Pixel Synchronization:

Solving Old Graphics Problems with New Data Structures

Marco Salvi

Advanced Rendering Technology

Intel - San Francisco

My Background

- 7 yrs as Gfx Engineer on PC and two generations of Sony & MS consoles
  - High performance 3D engines
  - Exponential shadow maps & deferred shadowing
  - HDR rendering & MSAA with LogLuv buffers (aka nao32 ☺)

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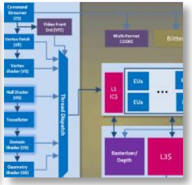
- Intel R&D – Tech Lead in Advanced Rendering Technology team (2008 – present)
  - Shadow map filtering & partitioning schemes
  - OIT, anti-aliasing, volumetric shadows
  - Stochastic rasterization & shader caches
  - New graphics architectures





Talk Outline

- Introduction and Problem Statement
- Pixel Synchronization
- Applications & Demos
- Performance Tips & Tricks
- Summary
- Q&A

Problem Statement

- Programmable shaders had (and continue to have) huge impact
  - Spurred the development of countless new rendering techniques

*3D pipeline stages post pixel/fragment shading

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- Pipeline back-end* still not programmable
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  - ..but very fast and power efficient

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- Pipeline back-end* still not programmable
  - Can only order color, z & stencil operations from a fixed menu..
  - ..but very fast and power efficient
- Add new programmable back-end?
  - Let it coexist side by side with fixed function HW to leverage respective strengths

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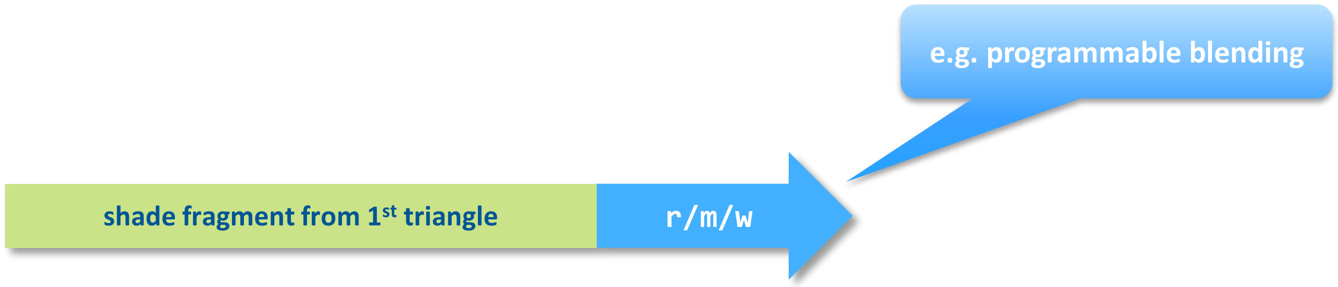

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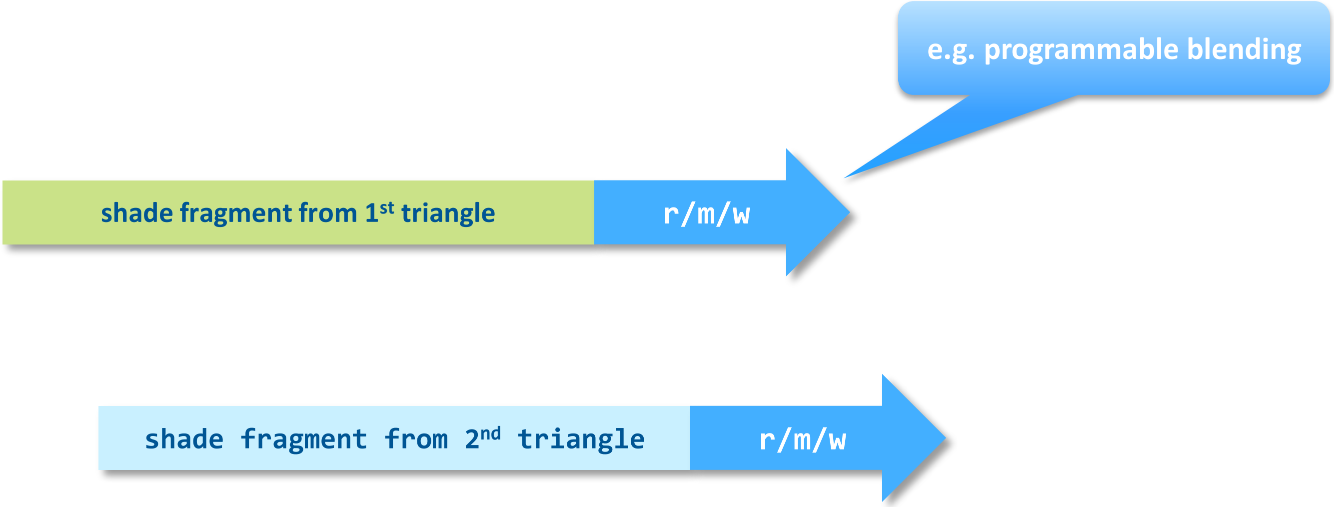

