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]

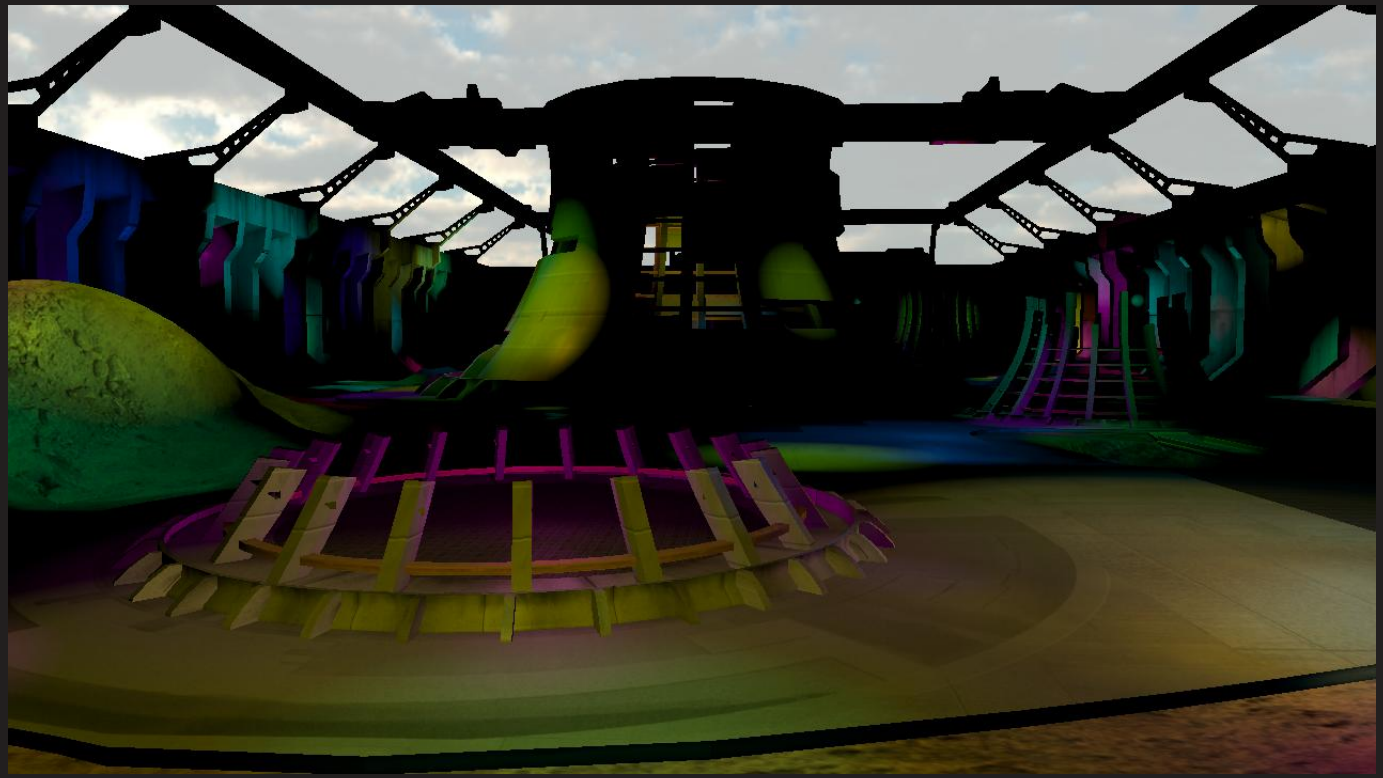
Conventional Deferred Shading

- 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)



Quad-Based Light Culling

Deferred Shading Problems

- Bandwidth overhead when lights overlap
  - for each light
    - Use rasterizer to scatter light volume and cull
    - Read lighting inputs from G-buffer ← **overhead**
    - Compute lighting
    - Accumulate lighting with additive blending ← **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

