



Environment Reflection/Refraction and Fog

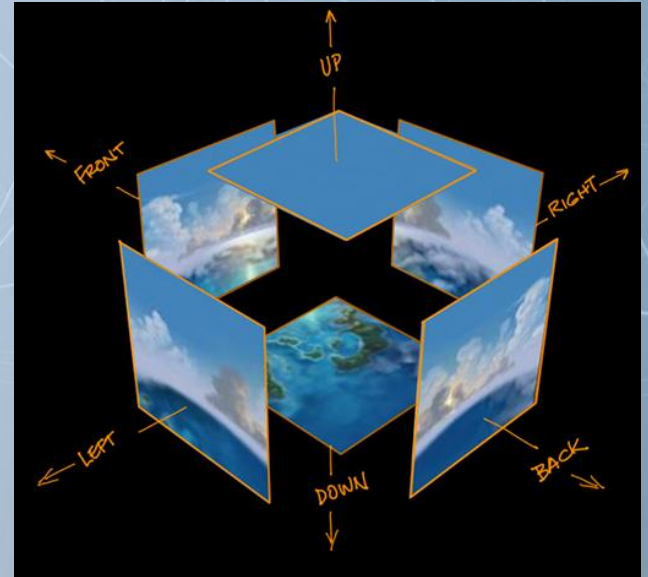
CSU0021: Computer Graphics

Cubic Environment Mapping (Cubemap)

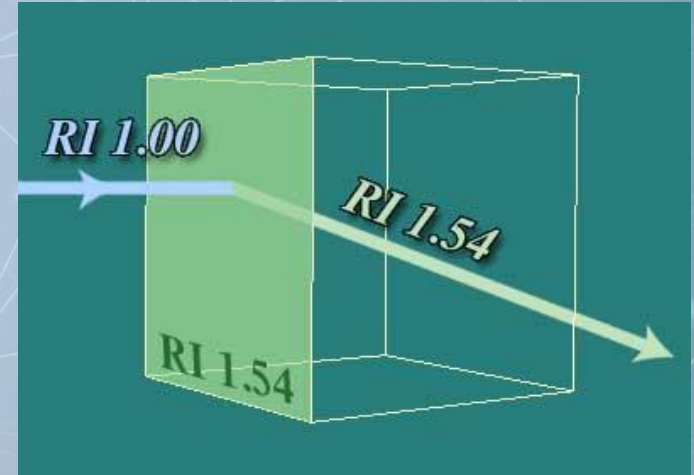
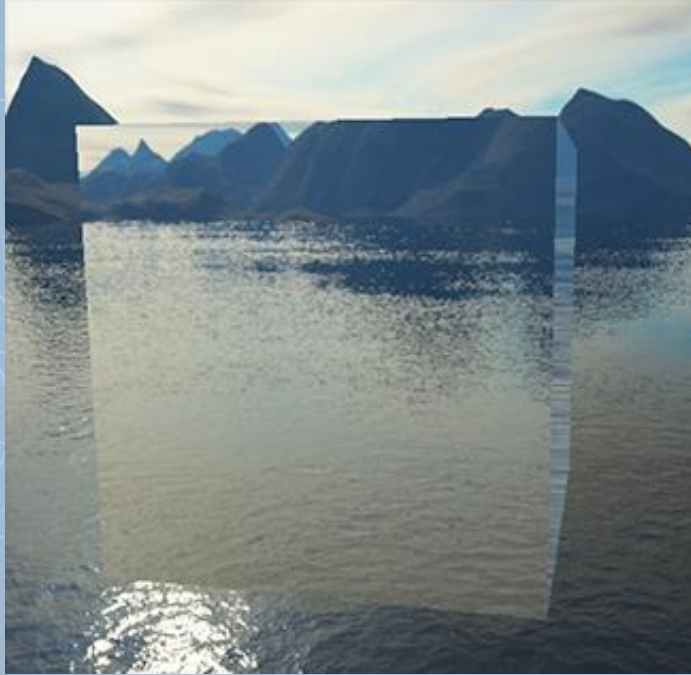
- Applications
 - Skybox (last topic)
 - **Environment refraction**
 - **Environment reflection**
 - Dynamic reflection (next topic)
- Fog?
 - Fog implementation is nothing about cubemap

Skybox

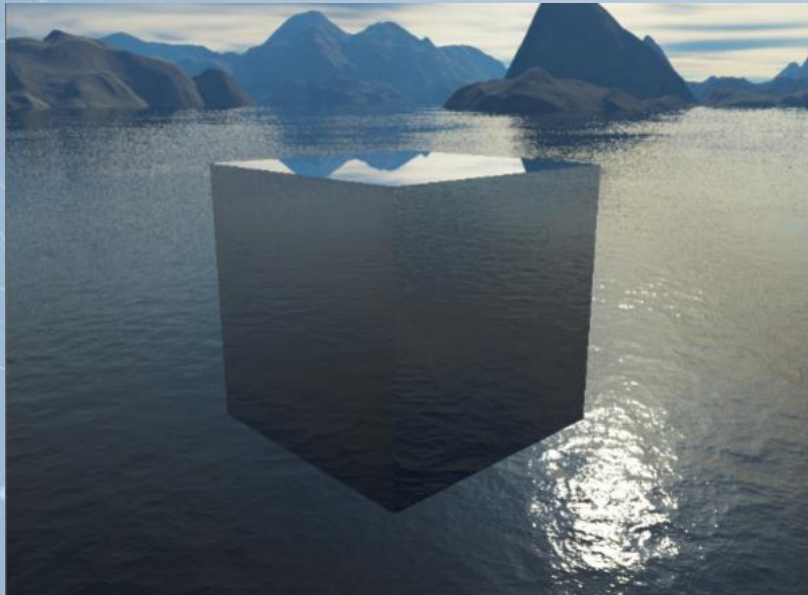
- The background comes from cube map images



