Curs 13

Grafică pe calculator *(MLR5060)*

Elemente de grafică 3_D

Programare *OpenGl 4 (Part d)*

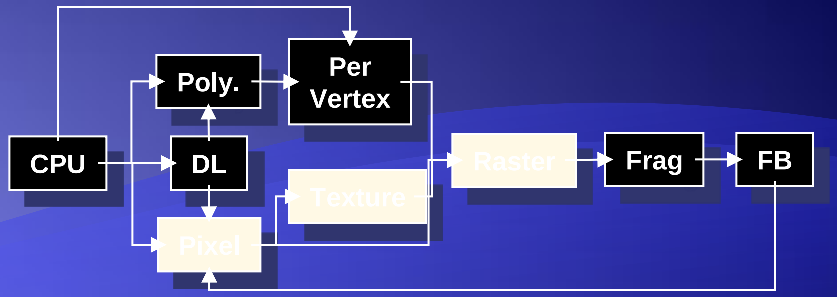
- Introduction
- Rendering Primitives
- Rendering Modes
- Lighting
- Texture Mapping
- Additional Rendering Attributes
- Imaging

8 Ian. 2020

TEXTURE MAPPING

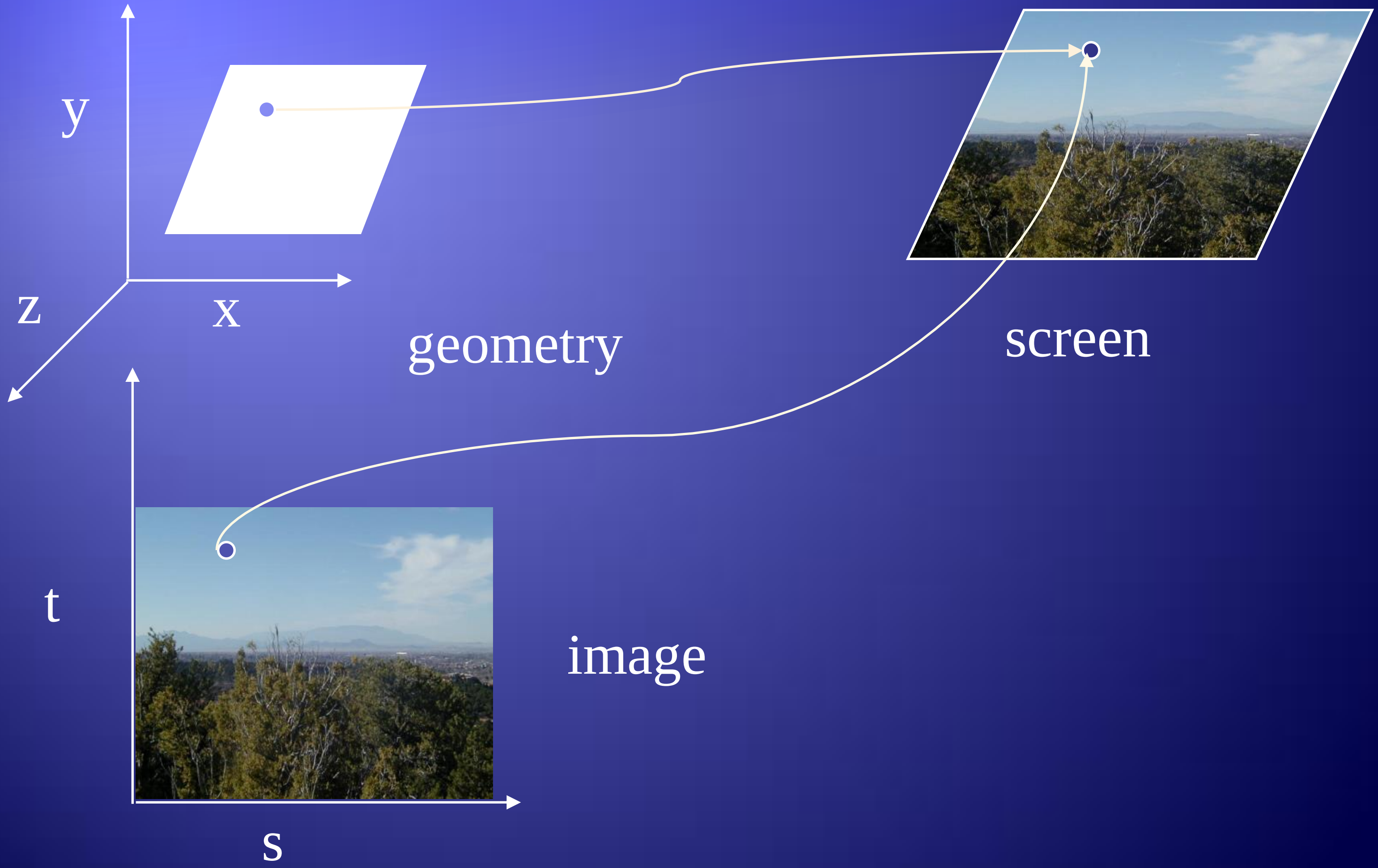
Ed Angel

Texture Mapping



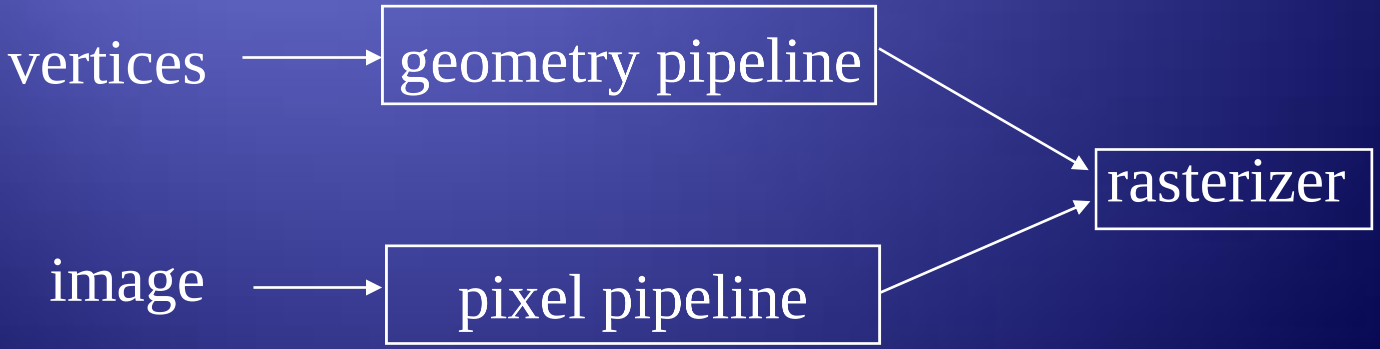
- Apply a 1D, 2D, or 3D image to geometric primitives
- Uses of Texturing
  - simulating materials
  - reducing geometric complexity
  - image warping
  - reflections

