Visual Computing Exercise 6: Introduction to OpenGL

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Schedule

Lecture	Exercise	Assistant
Nov 07/09	Exercise 6: OpenGL Rendering	Leonhard
Nov 14/16	Exercise 7: Shaders in OpenGL	Leonhard
Nov 21/23	Exercise 8: Theory: Light and Colors	Riccardo
Nov 28/30	Exercise 9: Matrices and Quaternions	James
Dec 05/07	Exercise 10: Lighting and Shading	Riccardo
Dec 12/14	Exercise 11: Rigid body dynamics	James
Dec 19/21	Q&A	All

Overview

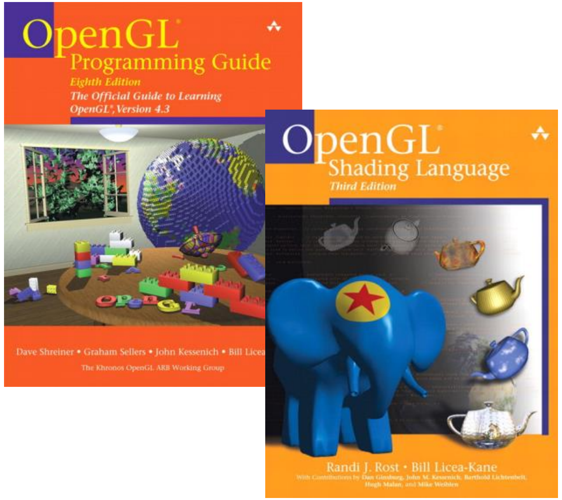
- Introduction to OpenGL
  - What is OpenGL?
  - Shaders
  - OpenGL-related libraries
- Exercise 6

What is OpenGL?

- Software interface to graphics hardware
- API for creating 2D and 3D computer graphics applications
- Hardware independent – implemented on many different platforms

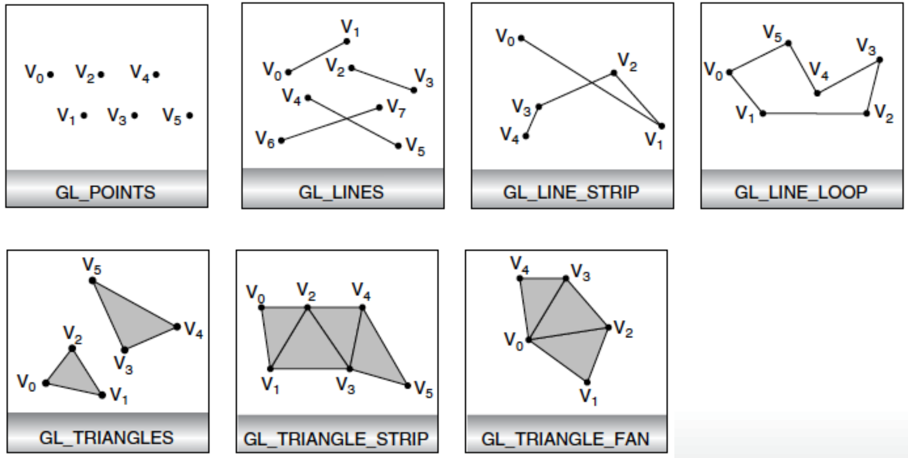
Documentation

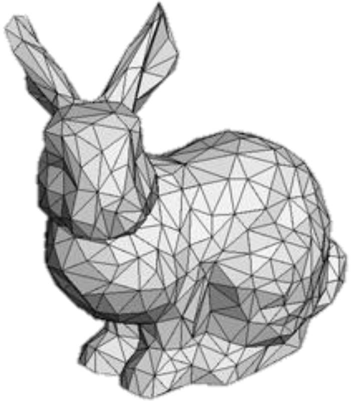
- OpenGL:
  The red book
- OpenGL shading language:
  The orange book
- http://www.opengl.org/registry


OpenGL
Programming Guide
Eighth Edition
The Official Guide to Learning OpenGL, Version 4.3
Dave Shreiner • Graham Sellers • John Kessenich • Bill Licea
The Khronos OpenGL ARB Working Group
OpenGL
Shading Language
Third Edition
Randi J. Rost • Bill Licea-Kane
With Contributions by Dan Ginsburg, John M. Kessenich, Barthold Lichtenbelt, Hugh Malan, and Mike Weiblen

Rendering with OpenGL (1)

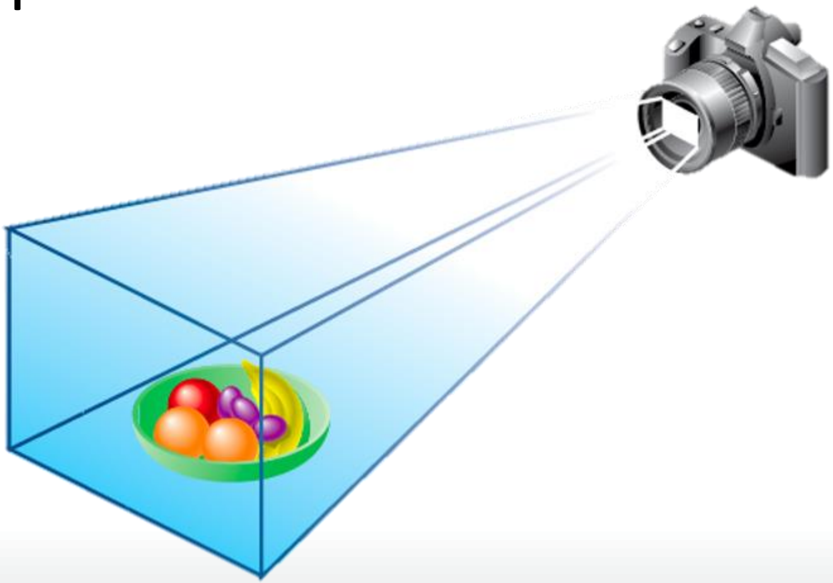
- Construct shapes from geometric primitives