Environment Refraction



Environment Reflection

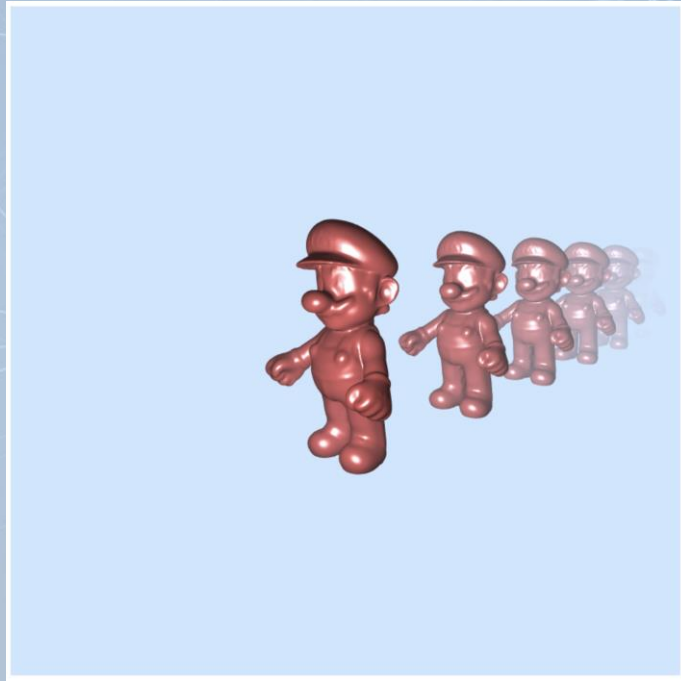


Dynamic Reflection



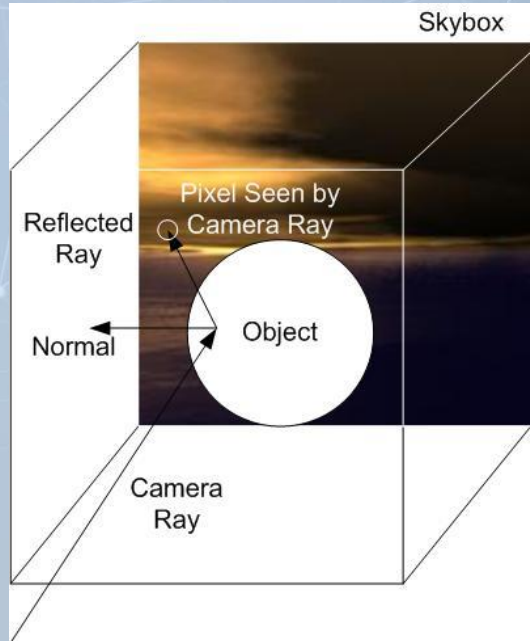
Fog

- Fog implementation does not use cube map



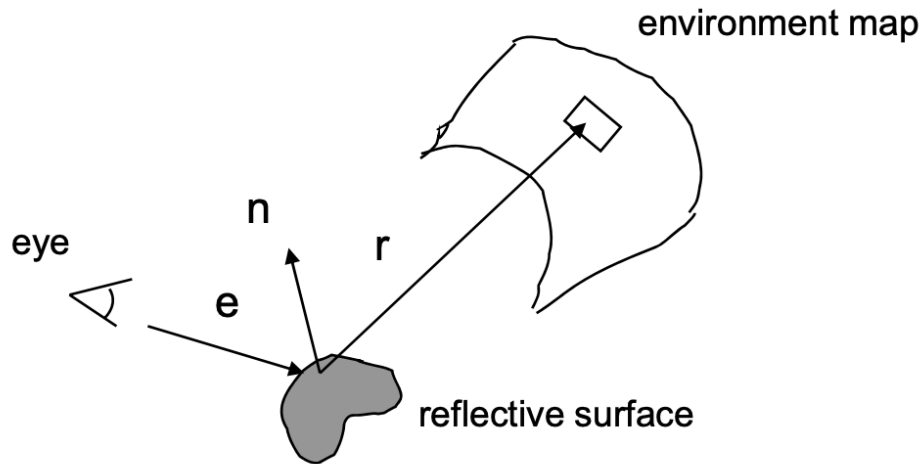
Environment Map Reflection

- A cheap way to implement reflection
- But, it does not reflect any 3D model in the scene



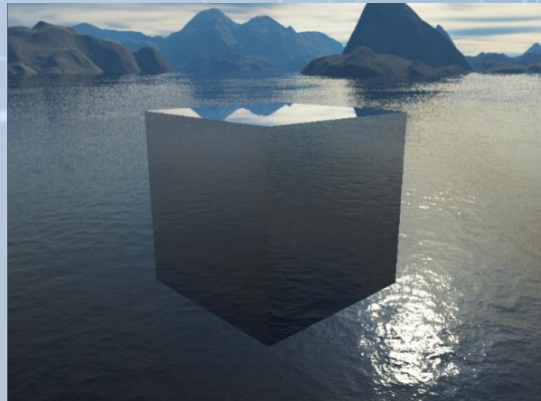
Basic Idea

- Assuming the environment is far away and the object does not reflect itself and other objects
 - The reflection at a point can be solely decided by the reflection vector



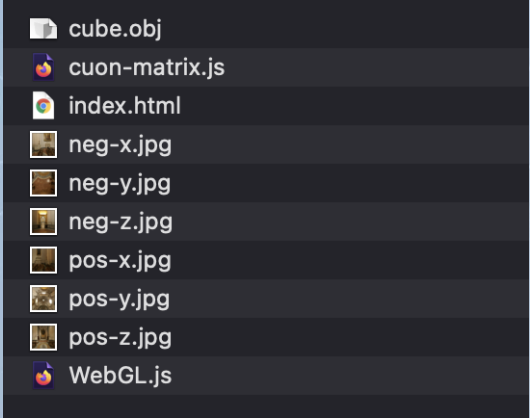
Basic Steps











- Load images to create an environment cube map texture
 - For each pixel on a reflective object, get its normal vector
 - Compute the reflection vector based on the eye position and the normal vector
 - Use the reflection vector to compute an index into the environment cube map texture
 - Use the corresponding texel to color the pixel
- Note: you can have the environment reflection on an object without the environment background in the scene



