Introduction to OpenGL 3.x and Shader-Programming using GLSL Part 1

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Topics for today

- OpenGL 3.x and OpenGL Evolution
- OpenGL-Program-Skeleton and OpenGL-Extensions, GLEW
- State-machines and OpenGL-objects life-cycle
- Introduction to Shader-Programming using GLSL

OpenGL 3.x

What is OpenGL?

- OpenGL [1] = Open Graphics Library
- An open industry-standard API for hardware accelerated graphics drawing
- Implemented by graphics-card vendors
- As of 10th March 2010:
  - Current versions: OpenGL 4.0, GLSL 4.0
- Bindings for lots of programming-languages:
  - C, C++, C#, Java, Fortran, Perl, Python, Delphi, etc.

- Maintained by the Khronos-Group [2]:

KHRONOS GROUP

- Members:

What is OpenGL?

- Pros & Cons:
  - + Full specification freely available
  - + Everyone can use it
  - + Can use it anywhere (Windows, Linux, Mac, BSD, Mobile phones, Web-pages (soon), …)
  - + Long-term maintenance for older applications
  - + New functionality usually earlier available through Extensions
  - - Inclusion of Extensions to core may take longer
  - ? Game-Industry

Setup OpenGL Project

- Include OpenGL-header:

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

- Link OpenGL-library “opengl32.lib”
- If needed, also link other libraries (esp. GLEW, see later!).

OpenGL in more detail

- OpenGL-functions prefixed with “gl”:

```
glFunction{1234}{bsifd...}{v}(T arg1, T arg2, ...);

Example: glDrawArrays(GL_TRIANGLES, 0, vertexCount);
```

- OpenGL-constants prefixed with “GL_”:

```
GL_SOME_CONSTANT

Example: GL_TRIANGLES
```

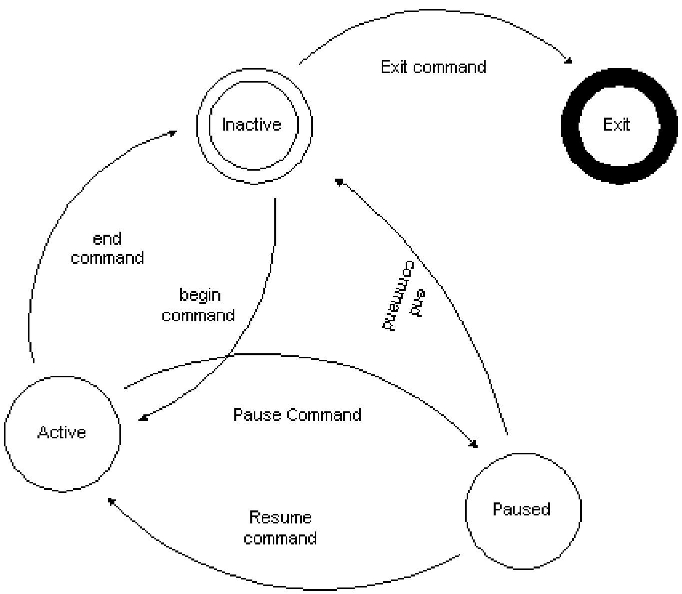
- OpenGL-types prefixed with “GL”:

```
GLtype

Example: GLfloat
```

OpenGL in more detail

- OpenGL is a **state-machine**
- Remember state-machines:
  - Once a state is set, it remains active until the state is changed to something else via a transition.
  - A transition in OpenGL equals a function-call.
  - A state in OpenGL is defined by the OpenGL-objects which are current.



OpenGL in more detail

- Set OpenGL-states:

```
glEnable(...);
glDisable(...);
gl*(...);  // several call depending on purpose
```

- Query OpenGL-states with Get-Methods:

```
glGet*(...);  // several calls available, depending on what to query
```

- For complete API see [3] and especially the quick-reference [4]!
  - Note: In the references the gl-prefixes are omitted due to readability!