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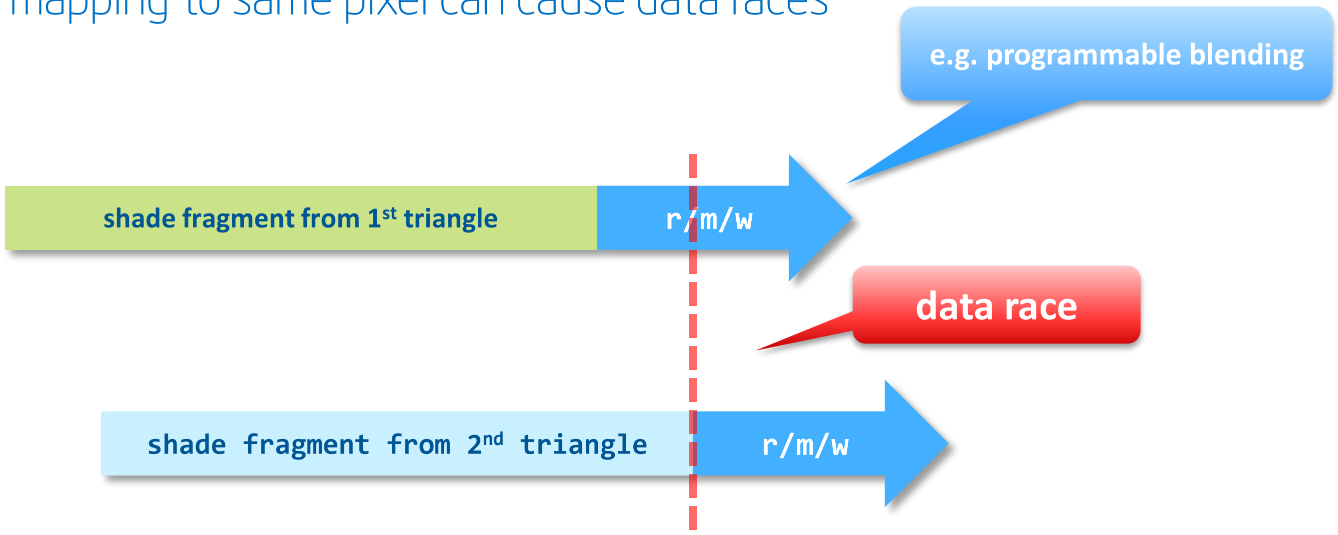

