UCLA

CS174A : Introduction to Computer Graphics

Royce 190
TT 4-6pm

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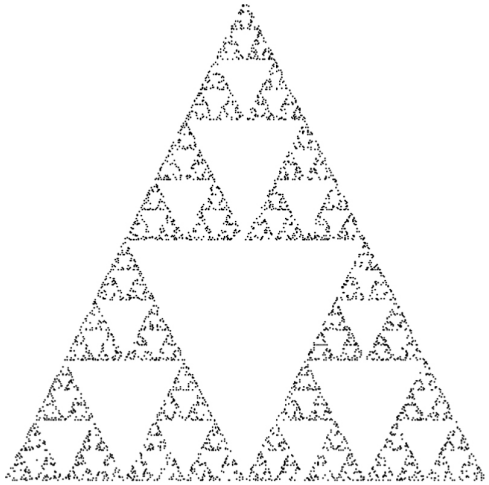
Let's get something on the screen

- Make that *thing* the example from Ch.2
  - Sierpinski Gasket
    - Fractal Geometry
    - More interesting than a triangle or square



Immediate / Retained Mode

- This example helps you see the difference between the two "modes".
- They are really programming styles.
- These styles are *performance* related.
- The output is the same no matter which you use.

Immediate / Retained Mode

- Immediate Mode
  - Points generated every time.
  - No storage required.
  - Transfer to GPU every time.

```
main( )
{
          initialize_the_system( );
          p = find_initial_point( );
          for ( some_number_of_points )
          {
                    q = generate_a_point( p );
                    display_the_point( q );
                    p = q;
          }
          cleanup( );
}
```

Immediate / Retained Mode

- Retained Mode #1
  - Points only generated *once*.
  - Storage required for all points.
  - Transfer to GPU every time.

```
main( )
{
          initialize_the_system( );
          p = find_initial_point( );
          for ( some_number_of_points )
          {
                    q = generate_a_point( p );
                    store_the_point( q );
                    p = q;
          }
          display_all_points( );
          cleanup( );
}
```

Immediate / Retained Mode

- Retained Mode #2
  - Points only generated *once*.
  - Storage required for all points *once**.
  - Transfer to GPU *once*.

```
main( )
{
        initialize_the_system( );
        p = find_initial_point( );
        for ( some_number_of_points )
        {
                q = generate_a_point( p );
                store_the_point( q );
                p = q;
        }
        send_all_points_to_GPU( );
        cleanup( );
        display_all_points_on_GPU( );
}
```

* for static data

Immediate / Retained Mode

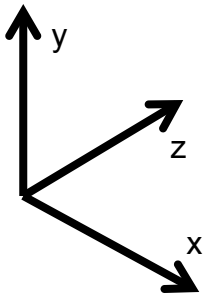
- Immediate Mode
  - Most work, but no storage.
- Retained Mode #1
  - Less work (after first time), but need storage and transfer to GPU every time.
- Retained Mode #2
  - Same work as #1, temporary storage on host, storage on GPU, single transfer time.

Baby Steps in 2D

- Sierpinski Gasket is a 2D object.
  - Lame, not what I signed up for! ☹
- Relax, 2D will be a restricted version of 3D for our exercise.
  - Specifically we will restrict ourselves to the x/y plane.

$$z = 0, p = (x, y, 0)$$

$$p = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x \\ y \\ 0 \end{bmatrix}$$



Points and vertices

- A point p is a thing in and of itself.
- A vertex v is understood to be part of the description of something more complex.
  - A point is a point.
  - A vertex defines part of a line, triangle, some other OpenGL primitive.

Sierpinski Gasket Code

- Code
  - Nothing fancy but will get us something to render on our display.

```
#include "vec.h"
typedef vec2 point2;
main( )
{
    const int NumPoints = 5000;
    // define a triangle in plane z=0
    point2 verticies[3]={point2(-1.0,-1.0),point2(0.0,1.0),point2(1.0,-1.0);
    // arbitrary point within triangle
    points[0] = point2(0.25,0.5);
    // compute and store NumPoints-1 new points
    for ( int k=1; k<NumPoints; k++ )
    {
        int j = rand( ) % 3; // pick a vertex at random
        // compute the point halfway between selected vertex and previous point
        points[k] = ( points[k-1] + vertices[j] ) / 2.0;
    }
}
```

Great, now what?

- Things we need to know (decide)
  - What color to use for rendering?
  - Where on display should rendering appear?
  - How large will rendering be?
  - How to we create a window to render into?
  - How much of the rendering plane will appear?
  - How long will the image appear on the display?

Use OpenGL API

- OpenGL provides various functionality
- Broken into various categories
  - Primitive functions
  - Attribute functions
  - Viewing functions
  - Transformation functions
  - Input functions
  - Control functions
  - Query functions

Primitive Functions

- Represent low level object we can draw.
- They are the "what" of the API
  - Points
  - Lines
  - Triangles
- Everything else made up from these.

Attribute Functions

- This is the "how" of the API
  - Color
  - Lines style
  - Point size
- Attributes can apply to different contexts
  - Globally
  - Per vertex
  - Per pixel (fragment)

Viewing Functions

- Camera model (from last time)
  - What can be seen (rendered) and how.
  - Position of eye and size of window
- There actually are not any functions specifically dedicated to the camera!
- We "define" the camera through a set of transformations.

Transformation Functions

- OpenGL it sometimes seems is mostly made up of these transformations.
- Transformation functions for
  - Translation, scaling, rotation of geometry.
  - Viewing uses transformation heavily.
- Transformations occur in the application itself or within a Shader.

Input Functions

- Required for any type of interaction.
- There are almost too many input devices to mention.
- We will stick to the basics
  - The trusty keyboard and mouse
- Feel free to explore others for your term project.

Control Functions

- Catch-all for handing the OS and GPU.
- Interfacing with the windowing system.
  - This is required for almost any graphics program today.
  - Can be very complex in and of itself.
  - We will use portable library to abstract things
    - HTML, CSS
    - GLUT: GL Utility Toolkit
    - Available for all three platforms.
    - We will return to this topic very shortly.

Query Functions

- Used to interrogate OpenGL state.
- Also can be used to find out about
  - Underlying host system (e.g. # cpus, memory)
  - Available GPUs (e.g. capabilities, driver rev.)
- WebGL which is based on OpenGL ES
  - Restricted version of the full OpenGL spec.

