Intro to GLSL

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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Practical Session #2

```
~/: git clone https://git.epfl.ch/repo/icg15.git
~/: ...
~/: ...
~/: cd icg15
~/: git pull
```

https://git.epfl.ch/polyrepo/private/files.go?repositoryId=8376

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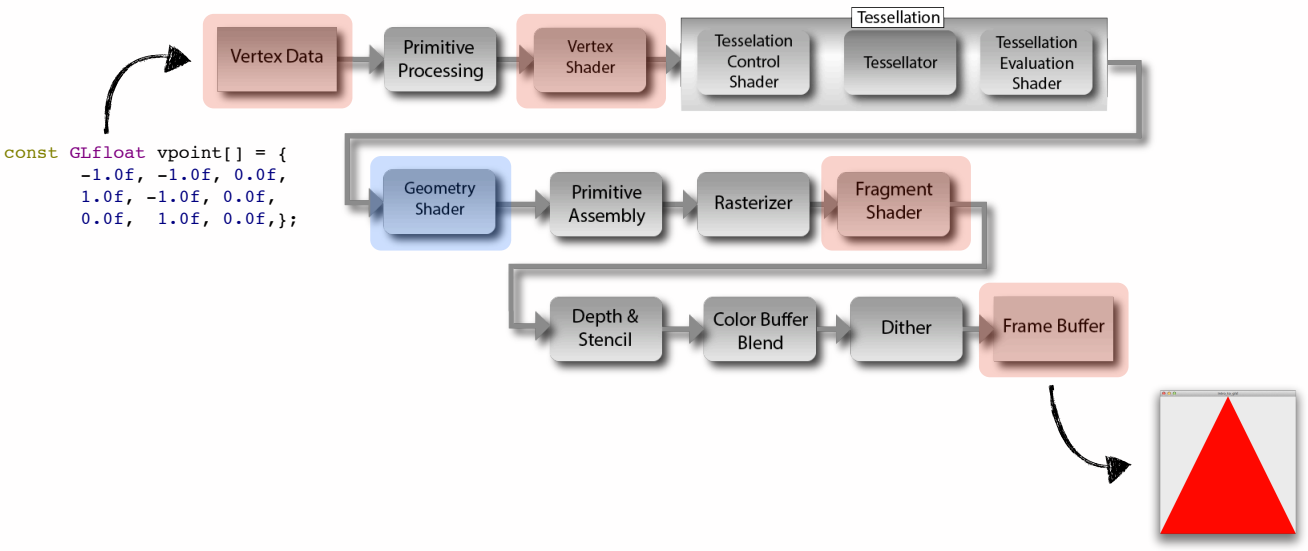
Structure of Practicals

Week	Topic	Practical	Homework
2	2D OpenGL	Intro to GLSL Interfacing GLSL / C++ Working with Textures	Triangle Spirals Checkerboard 2D Planet System
3	3D OpenGL		
4	Screen Space Techniques	**invited talk:** R.Ziegler (45m)	
5	FrameBuffers	FrameBuffer Setup Post Processing (blurring) Screen Space Reflections	Deferred Rendering Environment Light Scattering Screen Space Motion Blur

Mention how you cannot get started on HW without finishing practical

OpenGL Pipeline

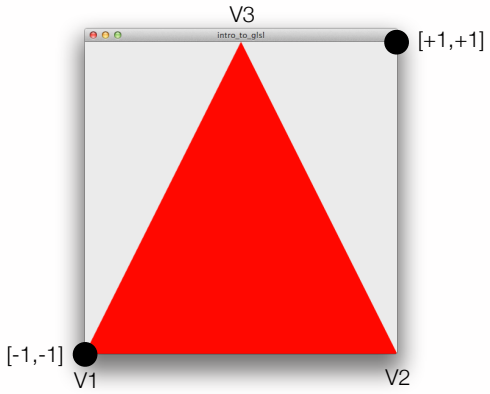


Vertex / Fragment Shaders

```
const GLfloat vpoint_buffer[] = {
 /*V1*/ -1.0f, -1.0f, 0.0f,
 /*V2*/  1.0f, -1.0f, 0.0f,
 /*V3*/  0.0f,  1.0f, 0.0f};


// intro_to_glsl/triangle_vshader.glsl
#version 330 core
in vec3 vpoint;
void main(){
    gl_Position = vec4(vpoint, 1.0);
}

// intro_to_glsl/triangle_fshader.glsl
#version 330 core
out vec3 color;
void main(){
    color = vec3(1.0, 0.0, 0.0);
}
```



