Textures

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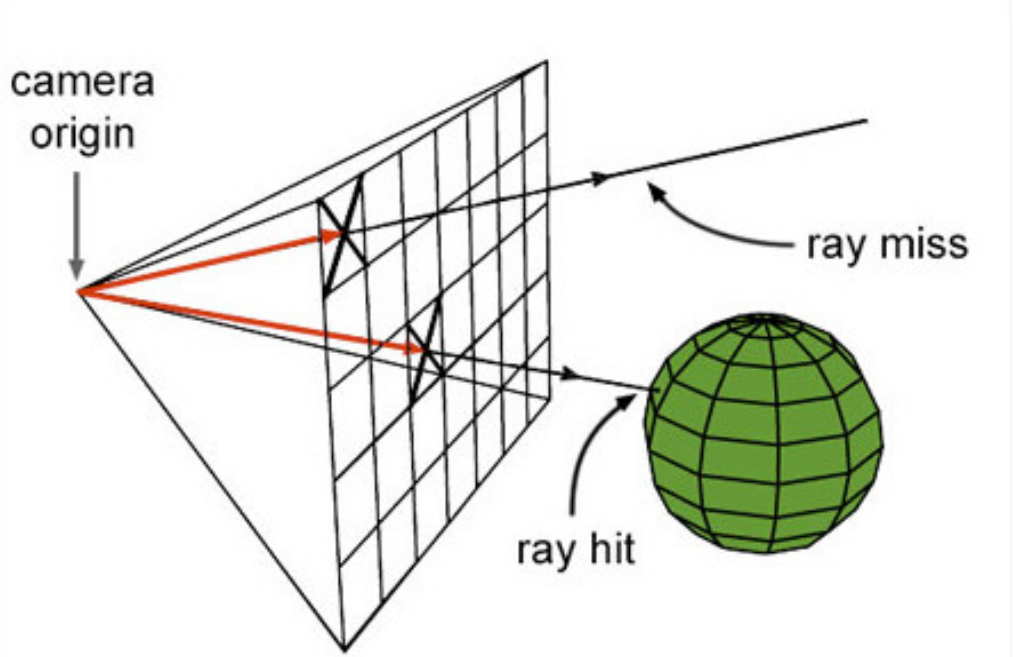
Sommaire

Rappels

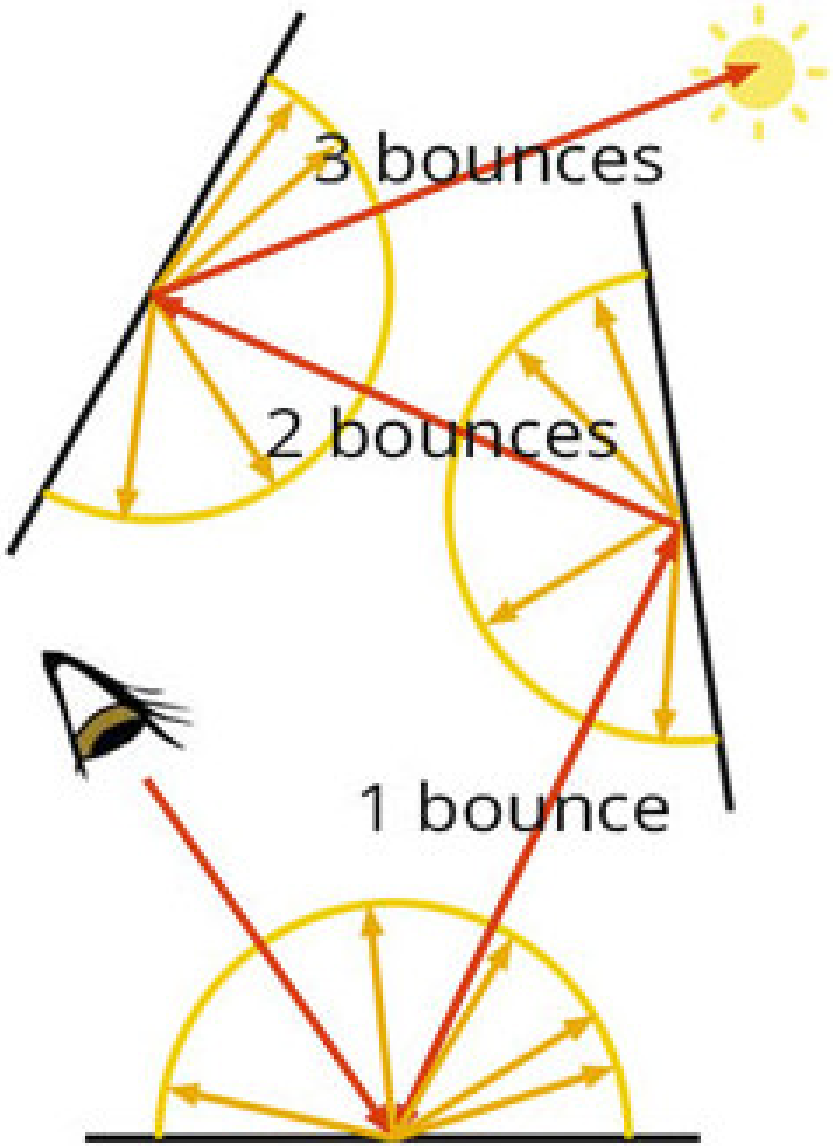
Techniques de rendu : Ray tracing



Lancer de rayons

- Lent
- Simulation
- Rendus photo-réaliste

Techniques de rendu : Ray tracing



Lancer de rayons

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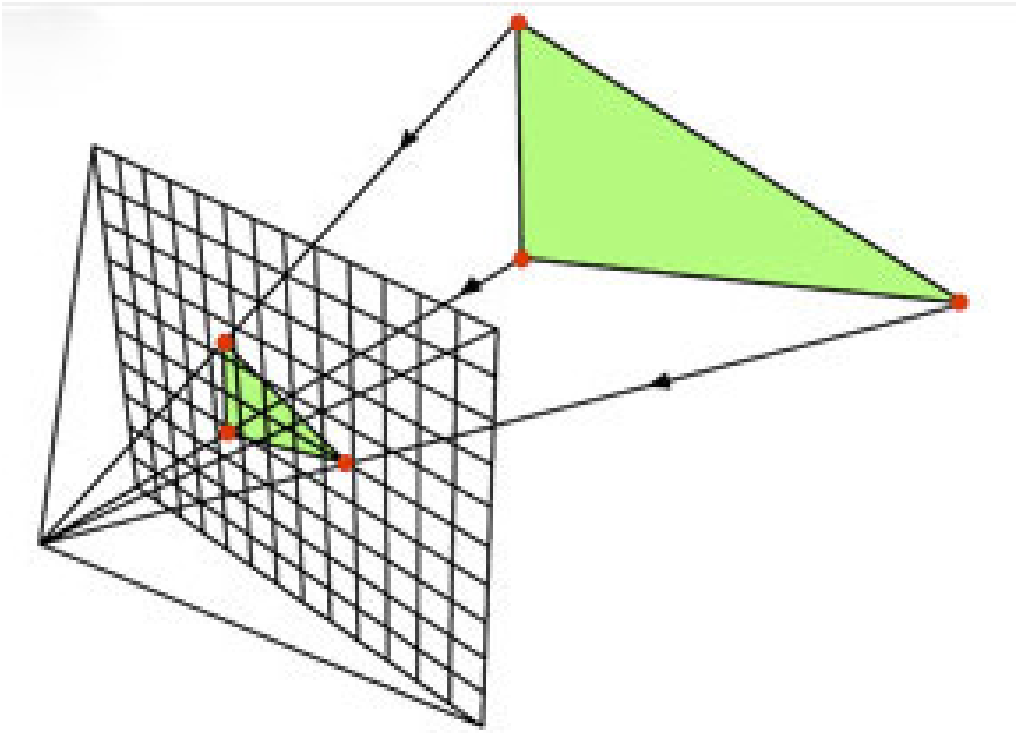
Techniques de rendu : Rasterization



Rastérisation

- Rapide
- Approximatif
- Temps réel

Caméra : Modèle-Vue-Projection

Définition

Trois matrices de transformation (Mat4x4) pour représenter un objet 3D à travers une caméra :

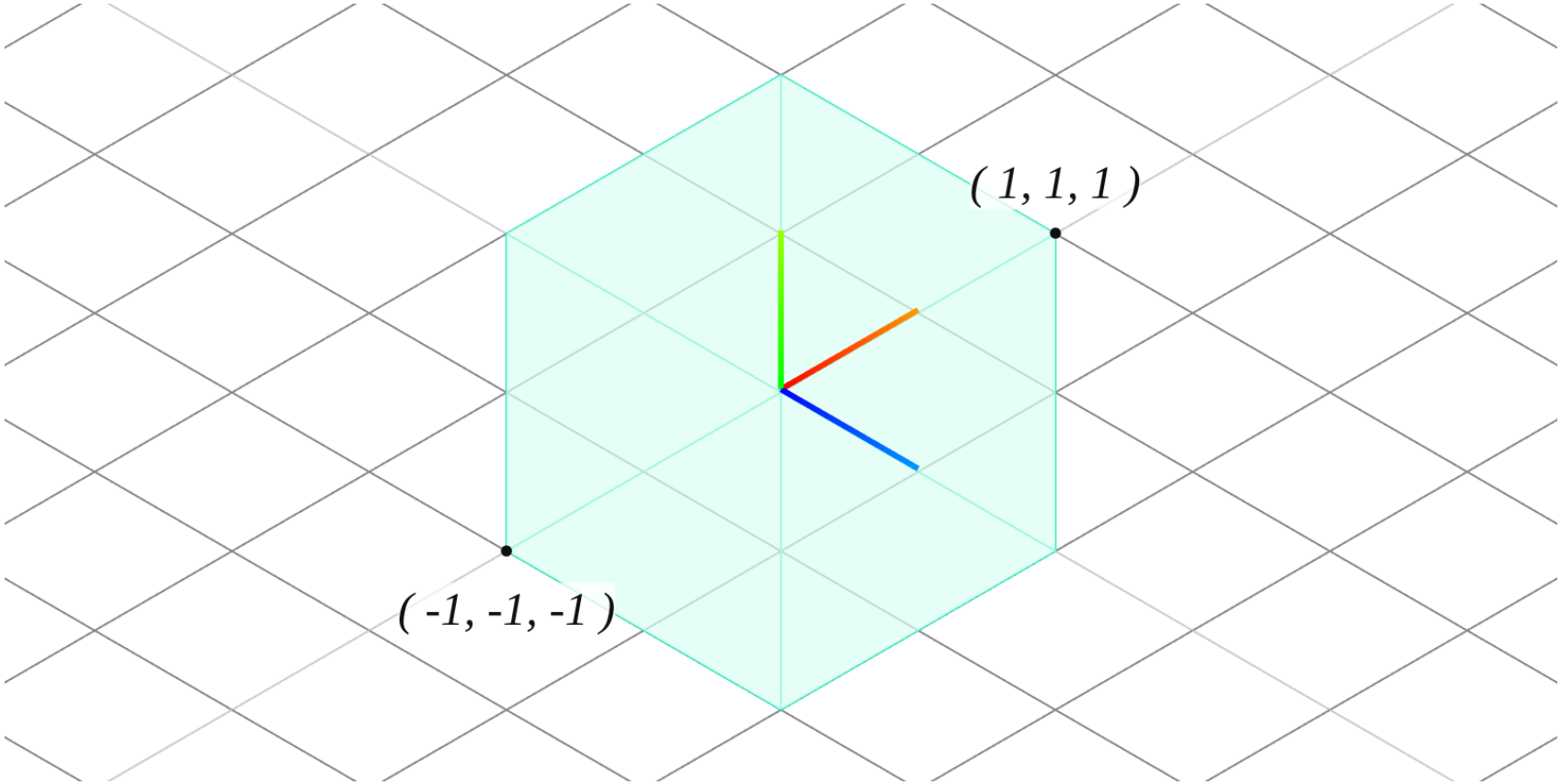
- Modèle
- Vue
- Projection

On écrit Modèle - Vue - Projection, mais c'est utilisé dans l'autre sens :