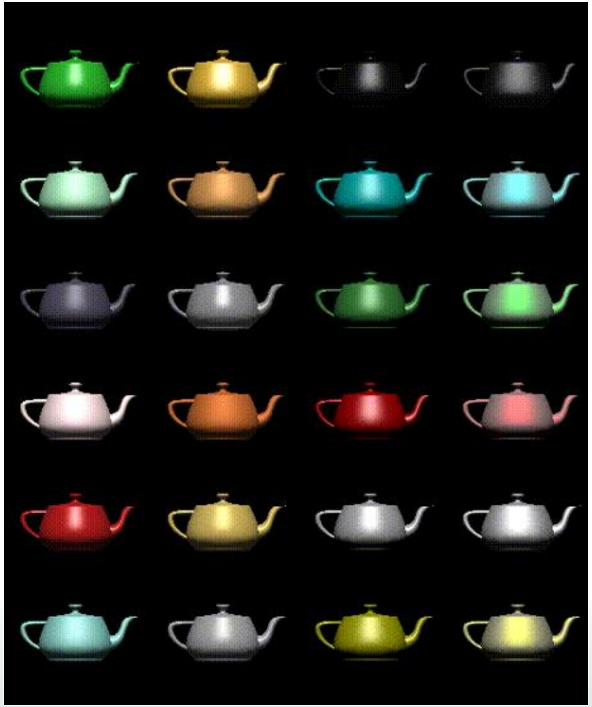
Rendering with OpenGL (2)

- Arrange objects in 3D space
- Specify viewpoint



Rendering with OpenGL (3)

- Calculate colors of objects
  - Textures, materials, lighting
- Colors explicitly controlled with shaders



OpenGL is a state machine

- OpenGL can be put into various states or modes
- Settings remain in effect until changed again
- Examples: drawing color, characteristics of lights, viewing parameters

OpenGL is a state machine

```
struct object_name {
   float option1;
   int   option2;
   char[] name;
}
```

```
struct OpenGL_Context {
   ...
   object* object_Window_Target;
   ...
};
```

```
// create object
unsigned int objectId = 0;
glGenObject(1, &objectId);
// bind object to context
glBindObject(GL_WINDOW_TARGET, objectId);
// set options of object currently bound to GL_WINDOW_TARGET
glSetObjectOption(GL_WINDOW_TARGET, GL_OPTION_WINDOW_WIDTH, 800);
glSetObjectOption(GL_WINDOW_TARGET, GL_OPTION_WINDOW_HEIGHT, 600);
// set context target back to default
glBindObject(GL_WINDOW_TARGET, 0);
```

Exemplary

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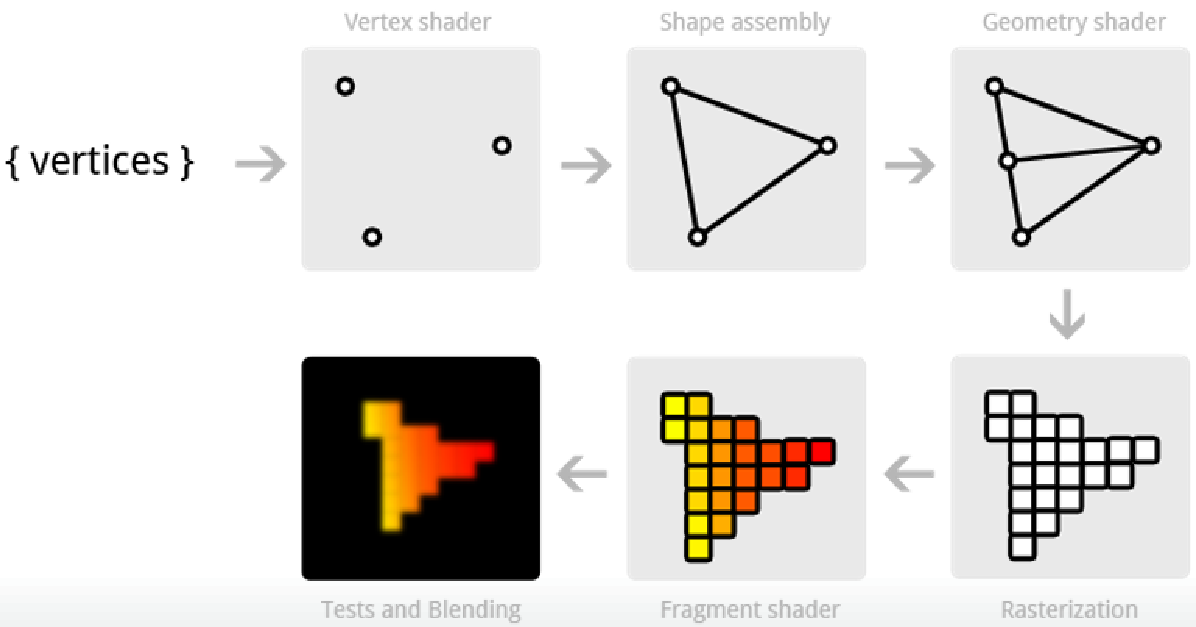
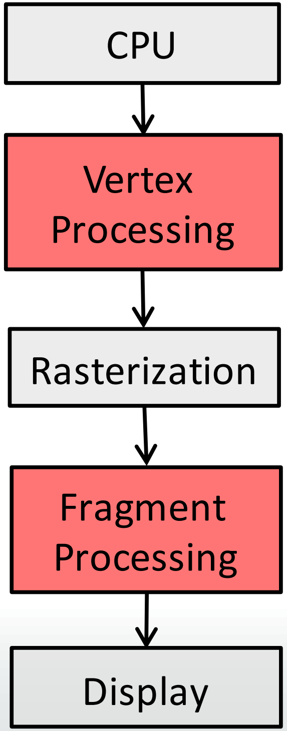
Graphics Pipeline