Example (Ex11-1)

- A reflective cube
- Files



-  cube.obj
-  cuon-matrix.js
-  index.html
-  neg-x.jpg
-  neg-y.jpg
-  neg-z.jpg
-  pos-x.jpg
-  pos-y.jpg
-  pos-z.jpg
-  WebGL.js



Example (Ex11-1)

- Shaders in WebGL.js

Calculate the vertex position in clip space

Calculate the vertex position in world space

Transform normal vector to world space

Draw the reflective cube

```
var VSHADER_SOURCE_ENVCUBE = `
attribute vec4 a_Position;
varying vec4 v_Position;
void main() {
    v_Position = a_Position;
    gl_Position = a_Position;
};
```

Shader to draw the
background quad (same as Ex10-3)

```
var FSHADER_SOURCE_ENVCUBE = `
precision mediump float;
uniform samplerCube u_envCubeMap;
uniform mat4 u_viewDirectionProjectionInverse;
varying vec4 v_Position;
void main() {
    vec4 t = u_viewDirectionProjectionInverse * v_Position;
    gl_FragColor = textureCube(u_envCubeMap, normalize(t.xyz / t.w));
};
```

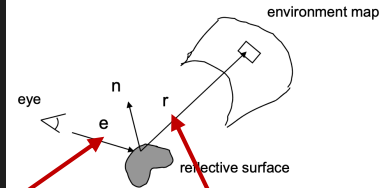
```
var VSHADER_SOURCE = `
attribute vec4 a_Position;
attribute vec4 a_Normal;
uniform mat4 u_MvpMatrix;
uniform mat4 u_modelMatrix;
uniform mat4 u_normalMatrix;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
void main(){
    gl_Position = u_MvpMatrix * a_Position;
    v_PositionInWorld = (u_modelMatrix * a_Position).xyz;
    v_Normal = normalize(vec3(u_normalMatrix * a_Normal));
};

var FSHADER_SOURCE = `
precision mediump float;
uniform vec3 u_ViewPosition;
uniform samplerCube u_envCubeMap;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
void main(){
    vec3 V = normalize(u_ViewPosition - v_PositionInWorld);
    vec3 normal = normalize(v_Normal);
    vec3 R = reflect(-V, normal);
    gl_FragColor = vec4(textureCube(u_envCubeMap, R).rgb, 1.0);
};
```


Example (Ex11-1)

- Shaders in WebGL.js

Draw the reflective cube



```
var VSHADER_SOURCE = `
attribute vec4 a_Position;
attribute vec4 a_Normal;
uniform mat4 u_MvpMatrix;
uniform mat4 u_modelMatrix;
uniform mat4 u_normalMatrix;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
void main(){
    gl_Position = u_MvpMatrix * a_Position;
    v_PositionInWorld = (u_modelMatrix * a_Position).xyz;
    v_Normal = normalize(vec3(u_normalMatrix * a_Normal));
}
```

```
var FSHADER_SOURCE = `
precision mediump float;
uniform vec3 u_ViewPosition;
uniform samplerCube u_envCubeMap;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
void main(){
    vec3 V = normalize(u_ViewPosition - v_PositionInWorld);
    vec3 normal = normalize(v_Normal);
    vec3 R = reflect(-V, normal);
    gl_FragColor = vec4(textureCube(u_envCubeMap, R).rgb, 1.0);
}
```

Calculate the vector from
an object point to eye

Use the reflective vector to look up
color from the cubemap to color the cube

Calculate the reflective vector

```
var VSHADER_SOURCE_ENVCUBE = `
attribute vec4 a_Position;
varying vec4 v_Position;
void main() {
    v_Position = a_Position;
    gl_Position = a_Position;
}
```

```
var FSHADER_SOURCE_ENVCUBE = `
precision mediump float;
uniform samplerCube u_envCubeMap;
uniform mat4 u_viewDirectionProjectionInverse;
varying vec4 v_Position;
void main() {
    vec4 t = u_viewDirectionProjectionInverse * v_Position;
    gl_FragColor = textureCube(u_envCubeMap, normalize(t.xyz / t.w));
}
```

Example (Ex11-1)

- main() in WebGL.js

Load the cube map images and create a cubemap texture

```
cubeMapTex = initCubeTexture("pos-x.jpg", "neg-x.jpg", "pos-y.jpg", "neg-y.jpg",  
                             "pos-z.jpg", "neg-z.jpg", 512, 512)
```

```
quadObj = initVertexBufferForLaterUse(gl, quad);
```

```
gl.enable(gl.DEPTH_TEST);
```

```
draw();//draw it once before mouse move
```

```
canvas.onmousedown = function(ev){mousedown(ev)};
```

```
canvas.onmousemove = function(ev){mousemove(ev)};
```

```
canvas.onmouseup = function(ev){mouseup(ev)};
```

```
document.onkeydown = function(ev){keydown(ev)};
```

```
var tick = function() {  
    rotateAngle += 0.25;  
    draw();  
    requestAnimationFrame(tick);  
}  
tick();
```

Make the cube rotate

```
async function main(){  
    canvas = document.getElementById('webgl');  
    gl = canvas.getContext('webgl2');  
    if(!gl){  
        console.log('Failed to get the rendering context for WebGL');  
        return ;  
    }  
}
```

```
var quad = new Float32Array(  
    [  
        -1, -1, 1, Background quad vertices  
        1, -1, 1,  
        -1, 1, 1,  
        -1, 1, 1,  
        1, -1, 1,  
        1, 1, 1  
    ]); //just a quad
```

