OpenGL 3.x Part 2: Textures and Objects

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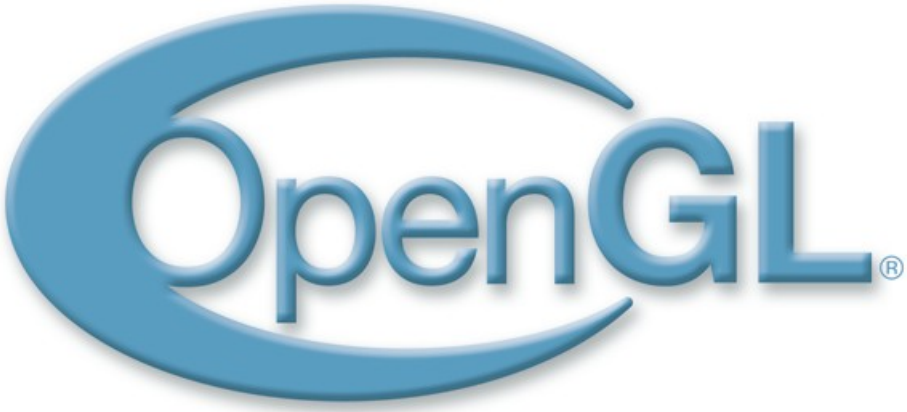
Topics for today

- OpenGL 3.x Part 1 - Revisited
- Textures
- Framebuffer Objects
- Vertexbuffer Objects
- Vertex Array Objects
- Uniform Buffer Objects
- Notes on CG2



Set up OpenGL-Project

Setup OpenGL Project

- Set up a MSVC-project as explained in the C++-lecture
- Version 1:
  - Include OpenGL-header:

```
#include <GL/gl.h> // basic OpenGL
```

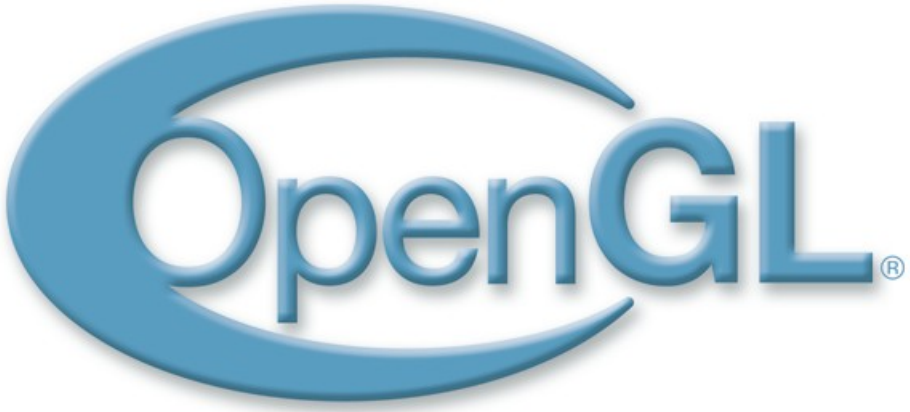
  - Link OpenGL-library “opengl32.lib”
  - Bind extensions manually
  - Cumbersome!

Setup OpenGL Project

- Better: Version 2:
  - Include GLEW-header:

```
#include <GL/glew.h>   // GLEW
```

  - Link OpenGL-library “opengl32.lib” and “glew32.lib”
  - Copy “glew32.dll” to bin folder
  - U’r ready to go. ☺



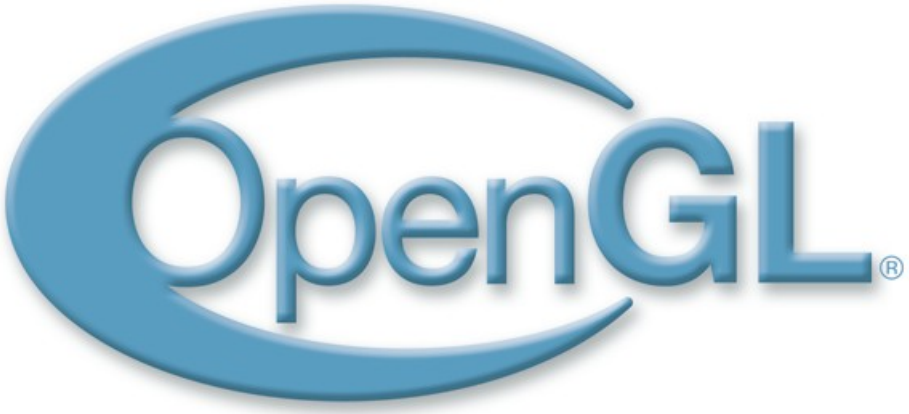
OpenGL-Object life-cycle revisited

OpenGL-Object life-cycle

- In OpenGL, all objects, like buffers and textures, are somehow treated the same way.
- On object creation and initialization:
  - First, create a *handle* to the object (in OpenGL often called a *name*). Do this ONCE for each object.
  - Then, *bind* the object to make it current.
  - *Pass data* to OpenGL. As long as the data does not change, you only have to do this ONCE.
  - *Unbind* the object if not used.

OpenGL-Object life-cycle

- On rendering, or whenever the object is used:
  - *Bind* it to make it current.
  - *Use* it.
  - *Unbind* it.
- Finally, when object is not needed anymore:
  - *Delete* object.
  - Note that in some cases you manually have to delete attached resources!
- NOTE: OpenGL-objects are **NOT** objects in an OOP-sense!