- the output window represents the [-1,+1]^2 domain (please do not resize the window)
- gl_Position output is implicitly defined in vshaders: http://www.opengl.org/wiki/Built-in_Variable_(GLSL)
- note that our positions must be converted to vec4 before assigning to gl_Position
- gl_FragColor is obsolete in core OpenGL >= 3.1

Shader Syntax

```
/// A global array
vec2 myvecs[2] = vec2[](
    vec2(1.0,0.0),
    vec2(0.0,1.0));


void main(){
    /// Example initialization
    int alpha = 30;
    float vx = 1.0;
    float vy = 1.0;
    vec2 vec = vec2(vx,vy);
    // vec2 vec(vx,vy); ///< wrong!

    /// Example function call
    mat2 rotmat = rotateme(vec, alpha);

    /// Call on some array data
    rotateme(myvecs[0], alpha);
    rotateme(myvecs[1], alpha);
}
```

```
mat2 rotateme(inout vec2 vec, in int alpha_deg){
    /// Conversion
    float alpha = radians(-alpha_deg);

    /// Build 2D rotation matrix
    mat2 rotmat;
    rotmat[0][0] = cos(alpha);
    rotmat[0][1] = sin(alpha);
    rotmat[1][0] = -rotmat[0][1];
    rotmat[1][1] = rotmat[0][0];

    /// Apply transformation
    vec = transpose(rotmat) * vec;

    return rotmat;
}
```

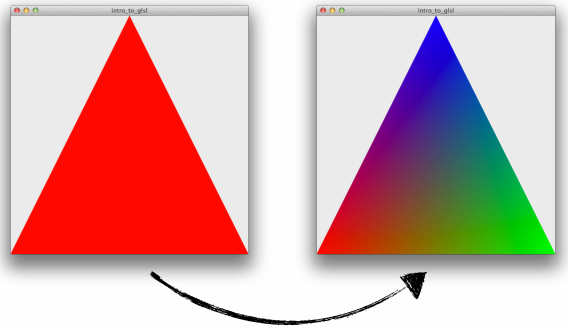

alternative ways of accessing a vec3:
- gl_Position.xyz = position;
- gl_Position.w = 1.0;

Task: color interpolation

linear interpolation

```
#version 330 core
in vec3 vpoint;
out vec3 fcolor;
void main() {
    gl_Position = vec4(vpoint, 1.0);
    fcolor = vec3(1,0,0);
}
```

```
#version 330 core
in vec3 fcolor;
out vec3 color;
void main() {
    color = fcolor;
}
```



What to use?

- `const vec3 COLORS[3] = ...`
- `gl_VertexID (vshader built-in)`

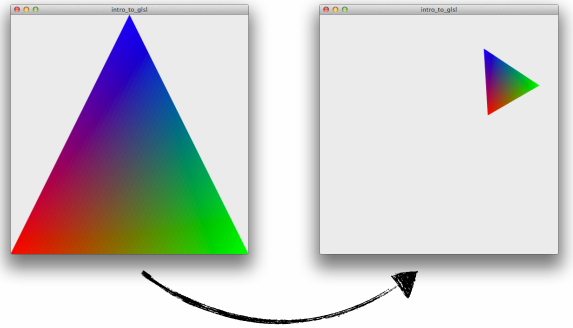
note that the out of vshader must have the same name of in fshader

Task: transformations

$$\mathbf{R_z} = \begin{bmatrix} cos(\alpha) & -sin(\alpha) & 0 & 0 \\ sin(\alpha) & cos(\alpha) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{S} = \begin{bmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



```
gl_Position = T*S*R*vec4(vpoint, 1.0);
```

Remember that **mat4** is **column-major**

- note before proceeding we must convert vertex position into homogeneous (vec4)
- note that above we apply rotation first, then scale, then translation
- note that T,S,R are mat4.
- mat4 M = mat4(1); creates an identity matrix
- M[col][row]: note the first index is COLUMN!!!!