OpenGL is a State Machine

- We spoke briefly about this last time.
  - As a fixed function pipeline
- A kind of Black Box
- Accepts two types of input
  - Something that alters the internal state
    - Changes or returns state
  - Something that causes some output
    - Specify primitives that flow through the pipeline

OpenGL is a State Machine

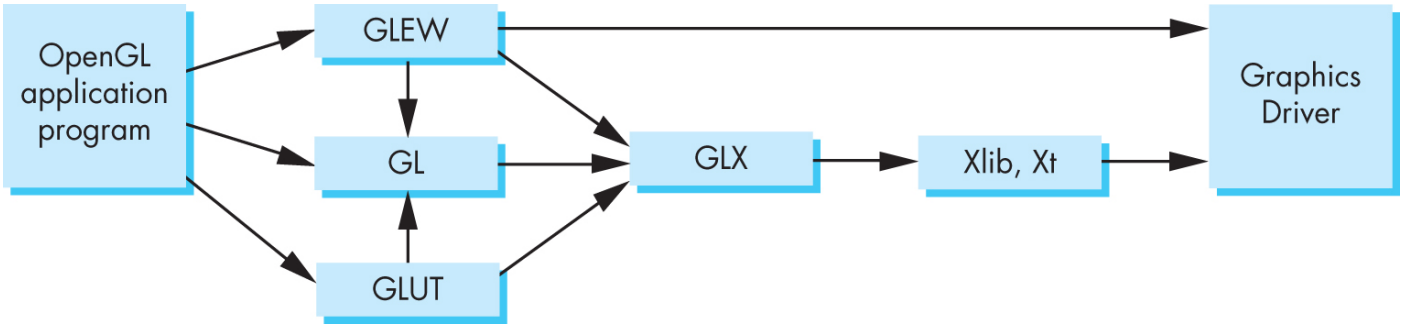
- State manipulation is primarily about
  - Enabling or disabling features
  - Parameter setting
- Older versions of OpenGL (<3.1)
  - Many many internal state variables
- Recent versions of OpenGL (>=3.1)
  - You define what you need and use via Shaders that you also define (program).
  - More work – but more power

OpenGL is a State Machine

- State is persistent.
  - Stays set until you change it.
  - Set color to red, it stays red until you change it.
    - This is the cause of a lot of heartache using OpenGL
- State is also not bound to primitives
  - This makes sense given the statement above
  - But we often want to think of things this way
    - Cube is yellow, grass is green, sun is yellow, etc.
  - You have to manage this yourself
    - Data structures to the rescue!!

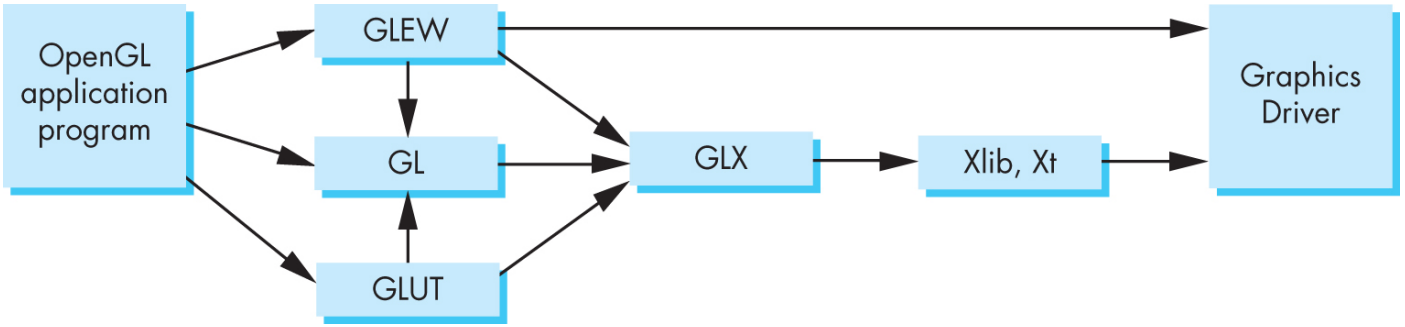
OpenGL is a Library

- Just like any other library you might use.
  - Usually libGL.{lib,so,ksym,dll,etc…}
  - All functions begin with "gl"
  - Shaders are written in a C-like language, GLSL



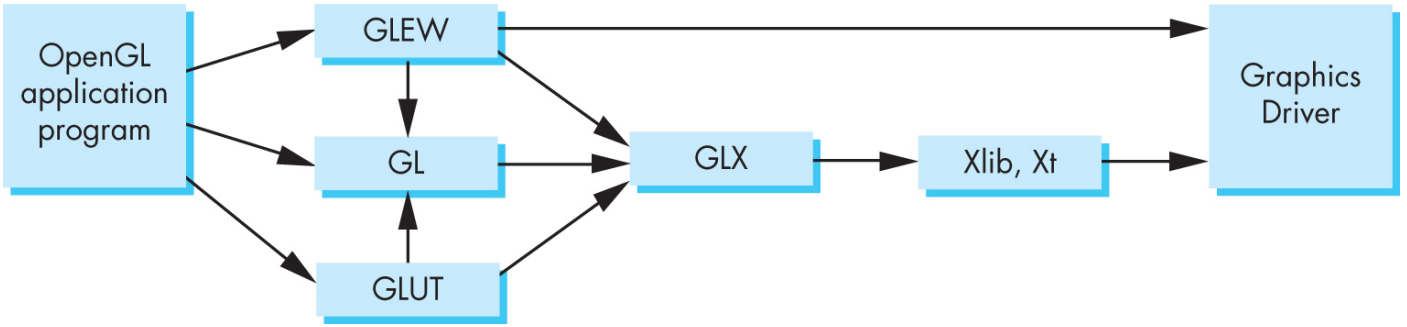
OpenGL is a Library

- Uses a "glue" library to interface with the hosts' underlying window system.
  - For linux it is called GLX
  - OSX it used to be called agl
  - Windows it is called wgl
  - Web, HTML



OpenGL and portability

- GLUT
  - Simple system independent windowing and input processing.
- GLEW
  - Removes OS specific dependencies w.r.t. OpenGL extensions.



