MSAA-Based Coarse Shading
for Power-Efficient Rendering on High Pixel-Density Displays

Pavlos Mavridis Georgios Papaioannou

Department of Informatics, Athens University of Economics & Business

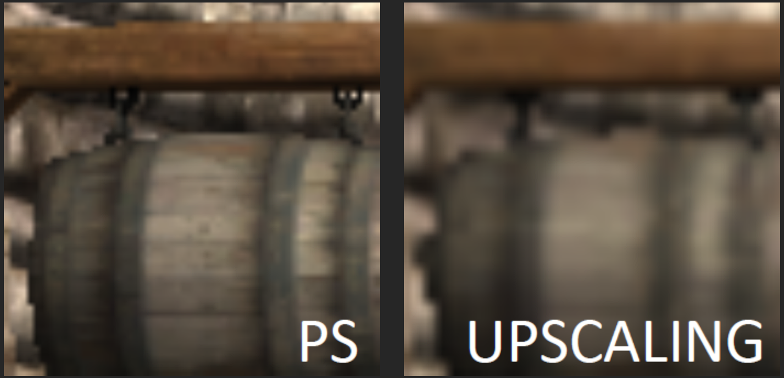
Motivation

- High-pixel-density displays are widely used on many devices
  - Mobile phones and tablets
  - Laptops
  - 4K monitors/TVs are now mainstream
  - 5K displays are introduced in the high-end
- High-pixel-density -> (very) high resolution
- Real-time rendering on such resolutions is challenging
  - The cost of shading all these pixels can be prohibitive, especially on **power-constrained mobile devices**

Typical Approaches

Render at a lower resolution and upscale

- Introduces blurriness
- Thin geometric features are under-sampled



Edge-preserving filters (bilateral) can be used for better results, but under-sampling is still an issue.

Images from [Vaidyanathan et al. 2014]

A Better Alternative

- Use a ***decoupled sampling*** approach, where visibility is sampled at a higher rate than shading.
- In particular, the desired approach will:
  - Sample visibility ***at least*** once per pixel, in order to preserve the clarity of geometric edges
  - Perform shading at a lower (more *coarse*) rate.

Decoupled Sampling: Previous Work

- Parametric-space shading
  - Reyes [Cook et al. 1987], [Andersson et al. 2014], …
  - Caveats: high overhead when implemented on existing GPUs, overshading.
- Deferred shading
  - Inherently decouples visibility from shading
  - Many decoupling opportunities [Lauritzen 2010; Kerzner and Salvi 2014; …]
  - Caveats: memory bandwidth (or tiling overhead), transparency.
- Multi Sample Anti-Aliasing (MSAA) [Akeley 1993]
  - Supported virtually on all shipping GPUs.
  - Caveat: Each covered primitive is shaded **at least once per pixel**
    -> Not directly applicable for coarse shading.

Decoupled Sampling: Previous Work

- Recent extensions of MSAA allow coarse and multi-rate shading [Vaidyanathan et al. 2014; He at al. 2014; Clarberg et al. 2014]
  - Hardware modifications are required.

- Can we perform **coarse shading** efficiently on **existing GPUs** in the context of **forward rendering**?

MSAA-based coarse shading

- **Main Idea:**
  - Starting from the render buffer with the final desired resolution.

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  - Every NxN block of pixels is replaced with one pixel with **at least** NxN MSAA samples.

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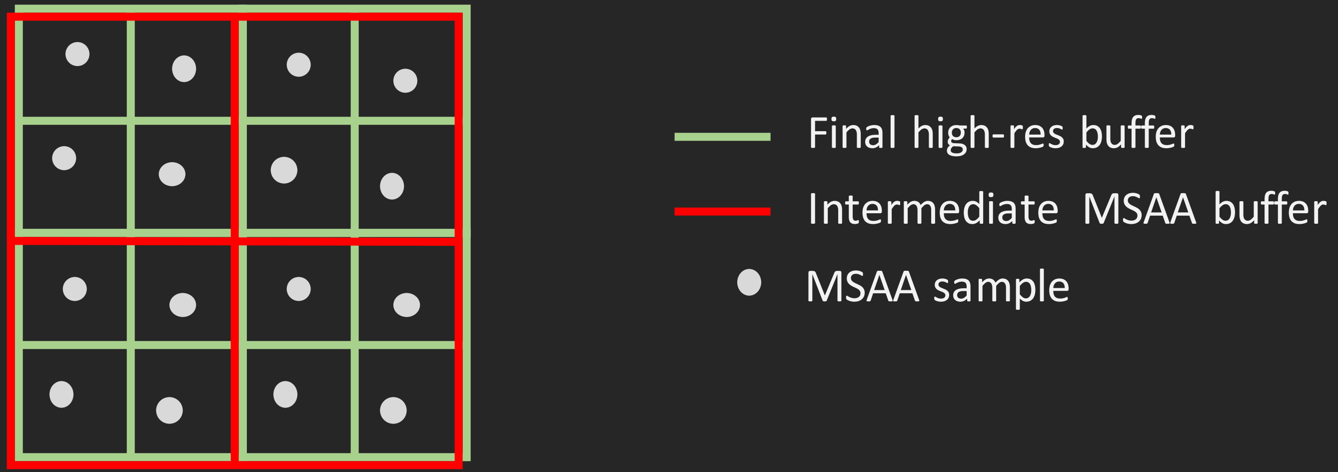
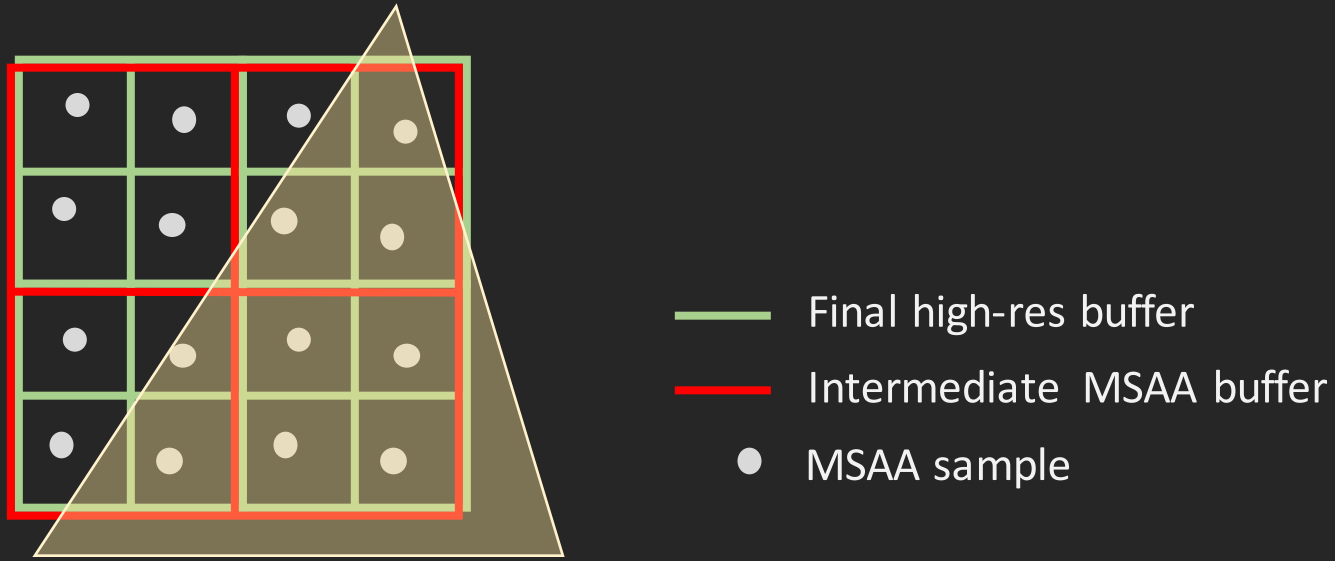
  - Starting from the render buffer with the final desired resolution.
  - Every NxN block of pixels is replaced with one pixel with **at least** NxN MSAA samples.
  - A custom resolve shader maps individual MSAA samples to screen pixels

