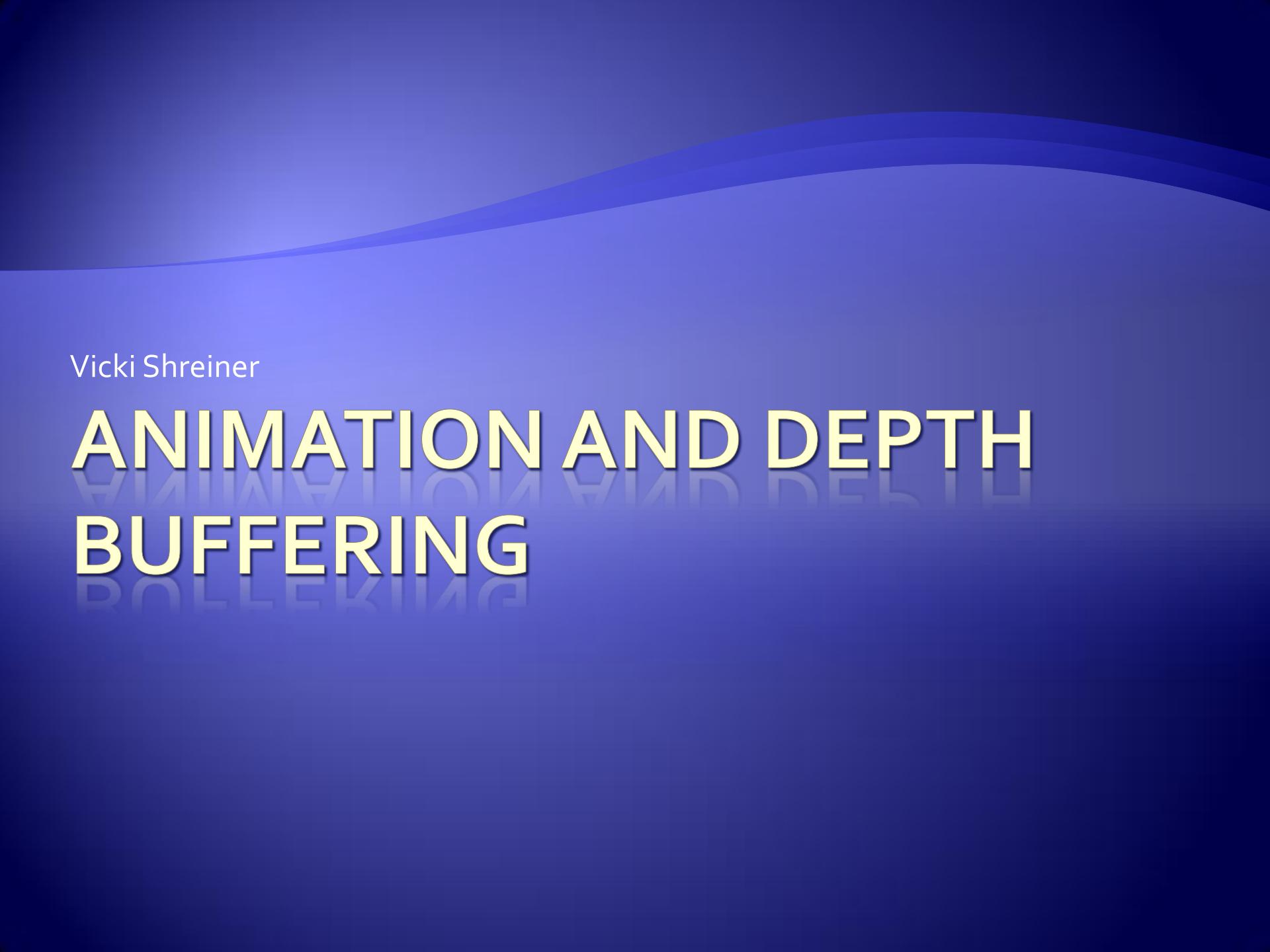


# Grafică pe calculator (MLR5060)

## Elemente de grafică 3\_D

### Programare OpenGL 2 (Part b)

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



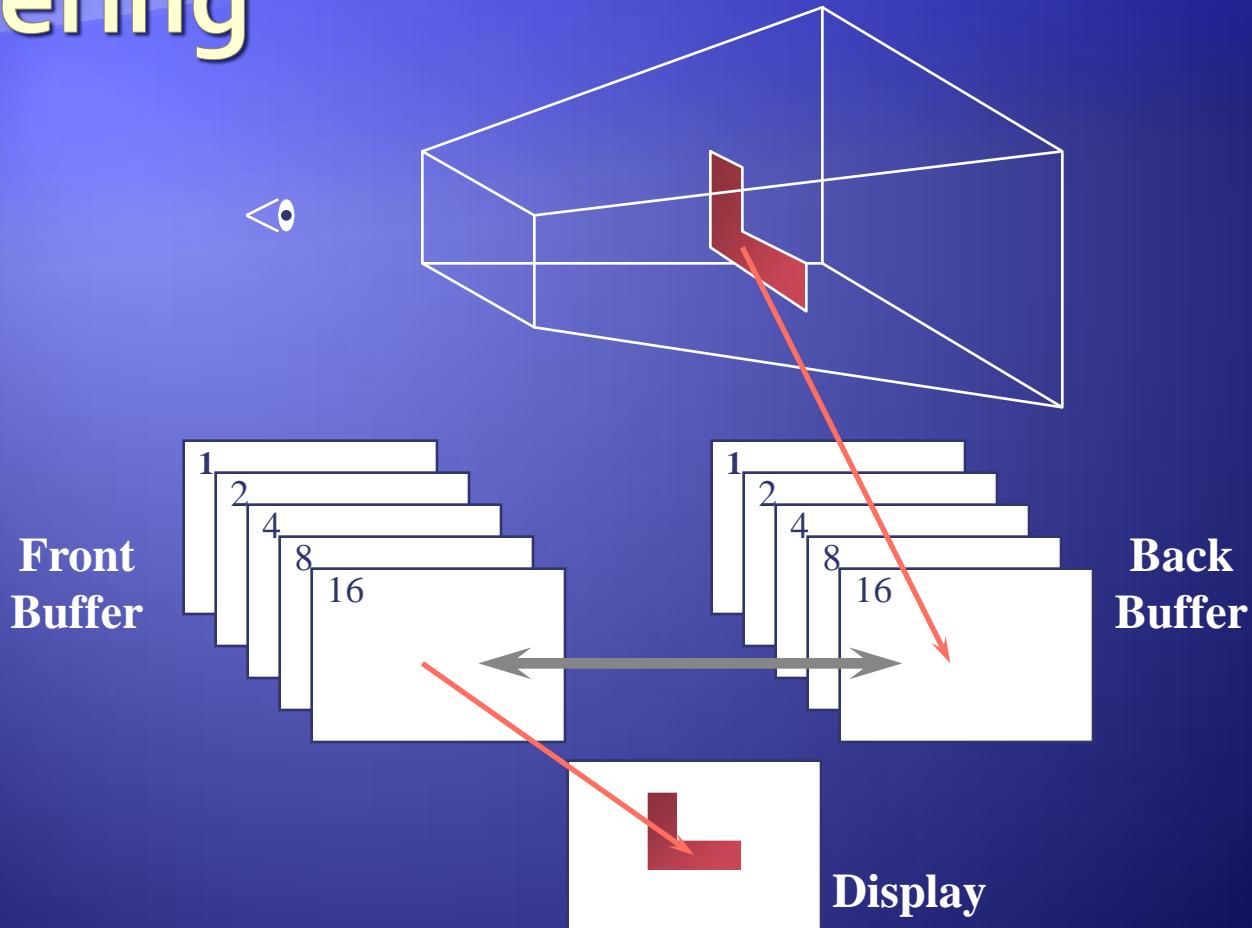
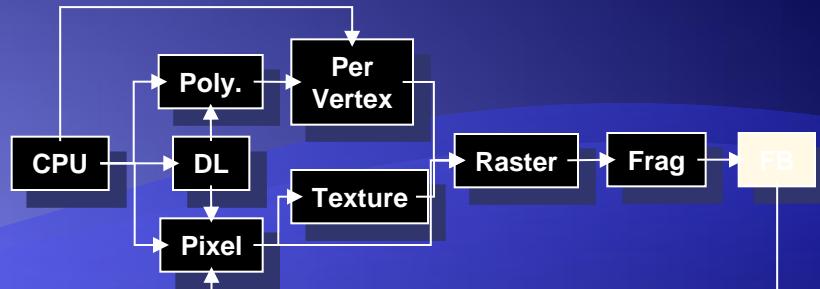
Vicki Shreiner

# **ANIMATION AND DEPTH BUFFERING**

# Animation and Depth Buffering

- ◆ Discuss double buffering and animation
- ◆ Discuss hidden surface removal using the depth buffer

# Double Buffering



# Animation Using Double Buffering

- ① Request a double buffered color buffer

```
glutInitDisplayMode ( GLUT_RGB |  
GLUT_DOUBLE );
```

- ② Clear color buffer

```
glClear ( GL_COLOR_BUFFER_BIT );
```

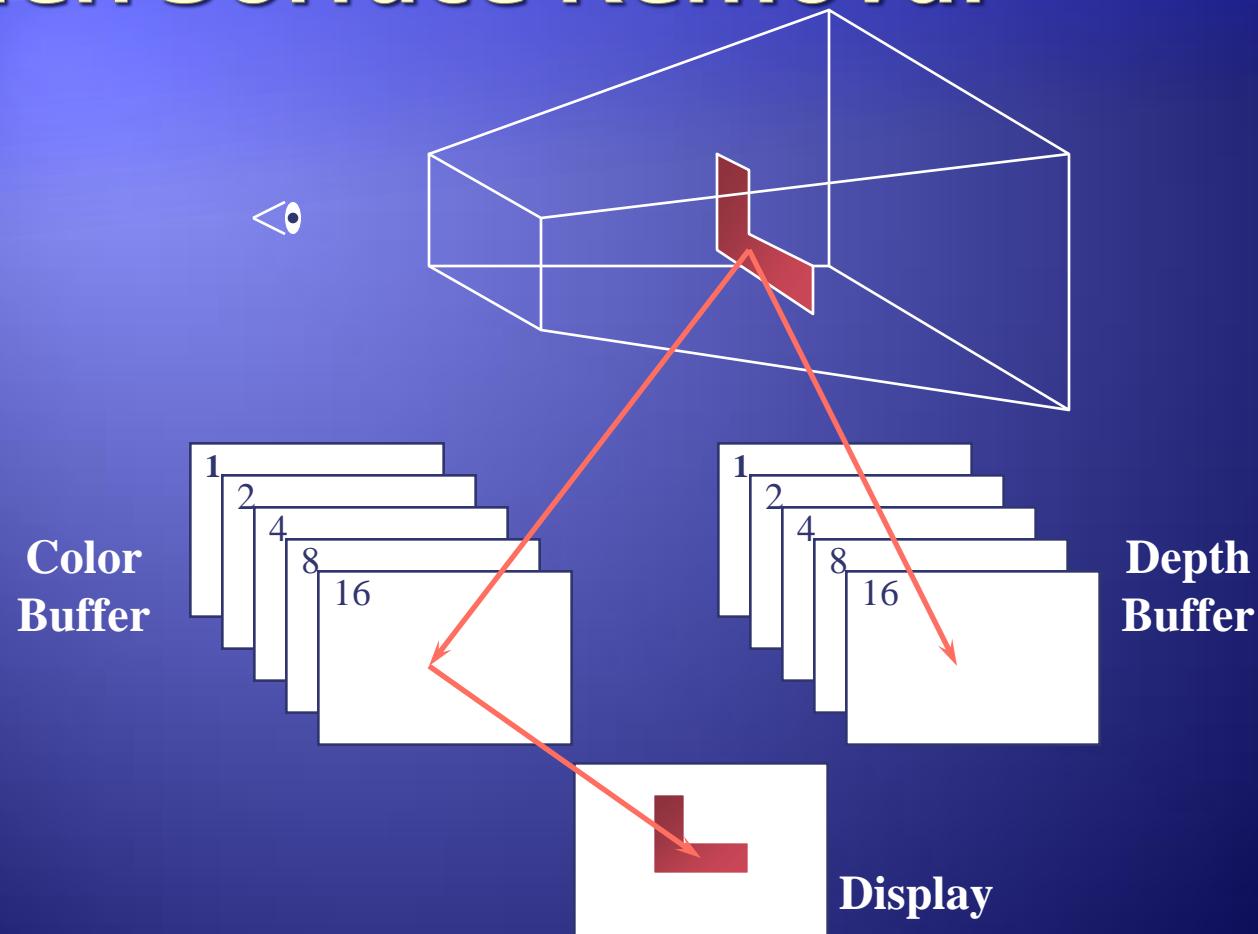
- ③ Render scene

- ④ Request swap of front and back buffers

```
glutSwapBuffers ();
```

- ◆ Repeat steps 2 - 4 for animation

# Depth Buffering and Hidden Surface Removal



# Depth Buffering Using OpenGL

- ① Request a depth buffer

```
glutInitDisplayMode( GLUT_RGB |  
                      GLUT_DOUBLE | GLUT_DEPTH );
```

