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Introductory Seminar

EDAF80: Computer Graphics

Rikard Olajos

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AGENDA

1. Lab info
2. OpenGL
3. C++ crash course

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LABS OVERVIEW

- 1 optional + 5 mandatory assignments
  - Week 2 – 7
  - “Lab 0” in week 2: optional attendance
  - Book sessions on course homepage
  - Labs take more than the 2 hours per week, so make sure to start in advance
- Work in pairs
  - Both must understand, and be able to present, the work done
  - If looking for a partner, post on forum `#seeking-lab-partner`
- E:Uranus
  - Located in E-huset basement
  - Windows 10, 64-bit, Core i5, 16GB RAM
  - Visual Studio 2022
  - Geforce GTX 560

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OPENGL

- Application Programming Interface (API)
  - Set of functions that create a 2D image of a 3D scene
  - 3D scene is made of:
    - Primitives – Triangles
    - Textures – 2D images
    - and much more!
- Controls a graphics pipeline (graphics hardware)
  - Graphics Processing Unit (GPU)

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OPENGL

- We will focus on the core profile
  - no fixed function/immediate mode
- OpenGL is a state machine
  - Current state is the “OpenGL context”
  - There are many functions that change the current state
  - OpenGL uses objects that are a part of the state
  - Drawing uses the most recently bound buffers

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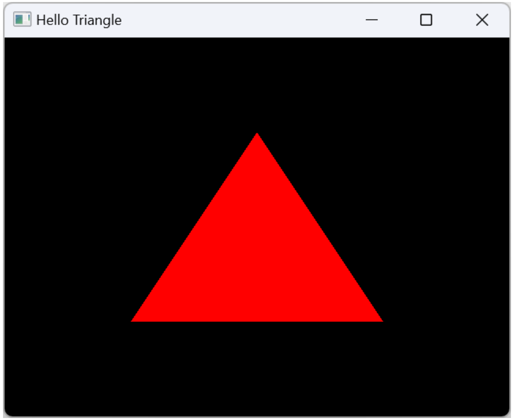
HELLO TRIANGLE



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APPLICATION SETUP

- First, make a window, use GLFW library
- Second, create a `while` loop i.e. the render loop:
  - Grab inputs
  - Render the screen
  - Swap the buffers
- Third, do some rendering in the render loop...

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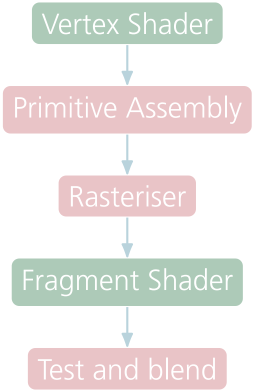
GRAPHICS PIPELINE



- Shaders are programmable, other parts are not
- There are no default vertex and fragment shaders, you must provide them
- Primitive Assembly (PA) puts the vertices into the primitive that is currently specified

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VERTICES

- 3 vertices in (x, y, z)
  - Range is [-1, +1]

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

- Output from VS is in Normalized Device Coordinates (NDC)
  - Also [-1, +1]
  - Origin is in the middle of the screen
- Put vertices into Vertex Buffer Objects (VBO)

```
GLuint VBO;
glGenBuffers(1, &VBO);
glBindBuffer(GL_ARRAY_BUFFER, VBO);
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices), vertices, GL_STATIC_DRAW);
```

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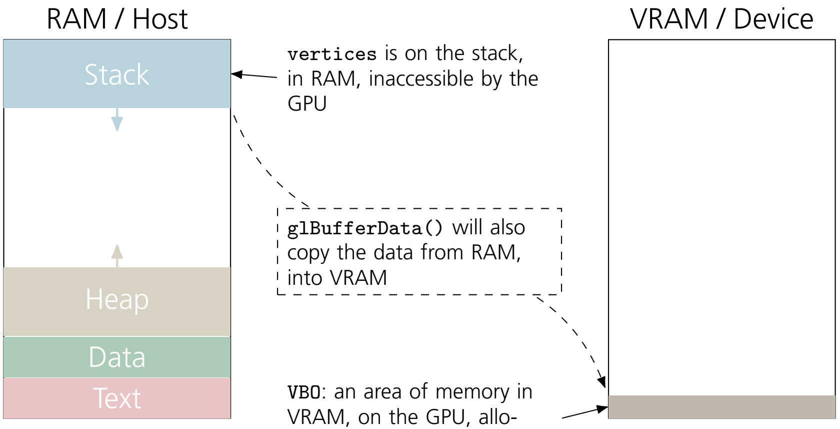
WHERE ARE YOUR VERTICES?



