Introduction to the Direct3D 11 Graphics Pipeline

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Key Takeaways

• Direct3D 11 focuses on
  – Increasing scalability,
  – Improving the development experience,
  – Extending the reach of the GPU,
  – Improving Performance.

• Direct3D 11 is a strict superset of D3D 10 & 10.1
  – Adds support for new features
  – Start developing on Direct3D 10/10.1 today

• Available on Windows Vista & future Windows operating systems

• Supports 10 / 10.1 level hardware
Outline

• Drilldown
  – Tessellation
    – Compute Shader
    – Multithreading
    – Dynamic Shader Linkage
    – Improved Texture Compression
    – Quick Glance at Other Features

• Availability
Character Authoring Pipeline

(Rocket Frog Taken From Loop & Schaefer, "Approximating Catmull-Clark Subdivision Surfaces with Bicubic Patches")

- Sub-D Modeling
- Animation
- Displacement Map

- Polygon Mesh
- Generate LODs
Character Authoring (Cont’d)

• Trends
  – Denser meshes, more detailed characters
    • ~5K triangles -> 30-100K triangles
  – Complex animations
    • Animations on polygon mesh vertices more costly

• Result
  – Integration in authoring pipeline painful
  – Larger memory footprints causing painful I/O issues

• Solution
  – Use the higher-level surface representation longer
    • Animate control cage (~5K vertices)
    • Generate displacement & normal maps
Direct3D 11 Pipeline

Direct3D 10 pipeline
Plus
Three new stages for Tessellation

Input Assembler
Vertex Shader
Hull Shader
Tessellator
Domain Shader
Geometry Shader
Rasterizer
Pixel Shader
Output Merger
Stream Output
Hull Shader (HS)

**HS input:**
*patch control pts*

**HS output:**
- Patch control pts after Basis conversion
- TessFactors (how much to tessellate)
- fixed tessellator mode declarations

One Hull Shader invocation per patch
**Fixed-Function Tessellator (TS)**

**Tessellator**
- Operates per patch
- Does not see control points

**TS input:**
- TessFactors (how much to tessellate)
- Fixed tessellator mode declarations

**TS output:**
- U V {W} domain points
- Topology (to primitive assembly)

**Hull Shader**

**Domain Shader**
Domain Shader (DS)

**DS input:**
- control points
- TessFactors

**DS output:**
- one vertex

One Domain Shader invocation per point from Tessellator
Direct3D 11 Pipeline

- D3D11 HW Feature
- D3D11 Only
- Fundamental primitive is patch (not triangle)
- Superset of Xbox 360 tessellation
Example Surface Processing Pipeline

Single-pass process!

- **vertex shader**: Animate/skin Control Points
- **hull shader**: Transform basis, Determine how much to tessellate
- **tessellator**: Tessellate!
- **domain shader**: Evaluate surface including displacement

- **patch control points**
- **transformed control points**
- **control points in Bezier patch**
- **U V \{W\} domain points**

- **displacement map**

Sub-D Patch

Bezier Patch
New Authoring Pipeline

(Rocket Frog Taken From Loop & Schaefer, "Approximating Catmull-Clark Subdivision Surfaces with Bicubic Patches")

Sub-D Modeling  Animation  Displacement Map

Optimally Tessellated Mesh

GPU
Tessellation: Summary

• Provides
  – Smooth silhouettes
  – Richer animations for less

• Scale visual quality across hardware configurations

• Supports performance improvements
  – Coarse model = compression, faster I/O to GPU
  – Cheaper skinning and simulation
  – Improve pixel shader quad utilization
  – Scalable rendering for each end user’s hardware

• Render content as artists intend it!
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GPGPU & Data Parallel Computing

- GPU performance continues to grow
- Many applications scale well to massive parallelism without tricky code changes
- Direct3D is the API for talking to GPU
- How do we expand Direct3D to GPGPU?
Direct3D 11 Pipeline

