DirectX® 9 High Level Shading Language

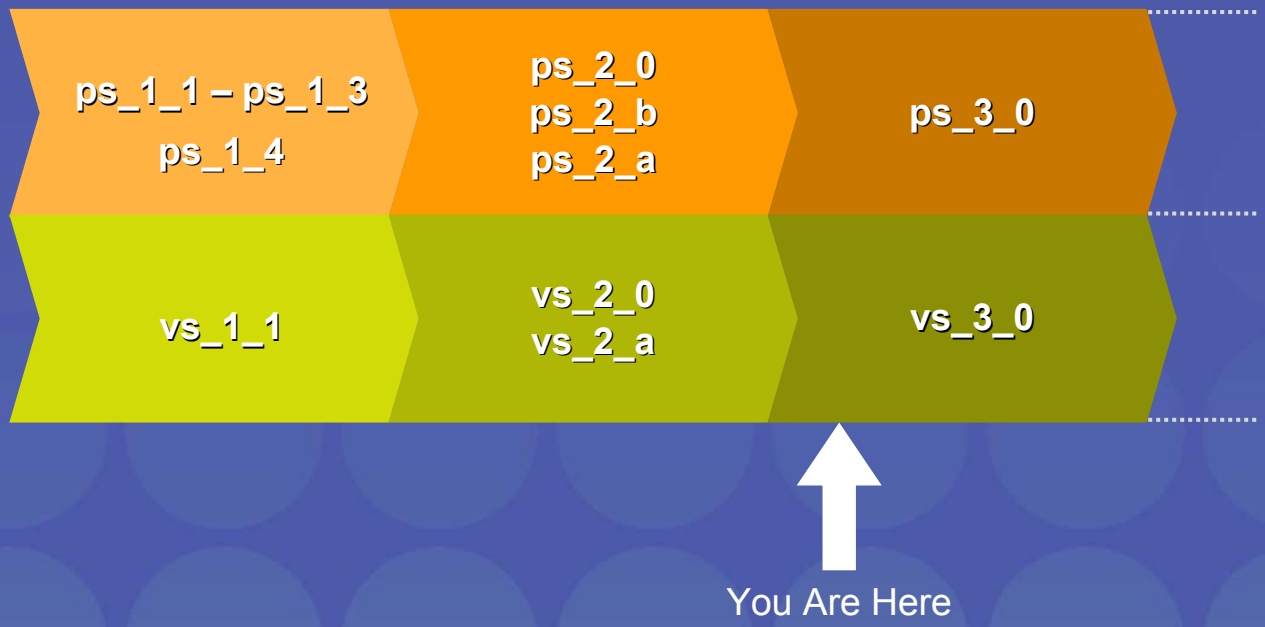
Jason Mitchell

ATI Research

Outline

- Targeting Shader Models
- Vertex Shaders
  - Flow Control
- Pixel Shaders
  - Centroid interpolation
  - Flow control

Shader Model Continuum



Tiered Experience

- PC developers have always had to scale the visual experience of their game across a range of platform capabilities
- Often, developers pick discrete tiers
  - DirectX 7, DirectX 8, DirectX 9 is one example
- Shader-only games are in development
- We’re starting to see developers target the three levels of shader support as the distinguishing factor among the tiered game experience

Caps in addition to Shader Models

- In DirectX 9, devices can express their abilities via a base shader version plus some optional caps
- At this point, the only “base” shader versions beyond 1.x are the 2.0 and 3.0 shader versions
- Other differences are expressed via caps:
  - `D3DCAPS9.PS20Caps`
  - `D3DCAPS9.VS20Caps`
  - `D3DCAPS9.MaxPixelShader30InstructionSlots`
  - `D3DCAPS9.MaxVertexShader30InstructionSlots`
- This may seem messy, but it’s not that hard to manage given that you all are writing in HLSL and there are a finite number of device variations in the marketplace
- Can determine the level of support on the device by using the `D3DXGet*ShaderProfile()` routines

Compile Targets / Profiles

- Whenever a new family of devices ships, the HLSL compiler team may define a new target
- Each target is defined by a base shader version and a specific set of caps
- Existing compile targets are:
  - Vertex Shaders
    - vs_1_1
    - vs_2_0 and vs_2_a
    - vs_3_0
  - Pixel Shaders
    - ps_1_1, ps_1_2, ps_1_3 and ps_1_4
    - ps_2_0, ps_2_b and ps_2_a
    - ps_3_0

