Grafică pe calculator (MLR5060)

Elemente de grafică 3_D

Programare *OpenGl*

- Introduction
- Rendering Primitives
- Rendering Modes
- Lighting
- Texture Mapping
- Additional Rendering Attributes
- Imaging

Goals

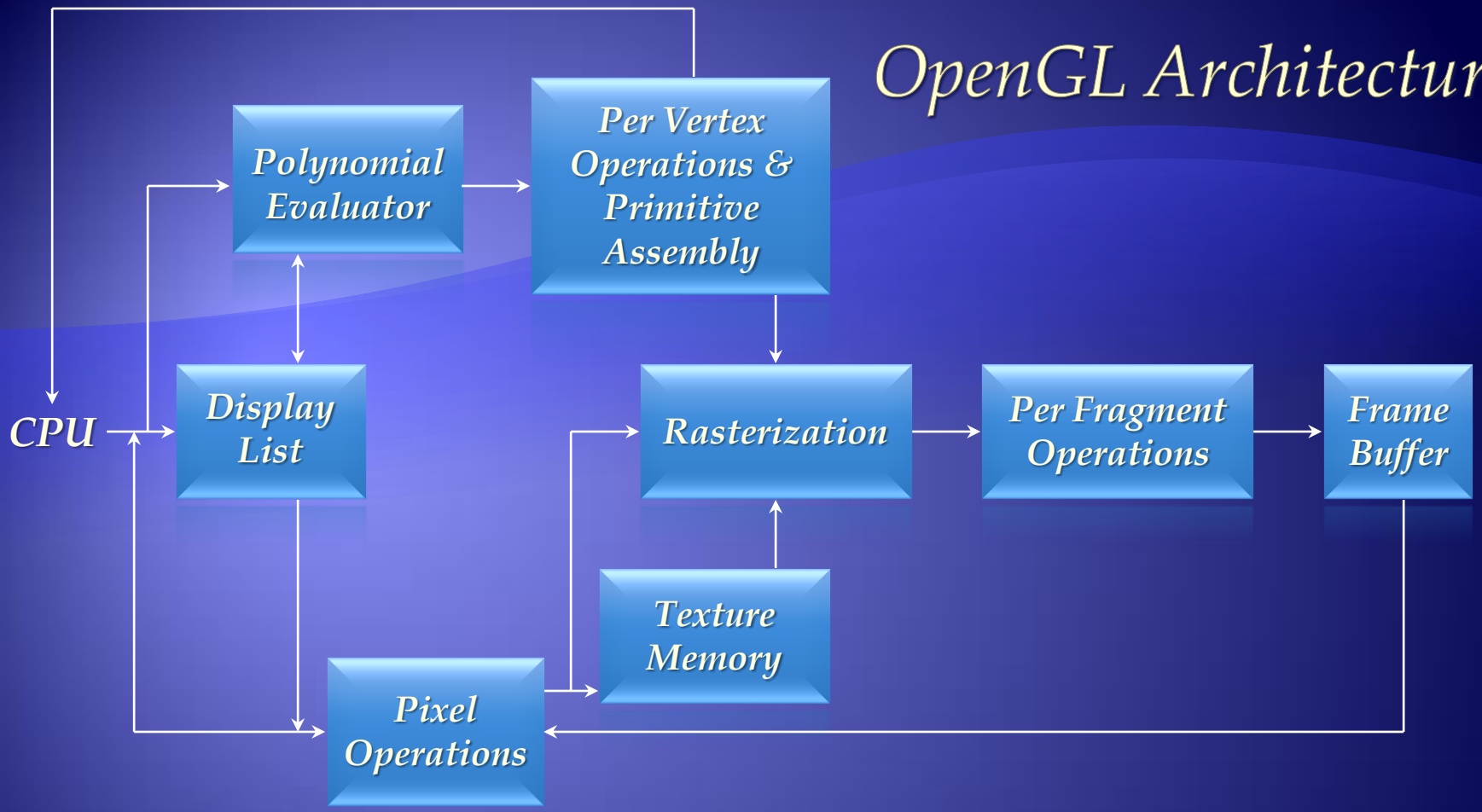
- Demonstrate enough *OpenGL* to write an interactive graphics program with
  - custom modeled 3D objects or imagery
  - lighting
  - texture mapping
- Introduce advanced topics for future investigation

OpenGL and *GLUT*

- *OpenGL*
  - Graphics rendering API
    - high-quality color images composed of geometric and image primitives
    - window system independent
    - operating system independentIntroduce advanced topics for future investigation

OpenGL is a library for doing computer graphics. By using it, you can create interactive applications which render high-quality color images composed of 3D geometric objects and images.
OpenGL is window and operating system independent. As such, the part of your application which does rendering is platform independent. However, in order for *OpenGL* to be able to render, it needs a window to draw into. Generally, this is controlled by the windowing system on whatever platform you're working on.

OpenGL Architecture



This is the most important diagram you will see today, representing the flow of graphical information, as it is processed from CPU to the frame buffer.
There are two pipelines of data flow. The upper pipeline is for geometric, vertex-based primitives. The lower pipeline is for pixel-based, image primitives. Texturing combines the two types of primitives together.
There is a pull-out poster in the back of the OpenGL Reference Manual ("Blue Book"), which shows this diagram in more detail.

OpenGL as a Renderer

- 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 as a Renderer

- As mentioned, OpenGL is a library for rendering computer graphics. Generally, there are two operations that you do with OpenGL:
  - draw something
  - change the state of how OpenGL draws
- OpenGL has two types of things that it can render: geometric primitives and image primitives. *Geometric primitives* are points, lines and polygons. *Image primitives* are bitmaps and graphics images (i.e. the pixels that you might extract from a JPEG image after you've read it into your program.) Additionally, OpenGL links image and geometric primitives together using *texture mapping*, which is an advanced topic we'll discuss this afternoon.
- The other common operation that you do with OpenGL is *setting state*. "Setting state" is the process of initializing the internal data that OpenGL uses to render your primitives. It can be as simple as setting up the size of points and color that you want a vertex to be, to initializing multiple mipmap levels for texture mapping.

