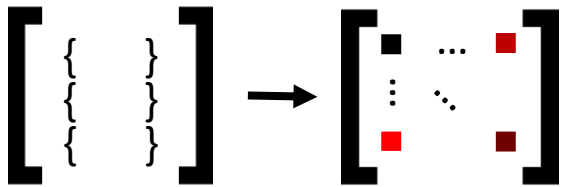# Working with shaders

Patrick SARDINHA

What's a shader?
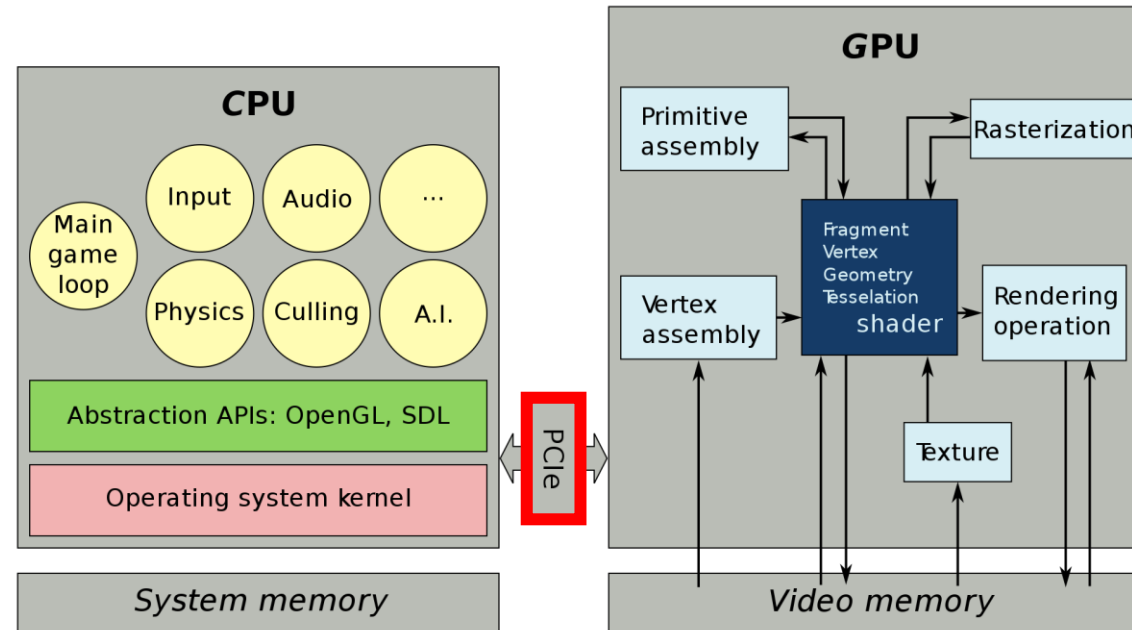
Small programs that run on the GPU

Executed for each specific section of the graphics pipeline

Isolated and not allowed to communicate with each other

It works with geometric primitives, lights, textures, …

Shaders in the Graphics Processing Unit

Shaders are executed by the GPU & are good to be executed in parallel

Sending data to the GPU goes through the PCI, it is relatively slow
& CPU/GPU must be synchronized

Different languages

DirectX High-Level Shader Language

Cg Shader Language

OpenGL Shading Language (GLSL)

Problem

In GLSL, there are no real data structures to easily get the attributes of a primitive (matrices, vectors, …)

The construction of shaders is very repetitive which implies a lot of copy and paste

Must reduce the data sent in the PCI to avoid multiple synchronizations between CPU & GPU
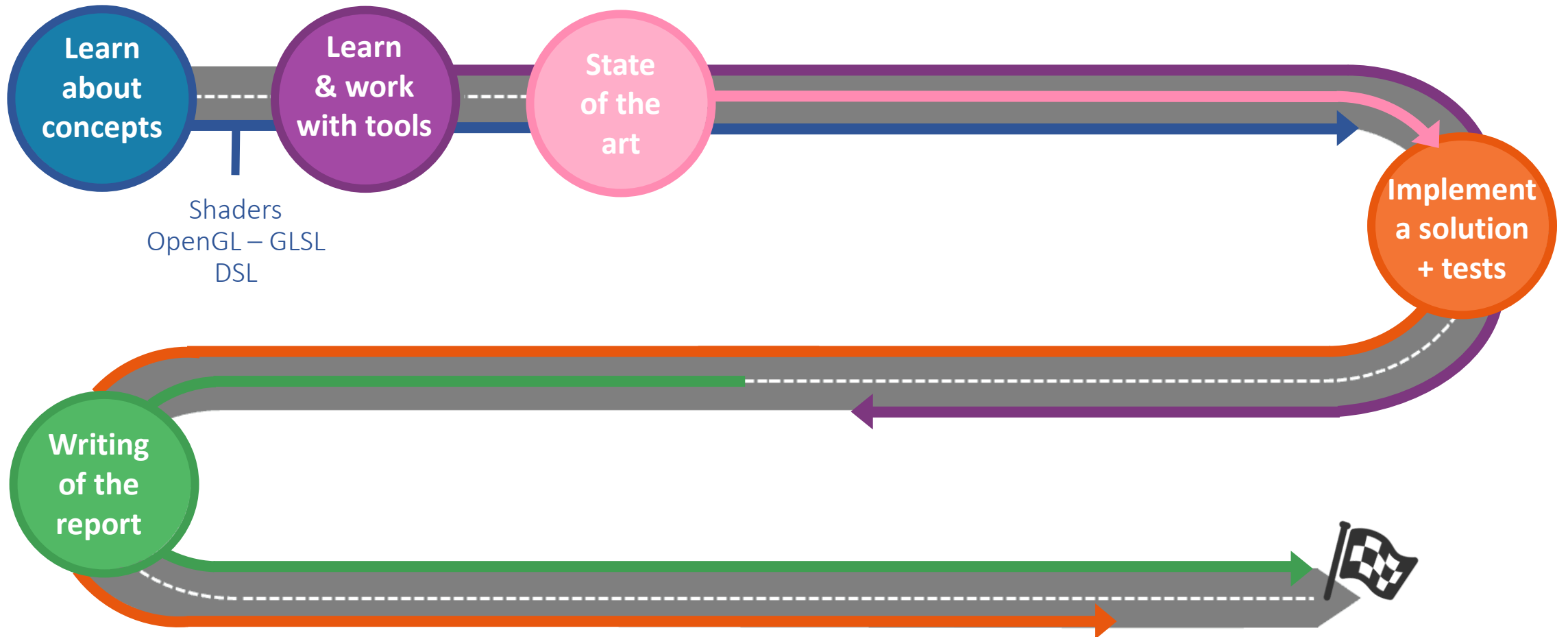
Goal of the project

Work with the representation of the data & abstract the types

Construct a DSL for shaders

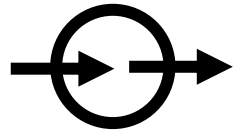# Road map

3D space to 2D screen space

The process of transforming 3D coordinates to 2D
pixel is done by the graphics pipeline

First big part: transforms 3D coordinates into 2D coordinates

Second big part: transforms the 2D coordinates into actual colored pixels

Graphics pipeline
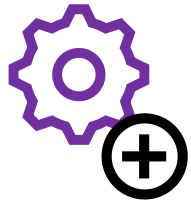
Input & Output Data

3 different shaders processing units

Vertex Shader

Geometry Shader

Fragment/Pixel Shader

Some others processes

Tessellation, Rasterization, Color blending

Input Data

Take as input a Vertex (or Vertices) [] which is a data structure that describes geometric primitives with certain attributes like:

Position (2D, 3D coordinates)

Color (RGB, …)

Texture coordinates
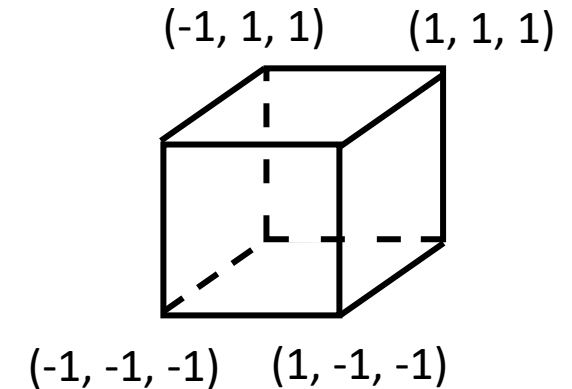
Example

In OpenGL, only the Normalize Device Coordinates (NDC) are visible on the screen

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

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

To render a single 2D triangle:

3D position (NDC) of each vertex

```
float vertices[] = {
    -0.5f, -0.5f, 0.0f,
     0.5f, -0.5f, 0.0f,
     0.0f,  0.5f, 0.0f
};
```

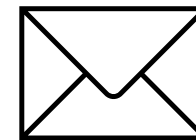(0, 1)

(-1, 0)   (1, 0)

(0, -1)
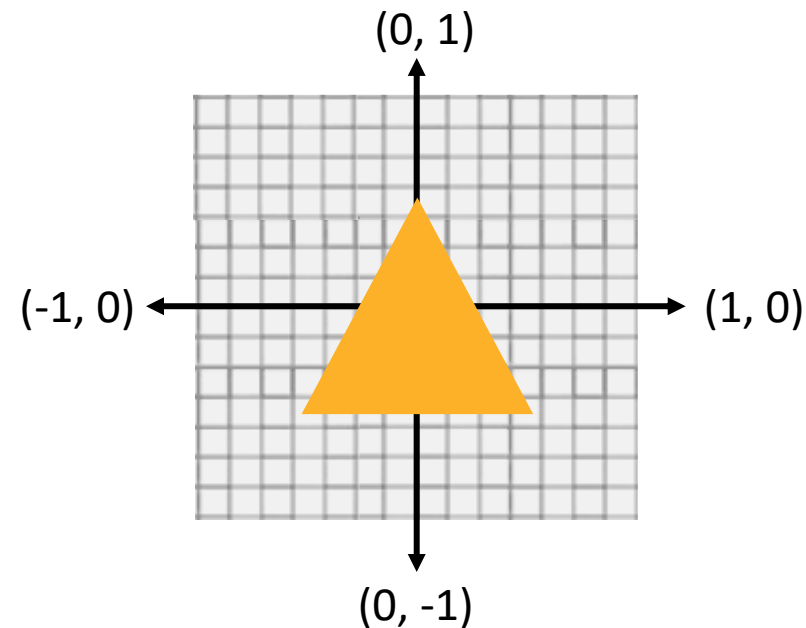
Linking vertex attributes

The input data will compose a Vertex Buffer Object (VBO) which can store a large number of vertices in the GPU memory

Then, we specify how the vertex data should be interpreted

Finally, it will be sent to the Vertex Shader

Example

Triangle with position attributes:

```
float vertices[] = {
    -0.5f, -0.5f, 0.0f,
     0.5f, -0.5f, 0.0f,
     0.0f,  0.5f, 0.0f
};
```

Copy our vertices array in a buffer

ID of the buffer which must be bind

Specifies the target buffer object
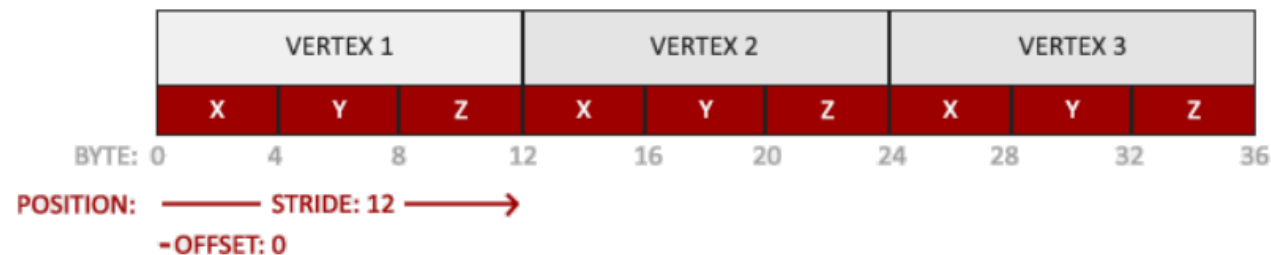
```
glBindBuffer(GL_ARRAY_BUFFER, VBO);
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices, GL_STATIC_DRAW);
```

