Computer Graphics

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Introduction to OpenGL

- General OpenGL Introduction
- An Example OpenGL Program
- Drawing with OpenGL
- Transformations
- Animation and Depth Buffering
- Lighting
- Evaluation and NURBS
- Texture Mapping
- Advanced OpenGL Topics
- Imaging

modified from
Dave Shreiner, Ed Angel, and Vicki Shreiner.
An Interactive Introduction to OpenGL Programming.
***ACM SIGGRAPH 2001 Conference Course Notes #54*.**
& *ACM SIGGRAPH 2004 Conference Course Notes #29*.

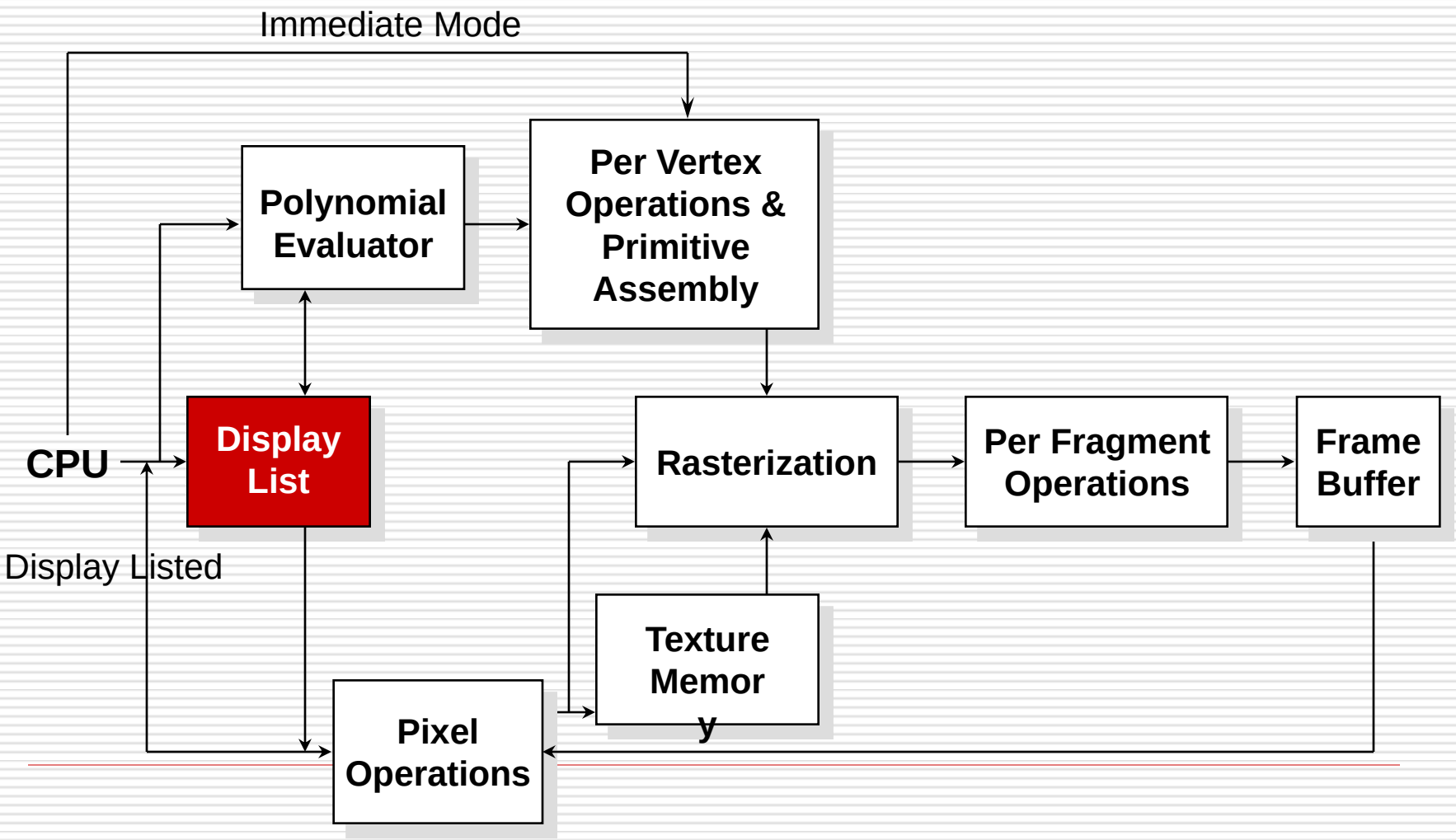
Advanced OpenGL Topics

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