- ② Enable depth buffering

```
glEnable( GL_DEPTH_TEST );
```

- ③ Clear color and depth buffers

```
glClear( GL_COLOR_BUFFER_BIT |  
          GL_DEPTH_BUFFER_BIT );
```

- ④ Render scene

- ⑤ Swap color buffers

# An Updated Program Template

```
void main( int argc, char** argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_RGB |
        GLUT_DOUBLE | GLUT_DEPTH );
    glutCreateWindow( "Tetrahedron" );
    init();
    glutIdleFunc( idle );
    glutDisplayFunc( display );
    glutMainLoop();
}
```

# An Updated Program Template (cont.)

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

```
void idle( void )
{
    glutPostRedisplay();
}
```

# An Updated Program Template (cont.)

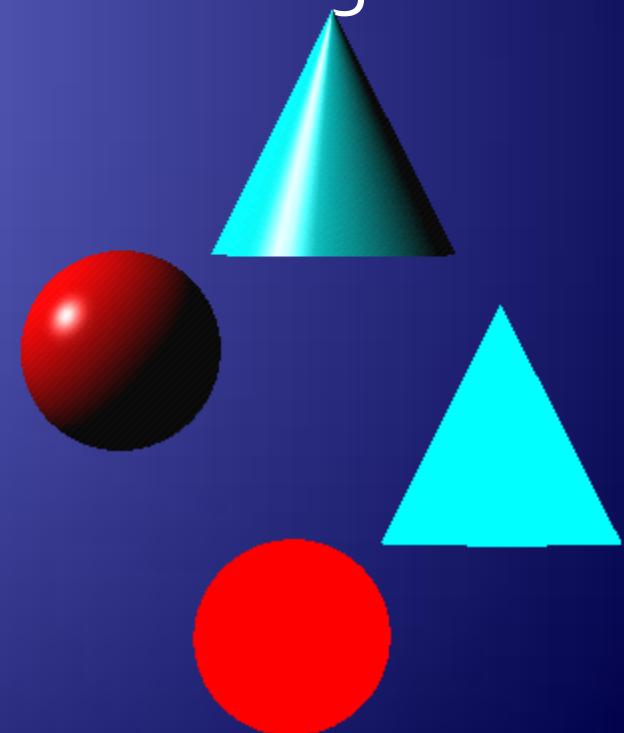
```
void drawScene( void )
{
    GLfloat vertices[] = { ... };
    GLfloat colors[] = { ... };
    glClear( GL_COLOR_BUFFER_BIT |
              GL_DEPTH_BUFFER_BIT );
    glBegin( GL_TRIANGLE_STRIP );
    /* calls to glColor*() and glVertex*() */
    glEnd();
    glutSwapBuffers();
}
```

Dave Shreiner

# LIGHTING

# Lighting Principles

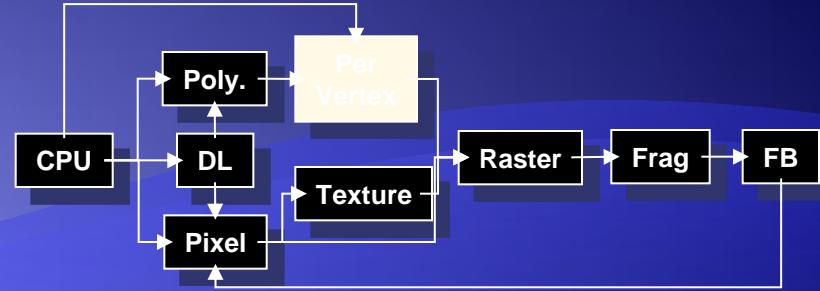
- ◆ Lighting simulates how objects reflect light
  - ◆ material composition of object
  - ◆ light's color and position
  - ◆ global lighting parameters
    - ◆ ambient light
    - ◆ two sided lighting
  - ◆ available in both color index and RGBA mode



# How OpenGL Simulates Lights

- ◆ Phong lighting model
  - ◆ Computed at vertices
- ◆ Lighting contributors
  - ◆ Surface material properties
  - ◆ Light properties
  - ◆ Lighting model properties

# Surface Normals



- ◆ Normals define how a surface reflects light

`glNormal3f( x, y, z )`

- ◆ Current normal is used to compute vertex's color
- ◆ Use *unit* normals for proper lighting
  - ◆ scaling affects a normal's length

`glEnable( GL_NORMALIZE )`

or

`glEnable( GL_RESCALE_NORMAL )`



# Material Properties

- ◆ Define the surface properties of a primitive

```
glMaterialfv( face, property, value )
```

<b>GL_DIFFUSE</b>	Base color
<b>GL_SPECULAR</b>	Highlight Color
<b>GL_AMBIENT</b>	Low-light Color
<b>GL_EMISSION</b>	Glow Color
<b>GL_SHININESS</b>	Surface Smoothness

- ◆ separate materials for front and back

# Light Properties

```
glLightfv( light, property, value );
```

- ♦ *light* specifies which light
  - ♦ multiple lights, starting with **GL\_LIGHT0**  
`glGetIntegerv( GL_MAX_LIGHTS, &n );`
- ♦ *properties*
  - ♦ colors
  - ♦ position and type
  - ♦ attenuation

# Light Sources (cont.)

- ◆ Light color properties
  - ◆ **GL\_AMBIENT**
  - ◆ **GL\_DIFFUSE**
  - ◆ **GL\_SPECULAR**

# Types of Lights

- ◆ OpenGL supports two types of Lights
  - ◆ Local (Point) light sources
  - ◆ Infinite (Directional) light sources
- ◆ Type of light controlled by w coordinate
  - $w = 0$    ***Infinite Light directed along***  $(x \quad y \quad z)$
  - $w \neq 0$    ***Local Light positioned at***  $\left( \begin{smallmatrix} x/w & y/w & z/w \end{smallmatrix} \right)$

# Turning on the Lights

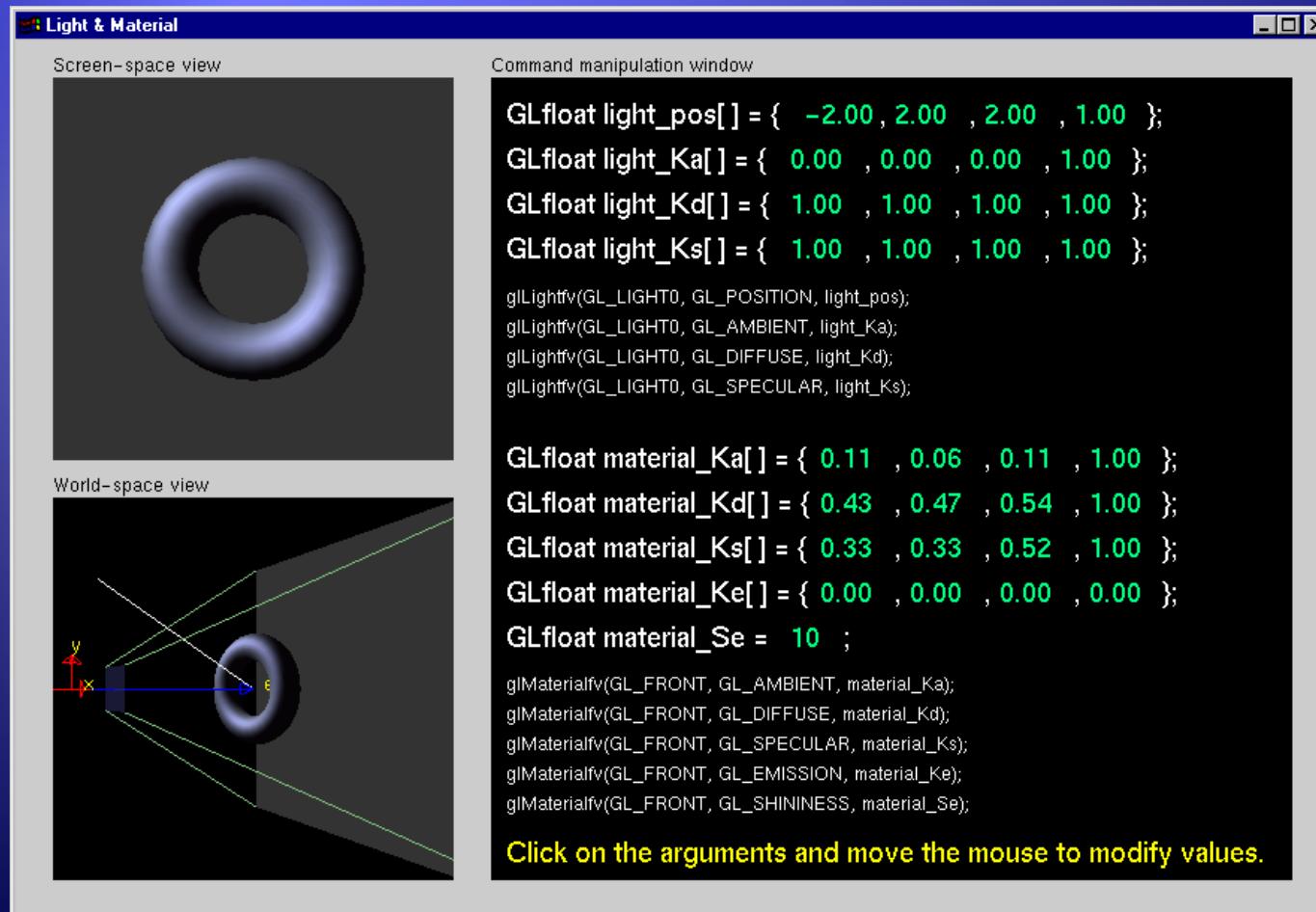
- ◆ Flip each light's switch

```
glEnable( GL_LIGHTn ) ;
```

