Shaders

EDAF80: Computer Graphics

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AGENDA

1. OpenGL Shader Language
2. Textures
3. Shading theory
4. Assignment 3

OpenGL Shader Language

OpenGL Shader Language (GLSL)

- C like language for programming GPUs
- Vertex & fragment shaders
- Labs: GLSL 4.10 (OpenGL 4.1)
  - Have geometry & tessellation shaders as well
- Compute shaders since OpenGL 4.3
- Newest OpenGL 4.6

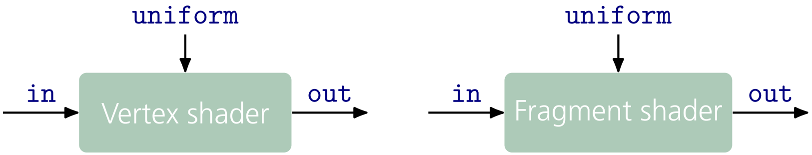
GLSL TYPES

- Types

```
float, int, bool, vec2, vec3, vec4, mat3 ...
sampler2D, samplerCube ...
```

- Type qualifiers

```
const        // compile-time constant
uniform      // constant per primitive
in, out      // attributes passed to/from, and between,
             // the vertex & pixel shader
```



GLSL OPERATORS AND FUNCTIONS

- Structures and arrays with built-in operators

```
vec2, vec3, vec4, mat3, mat4
vec3 v = vec4(1.0f).xyz;            // Swizzle
vec4 u = mat4(1.0f) * vec4(1.0f);   // Operator overloading
```

- User defined functions
- Built-in functions

```
sin(), cos(), pow(), normalize(), min(), max(), clamp(),
reflect(), refract(), sqrt(), noise(), ...
```

GLSL FLOW CONTROL AND PREPROCESSOR

- Flow control

```
if, if-else, for, while, do-while
discard     // Fragment shader only
```

- Preprocessor directives

```
#define, #undef, #if, #else, #endif, ...
```

- Comments

```
// Like this
/* Or, like this */
```

DEVELOPMENT TOOLS

- Shadertoy: `https://www.shadertoy.com/`
- NVIDIA Nsight Visual Studio Edition
- GLSL-Debugger
- This course: by hand ☺
  - Text-editor in Visual Studio
  - Compiler messages (from the GPU) written to ImGUI log window
- Check out `https://docs.gl/` and GLSL 4.10 Specification

DIFFUSE VERTEX SHADER

```
layout (location = 0) in vec3 vertex;
layout (location = 1) in vec3 normal;

uniform mat4 vertex_model_to_world;
uniform mat4 normal_model_to_world;
uniform mat4 vertex_world_to_clip;

out VS_OUT {
    vec3 vertex;
    vec3 normal;
} vs_out;

void main()
{
    vs_out.vertex = vec3(vertex_model_to_world * vec4(vertex, 1.0));
    vs_out.normal = vec3(normal_model_to_world * vec4(normal, 0.0));

    gl_Position = vertex_world_to_clip * vertex_model_to_world * vec4(vertex, 1.0);
}
```

VERTEX SHADER INPUTS

```
layout (location = 0) in vec3 vertex;
layout (location = 1) in vec3 normal;

uniform mat4 vertex_model_to_world;
uniform mat4 normal_model_to_world;
uniform mat4 vertex_world_to_clip;
```

- `layout` specifies the location of the input data in the vertex buffer
  - Sent from `node.cpp: Node::render()`
  - Other `mat4` also comes from there
- Matrix data is loaded with `glUniformMatrix4fv(...)`

```
glUseProgram(program);
GLint i = glGetUniformLocation(program, "vertex_model_to_world");
glUniformMatrix4fv(i, 1, GL_FALSE, glm::value_ptr(world));
```

