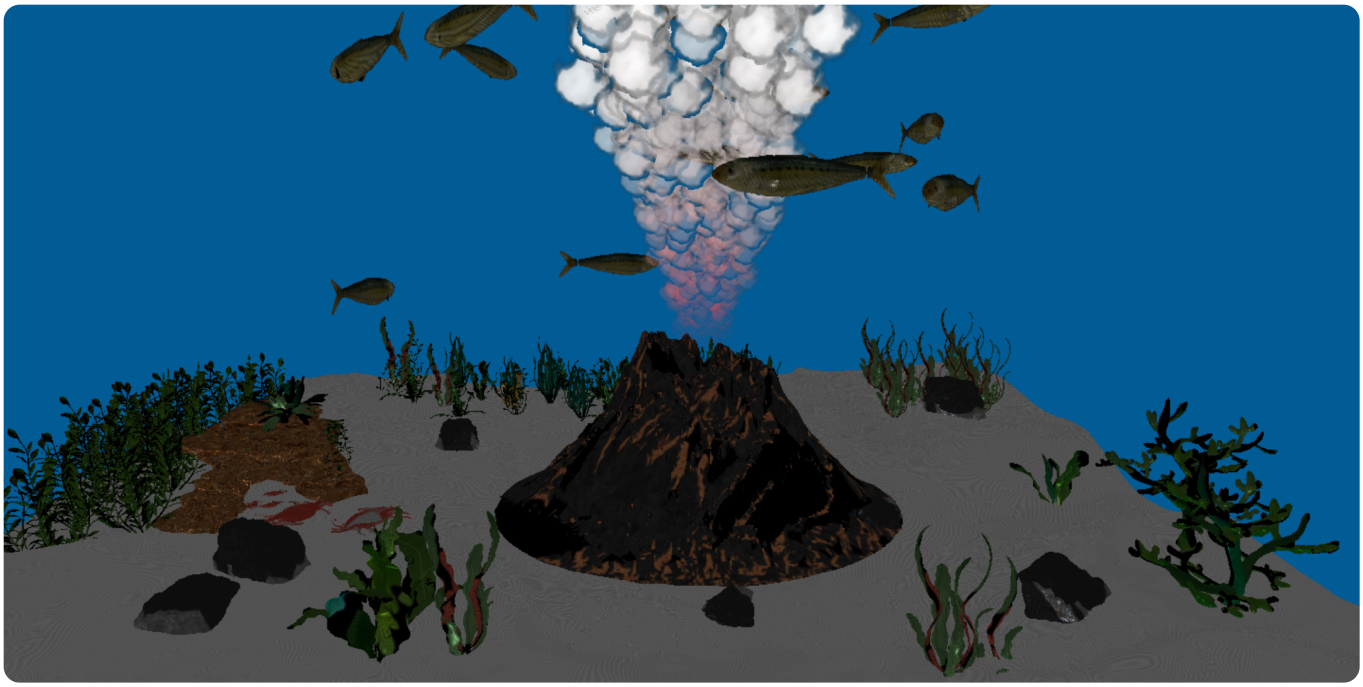
Underwater Volcano

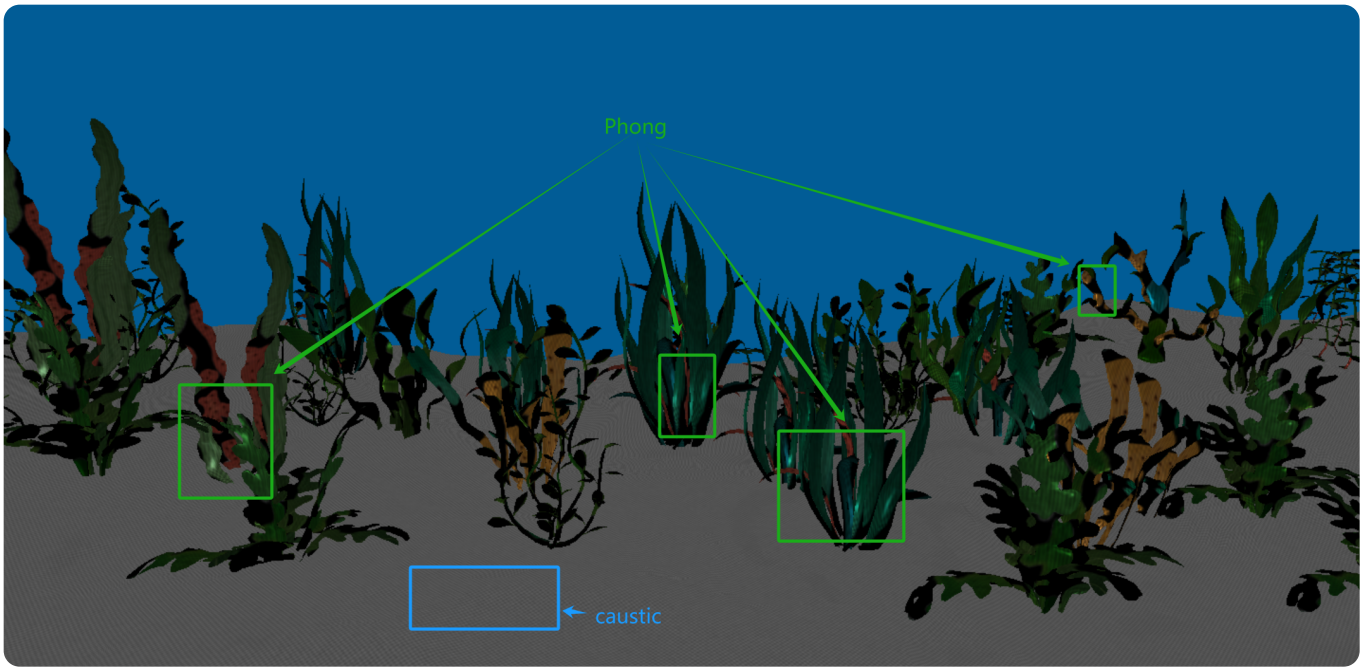
YouTube Link: https://www.youtube.com/watch?v=RfprQyhwirQ



Lighting, Shading and Texture Mapping:

The main shader is in charge of render all the models, which is implemented with Phong illumination with a waving sunlight and additional caustic effects. For the particle shader, there is a red directional light to simulate the effect of lava on the smoke.

Main Shader



1. A **ambient** lighting that is blue, simulates the color in the ocean. Which will illuminate all objects equally.

```
vec3 ambient = lightAmbient;
```

2. A **diffuse** lighting depends on the angle between the **constantly changing-direction sunlight** and the surface normal. It simulates the light scattered in many directions when it hits a rough surface. It also combines with **caustic effect** that simulate the underwater caustics.

```
void updateIllumination() // called each frame
{
    // Oscillate light position along an axis
    lightPosition = glm::vec3(
        10.0f * sin(timeInSeconds * 2.0), // Faster horizontal oscillation
        15.0f + sin(timeInSeconds * 2.0) * 2.0f, // Smaller vertical oscillation
        10.0f * cos(timeInSeconds * 2.0)  // Faster horizontal oscillation
    );

    // Calculate light direction based on the position of the light
    lightDirection = glm::normalize(lightPosition - glm::vec3(0.0f));
}
```

```
// fragmeng shader:
vec3 norm = normalize(Normal);
vec3 lightDir = normalize(-lightDirection);
```

```
float diff = max(dot(norm, lightDir), 0.2);
float causticEffect = caustics(FragPos) * causticIntensity;
vec3 diffuse = lightDiffuse * diff * causticEffect;
```

3. A **specular lighting** simulates the bright spot of light that appears on shiny surfaces. It depends on the view direction, light direction, and surface normal.

```
vec3 viewDir = normalize(viewPos - FragPos);
vec3 reflectDir = reflect(-lightDir, norm);
float spec = pow(max(dot(viewDir, reflectDir), 0.0), 64);
vec3 specular = vec3(0.8, 0.8, 1.0) * spec;
```

4. Light **attenuation** simulates the reduction of light intensity over distance, which is particularly important in underwater scenes.

```
float depth = abs(FragPos.y - 50);
float attenuation = exp(-depth * depthFalloff);
vec3 attenuatedLight = (ambient + diffuse + specular) * attenuation;
```

