Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie

Wydział Inżynierii Metali i Informatyki Przemysłowej

Sprawozdanie z Laboratorium:

Programowanie w OpenGL z użyciem shader'ów, Free look camera, szybkość działania

Przedmiot: Wizualizacja Danych

Kierunek: Inżynieria Obliczeniowa

Autor: Filip Rak

Prowadzący ćwiczenia: dr inż. Marynowski Przemysław

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Cel Ćwiczenia

Zapoznanie z programowaniem grafiki przy użyciu shader'ów, zastosowanie swobodnego poruszania kamery oraz kontroli szybkości działania pętli głównej.

Przebieg Ćwiczenia

Naszym pierwszym zadaniem była implementacja swobodnego poruszania się kamery z wykorzystaniem myszy i klawiatury.

Zmiany wprowadzone w kodzie źródłowym:

- Dodanie flagi sterującej aktywnością manipulacji kamery przez mysz.
- Deklaracja stałych trzymających rotacje kamery w odpowiednich granicach.
- Deklaracja funkcji zajmującej się aktualizacją macierzy widoku.
- Dodanie dodatkowych zmiennych opisujących kamerę i mysz.
- W głównej pętli, dodanie kodu zajmującego się obliczaniem ruchu kamery na podstawie ruchu myszy.
- Pomniejsze modyfikacje w celu ujednolicenia kontroli przez mysz i klawiaturę.

Stałe ograniczające rotacje kamery

```
// Camera
const float MAX_CAMERA_PITCH = 89;
const float MIN_CAMERA_PITCH = -89;
const float MAX_CAMERA_YAW = 360;
const float MIN_CAMERA_YAW = 0;
```

Zmienne opisujące kamerę i mysz

```
// Camera
glm::vec3 camera_pos = glm::vec3(0.0f, 0.0f, 3.0f);
glm::vec3 camera_front = glm::vec3(0.0f, 0.0f, -1.0f);
glm::vec3 camera_up = glm::vec3(0.0f, 1.0f, 0.f);
float camera_yaw = 270;
float camera_pitch = 0;
float camera_speed = 3;
float camera_rotation_speed = 200;
bool camera_pos_changed = false;    // Remove for damping implementation

// Mouse
double mouse_sensitivity = 0.05;
```

Obliczanie rotacji kamery na podstawie pozycji myszy

```
if (enable_mouse_movement)
{
	// Get the current mouse position and calculate the offset from the center
	sf::Vector2i center_pos(window.getSize().x / 2, window.getSize().y / 2);
	sf::Vector2i local_pos = sf::Mouse::getPosition(window);
	double x_offset = local_pos.x - center_pos.x;
	double y_offset = local_pos.y - center_pos.y;

	// Apply the offset to yaw and pitch
	camera_yaw += x_offset * mouse_sensitivity;
	camera_pitch -= y_offset * mouse_sensitivity;

	// Clamp pitch to prevent flipping
	if (camera_pitch > MAX_CAMERA_PITCH) camera_pitch = MAX_CAMERA_PITCH;
	else if (camera_pitch < MIN_CAMERA_PITCH) camera_pitch = MIN_CAMERA_PITCH;

	// Normalize yaw
	if (camera_yaw >= MAX_CAMERA_YAW) camera_yaw -= MAX_CAMERA_YAW;
	else if (camera_yaw < MIN_CAMERA_YAW) camera_yaw += MIN_CAMERA_YAW;

	// Set the flag to update view matrix
	camera_pos_changed = true;

	// Reset mouse position to the center of the window
	sf::Mouse::setPosition(center_pos, window);
}
```

Następnym zadaniem było uzależnienie szybkości poruszania się kamery od szybkości komputera:

- Dołączono bibliotekę `<SFML/System/Time.hpp>`
- Obliczono czas trwania pojedynczej klatki z wykorzystaniem zegara `sf::Clock`
- Każda aplikacja prędkości nadawana kamerze poprzez klawiaturę została pomnożona przez uzyskany czas trwania pojedynczej klatki
- Prędkość nadawana przez mysz **nie** została pomnożona przez czas trwania klatki

Fragment pętli głównej obliczający czas trwania klatki

```
while (running)
{
	// Update delta time
	delta_time = delta_clock.restart().asSeconds();

	// (...)
}
```

Przykład aplikacji uzyskanego czasu między klatkowego

```
if (sf::Keyboard::isKeyPressed(sf::Keyboard::W))   // Forward
{
	camera_pos += camera_speed * delta_time * camera_front;
	camera_pos_changed = true;
	std::cout << "Input: W\n";
}
```

Ostatnim zadaniem było wyświetlenie ilość otrzymanych klatek na sekundę w pasku tytułowym okienka.

