6800 LEAGUES UNDER THE SEA

NVIDIA

Shader Model 3.0, Best Practices

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Overview

- Short Pipeline Overview
- CPU Bound – new optimization opportunities
- Obscure bits of the pipeline that can trip you up
- Pixel Bound – new optimization opportunities
- 3.0 shader performance characteristics

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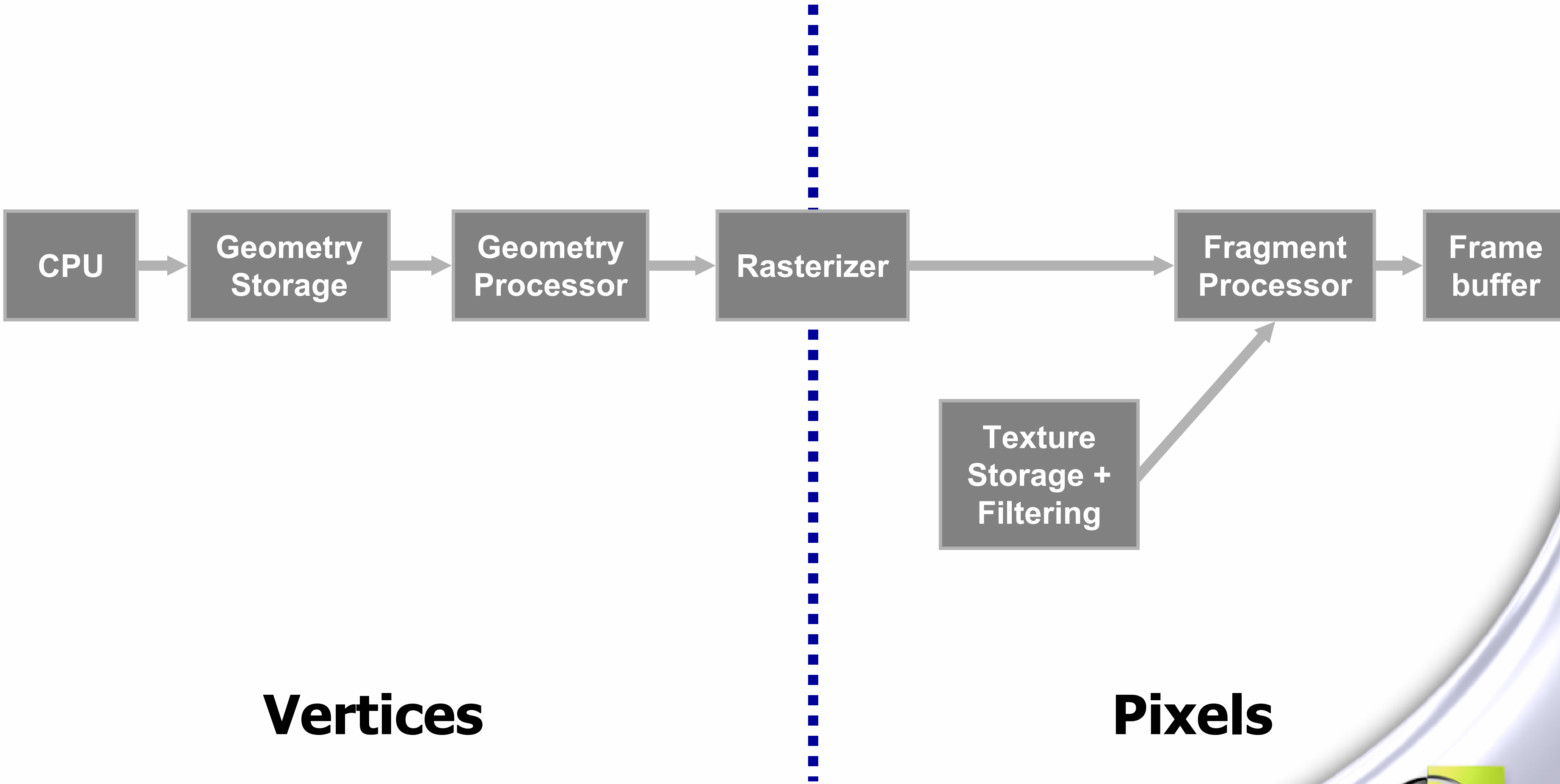
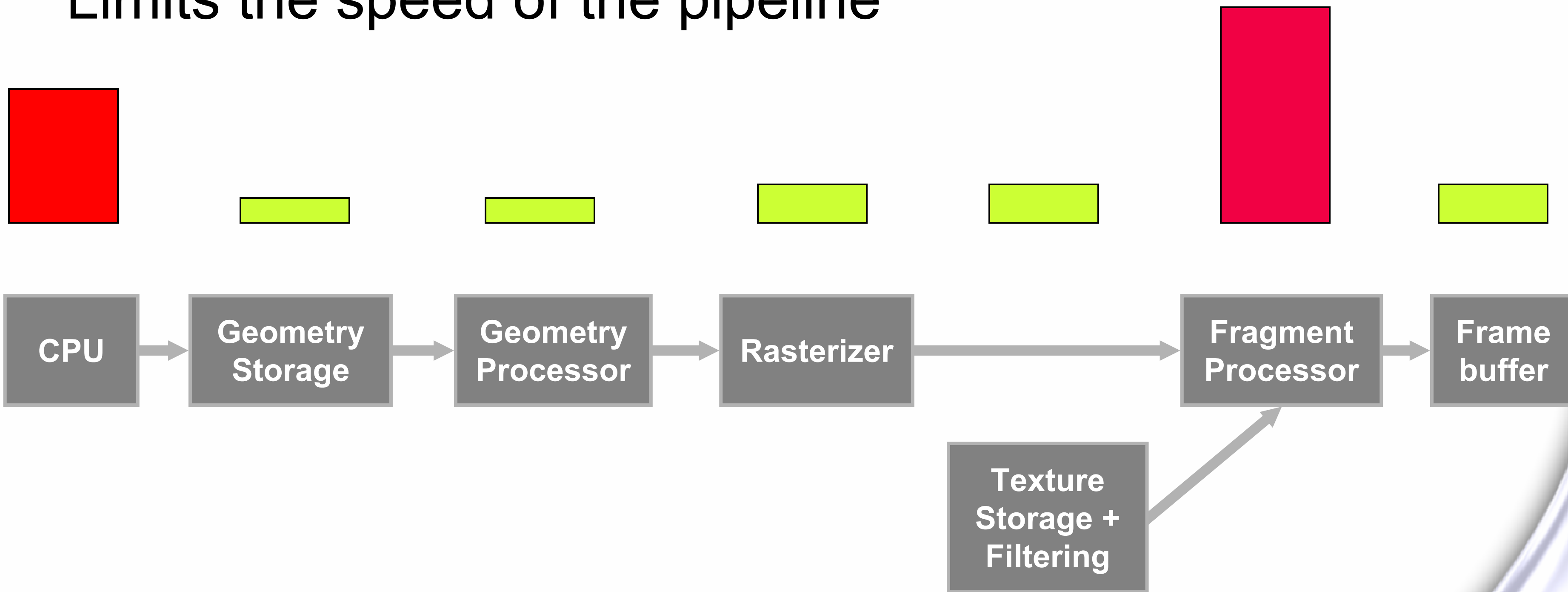
Pipelined Architecture (simplified view)