Compile two shaders

```
programEnvCube = compileShader(gl, VSHADER_SOURCE_ENVCUBE, FSHADER_SOURCE_ENVCUBE);  
programEnvCube.a_Position = gl.getAttribLocation(programEnvCube, 'a_Position');  
programEnvCube.u_envCubeMap = gl.getUniformLocation(programEnvCube, 'u_envCubeMap');  
programEnvCube.u_viewDirectionProjectionInverse = gl.getUniformLocation(programEnvCube, 'u_viewDirectionProjectionInverse');
```

```
program = compileShader(gl, VSHADER_SOURCE, FSHADER_SOURCE);  
program.a_Position = gl.getAttribLocation(program, 'a_Position');  
program.a_Normal = gl.getAttribLocation(program, 'a_Normal');  
program.u_MvpMatrix = gl.getUniformLocation(program, 'u_MvpMatrix');  
program.u_modelMatrix = gl.getUniformLocation(program, 'u_modelMatrix');  
program.u_normalMatrix = gl.getUniformLocation(program, 'u_normalMatrix');  
program.u_ViewPosition = gl.getUniformLocation(program, 'u_ViewPosition');  
program.u_envCubeMap = gl.getUniformLocation(program, 'u_envCubeMap');
```

```
response = await fetch('cube.obj');  
text = await response.text();  
obj = parseOBJ(text);
```

```
for( let i=0; i < obj.geometries.length; i ++ ){  
    let o = initVertexBufferForLaterUse(gl,  
        obj.geometries[i].data.position,  
        obj.geometries[i].data.normal,  
        obj.geometries[i].data.texcoord);  
    objComponents.push(o);  
}
```

Example (Ex11-1)

- draw() in WebGL.js

Just call shader to draw the cube

Prepare matrices and

draw the background quad (almost same as Ex-10-3)

```
//Draw the reflective cube
gl.useProgram(program);
gl.depthFunc(gl.LESS);
//model Matrix (part of the mvp matrix)
var modelMatrix = new Matrix4();
modelMatrix.setScale(objScale, objScale, objScale);
modelMatrix.rotate(rotateAngle, 1, 1, 1); //make the cube rotate
//mvp: projection * view * model matrix
var mvpMatrix = new Matrix4();
mvpMatrix.set(projMatrix).multiply(viewMatrix).multiply(modelMatrix);

//normal matrix
var normalMatrix = new Matrix4();
normalMatrix.setInverseOf(modelMatrix);
normalMatrix.transpose();

gl.uniform3f(program.u_ViewPosition, cameraX, cameraY, cameraZ);
gl.uniform1i(program.u_envCubeMap, 0);

gl.activeTexture(gl.TEXTURE0);
gl.bindTexture(gl.TEXTURE_CUBE_MAP, cubeMapTex);

gl.uniformMatrix4fv(program.u_MvpMatrix, false, mvpMatrix.elements);
gl.uniformMatrix4fv(program.u_modelMatrix, false, modelMatrix.elements);
gl.uniformMatrix4fv(program.u_normalMatrix, false, normalMatrix.elements);

for( let i=0; i < objComponents.length; i ++ ){
  initAttributeVariable(gl, program.a_Position, objComponents[i].vertexBuffer);
  initAttributeVariable(gl, program.a_Normal, objComponents[i].normalBuffer);
  gl.drawArrays(gl.TRIANGLES, 0, objComponents[i].numVertices);
}
```

Make the cube keep rotating

This shader also need the
environment cube map texture

```
function draw(){
  gl.viewport(0, 0, canvas.width, canvas.height);
  gl.clearColor(0.4, 0.4, 0.4, 1);
  gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);
  gl.enable(gl.DEPTH_TEST);

  //rotate the camera view direction
  let rotateMatrix = new Matrix4();
  rotateMatrix.setRotate(angleY, 1, 0, 0); //for mouse rotation
  rotateMatrix.rotate(angleX, 0, 1, 0); //for mouse rotation
  var viewDir= new Vector3([cameraDirX, cameraDirY, cameraDirZ]);
  var newViewDir = rotateMatrix.multiplyVector3(viewDir);

  var viewMatrix = new Matrix4();
  var projMatrix = new Matrix4();
  projMatrix.setPerspective(60, 1, 1, 15);
  viewMatrix.setLookAt(cameraX, cameraY, cameraZ,
    cameraX + newViewDir.elements[0],
    cameraY + newViewDir.elements[1],
    cameraZ + newViewDir.elements[2],
    0, 1, 0);

  var viewMatrixRotationOnly = new Matrix4();
  viewMatrixRotationOnly.set(viewMatrix);
  viewMatrixRotationOnly.elements[12] = 0; //ignore translation
  viewMatrixRotationOnly.elements[13] = 0;
  viewMatrixRotationOnly.elements[14] = 0;
  var vpFromCameraRotationOnly = new Matrix4();
  vpFromCameraRotationOnly.set(projMatrix).multiply(viewMatrixRotationOnly);
  var vpFromCameraInverse = vpFromCameraRotationOnly.invert();

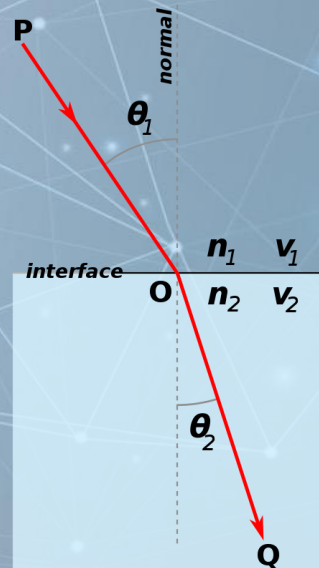
  //draw the background quad
  gl.useProgram(programEnvCube);
  gl.depthFunc(gl.LEQUAL);
  gl.uniformMatrix4fv(programEnvCube.u_viewDirectionProjectionInverse,
    false, vpFromCameraInverse.elements);
  gl.activeTexture(gl.TEXTURE0);
  gl.bindTexture(gl.TEXTURE_CUBE_MAP, cubeMapTex);
  gl.uniform1i(programEnvCube.u_envCubeMap, 0);
  initAttributeVariable(gl, programEnvCube.a_Position, quadObj.vertexBuffer);
  gl.drawArrays(gl.TRIANGLES, 0, quadObj.numVertices);
}
```

Try (5mins)

- If you comment the code to draw the background quad in draw() (Line244~Line253), can we still see the reflection on the cube?


