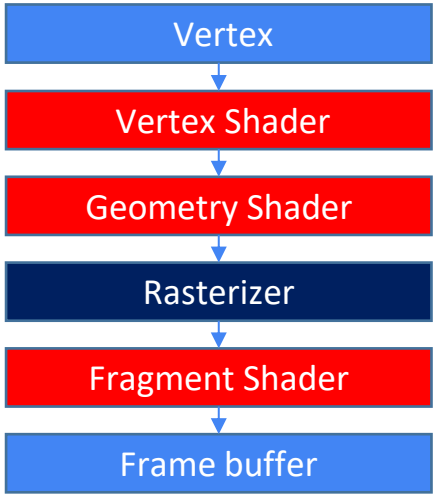
OpenGL shader & GLSL

HW2 Tutorial

OpenGL pipeline



Shader

A program designed by users.

Run in GPU pipeline.

Vertex Shader

- **Input:** Single vertex
- **Output:** Single vertex

Geometry Shader

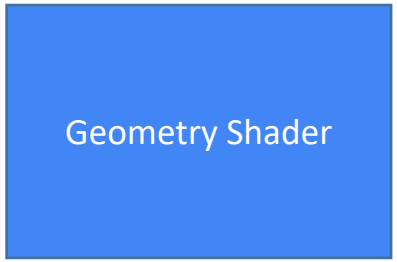
- **Input:** One primitive
- **Output:** Can be more than one primitive

Fragment Shader

- **Input:** One pixel
- **Output:** One or no pixel

Shader

- **Input:** Single vertex
- **Output:** Single vertex



- **Input:** One primitive
- **Output:** Can be more than one primitive

- **Input:** One pixel
- **Output:** One or no pixel

Shader setting

In the function : createShader()

GLuint **glCreateShader** (GLenum shaderType);

Specifies the type of shader to be created and creates an empty shader object.

shaderType : GL_COMPUTE_SHADER, GL_VERTEX_SHADER, GL_TESS_CONTROL_SHADER, GL_TESS_EVALUATION_SHADER, GL_GEOMETRY_SHADER, GL_FRAGMENT_SHADER

void **glShaderSource** (GLuint shader, GLsizei count, const GLchar **string, const GLint *length);

Sets the source code in shader to the source code in the array of strings specified by string.

Ex : string = & textFileRead("Shaders/example.vert")

void **glCompileShader**(GLuint shader);

Compile the shader.

Shader setting

In the function : createProgram()

GLuint **glCreateProgram**(void);

creates a program object.

void **glAttachShader** (GLuint program, GLuint shader);

Attach the shader object to the program object.

void **glLinkProgram** (GLuint program);

Link this program

void **glDetachShader** (GLuint program, GLuint shader);

Detaches the shader object from the program object.

Use program

```
void display() {
        glUseProgram(program_id);
        /* Shader program effect in this block
       */
        /* Pass parameters to shaders */
        glUseProgram(0);
        /* Pass 0 to stop the program*/
        glUseProgram(another_program_id);
        /* Another shader program effect */
        glUseProgram(0);
}
```

program_id is the return GLuint from **glCreateShader**

Vertex Buffer Objects (VBO)

Since the vertex shader access only one vertex at one time, we use Vertex Buffer Objects to make the execution be faster. The advantage of using these buffered objects is that we can send a large amount of vertex data from system memory to GPU memory at one time instead of sending it once per vertex.

Step 1 : Use **glGenBuffers()** to generate vertex buffer objects

void **glGenBuffers** (GLsizei n, GLuint * buffers);

n : Specifies the number of buffer object names to be generated.

buffers : Specifies an array in which the generated buffer object names are stored.

