Advanced Visual Effects with Direct3D®

Presenters: Cem Cebenoyan, Sim Dietrich, Richard Huddy, Greg James, Jason Mitchell, Ashu Rege, Guennadi Riguer, Alex Vlachos and Matthias Wloka

Today's Agenda

- **DirectX® 9 Features**
  - **Jason Mitchell & Cem Cebenoyan**

Coffee break – 11:00 – 11:15

- **DirectX 9 Shader Models**
  - **Sim Dietrich & Jason L. Mitchell**

Lunch break – 12:30 – 2:00

- **D3DX Effects & High-Level Shading Language**
  - **Guennadi Riguer & Ashu Rege**
- **Optimization for DirectX 9 Graphics**
  - **Matthias Wloka & Richard Huddy**

Coffee break – 4:00 – 4:15

- **Special Effects**
  - **Alex Vlachos & Greg James**
- **Conclusion and Call to Action**

DirectX® 9 Features

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Outline

- **Feeding Geometry to the GPU**
  - Vertex stream offset and VB indexing
  - Vertex declarations
  - Presampled displacement mapping
- **Pixel processing**
  - New surface formats
  - Multiple render targets
  - Depth bias with slope scale
  - Auto mipmap generation
  - Multisampling
  - Multihead
  - sRGB / gamma
  - Two-sided stencil
- **Miscellaneous**
  - Asynchronous notification / occlusion query

Feeding the GPU

In response to ISV requests, some key changes were made to DirectX 9:

- **Addition of new stream component types**
- **Stream Offset**
- **Separation of Vertex Declarations from Vertex Shader Functions**
- **BaseVertexIndex change to DIP()**

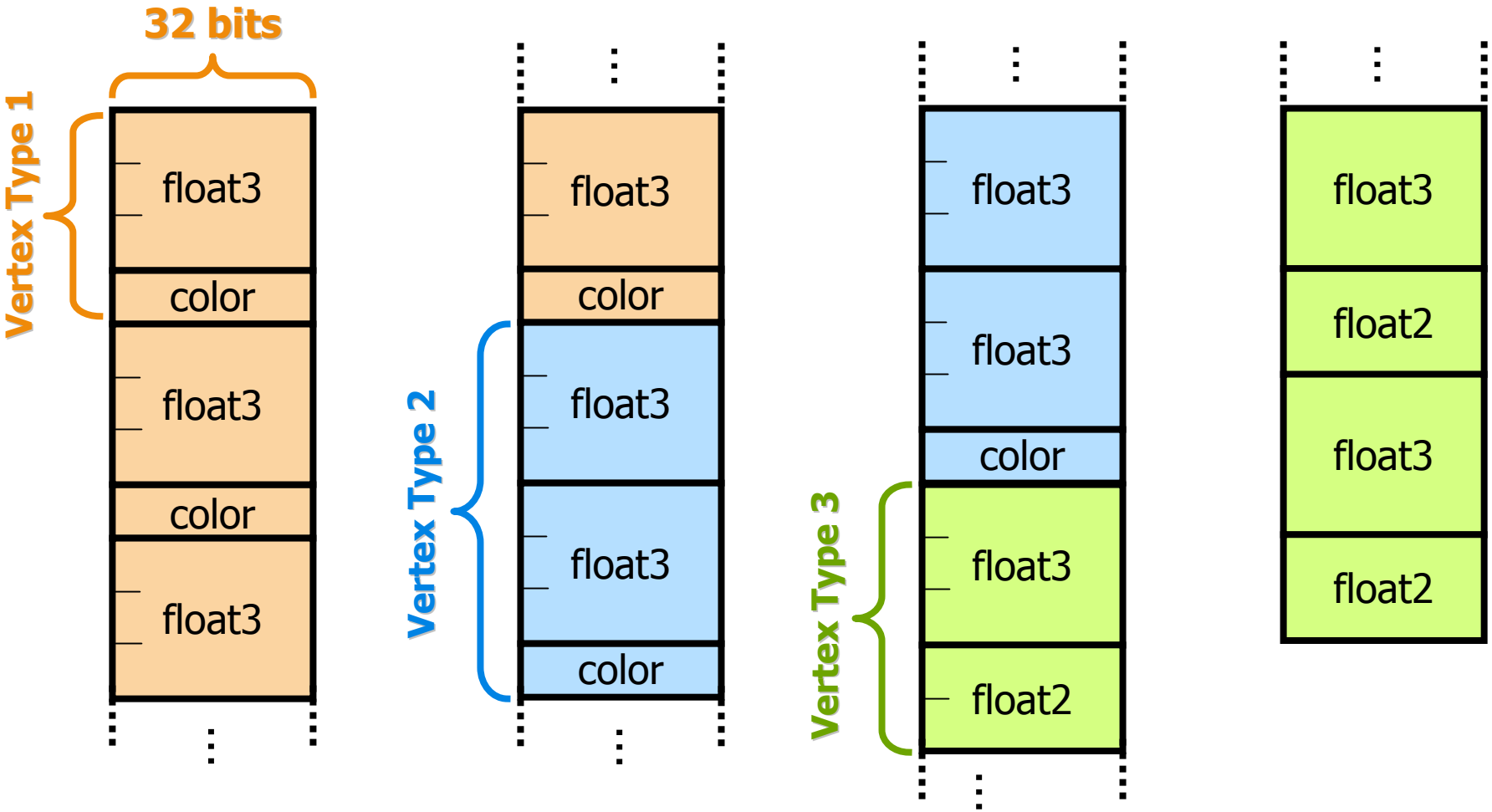
New stream component types

- `D3DDECLTYPE_UBYTE4N`
  - **Each of 4 bytes is normalized by dividing by 255.0**
- `D3DDECLTYPE_SHORT2N`
  - **2D signed short normalized (v[0]/32767.0,v[1]/32767.0,0,1)**
- `D3DDECLTYPE_SHORT4N`
  - **4D signed short normalized (v[0]/32767.0,v[1]/32767.0,v[2]/32767.0,v[3]/32767.0)**
- `D3DDECLTYPE_USHORT2N`
  - **2D unsigned short normalized (v[0]/65535.0,v[1]/65535.0,0,1)**
- `D3DDECLTYPE_USHORT4N`
  - **4D unsigned short normalized(v[0]/65535.0,v[1]/65535.0,v[2]/65535.0,v[3]/65535.0)**
- `D3DDECLTYPE_UDEC3`
  - **3D unsigned 10-10-10 expanded to (value, value, value, 1)**
- `D3DDECLTYPE_DEC3N`
  - **3D signed 10-10-10 normalized & expanded to (v[0]/511.0, v[1]/511.0, v[2]/511.0, 1)**
- `D3DDECLTYPE_FLOAT16_2`
  - **Two 16-bit floating point values, expanded to (value, value, 0, 1)**
- `D3DDECLTYPE_FLOAT16_4`
  - **Four 16-bit floating point values**

