Graphics Programming

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Credits: Some notes taken from Prof. Jeff Chastine

Lab Today

- Online now
- Build a simple GLUT/OpenGL program and alter it
- Visual C++ project
  - Install GLUT library
- Play around with it to get an understanding of how OpenGL works
  - Add a new response key

Unity 3D


testscene.unity – Bootcamp – PC and Mac Standalone
Pivot
Local
Layers
Layout
Game
Free Aspect
Maximize on Play
Gizmos
Stats
Inspector
Camera
Static
Tag
Untagged
Layer
Default
Transform
Position
X 17.74164
Y 3.618703
Z 17.97578
Rotation
X 8.649139
Y 330.9547
Z 0.0009765625
Scale
X 1
Y 1
Z 1
Camera
Clear Flags
Skybox
Background
Culling Mask
Mixed ...
Projection
Perspective
Field of View
36.84956
Clipping Planes
Near 0.3
Far 115
Normalized View Port Rect
X 0
Y 0
W 1
H 1
Depth
0
Rendering Path
Use Player Settings
Target Texture
None (Render Texture)
Flare Layer
GUILayer
Audio Listener
Animation
Color Correction Curves (Script)
Mode
Simple
Red
Green
Blue
Reset
Reset
Reset
Selective
Curve Resolution
256
Bloom And Flares (Script)
Mode
Advanced
Intensity
0.3
Blur iterations
3
Blur spread
1.188793
Hierarchy
Create
Camera
Soldier
SoldierFinalPos
EndTrigger
HudWeapons
MainMenuScreen
QualityManager
Radar
SargeManager
SoldierTargetHUD
SoundManager
SoundObjectManager
aquiris
beams_columns
Project
Create
CutsceneAnimations
Editor
Fonts
Robustik
Robustik-Bold
font material
font Texture
Robustik-Regular_9
Robustik-Regular_10
Robustik-Regular_12
Robustik-Regular_14
Robustik-Regular_14
Gizmos
Locomotion System
Inspector
Scene
Textured
RGB

Unreal Engine 4

Why OpenGL?

- No ready-to-use tools
- Graphics programming is hard
- Much, much longer to create a game
- 3D programming is very time consuming!

- Mastering OpenGL will lead you towards becoming a graphics programmer
- You will have a deeper understanding of how game engines have been built

Essential checklist

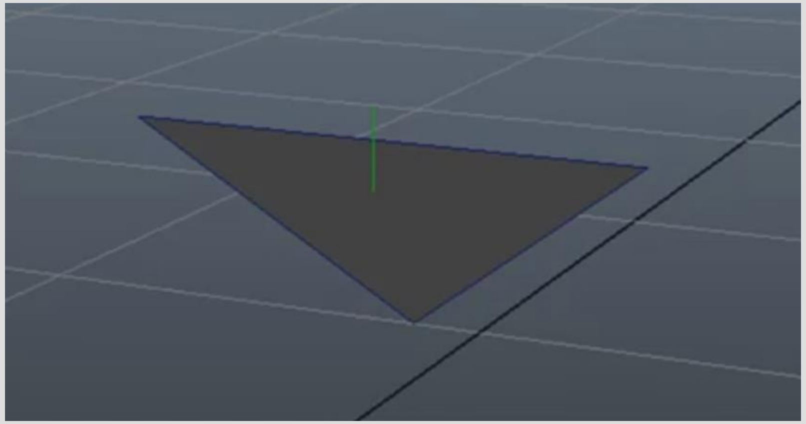
- ✔ always have a pencil and paper
- ✔ solve your problem before you start coding
- ✔ know how to compile and link against libraries
- ✔ know how to use memory, pointers, addresses
- ✔ understand the hardware pipeline
- ✔ make a 3d maths cheat sheet
- ✔ do debugging (visual and programmatic)
- ✔ print the Quick Reference Card for OpenGL
- ✔ start assignments ASAP

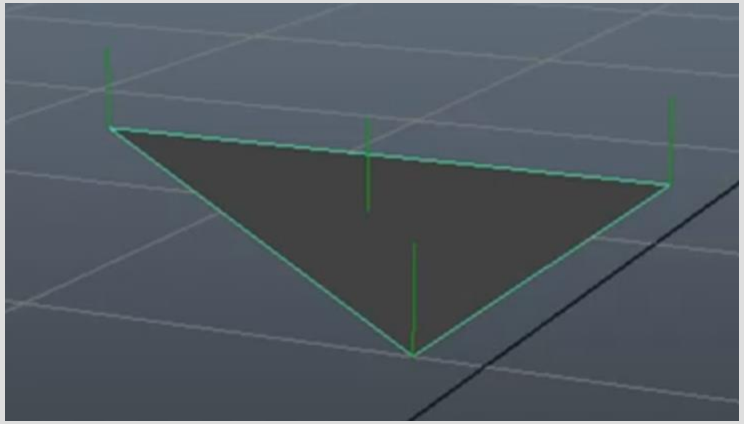
Overview

- OpenGL background
- OpenGL conventions,
- GLUT Event loop, callback registration
- OpenGL primitives, OpenGL objects
- Shaders
- Vertex Buffer Objects
- Books, resources, recommended reading

Quick Background

- A Vertex is a 3D point (x,y,z)
- A triangle
  - Is made from 3 vertices
  - Has a normal
  - Note: vertices can have normals too!

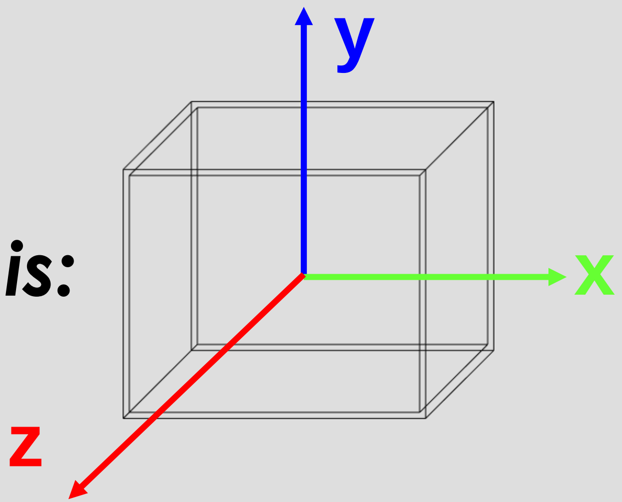




Sources of 3D data

Directly specify the Three-Dimensional data

Fine for this:



=

(-1, -1, -1)
(1, -1, -1)
(1, 1, -1)
(-1, 1, -1)
(-1, -1, 1)
(1, -1, 1)
(1, 1, 1)
(-1, 1, 1)

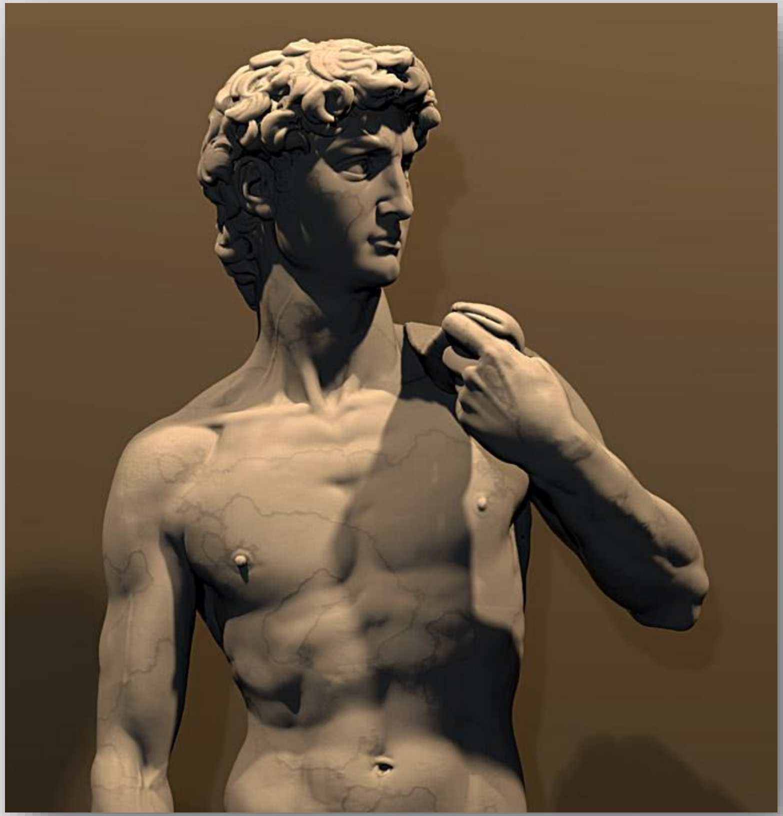
... *But not for this!*

Modelling Program

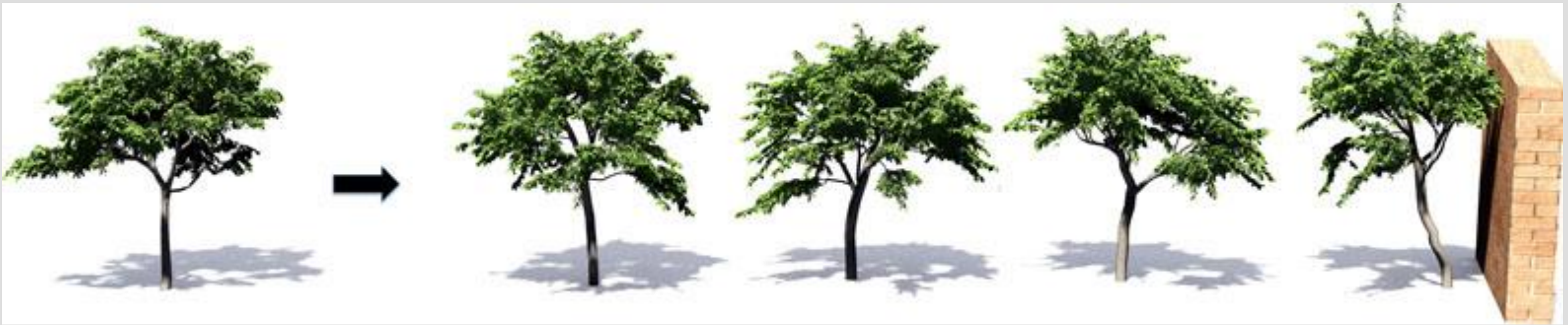
- 3ds Max, Maya, Softimage, Blender, Auto CAD etc.

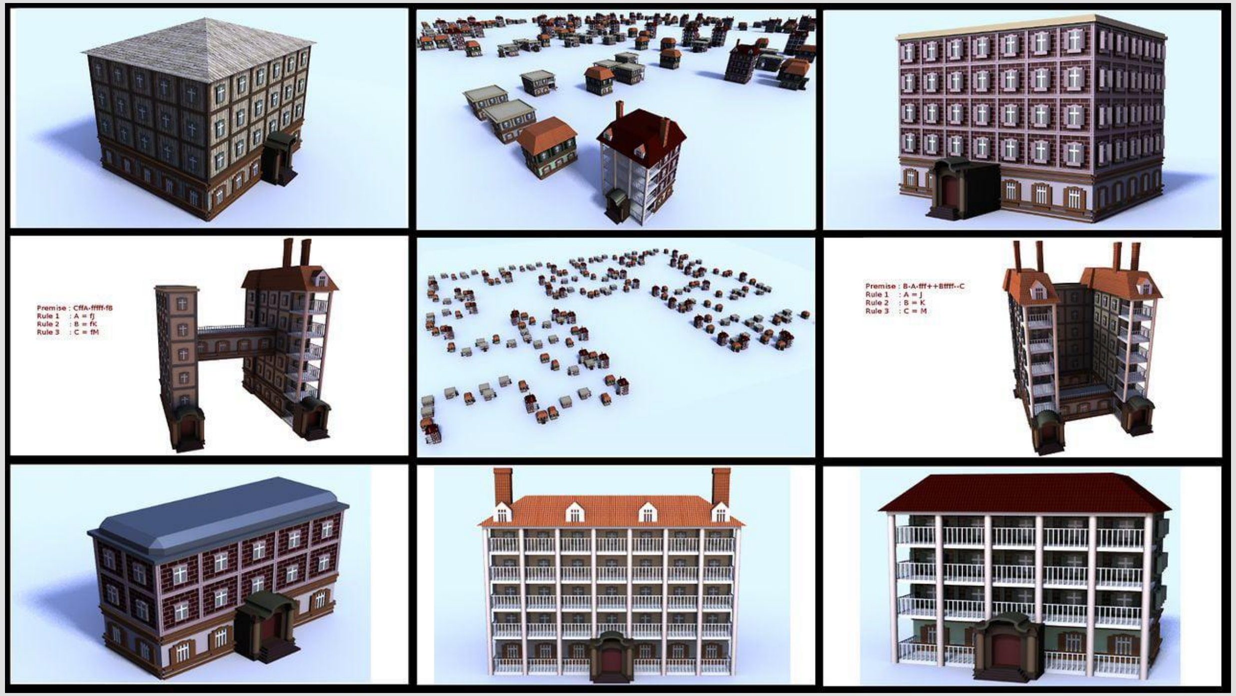
https://www.autodesk.com/education/free-software/all