- More in reference pages

VERTEX SHADER OUTPUTS

```
out VS_OUT {
    vec3 vertex;
    vec3 normal;
} vs_out;

void main()
{
    vs_out.vertex = vec3(vertex_model_to_world * vec4(vertex, 1.0));
    vs_out.normal = vec3(normal_model_to_world * vec4(normal, 0.0));

    gl_Position = vertex_world_to_clip * vertex_model_to_world * vec4(vertex, 1.0);
}
```

- `VS_OUT` is a struct with the output values
- This must match the input to the fragment shader

DIFFUSE FRAGMENT SHADER

```
uniform vec3 light_position;

in VS_OUT {
    vec3 vertex;
    vec3 normal;
} fs_in;

out vec4 frag_color;

void main()
{
    vec3 L = normalize(light_position - fs_in.vertex);
    frag_color = vec4(1.0) * clamp(dot(normalize(fs_in.normal), L), 0.0, 1.0);
}
```

DIFFUSE FRAGMENT SHADER

```
uniform vec3 light_position;

in VS_OUT {
    vec3 vertex;
    vec3 normal;
} fs_in;

out vec4 frag_color;

void main()
{
    vec3 L = normalize(light_position - fs_in.vertex);
    frag_color = vec4(1.0) * clamp(dot(normalize(fs_in.normal), L), 0.0, 1.0);
}
```

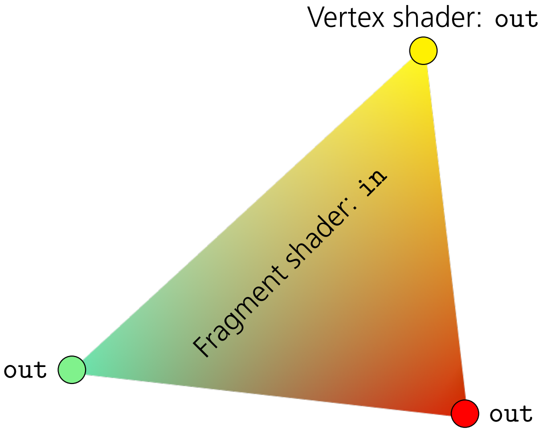
- `VS_OUT` struct matches the vertex shader output and contains interpolated values
- `vertex` is the world position of the current pixel
- `L` is the normalized to the light
- `light_position` set with

```
glUseProgram(program);
GLint i = glGetUniformLocation(program, "light_position");
glUniform3fv(i, 1, glm::value_ptr(light_position));
```

INTERPOLATION OVER TRIANGLE

Behaviour can be changed with

- `smooth` (default)
- `flat`
- `noperspective`



Seminar Exercise 3-1: In/Out Variables and Provoking Vertex

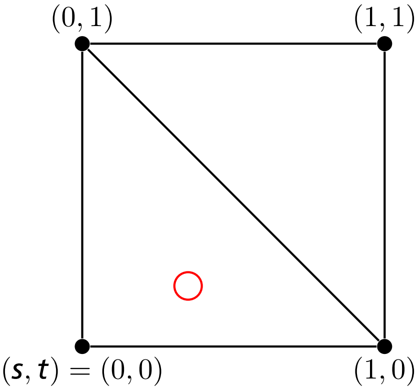
1. Replace the red color in the fragment shader with the varying `in` variable `var_color`.
2. Add a second triangle with indices $2, 1, 3$.
3. Put the keyword `flat` in front of the `var_color` variable in the vertex and fragment shaders. However, do ***not*** put it in front of the `out` variable in the fragment shader!
   - Try changing the order of the indices used to draw the triangle. What happens?

FOLLOW-UP

1. See provoking vertex in the OpenGL wiki

Textures

TEXTURES



Recognise the texture?