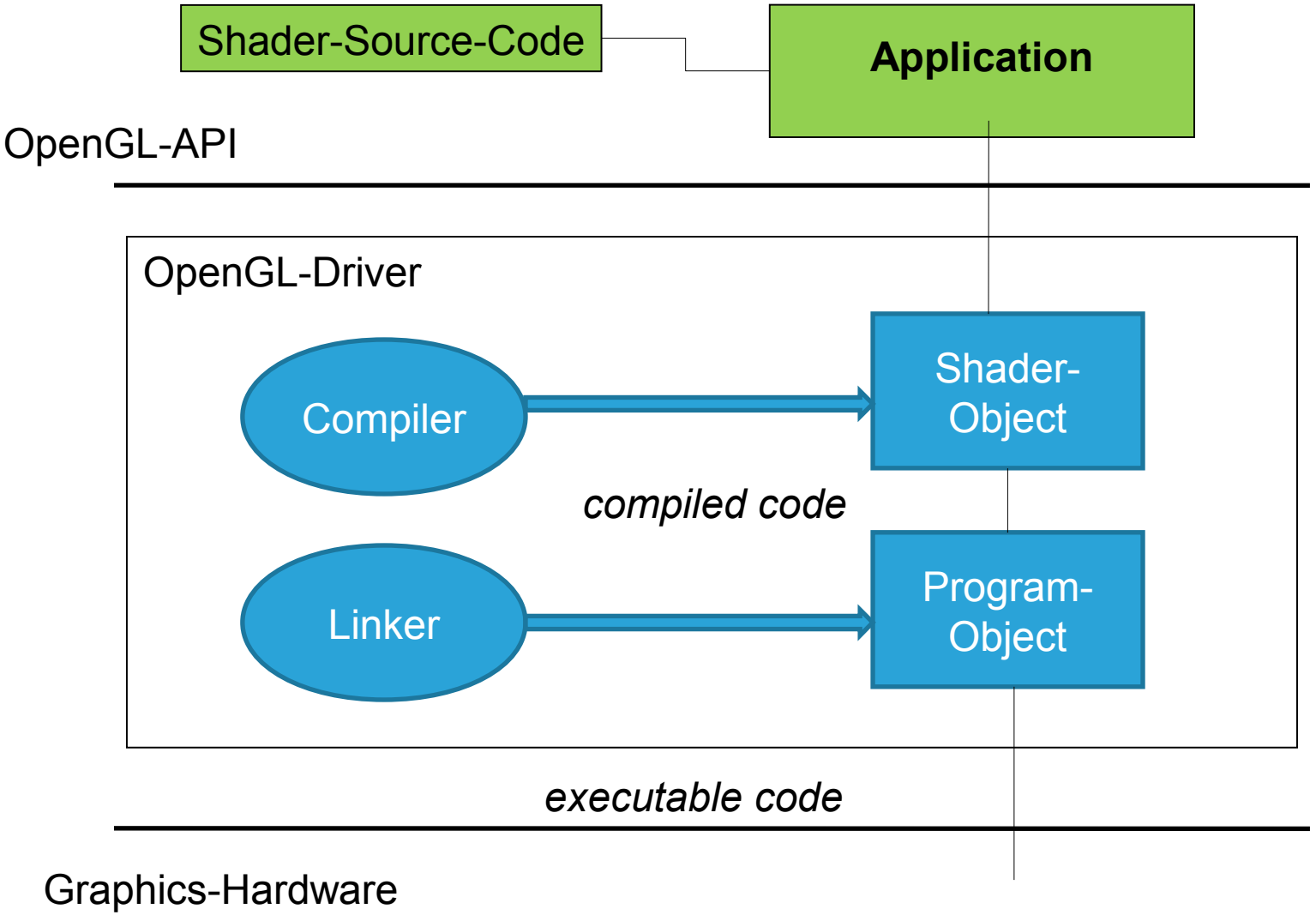


GLSL Shader revisited

What shaders are

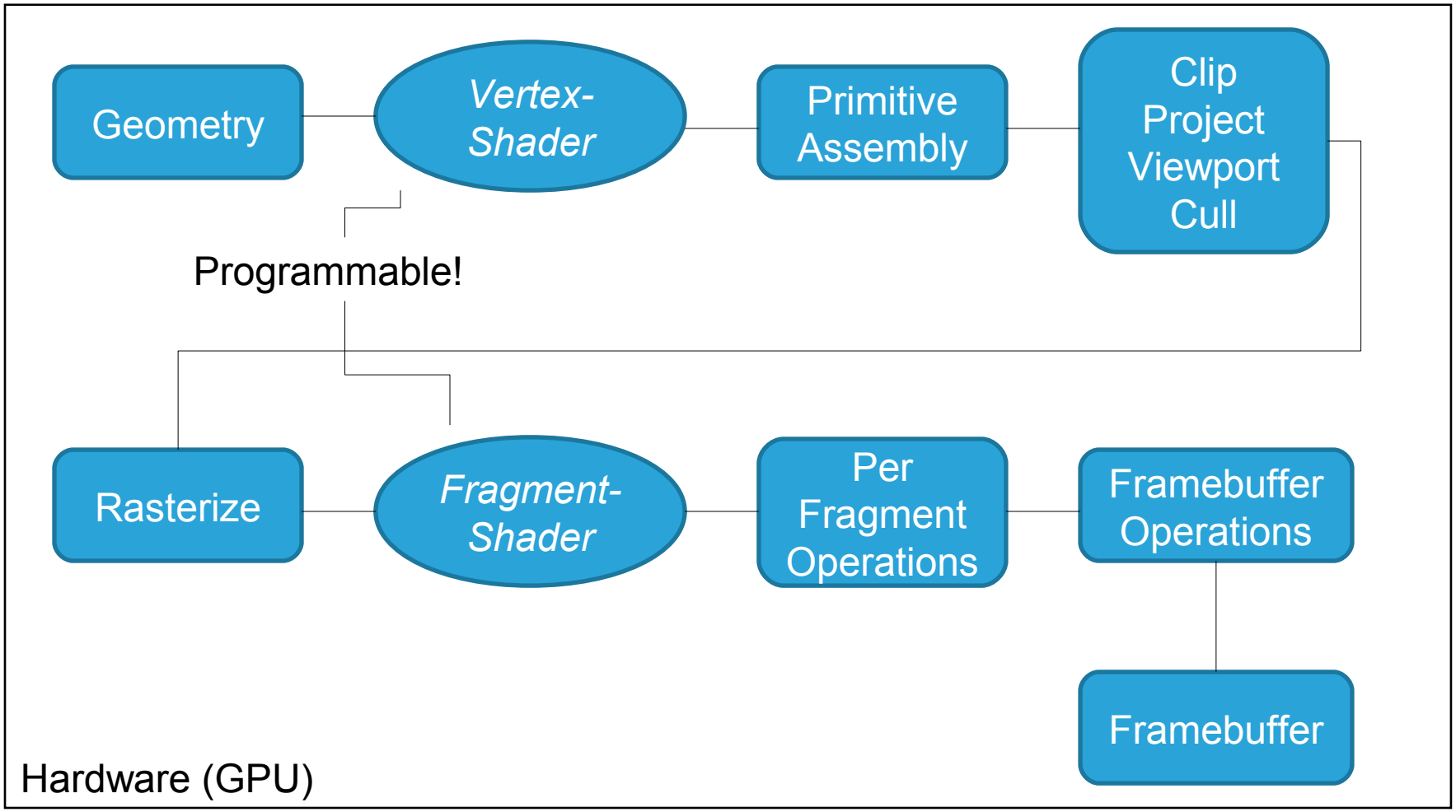
- Small C-like programs executed on the graphics-hardware
- Replace fixed function pipeline with shaders
- Shader-Types
  - Vertex Shader (VS): per vertex operations
  - Geometry Shader (GS): per primitive operations
  - Fragment shader (FS): per fragment operations
- Used e.g. for transformations and lighting