Size of the buffer object

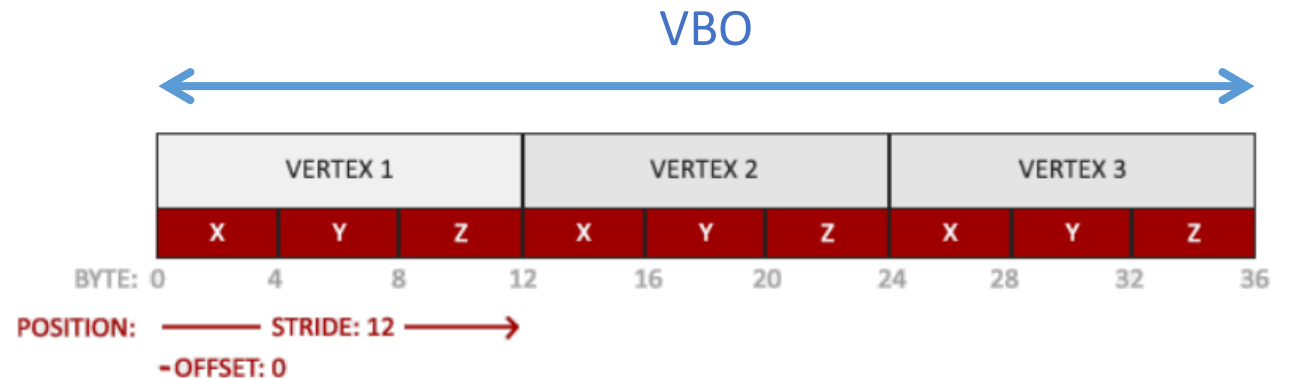Pointer to data

VBO

VERTEX 1			VERTEX 2			VERTEX 3		
X	Y	Z	X	Y	Z	X	Y	Z

BYTE: 0   4   8   12   16   20   24   28   32   36

POSITION: ⟶ STRIDE: 12 ⟶

◦ OFFSET: 0

Example (Cont.)

Define how the vertex data should be interpreted

VBO

VERTEX 1			VERTEX 2			VERTEX 3		
X	Y	Z	X	Y	Z	X	Y	Z

BYTE: 0   4   8   12   16   20   24   28   32   36

POSITION: ——— STRIDE: 12 ———→

↞OFFSET: 0

The size of the vertex attribute

Offset of where the position data begins in the buffer

Specifies which vertex attribute

Normalized data or not

```
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(float), (void*)0);
glEnableVertexAttribArray(0);
```

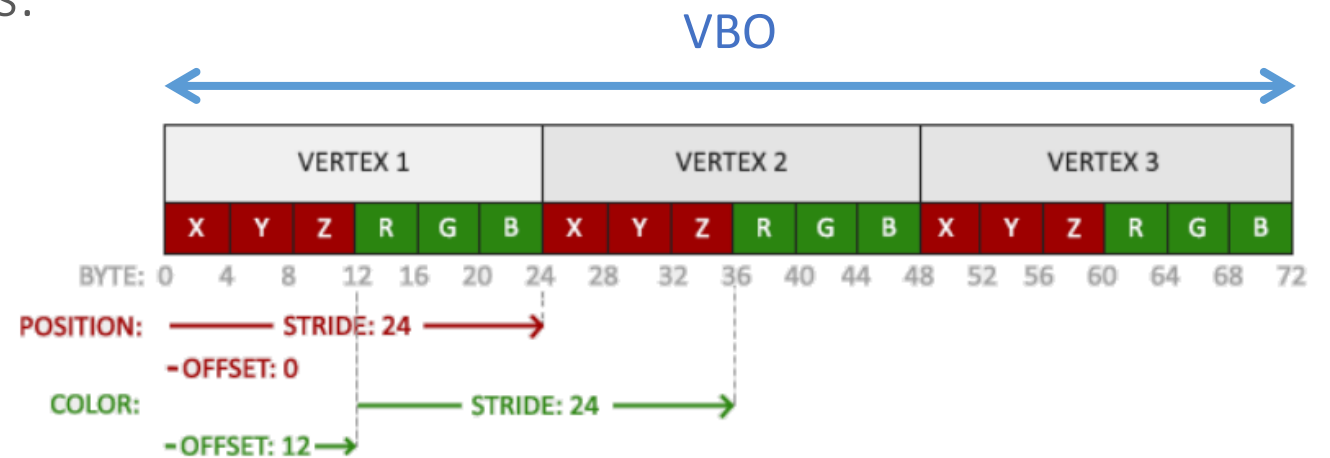Enable the vertex attribute

Type of the data

Stride: Space between consecutive vertex attributes

Example (Cont.)

Triangle with position & color attributes:

```
float vertices[] = {
    // positions        // colors
    0.5f, -0.5f, 0.0f,  1.0f, 0.0f, 0.0f,
   -0.5f, -0.5f, 0.0f,  0.0f, 1.0f, 0.0f,
    0.0f,  0.5f, 0.0f,  0.0f, 0.0f, 1.0f
};
```

VBO

VERTEX 1 | VERTEX 2 | VERTEX 3

X Y Z R G B X Y Z R G B X Y Z R G B

BYTE: 0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72

POSITION: ──── STRIDE: 24 ────►
-OFFSET: 0

COLOR: ──── STRIDE: 24 ────►
-OFFSET: 12 ►

Position offset

```
// position attribute
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 6 * sizeof(float), (void*)0);
glEnableVertexAttribArray(0);
// color attribute
glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 6 * sizeof(float), (void*)(3* sizeof(float))
glEnableVertexAttribArray(1);
```
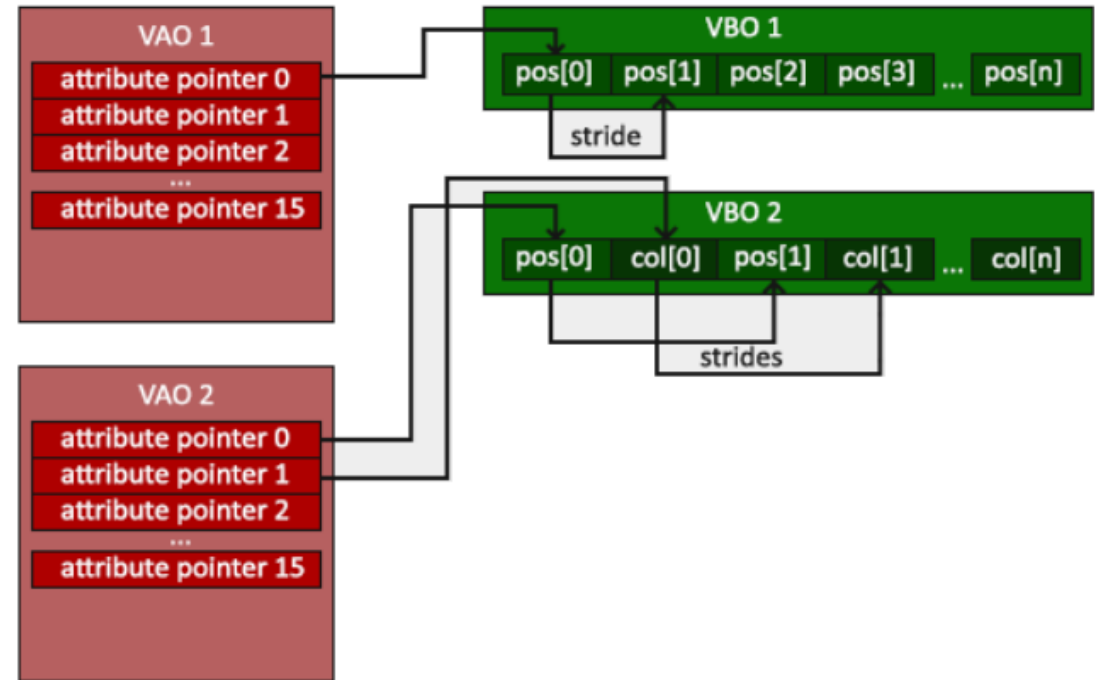
Stride

Color offset

Vertex Array Object (VAO)

Allows to configure vertex attribute pointers more easily

To draw an object, just bind the corresponding VAO

We generate a VAO like a VBO

```
unsigned int VAO;
glGenVertexArrays(1, &VAO);
```

Summary

```
// 1. bind Vertex Array Object
glBindVertexArray(VAO);


// 2. copy our vertices array in a buffer for OpenGL to use
glBindBuffer(GL_ARRAY_BUFFER, VBO);
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices, GL_STATIC_DRAW);


// 3. then set our vertex attributes pointers
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 3 * sizeof(float), (void*)0);
glEnableVertexAttribArray(0);


// (render loop)
// 4. draw the object
glUseProgram(shaderProgram);
glBindVertexArray(VAO);
someOpenGLFunctionThatDrawsOurTriangle();
```

Render & draw an object

The idea now is to render and draw an object.
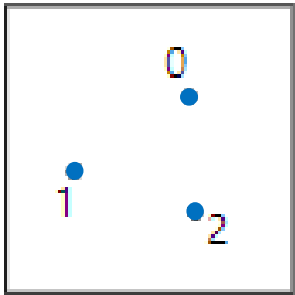To do that we will have to:

Set up a Vertex & a Fragment Shader

Compile these shaders

Link them to a shader program

Vertex Shader

Compute the projection of the vertices of primitives from 3D space into a different 3D space (NDC)

Input data: some properties of the vertices (position, color or texture coordinates)

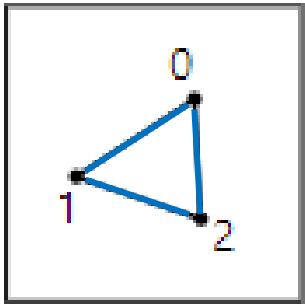Output data: the corresponding properties in the new space

Sample code

Shader's version (here 3.3)

All the input vertex attributes

```glsl
#version 330 core
layout (location = 0) in vec3 aPos;

void main()
{
    gl_Position = vec4(aPos.x, aPos.y, aPos.z, 1.0);
}
```

Specifically set the location of the input variable

(x, y, z) + w component

Output of the vertex shader

Primitives Assembly

This process takes all the vertex given by the step before and assemble them in order to create a geometric shape

Sample code:

```
glDrawArrays(GL_TRIANGLES, 0, 3);
```

Starting index in the array
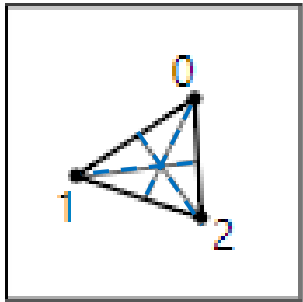
OpenGL function that draws a shape

Kind of primitive to render

Number of vertices to render

Tessellation

In 3D, the surfaces are built with triangular tiles
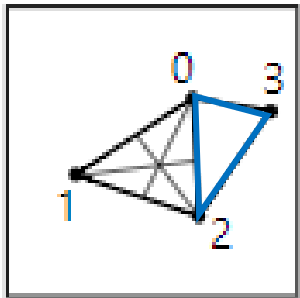
Tessellation allows to double triangles on a given surface and therefore increase the level of details

Geometry Shader

⚠ An unnecessary step
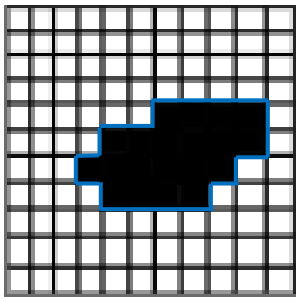
Allows to modify the geometry of each polygon and allows to create new polygons by emitting new vertices