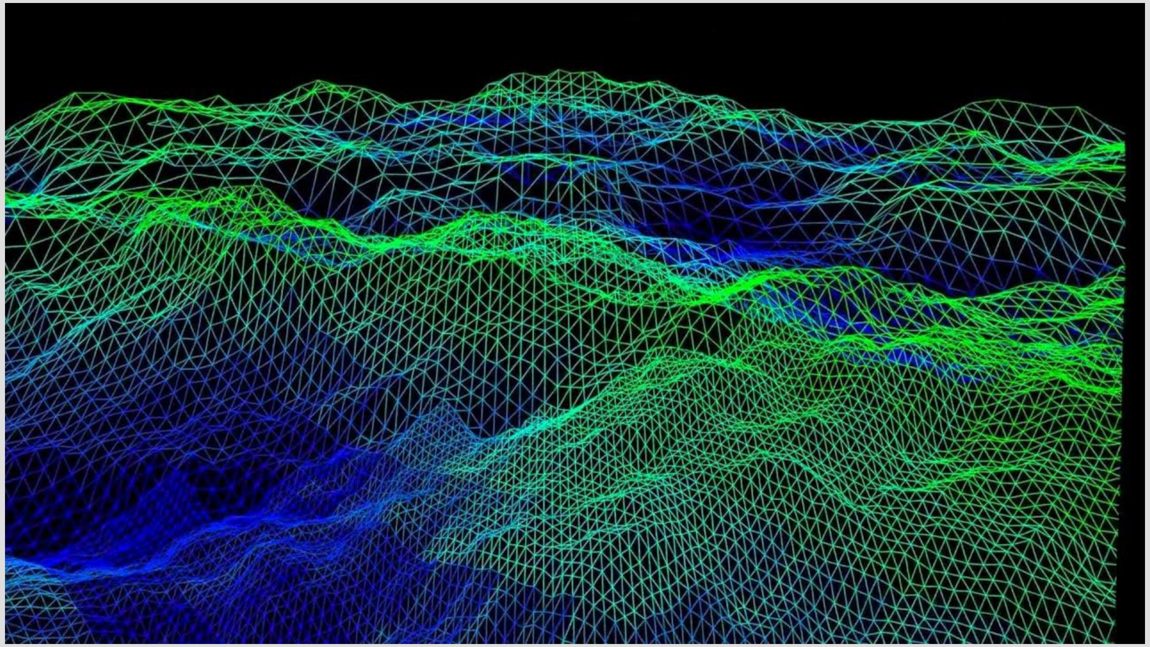
Laser Scanning



Procedural Models



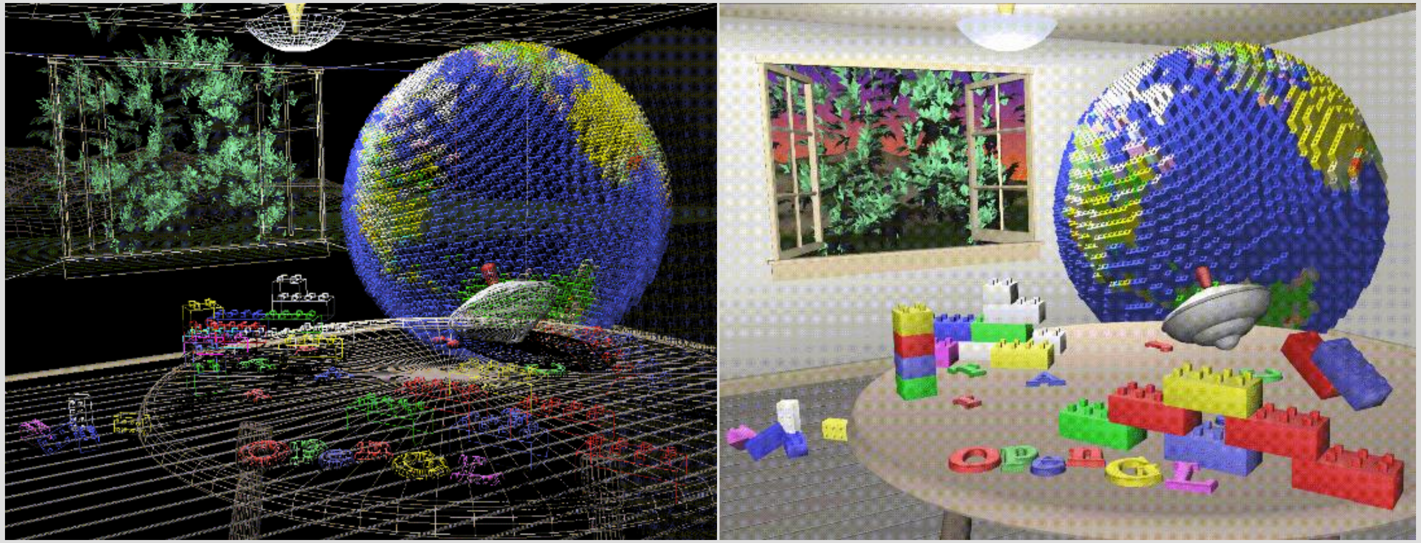




Algorithmic rules to generate complex models

Rendering

- *Rendering* is the process by which a computer creates images from models. These *models*, or objects, are constructed from geometric primitives - points, lines, and polygons - that are specified by their vertices
- The final rendered image consists of pixels drawn on the screen



A Graphics System

- Input devices
- Central Processing Unit
- Graphics Processing Unit
- Memory
- Frame buffer
- Output devices

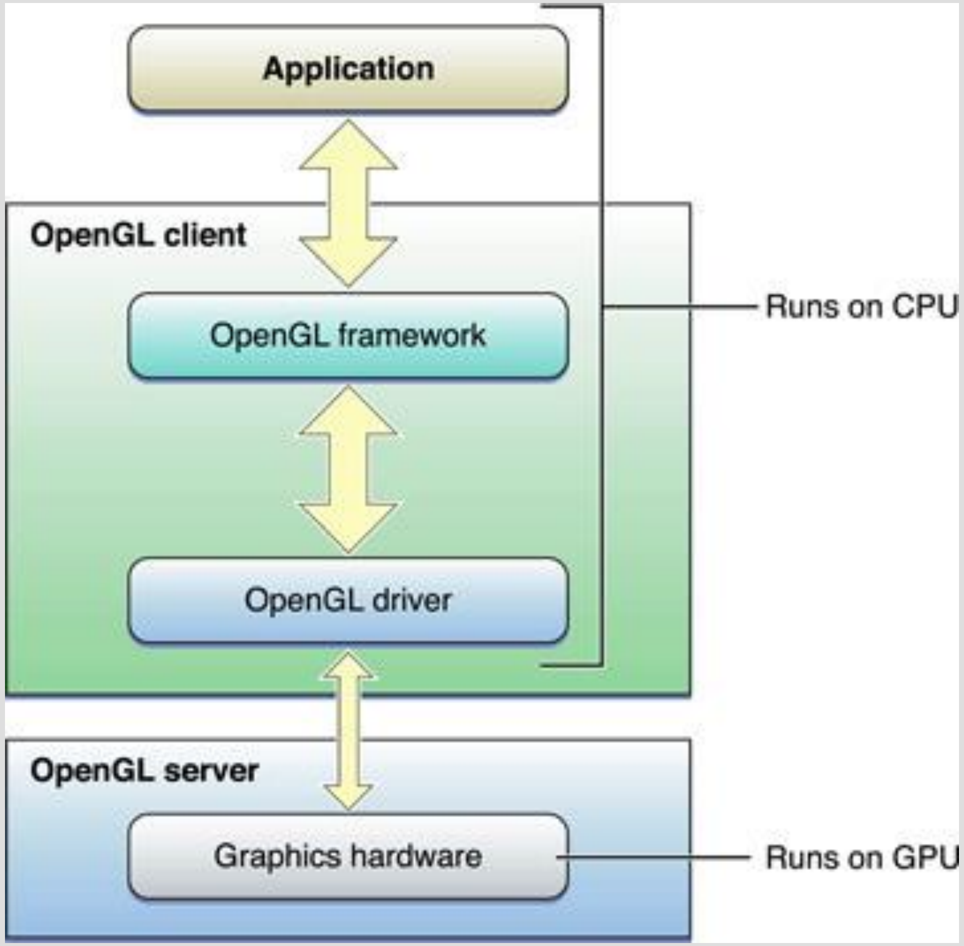
What is OpenGL?

- OpenGL = Open Graphics Library
- Application you can use to access and control the graphics subsystem of the device upon which it runs
- Developed at Silicon Graphics (SGI)
- It is *device independent*
- Cross Platform
  - (Win32, Mac OS X, Unix, Linux)
- Only does 3D Graphics. No Platform Specifics
  - (Windowing, Fonts, Input, GUI)

OpenGL

- OpenGL is a ***software library*** for accessing features in graphics hardware.
- About 500 distinct commands.
  - Not a single function relating to window, screen management, keyboard input, mouse input
- OpenGL uses a ***client-server*** model
  - Client is your application, server is OpenGL implementation on your graphics card/network graphics card
- Default language is **C/C++.**
- To the programmer OpenGL behaves like a **state machine**.
- The actual drawing operations are performed by the underlying *accelerated graphics hardware* (e.g. Nvidia, ATI, SGI etc).

Graphics API Architecture



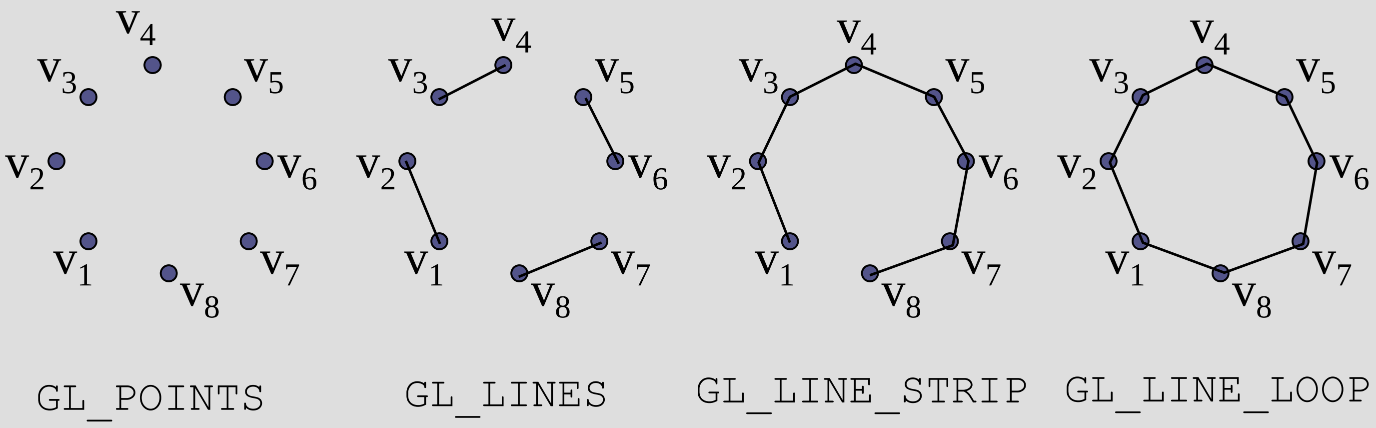
- Set-up & rendering loop run on CPU
- Copy mesh data to **buffers** in graphics hardware memory
- Write **shaders** to draw on the GPU
- CPU command queues drawing on GPU with *this* shader, and *that* mesh data
- CPU & GPU then run **asynchronously**

OpenGL Global State Machine

- Set various aspects of the state machine using the API
  - Colour, lighting, blending
- When rendering, everything drawn is affected by the current settings of the state machine
- Most **parameters are persistent**
  - Values remain unchanged until we explicitly change them through functions that alter the state
- Not uncommon to have **unexpected results** due to having one or more states set incorrectly