Texture Mapping



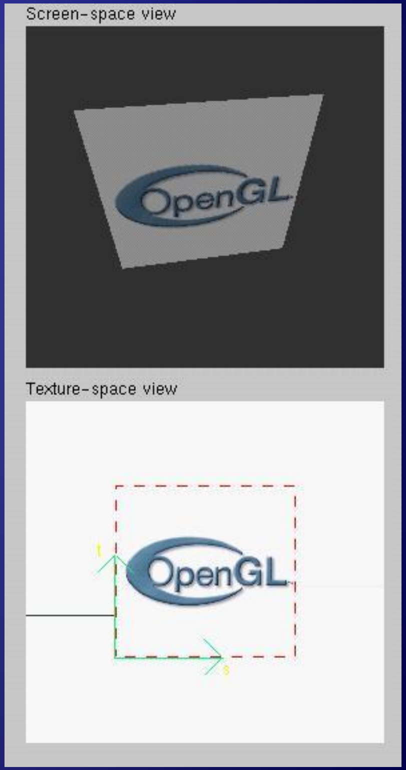
Texture Mapping and the OpenGL Pipeline

- 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 x 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 );
```

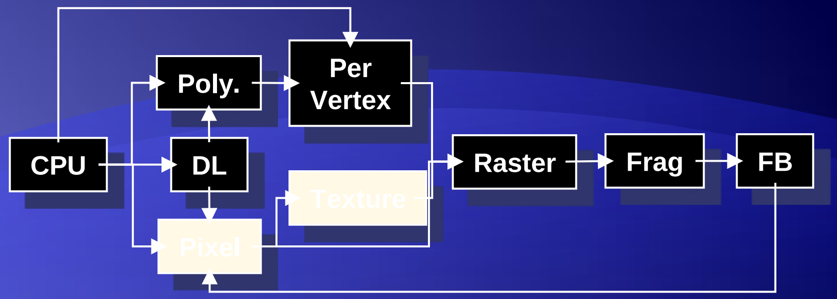
- Create texture objects with texture data and state

```
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

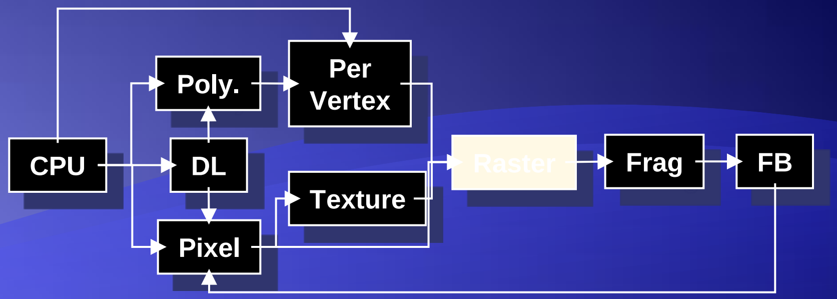
```
glCopyTexImage2D(...)
glCopyTexImage1D(...)
```

- Modify part of a defined texture

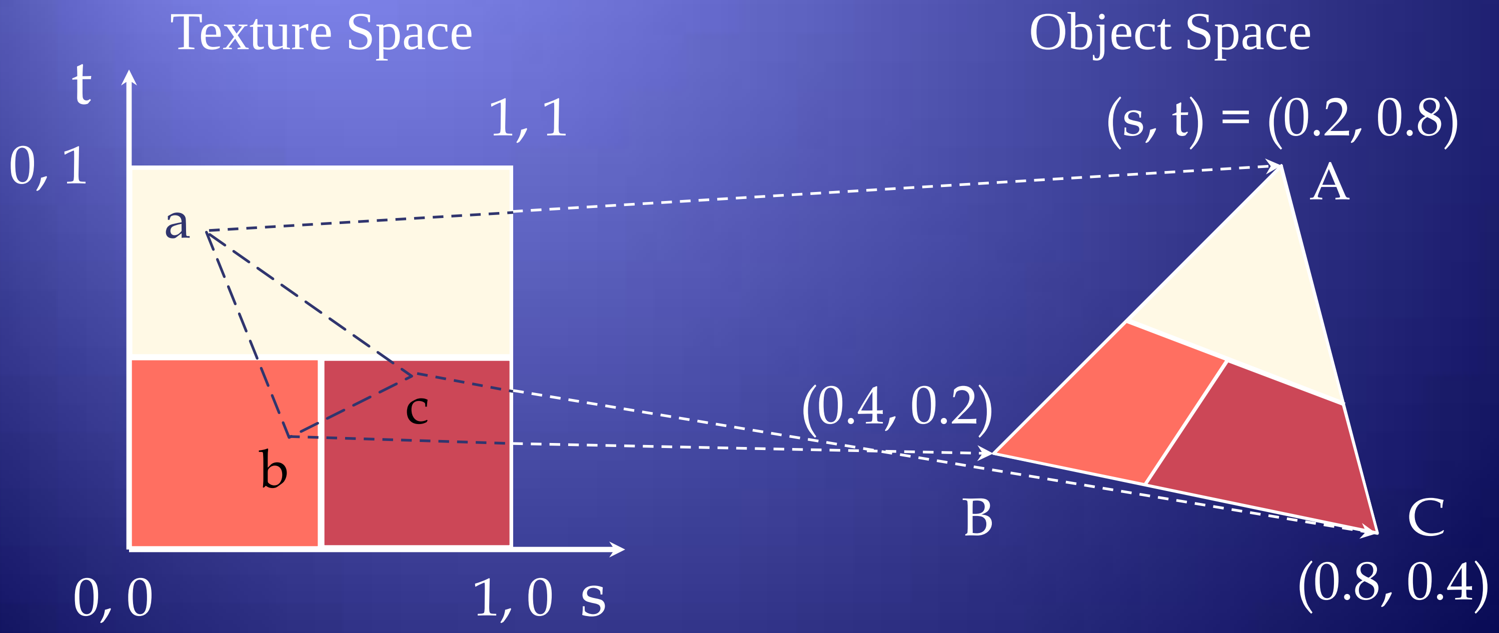
```
glTexSubImage2D(...)
glTexSubImage1D(...)
```

