Lecture 14 of 41

Surface Detail 5 of 5: Shading Languages OGLSL, Direct3D Shading

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KSOL course pages: http://bit.ly/hGvXlH / http://bit.ly/eVizrE
Public mirror web site: http://www.kddresearch.org/Courses/CIS636
Instructor home page: http://www.cis.ksu.edu/~bhsu

Readings:

Today: Section 3.2 – 3.4, Eberly 2e – see http://bit.ly/ieUq45; Direct3D handout
Next class: §4.1 – 4.3, Eberly 2e; Computer-Generated Animation handout
Reference – Christen tutorials: http://www.clockworkcoders.com/oglsl/
NeHe article #21 (*NB*: not an old lesson): http://bit.ly/gi9g47
Toymaker shading tutorial, K. Ditchburn: http://bit.ly/gBScYK

Lecture Outline

- Reading for Last Class: §3.1, Eberly 2e
- Reading for Today: §3.2 – 3.4, Eberly 2e; Direct3D handout
- Reading for Next Class: §4.1 – 4.3, Eberly 2e; CGA handout
- Last Time: Shaders and Programmable Hardware
  - Hardware rendering & APIs for programmable hardware
  - Vertex shaders: vertex attributes to illumination at vertices
  - Pixel shaders: lit vertices to pixel colors, transparency
- Today: Shader Languages, Especially OGLSL
  - OpenGL Shading Language (OGLSL or GLSL) – main topic
  - High-Level Shading Language (HLSL) & Direct3D
  - Pixar's RenderMan
- Shading in Direct3D
  - Tutorials from K. Ditchburn based on Direct3D 10, HLSL
  - For more info, see *Toymaker* site: http://bit.ly/gBScYK
- Coming Up: Computer-Generated Animation Demos, Videos

Where We Are

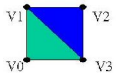
Lecture	Topic	Primary Source(s)
0	Course Overview	Chapter 1, Eberly 2e
1	**CG Basics: Transformation Matrices; Lab 0**	**Sections (§) 2.1, 2.2**
2	Viewing 1: Overview, Projections	§ 2.2.3 – 2.2.4, 2.8
3	Viewing 2: Viewing Transformation	§ 2.3 esp. 2.3.4; FVFH slides
4	**Lab 1a: Flash & OpenGL Basics**	**Ch. 2, 16[1], Angel *Primer***
5	Viewing 3: Graphics Pipeline	§ 2.3 esp. 2.3.7; 2.5, 2.7
6	Scan Conversion 1: Lines, Midpoint Algorithm	§ 2.5.1, 3.1; FVFH slides
7	**Viewing 4: Clipping & Culling; Lab 1b**	**§ 2.3.5, 2.4, 3.1.3**
8	Scan Conversion 2: Polygons, Clipping Intro	§ 2.4, 2.5 esp. 2.5.4, 3.1.6
9	Surface Detail 1: Illumination & Shading	§ 2.5, 2.6.1 – 2.6.2, 4.3.2, 20.2
10	**Lab 2a: Direct3D / DirectX Intro**	**§ 2.7, Direct3D handout**
11	Surface Detail 2: Textures; OpenGL Shading	§ 2.6.3, 20.3 – 20.4, *Primer*
12	Surface Detail 3: Mappings; OpenGL Textures	§ 20.5 – 20.13
13	**Surface Detail 4: Pixel/Vertex Shad.; Lab 2b**	**§ 3.1**
14	Surface Detail 5: Direct3D Shading; OGLSL	§ 3.2 – 3.4, Direct3D handout
15	Demos 1: CGA, Fun; Scene Graphs: State	§ 4.1 – 4.3, CGA handout
16	**Lab 3a: Shading & Transparency**	**§ 2.6, 20.1, *Primer***
17	**Animation 1: Basics, Keyframes; HW/Exam**	**§ 5.1 – 5.2**
	Exam 1 review; Hour Exam 1 (evening)	**Chapters 1 – 4, 20**
18	**Scene Graphs: Rendering; Lab 3b: Shader**	**§ 4.4 – 4.7**
19	Demos 2: SFX; Skinning; Morphing	§ 5.3 – 5.5, CGA handout
20	Demos 3: Surfaces; B-reps/Volume Graphics	§ 10.4, 12.7, Mesh handout

Lightly-shaded entries denote the due date of a written problem set; heavily-shaded entries, that of a machine problem (programming assignment); blue-shaded entries, that of a paper review; and the green-shaded entry, that of the term project.

