OpenGL (and Friends) in the Future
A Notional View

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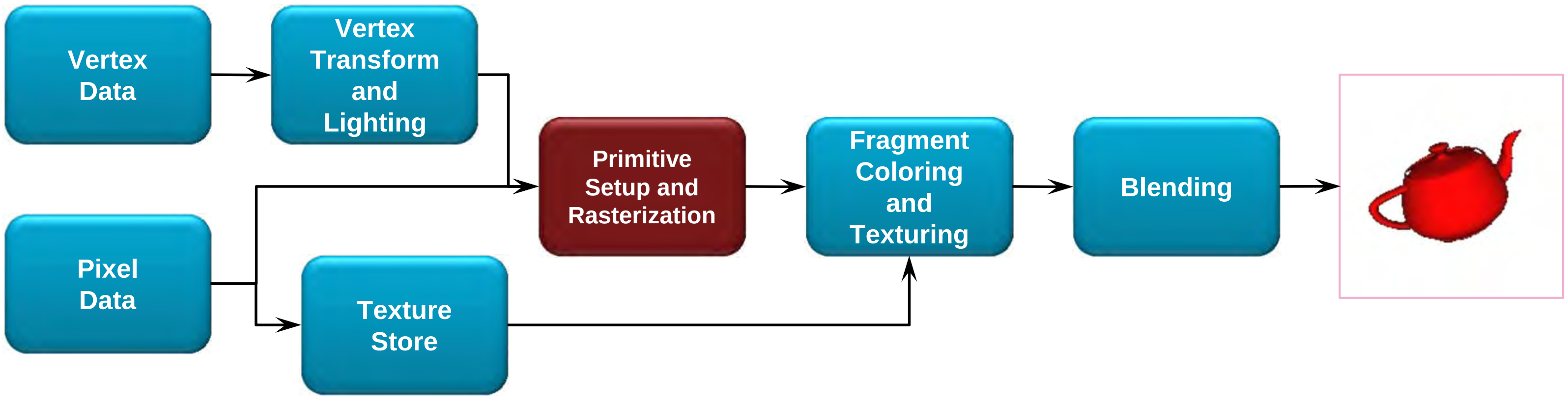
First: A Retrospective

The Evolution of the OpenGL Pipeline

In the Beginning …

- OpenGL 1.0 was released on July 1st, 1994
- Its pipeline was entirely *fixed-function*
  - the only operations available were fixed by the implementation



- The pipeline evolved, but remained fixed-function through OpenGL versions 1.1 through 2.0 (released Sept. 7th, 2004)

Fixed-Function Application Interface

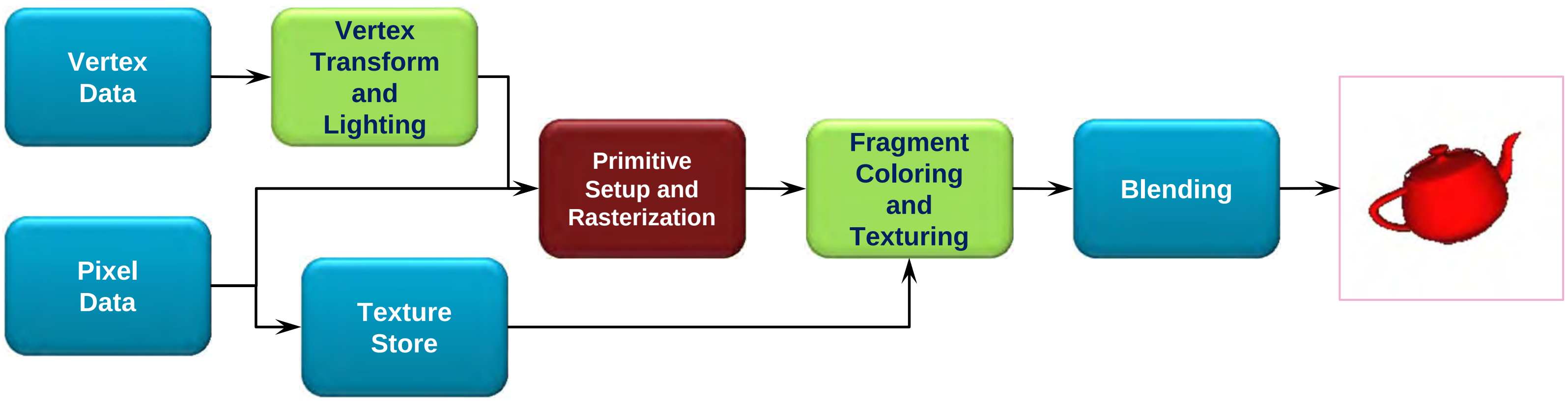
```
glColor3f( … );
glBegin( GL_TRIANGLES );
  glVertex3f( … );
  glVertex3f( … );
  glVertex3f( … );
glEnd();
```

```
GLfloat data[] = { … };
glColor3f( … );
glVertexPointer( 3, GL_FLOAT,
   0, data );
glDrawArrays( GL_TRIANGLES, 0, 3 );
```