$$v_{\text{clip}} = P.V.M.v_{\text{model}}$$

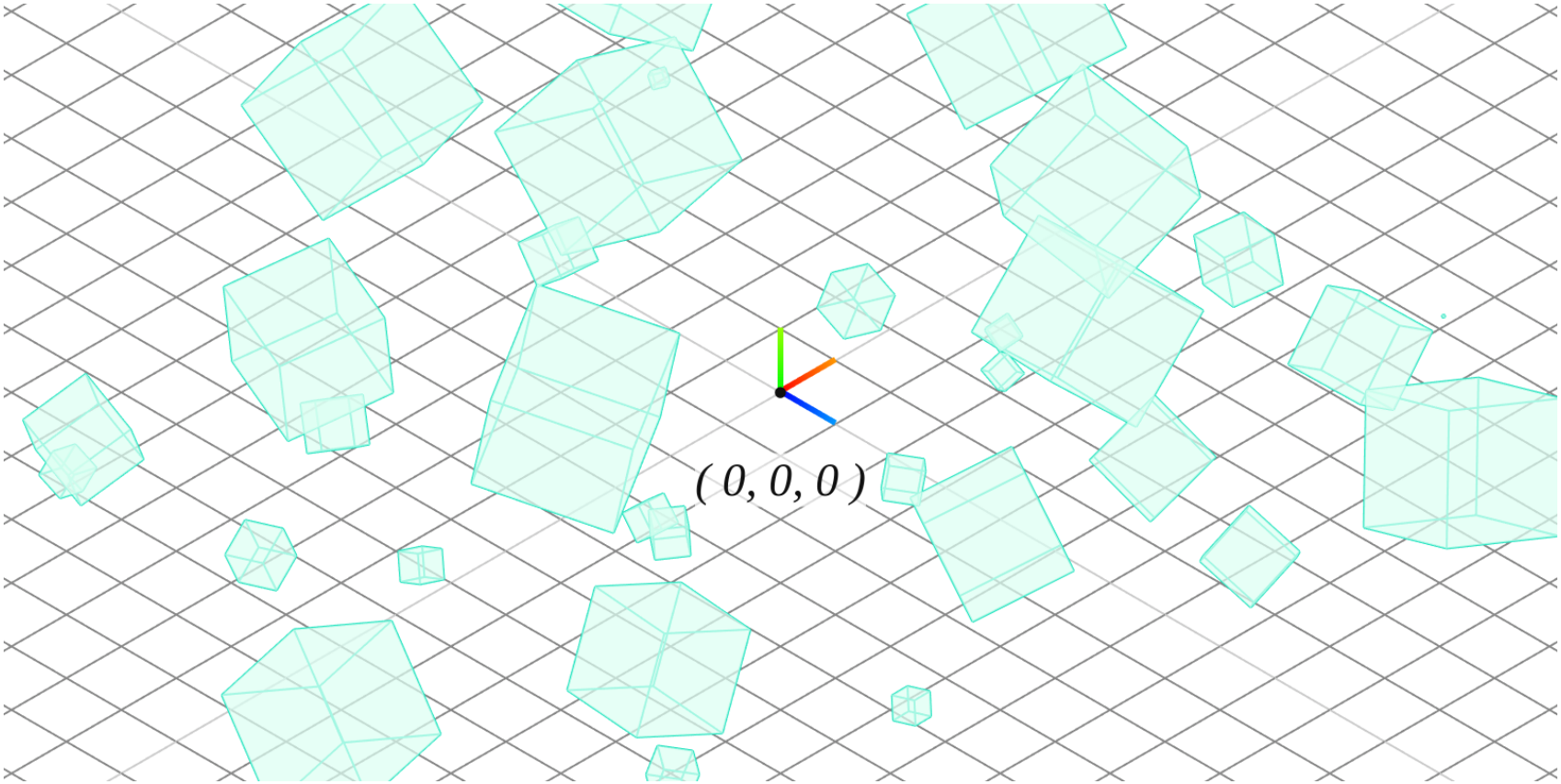
Caméra : Modèle

$$v_{\text{world}} = M.v_{\text{model}}$$



Caméra : Modèle

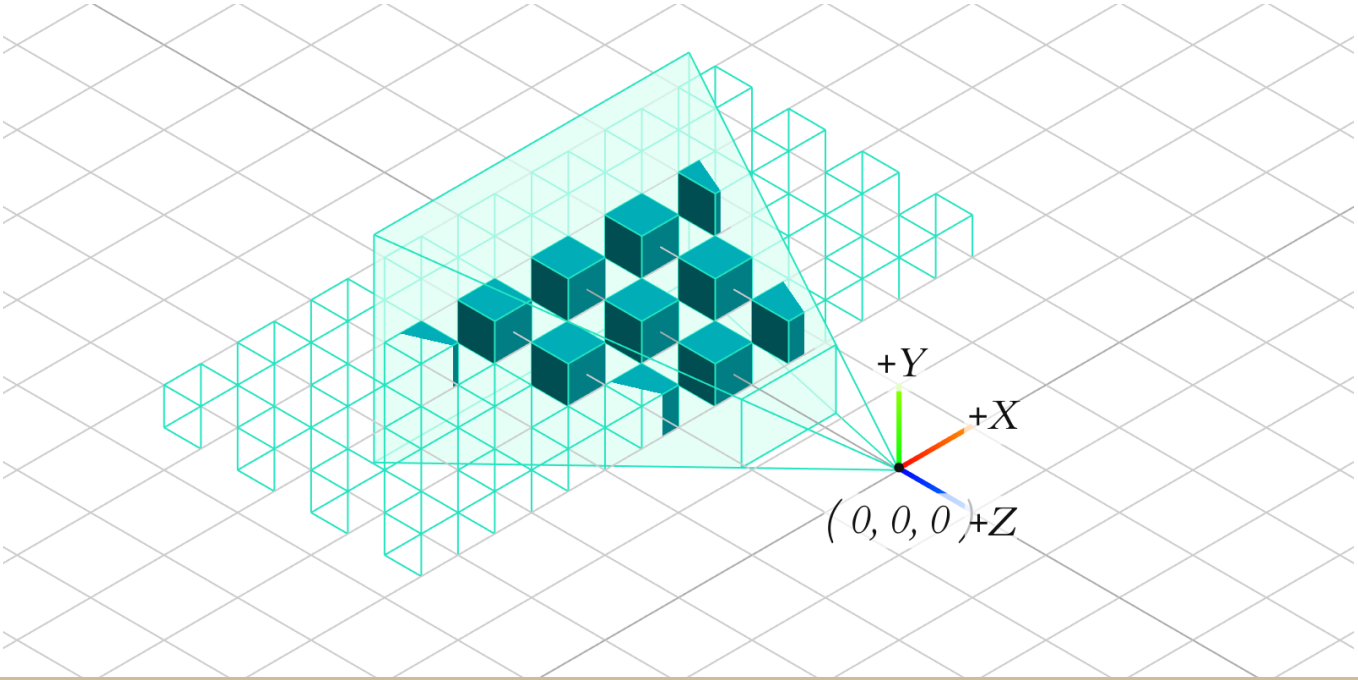
$$v_{\text{world}} = M.v_{\text{model}}$$



Caméra : Vue

Matrice Caméra C

- Position p
- Direction (Eye) t => Vecteur $forward$
- Définition de la direction de haute => Vecteur up
- $V = C^{-1}$



Caméra : Vue

Matrice Caméra C

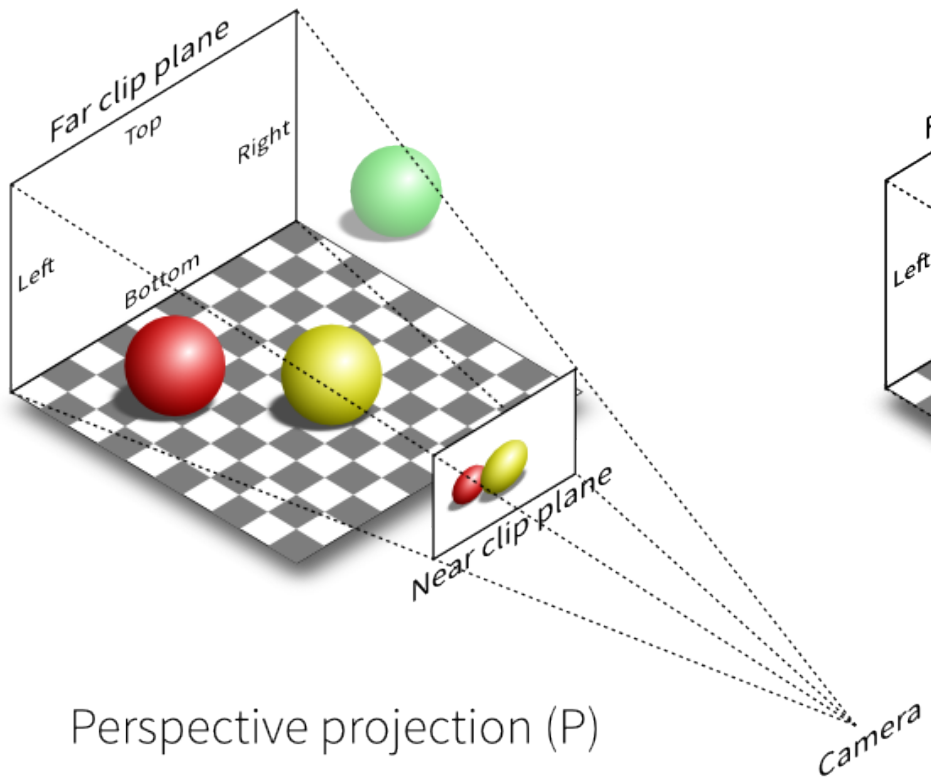
- Position p
- Direction (Eye) t => Vecteur $forward$
- Définition de la direction de haute => Vecteur up
- $V = C^{-1}$

$$v_{\text{camera}} = V.v_{\text{world}}$$

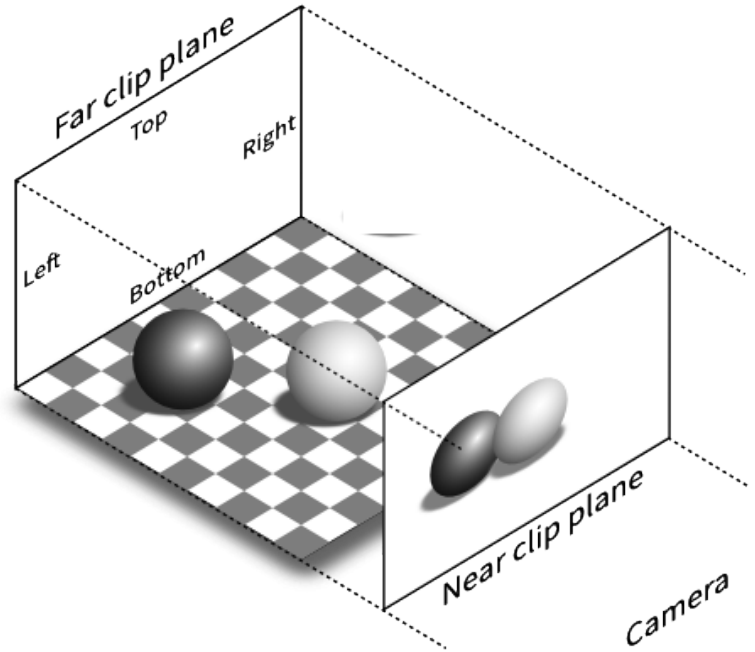
Caméra : Projection

Deux type de projection

- Perspective (fov, ar, near, far)
- Orthographique (left, right, top, down, near, far)

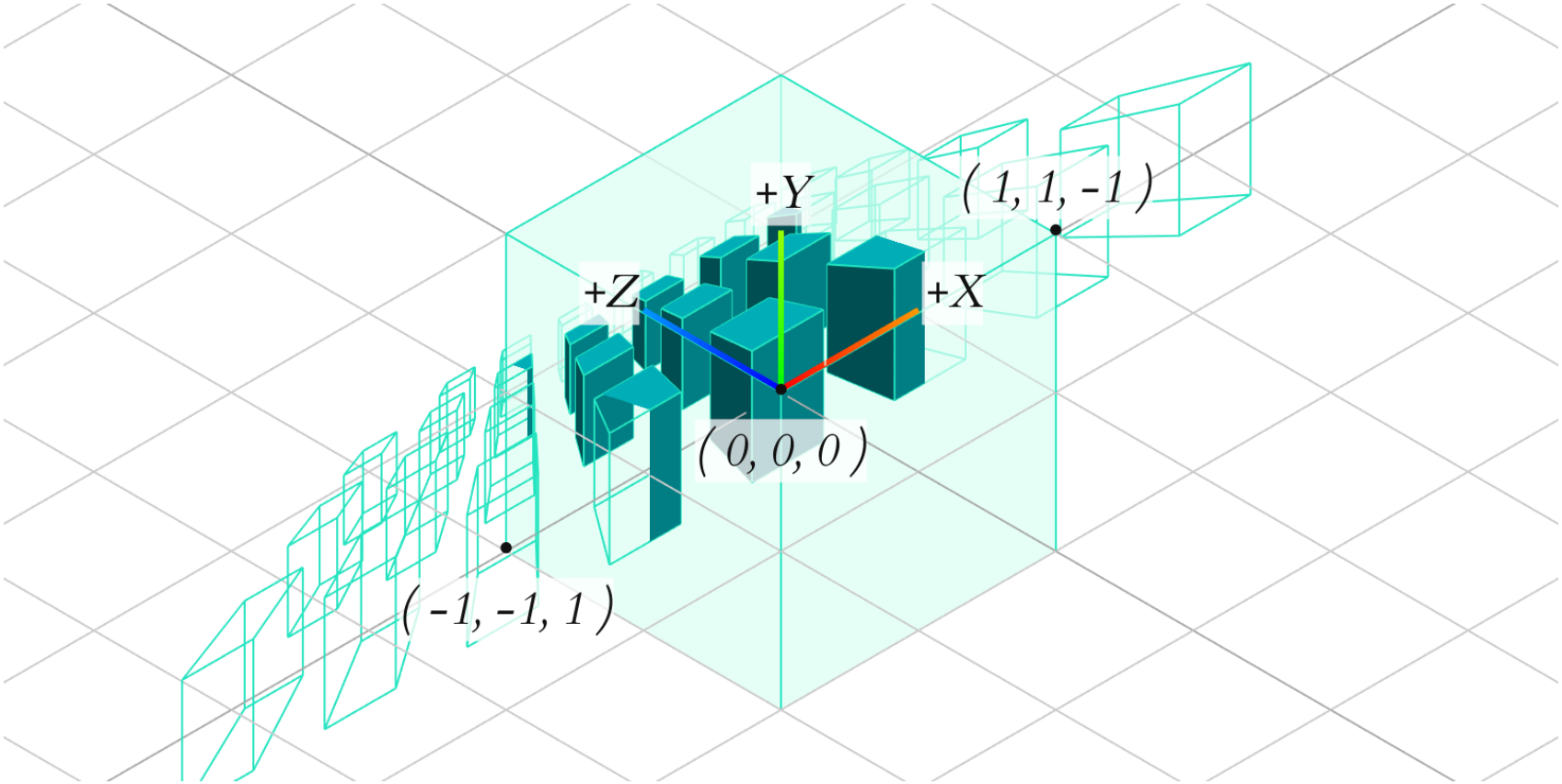


Perspective projection (P)