Green, **blue** and **red** letters denote **exam review**, **exam**, and **exam solution review** dates.

Review: Drawing in Direct3D

- Specify the material we wish to use for the following triangles
- Specify the texture we wish to use (if we want one or NULL if not)
- Set the stream source to our vertex buffer
- Set the FVF we will be using
- Set the index buffer we will be using
- Call the required `DrawPrimitive` function




```
void CGfxEntityCube::Render()
   {
   gD3dDevice->SetMaterial( &m_material );
      gD3dDevice->SetTexture(0,NULL);
      gD3dDevice->SetStreamSource( 0, m_vb,0, sizeof(CUBEVERTEX) );
      gD3dDevice->SetFVF( D3DFVF_CUBEVERTEX );
      gD3dDevice->SetIndices( m_ib);

      // draw a triangle list using 24 vertices and 12 triangles
      gD3dDevice->DrawIndexedPrimitive( D3DPT_TRIANGLELIST,0,0,24,0,12);
}
```


Toymaker © 2004 – 2010 K. Ditchburn, Teesside University
http://bit.ly/hMqxMl

Acknowledgements

Nathan H. Bean
Instructor
Outreach Coordinator
Department of Computing and Information Sciences
Kansas State University
http://bit.ly/gC3vwH

Direct3D material from slides © 2006 – 2010 N. Bean, Kansas State University
http://bit.ly/gC3vwH

Martin Christen, ClockworkCoders.com
http://bit.ly/et5qOp

Wolfgang Engel, http://www.wolfgang-engel.info
Visiondays 2003, http://bit.ly/hhkANP

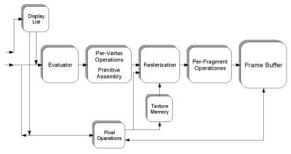
Florian Rudolf, NeHe Productions
http://bit.ly/gi9g47

Koen Samyn
http://knol.google.com/k/hlsl-shaders

Keith Ditchburn, Teesside University
http://bit.ly/hMqxMl

Andy van Dam
T. J. Watson University Professor of Technology and Education & Professor of Computer Science
Brown University
http://www.cs.brown.edu/~avd/

Review: Shader Languages Overview



OpenGL State Machine (Simplified) from Wikipedia: *Shader*
http://bit.ly/fi8tBP

- **HLSL**: Shader language and API developed by **Microsoft**, only usable from within a DirectX application.
- **Cg**: Shader language and API developed by **Nvidia**, usable from within a DirectX and OpenGL application. Cg has a stark resemblance to HLSL.
- **GLSL**: Shader language and API developed by the **OpenGL** consortium and usable from withing an OpenGL application.

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http://knol.google.com/k/hlsl-shaders

Review: Programmable Hardware

Crysis 2
© 2011 Electronic Arts, Inc. – http://bit.ly/idNET9

Starcraft II: Wings of Liberty
© 2010 Blizzard Entertainment, Inc. – http://bit.ly/9B1qZp

Rage & id Tech 5
© 2011 id Software, Inc. – http://bit.ly/eR0m2B

Unreal Tournament 3 & Steamworks
© 2010 Epic Games & Valve – http://bit.ly/9QKAS7

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Review: HLSL Overview

- High-Level Shader Language (HLSL) is Microsoft 's language for programming GPUs
- Looks like C
- Example vertex and pixel shader for projective texturing (texture should appear to be projected onto the scene, as if from a slide projector)

```
struct VS_OUTPUTPROJTEX       // output structure
{
    float4 Pos : POSITION;
    float4 Tex : TEXCOORD0;
};

VS_OUTPUTPROJTEX VSProjTexture(float4 Pos : POSITION, float3 Normal : NORMAL)
{
    VS_OUTPUTPROJTEX Out = (VS_OUTPUTPROJTEX)0;
    Out.Pos = mul(Pos, matWorldViewProj);         // transform Position
    Out.Tex = mul(ProjTextureMatrix, Pos);        // project texture coordinates

   return Out;
}

float4 PSProjTexture(float4 Tex: TEXCOORD0) : COLOR
{
    return tex2Dproj(ProjTexMapSampler, Tex);
}
```

Adapted from slide 2003 Wolfgang Engel, http://www.wolfgang-engel.info
Visiondays 2003, http://bit.ly/hhkANP