5. **Texture mapping**: load and map vertex to corresponding texture part

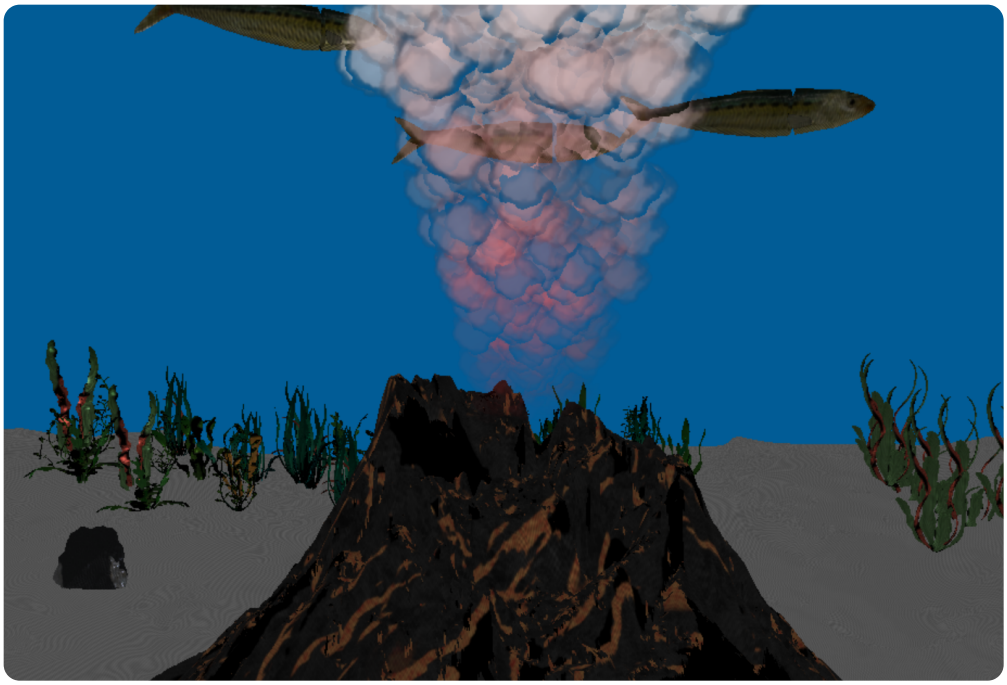
```
vec4 texColor = texture(texture1, TexCoords);
```

6. Combine all the lighting together:

```
const vec3 shallowColor = vec3(0.0f, 0.4f, 0.8f); // Bright blue
const vec3 deepColor = vec3(0.0f, 0.1f, 0.3f);    // Dark blue
vec3 waterColor = mix(shallowColor, deepColor, depth / 100.0f);
vec3 finalLight = mix(waterColor, attenuatedLight, attenuation);
FragColor = vec4(finalLight * texColor.rgb, 1.0);
```

Particle Shader

A **red directional light** is also added to simulate the light from crater of the volcano, and be faded as it goes up.



```
// Calculate direction to volcano
vec3 toVolcano = normalize(FragPos - volcanoPosition);

// Calculate alignment (cosine of angle)
float alignment = dot(toVolcano, redLightDirection);

// Beam effect using smoothstep
float beamEffect = smoothstep(1.0 - beamWidth, 1.0, alignment);

// Apply red light with beam effect
float distanceToVolcano = length(FragPos - volcanoPosition);
float falloff = exp(-distanceToVolcano * redLightFalloff);
vec3 redLight = redLightColor * redLightIntensity * beamEffect * falloff;

// Combine particle color with red light
FragColor = vec4((texColor.rgb * particleColor.rgb + redLight) * alpha, texColor.a *
```

Advanced Feature: Particle System

To better simulate the smoke from volcano, I build the whole particle system which would spawn several particles each frame For each particle:

- Has velocity, position and lifetime. A velocity is mostly upward and with some random horizontal offsets, and will be slightly changed each frame to make it more realistic