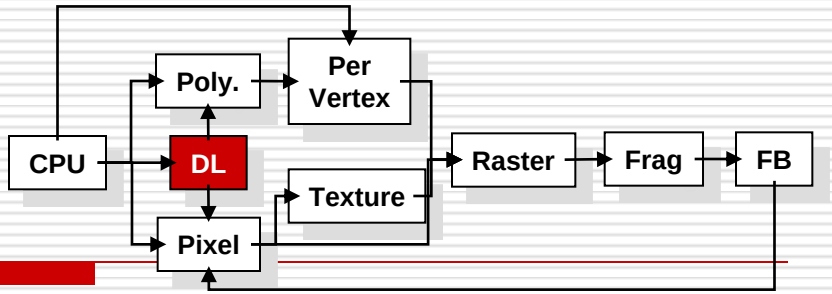
Immediate Mode versus Display Listed Rendering

- 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 );
}
```

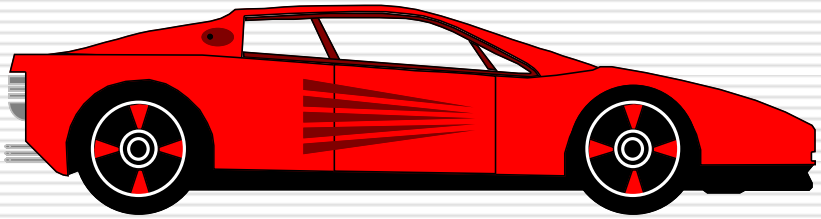
Display Lists

- 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

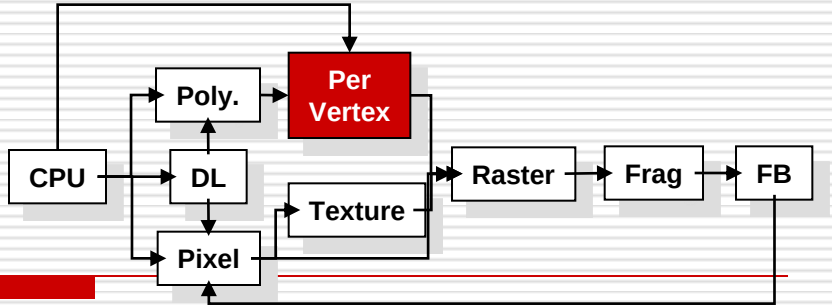
```
glNewList( CAR, GL_COMPILE );
   glCallList( CHASSIS );
   glTranslatef( … );
   glCallList( WHEEL );
   glTranslatef( … );
   glCallList( WHEEL );
      …
glEndList();
```



Advanced Primitives

- Vertex Arrays
- Bernstein Polynomial Evaluators
  - basis for GLU NURBS
    - NURBS (Non-Uniform Rational B-Splines)
- 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?