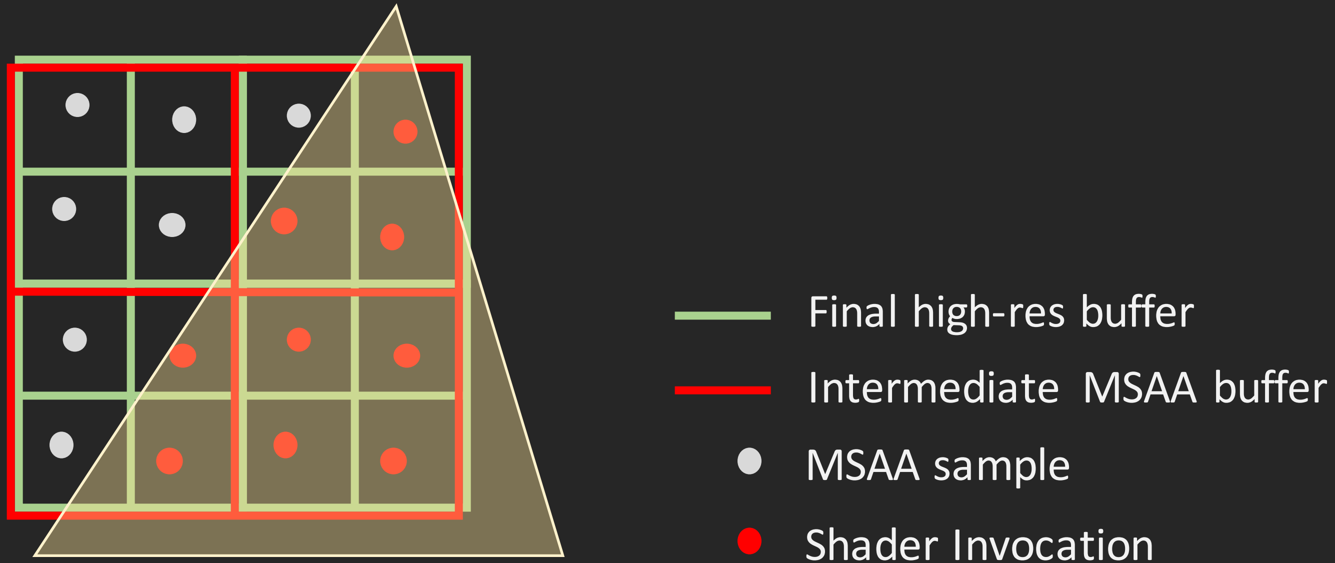


MSAA-based coarse shading



MSAA-based coarse shading

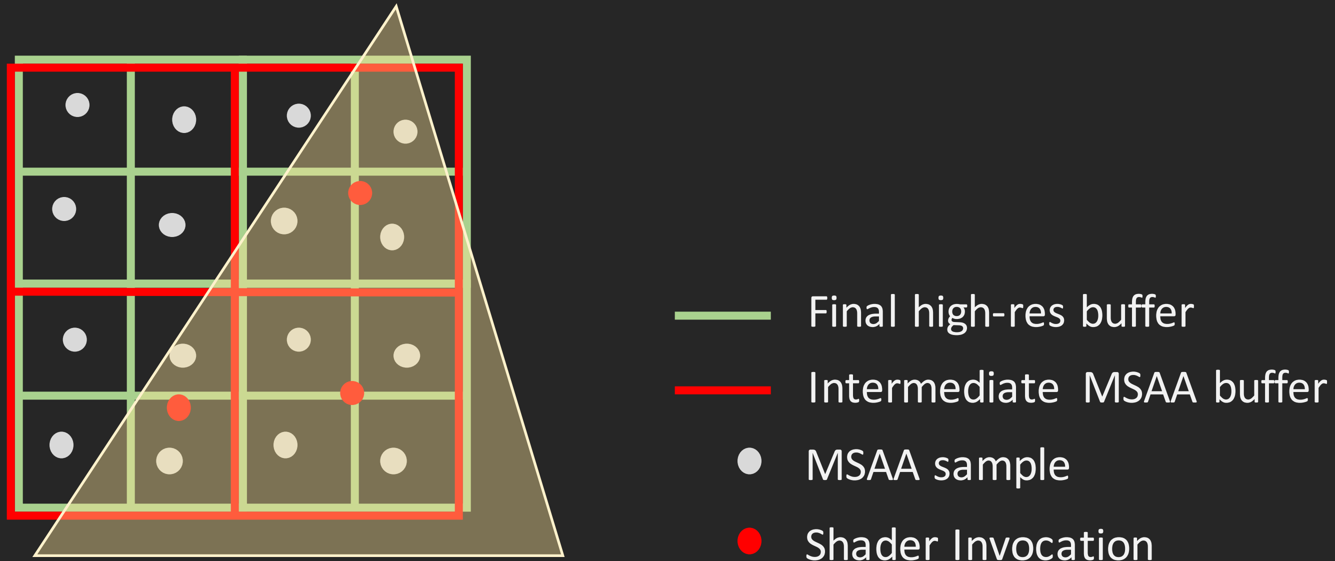
- **Per pixel shading:** Nine fragment shader invocations



