DirectX 10 Performance

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Outline

- General DX10 API usage
  - Designed for performance
  - Batching and Instancing
  - State Management
  - Constant Buffer Management
  - Resource Updates and Management
  - Reading the Depth Buffer
  - MSAA
- Optimizing your DX10 Game
  - or how to work around GPU bottlenecks

DX10 Runtime and Driver. Designed for Performance

- DX10 validation moved from runtime to creation time
  - Only basic error checking at runtime
- Immutable state objects
  - Can be pre-computed and cached
  - Subset of command buffer at creation time
- Vista driver model delegates scheduling and memory management to OS
  - Pro: more responsive system, GPU sharing across apps
  - Con: harder to guarantee performance if multiple apps share the GPU
    - Fullscreen mode should be fine

Batch Performance

- The truth about DX10 batch performance
- “Simple” porting job will not yield expected performance
- Need to use DX10 features to yield gains:
  - Geometry instancing or batching
  - Intelligent usage of state objects
  - Intelligent usage of constant buffers
  - Texture arrays

Geometry Instancing

- Better instancing support in DX10
- Use "System Values" to vary rendering
  - `SV_InstanceID, SV_PrimitiveID, SV_VertexID`
  - Additional streams not required
  - Pass these to PS for texture array indexing
  - Highly-varied visual results in a single draw call
- Watch out for:
  - Texture cache trashing if sampling textures from system values (SV_PrimitiveID)
  - Too many attributes passed from VS to PS
  - InputAssembly bottlenecks due to instancing
  - Solution: Load() per-instance data from Buffer in VS or PS using SV_InstanceID

State Management

- **DX10 uses immutable "state objects"**
  - **Input Layout Object**
  - **Rasterizer Object**
  - **DepthStencil Object**
  - **Blend Object**
  - **Sampler Object**

- **DX10 requires a new way to manage states**
  - **A naïve DX9 to DX10 port *will* cause problems here**
  - Always create state objects at load-time
  - **Avoid duplicating state objects**
  - **Recommendation to sort by states still valid in DX10!**

Constant Buffer Management (1)

- Probably a major cause of poor performance in initial naïve DX10 ports!
- Constants are declared in buffers in DX10:

```
cbuffer PerFrameConstants
{
    float4x4 mView;
    float    fTime;
    float3   fWindForce;
};
```

```
cbuffer SkinningMatricesConstants
{
    float4x4 mSkin[64];
};
```

- When any constant in a cbuffer is updated the full cbuffer has to be uploaded to GPU
- Need to strike a good balance between:
  - Amount of constant data to upload
  - Number calls required to do it (== # of cbuffers)

Constant Buffer Management (2)

- Use a pool of constant buffers *sorted by frequency of updates*
- Don't go overboard with number of cbuffers!
  - (3-5 is good)
- Sharing cbuffers between shader stages can be a good thing
- Example cbuffers:
  - PerFrameGlobal (time, per-light properties)
  - PerView (main camera xforms, shadowmap xforms)
  - PerObjectStatic (world matrix, static light indices)
  - PerObjectDynamic (skinning matrices, dynamic lightIDs)

Constant Buffer Management (3)

