

# Working with shaders

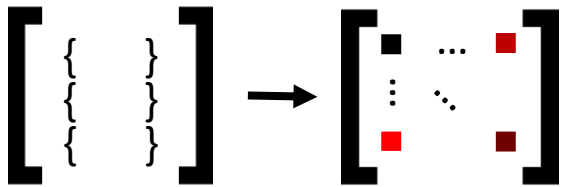
Patrick SARDINHA

# What's a shader?

Small programs that run on the GPU

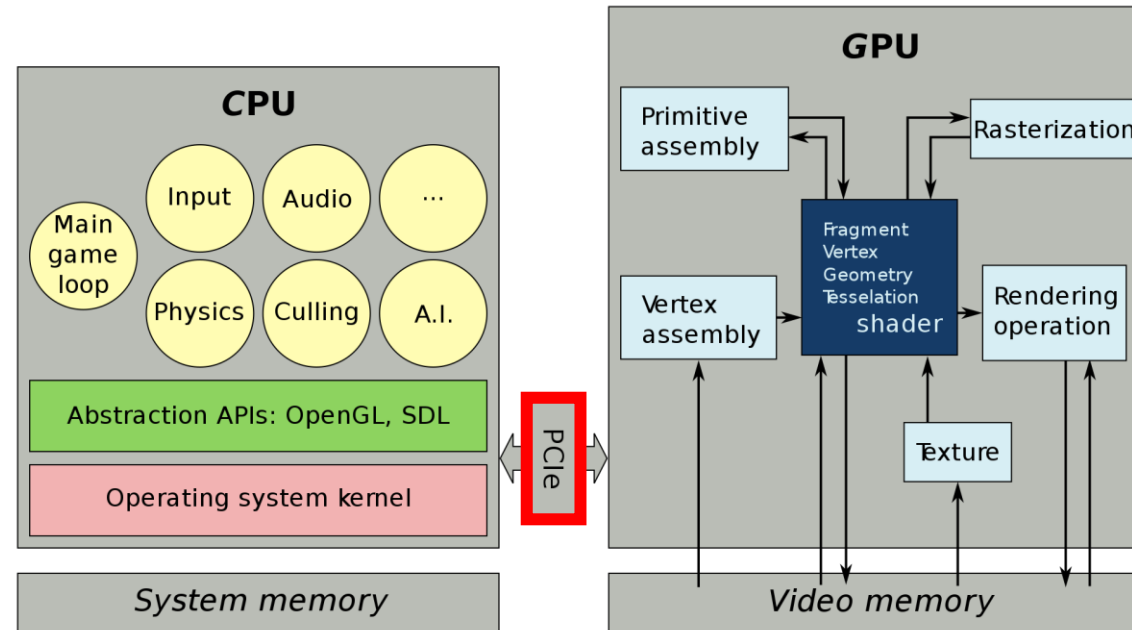
Executed for each specific section of the graphics pipeline

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)

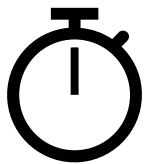
# Problem



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

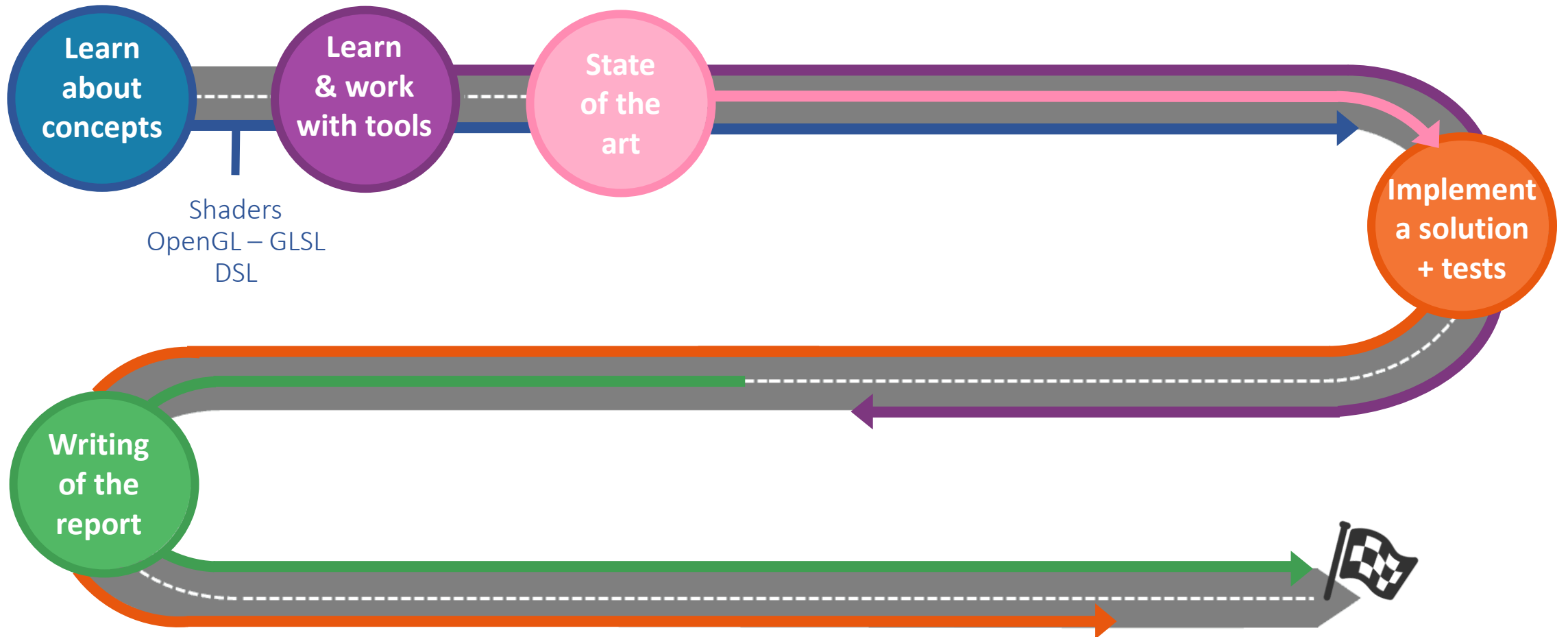


Work with the representation of the data  
& abstract the types



Construct a DSL for shaders

# Road map



# 3D space to 2D screen space



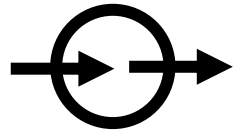
The process of transforming 3D coordinates to 2D pixel is done by the [graphics pipeline](#)

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

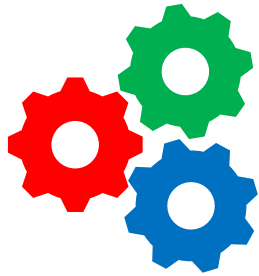
Second big part: transforms the 2D coordinates into actual colored pixels



# Graphics pipeline



Input & Output Data

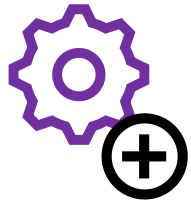


3 different shaders processing units

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 (**R****G****B**, ...)

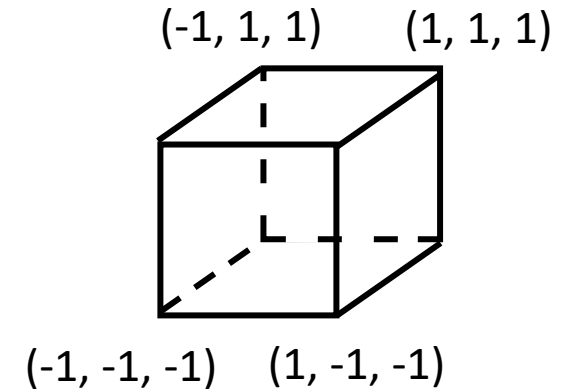


Texture coordinates



# Example

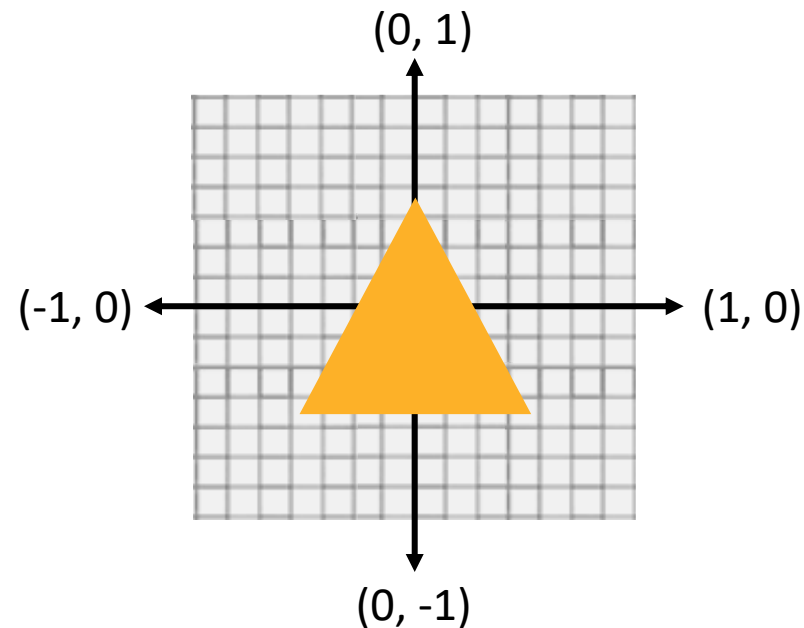
In OpenGL, only the Normalize Device Coordinates (NDC) are visible on the screen



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  
};
```



# Linking vertex attributes

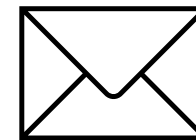


The input data will compose a **Vertex Buffer Object (VBO)** which can store a large number of vertices in the GPU memory

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

Specifies the target buffer object

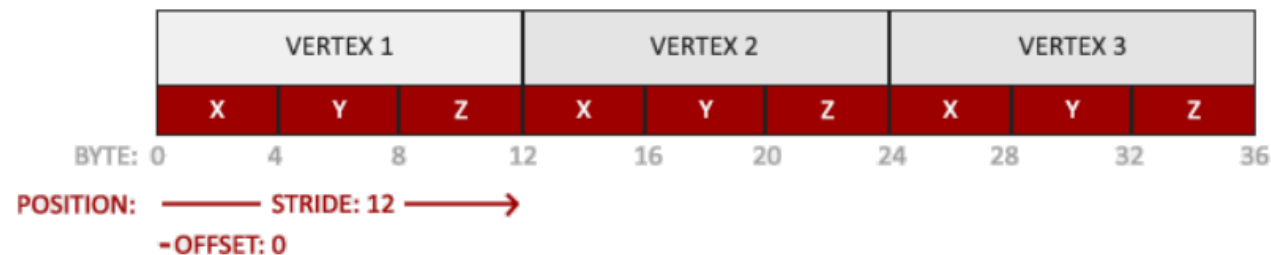
ID of the buffer which must be bind

