Working with
Graphics Programming

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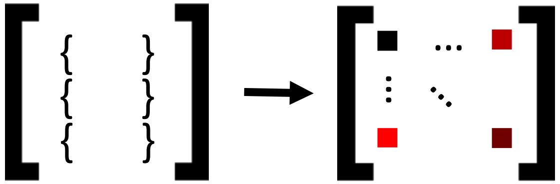
What’s a shader?

Small programs that run on the GPU

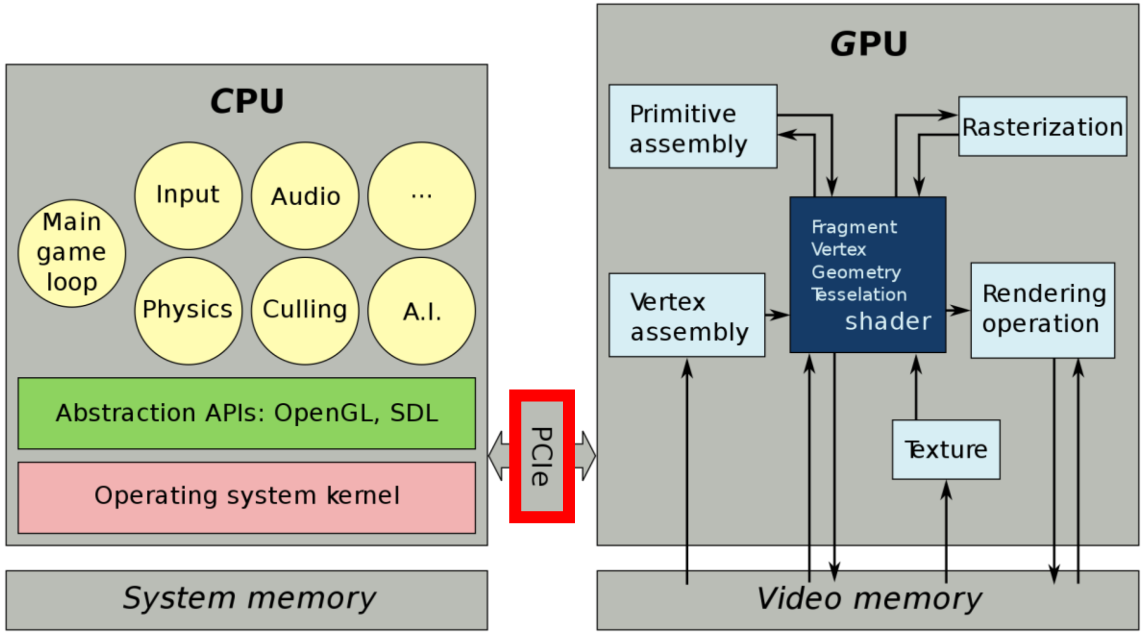
Executed for each specific section of the graphics pipeline

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

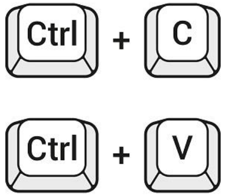
Microsoft DirectX — DirectX High-Level Shader Language

NVIDIA — Cg Shader Language

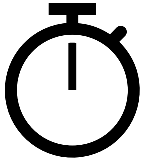
OpenGL — OpenGL Shading Language (GLSL)

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



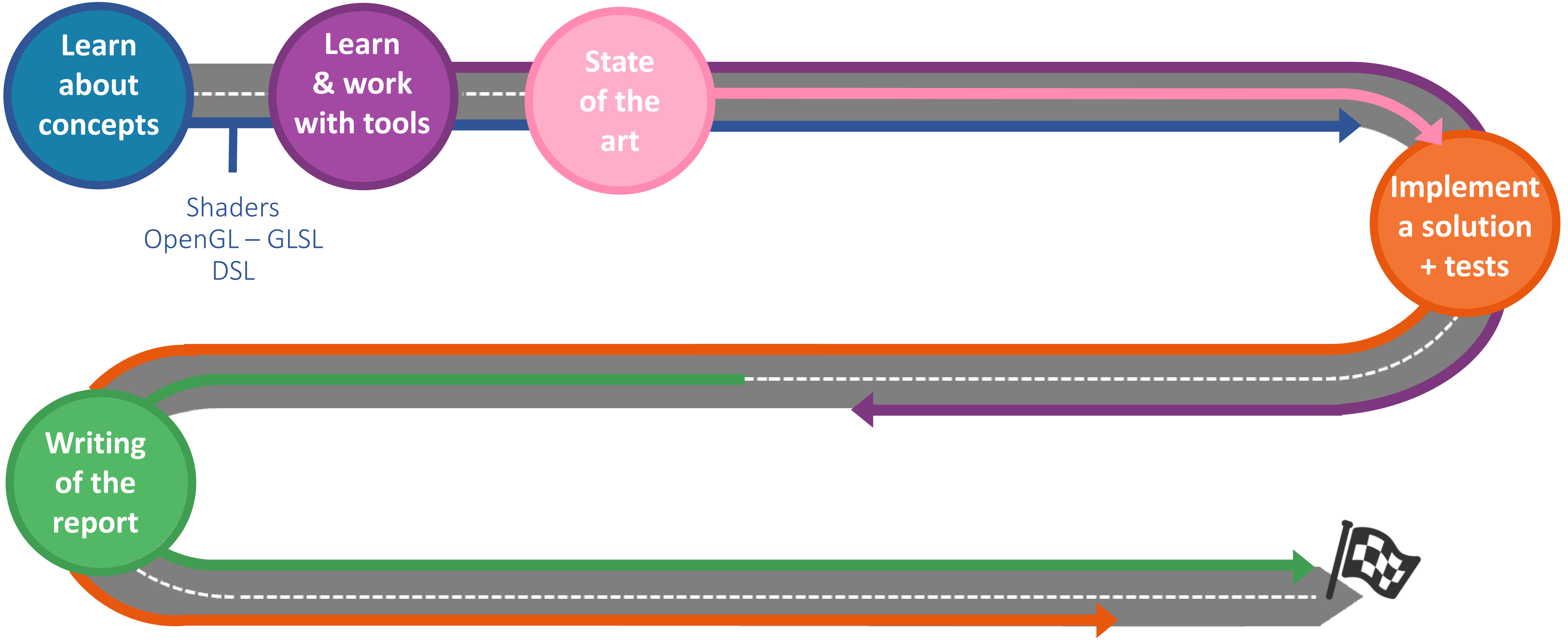
Must reduce the data sent in the PCI to avoid multiple synchronizations between CPU & GPU

Goal of the project

Work with the representation of the data & abstract the types

Construct a DSL for shaders

Road map


Learn about concepts
Learn & work with tools
State of the art
Shaders
OpenGL – GLSL
DSL
Implement a solution + tests
Writing of the report

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

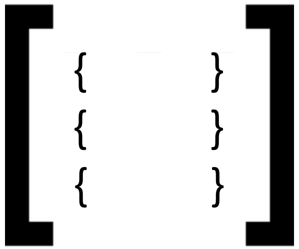
Geometry Shader

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:

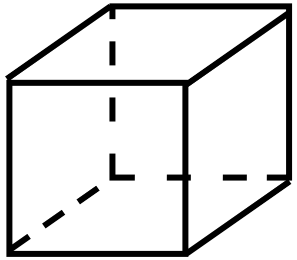
Position (2D, 3D coordinates)

Color (RGB, …)

Texture coordinates

Example

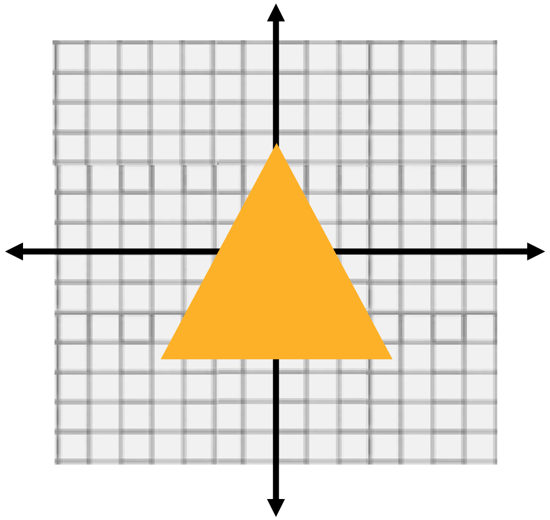
In OpenGL, only the Normalize Device Coordinates (NDC) are visible on the screen



To render a single 2D triangle:

3D position (NDC) of each vertex

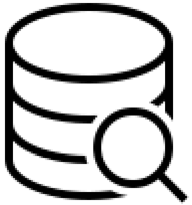
```
float vertices[] = {
    -0.5f, -0.5f, 0.0f,
     0.5f, -0.5f, 0.0f,
     0.0f,  0.5f, 0.0f
};
```



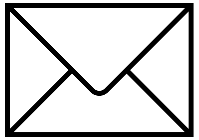
Linking vertex attributes

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

ID of the buffer which must be bind

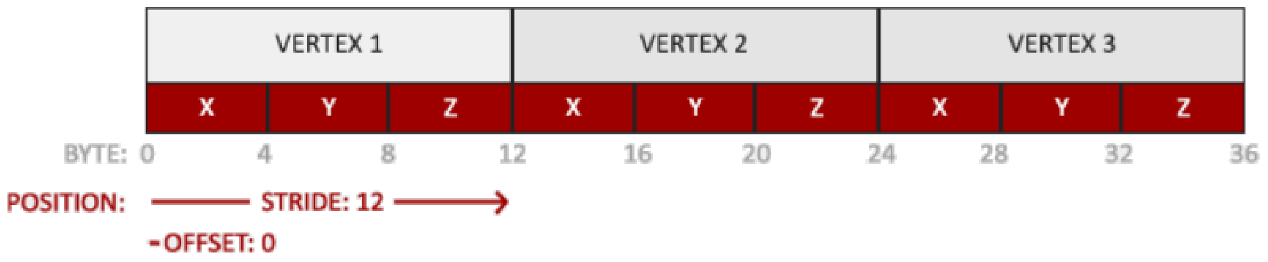
Specifies the target buffer object

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

Size of the buffer object

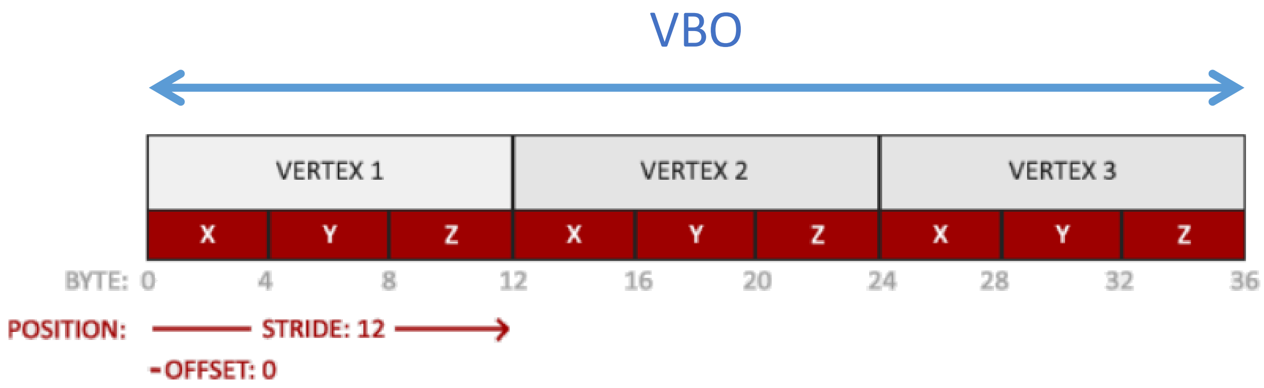
Pointer to data

VBO



Example (Cont.)

Define how the vertex data should be interpreted



The size of the vertex attribute

Specifies which 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

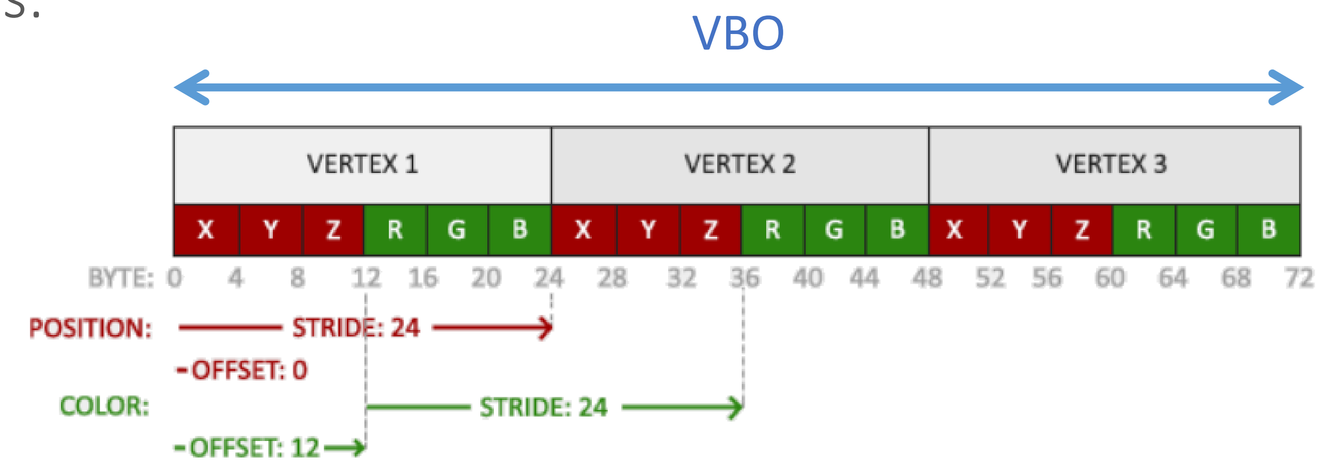
Type of the data

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 offset

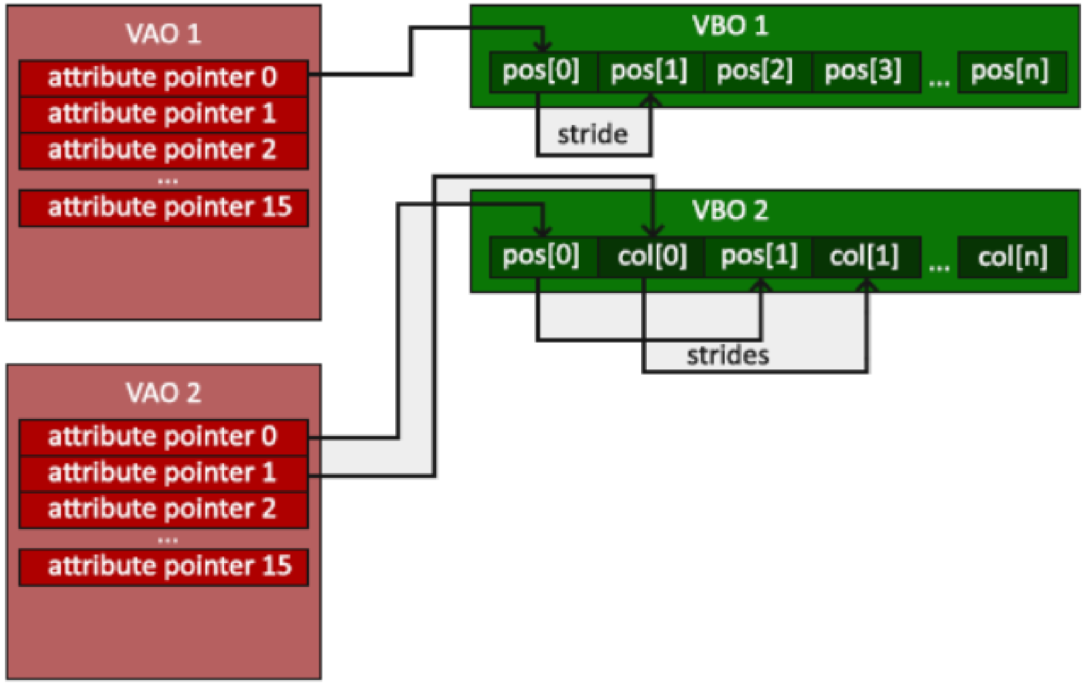
```
// position attribute
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 6 * sizeof(float), (void*)0);
glEnableVertexAttribArray(0);
// color attribute
glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 6 * sizeof(float), (void*)(3* sizeof(float))
glEnableVertexAttribArray(1);
```

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);
```

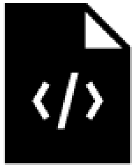
Summary

```
// 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();
```

Source: https://learnopengl.com/Getting-started/Hello-Triangle

Render & draw an object

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

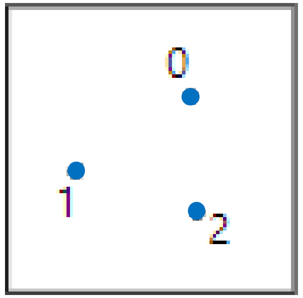


Set up a Vertex & a Fragment Shader

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

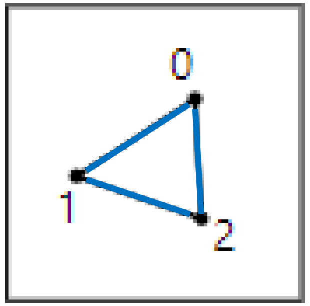
```
#version 330 core
layout (location = 0) in vec3 aPos;

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:

Starting index in the array

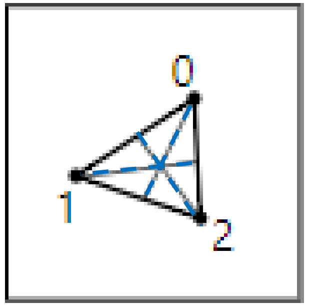
```
glDrawArrays(GL_TRIANGLES, 0, 3);
```

OpenGL function that draws a shape

Kind of primitive to render

Number of vertices to render

Tessellation

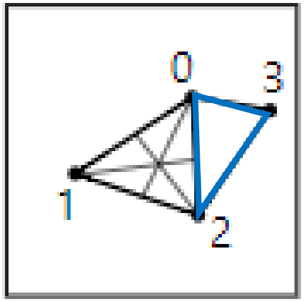


In 3D, the surfaces are built with triangular tiles

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

Geometry Shader

An unnecessary step

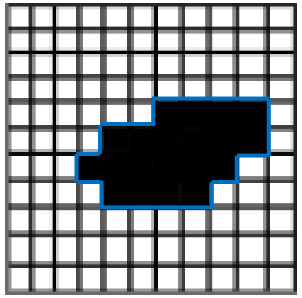


Allows to modify the geometry of each polygon and allows to create new polygons by emitting new vertices

Input data: data of a geometric primitive

Output data: data of one or more geometric primitive

Rasterization

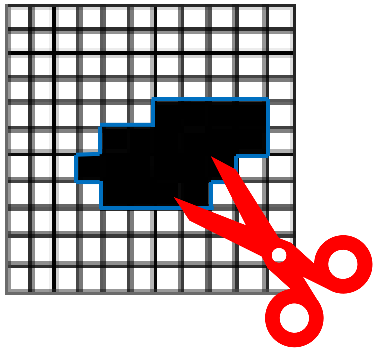


Method of converting a vector image into a raster image to be displayed on a screen

Vector image
composed of geometric objects

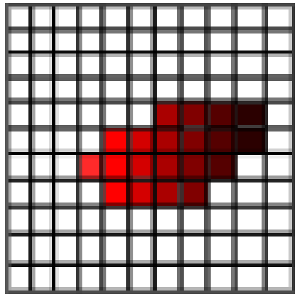
Raster image or Bitmap
composed of pixels

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);
```

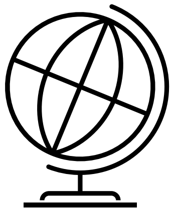
We can now activate this program to render and draw an object

```
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

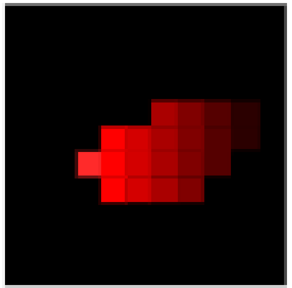
These are global variables

Sample code:

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

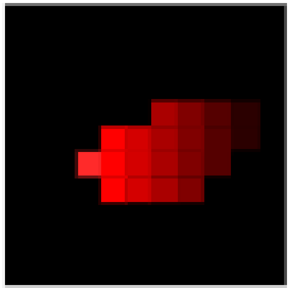
NOT DISCARDED ← in front | behind → DISCARDED

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:

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

Impact of the alpha value

Final color of the fragment

Impact of the alpha value

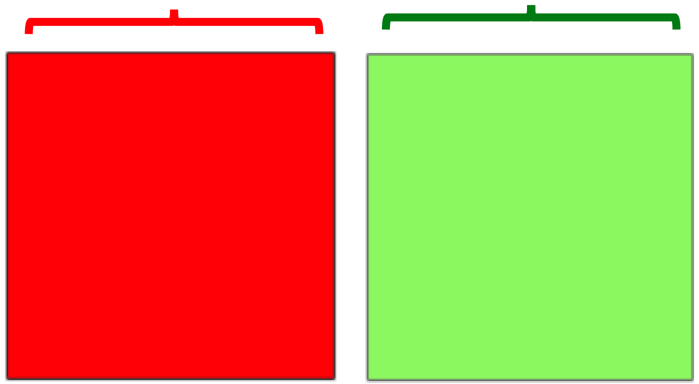
Color output of the fragment shader

Color currently stored in the color buffer

Example (Cont.)