Environment Refraction

- What is it?
- Bending of light as it passes from one medium with **refraction index** n_1 , to the other medium with **refraction index** n_2
 - Snell's law
 - $\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_1}{n_2}$
 - List of refractive indices
 - https://en.wikipedia.org/wiki/List_of_refractive_indices
 - Use the refraction index to determine the Incident angle and refractive angle
- Same, neighboring 3D objects do not have impact on environment refraction



Example (Ex11-2)

- A refractive cube
- Files



- cube.obj
- cuon-matrix.js
- index.html
- neg-x.jpg
- neg-y.jpg
- neg-z.jpg
- pos-x.jpg
- pos-y.jpg
- pos-z.jpg
- WebGL.js



Example (Ex11-2)

- Ex11-2 and Ex11-1 are almost the same, the only differences is this small segment of code in this shader
 - The shader to draw the cube

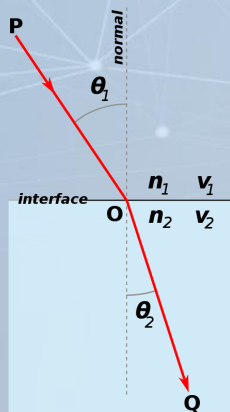
```
var VSHADER_SOURCE = `
attribute vec4 a_Position;
attribute vec4 a_Normal;
uniform mat4 u_MvpMatrix;
uniform mat4 u_modelMatrix;
uniform mat4 u_normalMatrix;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
void main(){
    gl_Position = u_MvpMatrix * a_Position;
    v_PositionInWorld = (u_modelMatrix * a_Position).xyz;
    v_Normal = normalize(vec3(u_normalMatrix * a_Normal));
}
;`
```

```
var FSHADER_SOURCE = `
precision mediump float;
uniform vec3 u_ViewPosition;
uniform samplerCube u_envCubeMap;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
void main(){
    float ratio = 1.00 / 1.1; //glass
    vec3 V = normalize(u_ViewPosition - v_PositionInWorld);
    vec3 normal = normalize(v_Normal);
    vec3 R = refract(-V, normal, ratio);
    gl_FragColor = vec4(textureCube(u_envCubeMap, R).rgb, 1.0);
}
;`
```

Example (Ex11-2)

- `refract(I, N, eta)`
 - <https://www.khronos.org/registry/OpenGL-Refpages/gl4/html/refract.xhtml>
 - I: incident vector
 - N: normal vector
 - eta: ratio of indices of refraction

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_1}{n_2}$$



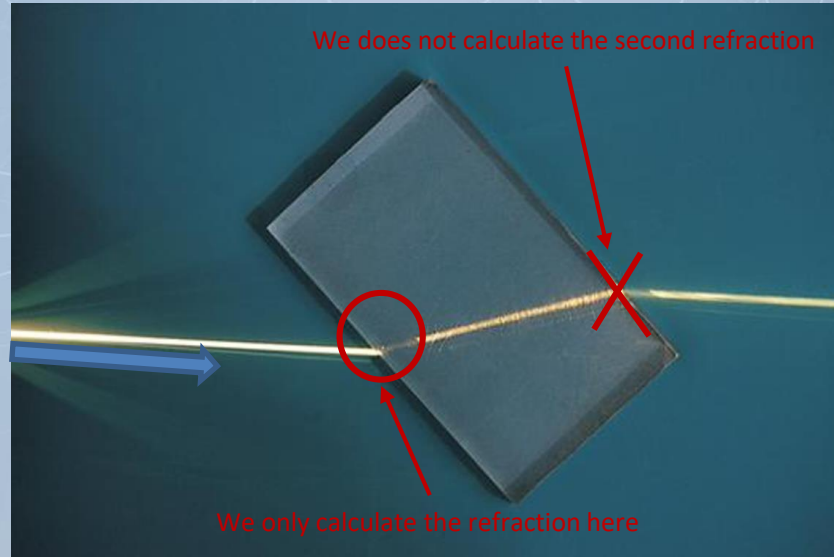
```
var VSHADER_SOURCE = `
attribute vec4 a_Position;
attribute vec4 a_Normal;
uniform mat4 u_MvpMatrix;
uniform mat4 u_modelMatrix;
uniform mat4 u_normalMatrix;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
void main(){
    gl_Position = u_MvpMatrix * a_Position;
    v_PositionInWorld = (u_modelMatrix * a_Position).xyz;
    v_Normal = normalize(vec3(u_normalMatrix * a_Normal));
}
```

We assume the material of the cube is glass
(refractive index is 1.1)

```
var FSHADER_SOURCE = `
precision mediump float;
uniform vec3 u_ViewPosition;
uniform samplerCube u_envCubeMap;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
void main(){
    float ratio = 1.00 / 1.1; //glass
    vec3 V = normalize(u_ViewPosition - v_PositionInWorld);
    vec3 normal = normalize(v_Normal);
    vec3 R = refract(-V, normal, ratio);
    gl_FragColor = vec4(textureCube(u_envCubeMap, R).rgb, 1.0);
}
```