- Being updated in each frame before their life time ends

```
// initialize or reset a particle
for (int i = 0; i < NewParticlePerFrame; ++i) {

    // ...
    // ... search for unused particles

     if (particles[particleIndex].lifetime <= 0.0f)
     {
         // Reset a particle
         Particle& p = particles[particleIndex];
         // start from crater of the volcano
         p.position = startPosition + glm::vec3(horizontalDist(rng), 0.0f,
                     horizontalDist(rng));
         p.velocity = glm::vec3(horizontalDist(rng), verticalDist(rng),
                     horizontalDist(rng)); // Mostly upward velocity
         p.lifetime = PARTICLE_LIFETIME;
     }
}

// Update all alive particles
const float dampingFactor = 0.75f; // Slow down speed
for (auto& p : particles) {
    if (p.lifetime > 0.0f) {

        // randomize the velocity
        float randomX = ((rand() % 100) / 100.0f - 0.5f) * 0.01f;
        float randomZ = ((rand() % 100) / 100.0f - 0.5f) * 0.01f;
        p.velocity.x += randomX;
        p.velocity.z += randomZ;

        p.position += p.velocity * deltaTime * dampingFactor;
        p.lifetime -= deltaTime;
    }
}
```

- Smoke texture mapping to make it look more realistic.

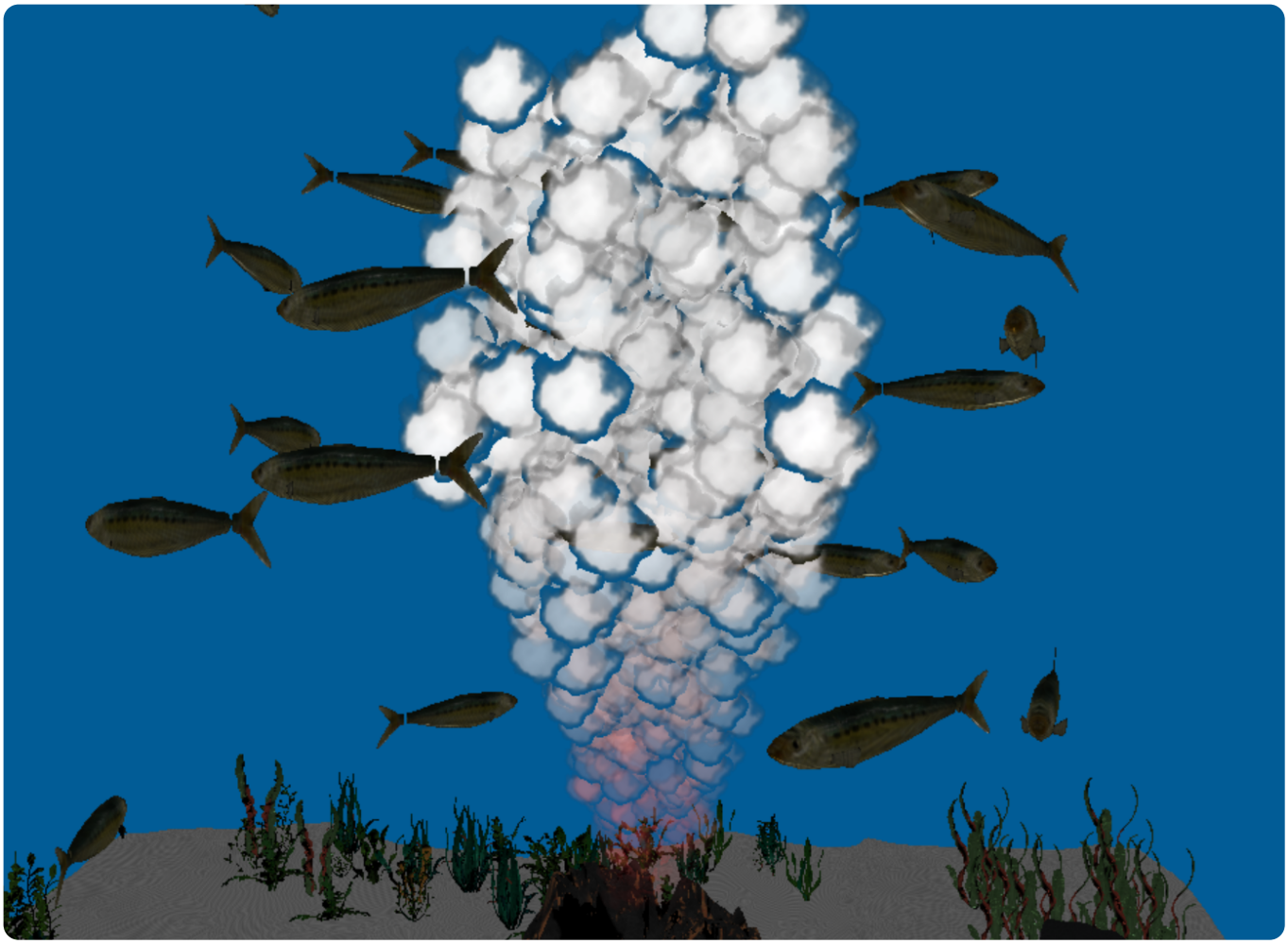
```
// Particle quad vertices
float quadVertices[] = {
    // Positions      // Texture Coords
    -0.05f, -0.05f, 0.0f, 0.0f, 0.0f,
     0.05f, -0.05f, 0.0f, 1.0f, 0.0f,
    -0.05f,  0.05f, 0.0f, 0.0f, 1.0f,
```

```
    -0.05f,  0.05f, 0.0f, 0.0f, 1.0f,
     0.05f, -0.05f, 0.0f, 1.0f, 0.0f,
     0.05f,  0.05f, 0.0f, 1.0f, 1.0f,
};
glBindBuffer(GL_ARRAY_BUFFER, particleVBO);
glBufferData(GL_ARRAY_BUFFER, sizeof(quadVertices), quadVertices, GL_STATIC_DRAW

// vertex shader:
gl_Position = projection * view * vec4(vertex * currentScale + instanceOffset, 1

// fragment shader:
vec4 texColor = texture(particleTexture, TexCoords) * vec4(1.0, 1.0, 1.0, alpha)
if (texColor.a < 0.1) discard;
FragColor = vec4((texColor.rgb * particleColor.rgb + redLight) * alpha, texColor
```