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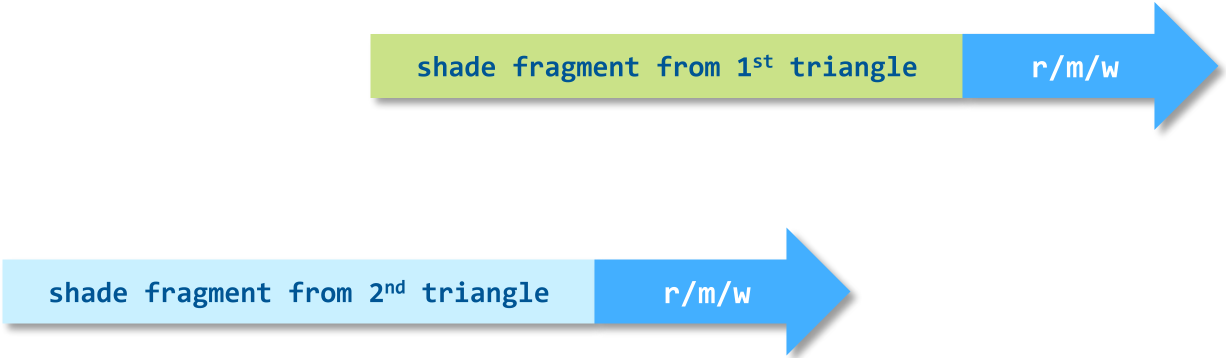

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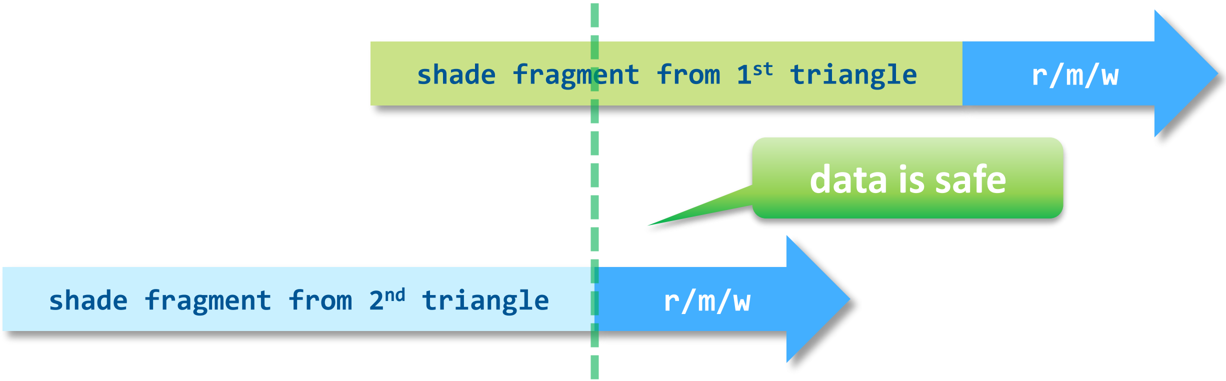

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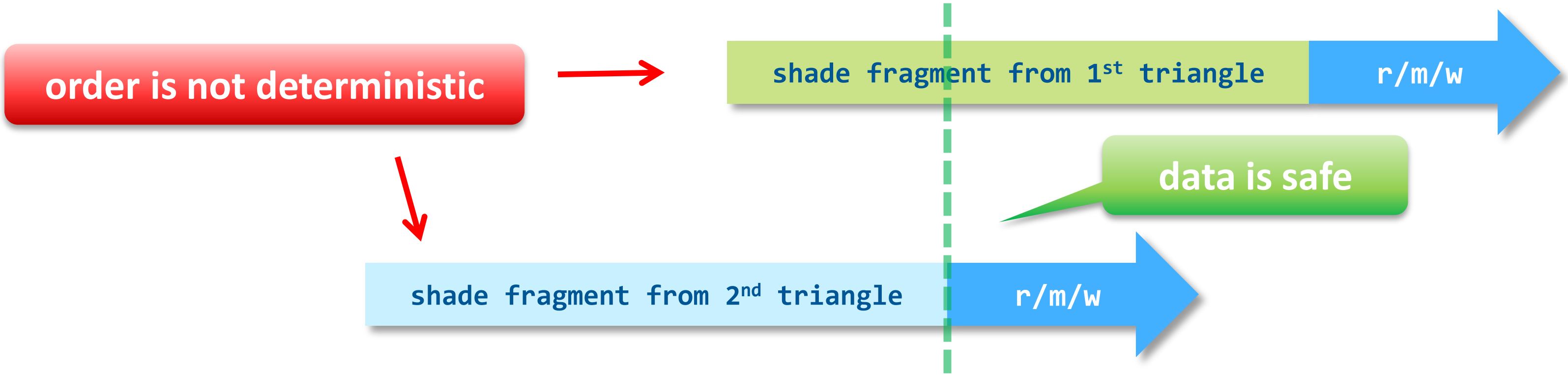
  - Fragments can be shaded out-of-order, can't support order-dependent algorithms