Vertex Shader HLSL Targets

- vs_2_0
  - 256 Instructions
  - 12 temporary registers
  - Static flow control (`StaticFlowControlDepth = 1`)
- vs_2_a
  - 256 Instructions
  - 13 temporary registers
  - Static flow control (`StaticFlowControlDepth = 1`)
  - Dynamic flow control (`DynamicFlowControlDepth = 24`)
  - Predication (`D3DVS20CAPS_PREDICATION`)
- vs_3_0
  - Basically vs_2_0 with all of the caps
  - No fine-grained caps like in vs_2_0. Only one:
    - `MaxVertexShader30InstructionSlots` (512 to 32768)
  - More temps (32)
  - Indexable input and output registers
  - Access to textures
    - texldl
    - No dependent read limit

Vertex Shader Registers

- Floating point registers
  - 16 Inputs ($\mathbf{v}_n$)
  - Temps ($\mathbf{r}_n$)
    - 12 in vs_1_1 through vs_2_0
    - 32 in vs_3_0
  - At least 256 Constants ($\mathbf{c}_n$)
    - Cap'd: **`MaxVertexShaderConst`**
- Integer registers
  - 16 ($\mathbf{i}_n$)
- Boolean scalar registers
  - 16 Control flow ($\mathbf{b}_n$)
- Address Registers
  - 4D vector: **`a0`**
  - Scalar loop counter (only valid in loop): **`aL`**
- Sampler Registers
  - 4 of these in vs_3_0

Vertex Shader Flow Control

- Goal is to reduce shader permutations
  - Control the flow of execution through a small number of key shaders
- Code size reduction is a goal as well, but code is also harder for compiler and driver to optimize

- Static Flow Control
  - Based solely on constants
  - Same code path for every vertex in a given draw call
- Dynamic Flow Control
  - Based on data read in from VB
  - Different vertices in a primitive can take different paths