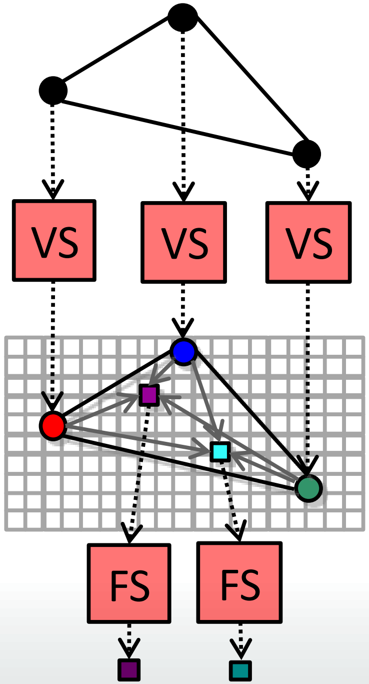


Graphics Pipeline



- Programmable pipeline
  - Before OpenGL 3.0, it was called fixed function pipeline
- OpenGL shading language (GLSL)
  - Part of OpenGL > 2.0
  - C-based

Vertex and fragment shaders



Attributes given per vertex

Vertex shader computes varying

Interpolation of varying values

Fragment shader computes pixel color

Shader input/output

- Uniforms (vertex/fragment shader)
  - Global constants (for every vertex)
  - Examples: Light position, texture map

```
uniform vec3 lightPos;
```

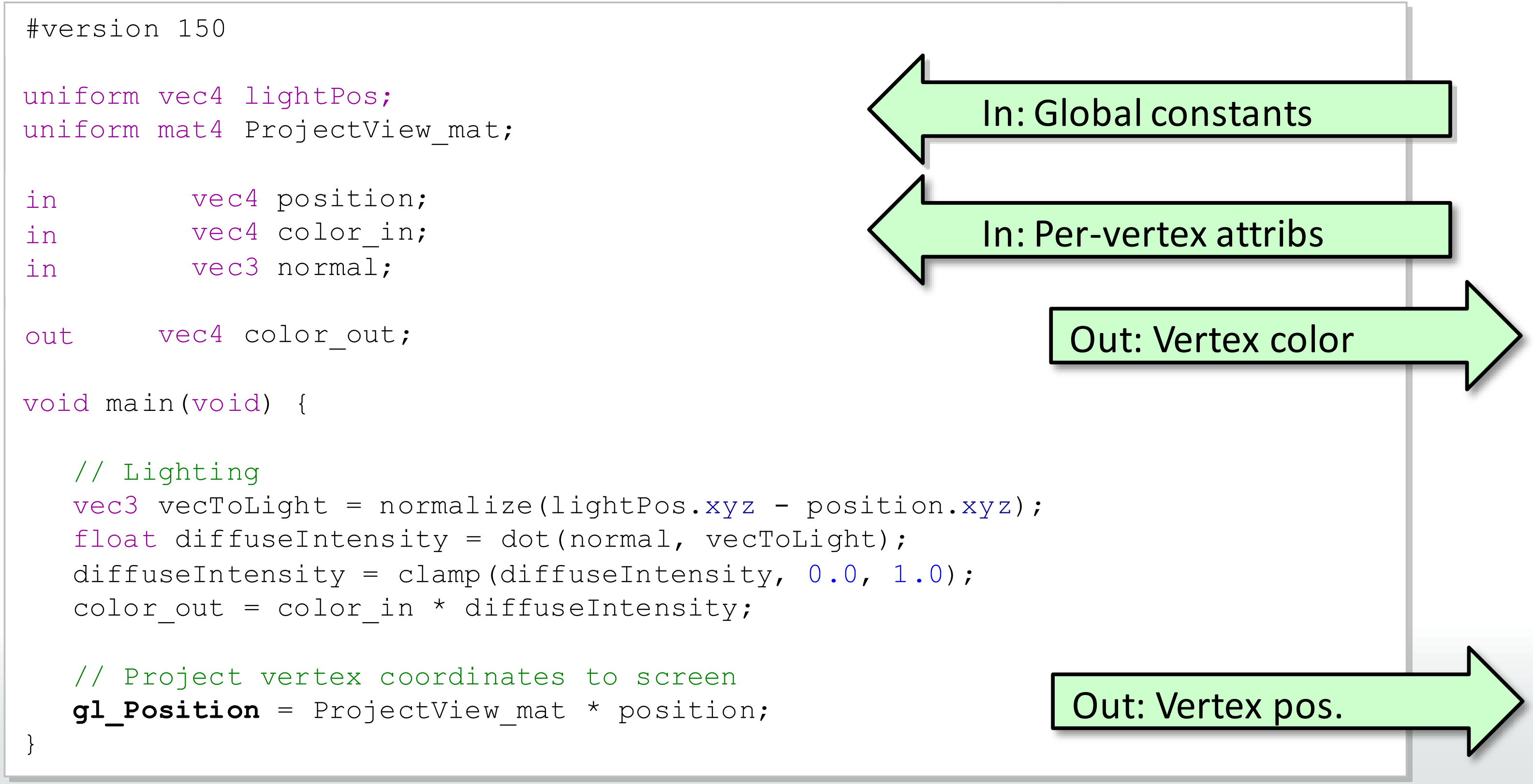
- Attributes (vertex shader)
  - Vertex-specific values
  - Examples: vertex position, normal

```
in vec4 position;
```