- ◆ Turn on the power

```
glEnable( GL_LIGHTING ) ;
```

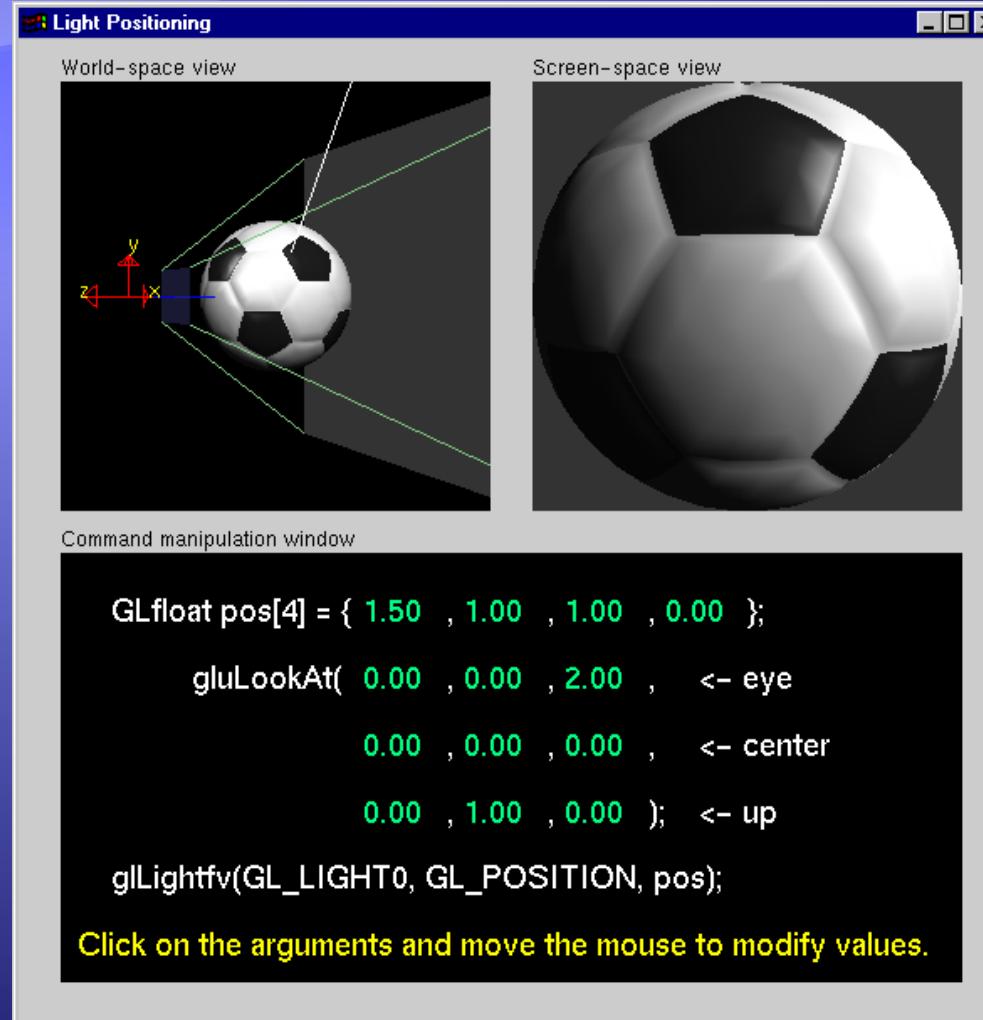
# Light Material Tutorial



# Controlling a Light's Position

- ◆ Modelview matrix affects a light's position
  - ◆ Different effects based on when position is specified
    - ◆ eye coordinates
    - ◆ world coordinates
    - ◆ model coordinates
  - ◆ Push and pop matrices to uniquely control a light's position

# Light Position Tutorial



# Advanced Lighting Features

- ◆ Spotlights
  - ◆ localize lighting affects
    - ◆ *GL\_SPOT\_DIRECTION*
    - ◆ *GL\_SPOT\_CUTOFF*
    - ◆ *GL\_SPOT\_EXPONENT*

# Advanced Lighting Features

- ◆ Light attenuation
  - ◆ decrease light intensity with distance
    - ◆ ***GL\_CONSTANT\_ATTENUATION***
    - ◆ ***GL\_LINEAR\_ATTENUATION***
    - ◆ ***GL\_QUADRATIC\_ATTENUATION***

$$f_i = \frac{1}{k_c + k_l d + k_q d^2}$$

# Light Model Properties

`glLightModelfv( property, value );`

- ◆ Enabling two sided lighting  
`GL_LIGHT_MODEL_TWO_SIDE`
- ◆ Global ambient color  
`GL_LIGHT_MODEL_AMBIENT`
- ◆ Local viewer mode  
`GL_LIGHT_MODEL_LOCAL_VIEWER`
- ◆ Separate specular color  
`GL_LIGHT_MODEL_COLOR_CONTROL`

# Tips for Better Lighting

- ◆ Recall lighting computed only at vertices
  - ◆ model tessellation heavily affects lighting results
    - ◆ better results but more geometry to process
- ◆ Use a single infinite light for fastest lighting
  - ◆ minimal computation per vertex

Vicki Shreiner

# IMAGING AND RASTER PRIMITIVES

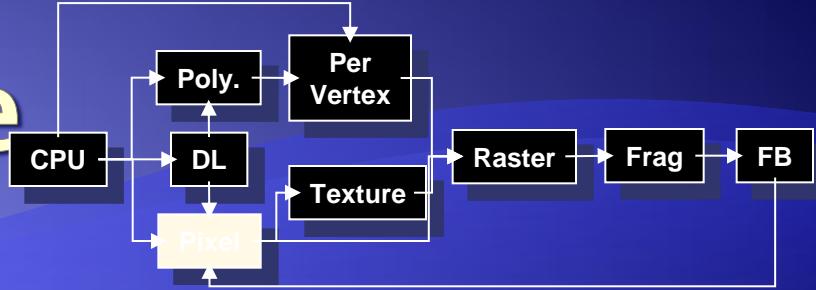
# Imaging and Raster Primitives

- ◆ Describe OpenGL's raster primitives: bitmaps and image rectangles
- ◆ Demonstrate how to get OpenGL to read and render pixel rectangles

# Pixel-based primitives

- ◆ Bitmaps
  - ◆ 2D array of bit masks for pixels
    - ◆ update pixel color based on current color
- ◆ Images
  - ◆ 2D array of pixel color information
    - ◆ complete color information for each pixel
- ◆ OpenGL doesn't understand image formats

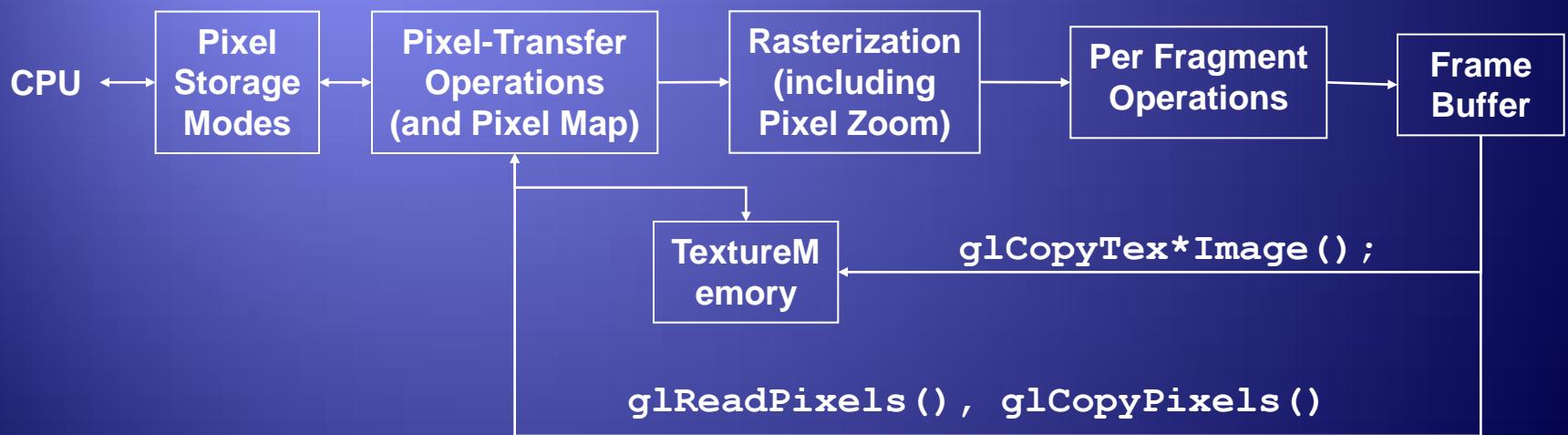
# Pixel Pipeline



- ◆ Programmable pixel storage

and transfer operations

`glBitmap()`, `glDrawPixels()`



# Positioning Image Primitives

`glRasterPos3f( x, y, z )`

- ◆ raster position transformed like geometry
- ◆ discarded if raster position is outside of viewport
  - ◆ may need to fine tune viewport for desired results

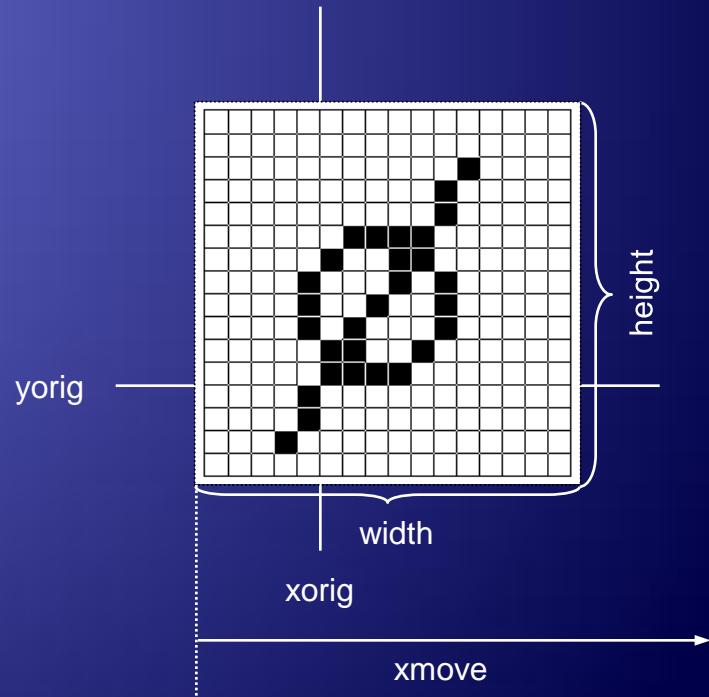


Raster Position

# Rendering Bitmaps

```
glBitmap( width, height, xorig, yorig, xmove,  
          ymove, bitmap )
```

- render bitmap in current color  
at  $(\lfloor x - x_{orig} \rfloor, \lfloor y - y_{orig} \rfloor)$
- advance raster position by  
 $(x_{move}, y_{move})$  after rendering



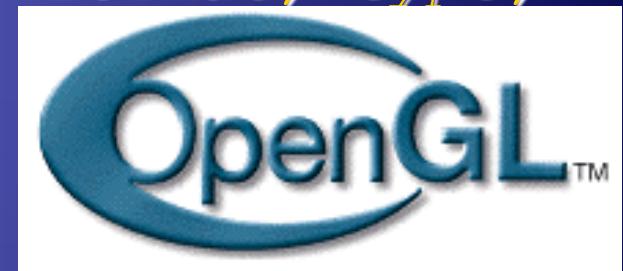
# Rendering Fonts using Bitmaps

- ◆ OpenGL uses bitmaps for font rendering
  - ◆ each character is stored in a display list containing a bitmap
  - ◆ window system specific routines to access system fonts
    - ◆ `glXUseXFont()`
    - ◆ `wglUseFontBitmaps()`

# Rendering Images

```
glDrawPixels( width, height, format, type,  
               pixels )
```

- ◆ render pixels with lower left of image at current raster position
- ◆ numerous formats and data types for specifying storage in memory
  - ◆ best performance by using format and type that matches hardware