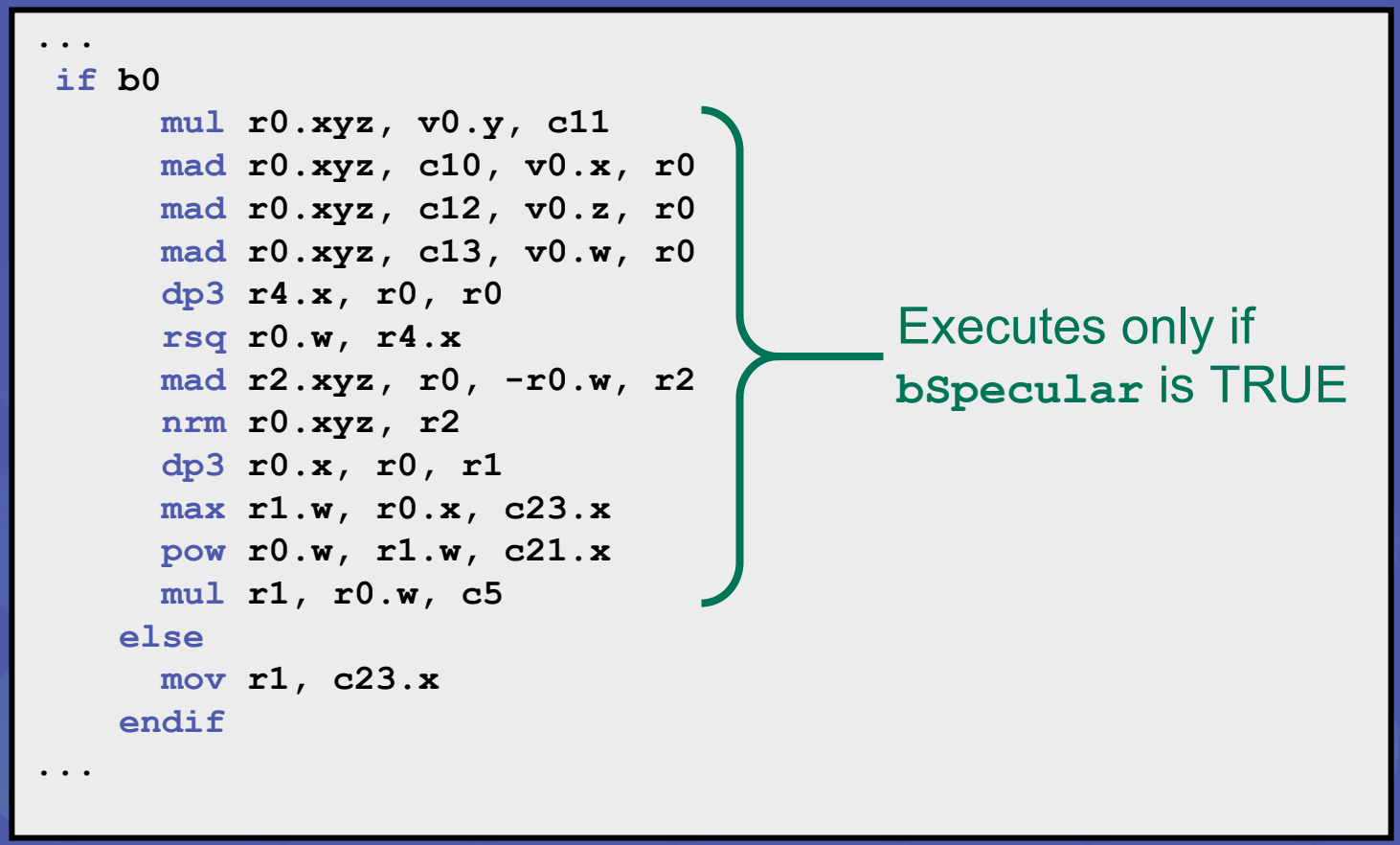
Static Conditional Example


```
COLOR_PAIR DoDirLight(float3 N, float3 V, int i)
{
   COLOR_PAIR Out;
   float3 L = mul((float3x3)matViewIT, -normalize(lights[i].vDir));
   float NdotL = dot(N, L);
   Out.Color = lights[i].vAmbient;
   Out.ColorSpec = 0;
   if(NdotL > 0.f)
   {
      //compute diffuse color
      Out.Color += NdotL * lights[i].vDiffuse;

      //add specular component
      if(bSpecular)
      {
         float3 H = normalize(L + V);   // half vector
         Out.ColorSpec = pow(max(0, dot(H, N)), fMaterialPower) * lights[i].vSpecular;
      }
   }
   return Out;
}
```

bSpecular is a boolean declared at global scope

Static Conditional Result



Two kinds of loops

- `loop aL, i`$_n$
  - `i`$_n$`.x` - Iteration count (non-negative)
  - `i`$_n$`.y` - Initial value of `aL` (non-negative)
  - `i`$_n$`.z` - Increment for `aL` (can be negative)
  - `aL` can be used to index the constant store
  - No nesting in vs_2_0
- rep `i`$_n$
  - `i`$_n$ - Number of times to loop
  - No nesting

Loops from HLSL

- The D3DX HLSL compiler has some restrictions on the types of for loops which will result in asm flow-control instructions. Specifically, they must be of the following form in order to generate the desired asm instruction sequence:

```
for(i = 0; i < n; i++)
```

- This will result in an asm loop of the following form:

```
rep i0
  ...
endrep
```

- In the above asm, `i0` is an integer register specifying the number of times to execute the loop
- The loop counter, `i0`, is initialized before the `rep` instruction and incremented before the `endrep` instruction.

Static Loop


```
...
   Out.Color = vAmbientColor;                    // Light computation

   for(int i = 0; i < iLightDirNum; i++)         // Directional Diffuse
   {
      float4 ColOut = DoDirLightDiffuseOnly(N, i+iLightDirIni);
      Out.Color += ColOut;
   }

   Out.Color *= vMaterialColor;                  // Apply material color

   Out.Color = min(1, Out.Color);                // Saturate

...
```