Shader-Execution model



Rendering-Pipeline

- OpenGL 3.x Rendering-Pipeline:



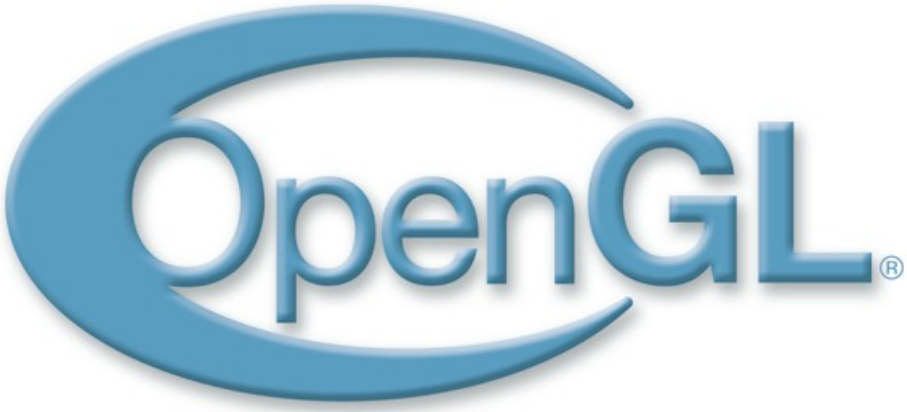
Rendering-Pipeline

- Remember:
  - The *Vertex-Shader* is executed ONCE per each vertex!
  - The *Fragment-Shader* is executed ONCE per rasterized fragment (~ a pixel)!
- A *Shader-Program* consists of both,
  - One VS
  - One FS

Example usage

- An application using shaders could basicially look like this:

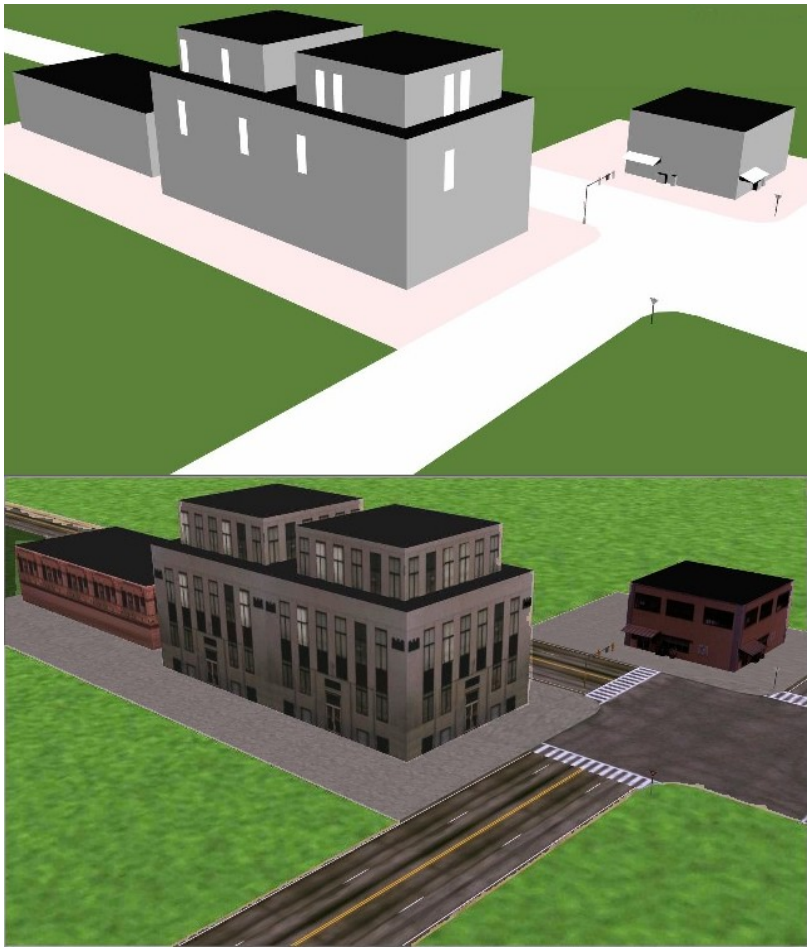
```
Load shader and initialize parameter-handles

Do some useful stuff like binding texture, activate
texture-units, calculate and update matrices, etc.

glUseProgram(programHandle);

Set shader-parameters
Draw geometry

glUseProgram(anotherProgramHandle);

...
```

Textures

Why Texturing?

- Idea: enhance visual appearance of plain surfaces by applying fine structured details



Textures

- First things first:
  - Load image-data from a file or
  - Generate it (i.e. procedurally)
- Use Library to read data from files:
  - GLFW: glfw.sourceforge.net
  - Devil: openil.sourceforge.net
- Enable Texturing in OpenGL:

```
// enable 2D-texturing
glEnable(GL_TEXTURE_2D);
```


Textures

- As usual in OpenGL:
  - Create texture-handle
  - Bind texture-handle to make it current
  - Pass data to OpenGL (next slide)

```
GLuint textureHandle;  // variable for our texture-handle

// get _one_ texture-handle
glGenTextures(1, &textureHandle);

// bind texture
glBindTexture(GL_TEXTURE_2D, textureHandle);  // could also
be 1D, 3D, ...
```

Textures

- Use `glTexImage*(...)` to pass loaded image-data stored in *`data`* to OpenGL
- If *`data`* is a null-pointer, the needed memory on the GPU will be allocated

```
int mipLevel = 0; int border = 0;
int internalFormat = GL_RGBA,
int width = 800; int height = 600;
int format = GL_RGBA;
int type = GL_UNSIGNED_BYTE;

// pass data for a 2D-texture
glTexImage2D(GL_TEXTURE_2D, mipLevel, internalFormat, width,
                    height, border, format, type, data);
```