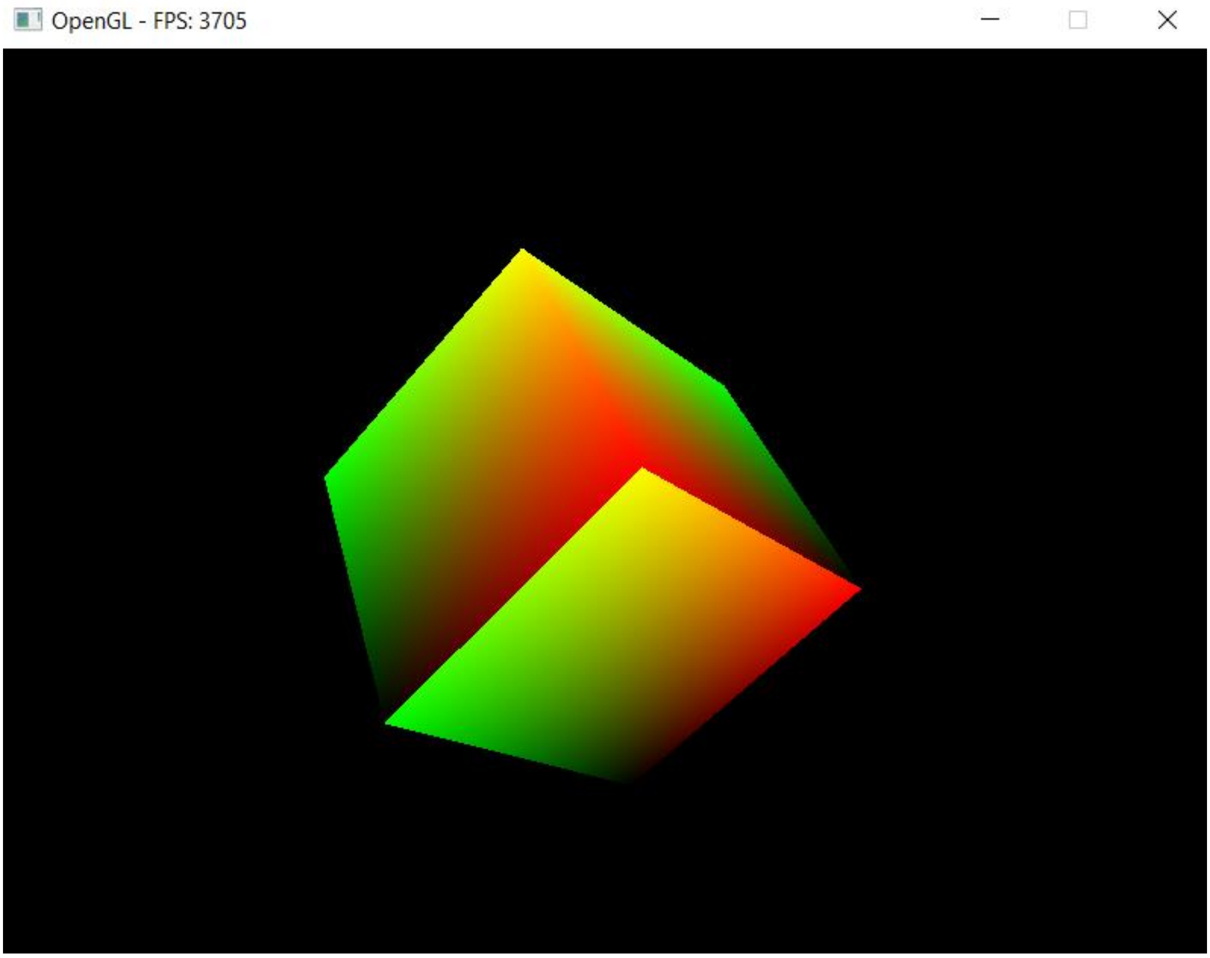
W tym celu:

- Dołączono bibliotekę `<string.h>`
- Zadeklarowano stałą będącą niezmienną częścią tytułu okienka
- Wewnątrz pętli obliczono ilość klatek w ciągu sekundy z użyciem czasu między klatkowego oraz dodano go do nazwy okienka.
- Ograniczono prędkość aktualizacji licznika, aby pozostał on czytelny.

