Implementation: Textures

Introduction to Computer Graphics

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Library

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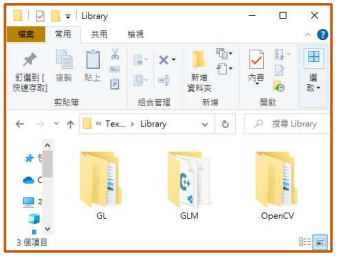
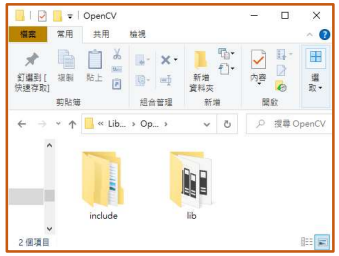
Library

- **OpenCV: Open Source Computer Vision Library (link)**
  - A cross-platform open-source C/C++ library for computer vision and image processing applications
  - We use it for loading image textures





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Program Overview

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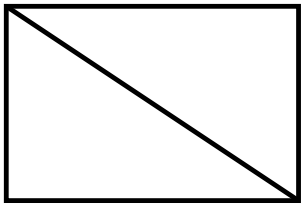
Recap: Textures

- Used to represent **spatially-varying** data
- **Decouple** materials from the geometry



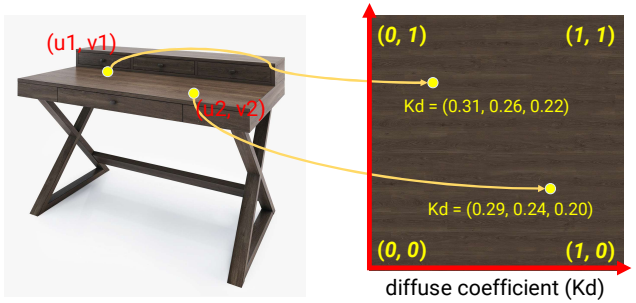
Geometry: two triangles
Material: Kd(1, 1, 1)

2D image texture

= **complex appearance**

Recap: Texture Coordinate

- A coordinate to look up the texture
- The way to map a point on an **arbitrary 3D surface** to a pixel (texel) on an **image** texture



diffuse coefficient (Kd)

Goal

- This slides demonstrates how to create an OpenGL texture and bind it to shader
- In the shader, the output color is determined by **per-vertex lighting multiplied by per-fragment texture color**
  - The way OpenGL 1.1 combines textures and lighting
  - Using the texture color as diffuse coefficients (Kd) needs per-fragment lighting, which is part of your HW2/HW3

Data Structure: ImageTexture

- Defined in imagetexture.h / imagetexture.cpp

```
#ifndef IMAGE_TEXTURE_H
#define IMAGE_TEXTURE_H

#include "headers.h"

// Texture Declarations.
class ImageTexture
{
public:
    // Texture Public Methods.
    ImageTexture(const std::string filePath);
    ~ImageTexture();

    void Bind(GLenum textureUnit);
    void Preview();
```

OpenGL texture object (ID)

```
private:
    // Texture Private Data.
    std::string texFileName;
    GLuint textureObj;
    int imageWidth;
    int imageHeight;
    int numChannels;
    cv::Mat texImage;
};
```

pixel data (2D array)

```
#endif
```

Data Structure: ImageTexture (cont.)

```
ImageTexture::ImageTexture(const std::string filePath)
    : texFileName(filePath)
{
    imageWidth = 0;
    imageHeight = 0;
    numChannels = 0;
    textureObj = 0;

    // Try to load texture image.
    texImage = cv::imread(texFileName);
    if (texImage.rows == 0 || texImage.cols == 0) {
        std::cerr << "[ERROR] Failed to load image texture: " << filePath << std::endl;
        return;
    }
    imageWidth = texImage.cols;
    imageHeight = texImage.rows;
    numChannels = texImage.channels();

    // Flip texture in vertical direction.
    // OpenCV has smaller y coordinate on top; while OpenGL has larger.
    cv::flip(texImage, texImage, 0);
```

load an image and store data in a cv::Mat (OpenCV's API)