Bottlenecks

Limits the speed of the pipeline



- **CPU / Fragment – focus of this talk**

CPU / Fragment Bound

- Still the two most likely cases these days in modern apps:
  - CPU bound
    - Becomes more and more likely the faster GPUs get
  - Fragment bound
    - Becomes more and more likely the longer shaders get
- Neither of these trends are likely to change soon
- Some new weapons for combating these
  - Instancing
  - HW Shadow Maps
  - Shader model 3.0

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DirectX 9 Instancing API

- What is it?
  - Allows you to avoid DIP calls and minimise batching overhead
  - Allows a single draw call to draw multiple instances of the same model
- What is required to use it?
  - Microsoft DirectX 9.0c
  - VS/PS 3.0 hardware

Why use instancing?

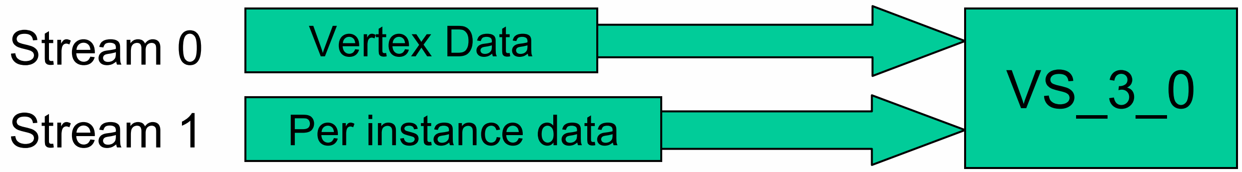
- Speed. Still the single most common performance suck in most games today is draw calls
- Yeah. Yeah. We all know draw calls are bad
  - But world matrices and other state often force us to separate draw calls
- The instancing API pushes the per instance draw logic down into the driver
  - Saves DIP call overhead in both D3D and Driver
  - Allows the driver to ensure minimal state changes between instances

When to use instancing?

- Scene contains many instances of the same model
  - Forest of Trees, Particles, Sprites
- If you can encode per instance data in 2^{nd} streams. I.e instance transforms, model color, indices to textures/constants.
- Less useful if your batch size is large
  - >1k polygons per draw
  - There is some fixed overhead to using instancing

How does it work?

- **DX Instancing API makes use of an extended vertex stream frequency divider API**



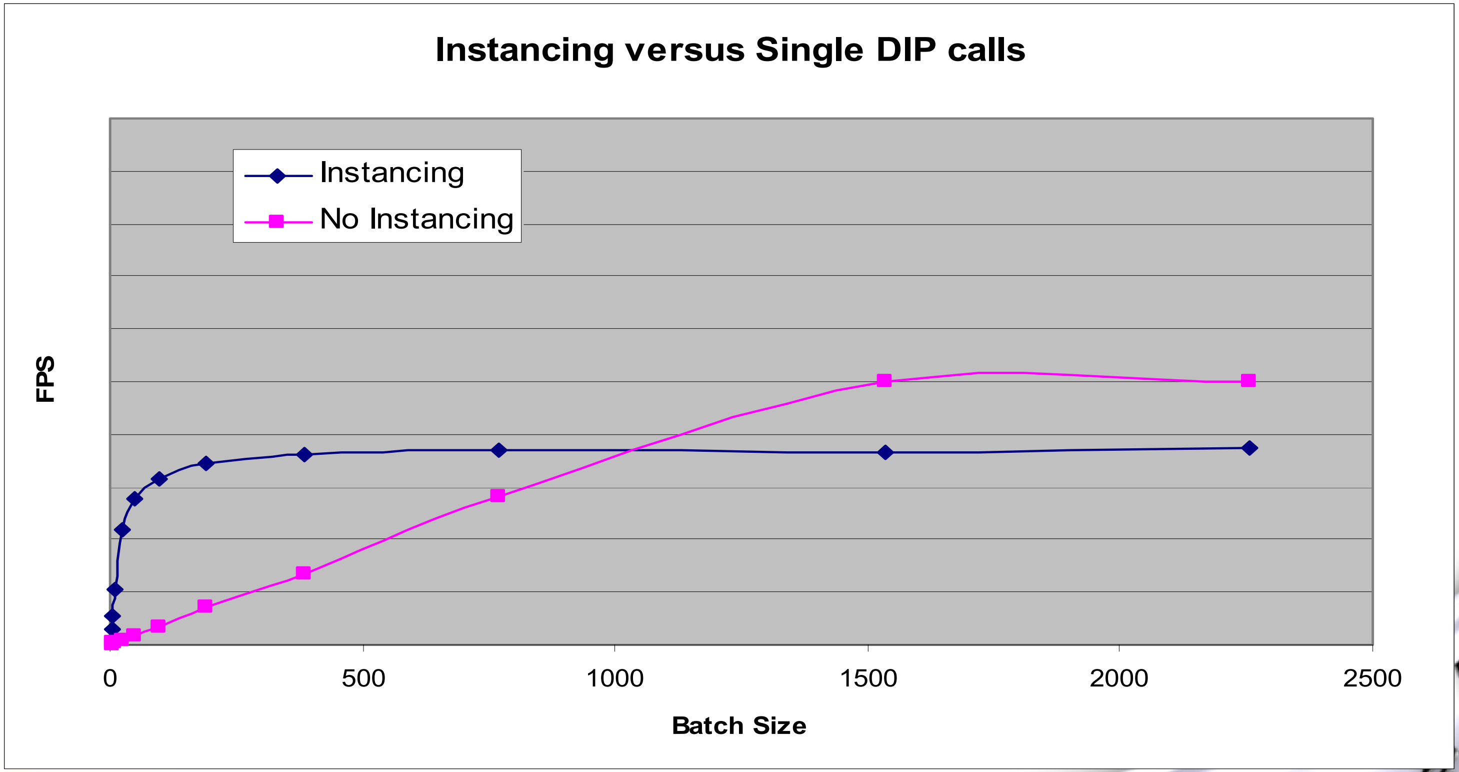
- **Primary stream is a single copy of the model data**
- **Secondary streams contain per instance data and stream pointer is advanced each time the primary stream is rendered.**
  - **Uses** IDirect3DDevice9::SetStreamSourceFreq **entry point**