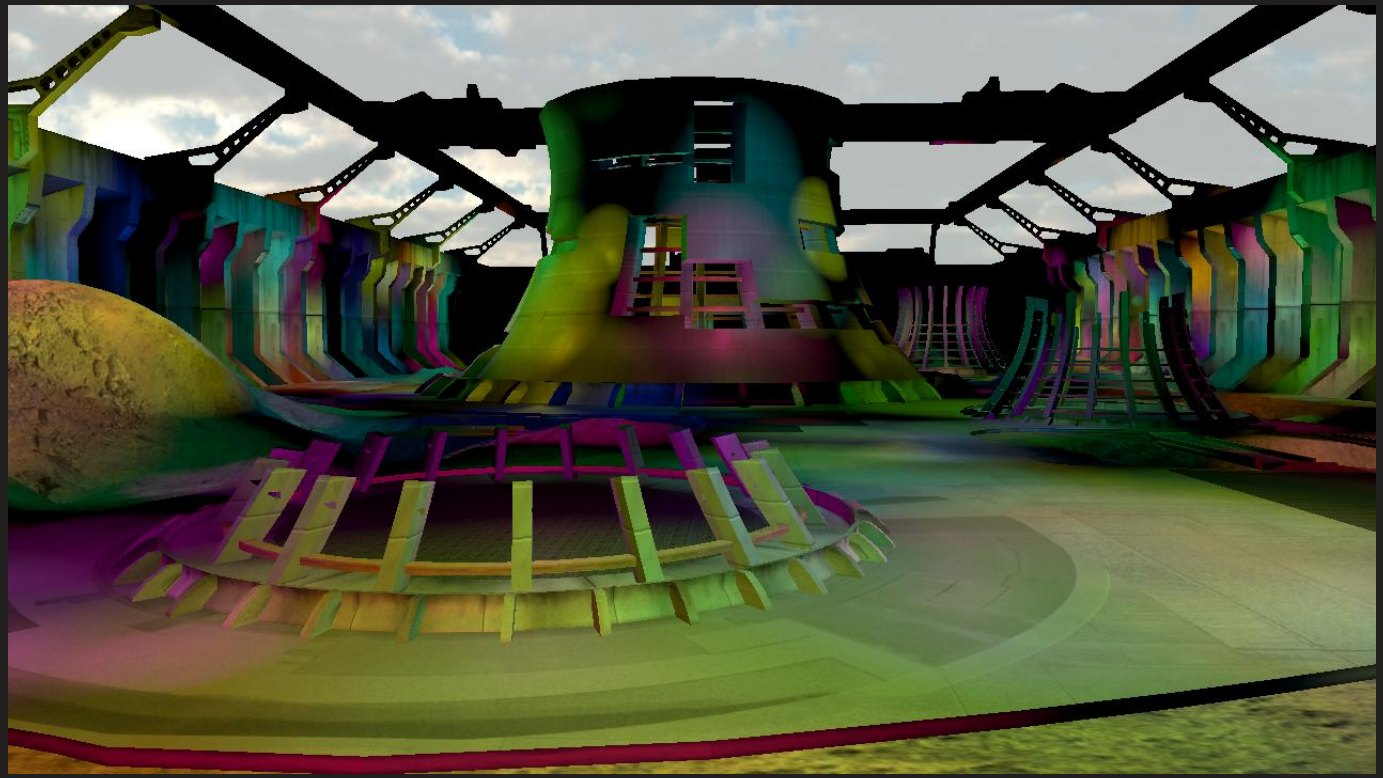
Deferred Lighting / Light Pre-Pass

- 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]