- Everything the API was capable of is accessed through function calls
- Lots of fine-grained memory writes
  - when this API was developed, most computer systems directly mapped device registers and poked values into them
  - API made sense for systems of that time

The Start of the Programmable Pipeline

- OpenGL 2.0 (officially) added programmable shaders
  - *vertex shading* augmented the fixed-function transform and lighting stage
  - *fragment shading* augmented the fragment coloring stage
- However, the fixed-function pipeline was still available



- The pipeline remained the same until OpenGL 3.1 (released March 24th, 2009)

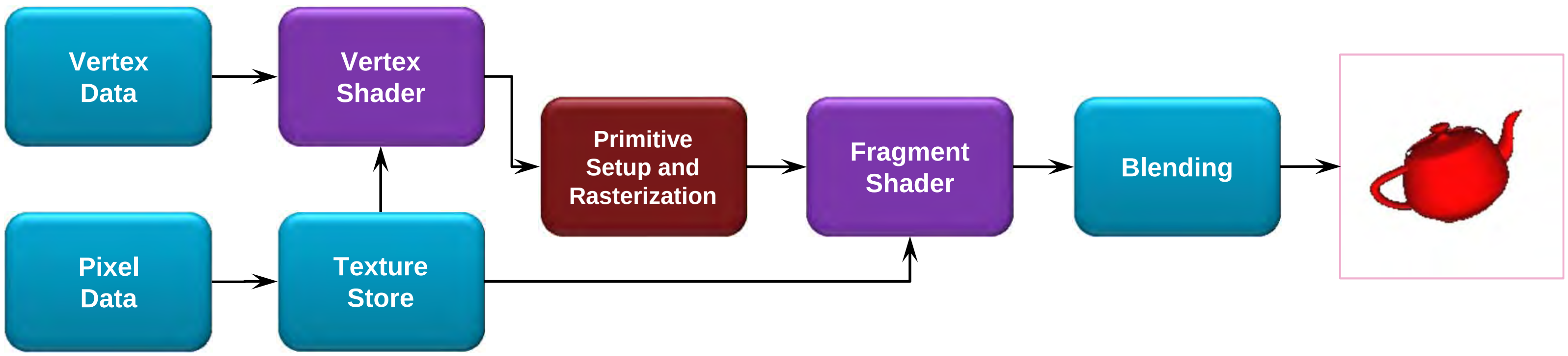
An Evolutionary Change

- OpenGL 3.0 introduced the *deprecation model*
  - the method used to remove features from OpenGL
- Introduced a change in how OpenGL contexts are used
  - an OpenGL *context* is the driver data structure that stores OpenGL state information (e.g., textures, shaders, etc.)
  - two types of contexts became available

Context Type	Description
Full	Includes all features (including those marked deprecated) available in the current version of OpenGL
Forward Compatible	Includes all non-deprecated features (i.e., creates a context that would be similar to the next version of OpenGL)

The Exclusively Programmable Pipeline

- OpenGL 3.1 removed(*) the fixed-function pipeline
  - programs were required to use only shaders