# Reading Pixels

```
glReadPixels( x, y, width, height, format,  
             type, pixels )
```

- ◆ read pixels from specified  $(x,y)$  position in framebuffer
- ◆ pixels automatically converted from framebuffer format into requested format and type
- ◆ Framebuffer pixel copy

```
glCopyPixels( x, y, width, height, type )
```

# Pixel Zoom

`glPixelZoom( x, y )`

- ◆ expand, shrink or reflect pixels around current raster position
- ◆ fractional zoom supported

Raster  
Position

`glPixelZoom(1.0, -1.0);`



# Storage and Transfer Modes

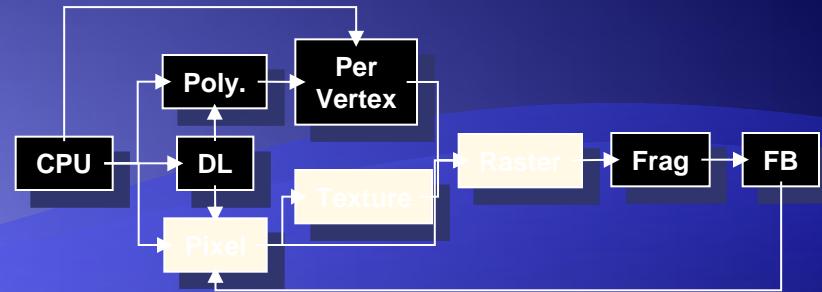
- ◆ Storage modes control accessing memory
  - ◆ byte alignment in host memory
  - ◆ extracting a subimage
- ◆ Transfer modes allow modify pixel values
  - ◆ scale and bias pixel component values
  - ◆ replace colors using pixel maps

The background features a smooth gradient from light blue at the top left to dark blue at the bottom right. Two thin, curved blue lines are visible: one diagonal line extending from the top left towards the center, and another curved line starting from the top center and sweeping down towards the bottom right.

Ed Angel

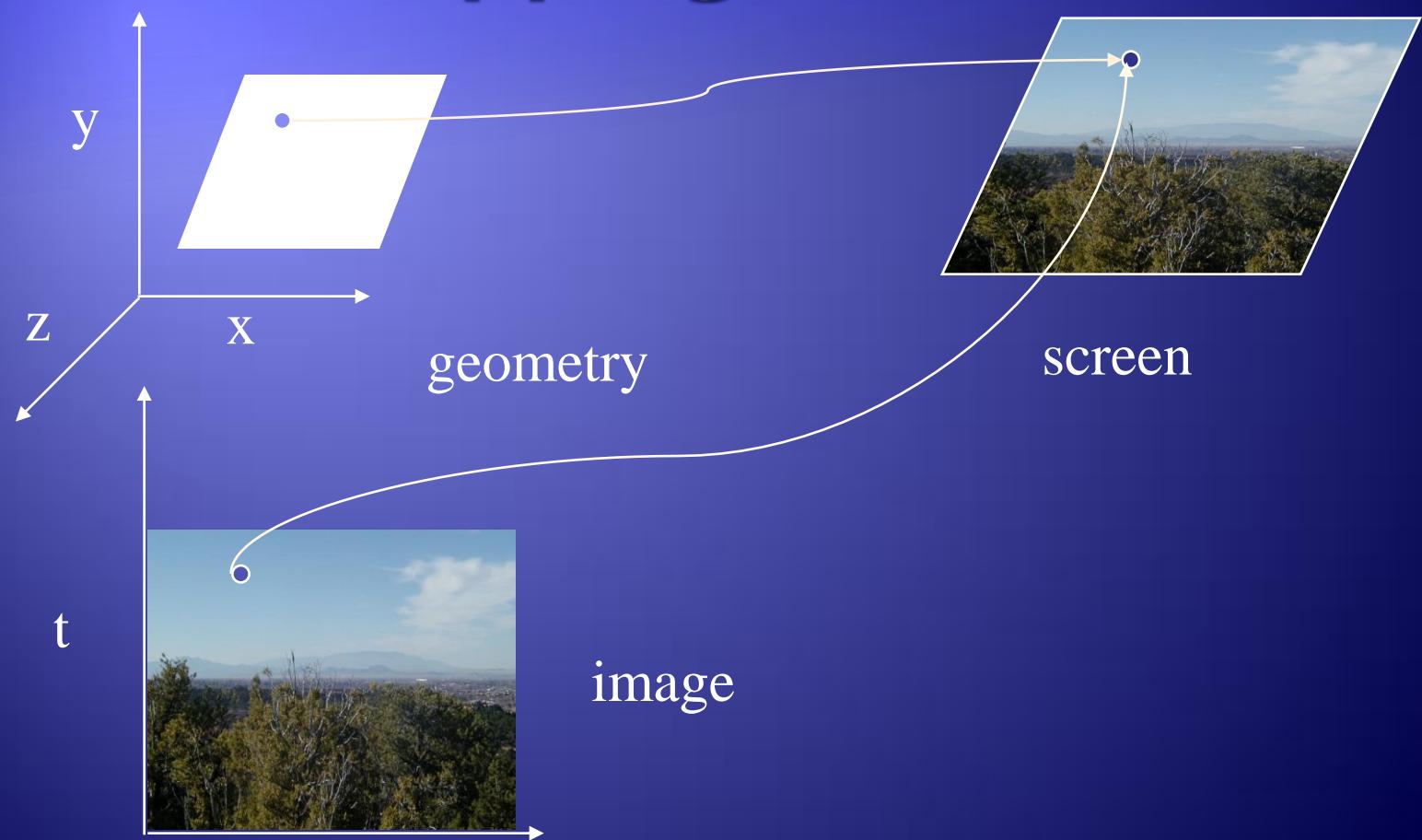
# TEXTURE MAPPING

# Texture Mapping



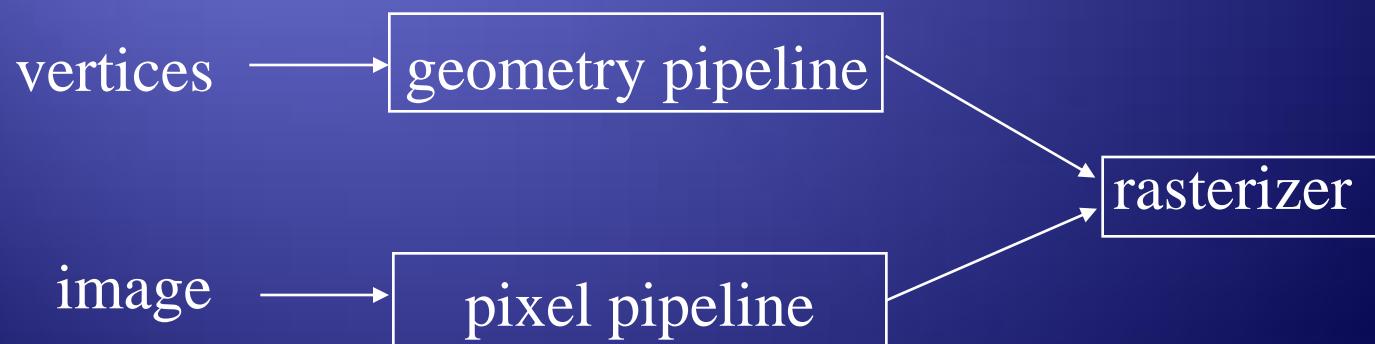
- ◆ Apply a 1D, 2D, or 3D image to geometric primitives
- ◆ Uses of Texturing
  - ◆ simulating materials
  - ◆ reducing geometric complexity
  - ◆ image warping
  - ◆ reflections

# Texture Mapping



# Texture Mapping and the OpenGL Pipeline

- ◆ Images and geometry flow through separate pipelines that join at the rasterizer
  - ◆ “complex” textures do not affect geometric complexity



# Texture Example

- ◆ The texture (below) is a  $256 \times 256$  image that has been mapped to a rectangular polygon which is viewed in perspective



# Applying Textures I

- ◆ Three steps
  - ① specify texture
    - ♦ read or generate image
    - ♦ assign to texture
  - ② assign texture coordinates to vertices
  - ③ specify texture parameters
    - ♦ wrapping, filtering

# Applying Textures II

- ◆ specify textures in texture objects
- ◆ set texture filter
- ◆ set texture function
- ◆ set texture wrap mode
- ◆ set optional perspective correction hint
- ◆ bind texture object
- ◆ enable texturing
- ◆ supply texture coordinates for vertex
  - ◆ coordinates can also be generated

# Texture Objects

- ◆ Like display lists for texture images
  - ◆ one image per texture object
  - ◆ may be shared by several graphics contexts
- ◆ Generate texture names

```
glGenTextures( n, *texIds );
```

# Texture Objects (cont.)

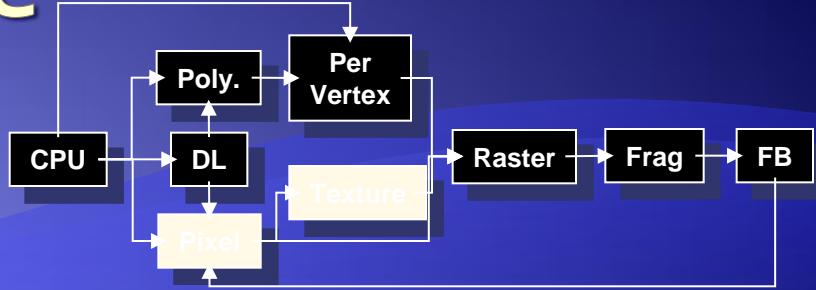
- ◆ Create texture objects with texture data and state

```
glBindTexture( target, id );
```

- ◆ Bind textures before using

```
glBindTexture( target, id );
```

# Specify Texture Image



- ◆ Define a texture image from an array of texels in CPU memory

```
glTexImage2D( target, level, components,  
    w, h, border, format, type, *texels );
```

- ◆ dimensions of image must be powers of 2
- ◆ Texel colors are processed by pixel pipeline
  - ◆ pixel scales, biases and lookups can be done

# Converting A Texture Image

- ◆ If dimensions of image are not power of 2

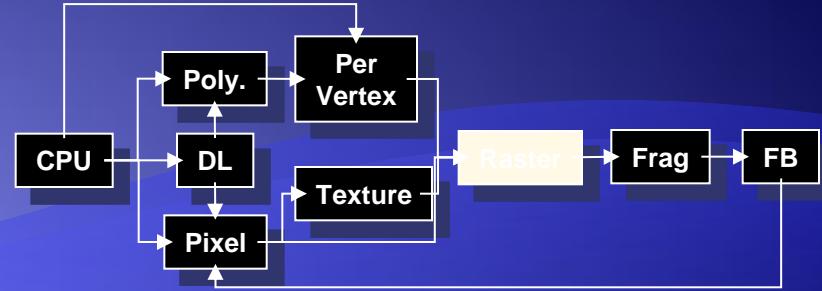
```
gluScaleImage( format, w_in, h_in,  
    type_in, *data_in, w_out, h_out,  
    type_out, *data_out );
```

- ◆ *\*\_in is for source image*
- ◆ *\*\_out is for destination image*
- ◆ Image interpolated and filtered during scaling