3 for RGB images
4 for RGBA images

flip image vertically (OpenCV's API)

Data Structure: ImageTexture (cont.)

```
    glGenTextures(1, &textureObj);
    glBindTexture(GL_TEXTURE_2D, textureObj);
    switch (numChannels) {
    case 1:
        glTexImage2D(GL_TEXTURE_2D, 0, GL_RED, imageWidth, imageHeight,
                     0, GL_RED, GL_UNSIGNED_BYTE, texImage.ptr());
        break;
    case 3:
        glTexImage2D(GL_TEXTURE_2D, 0, GL_RGB, imageWidth, imageHeight,
                     0, GL_BGR, GL_UNSIGNED_BYTE, texImage.ptr());
        break;
    case 4:
        glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA, imageWidth, imageHeight,
                     0, GL_BGRA, GL_UNSIGNED_BYTE, texImage.ptr());
        break;
    default:
        std::cerr << "[ERROR] Unsupport texture format" << std::endl;
        break;
    }
```

generate an OpenGL texture object (ID)

bind the texture object for follow-up operations

set image data to texture

OpenCV stores images in BGR/BGRA format

Data Structure: ImageTexture (cont.)

setup texture sampling and filtering mode

```
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    // glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR_MIPMAP_LINEAR);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT);

    glGenerateMipmap(GL_TEXTURE_2D);

    glBindTexture(GL_TEXTURE_2D, 0);
}
```

generate mipmap

unbind texture

Texture Related APIs

- Set image data to texture (ref: https://reurl.cc/NGG805)

void ***glTexImage2D*** *(*
- *GLenum target,* — GL_TEXTURE_2D, GL_TEXTURE_CUBE_MAP_POSITIVE_X, … etc.
- *GLint level,* — level of details, usually set to 0
- *GLint internalformat,* — the internal format of the **texture** GL_RED, GL_RG, GL_RGB, GL_RGBA, GL_DEPTH_COMPONENT … etc.
- *GLsizei width,*
- *GLsizei height,*
- *GLint border,* — must be 0
- *GLenum format,* — the format of the **image data** GL_RED, GL_RG, GL_RGB, GL_RGBA … etc.
- *GLenum type,* — the data type of the **pixel data** GL_UNSIGNED_BYTE, GL_FLOAT … etc.
- *const void * data* — a pointer to the image data in memory

);

Texture Related APIs (cont.)

- Set the sampling and filtering mode of the bound texture (ref: https://reurl.cc/911AMv)

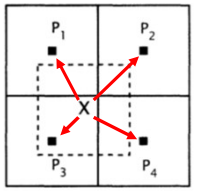
```
void glTexParameteri(f) (
    GLenum target,
    GLenum pname,
    GLint (GLfloat) param
);
```

Specifies the symbolic name of a single-valued texture parameter, such as
GL_TEXTURE_MIN_FILTER
GL_TEXTURE_MAG_FILTER
GL_TEXTURE_WRAP_S
GL_TEXTURE_WRAP_T … etc.

parameter value
GL_LINEAR
GL_LINEAR_MIPMAP_LINEAR
GL_CLAMP_TO_EDGE
GL_REPEAT … etc.