```
glBindBuffer(GL_ARRAY_BUFFER, VBO);  
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices, GL_STATIC_DRAW);
```

Size of the buffer object

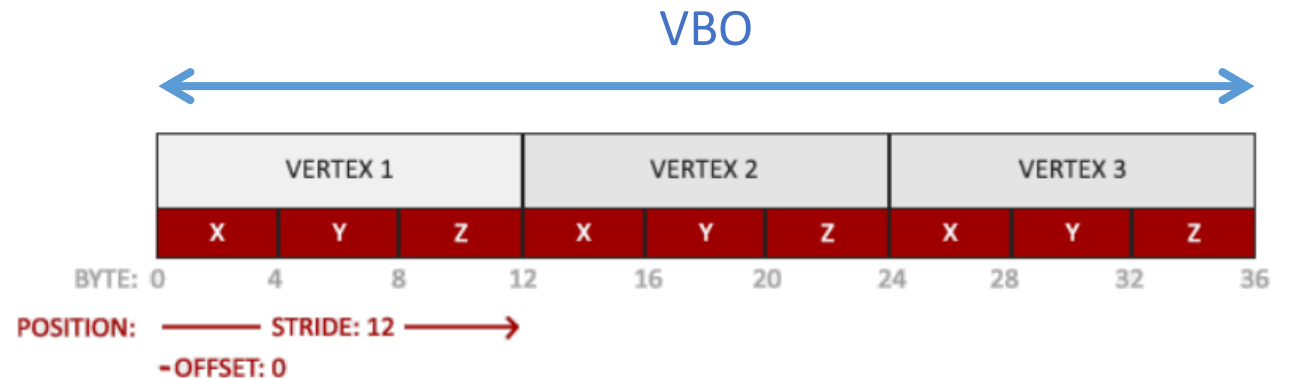
Pointer to data

VBO



# Example (Cont.)

Define how the vertex data should be interpreted



Specifies which vertex attribute

The size of the vertex attribute

Normalized data or not

Offset of where the position data begins in the buffer

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

Enable the vertex attribute

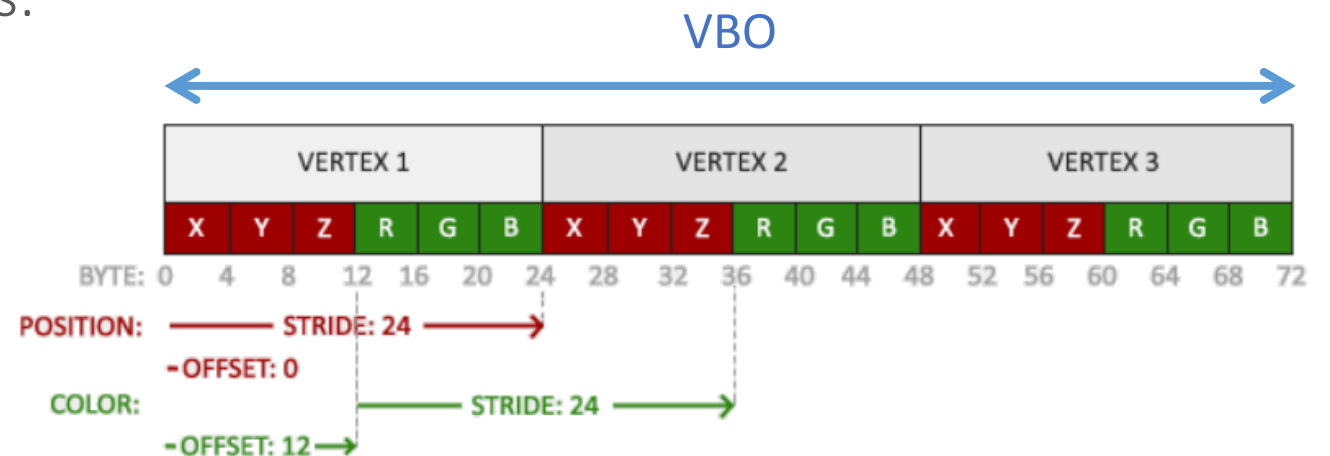
Type of the data

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  
};
```



```
// 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);
```

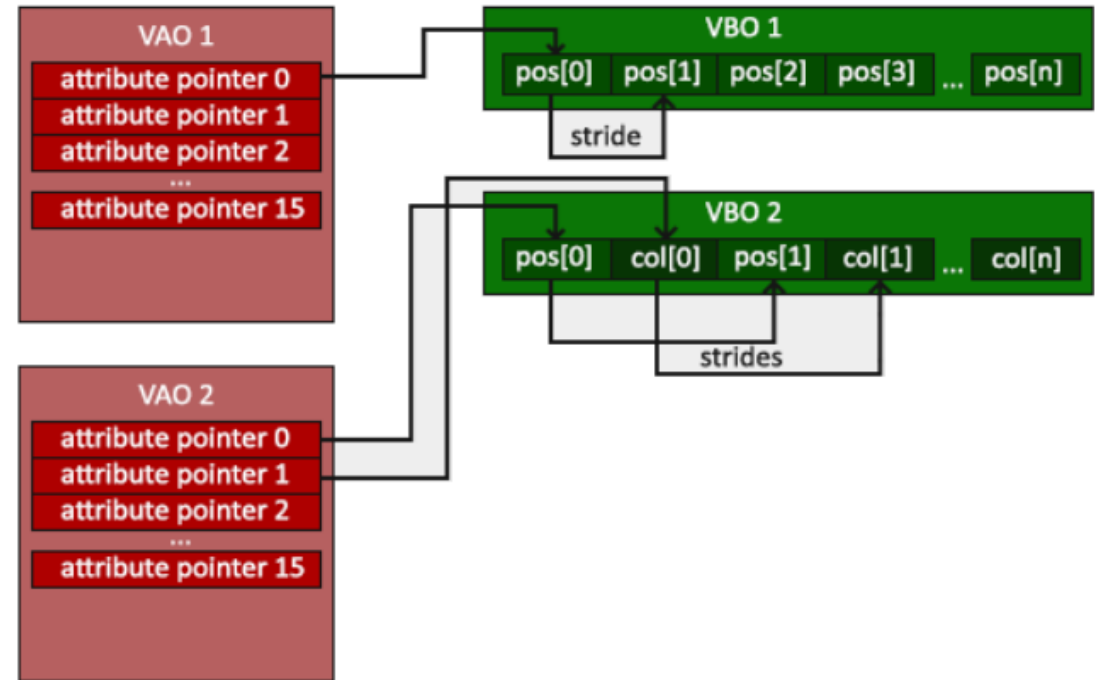
Stride

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:

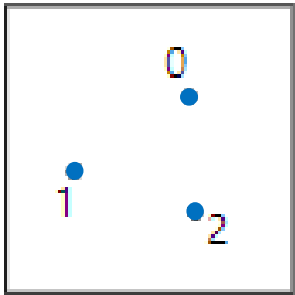


Set up a Vertex & a Fragment Shader

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

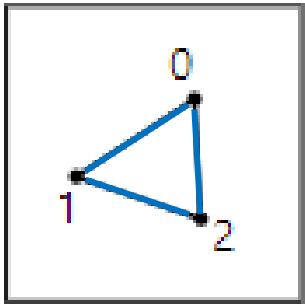
The diagram shows a GLSL vertex shader code snippet with several annotations:

- Shader's version (here 3.3)**: A red arrow points to the `#version 330 core` line, which is enclosed in a red box.
- Specifically set the location of the input variable**: A blue arrow points to the `location = 0` part of the `layout` statement, which is underlined in blue.
- All the input vertex attributes**: A pink arrow points to the `in vec3 aPos;` line, which is enclosed in a pink box.
- Output of the vertex shader**: A brown arrow points to the `gl_Position` variable in the assignment statement, which is underlined in brown.
- (x, y, z) + w component**: A green arrow points to the `aPos.x, aPos.y, aPos.z, 1.0` list of arguments in the `vec4` constructor, which is underlined in green.

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

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

# 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);
```

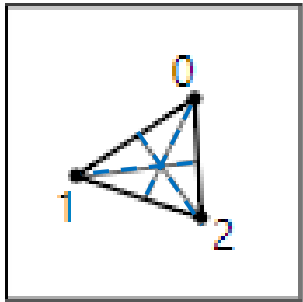
OpenGL function  
that draws a shape

Kind of primitive to render

Starting index in the array

Number of vertices to render

# Tessellation



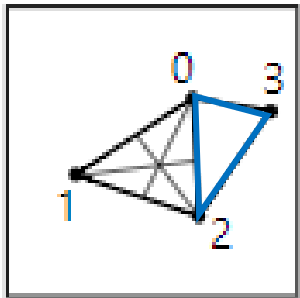
In 3D, the surfaces are built with triangular tiles

Tessellation allows to double triangles on a given surface and therefore increase the level of details

# Geometry Shader



An unnecessary step



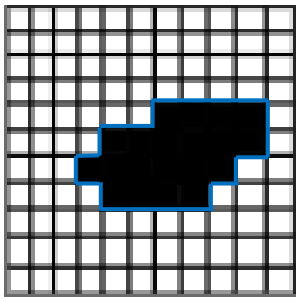
Allows to modify the geometry of each polygon and allows to create new polygons by emitting new vertices

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

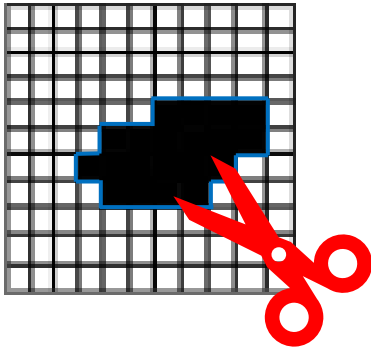


Vector image  
composed of geometric objects

Raster image or Bitmap  
composed of pixels

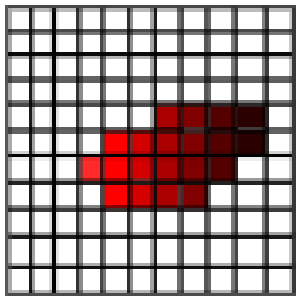


# Clipping



This step discards 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)

Output variable which is  
the final color output

```
#version 330 core
out vec4 FragColor;

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

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"
    "}\n0";
```

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);
```

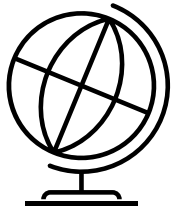
We can now activate this program to render and draw an object

```
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:

Usage of uniform keyword

```
#version 330 core
out vec4 FragColor;

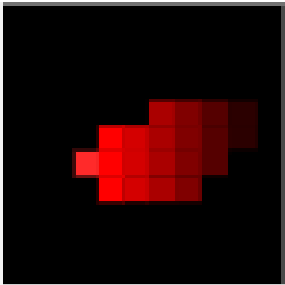
uniform vec4 ourColor;