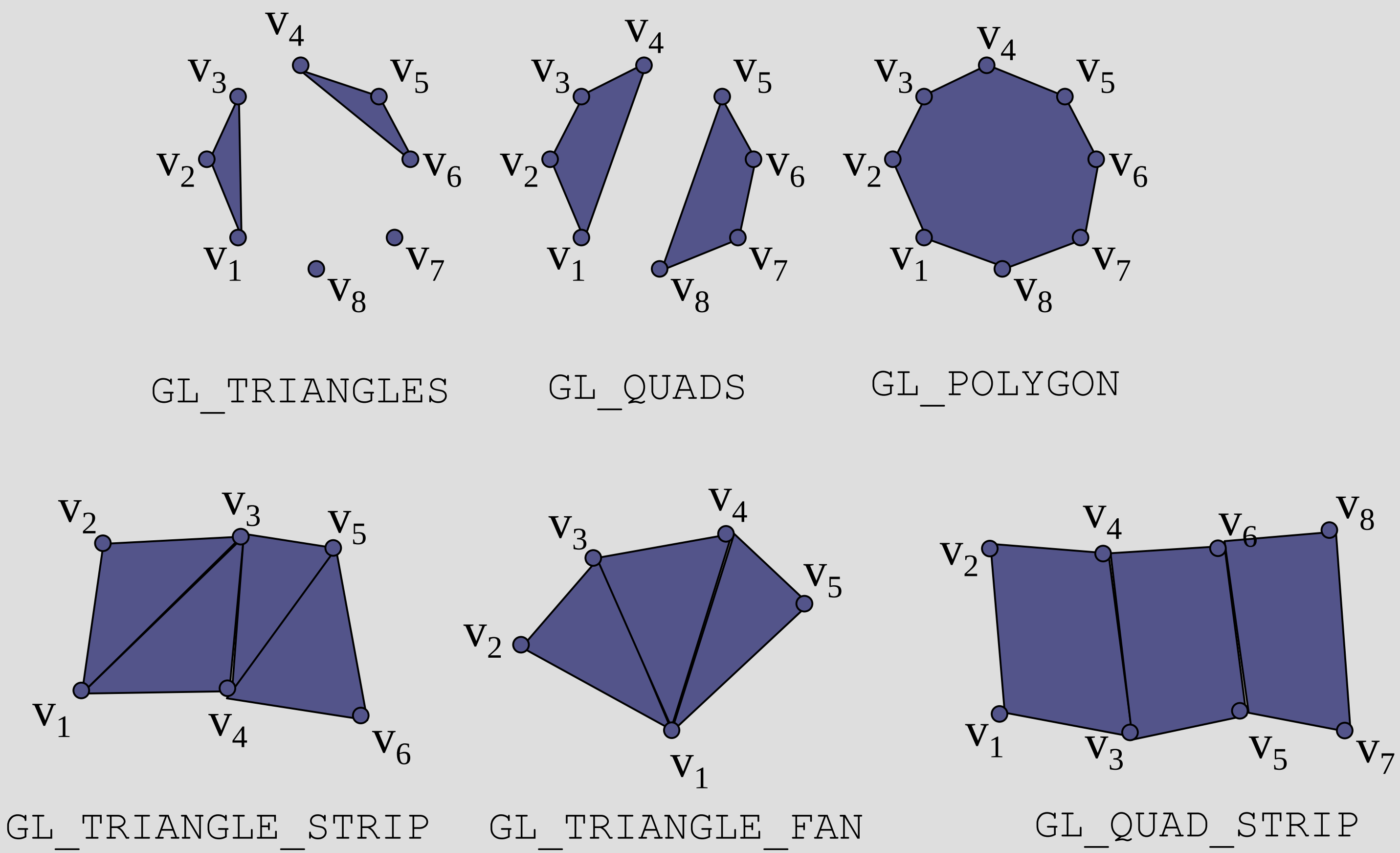
OpenGL Primitives

- All geometric objects in OpenGL are created from a set of basic *primitives*.
- Certain primitives are provided to allow optimisation of geometry for improved rendering speed.
- Line based primitives:



OpenGL® Primitives

- Polygon primitives



OpenGL Conventions

- Conventions:
  - all function names begin with **`gl`**, or **`glut`**
    - **`glBegin(…)`**
    - **`glutInitDisplayMode(…)`**
  - constants begin with **`GL_`**, **`GLU_`**, or **`GLUT_`**
    - **`GL_POLYGON`**
  - Function names can encode parameter types, e.g. **`glVertex*`**:
    - **`glVertex2i(1, 3)`**
    - **`glVertex3f(1.0, 3.0, 2.5)`**
    - **`glVertex4fv(array_of_4_floats)`**

http://www.opengl.org/sdk/docs/man/

The Drawing Process

- `ClearTheScreen();`
- `DrawTheScene();`
- `CompleteDrawing();`
- `SwapBuffers();`

- In animation there are usually two buffers. Drawing usually occurs on the background buffer.
- When it is complete, it is brought to the front (swapped). This gives a smooth animation without the viewer seeing the actual drawing taking place. Only the final image is viewed.

- The technique to swap the buffers will depend on which windowing library you are using with OpenGL.

Clearing the Window

- `glClearColor(0.0, 0.0, 0.0, 0.0);`
- `glClear(GL_COLOR_BUFFER_BIT);`

- Typically you will clear the color and depth buffers.

- `glClearColor(0.0, 0.0, 0.0, 0.0);`
- `glClearDepth(0.0);`
- `glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);`

- You can also clear the accumulation and stencil buffers.
  - `GL_ACCUM_BUFFER_BIT` and `GL_STENCIL_BUFFER_BIT`

Specifying a Colour

- It is possible to represent almost any colour by adding red, green and blue
- Colour is specified in (R,G,B,A) form [Red, Green, Blue, Alpha], with each value being in the range of 0.0 to 1.0.
  - 0.0 means "all the way off"
  - 1.0 means "all the way on"
- Examples:
  - `(red, green, blue, alpha);`
  - `(0.0, 0.0, 0.0); /* Black */`
  - `(1.0, 0.0, 0.0); /* Red */`
  - `(0.0, 1.0, 0.0); /* Green */`
  - `(1.0, 1.0, 0.0); /* Yellow */`
  - `(1.0, 0.0, 1.0); /* Magenta */`
  - `(1.0, 1.0, 1.0); /* White */`

Colours

- What colour does this represent in OpenGL?
  - `(0.0, 1.0, 0.0);`

Complete Drawing the Scene

- Need to tell OpenGL you have finished drawing your scene.
- `glFinish();`

  or
- `glFlush();`
- For more information see Chapter of the Red Book:
  - http://fly.srk.fer.hr/~unreal/theredbook/chapter02.html

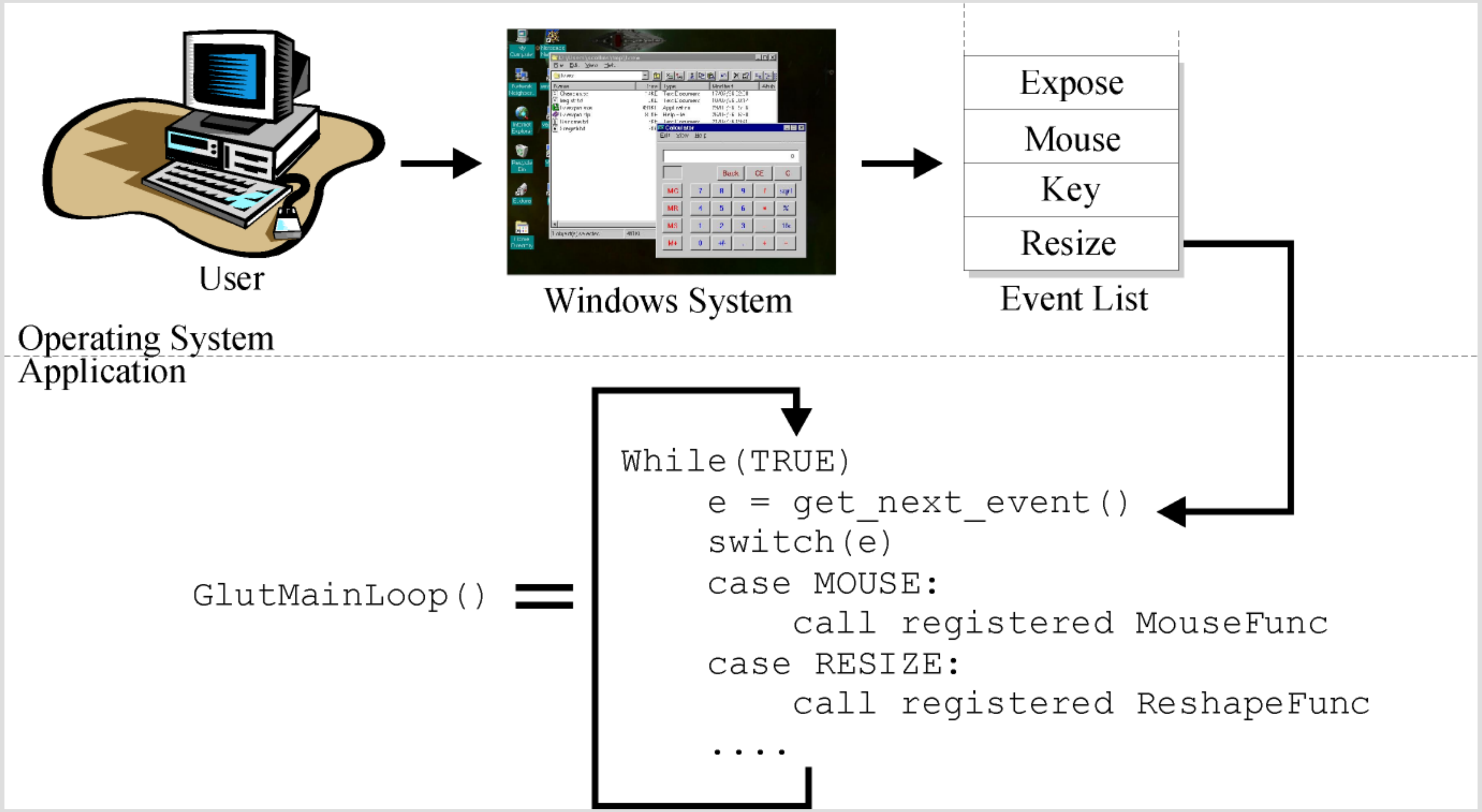
OpenGL `GLUT` Overview

- Initialise GLUT and create a window
- GLUT enters event processing loop and gains control of the application
- GLUT waits for an event to occur & then checks for a function to process it
- Tell GLUT which functions it must call for each event

OpenGL GLUT Event Loop

- Interaction with the user is handled through an *event loop*.
- Application registers *handlers* (or *callbacks*) to be associated with particular events:
  - mouse button, mouse motion, timer, resize, redraw
- GLUT provides a wrapper on the X-Windows or Win32 core event loop.
- X-Windows or Win32 manages event creation and passing, GLUT uses them to catch events and then invokes the appropriate callback.
- GLUT is more general than X or Win32 etc.
  - ⇒ <u>more portable</u>: user interface code need not be changed.
  - ⇒ <u>less powerful</u>: implements a common subset

OpenGL GLUT Event Loop



OpenGL `GLUT` Event Loop

- To add handlers for events we call a callback registering function, e.g:

```
void glutKeyboardFunc(void (*func)(unsigned char key, int x, int y));
```

- Takes a function (the required callback) as a parameter.
- Handlers must conform to the specification defined.
- Example:

```
void key_handler(unsigned char key, int x, int y);

glutKeyboardFunc(key_handler);
```

- In this case, **`key`** is the ascii code of the key hit and **`(x,y)`** is the mouse position within the window when the key was hit.
- The callback function is *automatically* called when a key is hit.

```
//----------------------------------------------------------------------
//
// main
//

int
main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_RGBA);
    glutInitWindowSize(512, 512);
    glutInitContextVersion(4, 3);
    glutInitContextProfile(GLUT_CORE_PROFILE);
    glutCreateWindow(argv[0]);

    if (glewInit()) {
        cerr << "Unable to initialize GLEW ...  exiting" << endl;
        exit(EXIT_FAILURE);
    }

    init();

    glutDisplayFunc(display);

    glutMainLoop();
}
```

Creates a Window using GLUT

Call init()

Event Loop

```
//---------------------------------------------------------------------------
//
// init
//

void
init(void)
{
    glGenVertexArrays(NumVAOs, VAOs);
    glBindVertexArray(VAOs[Triangles]);

    GLfloat  vertices[NumVertices][2] = {
        { -0.90, -0.90 },  // Triangle 1
        {  0.85, -0.90 },
        { -0.90,  0.85 },
        {  0.90, -0.85 },  // Triangle 2
        {  0.90,  0.90 },
        { -0.85,  0.90 }
    };

    glGenBuffers(NumBuffers, Buffers);
    glBindBuffer(GL_ARRAY_BUFFER, Buffers[ArrayBuffer]);
    glBufferData(GL_ARRAY_BUFFER, sizeof(vertices),
                 vertices, GL_STATIC_DRAW);

    ShaderInfo  shaders[] = {
        { GL_VERTEX_SHADER, "triangles.vert" },
        { GL_FRAGMENT_SHADER, "triangles.frag" },
        { GL_NONE, NULL }
    };

    GLuint program = LoadShaders(shaders);
    glUseProgram(program);

    glVertexAttribPointer(vPosition, 2, GL_FLOAT,
                          GL_FALSE, 0, BUFFER_OFFSET(0));
    glEnableVertexAttribArray(vPosition);
}
```