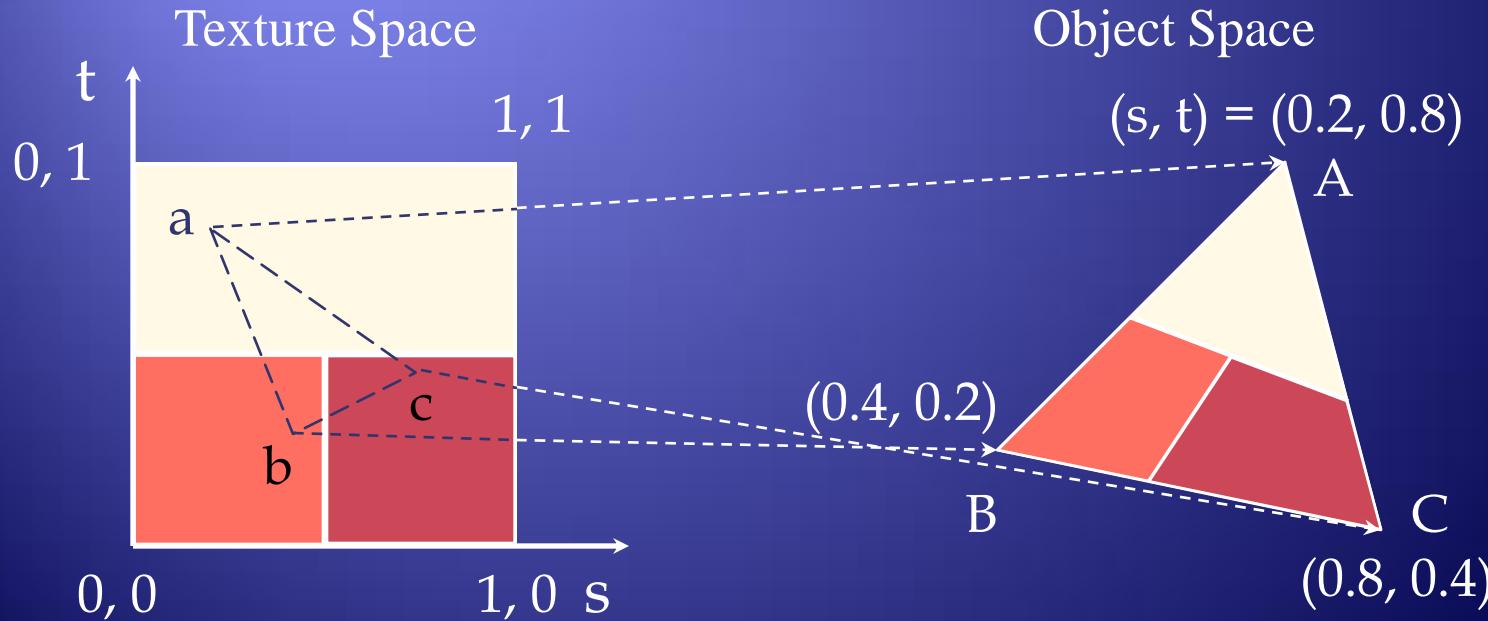
# Specifying a Texture: Other Methods

- ◆ Use frame buffer as source of texture image
  - uses current buffer as source image
    - `glCopyTexImage2D( . . . )`
    - `glCopyTexImage1D( . . . )`
- ◆ Modify part of a defined texture
  - `glTexSubImage2D( . . . )`
  - `glTexSubImage1D( . . . )`
- ◆ Do both with `glCopyTexSubImage2D( . . . )`, etc.

# Mapping a Texture



- ◆ Based on parametric texture coordinates
- ◆ `glTexCoord*()` specified at each vertex



# Generating Texture Coordinates

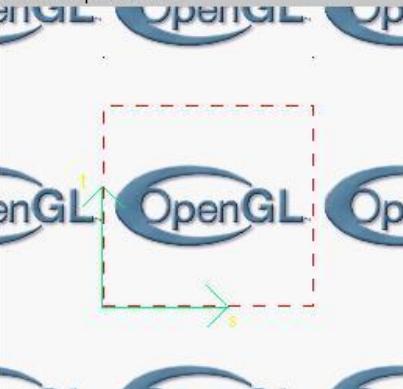
- ◆ Automatically generate texture coords  
`glTexGen{ifd} [v] ()`
- ◆ specify a plane
  - ◆ generate texture coordinates based upon distance from plane  
 $Ax + By + Cz + D = 0$
- ◆ generation modes
  - ◆ `GL_OBJECT_LINEAR`
  - ◆ `GL_EYE_LINEAR`
  - ◆ `GL_SPHERE_MAP`

# Tutorial: Texture

Screen-space view



Texture-space view



Command manipulation window

```
GLfloat border_color[] = { 1.00, 0.00, 0.00, 1.00 };
GLfloat env_color[] = { 0.00, 1.00, 0.00, 1.00 };

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_BORDER_COLOR, border_color);
glTexEnvfv(GL_TEXTURE_ENV, GL_TEXTURE_ENV_COLOR, env_color);

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT);
glTexEnvi(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_MODULATE);

glEnable(GL_TEXTURE_2D);
glBuild2DMipmaps(GL_TEXTURE_2D, 3, w, h, GL_RGB, GL_UNSIGNED_BYTE, image);

	glColor4f( 0.60, 0.60, 0.60, 1.00 );
 glBegin(GL_POLYGON);
 glTexCoord2f( 0.0, 0.0 ); glVertex3f( -1.0, -1.0, 0.0 );
 glTexCoord2f( 1.0, 0.0 ); glVertex3f( 1.0, -1.0, 0.0 );
 glTexCoord2f( 1.0, 1.0 ); glVertex3f( 1.0, 1.0, 0.0 );
 glTexCoord2f( 0.0, 1.0 ); glVertex3f( -1.0, 1.0, 0.0 );
 glEnd();
```

Click on the arguments and move the mouse to modify values.

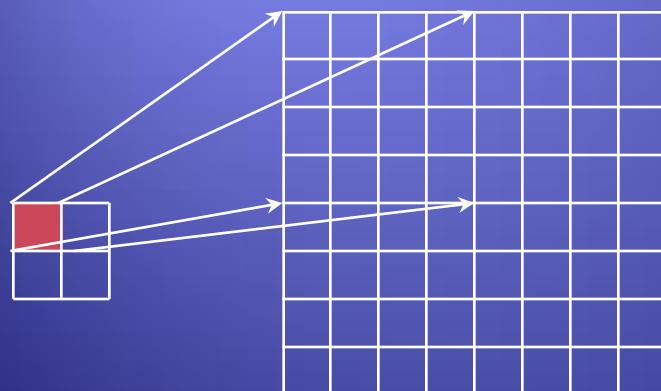
# Texture Application Methods

- ◆ Filter Modes
  - ◆ minification or magnification
  - ◆ special mipmap minification filters
- ◆ Wrap Modes
  - ◆ clamping or repeating
- ◆ Texture Functions
  - ◆ how to mix primitive's color with texture's color
    - ◆ blend, modulate or replace texels

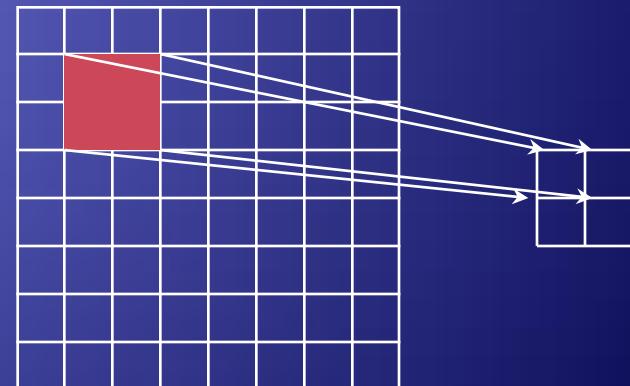
# Filter Modes

Example:

```
glTexParameter( target, type, mode );
```



Texture  
Magnification



Texture  
Minification

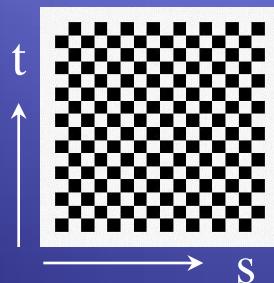
# Mipmapped Textures

- ◆ Mipmap allows for prefiltered texture maps of decreasing resolutions
- ◆ Lessens interpolation errors for smaller textured objects
- ◆ Declare mipmap level during texture definition  
`glTexImage*D( GL_TEXTURE_D, level, ... )`
- ◆ GLU mipmap builder routines  
`gluBuild*DMipmaps( ... )`
- ◆ OpenGL 1.2 introduces advanced LOD controls

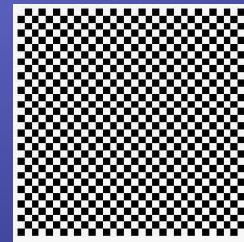
# Wrapping Mode

- ◆ Example:

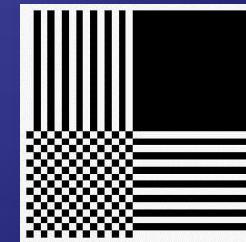
```
glTexParameteri( GL_TEXTURE_2D,  
                  GL_TEXTURE_WRAP_S, GL_CLAMP )  
  
glTexParameteri( GL_TEXTURE_2D,  
                  GL_TEXTURE_WRAP_T, GL_REPEAT )
```



texture



GL\_REPEAT  
wrapping



GL\_CLAMP  
wrapping

# Texture Functions

- ◆ Controls how texture is applied

```
glTexEnv{fi}[v] ( GL_TEXTURE_ENV, prop, param )
```

- ◆ *GL\_TEXTURE\_ENV\_MODE* modes
  - ◆ ***GL\_MODULATE***
  - ◆ ***GL\_BLEND***
  - ◆ ***GL\_REPLACE***
- ◆ Set blend color with *GL\_TEXTURE\_ENV\_COLOR*

# Perspective Correction Hint

- ◆ Texture coordinate and color interpolation
  - ◆ either linearly in screen space
  - ◆ or using depth/perspective values (slower)
- ◆ Noticeable for polygons “on edge”

`glHint( GL_PERSPECTIVE_CORRECTION_HINT, hint )`

where *hint* is one of

- ◆ *GL\_DONT\_CARE*
- ◆ *GL\_NICEST*
- ◆ *GL\_FASTEST*

# Is There Room for a Texture?

- ◆ Query largest dimension of texture image
  - ◆ typically largest square texture
  - ◆ doesn't consider internal format size

```
glGetIntegerv( GL_MAX_TEXTURE_SIZE, &size )
```

- ◆ Texture proxy
  - ◆ will memory accommodate requested texture size?
  - ◆ no image specified; placeholder
  - ◆ if texture won't fit, texture state variables set to 0
    - ◆ doesn't know about other textures
    - ◆ only considers whether this one texture will fit all of memory

# Texture Residency

- ◆ Working set of textures
  - high-performance, usually hardware accelerated
  - textures must be in texture objects
  - a texture in the *working set* is *resident*
  - for residency of current texture, check **GL\_TEXTURE\_RESIDENT** state
- ◆ If too many textures, not all are resident
  - can set priority to have some kicked out first
  - establish 0.0 to 1.0 priorities for texture objects

The background features a gradient from light blue at the top left to dark blue at the bottom right. It includes several thin, curved blue lines of varying lengths that intersect and overlap each other.