C++ / GLSL interface

```
int main(int, char**){
    glfwInitWindowSize(512, 512);
    glfwCreateWindow("intro_to_glsl");
    glfwDisplayFunc(display);
    init();
    glfwMainLoop();
    return EXIT_SUCCESS;
}
```

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Compiling the Shader

```
void init(){
    glClearColor(/*gray*/ .937,.937,.937, /*solid*/1.0 );

    GLuint programID = opengp::load_shaders("triangle_vshader.glsl", "triangle_fshader.glsl");
    if(!programID) exit(EXIT_FAILURE);
    glUseProgram(programID);

    GLuint VertexArrayID;
    glGenVertexArrays(1, &VertexArrayID);
    glBindVertexArray(VertexArrayID);

    GLuint vertexbuffer;
    glGenBuffers(1, &vertexbuffer);
    glBindBuffer(GL_ARRAY_BUFFER, vertexbuffer);
    glBufferData(GL_ARRAY_BUFFER, sizeof(vpoint), vpoint, GL_STATIC_DRAW);

    GLuint position = glGetAttribLocation(programID, "vpoint");
    glEnableVertexAttribArray(position); /// Enable it
    glVertexAttribPointer(position, 3, GL_FLOAT, DONT_NORMALIZE, ZERO_STRIDE, ZERO_BUFFER_OFFSET);
}
```


glUseProgram: before setting uniforms and before drawing!

Vertex Buffers

```
void init(){
    glClearColor(/*gray*/ .937,.937,.937, /*solid*/1.0 );

    GLuint programID = opengp::load_shaders("vshader.glsl", "fshader.glsl");
    if(!programID) exit(EXIT_FAILURE);
    glUseProgram(programID);

    GLuint VertexArrayID;
    glGenVertexArrays(1, &VertexArrayID);
    glBindVertexArray(VertexArrayID);

    GLuint vertexbuffer;
    glGenBuffers(1, &vertexbuffer);
    glBindBuffer(GL_ARRAY_BUFFER, vertexbuffer);
    glBufferData(GL_ARRAY_BUFFER, sizeof(vpoint), vpoint, GL_STATIC_DRAW);

    GLuint position = glGetAttribLocation(programID, "vpoint");
    glEnableVertexAttribArray(position); /// Enable it
    glVertexAttribPointer(position, 3, GL_FLOAT, DONT_NORMALIZE, ZERO_STRIDE, ZERO_BUFFER_OFFSET);
}
```

```
const GLfloat vpoint[] = {
    -1.0f, -1.0f, 0.0f,
    1.0f, -1.0f, 0.0f,
    0.0f,  1.0f, 0.0f,};
```


We need to specify its location, its size and a “hint” of how we will be using it (optimization).

Attribute Arrays

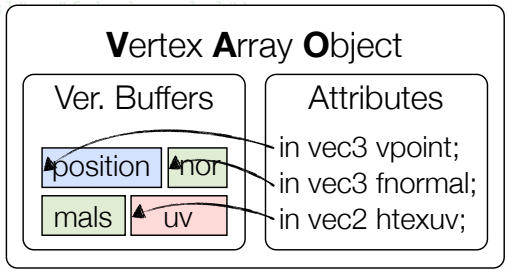
```
void init(){
    glClearColor(/*gray*/ .937,.937,.937, /*solid*/1.0 );

    GLuint programID = opengp::load_shaders("vshader.glsl", "fshader.glsl");
    if(!programID) exit(EXIT_FAILURE);
    glUseProgram(programID);

    GLuint VertexArrayID;
    glGenVertexArrays(1, &VertexArrayID);
    glBindVertexArray(VertexArrayID);

    GLuint vertexbuffer;
    glGenBuffers(1, &vertexbuffer);
    glBindBuffer(GL_ARRAY_BUFFER, vertexbuffer);
    glBufferData(GL_ARRAY_BUFFER, sizeof(vpoint), vpoint, GL_STATIC_DRAW);

    GLuint vpoint_id = glGetAttribLocation(programID, "vpoint");
    glEnableVertexAttribArray(vpoint_id);
    glVertexAttribPointer(vpoint_id, 3, GL_FLOAT, DONT_NORMALIZE, ZERO_STRIDE, ZERO_BUFFER_OFFSET);
}
```

```
#version 330 core
in vec3 vpoint;
void main() {
    gl_Position = vec4(vpoint, 1.0);
}
```