OpenGL and portability

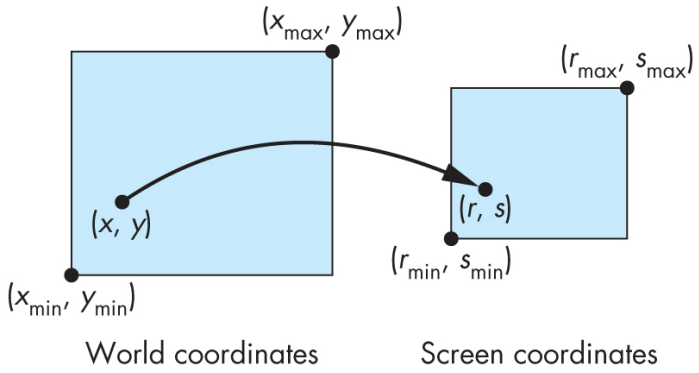
- OpenGL defines many types
  - Almost always as a `typedef`
  - Hides differences between systems representation of things like `int` and `float`
  - The type `Glfloat` will always have the same physical representation.
- Function names follow a pattern (nt, ntv)
  - n=(1,2,3,4,matrix) and specifies dimensions
  - t=(I,f,d) and specifies data type
  - v=pointer to an array of specified type.

Coordinate systems

- Device independent graphics
  - We do not specify pixels on the display.
  - There are no units in OpenGL
- World coordinate system
  - This is where our geometry is defined
  - Represented with floats
- Window coordinate system
  - This is the physical display (or window)
  - It has a width and height in pixels

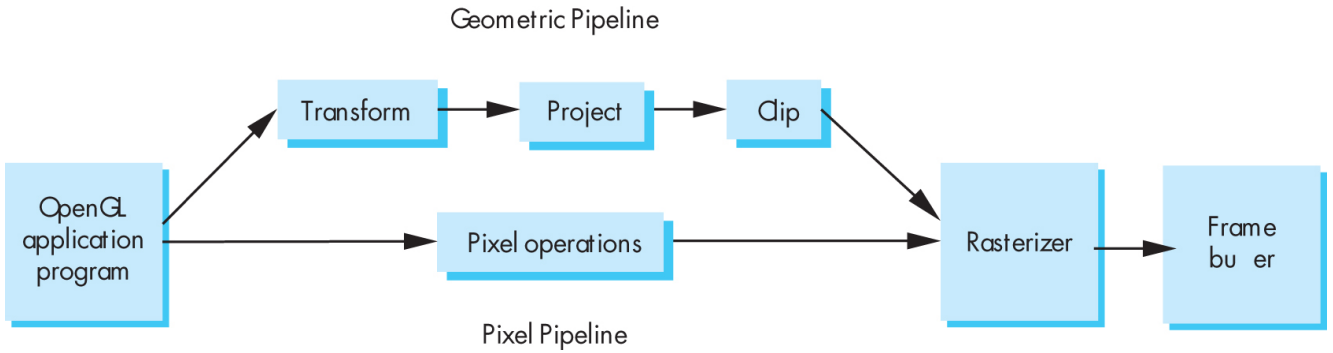
Coordinate systems

- The can be (are) others…but for now
- Transformations FTW!
  - Gets us from the world coordinate system to the window (screen) coordinate system.
  - Gets *what* exactly from world to window?



Primitives of course!

- Primitives go down the OpenGL pipeline and onto our display.
  - Two types: geometry and raster primitives
  - Geometry, in world space, has to be transformed, projected and clipped.
  - Raster data is already in screen space (later)



Primitives of course!

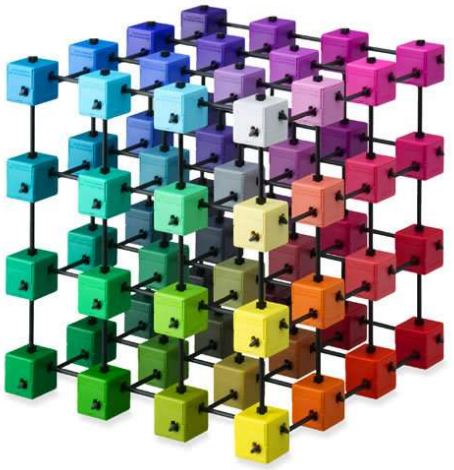
- Recall the types available
  - Points, lines and triangles + strip variations
  - Hardware can render these *very quickly*
  - More complex geometry made from these
    - Specifically, approximated using these types
    - Curves, surfaces and four or more sided polygons
  - All primitives are made up of vertices
    - Attributes assigned define how vertices are processed by GPU

Primitives of course!

- Given an OpenGL primitive type
  - GL_POINT, GL_LINE, GL_TRIANGLE, etc.
- A primitive can be drawn with command
  - `glDrawArrays(GL_POINT,0,numPoints)`
  - OMG – first line of OpenGL at slide 31!
- Actually quite a bit required before this will work, unfortunately.

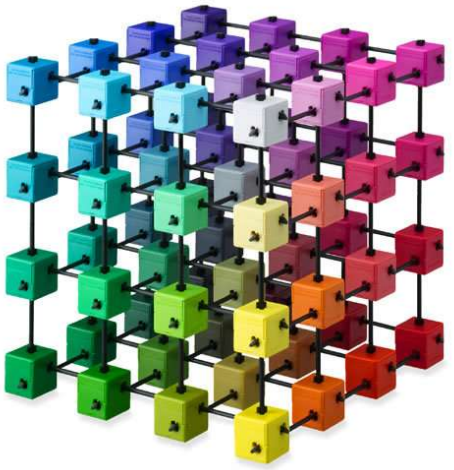
For starters…

- Need at least one attribute, like color.
- CG uses additive color
  - Add color to black (nothing)
- Finger painting is subtractive (and messy)
  - Subtract from white (absorb)



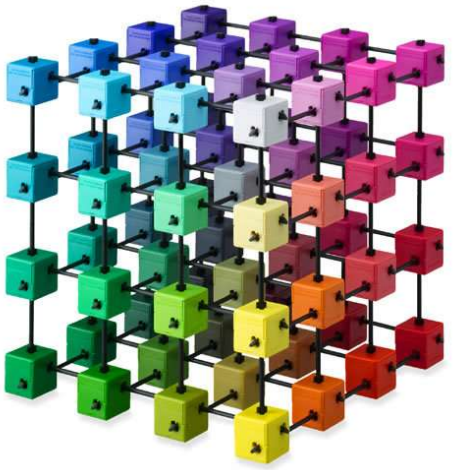
Super Basic Color

- The three primaries are
  - Red, Green and Blue – lets make a cube!
  - Intensities along each axis give all colors
  - Including white and black
    - White=all colors max intensity
    - black=seriously?
  - Hardware stores as bits
    - Typically 8-bits for each color
    - Plus one more for "alpha"
  - You will see RGB and RGBA
  - We will revisit the A later on