Step 2 : Use **glBindBuffer()** to bind the target buffer, which is GL_ARRAY_BUFFER here.

void **glBindBuffer** (GLenum target, GLuint buffer);

target : GL_ARRAY_BUFFER、GL_TEXTURE_BUFFER、…….

buffer : Specifies the name of a buffer object.

```
GLuint vboName;
glGenBuffers(1, &vboName);
glBindBuffer(GL_ARRAY_BUFFER, vboName);
```

Vertex Buffer Objects (VBO)

Step 3 : Set up the data

Step 4 : Use **glBufferData()** to copy the data into the target.

void **glBufferData** (GLenum target, GLsizeiptr size, const GLvoid * data, GLenum usage);

target : GL_ARRAY_BUFFER、GL_TEXTURE_BUFFER、…….

size : Specifies the size in bytes of the buffer object's new data store.

data : Specifies a pointer to data that will be copied into the data store for initialization, or NULL if no data is to be copied.

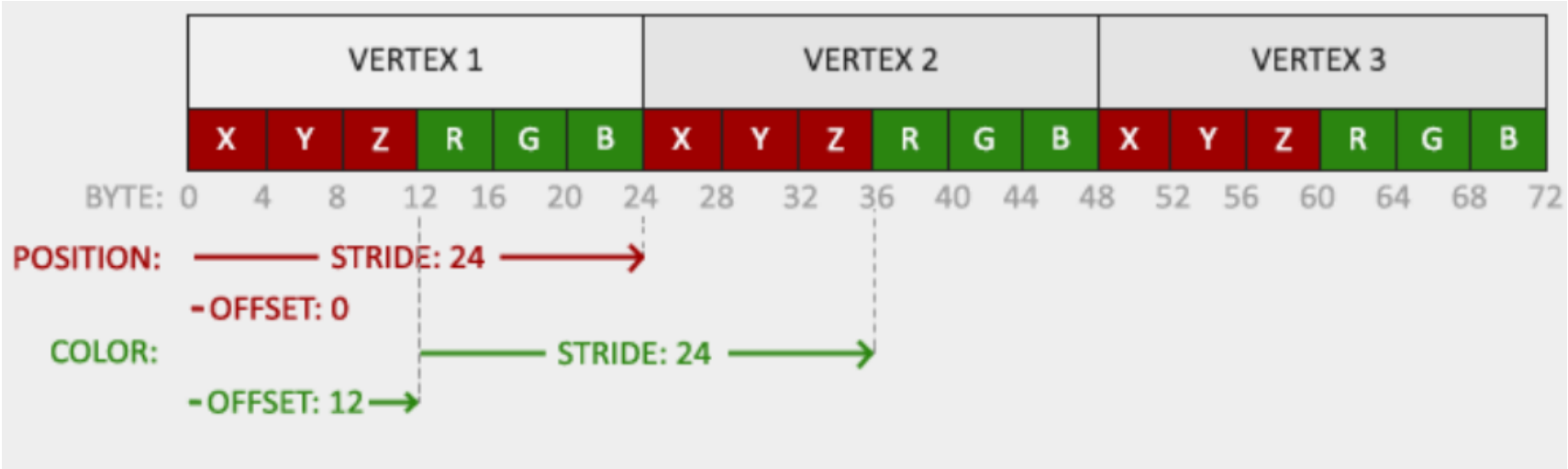
usage : Specifies the expected usage pattern of the data store. Ex: GL_STATIC_DRAW means the data store contents will be modified once and used at most a few times.

```
VertexAttribute *vertices;
vertices = drawTriangle();
glBufferData(GL_ARRAY_BUFFER, sizeof(VertexAttribute) * verticeNumber, vertices, GL_STATIC_DRAW);
```

Implementation in OpenGL

```
struct VertexAttribute{ GLfloat position[3]; ... };

VertexAttribute *vertices;
GLunit vboName;

glGenBuffers(1, &vboName);  //generate 1 buffer
glBindBuffer(GL_ARRAY_BUFFER, vboName);
glBufferData(GL_ARRAY_BUFFER, sizeof(VertexAttribute) * vertices_length,
vertices, GL_STATIC_DRAW);
```

Vertex Buffer Objects (VBO)



Vertex Attribute Pointer

We can use **glVertexAttribPointer()** to link the vertex buffer with the vertex shader input.

void **glVertexAttribPointer** (GLuint index, GLint size, GLenum type, GLboolean normalized, GLsizei stride, const GLvoid * pointer);

index : Specifies the index of the generic vertex attribute to be modified.

size : Specifies the number of components per generic vertex attribute.

type : Specifies the data type of each component in the array. Ex: GL_FLOAT

normalized : Specifies whether fixed-point data values should be normalized or not.

stride : Specifies the byte offset between consecutive generic vertex attributes.

pointer : Specifies a offset of the first component of the first generic vertex attribute in the array in the data store of the buffer currently bound to the GL_ARRAY_BUFFER target. The initial value is 0.