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

# 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 

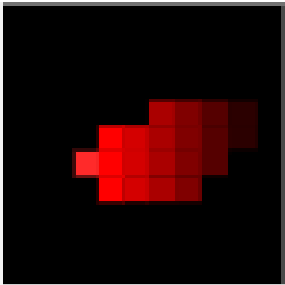


Done with the depth testing using a **Z-buffer** (in which the depth value of the fragments is stored)

```
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:

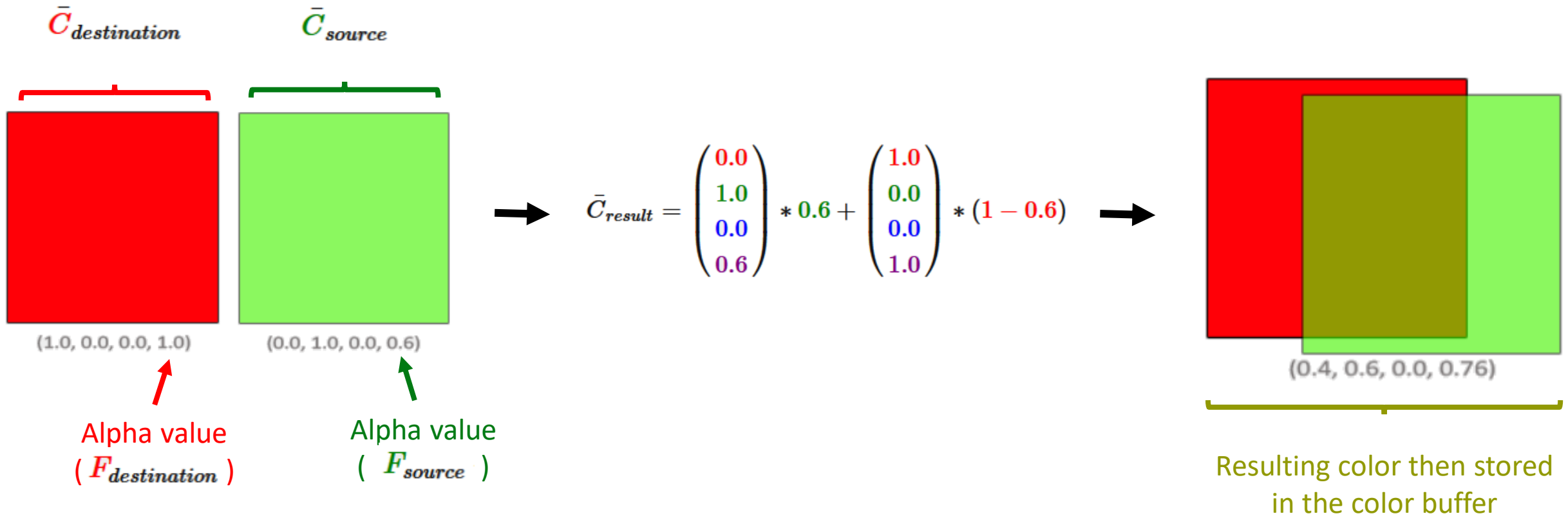
$$\bar{C}_{result} = \bar{C}_{source} * F_{source} + \bar{C}_{destination} * F_{destination}$$

The diagram illustrates the blending equation with color-coded terms and arrows explaining their meaning:

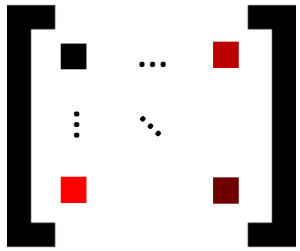
- $\bar{C}_{result}$ : Final color of the fragment (indicated by a blue arrow)
- $\bar{C}_{source}$ : Color output of the fragment shader (indicated by a green arrow)
- $F_{source}$ : Impact of the alpha value (indicated by a green arrow)
- $\bar{C}_{destination}$ : Color currently stored in the color buffer (indicated by a red arrow)
- $F_{destination}$ : Impact of the alpha value (indicated by a red arrow)

## Example (Cont.)

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



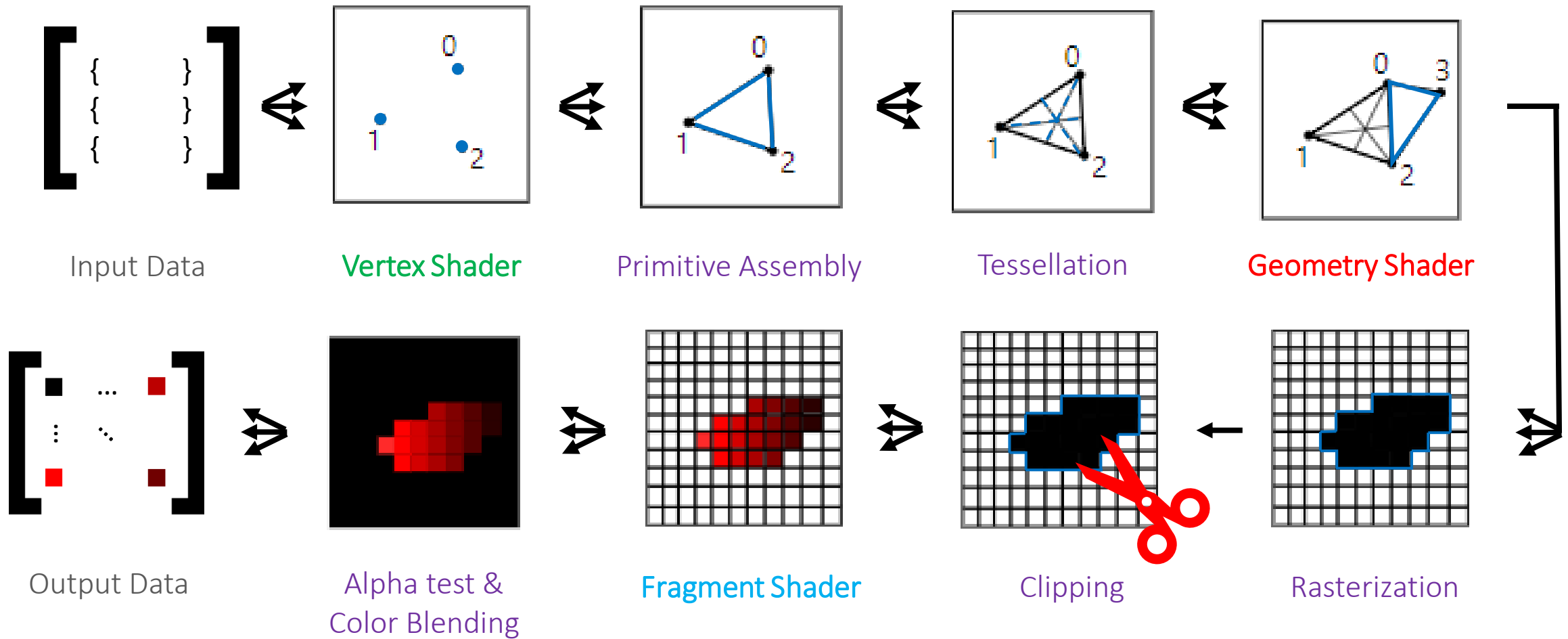
# Output Data



Return a **Framebuffer**

The information in this buffer are the values of the color components (**R****G****B**) for each pixel

# Overall view



# Textures

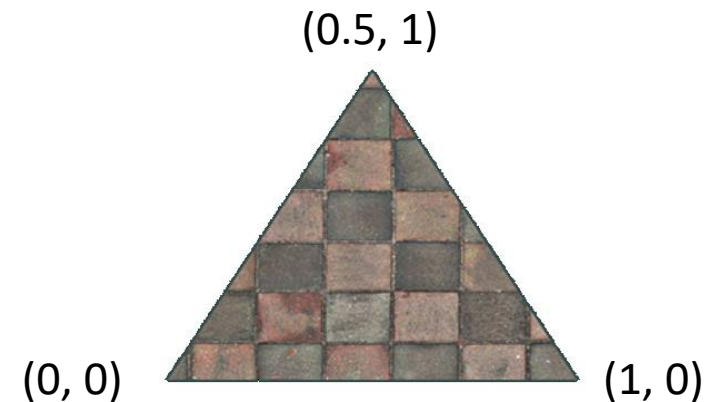
Allows to give the illusion the object is detailed  
without having to specify vertices

Associate each vertex to a texture coordinate

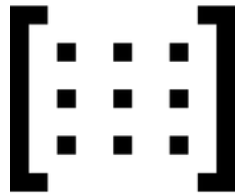
A fragment interpolation is then done for the other fragments

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  
};
```



# 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

## 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

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

## Rotation Matrix

### 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

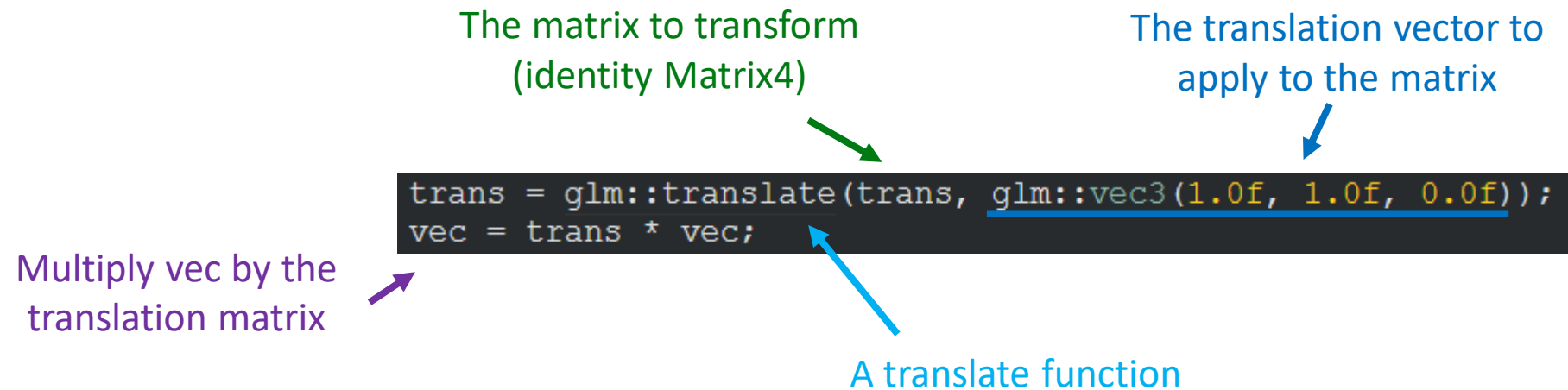
$$\begin{bmatrix} \cos \theta & 0 & \sin \theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin \theta & 0 & \cos \theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix} = \begin{pmatrix} \cos \theta \cdot x + \sin \theta \cdot z \\ y \\ -\sin \theta \cdot x + \cos \theta \cdot z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

### 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 diagram illustrates the process of translating a vector using GLM. It features a code block with two lines of C++ code. Four annotations with arrows point to specific parts of the code: a green arrow points to the first 'trans' argument in the `glm::translate` function call, labeled 'The matrix to transform (identity Matrix4)'; a blue arrow points to the `glm::vec3(1.0f, 1.0f, 0.0f)` argument, labeled 'The translation vector to apply to the matrix'; a purple arrow points to the `vec = trans * vec;` line, labeled 'Multiply vec by the translation matrix'; and a light blue arrow points to the `glm::translate` function name, labeled 'A translate function'.

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

The matrix to transform  
(identity Matrix4)

The translation vector to  
apply to the matrix

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

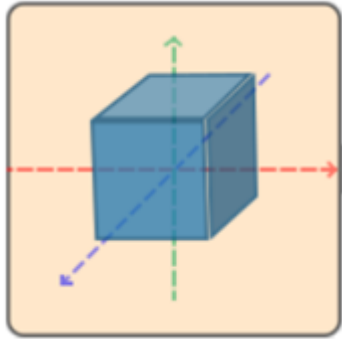
Clip Space



Screen Space



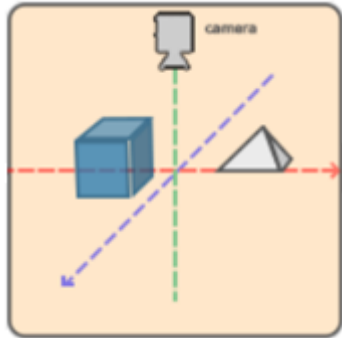
# Local Space



Coordinates of the object relative to its local origin

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

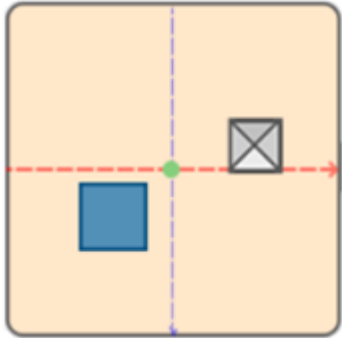
# World Space



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

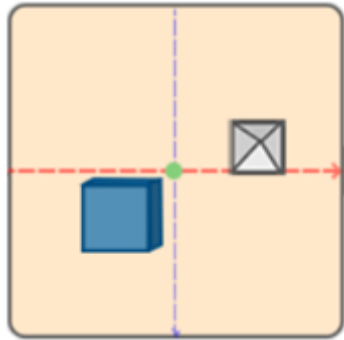
# View Space



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 view matrix

# Clip Space



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

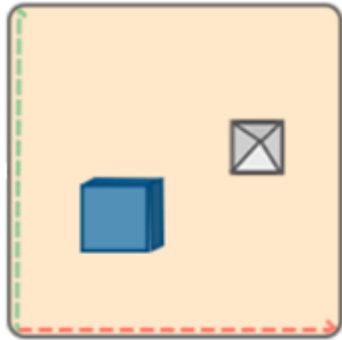
For this step, we use a projection matrix which transform the coordinates into NDC

Example:

Specified range  $[-1000, 1000]$   
for each dimension

{	$(1250, 500, 750)$	→	Not visible
	$(900, 500, 750)$	→	Visible

# Screen Space

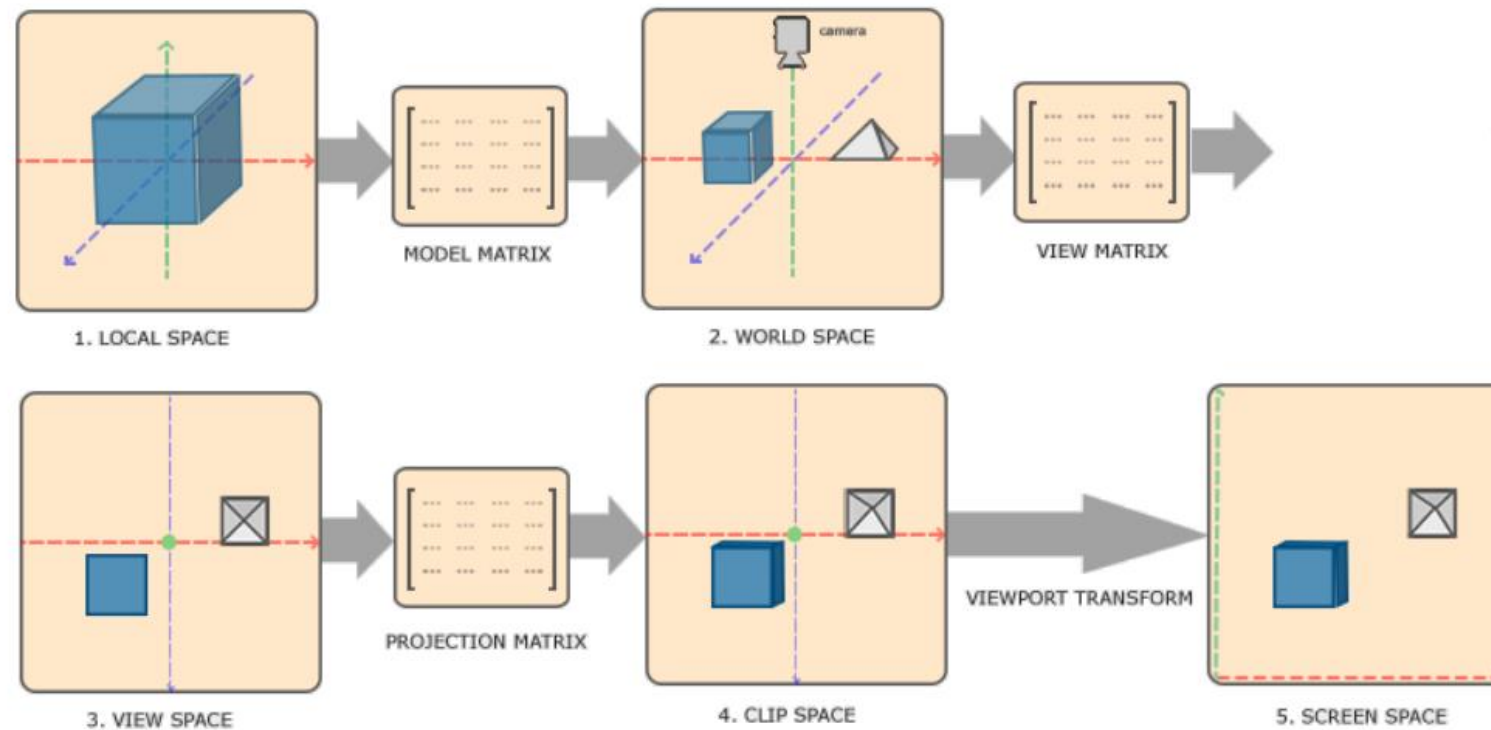


Transforms the NDC coordinates to the window coordinates with the *glViewport()* function