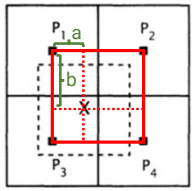
Recap: Texture Filtering

- Strategies
  - **Nearest neighbor**
  - **Bilinear interpolation**



nearest neighbor

P_3 is closest
Use P_3's pixel value

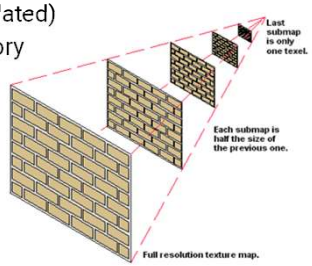


bilinear interpolation

$(1-a)(1-b)P_1 + (a)(1-b)P_2 + (1-a)(b)P_3 + (a)(b)P_4$

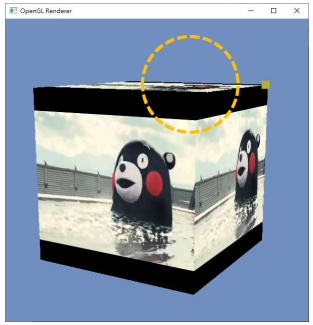
Recap: Mipma

- Mipmap provides a clever way to solve this problem
- **Pre-process**
  - Build a **hierarchical representation** of the texture image
  - Each level has a half resolution of its previous level (generated by linearly interpolated)
  - Take at most **1/3** more memory



Texture Related APIs (cont.)

- Mipmap off v.s. on



off

on

Texture Related APIs (cont.)

- **Texture clamping mode**
  - Determine what will happen when the texture coordinates do not locate within [0, 1]

GL_REPEAT GL_MIRRORED_REPEAT GL_CLAMP_TO_EDGE GL_CLAMP_TO_BORDER

Data Structure: ImageTexture (cont.)

```
void ImageTexture::Bind(GLenum textureUnit)
{
    glActiveTexture(textureUnit);
    glBindTexture(GL_TEXTURE_2D, textureObj);
}

void ImageTexture::Preview()
{
    std::string windowText = "[DEBUG] TexturePreview: " + texFileName;
    cv::Mat previewImg = cv::Mat(texImage.rows, texImage.cols, texImage.type());
    cv::cvtColor(texImage, previewImg, cv::COLOR_BGR2RGB);
    cv::imshow(windowText, previewImg);
    cv::waitKey(0);
}
```

the n^{th} texture in the shader

Shader

gouraud_shading_demo.vs - 記事本

```
#version 330 core

layout (location = 0) in vec3 Position;
layout (location = 1) in vec3 Normal;
layout (location = 2) in vec2 TexCoord;

// Transformation matrices.
uniform mat4 worldMatrix;
uniform mat4 viewMatrix;
uniform mat4 normalMatrix;
uniform mat4 MVP;
// Material properties.
uniform vec3 Ka;
uniform vec3 Kd;
uniform vec3 Ks;
uniform float Ns;
// Light data.
uniform vec3 ambientLight;
uniform vec3 dirLightDir;
uniform vec3 dirLightRadiance;
uniform vec3 pointLightPos;
uniform vec3 pointLightIntensity;

// Data pass to fragment shader.
out vec3 iLightingColor;
out vec2 iTexCoord;
```

```
void main()
{
    gl_Position = MVP * vec4(Position, 1.0);
    iTexCoord = TexCoord;
}
```

vertex shader

gouraud_shading_demo.fs - 記事本

```
#version 330 core

in vec3 iLightingColor;
in vec2 iTexCoord;

uniform sampler2D mapKd;

out vec4 FragColor;

void main()
{
    vec3 texColor = texture2D(mapKd, iTexCoord).rgb;
    // FragColor = vec4(iLightingColor, 1.0);
    // FragColor = vec4(texColor, 1.0);
    FragColor = vec4(iLightingColor * texColor, 1.0);
}
```

interpolated texture coordinate

sample the texture using texture coordinate

fragment shader

Adding TexCoord in Vertex Buffer

```
glEnableVertexAttribArray(0);
glEnableVertexAttribArray(1);
glEnableVertexAttribArray(2);
glBindBuffer(GL_ARRAY_BUFFER, vboId);
glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, sizeof(VertexPTN), 0);
glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, sizeof(VertexPTN), (const GLvoid*)12);
glVertexAttribPointer(2, 2, GL_FLOAT, GL_FALSE, sizeof(VertexPTN), (const GLvoid*)24);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, iboId);
glDrawElements(GL_TRIANGLES, GetNumIndices(), GL_UNSIGNED_INT, 0);
glDisableVertexAttribArray(0);
glDisableVertexAttribArray(1);
glDisableVertexAttribArray(2);
```

the byte offset of the first element of the attribute

stride = 32

Data Structure: ShaderProgram

- Modify the ***GouraudShadingDemoShaderProg*** class in ShaderProg.h / ShaderProgram.cpp

new private data

```
// Texture data.
GLint locMapKd;
```

new public method

```
GLint GetLocMapKd() const { return locMapKd; }
```

get variable location

```
void GouraudShadingDemoShaderProg::GetUniformVariableLocation()
{
    ⋮

    locMapKd = glGetUniformLocation(shaderProgId, "mapKd");
}
```


