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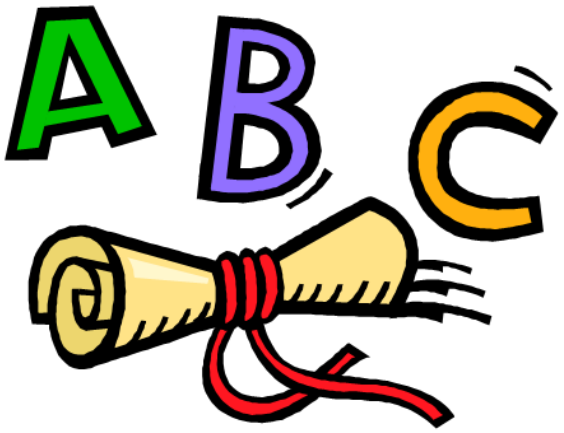
The A to Z of DX10 Performance



Cem Cebenoyan, NVIDIA

Nick Thibieroz, AMD

Color Coding

ATI

NVIDIA

API Presentation

- DX10 is designed for performance
  - No legacy code
  - No support for fixed function pipeline
- Most validation moved from runtime to creation time
- User mode drivers
  - Less time spent in kernel transitions
- Memory manager now part of OS
  - Vista handles memory operations
- DX10.1 update adds new features
  - Requires Vista SP1

Benchmark Mode

- Benchmark mode in game essential tool for performance profiling
  - Application-side optimizations
  - IHVs app and driver profiling
- Ideal benchmark:
  - Can be run in automated environment
    - Run from command line or config file
    - Prints results to log or trace file
  - Deterministic workload!
    - Watch out for physics, AI, etc.
  - Internet access not required!
  - Benchmarks can be recorded in-game

Constant Buffers

- Incorrect CB management major cause of slow performance!
- When a CB is updated its *whole* contents are uploaded to the GPU
  - But multiple small CBs mean more API overhead!
- Need a good balance between:
  - Amount of data to upload
  - Number of calls required to do it
- Solution: use a pool of constant buffers *sorted by frequency of updates*

Constant Buffers (2)

- Don’t bind too many CBs to shader stages
  - No more than 5 is a good target
- Sharing CBs between different shader types can be done *when it makes sense*
  - E.g. same constants used in both VS and PS
- Group constants by access pattern

```
float4 PS_main(PSInput in)
{
  float4 diffuse = tex2D0.Sample(mipmapSampler, in.Tex0);
  float ndotl = dot(in.Normal, vLightVector.xyz);
  return ndotl * vLightColor * diffuse;
}
```

```
cbuffer PerFrameConstants
{
   float4   vLightVector;
   float4   vLightColor;
   float4   vOtherStuff[32];
};
```

GOOD

```
cbuffer PerFrameConstants
{
   float4   vLightVector;
   float4   vOtherStuff[32];
   float4   vLightColor;
};
```

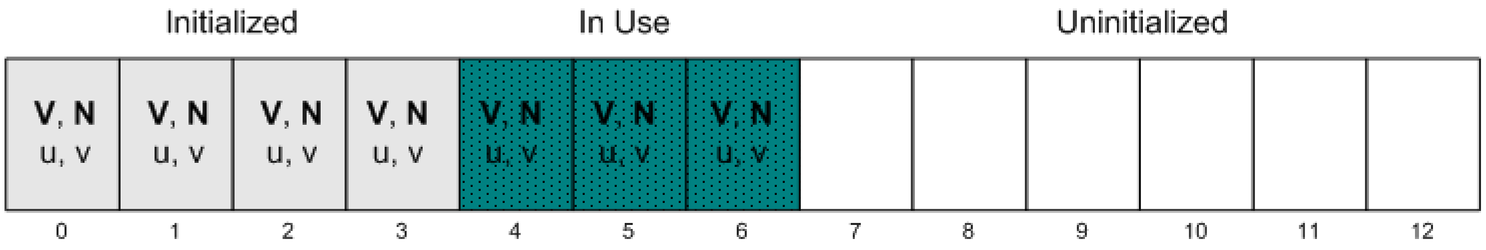
BAD

Constant Buffers (3)