Static Loop Result


```
vs_2_0
def c58, 0, 9, 1, 0
dcl_position v0
dcl_normal v1
          ...
rep i0
  add r2.w, r0.w, c57.x
  mul r2.w, r2.w, c58.y
  mova a0.w, r2.w
  nrm r2.xyz, c2[a0.w]
  mul r3.xyz, -r2.y, c53
  mad r3.xyz, c52, -r2.x, r3
  mad r2.xyz, c54, -r2.z, r3
  dp3 r2.x, r0, r2
  slt r3.w, c58.x, r2.x
  mul r2, r2.x, c4[a0.w]
  mad r2, r3.w, r2, c3[a0.w]
  add r1, r1, r2
  add r0.w, r0.w, c58.z
endrep
mov r0, r1
mul r0, r0, c55
min oD0, r0, c58.z
```

Executes once for each directional diffuse light

Subroutines

- Currently, the HLSL compiler inlines all function calls
- Does not generate `call` / `ret` instructions and likely won't do so until a future release of DirectX
- Subroutines aren't needed unless you find that you're running out of shader instruction store

Dynamic Flow Control

- If `D3DCAPS9.VS20Caps.DynamicFlowControlDepth > 0`, dynamic flow control instructions are supported:
  - `if_gt  if_lt  if_ge  if_le  if_eq  if_ne`
  - `break_gt break_lt break_ge break_le break_eq break_ne`
  - `break`

- HLSL compiler has a set of heuristics about when it is better to emit an algebraic expansion, rather than use actual dynamic flow control
  - Number of variables changed by the block
  - Number of instructions in the body of the block
  - Type of instructions inside the block
  - Whether the HLSL has texture or gradient instructions inside the block

Obvious Dynamic Early-Out Optimizations

- Zero skin weight(s)
  - Skip bone(s)
- Light attenuation to zero
  - Skip light computation
- Non-positive Lambertian term
  - Skip light computation
- Fully fogged pixel
  - Skip the rest of the pixel shader
- Many others like these…

Dynamic Conditional Example


```
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    COLOR_PAIR Out;
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    float NdotL = dot(N, L);
    Out.Color = lights[i].vAmbient;
    Out.ColorSpec = 0;
    if(NdotL > 0.0f)
    {
       //compute diffuse color
       Out.Color += NdotL * lights[i].vDiffuse;

       //add specular component
       if(bSpecular)
       {
          float3 H = normalize(L + V);    // half vector
          Out.ColorSpec = pow(max(0, dot(H,N)), fMaterialPower) * lights[i].vSpecular;
       }
    }
    return Out;
}
```
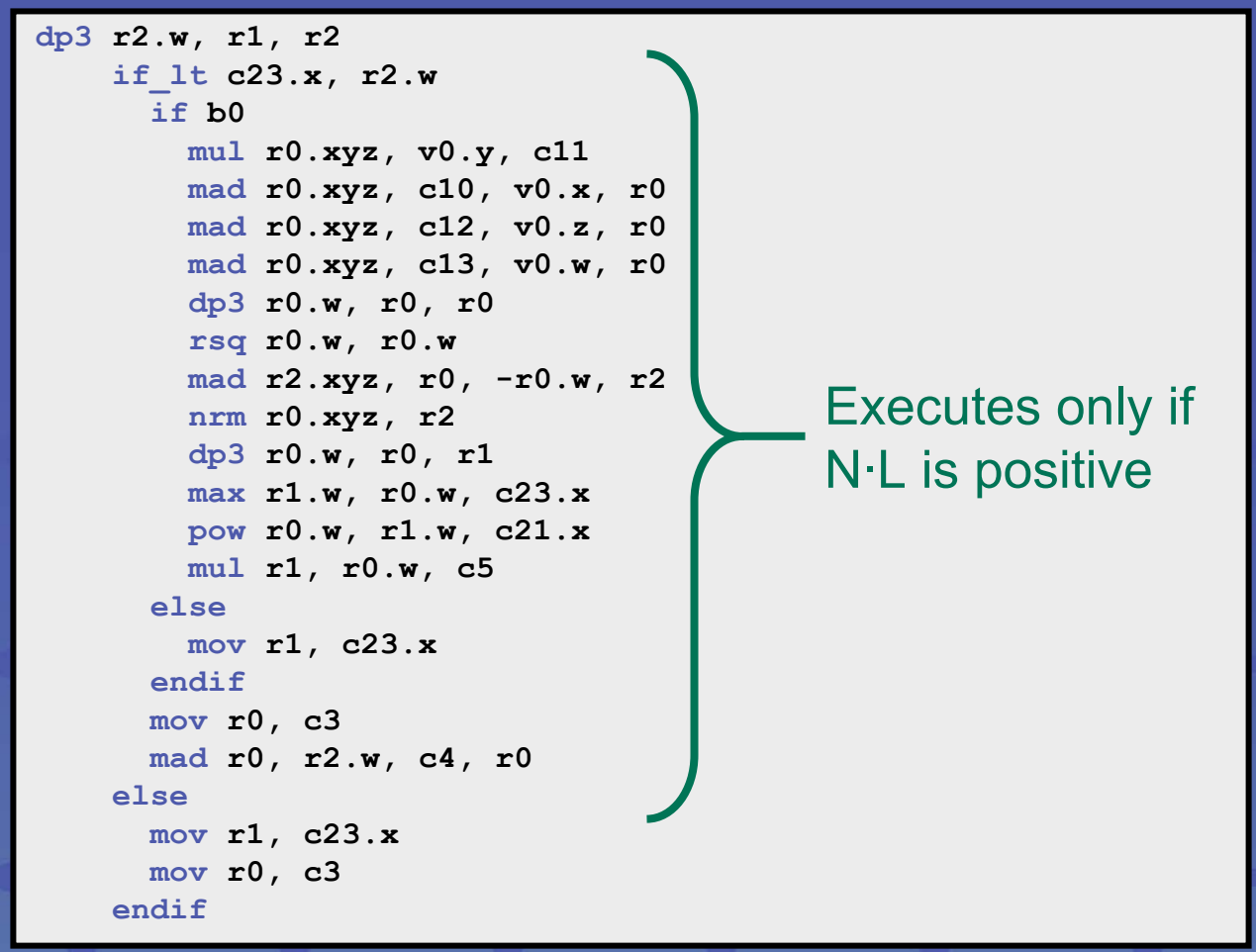

