U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

TP5 - Shaders

Concepts and Practice

Teresa Matos
18 March 2024

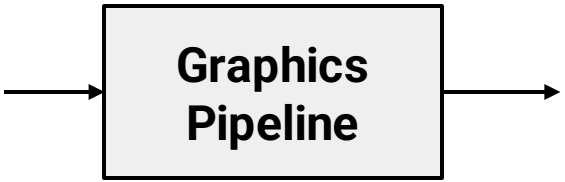
From object definition to rendering

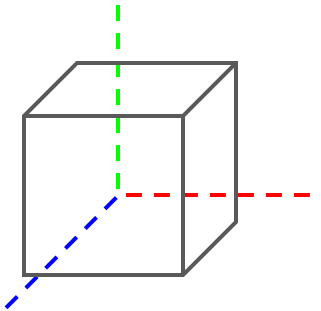
Objects are defined by **vertices**, **indices**, **normals** and **texture coordinates**

Let’s see how this data is used to render objects in the scene

```
…
initBuffers(){
  this.vertices = [...]
  this.indices = [...]
  this.normals = [...]
  this.texCoords = [...]
}
```

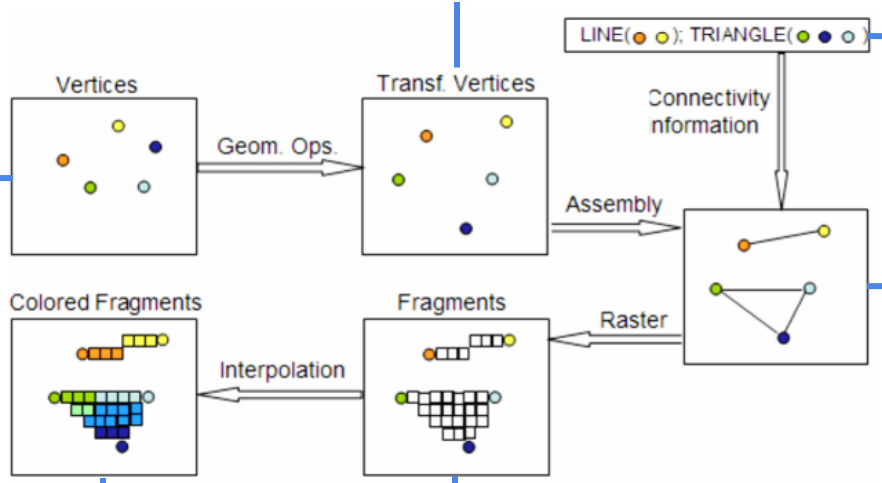
Object definition using ***CGFobject*** class





Rendered scene in screen

Graphics Pipeline - Visualization



Vertices positioned in screen space

Type of primitive defined in CGFobject

Vertices defined for CGFobject

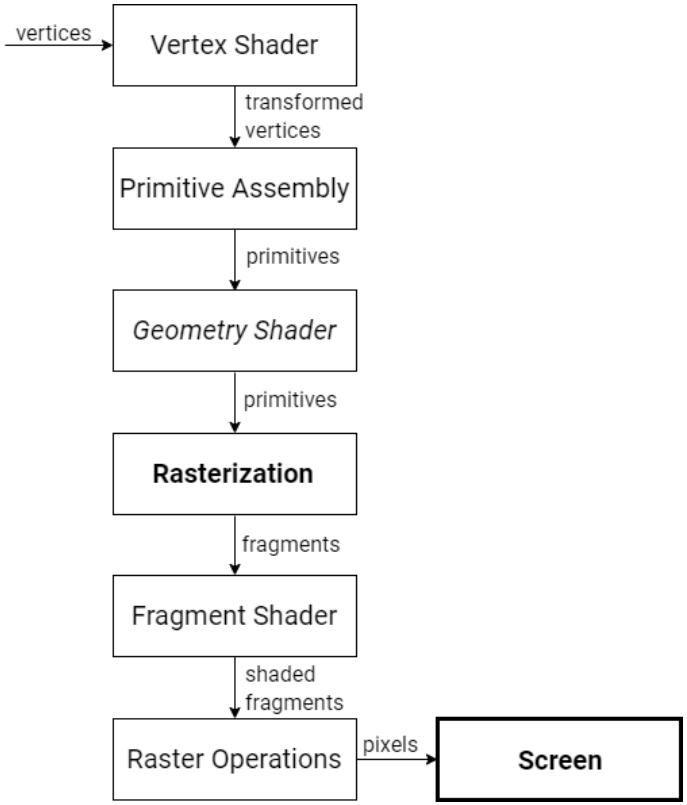
Connecting vertices according to indices from CGFobject