- **Group constants by access pattern to help cache reuse due to locality of access**
- **Example:**

```
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 Buffer Management (4)

- **Careless DX9 port results in a single** `$Globals cbuffer` **containing all constants, many of them unused**
- `$Globals cbuffer` **typically yields bad performance:**
  - **Wasted CPU cycles updating unused constants**
    - **Check if used: D3D10_SHADER_VARIABLE_DESC.uFlags**
  - **cbuffer contention**
  - **Poor cbuffer cache reuse due to suboptimal layout**
- **When compiling SM3 shaders for SM4+ target with** `D3D10_SHADER_ENABLE_BACKWARDS_COMPATIBILITY`**: use conditional compilation to declare** `cbuffers`
  `(e.g. #ifdef DX10 cbuffer{ #endif )`

Constant Buffer Management (5)

- Consider `tbuffer` if access pattern is more random than sequential
  - `tbuffer` access uses texture Loads, so higher latency but higher performance sometimes
  - Watch out for texture-bound cases resulting from `tbuffer` usage
- Use `tbuffer` if you need more data in a single buffer
  - `cbuffer` limited to 4096*128-bit
  - `tbuffer` limited to 128 megabytes

Resource Updates

- In-game destruction and creation of Texture and Buffer resources has a significant impact on performance:
  - Memory allocation, validation, driver checks
- Create all resources up-front if possible
  - During level load, cutscenes, or any non-performance critical situations
- At runtime: replace contents of existing resources, rather than destroying/creating new ones

Resource Updates: Textures

- **Avoid `UpdateSubresource()` for textures**
  - **Slow path in DX10 (think `DrawPrimitiveUP()` in DX9)**
  - **Especially bad with larger 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 time)**
  - **Copy to textures in video memory (`D3D10_USAGE_DEFAULT`):**
    - `CopyResource()` **or** `CopySubresourceRegion()`

Resource Updates: Buffers

- To update a Constant buffer
  - `Map(D3D10_MAP_WRITE_DISCARD, …);`
  - `UpdateSubResource()`
  - Recall full buffer must be updated, but with Map() CPU can skip parts that the shader does not care about. All the data must be uploaded to GPU though

- To update a dynamic Vertex/Index buffer
  - Use a *large* shared ring-buffer type; writing to unused portions of buffer using:
    - `Map(D3D10_MAP_WRITE_DISCARD,…)` when full or if possible the first time it is mapped at every frame
    - `Map(D3D10_MAP_WRITE_NO_OVERWRITE, …)` thereafter
  - Avoid `UpdateSubResource()`
    - not as good as `Map()` in this case either

Accessing Depth and Stencil

- DX10 enables the depth buffer to be read back as a texture
- Enables features without requiring a separate depth render
  - Atmosphere pass
  - Soft particles
  - Depth of Field
  - Deferred shadow mapping
  - Screen-space ambient occlusion
  - Etc.
- Popular features in most recent game engines

Accessing Depth and Stencil with MSAA

- DX10.0: reading a depth buffer as SRV is only supported in single sample mode
  - Requires a separate render path for MSAA
- Workarounds:
  - Store depth in alpha of main FP16 RT
  - Render depth into texture in a depth pre-pass
  - Use a secondary rendertarget in main color pass

MultiSampling Anti-Aliasing

- MSAA resolves cost performance
  - Cost varies across GPUs but it is never free
  - Avoid redundant resolves as much as possible

    E.g.: no need to perform most post-process ops on MSAA RT. Resolve once, *then* apply p.p. effects
- No need to allocate SwapChain as MSAA
  - Apply MSAA only to rendertargets that matter
- Be aware of CSAA:

  Certain `DXGI_SAMPLE_DESC.Quality` values will enable higher-quality but slightly costlier MSAA mode

  See http://developer.nvidia.com/object/coverage-sampled-aa.html

Optimizing your DX10 Game

- Use PerfHUD to identify bottlenecks:
  - Step 1: are you GPU or CPU bound?
    - Check GPU idle time
    - If GPU is idle you are probably CPU bound either by other CPU workload on your application or by CPU-GPU synchronization
  - Step 2: if GPU bound, identify the top buckets and their bottlenecks
    - Use PerfHUD Frame Profiler for this
  - Step 3: try to reduce the top bottleneck/s

If Input Assembly is the bottleneck

- Optimize IB and VB for cache reuse
  - Use ID3DXMesh::Optimize() or other tools