Vertex Attribute Pointer

```
glEnableVertexAttribArray(0);

glVertexAttribPointer(0,
3,
GL_FLOAT,
GL_FALSE,
sizeof(VertexAttribute),  // stride
(void*)(offsetof(VertexAttribute, position)));
```

OpenGL

```
layout(location = 0) in vec3 in_position;
```

GLSL (vertex shader)

Unbind the VBO

Use **glBindBuffer()** with the buffer set to zero to unbind the target buffer.

```
glBindBuffer(GL_ARRAY_BUFFER, 0);
```

Vertex Array Object (VAO)

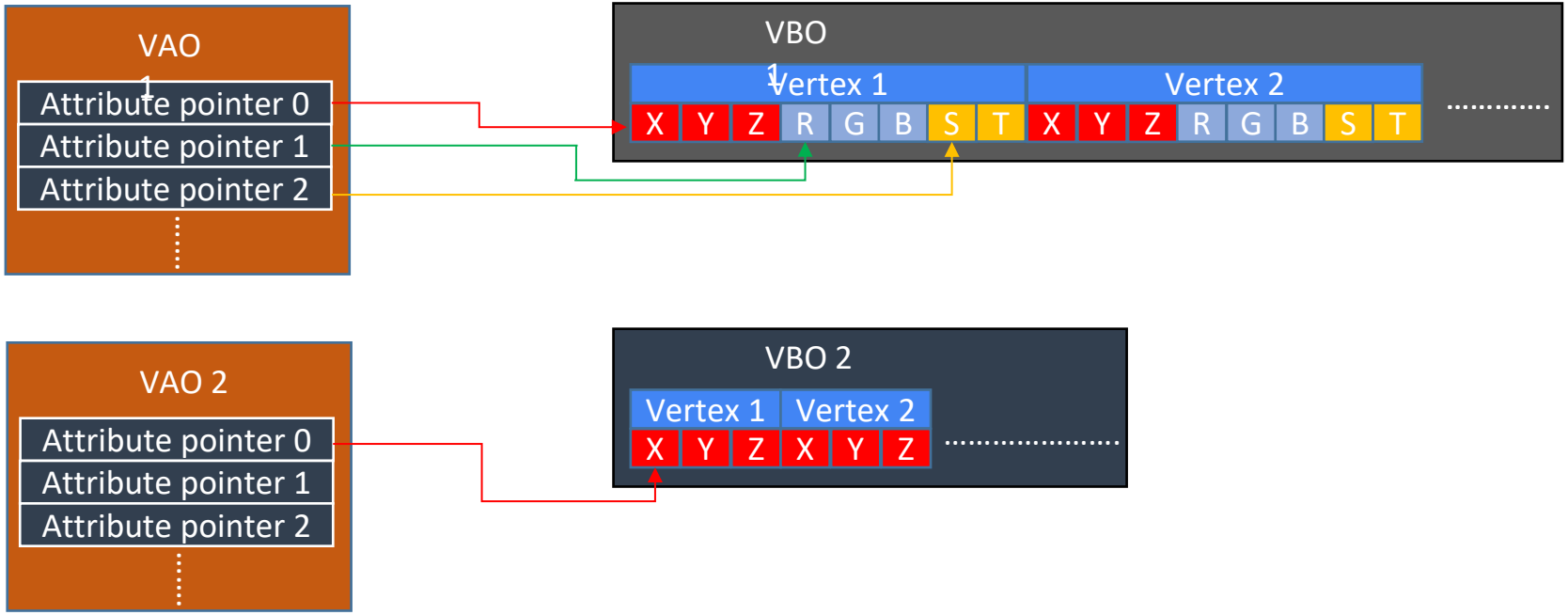
If you want to render more than one objects, you have to repeat above steps (slides 8 ~14).