Per-pixel Shading

MSAA-based coarse shading

- **Per pixel shading:** Nine fragment shader invocations
- **Coarse shading:** Three fragment shader invocations **(3x reduction)**

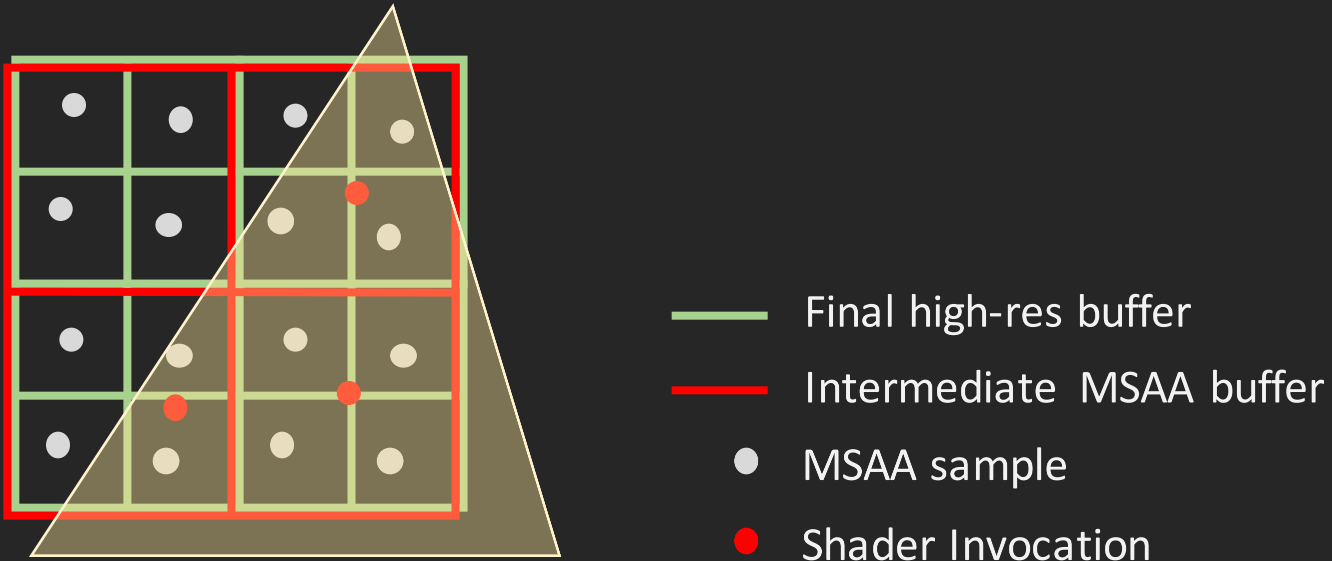


Coarse Shading

MSAA-based coarse shading

- **Per pixel shading:** Nine fragment shader invocations
- **Coarse shading:** Three fragment shader invocations **(3x reduction)**

Centroid sampling should be used in order to evaluate shaders near the covered sample positions.



Coarse Shading

Practical Configurations

Configuration #1

¼ resolution + **4x**MSAA

Visibility: 1 sample/pixel

Shading: *at least* 1 sample per 2x2 block

Resolve: **1:1 mapping** (nearest filtering)

Practical Configurations

Configuration #1

¼ resolution + **4x**MSAA

Visibility: 1 sample/pixel

Shading: *at least* 1 sample per 2x2 block

Resolve: **1:1 mapping** (nearest filtering)

Configuration #2

¼ resolution + **8x**MSAA

Visibility: 2 samples/pixel

Shading: *at least* 1 sample per 2x2 block

Resolve: **2:1 mapping** (weighted average of 2 values)

Practical Configurations

Configuration #1 (alternative)

1. Bind a normal high-res buffer
2. “Pretend” it is a low-res MSAA buffer during rendering

(it could be done on some consoles exploiting non-standard APIs and H/W behavior)

Configuration #2

¼ resolution + **8x**MSAA

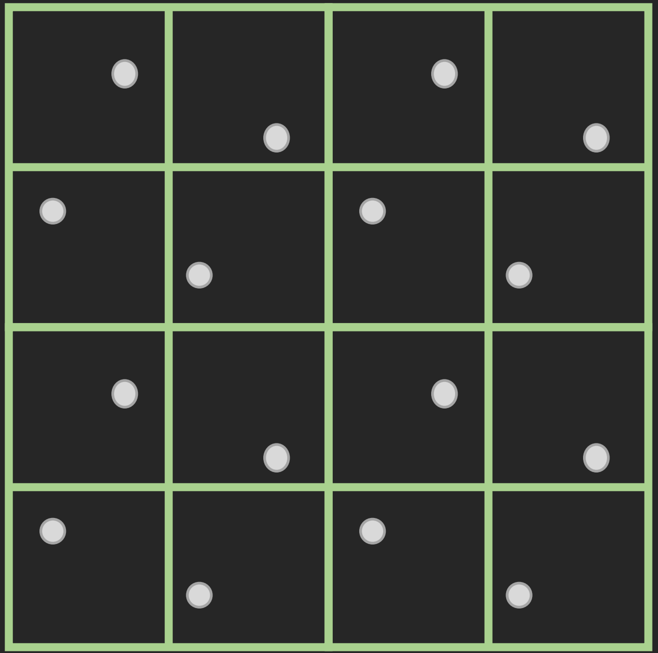
Visibility: **2** samples/pixel

Shading: *at least* 1 sample per 2x2 block

Resolve: **2:1 mapping**
(weighted average of 2 values)

