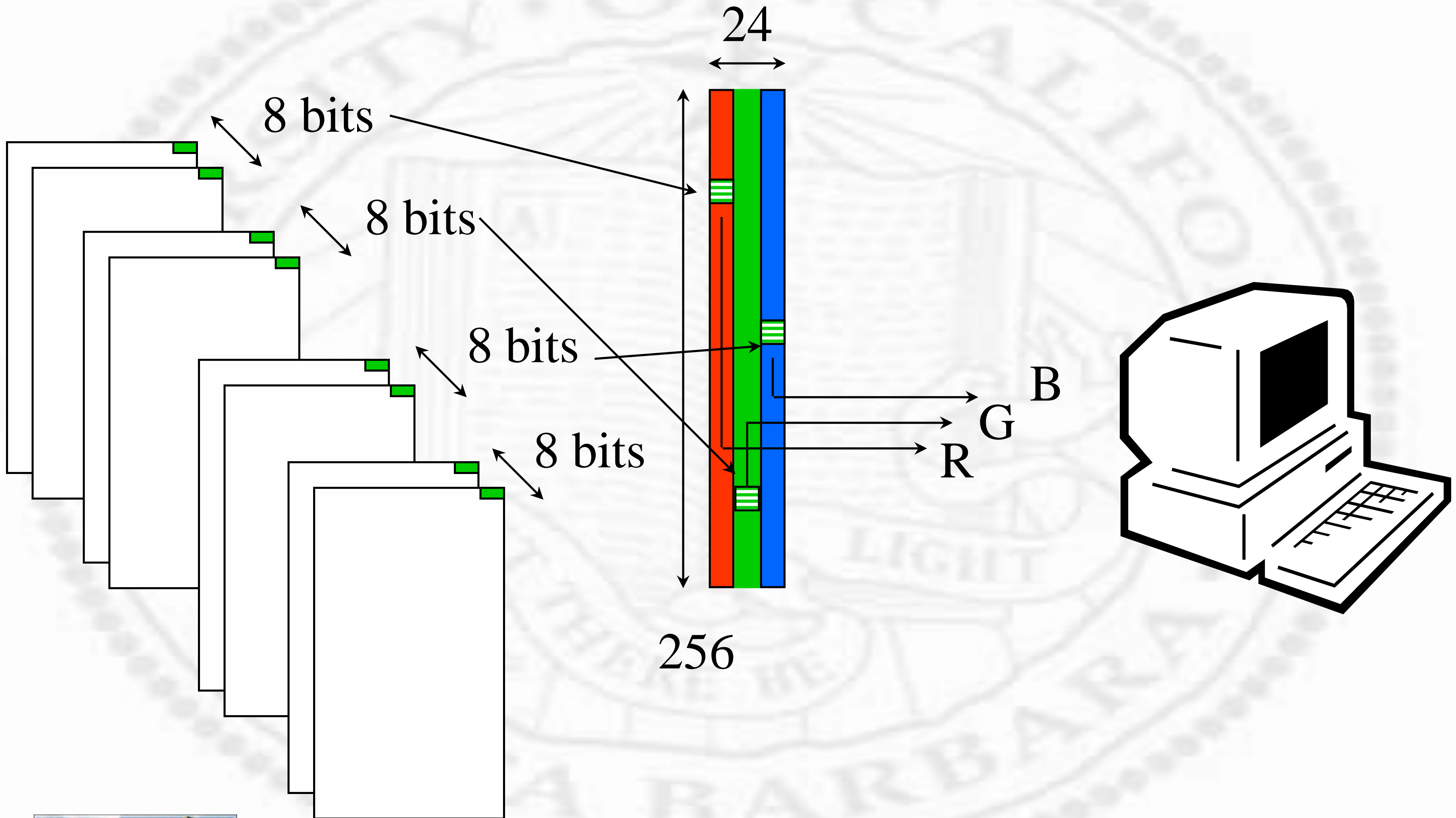
OpenGL Buffers

- Color Indexed Buffer



OpenGL Buffers

- RGBA Buffer



Other OpenGL Buffers

- Depth buffers:
  - for determining hidden surface effects
- Stencil buffers:
  - acts like a cardboard stencil (“dirty windshield effect”)
- Accumulation buffers:
  - for accumulating multiple images into one (e.g. for anti-aliasing, motion blur)

OpenGL Buffer Operations

- Clear
  - void glClear[Color,Index,Depth,Stencil,Accum]
    - E.g. glClearColor(0.0,0.0,0.0,0.0);
    - glClearDepth(1.0);
    - Set clear color, depth values
  - void glClear (GLbitfield mask)
    - GL_COLOR_BUFFER_BIT
    - GL_DEPTH_BUFFER_BIT
    - GL_STENCIL_BUFFER_BIT
    - GL_ACCUM_BUFFER_BIT
- Etc.