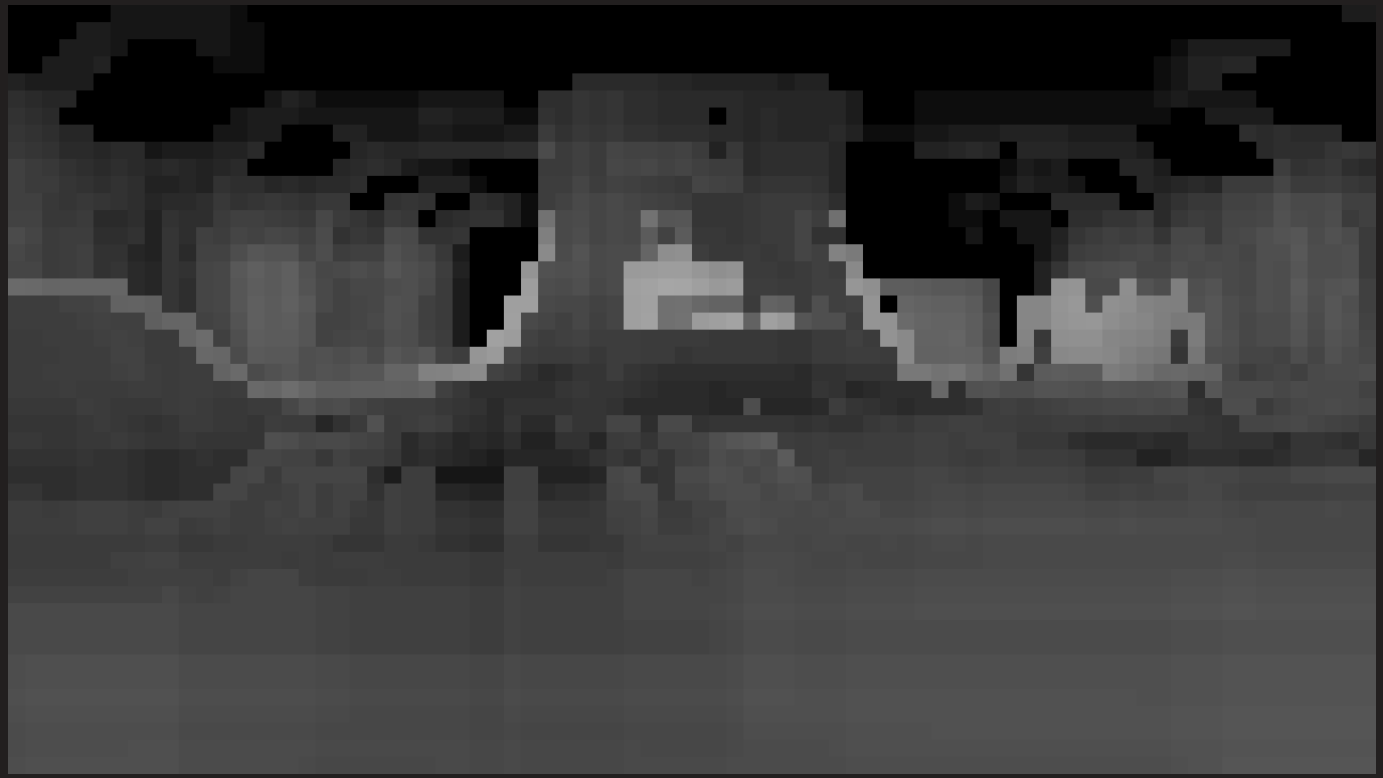
Tile-Based Deferred Shading

- 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)