Direct3D 10 pipeline

*Plus*

Three new stages for Tessellation

*Plus*

Compute Shader

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Input Assembler
Vertex Shader
Hull Shader
Tessellator
Domain Shader
Geometry Shader
Rasterizer
Pixel Shader
Output Merger

Data Structure

Stream Output

Compute Shader
Integration with Direct3D

- Fully supports all Direct3D resources
- Targets graphics/media data types
- Evolution of DirectX HLSL
- Graphics pipeline updated to emit general data structures...
  - ...which can then be manipulated by compute shader...
- And then rendered by Direct3D again
Example Scenario

- Render scene
- Write out scene image
- Use Compute for image post-processing
- Output final image
Target Applications

• Image/Post processing:
  – Image Reduction
  – Image Histogram
  – Image Convolution
  – Image FFT

• A-Buffer/OIT

• Ray-tracing, radiosity, etc.

• Physics

• AI
Compute Shader: Summary

- Enables much more general algorithms
- Transparent parallel processing model
- Full cross-vendor support
  - Broadest possible installed base
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D3D11 Multithreading Goals

• Asynchronous resource loading
  – Upload resources, create shaders, create state objects in parallel
  – Concurrent with rendering

• Multithreaded draw & state submission
  – Spread out render work across many threads

• Limited support for per-object display lists
Devices and Contexts

• D3D device functionality now split into three separate interfaces

• Device, Immediate Context, Deferred Context
  – Device has free threaded resource creation
  – Immediate Context is your single primary device for state, draws, and queries
  – Deferred Contexts are your per-thread devices for state & draws
D3D11 Interfaces

Immediate Context
- DrawPrim
- DrawPrim
- DrawPrim
- DrawPrim
- DrawPrim

Render Thread

Load Thread 1
- CreateTexture
- CreateVB
- CreateShader
- CreateIB

Load Thread 2
- CreateShader
- CreateTexture
- CreateShader
- CreateVB
Async Resources

- Use the Device interface for resource creation
- All functions are free threaded
  - Uses fine-grained sync primitives
- Resource upload and shader compilation can happen concurrently
State & Draw Submission

• First priority: multithreaded submission
  – Single-use display lists
• Lower priority: per-object display lists
  – Multiple reuse
• D3D11 display lists are immutable
D3D11 Interfaces

Immediate Context
- DrawPrim
- DrawPrim
- DrawPrim
- Execute
- Execute

Deferred Context
Display List
- DrawPrim
- DrawPrim
- DrawPrim
- Execute

Deferred Context
Display List
- DrawPrim
- DrawPrim
- DrawPrim

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THE WORLD OF VISUAL COMPUTING
Deferred Contexts

• Can create many deferred contexts
  – Each one is single threaded (thread unsafe)

• Deferred context generates a Display List
  – Display List is consumed by Immediate or Deferred contexts

• No read-backs or downloads from the GPU
  – Queries
  – Resource locking

• Lock with DISCARD is supported on deferred contexts
D3D11 on D3D10 H/W

- Deferred contexts are implemented at an API-capture level
- Async resource creation uses coarse sync primitives
  - No longer free threaded; thread safe though
- D3D10 drivers can be updated to better support D3D11 features
- Will work on Windows Vista as well as future Windows releases
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Shader Issues Today

- Shaders getting bigger, more complex
- Shaders need to target wide range of hardware
- Optimization of different shader configurations drives shader specialization
Options: Über-shader

Über-shader

```cpp
foo (...) {
    if (m == 1) {
        // do material 1
    } else if (m == 2) {
        // do material 2
    }
    if (l == 1) {
        // do light model 1
    } else if (l == 2) {
        // do light model 2
    }
}
```
Options: Über-shader

“One Shader to Rule them All”

• **Good:**
  – All functionality in one place
  – Reduces state changes at runtime
  – One compile step
  – Seems to be most popular coding method

• **Bad:**
  – Complex, unorganized shaders
  – Register usage is always worst case path
Options: Specialization