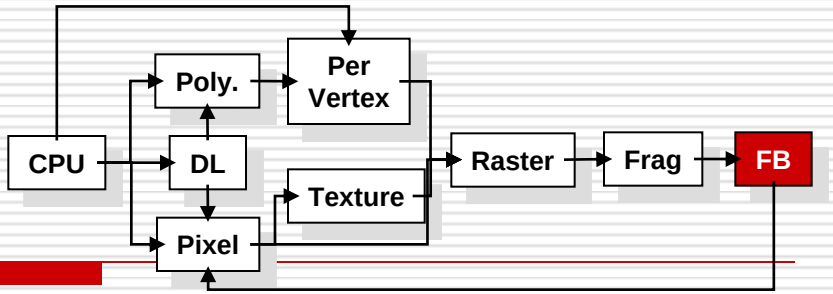
- May provide better performance than immediate mode rendering
- Display lists can be shared between multiple OpenGL context
  - reduce memory usage for multi-context applications
- Vertex arrays may format data for better memory access

Alpha: the 4th Color Component

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

```
glEnable( GL_BLEND )
```

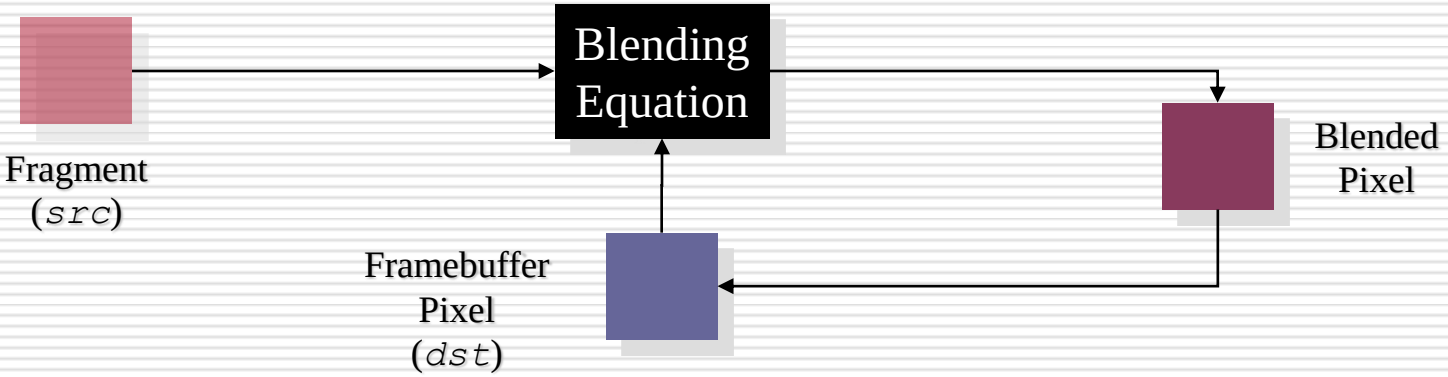