WRAPPING

- Wrapping defines behaviour of texture, outside $(s, t) \in [0, 1]$
- `GL_REPEAT`: Coordinates wrap around the texture $(-0.2 \rightarrow 0.8)$
- `GL_MIRRORED_REPEAT`: Coordinates wraps with mirrored value $(-0.2 \rightarrow 0.2)$
- `GL_CLAMP_TO_EDGE`: Clamp coordinates to $[0, 1]$, edge value get copied
- `GL_CLAMP_TO_BORDER`: Clamp coordinates to $[0, 1]$, border colour is used
  - `GL_TEXTURE_BORDER_COLOR` needs to be set

```
glBindTexture(GL_TEXTURE_2D, texture);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_MIRRORED_REPEAT);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_MIRRORED_REPEAT);
```

WRAPPING

GL_REPEAT (default)

GL_MIRRORED_REPEAT

WRAPPING

GL_CLAMP_TO_EDGE

GL_CLAMP_TO_BORDER

MAGNIFICATION

- Magnification filter defines behaviour of texture when a texel covers more than one pixel
- `GL_NEAREST`: Use the nearest texel only
- `GL_LINEAR`: Use linear interpolation of four closest texels

```
glBindTexture(GL_TEXTURE_2D, texture);
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_NEAREST);
```

- (Minification is discussed in EDAN35 ☺)

MAGNIFICATION

GL_LINEAR (default)

GL_NEAREST

Seminar Exercise 3-2: Texture Mapping

1. Inspect the values of texture coordinates by outputting the `var_tex` vector as the red and green channels.
2. Use `texture()` to replace the color in the fragment shader with the pixels from the texture image.
3. Change the 1.0 values for the s texture coordinate in the vertex buffer to 2.0. The flower should repeat horizontally.
4. Change the t texture coordinate as well so a grid of flowers form.
5. Try `bricks_seamless.jpg` and study the behavior of it for different wrapping modes. How does it compare to `flower.jpg`?

FOLLOW-UP QUESTION

1. What happens for non-integer values of s and t?

Shading theory

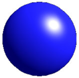
PHONG SHADING

- Phong shading per pixel
- Assuming normalized vectors

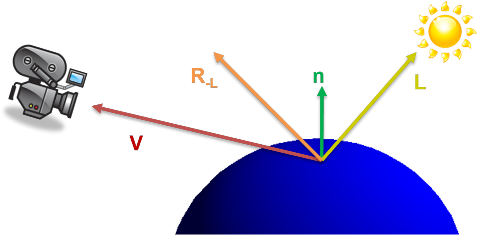
$$\begin{aligned}\texttt{color} = {} & \texttt{ambientColor} + \\ & \texttt{diffuseColor} * \max(\mathbf{n} \cdot \mathbf{L}, 0) + \\ & \texttt{specularColor} * (\max(\text{reflect}(-\mathbf{L}, \mathbf{n}) \cdot \mathbf{V}, 0))^{\texttt{shininess}}\end{aligned}$$