Vertex Stream Offset

- New offset in *bytes* specified in `SetStreamSource()`
- Easily allows you to place multiple objects in a single Vertex Buffer
  - Objects can even have different structures/strides
- New DirectX 9 driver is required
  - DirectX 9 drivers must set `D3DDEVCAPS2_STREAMOFFSET`
- Doesn't work with post-transformed vertices
- This isn't an excuse for you to go and make one big VB that contains your whole world

Vertex Stream Offset Example



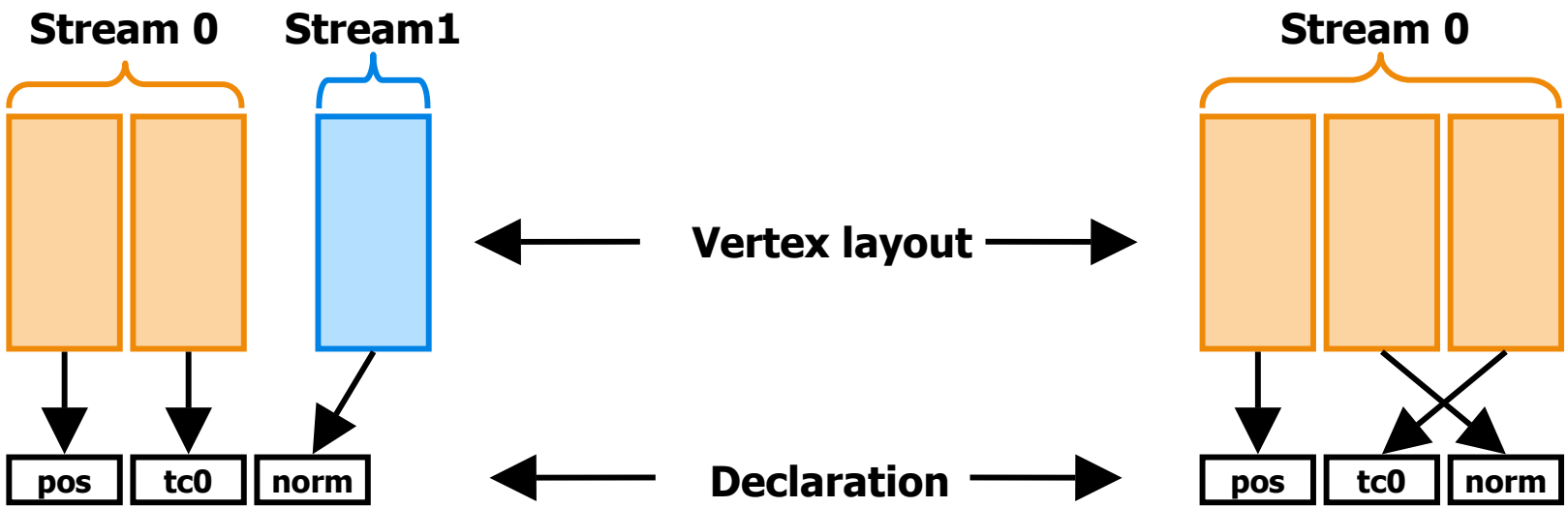
Vertex Declarations

- The mapping of vertex stream components to vertex shader inputs is much more convenient and flexible in DirectX 9
- New concept of Vertex *Declaration* which is separate from the *Function*
- Declaration controls mapping of stream data to semantics
- Function maps from semantics to shader inputs and contains the code
- Declaration and Function are separate, independent states
- Driver matches them up at draw time
  - This operation can fail if function needs data the declaration doesn't provide

Semantics

- **Usual Stuff:**
  - `POSITION`, `BLENDWEIGHT`, `BLENDINDICES`, `NORMAL`, `PSIZE`, `TEXCOORD`, `COLOR`, `DEPTH` **and** `FOG`
- **Other ones you'll typically want for convenience:**
  - `TANGENT`, `BINORMAL`
- **Higher-Order Primitives and Displacement mapping:**
  - `TESSFACTOR` **and** `SAMPLE`
- **Already-transformed Position:**
  - `POSITIONT`
- **Typically use** `TEXCOORD`*n* **for other engine-specific things**
- **Acts as symbol table for run-time linking of stream data to shader or FF transform input**

Vertex Declaration



asm:

```
vs 1.1
dcl_position  v0
dcl_normal    v1
dcl_texcoord0 v2

mov r0, v0
…
```

HLSL:

```
VS_OUTPUT main (
float4 vPosition : POSITION,
float3 vNormal   : NORMAL,
float2 vTC0      : TEXCOORD0)
{
    …
}
```