Set up your object's initial position

Specify Shaders

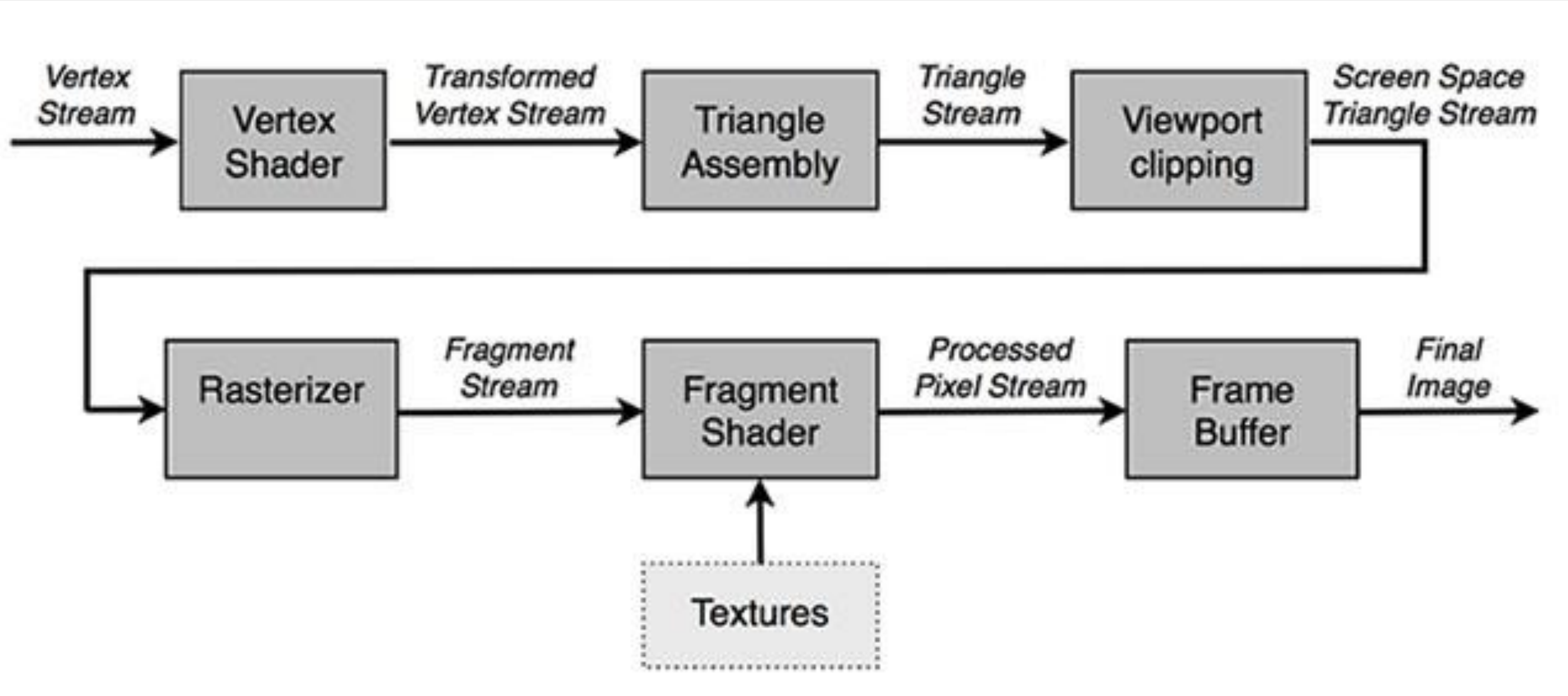
```
//----------------------------------------------------------------
//
// display
//

void
display(void)
{
    glClear(GL_COLOR_BUFFER_BIT);

    glBindVertexArray(VAOs[Triangles]);
    glDrawArrays(GL_TRIANGLES, 0, NumVertices);

    glFlush();
}
```

Does the actual Drawing on the Screen

Request that image is presented on screen

Pick current vertex array

Programmable Pipeline



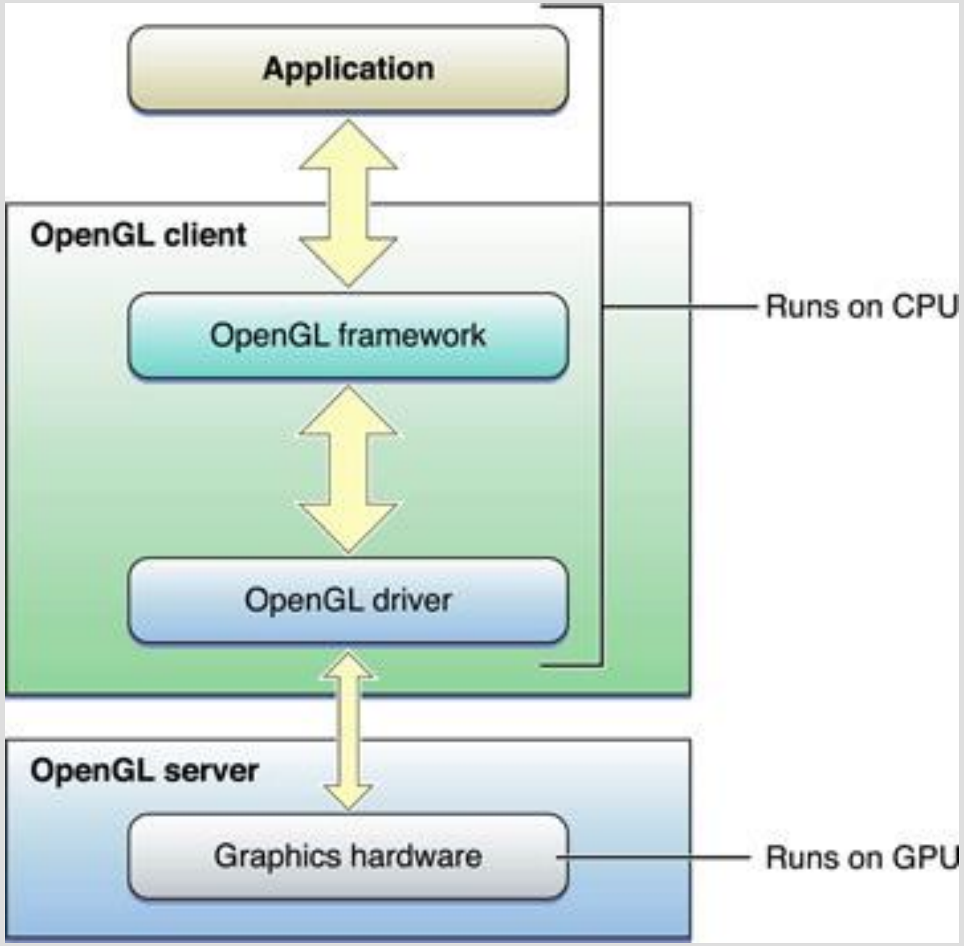
Quick Background

- Hardware has changed!
  - Was “fixed”
  - More of the graphics pipeline is programmable
- OpenGL has changed!
  - Was “fixed”
  - Now shader-based

Overview

- Shaders
- Vertex Buffer Objects

Graphics API Architecture



- Set-up & rendering loop run on CPU
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- Write **shaders** to draw on the GPU
- CPU command queues drawing on GPU with *this* shader, and *that* mesh data
- CPU & GPU then run **asynchronously**

Shadertoy

- WebGL tool to experiment with shaders on-the-fly
- implemented entirely in a fragment shader

https://www.shadertoy.com/

Shaders

- A shader is a program with *main* as its entry point
  - Has source code (text file)
  - Cg, HLSL and **GLSL**
  - GLSL is a C-like language
  - Is compiled into a program
  - We get back IDs, which are just ints!

SIGGRAPH University "An Introduction to OpenGL Programming": https://www.youtube.com/watch?v=6-9XFm7XAT8

GLSL Data Types

- Scalar types: `float, int, bool`
- Vector types: `vec2, vec3, vec4`
- Matrix types: `mat2, mat3, mat4`
- Texture sampling; `sampler1D, sampler2D, sampler3D, sampleCube`
- C++ Style Constructors
  - `vec3 a = vec3(1.0, 2.0, 3.0);`

Operators

- Standard C/C++ arithmetic and logic operators
- Overloaded operators for matrix and vector operations

```
mat4 m;
vec4 a, b, c;

b = a*m;
c = m*a;
```

Components

- Access vector components using either:
  - [ ] (c-style array indexing)
  - `xyzw`, `rgba`, or `stpq` (named components)

- For example:
  - `vec3 v;`
  - `v[1], v.y, v.g, v.t` – all refer to the same elements

Qualifiers

- `in, out`
  - Copy vertex attributes and other variable info into and out of shaders

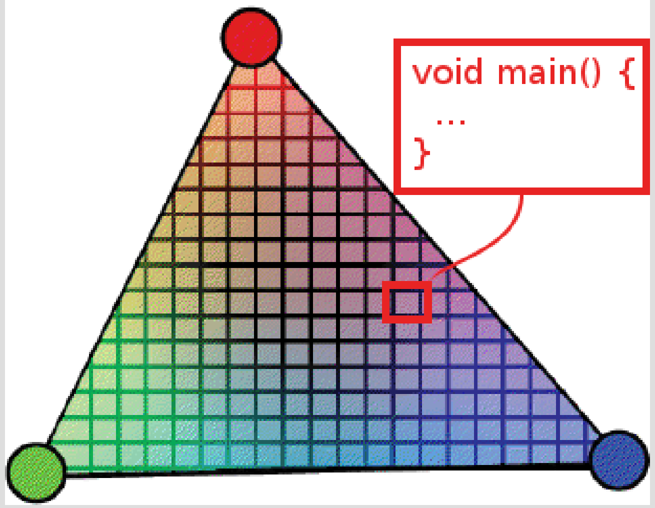
```
in vec2 texCoord;
out vec4 color;
```

- `uniform`
  - Shader-constant variable from application

```
uniform float time;
uniform vec4 rotation;
```

Shaders

- Two primary types of shaders:
  - **Vertex shader**
    - Changes the position of a vertex (trans/rot/skew)
    - May determine colour of the vertex
  - **Fragment shader**
    - Determines the colour of a pixel
    - Uses lighting, materials, normals, etc…



Vertex Shader

- Processes vertices
- Data describing what triangles are formed is unavailable to the vertex shader
- At a minimum, a vertex shader must always output vertex location
- Usually transforms vertices into homogeneous clip space

Fragment/Pixel Shader

- Vertex shader outputs become pixel shaders inputs
- A total of 16 vectors can be passed from the vertex to fragment shader
  - E.g., flag to determine which side of a triangle is visible
- Limitation: can only influence the fragment handed it
  - It cannot send its results directly to neighbouring pixels
  - It uses the data interpolated from the vertices along with stored constants and texture data
- Not severe limitation
  - Other ways to affect neighbouring pixels

Making a shader program

- Compile a vertex shader (get an ID)
- Compile a fragment shader (get an ID)
- Check for compilation errors
- Link those two shaders together (get an ID)
  - Keep that ID!
  - Use that ID before you render triangles
  - Can have separate shaders for each model

Examples

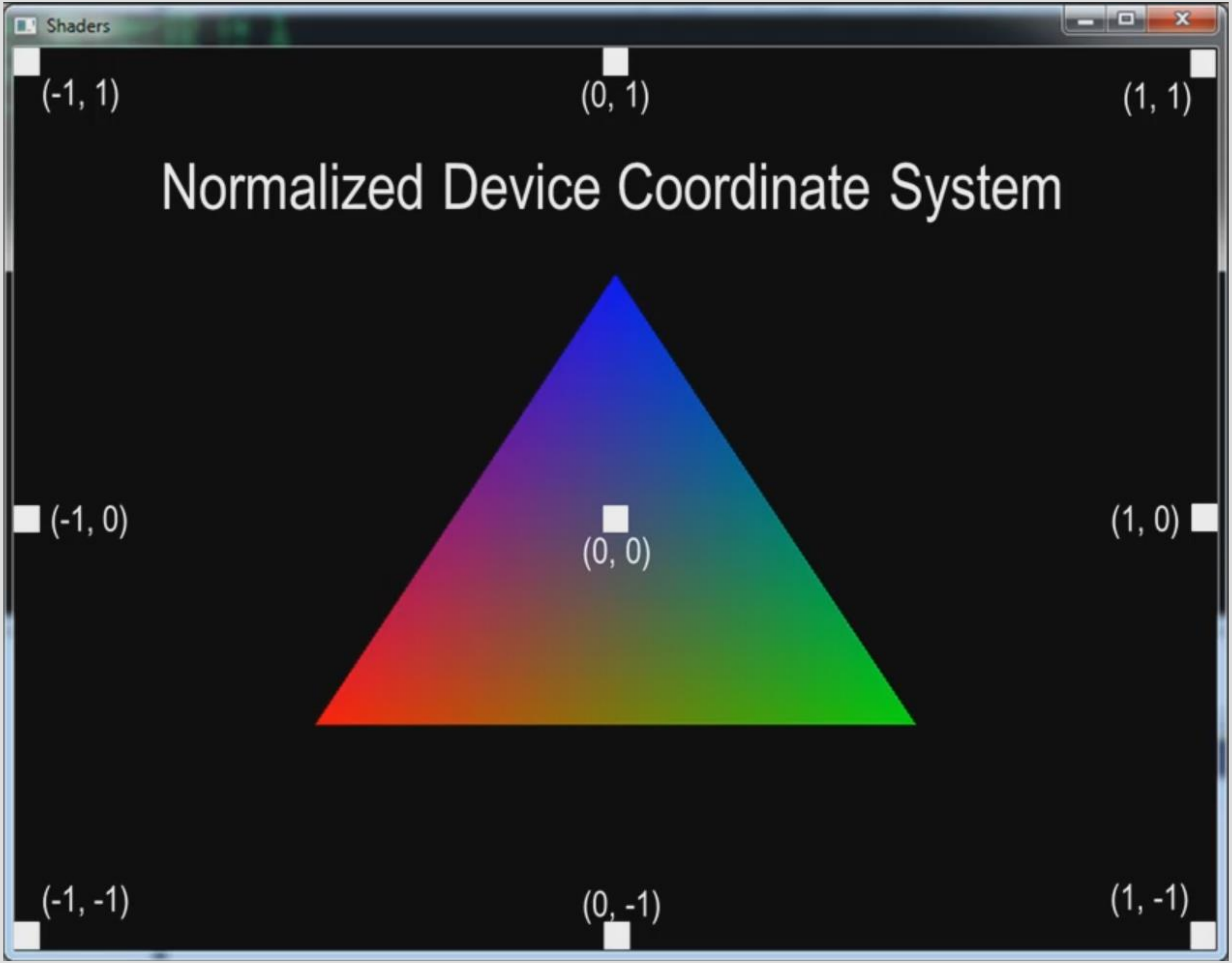
```
#version 430
in vec4 vPosition;

void main () {
  // The value of vPosition should be between -1.0 and +1.0
  gl_Position = vPosition;
}
---------------------------------------
out vec4 fColor ;

void main () {
  // No matter what, color the pixel red!
  fColor = vec4 (1.0, 0.0, 0.0, 1.0);
}
```

