Tutorial 5: Programming Graphics Hardware

Programming the GPU: High-Level Shading Languages

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Talk Overview

- The Evolution of GPU Programming Languages
- GPU Programming Languages and the Graphics Pipeline
- Syntax
- Examples
- HLSL FX framework

The Evolution of GPU Programming Languages

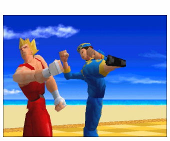
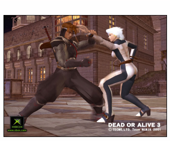
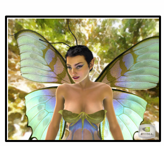
- C (AT&T, 1970s) → C++ (AT&T, 1983) → Java (Sun, 1994)
- IRIS GL (SGI, 1982) → OpenGL (ARB, 1992) → Reality Lab (RenderMorphics, 1994) → Direct3D (Microsoft, 1995)
- RenderMan (Pixar, 1988) → PixelFlow Shading Language (UNC, 1998) → Real-Time Shading Language (Stanford, 2001)

- HLSL (Microsoft, 2002)
- Cg (NVIDIA, 2002)
- GLSL (ARB, 2003)

NVIDIA's Position on GPU Shading Languages

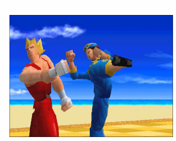
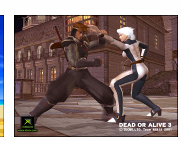
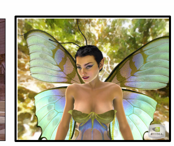
- Bottom line: please take advantage of all the transistors we pack into our GPUs!
- Use whatever language you like
- We will support you
  - Working with Microsoft on HLSL compiler
  - NVIDIA compiler team working on Cg compiler
  - Working with OpenGL ARB on GLSL compiler
- If you find bugs, send them to us and we'll get them fixed

The Need for Programmability

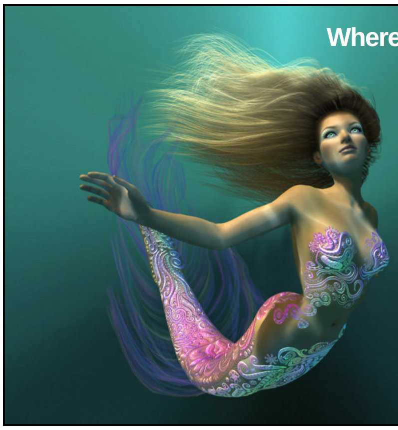
Virtua Fighter (SEGA Corporation)	Dead or Alive 3 (Tecmo Corporation)	Dawn (NVIDIA Corporation)
NV1	Xbox (NV2A)	GeForce FX (NV30)
50K triangles/sec	100M triangles/sec	200M triangles/sec
1M pixel ops/sec	1G pixel ops/sec	2G pixel ops/sec
1M transistors	20M transistors	120M transistors
1995	2001	2003

The Need for Programmability

Virtua Fighter (SEGA Corporation)	Dead or Alive 3 (Tecmo Corporation)	Dawn (NVIDIA Corporation)
NV1	Xbox (NV2A)	GeForce FX (NV30)
16-bit color	32-bit color	128-bit color
640 x 480	640 x 480	1024 x 768
Nearest filtering	Trilinear filtering	8:1 Aniso filtering
1995	2001	2003

Where We Are Now



- 222M Transistors
- 660M tris/second
- 64 Gflops
- 128-bit color
- 1600 x 1200
- 16:1 aniso filtering

The Motivation for High-Level Shading Languages

- Graphics hardware has become increasingly powerful
- Programming powerful hardware with assembly code is hard
- GeForce FX and GeForce 6 Series GPUs support programs that are thousands of assembly instructions long
- Programmers need the benefits of a high-level language:
  - Easier programming
  - Easier code reuse
  - Easier debugging