Dave Shreiner

# ADVANCED OPENGL TOPICS

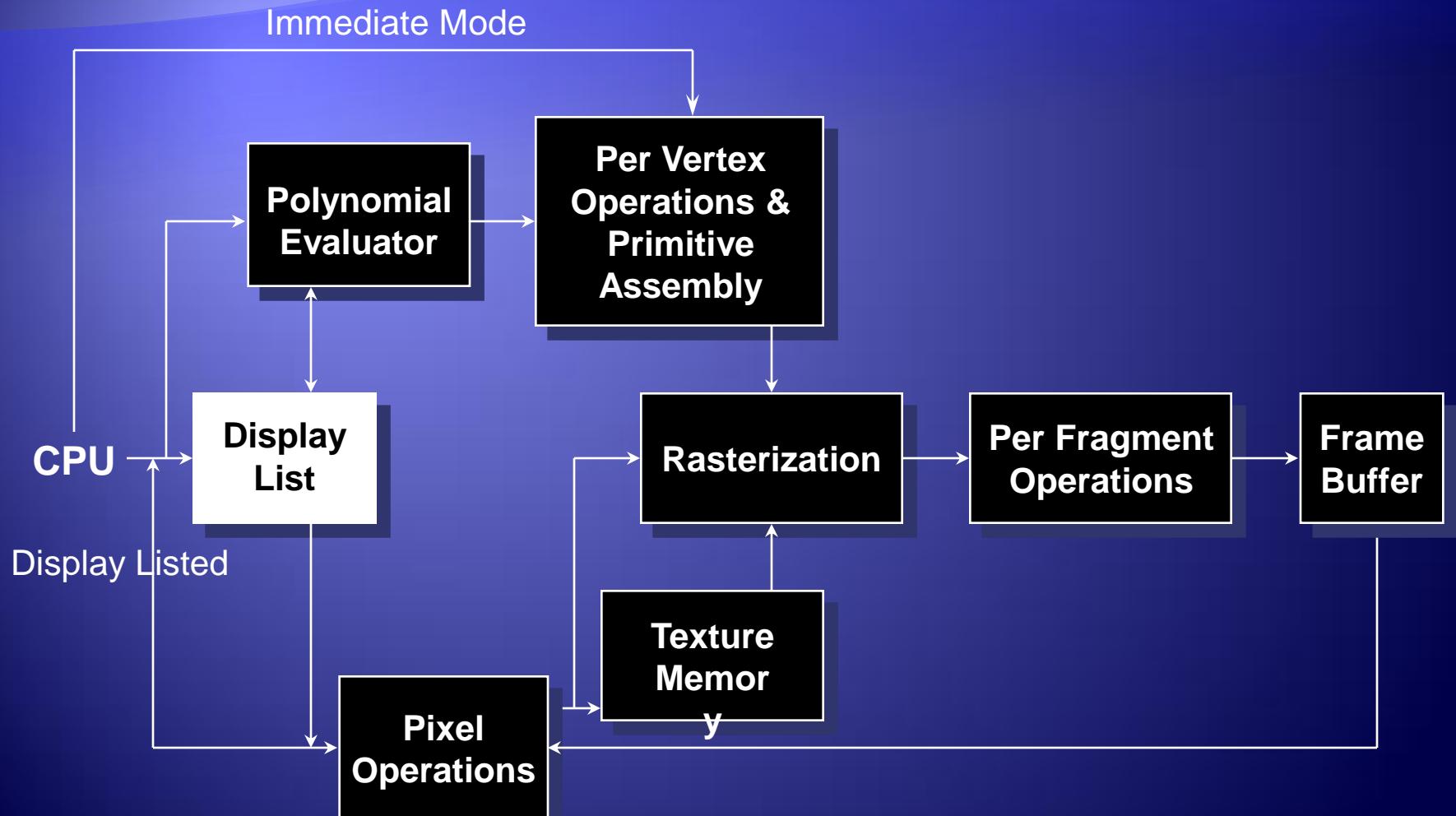
# Advanced OpenGL Topics

- ◆ Display Lists and Vertex Arrays
- ◆ Alpha Blending and Antialiasing
- ◆ Using the Accumulation Buffer
- ◆ Fog
- ◆ Feedback & Selection
- ◆ Fragment Tests and Operations
- ◆ Using the Stencil Buffer

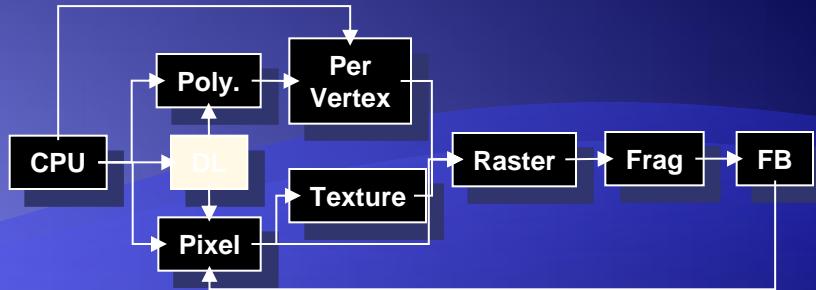
# Immediate Mode versus Display Listed Rendering

- ◆ Immediate Mode Graphics
  - ◆ Primitives are sent to pipeline and display right away
  - ◆ No memory of graphical entities
- ◆ Display Listed Graphics
  - ◆ Primitives placed in display lists
  - ◆ Display lists kept on graphics server
  - ◆ Can be redisplayed with different state
  - ◆ Can be shared among OpenGL graphics contexts

# Immediate Mode versus Display Lists



# Display Lists



- ◆ Creating a display list

```
GLuint id;  
void init( void )  
{  
    id = glGenLists( 1 );  
    glNewList( id, GL_COMPILE );  
    /* other OpenGL routines */  
    glEndList();  
}
```

- ◆ Call a created list

```
void display( void )  
{  
    glCallList( id );  
}
```

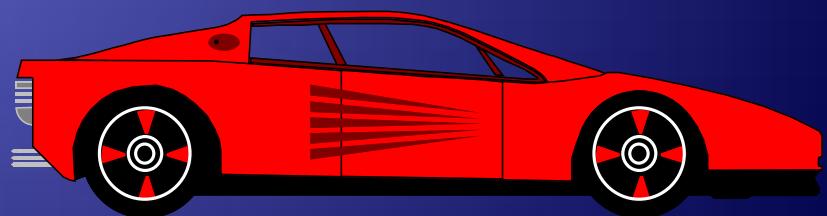
# Display Lists

- ◆ Not all OpenGL routines can be stored in display lists
- ◆ State changes persist, even after a display list is finished
- ◆ Display lists can call other display lists
- ◆ Display lists are not editable, but you can fake it
  - ◆ make a list (A) which calls other lists (B, C, and D)
  - ◆ delete and replace B, C, and D, as needed

# Display Lists and Hierarchy

- ◆ Consider model of a car
  - ◆ Create display list for chassis
  - ◆ Create display list for wheel

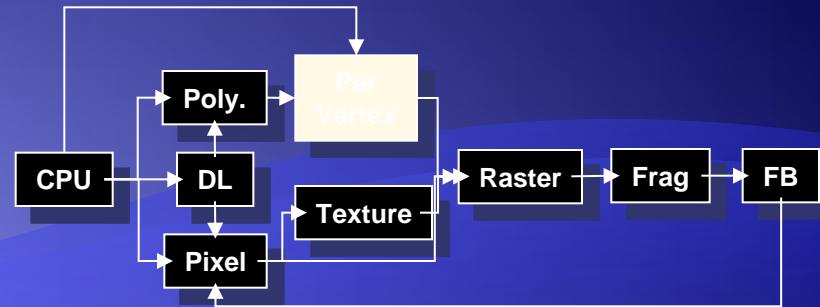
```
glNewList( CAR, GL_COMPILE ) ;  
    glCallList( CHASSIS ) ;  
    glTranslatef( ... ) ;  
    glCallList( WHEEL ) ;  
    glTranslatef( ... ) ;  
    glCallList( WHEEL ) ;  
    ...  
glEndList() ;
```



# Advanced Primitives

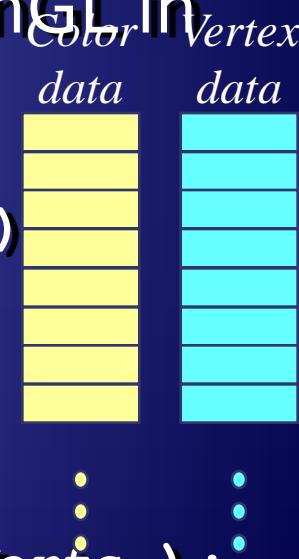
- ◆ Vertex Arrays
- ◆ Bernstein Polynomial Evaluators
  - ◆ basis for GLU NURBS
    - ◆ NURBS (Non-Uniform Rational B-Spines)
- ◆ GLU Quadric Objects
  - ◆ sphere
  - ◆ cylinder (or cone)
  - ◆ disk (circle)

# Vertex Arrays



- ◆ Pass arrays of vertices, colors, etc. to OpenGL in a large chunk

```
glVertexPointer( 3, GL_FLOAT, 0, coords )
glColorPointer( 4, GL_FLOAT, 0, colors )
 glEnableClientState( GL_VERTEX_ARRAY )
 glEnableClientState( GL_COLOR_ARRAY )
 ...
 glDrawArrays( GL_TRIANGLE_STRIP, 0, numVerts );
```



- ◆ All active arrays are used in rendering

# Why use Display Lists or Vertex Arrays?

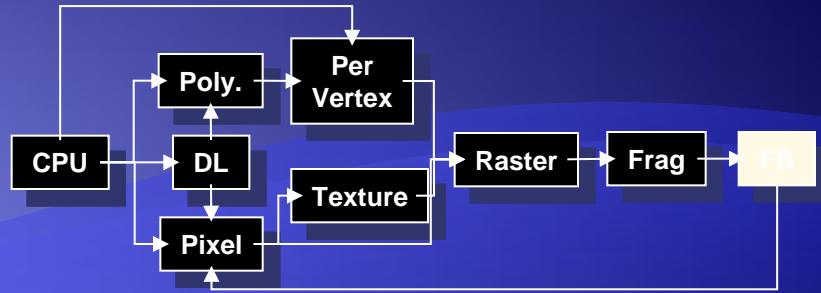
- ◆ May provide better performance than immediate mode rendering
- ◆ Display lists can be shared between multiple OpenGL context
  - ◆ reduce memory usage for multi-context applications
- ◆ Vertex arrays may format data for better memory access

# Alpha: the 4<sup>th</sup> Color Component

- ◆ Measure of Opacity
  - ◆ simulate translucent objects
    - ◆ glass, water, etc.
  - ◆ composite images
  - ◆ antialiasing
  - ◆ ignored if blending is not enabled

`glEnable( GL_BLEND )`

# Blending

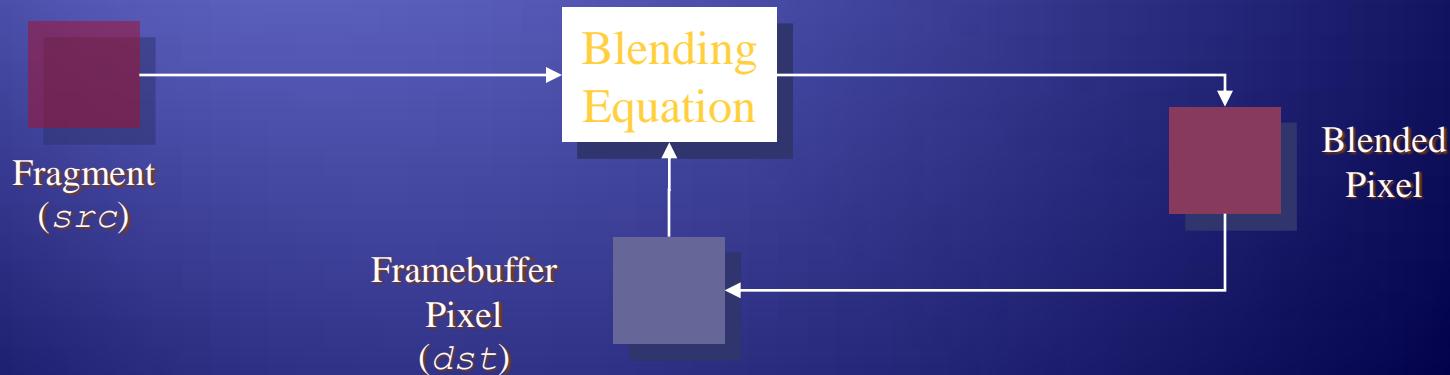


- ◆ Combine pixels with what's in already in the framebuffer

```
glBlendFunc( src, dst )  

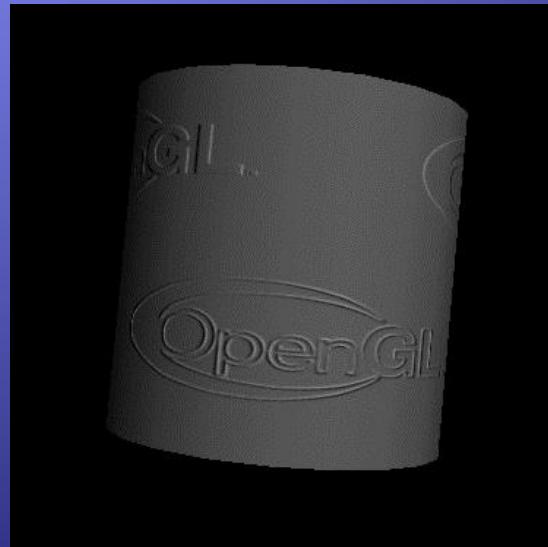
$$\vec{C}_r = src \vec{C}_f + dst \vec{C}_p$$