- Reduce number of vector attributes
  - Pack several scalars into single 4-scalar vector
- Reduce vertex size using packing tricks:
  - Pack normals into a float2 or even RGBA8
  - Calculate binormal in VS
  - Use lower-precision formats
- Use reduced set of VB streams in shadow and depth-only passes
  - Separate position and 1 texcoord into a stream
  - Improves cache reuse in pre-transform cache
  - Also use shortest possible shaders

Attribute Boundedness

- Interleave data when possible into a less VB streams:
  - at least 8 scalars per stream
- Use Load() from Buffer or Texture instead
- Dynamic VBs/IBs might be on system memory accessed over PCIe:
  - maybe CopyResource to USAGE_DEFAULT before using (especially if used multiple times in several passes)
- Passing too many attributes from VS to PS may also be a bottleneck
  - packing and Load() also apply in this case

If Vertex Shader is the bottleneck

- Improve culling and LOD (also helps IA):
  - Look at wireframe in debugging tool and see if it's reasonable
  - Check for percentage of triangles culled:
    - Frustum culling
    - Zero area on screen
  - Use other scene culling algorithms
    - CPU-based culling
    - Occlusion culling
- Use Stream-Output to cache vertex shader results for multiple uses
  - E.g.: StreamOut skinning results, then render to shadowmap, depth prepass and shading pass
  - StreamOut pass writes point primitives (vertices) Same index buffer used in subsequent passes

If Geometry Shader is the bottleneck

- Make sure *maxvertexcount* is as low as possible
  - *maxvertexcount* is a shader constant declaration → need different shaders for different values
  - Performance drops as output size increases
- Minimize the size of your output and input vertex structures
- GS not designed for large-expansion algorithms like tessellation
  - Due to required ordering and serial execution
- Consider using instancing in current hardware
- Move some computation to VS to avoid redundancy
- Keep GS shaders short

If Stream-Output is the bottleneck

- Avoid reordering semantics in the output declaration
  - Keep them in same order as in output structure
- You may have hit bandwidth limit
  - SO bandwidth varies by GPU
- Remember you don't need to use a GS if you are just processing vertices
  - Use ConstructGSWithSO on Vertex Shader
- Rasterization can be used at the same time
  - Only enable it if needed (binding RenderTarget)

If Pixel Shader is the bottleneck (1)

- Verify by replacing with simplest PS (PerfHUD)
- Move computations to Vertex Shader
- Use pixel shader LOD
- Only use `discard` or `clip()` when required
- `discard` or `clip()` as early as possible
  - GPU can skip remaining instructions if test succeeds
- Use common app-side solutions to maximize pixel culling efficiency:
  - Depth prepass (most common)
  - Render objects front to back
  - Triangle sort to optimize both for post-transform cache and Z culling within a single mesh
  - Stencil/scissor/user clip planes to tag shading areas
  - Deferred shading

If Pixel Shader is the bottleneck (2)

- **Shading can be avoided by Z/Stencil culling**
  - **Coarse (ZCULL)**
  - **Fine-grained (EarlyZ)**
- **Coarse Z culling is transparent, but it** may underperform **if:**
  - **If shader writes depth**
  - **High-frequency information in depth buffer**
  - **If you don’t clear the depth buffer using a “clear” (avoid clearing using fullscreen quads)**

If Pixel Shader is the bottleneck (3)

- Fine-grained Z culling is not always active
- Disabled on current hardware if:
  - PS writes depth (SV_Depth)
  - Z or Stencil writes combined with:
    - Alpha test is enabled (DX9 only)
    - discard / texkill in shaders
    - AlphaToCoverageEnable = true
- Disabled on current NVIDIA hardware if:
  - PS reads depth (.z) from SV_Position input
    - Use .w (view-space depth) if possible
  - Z or Stencil writes combined with:
    - Samplemask != 0xffffffff

Any Shader is *still* the bottleneck (1)

- Use NVIDIA's ShaderPerf
- Be aware of appropriate ALU to TEX *hardware* instruction ratios:
  - 10 scalar ALU per TEX on NVIDIA GeForce 8 series
- Check for excessive register usage
  - > 10 vector registers is high on GeForce 8 series
  - Simplify shader, disable loop unrolling