Note that the description in glVertexAttribPointer applies to the vertexbuffer that was bound by glBindBuffer!
The bound buffer contains GL_FLOATs, each attribute is composed by 3 elements (thus vec3) and... nothing else special

Vertex Array Object

```
void init(){
    glClearColor(/*gray*/ .937,.937,.937, /*solid*/1.0 );

    GLuint programID = opengp::load_shaders("vshader.gls
    if(!programID) exit(EXIT_FAILURE);
    glUseProgram(programID);

    GLuint VertexArrayID;
    glGenVertexArrays(1, &VertexArrayID);
    glBindVertexArray(VertexArrayID);

    GLuint vertexbuffer;
    glGenBuffers(1, &vertexbuffer);
    glBindBuffer(GL_ARRAY_BUFFER, vertexbuffer);
    glBufferData(GL_ARRAY_BUFFER, sizeof(vpoint), vpoint, GL_STATIC_DRAW);

    GLuint position = glGetAttribLocation(programID, "vpoint");
    glEnableVertexAttribArray(position); /// Enable it
    glVertexAttribPointer(position, 3, GL_FLOAT, DONT_NORMALIZE, ZERO_STRIDE, ZERO_BUFFER_OFFSET);
}
```



VertexArrayObjects: is a container that wraps data (buffers) and its specification (attributes)
In initialization we fill-in the container, when we draw we just have to “bind” it
Creating it before anything else is **mandatory** in modern OpenGL/GPUs

Drawing Function

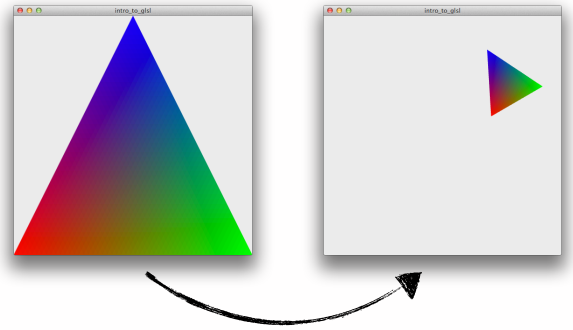
```
void display(){
    glClear(GL_COLOR_BUFFER_BIT);
    glUseProgram(programID);
    glBindVertexArray(VertexArrayID);
    glDrawArrays(GL_TRIANGLES, 0, 3);
}
```

```
const GLfloat vpoint[] = {
       -1.0f, -1.0f, 0.0f,
       1.0f, -1.0f, 0.0f,
       0.0f,  1.0f, 0.0f,};
```


we are drawing “3” points
in the buffer we start with offset “0”

TASK: Shader Uniforms

```
uniform mat4 M;
in vec3 vpoint;
out vec3 fcolor;

void main() {
    gl_Position = M*vec4(vpoint, 1.0);
    fcolor = ...
}
```



```
void init(){
    /// compile and bind shader

    mat4 M = mat4::Identity(); ///< typedef Eigen:Matrix4f mat4;
    M(0,0) = ...
    GLuint M_id = glGetUniformLocation(programID, "M");
    glUniformMatrix4fv(M_id, 1, GL_FALSE, M.data());
}
```

http://eigen.tuxfamily.org/dox/AsciiQuickReference.txt

OpenGL Error Checking

```
/// @file common/check_error_gl.h
#pragma once

static inline const char* ErrorString(GLenum error) {
  const char* msg;
  switch (error) {
#define Case(Token)  case Token: msg = #Token; break;
  Case(GL_INVALID_ENUM);
  Case(GL_INVALID_VALUE);
  Case(GL_INVALID_OPERATION);
  Case(GL_INVALID_FRAMEBUFFER_OPERATION);
  Case(GL_NO_ERROR);
  Case(GL_OUT_OF_MEMORY);
#undef Case
  }

  return msg;
}

static inline void _glCheckError(const char* file, int line) {
  GLenum error;
  while ((error = glGetError()) != GL_NO_ERROR) {
    fprintf(stderr, "ERROR: file %s, line %i: %s.\n", file, line,
            ErrorString(error));
  }
}

#ifndef NDEBUG
    #define check_error_gl() _glCheckError(__FILE__, __LINE__)
#else
    #define check_error_gl() ((void)0)
#endif
```

```
2  #include "check_error_gl.h"

3  void init(){
       ///...

27     GLuint VertexArrayID;
28     glGenVertexArrays(1, &VertexArrayID);
29     check_error_gl();
30     glBindVertexArray(1234567890);
31     check_error_gl();

       ///...
   }
```

ERROR: file /Users/andrea/Developer/icg15/src/intro_to_glsl/**main.cpp, line 31**: **GL_INVALID_OPERATION**.