- very troublesome

Use VAO(Vertex Array Object) to handle this problem.

First, you have to set up all the VAOs with its corresponding VBO, including all VertexAttributePointer. After that, every time you want to render a certain object, you just need to bind its VAO.

Vertex Array Object (VAO)



Vertex Array Object (VAO)

Step 1 : Use **glGenVertexArrays()** to generate vertex array objects

void **glGenVertexArrays** (GLsizei n, GLuint * arrays);

n : Specifies the number of vertex array object names to be generated.

arrays : Specifies an array in which the generated vertex array object names are stored.

Step 2 : Use **glBindVertexArray()** to bind a vertex array object.

void **glBindVertexArray** (GLuint array)

array : Specifies the name of the vertex array to bind.

```
GLuint VAO;
glGenVertexArrays(1, &VAO);
glBindVertexArray(VAO);
```

Vertex Array Object (VAO)

Step 3 : Setting up its corresponding VBO, for example :

```
glBindBuffer(GL_ARRAY_BUFFER, VBO);
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices, GL_STATIC_DRAW);
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(GLfloat), (GLvoid*)0);
glEnableVertexAttribArray(0);
```

Step 4 : Use **glBindVertexArray (0)** with the array's name set to zero to unbind the array object.

void **glBindVertexArray** (GLuint array)

Ex: glBindVertexArray(0) means to unbind the VAO previously bound.

When Rendering

Step 1 : Use **glBindVertexArray(VAO)** to bind the VAO you want.

Step 2 : Use **glDrawArrays()** to render primitives from vertex array data.

void **glDrawArrays()** (GLenum mode, GLint first, GLsizei count);

mode : Specifies what kind of primitives to render. Ex: GL_POINTS, GL_LINES, GL_TRIANGLE_STRIP……

first : Specifies the starting index in the enabled arrays.

count : Specifies the number of indices to be rendered.

Step 3 : Remember to unbind the VAO. (**glBindVertexArray(0)**)

*Every time you want to render another object, you just need to bind another VAO.

Data Connection - Uniform

```
GLfloat pmtx[16];
glGetFloatv(GL_PROJECTION_MATRIX, pmtx);
GLint pmatLoc = glGetUniformLocation(program, "Projection");

glUseProgram(program);
glUniformMatrix4fv(pmatLoc, 1, GL_FALSE, pmtx);
glUseProgram(0);
```

OpenGL

```
uniform mat4 Projection;
```

GLSL (vertex shader)

GLSL Syntax

Basic Variable Types

- vec2, vec3, vec4, …
- mat2, mat3, mat4, …
- float, int, bool, …
- sampler2D, …

Basic Functions

- max, min, sin, cos, pow, log, …
- dot, normalize, reflect, …
- transpose, inverse, …