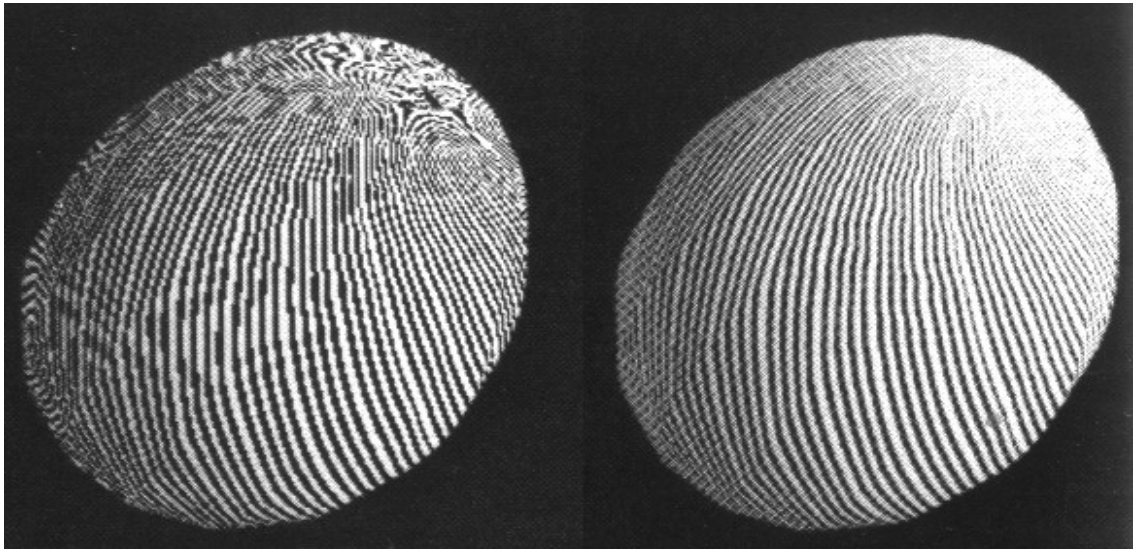

Textures

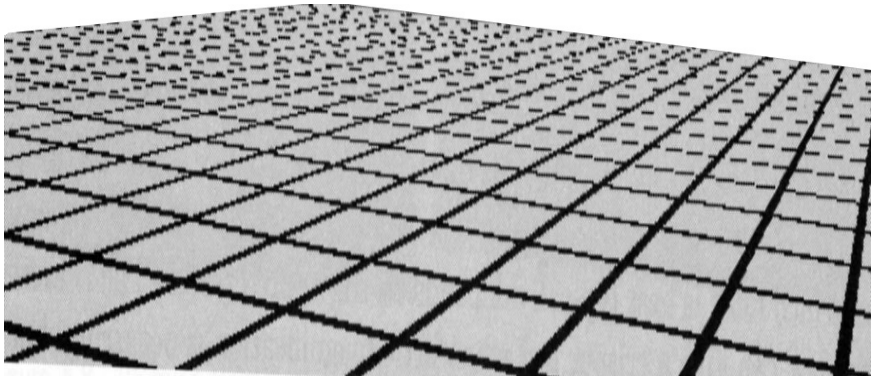
- As usual in OpenGL:
  - After using it, don’t forget to unbind
  - Finally, if not needed anymore, delete the texture

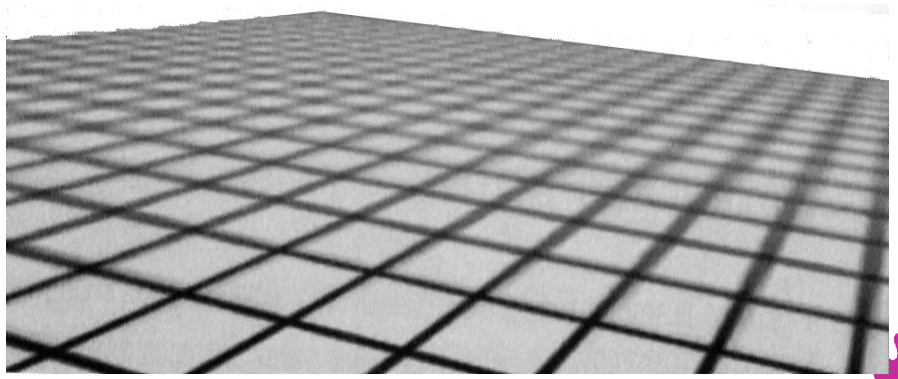
```
// unbind texture
glBindTexture(GL_TEXTURE_2D, 0);

...

// delete texture
glDeleteTextures(1, &textureHandle);
```


Texture Aliasing / Mipmaps

- Problem: One pixel in image space covers many texels
- Solution: Mipmaps







Mip-Maps

- (Pre-)Calculate different Levels of detail:
  - From original size (level 0) down to size of 1x1 pixel
- After data has been passed to OpenGL:
  - Use `glGenerateMipmap(…)` to generate a set of mipmaps for currently bound texture

```
// generate mipmaps for current bound 2D-texture
glGenerateMipmap(GL_TEXTURE_2D);
```

Texture Parameters

- Magnification-Filter:
  - Nearest vs. Linear

```
// set filter-mode for currently bound 2D-texture
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER,
                               filter);
For filter-types see specification!
```

Texture Parameters

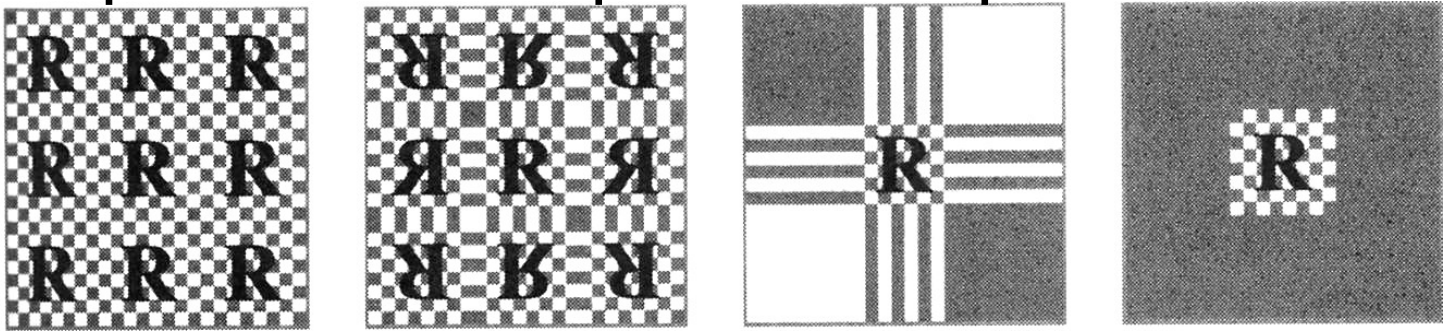
- Minification-Filter:
  - Without Mipmaps:
    - GL_*
  - With Mipmaps:
    - GL_*_MIPMAP_*
  - where * = NEAREST || LINEAR
  - **Recommended**:
    - Mipmaps with GL_LINEAR_MIPMAP_LINEAR

```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER,
                               filter);
```