!!!ONLY ACTIVE IN DEBUG MODE

```
set(CMAKE_BUILD_TYPE "Release")
set(CMAKE_BUILD_TYPE "Debug")
```

Compiling with CMake

```
add_executable(intro_to_glsl main.cpp Quad.h Triangle.h)

target_link_libraries(intro_to_glsl ${COMMON_LIBS})

target_deploy_file(intro_to_glsl triangle_vshader.glsl)
target_deploy_file(intro_to_glsl triangle_fshader.glsl)
target_deploy_file(intro_to_glsl quad_vshader.glsl)
target_deploy_file(intro_to_glsl quad_fshader.glsl)
target_deploy_file(intro_to_glsl mrt.tga)
```

custom-built cmake macro

these files will be copied from the **source** to the **build** directory

shaders and textures need to be found at runtime by the executable!
target_deploy_file is a custom macro we defined in **icg_settings.cmake**

Task: refactoring C++

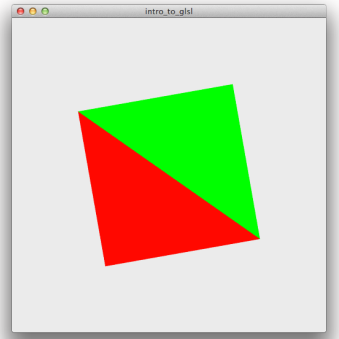
```
#include "icg_common.h"

#include "Triangle.h"
Triangle triangle;

void init(){
    glClearColor(.9,.9,.9,1);
    triangle.init();
}
void display(){
    glClear(GL_COLOR_BUFFER_BIT);
    triangle.draw();
}
int main(int, char**){
    glfwInitWindowSize(512, 512);
    glfwCreateWindow("intro_to_glsl");
    glfwDisplayFunc(display);
    init();
    glfwMainLoop();
    triangle.cleanup();
    return EXIT_SUCCESS;
}
```

Triangle.h

```
#pragma once
#include "icg_common.h"

class Triangle{
private:
    GLuint _vao; ///< Vertex array objects
    GLuint _pid; ///< GLSL program ID
    GLuint _tex; ///< Texture IDs

public:
    void init(){
        // ...
    }

    void cleanup(){
        // ...
    }

    void draw(){
        // ...
    }
};
```

Task: create Quad.h

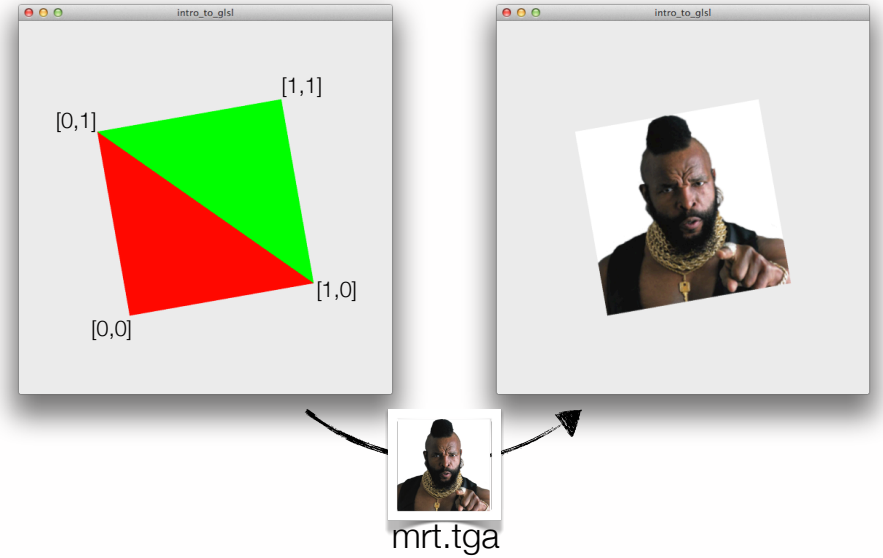
```
const GLfloat vpoint[] = {
    /*V1*/ -1.0f, -1.0f, 0.0f,
    /*V2*/ +1.0f, -1.0f, 0.0f,
    /*V3*/ -1.0f, +1.0f, 0.0f,
    /*V4*/ +1.0f, +1.0f, 0.0f };

glDrawArrays(GL_TRIANGLE_STRIP, ...);
```




```
#version 330 core
out vec3 color;
const vec3 COLORS[2] = vec3[](
    vec3(1.0,0.0,0.0),
    vec3(0.0,1.0,0.0));
void main() {
    color = COLORS[gl_PrimitiveID];
}
```