Orthographic projection (O)

Caméra : Projection



OpenGL : MVP

- OpenGL stocke un *state* de matrices (A ne plus utiliser). Gérer soi-même ses matrices ou utiliser des librairies, par exemple :
  - OpenGL Mathematics (ou GLM)

```
#include <glm/glm.hpp>
#include <glm/gtc/matrix_transform.hpp>
#include <glm/gtx/transform.hpp>
#include <glm/gtc/type_ptr.hpp>

// View
glm::mat4 view = glm::lookAt(position, target, upVector);
// Projection
glm::mat4 projection;
projection = glm::perspective(fov_in_rads, width/height,
near, far);
// glm::radians(degree) to convert

// Translation
glm::mat4 translation = glm::mat4(1.0f);// Identity
translation = glm::translate(translation, glm::vec3(-0.5f, -0.5f, 0.0f));
// Scaling
glm::mat4 scaling = glm::scale(2.0f, 2.0f, 2.0f);
// Rotation (Euler angles)
glm::vec3 rotationAxis(1.0f, 0.0f, 0.0f);
glm::mat4 rotation = glm::rotate(angle_in_degree, rotationAxis);
// Model
glm::mat4 model = translation * rotation * scaling;
```

OpenGL : Vertex Buffer Object

- Création (Attributs de sommet)

```
GLuint vboId;
float* vertices = new float[vCount*3]; // create vertex array
GLuint dataSize = sizeof(float) * vCount * 3;
glGenBuffers(1, &vboId);
glBindBuffer(GL_ARRAY_BUFFER, vboId);
glBufferData(GL_ARRAY_BUFFER, dataSize, vertices, GL_STATIC_DRAW);

// it is safe to delete after copying data to VBO
delete[] vertices;
```

- Création (Indices)

```
GLuint vboId2;
int* indices = new int[vCount*3]; // create vertex array
// ... populates array
GLuint dataSize = sizeof(int) * vCount * 3;
glGenBuffers(1, &vboId2);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, vboId2);
glBufferData(GL_ELEMENT_ARRAY_BUFFER, dataSize, indices, GL_STATIC_DRAW);
```

OpenGL : Vertex Buffer Object

- Utilisation

```
// bind VBOs for vertex array and index array
glBindBuffer(GL_ARRAY_BUFFER, vboId1);              // for vertex coordinates
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, vboId2);      // for indices
// OpenGL 2.0 with custom shader
glEnableVertexAttribArray(attribVertex);            // activate vertex position
     array (explanation of attribVertex later)
// set vertex arrays with generic API
glVertexAttribPointer(attribVertex, 3, GL_FLOAT, false, 0, 0);
// draw 6 faces using offset of index array
glDrawElements(GL_TRIANGLES, 36, GL_UNSIGNED_INT, 0);
// bind with 0, so, switch back to normal pointer operation
glBindBuffer(GL_ARRAY_BUFFER, 0);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, 0);
```

Usages

- Attributs par sommet (position, normal, couleur, ...)
- Listes d'éléments indexés
- Utilisable avec des *structs*

OpenGL : Vertex Array Object

- Création (Attributs de sommet)

```
GLuint vaoID;
glGenVertexArrays(1, &vaoID); // Create VAO
glBindVertexArray(vaoID); // Bind VAO

// ... Use VBO
glGenBuffers(1, vboID); // Generate VBO
glBindBuffer(GL_ARRAY_BUFFER, vboID[0]); // Lier le VBO
glBufferData(GL_ARRAY_BUFFER, 18 * sizeof(GLfloat), vertices, GL_STATIC_DRAW);
// Assign vertex attribute pointer
glVertexAttribPointer((GLuint)0, 3, GL_FLOAT, GL_FALSE, 0, 0);

glEnableVertexAttribArray(0); // Unbind VAO
glBindVertexArray(0); // Unbind VBO
```

- Création (Indices)

```
GLuint vboId2;
int* indices = new int[vCount*3]; // create vertex array
// ... populates array
GLuint dataSize = sizeof(int) * vCount * 3;
glGenBuffers(1, &vboId2);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, vboId2);
glBufferData(GL_ELEMENT_ARRAY_BUFFER, dataSize, indices, GL_STATIC_DRAW);
```

OpenGL : Vertex Array Object

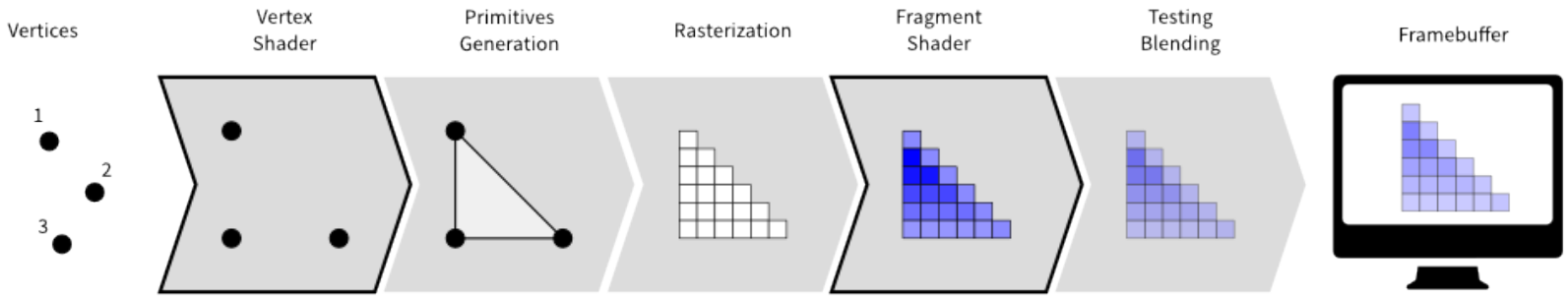
- Utilisation

```
glBindVertexArray(vaoID); // Bind VAO
// ... no more vertexAttribPointer here
glDrawArrays(GL_TRIANGLES, 0, 6); // Draw
glBindVertexArray(0); // Unbind VAO
```

Usages

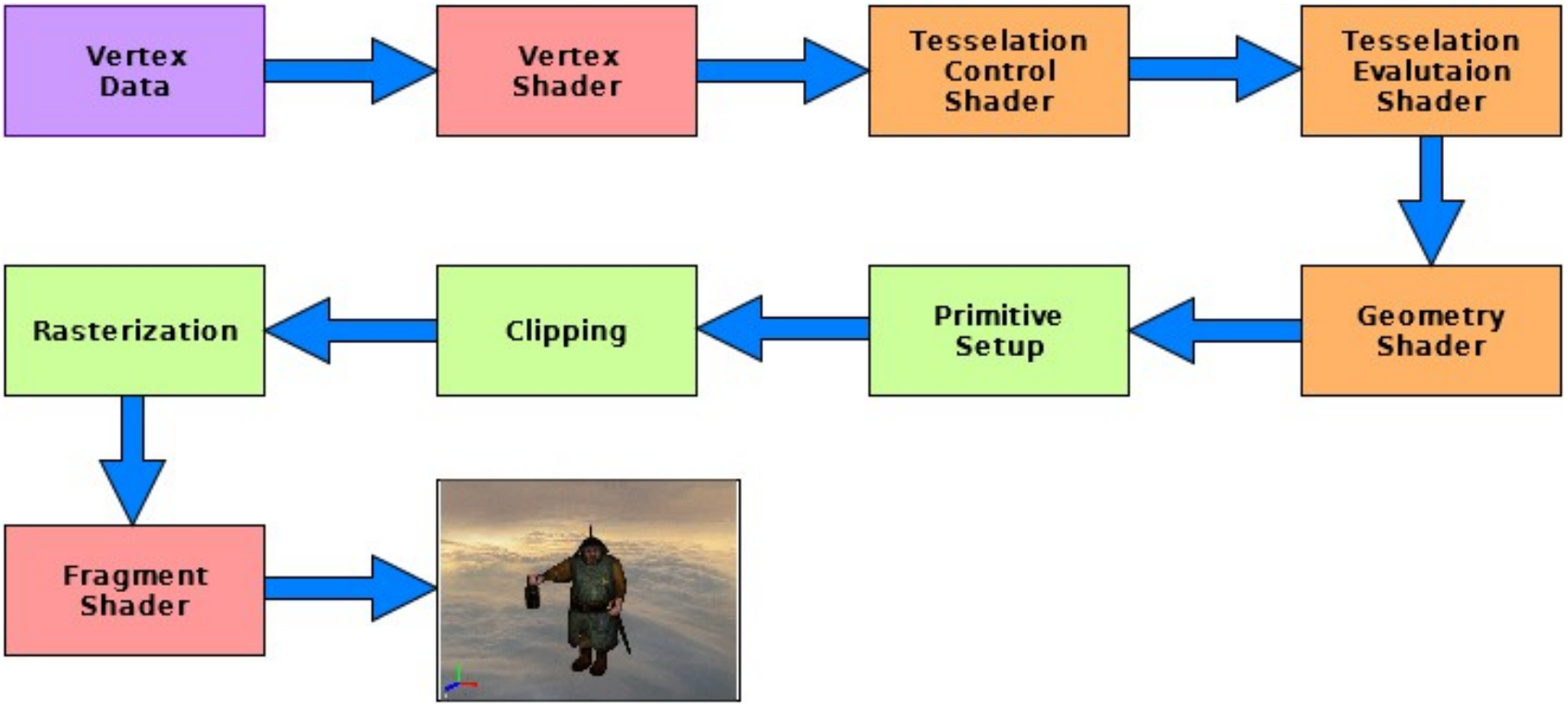
- Enregistrer des appels récurrents
- Réduire le temps d'exécution

Pipeline OpenGL



https://www.khronos.org/files/opengl46-quick-reference-card.pdf

Pipeline OpenGL



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Exemple de shader GLSL

Vertex shader

```
// Vertex attributes
//attribute vec3 a_position;// (deprecated)
//attribute vec3 a_normal; // (unused)
// OR (since OpenGL 3.0 / GLSL 1.3)
in vec3 a_position;
in vec3 a_normal;
// Uniforms
// Matrices, Material, etc
uniform mat4 u_projection, u_modelview;
// Textures
uniform sampler2D texture1;
// Interpolated values to transmit to fragment
     shaders
//varying vec3 v_worldVertexPosition;
out vec3 v_worldVertexPosition;
// Main program
void main(){
  vec4 vertPos4 = u_modelview * vec4(a_position,
       1.0);
  v_worldVertexPosition = vec3(vertPos4) /
      vertPos4.w;
//    vec3 rgb = texture(ourTexture, vertPos4.xy)
     ;
  gl_Position = u_Projection * vertPos4;
}
```

Fragment shader

```
precision mediump float;
// Recover interpolated values
varying vec3 v_worldVertexPosition;
// Uniforms
uniform float u_intensity;

void main() {
  gl_FragColor = u_Intensity * vec4(
       v_worldVertexPosition, 1.0);
}
```

OpenGL : Shader

- Création

```
GLuint fragmentshader = glCreateShader(GL_FRAGMENT_SHADER);

glShaderSource(fragmentshader, 1, (const GLchar**)&fragmentsource, 0);

glCompileShader(fragmentshader);

glGetShaderiv(fragmentshader, GL_COMPILE_STATUS, &IsCompiled_FS);
if (IsCompiled_FS == FALSE) {
   glGetShaderiv(fragmentshader, GL_INFO_LOG_LENGTH, &maxLength);

   /* The maxLength includes the NULL character */
   fragmentInfoLog = (char *)malloc(maxLength);

   glGetShaderInfoLog(fragmentshader, maxLength, &maxLength, fragmentInfoLog);

   /* Handle the error in an appropriate way such as displaying a message or
        writing to a log file. */
   /* In this simple program, we'll just leave */
   free(fragmentInfoLog);
   return;
}

/* If we reached this point it means the vertex and fragment shaders compiled and
      are syntax error free. */
```

OpenGL : Shader Program

- Création

```
// Create a shader program
GLuint shaderprogram = glCreateProgram();
/* Attach our shaders to our program */
glAttachShader(shaderprogram, vertexshader);
glAttachShader(shaderprogram, fragmentshader);
// Link programs (should show error of shaders)
glLinkProgram(shaderprogram);
// Show link status
glGetProgramiv(shaderprogram, GL_LINK_STATUS, (int *)&IsLinked);
if (IsLinked == FALSE) {
   GLint maxLength = 0;
   glGetProgramiv(shaderprogram, GL_INFO_LOG_LENGTH, &maxLength);
   char * spInfoLog =  new char[maxLength];
   glGetProgramInfoLog(shaderprogram, maxLength, &maxLength, spInfoLog);
   delete[] shaderProgramInfoLog;
   return;
}
// Now those shaders can be deleted after linking
glDeleteShader(vertexshader);
glDeleteShader(fragmentshader);
```