Spatial Interleaving

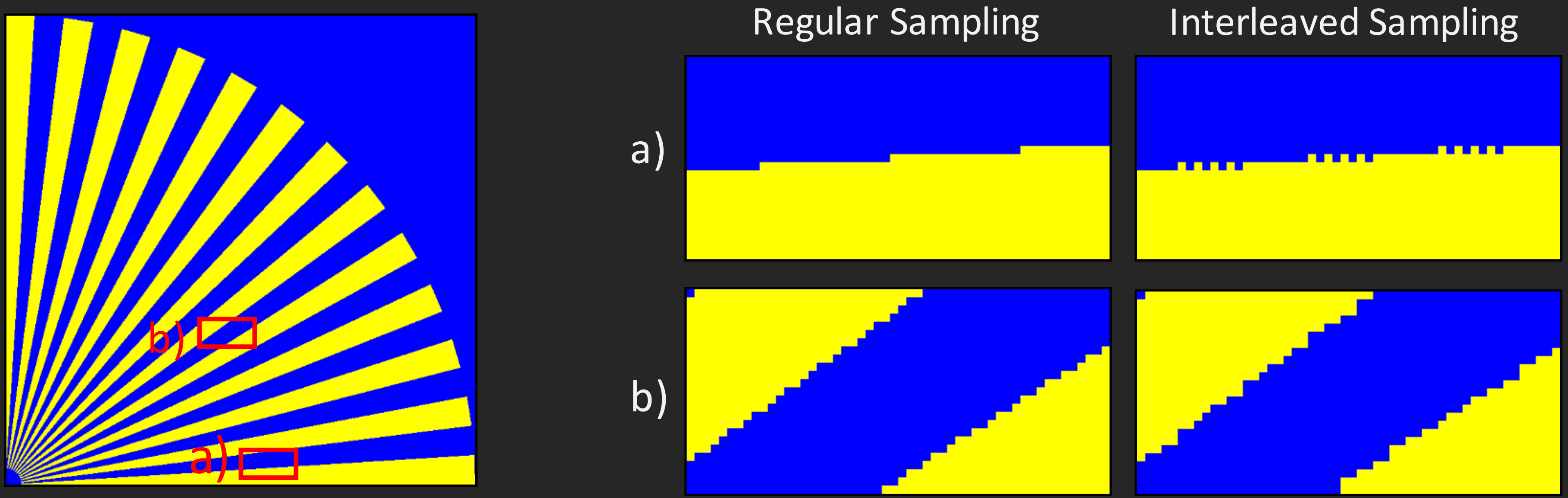
- The method Inherently creates **interleaved sampling** patterns [Keller et al. 2001]



Neighboring pixels are always sampled at different positions.

Spatial Interleaving

- Masks *inter-pixel* aliasing with noise
  (well-known concept from stochastic sampling)



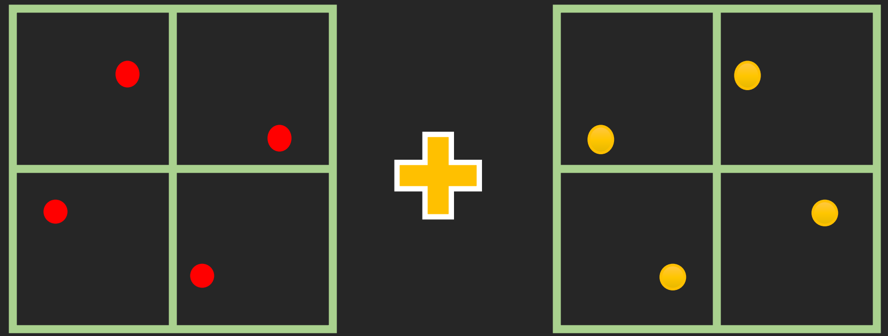
Spatial Interleaving

- Beneficial even when one visibility sample per pixel is used on high-pixel-density displays.
  - But the more samples the better.
  - **Limitation:** Up to two visibility samples per pixel on 8xMSAA hardware (when 2x2 pixel blocks are used for coarse shading)
- On low-pixel-density displays regular sampling + MLAA/FXAA/etc… might be preferable (highly subjective).
  - Revert to regular sampling using **programmable sample positions**.

Note: NVIDIA's Maxwell architecture supports interleaved sampling with MSAA (>1 sample/pixel).

Temporal Interleaving

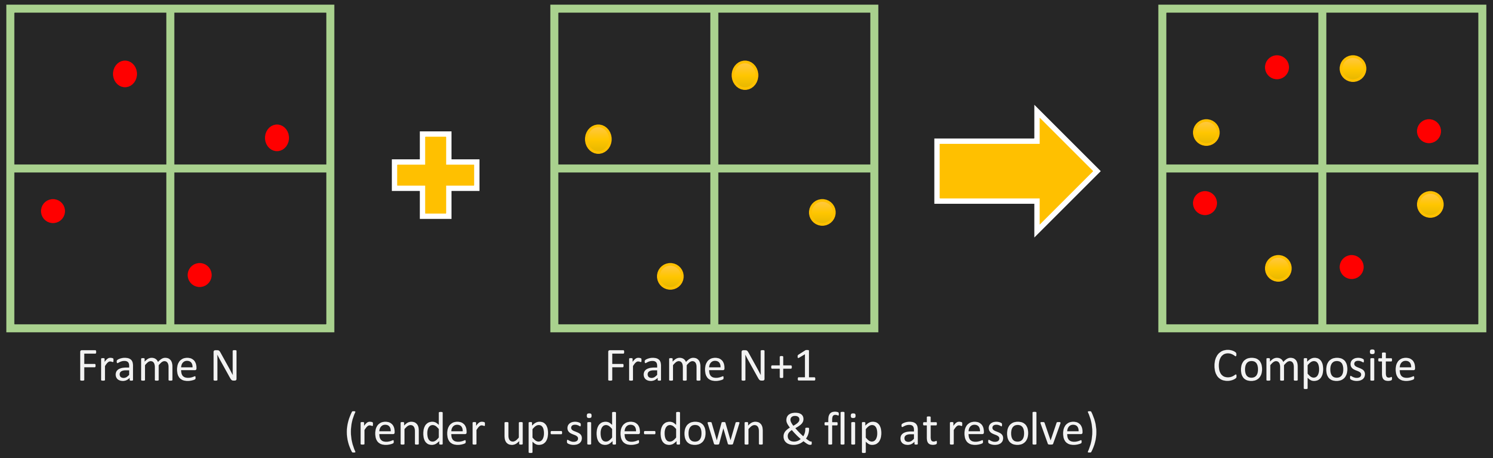
- Alternate between two sampling patterns at successive frames