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

$\bar{C}_{destination}$ $\bar{C}_{source}$

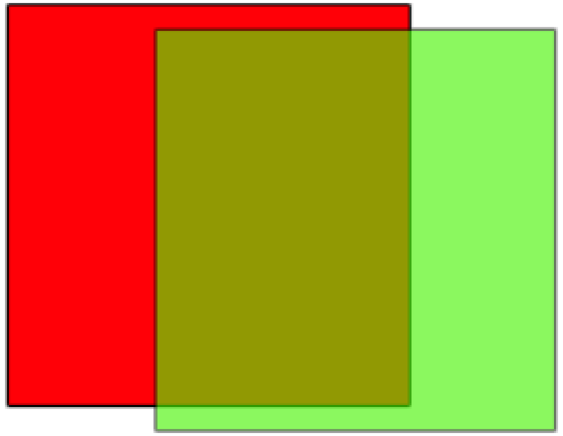


(1.0, 0.0, 0.0, 1.0) (0.0, 1.0, 0.0, 0.6)

Alpha value ($F_{destination}$)

Alpha value (F_{source})

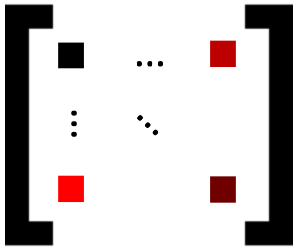
$$\bar{C}_{result} = \begin{pmatrix} 0.0 \\ 1.0 \\ 0.0 \\ 0.6 \end{pmatrix} * 0.6 + \begin{pmatrix} 1.0 \\ 0.0 \\ 0.0 \\ 1.0 \end{pmatrix} * (1 - 0.6)$$



(0.4, 0.6, 0.0, 0.76)

Resulting color then stored in the color buffer

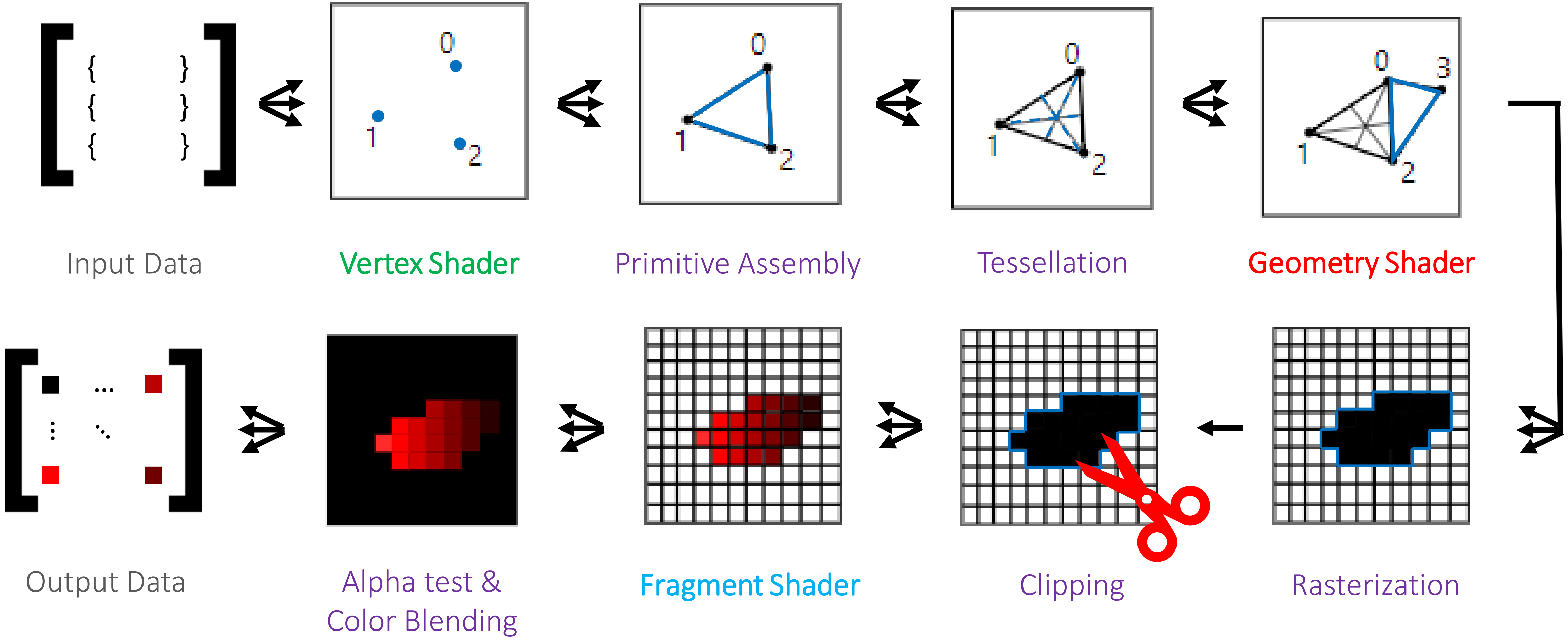
Output Data



Return a Framebuffer

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

Overall view



Textures

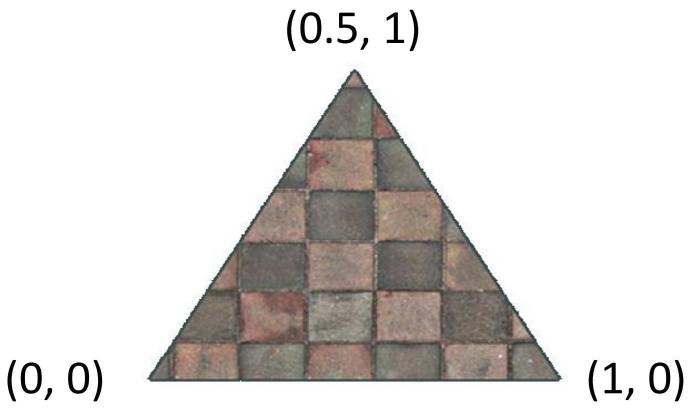
Allows to give the illusion the object is detailed
without having to specify vertices

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 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

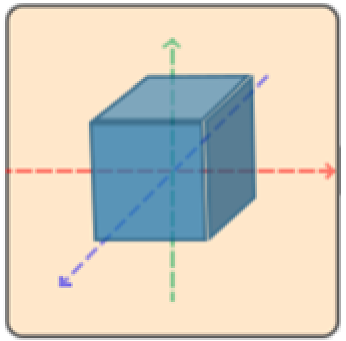
World Space

View Space

Clip Space

Screen Space

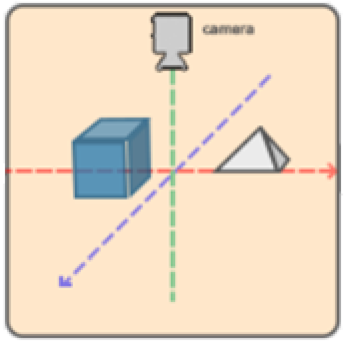
Local Space



Coordinates of the object relative to its local origin

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

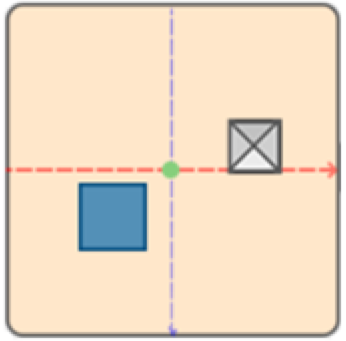
World Space



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

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

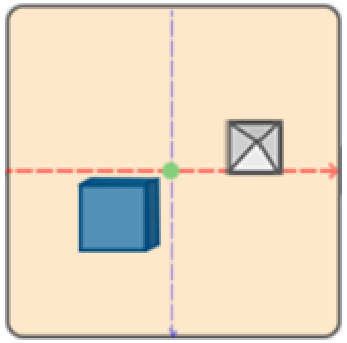
View Space



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

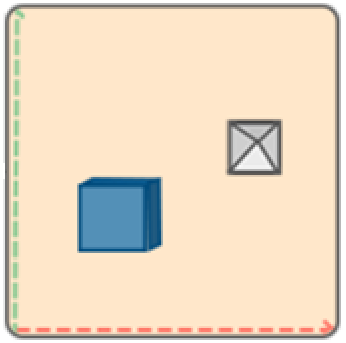
Example:

Specified range [-1000, 1000] for each dimension

(1250, 500, 750) → Not visible

(900, 500, 750) → Visible

Screen Space

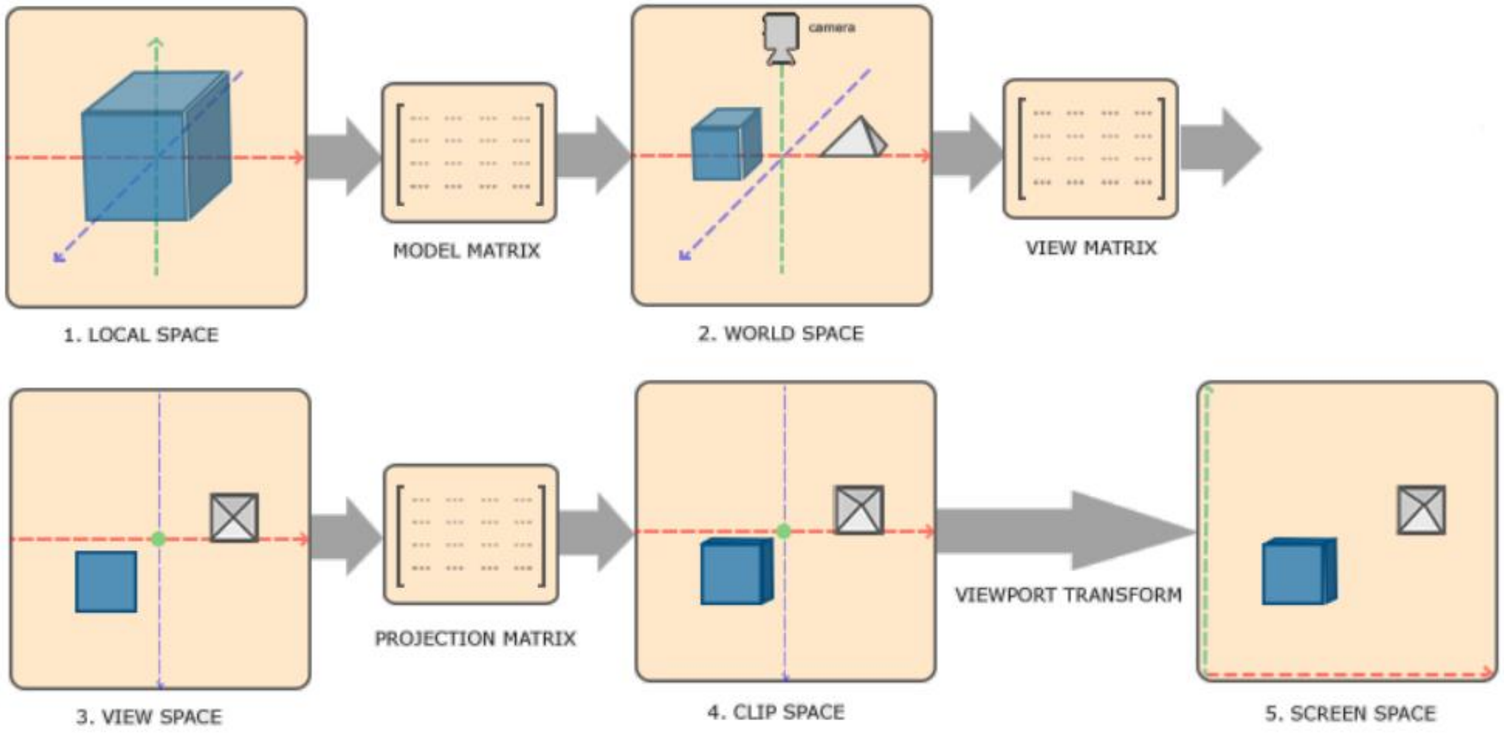


Transforms the NDC coordinates to the window coordinates with the *glViewport()* function

Resulting coordinates are then sent to the rasterizer

Overall view

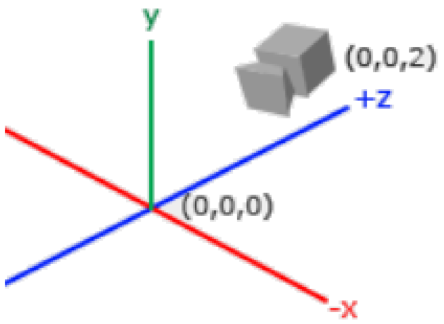
A vertex coordinate is transformed to clip coordinates as follow: $V_{clip} = \underline{M_{projection} \cdot M_{view} \cdot M_{model}} \cdot V_{local}$



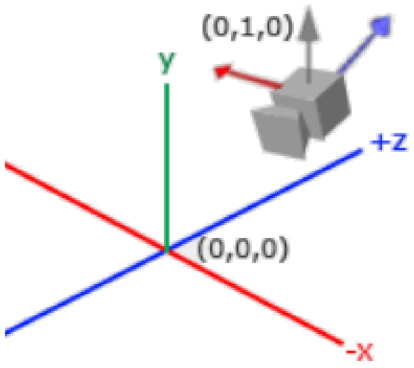
Source: https://learnopengl.com/Getting-started/Coordinate-Systems

Camera

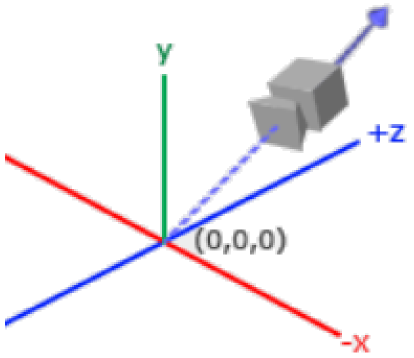
To define a camera we need 4 pieces of information