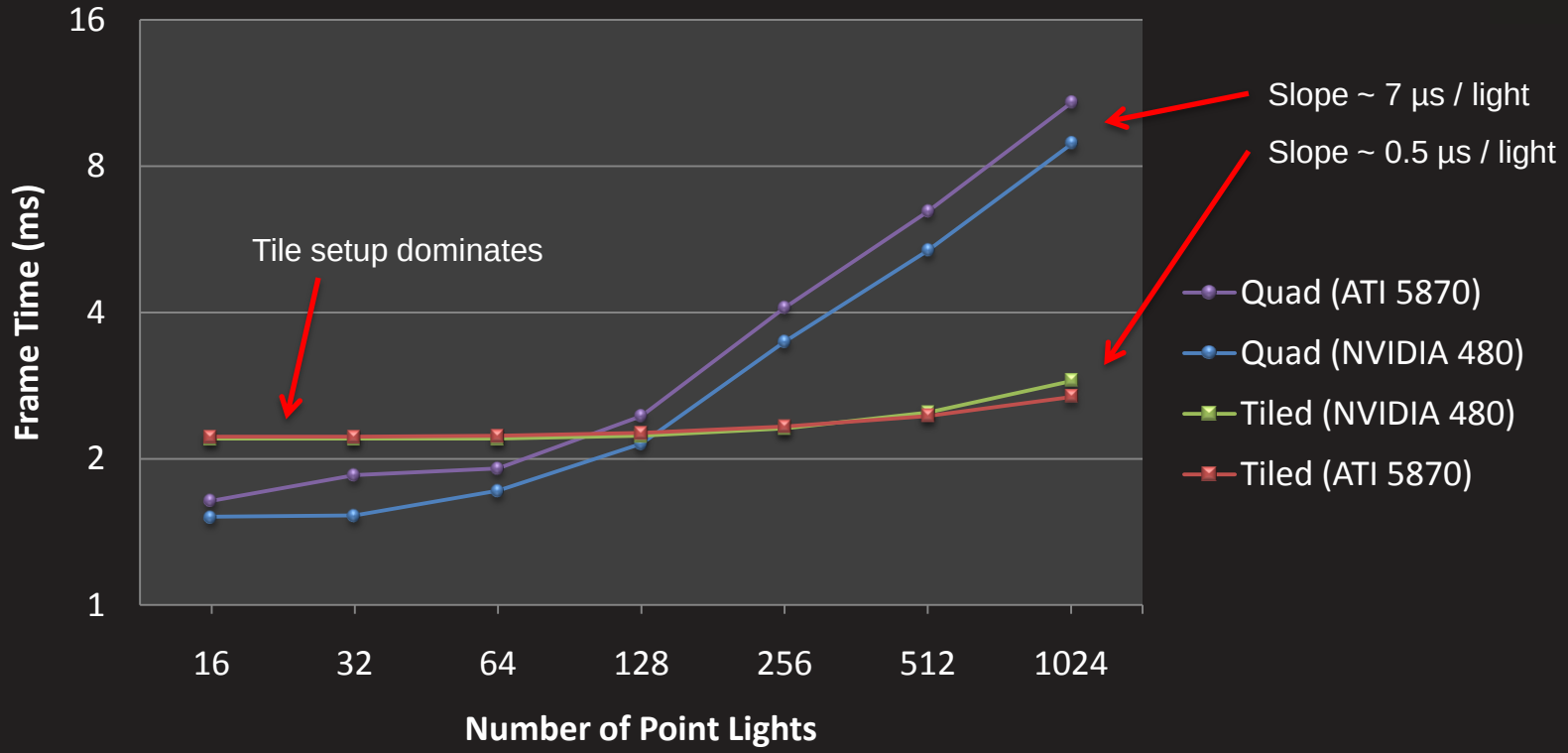


Tile-Based Light Culling

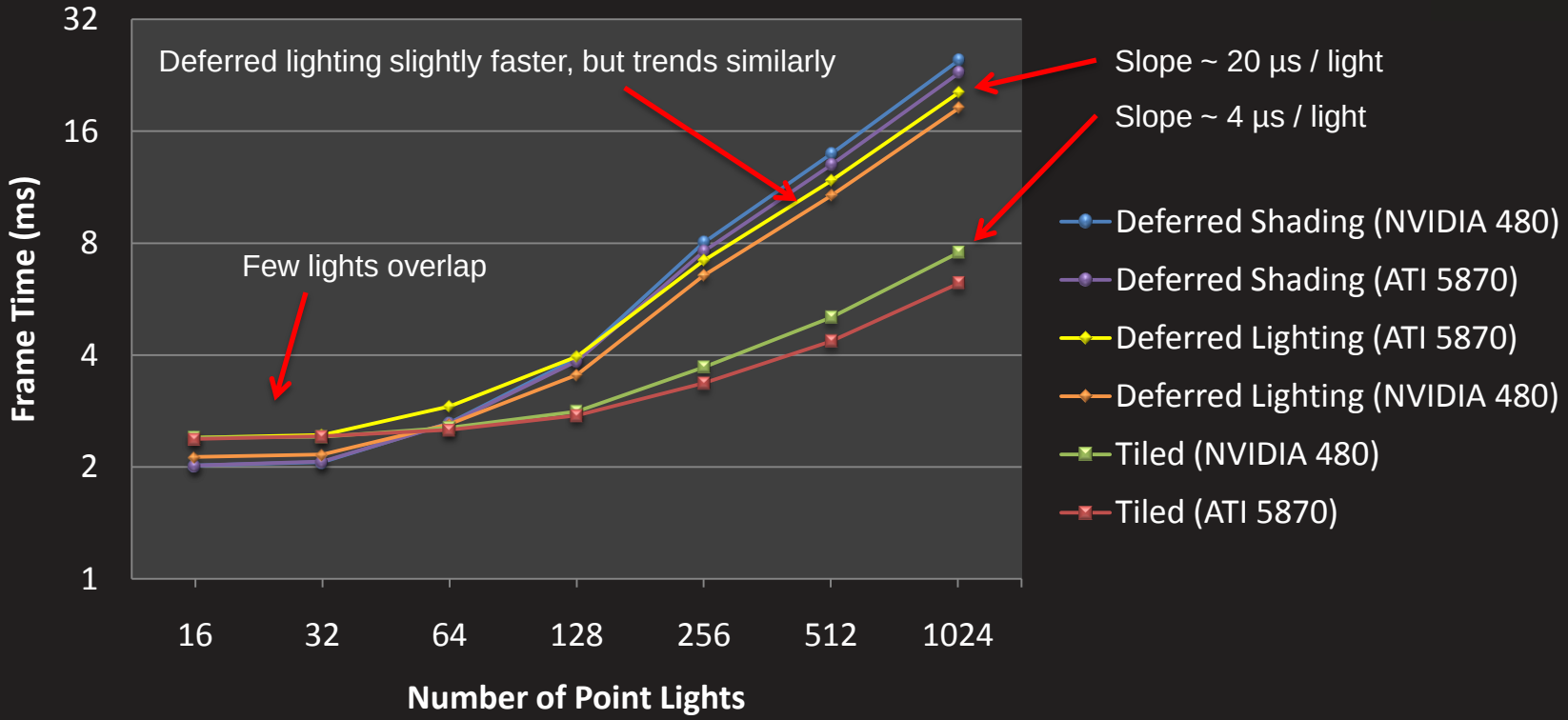


Quad-Based Lighting Culling