(render up-side-down & flip at resolve)

Temporal Interleaving

- Alternate between two sampling patterns at successive frames
- **Static content:** Render at a high frame rate (>60Hz **v-sync locked**) and let the human visual system perform the required averaging.
- **Dynamic content:** Temporal sample re-projection…



“Side Effects”

“Side effect”: triangle size

- The pixel footprint gets bigger-> relative triangle size is decreased.
- Can negatively affect the efficiency of rasterization
  (due to increased *“**quad over-shading**”)*
- Techniques like ***Quad-Fragment Merging*** [Fatahalian et al. 2010], ***Pixel Merge Unit*** [Sathe et al. 2015] or similar can be highly beneficial.

“Side effect”: frame buffer compression

- Neighboring pixels share the same color
  - -> good opportunity for better compression.
- But, our implementation binds an MSAA render target for reading
  - this disables compression or triggers a decompression operation on some architectures -> *high overhead.*
- An implementation that avoids this issue *might* be possible
  - Mobile architectures: read directly from the on-chip *tile local storage*.

Expect different behavior on different GPUs
(tests show more gains on Intel GPUS than on NVIDIA or AMD)

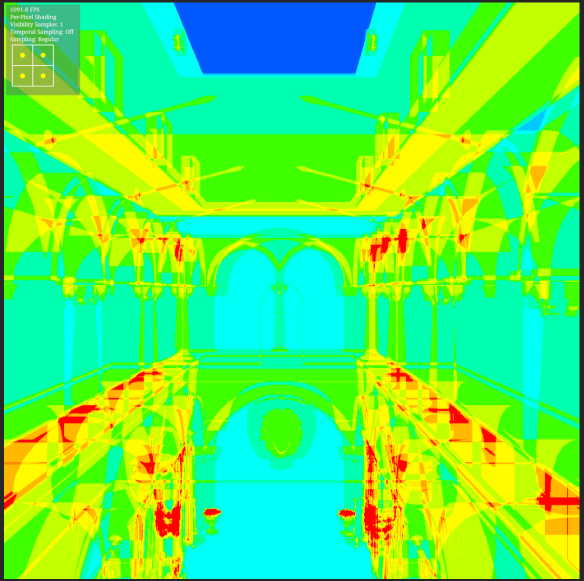
Results

Methodology

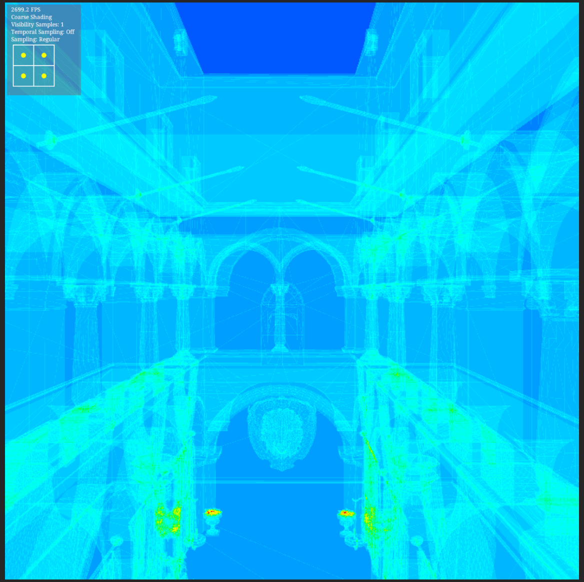
- Test Hardware: Apple MacBook Pro 13’’ / Intel Iris 5100 GPU
- *Intel Power Gadget* tool for energy measurements
  - Measurements include both CPU and GPU consumption.
  - **V-Sync** ensures that all methods perform the same amount of work.
- ARB_pipeline_statistics_query for shader invocation measurements
  - Includes “helper” invocations for derivative calculations

Shader Invocations (per 2x2 pixel block)

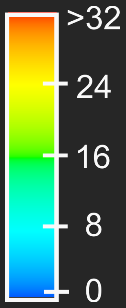
Sponza Atrium
262k Triangles



Per Pixel Shading



Coarse Shading



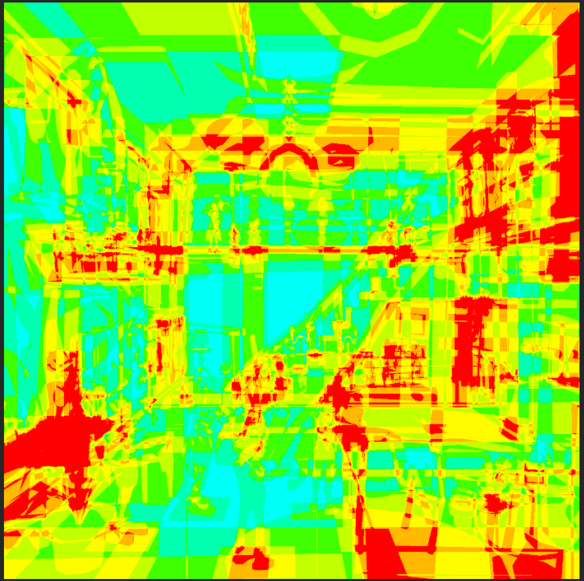
Invocations: 69.3% reduction (3.5M vs 1.1M)

Power usage: 45.7% reduction (32 vs 17 Watts)

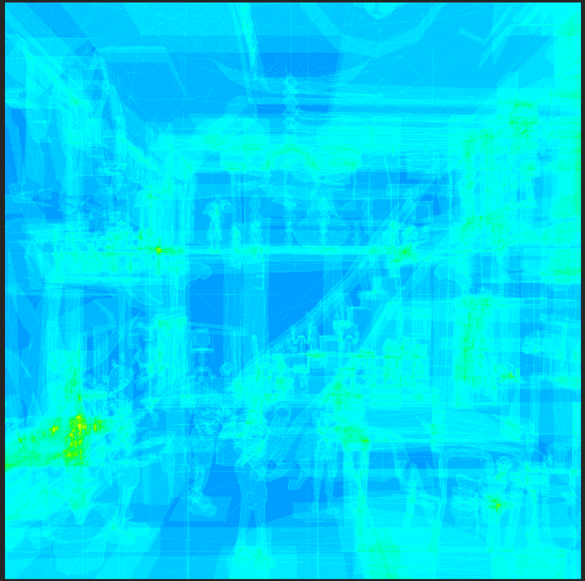
OR 1.73x speedup in rendering

Shader Invocations (per 2x2 pixel block)