Fragment pętli głównej zajmujący się licznikiem FPS

```
float update_interval = 0.2;     // Timer for FPS update
float time_accumulator = 0;      // Time passed since last FPS update
int frame_count = 0;

while (running)
{
	// Update delta time
	delta_time = delta_clock.restart().asSeconds();

	// Accumulate time and count frames
	time_accumulator += delta_time;
	frame_count++;

	// Set the window title to current FPS
	if (time_accumulator >= update_interval)
	{
		 // Get FPS from average time passed since last update
		int FPS = round(frame_count / time_accumulator);
		window.setTitle(WINDOW_TITLE + " - FPS: " + std::to_string(FPS));

		// Reset for next FPS update
		time_accumulator = 0;
		frame_count = 0;

	}

	// (...)
}
```

Poniżej znajduje się prezentacja efektu końcowego



Pełny kod źródłowy

```
// Headers for OpenGL and SFML
// #include "stdafx.h"  // This line might be needed in some IDEs

#pragma once
#include <GL/glew.h>
#include <SFML/Window.hpp>
#include <SFML/System/Time.hpp>
#include <glm.hpp>
#include <gtc/matrix_transform.hpp>
#include <gtc/type_ptr.hpp>
#include <iostream>
#include <time.h>
#include <string.h>
#include <cmath>

// Constants
// --------------------

// Flags
const bool enable_keyboard_movement = true;
const bool enable_mouse_movement = true;
const bool enable_vert_manip = false;
const bool enable_primitve_manip = true;

// Primitives
const int primitives_num = 10;
const GLenum primitives[primitives_num] =
{
    GL_POINTS,         // 0
    GL_LINES,          // 1
    GL_LINE_LOOP,      // 2
    GL_LINE_STRIP,     // 3
    GL_TRIANGLES,      // 4
    GL_TRIANGLE_STRIP,// 5
    GL_TRIANGLE_FAN,   // 6
    GL_QUADS,          // 7
    GL_QUAD_STRIP,     // 8
    GL_POLYGON         // 9
};

const std::string primitives_names[primitives_num] =
{
    "GL_POINTS",         // 0
    "GL_LINES",          // 1
    "GL_LINE_LOOP",      // 2
    "GL_LINE_STRIP",     // 3
    "GL_TRIANGLES",      // 4
    "GL_TRIANGLE_STRIP",// 5
    "GL_TRIANGLE_FAN",   // 6
    "GL_QUADS",          // 7
    "GL_QUAD_STRIP",     // 8
    "GL_POLYGON",        // 9
};

const int DATA_PER_VERT = 6;
const double PI = 3.14159265358979323846;
const float WINDOW_WIDTH = 800.0;
const float WINDOW_HEIGHT = 600.0;
const int MIN_VERTS = 1;
const int MAX_VERTS = 36;
```

```cpp
// Camera
const float MAX_CAMERA_PITCH = 89;
const float MIN_CAMERA_PITCH = -89;
const float MAX_CAMERA_YAW = 360;
const float MIN_CAMERA_YAW = 0;

// Strings
const std::string WINDOW_TITLE = "OpenGL";
const std::string SEPARATOR = std::string(45, '-') + "\n";

// Shaders
// --------------------

// Vertex shader takes care of positioning on the screen
const GLchar* vertex_source = R"glsl(
#version 150 core

in vec3 position; // Input vertex position
in vec3 color;     // Input vertex color
out vec3 Color;    // Output color passed to the fragment shader

// Set outside the shader
uniform mat4 model_matrix;  // Model
uniform mat4 view_matrix;   // View (camera)
uniform mat4 proj_matrix;   // Projection

void main()
{
    // Pass the color to the fragment shader
    Color = color;

    // Set the position of the vertex
    gl_Position = proj_matrix * view_matrix * model_matrix * vec4(position, 1.0);
}
)glsl";

// Fragment shader's job is to figure out area between surfaces
const GLchar* fragment_source = R"glsl(
#version 150 core
in vec3 Color;      // Color received from the vertex shader
out vec4 outColor;   // Output color to the framebuffer

void main()
{
    outColor = vec4(Color, 1.0);  // Set the fragment color with full opacity
}
)glsl";


// Shapes
GLfloat cube_vertices[] =
{
    // Front
    -0.5f, -0.5f, -0.5f, 0.0f, 0.0f, 0.0f,
    0.5f, -0.5f, -0.5f, 1.0f, 0.0f, 0.0f,
    0.5f, 0.5f, -0.5f, 1.0f, 1.0f, 0.0f,
    0.5f, 0.5f, -0.5f, 1.0f, 1.0f, 0.0f,
    -0.5f, 0.5f, -0.5f, 0.0f, 1.0f, 0.0f,