Super Basic Color

- OpenGL doesn't know how many 'bits'
- It does not want to…
  - So it abstracts the color to floats
  - RGB and A are represented by a range from (0.0-1.0)
  - White=(1.0, 1.0, 1.0, 1.0)
  - Black=(0.0, 0.0, 0.0, 1.0)
  - Wait, what's that last 1.0?
    - A = Alpha!
    - 0.0=transparent, 1.0=opaque

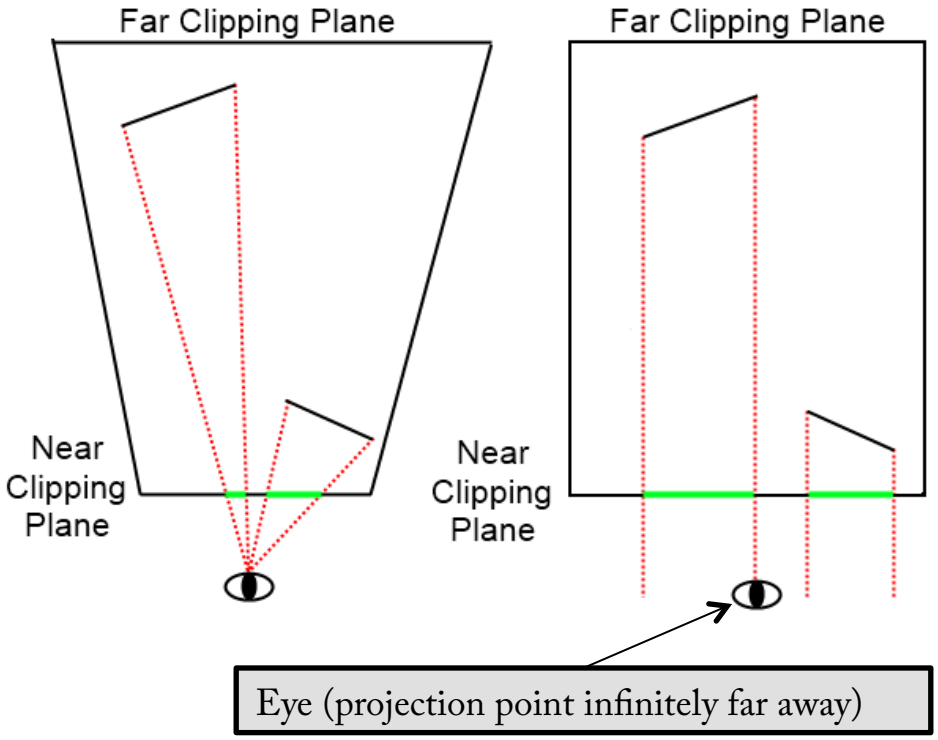


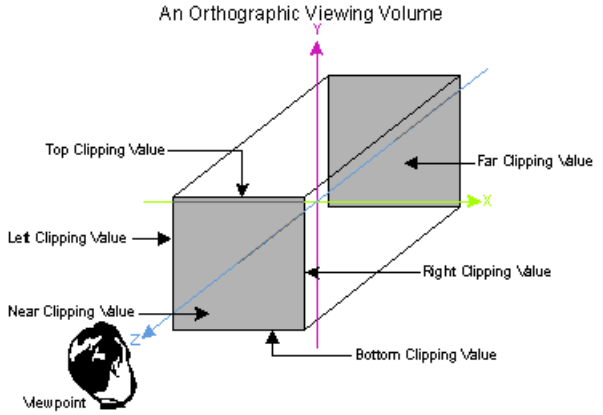
Getting there - Viewing

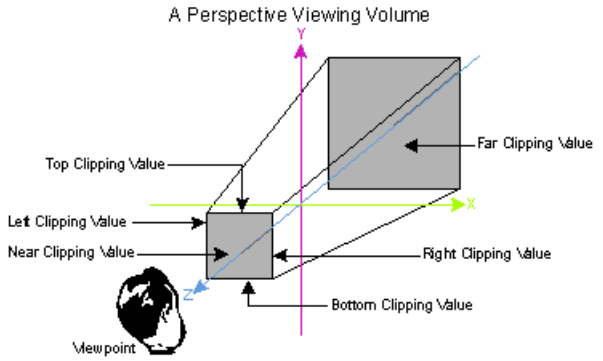
- Two types, generally, good for viewing
  - Perspective
    - What we talked about last time
    - Single projection point
    - Appearance of depth (like our own vision)
  - Orthographic
    - Move projection point infinitely far away
    - Projection lines parallel to image plane
    - As if projection point is always coincident with image plane

Getting there - Viewing

- Two views to illustrate the difference.





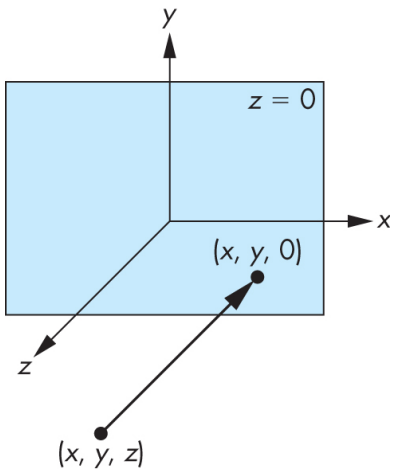


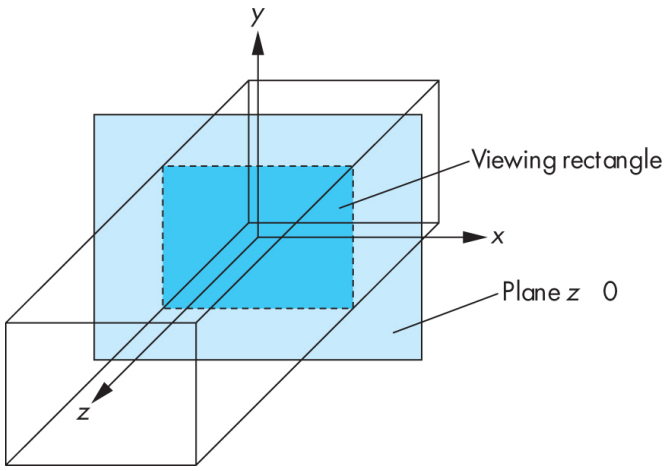
Getting there - Viewing

- What's orthographic projection good for in a 3D environment?
  - 2D data
  - Text "on the glass", e.g. high-score
  - Head-up Displays (HUD, think cockpit display)