- When porting from DX9 make sure to port your shaders too!
  - By default *all* constants will go into a single CB
- **`$Globals`** CB often cause poor performance
  - Wasted cycles transferring unused constants
    - Check if used with D3D10_SHADER_VARIABLE_DESC.uFlags
  - Constant buffer contention
  - Poor CB cache reuse due to suboptimal layout
- Use conditional compiling to declare CBs when targeting multiple versions of DX
  - **`e.g. #ifdef DX10 cbuffer{ #endif`**

Dynamic Buffers Updates

- Created with D3D10_USAGE_DYNAMIC flag
  - Used on geometry that cannot be prepared on the GPU
  - E.g. particles, translucent geometry etc.
- Allocate as a large ring-buffer
- Write new data into buffer using:
  - **`Map(D3D10_MAP_WRITE_NOOVERWRITE,…)`**
    - Only write to uninitialized portions of the buffer
  - **`Map(D3D10_MAP_WRITE_DISCARD,…)`**
    - When buffer full



Early Z Optimizations

- Hardware early Z optimizations essential to reduce pixel shader workload
- Coarse Z culling impacted in some cases:
  - Pixel shader writes to output depth register
  - High-frequency data in depth buffer
  - Depth buffer not Clear()ed
- Fine-grain Z culling impacted in some cases:
  - Pixel shader writes to output depth register
  - **`clip()/discard()`** shader with Z/stencil writes
  - Alpha to coverage with Z/stencil writes
  - PS writes to coverage mask with Z/stencil writes
- Z prepass is usually an efficient way to take advantage of early Z optimizations

Formats (1) Textures

- Lower rate texture read formats:
  - DXGI_FORMAT_R16G16B16A16_* and up
  - DXGI_FORMAT_R32_*
  - **ATI:** Unless point sampling is used
  - Consider packing to avoid those formats
- DX10.1 supports resource copies to BC
  - From RGBA formats with the same bit depth
  - Useful for real-time compression to BC in PS

Formats (2) Render Targets

- Slower rate render target formats:
  - DXGI_FORMAT_R32G32B32A32_*
  - **ATI:** DXGI_FORMAT_R16G16B16A16 and up **int** format
  - **ATI:** Any 32-bit per channel formats
- Performance cost increase for every additional RT
- Blending increases output rate cost on higher bit depth formats
- **DX10.1**'s MRT independent blend mode can be used to avoid multipass
  - E.g. Deferred Shading decals
  - May increase output cost depending on what formats are used

Geometry Shader

- GS not designed for large-scale expansion
  - DX11 tessellation is a better match for this
  - See DX11 presentation this afternoon
- "Less is better" concept works well here
  - Reduce [maxvertexcount]
  - Reduce size of output/input vertex structure
- Move some computation from GS to VS
- **NVIDIA:** Keep GS shaders short
- **ATI:** Free ALUs in GS because of export rate
  - Can be used to cull geometry (backface, frustum)

High Batch Counts

- “Naïve” porting job will not result in better batch performance in DX10
- Need to use API features to bring gains
- Geometry Instancing!
  - Most important feature to improve batch perf.
  - Really powerful in DX10
  - System values are here to help
    - E.g. SV_InstanceID, SV_PrimitiveID
- Instance data:
  - **ATI:** Ideally should come from additional streams (up to 32 with **DX10.1**)
  - **NVIDIA:** Ideally should come from CB indexing

Input Assembly

- Remember to optimize geometry!
  - Non-optimized geometry can cause BW issues
- Optimize IB locality first, then VB access
  - **`D3DXOptimize[Faces][Vertices]()`**
- Input packing/compression is your friend
  - E.g. 2 pairs of texcoords into one float4
  - E.g. 2D normals, binormal calculation, etc.
- Depth-only rendering
  - Only use the minimum input streams!
    - Typically one position and one texcoord
  - This improves re-use in pre-VS cache