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

… Related APIs

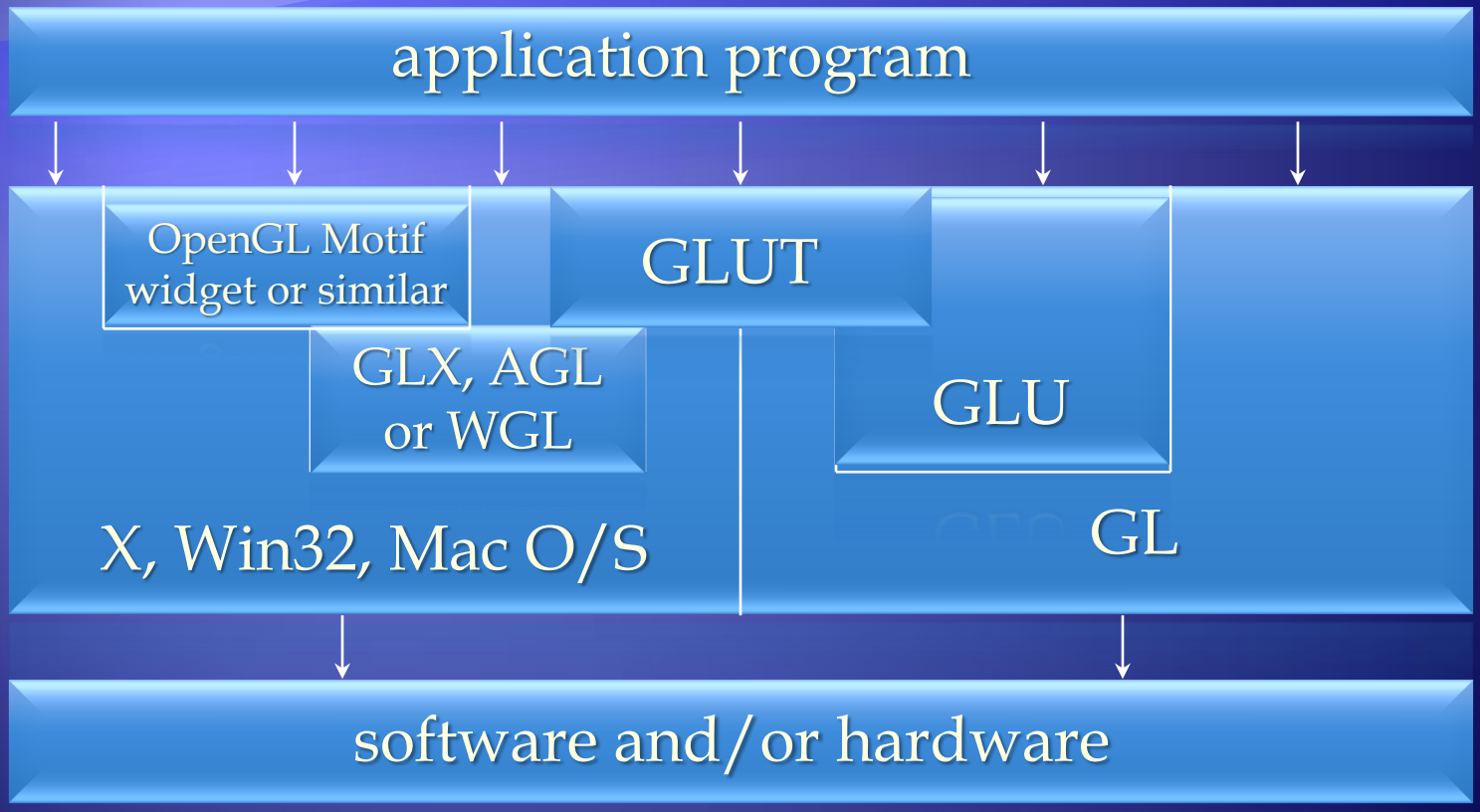
As mentioned, OpenGL is window and operating system independent. To integrate it into various window systems, additional libraries are used to modify a native window into an OpenGL capable window. Every window system has its own unique library and functions to do this. Some examples are:

- GLX for the X Windows system, common on Unix platforms
- AGL for the Apple Macintosh
- WGL for Microsoft Windows

OpenGL also includes a utility library, GLU, to simplify common tasks such as: rendering quadric surfaces (i.e. spheres, cones, cylinders, etc.), working with NURBS and curves, and concave polygon tessellation.

Finally to simplify programming and window system dependence, we'll be using the freeware library, GLUT. GLUT, written by Mark Kilgard, is a public domain window system independent toolkit for making simple OpenGL applications. It simplifies the process of creating windows, working with events in the window system and handling animation.

OpenGL and Related APIs



… OpenGL and Related APIs

The above diagram illustrates the relationships of the various libraries and window system components.

Generally, applications which require more user interface support will use a library designed to support those types of features (i.e. buttons, menu and scroll bars, etc.) such as Motif or the Win32 API.

Prototype applications, or one which don't require all the bells and whistles of a full GUI, may choose to use GLUT instead because of its simplified programming model and window system independence.

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.

… Preliminaries

- All of our discussions today will be presented in the C computer language.
- For C, there are a few required elements which an application must do:
  - *Header files* describe all of the function calls, their parameters and defined constant values to the compiler. OpenGL has header files for GL (the core library), GLU (the utility library), and GLUT (freeware windowing toolkit).
  - *Note*: glut.h includes gl.h and glu.h. On Microsoft Windows, including *only* glut.h is recommended to avoid warnings about redefining Windows macros.
  - *Libraries* are the operating system dependent implementation of OpenGL on the system you're using. Each operating system has its own set of libraries. For Unix systems, the OpenGL library is commonly named libGL.so and for Microsoft Windows, it's named opengl32.lib.
  - Finally, *enumerated types* are definitions for the basic types (i.e. float, double, int, etc.) which your program uses to store variables. To simplify platform independence for OpenGL programs, a complete set of enumerated types are defined. Use them to simplify transferring your programs to other operating systems.

GLUT Basics

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

… GLUT Basics

- Here's the basic structure that we'll be using in our applications. This is generally what you'd do in your own OpenGL applications.
- The steps are:
- 1) Choose the type of window that you need for your application and initialize it.
- 2) Initialize any OpenGL state that you don't need to change every frame of your program. This might include things like the background color, light positions and texture maps.
- 3) Register the *callback* functions that you'll need. Callbacks are routines you write that GLUT calls when a certain sequence of events occurs, like the window needing to be refreshed, or the user moving the mouse. The most important callback function is the one to render your scene, which we'll discuss in a few slides.
- 4) Enter the main event processing loop. This is where your application receives events, and schedules when callback functions are called.

Sample Program

Here's an example of the main part of a GLUT based OpenGL application. This is the model that we'll use for most of our programs in the course.
The glutInitDisplayMode() and glutCreateWindow() functions compose the window configuration step.

```
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();
}
```

We then call the init() routine, which contains our one-time initialization. Here we initialize any OpenGL state and other program variables that we might need to use during our program that remain constant throughout the program's execution.
Next, we register the callback routines that we're going to use during our program.
Finally, we enter the event processing loop, which interprets events and calls our respective callback routines.

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();
}
```

Idle Callbacks

- Use for animation and continuous update

glutIdleFunc(*idle*);