```



# Multi-pass Rendering

- ◆ Blending allows results from multiple drawing passes to be combined together
  - ◆ enables more complex rendering algorithms



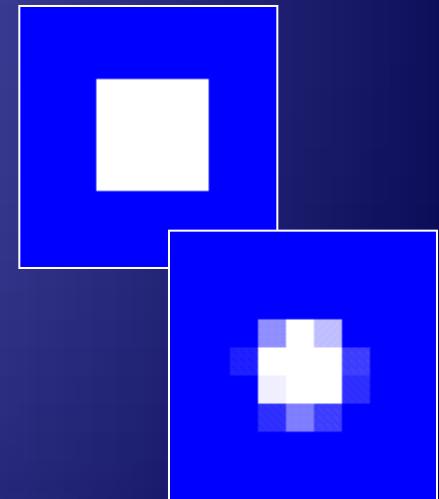
Example of bump-mapping  
done with a multi-pass  
OpenGL algorithm

# Antialiasing

- ◆ Removing the Jaggies

```
glEnable( mode )
```

- **GL\_POINT\_SMOOTH**
- **GL\_LINE\_SMOOTH**
- **GL\_POLYGON\_SMOOTH**
- alpha value computed by computing sub-pixel coverage
- available in both RGBA and colormap modes



# Accumulation Buffer

- ◆ Problems of compositing into color buffers
  - ◆ limited color resolution
    - ◆ clamping
    - ◆ loss of accuracy
  - ◆ Accumulation buffer acts as a “floating point” color buffer
    - ◆ accumulate into accumulation buffer
    - ◆ transfer results to frame buffer

# Accessing Accumulation Buffer

`glAccum( op, value )`

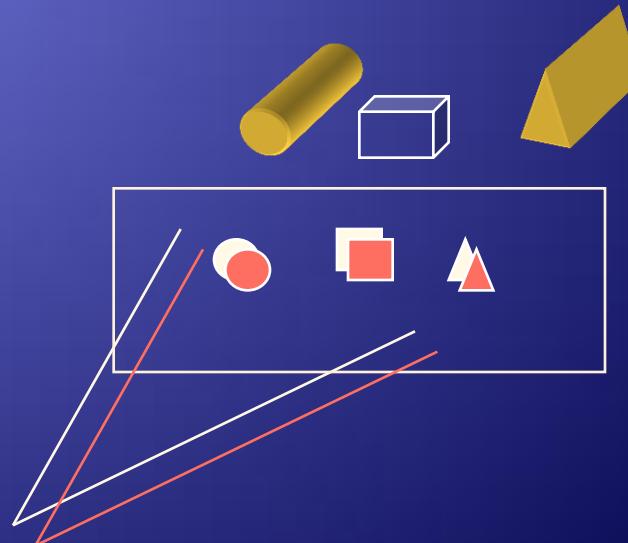
- ◆ operations
  - ◆ within the accumulation buffer: ***GL\_ADD***, ***GL\_MULT***
  - ◆ from read buffer: ***GL\_ACCUM***, ***GL\_LOAD***
  - ◆ transfer back to write buffer: ***GL\_RETURN***
- ◆ **`glAccum(GL_ACCUM, 0.5)`** multiplies each value in write buffer by 0.5 and adds to accumulation buffer

# Accumulation Buffer Applications

- ◆ Compositing
- ◆ Full Scene Antialiasing
- ◆ Depth of Field
- ◆ Filtering
- ◆ Motion Blur

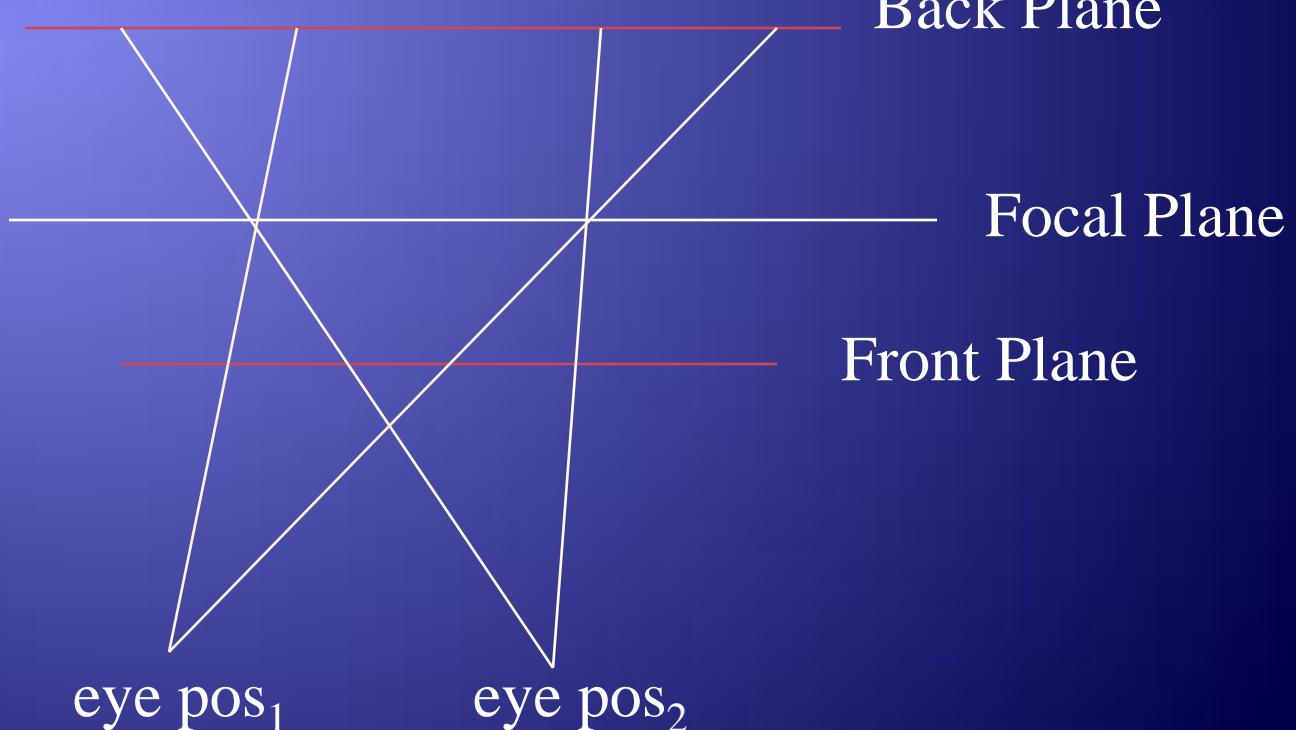
# Full Scene Antialiasing : *Jittering the view*

- ◆ Each time we move the viewer, the image shifts
  - ◆ Different aliasing artifacts in each image
  - ◆ Averaging images using accumulation buffer averages out these artifacts



# Depth of Focus : Keeping a Plane in Focus

- ◆ Jitter the viewer to keep one plane unchanged

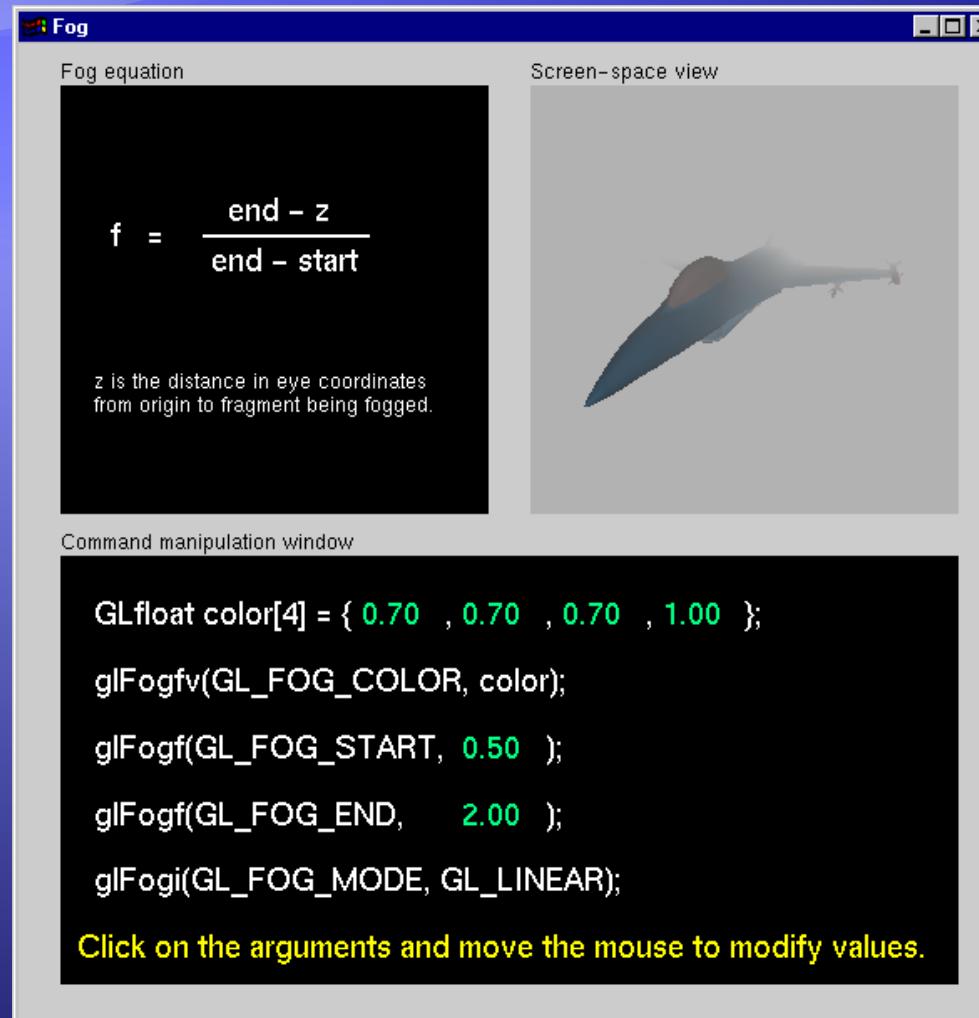


# Fog

`glFog( property, value )`

- ◆ Depth Cueing
  - ◆ Specify a range for a linear fog ramp
    - ◆ **GL\_FOG\_LINEAR**
- ◆ Environmental effects
  - ◆ Simulate more realistic fog
    - ◆ **GL\_FOG\_EXP**
    - ◆ **GL\_FOG\_EXP2**