- Varyings (vertex/fragment shader)
  - Values passed from vertex to fragment shader
  - Interpolated across primitive
  - Example: fragment color

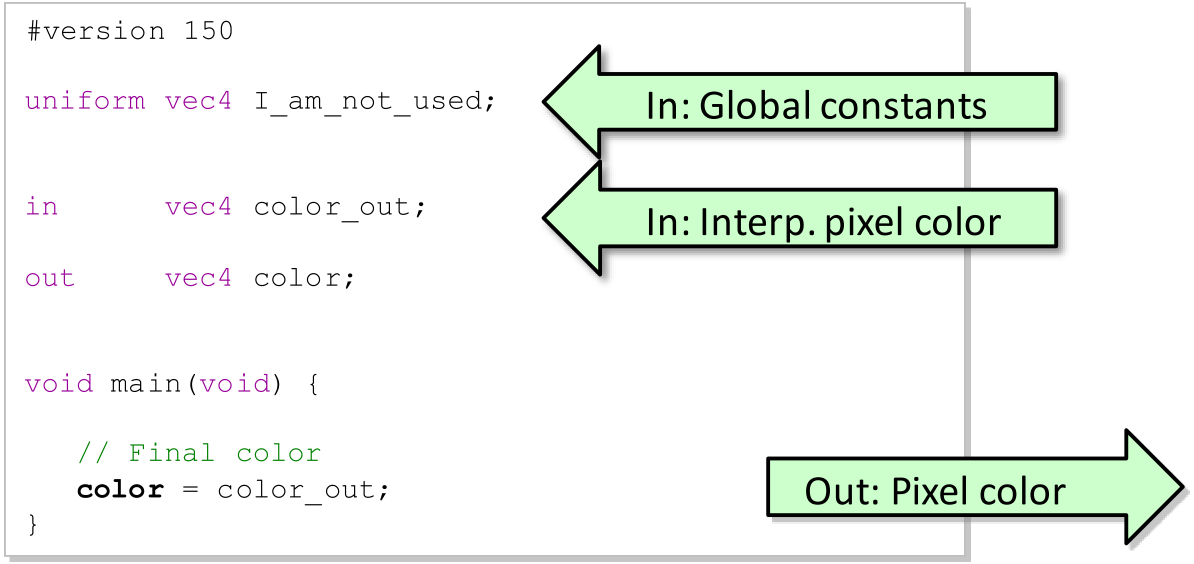
```
out vec3 color_out;
```

Vertex shader example



```
#version 150

uniform vec4 lightPos;
uniform mat4 ProjectView_mat;

in         vec4 position;
in         vec4 color_in;
in         vec3 normal;

out     vec4 color_out;

void main(void) {

   // Lighting
   vec3 vecToLight = normalize(lightPos.xyz - position.xyz);
   float diffuseIntensity = dot(normal, vecToLight);
   diffuseIntensity = clamp(diffuseIntensity, 0.0, 1.0);
   color_out = color_in * diffuseIntensity;

   // Project vertex coordinates to screen
   gl_Position = ProjectView_mat * position;
}
```

Fragment shader example



```
#version 150

uniform vec4 I_am_not_used;


in       vec4 color_out;

out      vec4 color;


void main(void) {

    // Final color
    color = color_out;
}
```

In: Global constants

In: Interp. pixel color

Out: Pixel color

(Trivial shader)

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API Overview

- OpenGL
  - Core functionality
- GLUT (OpenGL Utility Toolkit) / GLFW
  - Portable windowing API
  - Platform independent
  - Not officially part of OpenGL

GLUT / GLFW

- Commands for:
  - Window management: opening and configuring a window
  - Obtaining user input: mouse, keyboard, …

GLEW

- cross-platform C/C++ extension loading library
- it provides efficient run-time mechanisms for determining which OpenGL extensions are supported on the target platform

Using GLFW

```
int main()
{
    glfwInit();
    glfwWindowHint(GLFW_CONTEXT_VERSION_MAJOR, 3);
    glfwWindowHint(GLFW_CONTEXT_VERSION_MINOR, 2);
    glfwWindowHint(GLFW_OPENGL_PROFILE, GLFW_OPENGL_CORE_PROFILE);
    glfwWindowHint(GLFW_RESIZABLE, GL_FALSE);

    GLFWwindow* window = glfwCreateWindow(800, 600, "OpenGL", nullptr, nullptr);
    glfwMakeContextCurrent(window);

    glewExperimental = GL_TRUE;
    glewInit();

    // set callback function for key-inputs
    glfwSetKeyCallback(window, key_callback);
    glfwSetErrorCallback(error_callback);
    ...
```