OpenGL : Shader Program

Utilisation

```
// Usage of program
glUseProgram(shaderprogram);
// .. use program to render something
glUseProgram(0);// Reset to clasic opengl
```

Attributs

```
// get location of attribute "a_Position in shader program"
GLint vertexAttrib = glGetAttributeLocation(shaderProgram, "a_position");
if (vertexAttrib != -1) {
    glBindBuffer(GL_ARRAY_BUFFER, &vboId1);
    // activate vertex position array
    glEnableVertexAttribArray(attribVertex);
    // bind attribute with vbo
    glVertexAttribPointer(attribVertex, 3, GL_FLOAT, false, 0, 0);
}
```

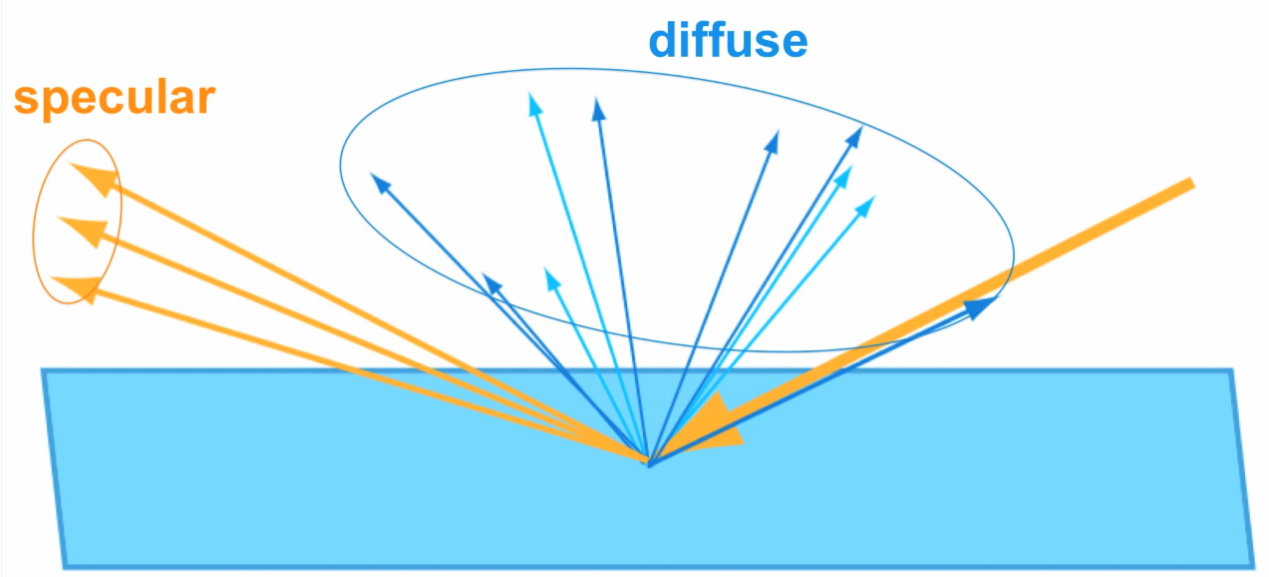
Uniformes

```
// Get location of attribute "a_Position in shader program"
GLint modelViewLocation = glGetUniformLocation(shaderProgram, "u_modelView");
if (modelViewLocation != -1) {
    // ... float modelViewMatrix[16];
    glUniformMatrix4fv(modelViewLocation, 1, GL_FALSE, modelViewMatrix);
}
glUniform1f(glGetUniformLocation(shaderProgram, "u_intensity"), 1.0f);
```

Modèle d'illumination direct Blinn-Phong

3 composantes

- Ambiant (Ambient)
- Diffusion (Diffuse)
- Spéculaire (Specular)



James F. Blinn

MODELS OF LIGHT REFLECTION FOR COMPUTER SYNTHESIZED PICTURES.

Proc. 4th annual conference on computer graphics and interactive techniques, 1977

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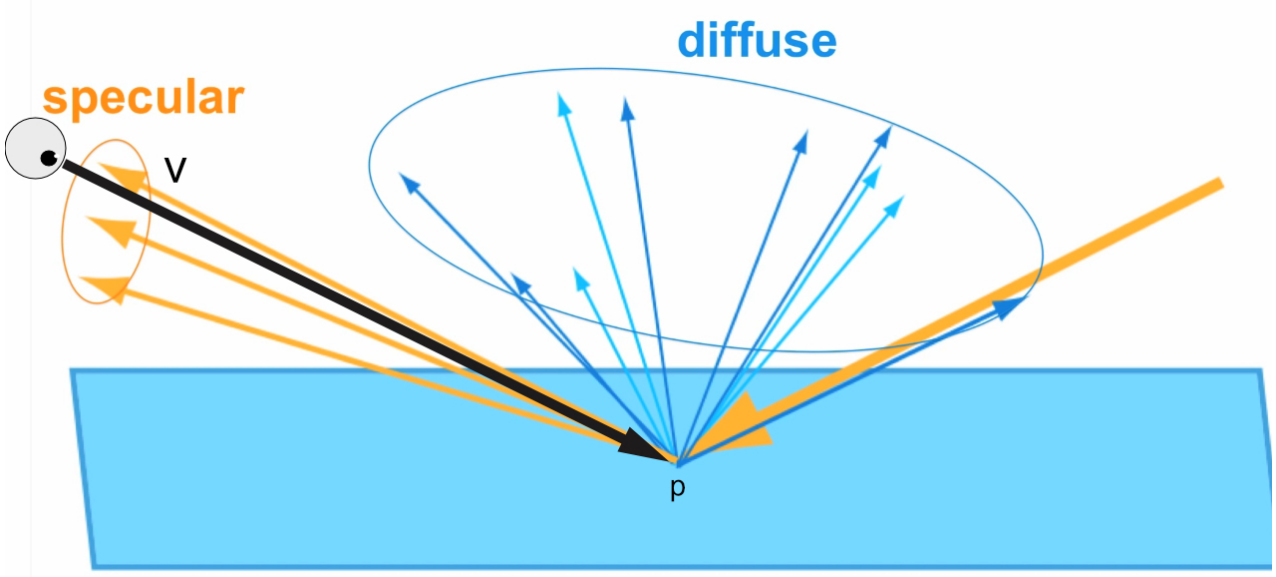

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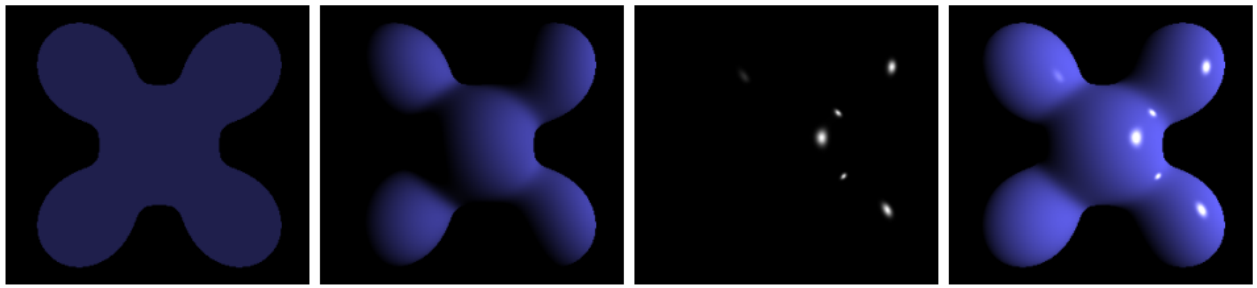

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Phong Shading

- Vertex Shader

```
#version 330 core
layout (location = 0) in vec3 aPos;
layout (location = 1) in vec3 aNormal;

out vec3 WorldFragPos;
out vec3 WorldNormal;

uniform mat4 model;
uniform mat4 view;
uniform mat4 projection;

void main()
{
    gl_Position = projection * view * model * vec4(aPos, 1.0);
    WorldFragPos = vec3(model * vec4(aPos, 1.0));
    // Normal Matrix
    WorldNormal = mat3(transpose(inverse(model))) * aNormal;
}
```

Phong Shading

- Fragment Shader

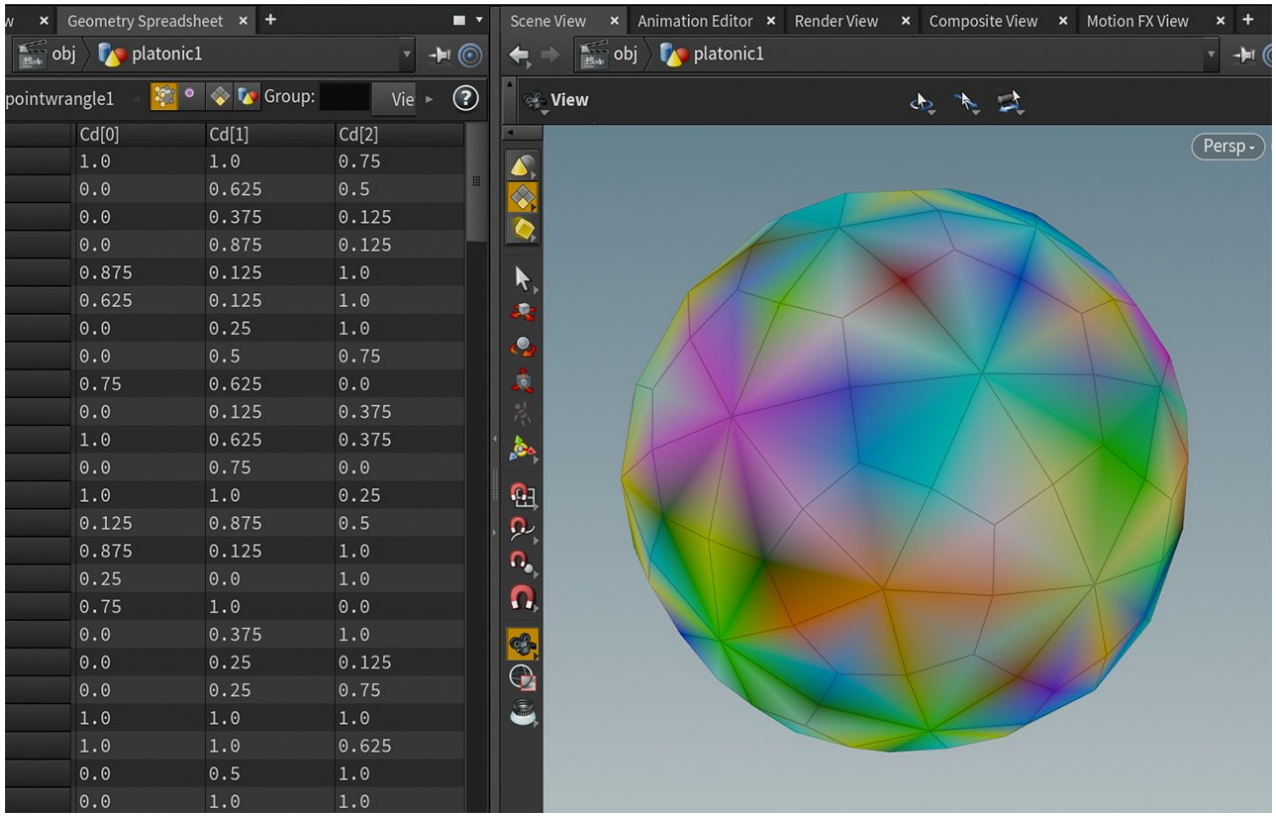
```
// Fragment shader:
// ================
#version 330 core
out vec4 FragColor;

in vec3 WorldFragPos;
in vec3 WorldNormal;

uniform vec3 lightPos;
uniform vec3 viewPos;

uniform vec3 lightColor;
uniform vec3 objectColor;
```

Phong Shading

```
void main()
{
    // ambient
    float ambientStrength = 0.1;
    vec3 ambient = ambientStrength * lightColor;

     // diffuse
    vec3 norm = normalize(WorldNormal);
    vec3 lightDir = normalize(lightPos - WorldFragPos);
    float diff = max(dot(norm, lightDir), 0.0);
    vec3 diffuse = diff * lightColor;

    // specular
    float specularStrength = 0.5;
    vec3 viewDir = normalize(viewPos - WorldPos);
    vec3 reflectDir = reflect(-lightDir, norm);
    float spec = pow(max(dot(viewDir, reflectDir), 0.0), 32);
    vec3 specular = specularStrength * spec * lightColor;

    vec3 result = (ambient + diffuse + specular) * objectColor;
    FragColor = vec4(result, 1.0);
}
```