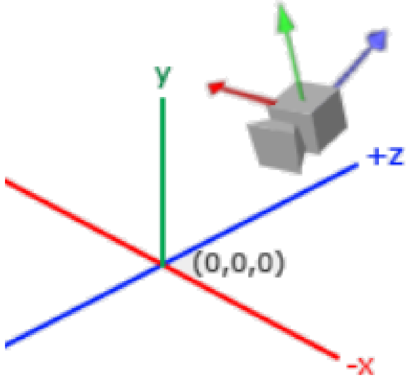
1. Its position in the world space



3. A vector pointing to the right

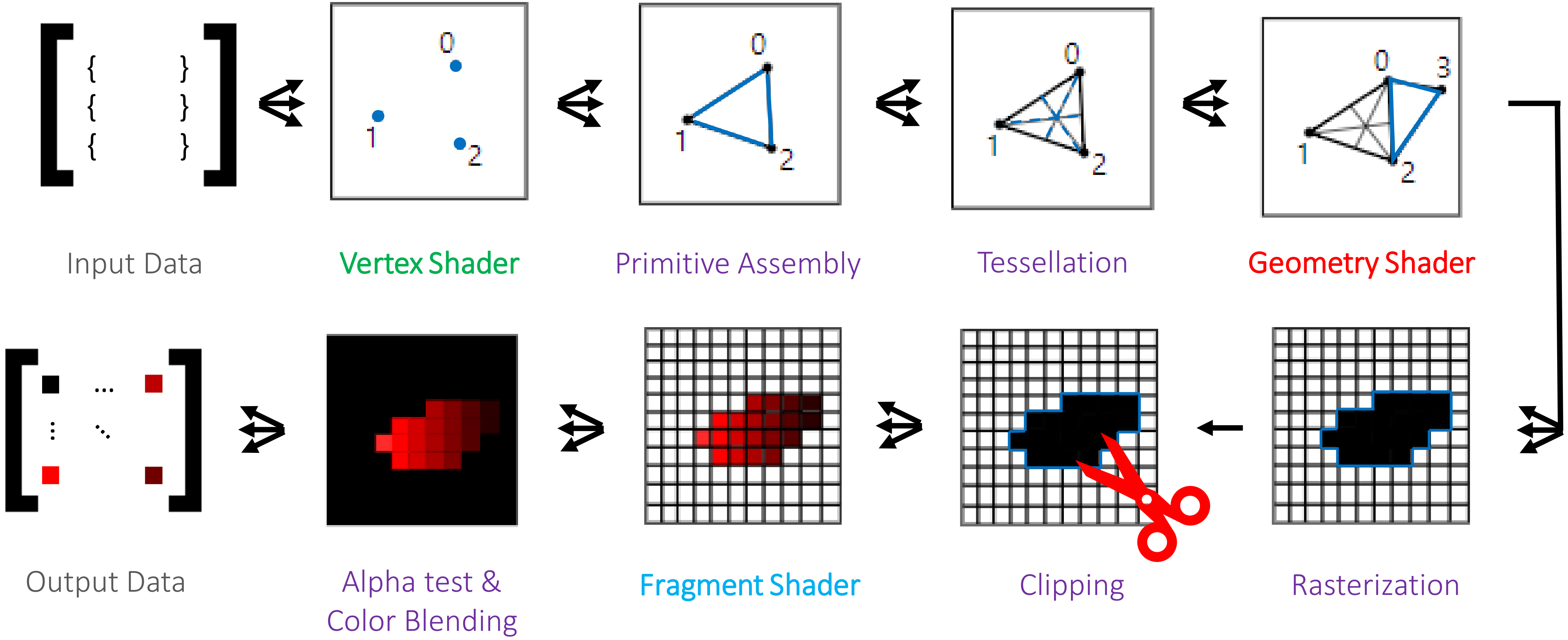


2. Its direction



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

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

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

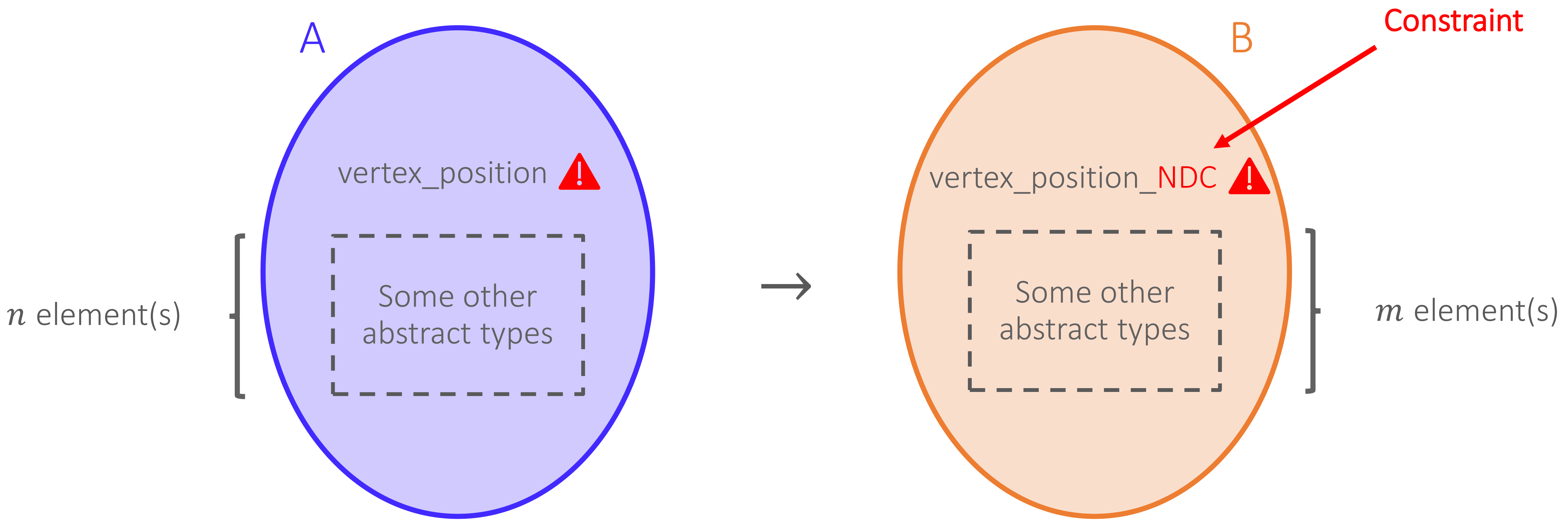
No longer working with containers of type

Ex: ~~vec3, vec4, ivec4~~, mat4, …

But with abstract type objects

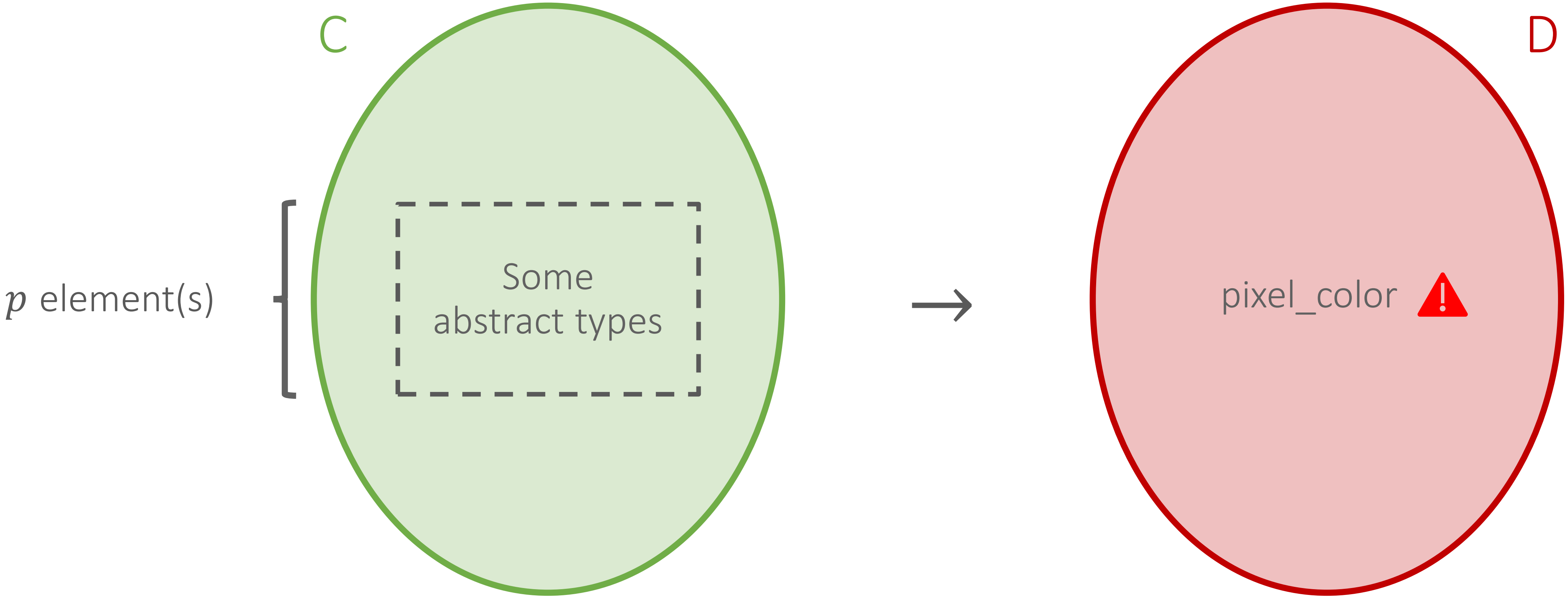
Ex: color, position, textures, …

Vertex Shader function vs : A → B



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

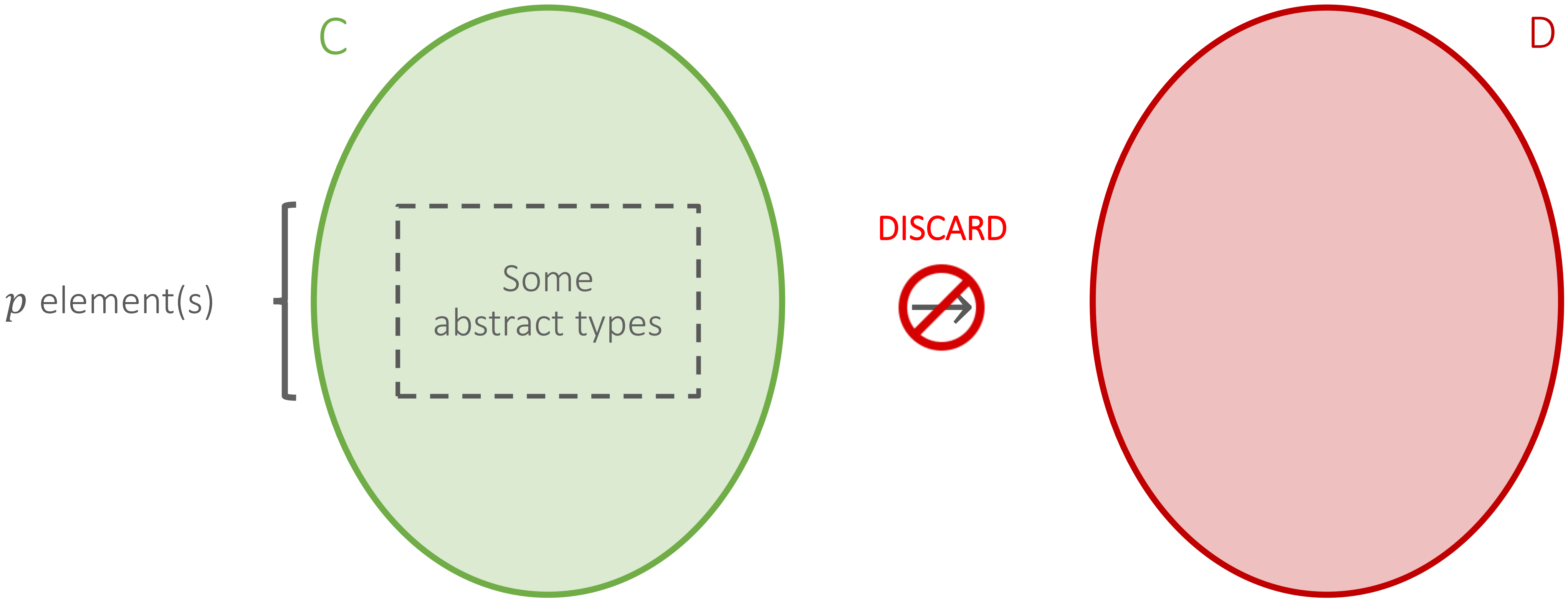
Fragment Shader function   fs : C → D



fs(_ : C_i)

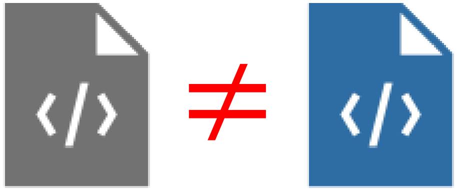
Fragment Shader function Alternative

$\text{fs} : C \rightarrow D$



$\text{fs}(\_ : C_i)$

Several signatures



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

Examples:

vs(_ : position)

vs(_ : position, _ : color)

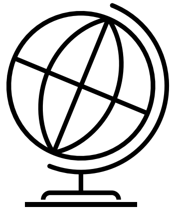
vs(_ : position, _ : color, _ : texture:)

fs()

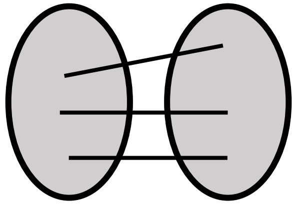
fs(_ : fragment, _ : light:)

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

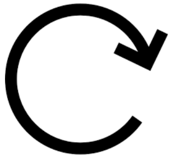
Uniforms



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);
}
```

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

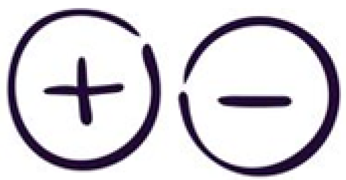
```
// input vertex
struct VertIn {
    float4 pos   : POSITION;
    float4 color : COLOR0;
};

// 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

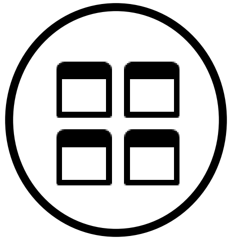
Calculate output coordinates & colors

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

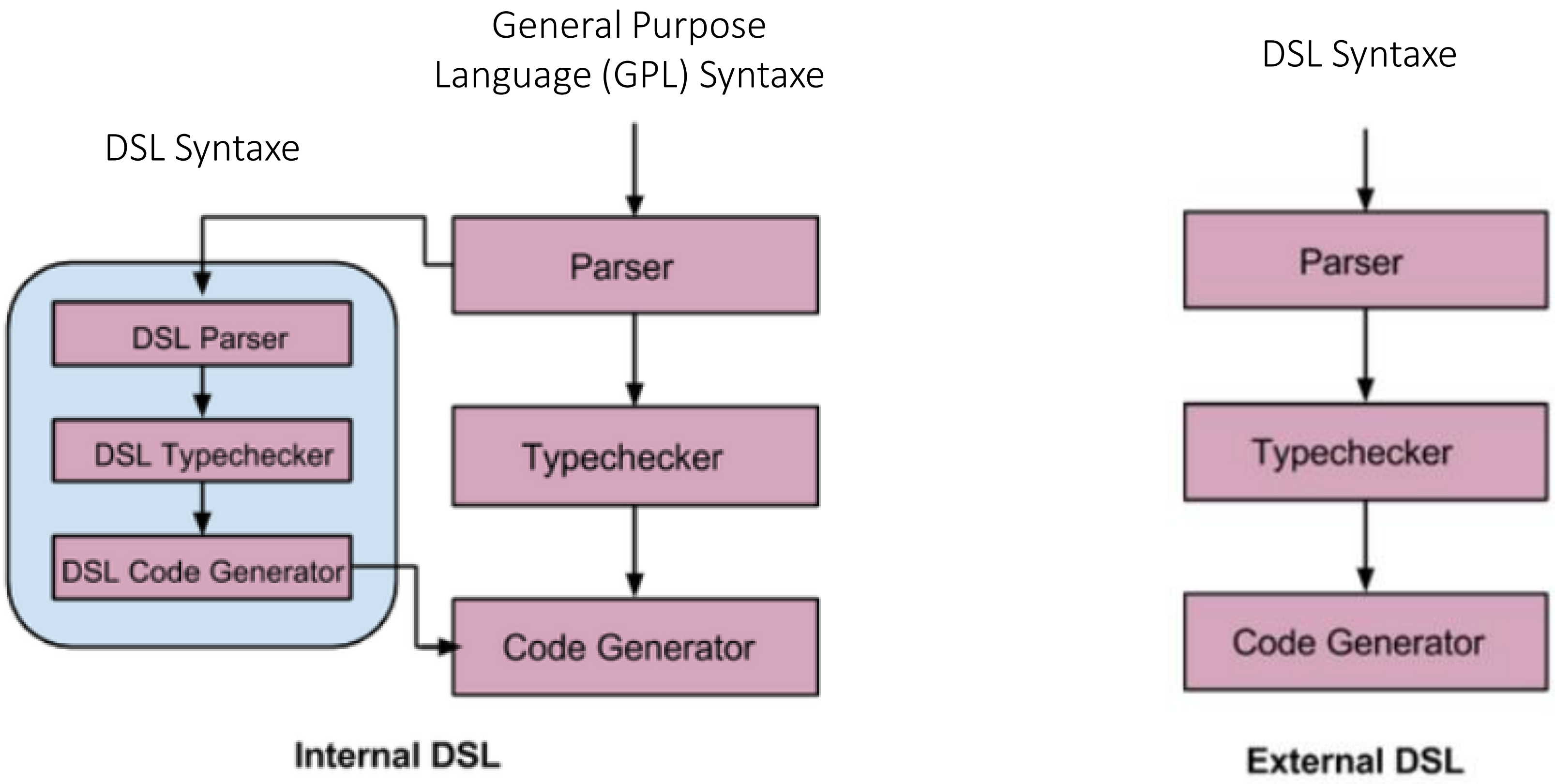
DSL can be reused for other purposes

✗

DSL maintenance is complicated

The cost of a DSL is expensive

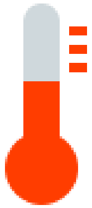
Different types of DSL



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

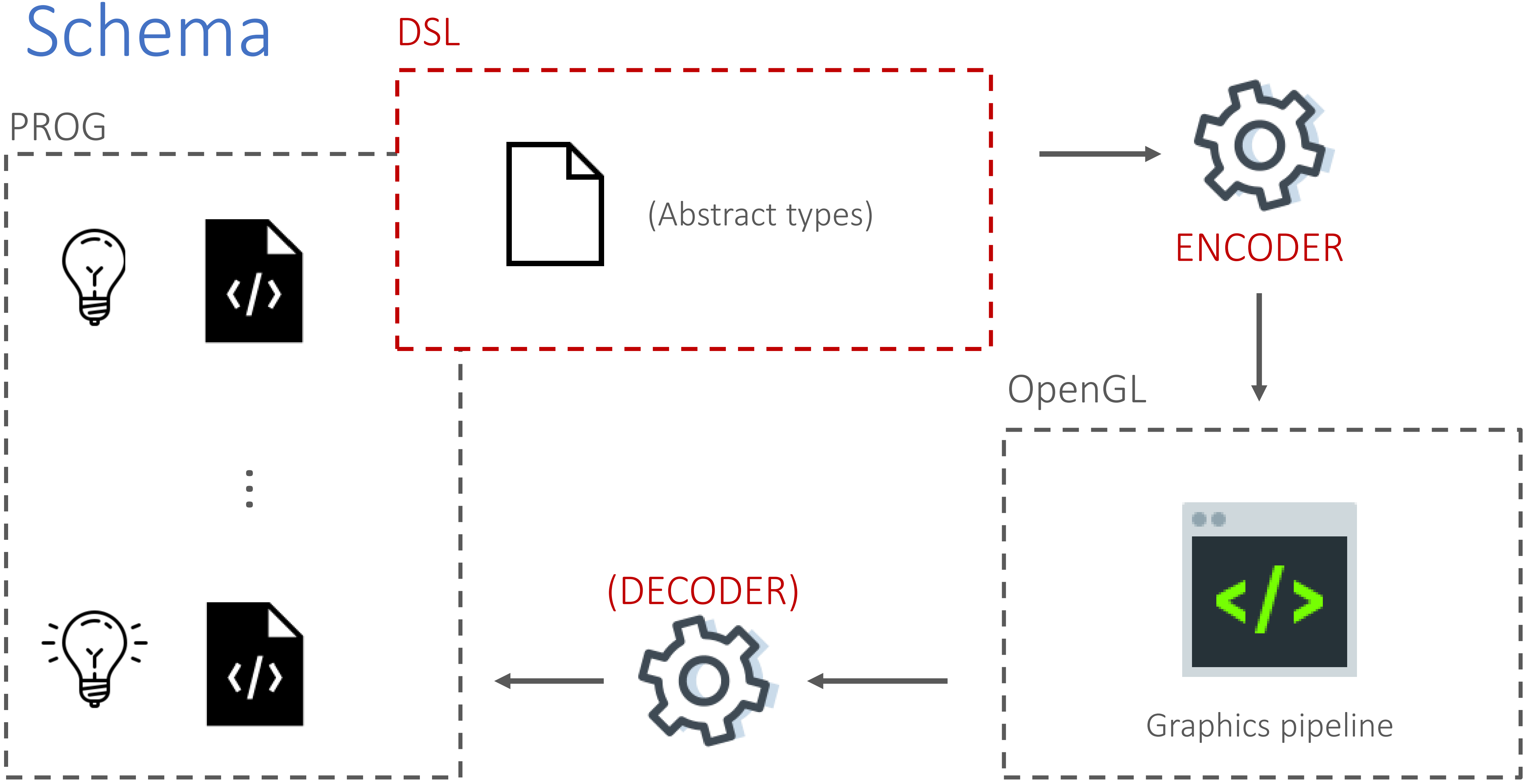
We write in our program a
vertex & a fragment shader with our DSL