`vertices` is on the stack, in RAM, inaccessible by the GPU

`glBufferData()` will also copy the data from RAM, into VRAM

`VBO`: an area of memory in VRAM, on the GPU, allocated by `glBufferData()`

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SIMPLE VERTEX SHADER

- Must set the predefined variable `gl_Position`
- Need to link vertex data to the vertex shader
    - A Vertex Array Object (VAO) is also required

```
#version 410

in vec3 position;

void main()
{
    gl_Position = vec4(position, 1.0);
}
```

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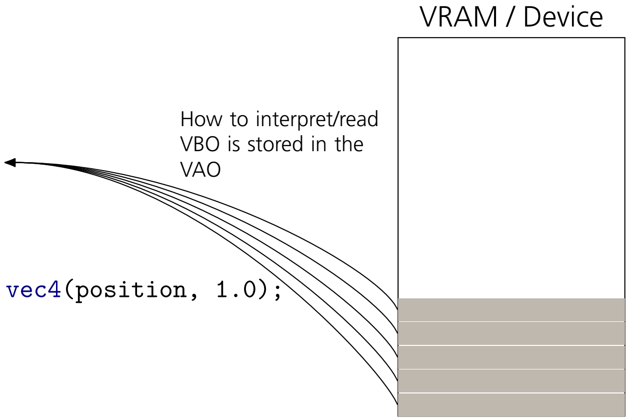
HOW TO ACCESS THE VERTICES

```
#version 410

in vec3 position;

void main()
{
    gl_Position = vec4(position, 1.0);
}
```

How to interpret/read VBO is stored in the VAO



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SIMPLE FRAGMENT SHADER

- Requires one output variable of `vec4`, for the colour

```
#version 410

out vec4 color;

void main()
{
    color = vec4(1.0, 0.0, 0.0, 1.0); // set color to red
}
```

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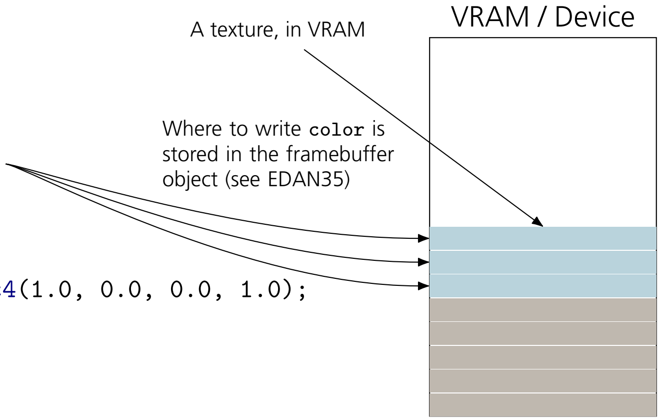
WHERE DOES FRAGMENT OUTPUT GO?

```
#version 410

out vec4 color;

void main()
{
    color = vec4(1.0, 0.0, 0.0, 1.0);
}
```



Where to write **color** is stored in the framebuffer object (see EDAN35)

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BUFFERS VERSUS TEXTURES

- Both reside in VRAM on the GPU
- Both represent a chunk of memory (both can be viewed as *n*-d arrays, with data in cells)

Buffers:

- Supports any data format (even custom)
- Only the cells can be read
- Stored linearly

Textures:

- Only specific data formats allowed
- You can read between cells, and get interpolated results
- Stored in tiles

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COMPILING SHADERS

- Shaders run on the **GPU**, not CPU
- They are written in GLSL, which is C-based
- Like for CPUs, need to compile to machine-specific instructions
- Unlike CPUs, shader compilation is done at runtime by your GPU driver

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COMPILING SHADERS

Done in two steps:

1. Compile each shader individually

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

   - Check for possible compile errors after `glCompileShader()`

2. Link all shaders into a single shader program

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

   - Check for possible linking errors after `glLinkProgram()`

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DRAWING

- Tell OpenGL what to render
  - `glDrawArrays(GL_TRIANGLES, 0, 3);`
  - (what to draw, starting index, number of vertices)