Vertex Shader

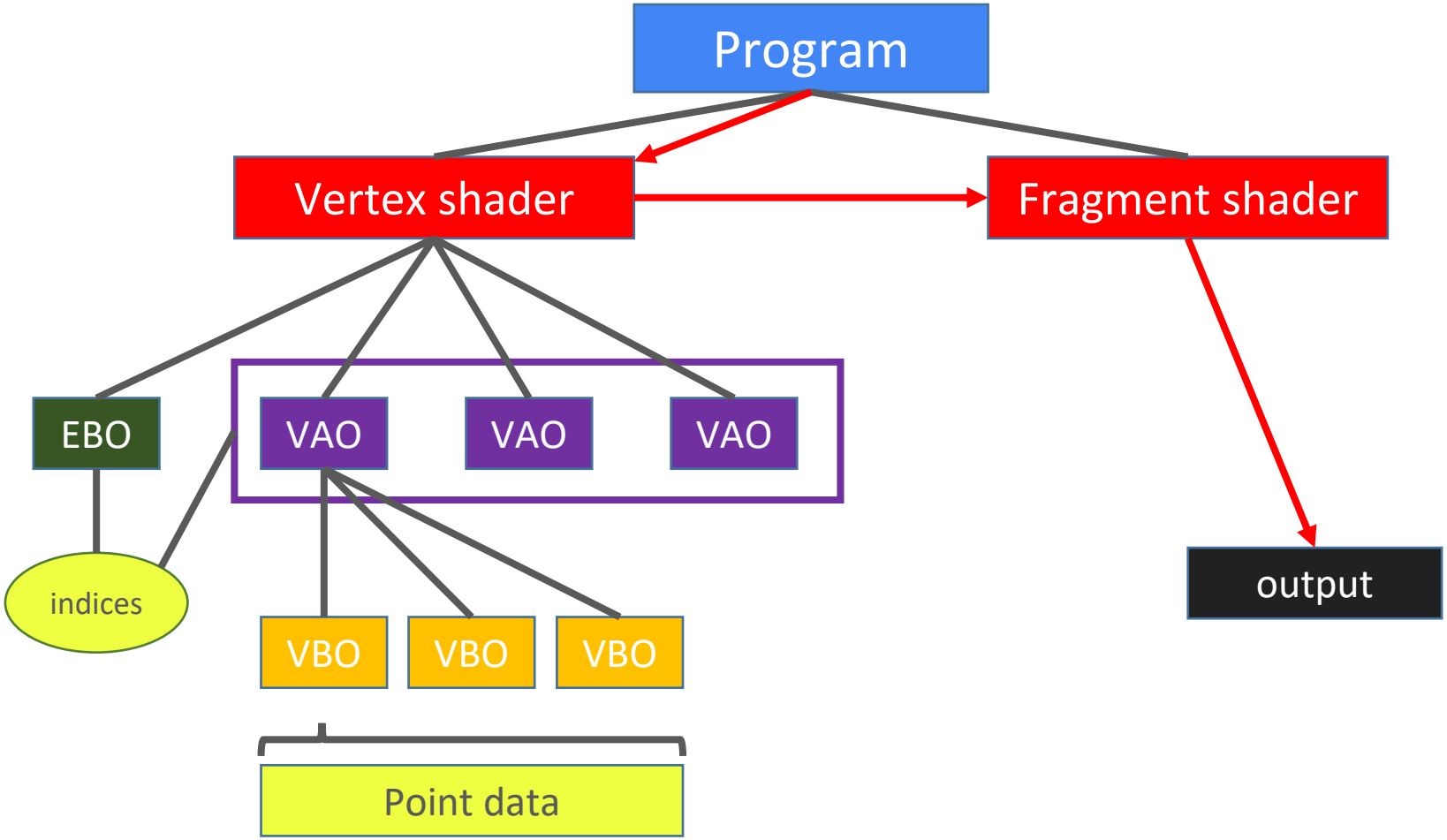
- must have gl_Position

```
/* Example of vertex shader */
#version 430

layout(location = 0) in vec3 position;

uniform mat4 Projection;
uniform mat4 ModelView;

out vec3 color; //to fragment shader

void main() {
  gl_Position = Projection * ModelView * vec4(position, 1.0);
  color = vec3(1.0, 0.0, 0.0);
}
```

Fragment Shader

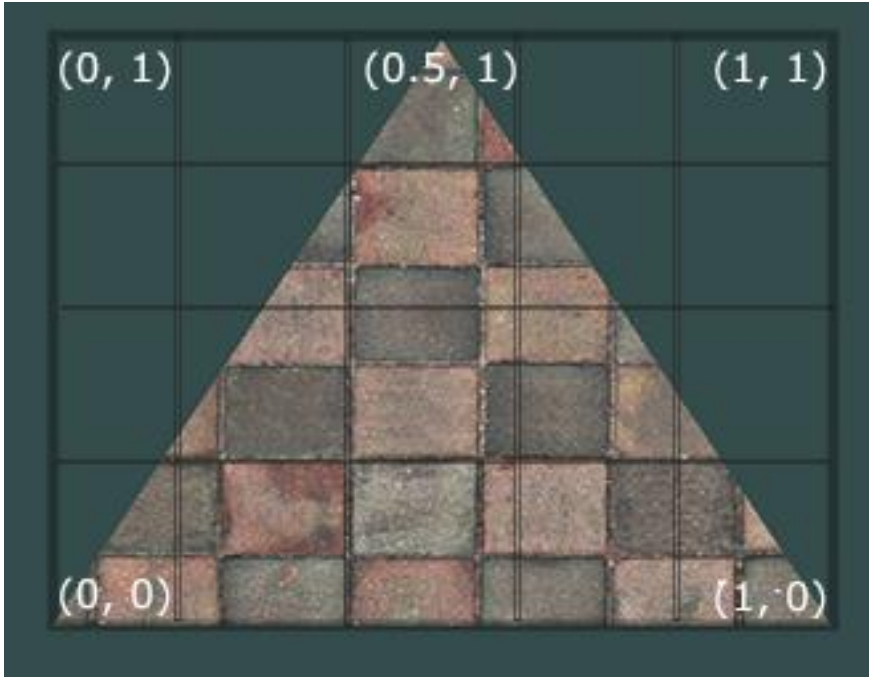
- must have a out vec4 for color buffer

```
/* Example of fragment shader */
#version 430

in vec3 color; //from vertex shader
out vec4 frag_color;

void main() {
   frag_color = vec4(color, 1.0);
}
```