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

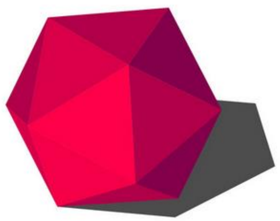
(Then a decoder allows us to get the results
with the desired abstract types)

Schema

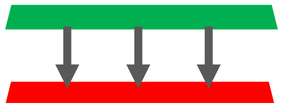

DSL
PROG
(Abstract types)
ENCODER
OpenGL
(DECODER)
Graphics pipeline

Gator

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

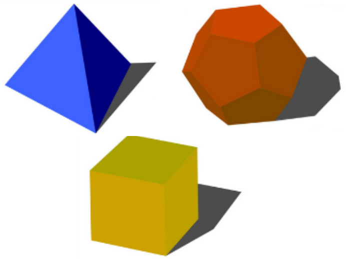


Higher level programming model that allows focus on the geometric semantics of programs

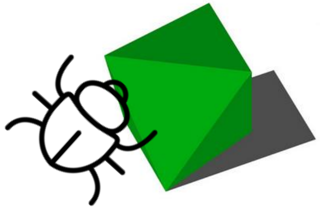


Gator is a surface language with an extended type system based on a target language with a type set (GLSL)
A type-directed translation allows to compile Gator to GLSL

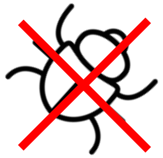
Problem & ideas



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

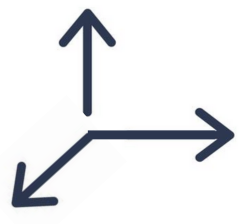


Geometry bugs are difficult to detect



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.)

```
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

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

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);
}
```

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

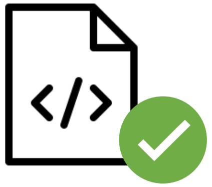
Subtype of float

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

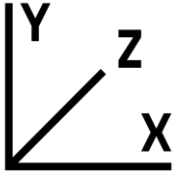
We can thus automatically generate a correct transformation code by construction

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

Gator helps to limit the number of geometry bugs

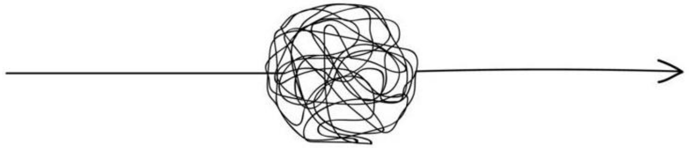
Limitations

The created abstraction remains low level

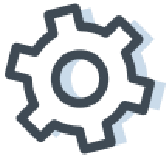


It’s only based on coordinate system transformations

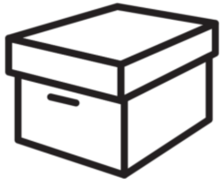
The syntax is a bit complicated



Inspiration



The notion of surface language



New types based on primitives

color, light, texture, normal, (position)

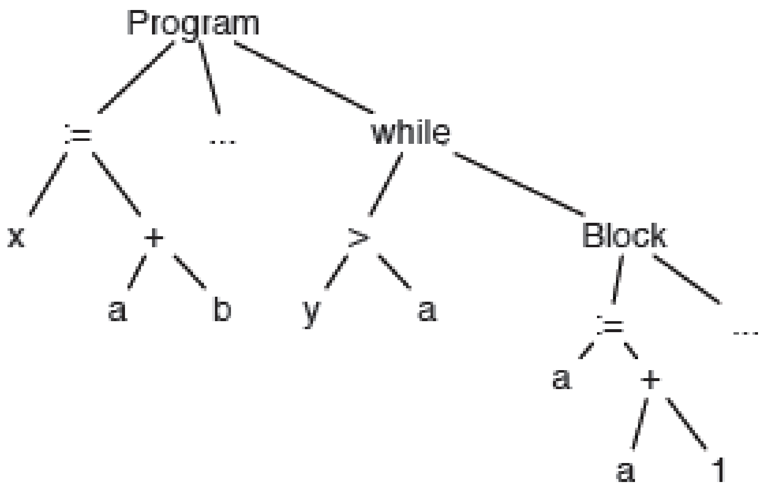
A little less complicated syntax

Abstract Syntax Tree (AST)

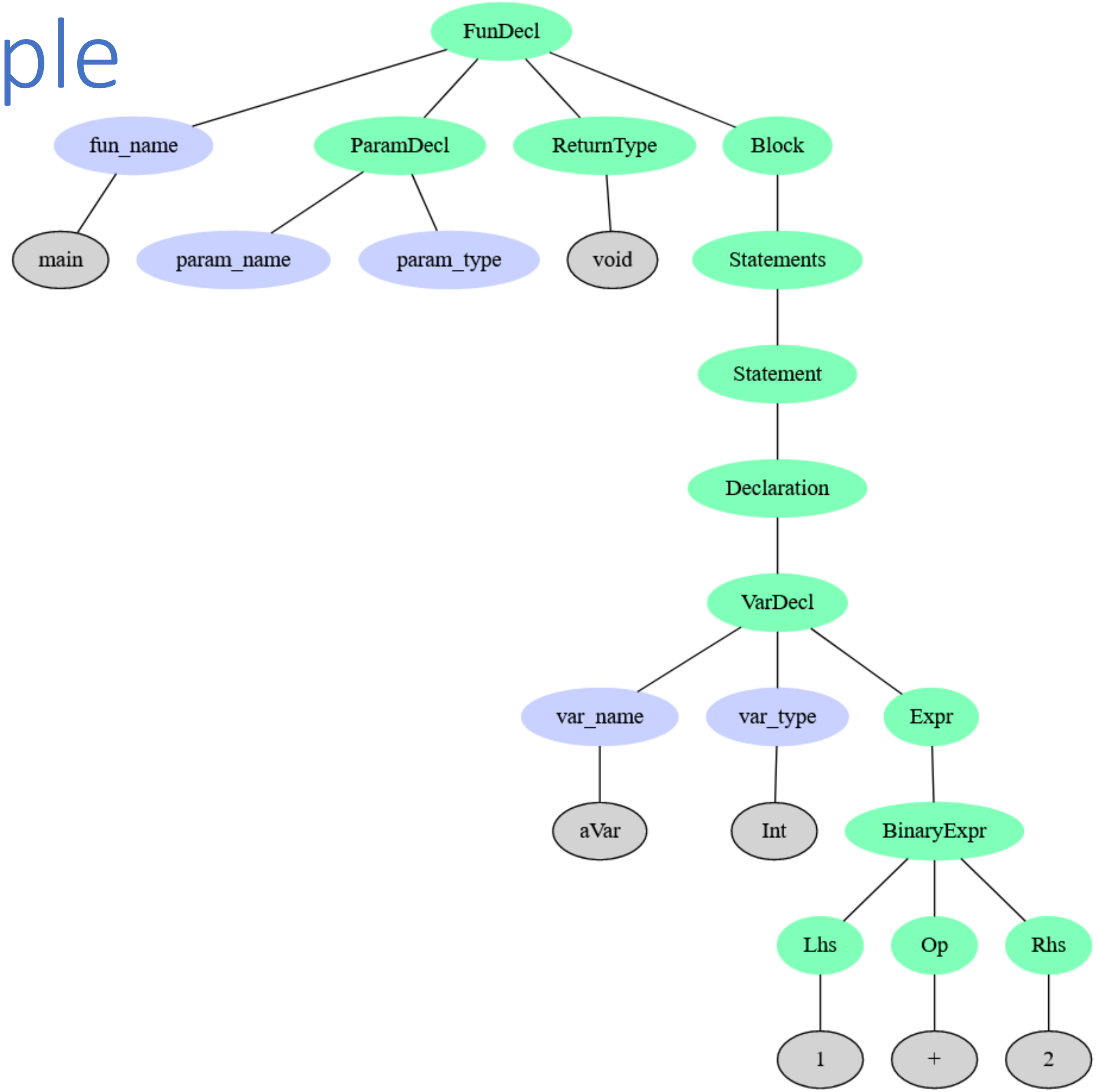
Tree in which, internal nodes are marked by operators and where external ones represent the operands

Example:

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



AST example


FunDecl
fun_name
ParamDecl
ReturnType
Block
main
param_name
param_type
void
Statements
Statement
Declaration
VarDecl
var_name
var_type
Expr
aVar
Int
BinaryExpr
Lhs
Op
Rhs
1
+
2

Some tools

Swift-AST-Explorer

Only supports Swift language

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

AST-Explorer

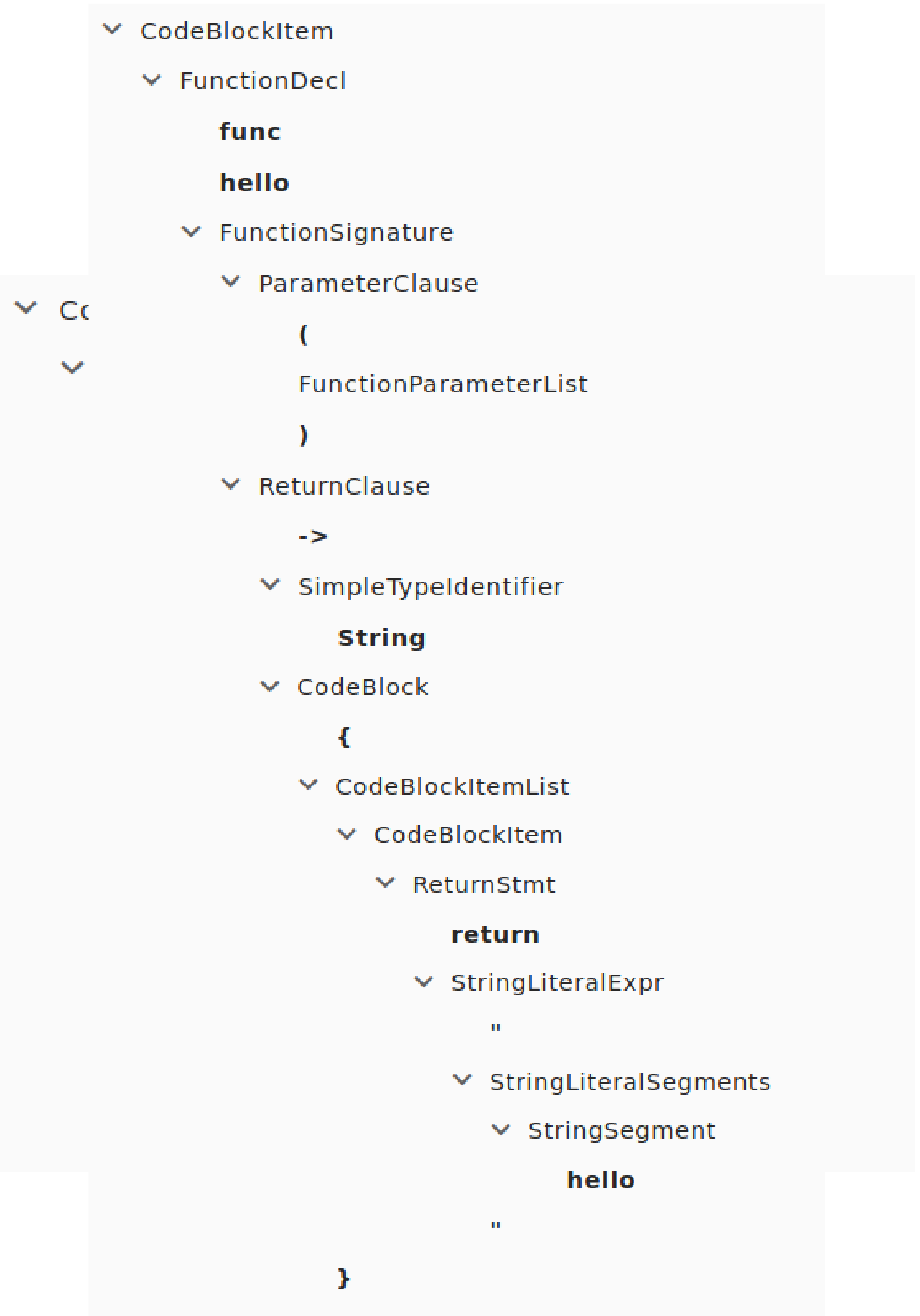
Supports a lot of languages like Java, HTML, Python, … & GLSL

Tree or JSON representation

Examples

Swift-AST-Explorer

```swift
import Foundation

let num: Int = 5

func hello() -> String {
    return "hello"
}
```



Examples (Cont.)

AST-Explorer

```
varying vec3 ourColor;

void main() {
  FragColor = vec4(ourColor, 1.0f);
}

```

```
- 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:

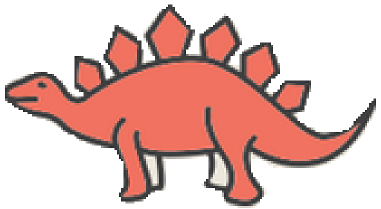
function_identifier:
  type_specifier
  IDENTIFIER
  FIELD_SELECTION

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



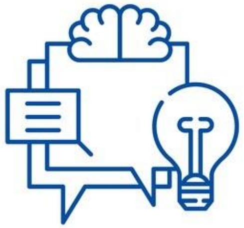
Which is an object-oriented language for manipulating objects

General idea

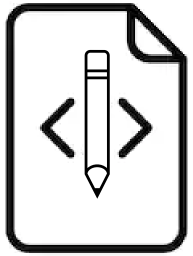
We want to have the perfect language for our use-cases

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

Development



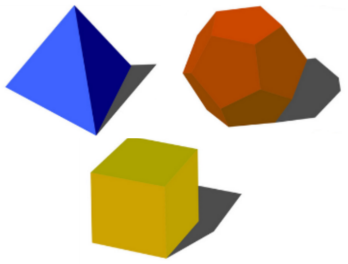
First, we must define our language and the concepts we want



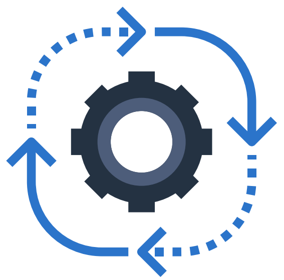
Then, we must specify the syntax of this language

Concepts

Use-cases



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

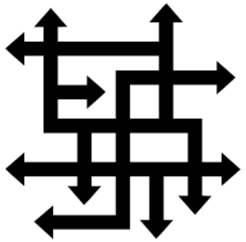


We want to call methods on them, do calculations, etc.

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

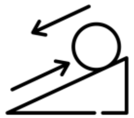
The abstractions that we need to write an application with 3D objects are:


The position of the objects


The type of the objects


The color of the objects

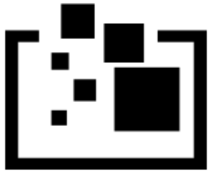

The operations linked to these objects


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

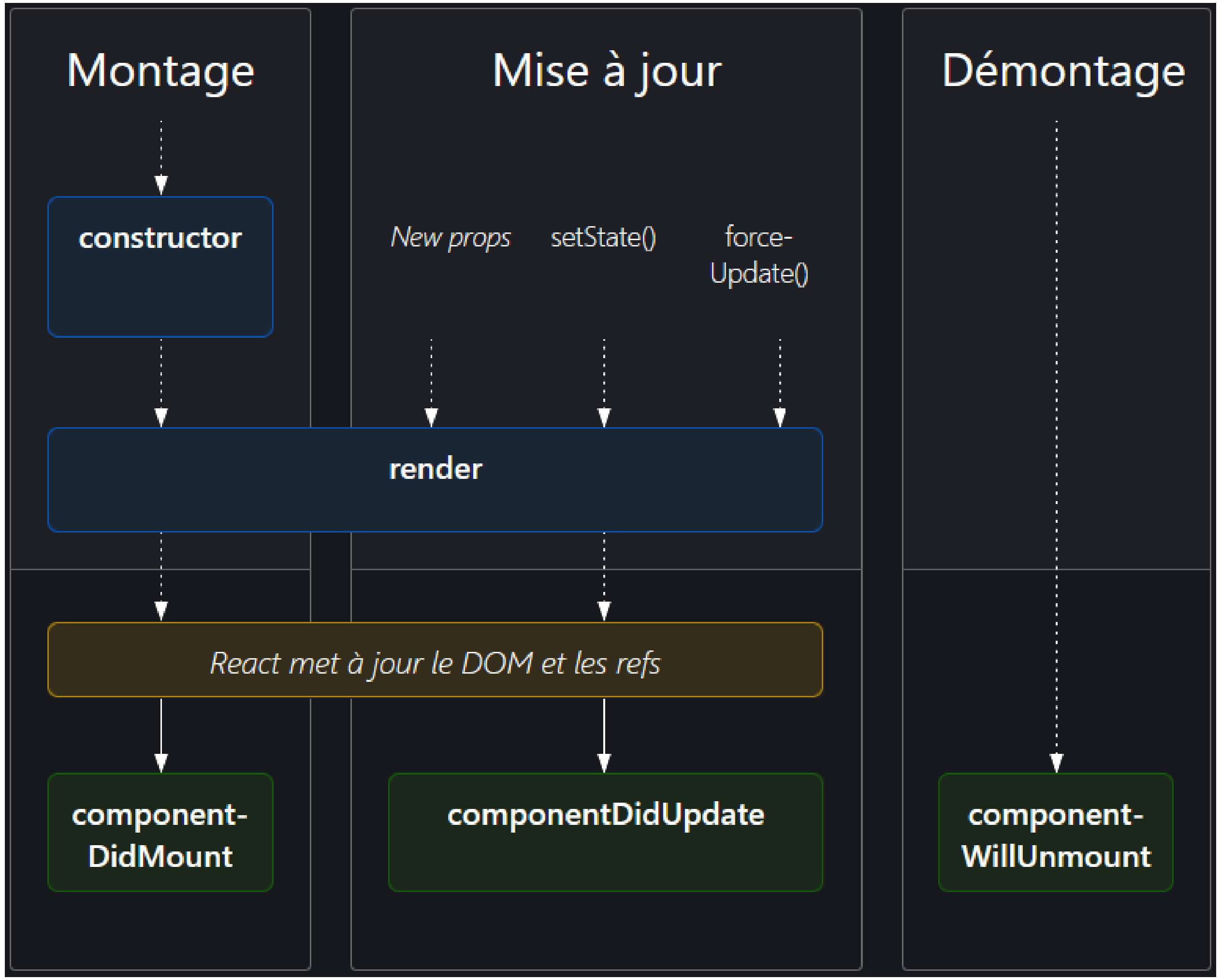
We can then combine different components to get something more complex

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()

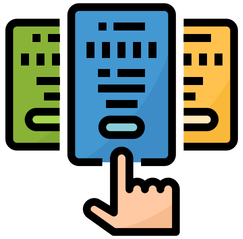
React - Render()

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.

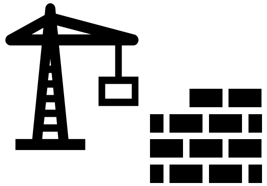
React - componentWillUnmount()

componentWillUnmount() is called immediately before a component is unmounted

Here we delete the subscriptions made in componentDidMount()

Idea for our language

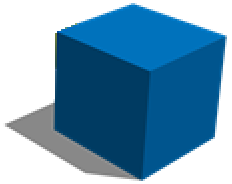
We give some basic geometric shapes



The idea is to use the notion of mesh (primitive), which is a complete object, composed of several shapes

Example:

A cube is a particular mesh constructed with two triangles per face



Syntax

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

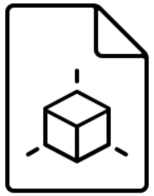
Our goal is to have a simple and meaningful syntax

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 global state, property, and render function



Use of the tick function to update every second / frame

Components (highest level)

Defines the global state of the application

It is only used in the highest component

Component declaration