OpenGL 2.1

- Released in August 2006
- Fully supported “fixed function” (FF) *)
- GLSL-Shaders supported as well
- Mix of FF and shaders was possible, which could get confusing or clumsy quickly in bigger applications
- Supported by all graphics-drivers

*) See “Introduction to Shader-Programming using GLSL” for more information on FF.

OpenGL 3.0

- Released in August 2008
- Introduced a deprecation model:
  - Mainly FF was marked deprecated
  - Use of FF still possible, but not recommend
- Also introduced Contexts:
  - Forward-Compatible Context (FWD-CC) vs.
  - Full Context
- With FWD-CC, no access to FF anymore, i.e. FF-function-calls create error “Invalid Call”.

OpenGL 3.0

- Furthermore, GLSL 1.3 was introduced
- Supported by recent Nvidia and ATI-graphics drivers.

OpenGL 3.1

- Released in March 2009
- Introduced GLSL 1.4
- Removed deprecated features of 3.0, but FF can still be accessed by using the "GL_ARB_compatibility"-extension.
- Supported by recent Nvidia and ATI-graphics drivers.

OpenGL 3.2

- Released in August 2009
- Profiles were introduced:
  - Core-Profile vs.
  - Compatibility-Profile
- With Core-Profile, only access to OpenGL 3.2 core-functions
- With Compatibility-Profile, FF can still be used
- Also introduced GLSL 1.5
- Supported by recent Nvidia and ATI-graphics drivers.

OpenGL 3.3

- Released on 10th March 2010
- Introduces GLSL 3.3
- Includes some new Extensions
- Maintains compatibility with older hardware
- Currently no drivers available
- Will be supported by Nvidia’s Fermi architecture immediately when Fermi will be released (scheduled: March 29th 2010).

OpenGL 4.0

- Released on 10th March 2010
- Introduces GLSL 4.0
- Introduces new shader-stages for hardware-tesselation.
- Adoption of new Extensions to Core.
- Currently no drivers available
- Will be supported by Nvidia's Fermi architecture immediately when Fermi will be released (scheduled: March 29th 2010).

OpenGL Evolution

- Overview of the evolution:
  - FF equals roughly in other versions:

2.1	3.0	3.1	3.2/3.3/4.0
FF	Deprecated Features and Non-FWD-CC	"GL_ARB_ compatibility" extension	Compatibility-Profile

- **Important!**
  See the **Quick-Reference Guide** [4] for the "current" (=3.2) OpenGL-API!

OpenGL Evolution

- Note that from OpenGL 3.x (FWD-CC || Core) onwards there is no more built-in:
  - Immediate-Mode
  - Matrix-Stacks and Transformations
  - Lighting and Materials
- You have to do “missing” stuff by yourself!
- That’s why there are shader. (More on shader later on.)

OpenGL Extensions

- Extensions are additional and newer functions which are not supported by the core of the current OpenGL-version.
- Collected and registered in the OpenGL Extension Registry [5].
- Extensions may eventually be adopted into the OpenGL core at the next version.

GLEW

- On Windows only OpenGL 1.1 supported natively.
- To use newer OpenGL versions, each additional function, i.e. ALL extensions (currently ~1900), must be loaded manually!
- → Lots of work!
- Therefore:
  Use GLEW [6] = OpenGL Extension Wrangler

GLEW

- Include it in your program and initialize it:

```
#include <GL/glew.h>  // include before other GL headers!
// #include <GL/gl.h>    included with GLEW already

void initGLEW()
{
   GLenum err = glewInit();  // initialize GLEW

   if (err != GLEW_OK)  // check for error
   {
      cout << "GLEW Error: " << glewGetErrorString(err);
      exit(1);
   }
}
```

GLEW

- Check for supported OpenGL version:

```
if (glewIsSupported("GL_VERSION_3_2"))
{
    // OpenGL 3.2 supported on this system
}
```

- To check for a specific extension:

```
if (GLEW_ARB_geometry_shader4)
{
    // Geometry-Shader supported on this system
}
```