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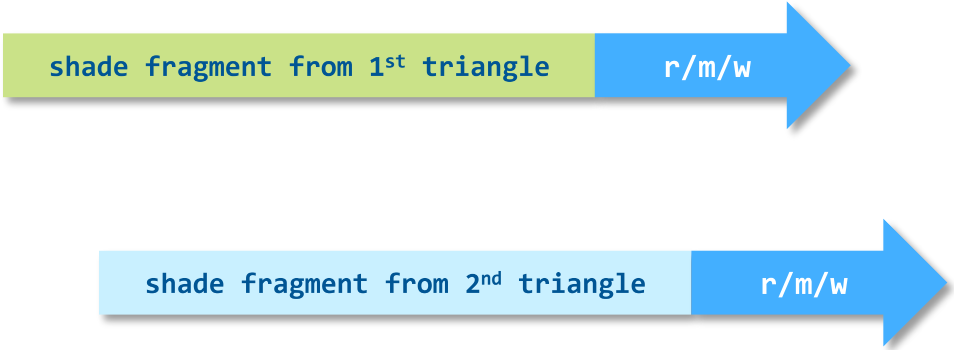

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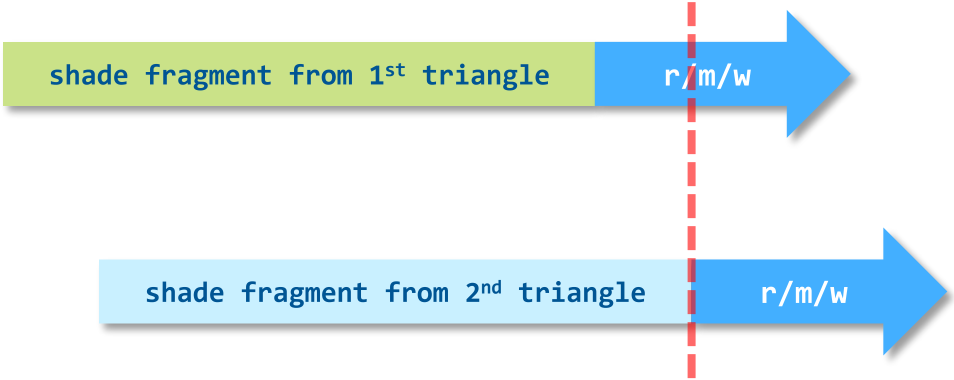

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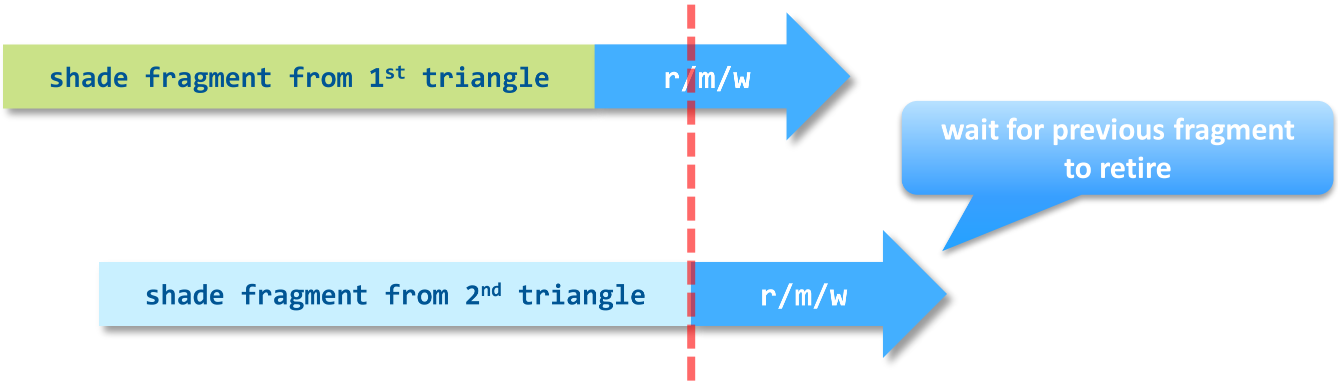