  - DX compiler behavior may unroll loops so check output
- Use dynamic branching to skip instructions
  - Make sure branching has high coherency

Any Shader is *still* the bottleneck (2)

- Some instructions operate at a slower rate
  - Integer multiplication and division
  - Type conversion (float to int, int to float)
- Too many of those can cause a bottleneck in your code
- In particular watch out for type conversions
  - Remember to declare constants in the same format as the other operands they're used with!

If Texture is the bottleneck (1)

- Verify by replacing textures with 1x1 texture
  - PerfHUD can do this
- Basic advice:
  - Enable mipmapping
  - Use compressed textures where possible
    - Block-compressed formats
    - Compressed float formats for HDR
  - Avoid negative LOD bias (aliasing != sharper)
- If multiple texture lookups are done in a loop
  - Unrolling partially may improve batching of texture lookups, reducing overall latency
  - However this may increase register pressure
  - Find the right balance

If Texture is the bottleneck (2)

- DirectX compiler moves texture instructions that compute LOD out of branches
  - Use SampleLevel (no anisotropic filtering)
  - SampleGrad can be used too, but beware of the extra performance cost
- Texture cache misses may be high due to poor coherence
  - In particular in post-processing effects
  - Modify access pattern
- Not all textures are equal in sample performance
  - Filtering mode
  - Volume textures
  - Fat formats (128 bits)

If ROP is the bottleneck: Causes

- Pixel shader is too cheap
- Large pixel formats
- High resolution
- Blending
- MSAA
- MRT
- Rendering to system memory over PCIe (parts with no video memory)
- Typical problem with particle effects: little geometry, cheap shading, but high overdraw using blending

If ROP is the bottleneck: Solutions

- Render particle effects to lower resolution offscreen texture
  - See GPUGems 3 chapter by Iain Cantlay
- Disable blending when not needed, especially in larger formats (R32G32B32A32_FLOAT)
- Unbind render targets that are not needed
  - Multiple Render Targets
  - Depth-only passes
- Use R11G11B10 float format for HDR (if you don't need alpha)

If performance is *hitchy* or irregular

- Make sure you are not creating/destroying critical resources and shaders at runtime
  - Remember to warm caches prior to rendering
- Excessive paging when the amount of required video memory is more than available
- Could be other engine component like audio, networking, CPU thread synchronization etc.

Clears

- Always Clear Z buffer to enable ZCULL
- Always prefer Clears vs. fullscreen quad draw calls
- Avoid partial Clears
  - Note there are no scissored Clears in DX10, they are only possible via draw calls
- Use Clear at the beginning of a frame on any rendertarget or depthstencil buffer
  - In SLI mode driver uses Clears as hint that no inter-frame dependency exist. It can then avoid synchronization and transfer between GPUs

Depth Buffer Formats

- Use `DXGI_FORMAT_D24_UNORM_S8_UINT`
- `DXGI_FORMAT_D32_FLOAT` should offer very similar performance, but may have lower ZCULL efficiency
- Avoid `DXGI_FORMAT_D16_UNORM`
  - will not save memory or increase performance
- CSAA will increase memory footprint

ZCULL Considerations

- **Coarse Z culling is transparent,**
  but it may underperform **if:**
  - **If depth test changes direction while writing depth (== no Z culling!)**
  - **Depth buffer was written using different depth test direction than the one used for testing**
    (testing is less efficient)
  - **If stencil writes are enabled while testing (it avoids stencil clear, but may kill performance)**
  - **If DepthStencilView has Texture2D[MS]Array dimension (on GeForce 8 series)**
  - **Using MSAA (less efficient)**
  - **Allocating too many large depth buffers**
    (it's harder for the driver to manage)

Conclusion

- DX10 is a well-designed and powerful API
- With great power comes great responsibility!
  - Develop applications with a “DX10” state of mind
  - A naïve port from DX9 will *not* yield expected gains
- Use performance tools available
  - NVIDIA PerfHUD
  - NVIDIA ShaderPerf
- Talk to us

Questions

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