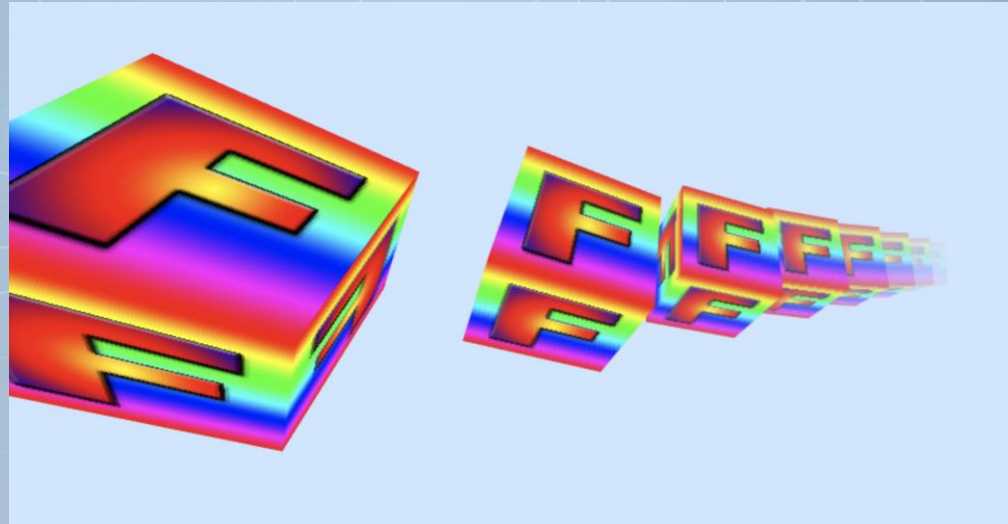

Try (5mins)

- Download the code and run
- Is this refraction implementation is good enough?
 - We only calculate the refraction once



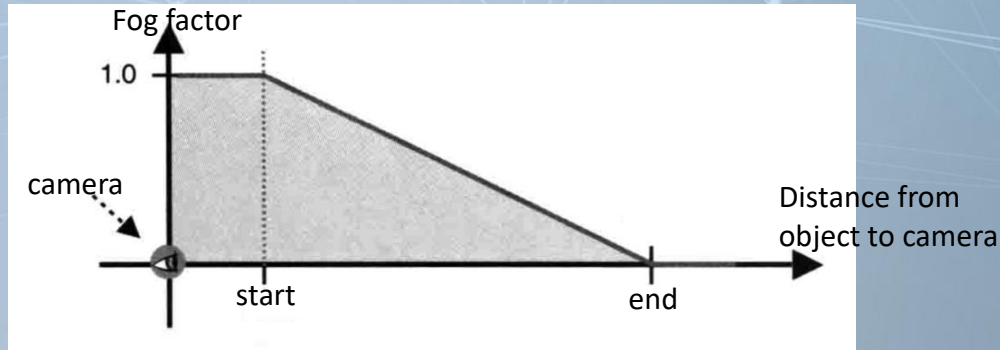
Fog

- Idea: if the object is further away from the camera, it should be blurred more
- We do not need cube map and texture for fog implementation



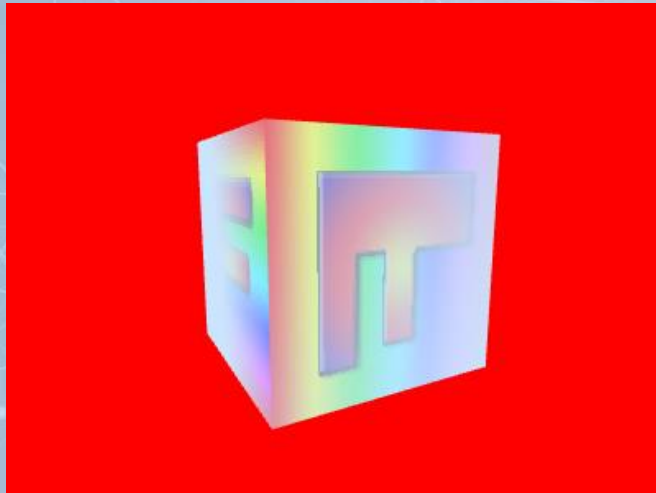
Linear Fog

- Linear Fog: a simple version of fog implementation
- We use “fog factor” to control how much we should blur the object
- Fog factor is determined by the distance from the object to the camera
 - **$\text{fogFactor} = (\text{end} - \text{distance}(\text{camera}, \text{objPoint})) / (\text{end} - \text{start})$**
 - start: the closest distance we want the fog effect
 - end: the farthest distance we still can see the object (a little bit)
 - **$\text{color} = (\text{fogFactor} * \text{objColor}) + ((1 - \text{fogFactor}) * \text{fogColor})$**



Fog Color

- Key: Fog color should be the same as the background color



Background color and
fog color are different



Background color and
fog color are the same

Example (Ex11-3)

- Put marios in fog
- Files



cuon-matrix.js



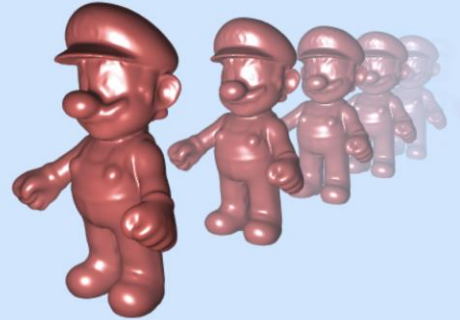
index.html



mario.obj



WebGL.js



Example (Ex11-3)