ambient

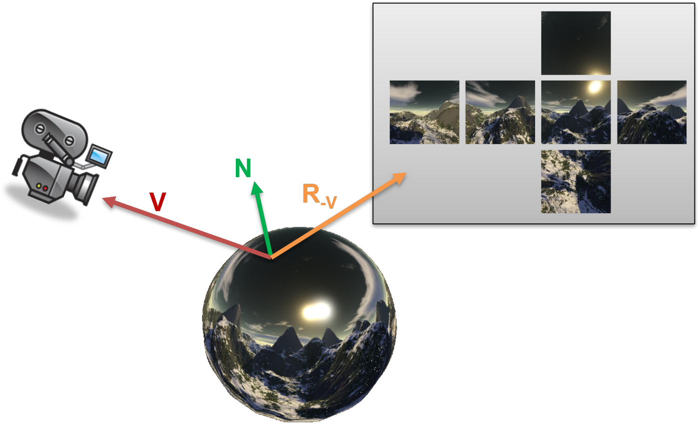
ambient + diffuse



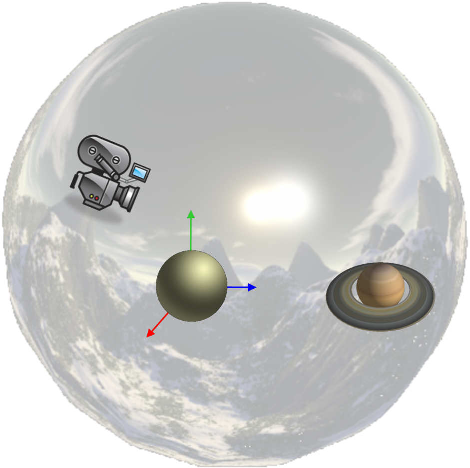
ambient + diffuse + specular



CUBE MAPPING



SKYBOX



SKYBOX

- Attach cube map to large sphere (large enough to contain all scene content)
- Write a "skybox"-shader that looks up colours from the cube map
  - in the normal direction,
  - or with world position coordinates(?)
- Create illusion of sphere placed at infinity
- Make sure back-face culling is disabled
- Inside of sphere will appear as surrounding sky/landscape

ADDING A CUBE MAP

- Complete `loadTextureCubeMap()` and use it

```
GLuint cubemap = bonobo::loadTextureCubeMap(
    config::resources_path("cubemaps/NissiBeach2/posx.jpg"),
    config::resources_path("cubemaps/NissiBeach2/negx.jpg"),
    config::resources_path("cubemaps/NissiBeach2/posy.jpg"),
    config::resources_path("cubemaps/NissiBeach2/negy.jpg"),
    config::resources_path("cubemaps/NissiBeach2/posz.jpg"),
    config::resources_path("cubemaps/NissiBeach2/negz.jpg"));
```

- Add a cube map to your sphere node

```
sphere.add_texture("cubemap", cubemap, GL_TEXTURE_CUBE_MAP);
```

- `node.cpp` will bind the cube map and set the uniform (check code)

ADDING A CUBE MAP

- In your fragment shader add

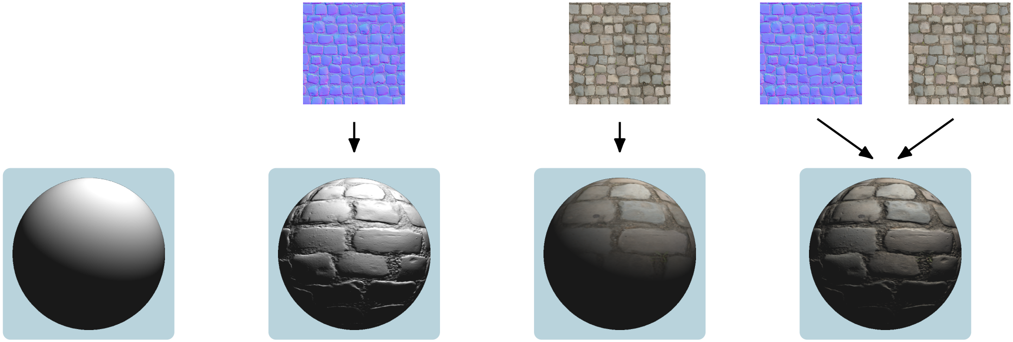
```
uniform samplerCube cubemap;
```

- Then use it in your fragment shader

```
frag_color = texture(cubemap, coordinates);
```

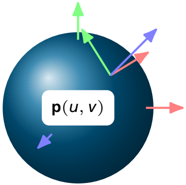
NORMAL MAPPING

- Obtain normal from normal map instead of interpolation from vertices
- Requires a defined ***tangent space***



TANGENT SPACE

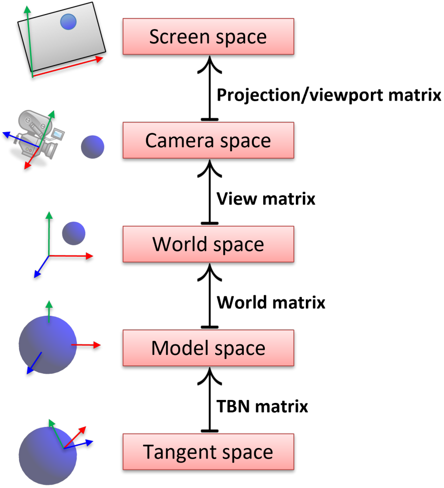
- Basis vectors: tangent $\mathbf{t}$, binormal $\mathbf{b}$, normal $\mathbf{n}$
- Basis matrix: **TBN**
- Derived from the surface equation, $\mathbf{p}(u, v)$
  - Assignment 2!