Compiling Shaders

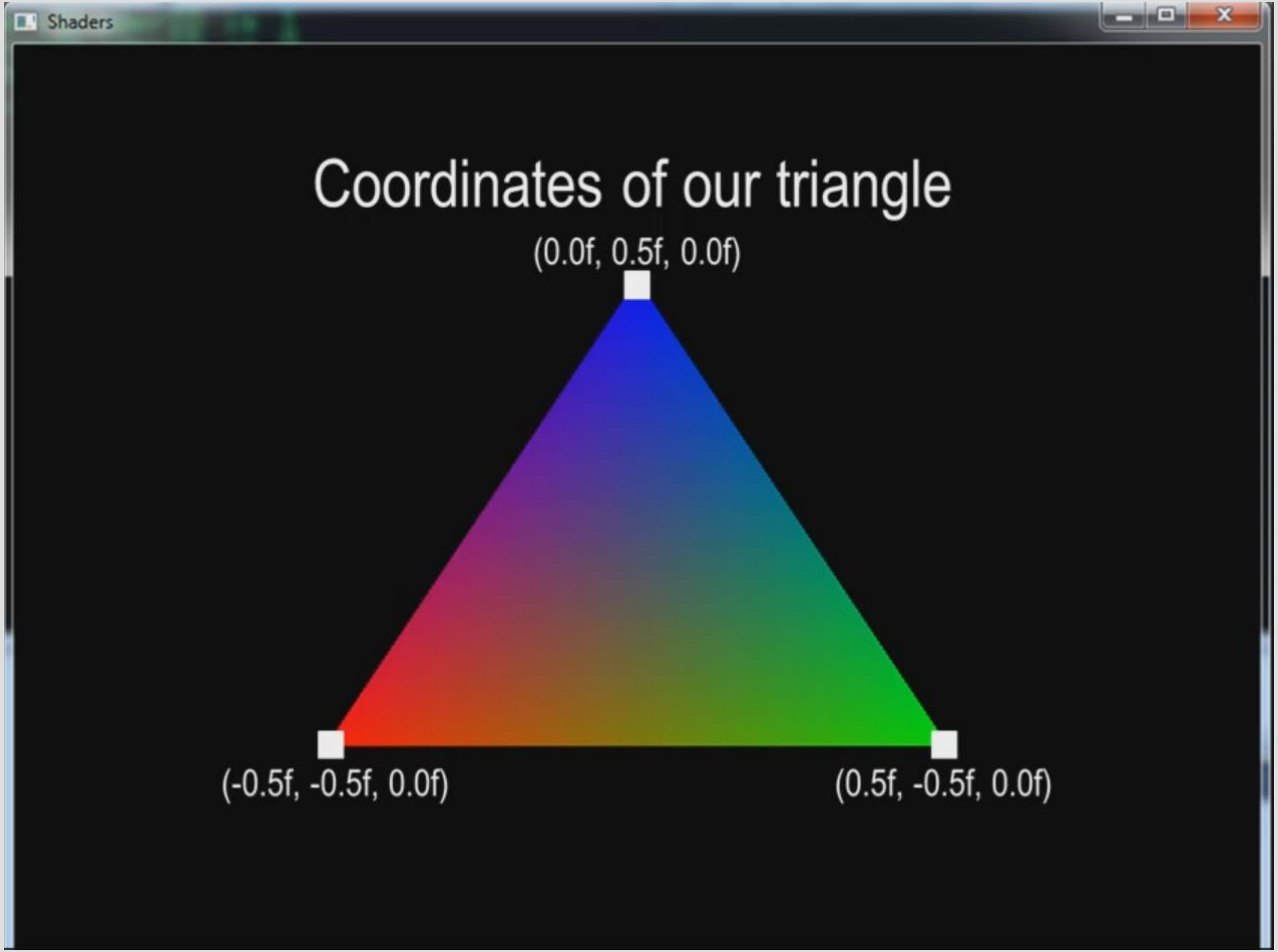
- <GLuint> glCreateShader (<type>)
  - Creates an ID (a GLuint) of a shader
  - Example: GLuint ID = glCreateShader(GL_VERTEX_SHADER);
- glShaderSource (<id>, <count>, <src code>, <lengths>)
  - Binds the source code to the shader
  - Happens before compilation
- glCompileShader (<id>)
  - Used to make the shader program

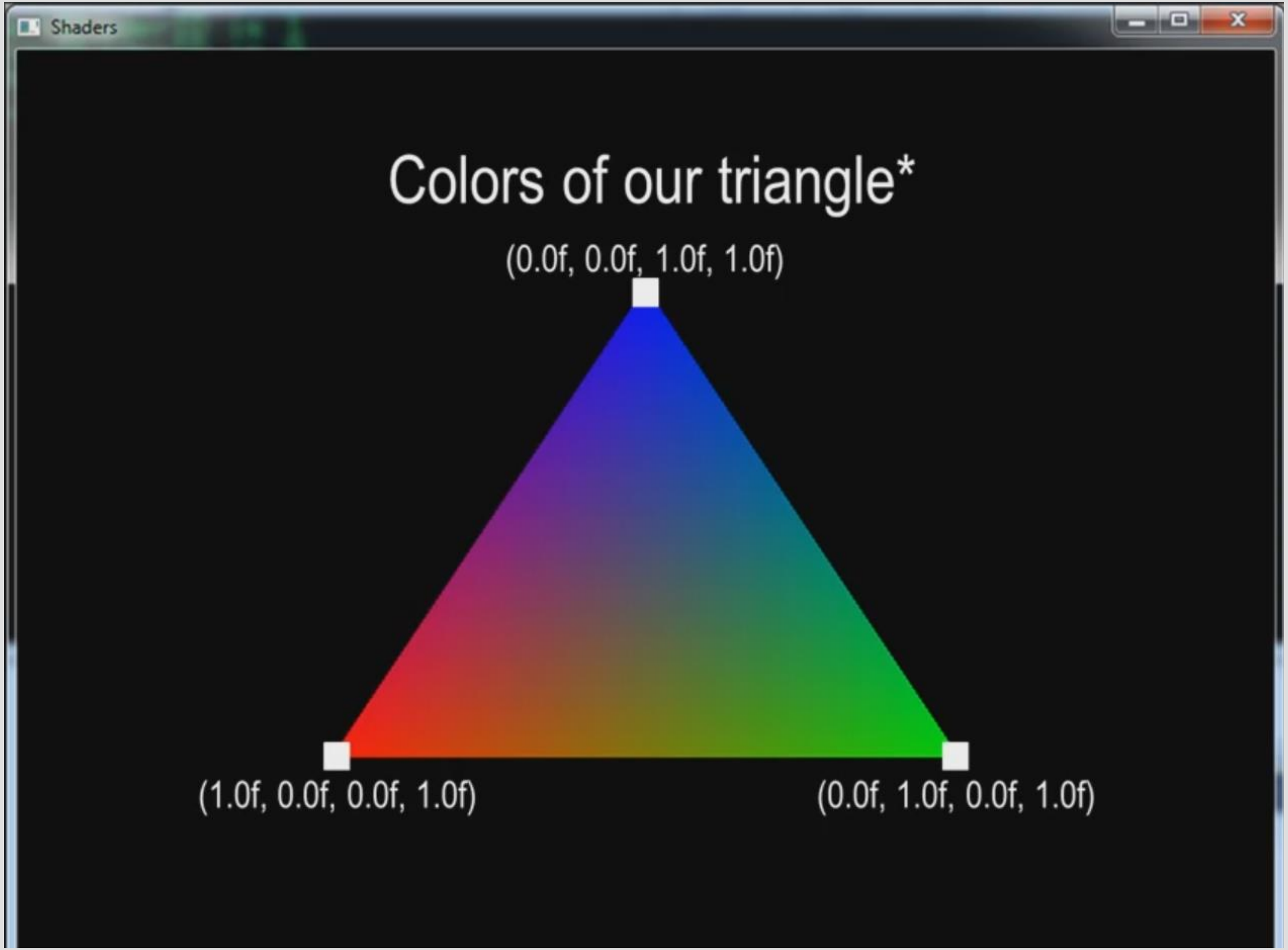
Creating/Linking/Using Shaders

- <GLuint> glCreateProgram()
  - Returns an ID – keep this for the life of the program
- glAttachShader (<prog ID>, <shader ID>)
  - Do this for both the vertex and fragment shaders
- glLinkProgram(<prog ID>)
  - Actually makes the shader program
- glUseProgram(<prog ID>)
  - Use this shader when you're about to draw triangles



Shaders
(-1, 1)
(0, 1)
(1, 1)
Normalized Device Coordinate System
(-1, 0)
(0, 0)
(1, 0)
(-1, -1)
(0, -1)
(1, -1)


Shaders
Coordinates of our triangle
(0.0f, 0.5f, 0.0f)
(-0.5f, -0.5f, 0.0f)
(0.5f, -0.5f, 0.0f)


Shaders
Colors of our triangle*
(0.0f, 0.0f, 1.0f, 1.0f)
(1.0f, 0.0f, 0.0f, 1.0f)
(0.0f, 1.0f, 0.0f, 1.0f)

VERTEX BUFFER OBJECTS

- How do we get the geometry and colour onto the GPU?
- Typically also need a *normal* and *texture coordinate* for each vertex!
- Ask the OpenGL driver to create a <u>buffer object</u>
  - This is just a chunk of memory (e.g. array)
  - Nothing to be afraid of!
  - Located on the GPU (probably)

Working with Buffers

- To create a buffer ID:

  // This will be the ID of the buffer

  ```
  GLuint buffer;
  ```

  // Ask OpenGL to generate exactly 1 unique ID

  ```
  glGenBuffers(1, &buffer);
  ```

- To set this buffer as the active one and specify which buffer we're referring to:

  ```
  glBindBuffer(GL_ARRAY_BUFFER, buffer);
  ```

- Notes:
  - That buffer is now bound and active!
  - Any "drawing" will come from that buffer
  - Any "loading" goes into that buffer

Loading the Buffer with Data

- Got some data in an array called "data" and want it to be in the GPU
- `glBufferData(GL_ARRAY_BUFFER, sizeof(data), data,`
  `GL_STATIC_DRAW);`

STREAM
STATIC
DYNAMIC
(how frequently data will change)

DRAW
READ
COPY

Loading the Buffer with Data

- Process:
  - Create the buffer and pass *no* data
  - Load the geometry
  - Load the colors
  - Load the normals, texture coordinates…
- Can organise buffer however you like

- **generateObjectBuffer**(GLfloat vertices[], GLfloat colors[]) {

```
GLuint VBO;
glGenBuffers(1, &VBO);
glBindBuffer(GL_ARRAY_BUFFER, VBO);
glBufferData(GL_ARRAY_BUFFER,
             numVertices*7*sizeof(GLfloat),
                   NULL, GL_STATIC_DRAW);
glBufferSubData (GL_ARRAY_BUFFER, 0,
                   numVertices*3*sizeof(GLfloat),
                         vertices);
glBufferSubData (GL_ARRAY_BUFFER,
             numVertices*3*sizeof(GLfloat),
             numVertices*4*sizeof(GLfloat), colors);
```

x,y,z + r,g,b,a

What we have so far..

- We have a buffer with an ID
- That buffer lives on the graphics card
- That buffer is full of vertex position/colour data
- How do we get that info to our shader?