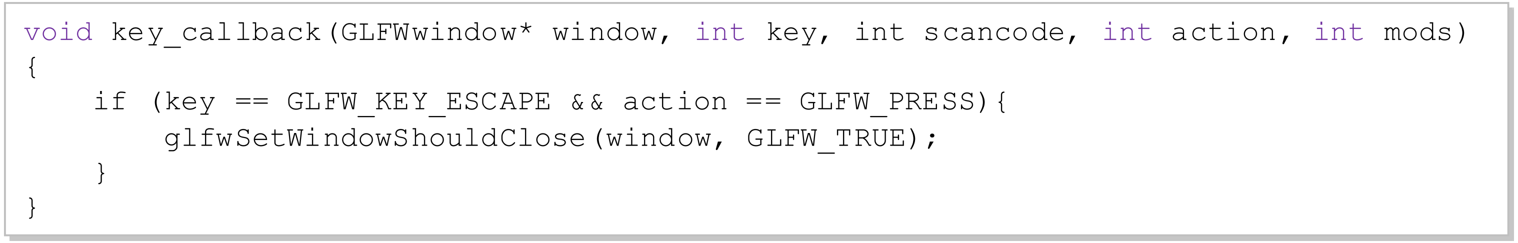
} Callback methods

Using GLFW

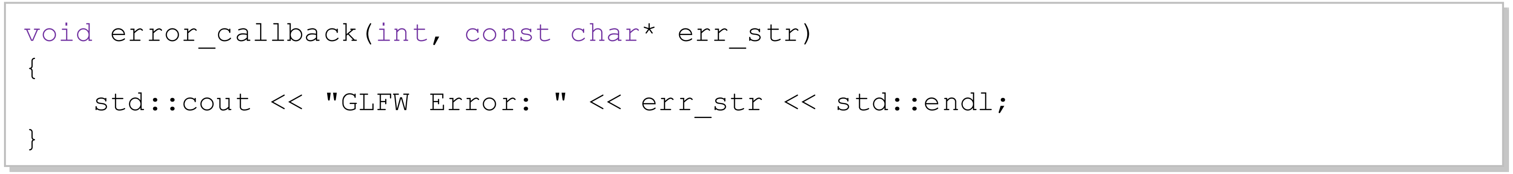
```
    ...
    while(!glfwWindowShouldClose(window))
    {
        glfwPollEvents();
        displayFunc();
        glfwSwapBuffers(window);
    }

    glfwTerminate();
    return 0;
}
```

Using GLFW

- Example callback functions



```
void key_callback(GLFWwindow* window, int key, int scancode, int action, int mods)
{
    if (key == GLFW_KEY_ESCAPE && action == GLFW_PRESS){
        glfwSetWindowShouldClose(window, GLFW_TRUE);
    }
}
```



```
void error_callback(int, const char* err_str)
{
    std::cout << "GLFW Error: " << err_str << std::endl;
}
```

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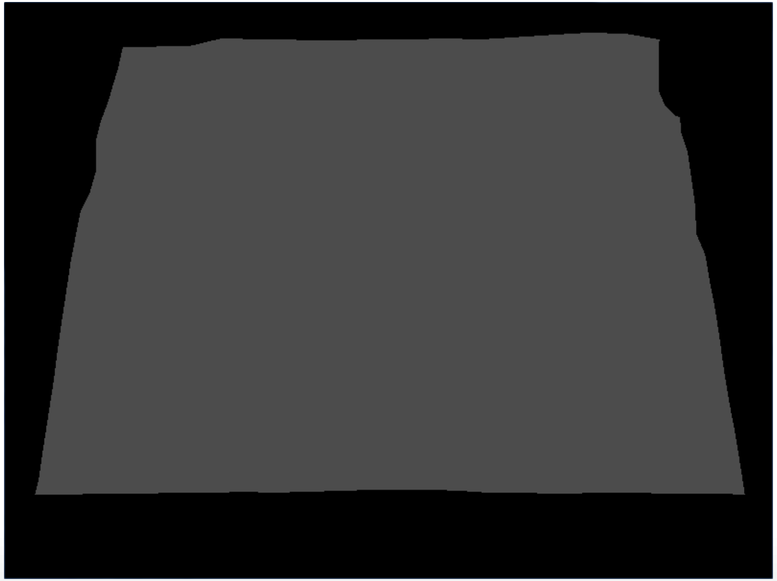
Compiling

- Makefile generation with CMake
  - Readme and scripts for Windows, Linux, OSX

- Backup solution: Use files from 2013
  - CGL homepage → Teaching → Former Courses