Light Culling Only at 1080p



Total Performance at 1080p



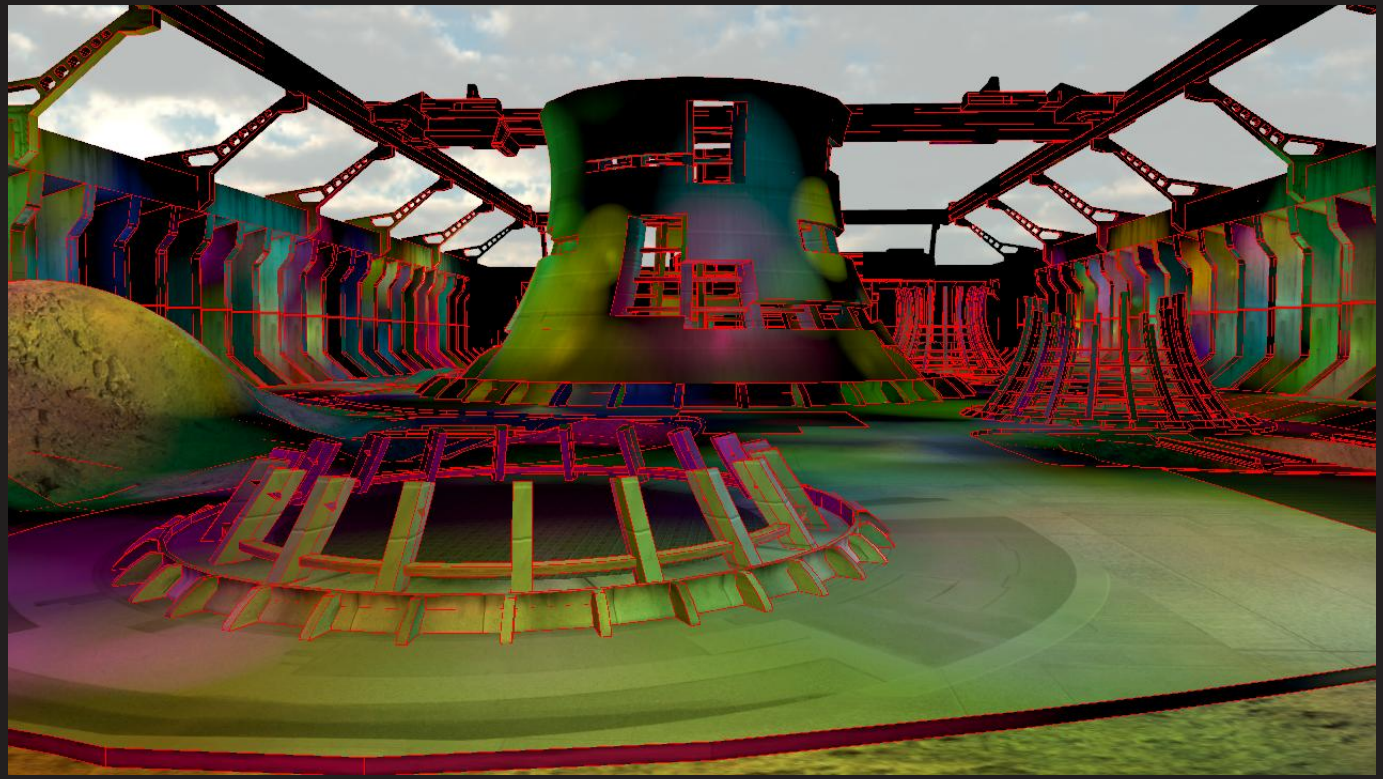
Anti-aliasing