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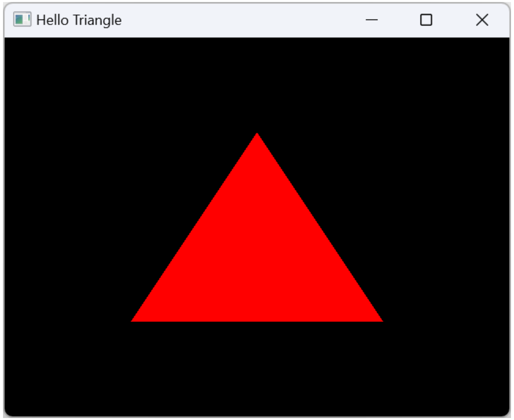
HELLO TRIANGLE (REVISITED)



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Seminar Exercise 0-1: Hello Triangle!

- `https://cs.lth.se/edaf80/`
  - Assignments > Exercises

1. Move the triangle by changing the positions in the vertices list.
2. Change the appearance of the triangle by altering the colour in the fragment shader.

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FOLLOW-UP QUESTIONS

1. How big is the viewport?
2. What happens when you change the z-coordinate?
3. How do you make the triangle yellow?
4. What happens with colour values above 1.0?

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MORE INFO

- `https://learnopengl.com/`
  - Joey de Vries
  - Most complete guide for modern OpenGL
- `https://open.gl/`
  - Alexander Overvoorde
- `https://antongerdelan.net/opengl/`
  - Anton Gerdelan

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HELLO C++

```
#include <iostream>

int main()
{
    std::cout << "Hello world!\n";
    return 0;
}
```

Output

```
> Hello world!
```

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ABOUT

- Based on C
- Create by Bjarne Stroustrup in 80's 🇩🇰
- Object-oriented (classes and structs)
- Constructors & destructors
- Inheritance & virtual functions
- Operator overloading (+, -, *, /, etc.)
- Templates
- C++11 began a 3-year cycle of updates

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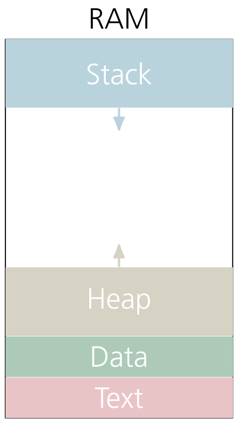
SIMPLIFIED MEMORY MODEL

- Stack
  - Stores local variables
  - Managed by the compiler
- Heap
  - Dynamic memory
  - Managed by the programmer
- Data
  - Stores global variables
  - Initialized and uninitialized
- Text
  - Stores code being executed



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STACK INTEGER DECLARATION

```
int x;

std::cout << x;
```

Output

```
> 698683442
```

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STACK INTEGER DECLARATION & INITIALIZATION

```
int x;
x = 35;

std::cout << x;
```

Output

```
> 35
```

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POINTER TO AN INTEGER

```
int* y;

std::cout << y;
```

Output

```
> 0000000B2394FB09
```

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ALLOCATE HEAP MEMORY

```
int* y;
y = new int(10);

std::cout << y;
```

Output

```
> 000001D7AD807FA0
```

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POINTER DEREFERENCING

```
int* y;
y = new int(10);

std::cout << *y;
```

Output

```
> 10
```

`*y` is dereferencing the pointer

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POINTER TO STACK INTEGER

```
int x = 35;
int* xp;
```

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POINTER TO STACK INTEGER

```
int x = 35;
int* xp = x; // Wrong!
```

`x` is an `int`, not an `int*` (pointer to an int)

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POINTER TO STACK INTEGER

```
int x = 35;
int* xp = &x;
```

`&x` takes the address of `x`

```
std::cout << *xp;
```

Output

```
> 35
```

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HEAP DEALLOCATION

```
int* y = new int(10);
...
delete y;
```

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C++ CLASS

```
class MyClass
{

};
```

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CLASS SCOPE

```
class MyClass
{
    // class scope
};
```

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CLASS ACCESS SPECIFIERS

```
class MyClass
{
private:
    // access within this class only (default)
protected:
    // access to this and inherited classes
public:
    // access to everyone
};
```

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CLASS CONSTRUCTOR

```
class MyClass
{
    float mX;

    MyClass(float x)
    {
        mX = x;
    }
};
```

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CLASS CONSTRUCTOR + INITIALIZATION

```
class MyClass
{
    float mX;

    MyClass(float x) : mX(x)
    {

    }
};
```