Review: HLSL Vertex Shader Example

```
// This is used by 3dsmax to load the correct parser
string ParamID = "0x0";
// DxMaterial specific
float4x4 wvp : WORLDVIEWPROJ;
struct VS_OUTPUT
{
    float4 Pos : POSITION;
    float4 Col : COLOR0;
};
VS_OUTPUT VS( float3 Pos : POSITION )
{
    VS_OUTPUT Out = (VS_OUTPUT)0;
    float4 hPos = float4( Pos, 1);
    Out.Pos = mul( hPos, wvp);
    Out.Col = float4( 1, 1, 1, 1);
    return Out;
}
technique Default
{
    pass P0
    {
        // shaders
        CullMode = None;
        VertexShader = compile vs_2_0 VS();
    }
}
```

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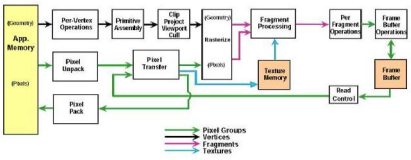
http://knol.google.com/k/hlsl-shaders

Review: OpenGL Fixed Function Pipeline

- OpenGL FFP Diagram (for v1.5)



OpenGL 1.5 Fixed Function Pipeline (see *OpenGL Reference Manual*)
"GLSL: An Introduction" © 2004 F. Rudolf, NeHe Productions – http://bit.ly/gl9g47

- New Function: Fragment (Pixel-Level) Shaders
  - Programmable pipeline – like HLSL, Cg
  - Compiles to shader objects
  - Runs on hardware: ATI Radeon 9x00+, nVidia GeForce 5x00+

Review: GLSL Hybrid Shader Example

Vertex Shader

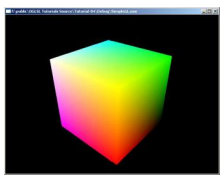
```
varying float xpos;
varying float ypos;
varying float zpos;
void main(void)
{
    xpos = clamp(gl_Vertex.x,0.0,1.0);
    ypos = clamp(gl_Vertex.y,0.0,1.0);
    zpos = clamp(gl_Vertex.z,0.0,1.0);

    gl_Position = gl_ModelViewProjectionMatrix *    gl_Vertex;
}
```

Fragment Shader

```
varying float xpos;
varying float ypos;
varying float zpos;

void main (void)
{
 gl_FragColor = vec4 (xpos, ypos, zpos, 1.0);
}
```



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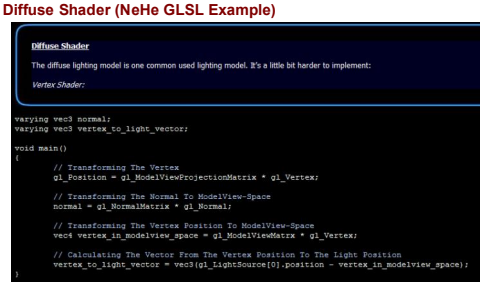
http://bit.ly/et5qOp

Review: GLSL Vertex Shader Example

- Diffuse Shader (NeHe GLSL Example)



Diffuse Shader

The diffuse lighting model is one common used lighting model. It's a little bit harder to implement:

Vertex Shader:

```
varying vec3 normal;
varying vec3 vertex_to_light_vector;

void main()
{
        // Transforming The Vertex
        gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;

        // Transforming The Normal To ModelView-Space
        normal = gl_NormalMatrix * gl_Normal;

        // Transforming The Vertex Position To ModelView-Space
        vec4 vertex_in_modelview_space = gl_ModelViewMatrix * gl_Vertex;

        // Calculating The Vector From The Vertex Position To The Light Position
        vertex_to_light_vector = vec3(gl_LightSource[0].position - vertex_in_modelview_space);
}
```

- Machine Problems, Projects: Will Use Combination of Shaders

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http://bit.ly/gl9g47

Review: GLSL Pixel Shader Example

- Consider BRDF (Especially $N \cdot L$) From Last Lecture

```
varying vec3 normal;
varying vec3 vertex_to_light_vector;

void main()
{
        // Defining The Material Colors
        const vec4 AmbientColor = vec4(0.1, 0.0, 0.0, 1.0);
        const vec4 DiffuseColor = vec4(1.0, 0.0, 0.0, 1.0);

        // Scaling The Input Vector To Length 1
        vec3 normalized_normal = normalize(normal);
        vec3 normalized_vertex_to_light_vector = normalize(vertex_to_light_vector);

        // Calculating The Diffuse Term And Clamping It To [0;1]
        float DiffuseTerm = clamp(dot(normal, vertex_to_light_vector), 0.0, 1.0);

        // Calculating The Final Color
        gl_FragColor = AmbientColor + DiffuseColor * DiffuseTerm;
}
```