```
Component <name_component>  {

  var state: [String: AnyObject] = [:]

  init() {

     self.state = ["key": value,
                       ...          ]

  }

  var <var_name> = <value>

  function <function_name>([<arg_name>: <type>]) -> <return_type> {
    <body>
    return <return_value>
  }
```

Variables or constants declaration

A way to sub and unsub to Tick()

Declares the functions relating to the component

Components (highest level)

Tick() function declaration

Function given in the standard library to update the global state

Component rendering function

```
function tick() {
  state = updateState(lastState: state,
                      newState: ["key": value,
                                  ...         ]
                      )
}

function render() {
  return (
    <container>

      <<component_name> ([<arg_name>=value])/>

    </container>

  )
}
```

Components (lowest level)

Get the properties passed to the component

Component declaration

```
Component <name_component>  {

  init() {
    super.init()
  }


  var <var_name> = <value>


  function <function_name>([<arg_name>: <type>]) -> <return_type> {
    <body>
    return <return_value>
  }

```

Components (lowest level)

Component rendering function

```
function render() {
  return (

    <mesh type=  <value>
          position=  <value>
          properties=  [<value>]   />


  )
}
```

Call a subcomponent or
render a mesh to graphically represent an object

⚠ Render a mesh is never in the highest component

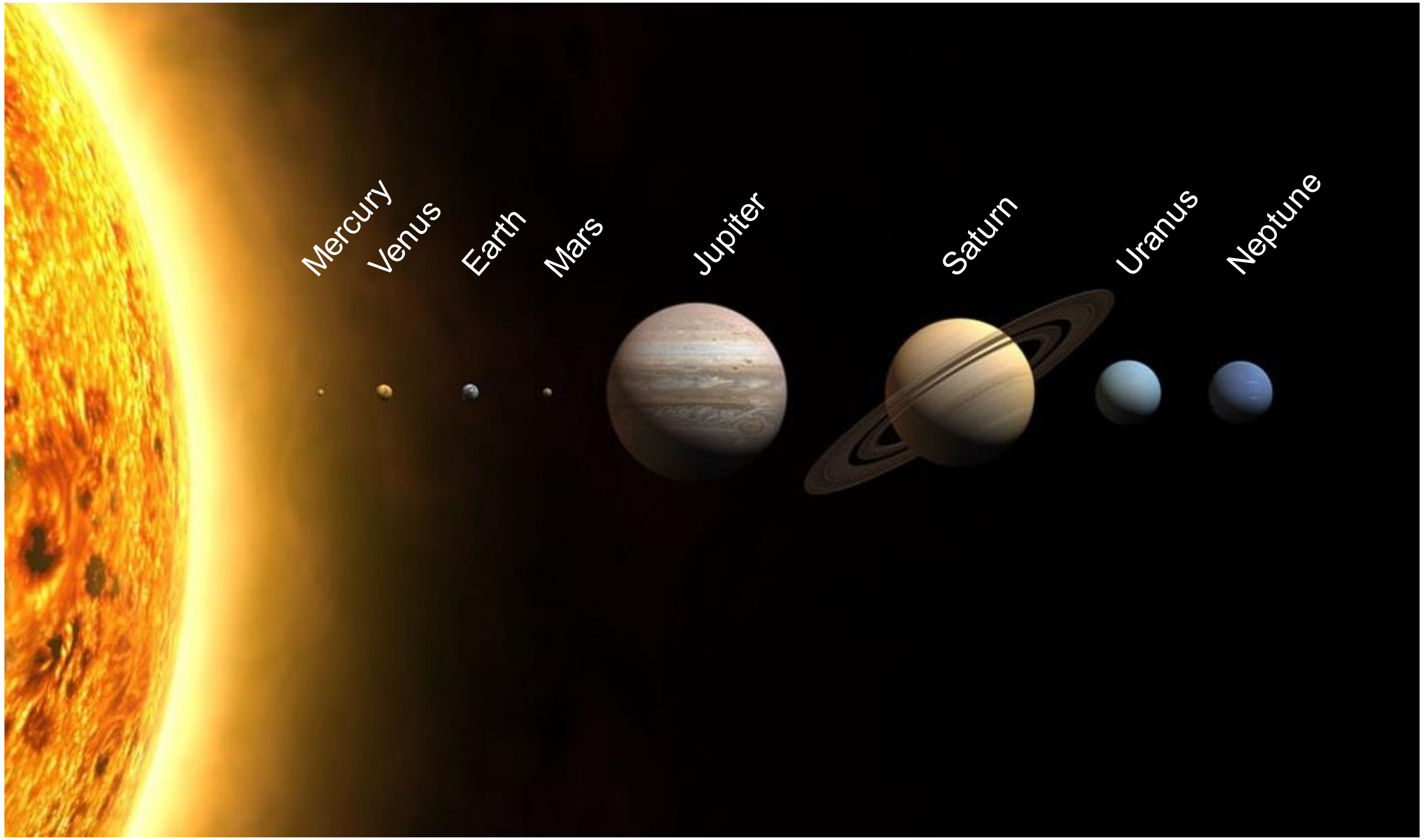
Entry point

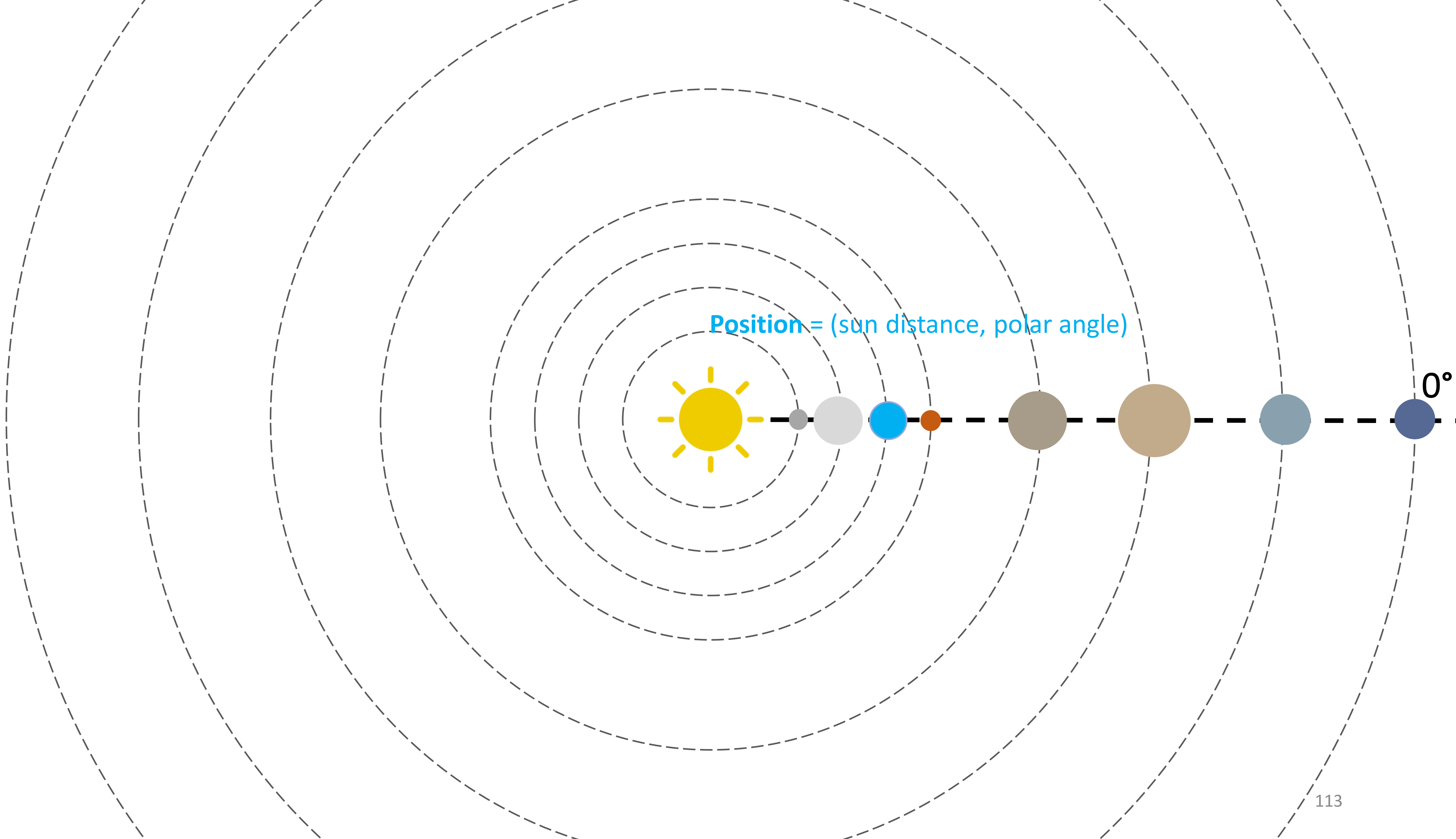
Users can define their own types in addition to what is given in the standard library

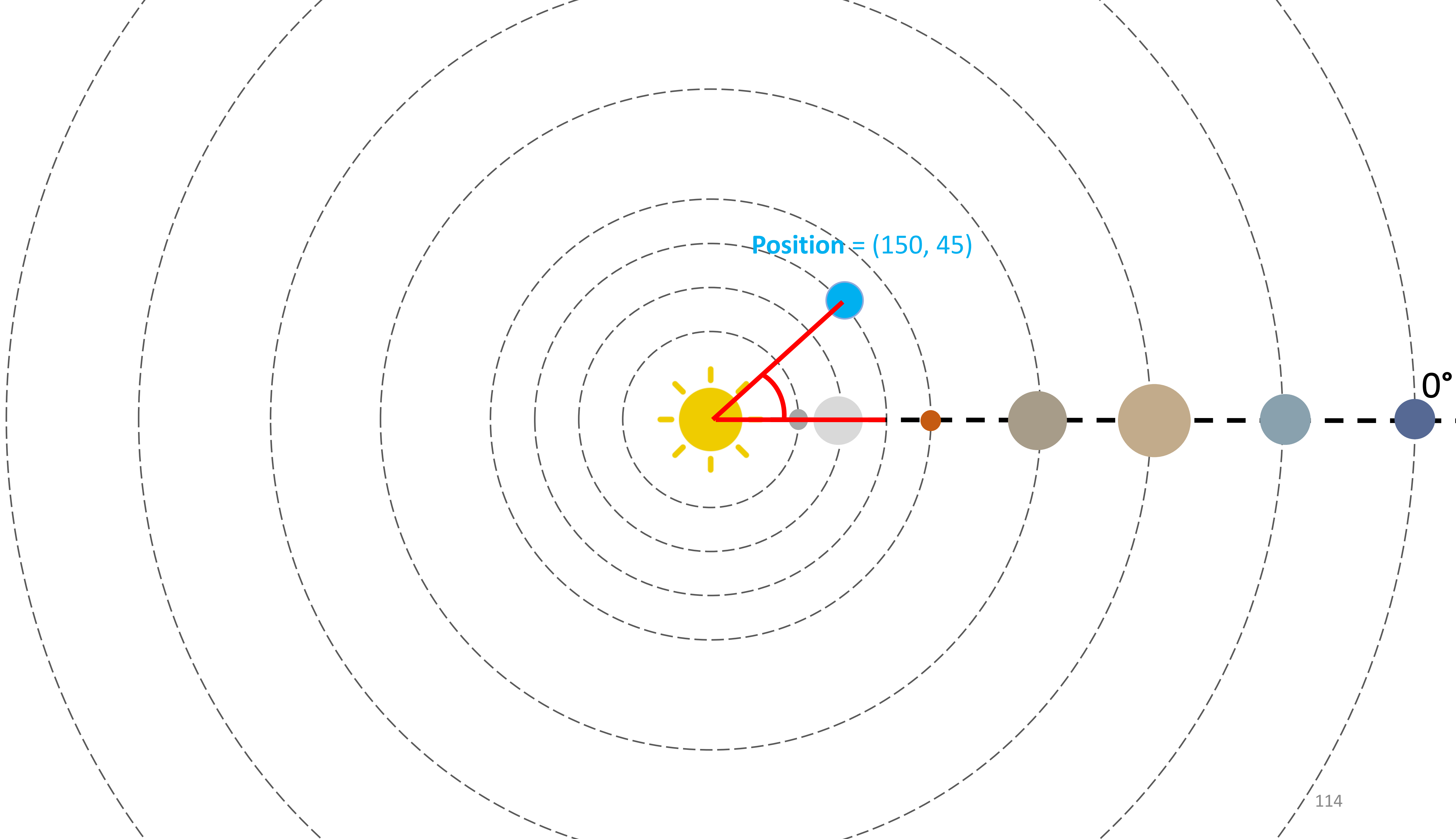
Then, we specify the top-level component

```
structure <name_structure> {
  var <var_name>: <type>
  ...

  init( <args> ) {

  }

  function <function_name>([<arg_name>: <type>]) -> <return_type> {
    <body>
    return <return_value>
  }

}

<<highest_level_component> ()/>
```

Example - Solar system




Position = (sun distance, polar angle)
0°


Position = (150, 45)
0°

```
Component SystemSolar {

  var state: [String: AnyObject] = [:]

  init() {
    self.state = ["solarCoord": Coord(polar: (0, Angle(deg: 0)), "solarRevo": 0, "solarRadius": 696340,
                  "mercuryCoord": Coord(polar: (58, Angle(deg: 0)), "mercuryRevo": 88, "mercuryRadius": 2440,
                  "venusCoord": Coord(polar: (108, Angle(deg: 0)), "venusRevo": 225, "venusRadius": 6050,
                  "earthCoord": Coord(polar: (150, Angle(deg: 0)), "earthRevo": 365, "earthRadius": 6370,
                  "marsCoord": Coord(polar: (228, Angle(deg: 0)), "marsRevo": 687, "marsRadius": 3390,
                  "jupiterCoord": Coord(polar: (779, Angle(deg: 0)), "jupiterRevo": 4380, "jupiterRadius": 69910,
                  "saturnCoord": Coord(polar: (1434, Angle(deg: 0)), "saturnRevo": 10585, "saturnRadius": 58230,
                  "uranusCoord": Coord(polar: (2871, Angle(deg: 0)), "uranusRevo": 30660, "uranusRadius": 25360,
                  "neptuneCoord": Coord(polar: (4495, Angle(deg: 0)), "neptuneRevo": 60225, "neptuneRadius": 24600
                 ]
  }
```

solarSystem.patl

The application has a global state which contains all the information

It is defined in the highest-level component

```
structure Angle {
    var deg: Double
    var rad: Double

    init(deg: Double = nil, rad: Double = nil) {
        self.deg = deg
        self.rad = rad
    }

    function degToRad() -> Double {
        return (deg * (pi/180))
    }

    function radToDeg() -> Double {
        return (rad * (180/pi))
    }
}
```

bibli.patl

```
structure Coord {
    var polar: (Double, Angle) // Angle(deg: _)
    var cart: (Double, Double)

    init(polar: (Double, Angle) = nil, cart: (Double, Double) = nil) {
        self.polar = polar
        self.cart = cart
    }

    function polarToCart() -> (Double, Double) {
        cons r = polar[0]
        cons t = polar[1]
        return (r*cos(t), r*sin(t))
    }

    function cartToPolar() -> (Double, Angle) {
        cons x = cart[0]
        cons y = cart[1]
        return (sqrt(x^2 + y^2), atan(y/x))
    }

}
```

bibli.patl

```
// Directly call when the component is created
let st = subTick(interval: 1)
```

solarSystem.patl

```
function subTick(interval: Double) {
    while(1) {
        sleep(interval)
        tick()
    }
}
```

bibli.patl

```
// Call when the component is removed
let _ = unsubTick(sub: st)
```

solarSystem.patl

```
function unsubTick(sub: _ ) {
    destroy(sub)
}
```

bibli.patl

```
function updatePlanetPos(currentAngle: Angle, revolution: Int) -> Angle {
  var newAngle = currentAngle+(360/revolution)
  return (newAngle % 360)
}

function tick() {
  state = updateState(lastState: state,
                      newState: ["mercuryCoord": Coord(polar: (58,
                                                              Angle(deg: this.updatePlanetPos(currentAngle: state["mercuryCoord"].polar[1],
                                                                                              revolution: state["mercuryRevo"])))),
                                 "venusCoord": Coord(polar: (108,
                                                            Angle(deg: this.updatePlanetPos(currentAngle: state["venusCoord"].polar[1],
                                                                                            revolution: state["venusRevo"])))),
                                 "earthCoord": Coord(polar: (150,
                                                            Angle(deg: this.updatePlanetPos(currentAngle: state["earthCoord"].polar[1],
                                                                                            revolution: state["earthRevo"])))),
                                 ...

                                ]
                      )
}
```

solarSystem.patl

```
function updateState(lastState: [String: AnyObject], newState: [String: AnyObject]) -> [String: AnyObject] {
    for key in newState {
        lastState[key] = newState[key]
    }
    return lastState
}
```

bibli.patl

```
function render() {
  return (
    <container>
      <Sphere (name="Solar", pos={state["solarCoord"]}, radius={state["solarRadius"]})/>
      <Sphere (name="Mercury", pos={state["mercuryCoord"]}, radius={state["mercuryRadius"]})/>
      <Sphere (name="Venus", pos={state["venusCoord"]}, radius={state["venusRadius"]})/>
      <Sphere (name="Earth", pos={state["earthCoord"]}, radius={state["earthRadius"]})/>

      ...