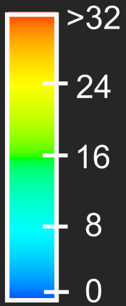
Mansion Scene
53k Triangles



Per Pixel Shading



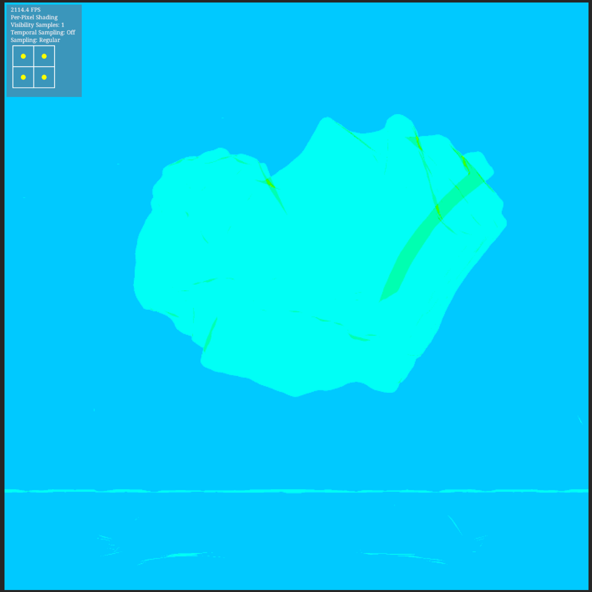
Coarse Shading



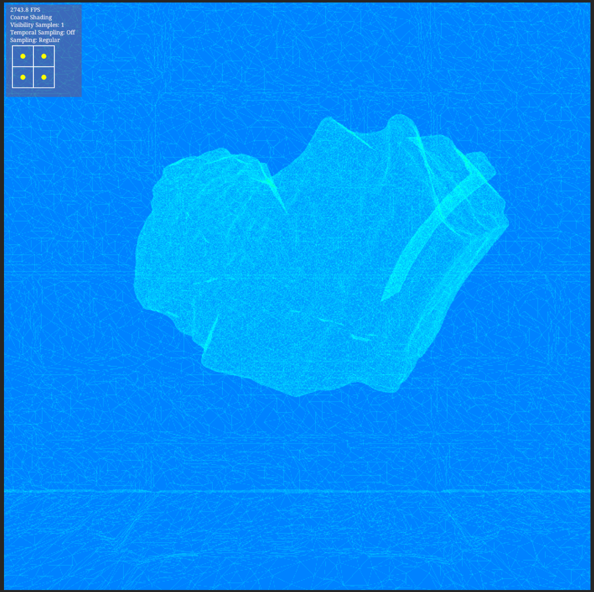
Invocations: 72.5% reduction (10M vs 2.7M)
Power usage: 12.6% reduction (8.7 vs 7.6 Watts)
OR 1.23x speedup in rendering

Shader Invocations (per 2x2 pixel block)

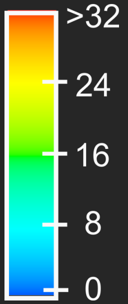
Volumetric Shadows
215k Triangles



Per Pixel Shading



Coarse Shading

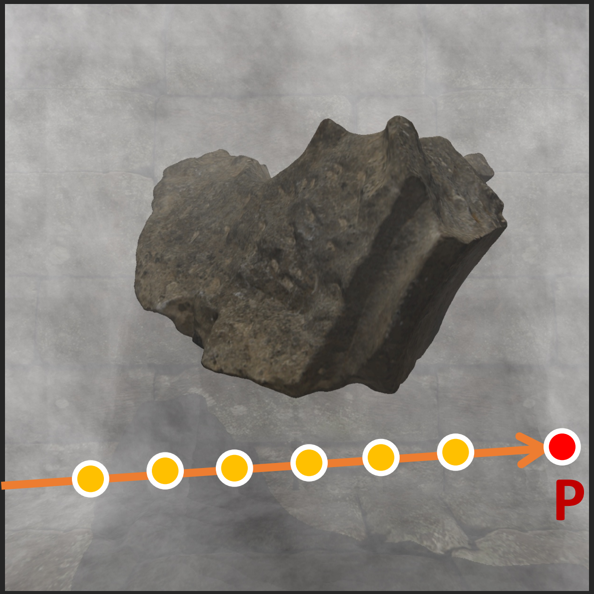


Invocations: **63.2%** reduction (1.9M vs 0.7M)

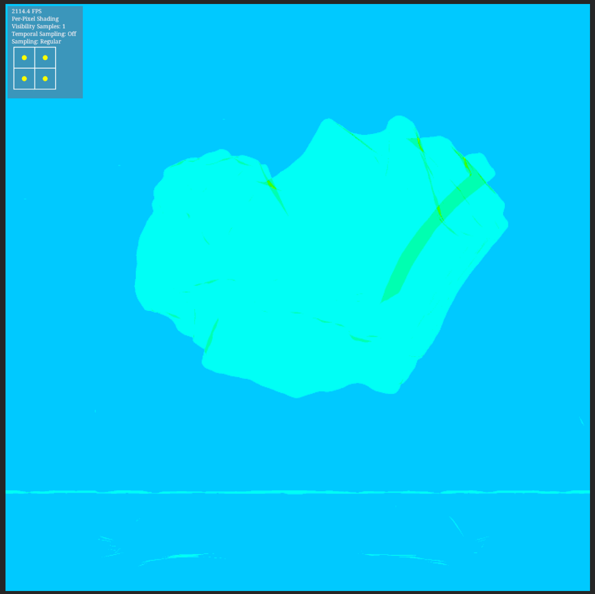
Power usage: **45.8%** reduction (30 vs 16 Watts)