    -0.5f, -0.5f, -0.5f, 0.0f, 0.0f, 0.0f,

    // Rear
    -0.5f, -0.5f, 0.5f, 0.0f, 0.0f, 0.0f,
```

```
    0.5f, -0.5f, 0.5f, 1.0f, 0.0f, 0.0f,
    0.5f, 0.5f, 0.5f, 1.0f, 1.0f, 0.0f,
    0.5f, 0.5f, 0.5f, 1.0f, 1.0f, 0.0f,
    -0.5f, 0.5f, 0.5f, 0.0f, 1.0f, 0.0f,
    -0.5f, -0.5f, 0.5f, 0.0f, 0.0f, 0.0f,

    // Left
    -0.5f, 0.5f, 0.5f, 1.0f, 0.0f, 0.0f,
    -0.5f, 0.5f, -0.5f, 1.0f, 1.0f, 0.0f,
    -0.5f, -0.5f, -0.5f, 0.0f, 1.0f, 0.0f,
    -0.5f, -0.5f, -0.5f, 0.0f, 1.0f, 0.0f,
    -0.5f, -0.5f, 0.5f, 0.0f, 0.0f, 0.0f,
    -0.5f, 0.5f, 0.5f, 1.0f, 0.0f, 0.0f,

    // Right
    0.5f, 0.5f, 0.5f, 1.0f, 0.0f, 0.0f,
    0.5f, 0.5f, -0.5f, 1.0f, 1.0f, 0.0f,
    0.5f, -0.5f, -0.5f, 0.0f, 1.0f, 0.0f,
    0.5f, -0.5f, -0.5f, 0.0f, 1.0f, 0.0f,
    0.5f, -0.5f, 0.5f, 0.0f, 0.0f, 0.0f,
    0.5f, 0.5f, 0.5f, 1.0f, 0.0f, 0.0f,

    // Bottom
    -0.5f, -0.5f, -0.5f, 0.0f, 1.0f, 0.0f,
    0.5f, -0.5f, -0.5f, 1.0f, 1.0f, 0.0f,
    0.5f, -0.5f, 0.5f, 1.0f, 0.0f, 0.0f,
    0.5f, -0.5f, 0.5f, 1.0f, 0.0f, 0.0f,
    -0.5f, -0.5f, 0.5f, 0.0f, 0.0f, 0.0f,
    -0.5f, -0.5f, -0.5f, 0.0f, 1.0f, 0.0f,

    // Top
    -0.5f, 0.5f, -0.5f, 0.0f, 1.0f, 0.0f,
    0.5f, 0.5f, -0.5f, 1.0f, 1.0f, 0.0f,
    0.5f, 0.5f, 0.5f, 1.0f, 0.0f, 0.0f,
    0.5f, 0.5f, 0.5f, 1.0f, 0.0f, 0.0f,
    -0.5f, 0.5f, 0.5f, 0.0f, 0.0f, 0.0f,
    -0.5f, 0.5f, -0.5f, 0.0f, 1.0f, 0.0f
};
// Main loop functions
// --------------------
void find_polygon_verts(GLfloat* vertices, int vert_num, float radius)
{
    // Starting angle and change of angles between every vert
    float start_angle = 0.0f;
    float angle_step = 2.0f * PI / vert_num;

    for (int i = 0; i < vert_num; i++)
    {
        // Angle of the current vert
        float angle = start_angle + i * angle_step;

        // Vertice coordinates
        vertices[i * DATA_PER_VERT] = radius * cos(angle);  // X
        vertices[i * DATA_PER_VERT + 1] = radius * sin(angle);  // Y
        vertices[i * DATA_PER_VERT + 2] = (float)rand() / RAND_MAX;  // Z

        // Colors
        vertices[i * DATA_PER_VERT + 3] = (float)rand() / RAND_MAX; // R
        vertices[i * DATA_PER_VERT + 4] = (float)rand() / RAND_MAX; // G
        vertices[i * DATA_PER_VERT + 5] = (float)rand() / RAND_MAX; // B
    }
}
```

```
int mouse_to_verts(float mouse_pos_y)
{
    // Normalize the mouse Y position (0 at the top, 1 at the bottom)
    float normalized_mouse_y = mouse_pos_y / WINDOW_HEIGHT;

    // Invert the Y position so it progresses from bottom (0) to top (1)
    float top_down_mouse_y = 1.0f - normalized_mouse_y;

    // Calculate the number of vertices based on the mouse position within the defined vertex range
    float vertex_range = MAX_VERTS - MIN_VERTS;
    float vertex_adj = vertex_range * top_down_mouse_y;

    // Set the vertex count by adjusting based on the mouse position
    int new_vert_num = (int)(MIN_VERTS + vertex_adj);

    return new_vert_num;
}

GLfloat* update_vertices(GLfloat* vertices, int vert_num, GLuint vbo)
{
    // Reallocate memory for the new number of vertices
    delete[] vertices;
    vertices = new GLfloat[vert_num * DATA_PER_VERT];

    // Update vertices based on the new vertex count
    find_polygon_verts(vertices, vert_num, 1.0f);

    // Upload the updated vertex data to the GPU
    glBindBuffer(GL_ARRAY_BUFFER, vbo);
    glBufferData(GL_ARRAY_BUFFER, vert_num * DATA_PER_VERT * sizeof(GLfloat), vertices,
GL_DYNAMIC_DRAW);

    return vertices;
}

void update_view_matrix(GLuint shader_program, const glm::vec3& camera_pos, glm::vec3& camera_front,
const glm::vec3& camera_up, float camera_yaw, float camera_pitch)
{
    // Get camera front based on yaw and pitch
    glm::vec3 new_front;
    new_front.x = cos(glm::radians(camera_yaw)) * cos(glm::radians(camera_pitch));
    new_front.y = sin(glm::radians(camera_pitch));