Program
Vertex shader
Fragment shader
EBO
VAO
VAO
VAO
indices
VBO
VBO
VBO
output
Point data

Texture in OpenGL

Texture coordinate



How to load and bind a texture

void glEnable(Glenum cap);

Use GL_TEXTURE_2D to enable texture

Use FreeImage library to load and free texture memory

void glActiveTexture(GLenum textureUnit);

selects which texture unit subsequent texture state calls will affect. You can using the textureUnit from GL_TEXTURE0 to GL_TEXTUREn , 0 <= n < GL_MAX_TEXTURE_UNITS , and texture units are subsequent, you can use GL_TEXTUREn or GL_TEXTURE0 + n. (Ex. GL_TEXTURE2 = GL_TEXTURE0 + 2)

void glGenTextures(GLsizei n, GLuint * textures);

Takes as input how many textures we want to generate and stores them in a unsigned int array

void glBindTexture(GLenum target, GLuint texture);

Bind a named texture to a texturing target (Ex.GL_TEXTURE_1D, GL_TEXTURE_2D, GL_TEXTURE_3D, GL_TEXTURE_1D_ARRAY)

void glTexImage2D(GLenum target, GLint level, GLint internalformat, GLsizei width, GLsizei height, GLint border, GLenum format, GLenum type, const GLvoid * data);

Generate a two-dimensional texture image

void glUniform1i(GLint location, GLint v0);

Pass Texture to shader sampler variable. v0 is the number of texture. (Ex. The V0 of GL_TEXTURE1 is 1)

How to load and bind a texture

void glTexParameteri(GLenum target, GLenum pname, GLint param);

Texture wrapping

Texture coordinates usually range from (0,0) to (1,1) but if we specify coordinates outside this range, the default behavior of OpenGL is to repeat the texture images

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT);

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT);

Texture filtering

Texture coordinates do not depend on resolution but can be any floating point value, thus OpenGL has to figure out which texture pixel to map the texture coordinate to

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_Nearest);

glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);

Data Connection - Texture

```
glActiveTexture(GL_TEXTURE0);
glGenTextures(1, &texture);
glBindTexture(GL_TEXTURE_2D, texture);
glTexParameteri(GL_TEXTURE_2D,GL_TEXTURE_MIN_FILTER, GL_LINEAR);
glTexParameteri(GL_TEXTURE_2D,GL_TEXTURE_MAG_FILTER, GL_LINEAR);
```

LoadTexture() function

```
/* load texture image as data*/
glTexImage2D(GL_TEXTURE_2D, 0, GL_RGB, width, height, 0, GL_RGB, GL_UNSIGNED_BYTE, data);
```

Different : No need to unbind texture object

```
glUseProgram(program);
glGetUniformLocation(program, "Texture");
glUniform1i(texLoc, 0);
/* draw objects */
glUseProgram(0);
```

OpenGL main loop

```
uniform sampler2D Texture;
in vec2 texcoord;
out vec4 outColor;
void main() { outColor = texture2D(Texture, texcoord); }
```

GLSL (fragment shader)

Homework 2 - Travel the world

One morning, I climbed into my helicopter, ready to start my journey to travel the world. But as I soared through the clouds, something strange happened. My helicopter began to change. The blades slowed down, and the body of the helicopter stretched and widened. Before I knew it, my helicopter had transformed into a sleek airplane! The controls shifted beneath my hands, but I adapted quickly, curious to see where this journey would take me.