Simple Instancing Example

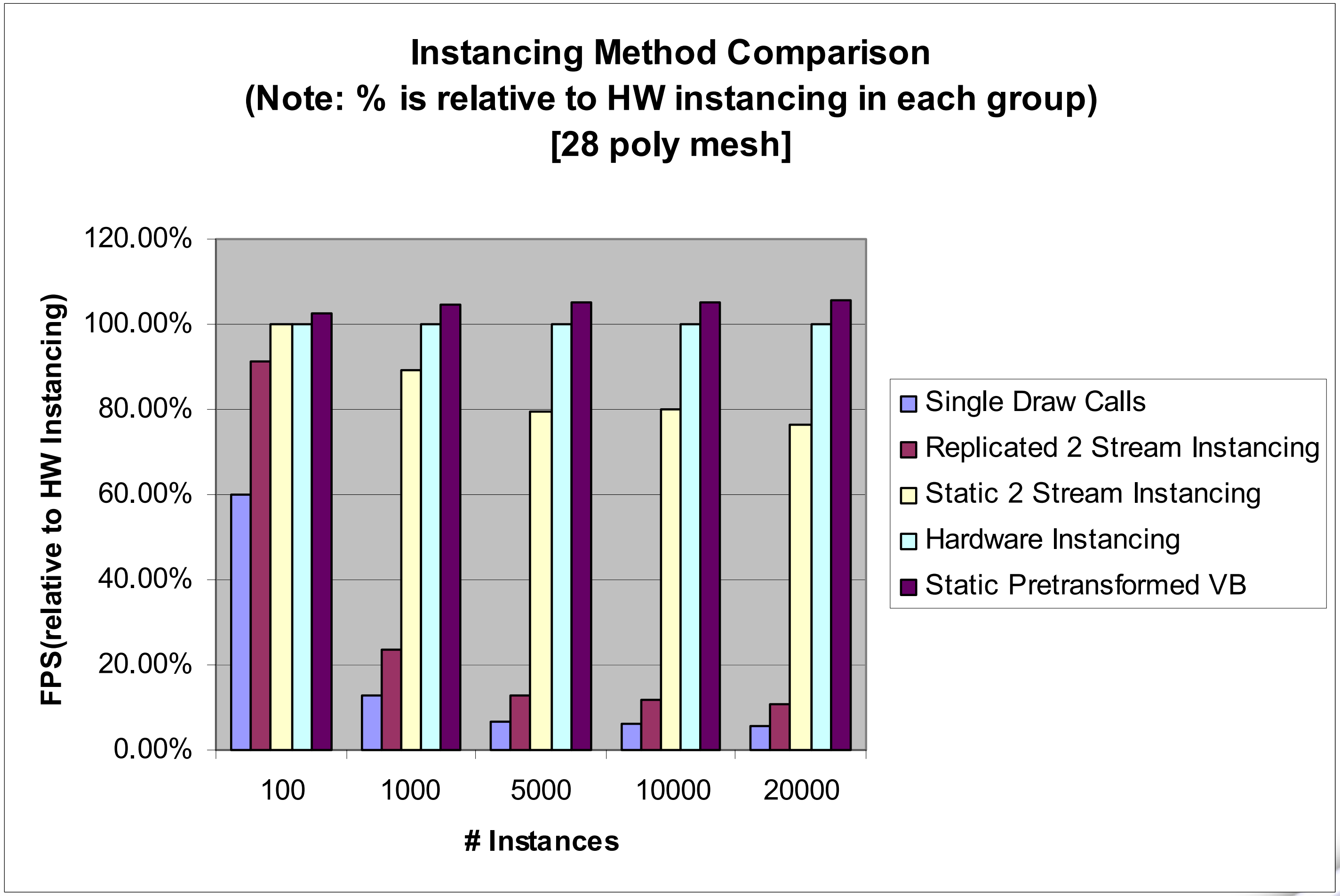
- 100 poly trees
  - Stream 0 contains just the one tree model
  - Stream 1 contains model WVP transforms
    - Possibly calculated per frame based on the instances in the view
  - Vertex Shader is the same as normal, except you use the matrix from the vertex stream instead of the matrix from VS constants
- If you are drawing 10k trees that's a lot of draw call savings!
  - You could manipulate the VB and pre-transform vertices, but it's often tricky, and you are replicating a lot of data