    new_front.z = sin(glm::radians(camera_yaw)) * cos(glm::radians(camera_pitch));

    // Update camera front and normalize it
    camera_front = glm::normalize(new_front);

    // Update the view matrix
    glm::mat4 view_matrix = glm::lookAt(camera_pos, camera_pos + camera_front, camera_up);
    GLint uni_view = glGetUniformLocation(shader_program, "view_matrix");
    glUniformMatrix4fv(uni_view, 1, GL_FALSE, glm::value_ptr(view_matrix));
}

void main_loop(sf::Window& window, GLuint shader_program, GLuint vao, GLuint vbo, int vert_num, GLfloat*
vertices)
{
    bool running = true;
    GLenum used_primitive = GL_TRIANGLES;

    // Camera
    glm::vec3 camera_pos = glm::vec3(0.0f, 0.0f, 3.0f);
    glm::vec3 camera_front = glm::vec3(0.0f, 0.0f, -1.0f);
    glm::vec3 camera_up = glm::vec3(0.0f, 1.0f, 0.f);
```

```
float camera_yaw = 270;
float camera_pitch = 0;
float camera_speed = 3;
float camera_rotation_speed = 200;
bool camera_pos_changed = false;    // Remove for damping implementation

// Mouse
double mouse_sensitivity = 0.05;

// Delta time
sf::Clock delta_clock;
float delta_time = 0;
float update_interval = 0.2;    // Timer for FPS update
float time_accumulator = 0; // Time passed since last FPS update
int frame_count = 0;

while (running)
{
    // Update delta time
    delta_time = delta_clock.restart().asSeconds();

    // Accumulate time and count frames
    time_accumulator += delta_time;
    frame_count++;

    // Set the window title to current FPS
    if (time_accumulator >= update_interval)
    {
        // Get FPS from average time passed since last update
        int FPS = round(frame_count / time_accumulator);
        window.setTitle(WINDOW_TITLE + " - FPS: " + std::to_string(FPS));

        // Reset for next FPS update
        time_accumulator = 0;
        frame_count = 0;
    }

    sf::Event window_event;
    while (window.pollEvent(window_event))
    {
        switch (window_event.type)
        {
        case sf::Event::Closed:
            running = false;
            break;

        case sf::Event::KeyPressed:
            // Exit condition
            if (window_event.key.code == sf::Keyboard::Escape)
            {
                running = false;
            }

            // Vertice number manipulation
            if (enable_vert_manip)
            {
                if (window_event.key.code == sf::Keyboard::Up)
                {
                    int new_vert_num = vert_num + 1;
                    if (new_vert_num > MAX_VERTS)
                        new_vert_num = MAX_VERTS;

                    // Avoid unnecessary updates
```

```
                if (new_vert_num == vert_num)
                    break;

                // Update vert number
                vert_num = new_vert_num;
                std::cout << "Vertices: " << vert_num << "\n";

                // Update the display
                vertices = update_vertices(vertices, vert_num, vbo);
            }

            if (window_event.key.code == sf::Keyboard::Down)
            {
                int new_vert_num = vert_num - 1;
                if (new_vert_num < MIN_VERTS)
                    new_vert_num = MIN_VERTS;

                // Avoid unnecessary updates
                if (new_vert_num == vert_num)
                    break;

                // Update vert number
                vert_num = new_vert_num;
                std::cout << "Vertices: " << vert_num << "\n";

                // Update the display
                vertices = update_vertices(vertices, vert_num, vbo);
            }
        }

        if (enable_primitve_manip)
        {
            // Primitive manipulation
            if (window_event.key.code >= sf::Keyboard::Num0 && window_event.key.code <=
sf::Keyboard::Num9)
            {
                // Save numerical key as an integer