Assembly

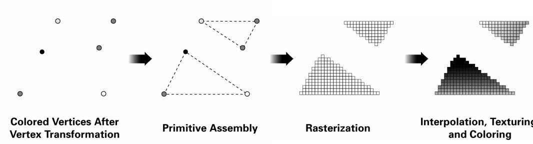
```
…
DP3 R0, c[11].xyzx, c[11].xyzx;
RSQ R0, R0.x;
MUL R0, R0.x, c[11].xyzx;
MOV R1, c[3];
MUL R1, R1.x, c[0].xyzx;
DP3 R2, R1.xyzx, R1.xyzx;
RSQ R2, R2.x;
MUL R1, R2.x, R1.xyzx;
ADD R2, R0.xyzx, R1.xyzx;
DP3 R3, R2.xyzx, R2.xyzx;
RSQ R3, R3.x;
MUL R2, R3.x, R2.xyzx;
DP3 R2, R1.xyzx, R2.xyzx;
MAX R2, c[3].z, R2.x;
MOV R2.z, c[3].y;
MOV R2.w, c[3].y;
LIT R2, R2;
...
```

High-Level Language

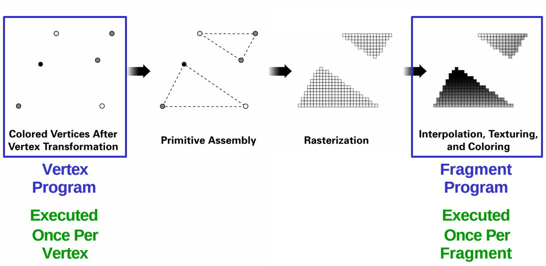
```
…
float3 cSpecular = pow(max(0, dot(Nf, H)),
                       phongExp).xxx;
float3 cPlastic = Cd * (cAmbient + cDiffuse) +
                  Cs * cSpecular;
…
```

GPU Programming Languages and the Graphics Pipeline

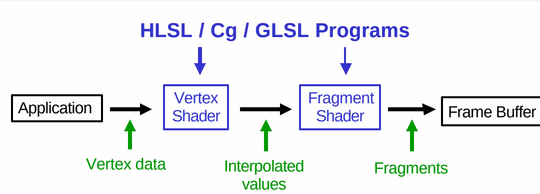
The Graphics Pipeline



The Graphics Pipeline



Shaders and the Graphics Pipeline



In the future, other parts of the graphics pipeline may become programmable through high-level languages.

Compilation

Application and API Layers

3D Application

Direct3D

HLSL | Cg | GLSL — Shading Language

GPU

Using GPU Programming Languages

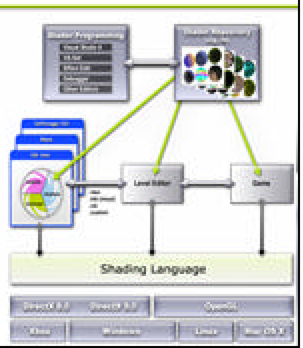
- Use 3D API calls to specify vertex and fragment shaders
- Enable vertex and fragment shaders
- Load/enable textures as usual
- Draw geometry as usual
- Set blend state as usual
- Vertex shader will execute for each vertex
- Fragment shader will execute for each fragment

Compilation Targets

- Code can be compiled for specific hardware
  - Optimizes performance
  - Takes advantage of extra hardware functionality
  - May limit language constructs for less capable hardware
- Examples of compilation targets:
  - vs_1_1, vs_2_0, vs_3_0
  - ps_1_1, ps_2_0, ps_2_x, ps_2_a, ps_3_0
  - vs_3_0 and ps_3_0 are the most capable profiles, supported only by GeForce 6 Series GPUs

Shader Creation

- Shaders are created (from scratch, from a common repository, authoring tools, or modified from other shaders)
- These shaders are used for modeling in Digital Content Creation (DCC) applications or rendering in other applications
- A shading language compiler compiles the shaders to a variety of target platforms, including APIs, OSes, and GPUs



Language Syntax

Let's Pick a Language

- HLSL, Cg, and GLSL have much in common
- But all are different (HLSL and Cg are much more similar to each other than they are to GLSL)
- Let's focus on just one language (HLSL) to illustrate the key concepts of shading language syntax
- General References:
  - HLSL: DirectX Documentation (http://www.msdn.com/DirectX)
  - Cg: The Cg Tutorial (http://developer.nvidia.com/CgTutorial)
  - GLSL: The OpenGL Shading Language

Data Types

- `float` 32-bit IEEE floating point
- `half` 16-bit IEEE-like floating point
- `bool` Boolean
- `sampler` Handle to a texture sampler
- `struct` Structure as in C/C++
- No pointers… yet.