Some Test Results

- Test scene that draws 1 million diffuse shaded polys
- Changing the batch size, changes the # of drawn instances
- For small batch sizes, can provide an extreme win as it gives savings PER DRAW CALL.
- There is a fixed overhead from adding the extra data into the vertex stream
- The sweet spot will change based on many factors (CPU Speed, GPU speed, engine overhead, etc)

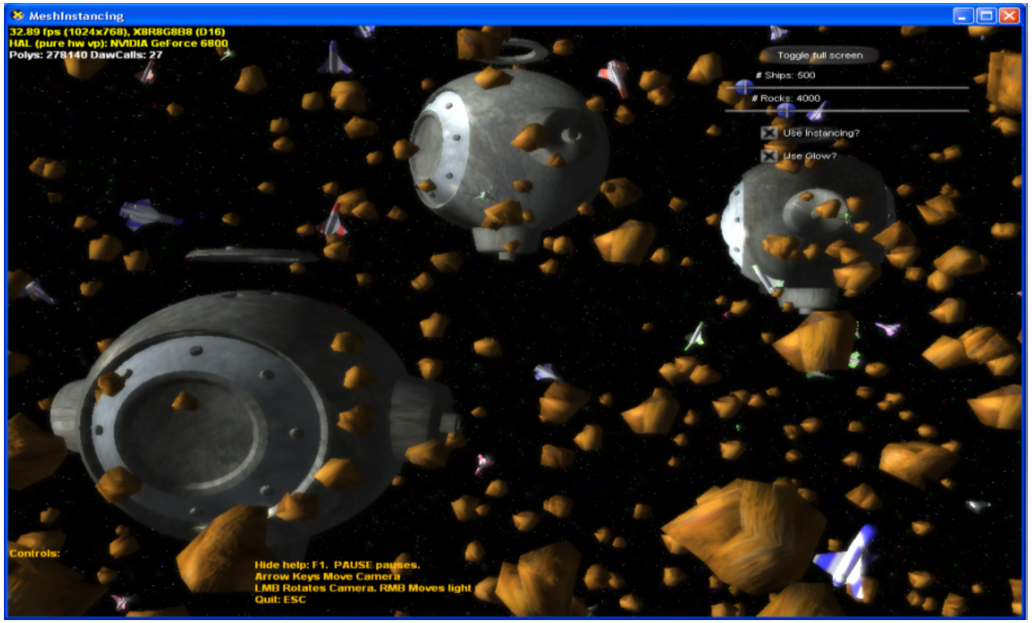


Instancing - More test results



Instancing Demo

- Space scene with 500+ ships, 4000+ rocks
- Complex lighting, post-processing
  - Some simple CPU collision work as well
- Dramatically faster with instancing



Instancing – Caution!

- You can quickly become "attribute bound" due to the extra data that needs to be fetched per instance
  - This explains the slowdown at the limit in the previous app
- Make sure you vertex cache optimize
  - Remember, a hit in the cache saves *all* previous work, including attribute access
- Pack input attributes as tightly as possible
  - Even if it requires a little vshader work to unpack, probably worth it
  - Be careful of things in the input stream that can be constants or easily derived in the vshader

What are attributes?

- Bits of vertex data fetched
- Positions
- Normals
- Texture coordinates
- etc...