Remaining fragments are defined using interpolation

Fragments contains data for each pixel of the primitive's vertices

Graphics Pipeline

- Inputs
- **Vertex shading**
- Primitive assembly
- Geometry shading
- Projection and rasterization
- **Fragment shading**
- Raster operations
- Output to screen



Shaders

Small programs receive and manipulate data on the 3D scene:

- **Vertex shaders** - Manipulate and define properties **for each vertex**
- **Fragment shaders** - Manipulate and define properties **for each fragment**

Custom data may be passed to the shaders from the application

Data may be passed **from vertex to fragment shader** (not inversely)

Shaders in WebGL/WebCGF

In **WebGL**, shaders may be loaded as strings and compiled in real time

To apply shaders to a scene using **WebCGF**, these are the general steps:

1. **Create** the shader files
2. Load the created files to a ***CGFshader*** class object
3. Set *CGFshader* object as the **scene's active shader**
4. **Pass values** from application to shaders (optional)

1 Creating Shaders - Structure

Shader may be defined in `.vert` or `.frag` files, for vertex or fragment shaders
A shader program commonly contains:

- List of **input/output** and **uniform** variables
- A ***main()* function**, where input data is processed and output is returned

The *main()* function runs for **each vertex** or for **each fragment**

1 Creating Shaders - Vertex Shader

A vertex shader receives **input** relative to:

- each **vertex** (position, normal, texture coordinate)
- lights, materials, camera (for illumination model and other functionalities)
- **custom data** provided from the application

A vertex shader creates as **output**:

- the **calculated position** for each vertex
- data to be passed to the **fragment shader**

1 Creating Shaders - Vertex Shader Example

```
attribute vec3 aVertexPosition;
attribute vec3 aVertexNormal;
attribute vec2 aTextureCoord;
uniform mat4 uMVMatrix;
uniform mat4 uPMatrix;
uniform mat4 uNMatrix;
...
void main() {
...
    gl_Position = uPMatrix * uMVMatrix * vec4(aVertexPosition, 1.0);
}
```

Input variables

Main function, processes each vertex

Output vertex position

1 Creating Shaders - Variables

```
attribute vec3 aVertexPosition
```

Qualifier

Data Type Qualifiers

- `uniform` - read-only global input, from WebGL or application
- `attribute` - read-only per-vertex input to vertex shader
- `varying` - writable output (vertex shader)
  - read-only input (fragment shader)
- `const` - read-only compile-time constant

1 Creating Shaders - Variables

```
attribute vec3 aVertexPosition
```

Type

Data Type

- **Scalars** - bool, int, float, ...
- **Vectors** - vec2, vec3, vec4, ...
- **Matrices** - mat2, mat3, mat4, ...
- **Textures** sampler1D, sampler2D, sampler3D, ...
- And others

1 Creating Shaders - Variables in Vertex Shader

```
attribute vec3 aVertexPosition;
attribute vec3 aVertexNormal;
attribute vec2 aTextureCoord;
uniform mat4 uMVMatrix;
uniform mat4 uPMatrix;
uniform mat4 uNMatrix;
...
void main() {
...
    gl_Position = uPMatrix * uMVMatrix * vec4(aVertexPosition, 1.0);
}
```

position of **each vertex** (attribute) as **3D vector** (vec3)

global (uniform) model-view **4x4 matrix** (mat4)

1 Creating Shaders - Vertex Shader main() function

```
void main() {
...
    gl_Position = uPMatrix * uMVMatrix * vec4(aVertexPosition, 1.0);
}
```