```
void idle( void )
{
  t += dt;
  glutPostRedisplay();
}
```

User Input Callbacks

- Process user input

glutKeyboardFunc(*keyboard*);

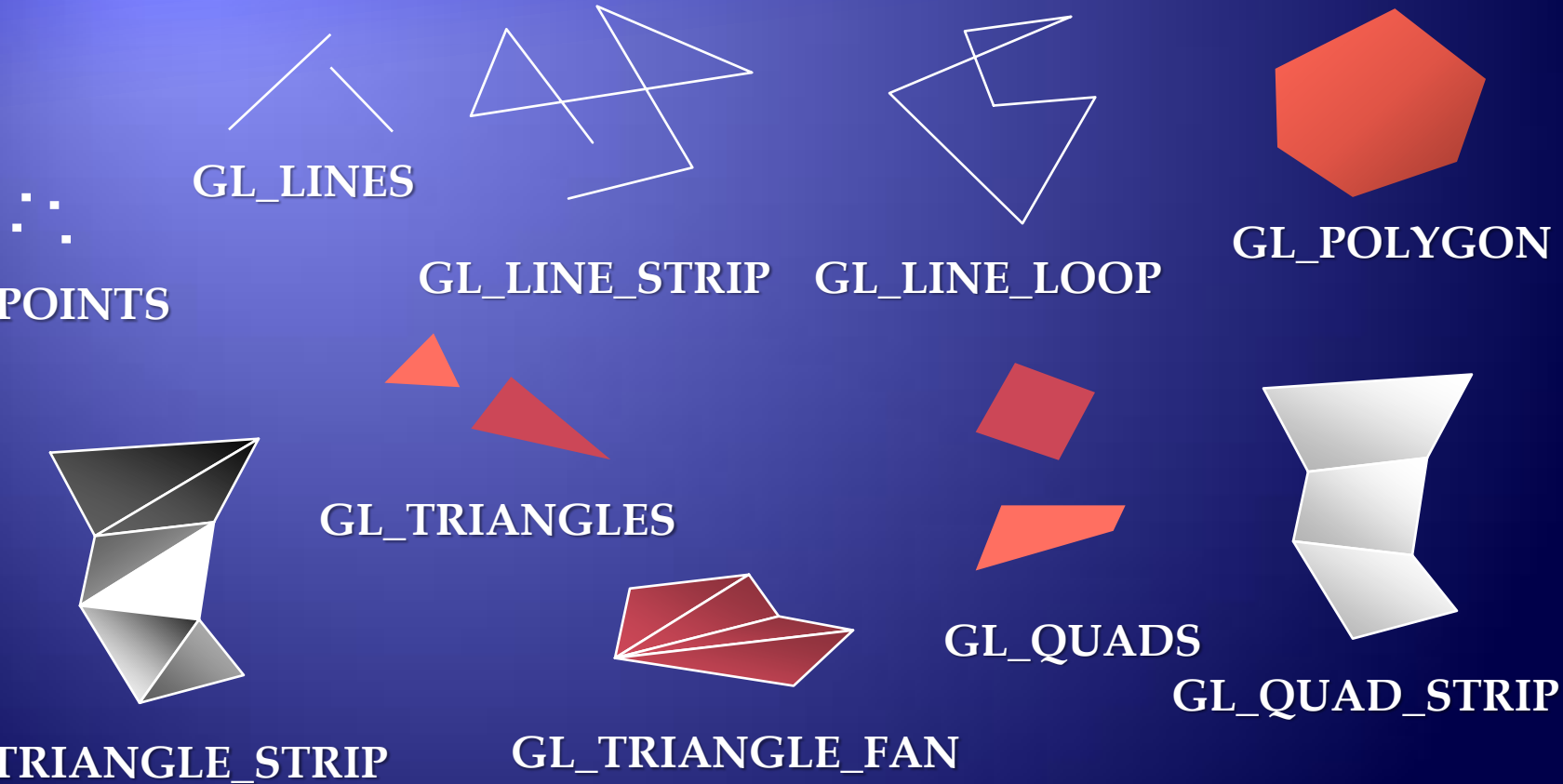
```
void keyboard( char key, int x, int y )
{
  switch( key ) {
    case 'q' : case 'Q' :
      exit( EXIT_SUCCESS );
      break;