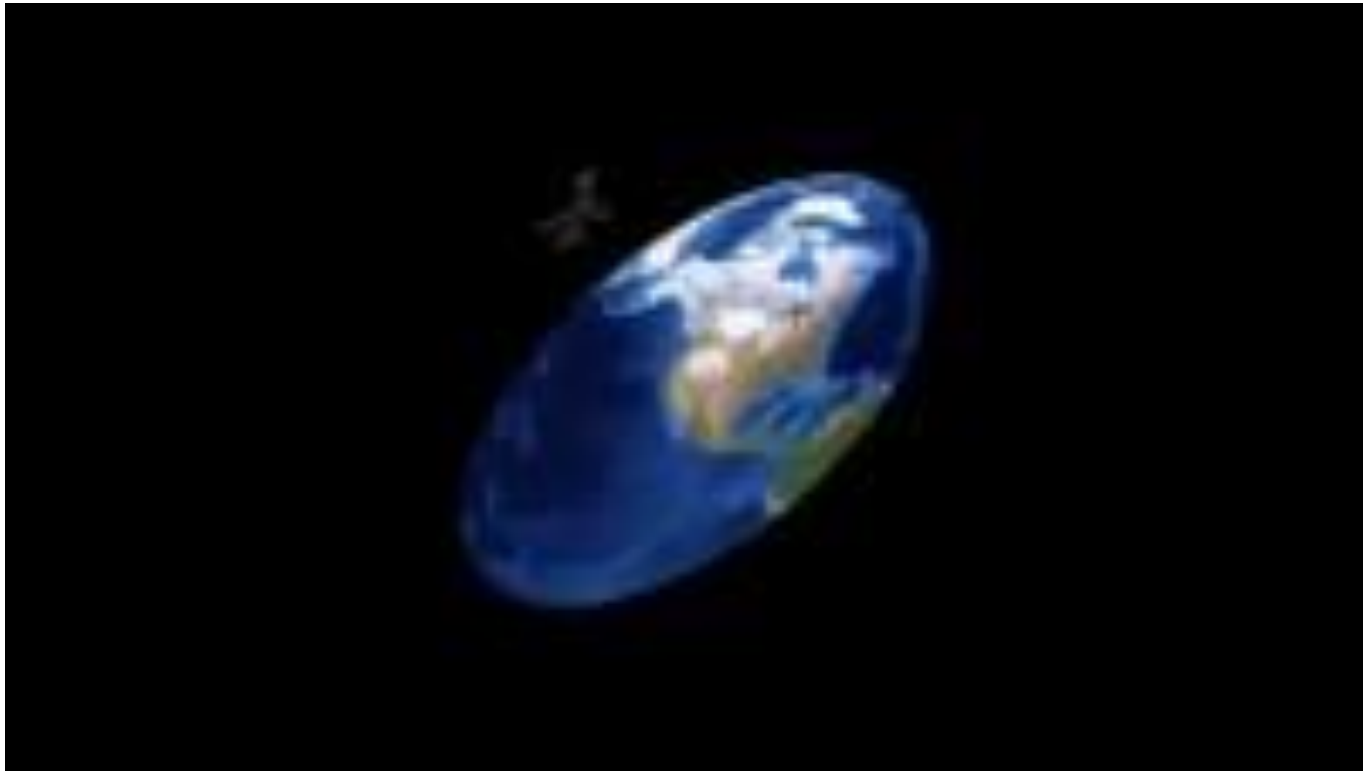
As I looked down, the Earth itself began to change. No longer a solid, stable surface, the planet started to stretch and shrink, as if it were made of rubber. The mountains rose and fell like waves, and the continents bent and flexed like a giant, living balloon. It was as though the entire Earth had become a rubber ball, expanding and contracting with every beat of my wings.