Blending



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

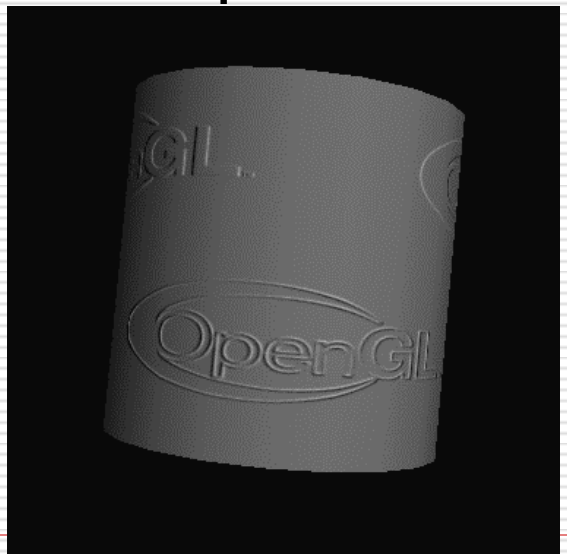
`glBlendFunc( src, dst )`

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



Multi-pass Rendering

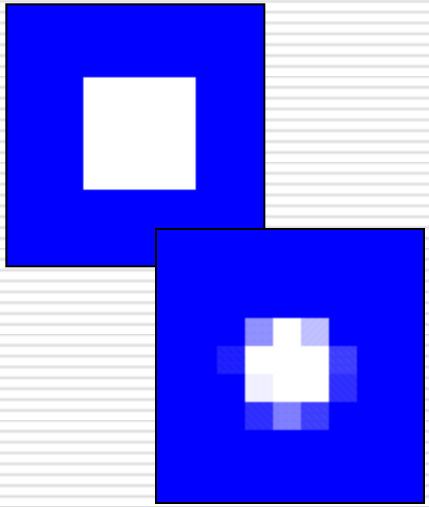
- Blending allows results from multiple drawing passes to be combined together
  - enables more complex rendering algorithms



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