    case 'r' : case 'R' :
      rotate = GL_TRUE;
      break;
  }
}
```

Elementary Rendering

- Geometric Primitives
- Managing OpenGL State
- OpenGL Buffers

OpenGL Geometric Primitives

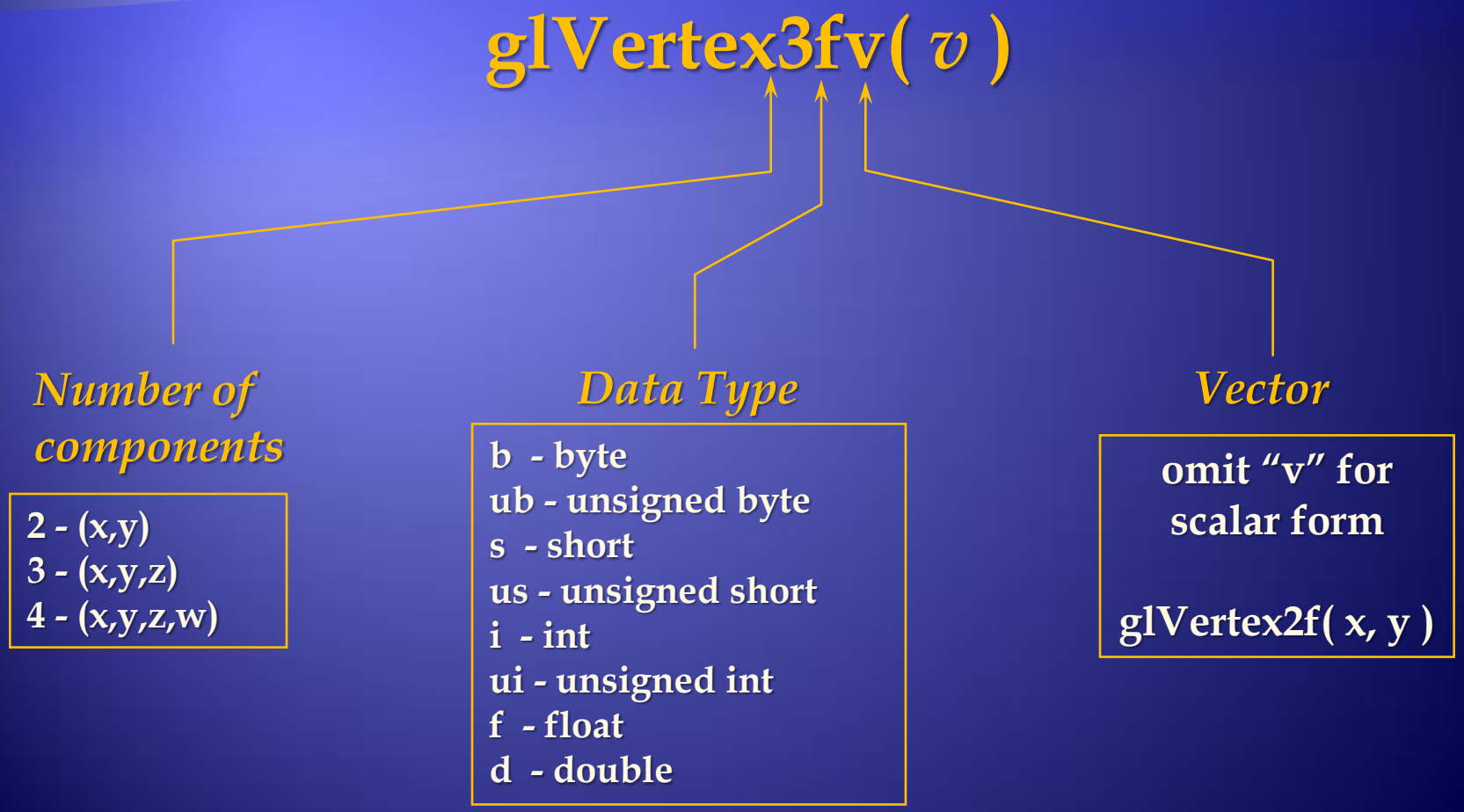
- All geometric primitives are specified by vertices



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



Specifying Geometric Primitives

- Primitives are specified using

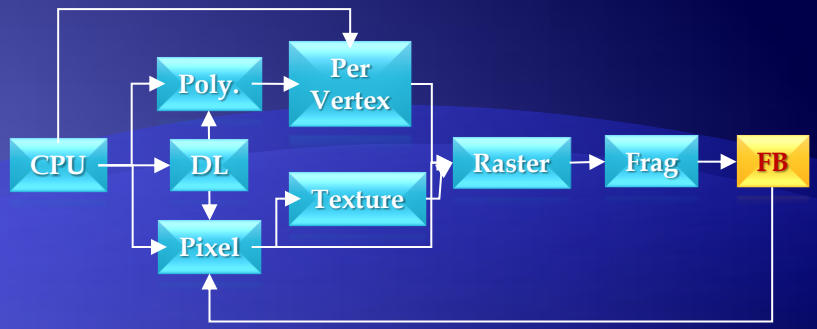
  glBegin(*primType*);

  glEnd();

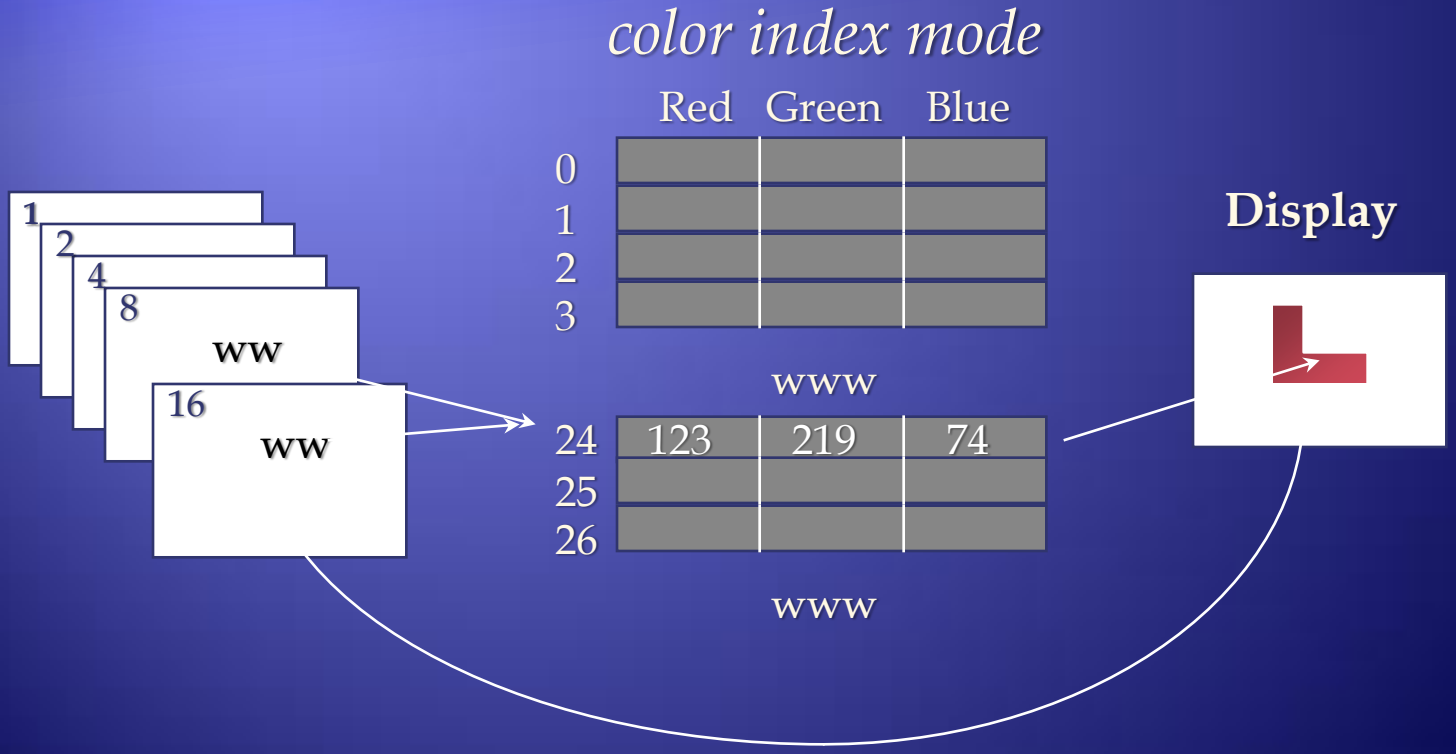