                int pressed_number = window_event.key.code - sf::Keyboard::Num0;
                used_primitive = primitives[pressed_number % primitives_num];
                std::cout << "Set primitive: " << primitives_names[used_primitive %
primitives_num] << "\n";
            }
        }

        break;
    case sf::Event::MouseMoved:

        if (enable_vert_manip)
        {
            // Convert mouse pos to vertices
            int new_vert_num = mouse_to_verts(window_event.mouseMove.y);
            if (new_vert_num == vert_num)   // Avoid updates if unnecessary
                break;

            // Update vert number
            vert_num = new_vert_num;
            std::cout << "Vertices: " << vert_num << "\n";

            // Update the display
            vertices = update_vertices(vertices, vert_num, vbo);
        }

        if (enable_mouse_movement)
```

```
                {
                    // Get the current mouse position and calculate the offset from the center
                    sf::Vector2i center_pos(window.getSize().x / 2, window.getSize().y / 2);
                    sf::Vector2i local_pos = sf::Mouse::getPosition(window);
                    double x_offset = local_pos.x - center_pos.x;
                    double y_offset = local_pos.y - center_pos.y;

                    // Apply the offset to yaw and pitch
                    camera_yaw += x_offset * mouse_sensitivity;
                    camera_pitch -= y_offset * mouse_sensitivity;

                    // Clamp pitch to prevent flipping
                    if (camera_pitch > MAX_CAMERA_PITCH) camera_pitch = MAX_CAMERA_PITCH;
                    else if (camera_pitch < MIN_CAMERA_PITCH) camera_pitch = MIN_CAMERA_PITCH;

                    // Normalize yaw
                    if (camera_yaw >= MAX_CAMERA_YAW) camera_yaw -= MAX_CAMERA_YAW;
                    else if (camera_yaw < MIN_CAMERA_YAW) camera_yaw += MIN_CAMERA_YAW;

                    // Set the flag to update view matrix
                    camera_pos_changed = true;

                    // Reset mouse position to the center of the window
                    sf::Mouse::setPosition(center_pos, window);
                }

                break;
            }
        }

        if (enable_keyboard_movement)
        {
            // Check camera movement keys in real-time
            if (sf::Keyboard::isKeyPressed(sf::Keyboard::W))   // Forward
            {
                camera_pos += camera_speed * delta_time * camera_front;
                camera_pos_changed = true;
                std::cout << "Input: W\n";
            }

            if (sf::Keyboard::isKeyPressed(sf::Keyboard::S))   // Backwards
            {
                camera_pos -= camera_speed * delta_time * camera_front;
                camera_pos_changed = true;
                std::cout << "Input: S\n";
            }

            if (sf::Keyboard::isKeyPressed(sf::Keyboard::A))   // Move left
            {
                camera_pos -= glm::normalize(glm::cross(camera_front, camera_up)) * camera_speed *
delta_time;
                camera_pos_changed = true;
                std::cout << "Input: A\n";
            }

            if (sf::Keyboard::isKeyPressed(sf::Keyboard::D))   // Move right
            {
                camera_pos += glm::normalize(glm::cross(camera_front, camera_up)) * camera_speed *
delta_time;
                camera_pos_changed = true;
                std::cout << "Input: D\n";
            }
```

```cpp
            if (sf::Keyboard::isKeyPressed(sf::Keyboard::Q))   // Rotation left
            {
                camera_yaw -= camera_rotation_speed * delta_time;
                camera_pos_changed = true;
                std::cout << "Input: Q\n";
            }

            if (sf::Keyboard::isKeyPressed(sf::Keyboard::E))   // Rotation right