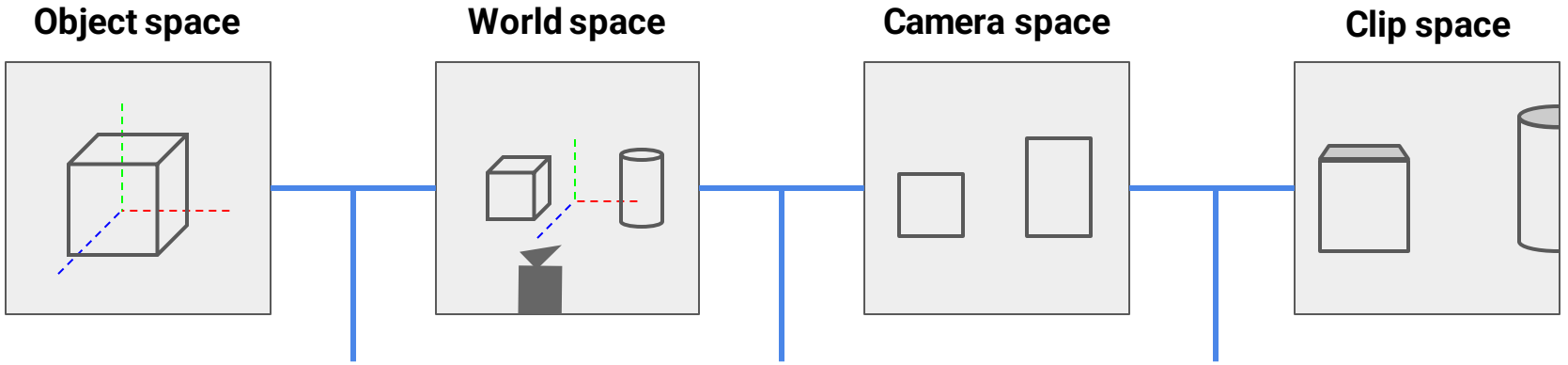
Output vertex position

Projection Matrix
Applies transformations related to camera frustum

Model-View Matrix
Represents transformations applied to scene and camera position

Input 3D position vector for vertex (as defined in application)

Model-View-Projection Matrix



Model Matrix

Matrix representing every **geometric transformation** applied in the scene

View Matrix

Matrix that transforms objects according to the **active camera.**

It is the inverse of the camera's transformation matrix.

Projection Matrix

Matrix that defines a viewing box (**frustum**) - visible area in the screen.

Coordinates outside the frustum are **clipped**.

1 Creating Shaders - Fragment Shader

A fragment shader receives as **input**:

- Data from previous operations in the graphics pipeline (e.g., vertex shader)
- Custom data from application

A fragment shader creates as **output**:

- the **color for the current fragment**

1 Creating Shaders - Fragment Shader Example

```
struct lightProperties {
    ...
};
#define N_LIGHTS 8
uniform lightProperties uLight[N_LIGHTS];

void main() {
    gl_FragColor = uLight[0].diffuse;
}
```

Local struct for light properties (position, ambient, diffuse,...)

Input array of lightProperties (length 8)

Main function, processes each fragment

Output fragment color

2 Loading Shaders using WebCGF library

The **WebCGF** library has a class for shaders - **CGFshader**

```
new CGFshader(gl, urlVertexShader, urlFragmentShader)
```

The scene has an **active shader** (default shader provided in library)

```
CGFscene.activeShader
```

Created shaders may be set as the scene's active shader

```
CGFscene.setActiveShader(CGFshader)
```

To set back to default, provide **`CGFscene.defaultShader`**

3 Applying Shaders - Example

```
CGFscene.init(){
        …
        this.shaderA = new CGFshader(...)
}
…
CGFscene.display(){
        …
        this.setActiveShader(this.shaderA);
        …
        this.object.display();
        …
        this.setActiveShader(this.defaultShader);
}
```

Initializing shaders and other objects

Scene setup (cameras, lights, matrices)

Drawn elements affected by the custom shader

4 Passing Data from Application to Shaders

Data may be passed from the application to the `CGFshader` object

```
CGFshader.setUniformsValues(dictionary)
```

Key-value pair collection, equivalent to JS object

This data is accessible in the shaders as uniform variables

```
uniform type variableKey;
```

The shaders may use this data to **transform the output**

4 Passing Scalar Data to Shader - Example

CGFscene

```
this.shaderA = new CGFshader(...)
this.shaderA.setUniformsValues(
        { scale: 2.0, key:value, ...});
```