Resulting coordinates are then sent to the rasterizer

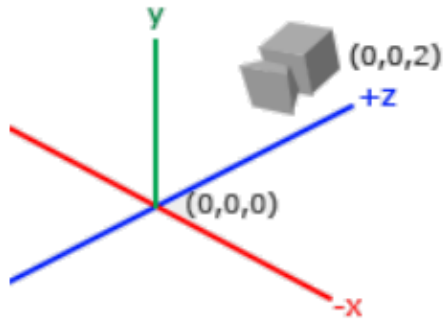
# Overall view

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

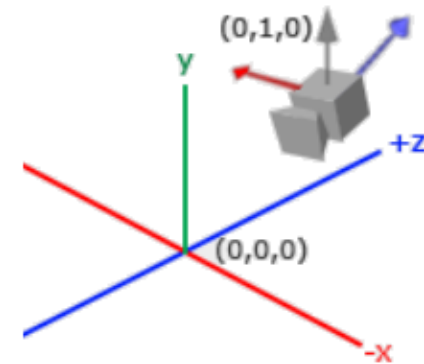


# Camera

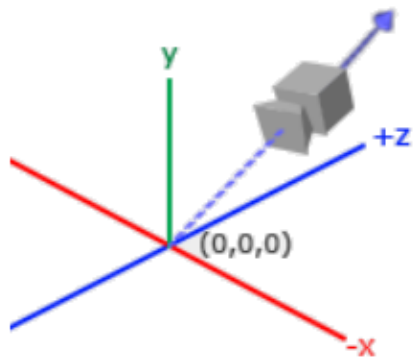
To define a camera we need 4 pieces of information



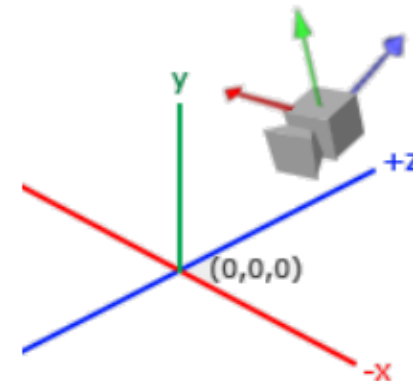
1. Its position in the world space



3. A vector pointing to the right



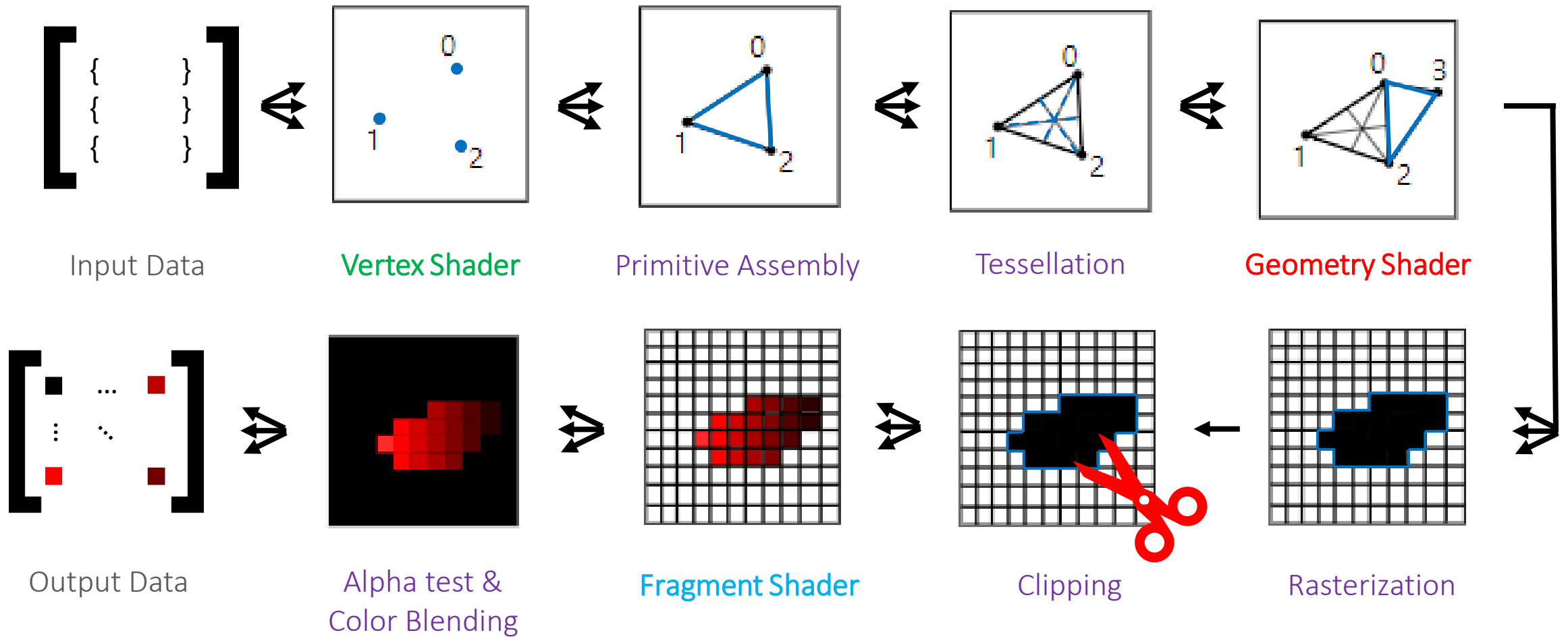
2. Its direction



4. A vector pointing upwards



# Recall : Graphics pipeline



# 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



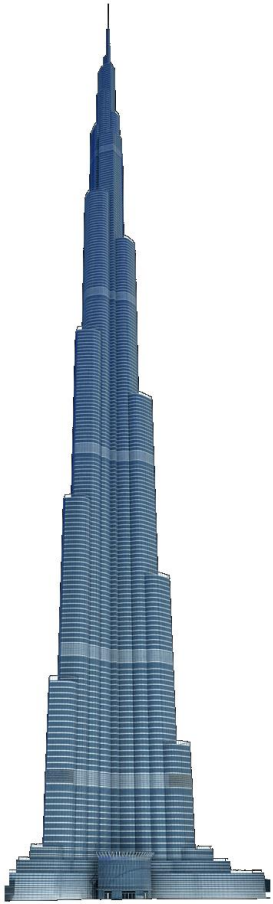
# Context

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

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

# 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

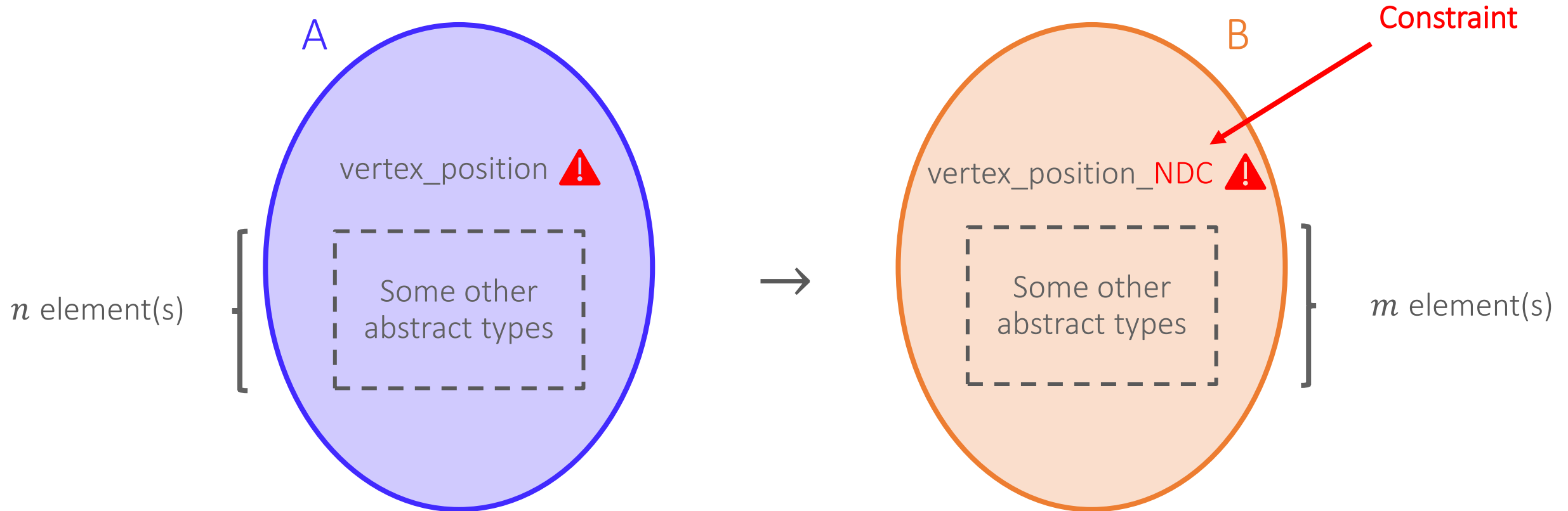
Ex: ~~vec3, vec4, ivec4, mat4, ...~~



But with abstract type objects

Ex: color, position, textures, ...

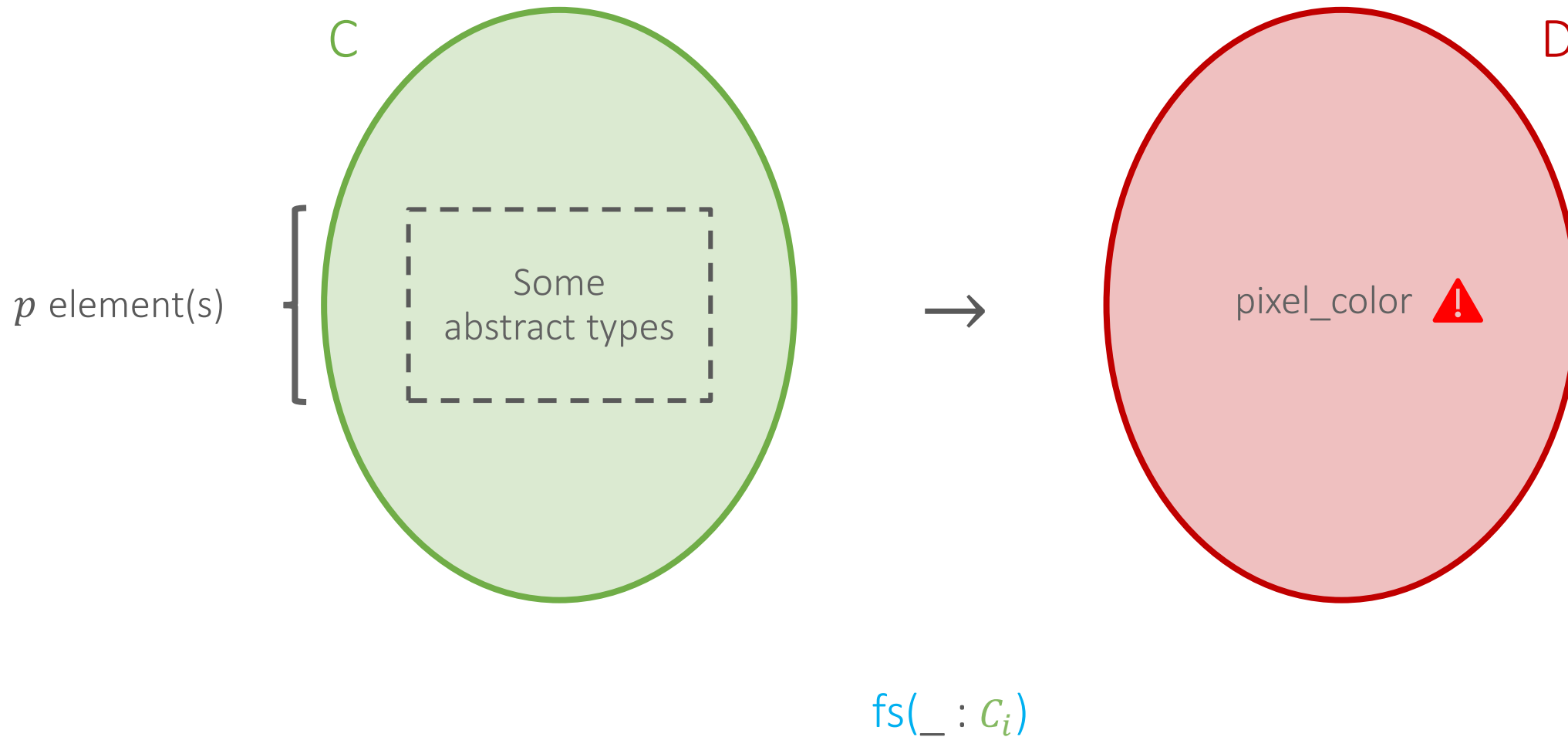
# Vertex Shader function $vs : A \rightarrow B$