            {
                camera_yaw += camera_rotation_speed * delta_time;
                camera_pos_changed = true;
                std::cout << "Input: E\n";
            }
        }

        if (camera_pos_changed)
        {
            update_view_matrix(shader_program, camera_pos, camera_front, camera_up, camera_yaw,
camera_pitch);
            camera_pos_changed = false;
        }

        // Clear the screen to black
        glClearColor(0.0f, 0.0f, 0.0f, 1.0f);
        glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

        // Draw the shape
        glDrawArrays(used_primitive, 0, vert_num);

        // Swap the front and back buffers
        window.display();
    }
}

// Validation functions
// -------------------
bool shader_compiled(GLuint shader, bool console_dump = true, std::string name_identifier = "")
{
    // Check for compilation error
    GLint success;
    glGetShaderiv(shader, GL_COMPILE_STATUS, &success);

    if (!success && console_dump)
    {
        // Get error log length
        GLint log_length;
        glGetShaderiv(shader, GL_INFO_LOG_LENGTH, &log_length);

        // Allocate space for error message
        std::string error_msg(log_length, ' ');  // Initialize the string with spaces

        // Retrieve the error log
        glGetShaderInfoLog(shader, log_length, NULL, &error_msg[0]);

        // Print the error message
        std::cerr << "ERROR: " << name_identifier << " Shader Compilation Failed!:\n\t" << error_msg <<
"\n";
    }

    return success;
}

bool program_linked(GLuint program, bool console_dump = true, std::string name_identifier = "")
```

```cpp
{
    GLint success;
    glGetProgramiv(program, GL_LINK_STATUS, &success);

    if (!success && console_dump)
    {
        // Get error log length
        GLint log_length;
        glGetProgramiv(program, GL_INFO_LOG_LENGTH, &log_length);

        // Allocate space for error message
        std::string error_msg(log_length, ' ');  // Initialize the string with spaces

        // Retrieve the error log
        glGetProgramInfoLog(program, log_length, NULL, &error_msg[0]);

        // Print the error message
        std::cerr << "ERROR: " << name_identifier << " Program Linking Failed!:\n\t" << error_msg <<
"\n";
    }

    return success;
}

// Main function
// --------------------
int main()
{
    // Init for random number generation
    srand(time(NULL));

    // Setup OpenGL context settings
    sf::ContextSettings settings;
    settings.depthBits = 24;     // Bits for depth buffer
    settings.stencilBits = 8;    // Bits for stencil buffer

    // Create a rendering window with OpenGL context
    sf::Window window(sf::VideoMode(WINDOW_WIDTH, WINDOW_HEIGHT, 32), WINDOW_TITLE, sf::Style::Titlebar
| sf::Style::Close, settings);

    window.setMouseCursorGrabbed(true);
    window.setMouseCursorVisible(false);

    // window.setFramerateLimit(20);

    // Enabling Z-buffer
    glEnable(GL_DEPTH_TEST);
    glDepthFunc(GL_LESS);

    // Initialize GLEW (must be done after creating the window and OpenGL context)
    glewExperimental = GL_TRUE;
    glewInit();

    // Create and bind a Vertex Array Object (VAO) to store vertex state
    GLuint vao;
    glGenVertexArrays(1, &vao);
    glBindVertexArray(vao);

    // Create a Vertex Buffer Object (VBO) and upload vertex data to it
    GLuint vbo;
    glGenBuffers(1, &vbo);

    // Vertex data: positions (x, y) and colors (r, g, b) for each vertex
```

```
    int vert_num = 3;
    GLfloat* vertices = new GLfloat[vert_num * DATA_PER_VERT];

    // Generate a polygon
    // find_polygon_verts(vertices, vert_num, 1.0f);

    // Generate a cube
    vert_num = 36;
    vertices = cube_vertices;

    glBindBuffer(GL_ARRAY_BUFFER, vbo);
    glBufferData(GL_ARRAY_BUFFER, vert_num * DATA_PER_VERT * sizeof(GLfloat), vertices, GL_STATIC_DRAW);