No-FF in OpenGL 2.1

- If OpenGL 3.x context can not be created on your hardware one can use 2.1 without the „fixed function“-pipeline:
  - Be sure to use the latest drivers, libs et al and test if our OpenGL 3.x demo is running!
  - If it doesn‘t work out, you can use OpenGL 2.1 w/o FF.
  - This means…

No-FF in OpenGL 2.1

- Do **NOT** use the following in OpenGL 2.1:
  - Built-In matrix-functions/stacks:
    - `glMatrixMode, glMult/LoadMatrix, glRotate/Translate/Scale, glPush/PopMatrix…`
  - Immediate Mode:
    - `glBegin/End, glVertex, glTexCoords…`
  - Material and Lighting:
    - `glLight, glMaterial, …`
  - Attribute-Stack:
    - `glPush/PopAttrib, …`

No-FF in OpenGL 2.1

- some Primitive Modes:
  - `GL_QUAD*, GL_POLYGON`

- Do **NOT** use the following in GLSL 1.1/1.2:
  - `ftransform()`
  - All built-in gl_*-variables, except:
    - `gl_Position` in vertex-shader
    - `gl_FragColor, gl_FragData[]` in fragment-shader

No-FF in OpenGL 2.1

- The list may not be complete!
- To see what can be used and what not, see the quick-reference guide [4]!
  Everything written in ***black*** is allowed; ***blue*** is not allowed. (But we will not be too strict about that in CG2LU.)
- If you are not sure what you can use, do it the way it works for you and ASK US in the forum or by PM.

Notes

- Be sure to use the most recent version working on your hardware (and use: no FF || no deprecation || Full-Context || Core-Profile)!
- Be sure to see the 8-page **Quick-Reference Guide [4]** for the current OpenGL-API!
- Use the (complete) specification [3] for detailed information on a particular OpenGL-method!

References

- [1] OpenGL, http://www.opengl.org
- [2] Khronos Group, http://www.khronos.org
- [3] OpenGL Specification, http://www.opengl.org/registry
- [4] OpenGL 3.2 API Quick Reference Card, http://www.khronos.org/files/opengl-quick-reference-card.pdf
- [5] OpenGL Extension Registry, http://www.opengl.org/registry
- [6] GLEW – OpenGL Extension Wrangler Library, http://glew.sourceforge.net
- [7] DGL Wiki, http://wiki.delphigl.com