Input data: data of a geometric primitive

Output data: data of one or more geometric primitive

Rasterization

Method of converting a vector image into a raster image to be displayed on a screen

Vector image
composed of geometric objects

Raster image or Bitmap
composed of pixels

Clipping
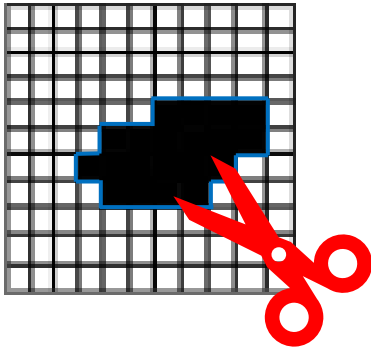
This step discard all fragments (which is the required data to render a single pixel) that are outside the view, increasing the performance

Fragment/Pixel Shader
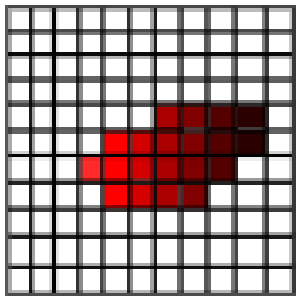
Calculates the final color of a pixel

Input data: pixel data
(position, texture coordinates, color)

Output data: the pixel color

Sample code

Shader's version (here 3.3)

```
#version 330 core
out vec4 FragColor;

void main()
{
    FragColor = vec4(1.0f, 0.5f, 0.2f, 1.0f);
}
```

Output variable which is the final color output

RGB + alpha component

Compile a Shader

First, we store the code in
a string constant

```
const char *vertexShaderSource = "#version 330 core\n"
    "layout (location = 0) in vec3 aPos;\n"
    "void main()\n"
    "{\n"
    "    gl_Position = vec4(aPos.x, aPos.y, aPos.z, 1.0);\n"
    "}\0";
```

Then, we store and create the shader

```
unsigned int vertexShader;
vertexShader = glCreateShader(GL_VERTEX_SHADER);
```

Type of shader we want to create

Finally, we link the source code to the
object and compile it

```
glShaderSource(vertexShader, 1, &vertexShaderSource, NULL);
glCompileShader(vertexShader);
```

Shader program

First, we create a program object

```
unsigned int shaderProgram;
shaderProgram = glCreateProgram();
```

We attach the previously compiled shaders to the program object and link them

```
glAttachShader(shaderProgram, vertexShader);
glAttachShader(shaderProgram, fragmentShader);
glLinkProgram(shaderProgram);
```

We can now activate this program to render and draw an object

```
glUseProgram(shaderProgram);
```

Final step is to delete our shader objects

```
glDeleteShader(vertexShader);
glDeleteShader(fragmentShader);
```

Uniforms variables
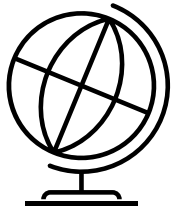
Useful to pass data from the application on the CPU to the shaders on the GPU

These are global variables

Sample code:

```glsl
#version 330 core
out vec4 FragColor;

uniform vec4 ourColor;

void main()
{
    FragColor = ourColor;
}
```

Usage of uniform keyword

Alpha test

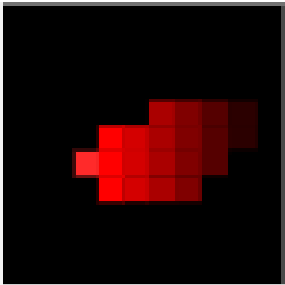Checks the corresponding depth value of a fragment to see if the resulting fragment is in front or behind another one

NOT DISCARDED ←   → DISCARDED
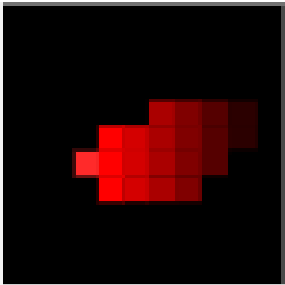
Done with the depth testing using a Z-buffer (in which the depth value of the fragments is stored)

```
glEnable(GL_DEPTH_TEST);
```

Then, checks for alpha values (opacity of an object) & blends the objects

Color Blending

The technique of gently blending two or more colors to create a gradual transition

Example of a blending function

First, we have to enable the OpenGL functionality

```
glEnable(GL_BLEND);
```

Then, blending can follow this equation:

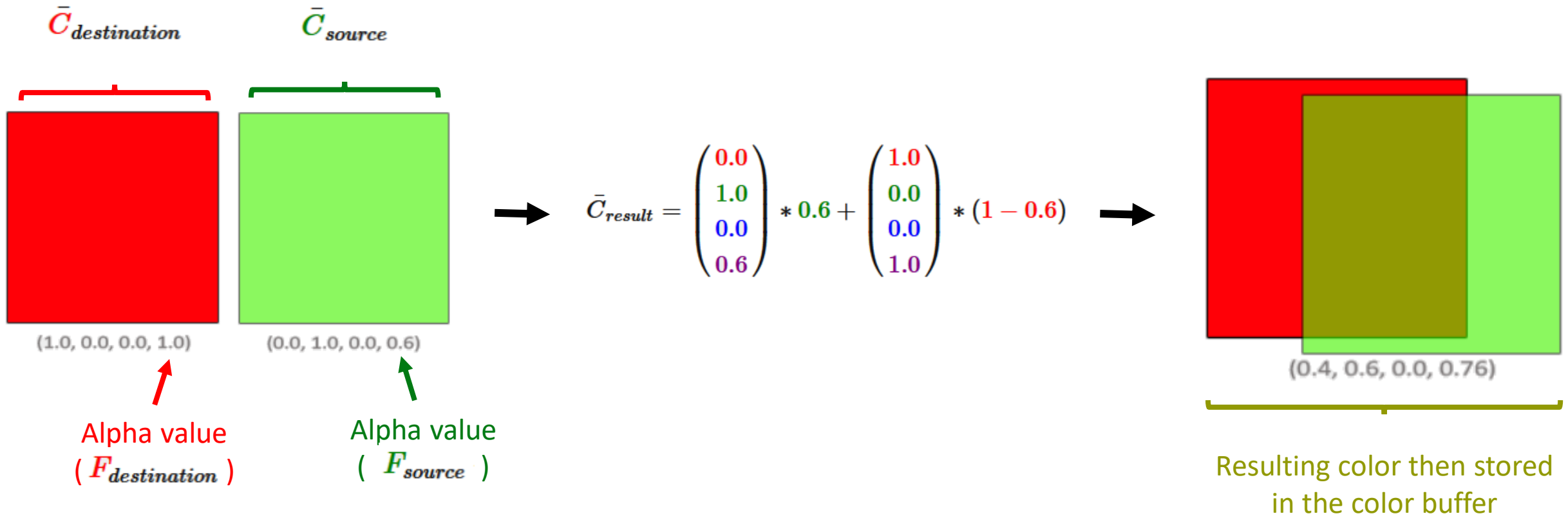$$\bar{C}_{result} = \bar{C}_{source} * F_{source} + \bar{C}_{destination} * F_{destination}$$

Final color of the fragment

Impact of the alpha value

Color output of the fragment shader

Impact of the alpha value

Color currently stored in the color buffer

Example (Cont.)

$$\bar{C}_{result} = \bar{C}_{source} * F_{source} + \bar{C}_{destination} * F_{destination}$$

$\bar{C}_{destination}$

$\bar{C}_{source}$

(1.0, 0.0, 0.0, 1.0)

(0.0, 1.0, 0.0, 0.6)

$$\bar{C}_{result} = \begin{pmatrix} 0.0 \\ 1.0 \\ 0.0 \\ 0.6 \end{pmatrix} * 0.6 + \begin{pmatrix} 1.0 \\ 0.0 \\ 0.0 \\ 1.0 \end{pmatrix} * (1 - 0.6)$$

(0.4, 0.6, 0.0, 0.76)

Alpha value
($F_{destination}$)

Alpha value
(F_{source})

Resulting color then stored
in the color buffer

Output Data
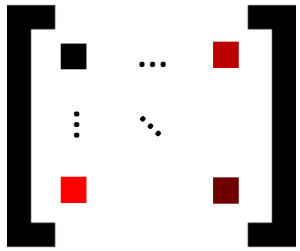
Return a Framebuffer

The information in this buffer are the values of the color components (RGB) for each pixel
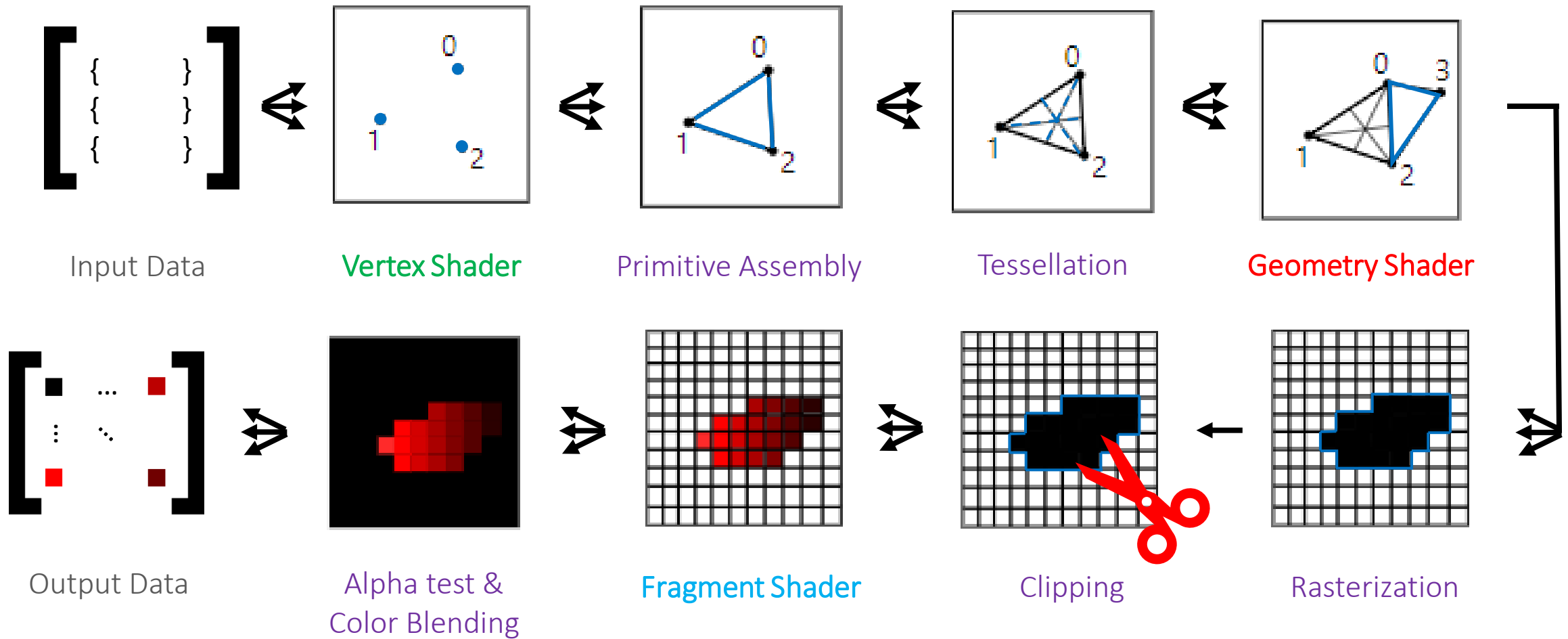
Overall view

Input Data   Vertex Shader   Primitive Assembly   Tessellation   Geometry Shader

Output Data   Alpha test & Color Blending   Fragment Shader   Clipping   Rasterization