- Do both with *`glCopyTexSubImage2D(...)`*, etc.

Mapping a Texture



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



Generating Texture Coordinates

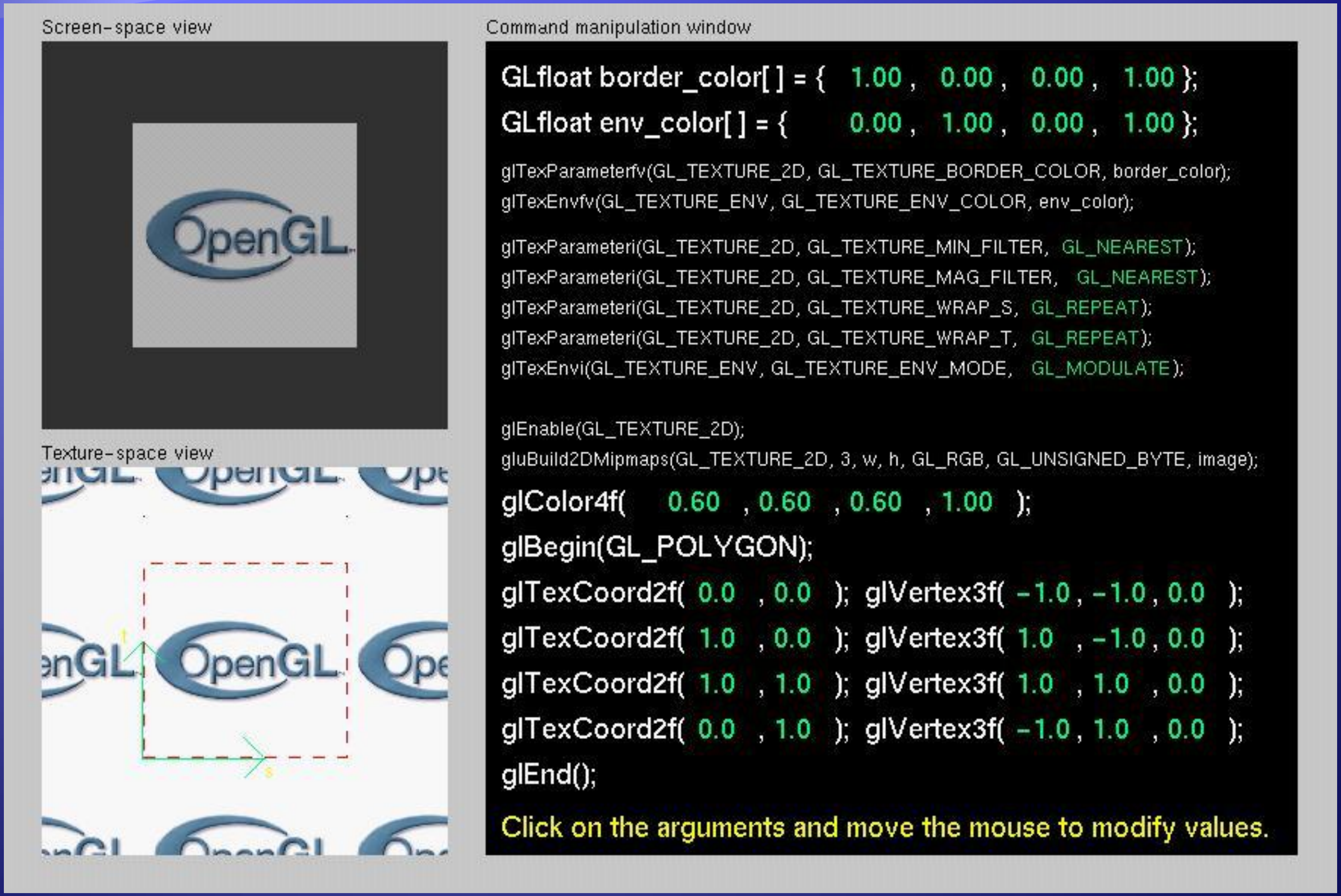
- Automatically generate texture coords

  `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



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

glTexParameterfv(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);
gluBuild2DMipmaps(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.