Juggling with States

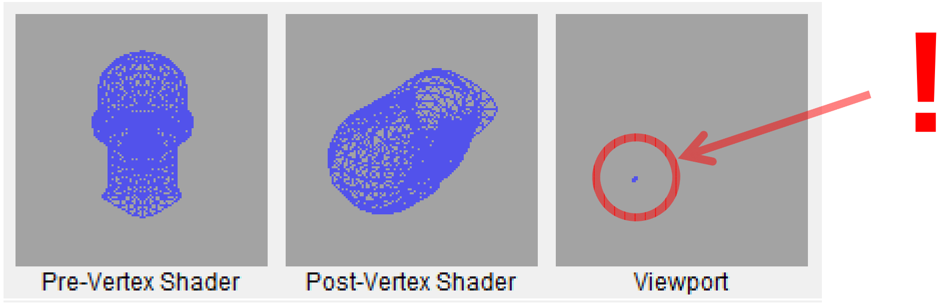
- DX10 uses immutable state objects
  - Input Layout Object
  - Rasterizer Object
  - DepthStencil Object
  - Sampler Object
  - Blend Object
- Always create states at load time
- Do not duplicate state objects:
  - More state switches
  - More memory used
- Implement “dirty states” mechanism
- Sort draw calls by states

Klears (C was already taken)

- Always clear Z buffer to allow Z culling opt.
  - Stencil clears are additional cost over depth so only clear if required
- Different recommendations for NV/ATI HW
  - Requires conditional coding for best performance
- **ATI:** Color `Clear()` is not free
  - Only `Clear()` color RTs when actually required
  - Exception: MSAA RTs always need clearing
- **NVIDIA:** Prefer `Clear()` to fullscreen quad clears

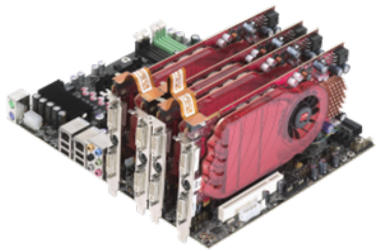
Level of Detail

- Lack of LOD causes poor quad occupancy
  - This happens more often than you think!
  - Check wireframe with PIX/other tools



- Remember to use MIPMapping
  - Especially for volume textures!
  - Those are quick to trash the TEX cache
- GenerateMips() can improve performance on RT textures
  - E.g. reflection maps

Multi GPU



- Multi-GPU configuration are common
  - Especially single-card solutions
    - GeForce 9800X2, Radeon 4870X2, etc.
  - This is **not** a niche market!
- Must systematically test on MGPU systems before release
- Golden rule of efficient MGPU performance: avoid inter-frame dependencies
  - This means no reading of a resource that was last written to in the previous frame
  - If dependencies must exist then ensure those resources are unique to each GPU
- Talk to your IHV for more complex cases

No Way Jose

- Things you really shouldn't do!
- Members of the "render the skybox first" club
  - Less and less members in this club – good!
  - Still a few resisting arrest
- Lack of or inefficient frustum culling
  - This results in transformed models not contributing at all to the viewport
  - Waste of Vertex Shading processing
- Passing constant values as VS outputs
  - Should be stored in Constant Buffers instead
  - Interpolators can cost performance!

Output Streaming

- Stream output allows the writing of GS output to a video memory buffer
  - Useful for multi-pass when VS/GS are complex
  - Store transformed data and re-circulate it
  - E.g. complex skinning, multi-pass displacement mapped triangles, non-NULL GS etc.
- GS not required if just processing vertices
  - Use **`ConstructGSWithSO()`** on VS in FX file
- Rasterization can be used at the same time
- Try to minimize output structure size
  - Similar recommendations as GS

Parallelism

- Good parallelism between CPU and GPU essential to best performance

- Direct access to DEFAULT resources
  - This will stall the CPU
  - If required, use CopyResource() to STAGING
  - Then Map() STAGING resource with D3D10_MAP_FLAG_DO_NOT_WAIT flag and only retrieve contents when available