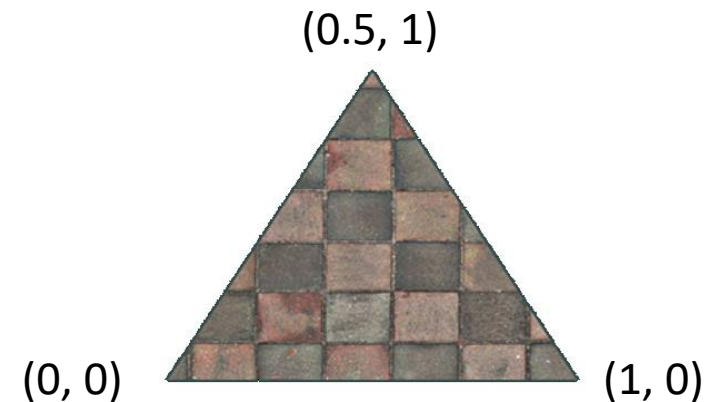# Textures

Allows to give the illusion the object is detailed
without having to specify vertices

Associate each vertex to a texture coordinate

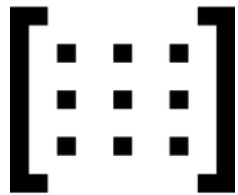A fragment interpolation is then done for the other fragments

Sample code:

```
float texCoords[] = {
    0.0f, 0.0f,   // lower-left corner
    1.0f, 0.0f,   // lower-right corner
    0.5f, 1.0f    // top-center corner
};
```

(0.5, 1)

(0, 0)

(1, 0)

Transformations

Make an object dynamic using matrix objects & by combining the matrices

Some library can be used like the GLM (OpenGL Mathematics) library

Useful matrices

Rotation Matrix

Scaling Matrix

$$\begin{bmatrix} S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} S_1 \cdot x \\ S_2 \cdot y \\ S_3 \cdot z \\ 1 \end{pmatrix}$$

Translation Matrix

$$\begin{bmatrix} 1 & 0 & 0 & T_x \\ 0 & 1 & 0 & T_y \\ 0 & 0 & 1 & T_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} x + T_x \\ y + T_y \\ z + T_z \\ 1 \end{pmatrix}$$

Around X-axis

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} x \\ \cos\theta \cdot y - \sin\theta \cdot z \\ \sin\theta \cdot y + \cos\theta \cdot z \\ 1 \end{pmatrix}$$
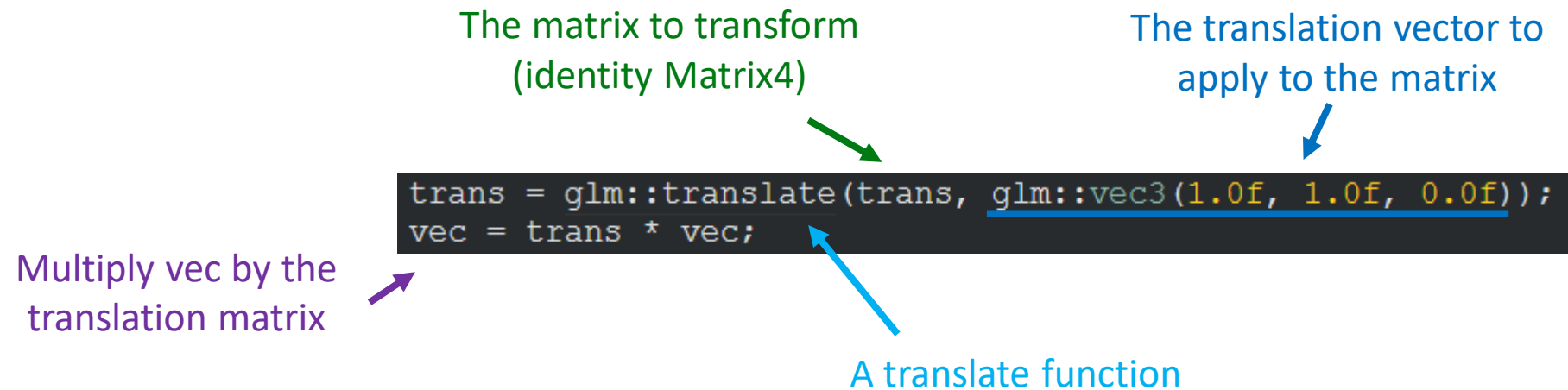
Around Y-axis

$$\begin{bmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} \cos\theta \cdot x + \sin\theta \cdot z \\ y \\ -\sin\theta \cdot x + \cos\theta \cdot z \\ 1 \end{pmatrix}$$

Around Z-axis

$$\begin{bmatrix} \cos\theta & -\sin\theta & 0 & 0 \\ \sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} \cos\theta \cdot x - \sin\theta \cdot y \\ \sin\theta \cdot x + \cos\theta \cdot y \\ z \\ 1 \end{pmatrix}$$

Sample code

Translating a vector of (1,0,0) by (1,1,0)

The matrix to transform (identity Matrix4)

The translation vector to apply to the matrix

```
trans = glm::translate(trans, glm::vec3(1.0f, 1.0f, 0.0f));
vec = trans * vec;
```

Multiply vec by the translation matrix

A translate function

Coordinates system

Transforming coordinates to NDC is done by a process regrouping several intermediate coordinate systems

Local Space

World Space

View Space

Clip Space

Screen Space

Local Space
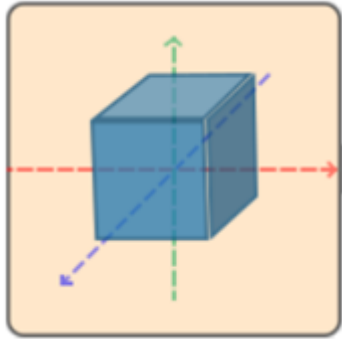
Coordinates of the object relative to its local origin

In general, all new objects have (0, 0, 0) as initial position

World Space
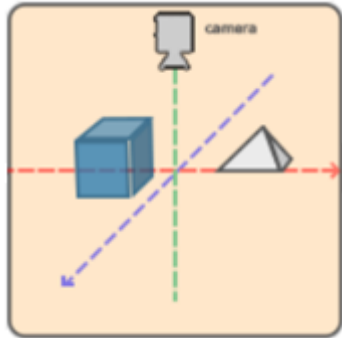
Coordinates of all the objects are relative to some global origin of the world

We use a model matrix which translates, scales and/or rotates the object to place it in the world

View Space
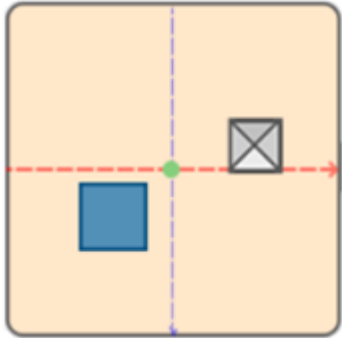
Each coordinates is seen from the camera's point of view

This is done by a combination of translations & rotations of the scene which is stored in a <u>view matrix</u>

Clip Space
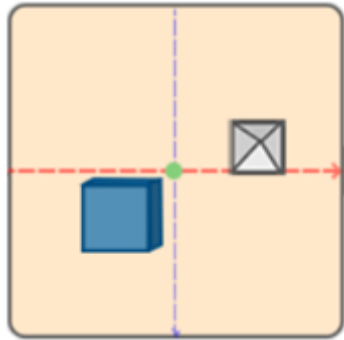
Each coordinates is seen from the camera's point of view

For this step, we use a **projection matrix** which transform the coordinates into NDC

Example:

Specified range [-1000, 1000] for each dimension

$(1250, 500, 750)$ ➡ Not visible

$(900, 500, 750)$ ➡ Visible

Screen Space
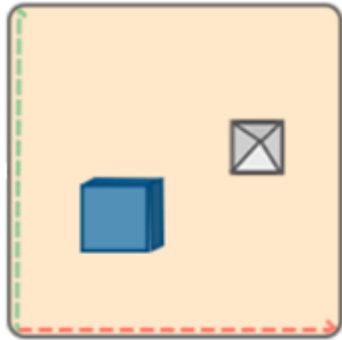
Transforms the NDC coordinates to the window coordinates with the *glViewport()* function

Resulting coordinates are then sent to the rasterizer

Overall view

A vertex coordinate is transformed to clip coordinates as follow: $V_{clip} = M_{projection} \cdot M_{view} \cdot M_{model} \cdot V_{local}$

1. LOCAL SPACE   MODEL MATRIX   2. WORLD SPACE   VIEW MATRIX

3. VIEW SPACE   PROJECTION MATRIX   4. CLIP SPACE   VIEWPORT TRANSFORM   5. SCREEN SPACE
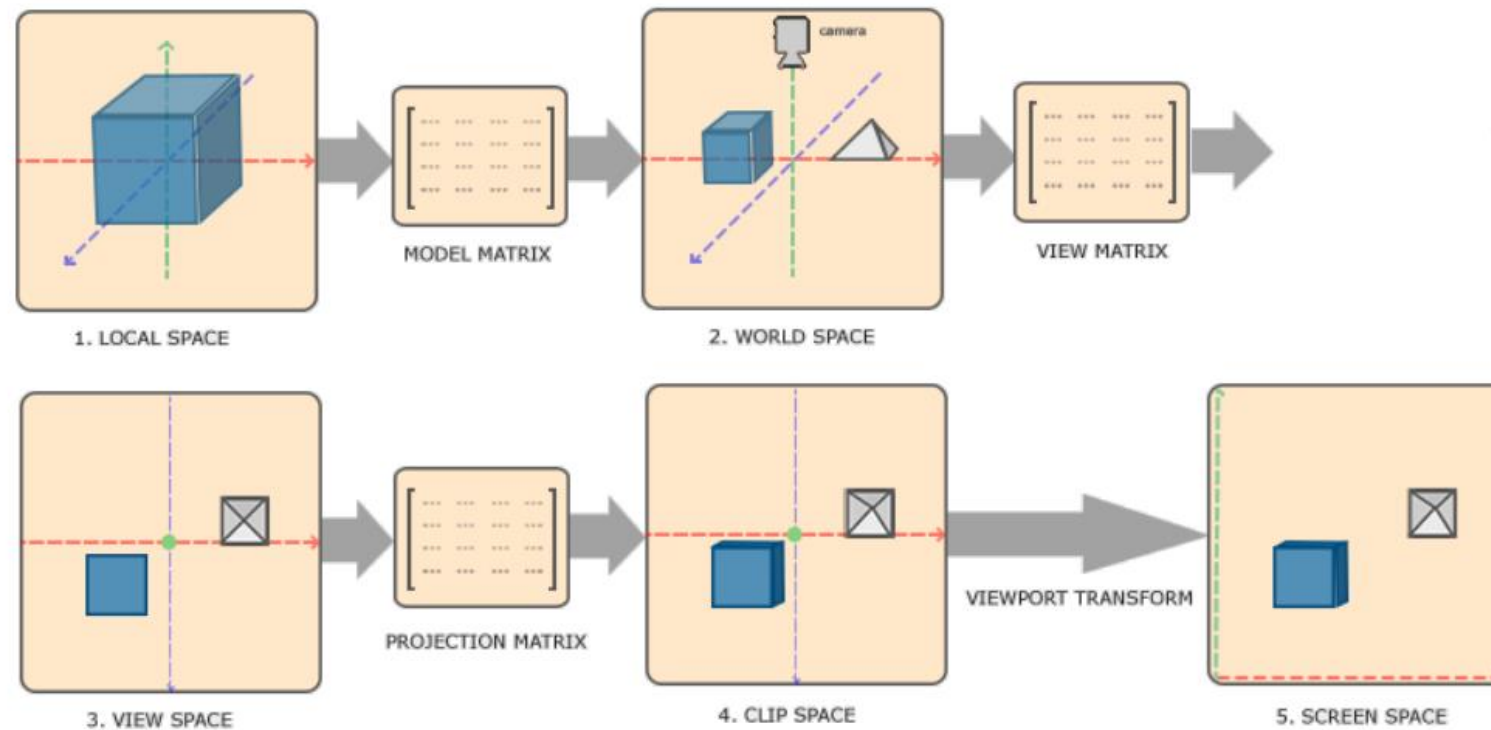
Camera