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

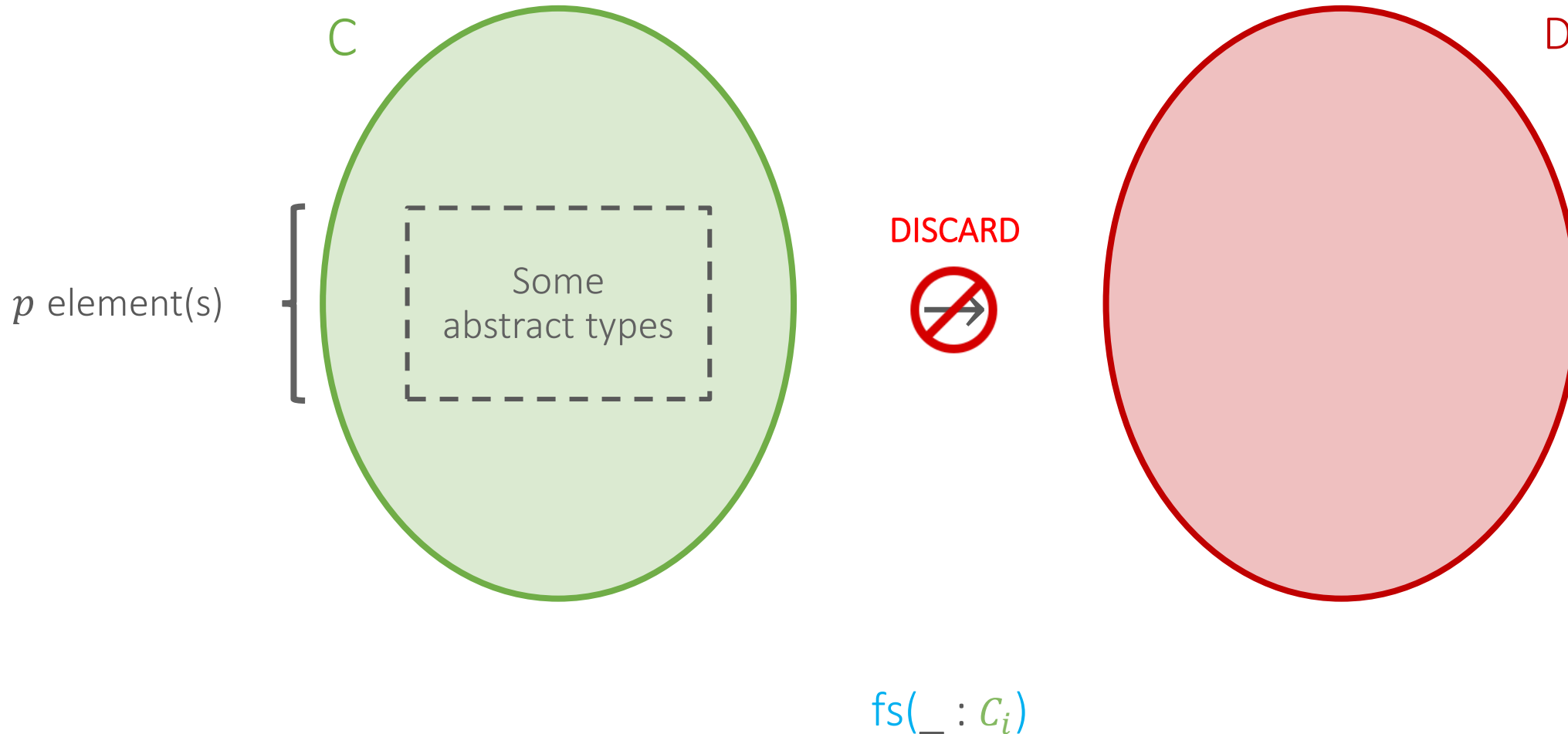
# Fragment Shader function

$$fs : C \rightarrow D$$



# Fragment Shader function Alternative

$fs : C \rightarrow D$





# Several signatures



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

Examples:

`vs(_ : position)`

`fs()`

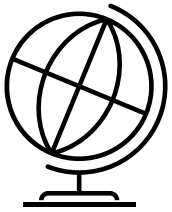
`vs(_ : position, _ : color)`

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

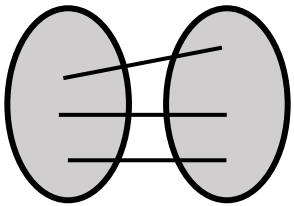
`vs(_ : position, _ : color, _ : texture:)`

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

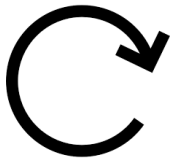
# Uniforms



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);
}
```

Vertex shader

```
#version 330 core
out vec4 FragColor;

in vec4 vertexColor;

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

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

Calculate output  
coordinates & colors

Output

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

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

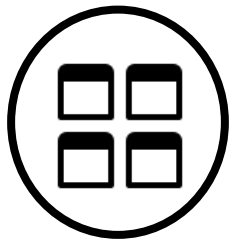
// vertex shader main entry
VertOut main(VertIn IN, uniform float4x4 modelViewProj) {
    VertOut OUT;
    {
        OUT.pos      = mul(modelViewProj, IN.pos);
        OUT.color    = IN.color;
    }
    return OUT;
}
```

Uniform keyword

# 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

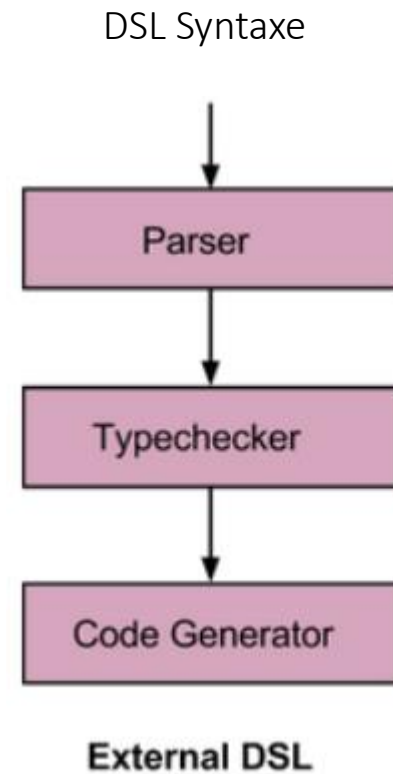
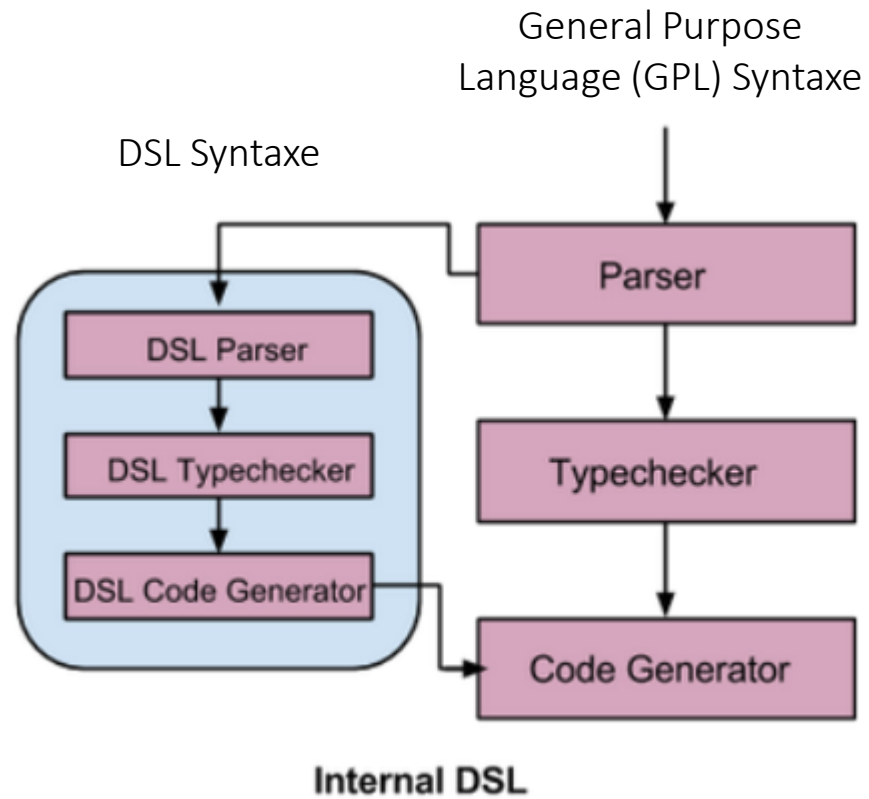


DSL maintenance is complicated

The cost of a DSL is expensive



# Different types of DSL



# 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



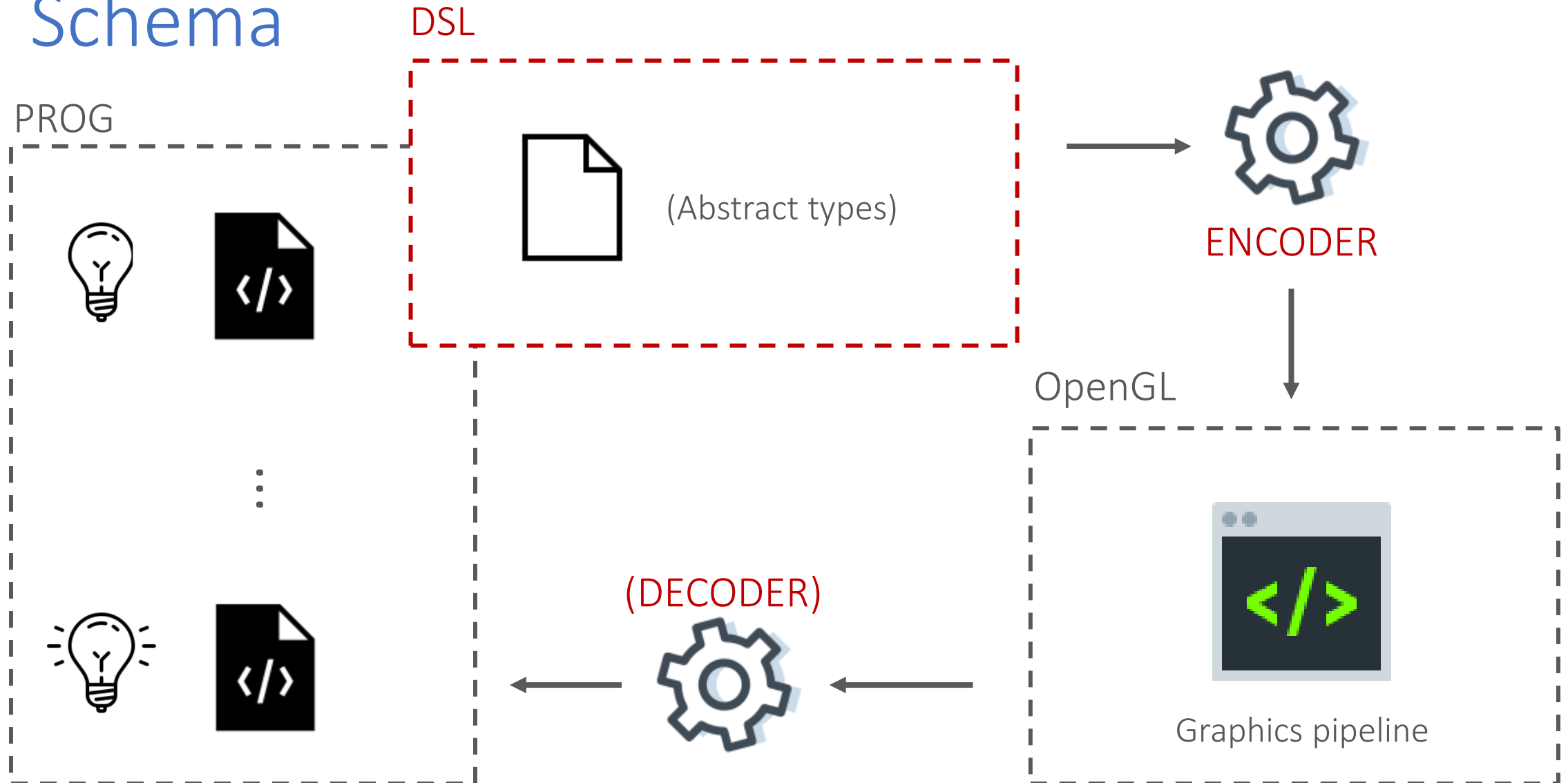
This translation can then be evaluated by the  
graphics pipeline of OpenGL



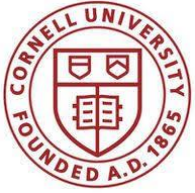
( Then a decoder allows us to get the results  
with the desired abstract types )



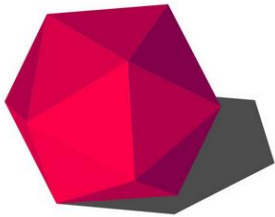
# Schema



# Gator



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

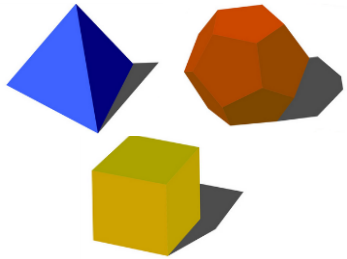


Higher level programming model that allows focus on the geometric semantics of programs

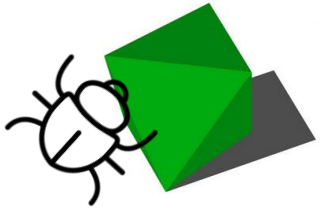


Gator is a **surface language** with an extended type system  
based on a **target language** with a type set (GLSL)  
A type-directed translation allows to compile Gator to GLSL

# Problem & ideas



3D scenes consist of many individual objects & the rendering code must combine vectors of different coordinate systems

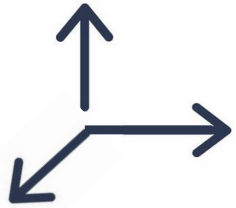


Geometry bugs are difficult to detect



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.)