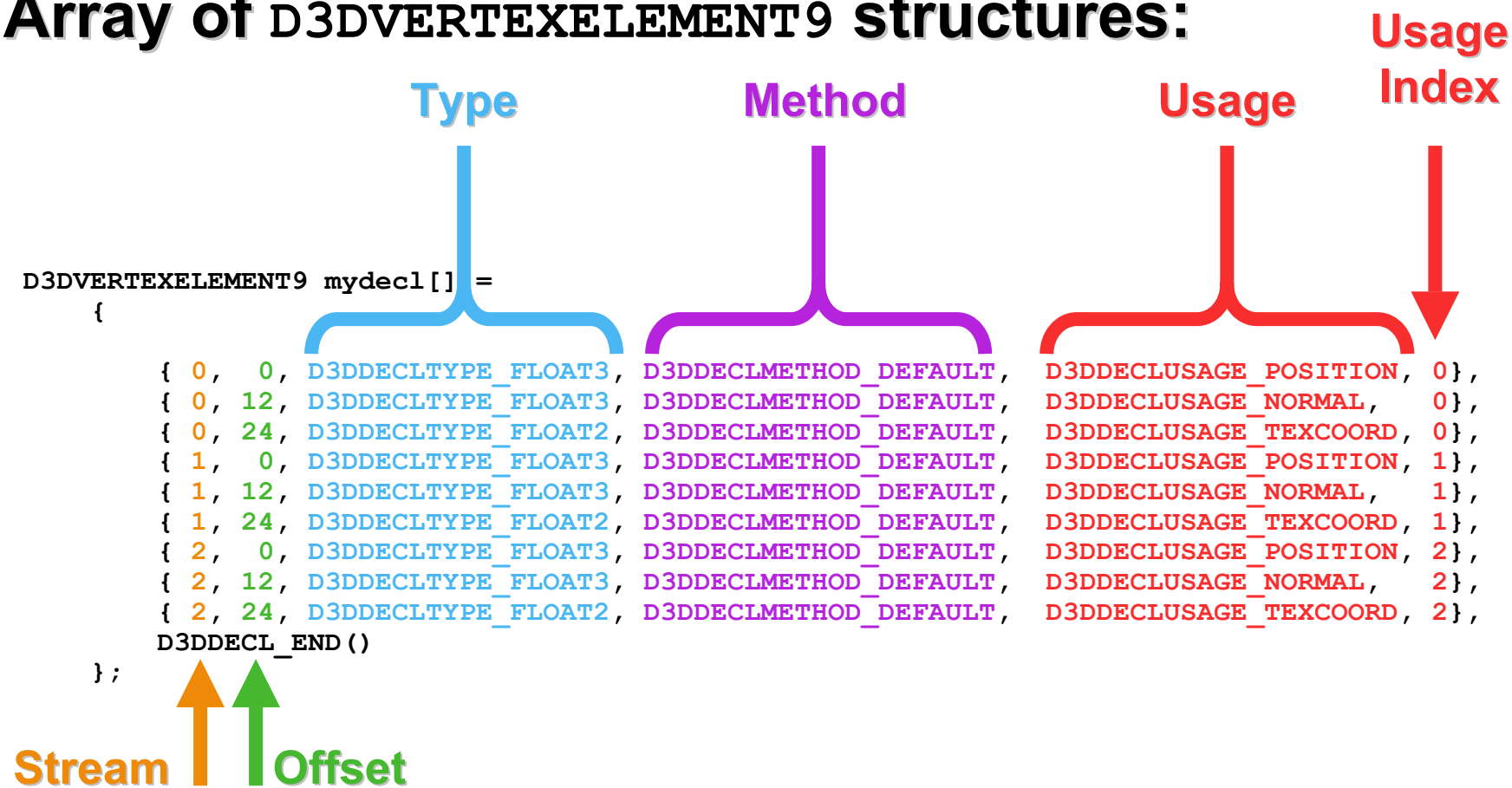
Creating a Vertex Declaration

Pass and array of `D3DVERTEXELEMENT9` structures to `CreateVertexDeclaration()`:

```
struct D3DVERTEXELEMENT9
{
        Stream;     // id from setstream()
        Offset;     // offset# verts into stream
        Type;       // float vs byte, etc.
        Method;     // tessellator op
        Usage;      // default semantic(pos, etc)
        UsageIndex // e.g. texcoord[#]
}
```

Example Vertex Declaration

Array of `D3DVERTEXELEMENT9` structures:



Creating a Vertex Shader Declaration

- Vertex **Stream**
  - Pretty obvious
- DWORD aligned **Offset**
  - Hardware requires DWORD aligned - Runtime validates
- Stream component **Type**
  - As discussed earlier, there are some additional ones in DX9
- **Method**
  - Controls tessellator. Won't talk a lot about this today
- **Usage** and **Usage Index**
  - Think of these as a tuple:
    - Think of `D3DDECLUSAGE_POSITION, 0` as Pos_0
    - Think of `D3DDECLUSAGE_TEXCOORD, 2` as Tex_2
  - A given (**Usage**, **Usage Index**) tuple must be unique
    - e.g. there can't be two Pos_0's
  - Driver uses this tuple to match w/ vertex shader func
- `D3DDECL_END()` terminates declaration

Matching Decls to Funcs

- New `dcl` instructions
  - These go at the top of the code of *all* shaders in DX9, *even vs.1.1*
  - These match the (Usage, Usage Index) tuples in the vertex declaration
  - Every `dcl` in the vertex shader func must have a (Usage, Usage Index) tuple in the current vertex declaration or DrawPrim will fail
  - HLSL compiler generates `dcl` instructions in bytecode based upon vertex shader input variables
- `dcl`s are followed by shader code
- More on this in shader section later…

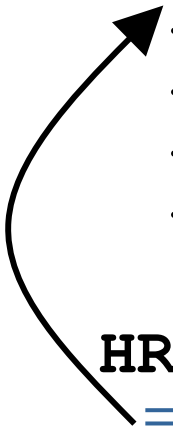
SetFVF()

- `SetVertexShaderDeclaration()` and `SetFVF()` step on each other
- Think of `SetFVF()` as shorthand for `SetVertexShaderDeclaration()` if you have a single stream that happens to follow FVF rules