  - *primType* determines how vertices are combined

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

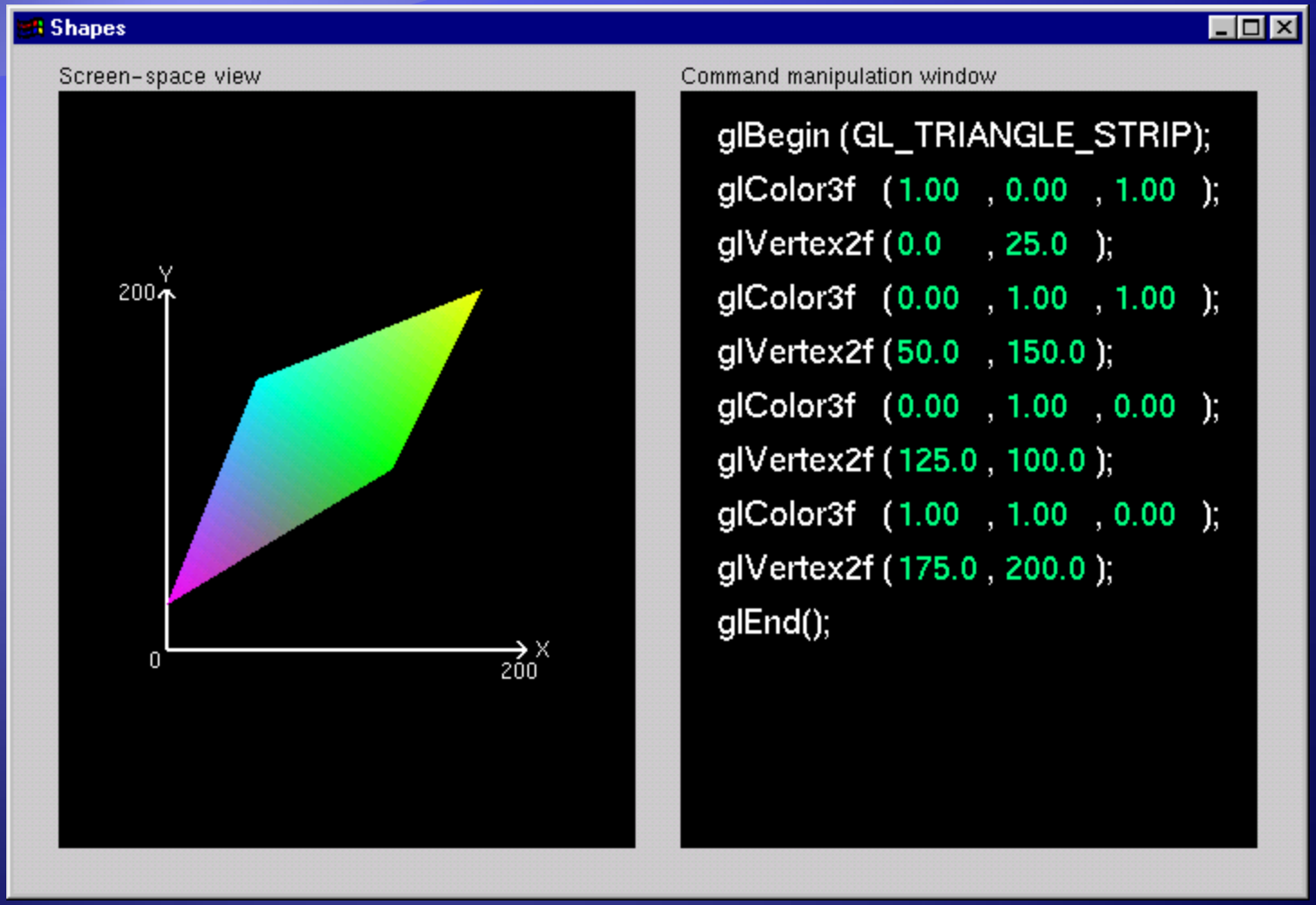
OpenGL Color Models



- RGBA or Color Index

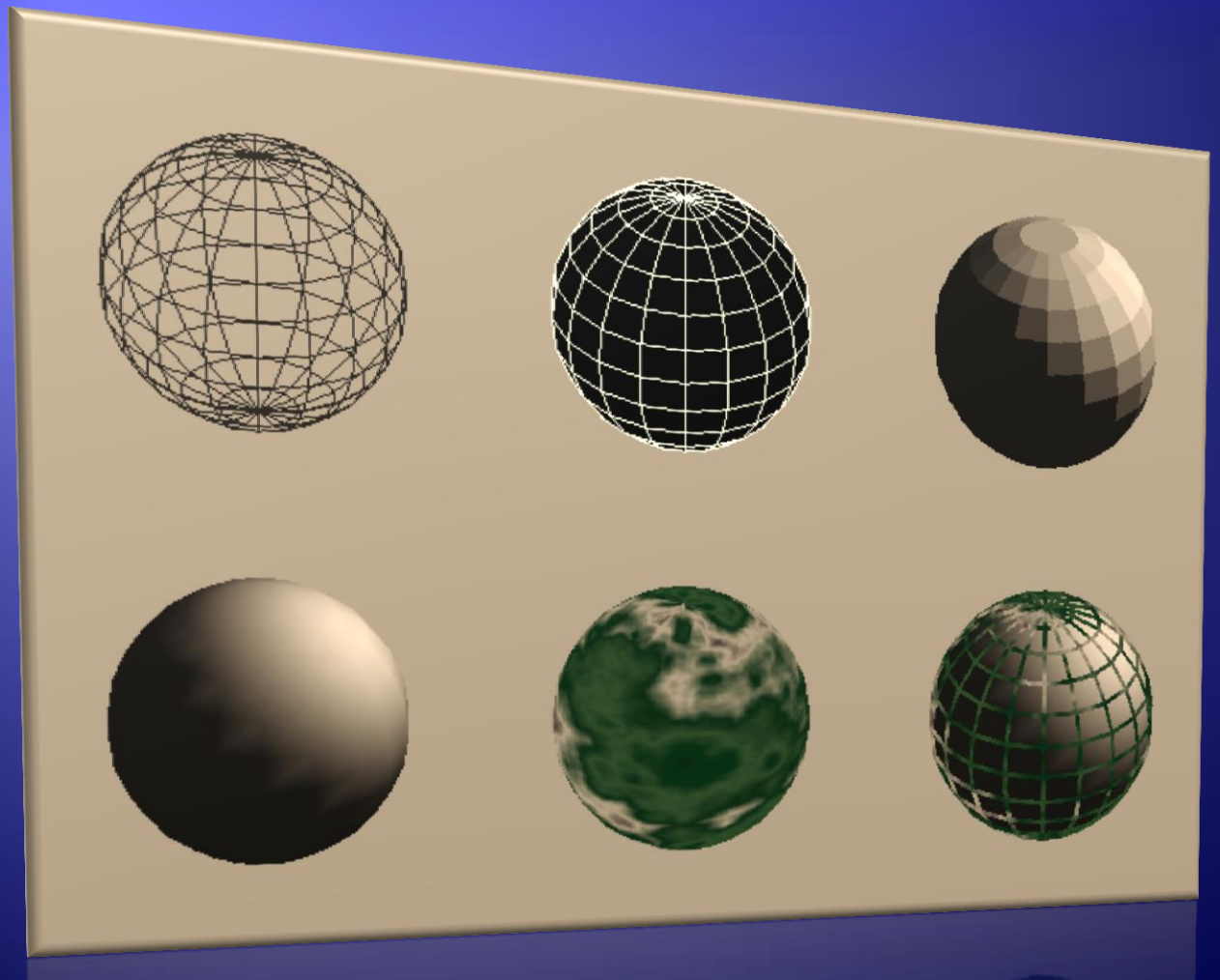


Shapes Tutorial



Controlling Rendering Appearance

- From Wireframe to Texture Mapped



OpenGL's State Machine

- All rendering attributes are encapsulated in the OpenGL State
  - rendering styles
  - shading
  - lighting
  - texture mapping

Manipulating OpenGL State

- Appearance is controlled by current state