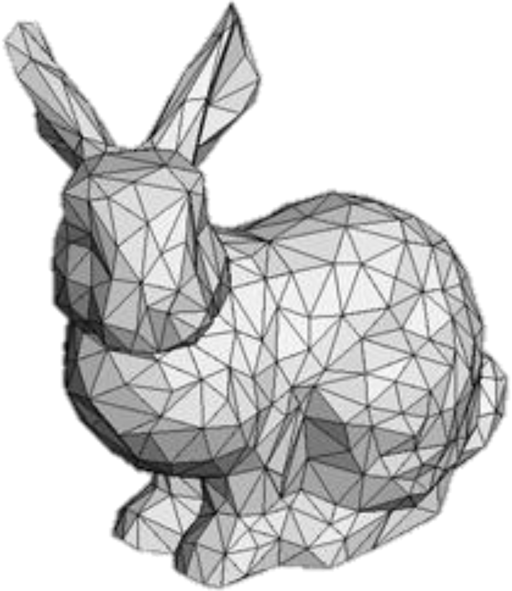
1) Mesh setup and initialization

- Setup vertex buffer and index buffer
- Pass data to vertex shader



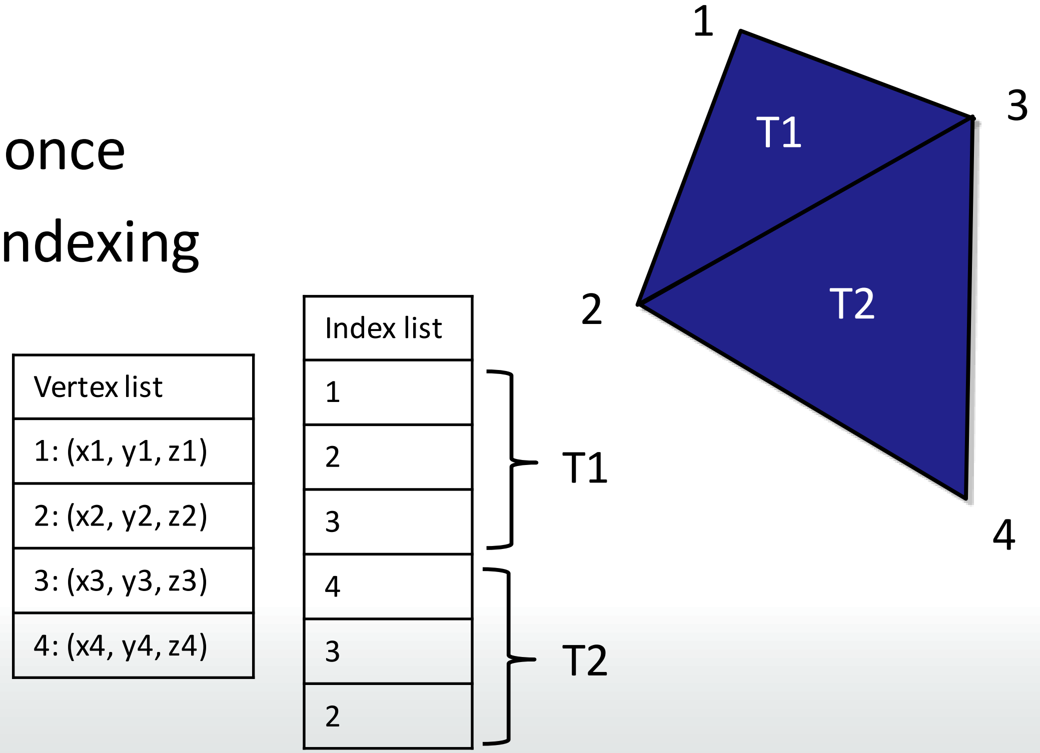
Mesh representations

- Focus on triangle meshes
- 3D mesh consists of:
  - vertices
  - faces
- Information stored:
  - vertex: position, color, normal, …
  - face: links to vertices, surface normal, …



Mesh representations

- Indexed triangle list
  - Stores vertices only once
  - Define triangles by indexing



Vertex list
1: (x1, y1, z1)
2: (x2, y2, z2)
3: (x3, y3, z3)
4: (x4, y4, z4)

Index list	
1	T1
2	
3	
4	T2
3	
2	

Vertex data structure

- Store vertex data in array

```
struct Vertex {
   GLfloat pos[4]; //homogeneous coordinates
   GLfloat color[4];
   GLfloat normal[3];
};

Vertex *pVertexArray = new Vertex[numVertices]

//now: fill buffer!
```

Vertex buffers

- Procedure
  - Generate buffer
  - Bind buffer
  - Load data to buffer (vertex array can be destroyed afterwards)

```
// pVertexArray has data

GLuint handleVBO = 0;
glGenBuffers(1, &handleVBO);
glBindBuffer(GL_ARRAY_BUFFER, handleVBO);
glBufferData(GL_ARRAY_BUFFER, sizeof(Vertex)*numVertices,
             pVertexArray, GL_STATIC_DRAW);
```

handles need to be stored in global variable in the exercise

Index buffers

- Define faces
  - Here: indexed triangles
  - Same procedure as for vertex buffers
  - Use GLshort array to store indices
  - Use GL_ELEMENT_ARRAY_BUFFER as target