- 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

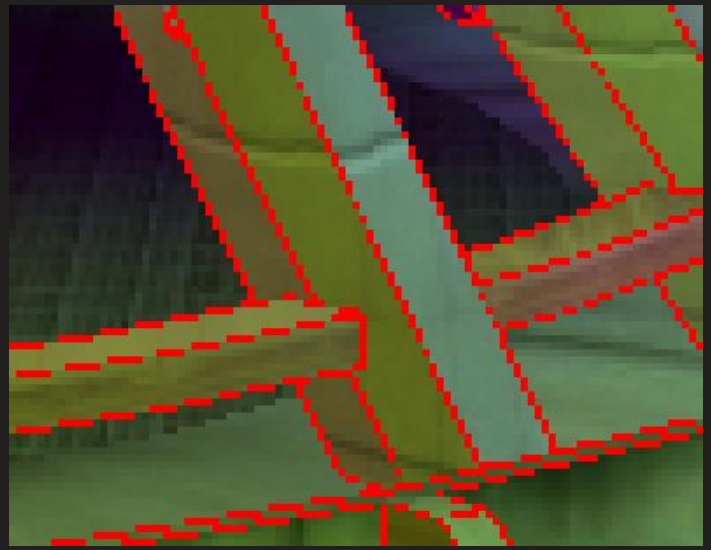


MSAA with Quad-Based Methods

- 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