Texture Mapping

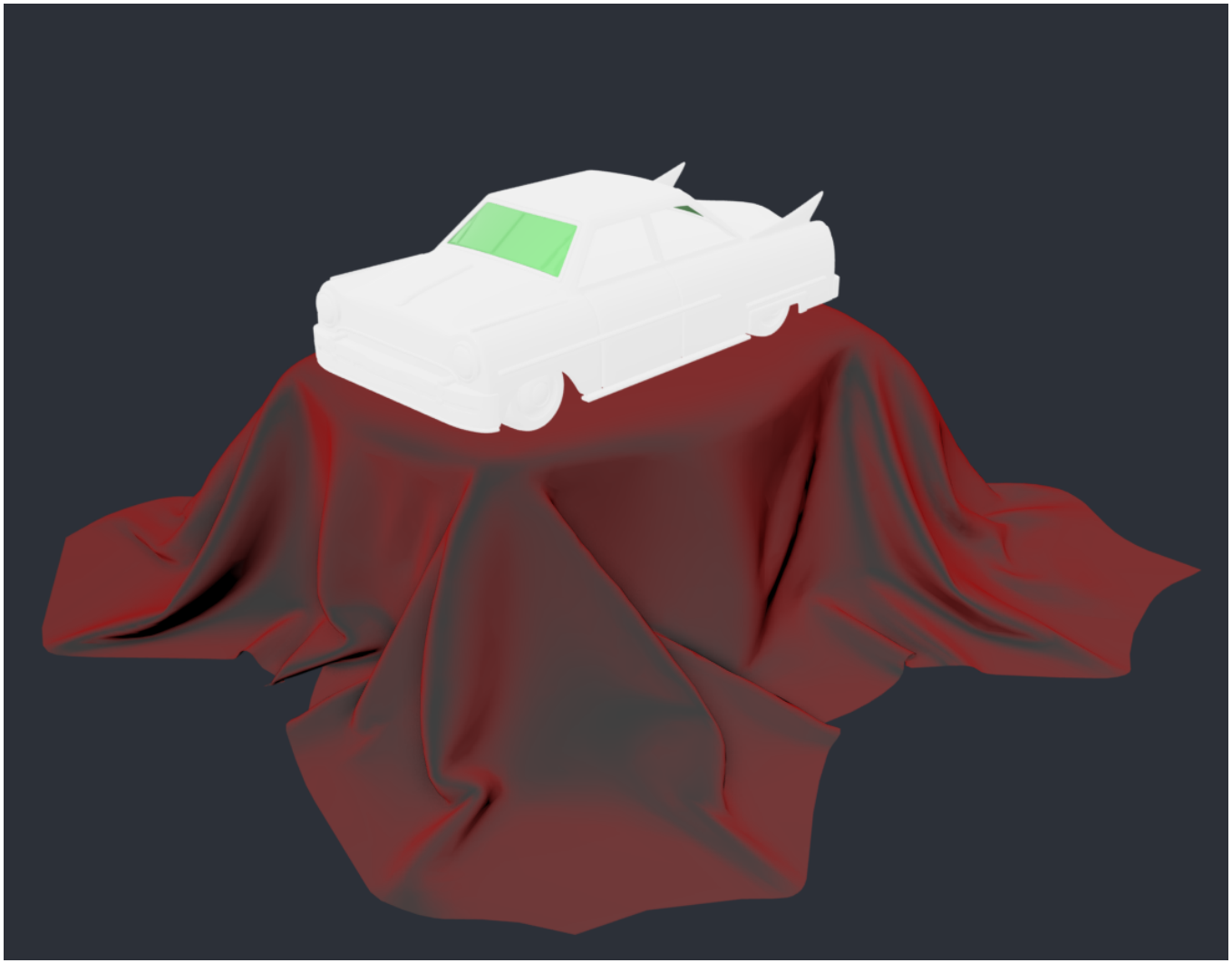
Problématique



Colorisation d'un modèle 3D

- Processus de colorisation long
- Demande une densité de sommets exhorbitante

Problématique

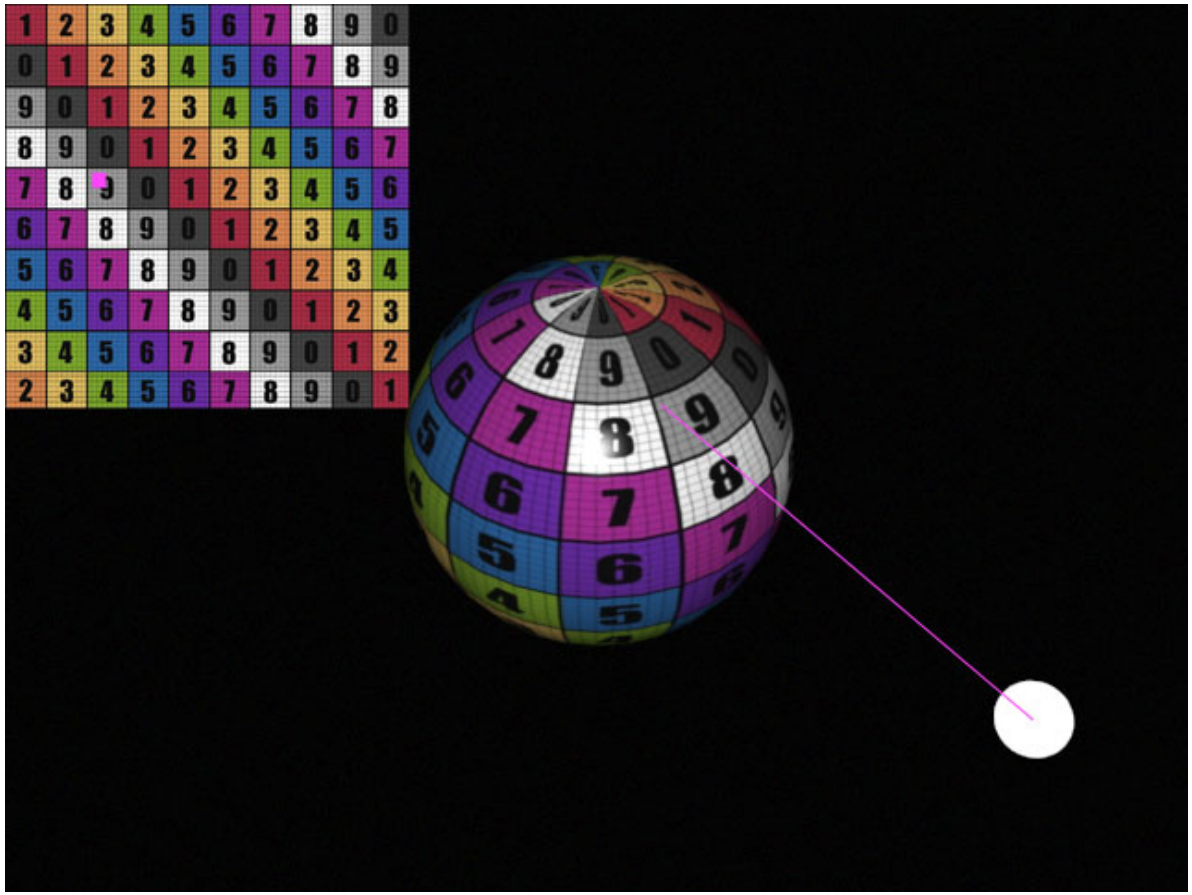


Problématique

Placage de texture

Définition

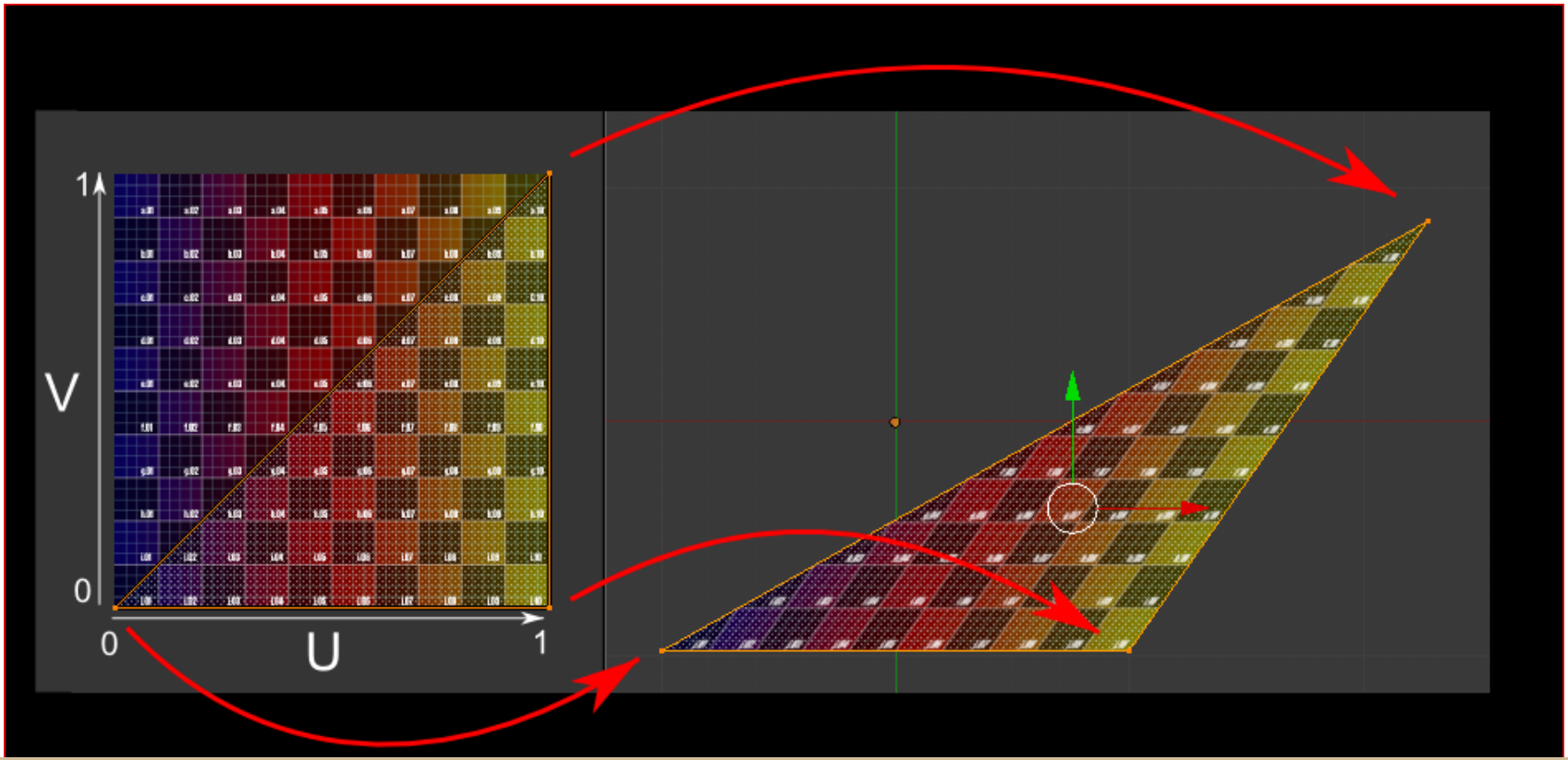
Application d'une image 1D, 2D, 3D sur des primitives géométries
Un pixel d'une texture est appelé *texel*



Coordonnées de texture

Nouvel attribut de sommet 3D

- Texture 2D : UV (ou ST)
- Texture 3D : UVW (ou STR)



Création d'une texture

- Assignation des coordonnées de texture aux points 3D
- Spécification d'une texture
  - Créer une unité de texture en GPU
  - Charger une image sur le GPU
  - Activer le plaquage
  - Paramétriser la texture (wrapping, filtering)

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Règles à savoir (en OpenGL)

- Les images en puissance de 2 (Po2) sont à privilégier
- Les dimensions des textures sont limitées (par le hardware)
- Le nombre de textures actives en parallèle est limité par OpenGL, le hardware ou le moteur

OpenGL : Assignation des coordonnées de texture

- Legacy OpenGL

```
// Create triangle
glBegin(GL_TRIANGLES);
glTexCoord2f(0.0f,0.0f);
glVertex3f(4.0f, 5.0f, 0.0f);
glTexCoord2f(1.0f,0.0f);
glVertex3f(10.0f, 5.0f, 0.0f);
glTexCoord2f(0.0f,1.0f);
glVertex3f(4.0f, 12.0f, 0.0f);
glEnd();
```

Ou bien

```
// Create buffer
float vertices = new float[vCount*3];
float* uvs = new float[vCount*2]; // create vertex array (set values)
glEnableClientState(GL_VERTEX_ARRAY);// activate texture coord array
glEnableClientState(GL_TEXTURE_COORD_ARRAY);// activate texture coord array
// ...
glTexCoordPointer(2/*numberOfCoordinates*/, GL_FLOAT, 0/*stride*/, uvs);
glVertexPointer(3, GL_FLOAT, 0, glVertexPointer);
glDrawArrays(GL_TRIANGLES, 0, vCount);
glDisableClientState(GL_VERTEX_ARRAY);
glDisableClientState(GL_TEXTURE_COORD_ARRAY_EXT);
```

OpenGL : Assignation des coordonnées de texture

- Modern OpenGL

```
// Create data
float* uvs = new float[vCount*2]; // create uv array

// Create VBO
GLuint dataSize = sizeof(float) * vCount * 2;
glGenBuffers(1, &vboId);
glBindBuffer(GL_ARRAY_BUFFER, vboId);
glBufferData(GL_ARRAY_BUFFER, dataSize, uvs, GL_STATIC_DRAW);
delete[] uvs;
// ...
// Use VBO as shader attribute
GLuint shaderProgram; // shader index
GLuint vertexAttrib = glGetAttribLocation(shaderProgram, "aUV");// cache this!
glBindBuffer(GL_ARRAY_BUFFER, vboId);
glVertexAttribPointer(vertexAttrib, 2, GL_FLOAT, GL_FALSE, 0, 0);
```