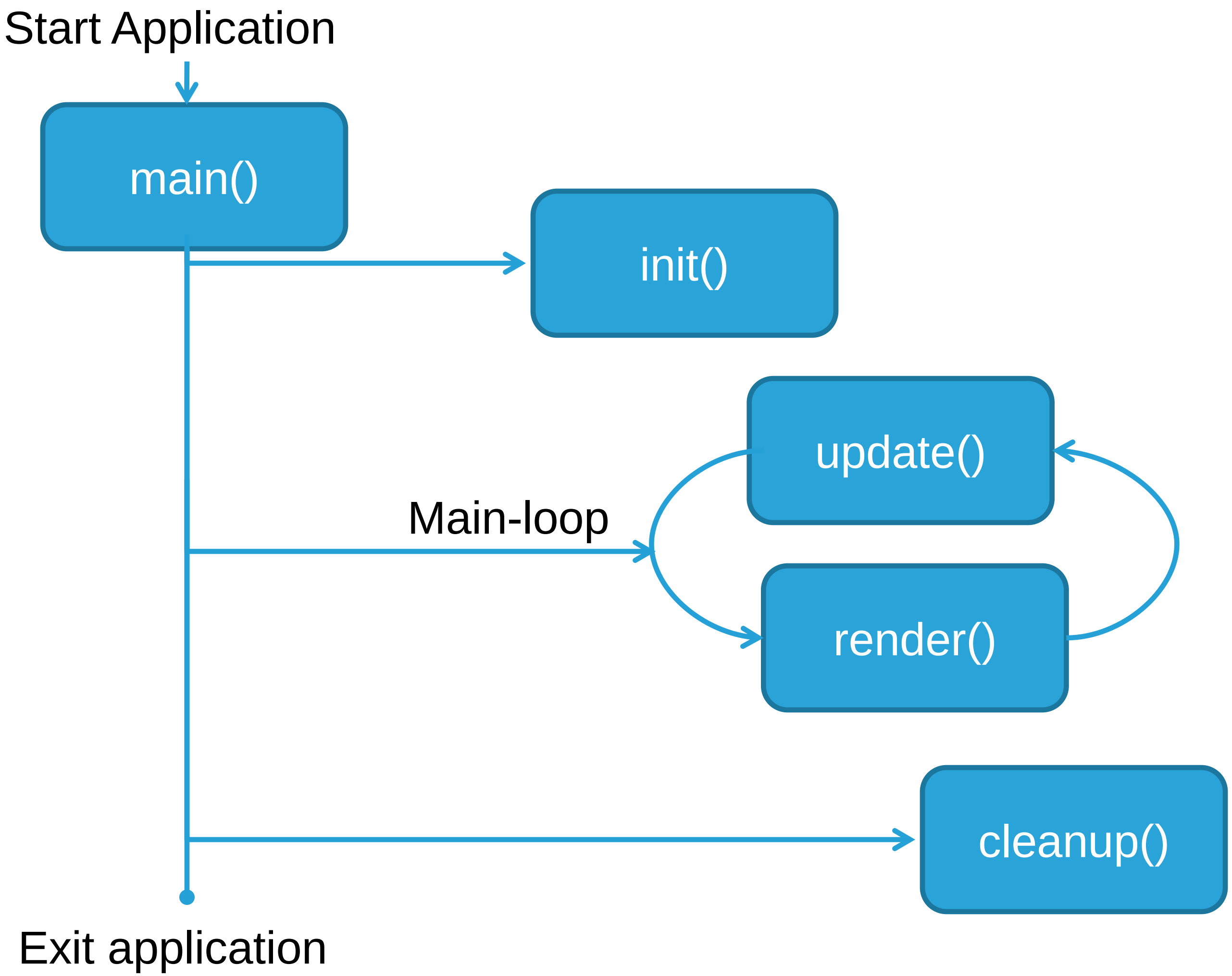
OpenGL Program-Skeleton

OpenGL Program Skeleton

- Typical OpenGL-program runs in a window (maybe fullscreen)
- Therefore: window-loop-based applications
- Independent of window-manager!
  - Can use: GLFW, SDL, WinAPI, (GLUT), Qt, …
  - Choose the one you like most.
  - We recommend using GLFW [1]. For more information about GLFW check the LU-HP [2]!

OpenGL Program Skeleton

- Typical OpenGL-Application:



OpenGL Program Skeleton

- main():
  - Program-Entry
  - Create window
  - Call init()
  - Start main window-loop
  - Call cleanup()
  - Exit application
- init():
  - Initialize libraries, load config-files, …
  - Allocate resources, preprocessing, …

OpenGL Program Skeleton

- update():
  - Handle user-input, update game-logic, …
- render():
  - Do actual rendering of graphics here!
  - Note: Calling render() twice without calling update() in between should result in the same rendered image!
- cleanup():
  - Free all resources

OpenGL Program Skeleton

- Example init()-function:

```
void init() {
    Create and initialize a window with depth-buffer and double-
    buffering. See your window-managers documentation.

    // enable the depth-buffer in OpenGL
    glEnable(GL_DEPTH_TEST);

    // enable back-face culling in OpenGL
    glEnable(GL_CULL_FACE);

    // define a clear color
    glClearColor(0.0f, 0.0f, 0.0f, 0.0f);

    // set the OpenGL-viewport
    glViewPort(0, 0, windowWidth, windowHeight);

    Do other useful things
}
```

OpenGL Program Skeleton

- The geometry of a 3D-object is stored in an array of vertices called *Vertex-Array*.
- Each vertex can have so called *Attributes*, like a Normal Vector and Texture-Coordinates.
- OpenGL also treats vertices as attributes!
- To render geometry in OpenGL, vertex-(attribute)-arrays are passed to OpenGL and then rendered.