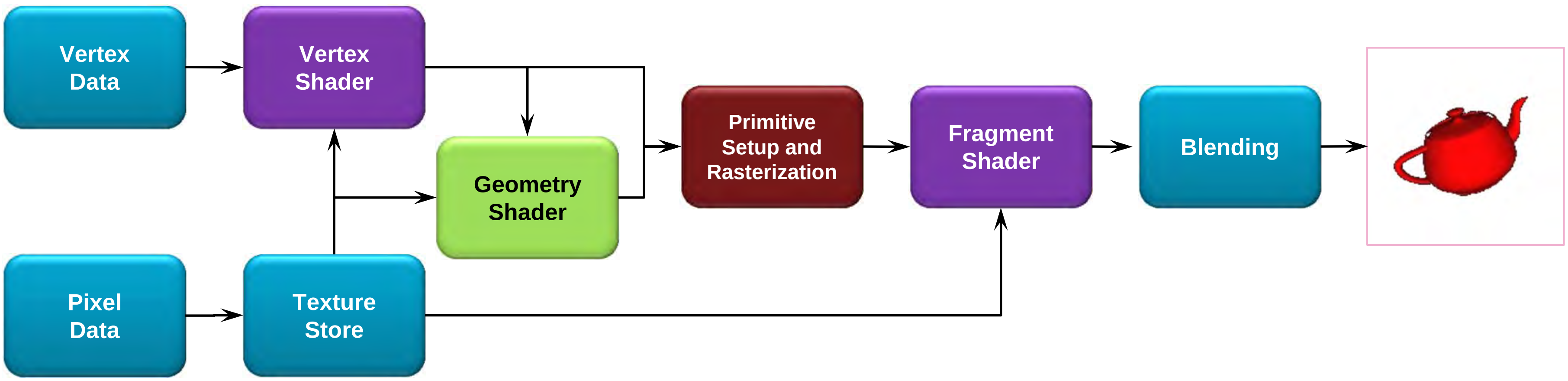


- Additionally, almost all data is *GPU-resident*
  - all vertex data sent using buffer objects

(*) OpenGL 3.1 included an extension – `GL_ARB_compatibility` – which re-enabled all removed functionality

More Programmability

- OpenGL 3.2 (released August 3rd, 2009) added an additional shading stage – *geometry shaders*



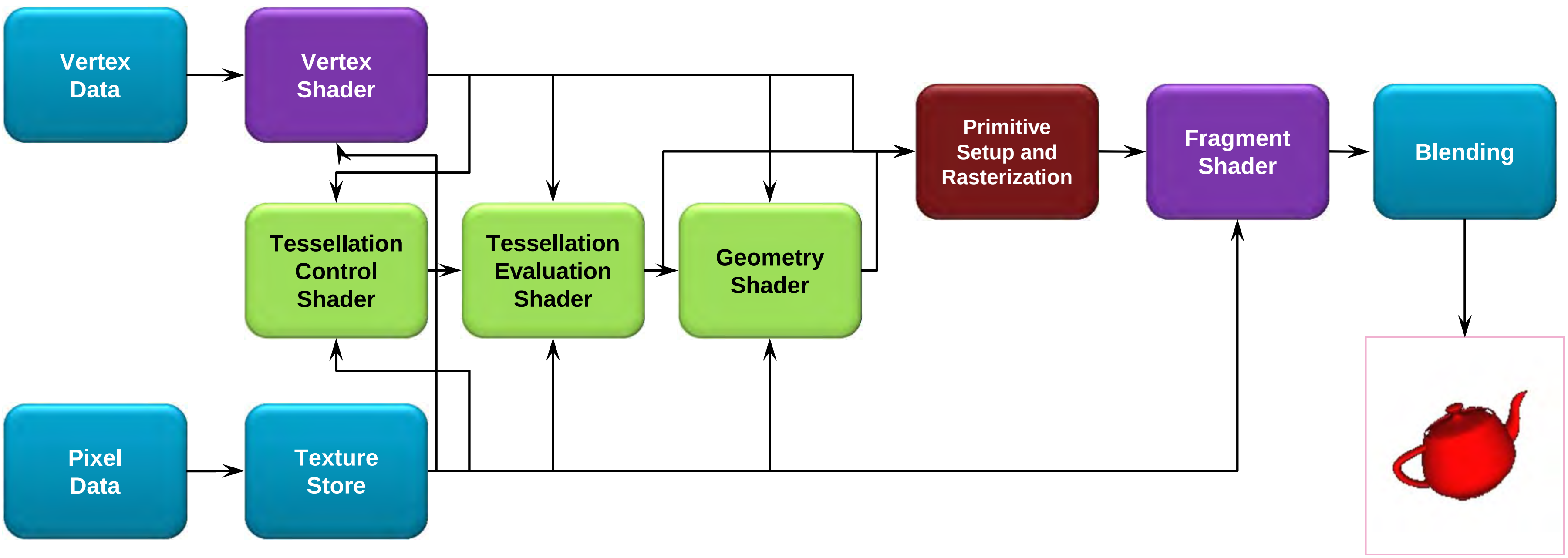
More Evolution – Context Profiles

- OpenGL 3.2 also introduced *context profiles*
  - profiles control which features are exposed
    - it's like `GL_ARB_compatibility`, only not insane ☺
  - currently two types of profiles: *core* and *compatible*