    </container>
  );
}
```

solarSystem.patl

```
Component Sphere {
  init() {
    super.init()
  }

  let meshPosition = pos.polarToCart()

  function render() {
    return (
        <mesh type="sphere"
              position={meshPosition}
              properties=[{radius}]/>
    )
  }
}
```

solarSystem.patl

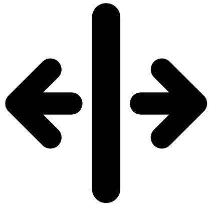
Local states are avoided in low-level components

We get the information with super.init()

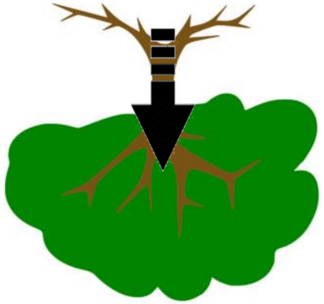
```
// Entry point
<SystemSolar ()/>
```

solarSystem.patl

In summary



The application state is separated from the rendering (graphic representation)

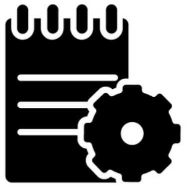


All properties descend from the highest component to the lowest component

Recall: Embedded DSL

The idea is to use Swift as the host language

This implies making some sacrifices on the syntax of our language …

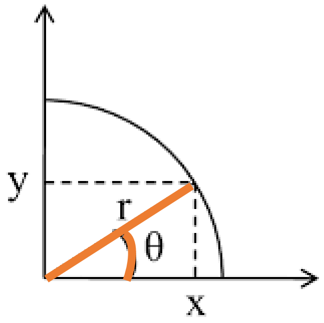


… but allows us to use the swift compiler

Example - Solar system: Using Swift

```
class SystemSolar {
    var state: Dictionary<String, Any> = [:]
    var callTick: Bool = true

    init() {
        self.state =  ["solarCoord": Coord(polar: (0, Angle(deg: 0))), "solarRevo": 0.0, "solarRadius": 696340.0,
                       "mercuryCoord": Coord(polar: (58, Angle(deg: 0))), "mercuryRevo": 88.0, "mercuryRadius": 2440.0,
                       "venusCoord": Coord(polar: (108, Angle(deg: 0))), "venusRevo": 225.0, "venusRadius": 6050.0,
                       "earthCoord": Coord(polar: (150, Angle(deg: 0))), "earthRevo": 365.0, "earthRadius": 6370.0,
                       "marsCoord": Coord(polar: (228, Angle(deg: 0))), "marsRevo": 687.0, "marsRadius": 3390.0,
                       "jupiterCoord": Coord(polar: (779, Angle(deg: 0))), "jupiterRevo": 4380.0, "jupiterRadius": 69910.0,
                       "saturnCoord": Coord(polar: (1434, Angle(deg: 0))), "saturnRevo": 10585.0, "saturnRadius": 58230.0,
                       "uranusCoord": Coord(polar: (2871, Angle(deg: 0))), "uranusRevo": 30660.0, "uranusRadius": 25360.0,
                       "neptuneCoord": Coord(polar: (4495, Angle(deg: 0))), "neptuneRevo": 60225.0, "neptuneRadius": 24600.0
                      ]
        self.subTick(interval: 1)
    }
```

main.patl




```
"solarCoord": Coord(polar: (0, Angle(deg: 0)))
```

main.patl

```
struct Coord {
    var polar: (Double, Angle)?
    var cart: (Double, Double)?

    init(polar: (Double, Angle)? = nil, cart: (Double, Double)? = nil) {
        self.polar = polar
        self.cart = cart
    }

    func polarToCart() -> (Double, Double) {
        let x = polar!.0 * cos(polar!.1.deg!)
        let y = polar!.0 * sin(polar!.1.deg!)
        return (x,y)
    }

    func cartToPolar() -> (Double, Angle) {
        let r = sqrt(pow(cart!.0, 2.0) + pow(cart!.1, 2.0))
        let t = Angle(deg: atan(cart!.1 / cart!.0))
        return (r,t)
    }

}
```

bibli.patl

```
"solarCoord": Coord(polar: (0, Angle(deg: 0)))
```

main.patl

```
struct Angle {
    var deg: Double?
    var rad: Double?

    init(deg: Double? = nil, rad: Double? = nil) {
        self.deg = deg
        self.rad = rad
    }

    func degToRad() -> Double {
        return (deg! * (Double.pi/180))
    }

    func radToDeg() -> Double {
        return rad! * (180/Double.pi)
    }
}
```

bibli.patl

```
// Directly call when the component is created
func subTick(interval: UInt32) {
    self.callTick = true
    while(callTick) {
        self.tick()
        sleep(interval)
    }
}
```

main.patl

```
// Call when the component is removed
func unsubTick() {
   self.callTick = false
}
```

main.patl

```
func updatePlanetPos(currentAngle: Angle, revolution: Double) -> Double {
  let newAngle = currentAngle.deg!+(360/revolution)
  return (newAngle.truncatingRemainder(dividingBy: 360.0))
}
```

main.patl

```
func tick() {
  self.state = updateState(currentState: state,
                           nextState: ["mercuryCoord": Coord(polar: ((state["mercuryCoord"] as! Coord).polar!.0,
                                                                    Angle(deg: self.updatePlanetPos(currentAngle: (state["mercuryCoord"] as! Coord).polar!.1,
                                                                                                    revolution: (state["mercuryRevo"] as! Double))))),
                                        "venusCoord": Coord(polar: ((state["venusCoord"] as! Coord).polar!.0,
                                                                  Angle(deg: self.updatePlanetPos(currentAngle: (state["venusCoord"] as! Coord).polar!.1,
                                                                                                  revolution: (state["venusRevo"] as! Double))))),
                                        ...
                                        ]
                           )
  let _ = self.render()
}
```

main.patl

`Coord(polar: (58, Angle(deg: 0)))`   `(58, Angle(deg: 0))`   `58`

```swift
func updateState(currentState: [String: Any], nextState: [String: Any]) -> [String: Any] {
    var tmpState = currentState
    for (key, _) in nextState {
        tmpState.updateValue(nextState[key]!, forKey: key)
    }
    return tmpState
}
```

bibli.patl

```
func render() -> (Sphere, Sphere, Sphere, Sphere, Sphere, Sphere, Sphere, Sphere, Sphere) {
  return (
    Sphere(name: "Solar", pos: (state["solarCoord"] as! Coord), props: [state["solarRadius"]]),
    Sphere(name: "Mercury", pos: (state["mercuryCoord"] as! Coord), props: [state["mercuryRadius"]]),
    Sphere(name: "Venus", pos: (state["venusCoord"] as! Coord), props: [state["venusRadius"]]),
    Sphere(name: "Earth", pos: (state["earthCoord"] as! Coord), props: [state["earthRadius"]]),
    Sphere(name: "Mars", pos: (state["marsCoord"] as! Coord), props: [state["marsRadius"]]),
    Sphere(name: "Jupiter", pos: (state["jupiterCoord"] as! Coord), props: [state["jupiterRadius"]]),
    Sphere(name: "Saturn", pos: (state["saturnCoord"] as! Coord), props: [state["saturnRadius"]]),
    Sphere(name: "Uranus", pos: (state["uranusCoord"] as! Coord), props: [state["uranusRadius"]]),
    Sphere(name: "Neptune", pos: (state["neptuneCoord"] as! Coord), props: [state["neptuneRadius"]])
  )
}
```

main.patl

```
class Sphere {
    // Here we work with 2D cartesian and 2D polar coordinates
    var name: String
    var pos: (Double, Double)
    var props: [Any?]

    init(name: String, pos: Coord, props: [Any?]) {
      self.name = name
      self.pos = pos.polarToCart()
      self.props = props

      let _ = self.render()
    }

    func render() -> Mesh {
      log(str: "render a Sphere for [\(name) at position: \(pos) with props: \(props)]")
      return (
          Mesh(meshType: "Sphere", meshPosition: pos, meshProps: props)
      )
    }
}
```

```
Coord(polar: (58, Angle(deg: 0)))
```

```
func polarToCart() -> (Double, Double) {
    let x = polar!.0 * cos(polar!.1.deg!)
    let y = polar!.0 * sin(polar!.1.deg!)
    return (x,y)
}
```

main.patl

```swift
struct Mesh {
    var meshType: String
    var meshPosition: (Double, Double)
    var meshProps: [Any?]

    init(meshType: String, meshPosition: (Double, Double), meshProps: [Any?]) {
        self.meshType = meshType
        self.meshPosition = meshPosition
        self.meshProps = meshProps
    }
}
```

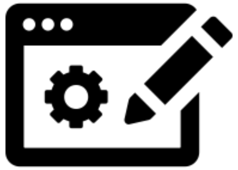
bibli.patl

```
// Entry: Call the highest component
let _ = SystemSolar()
```

main.patl

Syntax decoration

So, to get a different syntax from Swift we will go through:



The definition of custom operators

The creation of a template language to define our own keywords

Formalization

A Semantics for the Essence of React

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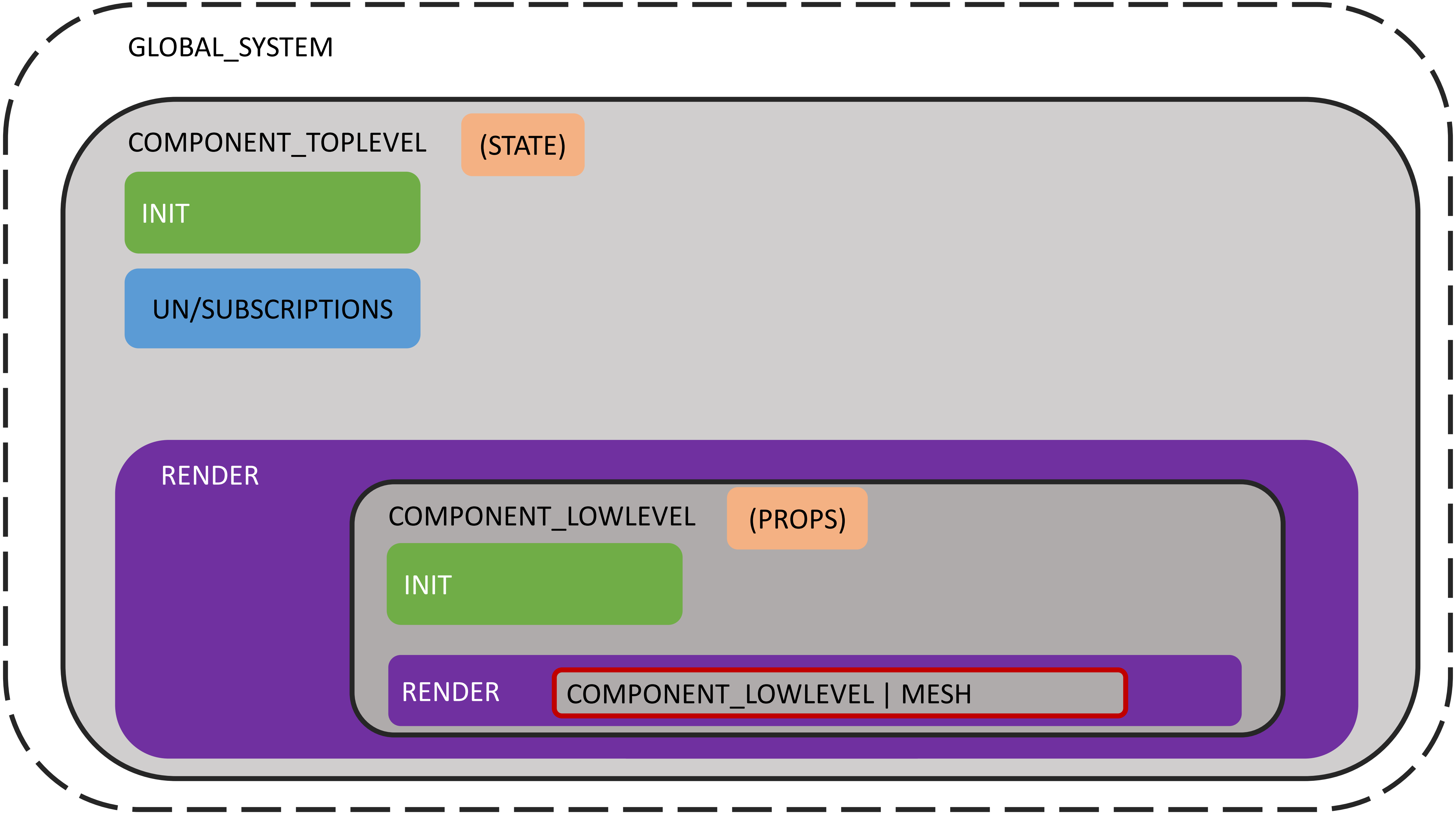
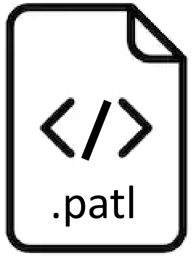

GLOBAL_SYSTEM
COMPONENT_TOPLEVEL
(STATE)
INIT
UN/SUBSCRIPTIONS
RENDER
COMPONENT_LOWLEVEL
(PROPS)
INIT
RENDER
COMPONENT_LOWLEVEL | MESH

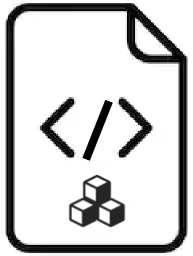
Static typing semantics

GLOBAL_SYSTEM

$$h : X \longrightarrow Y$$



$\in X$



$\in Y$

Set of .patl programs which are built with the concept of components top/low level

Set of Rendery programs composed of sequences of Rendery (Swift) instruction

Static typing semantics

COMPONENT_TOPLEVEL

Can be considered as a 4-tuple:

$$(\text{name} , \text{state} , \text{tick} , \text{render\_top})$$

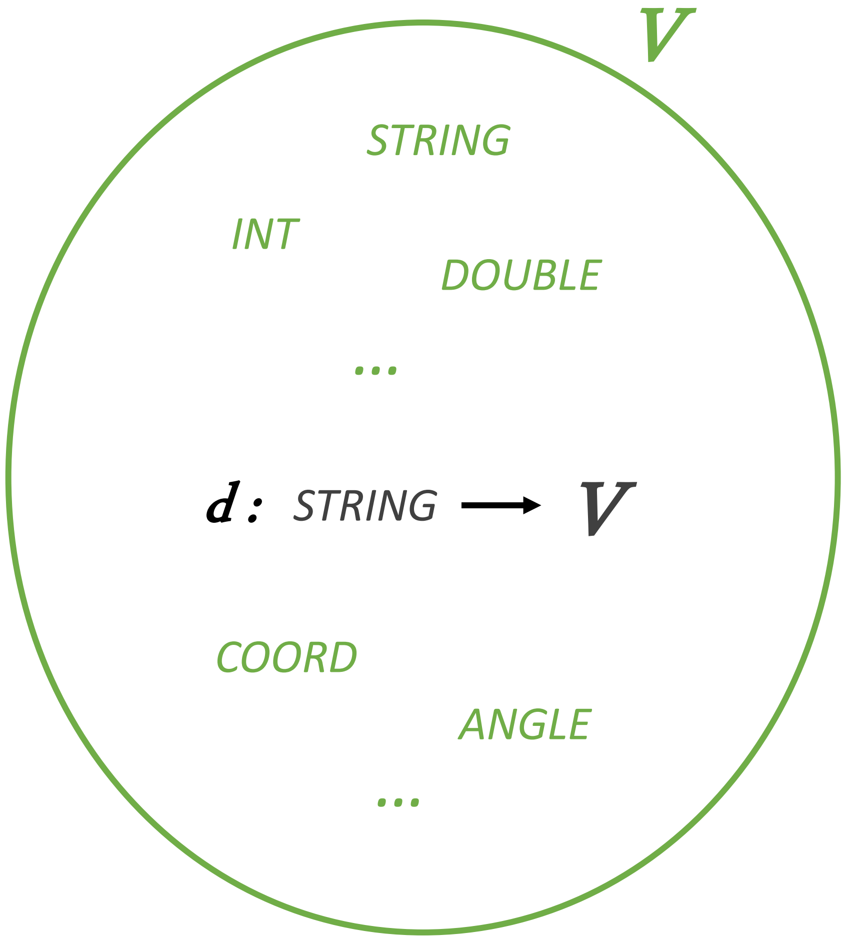
$$\text{name} \in \mathit{STRING}$$

Static typing semantics

state $\in V$

Where V is a set of some elements:

- Several primitives
- Dictionaries
- Abstract objects



Static typing semantics

render_top $\in$ $\boldsymbol{RT}$

Where $\boldsymbol{RT}$ is a set of partial function : $\boldsymbol{rt} :\ \boldsymbol{V} \longrightarrow (\ STRING \times \boldsymbol{P} \times \boldsymbol{RL}\ )^*$

A COMPONENT_LOWLEVEL can be considered as a 3-tuple:

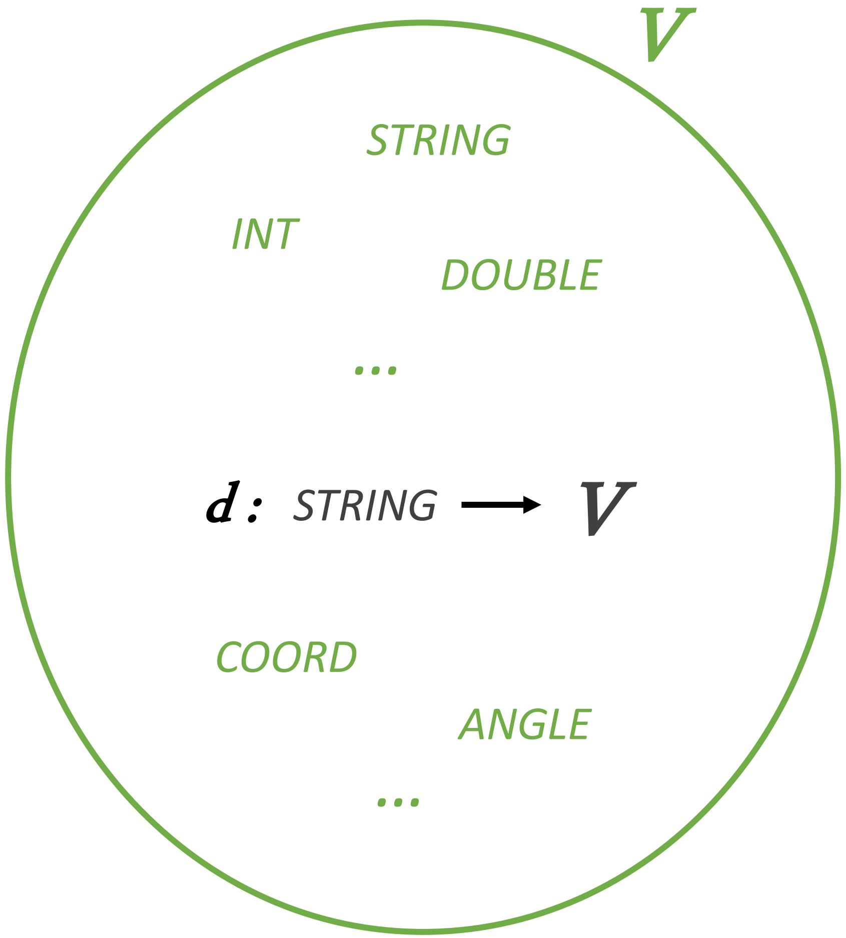
(name , props , render_low)

name $\in$ *STRING*

Static typing semantics

props $\in \boldsymbol{P}$

Where $\boldsymbol{P}$ is a set of partial function : $\boldsymbol{p}:$ *STRING* $\longrightarrow \boldsymbol{V}$



Static typing semantics

render_low $\in$ RL

Where RL is a set of partial function : $rl : P \longrightarrow ((\mathit{STRING} \times P \times RL) \cup M)^*$

MESH $\in$ M

Where M is a set of partial function : $m : P \longrightarrow I$

I is a set of OpenGL instructions

I

glBindBuffer()

glBindVertexArray()

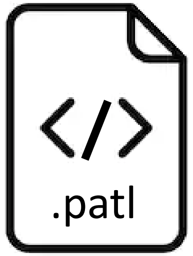
glDrawArray()

…

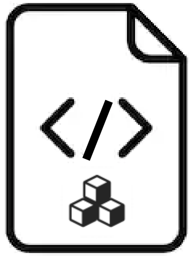
Static typing semantics

GLOBAL_SYSTEM

$$h : \color{red}{X} \longrightarrow \color{green}{Y}$$



$\in \color{red}{X}$



$\in \color{green}{Y}$

Set of .patl programs which are built with the concept of components top/low level

Set of Rendery programs composed of sequences of Rendery (Swift) instruction

→ Then we send it to an interpreter

Operational semantics

A Component Descriptor is written $\mathrm{C}(\ \mathrm{props}\ )$

A Mounted Component is written $\mathrm{C}\ @a(\ \mathrm{props}\ )$

Associated with an object in the heap stored at address a

A CONFIGURATION is a 5-tuple $(\ \sigma,\ \delta,\ \gamma,\ l,\ e\ )$

A heap : partial map from addresses to values

The component state map : partial map from component addresses to objects
→ contains the following state

The component shape map : partial map from component addresses to pairs of a mounted component and a sequence of addresses
→ contains the current "shape" of a mounted component

A listener map : partial map from componant addresses to a set of lambda expressions

Expression of the configuration

Operational semantics

INITIAL STATE

$\pi = \mathrm{C(\ props\ )}$

$(\ \emptyset,\ \emptyset,\ \emptyset,\ \emptyset,\ MOUNT(\ \pi\ )\ )$

Mount the highest level component descriptor

Operational semantics

MOUNT (Initialization step)

We want to mount component π

Choose a new address a

An object is stored with a copy of the props

Update the component state map

Update l

$$\pi = \mathrm{C(\ props\ )} \qquad a \notin dom(\sigma) \qquad \sigma' = \sigma[a \rightarrow \{props\}] \qquad \delta' = \delta[a] \qquad l' = l[a]$$

$$(\ \sigma,\ \delta,\ \gamma,\ l,\ MOUNT(\ \pi\ )\ ) \longrightarrow (\ \sigma',\ \delta',\ \gamma,\ l',\ MOUNTED(\mathrm{C}\ @a(\ \mathrm{props}\ ),\ MOUNTSEQ(RENDER(\pi)))\ )$$

Recursively mount its subcomponents

Update the component shape map to reflect the current ''shape'' of component a and its current subcomponents

$$\gamma' = \gamma[a \rightarrow (\mathrm{C}\ @a(\ \mathrm{props}\ ), \bar{a})]$$

$$(\ \sigma,\ \delta,\ \gamma,\ l,\ MOUNTED(\mathrm{C}\ @a(\ \mathrm{props}\ ), \bar{a})\ ) \longrightarrow (\ \sigma,\ \delta,\ \gamma',\ l,\ a\ )$$

Operational semantics

UNMOUNT

Subcomponents of a are known from γ

First, unmount subcomponents of a

Then, unmount a

$$\frac{\gamma(a) = (\mathrm{C}\ @a(\ \mathrm{props}\ ),\ \ \bar{a})}{(\ \sigma,\ \delta,\ \gamma,\ l,\ UNMOUNT(\ a\ )\ ) \longrightarrow (\ \sigma,\ \delta,\ \gamma,\ l,\ UNMOUNTSEQ(\bar{a})\ ; UNMOUNTED(a)\ )}$$

Once the subcomponents of a have been unmounted, remove all listener (event)

$$\frac{l' = l\ - a}{(\ \sigma,\ \delta,\ \gamma,\ l,\ UNMOUNTED(\ a\ )\ ) \longrightarrow (\ \sigma,\ \delta,\ \gamma,\ l',\ NIL)}$$

Operational semantics

OBJECT EQUALITY

They share the same keys

Compare the values of primitive types by equality

References are compared using reference equality

$$keys(o_1) = keys(o_2)$$

$$\frac{\forall k \in keys(o_1)\ \ o_1(k)\ is\ primitve \Rightarrow o_1(k) == o_2(k) \qquad \forall k \in keys(o_1)\ \ o_1(k)\ is\ reference \Rightarrow o_1(k) === o_2(k)}{o_1 \equiv o_2}$$

Operational semantics

STATE MERGES

Take all keys and values from the left object

Take all keys and values from the right object that did not appear in the left one

$$\frac{\forall k_i \in keys(o_1), o_1(k_i) = v_i \qquad \forall k_i' \in \big(keys(o_2) - keys(o_1)\big), o_2(k_i{}') = v_i{}' \qquad o_3 = \{k_1: v_1, \dots, k_n: v_n, k_1': v_1', \dots, k_n': v_n'\}}{\text{MERGE}(o_1, o_2) = o_3}$$

Add all keys and value into a new object

Operational semantics

RECONCILIATION (update a mounted component)

First case: a mounted component is replaced by another one

The new component we want

Replaces the component at the address

Descriptor and mounted components are different

$$\frac{\pi = \mathrm{C}_1(\,nextprops\,) \quad \gamma(a) = (\mathrm{C}_2\ @a(\,prevprops\,), \_) \quad C_1 \neq C_2}{(\,\sigma,\ \delta,\ \gamma,\ l,\ RECONCILE(\,\pi, a\,)\,) \longrightarrow (\,\sigma,\ \delta,\ \gamma,\ l,\ UNMOUNT(a)\ ;\ MOUNT(\pi)\,)}$$

Mounted component is unmounted & we mount π

Operational semantics

Second case: update a mounted component with news props & state

The same component with the news props we want

Update the component at the address a

Get the next state of the component

$$\dfrac{\pi = C(\,nextprops\,) \qquad \gamma(a) = (\mathrm{C}\ @a(\,prevprops\,), \bar{a}) \qquad nextstate = \delta(a) \\ \mathrm{o} = \sigma(a) \qquad o' = o[\mathrm{props} \rightarrow nextprops]\ [\mathrm{state} \rightarrow nextstate] \qquad \sigma' = \sigma[a \rightarrow o']}{(\,\sigma,\ \delta,\ \gamma,\ l,\ RECONCILE(\,\pi, a\,)\,) \longrightarrow (\,\sigma',\ \delta,\ \gamma,\ l,\ RECONCILED(\mathrm{C}\ @a(\,nextprops\,), RECONCILESEQ(RERENDER(a), \bar{a})))}$$

Object o represents the component object

Update the props & state fields

Update σ at the address a

Re render a which gives us $\bar{\pi}$ and apply $RECONCILE$ on the subcomponents

$$\dfrac{\gamma' = \gamma[a \rightarrow (\mathrm{C}\ @a(\,props\,), \bar{a})]}{(\,\sigma,\ \delta,\ \gamma,\ l,\ RECONCILED(\mathrm{C}\ @a(\,props\,), \bar{a})\,) \longrightarrow (\,\sigma,\ \delta,\ \gamma',\ l,\ a\,)}$$

Update the component shape map to reflect the current "shape" of component a and its current subcomponents

Operational semantics

RENDER

We want to render π

Invoke the render method of the component

$$\frac{\pi = C(\,\text{props}\,) \quad (\,\sigma,\ \delta,\ \gamma,\ l,\ render(\,)\,) \longrightarrow (\,\sigma,\ \delta,\ \gamma,\ l,\ \bar{\pi})}{(\,\sigma,\ \delta,\ \gamma,\ l,\ RENDER(\,\pi\,)\,) \longrightarrow (\,\sigma,\ \delta,\ \gamma,\ l,\ \bar{\pi})}$$

Return the sequence of remaining components

RERENDER (for a mounted component)

Use the address a to retrieve the component from γ

$$\frac{\gamma(a) = (\,\mathrm{C}\ @a\,(\,\text{props}\,), \_\,) \quad (\,\sigma,\ \delta,\ \gamma,\ l,\ render(\,)\,) \longrightarrow (\,\sigma,\ \delta,\ \gamma,\ l,\ \bar{\pi})}{(\,\sigma,\ \delta,\ \gamma,\ l,\ RERENDER(\,a\,)\,) \longrightarrow (\,\sigma,\ \delta,\ \gamma,\ l,\ \bar{\pi})}$$

Operational semantics

UPDATESTATE

Use the address a to retrieve the component from γ

Get the next state of the component

Merge the current next state with the new state

$$\gamma(a) = (\,\mathrm{C}\ @a\ (\,\mathrm{props}\,), \bar{a}) \qquad nextstate = \delta(a) \qquad \delta' = \delta[a \rightarrow \mathrm{MERGE}(newstate, nextstate)]$$

$$\overline{(\,\sigma,\ \delta,\ \gamma,\ l,\ UPDATESTATE(\,a\,,\ newstate\,)\,) \longrightarrow (\,\sigma,\ \delta',\ \gamma,\ l,\ RECONCILED(a\,,\ RECONCILESEQ(RENDER(a), \bar{a})))}$$

The *newstate* object is passed to the component

Changing the state of a component could change what is returned by its render method

Call OpenGL from Swift (Linux)

An OpenGL function loader in pure Swift

It can load any OpenGL function up to OpenGL 4.5