- draw() in WebGL.js
 - draw six marios

```
function any i(){  
    gl.clearColor(0.8, 0.9, 1.0, 1);  
    gl.clear(gl.COLOR_BUFFER_BIT | gl.DEPTH_BUFFER_BIT);  
  
    for( let depth = 0; depth< 6; depth++){  
        //model Matrix (part of the mvp matrix)  
        modelMatrix.setRotate(angleY, 1, 0, 0); //for mouse rotation  
        modelMatrix.rotate(angleX, 0, 1, 0); //for mouse rotation  
        modelMatrix.rotate(-30, 0, 1, 0);  
        modelMatrix.translate(0, 0, -3 * depth);  
        modelMatrix.scale(objScale, objScale, objScale);  
        //mvp: projection * view * model matrix  
        mvpMatrix.setPerspective(70, 1, 1, 100);  
        mvpMatrix.lookAt(cameraX, cameraY, cameraZ, 0, 0, 0, 1, 0);  
        mvpMatrix.multiply(modelMatrix);  
  
        //normal matrix  
        normalMatrix.setInverseOf(modelMatrix);  
        normalMatrix.transpose();  
  
        gl.uniform3f(program.u_LightPosition, 0, 0, 3);  
        gl.uniform3f(program.u_ViewPosition, cameraX, cameraY, cameraZ);  
        gl.uniform1f(program.u_Ka, 0.2);  
        gl.uniform1f(program.u_Kd, 0.7);  
        gl.uniform1f(program.u_Ks, 1.0);  
        gl.uniform1f(program.u_shininess, 10.0);  
        gl.uniform3f(program.u_Color, 1.0, 0.4, 0.4);  
        gl.uniform3f(program.u_EyePos, cameraX, cameraY, cameraZ);  
  
        gl.uniformMatrix4fv(program.u_MvpMatrix, false, mvpMatrix.elements);  
        gl.uniformMatrix4fv(program.u_modelMatrix, false, modelMatrix.elements);  
        gl.uniformMatrix4fv(program.u_normalMatrix, false, normalMatrix.elements);  
  
        for( let i=0; i < objComponents.length; i ++ ){  
            initAttributeVariable(gl, program.a_Position, objComponents[i].vertexBuffer);  
            initAttributeVariable(gl, program.a_Normal, objComponents[i].normalBuffer);  
            gl.drawArrays(gl.TRIANGLES, 0, objComponents[i].numVertices);  
        }  
    }  
}
```

Example (Ex11-3)

- shaders in WebGL.js

Calculate the distance between an object point to the camera in vertex shader

```
var VSHADER_SOURCE = `
attribute vec4 a_Position;
attribute vec4 a_Normal;
uniform mat4 u_MvpMatrix;
uniform mat4 u_modelMatrix;
uniform mat4 u_normalMatrix;
uniform vec3 u_EyePos;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
varying float v_Dist;
void main(){
    gl_Position = u_MvpMatrix * a_Position;
    v_PositionInWorld = (u_modelMatrix * a_Position).xyz;
    v_Normal = normalize(vec3(u_normalMatrix * a_Normal));
    v_Dist = distance( v_PositionInWorld, u_EyePos );
}
```

```
var FSHADER_SOURCE = `
precision mediump float;
uniform vec3 u_LightPosition;
uniform vec3 u_ViewPosition;
uniform float u_Ka;
uniform float u_Kd;
uniform float u_Ks;
uniform float u_shininess;
uniform vec3 u_Color;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
varying float v_Dist;
void main(){
    // let ambient and diffuse color are u_Color
    // (you can also input them from outside and make them different)
    vec3 ambientLightColor = u_Color;
    vec3 diffuseLightColor = u_Color;
    // assume white specular light (you can also input it from outside)
    vec3 specularLightColor = vec3(1.0, 1.0, 1.0);

    vec3 ambient = ambientLightColor * u_Ka;

    vec3 normal = normalize(v_Normal);
    vec3 lightDirection = normalize(u_LightPosition - v_PositionInWorld);
    float nDotL = max(dot(lightDirection, normal), 0.0);
    vec3 diffuse = diffuseLightColor * u_Kd * nDotL;

    vec3 specular = vec3(0.0, 0.0, 0.0);
    if(nDotL > 0.0) {
        vec3 R = reflect(-lightDirection, normal);
        // V: the vector, point to viewer
        vec3 V = normalize(u_ViewPosition - v_PositionInWorld);
        float specAngle = clamp(dot(R, V), 0.0, 1.0);
        specular = u_Ks * pow(specAngle, u_shininess) * specularLightColor;
    }

    vec3 illumination = ambient + diffuse + specular;

    //fog
    vec3 fogColor = vec3(0.8, 0.9, 1.0);
    vec2 fogDist = vec2(5.0, 20.0);
    float fogFactor = clamp((fogDist.y - v_Dist)/(fogDist.y - fogDist.x), 0.0, 1.0);

    gl_FragColor = vec4( fogColor * (1.0 - fogFactor) + illumination * fogFactor, 1.0 );
}
```

Example (Ex11-3)

- shaders in WebGL.js

```
var VSHADER_SOURCE = `
attribute vec4 a_Position;
attribute vec4 a_Normal;
uniform mat4 u_MvpMatrix;
uniform mat4 u_modelMatrix;
uniform mat4 u_normalMatrix;
uniform vec3 u_EyePos;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
varying float v_Dist;
void main(){
    gl_Position = u_MvpMatrix * a_Position;
    v_PositionInWorld = (u_modelMatrix * a_Position).xyz;
    v_Normal = normalize(vec3(u_normalMatrix * a_Normal));
    v_Dist = distance( v_PositionInWorld, u_EyePos );
}
```

```
var FSHADER_SOURCE = `
precision mediump float;
uniform vec3 u_LightPosition;
uniform vec3 u_ViewPosition;
uniform float u_Ka;
uniform float u_Kd;
uniform float u_Ks;
uniform float u_shininess;
uniform vec3 u_Color;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
varying float v_Dist;
void main(){
    // let ambient and diffuse color are u_Color
    // (you can also input them from outside and make them different)
    vec3 ambientLightColor = u_Color;
    vec3 diffuseLightColor = u_Color;
    // assume white specular light (you can also input it from outside)
    vec3 specularLightColor = vec3(1.0, 1.0, 1.0);

    vec3 ambient = ambientLightColor * u_Ka;

    vec3 normal = normalize(v_Normal);
    vec3 lightDirection = normalize(u_LightPosition - v_PositionInWorld);
    float nDotL = max(dot(lightDirection, normal), 0.0);
    vec3 diffuse = diffuseLightColor * u_Kd * nDotL;

    vec3 specular = vec3(0.0, 0.0, 0.0);
    if(nDotL > 0.0) {
        vec3 R = reflect(-lightDirection, normal);
        // V: the vector, point to viewer
        vec3 V = normalize(u_ViewPosition - v_PositionInWorld);
        float specAngle = clamp(dot(R, V), 0.0, 1.0);
        specular = u_Ks * pow(specAngle, u_shininess) * specularLightColor;
    }

    vec3 illumination = ambient + diffuse + specular;

    //fog
    vec3 fogColor = vec3(0.8, 0.9, 1.0);
    vec2 fogDist = vec2(5.0, 20.0);
    float fogFactor = clamp((fogDist.y - v_Dist)/(fogDist.y - fogDist.x), 0.0, 1.0);

    gl_FragColor = vec4( fogColor * (1.0 - fogFactor) + illumination * fogFactor, 1.0 );
}
```