- Result: Diffuse Term for Phong Shading (One Light, No Specular)

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Tutorial 1: Loading, Compiling, & Linking OGLSL Programs [1]

Vertex Shader

```
void main(void)
{
   vec4 a = gl_Vertex;
   a.x = a.x * 0.5;
   a.y = a.y * 0.5;
   gl_Position = gl_ModelViewProjectionMatrix * a;
}
```

Q: What does this do?
A:
Incoming x and y components are scaled with a factor 0.5
Scaled vertex is transformed with concatenated modelview and projection matrix.

Fragment Shader

```
void main (void)
{
   gl_FragColor = vec4 (0.0, 1.0, 0.0, 1.0);
}
```

Q: What does this do?
A: Makes everything green!

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Tutorial 1: Loading, Compiling, & Linking OGLSL Programs [2]

aShaderManager Class (Christen, 2003)

```
// globals:
aShaderManager shadermanager;
aShaderObject* shader;

// init:
shader = shadermanager.loadfromFile("test.vert","test.frag");

// draw:
shader->begin()
glutSolidSphere(1.0,32,32);
shader->end();
```

Methods

```
// load vertex/fragment shader from file
aShaderObject* loadfromFile(char* vertexFile, char* fragmentFile);
aShaderObject* loadfromMemory(const char* vertexMem, const char* fragmentMem);
bool free(aShaderObject* o);
```

loadFromFile: loads shader source code from file, compiles, links and returns a shader object.
loadfromMemory: instead of using files you can specify memory addresses containing a **null terminated** char array of the program string.
free: if you don't need a shader anymore you can free it. Usually this function isn't needed, the destructor of the ShaderManager frees memory.

This is the easy way!

Without this framework:
http://bit.ly/ePRyXN
... see next slide
(Christen, 2003)

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Tutorial 1: Loading, Compiling, & Linking OGLSL Programs [3]

AppInit Function (Christen, 2003) – Part 1 of 3

```
#include "../cwc/aGLSL.h"
#include <GL/glut.h>
#include <iostream>

using namespace std;

// Shader and Program Objects:
aShaderObject* myShader = 0;
aVertexShader* myVertexShader = 0;
aFragmentShader* myFragmentShader = 0;

void AppInit(void)
{
   // it is important a GL context is availble before creating
   // shader and Program objects.
   myShader = new aShaderObject;
   myVertexShader = new aVertexShader;
   myFragmentShader = new aFragmentShader;
```

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Tutorial 1: Loading, Compiling, & Linking OGLSL Programs [4]

AppInit Function (Christen, 2003) – Part 2 of 3

```
 // Load Vertex Program
if (myVertexShader->load("simple.vert") != 0)
{
   cout << "can't load vertex shader!\n";
   exit(-1); // if file is missing: major error, better exit
}

// Load Fragment Program
if (myFragmentShader->load("simple.frag") != 0)
{
   cout << "can't load fragment shader!\n";
   exit(-1); // if file is missing: major error, better exit
}

// Compile Vertex Program, if it fails output log
if (!myVertexShader->compile())
{
   cout << "***COMPILER ERROR:\n";
   cout << myVertexShader->getCompilerLog() << endl;
}
```

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Tutorial 1: Loading, Compiling, & Linking OGLSL Programs [5]

AppInit Function (Christen, 2003) – Part 3 of 3

```
   // Compile fragment Program, if it fails output log
   if (!myFragmentShader->compile())
   {
      cout << "***COMPILER ERROR:\n";
      cout << myFragmentShader->getCompilerLog() << endl;
   }

   // Add (compiled Programs) to object
   myShader->addShader(myVertexShader);
   myShader->addShader(myFragmentShader);

   // Link the Program
   if (!myShader->link())
   {
      cout << "**LINKER ERROR\n";
      cout << myShader->getLinkerLog() << endl;
   }
}  // AppInit()
```

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Tutorial 1: Loading, Compiling, & Linking OGLSL Programs [6]