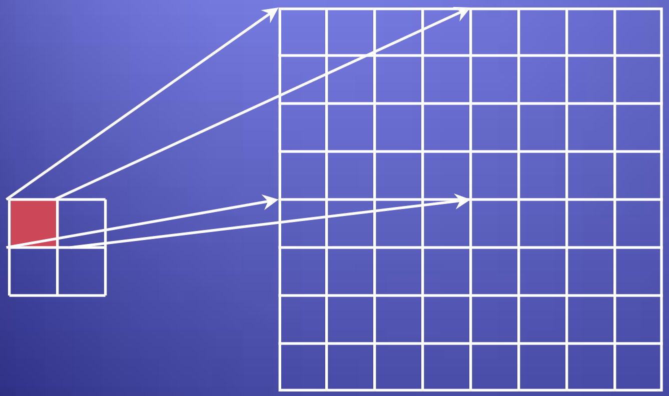
Texture Application Methods

- 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

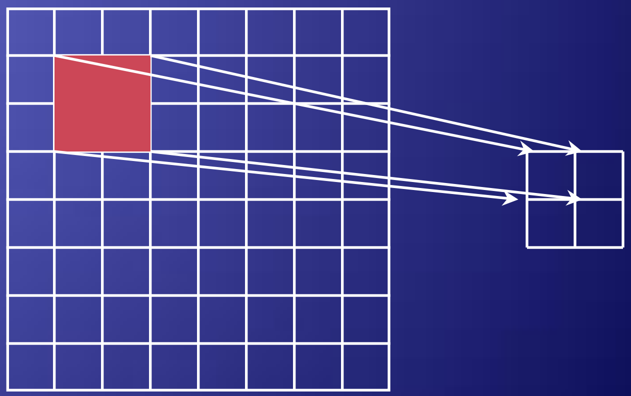
Filter Modes

Example:

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



Magnification



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

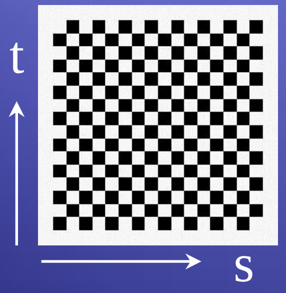
  ```
  glTexImage*D( GL_TEXTURE_*D, level, … )
  ```
- GLU mipmap builder routines

  ```
  gluBuild*DMipmaps( … )
  ```
- OpenGL 1.2 introduces advanced LOD controls

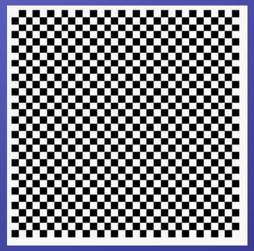
Wrapping Mode

- Example:

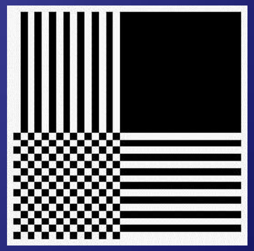
```
glTexParameteri( GL_TEXTURE_2D,
     GL_TEXTURE_WRAP_S, GL_CLAMP )
glTexParameteri( GL_TEXTURE_2D,
     GL_TEXTURE_WRAP_T, GL_REPEAT )
```