DrawIndexedPrimitive

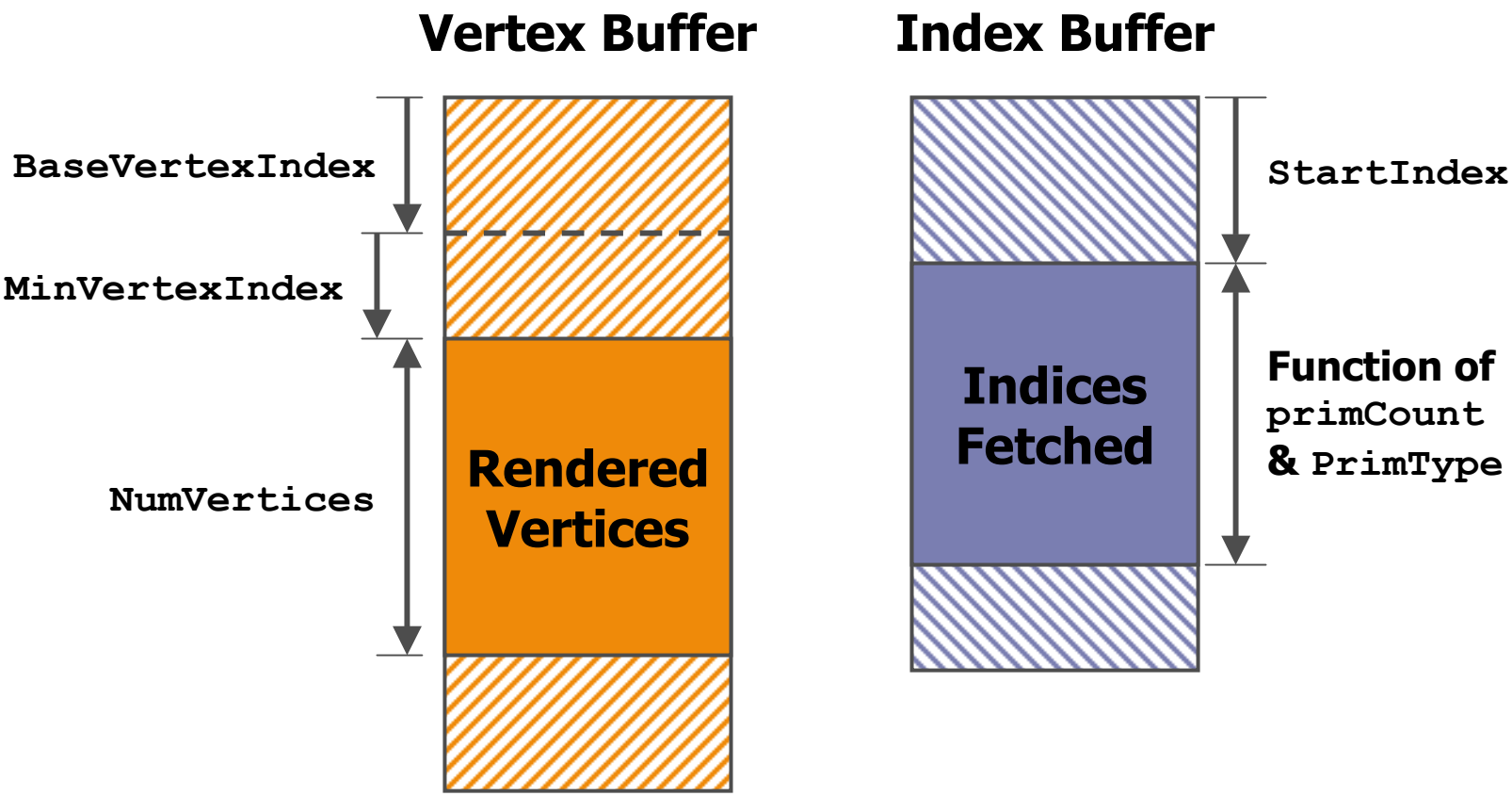
```
HRESULT
IDirect3DDevice9::DrawIndexedPrimitive(
  D3DPRIMITIVETYPE PrimType,
  INT BaseVertexIndex,
  UINT MinVertexIndex,
  UINT NumVertices,
  UINT startIndex,
  UINT primCount );

HRESULT IDirect3DDevice9::SetIndices(
  INT BaseVertexIndex,
  IDirect3DIndexBuffer9* pIndexData );
```



