Advanced OpenGL (versions ≥3.0)

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Content

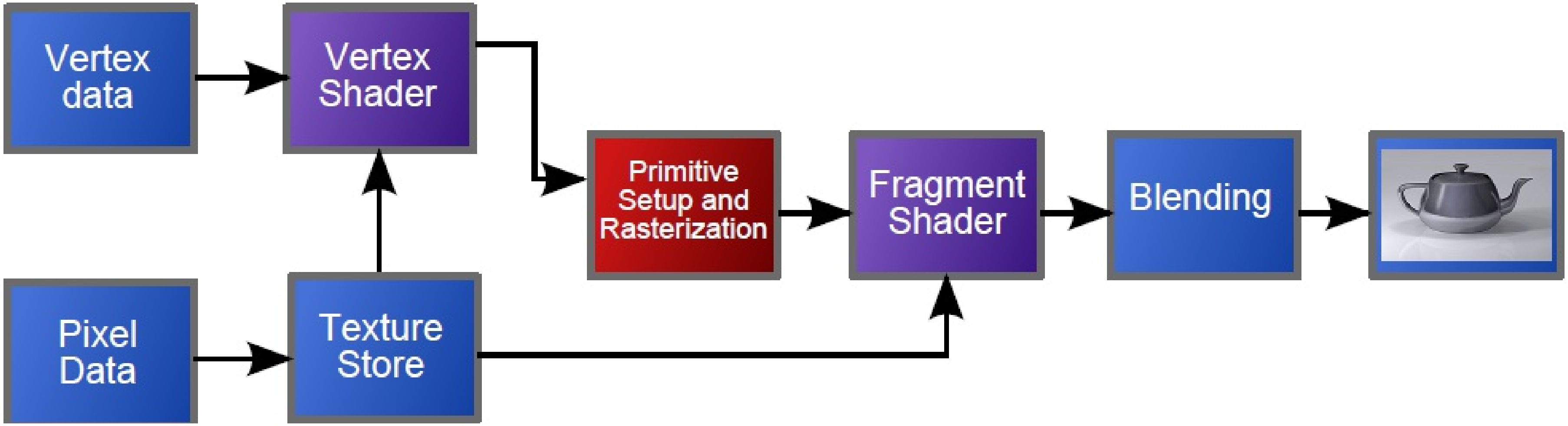
- OpenGL deprecation mechanisms
  - contexts, profiles
- New shader stages (geometry handling on GPU)
- Buffer Objects
- Shader Pipelines
- Shader subroutines
- Vertex Array Objects
- more little advances..

OpenGL contexts, deprecation

- “**deprecation model**” in OpenGL 3.0
  - removing outdated parts of the API
- **OpenGL context**
  - data structure in a driver holding all state information
  - context type defined in creation-time
- **Full**
  - complete functionality (even deprecated features)
- **Forward Compatible**
  - only non-deprecated features, similar to future OpenGL versions

Fixed–Functionality Pipeline

- **FFP deprecated** in OpenGL 3.1 (2009)
  - shaders are mandatory in current applications
  - FFP still usable in compatibility mode
- **server-side data** (stored on GPU: VBO, VAO, ..)