Getting there - Viewing

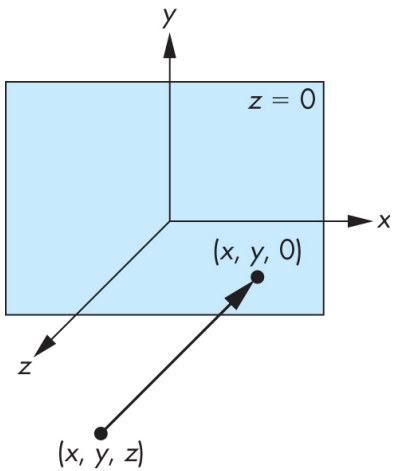
- 2D image plane will be defined by z=0
  - OpenGL defines a canonical view volume and projection point. *a.k.a. the default*.
  - We can use it without any transformations.
  - That default "looks" down the –z axis.

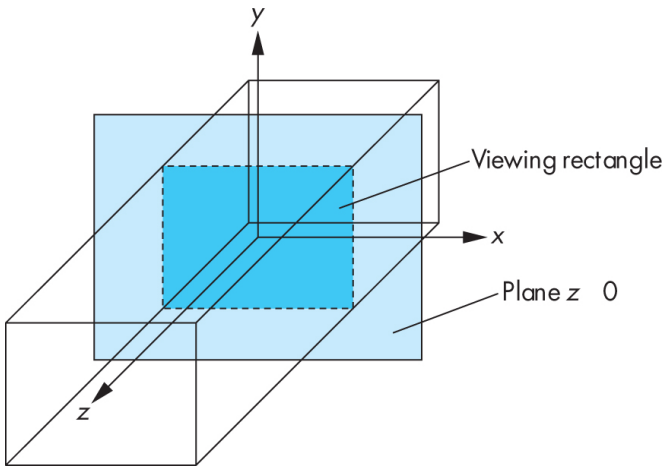




Getting there - Viewing

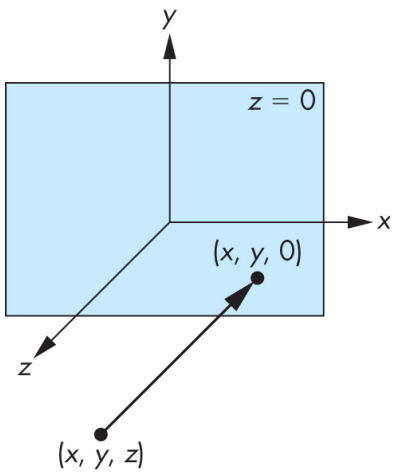
- The canonical view volume
  - Defines what is projected onto the window and what is clipped.
  - Defined by default as the cube, (-1,-1,-1) to (1,1,1)

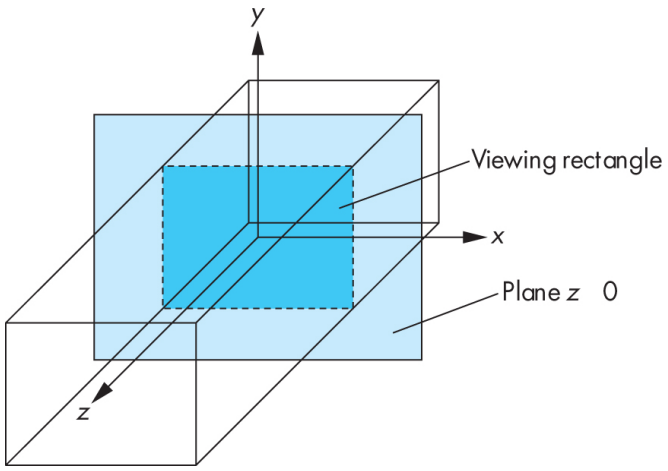




Getting there - Viewing

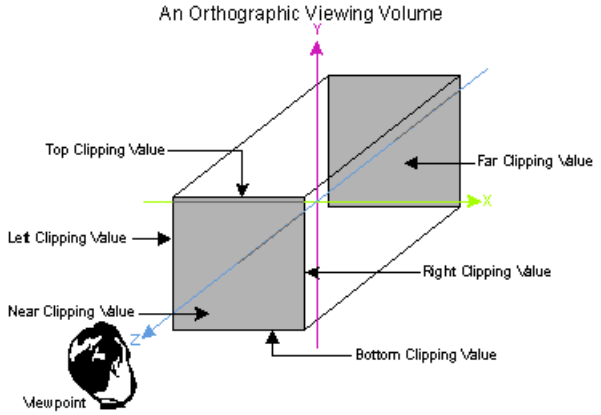
- Normally, a transformation would need to be defined to convert our desired projection view volume into the canonical view volume.

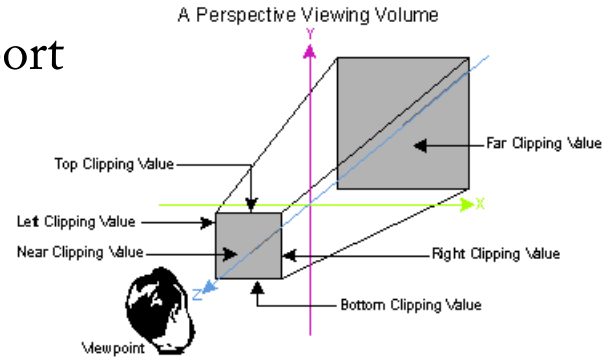




Getting there - Viewing

- Why do we even have a volume?
  - You said this is 2D!
  - Yes, but internally it's all 3D
  - So we need
    - Near clip
    - Far clip
    - As well as the "sides"
      which is what we call the viewport





Getting there - Viewing

- In any case…
  - Using the canonical view volume, for now, lets us avoid explaining transformation matrices for now.
  - As long as we use vertex coordinates that are within the range of (-1,-1) and (1,1) we will stay within the bounds of the view volume and avoid having anything clipped.
  - Which is a Good Thing™, for now