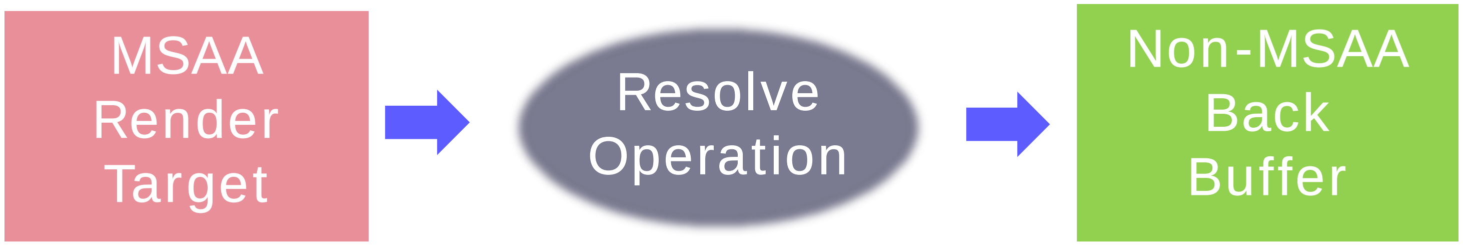
- Use PIX to check CPU/GPU overlap

Queries

- Occlusion queries used for some effects
  - Light halos
  - Occlusion culling
  - Conditional rendering
  - 2D collision detection
- Ideally only retrieve results when available
  - Or at least after a set number of frames
  - Especially important for MGPU!
  - Otherwise stalling will occur
- GetData() returns S_FALSE if no results yet
- Occlusion culling: make bounding boxes larger to account for delayed results

Resolving MSAA Buffers

- Resolve operations are **not** free
- Need good planning of post-process chain in order to reduce MSAA resolves
  - If no depth buffer is required then apply post-process effects on resolved buffer
- Do not create the back buffer with MSAA
  - All rendering occurs on external MSAA RTs



Shadow Mapping

- Shadow mapping DST formats
  - **ATI:** DXGI_FORMAT_D16_UNORM
  - **NVIDIA:** DXGI_FORMAT_D24_UNORM_S8_UINT
  - DXGI_FORMAT_D32_FLOAT (**NVIDIA:** lower Zcull eff.)
- Remember to disable color writes
  - Depth-only rendering is **much** faster
- Shadow map filtering
  - High number of taps can be a bottleneck
  - Probably don't need aniso
  - Optimizations:
    - **DX10.1**'s **`Gather()`**
    - Dynamic branching

Transparency

- Alpha test deprecated in DX10
  - Use **discard()** or **clip()** in PS
- This requires two versions of your shaders!
  - One with **clip()/discard()** for transparency
  - One without **clip()/discard()** for opacity
- Resist the urge of using a single shader with **clip()/discard()** for all object types
  - This will impact early Z optimizations!
- Put **clip()/discard()** as early as possible in pixel shaders
  - Compiler may be able to skip remaining code

Updating Textures

- Avoid creating/destroying textures at run-time
  - Significant overhead in these operations!
  - Will often lead to stuttering
- Create all resources up-front if possible
  - Level load, cut-scenes or other non-performance critical situations
- Perform updates by *replacing* contents of *existing* textures
  - Can be a problem if textures vary a lot in size
  - Texture atlases are a good way to avoid this

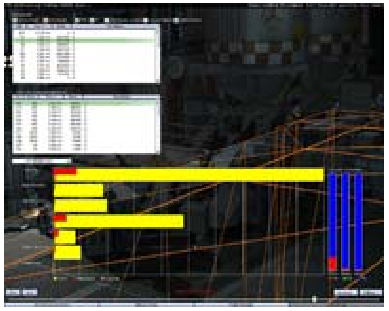
Updating Textures (2)

- Avoid **UpdateSubresource()** path for updating textures
  - Slow path in DX10
  - Especially bad with large textures
- Use ring buffer of intermediate D3D10_USAGE_STAGING textures
  - Call **Map(D3D10_MAP_WRITE,…)** with D3D10_MAP_FLAG_DO_NOT_WAIT to avoid stalls
  - If Map fails in all buffers: either stall waiting for Map or allocate another resource (cache warmup)
  - Copy to textures in video memory
    - **CopyResource()** or **CopySubresourceRegion()**

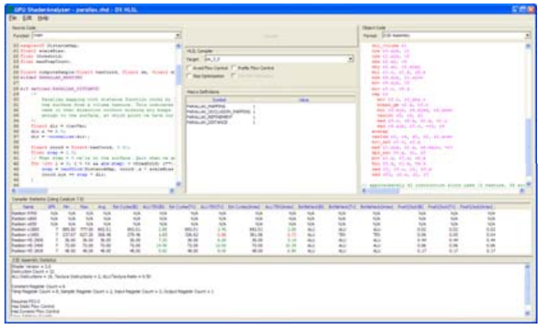
Verifying Performance

» Remember to use IHV tools to help with performance analysis!