OR **2.14x** speedup in rendering

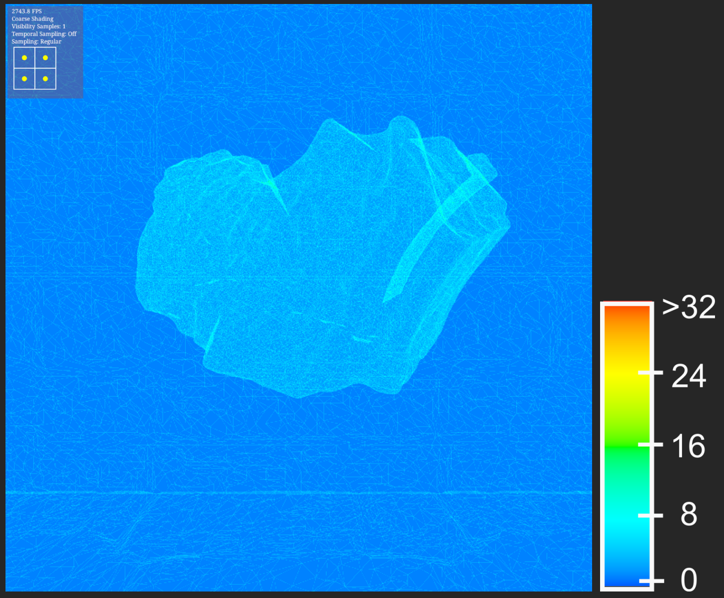
Shader Invocations (per 2x2 pixel block)



Volumetric Shadows
215k Triangles



Per Pixel Shading



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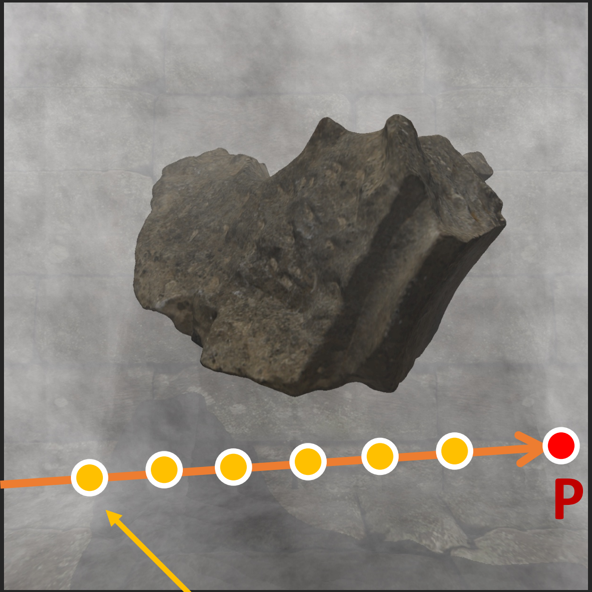
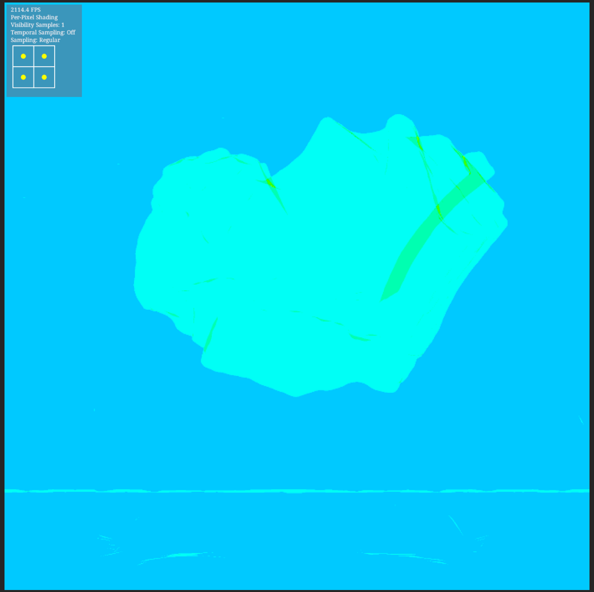
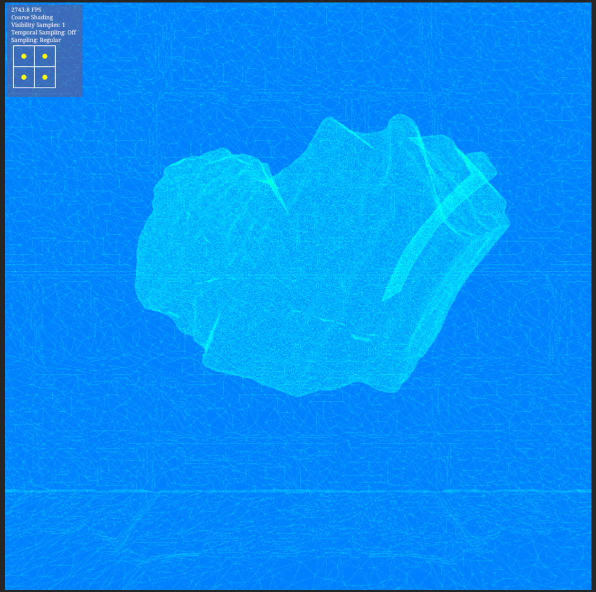


Volumetric Shadows
215k Triangles

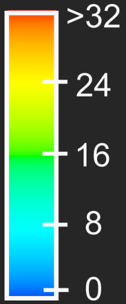
Shadow-map lookup +
4D Perlin Noise + math