DrawFrame & AppExit (Christen, 2003)

```
//*************************************************************
// Draw one Frame (don't swap buffers)
void DrawFrame(void)
{
   myShader->begin();
   glutSolidTeapot(1.0);
   myShader->end();
}

//*************************************************************
// use AppExit to clean up
void AppExit(void)
{
   if (myShader!=0) delete myShader;
   if (myVertexShader!=0) delete myVertexShader;
   if (myFragmentShader!=0) delete myFragmentShader;
}
//*************************************************************
```

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Tutorial 1: Loading, Compiling, & Linking OGLSL Programs [7]

Loading Programs without `aShaderManager` class (Steps 1 – 2a of 3)

`aGLSL.h` defines:

- `aVertexShader`: Class to manage vertex shader programs
- `aFragmentShader`: Class to manage fragment shader programs
- `aShaderObject`: Class to manage shader objects

Step 1: Declare shader programs and shader objects

```
aShaderObject* myShader = 0;
aVertexShader* myVertexShader = 0;
aFragmentShader* myFragmentShader = 0;
```

Step 2: Load, add and compile/link programs in `AppInit()`

Reserve memory and initialize objects (it is important an OpenGL context already exists when you do this)

```
myShader = new aShaderObject;
myVertexShader = new aVertexShader;
myFragmentShader = new aFragmentShader;
```

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http://bit.ly/et5qOp

Tutorial 1: Loading, Compiling, & Linking OGLSL Programs [8]

Loading Programs without `aShaderManager` class (Steps 2b – 2d of 3)

Step 2: Load, add and compile/link programs in `AppInit()` (continued)

Load:

```
myVertexShader->load("simple.vert");
myFragmentShader->load("simple.frag");
```

Compile:

```
myVertexShader->compile();
myFragmentShader->compile();
```

You can access compiler errors with:

```
char* getCompilerLog(void);
```

(`getCompilerLog` is defined in `aVertexShader` and `aFragmentShader`)

Add (compiled) programs to the object and link it:

```
myShader->addShader(myVertexShader);
myShader->addShader(myFragmentShader);
myShader->link();
```

You can access linker errors with "`myShader->getLinkerLog()`" similar to `compilerLog`.

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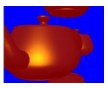
Tutorial 1: Loading, Compiling, & Linking OGLSL Programs [9]

Loading Programs without `aShaderManager` class (Step 3 of 3)

Step 3: Use shader (see rest of Tutorials, #2 – 10!)

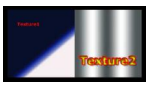
```
myShader->begin();
... {draw something with GL} ...
myShader->end();
```



#5 Phong shading in OpenGL
http://bit.ly/iSIFL0

#6 Texture Mapping
http://bit.ly/hRhFQD

#7 Color Keys (Transparency Masks)
http://bit.ly/hUEi62



#8 Multitexturing
http://bit.ly/gaYoY

#9 Procedural Texture (Procedural Materials)
http://bit.ly/ieeER5

#10 Cartoon Shading
http://bit.ly/qR5EH3

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http://bit.ly/et5qOp

Shading in Direct3D [1]: Writing Vertex Shaders

Defining `TVertex` data structure: position/normal/texture tuple:

```
struct TVertex
{
   D3DXVECTOR3 position;
   D3DXVECTOR3 Normal;
   D3DXVECTOR3 Tex;
};
```

Vertex declaration to describe this structure:

```
const D3DVERTEXELEMENT9 dec[4] =
{
  {0, 0,  D3DDECLTYPE_FLOAT3, D3DDECLMETHOD_DEFAULT, D3DDECLUSAGE_POSITION,0},
  {0, 12, D3DDECLTYPE_FLOAT3, D3DDECLMETHOD_DEFAULT, D3DDECLUSAGE_NORMAL,  0},
  {0, 24, D3DDECLTYPE_FLOAT2, D3DDECLMETHOD_DEFAULT, D3DDECLUSAGE_TEXCOORD,0},
  D3DDECL_END()
};
```

Each line corresponds to one of the elements in `TVertex`. The data in each line is:

```
WORD Stream; WORD Offset; BYTE Type; BYTE Method; BYTE Usage; BYTE UsageIndex
```

We need to tell Direct3D about our vertex declaration using the following call:

```
IDirect3DVertexDeclaration9 m_vertexDeclaration;
gDevice->CreateVertexDeclaration(dec,&m_vertexDeclaration);
```

To render:

```
gDevice->SetStreamSource( 0, m_vb,0, sizeof(TVertex));
gDevice->SetVertexDeclaration(m_vertexDeclaration);
```

Adapted from *Toymaker* © 2004 – 2010 K. Ditchburn, Teesside University
http://bit.ly/g8Q8hC

Shading in Direct3D [2]: Using Vertex Shaders

This example shows how to manipulate the vertex position data to create the effect of a fluttering flag.