```swift
import PackageDescription

let package = Package(
    name: "test_OpenGL_swift_linux_SPM",
    products: [
      .executable(name: "UsageExample", targets: ["UsageExample"]),
    ],
    dependencies: [
        // Dependencies declare other packages that this package depends on.
        // .package(url: /* package url */, from: "1.0.0"),
        .package(url: "https://github.com/apple/swift-numerics", from: "0.0.5"),
        .package(name: "GL", url:"https://github.com/kelvin13/swift-opengl.git", .branch("master"))
    ],
    targets: [
        // Targets are the basic building blocks of a package. A target can define a module or a test suite.
        // Targets can depend on other targets in this package, and on products in packages this package depends on.
        .target(name: "UsageExample", dependencies: ["test_OpenGL_swift_linux_SPM"]),
        .target(name: "test_OpenGL_swift_linux_SPM", dependencies: ["GL", "CGlad", "CGLFW", "CFreeType"]),
        .target(name: "CGlad", dependencies: []),

        .systemLibrary(name: "CFreeType", pkgConfig: "freetype2"),
        .systemLibrary(name: "CGLFW", pkgConfig: "glfw3"),

        .testTarget(
            name: "test_OpenGL_swift_linux_SPMTests",
            dependencies: ["test_OpenGL_swift_linux_SPM"]),
    ]
)
```

package.swift

```
CGLFW
    module.modulemap
    shim.h
```

Import the OpenGL function loader & the other important libraries

```swift
import GL
import CGLFW
import CFreeType
import Foundation
```

```swift
// Initialize GLFW
if(glfwInit() == 0) {
  print("Failed to initialize GLFW! I'm out!")
  exit(-1)
}
```

Open a window & attach an OpenGL context to the window surface

```swift
guard let window = glfwCreateWindow(600, 600, "OpenGL test - Swift", nil, nil)
else {
  print("Failed to open a window! I'm out!")
  glfwTerminate()
  exit(-1)
}

// Set the window context current
glfwMakeContextCurrent(window)
```

main.swift

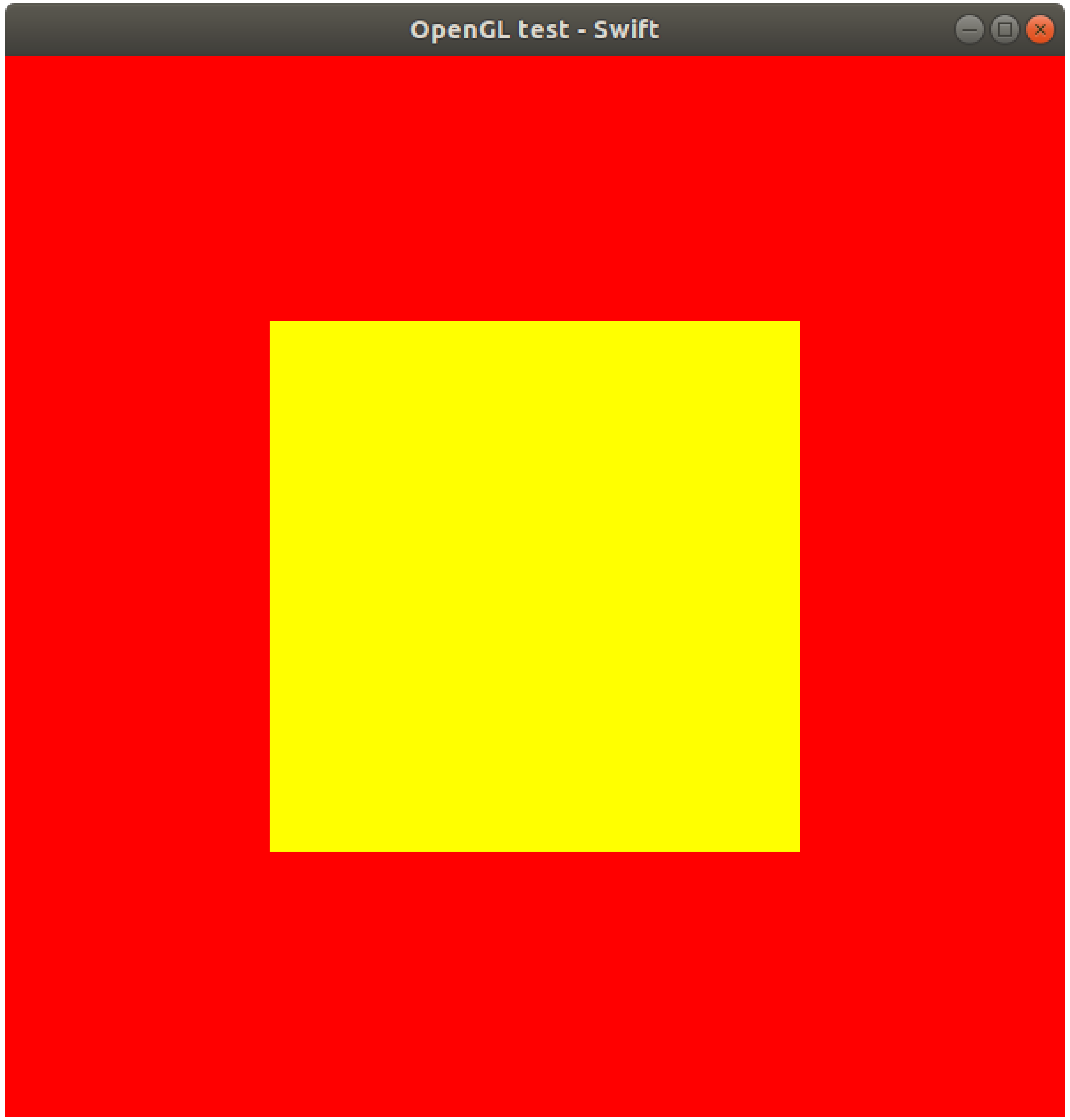
Red background

Draw a yellow square

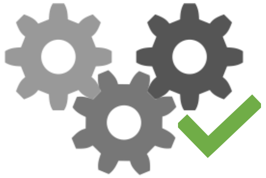
```swift
// Use red to clear the screen
glClearColor(1, 0, 0, 1)
while (glfwWindowShouldClose(window) == 0) {
  // Clear the screen (window background)
  glClear(UInt32(GL_COLOR_BUFFER_BIT))

  // Draw a square using the (deprecated) fixed pipeline functionality
  glColor3f(1.0, 1.0, 0.0)
  glBegin(GL_QUADS)
  glVertex2f(-0.5, -0.5)
  glVertex2f(0.5, -0.5)
  glVertex2f(0.5, 0.5)
  glVertex2f(-0.5, 0.5)
  glEnd()
  // Swap front and back buffers for the current window
  glfwSwapBuffers(window)
  // Poll for events
  glfwPollEvents()
}

// Destroy the window and its context
glfwDestroyWindow(window)