Initializing shaders and passing uniforms' values

Vertex shader

```
uniform float scale;
uniform valueType key;
...
void main() {
    gl_Position = uPMatrix * uMVMatrix * vec4(aVertexPosition*scale, 1.0);
}
```

Initializing the uniforms

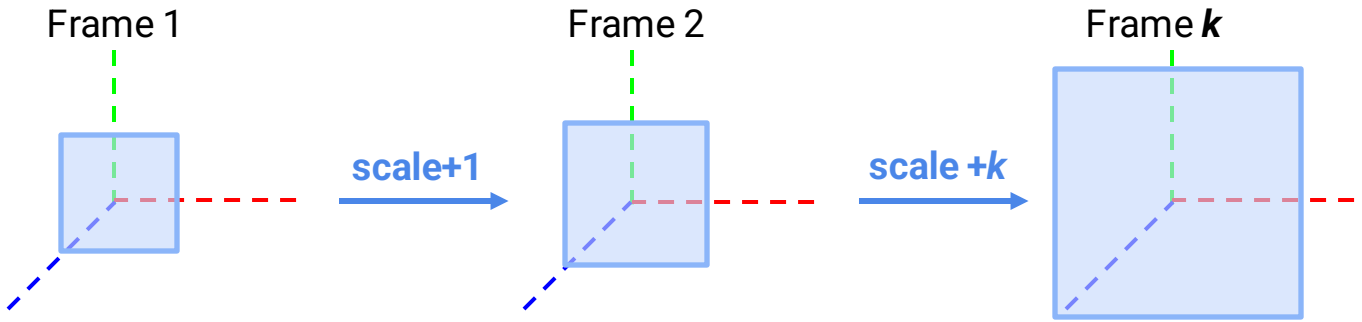
Applying uniform data to transform the output

4 Passing Scalar Data to Shader - Example

What happens if the value provided to the shader is altered periodically?

```
CGFscene.display(){
  this.scale++;
  this.shaderA.setUniformsValues({scale: this.scale});
}
```

Sequence of frames with variation in object - Animation



4 Passing Texture to Shader - Example

CGFscene

```
display(){
  …
  this.setActiveShader(this.shaderA);
  this.texture0.bind();
  this.object.display();
}
```

Bind texture0 to WebGL context

Vertex/Fragment shader

```
uniform sampler2D uSampler;
…
```

Where is `uSampler` defined?

And what if we want more than one texture?

4 Passing Multiple Textures to Shader

WebGL has a global array of references to textures – **texture units**

```
CGFtexture.bind(unit)
```

The ***unit*** parameter is the **texture unit** to which the texture is bound

By default, `CGFscene` passes the texture at `unit = 0` as `uSampler`

pseudo-code

```
activeShader.setUniformsValues({uSampler: 0});
```

4 Passing Multiple Textures - Example

```
CGFscene.init(){
  this.shaderA = new CGFshader(...)
  this.texture1 = new CGFtexture(...);
  this.texture2 = new CGFtexture(...);
  this.shaderA.setUniformsValues({texture2: 1});
}
CGFscene.display(){
  this.setActiveShader(this.shaderA);
  this.texture1.bind();
  this.texture2.bind(1);
  this.object.display();
  …
}
```

Passing as uniforms values the texture unit for the 2nd texture

Binding textures to units 0 and 1

4 Passing Multiple Textures - Example

```
varying vec2 vTextureCoord;

uniform sampler2D uSampler;

uniform sampler2D texture2;

void main() {
  vec4 color = texture2D(uSampler, vTextureCoord);
  …

  gl_FragColor = …
}
```

texture coordinates from vertex shader

Texture passed by CGFscene

Texture passed by our code

Shader function that retrieves a texel from the sampler at specified coordinates

Documentation and guides

Introduction to shaders using GLSL (presentation at Moodle)

GLSL Reference Card (available on Moodle)

WebCGF documentation for CGFshader

https://paginas.fe.up.pt/~ruirodrig/pub/sw/webcgf/docs/class/lib/CGF/CGFshader.js~CGFshader.html

Texture2D function

https://thebookofshaders.com/glossary/?search=texture2D

WebGL Shaders Tutorial

https://webglfundamentals.org/webgl/lessons/webgl-shaders-and-glsl.html