Link to the Shader

- Query the shader program for its variables
- The code below goes into the shader program and gets the "vPosition" ID

```
GLuint vpos;
vpos = glGetAttribLocation (programID, "vPosition");
```

- In OpenGL, we have to enable things (attributes, in this case):

```
glEnableVertexAttribArray(vpos); // turn on vPosition
```

- Finally, Tell those variables where to find their info in the currently bound buffer:

```
glVertexAttribPointer(vpos, 3, GL_FLOAT, GL_FALSE, 0, 0);

void glVertexAttribPointer(GLuint index, GLint size,
Glenum type, GLboolean normalized, GLsizei stride,
const GLvoid* offset);
```

Buffer→ | verts | colors |

```
vpos = glGetAttribLocation (programID, “vPosition”);
glEnableVertexAttribArray(vpos);
glVertexAttribPointer(vpos, 3, GL_FLOAT, GL_FALSE, 0, 0);
```

```
in vec4 vPosition;
in vec4 vColor;
out vec4 color;

void main () {
  gl_Position = s_vPosition;
  Color = vColor;
}
```

Bind that variable to a spot in the buffer

Where to find it in the buffer


```
cpos = glGetAttribLocation (programID, “vColor”);
glEnableVertexAttribArray(cpos);
glVertexAttribPointer(cpos, 4, GL_FLOAT, GL_FALSE, 0,
(BUFFER_OFFSET(numVertices * 3 * sizeof(Glfloat)));
```

```
in vec4 vPosition;
in vec4 vColor;
out vec4 color;

void main () {
  gl_Position = s_vPosition;
  Color = vColor;
}
```

Bind that variable to a spot in the buffer

Where to find it in the buffer

Graphics Programming

Lecturer: **Rachel McDonnell**

Assistant Professor in Creative Technologies

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Course www: https://www.scss.tcd.ie/Rachel.McDonnell/

Credits: Some notes taken from Prof. Jeff Chastine

Pause and Review

- What are the main components of a modern 3d graphics program?
- Where do we store mesh data (vertex points)?
- In what?
- What do we need to do before we tell OpenGL to draw with glDrawArrays() etc.?

Uniforms

- Pass data into a shader that stays the same – is uniform
  - e.g., transformation matrix
- Get data directly from application to shaders
- Two approaches
  - Declare in default block
  - Store in buffer object
- Simply place the keyword **uniform** at beginning of variable definition
  - uniform float fTime
  - uniform mat4 modelMatrix

Using Uniforms to Transform Geometry

- Now it is time to put all our knowledge together and build a program that does a little more than pass vertices through un-transformed

The Old Vertex Shader

```
in vec4 vPosition;

void main () {
  // The value of vPosition should be between -1.0 and +1.0
  gl_Position = vPosition;
}
-------------------------------------
out vec4 fColor ;

void main () {
  // No matter what, color the pixel red!
  fColor = vec4 (1.0, 0.0, 0.0, 1.0);
}
```

A Better Vertex Shader

```
in vec4 vPosition; // the vertex in local coordinate system
uniform mat4 mM; // the matrix for the pose of the model
uniform mat4 mV; // The matrix for the pose of the camera
uniform mat4 mP; // The projection matrix (perspective)


void main () {
   // The value of vPosition should be between -1.0 and +1.0
   gl_Position = mP * mV * mM * vPosition;
}
```

New position in NDC

Original (local) position

Code example – matrix

```
int matrix_location = glGetUniformLocation (shaderProgramID,
"model");
```

Load the data:

```
glUniformMatrix4fv (matrix_location, 1, GL_FALSE, model.m);
```

Shader code: uniform mat4 model;

Code example - float

```
glUseProgram(shaderProgramID);
gScaleLocation = glGetUniformLocation(shaderProgramID,
"gScale");


void display(){

glClear(GL_COLOR_BUFFER_BIT);
static float Scale = 0.0f;
    Scale += 0.001f;
    glUniform1f(gScaleLocation, sinf(Scale));
glDrawArrays(GL_TRIANGLES, 0, 3);
    glutSwapBuffers();
}
```

Drawing Geometric Primitives

- For contiguous groups of vertices

```
glDrawArrays( GL_Triangles, 0, numVertices);
```

- Usually invoked in display callback
- Initiates vertex shader

Resources

- OpenGL Home Page
  - http://www.opengl.org
- Anton's OpenGL Tutors
  - http://antongerdelan.net/opengl/
- Tutorials
  - http://ogldev.atspace.co.uk/
- OpenGL (Programming Guide)
  - http://www.glprogramming.com/
- Excellent OpenGL video tutorials on various topics
  - http://cse.spsu.edu/jchastin/courses/cs4363/lectures/videos/default.htm
  - https://www.youtube.com/watch?v=6-9XFm7XAT8
- Glut Tutorial
  - http://www.lighthouse3d.com/opengl/glut/index.php3?gameglut

Recommended Material

- Read Chapters 1-6 of OpenGL Red Book
- Familiarise yourself with OpenGL Blue Book
- Play with OpenGL Tutorials
- Learn about GLUT

Graphics Pipeline

Lecturer: **Rachel McDonnell**

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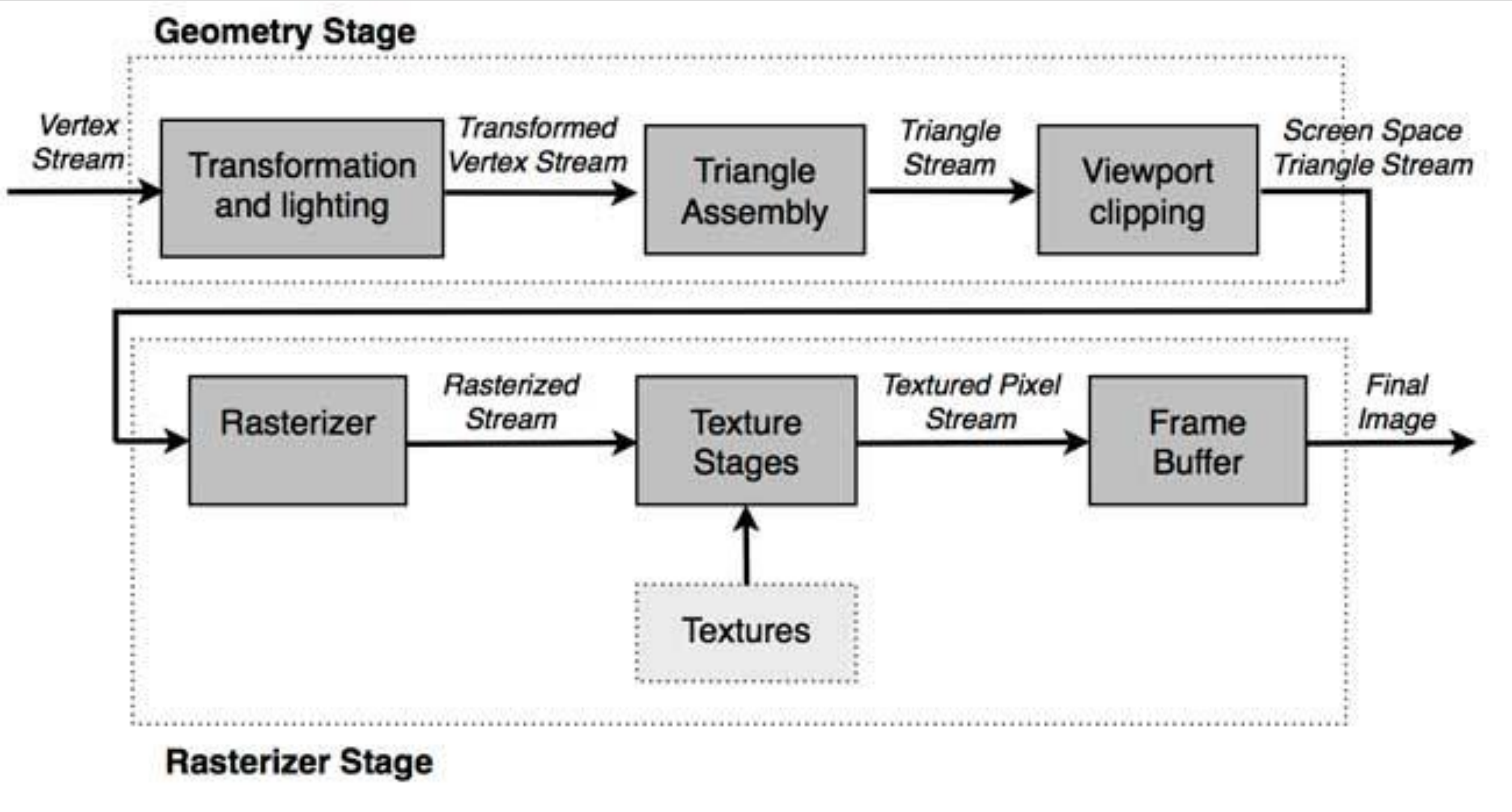
Course www: https://www.scss.tcd.ie/Rachel.McDonnell/

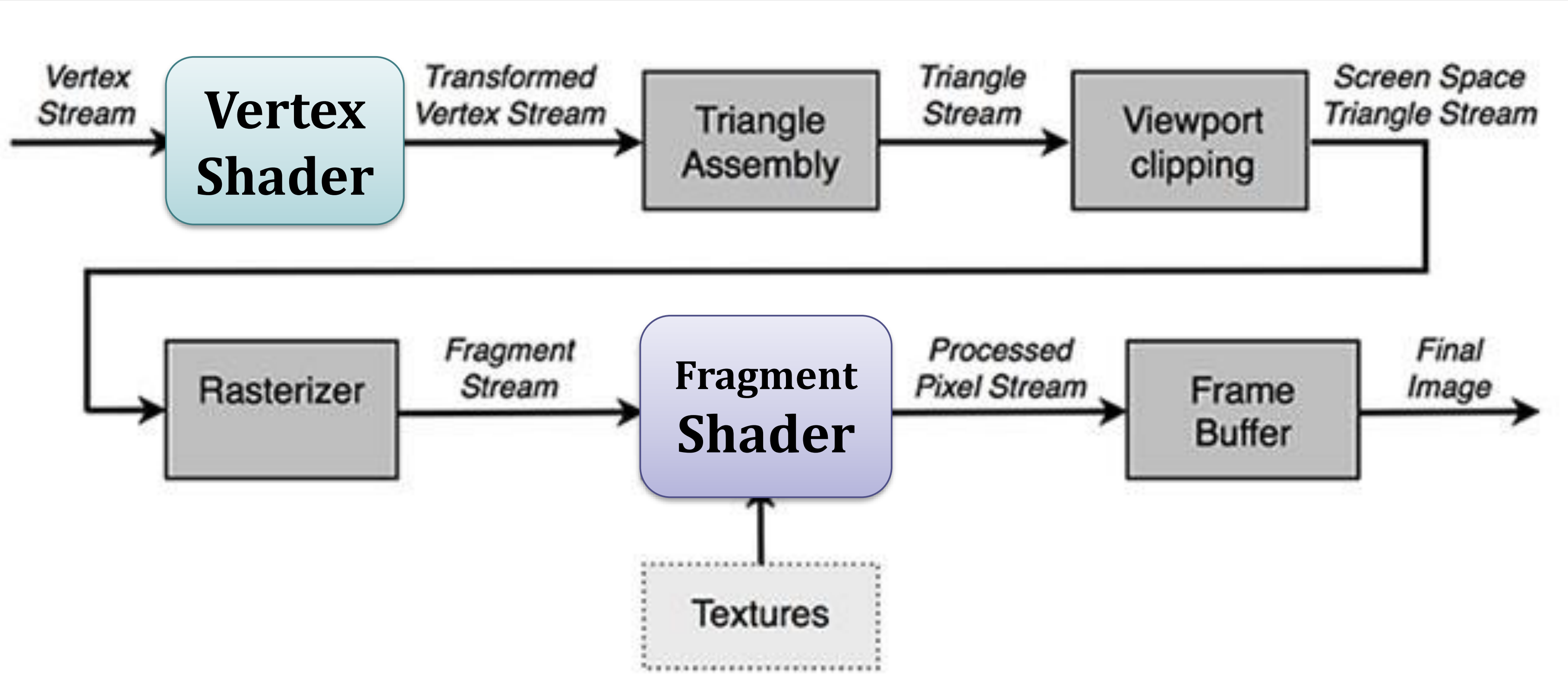
Credits: Real-time Rendering, 3rd Edition, Akenine-Moller

Fixed Function Pipeline



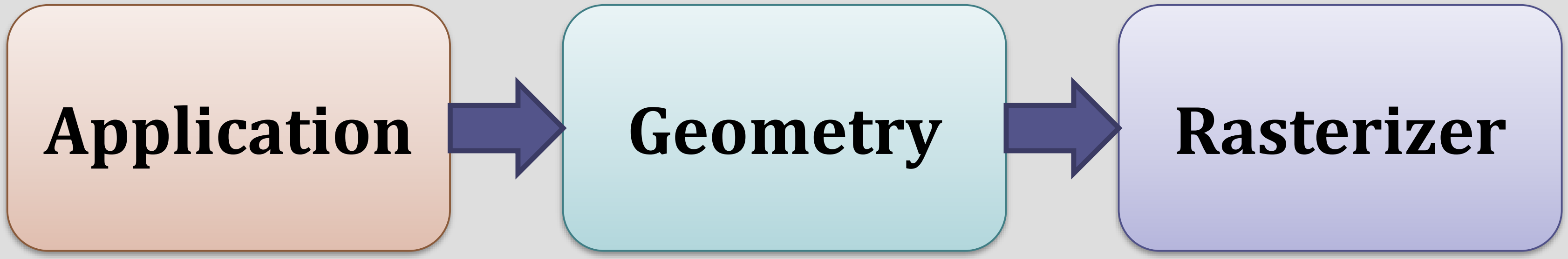
http://www.adobe.com/devnet/flashplayer/articles/how-stage3d-works.html