Context Type	Profile	Description
Full	core	All features of the current release
	compatible	All features ever in OpenGL
Forward Compatible	core	All non-deprecated features
	compatible	Not supported

The Latest Pipeline

- OpenGL 4.0 (released March 11th, 2010) added additional shading stages – *tessellation-control and tessellation-evaluation shaders*



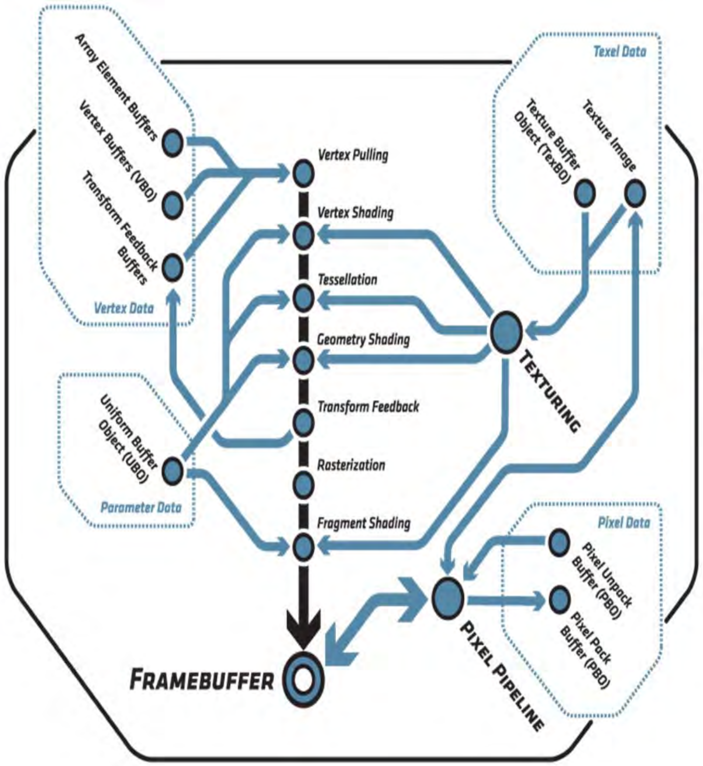
- OpenGL 4.1 (released July 26th, 2010) and 4.2 (released, August 10th, 2011) added features, but no new shading stages