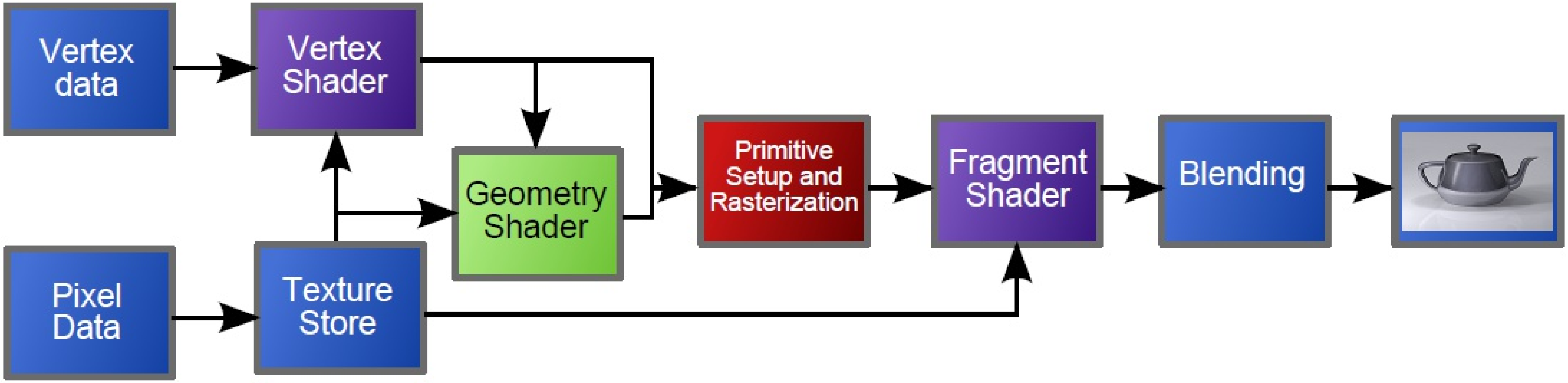
Context profiles

- introduced in OpenGL 3.2 (2009)
  - better control of compatibility/deprecation ..

Context type	**Profile**	**Description**
Full	core compatible	all from current version the whole OpenGL history
Forward Compatible	core	all “non-deprecated”

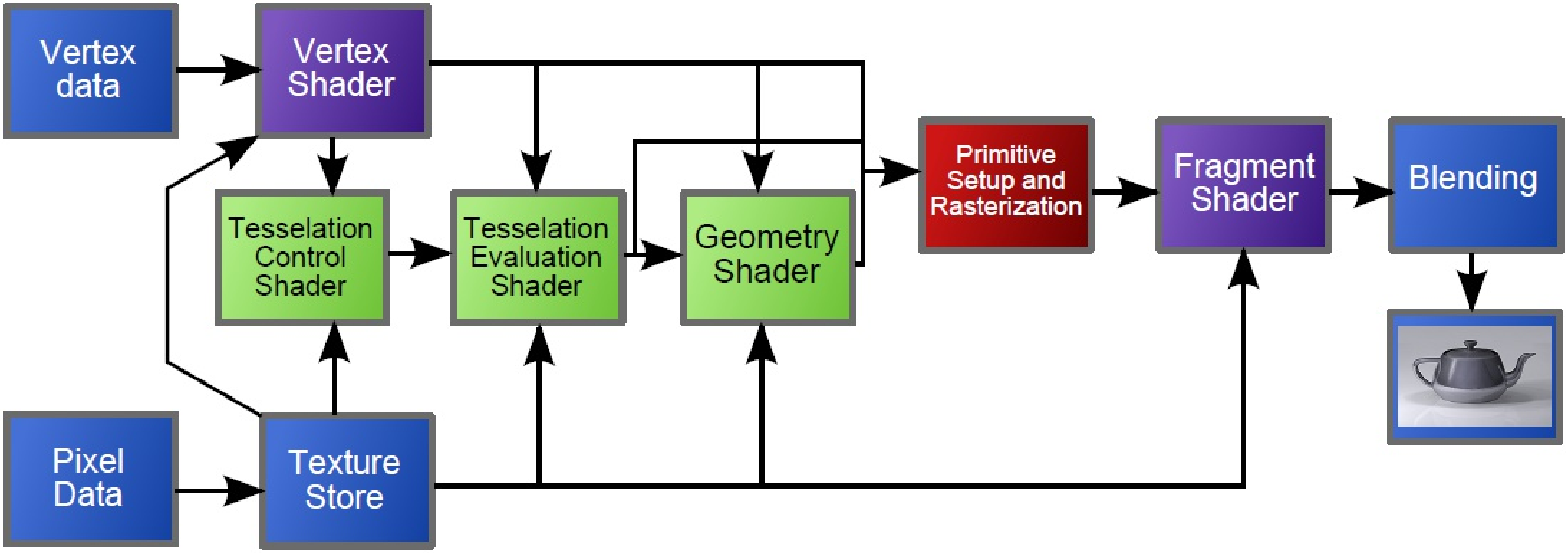
More GPU programming I

- new shader stage in OpenGL 3.2 (2009)
  - **geometry shader**
  - able to generate new geometry primitives on a GPU
  - optional shader stage