To define a camera we need 4 pieces of information
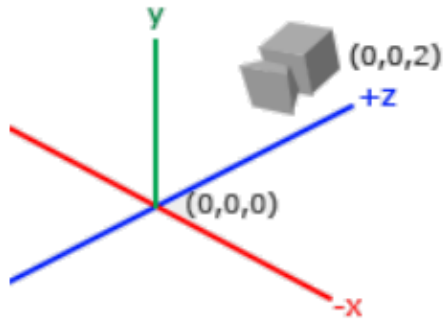
1. Its position in the world space
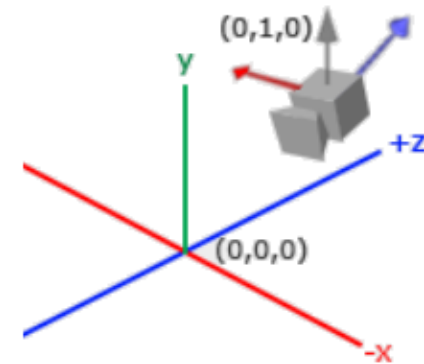
2. Its direction

3. A vector pointing to the right
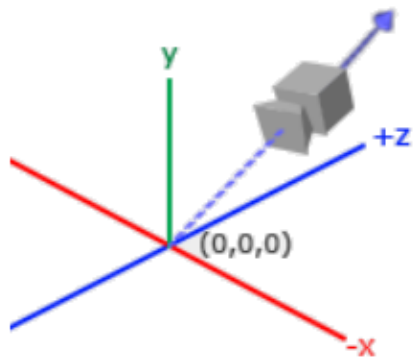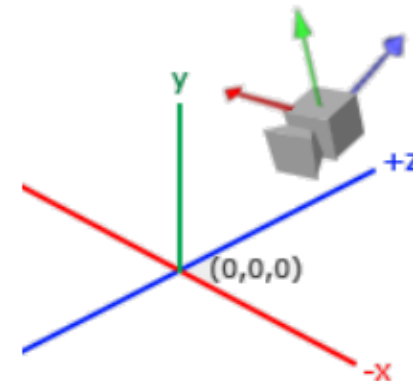
4. A vector pointing upwards

Recall : Graphics pipeline

Input Data   Vertex Shader   Primitive Assembly   Tessellation   Geometry Shader

Output Data   Alpha test & Color Blending   Fragment Shader   Clipping   Rasterization
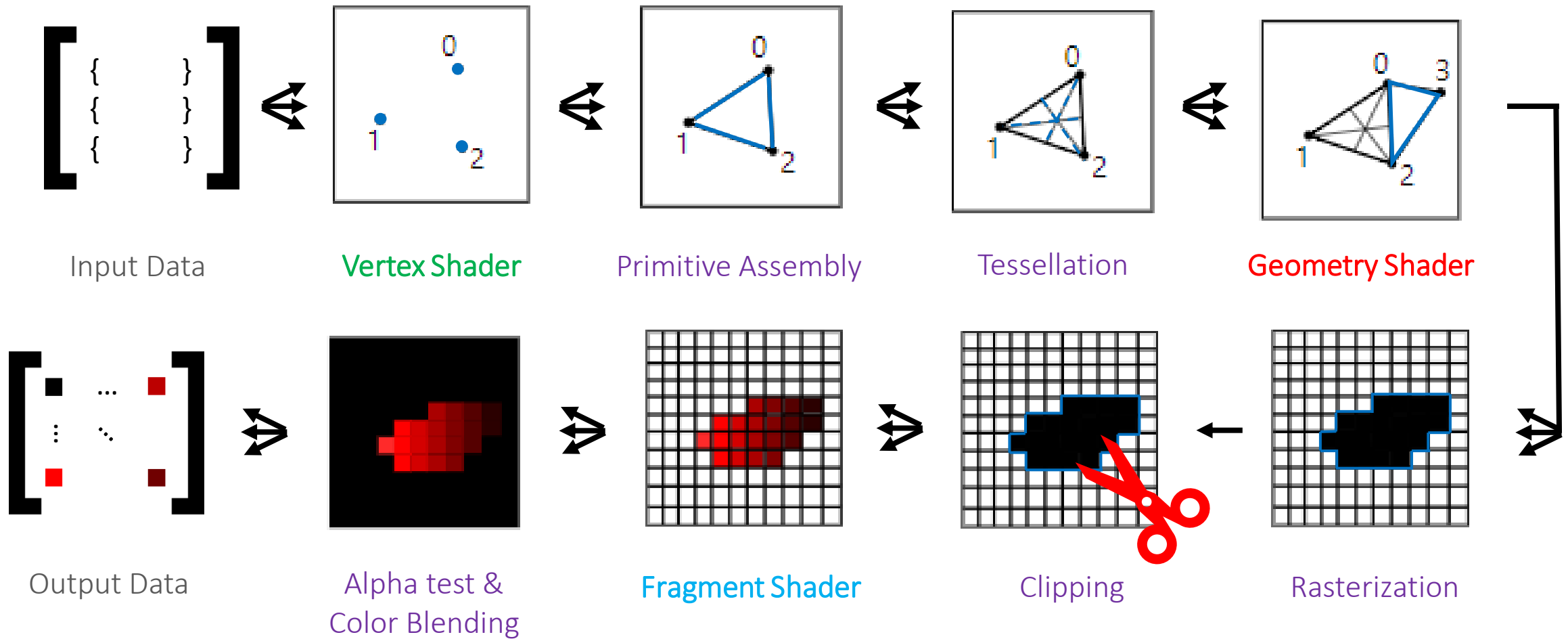
Pipeline abstraction

We can see the pipeline as a function composition
which can give us:

$$output\_data = (cb \circ at \circ fs \circ c \circ r \circ t \circ pa \circ vs) \, (input\_data)$$

Fragment Shader function

Vertex Shader function

Context

We can define the notion of context that gives
us the valid constants for a run (see after Uniforms)

The formula below is applied for every run

$$output\_data = (\text{cb} \circ \text{at} \circ \text{fs} \circ \text{c} \circ \text{r} \circ \text{t} \circ \text{pa} \circ \text{vs}) \ (input\_data)$$

Recall: Input data
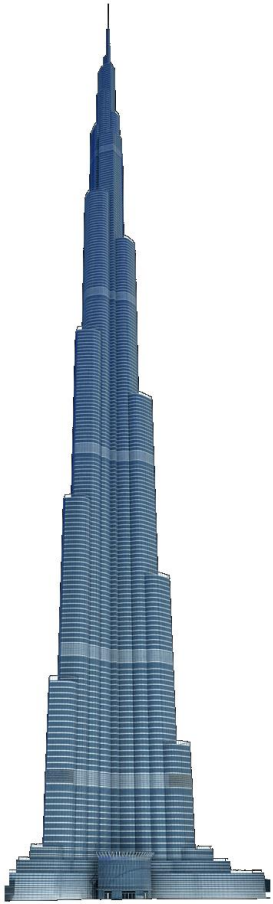
A VBO is built containing the attributes of all vertices
which give us a huge vector of data

To work with that, we have to use offsets, strides, etc.

Idea of the abstraction

No longer working with containers of type

Ex: vec3, ~~vec4, ivec4~~, mat4, …

But with abstract type objects

Ex: color, position, textures, …

Vertex Shader function   vs : A → B

A

vertex_position ⚠

n element(s)

Some other
abstract types

→

Constraint

B

vertex_position_NDC ⚠

Some other
abstract types

m element(s)
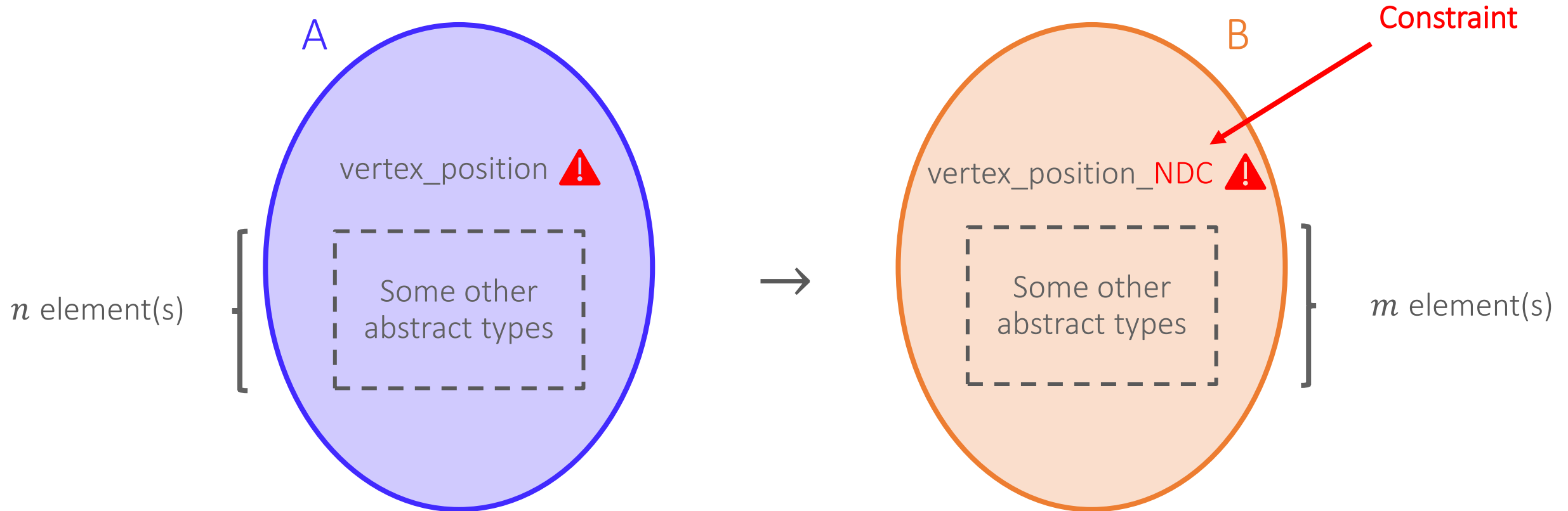
$$vs(\_ : vertex\_position, \cup \_ : (A_i \setminus vertex\_position))$$

Fragment Shader function   fs : C → D

C

D

p element(s)