    // Create and compile the vertex shader
    GLuint vertex_shader = glCreateShader(GL_VERTEX_SHADER);
    glShaderSource(vertex_shader, 1, &vertex_source, NULL);
    glCompileShader(vertex_shader);

    // Create and compile the fragment shader
    GLuint fragment_shader = glCreateShader(GL_FRAGMENT_SHADER);
    glShaderSource(fragment_shader, 1, &fragment_source, NULL);
    glCompileShader(fragment_shader);

    // Check for shader compilation
    if (!shader_compiled(vertex_shader, true, "Vertex") || !shader_compiled(fragment_shader, true,
"Fragment"))
    {
        // Cleanup: delete shaders, buffers, and close the window
        glDeleteShader(fragment_shader);
        glDeleteShader(vertex_shader);
        glDeleteBuffers(1, &vbo);
        glDeleteVertexArrays(1, &vao);

        window.close();  // Close the rendering window
        return -1;
    }

    // Declare shader uniform data
    glm::mat4 model_matrix = glm::mat4(1.0f);
    model_matrix = glm::rotate(model_matrix, glm::radians(45.0f), glm::vec3(0.0f, 0.0f, 1.0f));
    glm::mat4 view_matrix = glm::lookAt(glm::vec3(0.0f, 0.0f, 3.0f), glm::vec3(0.0f, 0.0f, 0.0f),
glm::vec3(0.0f, 1.0f, 0.0f));
    glm::mat4 proj_matrix = glm::perspective(glm::radians(45.0f), WINDOW_WIDTH / WINDOW_HEIGHT, 0.01f,
100.0f);

    // Link both shaders into a single shader program
    GLuint shader_program = glCreateProgram();
    glAttachShader(shader_program, vertex_shader);
    glAttachShader(shader_program, fragment_shader);
    glBindFragDataLocation(shader_program, 0, "outColor");  // Bind fragment output
    glLinkProgram(shader_program);

    // Use the program if linking succeeded
    if (program_linked(shader_program, true, "Shader"))
    {
        // Debug info
        std::cout << SEPARATOR;
        std::cout << "Version:\t" << glGetString(GL_VERSION) << "\n";
        std::cout << "Running on:\t" << glGetString(GL_RENDERER) << "\n";
        std::cout << SEPARATOR;

        // Use the program
        glUseProgram(shader_program);
```

```
        // Add uniform data
        GLint uni_trans = glGetUniformLocation(shader_program, "model_matrix");
        glUniformMatrix4fv(uni_trans, 1, GL_FALSE, glm::value_ptr(model_matrix));

        GLint uni_view = glGetUniformLocation(shader_program, "view_matrix");
        glUniformMatrix4fv(uni_view, 1, GL_FALSE, glm::value_ptr(view_matrix));

        GLint uni_proj = glGetUniformLocation(shader_program, "proj_matrix");
        glUniformMatrix4fv(uni_proj, 1, GL_FALSE, glm::value_ptr(proj_matrix));
    }
    else
    {
        // Cleanup: delete shaders, buffers, and close the window
        glDeleteProgram(shader_program);
        glDeleteShader(fragment_shader);
        glDeleteShader(vertex_shader);
        glDeleteBuffers(1, &vbo);
        glDeleteVertexArrays(1, &vao);

        window.close();  // Close the rendering window
        return -2;
    }


    // Specify the layout of the vertex data
    GLint pos_attrib = glGetAttribLocation(shader_program, "position");
    glEnableVertexAttribArray(pos_attrib);
    glVertexAttribPointer(pos_attrib, 3, GL_FLOAT, GL_FALSE, DATA_PER_VERT * sizeof(GLfloat), 0);

    GLint col_attrib = glGetAttribLocation(shader_program, "color");
    glEnableVertexAttribArray(col_attrib);
    glVertexAttribPointer(col_attrib, 3, GL_FLOAT, GL_FALSE, DATA_PER_VERT * sizeof(GLfloat), (void*)(3
* sizeof(GLfloat)));

    // Main event loop
    main_loop(window, shader_program, vao, vbo, vert_num, vertices);

    // Cleanup: delete shaders, buffers, and close the window
    glDeleteProgram(shader_program);
    glDeleteShader(fragment_shader);
    glDeleteShader(vertex_shader);
    glDeleteBuffers(1, &vbo);
    glDeleteVertexArrays(1, &vao);

    window.close();  // Close the rendering window
    return 0;
}
```