Texture Parameters

- Wrap and clamp:
  - GL_CLAMP, GL_REPEAT, GL_CLAMP_TO_BORDER, GL_CLAMP_TO_EDGE, GL_MIRRORED_REPEAT

repeat mirror/repeat clamp border



```
glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_*,
                               filter); // * = S || T || R
```

Passing Textures to Shader

- Use different texture-units for different textures
- Use `uniform sampler*` variables in shader to access texture-units

```
// get location of sampler
GLuint texLocation = glGetUniformLocation(programHandle,
                                          "colorTexture");

// activate the texture-unit to which the texture should be bound to
glActiveTexture(GL_TEXTURE0 + textureUnit);
glBindTexture(GL_TEXTURE_2D, textureHandle);

// pass the texture unit (i.e., it's id) to the shader
glUniform1i(texLocation, textureUnit);
```

Using texture in shader

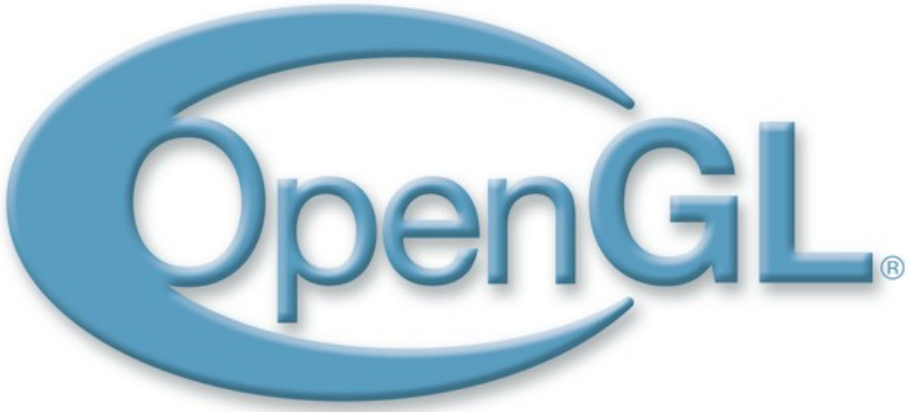
```
// Textures can be accessed with samplers
uniform sampler2D colorTexture;

// to access textures, coordinates are needed
in vec2 texCoord;

...

void main(void)
{
	...

	// Access texture at specified coordinates
	vec4 texel = texture2D(colorTexture, texCoord);

	...
}
```


Cleaning Up

- If texture is not needed anymore, delete it

```
glDeleteTextures(1, &texId); // delete texture
```

- References
  - OpenGL Registry, http://www.opengl.org/registry/
  - DGL Wiki, http://wiki.delphigl.com

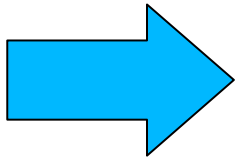


Framebuffer Objects
FBOs

What are FBOs used for?

- “Normal” rendering

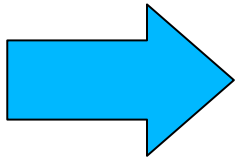
```
// GL Program
glBindBuffer(GL_ARRAY_BUFFER, vboHandle);
glVertexAttribPointer(vertexLocation, 4, GL_FLOAT,
GL_FALSE, 0, 0);
glEnableVertexAttribArray(vertexLocation);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, vboHandle)
glDrawElements(GL_TRIANGLES, 3, GL_UNSIGNED_INT, 0);
glDisableVertexAttribArray(vertexLocation);
glBindBuffer(GL_ARRAY_BUFFER, 0)
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, 0)
```

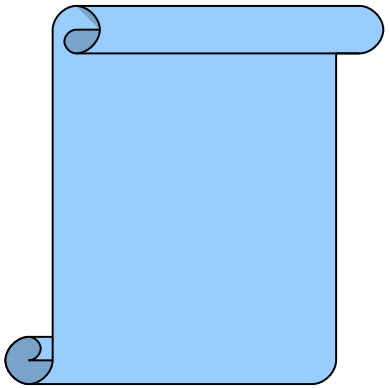


Screen

- With FBO

```
// GL Program
glBindBuffer(GL_ARRAY_BUFFER, vboHandle);
glVertexAttribPointer(vertexLocation, 4, GL_FLOAT,
GL_FALSE, 0, 0);
glEnableVertexAttribArray(vertexLocation);
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, vboHandle)
glDrawElements(GL_TRIANGLES, 3, GL_UNSIGNED_INT, 0);
glDisableVertexAttribArray(vertexLocation);
glBindBuffer(GL_ARRAY_BUFFER, 0)
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, 0)
```

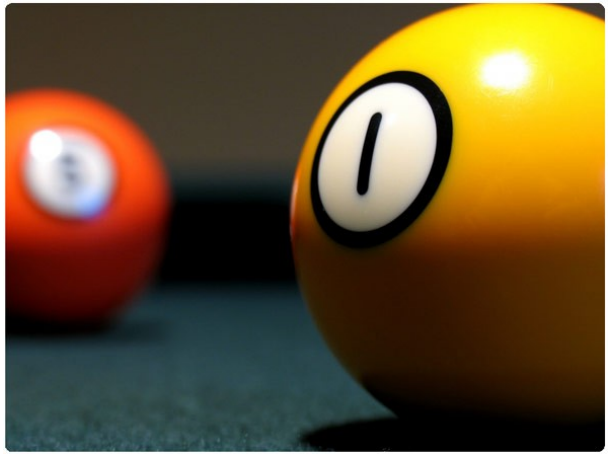




Texture

What are FBOs used for?

- Shadow Mapping
- Bloom
- HDR
- Motion Blur
- Depth of Field
- ...