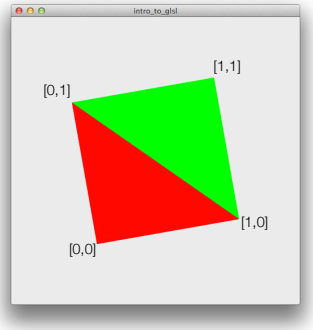

gl_PrimitiveID is a pre-defined variable for fragment shaders

Texturing the quad



Vertex Texture Coordinates

```
void init(){
    ...
    {
        const GLfloat vtexcoord[] = { /*V1*/ 0.0f, 0.0f,
                                      /*V2*/ 1.0f, 0.0f,
                                      /*V3*/ 0.0f, 1.0f,
                                      /*V4*/ 1.0f, 1.0f};
        ///--- Buffer
        glGenBuffers(1, &_vbo);
        glBindBuffer(GL_ARRAY_BUFFER, _vbo);
        glBufferData(GL_ARRAY_BUFFER, sizeof(vtexcoord), vtexcoord, GL_STATIC_DRAW);

        ///--- Attribute
        GLuint vtexcoord_id = glGetAttribLocation(_pid, "vtexcoord");
        glEnableVertexAttribArray(vtexcoord_id);
        glVertexAttribPointer(vtexcoord_id, 2, GL_FLOAT,
                              DONT_NORMALIZE, ZERO_STRIDE, ZERO_BUFFER_OFFSET);
    }
    ...
}
```




```
in vec2 vtexcoord; ///< for vshader only!!
```

Texturing the Quad

```
void init(){
    ...
    glGenTextures(1, &_tex);
    glBindTexture(GL_TEXTURE_2D, _tex);
    glfwLoadTexture2D("mrt.tga", 0);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
    GLuint tex_id = glGetUniformLocation(_pid, "tex");
    glUniform1i(tex_id, 0 /*GL_TEXTURE0*/);
    ...
}
```

```
void draw(){
    glUseProgram(_pid);
    glBindVertexArray(_vao);
        glActiveTexture(GL_TEXTURE0);
        glBindTexture(GL_TEXTURE_2D, _tex);
        glDrawArrays(...);
    glBindVertexArray(0);
    glUseProgram(0);
}
```

```
#version 330 core
uniform mat4 M;
in vec3 vpoint;
in vec2 vtexcoord;
out vec2 uv;

void main() {
    gl_Position = M * vec4(vpoint, 1.0);
    uv = vtexcoord;
}
```

```
#version 330 core
uniform sampler2D tex;
in vec2 uv;
out vec3 color;

void main() {
    color = texture(tex,uv).rgb;
}
```


GL_TEXTURE_MIN/MAG_FILTER determines how texture will be interpolated upon rescaling

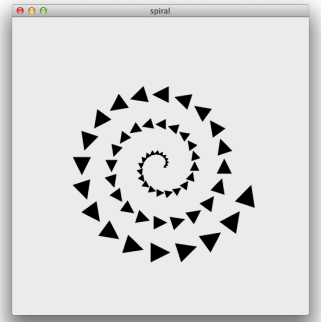
Homework 2

Submit **Hw1-Lastname-Lastname-Lastname.zip** with:

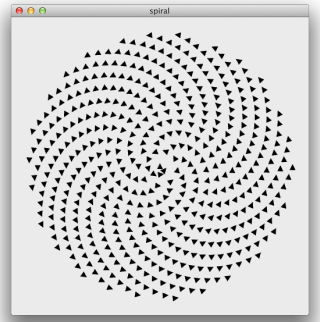
- source code - **do not** submit build folder!!!
  - **lose .5 points** if you include CMakeFiles, etc...
- executable - **must run** on the lab machines!!
  - **lose 1.5 points (each)** if the executable of an exercise doesn't run in the lab
- readme.txt - with any extra information

Each of the following exercises is **2 points** (**6 points total**)

Homework 2 - Part 1



Spiral



Fermat's spiral

```
/// http://eigen.tuxfamily.org/dox/group__TutorialGeometry.html
typedef Eigen::Transform<float,3,Eigen::Affine> Transform;
Transform _M = Transform::Identity();
_M *= Eigen::Translation3f(Tx,Ty,0);
_M *= Eigen::AngleAxisf(alpha, Eigen::Vector3f::UnitZ());
_M *= Eigen::AlignedScaling3f(scale, scale, scale);
mat4 M = _M.matrix(); ///< v_new = TRA*ROT*SCA*v
```

$$r = c * \sqrt{\theta}$$
$$\theta = n * 137.508$$
$$n = \{1, 2, \ldots, N\}$$

(optional) use the Eigen tutorial on transformations:
Draw multiple triangles by calling glDrawArrays multiple times
Use a combination of rotation, scale and translation to obtain the necessary transformation
For the sunflower pattern, also see http://en.wikipedia.org/wiki/Fermat%27s_spiral

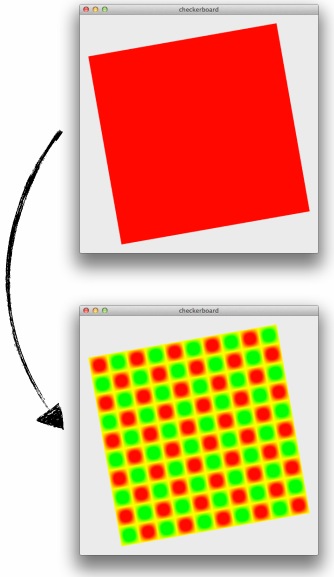
Homework 2 - Part 2

Create colormap 1D texture

```
///--- Create 1D texture (colormap)
{
    const int sz=3;
    GLfloat tex[3*sz] = {/*red*/    1.0, 0.0, 0.0,
                         /*yellow*/ 1.0, 1.0, 0.0,
                         /*green*/  0.0, 1.0, 0.0};
    glGenTextures(1, &_tex);
    glBindTexture(GL_TEXTURE_1D, _tex);
    glTexImage1D(GL_TEXTURE_1D, 0, GL_RGB, sz, 0, GL_RGB, GL_FLOAT, tex);
    glTexParameteri(GL_TEXTURE_1D, GL_TEXTURE_WRAP_S, GL_CLAMP_TO_EDGE);
    glTexParameteri(GL_TEXTURE_1D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_1D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
    GLuint tex_id = glGetUniformLocation(_pid, "colormap");
    glUniform1i(tex_id, 0 /*GL_TEXTURE0*/);
}
```

Access it in the fshader

```
uniform sampler1D colormap;
void main(){
    float value = ...
    color = texture(colormap, value).rgb;
}
```



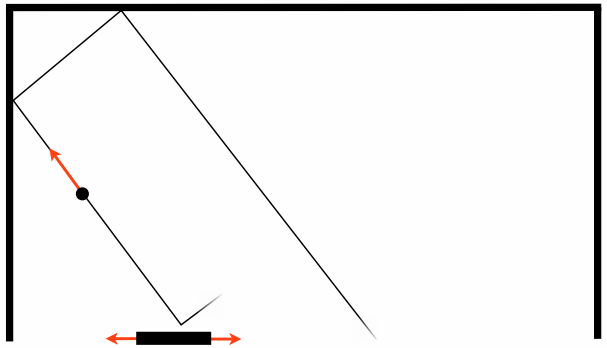
you only need to modify the fragment shader
use sine function (argument is quad texture coordinate) to generate a value in the range [0,1]
use this value to access the colormap texture

Homework 2 - Part 3

```
float time_secs = glfwGetTime(); ///< C++
```

Homework 2 - Part 4*

Simple Arkanoid ® game!!



*For the passionate!
2 point (but assignment points saturate at 6/6)