```
for each ( primitive to render ) {
    update OpenGL state
    render primitive
}
```

- Manipulating vertex attributes is most common way to manipulate state

glColor*() / glIndex*()
glNormal*()
glTexCoord*()

Controlling current state

- Setting State

  glPointSize(*size*);

  glLineStipple(*repeat, pattern*);

  glShadeModel(*GL_SMOOTH*);

- Enabling Features

  glEnable(*GL_LIGHTING*);

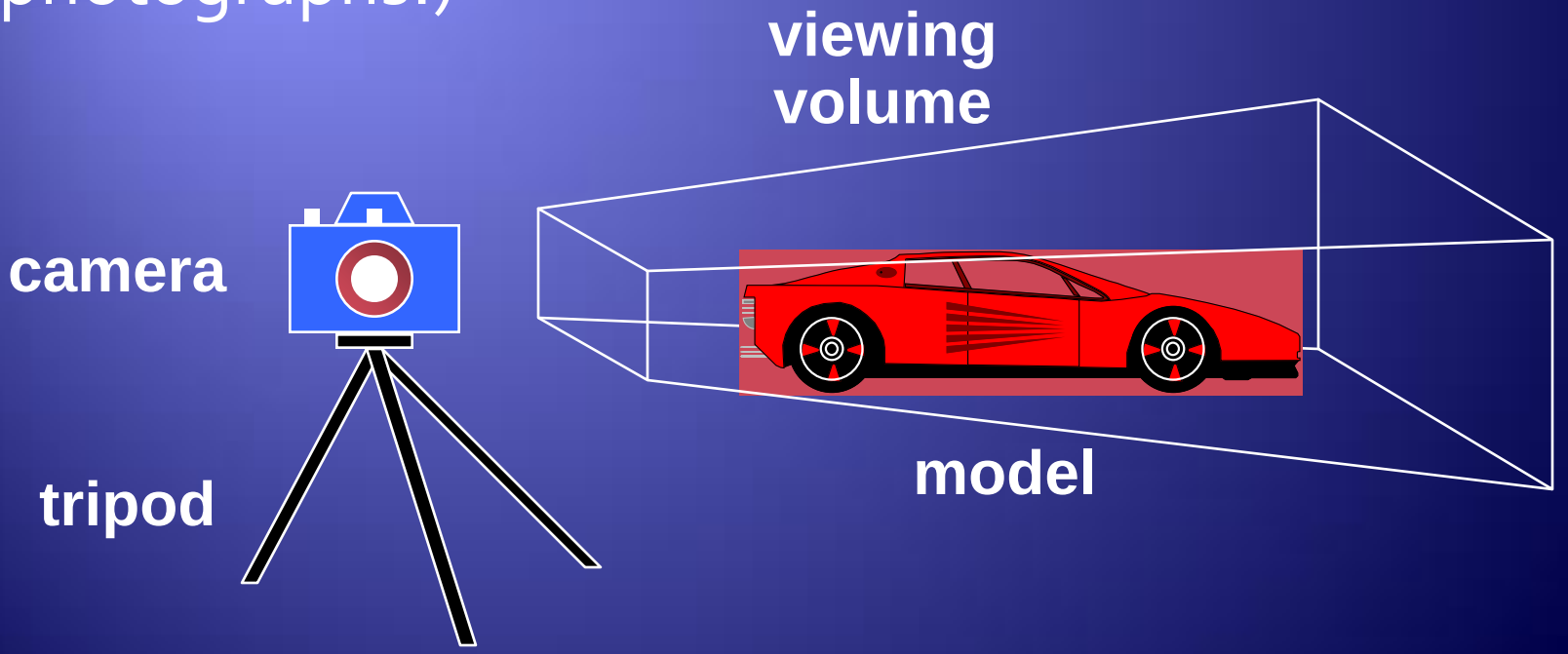
  glDisable(*GL_TEXTURE_2D*);

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 and 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

Coordinate Systems and Transformations

- 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)

Affine Transformations

- Want transformations which preserve geometry
  - lines, polygons, quadrics
- Affine = line preserving
  - Rotation, translation, scaling
  - Projection
  - Concatenation (composition)

Homogeneous Coordinates

- each vertex is a column vector

$$\vec{v} = \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

- w is usually 1.0
- all operations are matrix multiplications
- directions (directed line segments) can be represented with $w = 0.0$

3D Transformations

- A vertex is transformed by 4 x 4 matrices
  - all affine operations are matrix multiplications
  - all matrices are stored column-major in OpenGL
  - matrices are always post-multiplied
  - product of matrix and vector is $\mathbf{M}\vec{v}$

$$\mathbf{M} = \begin{bmatrix} m_0 & m_4 & m_8 & m_{12} \\ m_1 & m_5 & m_9 & m_{13} \\ m_2 & m_6 & m_{10} & m_{14} \\ m_3 & m_7 & m_{11} & m_{15} \end{bmatrix}$$

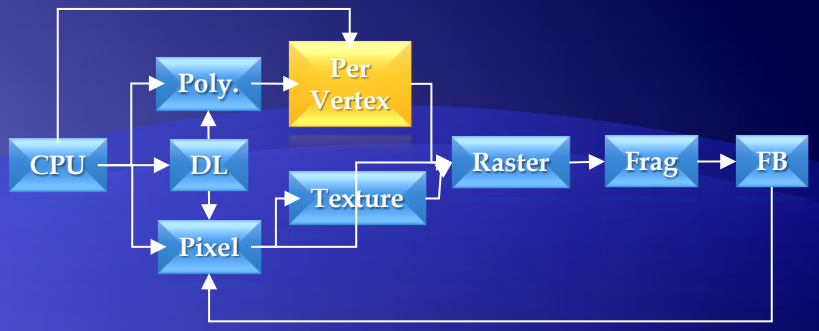
Specifying Transformations

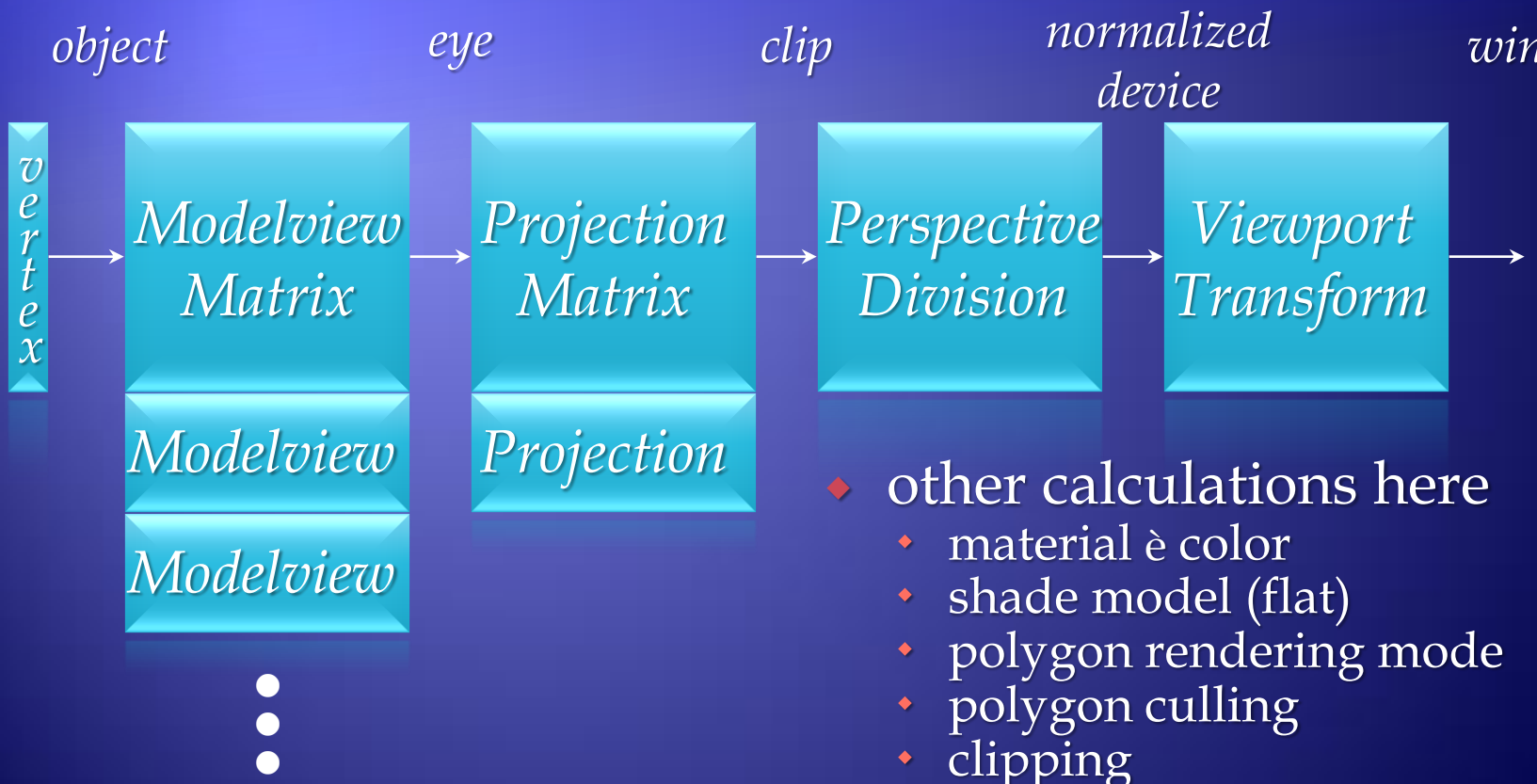
- Programmer has two styles of specifying transformations
  - specify matrices (`glLoadMatrix, glMultMatrix`)
  - specify operation (`glRotate, glOrtho`)
- Programmer does not have to remember the exact matrices
  - check appendix of Red Book (Programming Guide)

Programming Transformations

- Prior to rendering, view, locate, and orient:
  - eye/camera position
  - 3D geometry
- Manage the matrices