Global:

```
float4x4 matWorld : WORLD;
```

In application:

```
dxEffect->SetMatrix("matWorld",&mat)).
```

Shader output structure: transformed vertex position & texture coordinate

```
struct VS_OUTPUT
{
  float4 Pos : POSITION;
  float2 tex : TEXCOORD0;
};
VS_OUTPUT VS(float4 Pos : POSITION,float2 tex : TEXCOORD0)

float angle=(time%360)*2;     // angle to use for sine wave
Pos.z  = sin( Pos.x+angle);   // wave effect

// take y position of vertex into account
Pos.z += sin( Pos.y/2+angle);

// make left edge look as if it is attached to a flagpole
Pos.z *= Pos.x * 0.09f;
```

Adapted from *Toymaker* © 2004 – 2010 K. Ditchburn, Teesside University
http://bit.ly/g8Q8hC

Shading in Direct3D: Pixel Shading & Rest of Pipeline

- Application
  - Scene management
  - Vertices, tessellation
- Vertex Operations
  - Transformation and Lighting (T&L)
  - Culling, Clipping
- Pixel Operations
  - Triangle setup and rasterization
  - Shading, multitexturing
  - Fog, alpha test, depth buffering, antialiasing
  - Display

Per-Pixel Shader for Diffuse Lighting
http://bit.ly/hVQcnY

Adapted from *Toymaker* © 2004 – 2010 K. Ditchburn, Teesside University
http://bit.ly/gBScYK

Next: CGA Videos (Demos & Trailers)

Monsters Inc. (2001)
Monsters Inc. 2 (2012)
© Disney/Pixar

Tron: Legacy
© 2010
Walt Disney Pictures

Toy Story (1995)
Toy Story 2 (1999)
Toy Story 3 (2010)
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Kung-Fu Panda
© 2008 DreamWorks Animation SKG

Happy Feet
© 2006
Warner Brothers

Shrek (2001)
Shrek 2 (2004)
Shrek the Third (2007)
Shrek Forever After (2010)
© DreamWorks Animation SKG

Wall-E
© 2008 Disney/Pixar

Luxo Jr.
© 1986 Pixar Animation Studios

Summary

- Last Time: Shaders and Programmable Hardware
  - Hardware rendering & APIs for programmable hardware
  - Vertex shaders: vertex attributes to illumination at vertices
  - Pixel shaders: lit vertices to pixel colors, transparency
- Shader Languages, Especially OGLSL
  - OpenGL Shading Language (OGLSL or GLSL) – main topic
  - High-Level Shading Language (HLSL) & Direct3D
- Shading in Direct3D
  - Tutorials from K. Ditchburn based on Direct3D 10, HLSL
  - For more info, see *Toymaker* site: http://bit.ly/gBScYK
- Still to Come: Pixar's *RenderMan* Specification, Renderer, SL
- Many More Shading Techniques: Explore for Yourself!
  - References: GLSL, HLSL/D3D, Cg, Renderman (Apodaca & Gritz)
  - *Graphics Gems* & *GPU Gems* series (some chapters online)
  - Shader books by Wolfgang Engels

Terminology

- OpenGL Architecture Review Board – Standards Committee 2002 - 2006
- OpenGL Shading Language (OGLSL *aka* GLSL)
  - Introduced in 2002 by OpenGL ARB, part of OpenGL since v1.4
  - GLSL compiler builds programs to load on OpenGL graphics cards
  - `AppInit()`: function to `compile()`, `addShader()`, and `link()`
- High-Level Shading Language
  - Microsoft's programmable pipeline
  - Used in tandem with Direct3D
  - Shader Model *n*: used with D3D version (SM5 = Direct3D 11, *etc.*)
- Other Shader Languages (SLs)
  - Cg – Nvidia's general-purpose SL (surveyed in Lecture 13)
  - Gelato – Nvidia's production render farm SL (not covered)
  - RenderMan – Pixar's specification, renderer, or SL (surveyed later)