Boilerplate

- Let's write some code already…
- We are going to use GLUT
  - So let's see what is at the core of every GLUT based program so we can put this all together.
  - We will distribute basic GLUT code online that will help you get the linking right for your platform. (we hope)

Boilerplate GLUT

- Here is the basic code
  - Include the header which defines GLUT
    - A little different on OSX
    - It includes `#include <GL/gl.h>`

```
#include <GL/glut.h>
int main( int argc, char **argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_SINGLE, GLUT_RGB );
    glutInitWindowSize( 500, 500 );
    glutInitWindowPosition( 0, 0 );
    glutCreateWindow( "my window" );
    glutDisplayFunc( display );
    init( );
    glutMainLoop( );
}
```

Boilerplate GLUT

- Let's step through each line
  - Call `glutInit()`
    - Pass command line parameters through.
    - Should be called very near the start of your code.

```
#include <GL/glut.h>
int main( int argc, char **argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_SINGLE, GLUT_RGB );
    glutInitWindowSize( 500, 500 );
    glutInitWindowPosition( 0, 0 );
    glutCreateWindow( "my window" );
    glutDisplayFunc( display );
    init( );
    glutMainLoop( );
}
```

Boilerplate GLUT

- Let's step through each line
  - Call `glutInitDisplayMode()`
    - Sets single or double buffered mode.
    - Sets type of frame buffer we want.

```
#include <GL/glut.h>
int main( int argc, char **argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_SINGLE, GLUT_RGB );
    glutInitWindowSize( 500, 500 );
    glutInitWindowPosition( 0, 0 );
    glutCreateWindow( "my window" );
    glutDisplayFunc( display );
    init( );
    glutMainLoop( );
}
```

Boilerplate GLUT

- Let's step through each line
  - Call `glutInitWindowSize()`
    - Sets how big, in pixels, our window will be, width and height.

```
#include <GL/glut.h>
int main( int argc, char **argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_SINGLE, GLUT_RGB );
    glutInitWindowSize( 500, 500 );
    glutInitWindowPosition( 0, 0 );
    glutCreateWindow( "my window" );
    glutDisplayFunc( display );
    init( );
    glutMainLoop( );
}
```

Boilerplate GLUT

- Let's step through each line
  - Call `glutInitWindowPosition()`
    - Sets the location (windowing system dependent) where our window will display on the desktop.
    - Usually bad form to use this…

```
#include <GL/glut.h>
int main( int argc, char **argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_SINGLE, GLUT_RGB );
    glutInitWindowSize( 500, 500 );
    glutInitWindowPosition( 0, 0 );
    glutCreateWindow( "my window" );
    glutDisplayFunc( display );
    init( );
    glutMainLoop( );
}
```

Boilerplate GLUT

- Let's step through each line
  - Call `glutCreateWindow()`
    - Parameter is goes in the title bar of the window
    - Window does not actually show up – yet
    - Internal setup goes here (particularly for x-windows)

```
#include <GL/glut.h>
int main( int argc, char **argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_SINGLE, GLUT_RGB );
    glutInitWindowSize( 500, 500 );
    glutInitWindowPosition( 0, 0 );
    glutCreateWindow( "my window" );
    glutDisplayFunc( display );
    init( );
    glutMainLoop( );
}
```

Boilerplate GLUT

- Let's step through each line
  - Call `glutDisplayFunc()`
    - Set callback for when GLUT wants us to render into the window.
    - We'll return to this in a second.

```
#include <GL/glut.h>
int main( int argc, char **argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_SINGLE, GLUT_RGB );
    glutInitWindowSize( 500, 500 );
    glutInitWindowPosition( 0, 0 );
    glutCreateWindow( "my window" );
    glutDisplayFunc( display );
    init( );
    glutMainLoop( );
}
```

Boilerplate GLUT

- Let's step through each line
  - Call `init()`
    - Not strictly required, just good practice.
    - Perform any application specific OpenGL setup
    - Name does not matter – we'll come back to this too

```
#include <GL/glut.h>
int main( int argc, char **argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_SINGLE, GLUT_RGB );
    glutInitWindowSize( 500, 500 );
    glutInitWindowPosition( 0, 0 );
    glutCreateWindow( "my window" );
    glutDisplayFunc( display );
    init( );
    glutMainLoop( );
}
```

Boilerplate GLUT

- Let's step through each line
  - Call `glutMainLoop()`
    - This is the "event loop"
    - GLUT *never* returns from this function
    - Your code will run via event callbacks from now on.

```
#include <GL/glut.h>
int main( int argc, char **argv )
{
    glutInit( &argc, argv );
    glutInitDisplayMode( GLUT_SINGLE, GLUT_RGB );
    glutInitWindowSize( 500, 500 );
    glutInitWindowPosition( 0, 0 );
    glutCreateWindow( "my window" );
    glutDisplayFunc( display );
    init( );
    glutMainLoop( );
}
```

Boilerplate GLUT

- The `display()` function
  - Every time GLUT decides that the contents of the window need to be refreshed it will call the function assigned to the display callback.
  - The function does not take or return any parameters.
  - There are ways to cleanly pass data to the callback.
    - i.e. without using global variables. How?

```
void display( void )
{
    glClear( GL_COLOR_BUFFER_BIT );
    glDrawArrays( GL_POINTS, 0, numPoints );
    glFlush( );
}
```

Boilerplate GLUT

- The `display()` function
  - `glClear()` tells the GPU to set the contents of the frame buffer to a OpenGL state value.
    - You can set this color via `glClearColor()`
  - Other tokens, which we will talk about later, can be or'd together here.

```
void display( void )
{
    glClear( GL_COLOR_BUFFER_BIT );
    glDrawArrays( GL_POINTS, 0, numPoints );
    glFlush( );
}
```

Boilerplate GLUT

- The `display()` function
  - `glDrawArrays()` is a function we saw earlier.
  - It is what actually sends the array of vertices down the GPU pipeline to be rendered.
  - Here we are telling it to `numPoints` of vertices, stored in buffer `0` and to treat the data as points.
  - Need to define and load "buffer 0"

```
void display( void )
{
    glClear( GL_COLOR_BUFFER_BIT );
    glDrawArrays( GL_POINTS, 0, numPoints );
    glFlush( );
}
```