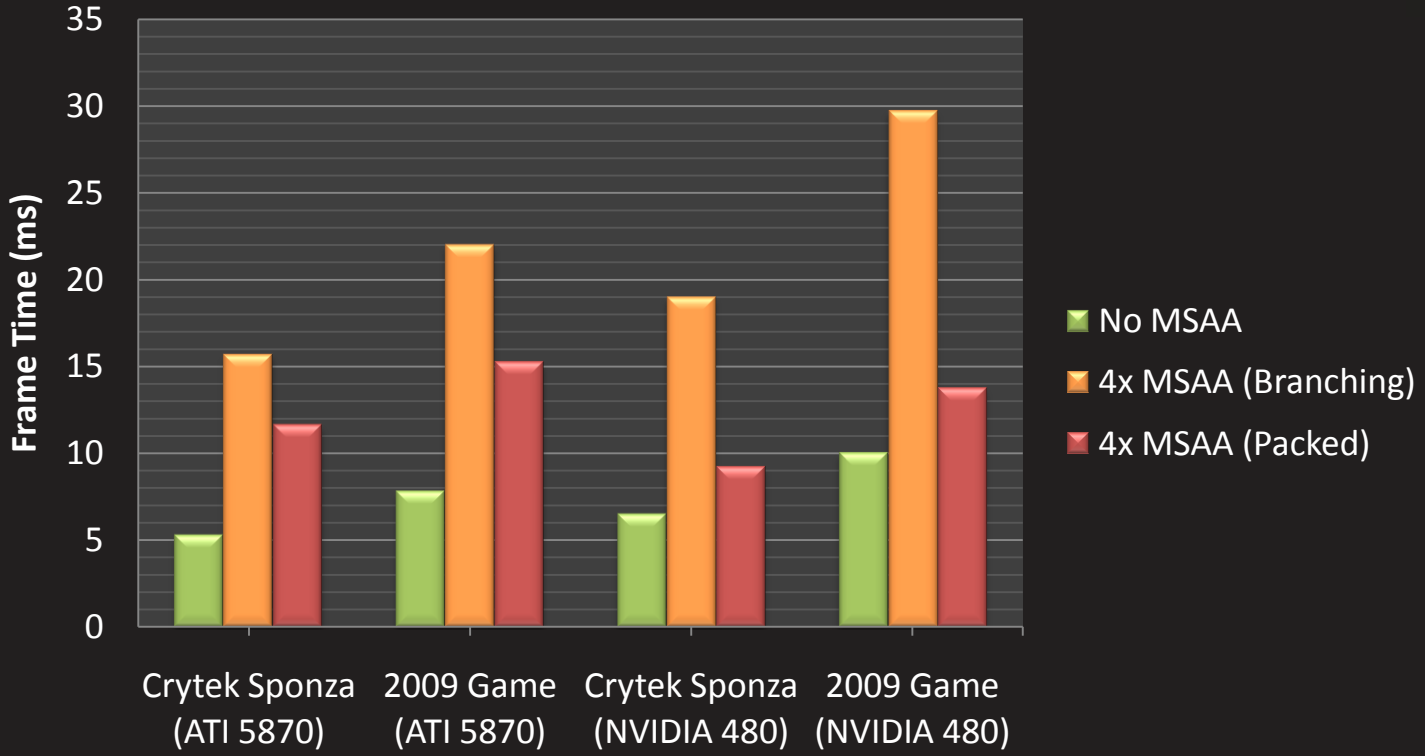
- Lack of spatial locality causes hardware scheduling inefficiency