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

ADVANCED OPENGL TOPICS

Dave Shreiner

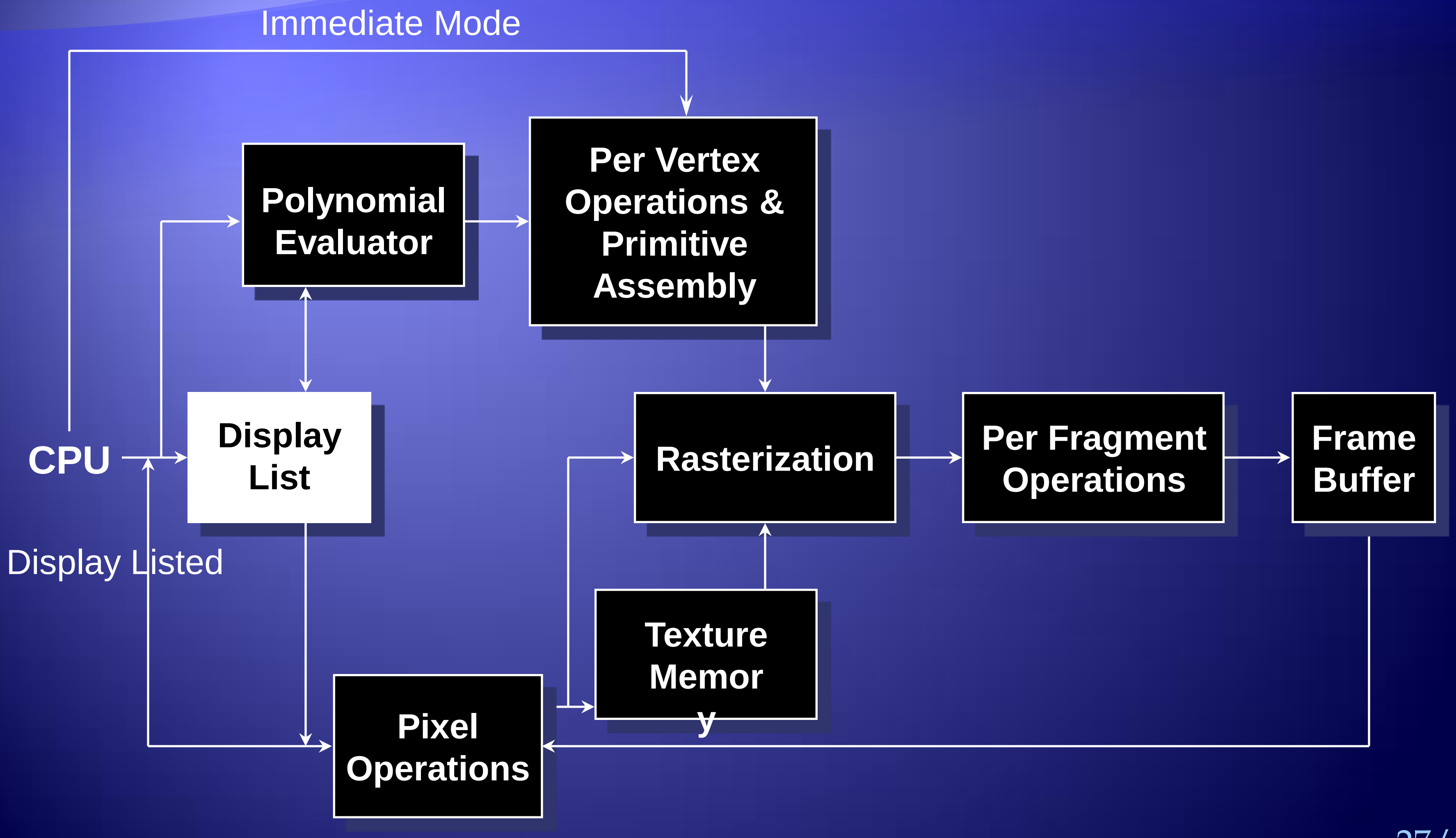
Advanced OpenGL Topics

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

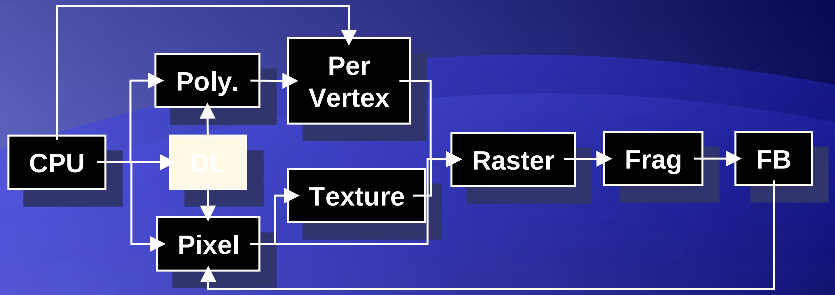
Immediate Mode versus Display Listed Rendering

- 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 );
}
```

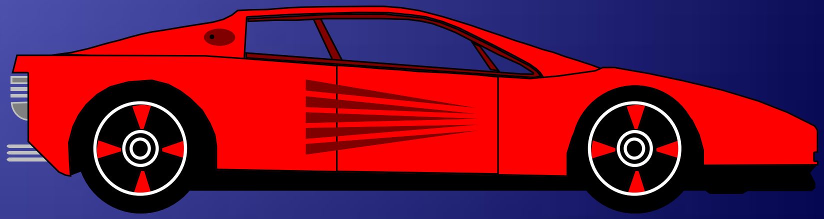
Display Lists

- 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

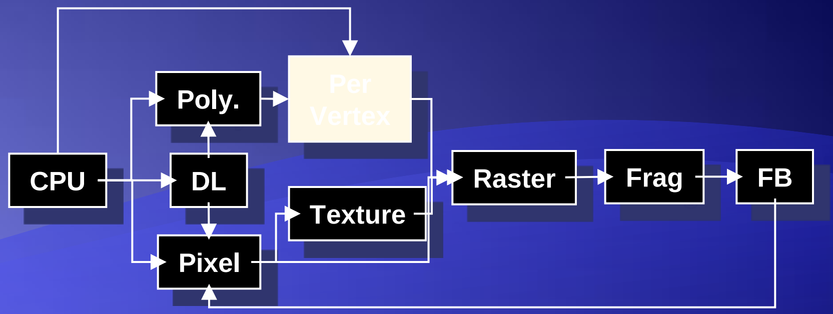
```
glNewList( CAR, GL_COMPILE );
  glCallList( CHASSIS );
  glTranslatef( … );
  glCallList( WHEEL );
  glTranslatef( … );
  glCallList( WHEEL );
      …
glEndList();
```



Advanced Primitives

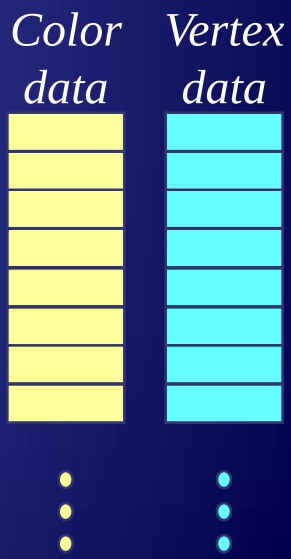
- Vertex Arrays
- Bernstein Polynomial Evaluators
  - basis for GLU NURBS
    - NURBS (Non-Uniform Rational B-Splines)
- GLU Quadric Objects
  - sphere
  - cylinder (or cone)
  - disk (circle)

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?

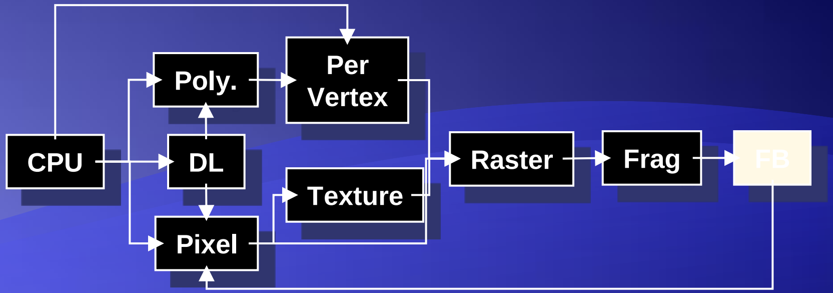
- May provide better performance than immediate mode rendering
- Display lists can be shared between multiple OpenGL context
  - reduce memory usage for multi-context applications
- Vertex arrays may format data for better memory access

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 )
```