What is an FBO?

- FBO is an encapsulation of attachments
- Attachments can be color- or renderbuffers
- Renderbuffers are objects that support off-screen rendering without an assigned texture
  - Depth- and stencil-buffer
- There can be more then one color attachment
  - Number depends on your HW
  - More than one is advanced stuff

Setting up an FBO

- Generating an FBO is done as usual in OpenGL:
  - First generate an OpenGL-”name”
  - Then bind it to do something with it

```
GLuint fbo; // this will store our fbo-name

// generate fbo
glGenFramebuffers(1, &fbo);

// bind FBO
glBindFramebuffer(GL_FRAMEBUFFER, fbo);
```


Setting up a renderbuffer

- An FBO on it's own isn't much
- Therefore: attach renderable objects
- So we want to add a depth buffer
- Again, create name and bind it:

```
GLuint depthbuffer; // this will store our db-name

// create a depth-buffer
glGenRenderbuffers(1, &depthbuffer);

// bind our depth-buffer
glBindRenderbuffer(GL_RENDERBUFFER, depthbuffer);
```


Creating storage-space

- We didn't create any storage for our render-buffer yet, so create it…
- …and attach it to our FBO

```
// create storage for our renderbuffer
glRenderbufferStorage(GL_RENDERBUFFER, GL_DEPTH_COMPONENT,
width, height);

// attach renderbuffer to FBO
glFramebufferRenderbuffer(GL_FRAMEBUFFER,
GL_DEPTH_ATTACHMENT, GL_RENDERBUFFER,  depthbuffer);
```


Attaching a texture to the FBO

- To render to a texture, we first need one
- We create it as usual
- Note: width and height are the same as those for the FBO and renderbuffers!

```
// create a texture
GLuint img;

glGenTextures(1, &img);
glBindTexture(GL_TEXTURE_2D, img);

glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA8, width, height,
    0, GL_RGBA, GL_UNSIGNED_BYTE, NULL);
```


Attaching a texture to the FBO (cont.)

- Simply attach the texture to the FBO

```
// attach texture to fbo
glFramebufferTexture2D(GL_FRAMEBUFFER,
    GL_COLOR_ATTACHMENT0, GL_TEXTURE_2D, img, 0);
```


Status checking

- Check, if the creation worked out correctly
- See specification for detailed error-codes

```
// fbo-creation error-checking
GLenum status =
    glCheckFramebufferStatus(GL_FRAMEBUFFER);

if (status != GL_FRAMEBUFFER_COMPLETE) {
    // error
}
```


Rendering to texture

- Bind FBO – render scene – unbind FBO
- Note: need to set viewport for FBO!

```
// bind fbo
glBindFramebuffer(GL_FRAMEBUFFER, fbo);
glViewport(0, 0, width, height);

// clear our color- and depth-buffer
glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

// render something here

// unbind fbo
glBindFramebuffer(GL_FRAMEBUFFER, 0);
```


Using the rendered to texture

- Just bind it like a regular texture
- Note: If you want to create MIP-maps from it, use glGenerateMipmap()! (For more see GameDev[1].)

```
// bind texture
glBindTexture(GL_TEXTURE_2D, img);
```


Cleaning up

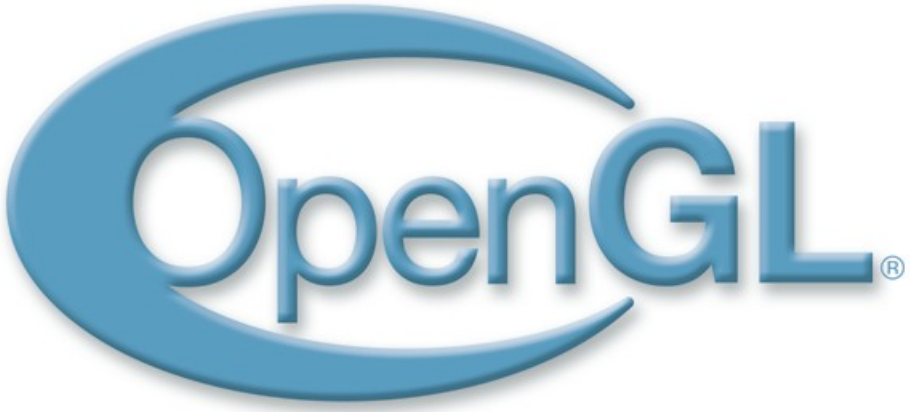
- If FBO is not needed anymore, delete it
- Delete also all with the FBO associated renderbuffers and textures!

```
// delete fbo
glDeleteFramebuffers(1, &fbo);

// delete renderbuffer
glDeleteRenderbuffers(1, &depthbuffer);

// delete texture
glDeleteTextures(1, &img);
```


That's all?

- With an FBO, you can render into more than one texture simultaneously
- For more check the tutorials at www.gamedev.net[1] about DrawBuffers

- References:
  - [1] Gamedev.net
    http://www.gamedev.net/reference/programming/features/fbo1/
    http://www.gamedev.net/reference/programming/features/fbo2/

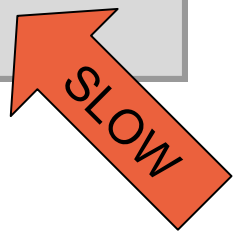


Vertexbuffer Objects
VBOs

Why use VBOs?

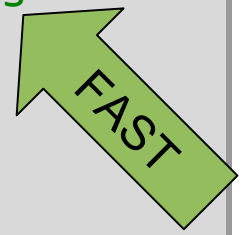
- Without VBOs

```
Init()
    Load model data from file



Render()
    Send model data to GPU
    Render model
```



- With VBOs

```
Init():
    Load model data from file
    Send model data to GPU and
        store it in VBOs

Render():
    Enable VBOs
    Render model
```



- Slow: Send model data often to GPU
- Fast: Send model data once to GPU
- Conclusion: Use VBOs

Create VBOs

- Generate VBO

```
glGenBuffers(1, &vboHandle)

glBindBuffer(target, vboHandle);

glBufferData(target, size, data, usage)
```

- *target*
  - GL_ARRAY_BUFFER
    - for vertex data: vertex position, normals, tex coords, tangent vector, ...
  - GL_ELEMENT_ARRAY_BUFFER
    - For index data

Create VBOs

- Generate VBO

```
glGenBuffers(1, &vboHandle)

glBindBuffer(target, vboHandle);

glBufferData(target, size, data, usage)
```