  - including matrix stack
- Combine (composite) transformations

Transformation Pipeline





- other calculations here
  - material è color
  - shade model (flat)
  - polygon rendering mode
  - polygon culling
  - clipping

Matrix Operations

- Specify Current Matrix Stack

  `glMatrixMode( GL_MODELVIEW or GL_PROJECTION )`

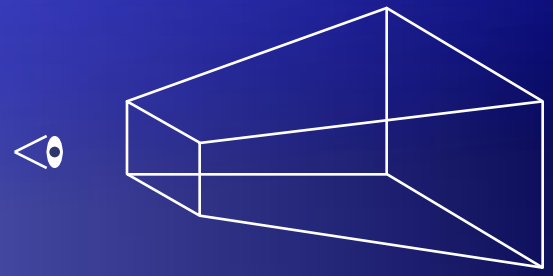
- Other Matrix or Stack Operations

  `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

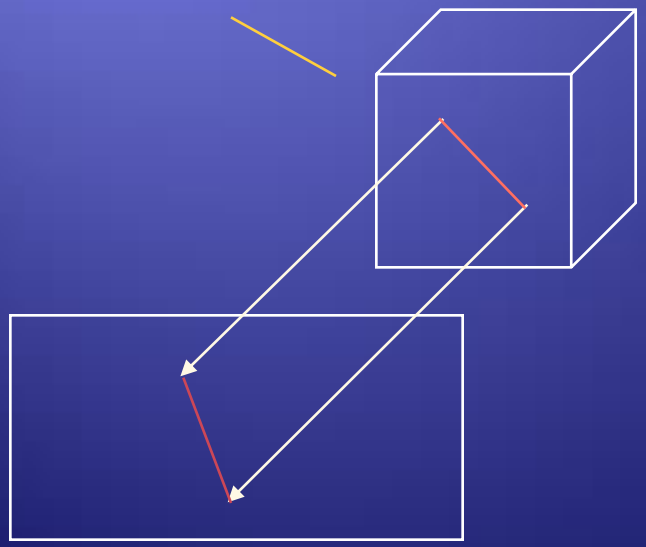
```
glOrtho( left, right, bottom, top, zNear, zFar )
gluOrtho2D( left, right, bottom, top )
```

  - calls `glOrtho` with z values near zero

Applying Projection Transformations

- Typical use (orthographic projection)

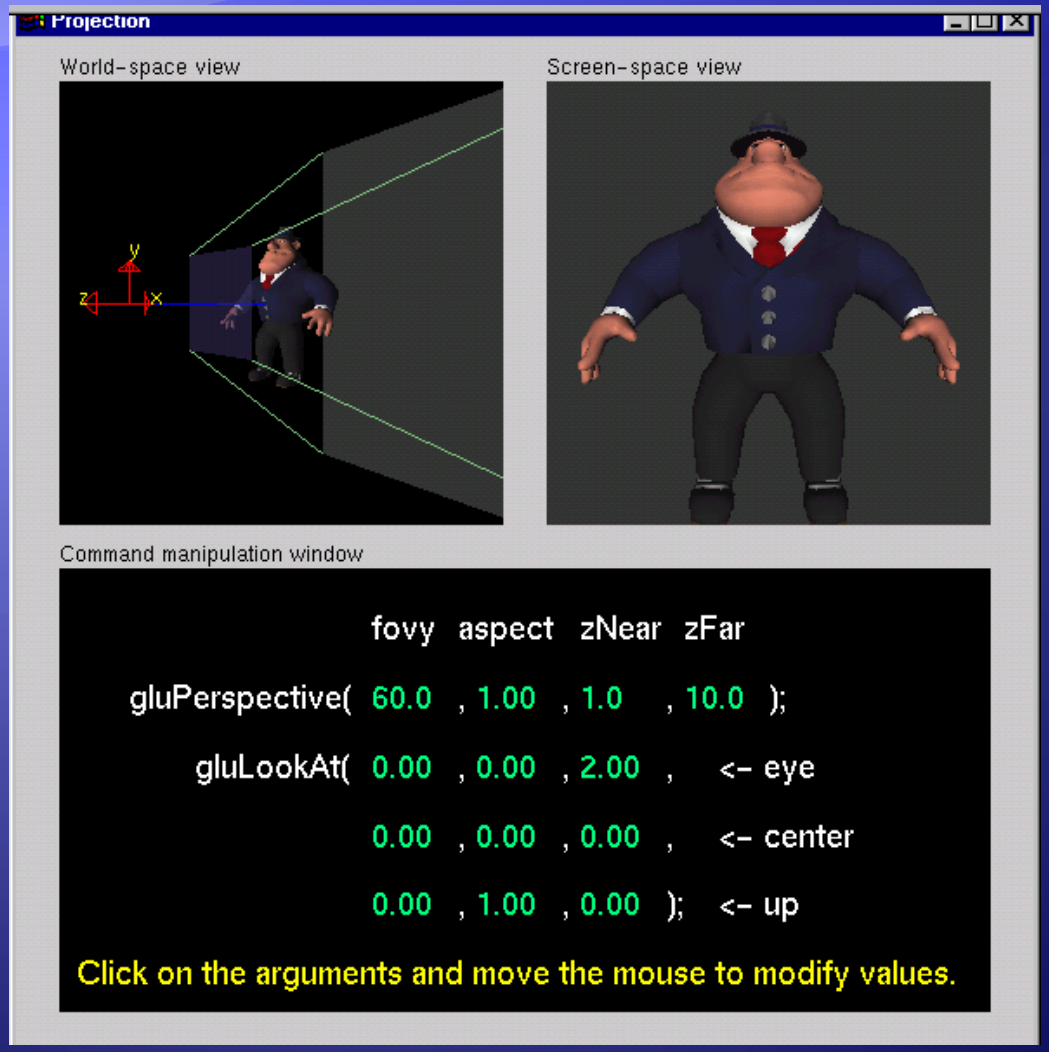
```
glMatrixMode( GL_PROJECTION );
glLoadIdentity();
glOrtho( left, right, bottom, top, zNear, zFar );
```



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

Projection Tutorial



Modeling Transformations

- Move object

  `glTranslate{fd}( x, y, z )`

- Rotate object around arbitrary axis $(x \quad y \quad z)$

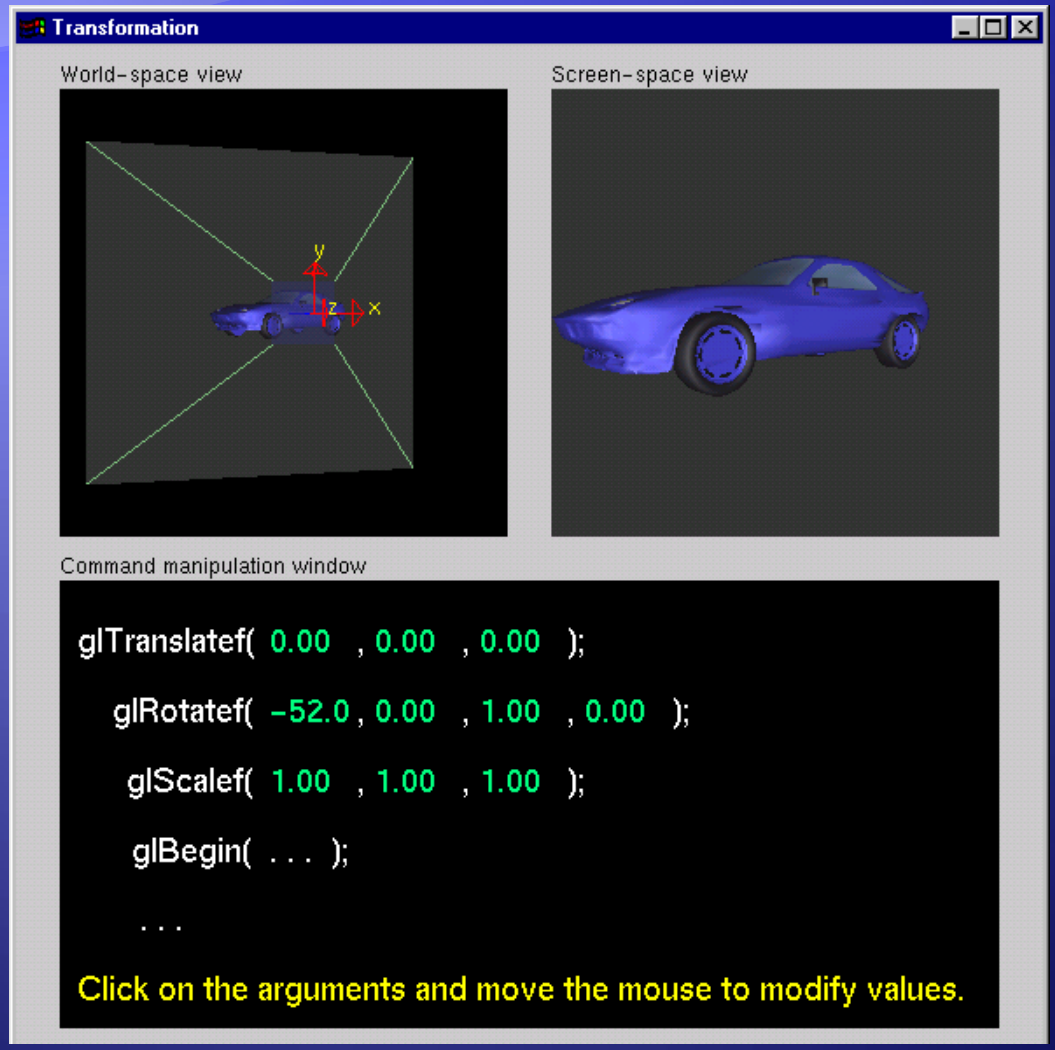
  `glRotate{fd}( angle, x, y, z )`

  - angle is in degrees

- Dilate (stretch or shrink) or mirror object

  `glScale{fd}( x, y, z )`

Transformation Tutorial



Connection: Viewing and Modeling

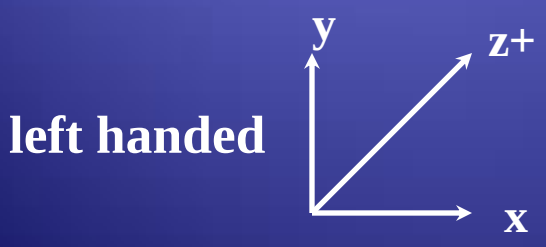
- Moving camera is equivalent to moving every object in the world towards a stationary camera
- Viewing transformations are equivalent to several modeling transformations

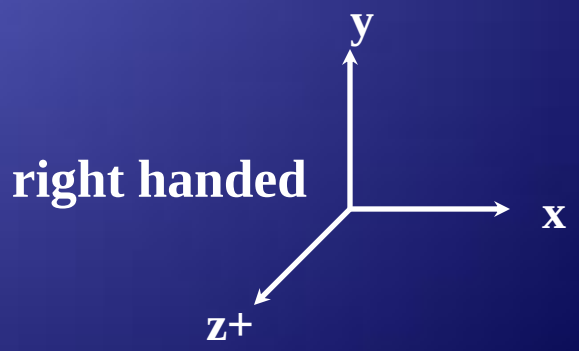
  `gluLookAt()` has its own command

  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 vertexes to be rendered





Common Transformation Usage

- 3 examples of `resize()` routine
  - restate projection & viewing transformations
- Usually called when window resized
- Registered as callback for `glutReshapeFunc()`

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(): Perspective & Translate

- Same effect as previous 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();
    glTranslatef( 0.0, 0.0, -5.0 );
}
```