Obscure Pipeline Bits

- For parts of the pipeline like vertex fetching and triangle setup, the old advice was always “don’t worry about it”
- No longer true!
  - This is not because these parts have become slower, everything around them just keeps getting exponentially faster
- Vertex fetch (attribute access) bound – Instancing
- Setup bound – Stencil Shadow Volumes
  - Two sided stencil
  - External triangles for extrusion

Fragment Perf - Hardware Shadow Maps

- **Many people developing new engines are already using R32F or R16F shadow maps**
  - **Multiple jittered samples for higher quality / soft edges**
- **NVIDIA Hardware Shadow Maps can just “drop in” to these engines**
  - **Same setup, same pipeline as any shadow map technique**

Fragment Perf - Hardware Shadow Maps

- Percentage-closer filtering is “free” on these
  - Use ¼ the taps for performance, or get 4x the quality for the same performance!
- In D3D, simply create a depth format texture (like D3DFMT_D24X8) and render to it
  - When sampled, the shadow map comparison happens automatically
- In OpenGL, use TEXTURE_COMPARE_MODE_ARB with COMPARE_R_TO_TEXTURE

3.0 Shaders Overview

- 3.0 shaders can help with both CPU boundedness and GPU boundedness
  - Improved batching / fewer passes
  - Early-outs with dynamic branching
- Gory performance details of 3.0 features
  - Vertex and Pixel

ps.3.0 – Better Batching / Fewer Passes

- Many engines have a primary lighting shader that does something like this:
  - `half3 diffuseTex = tex2D( DiffuseSampler );`
  - `half3 normalTex  = tex2D( NormalSampler );`
  - `half  shadow     = tex2D( ShadowMap );`
  - *`//do complex lighting`*
  - *`//output result`*

ps.3.0 – Better Batching / Fewer Passes

- A few possible perf pitfalls
  - One pass per light – means more DrawPrimitive() calls, worse batching
  - You have to refetch the diffuse map and normal map for every pass
    - With 16X aniso, this can be very expensive
  - Memory bandwidth / transform required for each pass

ps.3.0 – Better Batching / Fewer Passes

- Solution: branching in the pixel shader!
- Loop over a number of lights, accumulate lighting in the shader
  - Fetches from textures only once
  - Fewer batches
  - Less transform / attribute fetching, less bandwidth