Boilerplate GLUT

- The `display()` function
  - `glFlush()` ensures all the commands we have issued to the GPU have been sent.
  - Remember, the GPU is a separate asynchronous device – commands are fed to it via a queue.
  - The command is also useful in network based windowing systems like x-windows.

```
void display( void )
{
    glClear( GL_COLOR_BUFFER_BIT );
    glDrawArrays( GL_POINTS, 0, numPoints );
    glFlush( );
}
```

Vertex Array

- The `init()` function
  - Is a good place to create the vertex array we reference in the `display()` function.
  - We want to get the points that make up our sierpinski gasket copied into a buffer on the GPU

```
Gluint vArray, buffer;
void init( void )
{
    …
    glGenVertexArrays( 1, &vArray );
    glBindVertexArray( vArray );
    …
    glGenBuffers( 1, &buffer );
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
    glBufferData( GL_ARRAY_BUFFER, sizeof( points ), points, GL_STATIC_DRAW );
    …
}
```

Vertex Array

- Initialize a vertex array
  - Call `glGenVertexArrays()` to get an ID.
  - We pass in a pointer to an array of references.
  - In this case we are only asking for one (1) ID.

```
Gluint vArray, buffer;
void init( void )
{
    …
    glGenVertexArrays( 1, &vArray );
    glBindVertexArray( vArray );
    …
    glGenBuffers( 1, &buffer );
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
    glBufferData( GL_ARRAY_BUFFER, sizeof( points ), points, GL_STATIC_DRAW );
    …
}
```

Vertex Array

- Initialize a vertex array
  - Call `glBindVertexArray()` to bind, or enable, the vertex array referenced by `vArray`.
  - Once bound the array stays bound until we change it.
    - Binding is common in OpenGL – it's a form of state.

```
Gluint vArray, buffer;
void init( void )
{
    …
    glGenVertexArrays( 1, &vArray );
    glBindVertexArray( vArray );
    …
    glGenBuffers( 1, &buffer );
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
    glBufferData( GL_ARRAY_BUFFER, sizeof( points ), points, GL_STATIC_DRAW );
    …
}
```

Vertex Array

- Initialize a vertex array
  - We now have a vertex array with nothing in it.
  - Call `glGenBuffers()` to create a buffer reference.
  - Same pattern as before.

```
Gluint vArray, buffer;
void init( void )
{
    …
    glGenVertexArrays( 1, &vArray );
    glBindVertexArray( vArray );
    …
    glGenBuffers( 1, &buffer );
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
    glBufferData( GL_ARRAY_BUFFER, sizeof( points ), points, GL_STATIC_DRAW );
    …
}
```

Vertex Array

- Initialize a vertex array
  - Now we bind the buffer (make it active) and describe what kind of buffer it is – `GL_ARRAY_BUFFER`
  - Once bound it will remain active until we change it.

```
Gluint vArray, buffer;
void init( void )
{
    …
    glGenVertexArrays( 1, &vArray );
    glBindVertexArray( vArray );
    …
    glGenBuffers( 1, &buffer );
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
    glBufferData( GL_ARRAY_BUFFER, sizeof( points ), points, GL_STATIC_DRAW );
    …
}
```

Vertex Array

- Initialize a vertex array
  - Finally, we make the connection to our data.
  - We give the size of the *array* and a pointer.
  - `GL_STATIC_DRAW` tells the driver that the data doesn't change between calls to `glDrawArrays()`

```
Gluint vArray, buffer;
void init( void )
{
    …
    glGenVertexArrays( 1, &vArray );
    glBindVertexArray( vArray );
    …
    glGenBuffers( 1, &buffer );
    glBindBuffer( GL_ARRAY_BUFFER, buffer );
    glBufferData( GL_ARRAY_BUFFER, sizeof( points ), points, GL_STATIC_DRAW );
    …
}
```

Shaders

- Vertex shader
  - When we call `glDrawArrays()` each vertex triggers an execution of the vertex shader.
  - We are just passing the data through for now.
  - The shader is written in GLSL, a C-like language
  - The input is `vPosition` and the output is `gl_position`

```
in vec4 vPosition;
void main( )
{
    gl_position = vPosition;
}
```

Shaders

- Vertex shader
  - `gl_position` is a state variable in OpenGL
    - It's used to pass the final (transformed) vertex down the pipeline to the rasterizer from the shader.
  - The input to the shader is indicated by the `in` modifier to `vPosition`
    - Later we will see how the connection is made to our vertex array.

```
in vec4 vPosition;
void main( )
{
    gl_position = vPosition;
}
```

Shaders

- Fragment shader
  - The fragment shader executes on the output of the rasterizer.
  - The rasterizer will generate fragments corresponding to the primitives sent down the OpenGL pipeline destined for the frame buffer.
  - At a minimum each execution must output a color for the fragment by setting `gl_frag_color`

```
void main( )
{
    gl_frag_color = vec4( 1.0, 0.0, 0.0, 1.0 );
}
```

Shaders

- The shaders are actual programs
  - That execute *on the GPU*
  - That means they have to be compiled and linked.

```
…
Gluint program glCreateProgram( void );
Gluint vShader = glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vShader, 1, (const Glchar**)&vSource, NULL );
glCompileShader( vShader );
// should check for success here, see book code
glAttachShader( program, vShader );
Gluint fShader = glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fShader, 1, (const Glchar**)&fSource, NULL );
glCompileShader( fShader );
// should check for success here, see book code
glAttachShader( program, vShader );
glLinkProgram( program );
// should check for success here, see book code
glUseProgram( program );
…
```

Shaders

- A set of shaders exist within a *program*
  - First, we create the program with `glCreateProgram()`

```
…
Gluint program glCreateProgram( void );
Gluint vShader = glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vShader, 1, (const Glchar**)&vSource, NULL );
glCompileShader( vShader );
// should check for success here, see book code
glAttachShader( program, vShader );
Gluint fShader = glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fShader, 1, (const Glchar**)&fSource, NULL );
glCompileShader( fShader );
// should check for success here, see book code
glAttachShader( program, vShader );
glLinkProgram( program );
// should check for success here, see book code
glUseProgram( program );
…
```