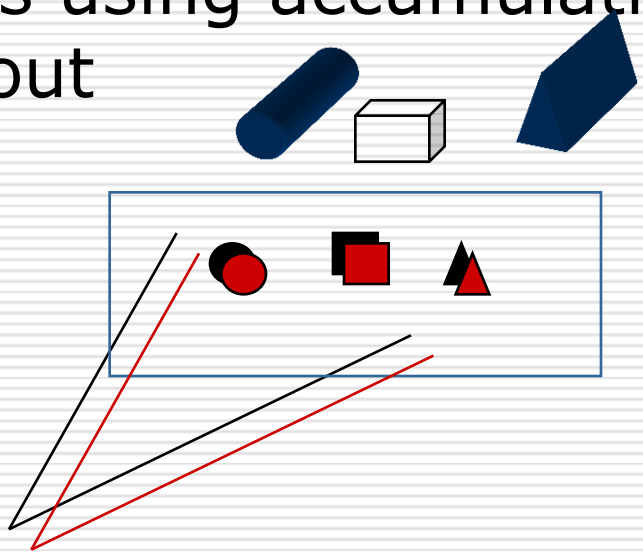
- **`glAccum( op, value )`**
  - operations
    - within the accumulation buffer: ***GL_ADD***, ***GL_MULT***
    - from read buffer: ***GL_ACCUM***, ***GL_LOAD***
    - transfer back to write buffer: ***GL_RETURN***
  - **`glAccum(`*GL_ACCUM*, *0.5*`)`** multiplies each value in write buffer by 0.5 and adds to accumulation buffer

Accumulation Buffer Applications