- *size*
  - used memory of data array
  - e.g. array_length * sizeof(float)
- *data*
  - Array containing vertex data

Create VBOs

- Generate VBO

```
glGenBuffers(1, &vboHandle)

glBindBuffer(target, vboHandle);

glBufferData(target, size, data, usage)
```

- *usage*
  - GL_STREAM_DRAW, GL_STREAM_READ, GL_STREAM_COPY, GL_STATIC_DRAW, GL_STATIC_READ, GL_STATIC_COPY, GL_DYNAMIC_DRAW, GL_DYNAMIC_READ, GL_DYNAMIC_COPY

Create VBOs

- usage

GL_STREAM_...	You will modify the data once, then use it once, and repeat this process many times.
GL_STATIC_...	You will specify the data only once, then use it many times without modifying it.
GL_DYNAMIC_...	You will specify or modify the data repeatedly, and use it repeatedly after each time you do this.
..._DRAW	The data is generated by the application and passed to GL for rendering.
..._READ	The data is generated by GL, and copied into the VBO to be used for rendering.
..._COPY	The data is generated by GL, and read back by the application. It is not used by GL.

- GL_STATIC_DRAW should be the most useful for CG2

Using VBOs

- Enable VBO and connect to Shader

```
// first get location
vertexLocation = glGetAttribLocation(programHandle,
"vertex");

// activate desired VBO
glBindBuffer(GL_ARRAY_BUFFER, vboHandle);

// set attribute-pointer
glVertexAttribPointer(vertexLocation, 4, GL_FLOAT,
GL_FALSE, 0, 0);

// finally enable attribute-array
glEnableVertexAttribArray(vertexLocation);
```


Using VBOs

- Render triangles with DrawArrays or with DrawElements (if you have indices)

```
glDrawArrays(GL_TRIANGLES, 0, 3);
```

```
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, vboHandle)

glDrawElements(GL_TRIANGLES, 3, GL_UNSIGNED_INT, 0);
```

- Disable VBOs

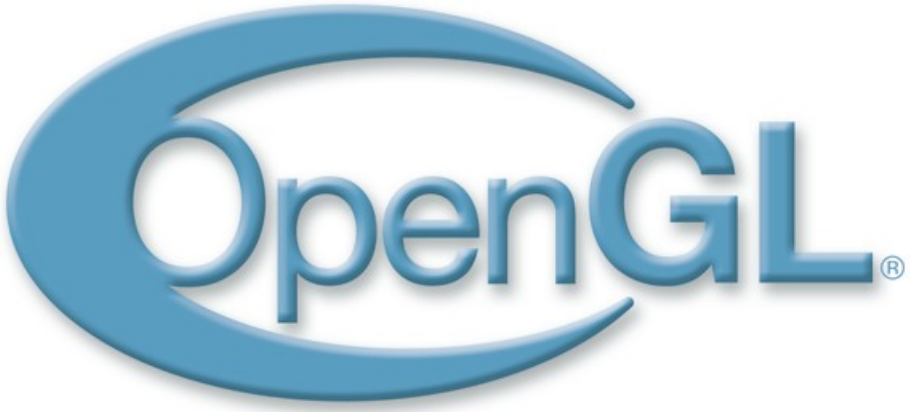
```
glDisableVertexAttribArray(vertexLocation);

glBindBuffer(GL_ARRAY_BUFFER, 0)
glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, 0)
```

Cleaning up

- If VBO is not needed anymore, delete it

```
glDeleteBuffers(1, &vboHandle)
```

- References
  - OpenGL, http://www.opengl.org/wiki/Vertex_Buffer_Objects
  - DGL Wiki, http://wiki.delphigl.com/index.php/Tutorial_Vertexbufferobject



Vertex Array Objects
VAOs

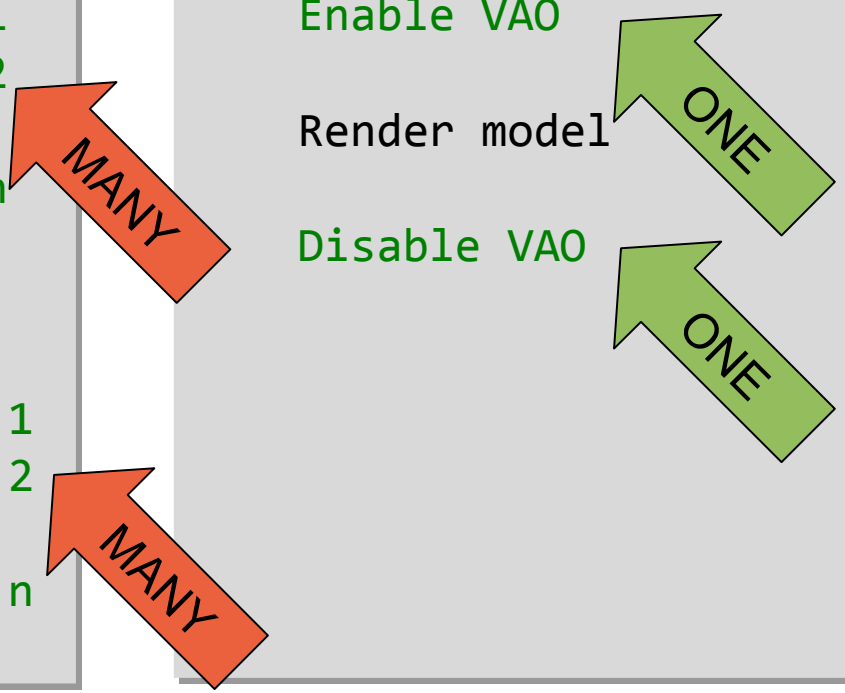
Why use VAOs?