OpenGL Program Skeleton

- To do so:
  - Query the attribute-location in the shader: *)

```
GLint vertexLocation = glGetAttribLocation(
          myShaderProgram, "in_Position");
```

  - Enable an array for the vertex-attribute:

```
glEnableVertexAttribArray(vertexLocation);
```

  - Then tell OpenGL which data to use:

```
glVertexAttribPointer(vertexLocation, 3, GL_FLOAT,
          GL_FALSE, 0, myVertexArray);
```

*) See “Introduction to Shader-Programming using GLSL” for more information on shader attribute-variables.

OpenGL Program Skeleton

- Draw ("render") the arrays:

```
glDrawArrays(GL_TRIANGLES, 0, 3);  // this does the actual drawing!
```

- Finally disable the attribute-array:

```
glDisableVertexAttribArray(vertexLocation);
```

- See the demo on the LU-HP for full program and code!

OpenGL Program Skeleton

- Example render()-function:

```
// triangle data
static GLfloat vertices[] = {-0.5, -0.333333, 0,   // x1, y1, z1
                             +0.5, -0.333333, 0,   // x2, y2, z2
                             +0.0, +0.666666, 0};  // x3, y3, z3
...

void render() {
    // clear the color-buffer and the depth-buffer
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    // activate a shader program
    glUseProgram(myShaderProgram);

    // Find the attributes
    GLint vertexLocation = glGetAttribLocation(
        myShaderProgram, "in_Position");
```

OpenGL Program Skeleton

```
    // enable vertex attribute array for this attribute
    glEnableVertexAttribArray(vertexLocation);

    // set attribute pointer
    glVertexAttribPointer(vertexLocation, 3, GL_FLOAT,
        GL_FALSE, 0, vertices);

    // Draw ("render") the triangle
    glDrawArrays(GL_TRIANGLES, 0, 3);

    // Done with rendering. Disable vertex attribute array
    glDisableVertexAttribArray(vertexLocation);

    // disable shader program
    glUseProgram(0);

    Swap buffers
}
```

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!

