The OpenGL Rendering Pipeline

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Overview

From the Documentation

OpenGL (for “Open Graphics Library”) is a software interface to graphics hardware. The interface consists of a set of several hundred procedures and functions that allow a programmer to specify the objects and operations involved in producing high-quality graphical images, specifically color images of three-dimensional objects.[1]

Design

- Abstract Specification for drawing 2D or 3D graphics
- Can be implemented in software or hardware ($\rightarrow$ driver)
- Plattform independent
- Language independent (Although C-ish style functions are used)
- Bindings for many languages (C, JavaScript, Java, ...)

What not?

- Windowing
- Audio
- Input
- $\Rightarrow$ Frameworks like GLFW, SDL, ...

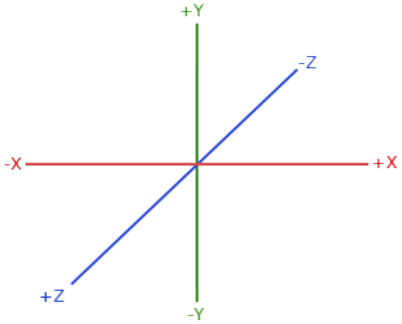
Goal

Render a 3D Object onto a 2D Plane (our Screen)

https://commons.wikimedia.org/wiki/File:Utah_teapot_simple_2.png

The OpenGL Coordinate System

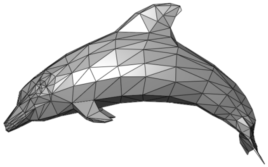
OpenGL uses a **right handed** coordinate system



https://learnopengl.com/Getting-started/Coordinate-Systems

Mesh

- Represented by a set of vertices in 3D space
- Vertices form triangle faces (in our case)
- Vertex data: **position**, normals, texture coordinates, lighting, ...



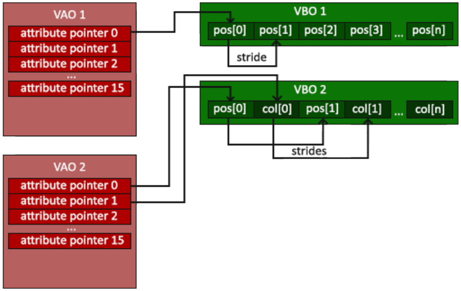
API Design

- One big state machine
- Tons of functions that manipulate that state machine

Shading Pipeline

Vertex Storage

- Vertex data is stored in *Vertex Buffer Objects* in graphic card memory
- *Vertex Array Objects* are used to index these Buffers
- Buffers must always be bound before they can be used



Shader

- Code executed on the graphics card
- Written in GLSL
- Different types: **VertexShader, FragmentShader**, GeometryShader, TesselationShader

Shading Pipeline

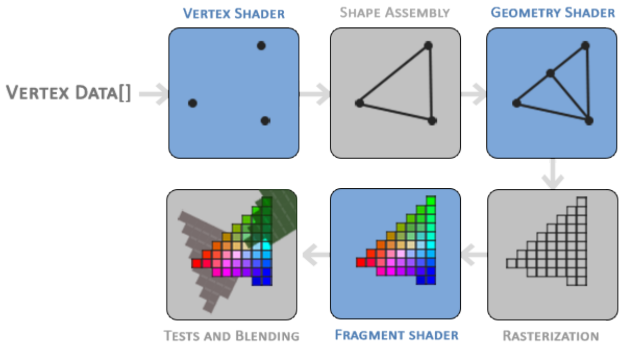


Figure: A simplified diagram of the rendering pipeline [1]

[1] https://learnopengl.com/img/getting-started/pipeline.png

Shader

VertexShader

- Executeted for each **vertex**
- Sets the vertex position

FragmentShader

- Executed for each **fragment** (pixel)
- Sets the final color of each fragment

Demo

Example 01 & 02

Uniforms

- Variables inside the shader code that can be set from outside
- Efficient method for modifying how models are displayed without the need for changing the raw vertex data
- used for nearly *anything* (e.g. translation, coloring, lighting)

Demo

Example 03

Element Buffers

- A vertex can be part of many triangles
- We don't want to store vertex data more than once
- Solution: use an Element Buffer to store which indices of the vertices in the VBO correspond to which triangles