OpenGL : Spécification d'une texture

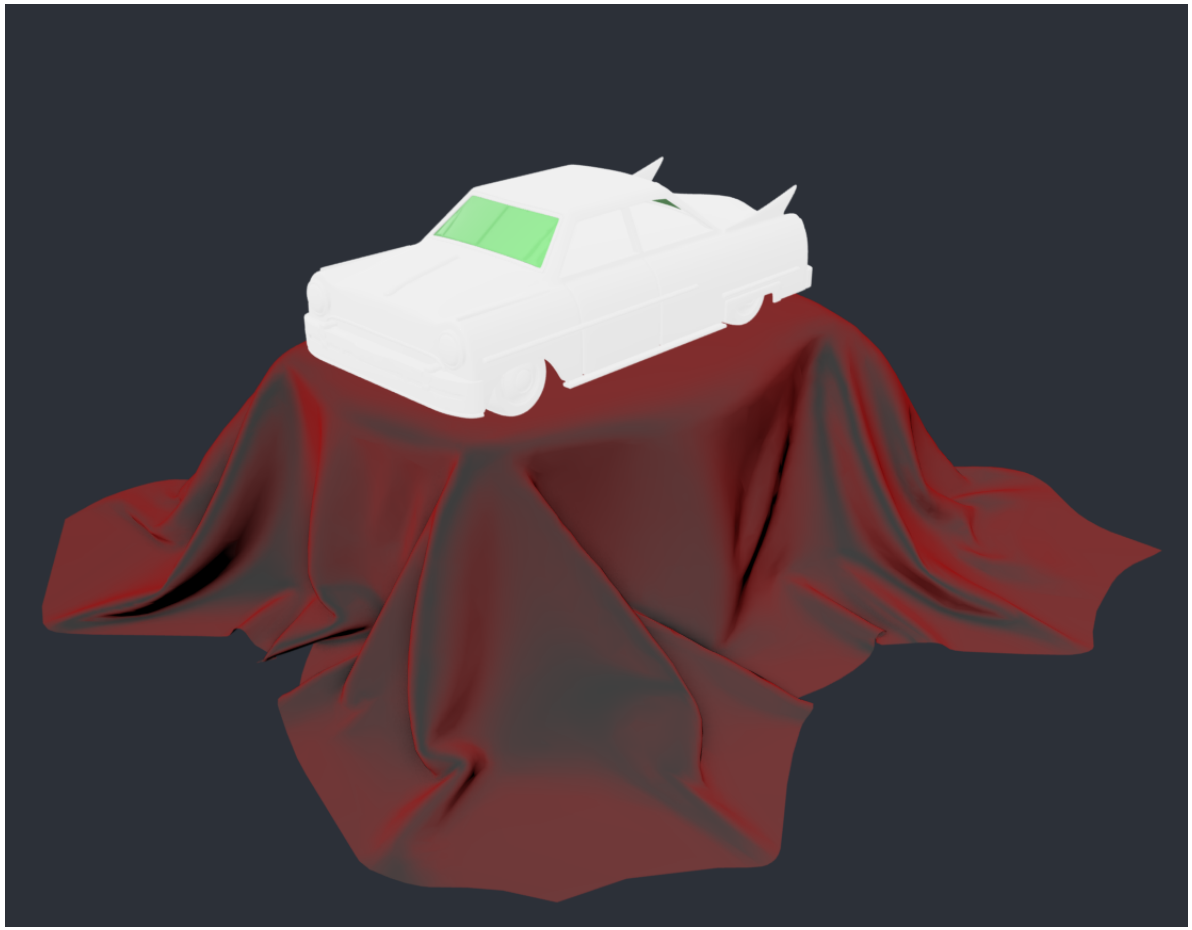
- Création & Chargement

```
unsigned int texture;
glGenTextures(1, &texture);
glBindTexture(GL_TEXTURE_2D, texture);
// load and generate the texture
int width, height, nrChannels;
unsigned char *data = stbi_load("container.jpg", &width, &height, &nrChannels, 0)
    ;
if (data) {
    glTexImage2D(GL_TEXTURE_2D, 0, GL_RGB, width, height, 0, GL_RGB,
        GL_UNSIGNED_BYTE, data);
    glGenerateMipmap(GL_TEXTURE_2D);
} else {
    std::cout << "Failed to load texture" << std::endl;
}
stbi_image_free(data);
```

- Suppression

```
glDeleteTexture(1, &texture);
```

Votre réaction Je vois rien



Rien ne s'affiche ! Car nous n'avons pas paramétriser notre texture.

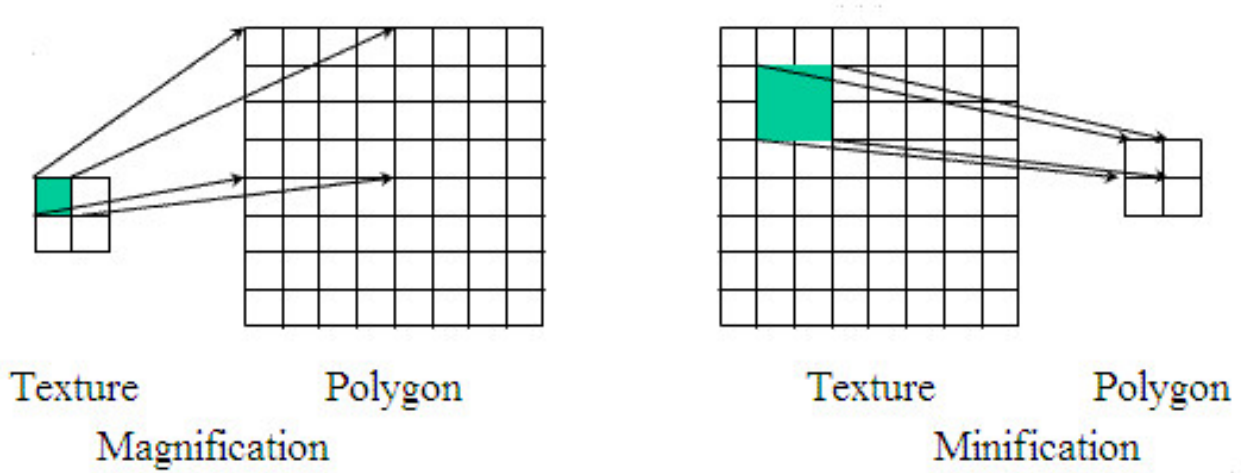
Paramétrisation d'une texture

- Mode de filtrage (Filtering)
  - Réduction, agrandissement
  - Mip-mapping
- Mode de bouclage (Wraping)
  - Répéter, tronquer
- Fonctions de textures (Blending)
  - Only for good ol' OpenGL

Filtrage

Réduction/Agradissement (Minify/Magnify)

Les textures et les objets texturés ont rarement la même taille (en pixel)

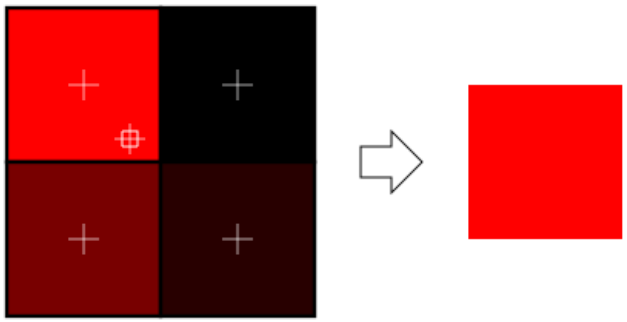


- GL_TEXTURE_MAG_FILTER
- GL_TEXTURE_MIN_FILTER

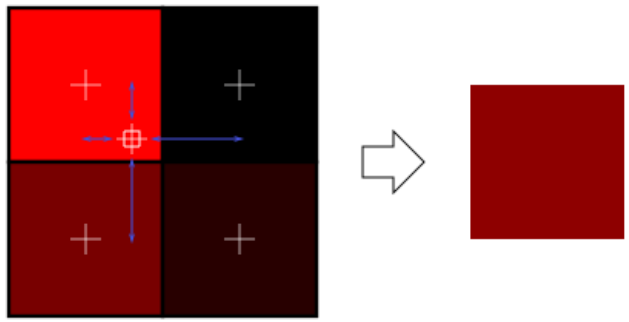
OpenGL : Paramétrisation du filtrage

- OpenGL

```
glBindTexture(GL_TEXTURE_2D, texture);
glTexParameteri(target, type, mode);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
```



Au plus proche



Interpolation linéaire

- Il existe également le filtrage anisotrope

Filtrage : Résultats

GL_NEAREST

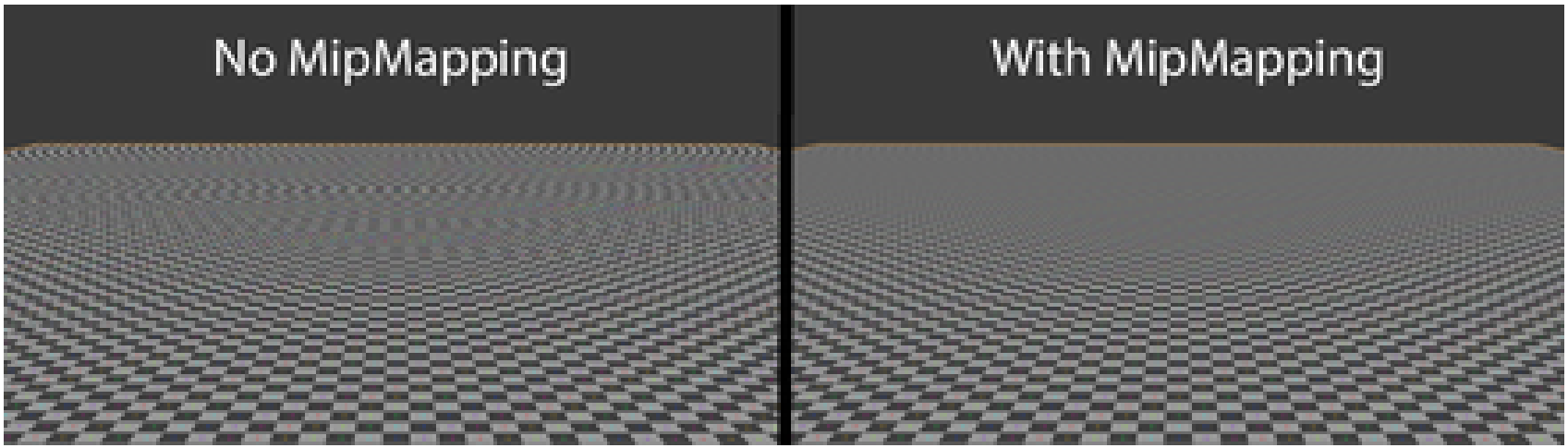
GL_LINEAR

(From learnopengl.com)

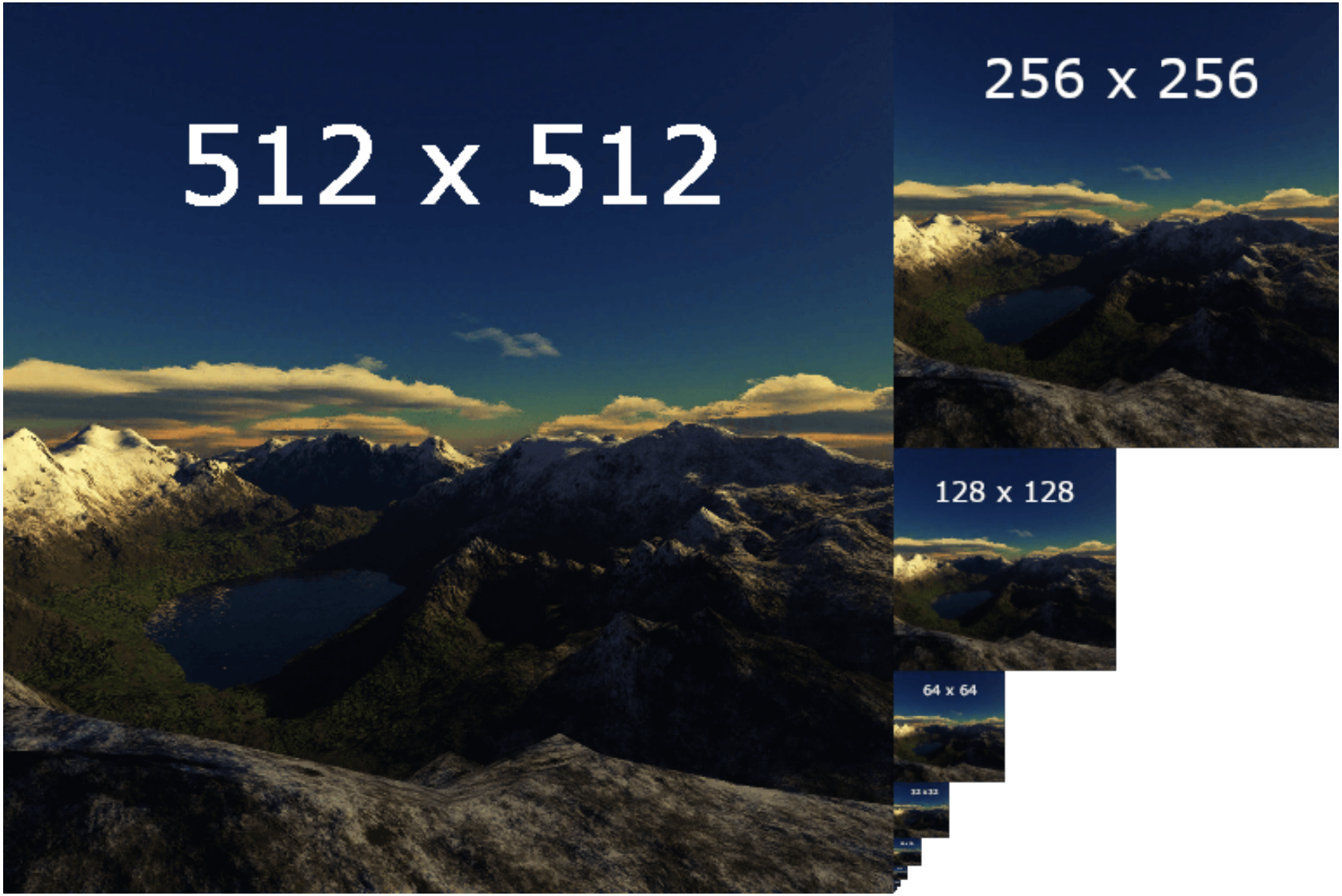
Filtrage

Mip-mapping

- Technique consistant à précalculer plusieurs versions réduite d'une même texture
- Adapte le niveau de détails en fonction de la distance