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();
}
```

Compositing Modeling Transformations

- Problem 1: hierarchical objects
  - one position depends upon a previous position
  - robot arm or hand; sub-assemblies
- Solution 1: moving local coordinate system
  - modeling transformations move coordinate system
  - post-multiply column-major matrices
  - OpenGL post-multiplies matrices

Compositing Modeling Transformations

- Problem 2: objects move relative to absolute world origin
  - my object rotates around the wrong origin
    - make it spin around its center or something else
- Solution 2: fixed coordinate system
  - modeling transformations move objects around fixed coordinate system
  - pre-multiply column-major matrices
  - OpenGL post-multiplies matrices
  - must reverse order of operations to achieve desired effect

Additional Clipping Planes

- At least 6 more clipping planes available
- Good for cross-sections
- Modelview matrix moves clipping plane
- $Ax + By + Cz + D < 0$ clipped
- `glEnable( GL_CLIP_PLANEi )`
- `glClipPlane( GL_CLIP_PLANEi, GLdouble* coeff )`

Reversing Coordinate Projection

- Screen space back to world space

```
glGetIntegerv( GL_VIEWPORT, GLint viewport[4] )
glGetDoublev( GL_MODELVIEW_MATRIX, GLdouble mvmatrix[16] )
glGetDoublev( GL_PROJECTION_MATRIX,
                GLdouble projmatrix[16] )
gluUnProject( GLdouble winx, winy, winz,
                mvmatrix[16], projmatrix[16],
                GLint viewport[4],
                GLdouble *objx, *objy, *objz )
```

- `gluProject` goes from world to screen space

On-Line Resources

- **http://www.opengl.org**
  - start here; up to date specification and lots of sample code
- **news:comp.graphics.api.opengl**
- **http://www.sgi.com/software/opengl**
- **http://www.mesa3d.org/**
  - Brian Paul's Mesa 3D
- **http://www.cs.utah.edu/~narobins/opengl.html**
  - very special thanks to Nate Robins for the OpenGL Tutors
  - source code for tutors available here!

Books

- OpenGL Programming Guide, 3rd Edition
- OpenGL Reference Manual, 3rd Edition
- OpenGL Programming for the X Window System
  - includes many GLUT examples
- Interactive Computer Graphics: A top-down approach with OpenGL, 2nd Edition

Referințe

1. *OpenGL Programming Guide*, Marin Vlada (*Computer Graphics and Virtual Reality*)
   - http://www.unibuc.ro/prof/vlada_m/docs/2011/apr/11_12_12_01OpenGL_Programming_Guide.pdf
2. *Intro to 3D Graphics using Tao.OpenGL*, Erika Troll, Josh Lavinder, Alton Ng, Andrew Padilla
   - http://www.math.ucla.edu/~wittman/10c.1.11s/Lectures/Raids/Graphics3D.pdf
3. *OpenGL Programming Guide* (*Addison-Wesley Publishing Company*), Denis Roegel, *Lorraine Laboratory of IT Research and its Applications* (*LORIA*)
   - http://www.loria.fr/~roegel/cours/iut/opengl/addison.pdf
4. *Learning Modern 3D Graphics Programming*, Jason L. McKesson
   - http://www.pdfiles.com/pdf/files/English/Designing_&_Graphics/Learning_Modern_3D_Graphics_Programming.pdf
5. *An Interactive Introduction to OpenGL Programming*, Dave Shreiner, Ed Angel, Vicki Shreiner
   - http://www.vis.uky.edu/~ryang/teaching/cs535-2012spr/Lectures/OpenGL.pptx, Lectures