Per Pixel Shading



Coarse Shading



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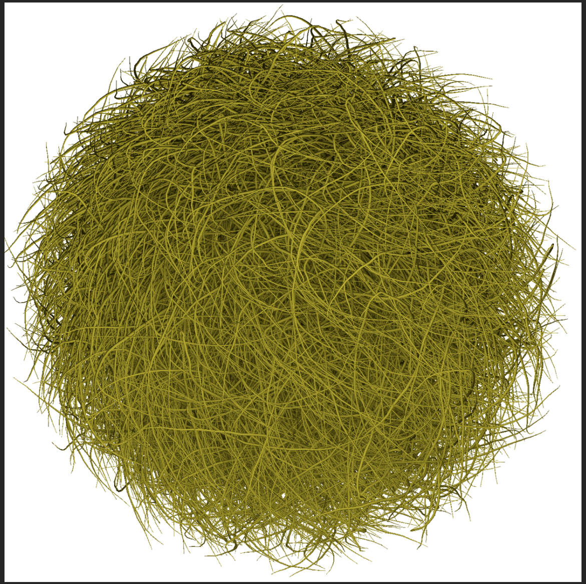
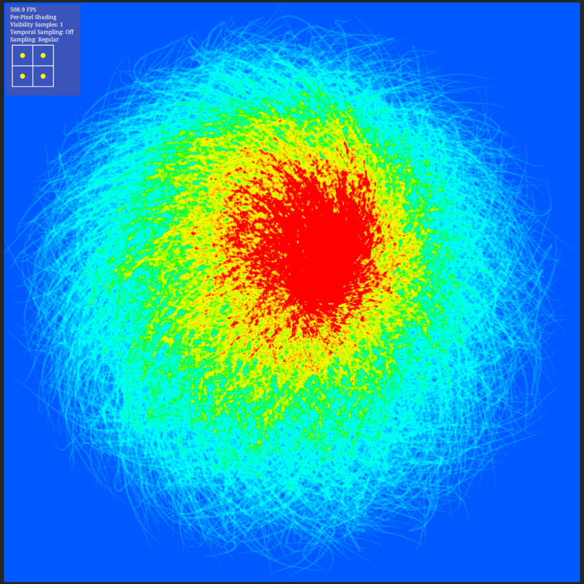
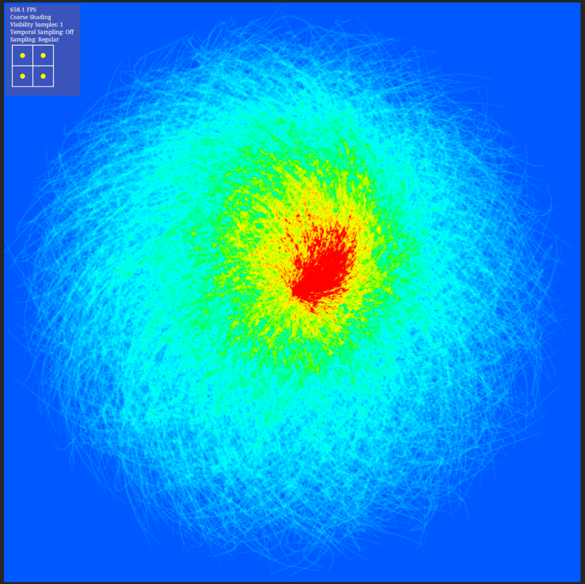
Shader Invocations (per 2x2 pixel block)



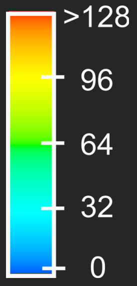
Hairball
2850k Triangles



Per Pixel Shading

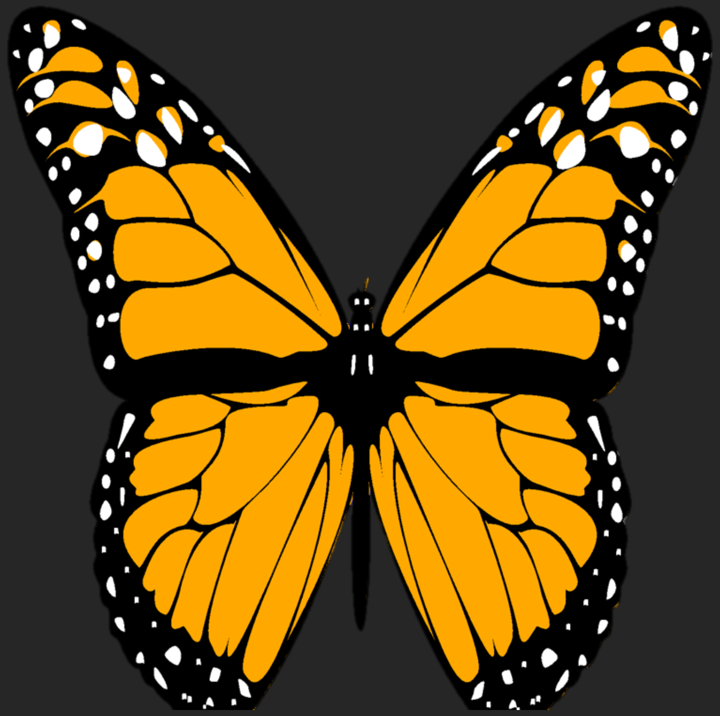


Coarse Shading



Invocations: **34.9%** reduction (3.2M vs 2.0M)
Power usage: **7.4% increase** (29 vs 31 Watts)
OR **0.82x** speedup in rendering

Vector Drawing



Butterfly Scene (SVG)

- Tested using the NanoVG library (vector drawing with OpenGL)
- Important for UI / Maps / 2D games
- Flat or smooth shaded regions exhibit very small loss of image quality.

Invocations: **74%** reduction (439K vs 114K)
Power usage: **14.3%** reduction (7 Watts vs 6 Watts)
OR **1.27x** speedup in rendering

Image Quality

- **Subjective evaluation:** we can switch between per-pixel and coarse shading without noticing any quality degradation on Hi-PPI displays **(see the demo!)**
- **Objective evaluation:**

Scene Name	SSIM (%)
Butterfly (2D SVG)	99.9
Mansion	95.6
Volumetric Shadows	96.5
Sponza	81.2
Hairball	97.6

Coarse shading compared to per-pixel shading

Extension: Selective Coarse Shading

- Apply coarse shading only on specific parts of the scene
  - Out of focus regions (defocus blur)
  - Fast moving objects (motion blur)
  - Distant objects (often covered by thin haze)
  - Peripheral objects in VR applications (foveated rendering)
- On existing hardware we can switch between coarse and fine shading between draw-calls
  - Not as fine-grained control as the proposed hardware implementations

Conclusions

- We have presented a method to perform coarse shading efficiently on commodity graphics hardware
  - Important for practitioners & software developers.
  - Important for IHVs: before designing new hardware extensions it is important to understand the limits of existing architectures.
- Performance and energy-consumption analysis on various scenes.
  - Up to **45% reduction in power consumption**.
- *Interleaved sampling* for improved antialiasing.

Thank you for your attention!

Acknowledgement
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