OpenGL : Mip-Mapping



OpenGL : Mip-Mapping

- Manuelle

```
glBindTexture(GL_TEXTURE_2D, texture);
glTexImage2D(GL_TEXTURE_2D, 0/* level */,
GL_RGB /* components*/, width, height, border, format, type, imgBase);
glTexImage2D(GL_TEXTURE_2D, 1/* level */,
GL_RGB /* components*/, width/2, height/2, border, format, type, imgDividedBy2);
glTexImage2D(GL_TEXTURE_2D, 2/* level */,
GL_RGB /* components*/, width/4, height/4, border, format, type, imgDividedBy4);
```

- Automatique

```
// GLU dependencies
glBindTexture(GL_TEXTURE_2D, texture);
gluBuild2DMipmaps(GL_TEXTURE_2D, GL_RGB, width, height, format, type, imgBase);
```

- Utilisation du *Mip-Map*

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR_MIPMAP_LINEAR);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR_MIPMAP_LINEAR);
```

Mode de bouclage (Wrap)

Définition

Fournit un comportement lorsque les coordonnées de texture sortent de l'intervalle $[0, 1]$

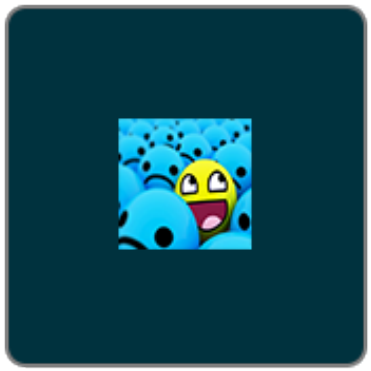
- Répéter (Repeat)
- Tronquer (Clamp)

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, mode);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, mode);
```

GL_REPEAT

GL_MIRRORED_REPEAT

GL_CLAMP_TO_EDGE



GL_CLAMP_TO_BORDER

OpenGL : Utilisation des textures dans les shaders

- Assigner une texture dans un shader

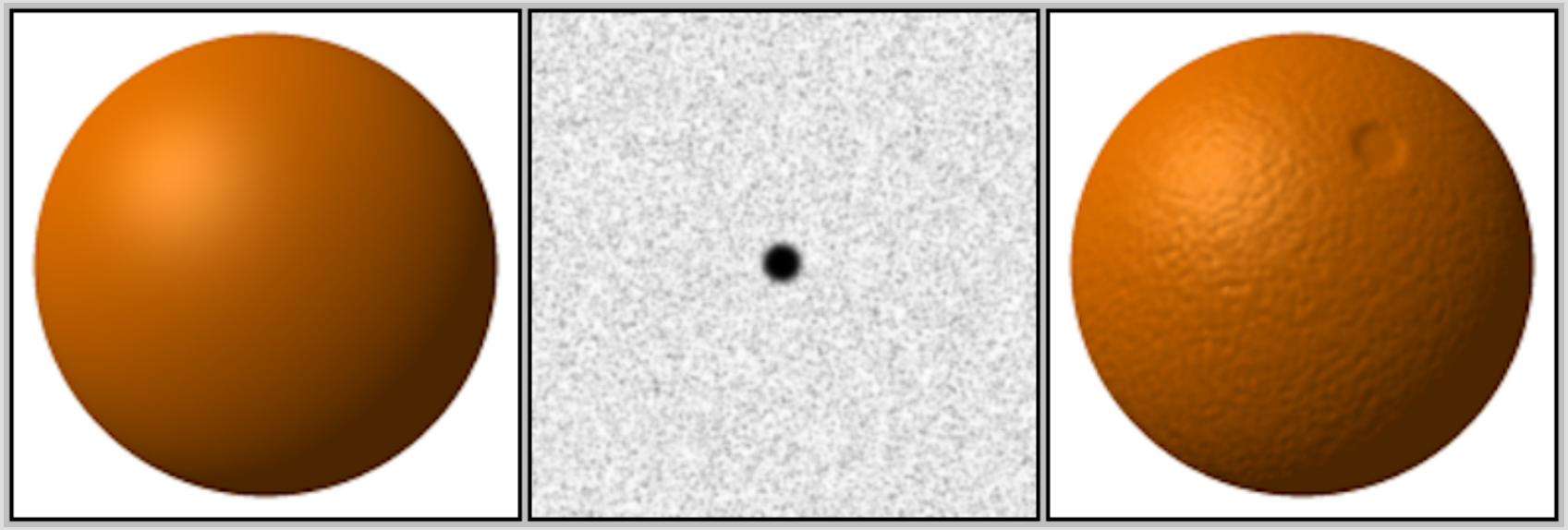
```
// activate usage of 2D textures
glEnable(GL_TEXTURE_2D);
// activate texture (limited to 32 or less depending on machine)
int indexActiveTexture = 0;// 0 to 31
// bind texture as Texture 0
glBindTexture(GL_TEXTURE_2D, texture);
glActiveTexture(GL_TEXTURE0 + indexActiveTexture);
// set used active texture (Modern OpenGL)
glUniform1i(glGetUniformLocation(shaderProgram, "texture"), indexActiveTexture);
```

Bump Mapping

Bump Mapping

Définition

- Simule les détails dans la géométrie sans ajouter de données à cette dernière
- Interaction avec la lumière (rugosité)
- Perturbation de la normale pour le calcul des lumières

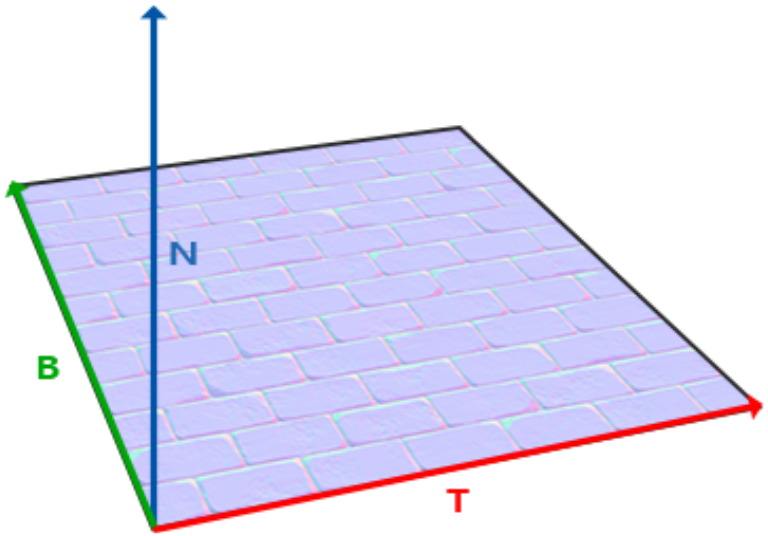


Bump Mapping : mathématiques

Théorie de la perturbation des normales

Modification de la position de la surface en ajoutant une petite perturbation (bump function) dans la direction de la normale :

$$P'(u,v) = P(u,v) + B(u,v) * N$$



- P point de la surface
- P_u tangente de P dans la direction u
- P_v tangente de P dans la direction v
- NNormale au point P
- $B(u,v)$ est un fonction

Théorie de la perturbation des normales

On ne modifie pas la position du sommet P, mais la normale interpolée par

- Pentes
  - $d_u = \frac{\Delta z}{\Delta x} = \frac{s}{2}[h(i+1,j) - h(i-1,j)]$
  - $d_v = \frac{\Delta z}{\Delta y} = \frac{s}{2}[h(i,j+1) - h(i,j-1)]$

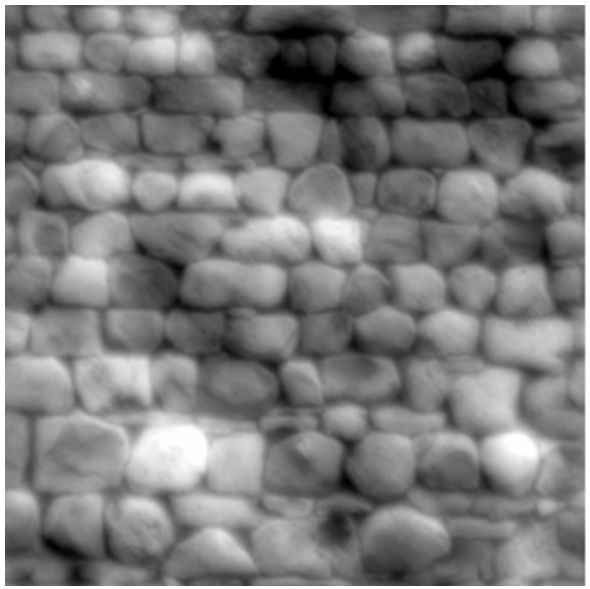
  où s est un facteur multiplicatif de la hauteur maximale en fonction de la taille d'un seul texel, $h(i,j)$ correspond aux texels de la texture.
- Calcul des directions dir_u, dir_v
  - $dir_u = (1, 0, d_u)$ et $dir_v = (0, 1, d_v)$
- Calcul de la nouvelle normale
  - $m = normalize(dir_u \times dir_v) = \frac{(-d_u, -d_v, 1)}{\sqrt{d_u^2 + d_v^2 + 1}}$

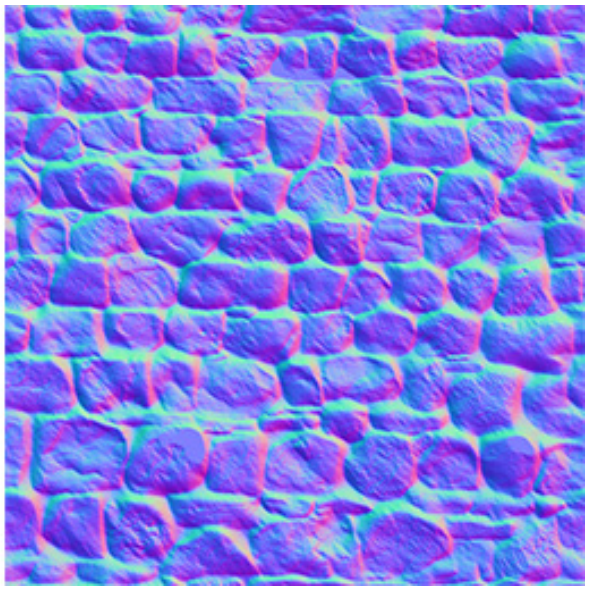
  où m est une normale dans l'espace tangent.