As I marveled at these changes, my airplane began to transform again. Its silver surface turned bright and colorful. The once ordinary plane now looked like a flying work of art, shining brilliantly against the ever-shifting landscape below.

I realized I was no longer just flying through the world—I was flying through a dream, where anything could change at any moment. And in this dream, the world and I were both transforming, together.

Homework 2 - Travel the world

video



Homework 2 - spec

Goal:

- Using GLSL to draw two model with its texture simultaneously
- Using shaders to achieve some special effects

spec:

- Airplane :
  - rotate 90 degree/sec around -X axis
  - radius 27
- Earth :
  - Scale 10x
  - rotate 30 degree/sec around Y axis
- keyboard function :
  - press key ‘D’ to rotate the rotation axis of the Airplane +1 degree around Y axis
  - press key ‘A’ to rotate the rotation axis of the Airplane -1 degree around Y axis
  - press key ‘S’ to start/stop squeezing the Earth
  - press key ‘R’ to switch the color mode of the Airplane between normal and rainbow

Red characters just let you know why I choose key S, R as input (´ ・ ω ・ `)

Homework 2 - spec

Squeezing:

For vertex(x, y, z),

y += z * sin(squeezeFactor) / 2;

z += y * sin(squeezeFactor) / 2;

When squeezing, squeezeFactor +90 degree/sec

Rainbow:

When the color mode of the Airplane is **normal**

the color of the Airplane should be the texture color

When the color mode of the Airplane is **rainbow**

the color of the Airplane should be the texture color*rainbow color

Rainbow color:

In HSV

H increases by 72 degree/sec

S and V set to 1

Convert HSV to RGB for the rendering

Restrictions !!

Your GLSL version should >= #version 330

Deprecated shader syntaxes are not allowed, e.g. attribute, varying

You are only allowed to use VBO and VAO when rendering model

You are only allowed to pass uniform data to shader using glUniform* series function

Using built-in uniform variables in shader is forbidden!

(That is, you cannot use gl_ModelViewMatrix or gl_NormalMatrix …etc)

The only gl_XXX term should be in your shader code is gl_Position.

Change window name

```
/* TODO#0: Change window title to "HW2 - [your student id]"
 *         Ex. HW2 - 312550000
 */

// glfw window creation
GLFWwindow *window = glfwCreateWindow(SCR_WIDTH, SCR_HEIGHT, "HW2 - [your student id]", NULL, NULL);
```

Remember to include your student ID in glfwCreateWindow(), or you will receive a 3% penalty.

Homework 2 - score

1. createShader (5%)
2. createProgram (5%)
3. modelVAO (5%)
4. loadTexture (5%)
5. draw the Airplane with texture (20%)
6. draw the Earth with texture (20%)
7. vertex shader (5%)
8. fragment shader (5%)
9. keyboard function (D, A, S, R) (each 2.5% / total 10%)
10. report (20%)
11. Bonus: Replace the Airplane with the helicopter you make in HW1 (10%)

Press ‘H’ to switch between airplane and helicopter.

Let your helicopter travel the world! ٩(´ᗜ`*)۹

Homework 2 - report

Please specify your name and student ID in the report.

Explain in detail how to use GLSL by taking screenshots.

(first create program ,second create VAO and VBO, third bind together.....etc.)
(You need to write additional explanation. Don’t just paste the code with comment.)

Describe the problems you met and how you solved them.

Homework 2 - submission

Deadline: 2024/11/19 23:59:59

10% penalty for each week late

Final score = original score * (1 – 0.1*weeks late)

Format

HW2_[studentID].zip e.g. HW2_123456789.zip

|- main.cpp

|- shaders (directory)

| |- fragmentShader.frag

| |- vertexShader.vert

|- report.pdf

If your uploading format doesn't match our requirement, there will be penalty to your score. (-5%)

If your uploading files can't run successfully, there will be penalty to your score. (-5%)

Reference

https://thebookofshaders.com/glossary/

https://learnopengl.com/Getting-started/Textures

https://learnopengl.com/Getting-started/Shaders

https://www.khronos.org/opengl/wiki/Built-in_Variable_(GLSL)