References

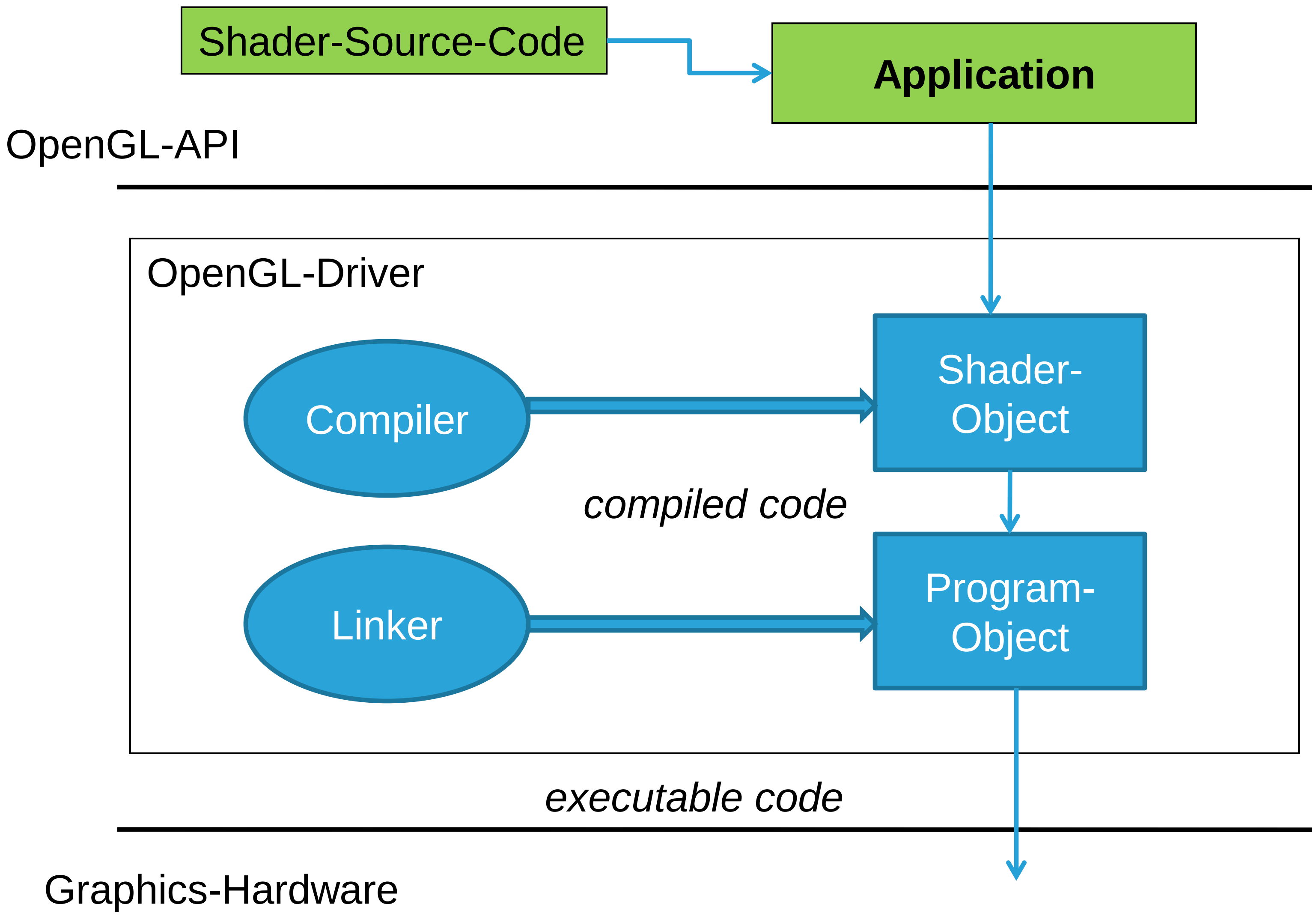
- [1] GLFW, http://glfw.sourceforge.net
- [2] Computergraphics 2 Lab, TU Vienna, http://www.cg.tuwien.ac.at/courses/CG23/LU.html