// Terminate GLFW
glfwTerminate()
```

main.swift

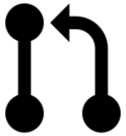
Swift build
Swift run



Rendery on Linux



Rendery is now operational on Linux



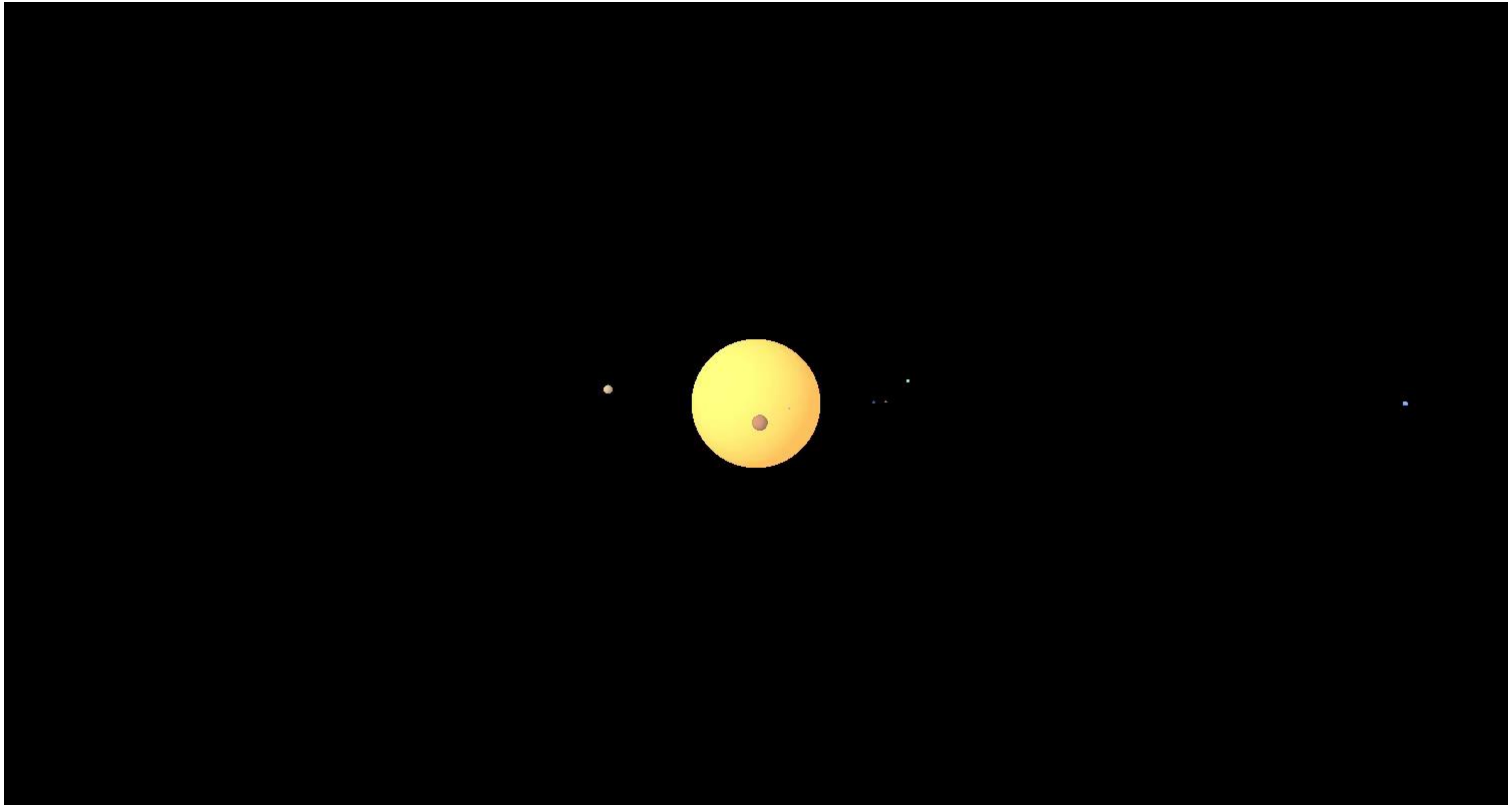
I sent a pull request

Then, the idea was to work on the example of the solar system

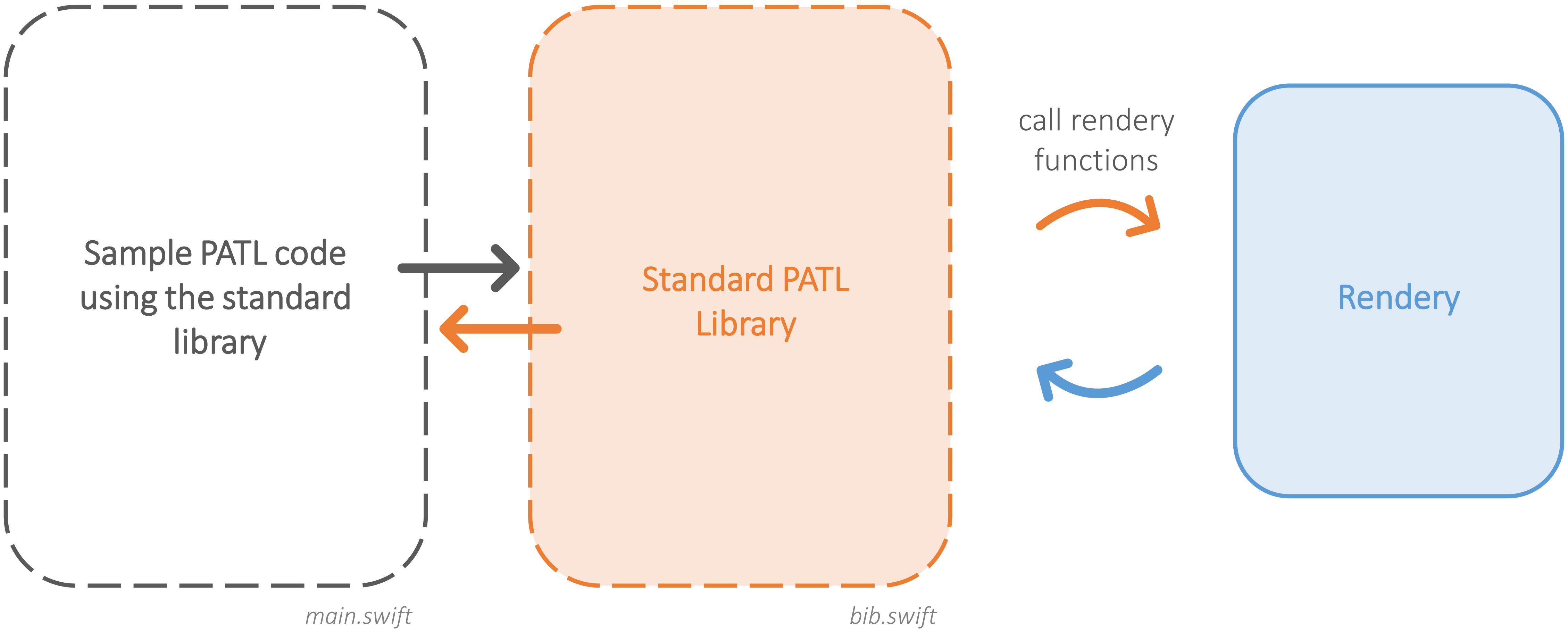
How it works

- Create a context and attach a window to it
  - Create a scene where we will place our 3D objects
    - Create child nodes that will define our objects
      - Define a camera that will be the point of view of the users
      - …
      - Create spheres representing our planets
        - Update the position of the planets

Solar system with Rendery



Principal idea of PATL



Example with the solar system

```swift
// Build the Scene related to ComponentTopLevel
open class ComponentTopLevel: Scene {
  public override init() {
// Set the background color of the scene
public func setBackgroundColor(colHexa: Color) -> Color {
  backgroundColor = colHexa
  return backgroundColor!
}
    cameraNode.translation = Vector3(x: 650.0, y: 90, z: 0.0)
    cameraNode.constraints.append(LookAtConstraint(target: root))
  }
```

bib.swift

```swift
class SystemSolar: ComponentTopLevel {

  var state: [String: [String: Any]] = [:]
  let solarRadius: Double = 50.0

  override init() {
    super.init()
    // Define the background color as "#______"
    self.setBackgroundColor(colHexa: "#000000")
    // Define the global state of the application: this is a dictionary of diction
    // Each object in the scene has some properties
    // Here, each planet has a name, a radius, coordinates (polar: which are represented by the distance from the sun and the polar angle),
    // a revolution and finally an image representing its texture
    self.state = ["root": ["name": "Solar",
                           "radius": solarRadius,
                           "coord": Coord(polar: (0.0, Angles(deg: 0.0), Angles(deg: 0.0))),
                           "tex": "/img/solar_tex.jpg"],
                  "obj0": ["name": "Mercury",
                           "radius": self.sizePlanet(s: solarRadius, p: 11440),
                           "coord": Coord(polar: (self.distPlanet(s: solarRadius, d: 35.791), Angles(deg: 0.0), Angles(deg: 0.0))),
                           "revo": 88.0,
                           "tex": "/img/mercury_tex.jpeg"],
                  ...

    self.render()
  }
```

main.swift

```swift
public struct Coord {

  public var polar: (Double, Angles, Angles) = (0.0, Angles(deg: 0.0), Angles(deg: 0.0))
  public var cart: (Double, Double, Double) = (0.0, 0.0, 0.0)

  public init(polar: (Double, Angles, Angles)) {
    self.polar = polar
  }

  public init(cart: (Double, Double, Double)) {
    self.cart = cart
  }

  public func polarToCart() -> (Double, Double, Double) {
    let x = polar.0 * sin(polar.1.deg) * cos(polar.2.deg)
    let y = polar.0 * sin(polar.1.deg) * sin(polar.2.deg)
    let z = polar.0 * cos(polar.1.deg)
    return (x,y,z)
  }
```

bib.swift

```swift
func render() {
    let solar = Sphere(name: (self.state["root"]!["name"] as! String),
                       scene: self,
                       coord: (self.state["root"]!["coord"] as! Coord),
                       props: [(self.state["root"]!["tex"] as! String), (self.state["root"]!["radius"] as! Double)]
                       ).render()
    let s0 = Sphere(name: (self.state["obj0"]!["name"] as! String),
                    scene: self,
                    coord: (self.state["obj0"]!["coord"] as! Coord),
                    props: [(self.state["obj0"]!["tex"] as! String), (self.state["obj0"]!["radius"] as! Double)]
                    ).render() // Call the low level render function

    ...

    self.tick(node: [s0 as! Node, s1 as! Node, s2 as! Node, s3 as! Node,
                     s4 as! Node, s5 as! Node, s6 as! Node, s7 as! Node])
}
```

main.swift

```swift
// Render function is called the firs
func render() -> Any {
  // createChildNode() allows to create a child node in the scene (roo
  let n = scene.createChildNode(name: self.name!)
  // Call createSphere() to create a sphere in the current scene
  scene.createSphere(node: n, segments: 100, rings: 100, radius: self.props![1] as! Double)
  // Apply a texture from an image
  scene.applyTexture(node: n, tex: self.props![0] as! String)

  let x = coord.polarToCart().0
  let y = coord.polarToCart().1
  let z = coord.polarToCart().2
  scene.setNodePosition(node: n, x: x, y: y, z:
  return n
}

// Rerender function is called for a mounted co
func rerender() {
  let x = coord.polarToCart().0
  let y = coord.polarToCart().1
  let z = coord.polarToCart().2
  print(x,y,z)
  scene.setNodePosition(node: node!, x: x, y: y
}
```

main.swift

```swift
// Apply the "tex" texture to the node
public func applyTexture(node: Node, tex: String) {
  node.model?.materials[0].diffuse = .texture(ImageTexture(image:
                                     Image(contentsOfFile: "Sources"+tex)!, wrapMethod: .repeat))
}
```

bib.swift

```swift
  return node
}
```

bib.swift

```swift
// Define a node as sphere with some properties: (segments, rings, radius)
public func createSphere(node: Node, segments: Int, rings: Int, radius: Double) {
  node.model = Model(
    meshes: [.sphere(segments: segments, rings: rings, radius: radius)],
```

```swift
}

pub
  materials: [Material()])
}
```

bib.swift

```swift
// Set the position of a node
public func setNodePosition(node: Node, x: Double, y: Double, z: Double) {
  node.translation.x = x
  node.translation.y = y
  node.translation.z = z
}
```

bib.swift

```swift
func tick(node: [Node]) {
  AppContext.shared.subscribe(frameListener: { _, delta in
    self.state = updateState(
      currentState: self.state,
      nextState: ["obj0": ["coord": Coord(polar: ((self.state["obj0"]!["coord"] as! Coord).polar.0,
                                                  Angles(deg: self.updatePlanetPos(currentAngle: (self.state["obj0"]!["coord"] as! Coord).polar.1,
                                                                                   revolution: (self.state["obj0"]!["revo"] as! Double))),
                                                  Angles(deg: (self.state["obj0"]!["coord"] as! Coord).polar.2.deg)))],
                  "obj1": ["coord": Coord(polar: ((self.state["obj1"]!["coord"] as! Coord).polar.0,
                                                  Angles(deg: self.updatePlanetPos(currentAngle: (self.state["obj1"]!["coord"] as! Coord).polar.1,
                                                                                   revolution: (self.state["obj1"]!["revo"] as! Double))),
                                                  Angles(deg: (self.state["obj1"]!["coord"] as! Coord).polar.2.deg)))],

                  ...
                 ]
    )
    self.rerender(newState: self.state, node: node)
  })
}
```

```swift
// Predefined function to update the global state of the application
public func updateState(currentState: [String: [String: Any]], nextState: [String: [String: Any]]) -> [String: [String: Any]] {
    var tmpState = currentState
    for (outerKey, _) in nextSta
        for (innerKey, _) in nex
            tmpState[outerKey]![
        }
    }
    return tmpState
}
```

```swift
uble) -> Double {

)
```

main.swift

```swift
func rerender(newState: [String: [String: Any]], node: [Node]) {
  Sphere(node: node[0],
         scene: self,
         coord: (self.state["obj0"]!["coord"] as! Coord)
        ).rerender() // Call the low level rerender function

  ...

}
```

main.swift

bib.swift

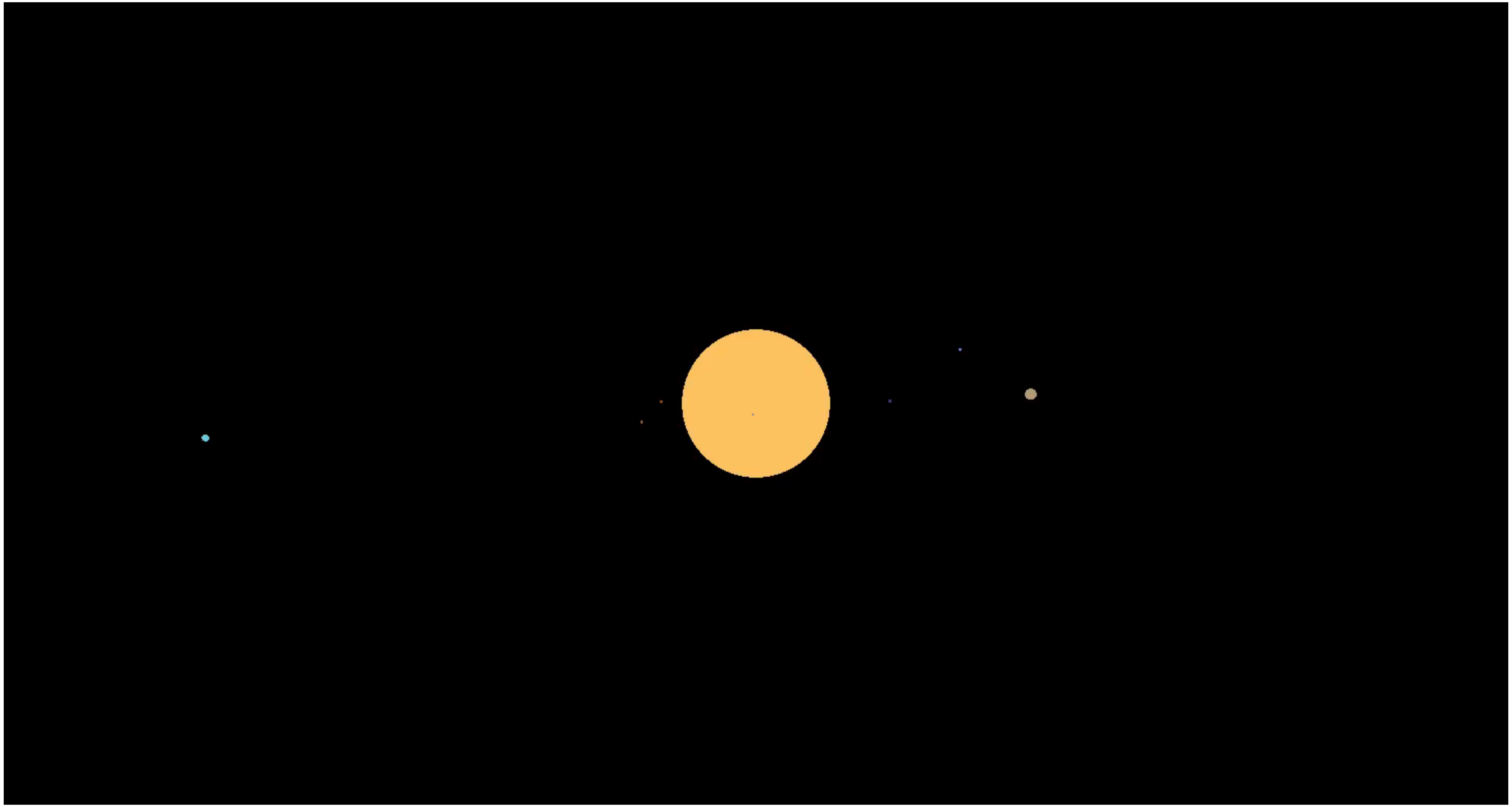
```swift
// Entry: Call the highest component
let _ = createScene(name: "Solar System", compTL: SystemSolar())
```

main.swift

```swift
public func createScene(name: String, compTL: Scene) {
  // Initialize Rendery's engine.
  guard let window = AppContext.shared.initialize(width: 1500, height: 800, title: name)
    else { fatalError() }
  //defer { AppContext.shared.clear() } #TODO: bug under linux

  // Create the game scene and present it in the window's viewport.
  let scene = compTL
  window.viewports.first?.present(scene: scene)

  // Run the rendering loop.
  AppContext.shared.targetFrameRate = 60
  AppContext.shared.render()
}
```

bib.swift

Solar system with PATL

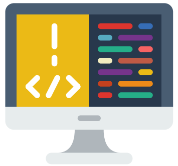


Work done

Successfully run Rendery on Linux

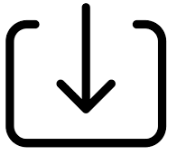
Implement the solar system example with Rendery

Advancement



Debugging and coding new Rendery features (PATL library) such as:

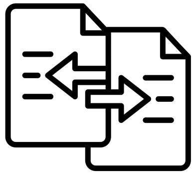
Abstract types



Import and use of shader programs

Events

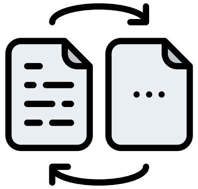
Shader part



Write shaders in GLSL and pass them to Rendery

We can use shader libraries for examples

Ex: (a Shader Editor: *shdr.bkcore.com* , …)



Then a step could be to create our custom shaders with a Swift syntax and convert them to GLSL shaders

→ With a parser, etc.

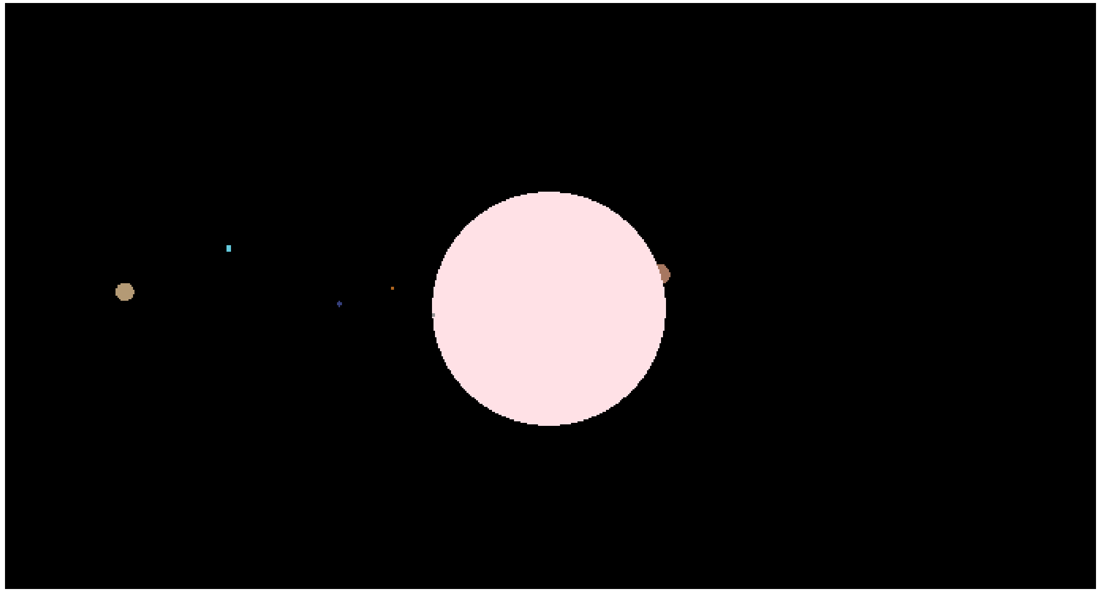
Shader part

```
public let fragmentSource = """
#version 330 core
out vec4 FragColor;
in vec4 vertexColor;
void main() {
  FragColor = vertexColor;
}
"""
```

pinkProgram.swift

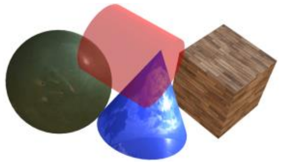
```
public let vertexSource = """
#version 330 core
layout (location = 0) in vec3 i_position;
uniform mat4 u_modelViewProjMatrix;
out vec4 vertexColor;
void main() {
  gl_Position = u_modelViewProjMatrix * vec4(i_position, 1.0);
  vertexColor = vec4(1.0, 0.75, 0.79, 1.0);
}
"""
```

pinkProgram.swift



Work in progress

Implement the PATL to Rendery translation system (PATL standard library) ~



Work on the shaders part and create examples of applications ~

Develop a tutorial to explain how to use PATL ~

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https://astexplorer.net/

https://codepen.io

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Tomaž Kosar, Pablo E. Martı´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.

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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

Add react semantics

Working with shaders

Patrick SARDINHA