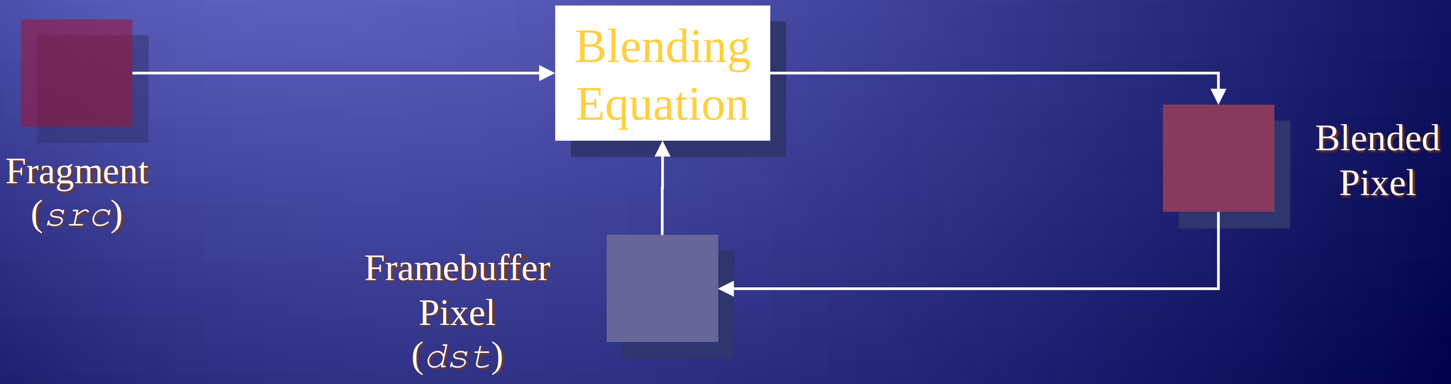
Blending



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

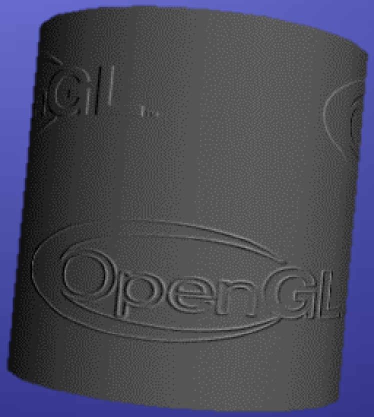
```
glBlendFunc( src, dst )
```

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



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

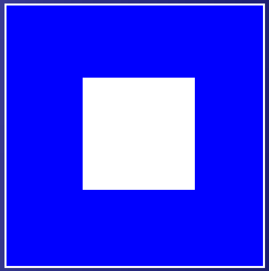
Antialiasing

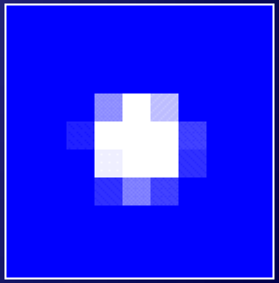
- Removing the Jaggies

  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 )`

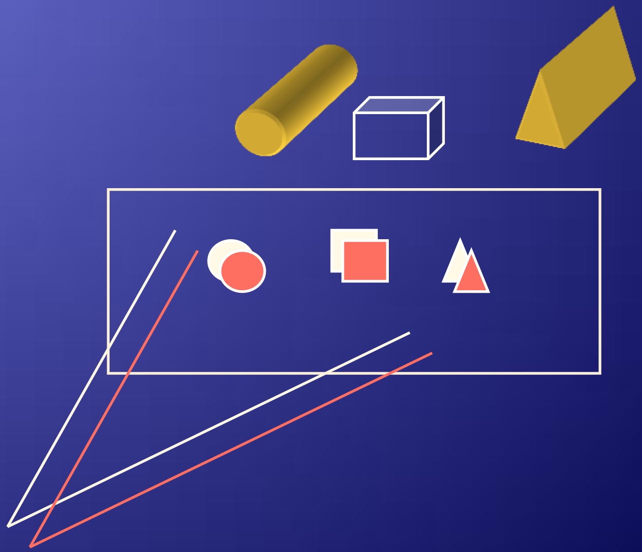
- operations
  - within the accumulation buffer: ***GL_ADD, GL_MULT***
  - from read buffer: ***GL_ACCUM, GL_LOAD***
  - transfer back to write buffer: ***GL_RETURN***
- **glAccum(*GL_ACCUM, 0.5*)** multiplies each value in write buffer by 0.5 and adds to accumulation buffer

Accumulation Buffer Applications

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

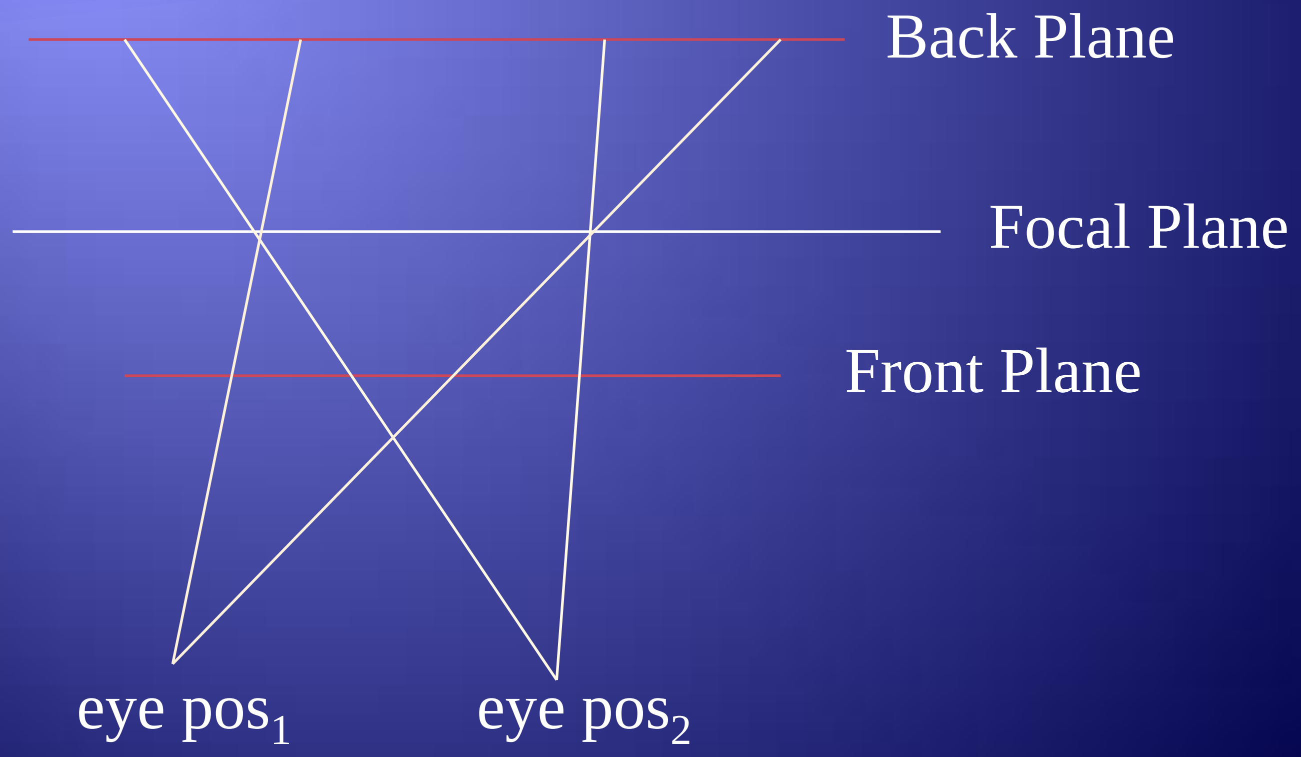
Full Scene Antialiasing : *Jittering the view*