- Without VAOs

```
Render()

    Enable vertex attribute 1
    Enable vertex attribute 2
    ...
    Enable vertex attribute n

    Render model

    Disable vertex attribute 1
    Disable vertex attribute 2
    ...
    Disable vertex attribute n
```

- With VAOs

```
Render():

    Enable VAO

    Render model

    Disable VAO
```



- VAOs are a collection of VBOs and attribute pointers

Create VAOs

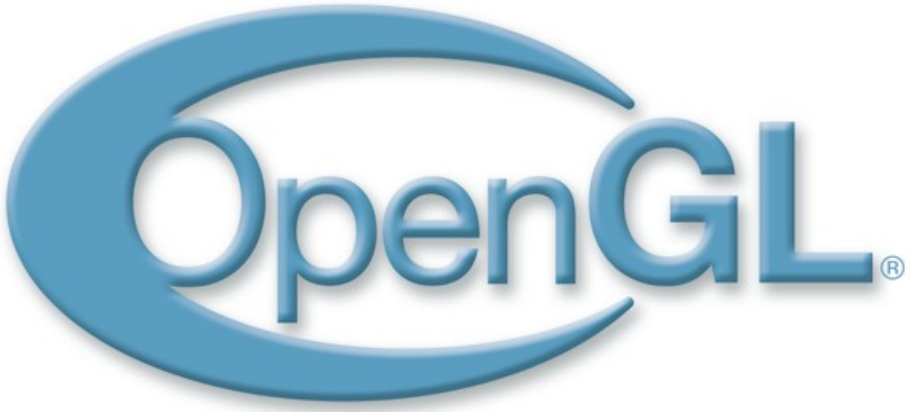
```
// Create and Bind VAO
glGenVertexArrays(1, &vaoId);
glBindVertexArray(vaoId);

// Bind VBO
glBindBuffer(GL_ARRAY_BUFFER, vbo1Id);
// Set Attribute Pointer
GLint loc = glGetAttribLocation(programHandle, "attrib1");
glEnableVertexAttribArray(loc);
glVertexAttribPointer(loc, 3, GL_FLOAT, GL_FALSE, 0, 0);

// Continue with other VBOs/AttribPointers
...

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

Rendering

```
// Enable Shader
glUseProgram(programHandle);

// Bind VAO
glBindVertexArray(vaoId);

// Set Render Calls
glDrawElements(GL_TRIANGLES, 3, GL_UNSIGNED_INT, 0);

// Unbind VAO
glBindVertexArray(0);

// Disable Shader
glUseProgram(0);
```


Notes

- Per combination of Shader and Model (VBOs) one VAO is needed
- Don't call glBindBuffer(GL_ELEMENT_ARRAY_BUFFER, 0); when a VAO is bound, or the VAO will loose the current set index vbo
- References:
  - OpenGL, http://www.opengl.org/registry/specs/ARB/vertex_array_object.txt

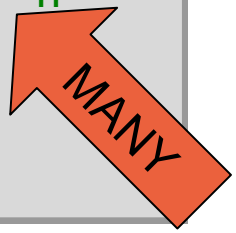


Uniform Buffer Objects
UBOs

Why use UBOs?

- Without UBOs

```
Render()

    Set uniform parameter 1
    Set uniform parameter 2
    ...
    Set uniform parameter n

    Render model
```



- With UBOs

```
Render():

    Enable UBO
    Pass uniform parameters
        at once

    Render model

    Disable UBO
```

Uniform Blocks

- In shaders: uniforms are grouped into blocks
- Blocks can have scope names
  - Access to uniform only via scope name

```
uniform MaterialBlock {
    vec3 ambient;
    vec3 diffuse;
    vec3 specular;
    float shininess;
};

void main(void)
{
    out_Color = ambient;
}
```

```
uniform MaterialBlock {
    vec3 ambient;
    vec3 diffuse;
    vec3 specular;
    float shininess;
} material;

void main(void)
{
    out_Color = material.ambient;
}
```


Uniform Blocks (cont.)

- Data layout should be specified
  - 3 layouts available: packed, shared, std140
  - Use std140

```
layout(std140) uniform MaterialBlock {
    vec3 ambient;
    vec3 diffuse;
    vec3 specular;
    float shininess;
};
```

- It is possible to choose between row-major and column-major for matrices

```
layout(row_major) uniform;
//Row major is now the default for matrices.
```


Data structure

- The same data structure is needed in both, the shader and the program

In the shader:

```
uniform MaterialBlock {
    vec3 ambient;
    vec3 diffuse;
    vec3 specular;
    float shininess;
};
```

In the program:

```
GLfloat material[] =
{
    0.3f, 0.3f, 0.3f, // ambient
    0.6f, 0.6f, 0.6f, // diffuse
    0.1f, 0.1f, 0.1f, // specular
    50                // shininess
};
```


Creating UBOs

- Start with getting an id for the UBO

```
GLuint uboId;
glGenBuffers(1, &uboId);
```

- Then get the index of the uniform block
  - This index helps us to identify a block

```
GLuint blockIdx;
blockIdx = glGetUniformBlockIndex(programHandle, "MaterialBlock");
```


Creating UBOs (cont.)

- You might wanna ask OpenGL for the size of the block
- The block size should be the same as the size of the data structure in the program

```
Glint blockSize;
glGetActiveUniformBlockiv(programHandle, blockIdx,
GL_UNIFORM_BLOCK_DATA_SIZE, &blockSize);

// Test if both data structures have the same size
if( sizeof(material) != blockSize )
        ERROR!
```


Creating UBOs (cont.)

- Create the buffer
- Choose DYNAMIC_DRAW since uniforms might be changed

```
glBindBuffer(GL_UNIFORM_BUFFER, uboId);
glBufferData(GL_UNIFORM_BUFFER, blockSize, NULL, GL_DYNAMIC_DRAW);
```


Rendering

- For rendering, just pass the data to the UBO
- The uniform blocks will automatically get the data since they are connected with the UBO

```
Enable Shader

Connect block/buffer to binding point (see next slide)

// Bind Buffer
glBindBuffer(GL_UNIFORM_BUFFER, uboId);
// And pass data to UBO
glBufferData(GL_UNIFORM_BUFFER, blockSize, material,
GL_DYNAMIC_DRAW);

Render Calls

Disable Shader
```

Connect to binding point

- At last, connect the uniform block and the uniform buffer to a binding point
- Binding points connect uniform blocks to uniform buffers
- Use different binding points for different blocks/buffers
  - Like you should use different texture units for different textures/samplers

```
GLuint bindingPoint = 0;
glBindBufferBase(GL_UNIFORM_BUFFER, bindingPoint, uboId);
glUniformBlockBinding(programHandle, blockIdx, bindingPoint);
```


Cleaning up

- If UBO is not needed anymore, delete it

```
glDeleteBuffers(1, &uboId);
```

- References
  - OpenGL, http://www.opengl.org/registry/specs/ARB/uniform_buffer_object.txt

Notes on CG2

Notes on CG2

- Textures/VBOs are mandatory
- You also have to implement (at least) one of the following:
  - FBOs
  - VAOs
  - UBOs