Some
abstract types

→

pixel_color ⚠
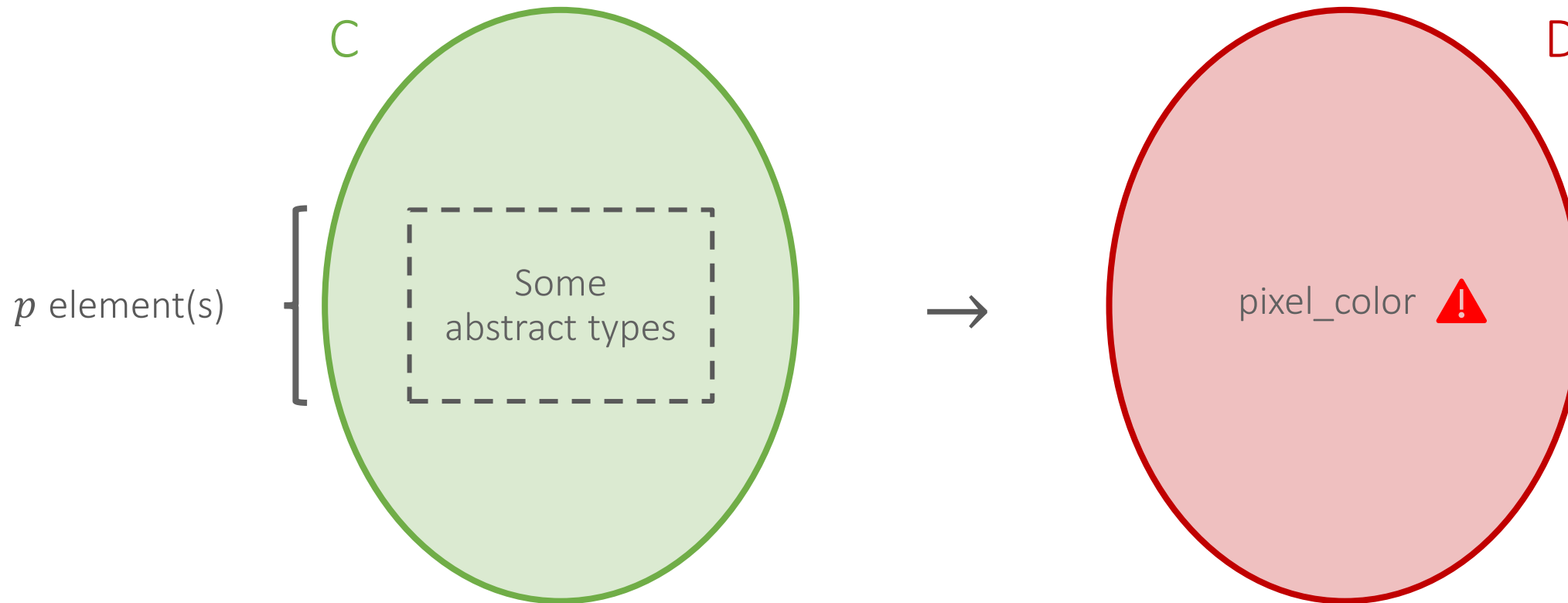
fs(_ : C_i)

Fragment Shader function Alternative   fs : C → D

C

p element(s)

Some abstract types

DISCARD

D

fs(_ : C_i)
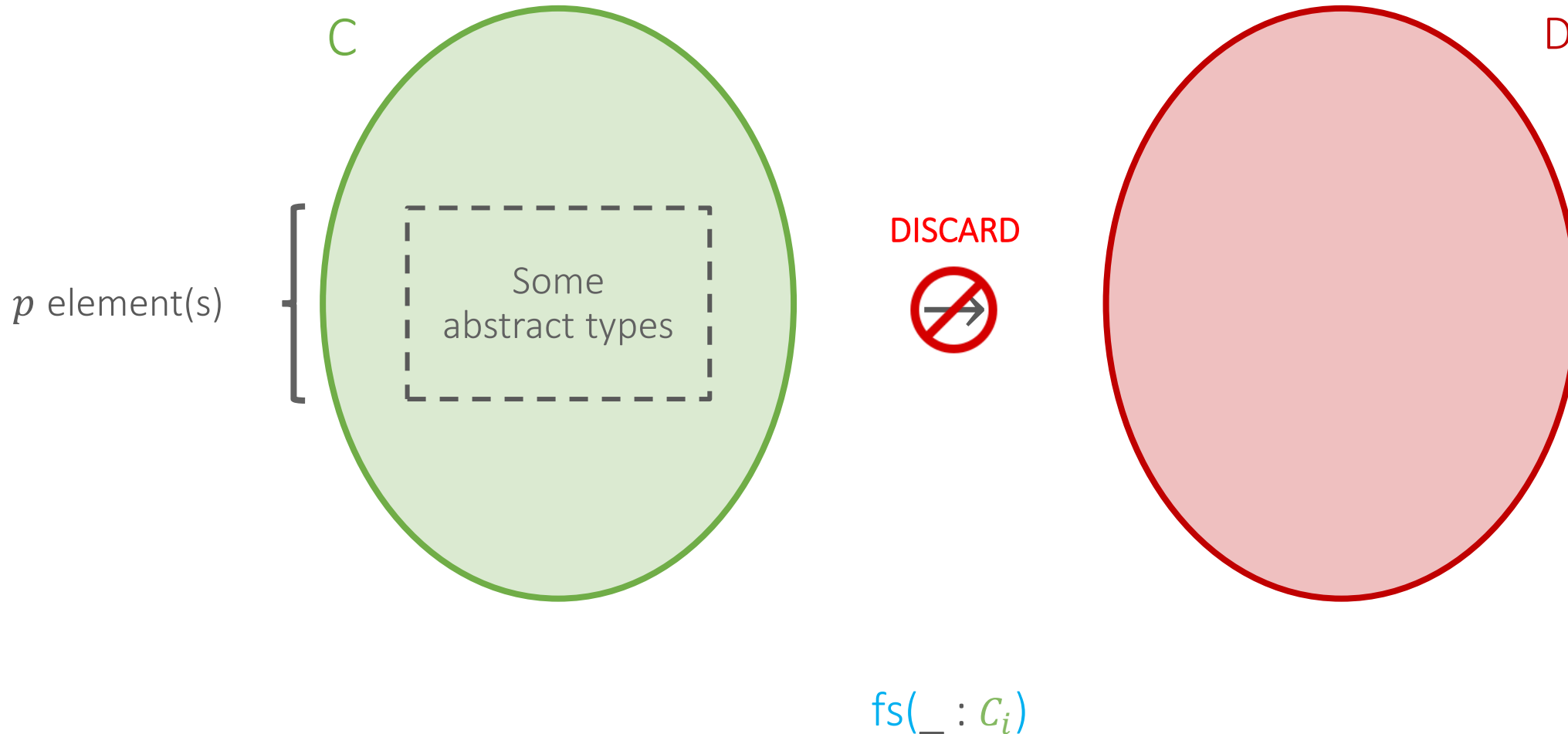
Several signatures

Depending on why a shader is created,
the signature will be different

Examples:

vs(_ : position)

vs(_ : position, _ : color)

vs(_ : position, _ : color, _ : texture:)

fs()

fs(_ : fragment, _ : light:)

fs(_ : fragment, _ : light, _ : texture:)

Uniforms
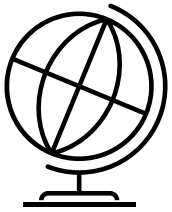
We saw that uniform variables are global variables
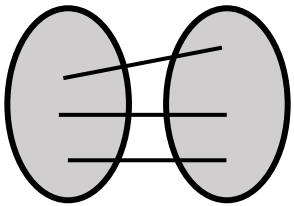
They are part of the domain and
the codomain of the vs() & fs() function
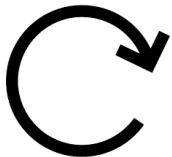
These variables are set for a run and define the context

Type checking between vs() & fs()

Check that names and types variables shared between
the vertex & the fragment shader are identical

Example:

```
#version 330 core
layout (location = 0) in vec3 aPos;

out vec4 vertexColor;

void main()
{
    gl_Position = vec4(aPos, 1.0);
    vertexColor = vec4(0.5, 0.0, 0.0, 1.0);
}
```

```
#version 330 core
out vec4 FragColor;

in vec4 vertexColor;

void main()
{
    FragColor = vertexColor;
}
```

Vertex shader

Fragment shader

Recall : Different languages

DirectX High-Level Shader Language

(Unreal Engine)

Cg Shader Language

(Unity)

OpenGL Shading Language

Similar structures

A sample Cg vertex shader:

Types definition

```
// input vertex
struct VertIn {
    float4 pos   : POSITION;
    float4 color : COLOR0;
};

// output vertex
struct VertOut {
    float4 pos   : POSITION;
    float4 color : COLOR0;
};

// vertex shader main entry
VertOut main(VertIn IN, uniform float4x4 modelViewProj) {
    VertOut OUT;
    OUT.pos     = mul(modelViewProj, IN.pos);
    OUT.color   = IN.color;
    return OUT;
}
```

Uniform keyword

Calculate output
coordinates & colors

Output

Same abstraction

The different shader languages are very similar
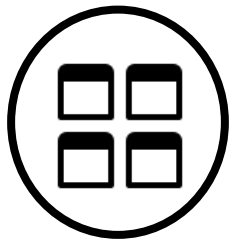
We could therefore use the same abstraction for any language

Domain-Specific Language (DSL)

A DSL is a programming language whose specifications
allow to overcome some constraints in a specific domain

The specific domain will be for us the shaders
and especially vertex & fragment shaders

Advantages & disadvantages

✓ DSL will allow us to gain in productivity

DSL can be reused for other purposes

✗ DSL maintenance is complicated

The cost of a DSL is expensive

Different types of DSL

DSL Syntaxe

General Purpose
Language (GPL) Syntaxe

DSL Syntaxe

Internal DSL

External DSL

65
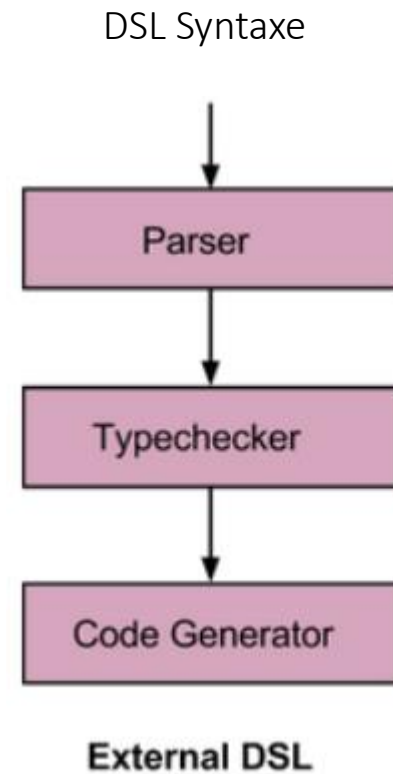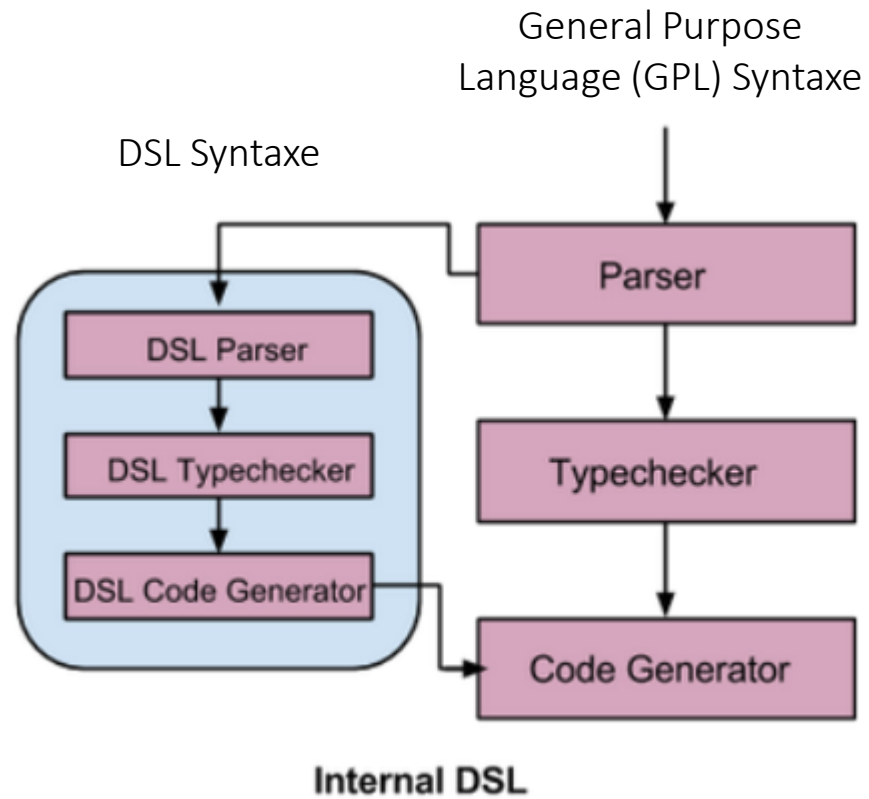
Our way

First, we will go on an Internal DSL based
on the Swift language

Later, we can potentially encounter
a lot of constraints relating to Swift

If so, we will go on an External DSL at this time

Main idea

We write in our program a
vertex & a fragment shader with our DSL

We send them to an encoder which will translate
the abstract types into containers of types