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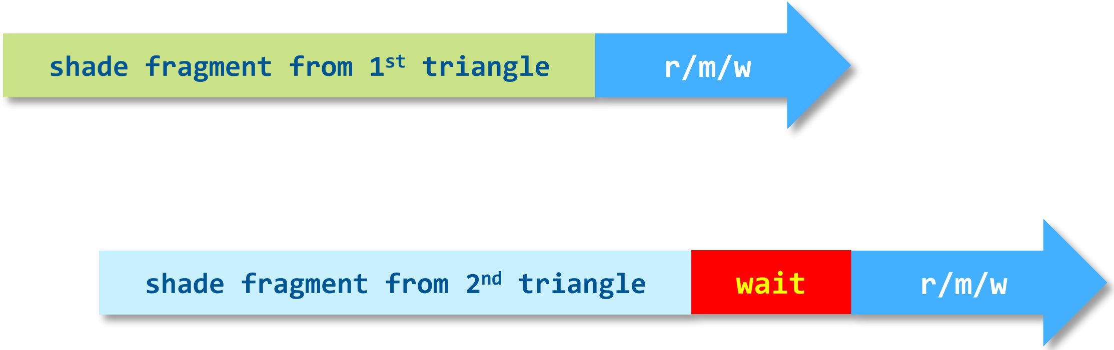

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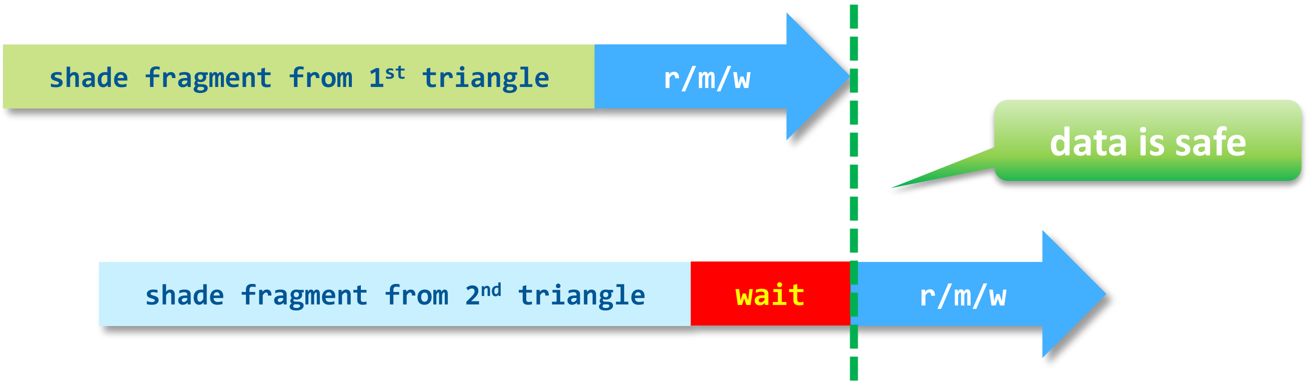