```
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.)

```
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:  $[x, y, z, w] \rightarrow [x/w, y/w, z/w]$

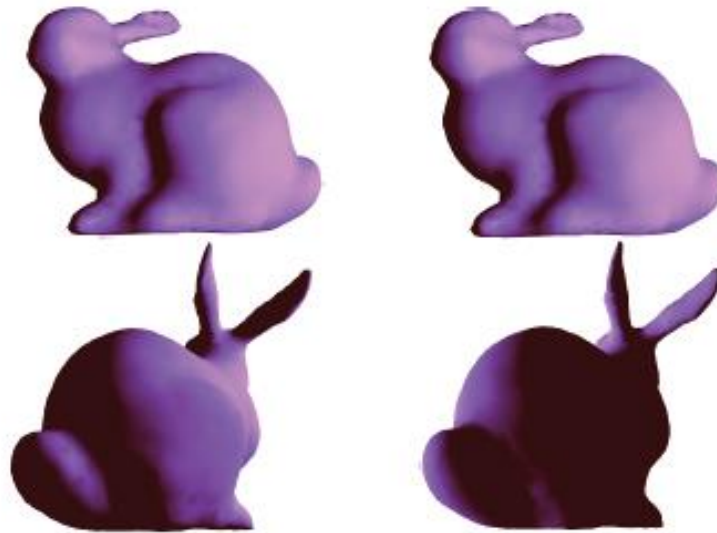
## GLSL implementation (Cont.)

```
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

frame model has dimension 3;  
frame world has dimension 3;

## 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

## 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.)

```
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);  
}
```

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

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

Example:

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

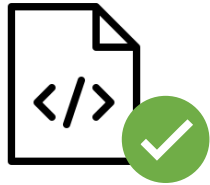
Subtype of float



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

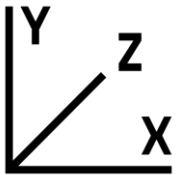


Gator helps to limit the number of geometry bugs

# 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



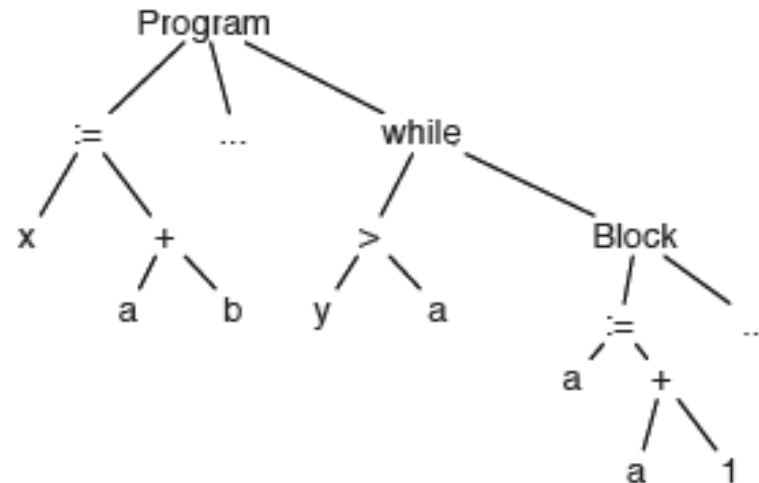
# Abstract Syntax Tree (AST)



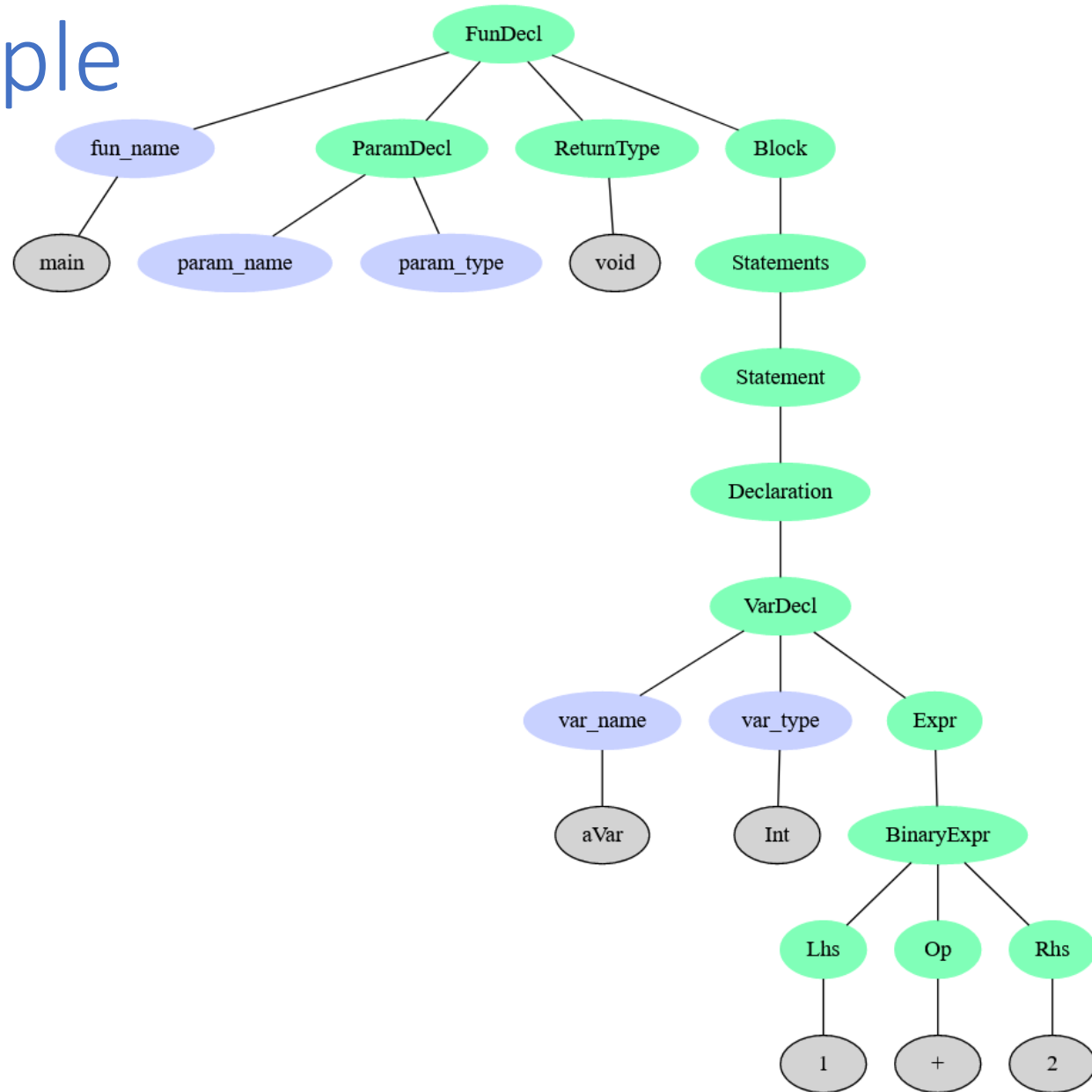
Tree in which, internal nodes are marked by operators and where external ones represent the operands

Example:

```
x := a + b;  
y := a * b;  
while (y > a) {  
    a := a + 1;  
    x := a + b  
}
```



# AST example



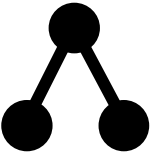
# Some tools



Swift-AST-Explorer

Only supports Swift language

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



AST-Explorer

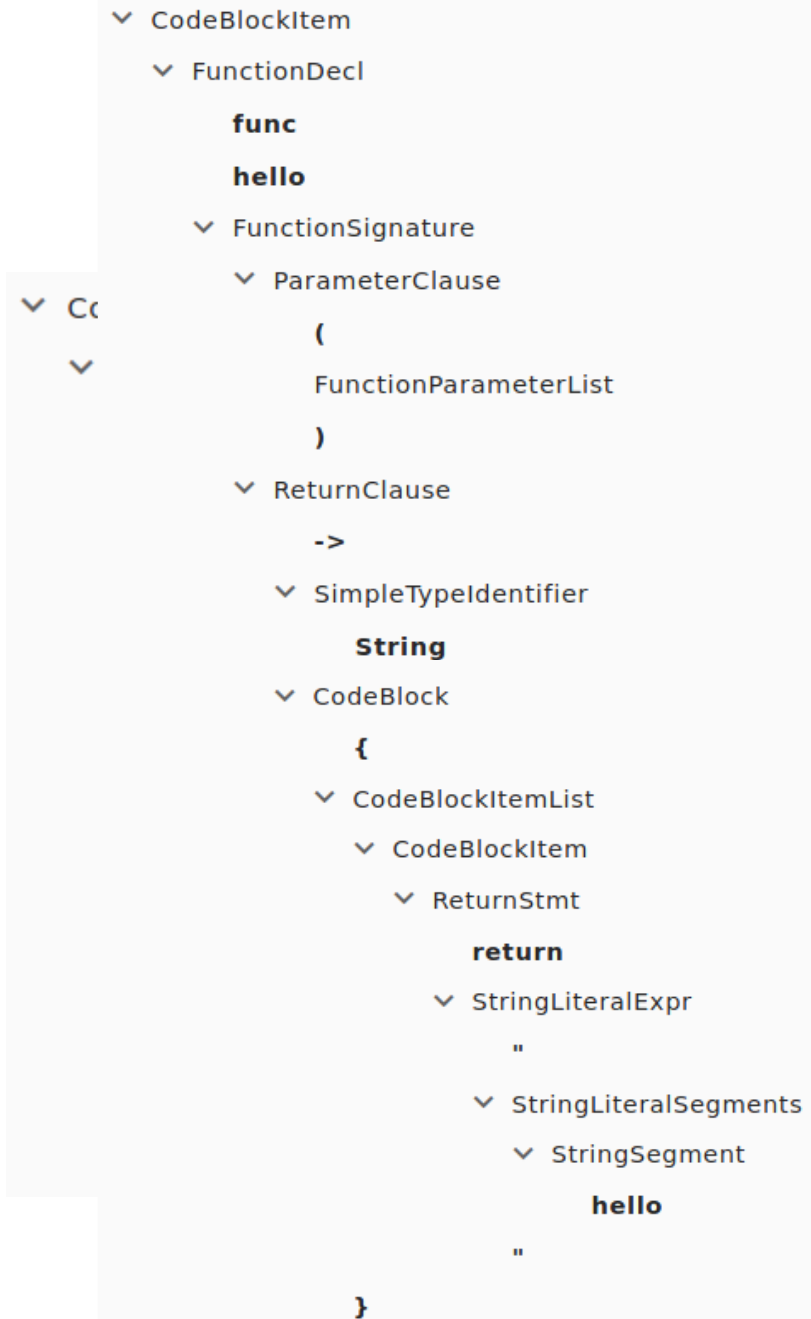
Supports a lot of languages like Java, HTML, Python, ... & GLSL