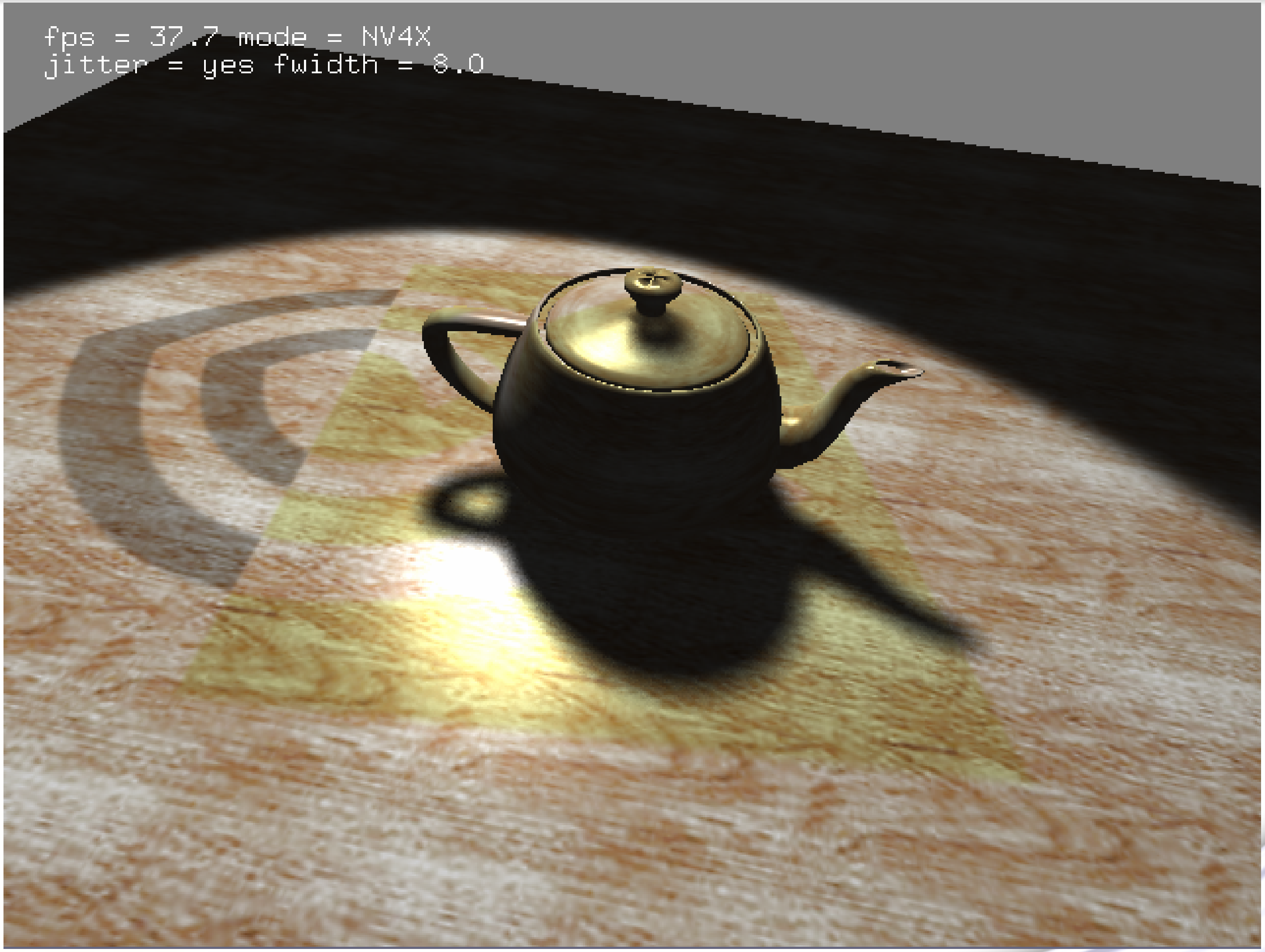
ps.3.0 – Potential Gotchas

- May require more interpolators
  - Good thing ps.3.0 has 10 high-precision interpolators
- May require more samplers
  - A shadow map per light
- Doesn't really work with stencil shadow volumes

ps.3.0 – Early Outs

- Early out is when you do a dynamic branch in the shader to reduce computation
- Some obvious examples:
  - If in shadow, don't do lighting computations
  - If out of range (attenuation zero), don't light
  - Obviously these apply to vs.3.0 as well
- Next – a novel example for soft shadows

ps.3.0 – Soft Shadows



ps.3.0 – Soft Shadows

- Works by taking 8 “test” samples from the shadowmap
  - If all 8 are in shadow or all 8 are in the light we’re done
  - If we’re on the edge (some are in shadow some are in light), do 56 more samples for additional quality
- 64 samples at much lower cost

ps.3.0 – Soft Shadows

- On GeForce6 GPUs, this demo runs more than twice as fast using dynamic branching vs. doing all 64 samples all the time
- Combined with hardware shadow maps, makes real-time cinematic shadows a reality

3.0 Shaders Perf – Pixel Nitty-Gritty

- **Pixel shader flow control instruction costs:**
- **Not free, but certainly usable**
- **Additional cost associated with divergent branches**

Instruction	Cost (Cycles)
if / endif	4
if / else / endif	6
call	2
ret	2
loop / endloop	4

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3.0 Shaders Perf - Pixel

- GeForce 6 series LOD texture instructions:
  - texldb – full perf
  - texldl – full perf
  - texldd – much lower perf
    - Factor of 10
- texldl has the additional benefit of not requiring the hw to calculate derivatives for LOD
  - Means you can branch over them dynamically
- With GeForceFX, all of these are lower perf

3.0 Shaders Perf - Pixel

- **Question: Does _pp (fp16) still matter in the pixel shader?**

- **Answer: YES**
  - **Critical for GeForceFX performance**
  - **Even helps GeForce6:**
    - **Less register pressure, better hiding of texture latency**
    - **Fast fp16 normalize (nrm_pp)**

3.0 Shaders Perf - Vertex

- Vertex flow control behaves a little differently
  - Branch instructions have a fixed cost of ~1 cycle
  - Divergence doesn’t matter (MIMD)
- The one big gotcha with vertex is VTF...

3.0 Shaders Perf - VTF

- Vertex Texture Fetch has potentially large latency
  - Equivalent to ~20 instructions
- So multiple dependent texture fetches will be slow
  - Using VTF to emulate a larger constant RAM is a bad idea in this generation of hw
- But, this is per-vertex, so certainly usable for many effects
  - See dynamic water displacement demo in NVSDK

Conclusion

- Complex pipeline
  - Some stages that used to be overlooked can bite you now that shading power has been increased so dramatically
- Most popular culprits still shading and CPU, however
  - A combination of instancing and 3.0 shaders can overcome these bottlenecks

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Questions?

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