- **Does not require a DirectX 9 driver**

Vertex Buffer Indexing



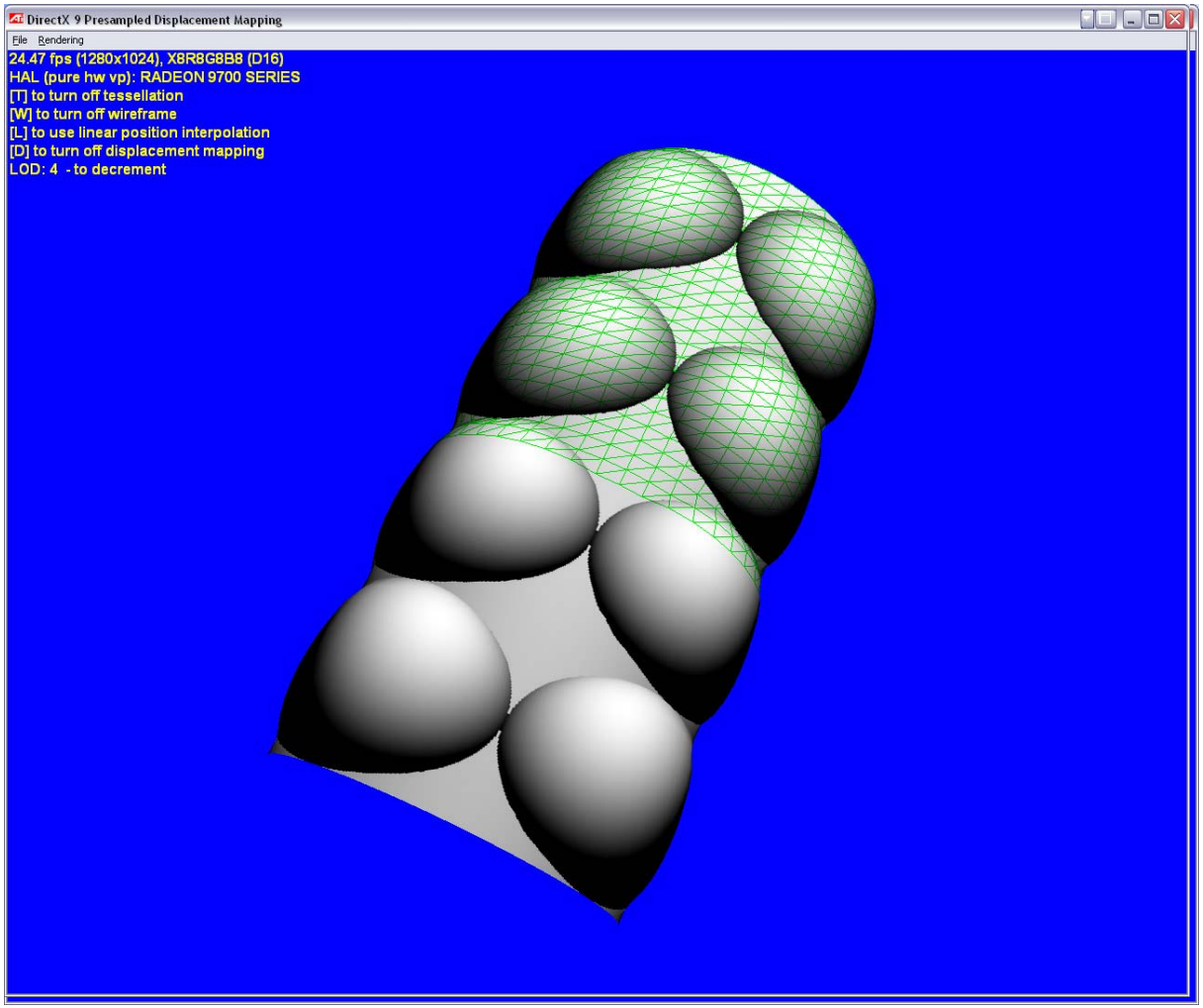
Higher Order Primitives

- **N-Patches have explicit call to enable and set tessellation level**
  - `SetNPatchMode(float* nSegments)`
- **Argument is number of segments per edge of each triangle**
- **Replaces previous renderstate**
- **Still captured in stateblocks**

Displacement Mapping

- Technique to add geometric detail by displacing vertices off of a mesh of triangles or higher order primitives
- Fits well with application LOD techniques
- But is it an API feature or an application technique?
- If the vertex shader can access memory, does displacement mapping just fall out?

Displacement Mapping

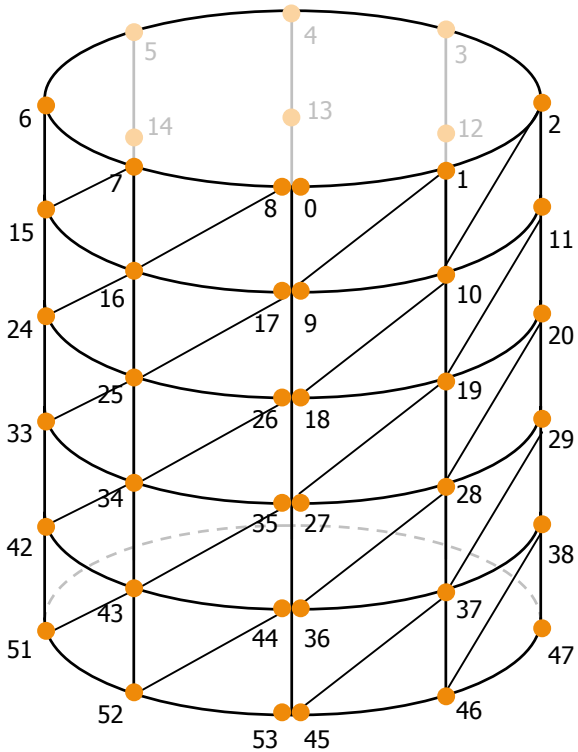


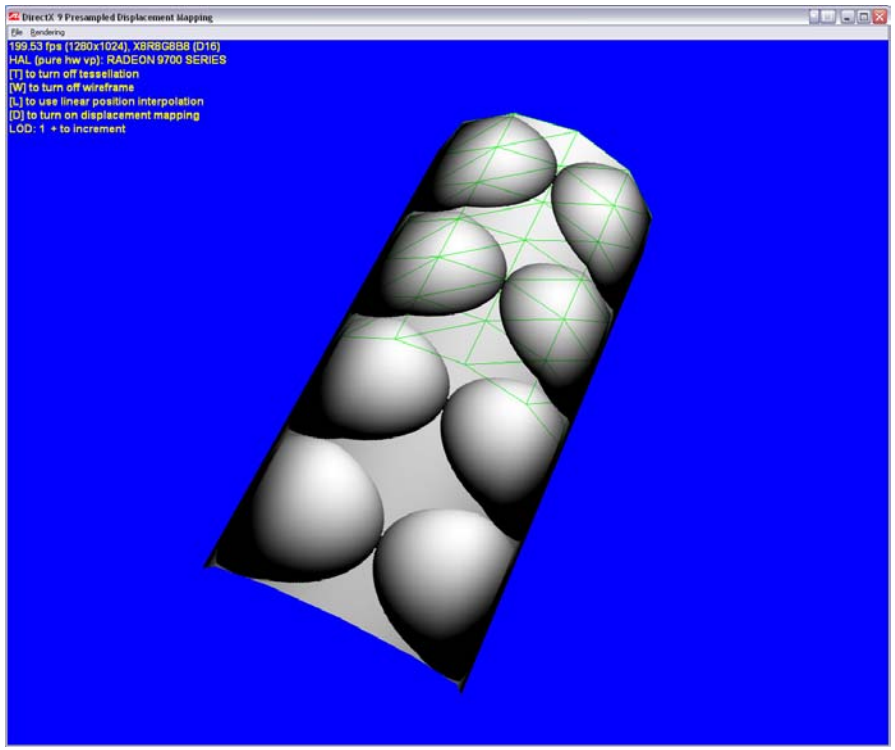
Base Mesh

The coming unification…

- As many of you have asked us: *What's the difference between a surface and a vertex buffer anyway?*
- As we'll glimpse in the next section, the 3.0 vertex shader model allows a fairly general fetch from memory
- Once you can access memory in the vertex shader, you can do displacement mapping
- There is a form of this in the API today: Presampled Displacement Mapping