This translation can then be evaluated by the
graphics pipeline of OpenGL

(Then a decoder allows us to get the results
with the desired abstract types)

Schema

PROG

DSL

(Abstract types)

ENCODER

OpenGL

(DECODER)

Graphics pipeline
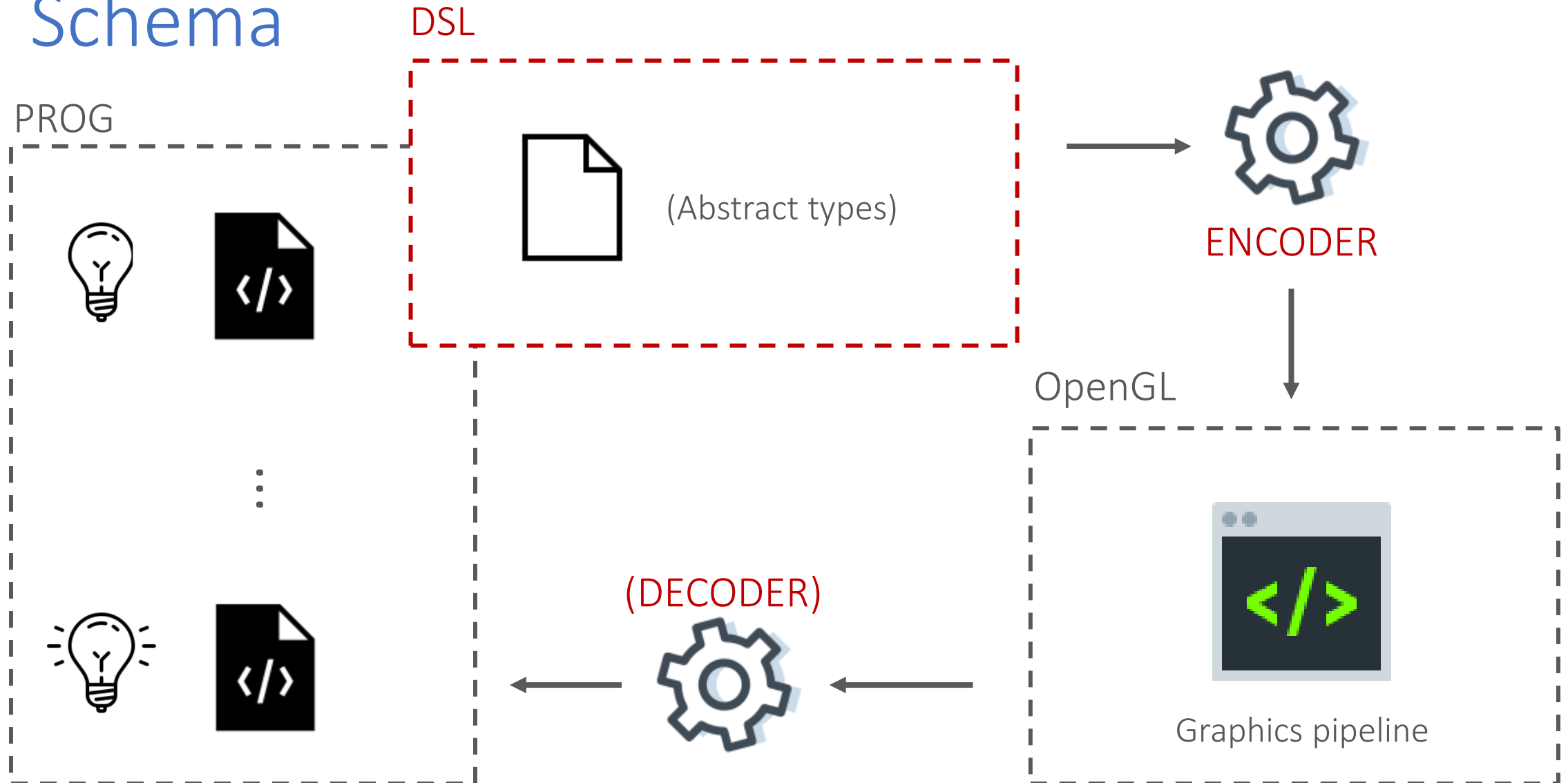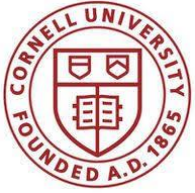
Gator

Language created by *Dietrich Geisler*, *Irene Yoon*, *Aditi Kabra*, *Horace He*, *Yinnon Sanders* & *Adrian Sampson*

Higher level programming model that allows focus on the geometric semantics of programs

Gator is a surface language with an extended type system based on a target language with a type set (GLSL)
A type-directed translation allows to compile Gator to GLSL

Problem & ideas
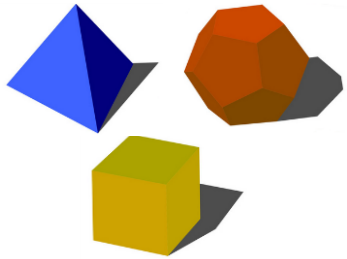
3D scenes consist of many individual objects & the rendering code must combine vectors of different coordinate systems
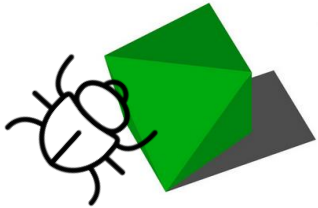
Geometry bugs are difficult to detect

Introduce a type system to eliminate this class of bugs & implement a mechanism that can exclude some bugs by construction

A geometry type
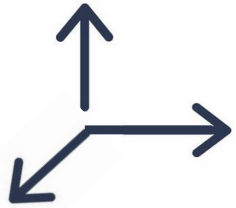
"Geometry types describe the coordinate system representing each value and the transformations that manipulate them"

A geometry type is made up of 3 components:

- Reference frame

- Geometric object

- Coordinate scheme

Define which operations are legal

Syntax

Geometry types give more information about the objects they represent than simple vector types in GLSL

Syntax for a geometry type is *scheme<frame>.object*

Example:

cart3<world>.point

represents the type of a point in world space represented in a 3D cartesian coordinate scheme

Example: Diffuse Lighting

GLSL implementation

```
float naiveDiffuse(vec3 lightPos, vec3 fragPos, vec3 fragNorm) {
  vec3 lightDir = normalize(lightPos - fragPos);
  return max(dot(lightDir, normalize(fragNorm)), 0.);
}
```

lightPos & fragPos have the same type but they are not geometrically compatible
We have different vectors in different coordinate systems

Subtraction between fragPos (model space) & lightPos (world space)

GLSL implementation (Cont.)

```glsl
float naiveDiffuse(vec3 lightPos, vec3 fragPos, vec3 fragNorm) {
    vec3 lightDir = normalize(lightPos - uModel * fragPos));
    return max(dot(lightDir, normalize(fragNorm)), 0.);
}
```

To correct the problem we transform the two vectors into a common coordinate system

We define a transformation matrix to go from model to world space

GLSL implementation (Cont.)

```glsl
float naiveDiffuse(vec3 lightPos, vec3 fragPos, vec3 fragNorm) {
  vec3 lightDir = normalize(lightPos - vec3(uModel * vec4(fragPos, 1.)));
  return max(dot(lightDir, normalize(fragNorm)), 0.);
}
```

3x3 Cartesian transformation matrices allow only linear transformations

4x4 transformation matrices in Homogeneous coordinates can express affine transformations

Cartesian to Homogeneous: $[x, y, z] \rightarrow [x, y, z, 1.]$
Homogeneous to Cartesian: $[x, y, z, w] \rightarrow [x/w, y/w, z/w]$

GLSL implementation (Cont.)

```
float naiveDiffuse(vec3 lightPos, vec3 fragPos, vec3 fragNorm) {
    vec3 lightDir = normalize(lightPos - vec3(uModel * vec4(fragPos, 1.)));
    return max(dot(lightDir, normalize(vec3(uModel * vec4(fragNorm, 0.)))));
}
```

The final calculation of the diffuse intensity

We must transform now fragNorm into world space
It's a direction so w should be 0

GLSL implementation (Cont.)
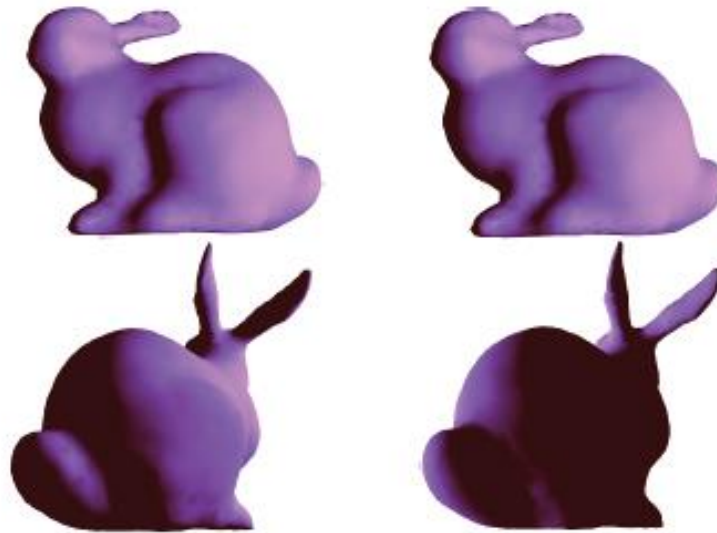
(a) Correct implementation. (b) With geometry bug.

Subtle differences can imply errors

Gator implementation

```
float diffuseNaive(
    cart3<world>.point lightPos,
    cart3<model>.point fragPos,
    cart3<model>.direction fragNorm) {
  cart3<world>.direction lightDir = normalize(lightPos - fragPos);
  return max(dot(lightDir, normalize(fragNorm)), 0.0);
}
```

lightPos & fragPos are both positions but their reference frames
are different : <world> vs <model>

The subtraction implies an error

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Gator implementation (Cont.)

```
with frame(3) r:
coordinate cart3 : geometry {
  object vector is float[3];
  ...
}
```

```
float diffuse(
    cart3<world>.point lightPos,
    cart3<model>.point fragPos,
    cart3<model>.direction fragNorm,
    hom3<model>.transformation<world> uModel) {
  cart3<world>.direction lightDir =
    normalize(lightPos - (uModel * fragPos));
  return max(dot(lightDir, normalize(uModel * fragNorm)), 0.0);
```

We need to define an affine transformation matrix to transform
fragPos & fragNorm into world reference frame

Multiplying uModel & fragPos implies an error because the coordinate schemes are different

Gator implementation (Cont.)

```
coordinate hom3 : geometry {
    object point is float[4];
    object direction is float[4];
    with frame(3) r:
    object transformation is float[4][4];
    ...
}
```

```
float diffuse(
    cart3<world>.point lightPos,
    cart3<model>.point fragPos,
    cart3<model>.direction fragNorm,
    hom3<model>.transformation<world> uModel) {
  cart3<world>.direction lightDir =
    normalize(lightPos - reduce(uModel * homify(fragPos)));
  return max(dot(lightDir, normalize(reduce(uModel * homify(fragNorm)))), 0.0);
}
```

homify() allows us to go from cart3<model>.point to hom3<model>.point (w=1)
or to go from cart3<model>.direction to hom3<model>.direction (w=0)

reduce() allows to map Homogeneous to Cartesian coordinates

Subtyping in Gator

Object & type declarations extend existing types

All types must be given a supertype which can be a primitive type (**bool**, **int**, **float**, **string**, *array*) or a geometry type

Subtype of float

Example:

```
type angle  is float;
type acute  is angle;
type obtuse is angle;
```

Subtype of angle

Conclusion
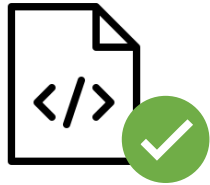
The Gator type system avoids statically incorrect coordinate system transformation codes