Main Program

global variable

```
// Texture.
ImageTexture* imageTex = nullptr;
```

modified SceneObject

```
// SceneObject.
struct SceneObject
{
    SceneObject() {
        mesh = nullptr;
        worldMatrix = glm::mat4x4(1.0f);
        Ka = glm::vec3(0.3f, 0.3f, 0.3f);
        Kd = glm::vec3(0.8f, 0.8f, 0.8f);
        Ks = glm::vec3(0.6f, 0.6f, 0.6f);
        Ns = 50.0f;
    }
    TriangleMesh* mesh;
    glm::mat4x4 worldMatrix;
    // Material properties.
    glm::vec3 Ka;
    glm::vec3 Kd;
    glm::vec3 Ks;
    float Ns;
    // Texture.
    ImageTexture* tex = nullptr;
};
```

SetupScene

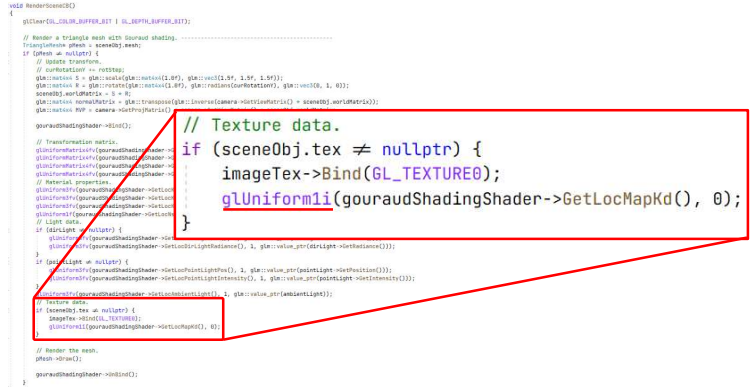
```
void SetupScene()
{
    // Scene object ------------------------------------------
    mesh = new TriangleMesh();
    // mesh->LoadFromFile("models/Koffing/Koffing.obj", true);
    mesh->LoadFromFile("models/TexCube/TexCube.obj", true);
    mesh->CreateBuffers();
    mesh->ShowInfo();
    sceneObj.mesh = mesh;
    // Load texture.
    // imageTex = new ImageTexture("models/Koffing/tex.png");
    imageTex = new ImageTexture("models/TexCube/kumamon.jpg");
    sceneObj.tex = imageTex;
```

ReleaseResource

```
void ReleaseResources()
{
    // Delete scene objects and lights.
    if (mesh != nullptr) {
        delete mesh;
        mesh = nullptr;
    }
    if (imageTex != nullptr) {
        delete imageTex;
        imageTex = nullptr;
    }
```

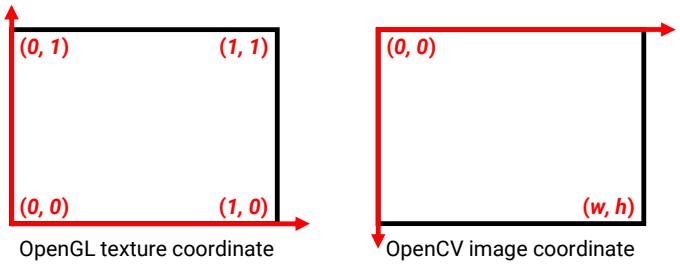

Main Program (cont.)

- RenderSceneCB



Any Questions?

OpenCV Image Format



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