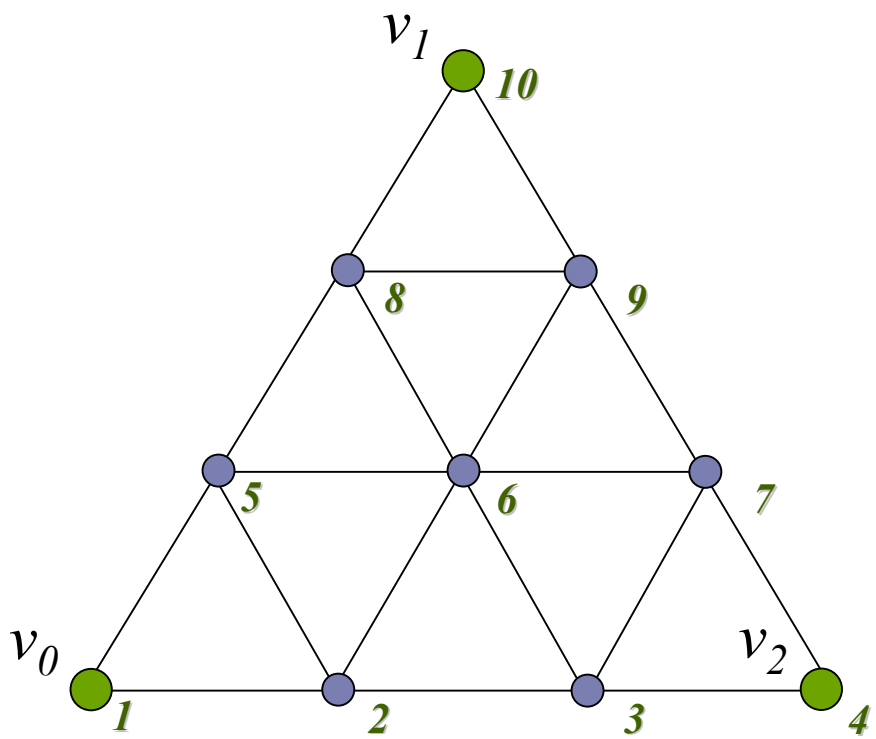
Simple example





Presampled Displacement Mapping

- **Provide displacement values in a "linearized" texture map which is accessed by the vertex shader**



New Surface Formats

- Higher precision surface formats
  - D3DFMT_ABGR8
  - D3DFMT_ABGR10
  - D3DFMT_ABGR16
  - D3DFMT_ABGR16f
  - D3DFMT_ABGR32f
- Order is consistent with shader masks
- Note: ABGR16f format is s10e5 and has max range of approx +/-32768.0

Typical Surface Capabilities (March 2003)

Format	Filter	Blend
AGBR8	➡	➡
ABGR10	➡	➡
ABGR16	➡	➔
ABGR16f	➔	➔
ABGR32f	➔	➔

- Use `CheckDeviceFormat()` with
  - `D3DUSAGE_FILTER` and `D3DUSAGE_ALPHABLEND`

Higher Precision Surfaces

- Some potential uses
  - Deferred shading
  - FB post-processing
  - HDR
  - Shadow maps
    - Can do percentage closer filtering in the pixel shader
    - Multiple samples / larger filter kernel for softened edges

Higher Precision Surfaces

- However, current hardware has these drawbacks:
  - Potentially slow performance, due to large memory bandwidth requirements
  - Potential lack of orthogonality with texture types
  - No blending
  - No filtering
- Use `CheckDeviceFormat()` with
  - `D3DUSAGE_FILTER` and `D3DUSAGE_ALPHABLEND`

Multiple Render Targets

- Step towards rationalizing textures and vertex buffers
- Allow writing out multiple values from a single pixel shader pass
  - Up to 4 color elements plus Z/depth
  - Facilitates multipass algorithms

Multiple Render Targets

- These limitations are harsh:
  - No support for FB pixel ops:
    - Channel mask, α-blend, α-test, fog, ROP, dither
    - Only z-buffer and stencil ops will work
  - No mipmapping, AA, or filtering
  - No surface Lock()
- Most of these will work better in the next hardware generation

SetRenderTarget() Split

- **Changed to work with MRTs**
- **Can only be one current ZStencil target**
- `RenderTargetIndex` **refers to MRT**
- `IDirect3DDevice9::SetRenderTarget(`
  `DWORD RenderTargetIndex,`
  `IDirect3DSurface9* pRenderTarget);`
- `IDirect3DDevice9::SetDepthStencilSur`
  `face (IDirect3DSurface9*`
  `pNewZStencil);`

Depth Bias

- **Bias = m * D3DRS_ZSLOPESCALE + D3DRS_ZBIAS**
  - **where, m is the max depth slope of triangle**
    m = max(abs(∂*z* / ∂*x*), abs(∂*z* / ∂*y*))
- **Cap Flag**
  - **D3DPRASTERCAPS_SLOPESCALEDEPTHBIAS**
- **Renderstates**
  - **D3DRS_DEPTHBIAS, <float>**
  - **D3DRS_SLOPESCALEDEPTHBIAS, <float> -new**
- **Important for depth based shadow buffers and overlaid geometry like tire marks**

Automatic Mip-map Generation

- **Very useful for render-to-texture effects**
  - **Dynamic environment maps**
  - **Dynamic bump maps for water, etc.**
- **Leverages hardware filtering**
  - **That means it's fast, and done in whatever path the driver decides is optimal for this piece of hardware**
- **Most modern GPUs can support this feature**

Automatic Mip-map Generation

- Checking Caps
  - D3DCAPS2_CANAUTOGENMIPMAP
- Mipmaps can be auto-generated by hardware for any texture format (with the exception of DXTC compressed textures)
- Use D3DUSAGE_AUTOGENMIPMAP when creating the texture
- Filter Type
  - `SetAutoGenFilterType(D3DTEXF_LINEAR);`
- Mip-maps will automatically be generated
  - Can force using GenerateMipSubLevels()