CLASS CONSTRUCTOR & DESTRUCTOR

```
class MyClass
{
    float mX;

    MyClass(float x)
    {
        mX = x;
    }

    ~MyClass()
    {
        // mX is on stack, so automatically deallocated
    }
};
```

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CLASS CONSTRUCTOR & DESTRUCTOR

```
class MyClass
{
    float* mXp;

    MyClass(float x)
    {
        mXp = new float(x);
    }

    ~MyClass()
    {
        delete mXp; // mX is on heap, so deallocate manually
    }
};
```

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CLASS MEMBER METHOD

```
class MyClass
{
    float mX;

    void setX(float x)
    {
        mX = x;
    }
};
```

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CLASS MEMBER ACCESS

Stack

```
MyClass myclass = MyClass(5);
myclass.setX(2);
```

Heap

```
MyClass* myclassp = new MyClass(5);
myclass->setX(2);
...
delete myclassp;
```

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CLASS DECLARATION + DEFINITION

MyClass.h

```
class MyClass {
    float mX;
    void setX(float x);
};
```

MyClass.cpp

```
#include "MyClass.h"

void MyClass::setX(float x) {
    mX = x;
}
```

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RAW ARRAYS: STACK & HEAP ALLOCATION

Stack

```
float numbers[3];
numbers[0] = 1.0f;
...
```

Stack: direct initialization

```
float numbers[3] = { 1.0f, 2.0f, 3.0f };
```

Heap

```
float* numbers = new float[3];
number[0] = 1.0f;
...
delete[] numbers;
```

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STL ARRAYS: VECTOR & ARRAY

Includes

```
#include <array>
#include <vector>
```

Initialization

```
std::array<int, 3> arr;       // Static array with 3 integers
std::vector<float> vec;       // Dynamic array with floats (on the heap)
```

Element access & size

```
arr[0] = 1;                   // Set first element to 1
vec.push_back(1.0f);          // Add 1.0f to end of vector
std::cout << vec[0];          // Print first element of 'vec'
std::cout << vec.size();      // Print number of elements in 'vec'
```

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PARAMETERS: VALUE, REFERENCE, POINTER

```
MyClass mc0 = MyClass(1);
MyClass mc1 = MyClass(1);
MyClass* mc2 = new MyClass(1);

foo(mc0, mc1, mc2);
```

```
int foo(MyClass mc0, MyClass& mc1, MyClass* mc2)
{
    mc0.setX(10);  // edits local copy      (pass by value)
    mc1.setX(10);  // edits original        (pass by reference)
    mc2->setX(10); // edits original        (pass by pointer)
}
```

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TYPES

```
int               a = -1;           (32 bits)
unsigned int      b = 1u;           (32 bits)
long              c = -2l;          (64 bits)
unsigned long     d = 2lu;          (64 bits)
float             e = 1.0f;         (32 bits)
double            f = 3.14;         (64 bits)
bool              g = true;         (8 bits)
char              h = 'x';          (8 bits)
char              i[] = "abcd";     (5 * 8 bits)
...               ...               ...
```

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OPERATOR OVERLOADING

- May customize +, -, *, /, and many others
- Very useful for linear algebra, e.g.:

```
glm::mat3 A, B;
glm::vec3 u;
...
glm::mat3 M = A * B;
glm::vec3 v = M * u;
```

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OUTPUT

- Include header for `std::cout`

```
#include <iostream>
```

- or, for `printf()`

```
#include <stdio.h>
```

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OUTPUT

- Print ”Rendering...” to standard output, followed by a new line:

```
std::cout << "Rendering...\n";
```

- Or, with the same result:

```
printf("Rendering...\n");
```

- Inclusion of variables (many formatting options available):

```
std::cout << "an integer: " << 1 << ", a float: " << 3.14f << '\n';
```

- Or, with the same result:

```
printf("an integer: %d, a float: %f\n", 1, 3.14f);
```

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MORE INFO

- EDAF50 – C++ Programming
- `https://cplusplus.com/`
- `https://en.cppreference.com/w/cpp`

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Seminar Exercise 0-2: Vertex ID

1. Move the triangle by offsetting the `gl_Position`.
   - `gl_Position.x += ...`
   - `gl_Position += vec4(...)`
2. Without changing the vertices list, move the top vertex of the triangle using `gl_VertexID`.

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FOLLOW-UP QUESTIONS

1. Can you find any alternative ways of altering `gl_Position`?
2. In which order are the three vertices of the triangle ordered?