Array / Vector / Matrix Declarations

- Native support for vectors (up to length 4) and matrices (up to size 4x4):

```
float4    mycolor;
float3x3 mymatrix;
```

- Declare more general arrays exactly as in C:

```
float lightpower[8];
```

- But, arrays are first-class types, not pointers

```
float v[4] != float4 v
```

- Implementations may subset array capabilities to match HW restrictions

Function Overloading

- Examples:

```
float myfuncA(float3 x);
float myfuncA(half3 x);

float myfuncB(float2 a, float2 b);
float myfuncB(float3 a, float3 b);
float myfuncB(float4 a, float4 b);
```

Very useful with so many data types.

Different Constant-Typing Rules

- In C, it's easy to accidentally use high precision

```
half x, y;
x = y * 2.0;      // Multiply is at
                  // float precision!
```

- Not in HLSL

```
x = y * 2.0;      // Multiply is at
                  // half precision (from y)
```

- Unless you want to

```
x = y * 2.0f;     // Multiply is at
                  // float precision
```


Support for Vectors and Matrices

- Component-wise + - * / for vectors
- Dot product
  - `dot(v1,v2);  // returns a scalar`
- Matrix multiplications:
  - assuming a `float4x4 M` and a `float4 v`
  - matrix-vector: `mul(M, v);   // returns a vector`
  - vector-matrix: `mul(v, M);   // returns a vector`
  - matrix-matrix: `mul(M, N);   // returns a matrix`

New Operators

- Swizzle operator extracts elements from vector or matrix

```
a = b.xxyy;
```

- Examples:

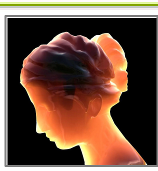
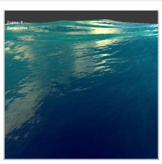
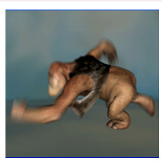
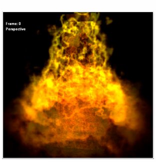
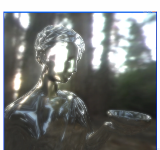
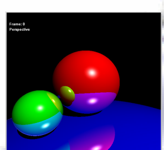
```
float4 vec1 = float4(4.0, -2.0, 5.0, 3.0);
float2 vec2 = vec1.yx;     // vec2 = (-2.0,4.0)
float scalar = vec1.w;     // scalar = 3.0
float3 vec3 = scalar.xxx;  // vec3 = (3.0, 3.0, 3.0)
float4x4 myMatrix;

// Set myFloatScalar to myMatrix[3][2]
float myFloatScalar = myMatrix._m32;
```

- Vector constructor builds vector

```
a = float4(1.0, 0.0, 0.0, 1.0);
```

Examples

Sample Shaders

Looking Through a Shader

- Demonstration in FX Composer

HLSL FX Framework

The Problem with Just a Shading Language

- A shading language describes how the vertex or fragment processor should behave
- But how about:
  - Texture state?
  - Blending state?
  - Depth test?
  - Alpha test?
- All are necessary to really encapsulate the notion of an "effect"
- Need to be able to apply an "effect" to any arbitrary set of geometry and textures
- Solution: .fx file format

HLSL FX

- Powerful shader specification and interchange format
- Provides several key benefits:
  - Encapsulation of multiple shader versions
    - Level of detail
    - Functionality
    - Performance
  - Editable parameters and GUI descriptions
  - Multipass shaders
  - Render state and texture state specification
- FX shaders use HLSL to describe shading algorithms
- For OpenGL, similar functionality is available in the form of CgFX (shader code is written in Cg)
- No GLSL effect format yet, but will appear eventually

Using Techniques

- Each .fx file typically represents an effect
- Techniques describe how to achieve the effect
- Can have different techniques for:
  - Level of detail
  - Graphics hardware with different capabilities
  - Performance
- A technique is specified using the `technique` keyword
- Curly braces delimit the technique's contents

Multipass

- Each technique may contain one or more passes
- A pass is defined by the `pass` keyword
- Curly braces delimit the pass contents
- You can set different graphics API state in each pass

HLSL .fx Example

- Demonstration in FX Composer

Questions?