- The alpha and scale of particle is changing each frame to simulate the boba gets bigger and more transparent as it floats up.

```
float currentScale = mix(50, 150, pow(instanceLifetimePercent, 1.5));
float alpha = pow(LifetimePercent, 0.5); // Fade out faster near the end
```

Scene Setup



The scene is centered with an active volcano that is spreading out smoke from its crater. A group of fishes are swimming circularly around the vivid smoke, where each fish is a hierarchical model that is able to perform a simple animation by waving the head and fin.

Fish Animation:

```
float currentAngle = 0.0f;
void updateAnimation()
{
    // Hierarichal Animation
    // Fin and head of a fish rotate in a sinusoidal pattern
    // relatively to the body
    rotate_fin = 0.5f * sin(timeInSeconds*1.5);
    rotate_body = 0.5f * sin(timeInSeconds*1.5 + glm::radians(45.0f));
    rotate_head = 0.5f * sin(timeInSeconds*1.5 + glm::radians(90.0f));

    // Swim circularly
    const float rotationSpeed = 0.05f; // radians
    const float deltaTime = 0.016f;
```

```
    float radius = 4.0f;

    currentAngle += rotationSpeed * deltaTime;
    // Keep angle within [0, 2*PI]
    if (currentAngle > glm::two_pi<float>()) {
        currentAngle -= glm::two_pi<float>();
    }

    for (int i = 0; i < fish_centers.size(); ++i)
    {
        glm::vec3 newPosition(
            radius * cos(currentAngle), // X position on the circle
            fish_centers[i].y - 5.0,               // Maintain the Y position and lo
            radius * sin(currentAngle)  // Z position on the circle
        );

        glm::vec3 forwardDirection(
            -radius * sin(currentAngle), // Tangent X
            0.0f,                        // Tangent Y (flat circle in XZ plane)
            radius * cos(currentAngle)   // Tangent Z
        );
        forwardDirection = glm::normalize(forwardDirection);

        glm::vec3 upVector(0.0f, 1.0f, 0.0f); // Assume Y is up
        glm::vec3 rightVector = glm::normalize(glm::cross(upVector, forwardDirection

        glm::mat4 transform = glm::mat4(1.0f);
        transform[0] = glm::vec4(rightVector, 0.0f);      // Right vector
        transform[1] = glm::vec4(upVector, 0.0f);         // Up vector
        transform[2] = glm::vec4(-forwardDirection, 0.0f); // Forward vector (negati
        transform[3] = glm::vec4(newPosition, 1.0f);      // Position
        fish_transforms[i] = transform;
    }
}
```

Declaration

This work is all by myself.