Introduction to Shader-Programming using GLSL

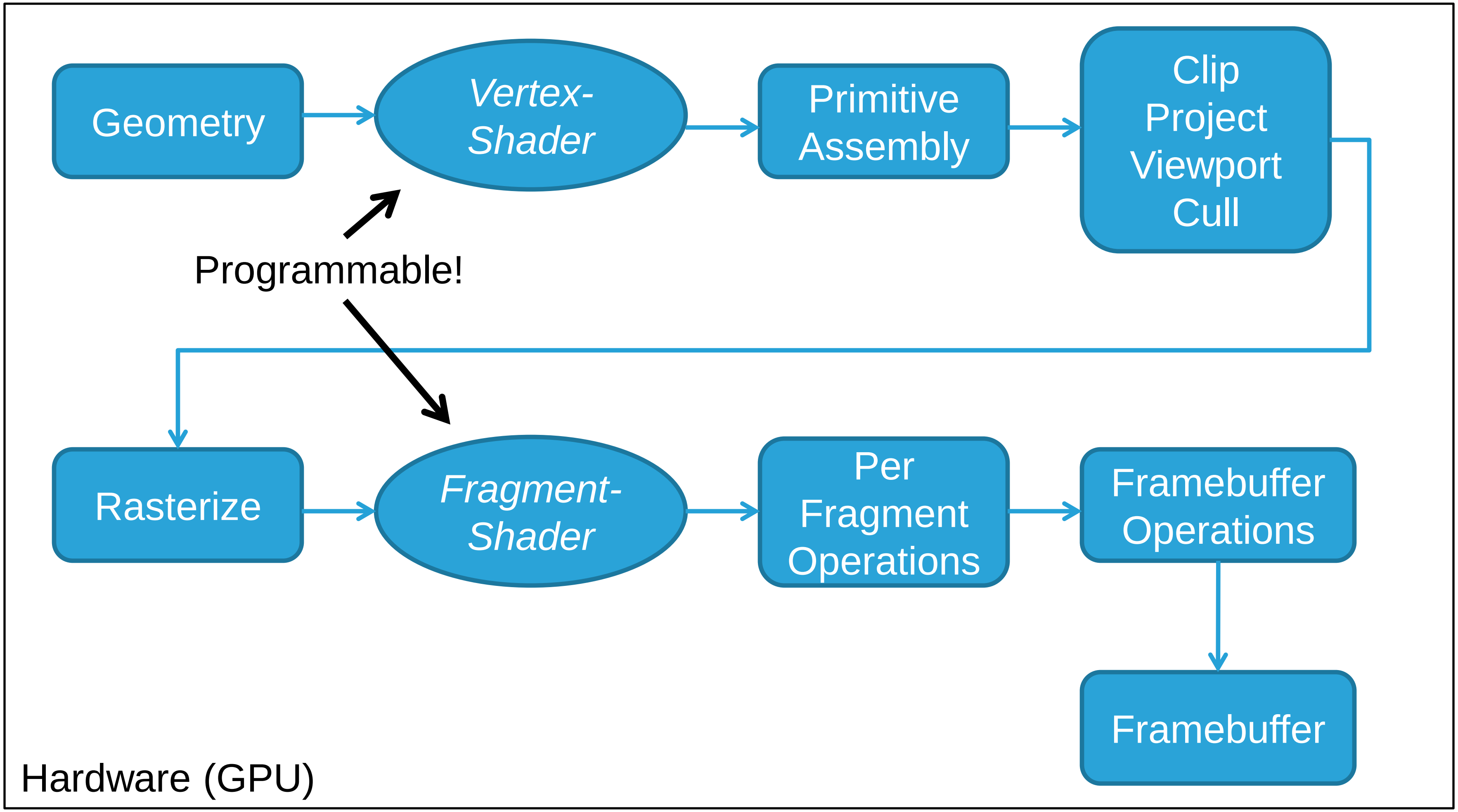
What shaders are

- 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



- 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

Setting up shaders and programs

- Compile shaders:

```
char* shaderSource;    // contains shadersource
int shaderHandle = glCreateShader(GL_SHADER_TYPE);
   // shader-types: vertex || geometry || fragment
glShaderSource(shaderHandle, 1, shaderSource, NULL);
glCompileShader(shaderHandle);
```

- Create program and attach shaders to it:

```
int programHandle = glCreateProgram();
glAttachShader(programHandle, shaderHandle); // do this
for vertex AND fragment-shader (AND geometry if needed)!
```

- Finally link program:

```
glLinkProgram(programHandle);
```

Enabling shaders

- Enable a GLSL program:

```
glUseProgram(programHandle); // shader-program now active
```

  - The active shader-program will be used until `glUseProgram()` is called again with another program-handle.
  - Call of `glUseProgram(0)` sets no program active (undefined state!).

Shader Error checking

- Do this for each shader to check for error:

```
bool succeeded = false;
glGetShader(shaderHandle, GL_COMPILE_STATUS, &succeeded);

if (!succeeded)  // check if something went wrong while compiling
{
    // get log-length
    int logLength = 0;
    glGetShader(shaderHandle, GL_INFO_LOG_LENGTH, &logLength);

    // get info-log
    std::string infoLog(logLength, '');
    glGetShaderInfoLog(shaderHandle, logLength, NULL, &infoLog[0]);

    // print info-log
    std::cout << "Shader compile error:\n\n" << infoLog <<
    std::endl;
}
```

Progam Error checking

- Do this for each program to check for error:

```
bool succeeded = false;
glGetProgram(programHandle, GL_LINK_STATUS, &succeeded);

if (!succeeded)  // check if something went wrong while compiling
{   // get log-length
    int logLength = 0;
    glGetProgram(programHandle, GL_INFO_LOG_LENGTH, &logLength);

    // get info-log
    std::string infoLog(logLength, '');
    glGetProgramInfoLog(programHandle, logLength, NULL,
        &infoLog[0]);

    // print info-log
    std::cout << "Program linking error:\n\n" << infoLog <<
    std::endl;
}
```