» NVPerfHUD / FXComposer / ShaderPerf



» GPUPerfStudio / GPUShaderAnalyzer



Writing Fast Shaders

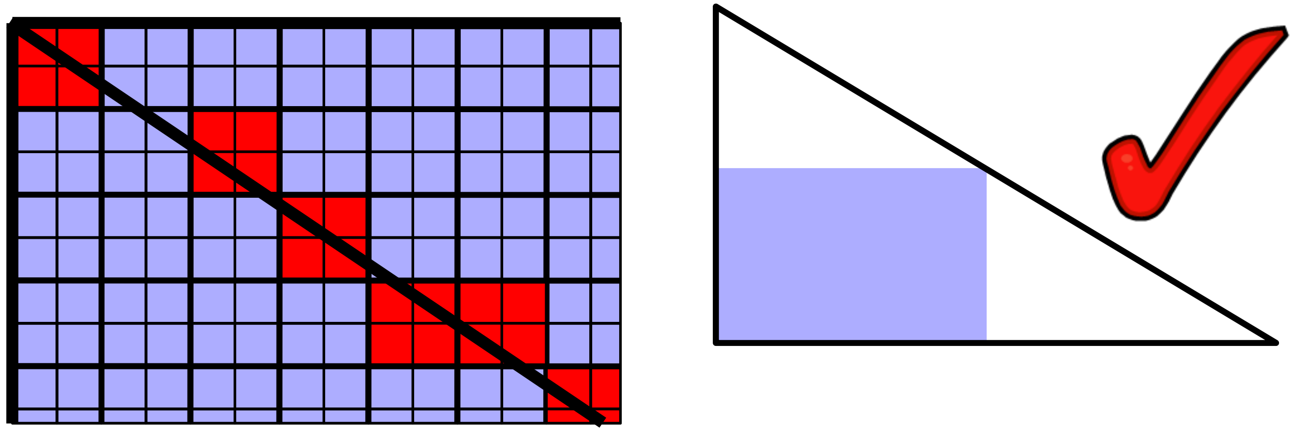
- Shader code has a direct impact on perf.
  - Writing quality code is essential
- Be aware of ALU:TEX HW ratios
  - **ATI:** 4 5D ALU per TEX on ATI HW
  - **NVIDIA:** 12 scalar ALUs per TEX on NV HW
- Can also be interpolators-limited!
  - Reduce total number of floats interpolated
  - **ATI:** Use packing to reduce PS inputs
- Write parallel code to maximize efficiency
- Check for excessive register usage
  - **NVIDIA:** >10 GPRs is high on GeForce
- Use dynamic branching to skip instructions
  - Make sure branching has high coherency though

Writing Fast Shaders (2)

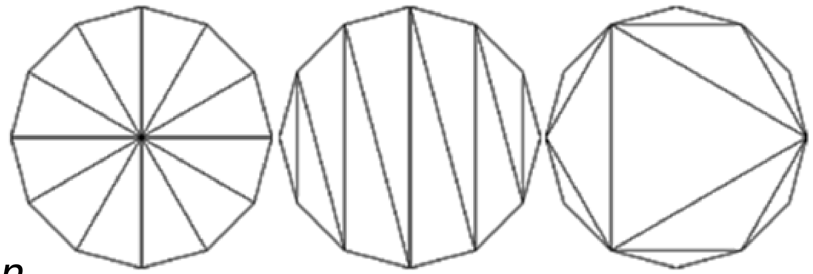
- Not all ALU instructions are equal
  - Integer multiplication and division
  - Type conversion (float to int, int to float)
  - Check with your IHV for list of slower instructions
- Same goes for TEX instructions
  - Sample>>SampleLevel>>SampleGrad
  - Texture type and filter mode impacts cost too!
    - E.g. Volume textures, 128 bits formats, aniso
- Temp registers indexing likely to be slow
  - Dynamic CB indexing in PS can be costly too
- Too many static branches may limit the scope for optimizations
  - Implement conditional compilation from the app

Xtra Performance

- Fullscreen Quad vs Fullscreen Triangle
  - Triangle = maximal quad occupancy!