Programmable Shader Interface

```
GLchar *vertPgm = "in vec4 vPosition; …";
GLchar *fragPgm = "…";

GLuint vertShdr =
   glCreateShader( GL_VERTEX_SHADER );
glShaderSource( vertShdr, 1,
   NULL, vertPgm );
glCompileShader( vertShdr );

GLuint fragShdr =
   glCreateShader( GL_FRAGMENT_SHADER );
glShaderSource( fragShdr, 1,
   NULL, fragPgm );
glCompileShader( fragShdr );

GLuint program = glCreateProgram();
glAttachShader( program, vertShdr );
glAttachShader( program, fragShdr );
glLinkProgram();

GLuint vPos = glGetAttribLocation(
   program, "vPosition" );
```

```
GLfloat data[] = { … };

GLuint VAO;
glGenVertexArrays( 1, &VAO );
glBindVertexArray( VAO );

GLuint VBO;
glGenBuffer( 1, &VBO );
glBindBuffer( GL_VERTEX_BUFFER, VBO );
glBufferData( GL_VERTEX_BUFFER,
   sizeof(data), data, GL_STATIC_DRAW );

glVertexAttribPointer( vPos, 3, GL_FLOAT,
   GL_FALSE, 0, BUFFER_OFFSET(0));
glEnableVertexAttribArray( vPos );

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

Accelerating OpenGL Innovation



Bringing state-of-the-art functionality to cross-platform graphics

OpenGL 4.1

OpenGL 3.3 / 4.0

OpenGL 3.2

OpenGL 3.1

OpenGL 2.0 | OpenGL 2.1 | OpenGL 3.0

2004 2005 2006 2007 2008 2009 2010 2011

DirectX 9.0c | DirectX 10.0 | DirectX 10.1 | DirectX 11

Trend Check …

- Almost all innovation of the latest versions has been in adding new shader stages or shader capabilities
  - less graphics focused– more compute focused
  - there are still a few stages that are “fixed-function” (e.g., blending), but those may become programmable soon as well

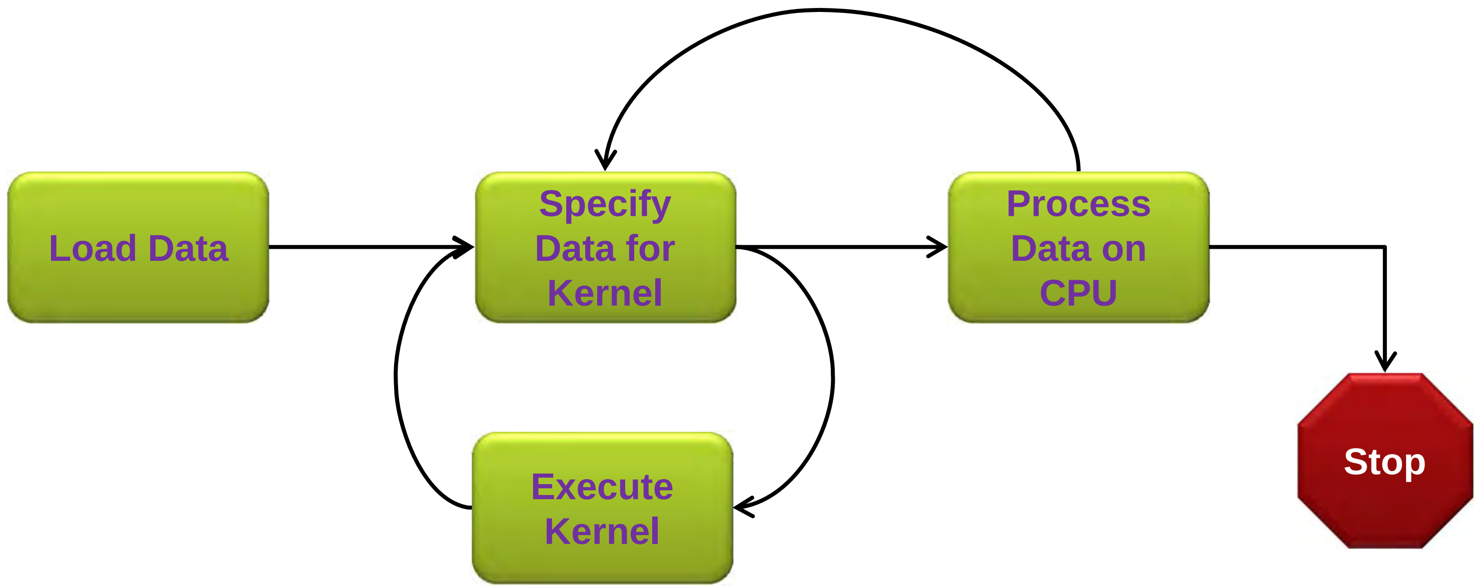
- Clear trend towards:
  1. initialize a chunk of data
  2. process it using a shader
  3. if (!done) go to 1

- That’s (generally) good news for driver developers
  - most changes confined to shader compiler

- Heading that direction (could) have a logical conclusion …

OpenCL

- OpenCL (Compute Language) provides a common framework for heterogeneous computing
  - write one “kernel” (OpenCL vernacular for “shader”), and OpenCL will make it available for each supported compute device in a system



A View Towards the Future

(from this point, it's likely anything I say will be false in a short time … or maybe not ☺)

Moving Data Downwards

- System buses are still the bottlenecks in almost all systems

- APIs are trying to limit programmer data interaction
  - move from small-grained API interaction to large data-block mechanisms

- Khronos APIs are trending (if not there already) to handing data to the GPU in chunks
  - OpenGL's buffer objects
    - VBOs, PBOs, TexBOs, UBOs, …
  - explicit loading/retrieval operations (through API calls)
    - actually, very useful for knowing when data's changed
      - ask anyone who's worked on client-side vertex arrays

Feature Convergence

- OpenGL's acquiring more OpenCL-like features:
  - Random-access reading and writing to images (i.e., buffers)
  - Atomic operations on shader variables
  - Asynchronous thread execution

- OpenCL comes with some graphics features as well:
  - Filtered image sampling
  - Writing to images

- What's still different?
  - Mostly hardware accelerated features:
    - rasterizer
    - blending and depth-buffering hardware
  - But it's possible to implement these in a kernel
    - it's just not an as optimal as having hardware

Impact on Device Drivers

- OpenGL and OpenCL are separate APIs
  - likely implemented in separate DSOs
- Data sharing is permitted between the APIs
  - KHR extension providing OpenCL access to OpenGL buffers
  - requires data synchronization
    - both APIs support fence-like facilities for synchronization

Thanks!

Questions?

(and maybe even some anwers ☺)