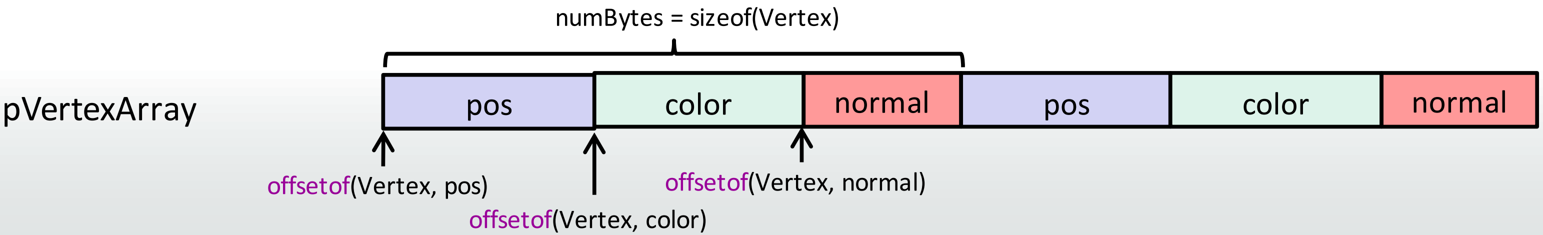
Binding shader inputs

- Binding attributes

```
location = glGetAttribLocation(shader, ”attrib name”);
glVertexAttribPointer(location, dimension, GL_FLOAT, GL_FALSE,
                      numBytes, offset);
glEnableVertexAttribArray(location);
```

e.g. 3 for vec3

  - Hint: use offsetof macro for offset
  - Pointers point to the currently bound buffer



numBytes = sizeof(Vertex)

pVertexArray

pos | color | normal | pos | color | normal

offsetof(Vertex, pos)

offsetof(Vertex, color)

offsetof(Vertex, normal)

Binding shader inputs

- Binding uniforms

```
location = glGetUniformLocation(shader, ”uniform name”);
glUniform4fv(location, count, data);
```

dimension (2,3,4)

1 for single constant

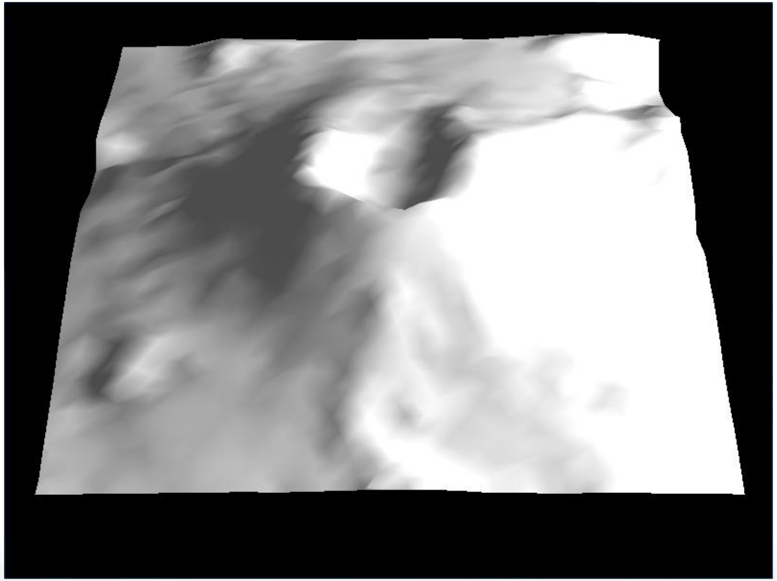
Rendering

- Render indexed triangles with vertex and index buffer

```
void displayFunc(void){
   glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
   glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, handleIndexBuffer);
   glDrawElements(GL_TRIANGLES, idxBufferSize, GL_UNSIGNED_SHORT, 0);
}
```

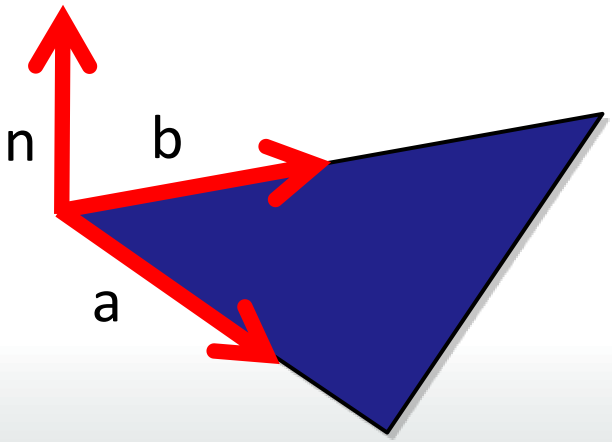
2) Normals for lighting

- Calculate face and vertex normals



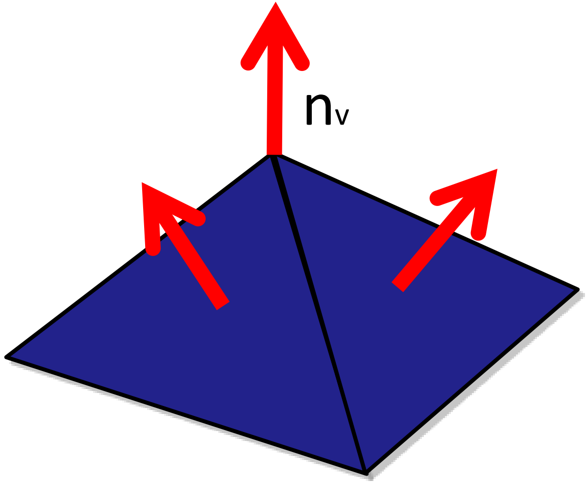
Normals

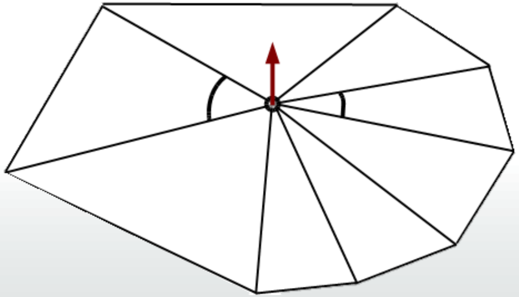
- Face normals
  - Normalized cross product of a and b