Multiple specialized shaders for each combination of settings

• Good:
  – Always optimal register usage
  – Easier to target optimizations

• Bad:
  – Huge number of resulting shaders
  – Pain to manage at runtime
Combinatorial Explosion

Number of Lights

Number of Materials

Environmental Effects
Solution: Dynamic Shader Linkage & OOP

- Introducing new OOP features to HLSL
  - Interfaces
  - Classes
- Can be used for static code
- Also used as the mechanism for linking specific functionality at runtime
Interfaces

```
interface Light
{
    float3 GetDirection(float3 eye);

    float3 GetColor();
}
```
```cpp
class DirectionalLight : Light
{
    float3 GetDirection(float3 eye)
    {
        return m_direction;
    }

    float3 GetColor()
    {
        return m_color;
    }

    float3 m_direction;
    float3 m_color;
};
```
Dynamic Shader Linkage

• Über-shader

foo (...) {
    if (m == 1) {
        // do material 1
    } else if (m == 2) {
        // do material 2
    }
    if (l == 1) {
        // do light model 1
    } else if (l == 2) {
        // do light model 2
    }
}

• Dynamic Subroutine

Material1(...) { ... }
Material2(...) { ... }
Light1(...) { ... }
Light2(...) { ... }

foo(...) {
    myMaterial.Evaluate(...);
    myLight.Evaluate(...);
}
In the Runtime

• Select specific class instances you want
• Runtime will inline class methods
  – Equivalent register usage to a specialized shader
• Inlining is done in the native assembly
  – Fast operation
• Applies to all subsequent Draw(...) calls
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Why New Texture Formats?

• Existing block palette interpolations too simple
• Results often rife with blocking artifacts
• No high dynamic range (HDR) support
• NB: All are issues we heard from developers
Two New BC’s for Direct3D11

• BC6 (aka BC6H)
  – High dynamic range
  – 6:1 compression (16 bpc RGB)
  – Targeting high (not lossless) visual quality

• BC7
  – LDR with alpha
  – 3:1 compression for RGB or 4:1 for RGBA
  – High visual quality
New BC’s: Compression

• Block compression (unchanged)
  – Each block independent
  – Fixed compression ratios

• Multiple block types (new)
  – Tailored to different types of content
  – Smooth gradients vs. noisy normal maps
  – Varied alpha vs. constant alpha

Also new: decompression results must be bit-accurate with spec
Multiple Block Types

• Different numbers of color interpolation lines
  – Less variance in one block means:
    • 1 color line
    • Higher-precision endpoints
  – More variance in one block means:
    • 2 (BC6 & 7) or 3 (BC7 only) color lines
    • Lower-precision endpoints and interpolation bits

• Different numbers of index bits
  – 2 or 3 bits to express position on color line

• Alpha
  – Some blocks have implied 1.0 alpha
  – Others encode alpha
Partitions

• When using multiple color lines, each pixel needs to be associated with a color line
  – Individual bits to choose is expensive

• For a 4x4 block with 2 color lines
  – $2^{16}$ possible partition patterns
  – 16 to 64 well-chosen partition patterns give a good approximation of the full set
  – BC6H: 32 partitions
  – BC7: 64 partitions, shares first 32 with BC6H
Example Partition Table

A 32-partition table for 2 color lines
Comparisons

Orig BC3

Orig BC7

Abs Error
Comparisons

Orig | BC3
--- | ---

Orig | BC7
--- | ---

Abs Error
Comparisons

HDR Original at given exposure

Abs Error

BC6 at given exposure
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Lots of Other Features

- Addressable Stream Out
- Draw Indirect
- Pull-model attribute eval
- Improved Gather4
- Min-LOD texture clamps
- 16K texture limits
- Required 8-bit subtexel, submip filtering precision
- Conservative oDepth
- 2 GB Resources
- Geometry shader instance programming model
- Optional double support
- Read-only depth or stencil views
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Questions?