Dynamic condition which can be different at each vertex

Result


dp3 r2.w, r1, r2
if_lt c23.x, r2.w
if b0
mul r0.xyz, v0.y, c11
mad r0.xyz, c10, v0.x, r0
mad r0.xyz, c12, v0.z, r0
mad r0.xyz, c13, v0.w, r0
dp3 r0.w, r0, r0
rsq r0.w, r0.w
mad r2.xyz, r0, -r0.w, r2
nrm r0.xyz, r2
dp3 r0.w, r0, r1
max r1.w, r0.w, c23.x
pow r0.w, r1.w, c21.x
mul r1, r0.w, c5
else
mov r1, c23.x
endif
mov r0, c3
mad r0, r2.w, c4, r0
else
mov r1, c23.x
mov r0, c3
endif
Executes only if
N·L is positive

Hardware Parallelism

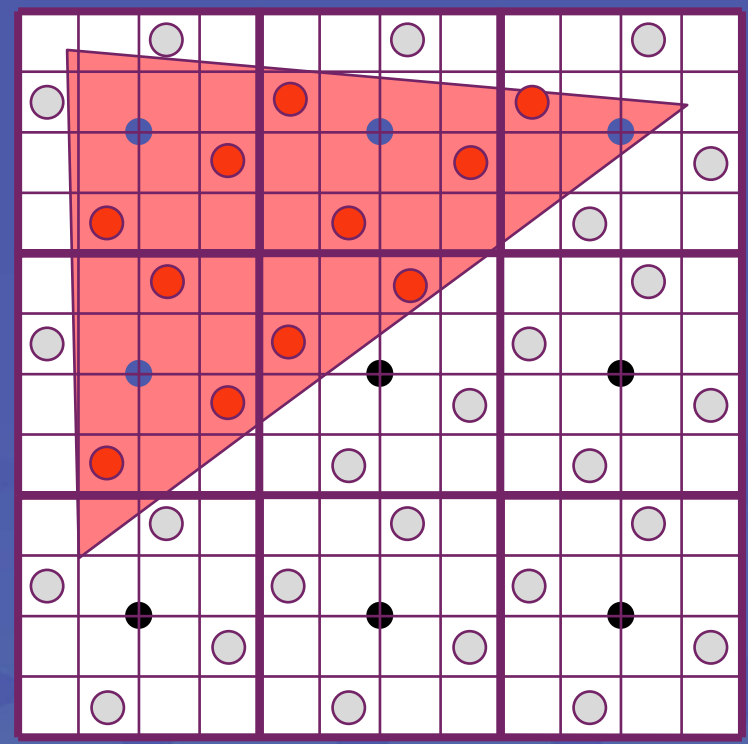
- This is not a CPU
- There are many shader units executing in parallel
  - These are generally in lock-step, executing the same instruction on different pixels/vertices at the same time
  - Dynamic flow control can cause inefficiencies in such an architecture since different pixels/vertices can take different code paths
- Dynamic branching is not always a performance win
- For an if…else, there will be cases where evaluating both the blocks is faster than using dynamic flow control, particularly if there is a small number of instructions in each block
- Depending on the mix of vertices, the worst case performance can be worse than executing the straight line code without any branching at all