OpenGL Buffer Operations *(cont.)*

- Draw
  - void glDrawBuffer(GLenum mode)
    - enabled for writing or clearing

    GL_FRONT, GL_BACK, GL_RIGHT, GL_LEFT

    GL_FRONT_RIGHT, GL_FRONT_LEFT, GL_BACK_RIGHT, GL_BACK_LEFT

    GL_AUXI, GL_FRONT_AND_BACK,

    GL_NONE

Misc. OpenGL Functions (cont.)

- Color
  - void glColor3f(r,g,b) $0 \le r, g, b \le 1$
  - "flat" color with no variation
  - affects subsequent primitives
- Proper depth cue
  - void glEnable (GL_DEPTH_TEST)
  - void glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT)

Misc. OpenGL Functions

- Forced completion
  - void glFlush(void)
    - asynchronous
  - void glFinish(void)
    - synchronous
  - One of them should be called (glFlush()) at the end of each frame

Helper Libraries

- Remember that OpenGL does *not* do
  - windowing, GUI, and modeling
- A real application will need all the above
- At least three choices
  - GLUT (GL Utility Library) or aux (obsolete)
    - simple windowing, GUI and models
    - /fs/contrib/src/mesa/current/sample_executable/glut for GLUT examples (aux examples very similar)
  - Togl
    - allow OpenGL to work with Tcl/Tk for a much more sophisticated GUI

GL Utility Library (glut)

- Convenient and easy-to-use
- For
  - specifying the display mode
  - creating window (size and location)
  - handling window and input events
  - convenient objects
  - Menu and buttons
- Replaced aux library after version 1.1
- Use X Window callback mechanism, ported to both MS Windows and Mac

GUI Programming

- Have little control of what user will do
  - Self (resize, minimize, maximize, reshape, key, mouse)
  - Others (overlap, pop up or down)
- Window manager is the master (UI policy)
- Prepare for all contingency (events) in advance and register with glut
- At run time, window manager delivers events and data to glut to invoke the right "callback"

GL Utility Library (glut)

- Void glutInit(int argc, char **argv)
  - initialize glut, process command line arguments such as -geometry, -display, etc.
- void glutInitDisplayMode(unsigned int mode)
  - Mode for later glutCreateWindow() call
  - GLUT_RGBA or GLUT_INDEX
  - GLUT_SINGLE or GLUT_DOUBLE
  - Associated GLUT_DEPTH, GLUT_STENCIL, GLUT_ACCUM buffers
  - default: RGBA & SINGLE (use RGBA, DOUBLE, and DEPTH)

GL Utility Library (glut)

- void glutInitWindowPosition(int x, int y)
- void glutInitWindowSize(int width, int height)
  - Window location and size
  - These are hints to the underlying window system and may not be honored
- Void glutPositionWindow(int x, int y)
- Void glutReshapeWindow(int width, int height)
- Void glutFullScreen(void)
  - For both top-level and subwindows
  - For top-level windows, hints to the underlying windowing system (may not be honored)

GL Utility Library (glut)

- int glutCreateWindow(char *name)
  - after Init, Displaymode, Position, and Size calls
  - will not appear until glutMainLoop
  - WinID starts at 1
- int glutCreatSubWindow(int win, int x, int y, int width, int height)
  - Hierarchical (nested windows)
  - (x,y) relative to the parent (win)

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GL Utility Library (glut)

- void glutSetWindow (int win)
- int glutGetWindow(void)
  - Set and get current widnow
- void glutDestroyWindow (int win)

GL Utility Library (glut)

- Windows may have layers (normal, back for double buffered windows)
- void glutSwapBuffers(void)
  - Swap the *layer in use* of the current buffer
  - No effect if not doubled buffered

GL Utility Library (glut)

- void glutDisplayFunc(void (*func) (void))
  - display function for initial display, de-iconfy and expose
- void glutReshapeFunc(void (*function) (width, height))
  - called when window is resized or moved
  - default glViewport(0,0,width,height)

GL Utility Library (glut)

- void glutKeyboardFunc(void *(func) (unsinged int key, int x, int y)
  - ASCII code for key
  - (x,y) for window location when the key was pressed

```
switch (key) {
    case 'z':
        // action
        break;
    case 'x':
        // action
        break;
    default:
        exit(0);
    }
}
```

GL Utility Library (glut)