Scissor Rect

- **Just after pixel shader**
- **API:**
  - `D3DDevice9::SetScissorRect(*pRect);`
  - `D3DDevice9::GetScissorRect(*pRect);`
  - `D3DRS_SCISSORRECTENABLE`
- **CAP:**
  - `D3DPRASTERCAPS_SCISSORTEST`

Multisample Buffers

- Now supports separate control of
- Number of samples/pixel:
  - D3DMULTISAMPLE_TYPE
  - indicates number of separately addressable subsamples accessed by mask bits
- Image quality level:
  - DWORD dwMultiSampleQuality
  - 0 is base/default quality level
  - Driver returns number of quality levels supported via CheckDeviceMultisample()

Multihead

- All heads in a multihead card can be driven by one Direct3D device
  - So video memory can be shared
- Fullscreen only
- Enables dual and triple head displays to use same textures on all 3 display devices

Multihead

- New members in `D3DCAPS9`
  - `NumberOfAdaptersInGroup`
  - `MasterAdapterOrdinal`
  - `AdapterOrdinalInGroup`
- One is the **Master** head and other heads on the same card are **Slave** heads
- The master and its slaves from one multi-head adapter are called a **Group**
- CreateDevice takes a flag (`D3DCREATE_ADAPTERGROUP_DEVICE`) indicating that the application wishes this device to drive all the heads that this master adapter owns

Multihead Examples

Wacky Example

	Single-head card	Dual-head card		Triple-head card		
Adapter Ordinal	0	1	2	3	4	5
NumberOfAdaptersInGroup	1	2	0	3	0	0
MasterAdapterOrdinal	0	1	1	3	3	3
AdapterOrdinalInGroup	0	0	1	0	1	2

Real Example

	Dual-head card	
Adapter Ordinal	0	1
NumberOfAdaptersInGroup	2	0
MasterAdapterOrdinal	0	0
AdapterOrdinalInGroup	0	1

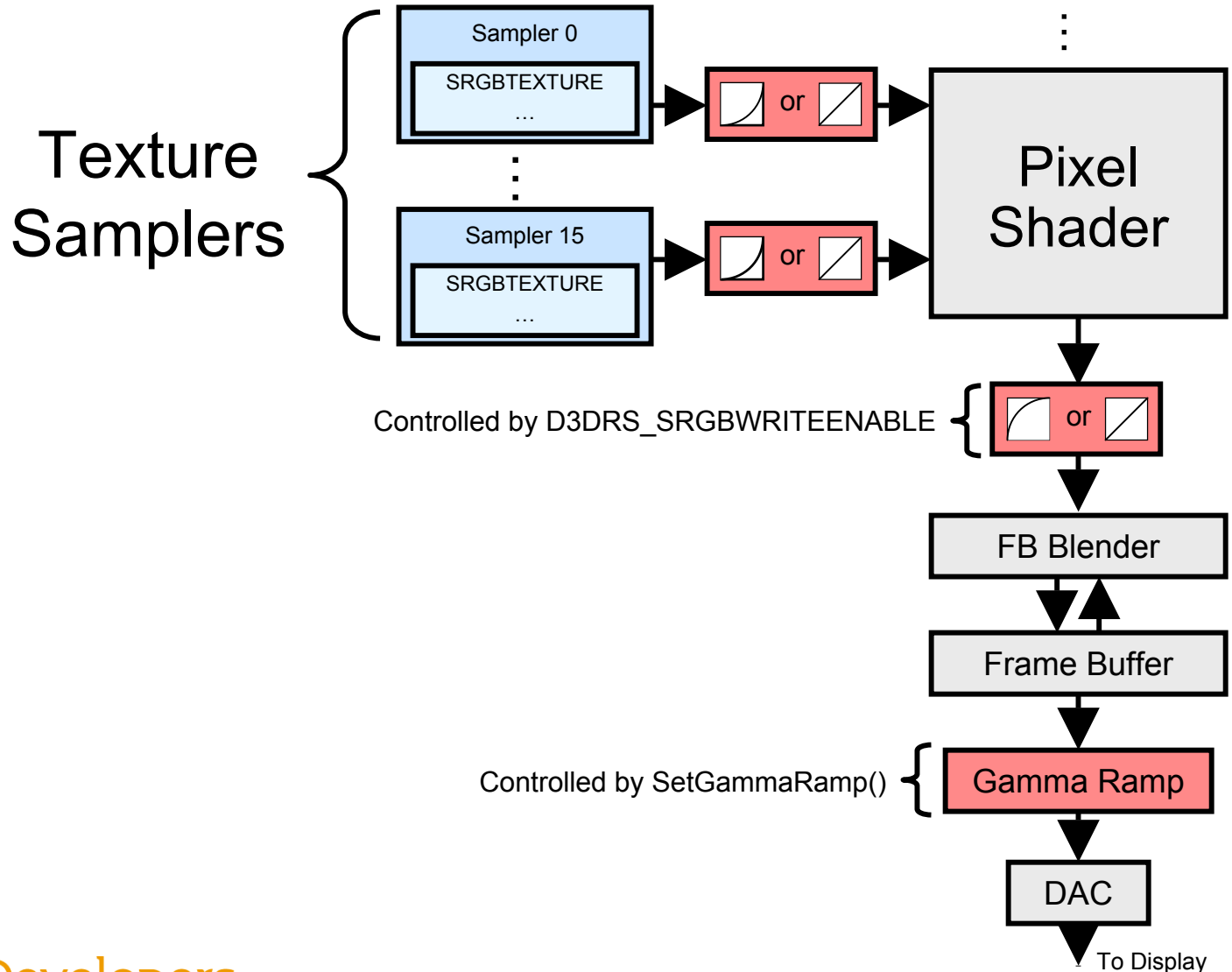
Constant Blend Color

- An additional constant is now available for use in the frame-buffer blender
- This is supported in most current hardware
- Set using D3DRS_BLENDFACTOR dword packed color
- Use in blending via
  - D3DBLEND_BLENDFACTOR
  - D3DBLEND_INVBLENDFACTOR