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

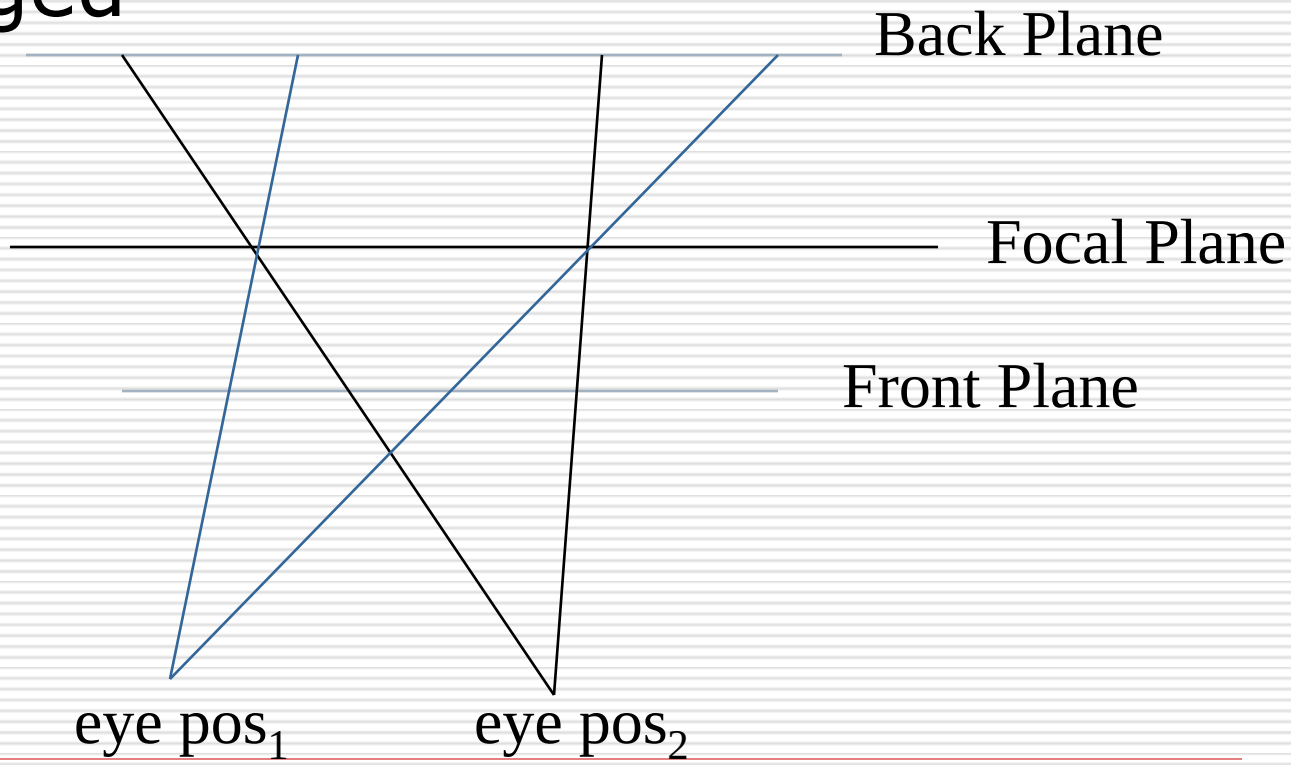
Full Scene Antialiasing : *Jittering the view*

- 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*

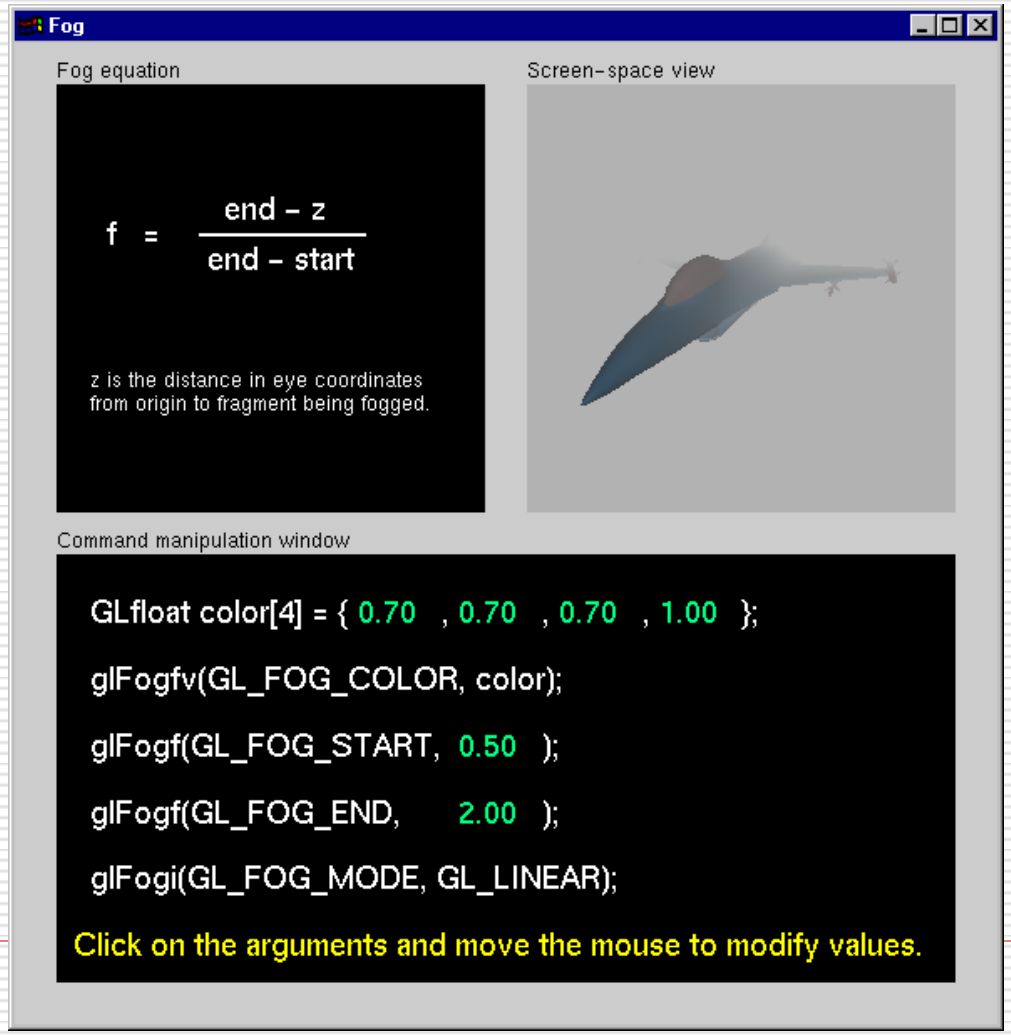
- Jitter the viewer to keep one plane unchanged



Fog

- **`glFog{if}(` *`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();
```

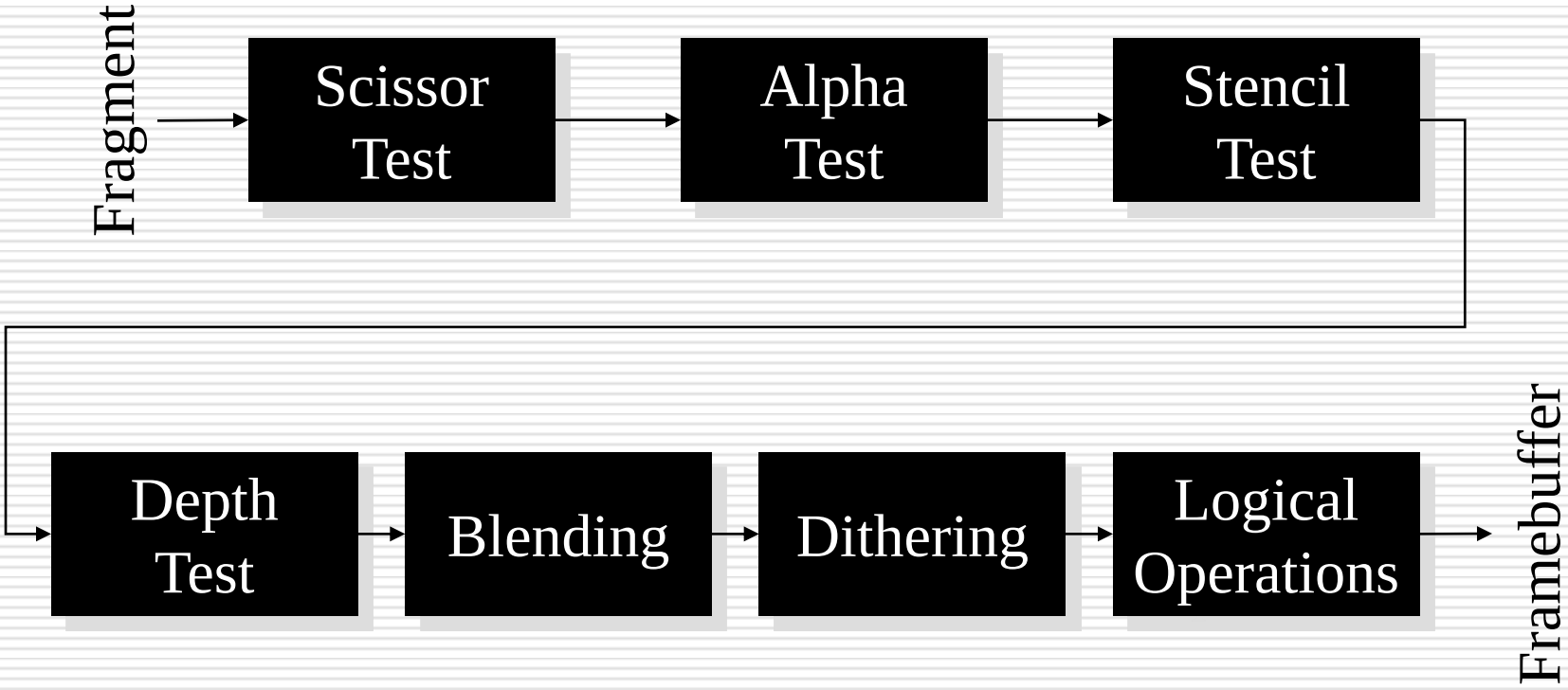
Picking Template (cont.)