Shaders

- Create a shader by selecting the type
  - First, the vertex shader `GL_VERTEX_SHADER`
  - Save the reference for later steps.

```
…
Gluint program glCreateProgram( void );
Gluint vShader = glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vShader, 1, (const Glchar**)&vSource, NULL );
glCompileShader( vShader );
// should check for success here, see book code
glAttachShader( program, vShader );
Gluint fShader = glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fShader, 1, (const Glchar**)&fSource, NULL );
glCompileShader( fShader );
// should check for success here, see book code
glAttachShader( program, vShader );
glLinkProgram( program );
// should check for success here, see book code
glUseProgram( program );
…
```

Shaders

- Next, assign the source to the shader.
  - `glShaderSource()` attaches source strings to the shader.

```
…
Gluint program glCreateProgram( void );
Gluint vShader = glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vShader, 1, (const Glchar**)&vSource, NULL );
glCompileShader( vShader );
// should check for success here, see book code
glAttachShader( program, vShader );
Gluint fShader = glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fShader, 1, (const Glchar**)&fSource, NULL );
glCompileShader( fShader );
// should check for success here, see book code
glAttachShader( program, vShader );
glLinkProgram( program );
// should check for success here, see book code
glUseProgram( program );
…
```

Shaders

- Compile the shader.
  - After which you should check the result by querying the shader – see the book exmaple.

```
…
Gluint program glCreateProgram( void );
Gluint vShader = glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vShader, 1, (const Glchar**)&vSource, NULL );
glCompileShader( vShader );
// should check for success here, see book code
glAttachShader( program, vShader );
Gluint fShader = glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fShader, 1, (const Glchar**)&fSource, NULL );
glCompileShader( fShader );
// should check for success here, see book code
glAttachShader( program, vShader );
glLinkProgram( program );
// should check for success here, see book code
glUseProgram( program );
…
```

Shaders

- Attach the shader to the program.

```
…
Gluint program glCreateProgram( void );
Gluint vShader = glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vShader, 1, (const Glchar**)&vSource, NULL );
glCompileShader( vShader );
// should check for success here, see book code
glAttachShader( program, vShader );
Gluint fShader = glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fShader, 1, (const Glchar**)&fSource, NULL );
glCompileShader( fShader );
// should check for success here, see book code
glAttachShader( program, vShader );
glLinkProgram( program );
// should check for success here, see book code
glUseProgram( program );
…
```

Shaders

- Repeat the process for the fragment shader.

```
…
Gluint program glCreateProgram( void );
Gluint vShader = glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vShader, 1, (const Glchar**)&vSource, NULL );
glCompileShader( vShader );
// should check for success here, see book code
glAttachShader( program, vShader );
Gluint fShader = glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fShader, 1, (const Glchar**)&fSource, NULL );
glCompileShader( fShader );
// should check for success here, see book code
glAttachShader( program, vShader );
glLinkProgram( program );
// should check for success here, see book code
glUseProgram( program );
…
```

Shaders

- Link the program's two shaders
  - You should, again, check the result – see the book example.

```
…
Gluint program glCreateProgram( void );
Gluint vShader = glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vShader, 1, (const Glchar**)&vSource, NULL );
glCompileShader( vShader );
// should check for success here, see book code
glAttachShader( program, vShader );
Gluint fShader = glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fShader, 1, (const Glchar**)&fSource, NULL );
glCompileShader( fShader );
// should check for success here, see book code
glAttachShader( program, vShader );
glLinkProgram( program );
// should check for success here, see book code
glUseProgram( program );
…
```

Shaders

- Finally we *use* the program
  - Use has the same effect as bind.
  - It stays in effect until we *use* something else.

```
…
Gluint program glCreateProgram( void );
Gluint vShader = glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vShader, 1, (const Glchar**)&vSource, NULL );
glCompileShader( vShader );
// should check for success here, see book code
glAttachShader( program, vShader );
Gluint fShader = glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fShader, 1, (const Glchar**)&fSource, NULL );
glCompileShader( fShader );
// should check for success here, see book code
glAttachShader( program, vShader );
glLinkProgram( program );
// should check for success here, see book code
glUseProgram( program );
…
```

Shaders

- Whew, but not done yet…
  - We still have to make the connection from our vertex array to our shiny new shader program.
  - The first step is to retrieve the location of the variable we are using for input in the vertex shader.

```
#define BUFFER_OFFSET( bytes ) ((Glvoid *)(bytes))
Gluint location;
location = glGetAttribLocation( program, "vPosition" );
glVertexAttribPointer( location, 2, GL_FLOAT, GL_FALSE, 0, BUFFER_OFFSET( 0 ) );
glEnableVertexAttribArray( location );
```

Shaders

- Attach our data to the shader
  - The 2 and **GL_FLOAT** describe our data in the vertex array – 2D points.
  - The next two values specify whether the data should be normalized and the stride of the data.
  - Lastly, we specify a pointer to the data.
    - This is not a pointer to the memory itself but a pointer to the location in the buffer object – can be confusing.

```
#define BUFFER_OFFSET( bytes ) ((Glvoid *)(bytes))
Gluint location;
location = glGetAttribLocation( program, "vPosition" );
glVertexAttribPointer( location, 2, GL_FLOAT, GL_FALSE, 0, BUFFER_OFFSET( 0 ) );
glEnableVertexAttribArray( location );
```

All the pieces

- At this point, there is enough to get something on the display.
- This is a lot of work for something simple.
  - If you are thinking this, you're right, it is.
  - For such a simple program this is overkill and I won't show you how easy it is to do the "old way".
  - However, time marches on and it is time to learn the "new way" since no one would ever write such a simple program anyway, except for learning.
  - Plus this approach allows for much more control.

Interaction Basics

- GLUT provides callbacks for user input.
  - Mouse input is collected by registering a function with `glutMouseFunc()`
  - Keyboard input is collected by registering a function with `glutKeyboardFunc()`

```
void mouseHandler( int button, int state, int x, int y )
{
    if ( button == GLUT_RIGHT_BUTTON && state == GLUT_DOWN ) exit( 0 );
}

void keyHandler( unsigned char key, int x, int y )
{
    if ( key == 'q' || key == 'Q' ) exit( 0 );
}
```

Assignment #1

- Due Wednesday (10/15) by 11:55pm
  - Upload to CCLE
- Implement Sierpinski Gasket in 2D.
  - Details in assignment which you can download from.
  - Get started! It's simple, but you may run into problems.

Next Time

- More FUN!
- Move on to setting up first real assignment