Alternative : Normal Mapping

Nouvelle forme de bump mapping

- Les calculs sont stockées directement dans l'image (baking)
- Attention : stockée dans l'espace tangent et normalisée
- $RGB = 0.5 * m + 0.5$



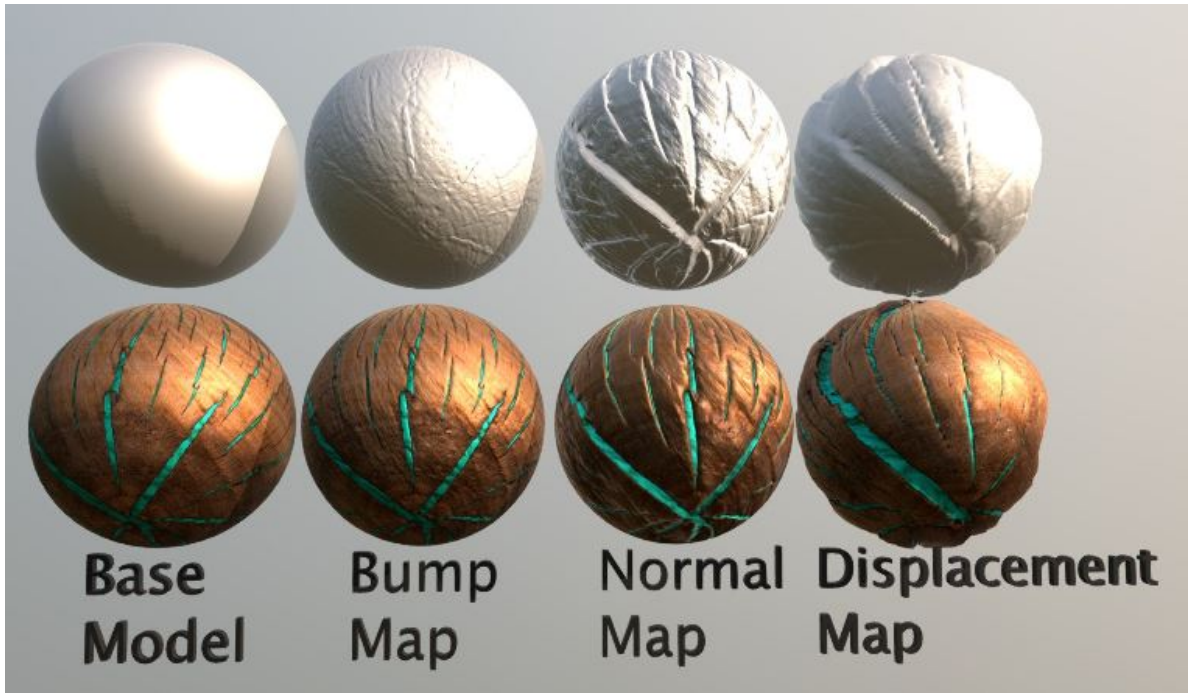


Displacement Mapping

Displacement Mapping

Définition

- Permet d'ajouter du détails géométrique depuis une texture
- Modification directe dela géométrie
- Vertex Shader / Tessalation Shaders (plus fin)



Displacement Mapping : GLSL

- Vertex Shader

```
#version 330 core
in vec3 aPosition;
in vec3 aNormal;
in vec2 aUV;

uniform sampler2D texDisplacement;

void main() {
  float displacement = texture(texDisplacement, aUV);
  // move the position along the normal and transform it
  vec3 newPosition = aPosition + aNormal * displacement;
  gl_Position = projectionMatrix * modelViewMatrix * vec4( newPosition, 1.0 );
}
```

Environment Mapping

Environment Mapping

Définition

Simulation de l'effet de réflexion d'un environnement sur un objet réflectif (brillant)

- Skybox, Panorama (Réflexion statique)
- La scène 3D (Réflexion dynamique)

Comment générer un environnement

Différentes approches

- (pré-)Calculé (Google Map, 3D)
- Capturé (Photo, HDRI)

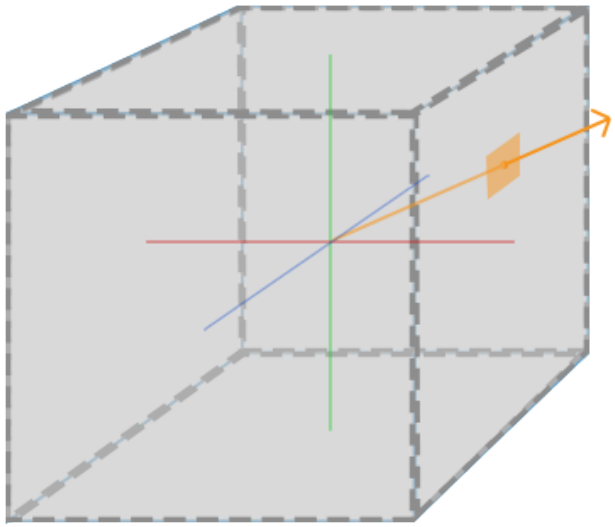
Skybox

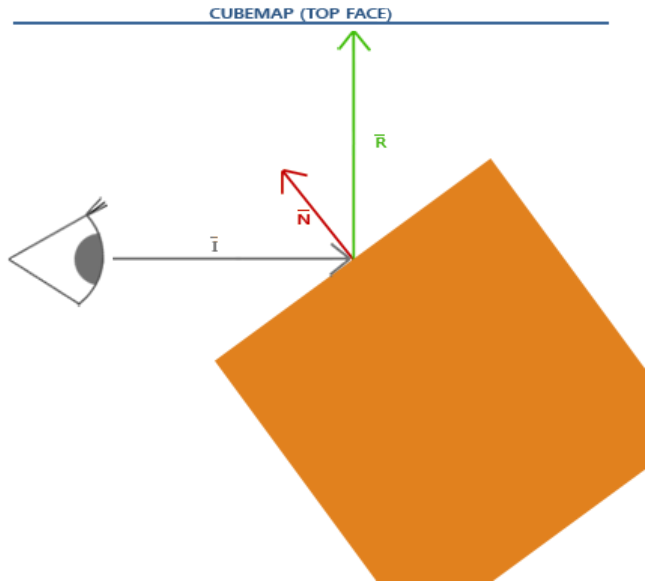
pre-rendered panoramic sky images

Skybox

Cubemap

- 6 faces utilisant 6 images
- Lancer de rayon





(from learnopengl.com)

OpenGL : Texture Cube

- Création et chargement (avec stb_image.h)

```
unsigned int loadCubemap(vector<std::string> facesPath) {
    unsigned int textureID;
    glGenTextures(1, &textureID);
    glBindTexture(GL_TEXTURE_CUBE_MAP, textureID);
    int width, height, nrChannels;
    for (unsigned int i = 0; i < faces.size(); i++) {
        unsigned char *data = stbi_load(faces[i].c_str(), &width, &height, &
             nrChannels, 0);
        if (data) {
            glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_X + i,
                         0, GL_RGB, width, height, 0, GL_RGB, GL_UNSIGNED_BYTE,
                              data);
        } else {
            std::cout << "Cubemap tex failed: " << faces[i] << std::endl;
        }
        stbi_image_free(data);
    }
    glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_WRAP_S, GL_CLAMP_TO_EDGE);
    glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_WRAP_T, GL_CLAMP_TO_EDGE);
    glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_WRAP_R, GL_CLAMP_TO_EDGE);
    return textureID;
}
```

OpenGL : Texture Cube dans le shader

- Vertex Shader

```
#version 330 core
layout (location = 0) in vec3 aPos;
layout (location = 1) in vec3 aNormal;

out vec3 Normal;
out vec3 Position;

uniform mat4 model;
uniform mat4 view;
uniform mat4 projection;

void main()
{
    mat3 normalMatrix = mat3(transpose(inverse(model)));
    Normal = normalMatrix * aNormal;// world normal
    Position = vec3(model * vec4(aPos, 1.0));// world Position
    gl_Position = projection * view * vec4(Position, 1.0);
}
```

OpenGL : Texture Cube dans le shader

- Fragment shader

```
#version 330 core
out vec4 FragColor;

in vec3 Normal;
in vec3 Position;

uniform vec3 cameraPos;
uniform samplerCube skybox;

void main()
{
    vec3 I = ...;// camera to position
    vec3 R = reflect(<vec3>, <vec3>);
    FragColor = vec4(texture(skybox, R).rgb, 1.0);
}
```

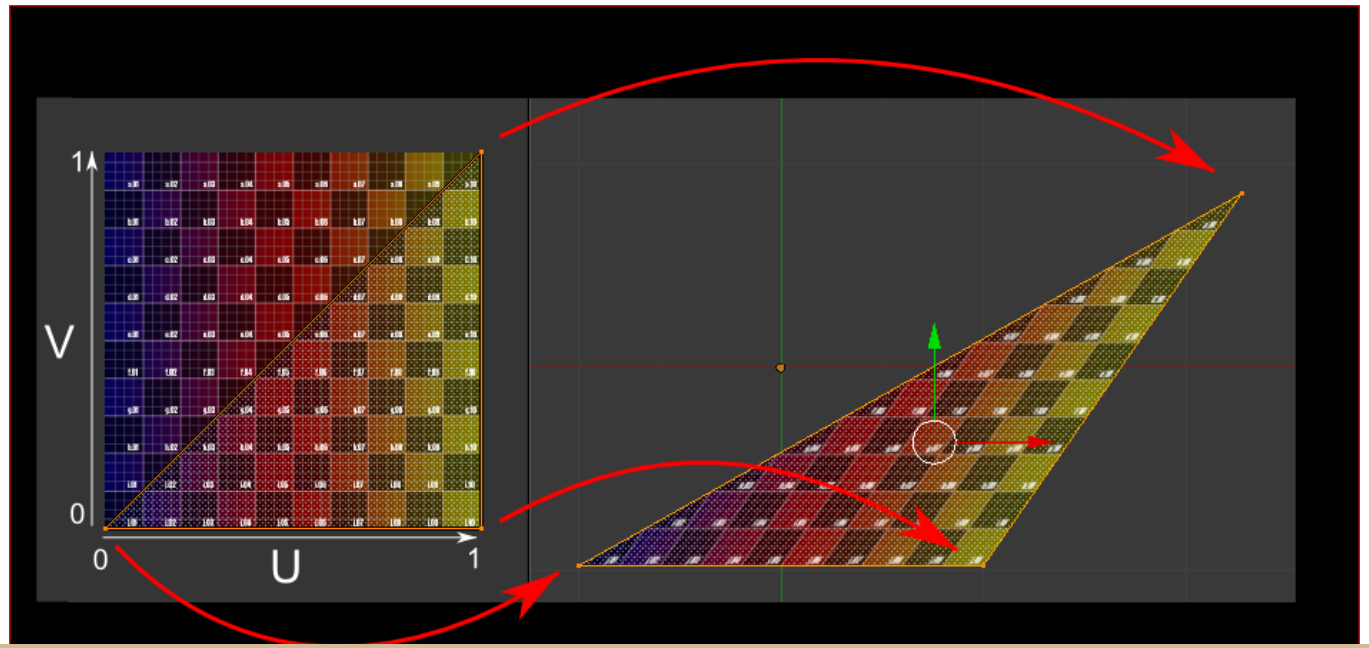
Comment convertir un panorama HDR en Texture Cube

TP

Travaux pratiques

Niveau 0 : Plaquage d'une texture 2D sur un plan 3D

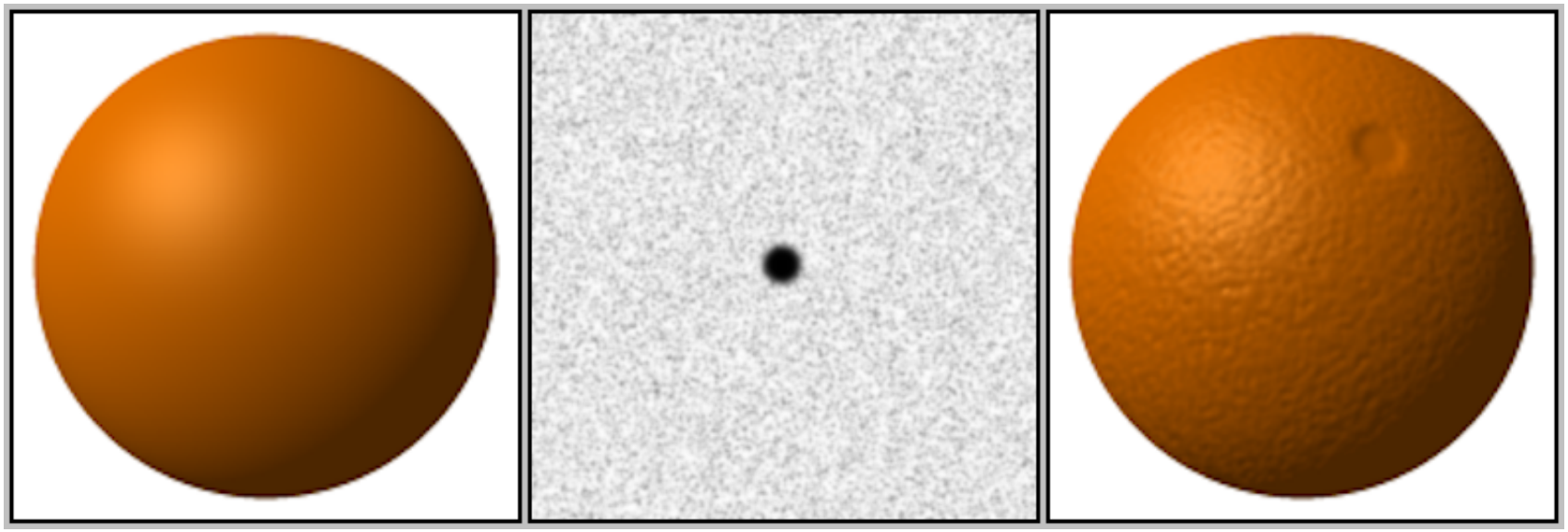
- Créer un plan 3D (avec des coordonnées 3D, UV et normales)
- Charger une texture 2D (stb_image.h)
- Plaquer la texture 2D sur le plan 3D
  - modifier le shader pour utiliser la couleur RGB de la texture



Travaux pratiques

Niveau 1 : Bump Mapping

- Charger une texture en niveau de gris
- Utiliser cette seconde texture pour modifier les normales de votre modèle
- Alternative : Normal Mapping



Travaux pratiques

Niveau 2 : Environnement Mapping

- Créer un cube 3D pour la skybox
- Charger une texture cube
- Créer un shader faisant le rendu de la sky
- Faire un premier rendu de la skybox
- Faire un rendu réflectif d'un objet 3D