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 }
```





# 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*

# DynaSOAr

Here, we will be based on the idea of DynaSOAr



Which is an object-oriented language for manipulating objects

# General idea

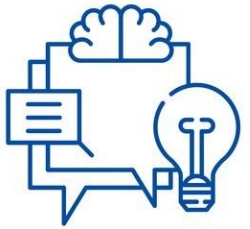


We want to have the perfect language for our use-cases

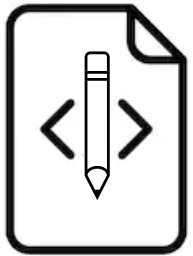


We want to have high-level objects that can be handled in a simple way

# Development



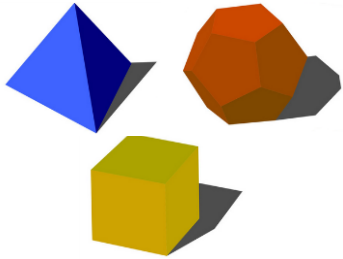
First, we must define our language and the concepts we want



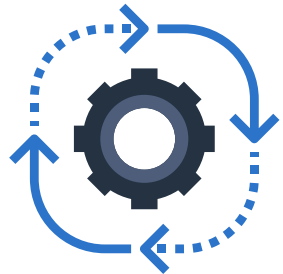
Then, we must specify the syntax of this language

# Concepts

## Use-cases



Our needs are to write graphics applications  
in which we manipulate 3D objects



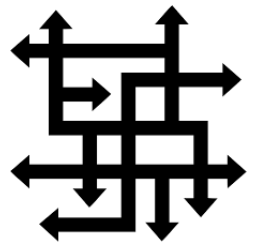
We want to call methods on them, do calculations, etc.

# Concepts

## Limitations



Here, we want to define everything that it would be possible to do for users ...



... but it's complicated to be complete

# Concepts

The abstractions that we need to write an application with 3D objects are:



The position of the objects



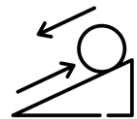
The type of the objects



The color of the objects



The operations linked to these objects

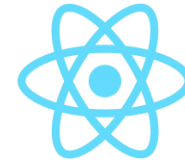


The physics of the objects

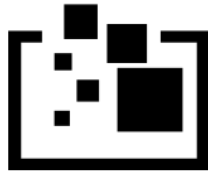


# Declarative Language

We are moving towards a **declarative** language inspired by React



React is based on the notions of:



Components, Properties and States



Render function, Update functions

# React - Component



The component system allows us to consider each piece of code independently



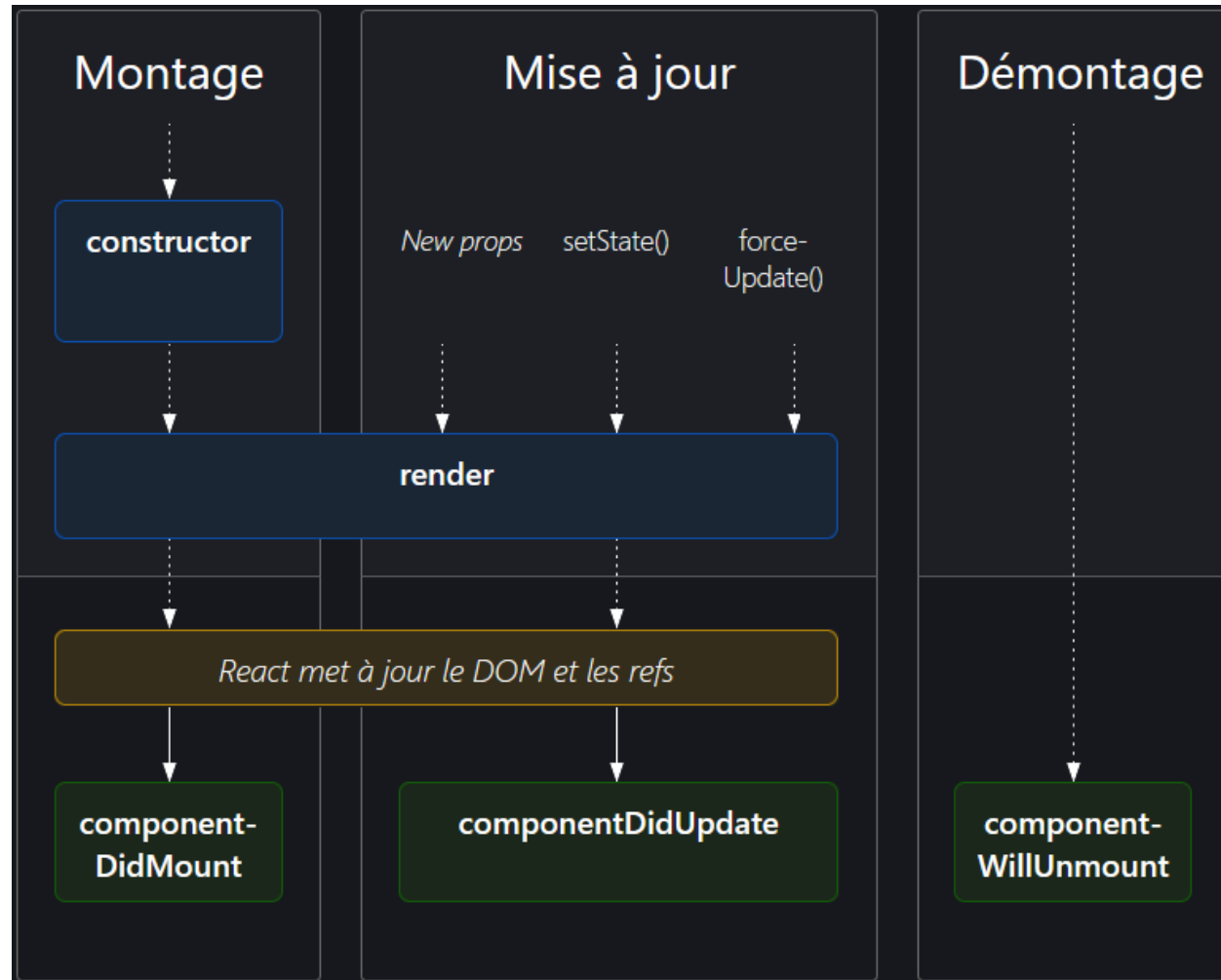
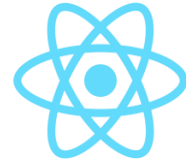
We can then combine different components to get something more complex

Example:

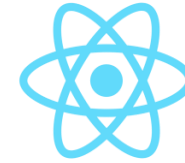
```
function Welcome(props) {  
  return <h1>Bonjour, {props.name}</h1>;  
}
```