Graphics Programmable Pipeline



Graphics Pipeline Overview

- Coarse Division
- Each stage is a pipeline in itself



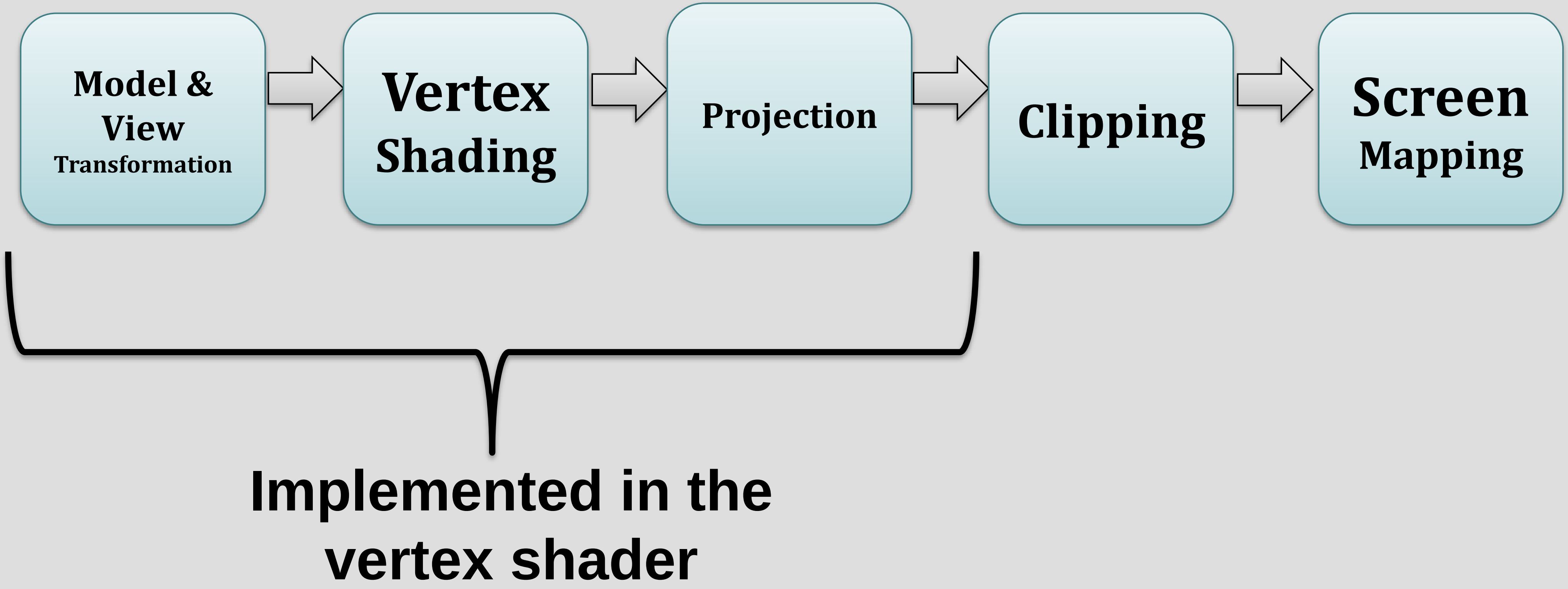
- The slowest pipeline stage determines the *rendering speed (fps)*

The Application Stage

- Developer has full control
- Executes on the CPU
- At the end of the application stage, the rendering primitives are fed to the geometry stage

The Geometry Stage

- Responsible for the per-polygon and per-vertex operations



OpenGL Vertices

- OpenGL uses a 4 component vector to represent a vertex.
- Known as a homogenous coordinate system
- z = 0 in 2D space
- w = 1 usually

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

For further information on homogenous coordinate system, see Appendix G of the Red Book: http://fly.cc.fer.hr/~unreal/theredbook/appendixg.html

Model & View Transformation

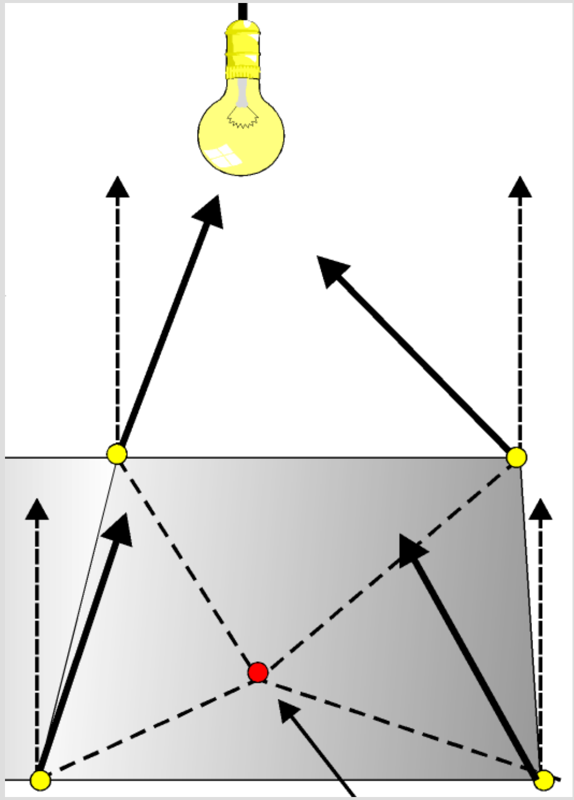
Model & View Transform

- Models are transformed into several *spaces* or *coordinate systems*
- Models initially reside in *model space*
  - i.e. no transformation
- *“Model transform”* positions the object in *world coordinates* or *world space*
- The *view transform*

Vertex Shading

Vertex Shading

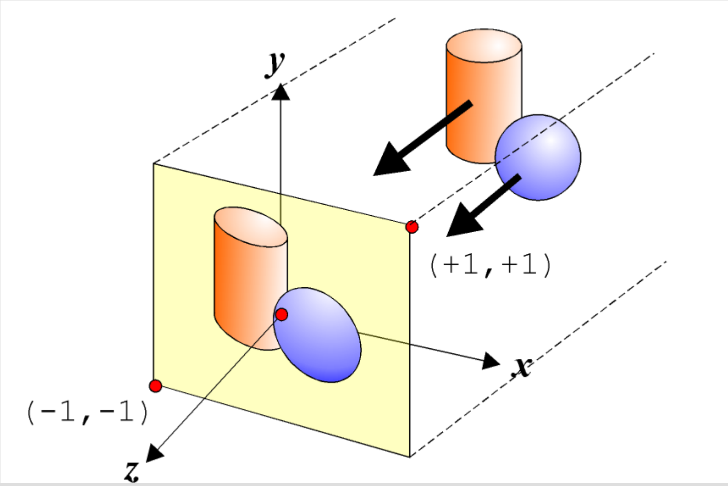
- Shading means determining the effect of a light on a material
- A variety of material data can be stored at each vertex
  - Points location
  - Normal
  - Color
- Vertex shading results (colors, vectors, texture coordinates, or any other kind of shading data) are then send to the rasterization stage to be interpolated



Projection

Projection

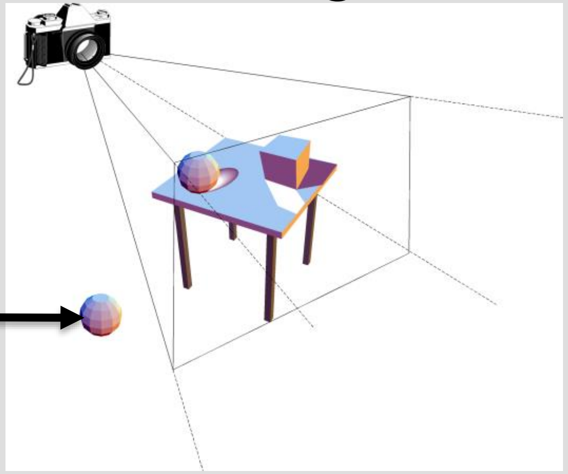
- After shading, rendering systems perform *projection*
- Models are projected from three to two dimensions
- *Perspective* or *orthographic* viewing



Clipping

Clipping

- The computer may have model, texture, and shader data for all objects in the scene in memory
- The virtual camera viewing the scene only “sees” the objects within the field of view
- The computer does not need to transform, texture, and shade the objects that are behind or on the sides of the camera
- A clipping algorithm skips these objects making rendering more efficient

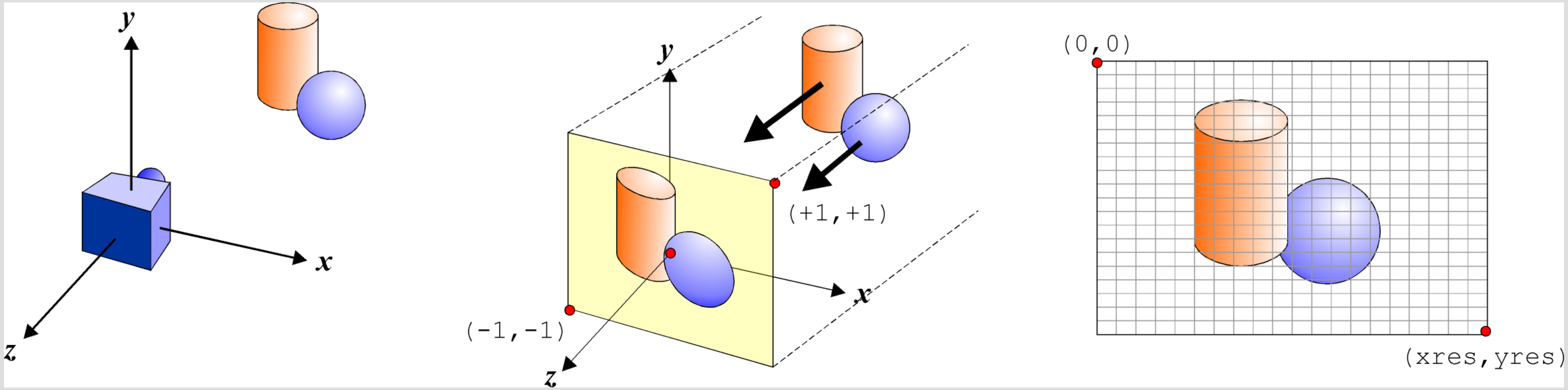


Outside view so must be clipped

Screen
Mapping

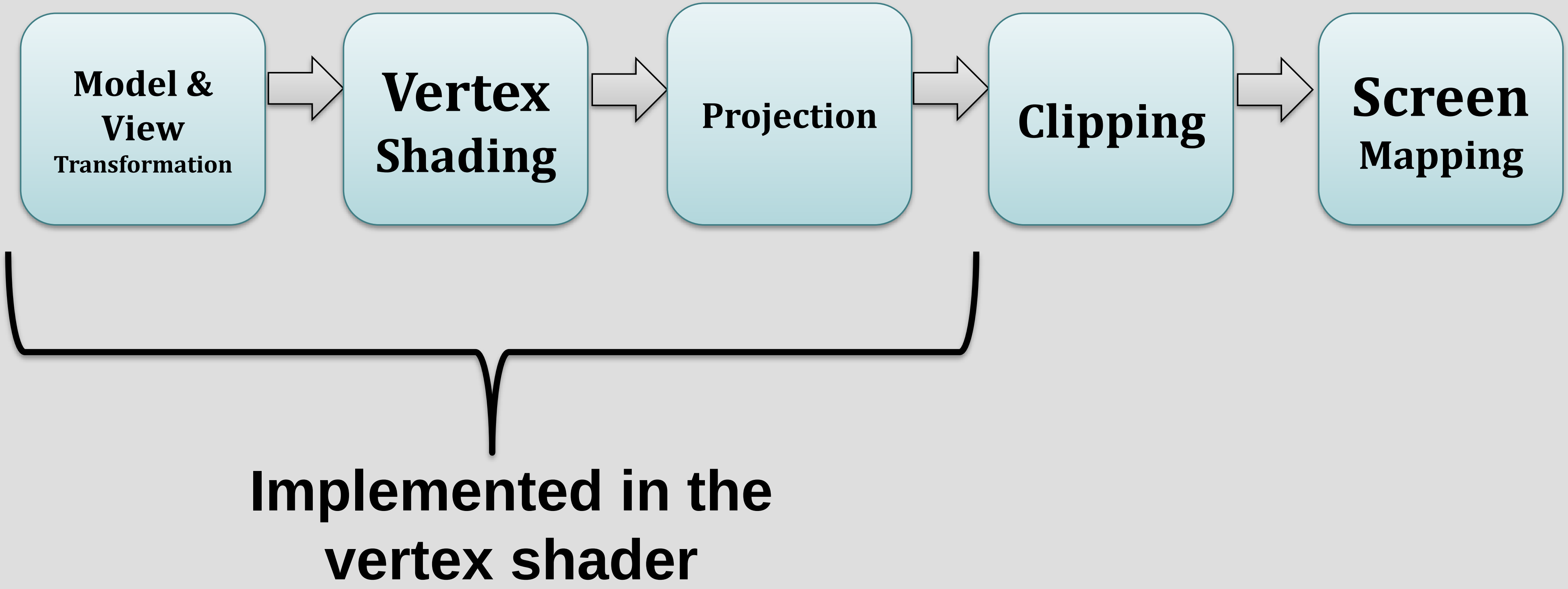
Screen Mapping

- Only the clipped primitives inside the view volume are passed to this stage
- Coordinates are in 3D
- The x- and y-coordinates of each primitive are transformed to the *screen coordinates*