More GPU programming II

- two more shader stages in OpenGL 4.0 (March 2010)
  - **tesselation shaders**
    - **tesselation control- & evaluation- shader**
  - efficient but geometrically simple surface tesselation
  - optional



More GPU programming III

- **compute shaders** since OpenGL 4.3
  - reaction to CUDA, OpenCL

Shaders in OpenGL 4.x:

Shader type	Input
GL_VERTEX_SHADER	one *vertex*
GL_FRAGMENT_SHADER	one *fragment*
GL_TESSELATION_CONTROL_SHADER	input vertices of one *patch*
GL_TESSELATION_EVALUATION_SHADER	output vertices of one *patch* tesselation coordinates
GL_GEOMETRY_SHADER	vertices of one *primitive*
GL_COMPUTE_SHADER	data in buffers invocation indices

Buffer objects (version 4.x)

- **general unformatted memory** on GPU side
  - vertex data, pixel data, uniforms, compute inputs / results, ...
- **management** similar to textures/VBOs
  - glGenBuffers(), glDeleteBuffers(), glBindBuffer(), ..
- **Immutable Storage** (unable to reallocate)
  - glBufferStorage(), ..
  - pure in-OpenGL buffers, static data, image reading, ..
- **Mutable Storage**
  - glBufferData(), ..

Immutable Storage

- always valid operations (**server-side**)
  - writing by rendering pipeline
    - Transform feedback, Image load store, Atomic counter, Shader storage buffer storage
  - clearing / copying / invalidating the buffer (server-side)
  - asynchronous pixel transfer into the buffer (pure-OpenGL)
  - glGetBufferSubData() is always available (GPU → CPU)
- **client-side behavior** controlled by flags:
  - mapping: **GL_MAP_READ_BIT**, **GL_MAP_WRITE_BIT**, **GL_PERSISTENT_BIT** (mapped & used simultaneously)
  - **GL_COHERENT_BIT** (explicit barrier not needed)
  - **GL_CLIENT_STORAGE_BIT** (client-side buffer)

Popular settings

- **pure in-OpenGL** buffers
  - pipeline data, flags set to zero
- **static data** buffers
  - e.g. input data from the application (set once – used many times), flags set to zero
- **image reading** buffers
  - for asynchronous pixel transfer operation (Pixel Buffer Objects), flags = **`GL_MAP_READ_BIT`**
- **modifiable** buffers
  - by setting flags = **`GL_MAP_WRITE_BIT`**, you promise not to use glBufferSubData()

Mutable Storage

- `glBufferData()`
  - update data + **reallocate the buffer !**
  - hints (usage): **DRAW**, **READ**, **COPY**
  - hints (frequency of a change): **STATIC**, **DYNAMIC**, **STREAM**
- `glBufferSubData()`
  - setting data **without reallocating** the buffer
- `glClearBufferSubData()` / `glClearBufferData()`
  - fills the part/whole buffer with the given pixel value
- `glCopyBufferSubData()`
- `glMapBufferRange()`

Selected Buffer Object Targets

- **GL_ARRAY_BUFFER**
  - vertex data
- **GL_ELEMENT_ARRAY_BUFFER**
  - vertex indices
- **GL_COPY_READ_BUFFER** / **GL_COPY_WRITE_BUFFER**
  - no explicit meaning
- **GL_PIXEL_UNPACK_BUFFER** / **GL_PIXEL_PACK_BUFFER**
  - async pixel transfer operations
- **GL_TEXTURE_BUFFER**
- **GL_TRANSFORM_FEEDBACK_BUFFER**
- **GL_UNIFORM_BUFFER**