We can thus automatically generate a correct transformation code by construction

→ Programmers do not write vector-matrix multiplication calculations
→ Let the compiler find the right transformations

Gator helps to limit the number of geometry bugs

Limitations

The created abstraction remains low level
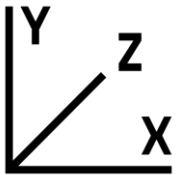
It's only based on coordinate system transformations

The syntax is a bit complicated

Inspiration

The notion of surface language

New types based on primitives

      color, light, texture, normal, (position)

A little less complicated syntax

Plan work

We will first build our AST (Abstract Syntax Tree)
by defining constructors

Then, we will build the DSL (Domain-Specific Language)

Abstract Syntax Tree (AST)

Tree in which, internal nodes are marked by operators and where external ones represent the operands

Examples:

Program

Root

Block

Internal

1
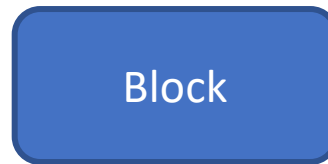
External

AST example
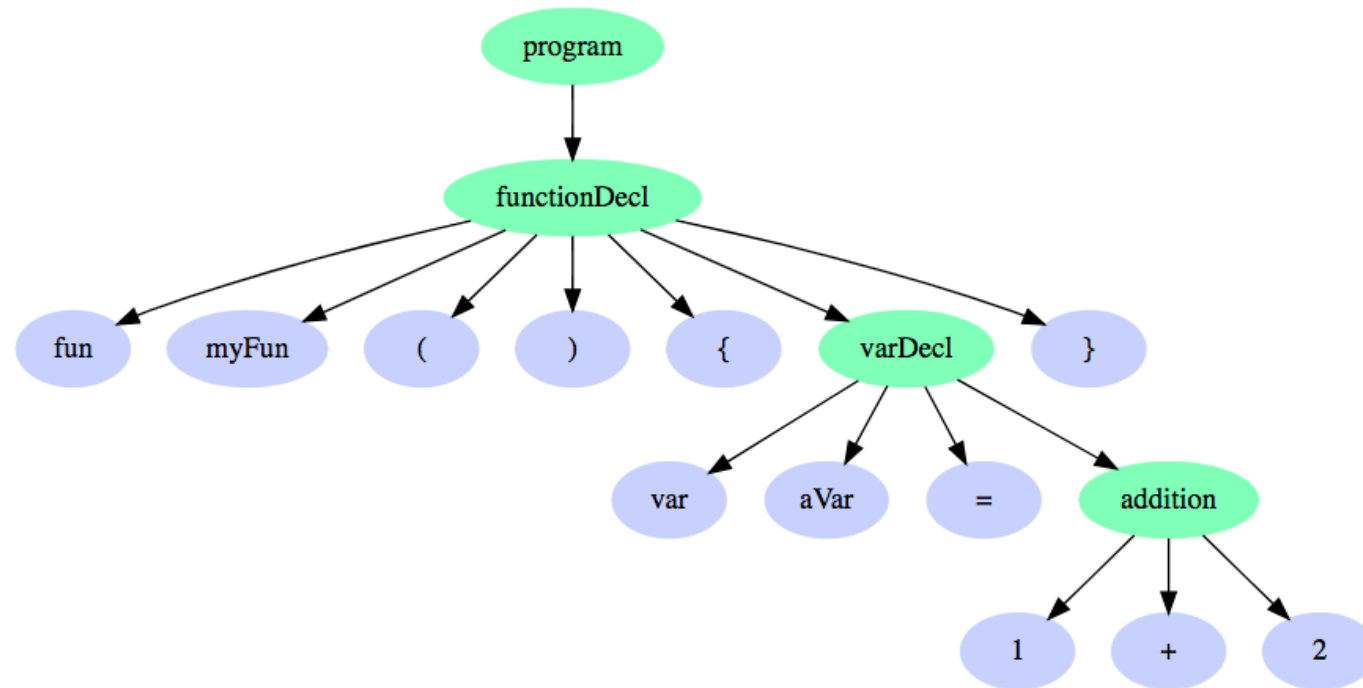
Some tools

Swift-AST-Explorer

Only supports Swift language

Structure representation with pop-up details
for each element of the code
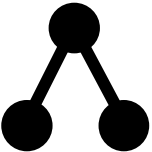
AST-Explorer

Supports a lot of languages like Java, HTML, Python, ... & GLSL

Tree or JSON representation

Examples

Swift-AST-Explorer

```
1 import Foundation
2
3 let num: Int = 5
4
5 func hello() -> String {
6     return "hello"
7 }
```

```
∨ CodeBlockItem
  ∨ FunctionDecl
      func
      hello
    ∨ FunctionSignature
      ∨ ParameterClause
          (
          FunctionParameterList
          )
      ∨ ReturnClause
          ->
        ∨ SimpleTypeIdentifier
            String
      ∨ CodeBlock
          {
        ∨ CodeBlockItemList
          ∨ CodeBlockItem
            ∨ ReturnStmt
                return
              ∨ StringLiteralExpr
                  "
                ∨ StringLiteralSegments
                  ∨ StringSegment
                      hello
                  "
          }
```

∨ Co

∨
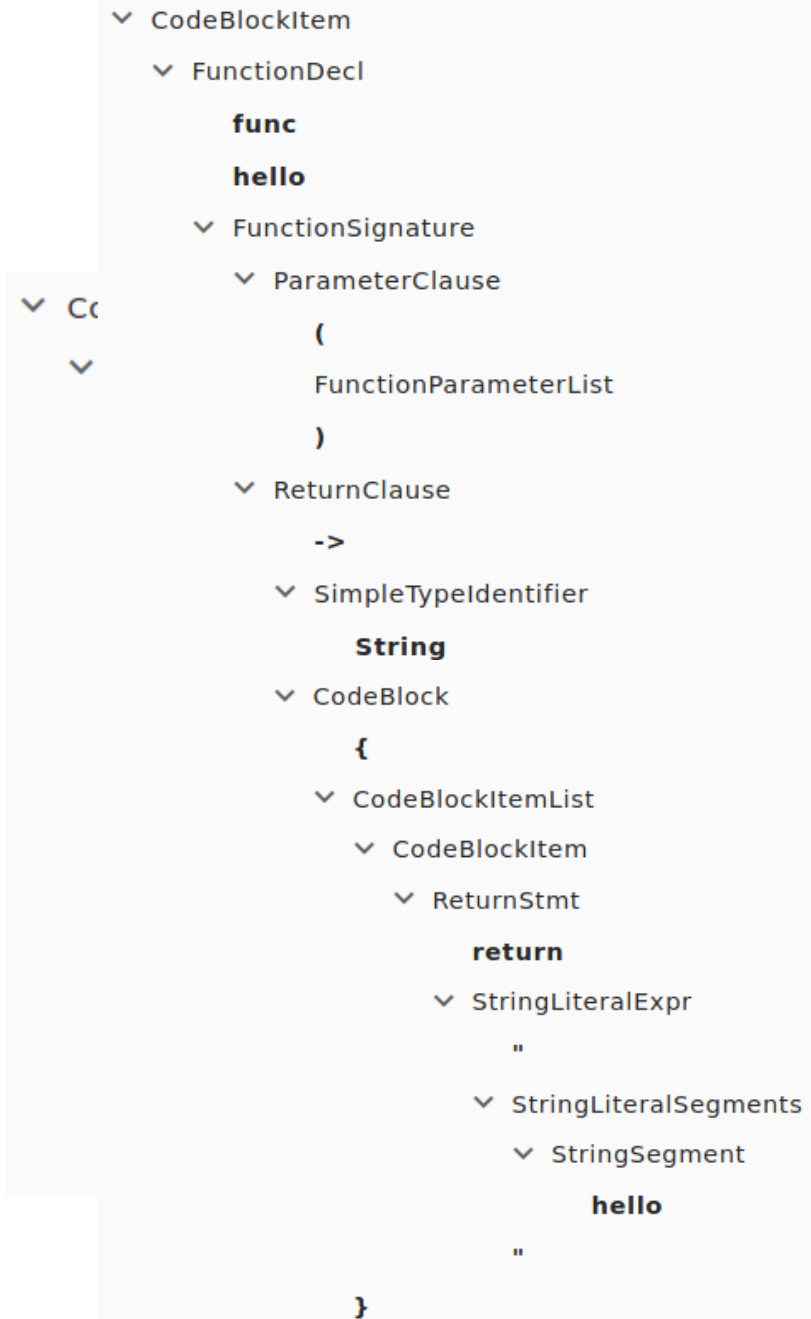
Examples (Cont.)

AST-Explorer

```
1 varying vec3 ourColor;
2
3 void main() {
4   FragColor = vec4(ourColor, 1.0f);
5 }
6
```

```
- children:  [
    + placeholder {mode, token, children, type, id}
    + placeholder {mode, token, children, type, id}
    + placeholder {mode, token, children, type, id}
    + placeholder {mode, token, children, type, id}
    + keyword {mode, token, children, type, id}
    - function  {
        mode: 4
      + token: operator {type, data, position, line, column}
        - children:  [
            + ident {mode, token, children, type, id, ... +2}
            + functionargs {mode, token, children, type, id}
            - stmtlist  {
                mode: 2
              + token: ident {type, data, position, line, column, ... +2}
                - children:  [
                    - stmt  {
                        mode: 1
                      + token: ident {type, data, position, line, column, ... +2}
                        - children:  [
                            - expr  {
                                mode: 11
                              + token: ident {type, data, position, line, column, ... +2}
                              + children: [1 element]
                                type: "expr"
                                id: "399d8c18.17fc04"
                              + expecting: [1 element]
                              + tokens: [8 elements]
                                parenlevel: 0
                                bracelevel: 0
                            }
```

GLSL 3.0 Grammar

Examples:

function_identifier:
    type_specifier
    IDENTIFIER
    FIELD_SELECTION

parameter_declarator:
    type_specifier IDENTIFIER
    type_specifier IDENTIFIER LEFT_BRACKET constant_expression RIGHT_BRACKET

expression:
    assignment_expression
    expression COMMA assignment_expression

First step

```
// inheritting from AST
class FunDecl: AST {
    let parameters: Parameter

    init(parameters: Parameter) {
        self.parameters = parameters
    }

    func build() {
      switch self.parameters.name {
      case .ident(let name):
        print("""
        \n#version 330 core\n\n
        \(self.parameters.retour) \(name)() {\n
        \(self.parameters.body)\n\n}
        """)
      case .ope(let name):
        print("""
        \n#version 330 core\n\n
        \(self.parameters.retour) \(name)() {\n
        \(self.parameters.body)\n\n}
        """)
      }

    }
}
```

```
struct Parameter {
    let retour: String
    let name: Name
    let body: String
}
```

```
// function name is: identifier | operator
enum Name {
    case ident(String)
    case ope(Ope)
}

// Here need to redefine +,-,*,/
enum Ope {
    case plus
    case minus
    case mult
    case div
}
```

First step (Cont.)

```
let retourFunc = "void"
//let nameFunc = Name.ope(Ope.plus)
let nameFunc = Name.ident("main")
let bodyFunc = "FragColor = vec4(ourColor, 1.0f);"

let param: Parameter = Parameter(retour: retourFunc, name: nameFunc, body: bodyFunc)
let function = FunDecl(parameters: param)

function.build()
```

```
#version 330 core

void main() {

FragColor = vec4(ourColor, 1.0f);

}
```

Some questions

Do we need to create an AST for every operation we can do in a shader?
(import statement, variables & constants definition, create struct, etc.)

Do we need to create a lexer (tokens, whitespaces, etc) / interpreter ?

About abstract types, what is exactly Datastructure ?

Work incoming

Construct the AST

Define the abstract types

References (Links)

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https://fr.wikipedia.org/wiki/Grammaire_formelle

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https://astexplorer.net/

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Working with shaders

Patrick SARDINHA