```
class Welcome extends React.Component {  
  render() {  
    return <h1>Bonjour, {this.props.name}</h1>;  
  }  
}
```

# React - Life cycle



# React - Constructor, Props & State



`this.props` contains the properties defined by the caller of the component

A component should never modify its own properties



Local state contains component-specific data, which may change over time

To modify the local state of a component we use `setState()`

# React - Render()



The render() method takes data as input and returns what should be displayed.

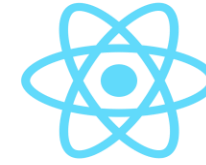


When the local state of a component changes, its display is updated by calling render()



We use a tick() function to update every second / frame

# React - componentDidMount() & componentDidUpdate()



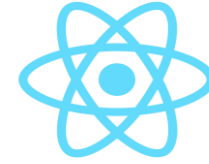
`componentDidMount()` is called immediately after the component is mounted

This is where we make the subscriptions



`componentDidUpdate()` is called immediately after the update has taken place.

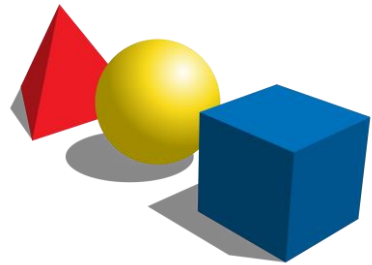
# React - `componentWillUnmount()`



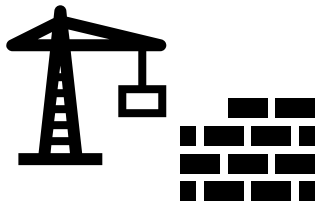
`componentWillUnmount()` is called immediately before a component is unmounted or destroyed.

Here we delete the subscriptions made in `componentDidMount()`

# Idea for our language



We give basic geometric objects which are the **cube**, the **sphere** and the **pyramid**



Users can combine its different geometric shapes to get more complex objects



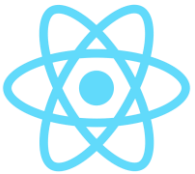
# Syntax



We define in the syntax how we would like to define and manipulate the objects



Our goal is to have a simple and meaningful syntax



The syntax will be based on React

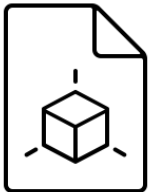
# React to our language



We use this notion of components to declare and define a geometric object

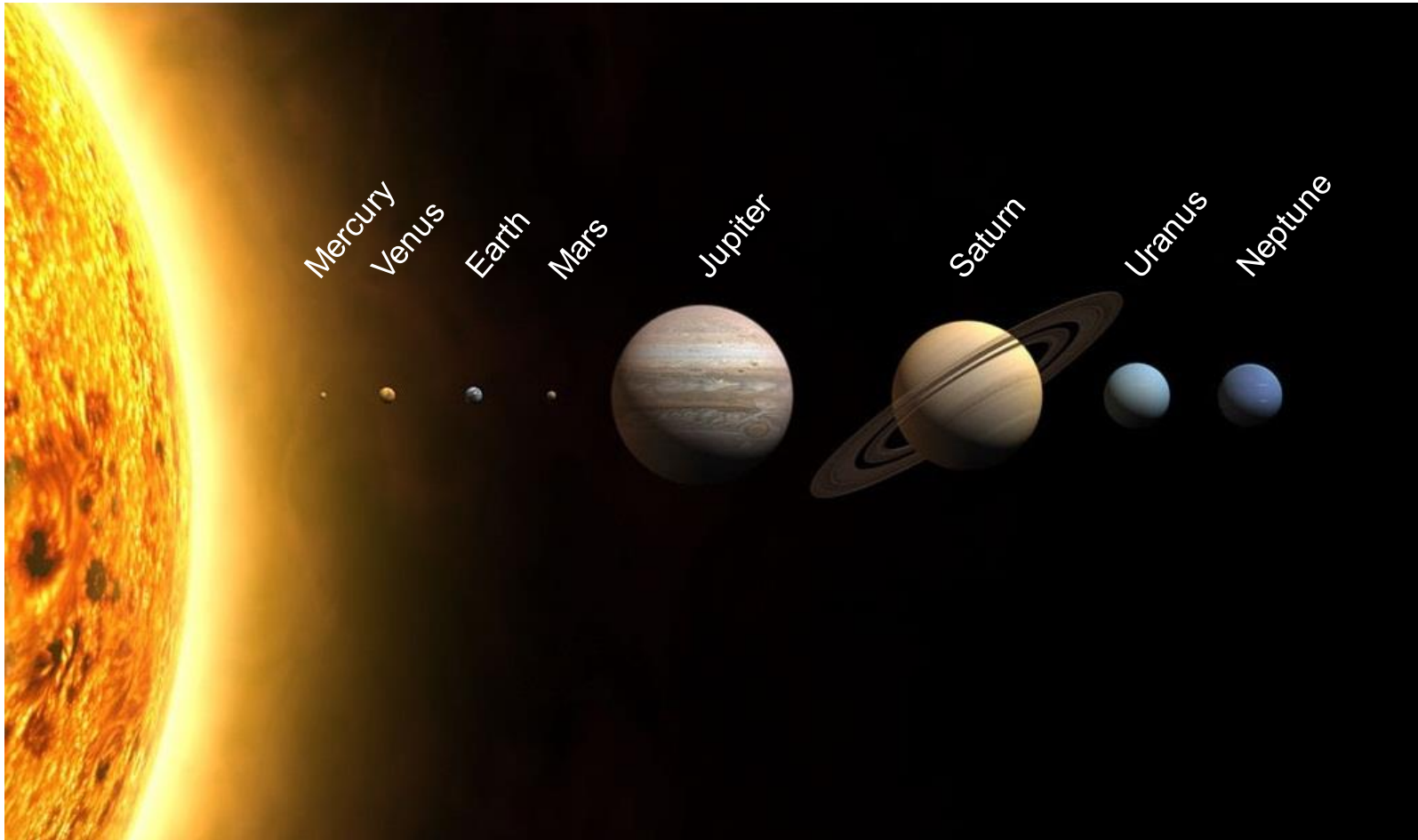


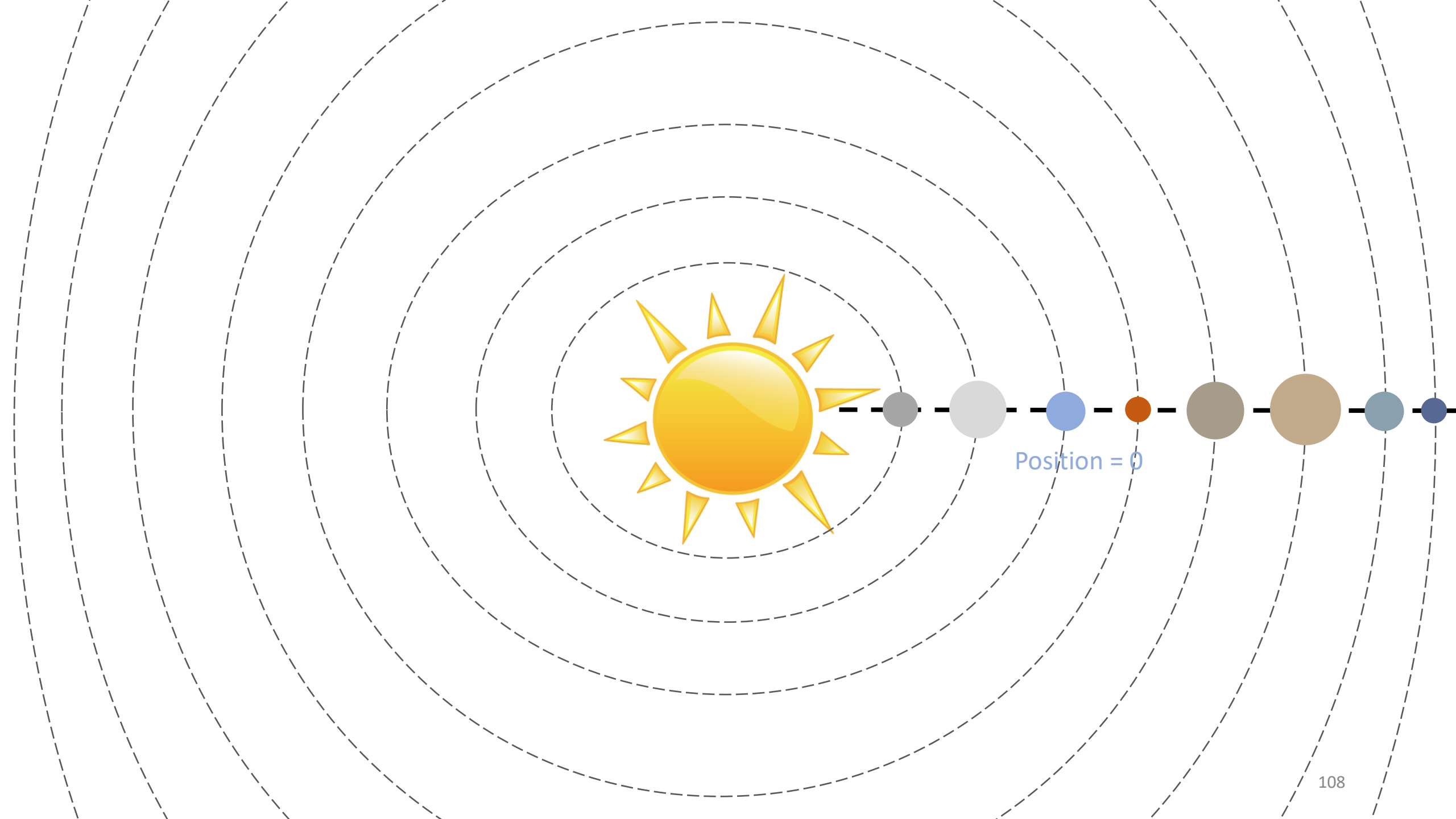
We use the same principle of property, local state and render function



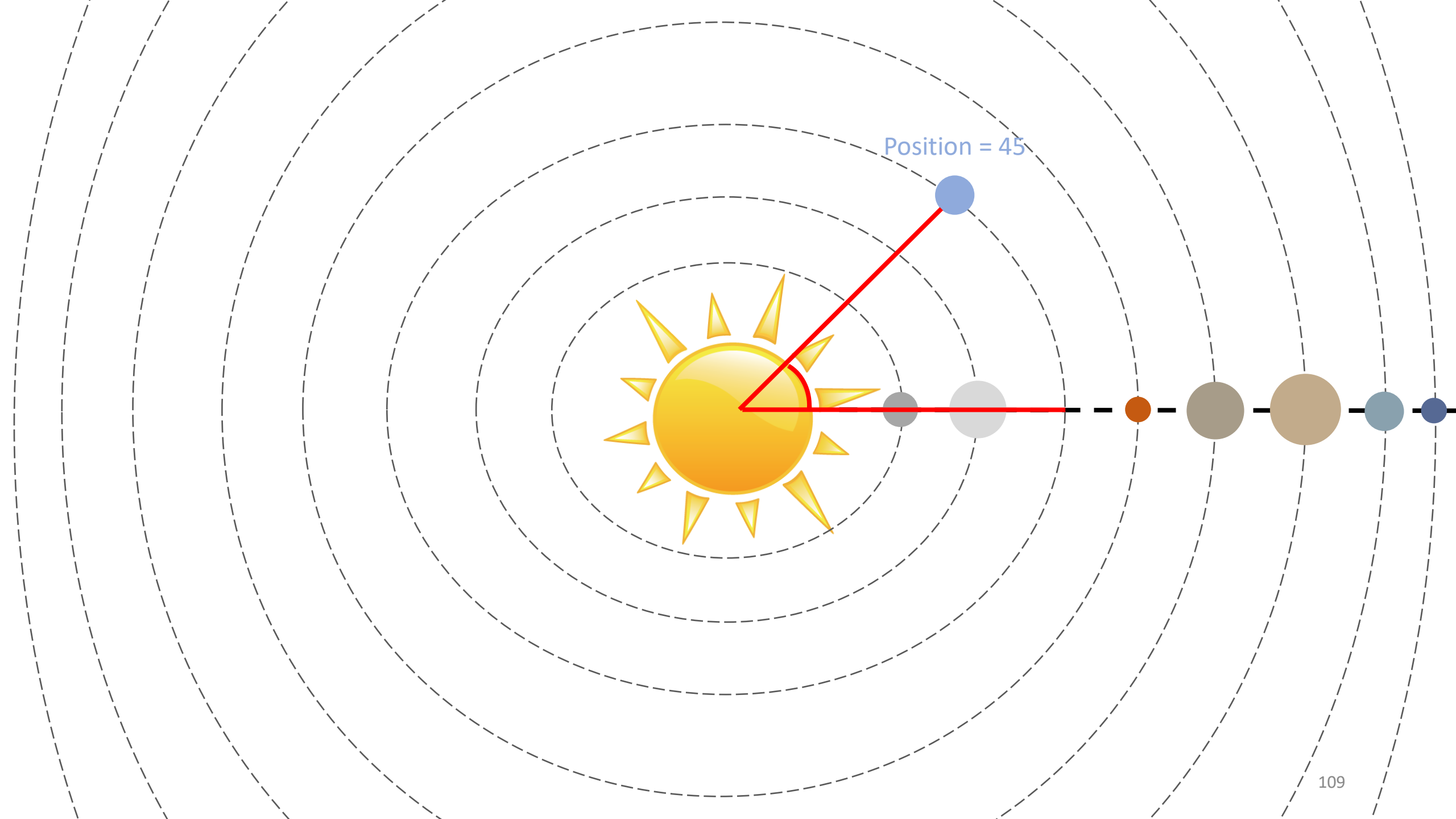
Use of the tick function to update every second / frame

# Example - Solar system





Position = 0



```
class SystemSolar extends React.Component {  
  constructor(props) {  
    super(props);  
    this.name = "Solar System";  
    this.solarPos = 0;  
    this.mercuryPos = 0; this.mercuryRevo = 88;  
    this.venusPos = 0; this.venusRevo = 225;  
    this.earthPos = 0; this.earthRevo = 365;  
    this.marsPos = 0; this.marsRevo = 687;  
    this.jupiterPos = 0; this.jupiterRevo = 4380;  
    this.saturnPos = 0; this.saturnRevo = 10585;  
    this.uranusPos = 0; this.uranusRevo = 30660;  
    this.neptunePos = 0; this.neptuneRevo = 60225;  
  }  
}
```

```
render() {  
  return (  
    <Star name="Solar" position={this.solarPos}/>  
    <Planet name="Mercury" position={this.mercuryPos} revo={this.mercuryRevo}/>  
    <Planet name="Venus" position={this.venusPos} revo={this.venusRevo}/>  
    <Planet name="Earth" position={this.earthPos} revo={this.earthRevo}/>  
    <Planet name="Mars" position={this.marsPos} revo={this.marsRevo}/>  
    <Planet name="Jupiter" position={this.jupiterPos} revo={this.jupiterRevo}/>  
    <Planet name="Saturn" position={this.saturnPos} revo={this.saturnRevo}/>  
    <Planet name="Uranus" position={this.uranusPos} revo={this.uranusRevo}/>  
    <Planet name="Neptune" position={this.neptunePos} revo={this.neptuneRevo}/>  
  );  
}  
}
```

```
class Star extends React.Component {  
  constructor(props) {  
    super(props);  
    this.state = {pos: this.props.position  
                  };  
  }  
  
  render() {  
    return (  
      <Sphere name={this.props.name} pos={0}/>  
    );  
  }  
}
```



```
class Planet extends React.Component {
  constructor(props) {
    super(props);
    this.state = {pos: this.props.position,
                  revo: 360/this.props.revo
                  };
  }

  componentDidMount() {
    this.intervalID = setInterval(
      () => this.tick(),
      1000
    );
  }

  componentWillUnmount() {
    clearInterval(this.intervalID);
  }
}
```

```
tick() {  
  const newPos = this.state.pos + this.state.revo;  
  this.setState({  
    pos: newPos % 360  
  });  
}  
  
render() {  
  return (  
    <Sphere name={this.props.name} pos={this.state.pos}/>  
  );  
}  
}
```

```
class Sphere extends React.Component {  
  constructor(props) {  
    super(props);  
  }  
  
  render() {  
    return (  
      {this.props.name}: {this.props.pos}  
    );  
  }  
}
```

```
ReactDOM.render(  
  <SystemSolar />,  
  document.getElementById('root')  
);
```

# Some questions

How to render 3D geometric shapes with this component concept ?

How and what kinds of abstraction we must then build on this system ?

# Work incoming



Update by frames (30/60 FPS) and not by second



Describe in detail our language (based on the React doc.)



See how to translate this declarative part to GLSL (DynaSOAr)

# References (Links)

<https://learnopengl.com>

<https://fr.wikipedia.org/wiki/Shader>

<https://fr.wikipedia.org/wiki/OpenGL>

<https://fr.wikipedia.org/wiki/DirectX>

<https://developer.apple.com/metal>

<https://github.com/RenderEngine/Rendery>

<https://www.khronos.org/opengl/wiki>

# References (Links)

[https://en.wikipedia.org/wiki/Domain-specific\\_language](https://en.wikipedia.org/wiki/Domain-specific_language)

<https://tomassetti.me/domain-specific-languages/>

<http://adv-r.had.co.nz/dsl.html>

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# References (Links)

<https://thebookofshaders.com/>

<https://github.com/yanagiba/swift-ast/tree/master>

<https://medium.com/@DAloG/swift-ast-wrote-in-swift-part-1-of-e8768cae9cd3>

<https://ruslanspivak.com/lrbasi-part7/>

<https://docs.swift.org/swift-book/ReferenceManual/zzSummaryOfTheGrammar.html#>

<https://developer.apple.com/documentation/swift/mirror>

# References (new links)

<https://craftinginterpreters.com/representing-code.html>

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<https://2020.splashcon.org/details/splash-2020-oopsla/49/Geometry-Types-for-Graphics-Programming>

<https://github.com/anzen-lang/anzen>

<http://sdz.tdct.org/sdz/les-shaders-en-glsl.html>

# References (Tools)

<https://swift-ast-explorer.com/>

<https://github.com/kishikawakatsumi/swift-ast-explorer>

<https://astexplorer.net/>

<https://codepen.io>

# References (Research)

Dietrich Geisler, Irene Yoon, Aditi Kabra, Horace He, Yinnon Sanders, and Adrian Sampson. 2020. Geometry Types for Graphics Programming. Proc. ACM Program. Lang. 4, OOPSLA, Article 173 (November 2020), 25 pages.

Joey de Vries. 2020. Learn OpenGL – Graphics programming. (Juin 2020), 523 pages.

Marjan Mernik, Jan Heering, and Anthony M. Sloane. 2005. When and how to develop Domain-Specific Languages. ACM Comput. Surv. 37, 4, (December 2005), Pages 316-344.

Tomaž Kosar, Pablo E. Martí'nez López, Pablo A. Barrientos, Marjan Mernik. A preliminary study on various implementation approaches of domain-specific language. Information and Software Technology, Volume 50, Issue 5, 2008, Pages 390-405.

# References (Research)

Khronos Group. 2016. The OpenGL ES Shading Language. (Janvier 2016), 161 pages.

<https://arxiv.org/abs/1908.05845> (ex: game of life, ..) DynaSOAR

<https://fr.reactjs.org/>

<https://fr.reactjs.org/docs/hello-world.html>

# Working with shaders

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