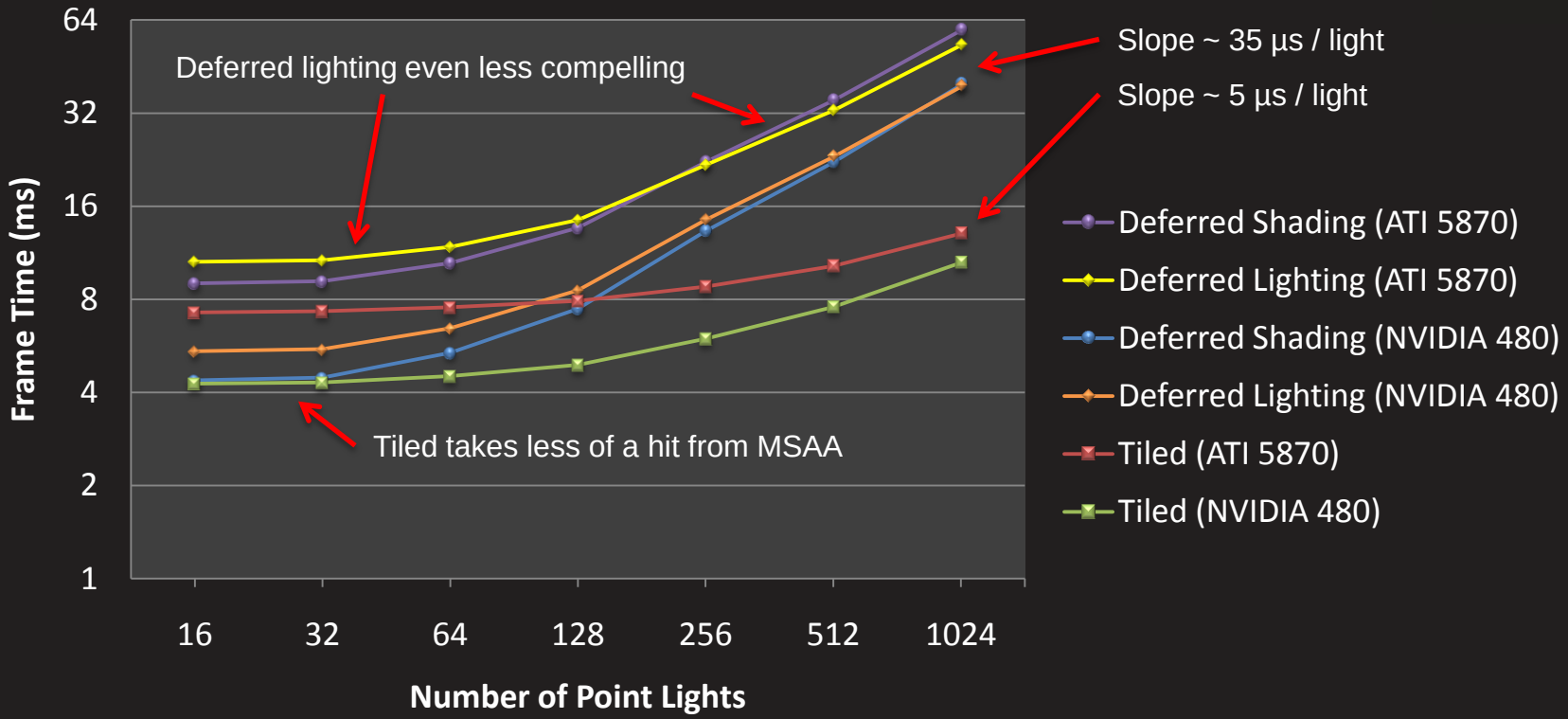
MSAA with Tile-Based Methods

- 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

Tile-Based MSAA at 1080p, 1024 Lights



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

- [Andersson 2009] Johan Andersson, “Parallel Graphics in Frostbite - Current & Future”, http://s09.idav.ucdavis.edu/
- [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.intel-research.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