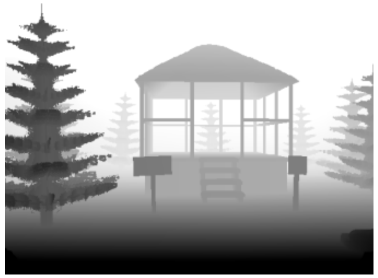


- No BC2/BC3 for fully opaque textures!
- Efficient triangulation
  - Max area is best



Credit: Emil Persson

Z-Buffer Access

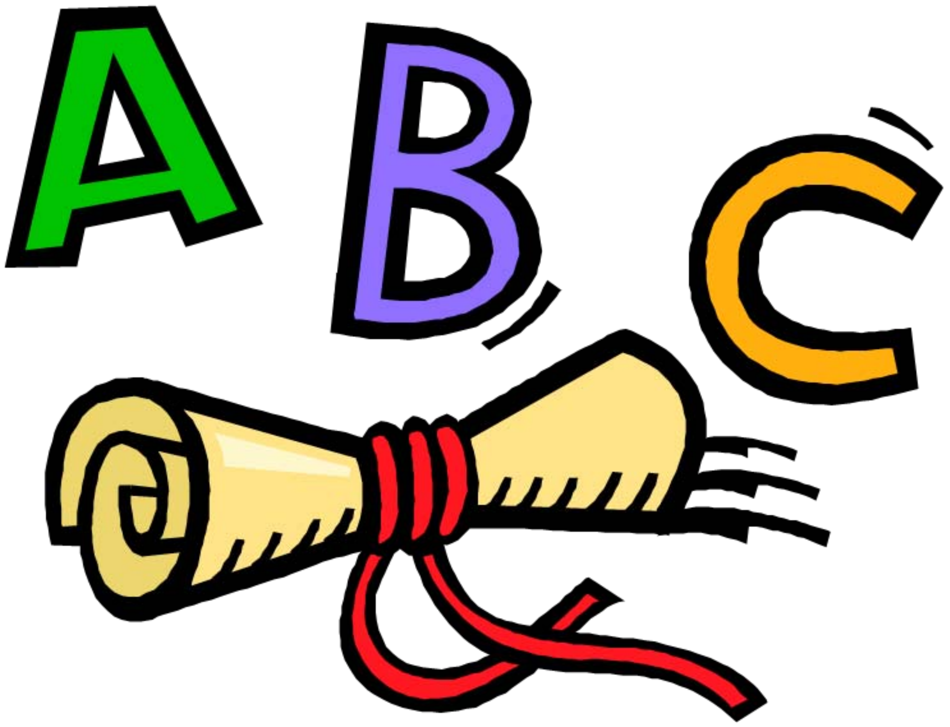


- Accessing the depth buffer as a texture
- Useful for a number of effects requiring Z
  - No need to write Z separately in RT or extra pass
- DX10.1 vs DX10.0 differences
  - DX10.0: SRV only allowed for single-sample DB
  - DX10.1: SRV allowed for multi-sampled DB too
- Accessing multisampled DB:
  - No need to fetch all samples and average them
  - Just use the first sample and output to RT
    - No visual issue will ensue on low-freq operations
    - E.g. DOF, SSAO, soft particles, etc.
  - Can also be done to produce a single-sample DB
    - Disable color writes and writes 1st sample to oDepth

Your Call To Action

- Proper managing of resources is key to good DX10/DX10.1 performance
  - Constant Buffers
  - Texture/Buffers updates
- Geometry instancing to improve batch performance
- Shader balancing
  - Use the right tools for the job
- Keep multi-GPU in mind when testing *and* developing

Questions?



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