- void glutMouseFunc(void *(func) (int button, int state, int x, int y))
  - button: GLUT_{LEFT,MIDDLE,RIGHT}_BUTTON
    - Be careful of GLUT_MIDDLE_BUTTON (3 for 4)
  - mode: GLUT_UP, GLUT_DOWN

```
if (button==GLUT_LEFT_BUTTON) {
        if (state==GLUT_DOWN) { // left mouse button down
        } else if (state==GLUT_UP) {
        }
} else if(button==GLUT_RIGHT_BUTTON) {
        if (state==GLUT_DOWN) {  // right mouse button down
        } else if (state==GLUT_UP) {
        }
} else if (button==3) {      // mouse wheel scroll up
} else if (button==4) {      // mouse wheel scroll down
}
```

GL Utility Library (glut)

- void glutMotionFunc(void *(func) (int x, int y))
  - mouse pointer move while one or more mouse buttons is pressed

GL Utility Library (glut)

- glut{Wire,Solid}Sphere()
- glut{Wire,Solid}Cube()
- glut{Wire,Solid}Box()
- glut{Wire,Solid}Torus()
- glut{Wire,Solid}Cylinder()
- glut{Wire,Solid}Cone()
- glut{Wire,Solid}Teapot()
  - centered at the origin
- glut{Wire,Solid}(Icosahedron,Octahedron,Tetrahedron,dodecahedron)

GL Utility Library (glut)

- void glutMainLoop (void)
  - GLUT main loop, never returns

Sample Programs

- Close to a hundred of them under http://www.cs.ucsb.edu/~cs180/sampleprograms.tar.gz
- Note that they are all C functions
- You can use C++ for sure
- Caveats:
  - Missing data/images files (may not compile)
  - Have to fix Makefile manually (depending on your OS)
  - Work one year but not next
    - Must have GL (/usr/include/GL)
    - Must have glut (/usr/include/GL)
    - Must have X (/usr/X11R6/ or /usr/)
    - Libraries got split/merged (/usr/lib -> /usr/lib64)

GLUT Example

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

```
void init(void)
{
   glClearColor (0.0, 0.0, 0.0, 0.0);
   glShadeModel (GL_FLAT);
}
void display(void)
{
   glClear (GL_COLOR_BUFFER_BIT);
   glColor3f (1.0, 1.0, 1.0);
   glLoadIdentity ();             /* clear the matrix */
           /* viewing transformation  */
   gluLookAt (0.0, 0.0, 5.0, 0.0, 0.0, 0.0, 0.0, 1.0, 0.0);
   glScalef (1.0, 2.0, 1.0);      /* modeling transformation */
   glutWireCube (1.0);
   glFlush ();
}
```

```
void reshape (int w, int h)
{
   glViewport(0, 0, w, h);
   glMatrixMode(GL_PROJECTION);
   glLoadIdentity();
   /* set view volume according to camera parameters
     but with aspect ratio equal to viewport. */
   gluPerspective(60.0, (GLfloat) w / (GLfloat) h, 1.0, 100000000000.0);
   glMatrixMode(GL_MODELVIEW);
}
void keyboard(unsigned char key, int x, int y)
{
  switch (key) {
    case 27:
      exit(0);
      break;
  }
}
```

```
int main(int argc, char** argv)
{
  glutInit(&argc, argv);
  glutInitDisplayMode (GLUT_SINGLE | GLUT_RGB);
  glutInitWindowSize (500, 500);
  glutInitWindowPosition (100, 100);
  glutCreateWindow (argv[0]);
  init ();
  glutDisplayFunc(display);
  glutReshapeFunc(reshape);
  glutKeyboardFunc(keyboard);
  glutMainLoop();
  return 0;
}
```

ToGL

- A special widget (like the Canvas widget) that allows OpenGL to draw to it
- Tcl+Tk for GUI and OpenGL for 3D graphics
- Need togl.c togl.h and tkInit4.0.h
- Otherwise, very easy to use
- /fs/contrib/src/Togl/current/

Togl Widget

- Initialization
  - Togl_Init(Tcl_Interp *interp)
  - *main* calls *Tk_Main* calls *your_main* calls *Togl_Init*
- Callbacks
  - void Togl_CreateFunc(void (*function) (struct Togl*))
  - void Togl_DisplayFunc(void (*function) (struct Togl*))
  - void Togl_ReshapeFunc(void (*function) (struct Togl*))
  - void Togl_DestroyFunc(void (*function) (struct Togl*))
    - called when Togl widget is created, redrawn, resized and destroyed

Togl Widget

- Tcl/Tk commands for Togl
  - Togl_CreateCommand("tcl_name", c_name)

```
int c_name(struct Togl*, int argc, int argv**) {
    …
    return TCL_OK or TCL_ERROR
}
```

- Check Togl homepage for more functions