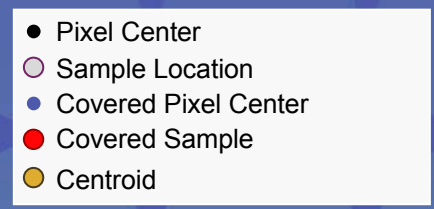
Pixel Shader HLSL Targets

	ps_2_0	ps_2_b	ps_2_a	ps_3_0
Instructions	64 + 32	512	512	≥ 512
Temp Registers	12	32	22	32
Levels of dependency	4	4	Unlimited	Unlimited
Arbitrary swizzles	✗	✗	✓	✓
Predication	✗	✗	✓	✓
Static flow control	✗	✗	✓	✓
Gradient Instructions	✗	✗	✓	✓
Dynamic Flow Control	✗	✗	✗	✓
vFace	✗	✗	✗	✓
vPos	✗	✗	✗	✓

Centroid Interpolation

- When multisample antialiasing, some pixels are partially covered
- Pixel shader is run once per pixel
- Interpolated quantities are evaluated at pixel center
- However, the center of the pixel may lie outside of the primitive
- Depending on the meaning of the interpolator, this may be bad, due to what is effectively extrapolation beyond the edge of the primitive
- Centroid interpolation evaluates the interpolated quantity at the centroid of the covered samples
- Available in ps_2_0 as of DX9.0c





4-Sample Buffer

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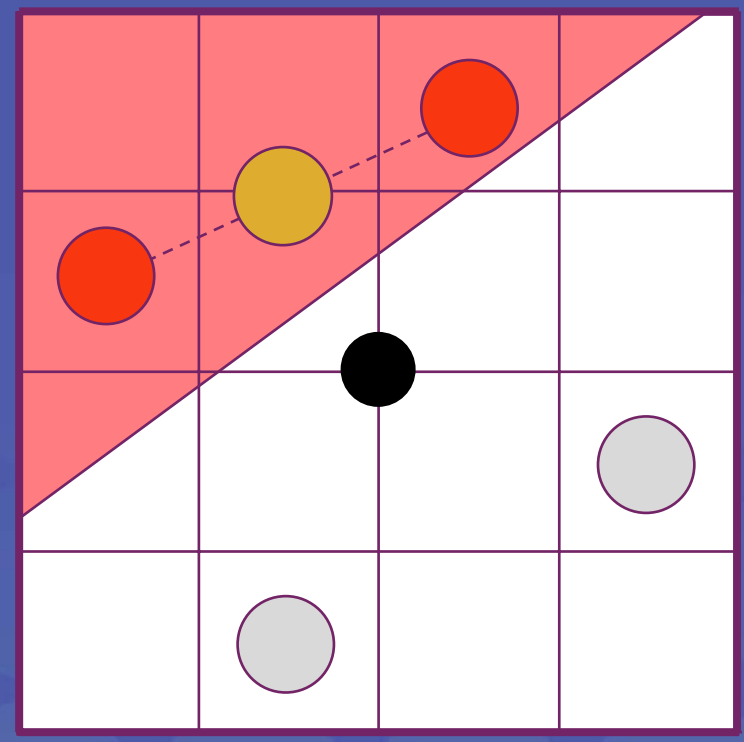