Regular illumination code and store the result in the variable "illumination"

Example (Ex11-3)

- shaders in WebGL.js

Define fog color here

(this is the same as the background color we use)

“start” and “end” in the fog factor calculation equation

```
var VSHADER_SOURCE = `
attribute vec4 a_Position;
attribute vec4 a_Normal;
uniform mat4 u_MvpMatrix;
uniform mat4 u_modelMatrix;
uniform mat4 u_normalMatrix;
uniform vec3 u_EyePos;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
varying float v_Dist;
void main(){
    gl_Position = u_MvpMatrix * a_Position;
    v_PositionInWorld = (u_modelMatrix * a_Position).xyz;
    v_Normal = normalize(vec3(u_normalMatrix * a_Normal));
    v_Dist = distance( v_PositionInWorld, u_EyePos );
}
```

```
var FSHADER_SOURCE = `
precision mediump float;
uniform vec3 u_LightPosition;
uniform vec3 u_ViewPosition;
uniform float u_Ka;
uniform float u_Kd;
uniform float u_Ks;
uniform float u_shininess;
uniform vec3 u_Color;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
varying float v_Dist;
void main(){
    // let ambient and diffuse color are u_Color
    // (you can also input them from outside and make them different)
    vec3 ambientLightColor = u_Color;
    vec3 diffuseLightColor = u_Color;
    // assume white specular light (you can also input it from outside)
    vec3 specularLightColor = vec3(1.0, 1.0, 1.0);

    vec3 ambient = ambientLightColor * u_Ka;

    vec3 normal = normalize(v_Normal);
    vec3 lightDirection = normalize(u_LightPosition - v_PositionInWorld);
    float nDotL = max(dot(lightDirection, normal), 0.0);
    vec3 diffuse = diffuseLightColor * u_Kd * nDotL;

    vec3 specular = vec3(0.0, 0.0, 0.0);
    if(nDotL > 0.0) {
        vec3 R = reflect(-lightDirection, normal);
        // V: the vector, point to viewer
        vec3 V = normalize(u_ViewPosition - v_PositionInWorld);
        float specAngle = clamp(dot(R, V), 0.0, 1.0);
        specular = u_Ks * pow(specAngle, u_shininess) * specularLightColor;
    }

    vec3 illumination = ambient + diffuse + specular;

    //fog
    vec3 fogColor = vec3(0.8, 0.9, 1.0);
    vec2 fogDist = vec2(5.0, 20.0);
    float fogFactor = clamp((fogDist.y - v_Dist)/(fogDist.y - fogDist.x), 0.0, 1.0);

    gl_FragColor = vec4( fogColor * (1.0 - fogFactor) + illumination * fogFactor, 1.0 );
}
```


Example (Ex11-3)

- shaders in WebGL.js

Calculate the “fogFactor“, and clamp it to 0 ~ 1

mix the fog color and object color

```
var VSHADER_SOURCE = `
attribute vec4 a_Position;
attribute vec4 a_Normal;
uniform mat4 u_MvpMatrix;
uniform mat4 u_modelMatrix;
uniform mat4 u_normalMatrix;
uniform vec3 u_EyePos;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
varying float v_Dist;
void main(){
    gl_Position = u_MvpMatrix * a_Position;
    v_PositionInWorld = (u_modelMatrix * a_Position).xyz;
    v_Normal = normalize(vec3(u_normalMatrix * a_Normal));
    v_Dist = distance( v_PositionInWorld, u_EyePos );
}
```

```
var FSHADER_SOURCE = `
precision mediump float;
uniform vec3 u_LightPosition;
uniform vec3 u_ViewPosition;
uniform float u_Ka;
uniform float u_Kd;
uniform float u_Ks;
uniform float u_shininess;
uniform vec3 u_Color;
varying vec3 v_Normal;
varying vec3 v_PositionInWorld;
varying float v_Dist;
void main(){
    // let ambient and diffuse color are u_Color
    // (you can also input them from outside and make them different)
    vec3 ambientLightColor = u_Color;
    vec3 diffuseLightColor = u_Color;
    // assume white specular light (you can also input it from outside)
    vec3 specularLightColor = vec3(1.0, 1.0, 1.0);

    vec3 ambient = ambientLightColor * u_Ka;

    vec3 normal = normalize(v_Normal);
    vec3 lightDirection = normalize(u_LightPosition - v_PositionInWorld);
    float nDotL = max(dot(lightDirection, normal), 0.0);
    vec3 diffuse = diffuseLightColor * u_Kd * nDotL;

    vec3 specular = vec3(0.0, 0.0, 0.0);
    if(nDotL > 0.0) {
        vec3 R = reflect(-lightDirection, normal);
        // V: the vector, point to viewer
        vec3 V = normalize(u_ViewPosition - v_PositionInWorld);
        float specAngle = clamp(dot(R, V), 0.0, 1.0);
        specular = u_Ks * pow(specAngle, u_shininess) * specularLightColor;
    }

    vec3 illumination = ambient + diffuse + specular;

    //fog
    vec3 fogColor = vec3(0.8, 0.9, 1.0);
    vec2 fogDist = vec2(5.0, 20.0);
    float fogFactor = clamp((fogDist.y - v_Dist)/(fogDist.y - fogDist.x), 0.0, 1.0);

    gl_FragColor = vec4( fogColor * (1.0 - fogFactor) + illumination * fogFactor, 1.0 );
}
```