- 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

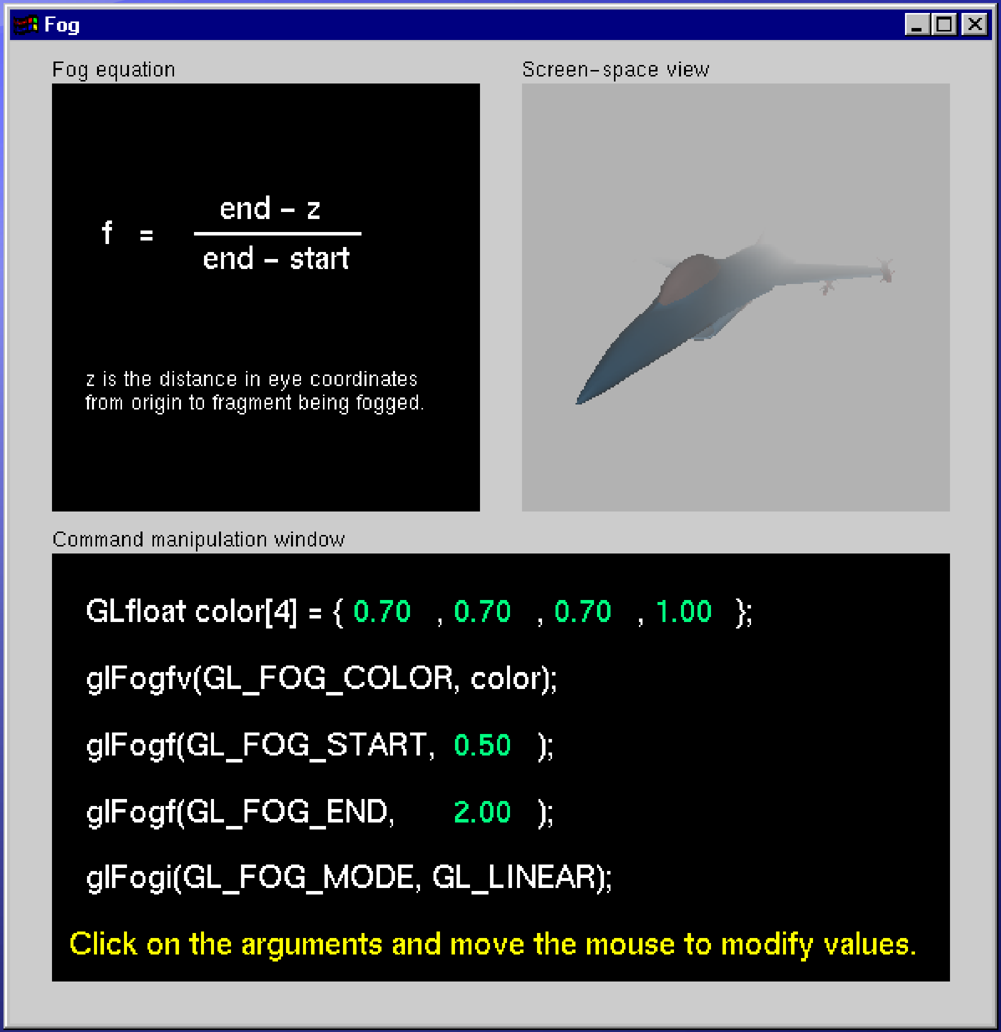


Fog

`glFog( 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



Fog equation

$$f = \frac{\text{end} - z}{\text{end} - \text{start}}$$

z is the distance in eye coordinates
from origin to fragment being fogged.