Centroid Usage

- When?
  - Light map paging
  - Interpolating light vectors
  - Interpolating basis vectors
    - Normal, tangent, binormal
- How?
  - Colors already use centroid interpolation automatically
  - In asm, tag texture coordinate declarations with `_centroid`
  - In HLSL, tag appropriate pixel shader input semantics:

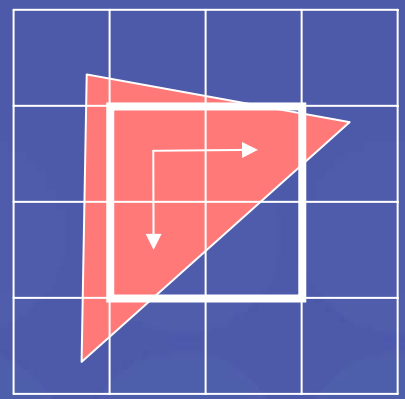
```
float4 main(float4 vTangent : TEXCOORD0_centroid){}
```

Aliasing due to Conditionals

- Conditionals in pixel shaders can cause aliasing!
- Avoid doing a conditional with a quantity that is key to determining your final color
  - Do a procedural smoothstep, use a pre-filtered texture for the function you're expressing or bandlimit the expression
  - This is a fine art. Huge amounts of effort go into this in the offline world where procedural RenderMan shaders are a staple

Shader Antialiasing

- Computing derivatives (actually first differences in hardware) of shader quantities with respect to screen x, y coordinates is fundamental to procedural shading
- For regular texturing, LOD is calculated automatically based on a 2×2 pixel quad, so you don't generally have to think about it, even for dependent texture fetches
- The HLSL **`ddx()`**, **`ddy()`** derivative intrinsic functions, available when compiling for ps_2_a or ps_3_0, can compute these derivatives



Derivatives and Dynamic Flow Control

- The result of a gradient calculation on a computed value (i.e. not an input such as a texture coordinate) inside dynamic flow control is ambiguous when adjacent pixels may go down separate paths
- Hence, nothing that requires a derivative of a computed value may exist inside of dynamic flow control
  - This includes most texture fetches, **`ddx()`** and **`ddy()`**
  - **`texldl`** and **`texldd`** work since you have to compute the LOD or derivatives outside of the dynamic flow control
- RenderMan has similar restrictions

Dynamic Texture Loads


```
...
   float edge;
   float2 duvdx, duvdy;
   edge = tex2D(EdgeSampler, oTex0).r;
   duvdx = ddx(oTex0);
   duvdy = ddy(oTex0);

   if(edge > 0)
   {
      return tex2D(BaseSampler, oTex0, duvdx, duvdy);
   }
   else
   {
      return 0;
   }
...
```

Compute gradients outside of flow control

Resulting ASM


```
ps_3_0
def c0, 0, 1, 0, 0
def c1, 0, 0, 0, 0
dcl_texcoord v0.xy
dcl_2d s0
dcl_2d s1
texld r0, v0, s1
cmp r0.w, -r0.x, c0.x, c0.y
dsx r0.xy, v0
dsy r1.xy, v0
if_ne r0.w, -r0.w
  texldd oC0, v0, s0, r0, r1
else
 mov oC0, c0.x
endif
```

Dynamic Texture Load on a non-mipmapped texture


```
...
   float edge;

   edge = tex2D(EdgeSampler, oTex0).r;

   if(edge > 0)
   {
      return tex2Dlod(BaseSampler, oTex0);
   }
   else
   {
     return 0;
   }
...
```

oTex0.zw should be set to zero

Resulting ASM


```
ps_3_0
def c0, 0, 1, 0, 0
def c1, 0, 0, 0, 0
dcl_texcoord v0
dcl_2d s0
dcl_2d s1
texld r0, v0, s1
cmp r0.w, -r0.x, c0.x, c0.y
if_ne r0.w, -r0.w
  texldl oC0, v0, s0
else
  mov oC0, c0.x
endif
```

vFace & vPos

- **`vFace`** – Scalar facingness register
  - Positive if front facing, negative if back facing
  - Can do things like two-sided lighting
  - Appears as either +1 or -1 in HLSL
- **`vPos`** – Screen space position
  - *x*, *y* contain screen space position
  - *z*, *w* are undefined

Acknowledgements

- Thanks to Craig Peeper and Dan Baker of Microsoft for HLSL compiler info