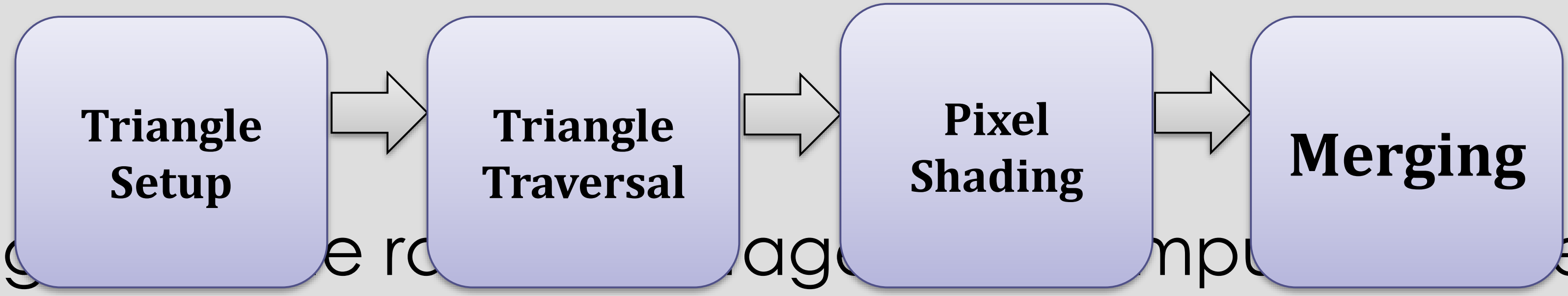
The Geometry Stage

- Responsible for the per-polygon and per-vertex operations



The Rasterizer Stage

- Given the transformed and projected vertices with their associated shading data (from geometry stage)



- The g e ro age mpu et colors for the pixels covered by the object
- *Rasterization:* conversion from 3D vertices in screen-space to pixels on the screen

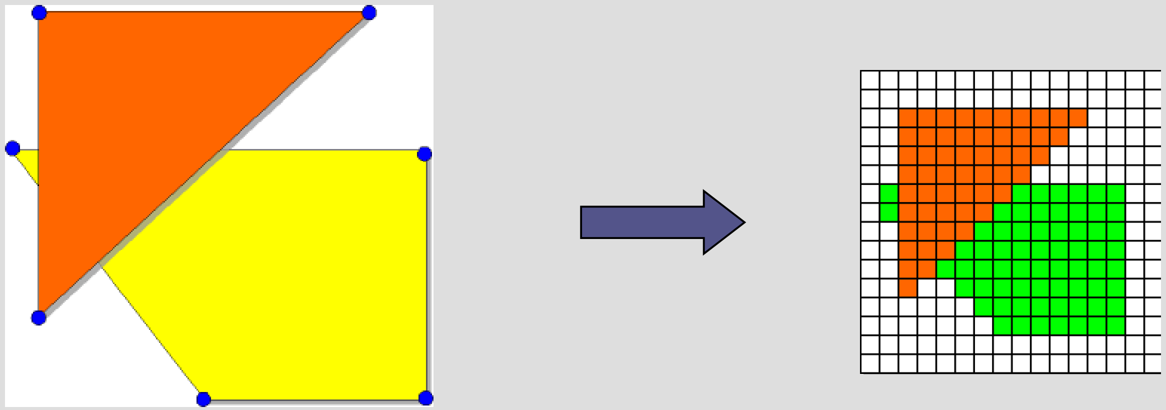
Triangle Setup

Triangle Setup

- Vertices are collected and converted into triangles.
- Information is generated that will allow later stages to accurately generate the attributes of every pixel associated with the triangle.

Triangle Traversal

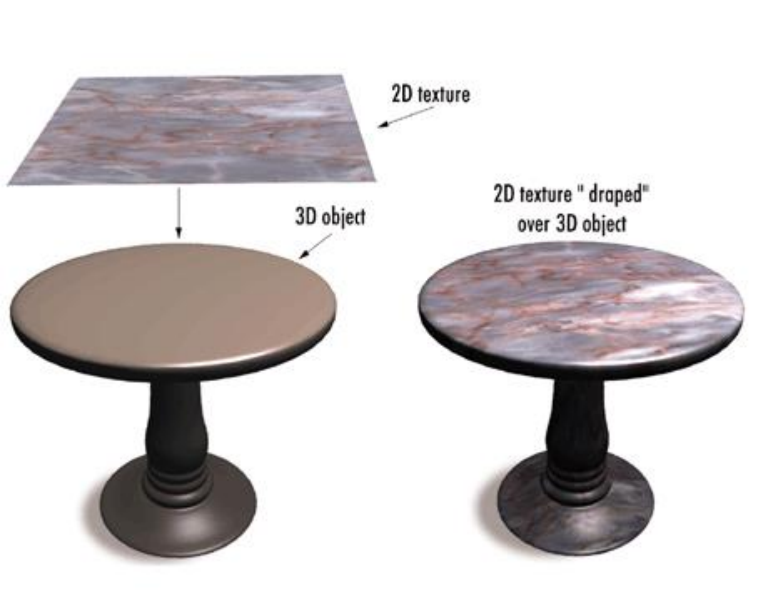
- Which pixels are inside a triangle?
- Each pixel that has its centre covered by the triangle is checked
- A *fragment* is generated for the part of the pixel that overlaps the triangle
- Triangle vertices interpolation



Pixel Shading

Pixel Shading

- Per-pixel shading computations are performed here
- End result is one or more colours to be passed to the next stage
- Executed by programmable GPU cores
- NB: Texturing is employed here



Merging

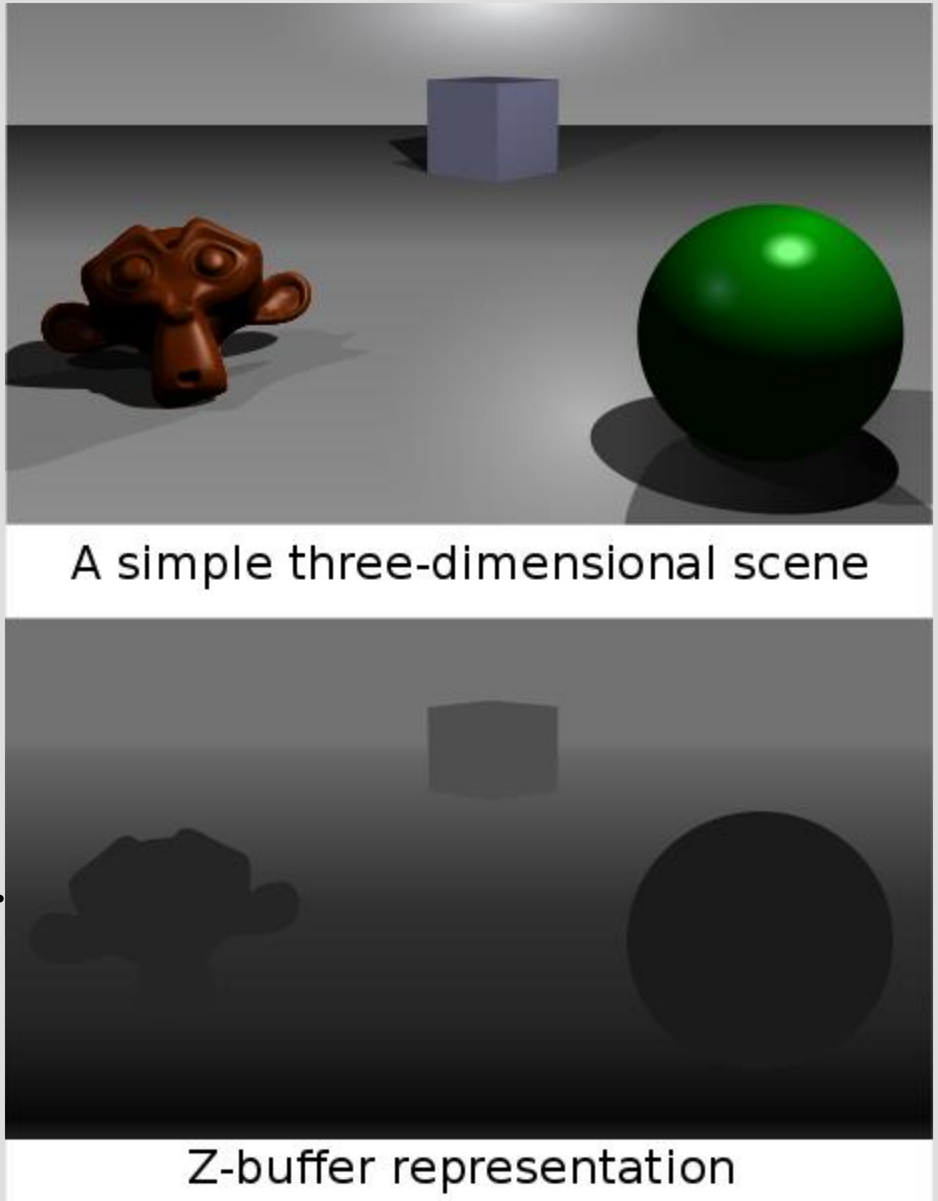
Merging

- Information for each pixel is stored in the *colour buffer* (a rectangular array of colours)
- Combine the fragment colour produced by the shading stage with the colour currently stored in the buffer

- This stage is also responsible for resolving visibility
  - Using the z-buffer

Z-Buffer

- Arranged as a 2D array with one element for each screen pixel.
- Stores the z-value from the camera to the currently closest primitive
- If another object of the scene must be rendered in the same pixel, the method compares the two depths and chooses the one closer to the observer.
- The chosen depth is then saved to the z-buffer, replacing the old one.



A simple three-dimensional scene

Z-buffer representation

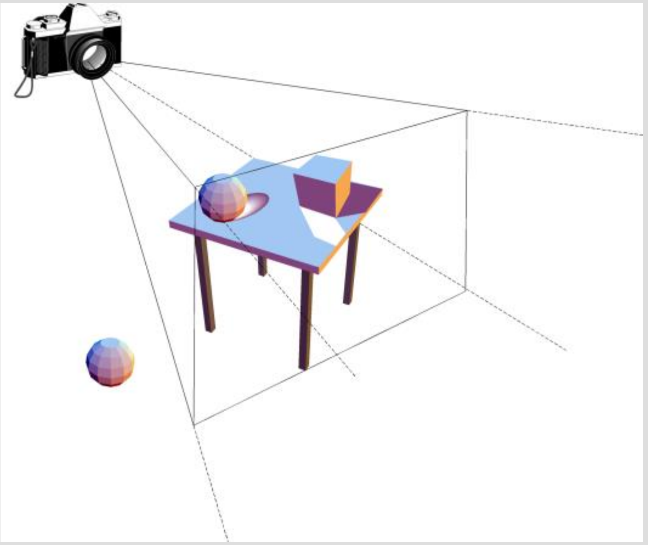
Double Buffering

- Passed the rasterizer stage, those primitives that are visible from the point of view of the camera are displayed on screen
- The screen displays the contents of the color buffer
- To avoid perception of primitives being rasterized, *double buffering* is used
- Rendering takes place off screen in a *back buffer*
- Once complete, contents are swapped with the *front buffer*

Question?

- Responsible for the per-polygon and per-vertex operations

Model & View Transformation → Vertex Shading → Projection → ?? → Screen Mapping



Further Reading

Step by Step OpenGL tutorials

These are good OpenGL tutorials which will help you to understand the basics of creating and rendering objects in OpenGL.

OpenGL Tutorials

Another set of tutorials that will step you through the basics of modern shader-based OpenGL

Anton's OpenGL Tutorials

Anton has created a series of OpenGL tutorials that cover the basics well. A good idea would be to start a Visual Studio project from scratch and work through the first few tutorials to get a good understanding of the basics.

Video Tutorials on OpenGL

Excellent set of video tutorials which take you through shaders and OpenGL step by step.

GLUT tutorial

Understanding the event loop and how GLUT works.

Blender Tutorial

Model View Projection Matrix

Camera in OpenGL.

OpenGL reference card

Quick reference card for OpenGL 4.x. Very useful when checking for the most up to date functions and checking if a function that you are trying to use is from an older version of OpenGL

Transformations Demo

Use this to look at how matrices work on tranformations