Normals

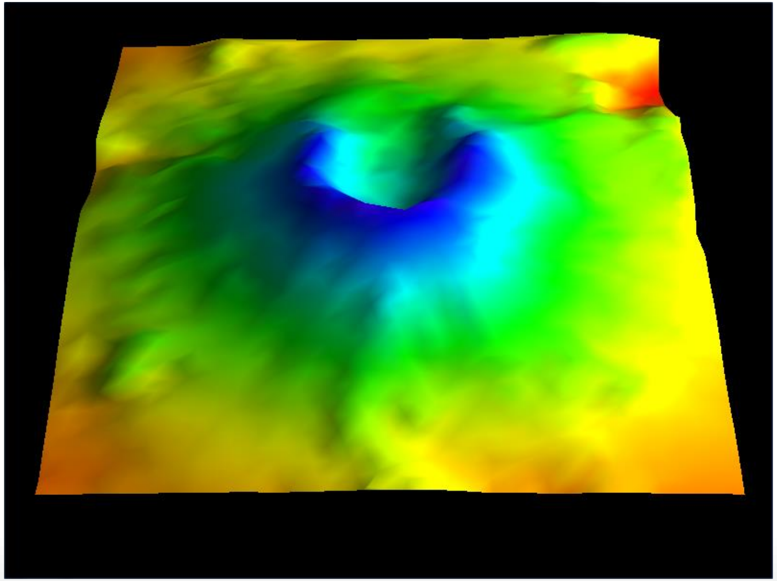
- Vertex normal
  - Average of surrounding face normals
  - Actually better to weight according to angles (optional)





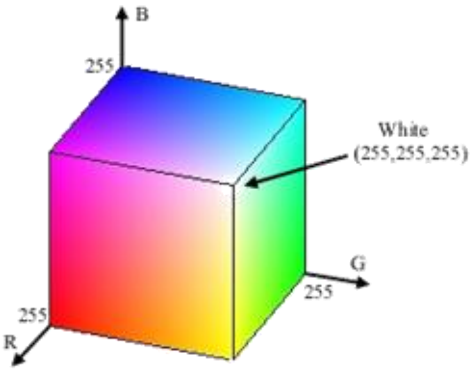
3) Coloring the mesh

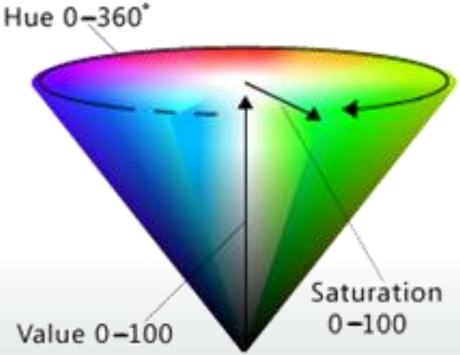
- Color vertices depending on height



Color spaces

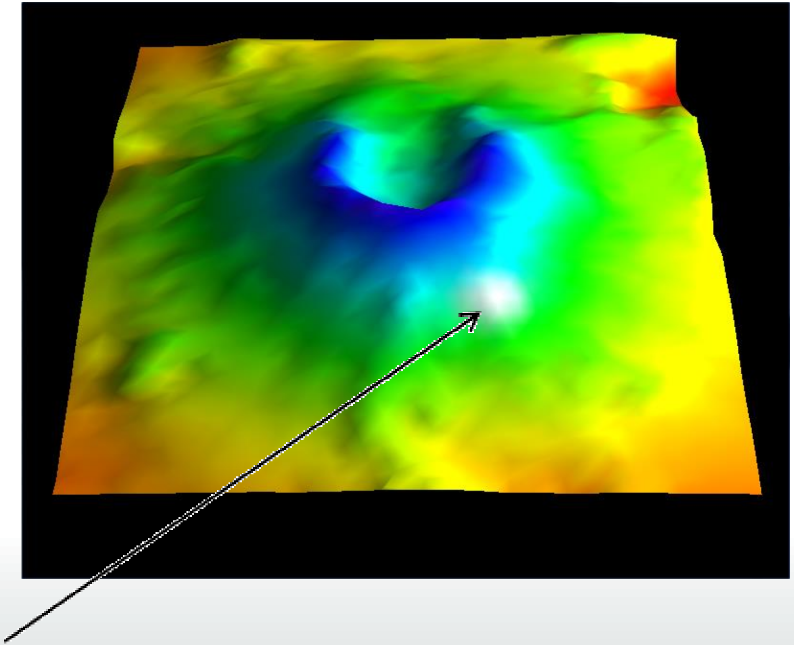
- RGB (red, green, blue)
  - normalized to [0, 1]
- HSV
  - hue (Farbton)
  - saturation (Sättigung)
  - value (Helligkeit)
- Transformation HSV to RGB provided





4) Adding color effects

- Modify shader to highlight point on mesh



interesting point

Questions

?

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References

- https://learnopengl.com/
- https://open.gl/
- http://www.opengl.org/registry