$$\mathbf{TBN} = \begin{pmatrix} t_x & b_x & n_x \\ t_y & b_y & n_y \\ t_z & b_z & n_z \end{pmatrix}$$

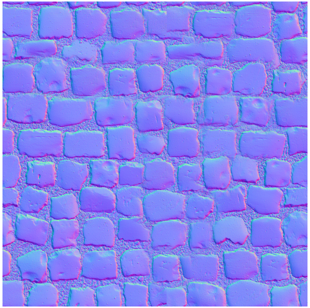
tangent space $\mapsto$ model space

SPACES OVERVIEW



NORMAL MAP LOOK-UP

- Normals stored as (r, g, b) where each component lies in $[0, 1]$
- Map to $[-1, 1]$: $\mathbf{n} = (r, g, b) \times 2 - 1$
- Blue-ish colour since "unmodified" normal, $\mathbf{n} = (0, 0, 1)$, maps to $RGB = (0.5, 0.5, 1.0)$



NORMAL TRANSFORMATIONS

- Normal not ready to use yet; light vector is in world space, so normal must be as well
- Transform normal from tangent to world space:

$$\mathbf{WORLD}^{-T} * \mathbf{TBN} * \mathbf{n}$$

- Available as `normal_model_to_world` in Bonobo shaders (check `node.cpp`)
- Now we can proceed with light calculations

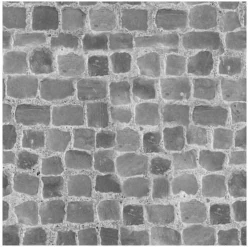
SUMMARY

1. Look up (r, g, b) from texture
2. Create **n** by mapping from $[0, 1]$ to $[-1, 1]$
3. Transform to world space: $\mathbf{WORLD}^{-T} \cdot \mathbf{TBN} \cdot \mathbf{n}$
4. Use this normal when performing light calculations

ROUGHNESS MAPPING

- Similar to normal mapping
  - Store material properties in a texture
  - During lighting calculations, do texture look-ups and apply value
- Replace specular component of Phong model
- Many other material properties are also common to store in textures

Diffuse texture



Roughness texture

Assignment 3

ASSIGNMENT 3

- Implement the following shader techniques:
  - Phong shading
  - Cube mapping using a skybox
  - Normal mapping
- Finish implementation of cube map loading
- Files you have to modify (or add)
  - `src/EDAF80/assignment3.cpp`
  - `src/EDAF80/parametric_shapes.cpp`
  - `src/core/helpers.cpp`
  - Any shader files that you created

HINTS

- Create new shader programs as needed
  - `skybox.vert`, `skybox.frag`...
- Use `R` key to do hot reload of shaders
  - Performs read from disk and compilation
  - Check log for error messages
- In `shaders/EDAF80/`, look at `diffuse.vert` and `diffuse.frag` for guidance

NORMAL MAPPING IN SHADER

- All tangent space basis vectors are needed (normal, tangent, binormal)
- Complete vertex definition:

```
struct Vertex {
    float   x, y, z,        /* vertex position */
            s, t,           /* texture coords */
            nx, ny, nz,     /* normal */
            tx, ty, tz,     /* tangent */
            bx, by, bz;     /* binormal */
};
```

NORMAL MAPPING IN SHADER

- Hint:
  - Set **t**, **b**, **n** as `in`-attributes to the vertex shader and make them vary per fragment using `out`
  - Construct **TBN**-matrix in fragment shader using `mat4`
- Check out `res/textures/` for more textures

DEMO