# Fog Tutorial



# Feedback Mode

- ◆ Transformed vertex data is returned to the application, not rendered
  - ◆ useful to determine which primitives will make it to the screen
- ◆ Need to specify a feedback buffer

```
glFeedbackBuffer( size, type, buffer )
```
- ◆ Select feedback mode for rendering

```
glRenderMode( GL_FEEDBACK )
```

# Selection Mode

- ◆ Method to determine which primitives are inside the viewing volume
- ◆ Need to set up a buffer to have results returned to you

**glSelectBuffer( size, buffer )**

- ◆ Select selection mode for rendering

**glRenderMode( GL\_SELECT )**

# Selection Mode (cont.)

- ◆ To identify a primitive, give it a name
  - ◆ “names” are just integer values, not strings
- ◆ Names are stack based
  - ◆ allows for hierarchies of primitives
- ◆ Selection Name Routines

```
glLoadName( name )    glPushName( name )  
glInitNames()
```

# Picking

- ◆ Picking is a special case of selection
- ◆ Programming steps
  - ◆ restrict “drawing” to small region near pointer  
use `gluPickMatrix()` on projection matrix
  - ◆ enter selection mode; re-render scene
  - ◆ primitives drawn near cursor cause hits
  - ◆ exit selection; analyze hit records

# Picking Template

```
glutMouseFunc( pickMe ) ;  
  
void pickMe( int button, int state, int x, int y )  
{  
    GLuint nameBuffer[256] ;  
    GLint hits ;  
    GLint myViewport[4] ;  
    if (button != GLUT_LEFT_BUTTON ||  
        state != GLUT_DOWN) return ;  
    glGetIntegerv( GL_VIEWPORT, myViewport ) ;  
    glSelectBuffer( 256, nameBuffer ) ;  
    (void) glRenderMode( GL_SELECT ) ;  
    glInitNames() ;
```

# Picking Template (cont.)

```
glMatrixMode( GL_PROJECTION );
glPushMatrix();
glLoadIdentity();
gluPickMatrix( (GLdouble) x, (GLdouble)
               (myViewport[3]-y), 5.0, 5.0, myViewport );
/*  gluPerspective or glOrtho or other projection */
glPushName( 1 );
/*  draw something  */
glLoadName( 2 );
/*  draw something else ... continue ... */
```

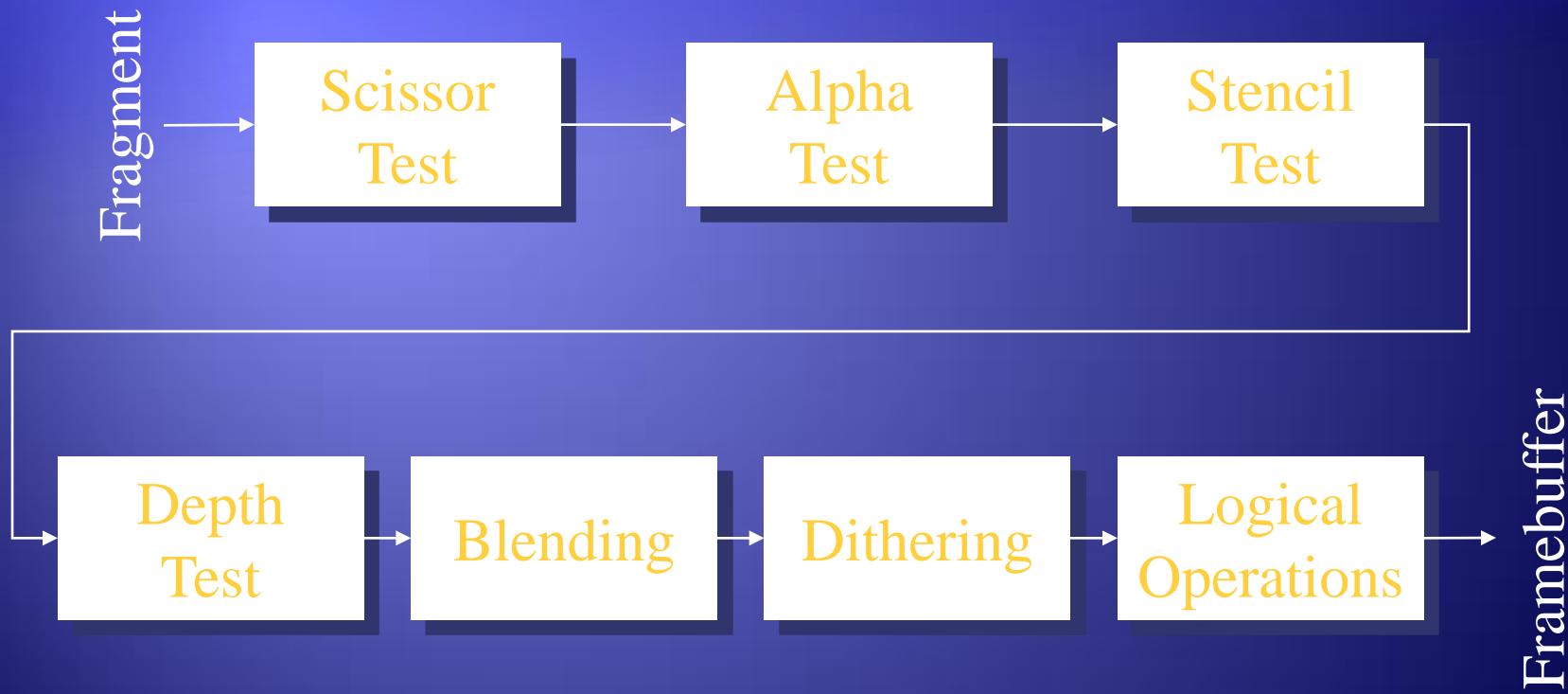
# Picking Template (cont.)

```
glMatrixMode( GL_PROJECTION ) ;  
glPopMatrix() ;  
hits = glRenderMode( GL_RENDER ) ;  
/* process nameBuffer */  
}
```

# Picking Ideas

- ◆ For OpenGL Picking Mechanism
  - ◆ only render what is pickable (e.g., don't clear screen!)
  - ◆ use an "invisible" filled rectangle, instead of text
  - ◆ if several primitives drawn in picking region, hard to use z values to distinguish which primitive is "on top"
- ◆ Alternatives to Standard Mechanism
  - ◆ color or stencil tricks (for example, use `glReadPixels()` to obtain pixel value from back buffer)

# Getting to the Framebuffer



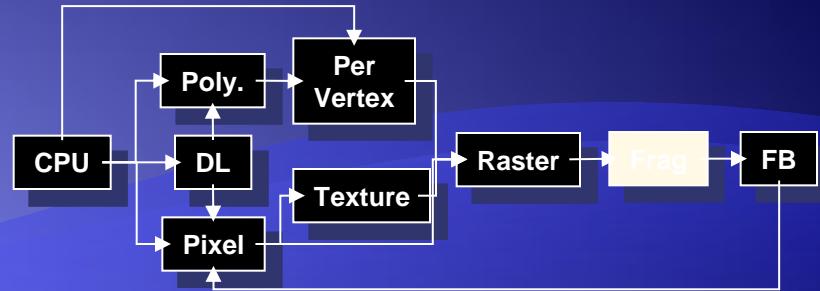
# Scissor Box

- ◆ Additional Clipping Test

```
glScissor( x, y, w, h )
```

- ◆ any fragments outside of box are clipped
- ◆ useful for updating a small section of a viewport
  - ◆ affects **glClear()** operations

# Alpha Test



- ◆ Reject pixels based on their alpha value

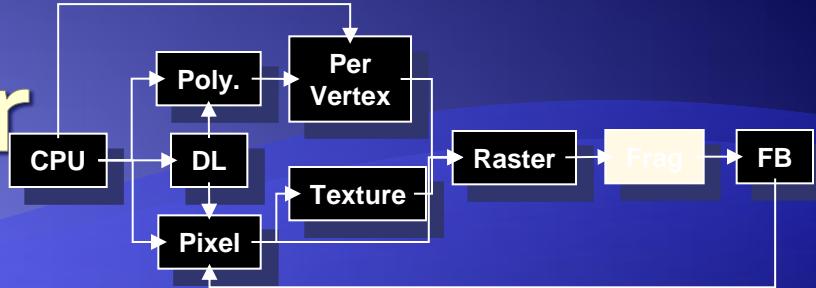
```
glAlphaFunc( func, value )
```

```
glEnable( GL_ALPHA_TEST )
```

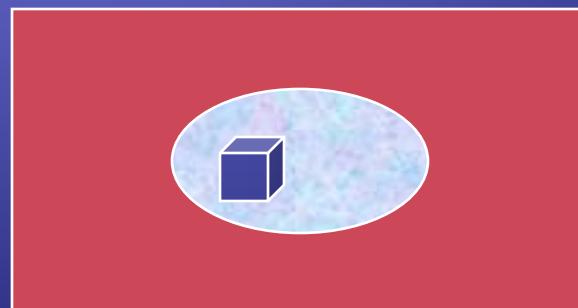
- ◆ use alpha as a mask in textures



# Stencil Buffer



- Used to control drawing based on values in the stencil buffer
  - Fragments that fail the stencil test are not drawn
  - Example: create a mask in stencil buffer and draw only objects not in mask area



# Controlling Stencil Buffer

`glStencilFunc( func, ref, mask )`

- compare value in buffer with **ref** using **func**
- only applied for bits in **mask** which are 1
- **func** is one of standard comparison functions

`glStencilOp( fail, zfail, zpass )`

- Allows changes in stencil buffer based on passing or failing stencil and depth tests: **GL\_KEEP**, **GL\_INCR**

# Creating a Mask

```
glInitDisplayMode( ... | GLUT_STENCIL | ... ) ;  
	glEnable( GL_STENCIL_TEST ) ;  
	glClearStencil( 0x1 ) ;
```

```
glStencilFunc( GL_ALWAYS, 0x1, 0x1 ) ;  
glStencilOp( GL_REPLACE, GL_REPLACE,  
             GL_REPLACE ) ;
```

- ◆ *draw mask*

# Using Stencil Mask

```
glStencilFunc( GL_EQUAL, 0x1, 0x1 )
```

- ◆ draw objects where stencil = 1

```
glStencilFunc( GL_NOTEQUAL, 0x1, 0x1  
);
```

```
glStencilOp( GL_KEEP, GL_KEEP, GL_KEEP  
);
```

- ◆ draw objects where stencil != 1

# Dithering

```
glEnable( GL_DITHER )
```

- ◆ Dither colors for better looking results
  - ◆ Used to simulate more available colors

# Logical Operations on Pixels

- ◆ Combine pixels using bitwise logical operations
    - ◆ Common modes
      - ◆ **GL\_XOR**
      - ◆ **GL\_AND**
- `glLogicOp( mode )`

# Advanced Imaging

- ◆ Imaging Subset
  - ◆ Only available if **GL\_ARB\_imaging** defined
    - ◆ Color matrix
    - ◆ Convolutions
    - ◆ Color tables
    - ◆ Histogram
    - ◆ MinMax
    - ◆ Advanced Blending

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Ed Angel

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# SUMMARY / Q & A

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

# Thanks for Coming

- ◆ Questions and Answers

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# AN INTERACTIVE INTRODUCTION TO OPENGL PROGRAMMING

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# 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](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.pdffiles.com/pdf/files/English/Designing\\_&\\_Graphics/Learning\\_Modern\\_3D\\_Graphics\\_Programming.pdf](http://www.pdffiles.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](#)

# Temă

Realizarea unei aplicatii simple care sa permita:

- ✓ să unui obiect 3D,
- ✓ .