```
    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  */
    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)

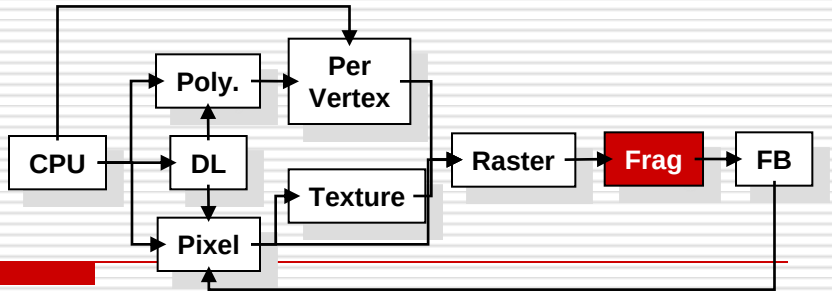
Getting to the Framebuffer



Scissor Box

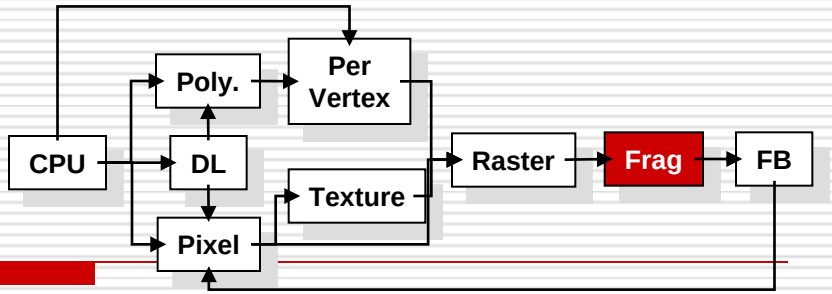
- Additional Clipping Test
- **`glScissor( x, y, w, h )`**
  - any fragments outside of box are clipped
  - useful for updating a small section of a viewport
    - affects **`glClear()`** operations

Alpha Test

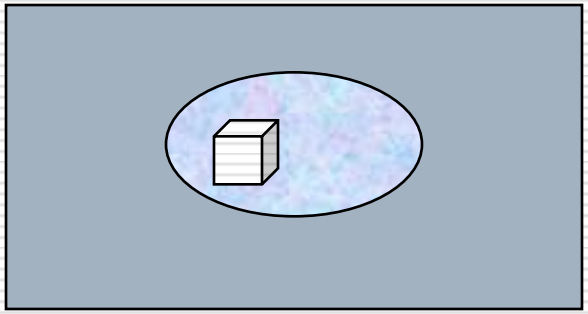


- Reject pixels based on their alpha value
- **`glAlphaFunc( func, value )`**
- **`glEnable( GL_ALPHA_TEST )`**
  - use alpha as a mask in textures

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( 0x0 );`

- `glStencilFunc( GL_ALWAYS, 0x1, 0x1 );`
- `glStencilOp( GL_REPLACE, GL_REPLACE, GL_REPLACE );`
- draw mask

Using Stencil Mask

- Draw objects where stencil = 1

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

- Draw objects where stencil != 1

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

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
- **`glLogicOp( mode )`**
  - Common modes
    - **`GL_XOR`**
    - **`GL_AND`**

Advanced Imaging

- Imaging Subset
  - Only available if **`GL_ARB_imaging`** defined
    - Color matrix
    - Convolutions
    - Color tables
    - Histogram
    - MinMax
    - Advanced Blending