

Beyond Programmable Shading Course ACM SIGGRAPH 2010

Deferred Rendering for Current and Future Rendering Pipelines

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Overview



- Forward shading
- Deferred shading and lighting
- Tile-based deferred shading
- Deferred multi-sample anti-aliasing (MSAA)

Forward Shading



- Do everything we need to shade a pixel
 - for each light
 - Shadow attenuation (sampling shadow maps)
 - Distance attenuation
 - Evaluate lighting and accumulate
- Multi-pass requires resubmitting scene geometry

 Not a scalable solution

Forward Shading Problems



- Ineffective light culling
 - Object space at best
 - Trade-off with shader permutations/batching
- Memory footprint of all inputs
 - Everything must be resident at the same time (!)
- Shading small triangles is inefficient
 - Covered earlier in this course: [Fatahalian 2010]

Conventional Deferred Shading



- Store lighting inputs in memory (G-buffer)
 - for each light
 - Use rasterizer to scatter light volume and cull
 - Read lighting inputs from G-buffer
 - Compute lighting
 - Accumulate lighting with additive blending
- Reorders computation to extract coherence

Modern Implementation



- Cull with screen-aligned quads
 - Cover light extents with axis-aligned bounding box
 - Full light meshes (spheres, cones) are generally overkill
 - Can use oriented bounding box for narrow spot lights
 - Use conservative single-direction depth test
 - Two-pass stencil is more expensive than it is worth
 - Depth bounds test on some hardware, but not batch-friendly

Lit Scene (256 Point Lights)





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Quad-Based Light Culling





Deferred Shading Problems



- Bandwidth overhead when lights overlap
 - for each light
 - Use rasterizer to scatter light volume and cull

 - Compute lighting
 - Accumulate lighting with additive blending \leftarrow overhead
- Not doing enough work to amortize overhead

Improving Deferred Shading



- Reduce G-buffer overhead
 - Access fewer things inside the light loop
 - Deferred lighting / light pre-pass
- Amortize overhead
 - Group overlapping lights and process them together
 - Tile-based deferred shading

Deferred Lighting / Light Pre-Pass



- Goal: reduce G-buffer overhead
- Split diffuse and specular terms
 - Common concession is monochromatic specular
- Factor out constant terms from summation
 - Albedo, specular amount, etc.
- Sum inner terms over all lights

Deferred Lighting / Light Pre-Pass



- Resolve pass combines factored components
 - Still best to store all terms in G-buffer up front
 - Better SIMD efficiency
- Incremental improvement for some hardware
 - Relies on pre-factoring lighting functions
 - Ability to vary resolve pass is not particularly useful
- See [Hoffman 2009] and [Stone 2009]

Tile-Based Deferred Shading



- Goal: amortize overhead
- Use screen tiles to group lights
 - Use tight tile frusta to cull non-intersecting lights
 - Reduces number of lights to consider
 - Read G-buffer once and evaluate all relevant lights
 - Reduces bandwidth of overlapping lights
- See [Andersson 2009] for more details

Lit Scene (1024 Point Lights)





Tile-Based Light Culling





Quad-Based Lighting Culling





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Light Culling Only at 1080p 16 Slope ~ 7 µs / light Slope ~ $0.5 \,\mu s$ / light 8 Frame Time (ms) Tile setup dominates -•-Quad (ATI 5870) 4 ---Quad (NVIDIA 480) ———Tiled (NVIDIA 480) —**■**—Tiled (ATI 5870) 2 1 16 32 64 128 256 512 1024 **Number of Point Lights**

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Total Performance at 1080p



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Anti-aliasing



- Multi-sampling with deferred rendering requires some work
 - Regular G-buffer couples visibility and shading
- Handle multi-frequency shading in user space
 - Store G-buffer at sample frequency
 - Only apply per-sample shading where necessary
 - Offers additional flexibility over forward rendering

Identifying Edges



- Forward MSAA causes redundant work
 - It applies to all triangle edges, even for continuous, tessellated surfaces
- Want to find *surface* discontinuities
 - Compare sample depths to depth derivatives
 - Compare (shading) normal deviation over samples

Per-Sample Shading Visualization





MSAA with Quad-Based Methods



- Mark pixels for per-sample shading
 - Stencil still faster than branching on most hardware
 - Probably gets scheduled better
- Shade in two passes: per-pixel and per-sample
 - Unfortunately, duplicates culling work
 - Scheduling is still a problem

Per-Sample Scheduling



 Lack of spatial locality causes hardware scheduling inefficiency



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MSAA with Tile-Based Methods



- Handle per-pixel and per-sample in one pass
 - Avoids duplicate culling work
 - Can use branching, but incurs scheduling problems
 - Instead, reschedule per-sample pixels
 - Shade sample 0 for the whole tile
 - Pack a list of pixels that require per-sample shading
 - Redistribute threads to process additional samples
 - Scatter per-sample shaded results



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4x MSAA Performance at 1080p





Conclusions



- Deferred shading is a useful rendering tool
 - Decouples shading from visibility
 - Allows efficient user-space scheduling and culling
- Tile-based methods win going forward
 - Fastest and most flexible
 - Enable efficient MSAA

Future Work



- Hierarchical light culling
 - Straightforward but would need lots of small lights
- Improve MSAA memory usage
 - Irregular/compressed sample storage?
 - Revisit binning pipelines?
 - Sacrifice higher resolutions for better AA?

Acknowledgements



- Microsoft and Crytek for the scene assets
- Johan Andersson from DICE
- Craig Kolb, Matt Pharr, and others in the Advanced Rendering Technology team at Intel
- Nico Galoppo, Anupreet Kalra and Mike Burrows from Intel

References



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- [Fatahalian 2010] Kayvon Fatahalian, "Evolving the Direct3D Pipeline for Real-Time Micropolygon Rendering", http://bps10.idav.ucdavis.edu/
- [Hoffman 2009] Naty Hoffman, "Deferred Lighting Approaches", http://www.realtimerendering.com/blog/deferred-lighting-approaches/
- [Stone 2009] Adrian Stone, "Deferred Shading Shines. Deferred Lighting? Not So Much.", http://gameangst.com/?p=141

Questions?



• Full source and demo available at:

 http://visual-computing.intelresearch.net/art/publications/deferred_rendering/

Backup



Quad-Based Light Culling



- Accumulate many lights per draw call
 - Render one point per light
 - Vertex shader computes quad bounds for light
 - Geometry shader expands into two triangles (quad)
 - Pixel shader reads G-buffer and evaluates lighting

Tile-Based Deferred Lighting?



- Can do deferred lighting with tiling...
 - Not usually worth sacrificing the flexibility
 - Bandwidth already minimized
 - Additional resolve pass can make it slower overall
- Exception: hardware considerations
 - SPU lighting on Playstation 3
 - Moving less data across the bus can be an overall win