Demo

Example 04

Goal

Render a 3D Object onto a 2D Plane (our Screen)

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Vectors

- Vertex position represented by a **4D** vector
- "Homogeneous coordinates"
- $$\begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix} \text{ with } w = \begin{cases} 1 \text{ for location vectors} \\ 0 \text{ for direction vectors} \end{cases}$$
- Allows us to do all kinds of transformations with 4x4 Matrices

Matrices

- Translation: $$\begin{bmatrix}1 & 0 & 0 & dx\\ 0 & 1 & 0 & dy\\ 0 & 0 & 1 & dz\\ 0 & 0 & 0 & 1\end{bmatrix} * \begin{bmatrix}x\\ y\\ z\\ 1\end{bmatrix} = \begin{bmatrix}x+dx\\ y+dy\\ z+dz\\ 1\end{bmatrix}$$
- Scale: $$\begin{bmatrix}sx & 0 & 0 & 0\\ 0 & sy & 0 & 0\\ 0 & 0 & sz & 0\\ 0 & 0 & 0 & 1\end{bmatrix} * \begin{bmatrix}x\\ y\\ z\\ 1\end{bmatrix} = \begin{bmatrix}x*sx\\ y*sy\\ z*sz\\ 1\end{bmatrix}$$
- Rotation: $$\begin{bmatrix}x & 0 & 0 & 0\\ 0 & \cos\theta & -\sin\theta & 0\\ 0 & \sin\theta & -\cos\theta & 0\\ 0 & 0 & 0 & 1\end{bmatrix} * \begin{bmatrix}x\\ y\\ z\\ 1\end{bmatrix} = \begin{bmatrix}x\\ \cos\theta y - \sin\theta z\\ \sin\theta y + \cos\theta z\\ 1\end{bmatrix}$$

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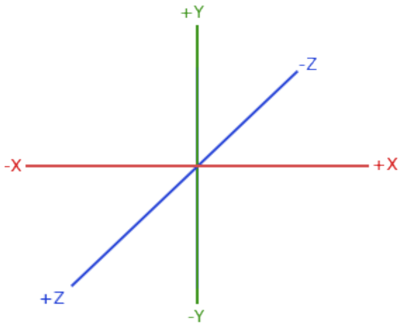

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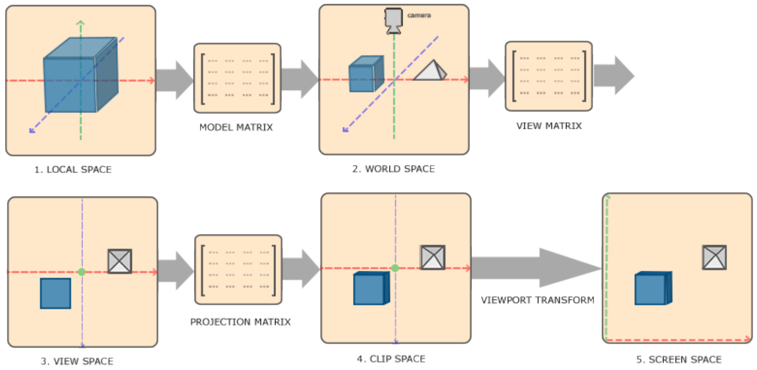
From a 3D model to a 2D image



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From a 3D model to a 2D image

- Model: Object position relative to world origin
- View: Camera position
- Projection: Project 3D scene onto a 2D image
- Clipping: All vertices not within $[-1.0 \ldots 1.0]$ will be discarded

Demo

Example 0x

What is Vulkan?

- Vulkan is a ”next-gen” graphics API
- Developed by the same people as OpenGL (Khronos Group)
- Will **not** replace OpenGL in the near future
- Orientated around a command buffer / command pipeline structure

Advantages

- Far more low level than OpenGL
- Thread and memory management left to application
- sophisticated validation and diagnostic layers
- similar API between mobile and desktop

Disadvantages

- Far more low level than OpenGL
- No thread and memory management
- A lot more boilerplate to set up

References

OpenGL Specification
The OpenGL © Graphics System: A Specification (Version 4.0 (Core Profile) - March 11, 2010)
https://www.khronos.org/registry/OpenGL/specs/gl/glspec40.core.pdf

Learn OpenGL
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