Indexed targets

- `glBindBufferRange( target, index, buffer, offset, size )`
  - internally: target[index]
  - data: buffer + offset … buffer + offset + size
  - `offset` is in bytes
  - `size` is in bytes and can be zero (unlimited)
- **Uniform Buffer Object**
  - uniforms stored in one GPU object
  - efficiency
  - GLSL: **uniform blocks** (vs. storage blocks)

Shader pipelines (OpenGL ≥4.0)

- independent shader program with only **one stage**
  - `glProgramParameteri( program, GL_PROGRAM_SEPARABLE, GL_TRUE )`
- `glGenProgramPipelines()` / `glDelete*()`
- `glBindProgramPipeline(pipeline)`
  - use the pipeline for subsequent calls, use it for rendering
- `glUseProgramStages(pipeline,stages,program)`
  - configure (import) individual stage[s] from program
- `glActiveShaderProgram(pipeline,program)`
  - activate the program for the pipeline

Shader subroutines I

```
in vec3 n;
out vec4 fragColor;
uniform int mode;

vec4 AmbientColor ( vec3 n )
{ … }
vec4 DiffuseColor ( vec3 n )
{ … }

void main ()
{
  if ( mode == 0 )
    fragColor = AmbientColor( n );
  else
    fragColor = DiffuseColor( n );
}
```

Shader subroutines II

- more GPU-friendly solution using **shader subroutines** (“function pointers”)

```
#version 400 core

subroutine vec4 LightFunc ( vec3 n ); // subroutine type

subroutine (LightFunc) vec4 AmbientColor ( vec3 n ) { … }
subroutine (LightFunc) vec4 DiffuseColor ( vec3 n ) { … }

subroutine uniform LightFunc matShader; // current subrout

void main ()
{
  matShader( n );
}
```

Shader subroutines III – application

```
// subroutine indices:
GLuint ambient = glGetSubroutineIndex( program,
                 GL_FRAGMENT_SHADER, "AmbientColor" );
GLuint diffuse = glGetSubroutineIndex( program,
                 GL_FRAGMENT_SHADER, "DiffuseColor" );

// matShader subroutine uniform index
GLuint materialShaderLoc = glGetSubroutineUniform( program,
                           "matShader");

// set subroutine indices:
GLint numSubroutines;
glGetIntegerv( GL_ACTIVE_SUBROUTINE_UNIFORM_LOCATIONS,
               &numSubroutines );
GLuint* indices = new Gluint[ numSubroutines ];
indices[ materialShaderLoc ] = ambient;
glUniformSubroutinesuiv( GL_FRAGMENT_SHADER,
                         numSubroutines, indices );
```

Vertex Array Objects (VAOs)

- more compact approach to setting/usage of geometry & index data
  - all **VBO bindings** concentrated in one call
- `glGenVertexArrays()`
- `glBindVertexArray()`
  - update all the VBOs associated with it, including index buffer
- `glBindVertexArray()` - sets everything up in one call
  - subsequent `glDraw*()` calls use the current VAO

Survey of more advances I

- **'double' arithmetic** (OpenGL 4.0)
  - not common on commodity GPUs
  - specialized GPU cards for computing (NVIDIA Tesla..)
- **`GL_ARB_debug_output`** (4.1)
  - callback-function based error handling, can replace `glGetError()`
- **`GL_ARB_get_program_binary`** (4.1)
  - not portable feature!
  - useful for shader-binary caching..?

Survey of more advances II

- **`GL_ARB_shader_image_load_store`** (4.2)
  - loading & storing of texture data
  - atomic texture operations
- **atomic counters** (4.2)

Sources

- Tomas Akenine-Möller, Eric Haines: ***Real-time rendering, 3rd edition***, A K Peters, 2008, ISBN: 9781568814247
- OpenGL Architecture Review Board: ***OpenGL Programming: The Official Guide to Learning OpenGL***, Addison-Wesley, latest edition (8th edition for the OpenGL 4.1)
- The Khronos Group: ***The OpenGL Graphics System: A Specification (Core/Compatibility profile)***, `http://www.opengl.org/registry/`