sRGB

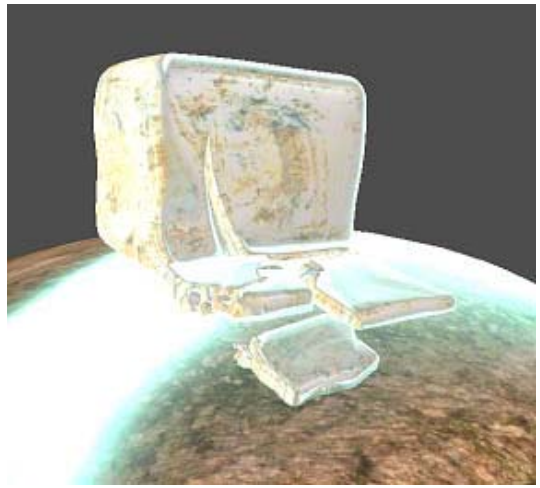
- **Microsoft-pushed industry standard (γ 2.2) format**
- **In Direct3D, sRGB is a sampler state, not a texture format**
- **May not be valid on all texture formats, however**
  - **Determine this through `CheckDeviceFormat` API**

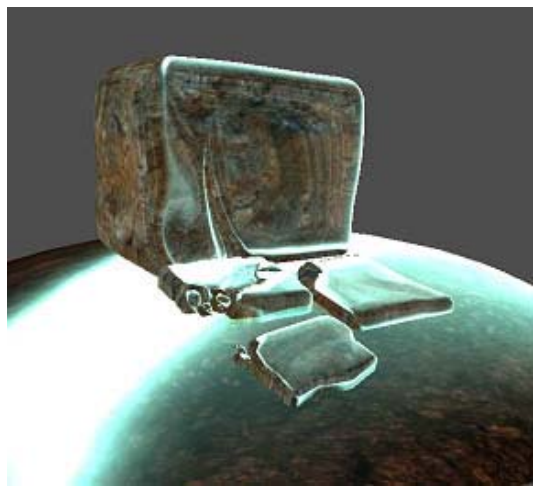
sRGB and Gamma in DirectX 9



sRGB

- Symptoms of ignoring gamma:
- Screen/textures may look washed out
  - Low contrast, greyish
- Addition may seem too bright
- Division may seem too dark
  - ½ should be 0.73
- User shouldn't have to adjust monitor





sRGB

- Problem
  - Math in gamma space is not linear (50% + 50% ≠ 1.0)
    - Input textures authored in sRGB
  - Math in pixel shader is linear (50% + 50% = 1.0)
- Solution
  - Texture inputs converted to linear space (rgbγ)
    - D3DUSAGE_QUERY_SRGBREAD
    - D3DSAMP_SRGBTEXTURE
  - Pixel shader output converted to gamma space (rgb1/γ)
    - D3DUSAGE_QUERY_SRGBWRITE
    - D3DRS_SRGBWRITEENABLE
    - Limited to the first element of MET

sRGB

- sRGB defined only for 8-bit unsigned RGB surfaces
  - Alpha is linear
- Color clears are linear
- Windowed applications either
  - Perform a gamma correction blit
  - Or use D3DPRESENT_LINEAR_CONTENT if exposed
    - D3DCAPS3_LINEAR_TO_SRGB_PRESENTATION
- Frame buffer blending is *NOT* correct
  - Neither is texture filtering
- D3DX provides conversion functionality

Two-sided Stencil

- Stencil shadows volumes can now be rendered in 1 pass instead of two
  - Biggest savings is in transform
- Check caps bit
  - D3DSTENCILCAPS_TWOSIDED
- Set new render state to TRUE
  - D3DRS_TWOSIDEDSTENCILMODE
- Current stencil ops then apply to CW polygons
- A new set then applies to CCW polygons
  - D3DRS_CCW_STENCILFAIL
  - D3DRS_CCW_STENCILPASS
  - D3DRS_CCW_STENCILFUNC

Discardable Depth-Stencil

- Significant performance boost on some implementations
- Not the default: App has to ask for discardable surface in presentation parameters on Create or it will not happen
- If enabled, implementation need not persist Depth/Stencil across frames
- Most applications should be able to enable this

Asynchronous Notification

- Mechanism to return data to app from hardware
- App posts query and then can poll later for result without blocking
- Works on some current and most future hardware
- Most powerful current notification is “occlusion query”

Occlusion Query

- Returns the number of pixels that survive to the framebuffer
  - So, they pass the z test, stencil test, scissor, etc.
- Useful for a number of algorithms
  - Occlusion culling
  - Lens-flare / halo occlusion determination
  - Order-independent transparency

Occlusion Query – Example

- **Create `IDirect3DQuery9` object**
  - `CreateQuery(D3DQUERYTYPE_OCCLUSION)`
  - **You can have multiple outstanding queries**
- `Query->Issue(D3DISSUE_BEGIN)`
- **Render geometry**
- `Query->Issue(D3DISSUE_END)`
- **Potentially later, `Query->GetData()` to retrieve number of rendered pixels between Begin and End**
  - **Will return S_FALSE if query result is not available yet**

Occlusion Query – Light halos

- Render light's geometry while issuing occlusion query
- Depending on the number of pixels passing, fade out a halo around the light
- If occlusion info is not yet available, potentially just use the last frame's data
  - Doesn't need to be perfect

Occlusion Query - Multipass

- A simple form of occlusion culling
- If a rendering equation takes multiple passes, use occlusion queries around objects in the initial pass
- In subsequent passes, only render additional passes on objects where the query result != 0
  - Doesn't cost perf because occlusion query around geometry you're rendering anyway is "free"

Summary

- Feeding Geometry to the GPU
  - Vertex stream offset and VB indexing
  - Vertex declarations
  - Presampled displacement mapping
- Pixel processing
  - New surface formats
  - Multiple render targets
  - Depth bias with slope scale
  - Auto mipmap generation
  - Multisampling
  - Multihead
  - sRGB / gamma
  - Two-sided stencil
- Miscellaneous
  - Asynchronous notification / occlusion query