Basic shader layout

- Shader-Programs must have a `main()`-method
- Vertex-Shader outputs to at least `gl_Position`
- Fragment-Shader to custum defined output

```
//preprocessor directives like:
#version 150

variable declarations

void main()
{
   do something and write into output variables
}
```

Shader Parameter

- Shader variable examples:

```
uniform   mat4 projMatrix;    // uniform input
in        vec4 vertex;        // attribut-input
out       vec3 fragColor;     // shader output
```

- Three types:
  - *uniform*: does not change per primitive; read-only in shaders
  - *in*: VS: input changes per vertex, read-only; FS: interpolated input; read-only
  - *out*: shader-output; VS to FS; FS output.

Uniform Parameter

- Set uniform parameters in an application:

```
// first get location
projMtxLoc = glGetUniformLocation(programHandle,
    "projMatrix");

// then set current value
glUniformMatrix4fv(projMtxLoc, 1, GL_FALSE,
    currentProjectionMatrix);
```

  - First get the „location“ of the uniform-variable
  - Then set the current value
  - Can pass values to vertex- and fragment-shader

Attribute Parameter

- A vertex can have attributes like a normal-vector or texture-coordinates
- OpenGL also treats the vertex itself as an attribute
- We want to access our current vertex within our vertex-shader (as we used to do with gl_Vertex in former GLSL-versions):
  - Therefore, we declare in our vertex-shader:

```
in          vec4 vertex;          // vertex attribut
```

Attribute Parameter

- Now, there are two ways to pass data to this shader attribute-variable, depending on:
  - if you just have an array of vertices (*Vertex Array*),
  - or an VBO (*Vertex Buffer Object*, more about that next week!).
- To do so: Query shader-variable location
  - Enable vertex-attribute array
  - Set pointer to array
  - Draw and disable array

Attribute Parameter

- For a Vertex-Array, pass data like this:

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

// enable an array for the attribute
glEnableVertexAttribArray(vertexLocation);

// set attribute pointer
glVertexAttribPointer(vertexLocation, 3, GL_FLOAT,
    GL_FALSE, 0, myVertexArray);

// Draw ("render") the triangle
glDrawArrays(GL_TRIANGLES, 0, 3);

// Done with rendering. Disable vertex attribute array
glDisableVertexAttribArray(vertexLocation);
```

Attribute Parameter

- Setting attribute parameters with VBOs:

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

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

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

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

...
```

Fragment Output

- Since GLSL 1.3, `gl_FragColor` is depreceated.
- Therefore, need to define output on our own.
- Declare output variable in FS:

```
out          vec4 fragColor;       // fragment color output
```

- In the application, ***before*** linking the shader-program with `glLinkProgram()`, bind the FS-output:

```
glBindFragDataLocation(programHandle, 0, "fragColor");
```

- Finally assign a value to fragColor in the 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);

...
```

Conclusion and Tips

- Setup is more complicated nowadays, but more flexible.
- Use the info-log to debug!
- Use tools like gDebugger (see some LU-HP and forum!) for better debugging!
- See the specifications [1] for exact information on methods!
- Look at useful examples at [2]!
- Have fun with OpenGL! ☺

References

- [1] OpenGL Registry, http://www.opengl.org/registry/
- [2] Norbert Nopper, http://nopper.tv/opengl_3_1.html

Resources

- OpenGL „Red Book“
- OpenGL „Orange Book“
- OpenGL Registry, http://www.opengl.org/registry/
- DGL Wiki, http://wiki.delphigl.com
- Norbert Nopper, http://nopper.tv/opengl_3_2.html
- LightHouse 3D, http://www.lighthouse3d.com/opengl/
- NeHe, http://nehe.gamedev.net
- GameDev, http://www.gamedev.net
- Nvidia Developer pages, esp. the OpenGL SDK, http://developer.nvidia.com
- Graphic Remedy‘s gDEBugger, http://www.gremedy.com
  We have a academic license for it, so USE it!!

Questions?

Thanks for your time!