Screen-space view

Command manipulation window

```
GLfloat color[4] = { 0.70  , 0.70  , 0.70  , 1.00  };

glFogfv(GL_FOG_COLOR, color);

glFogf(GL_FOG_START,  0.50  );

glFogf(GL_FOG_END,    2.00  );

glFogi(GL_FOG_MODE, GL_LINEAR);
```

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

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();
```

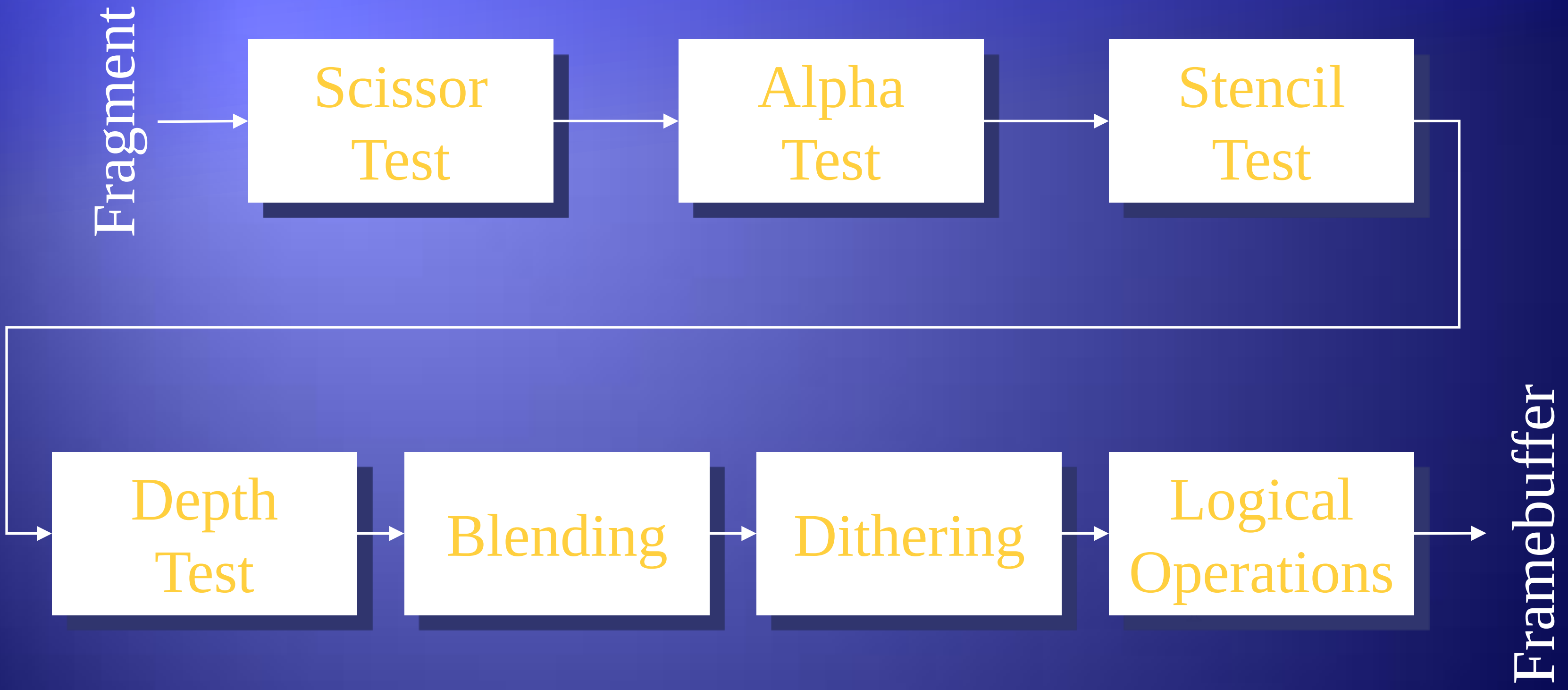
… Picking Template

```
   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 …  */
 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



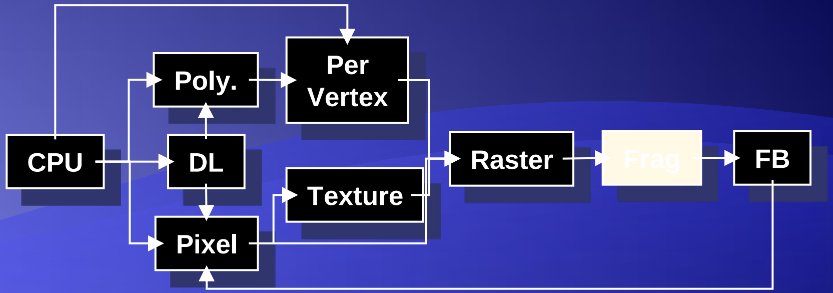
Scissor Box

- 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

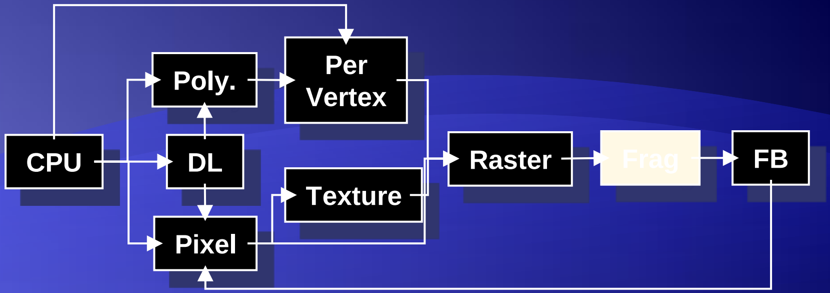


- Reject pixels based on their alpha value

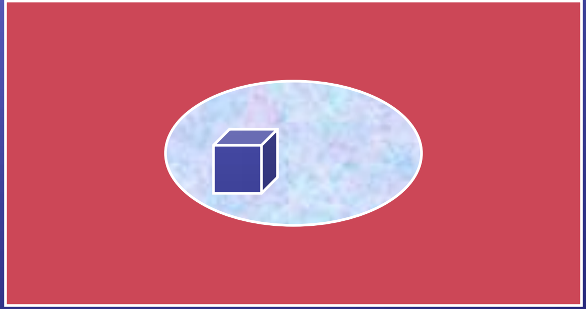
```
glAlphaFunc( func, value )
glEnable( GL_ALPHA_TEST )
```

  - 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_NOT_EQUAL, 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

  `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

SUMMARY / Q & A

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Questions and Answers

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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

AN INTERACTIVE INTRODUCTION TO OPENGL PROGRAMMING

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Temă

Realizarea unei aplicatii simple care sa contina:

- *Texture Mapping*
- *Additional Rendering Attributes*
- *Imaging*

Succes!