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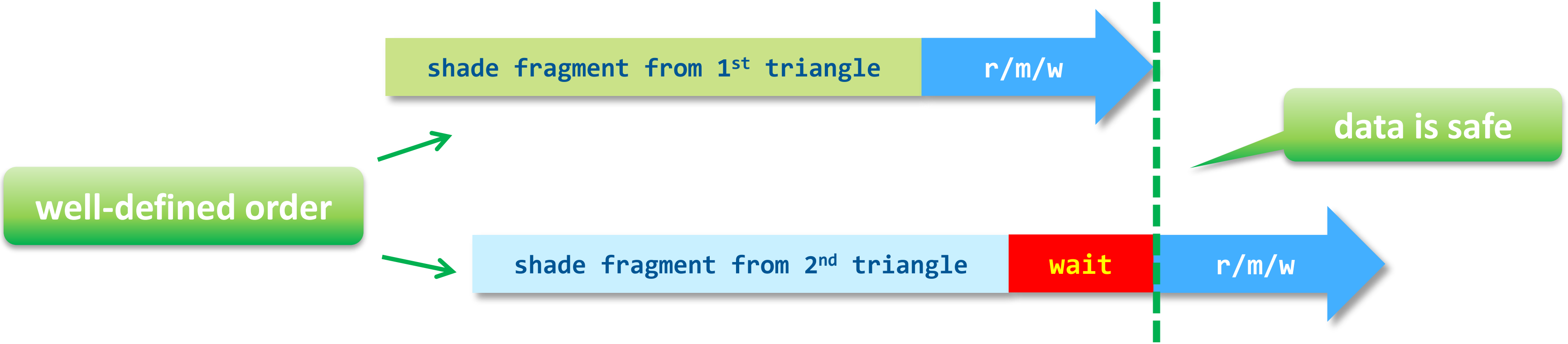
  - Guarantee primitive submission order for R/M/W memory operations



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- Simple extension for pixel/fragment shaders
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- Very good performance
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  - R/W memory accesses are backed by the full SoC cache hierarchy
- More powerful than reading back the frame buffer from a pixel shader
  - Build and access data structures of arbitrary size/type/dimensionality (including voxels ☺)
  - Decoupled from MSAA, can work with per-pixel and/or per-sample data structures

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Alpha-blending in RGB space

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Conversion to RGBE & buffer write

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A Few Programmable Blending Applications

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- Blending for deferred shaders
  - e.g. Apply decals by blending normals and other material attributes

*Bavoil et al. *"Multi-fragment effects on the GPU using the *k*-buffer".* Proceedings of the 2007 symposium on Interactive 3D graphics and games

K-Buffer

- Generalization of the Z-Buffer*
  - Render N-layers of the image in a single pass

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- Countless applications:
  - Depth-peeling
  - Constructive solid geometry
  - Depth-of-field & motion blur
  - Volume rendering
  - …
  - <insert your idea here ☺>

K-Buffer: Single-Pass Depth Peeling

Compute fragment color, z, etc..

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void PSMain(...)
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    Fragment frag = {...};
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Bubble sort (1 pass)

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       if (frag.Z < fragArray[i].Z) {
            Fragment temp = frag;
            frag          = fragArray[i];
            fragArray[i]  = temp;
        }
    }
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  - Requires unbounded memory (per-pixel lists)
  - Not so great performance due to global atomics, fragments sorting, etc.
- Pixel Synchronization enables new methods
  - Single geometry pass and fixed memory requirements
  - Stable and predictable performance
  - Scalable: easily trade-off image quality for performance/memory

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- Step 3: Use more layers to trade-off image quality for perf/memory

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Deep Shadow Maps

- DSMs encode per-pixel visibility function from light point-of-view
  - Typically used to render volumetric shadows
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- Pixel synchronization enables first fixed memory implementation of AVSM
  - Demo ☺

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- Use pixel synchronization to build 3D data structures at voxelization time
  - Problem: fragment dependencies cannot be tracked over multiple 2D planes
- Easy fix: voxelize onto one 2D plane at time
  - 3 draw calls per mesh, one per 2D plane (i.e. reject triangles that map to other planes)
  - Number of generated voxels doesn't change & more flexible than using global atomics

Advanced Anti-Aliasing

- Use pixel synchronization to improve or replace multi-sampling anti-aliasing
  - Higher image quality vs. lower memory requirements vs. better performance

*Jouppi et al. *"Z³: an economical hardware technique for high-quality antialiasing and transparency"*. Proceedings of the ACM SIGGRAPH/EUROGRAPHICS workshop on Graphics hardware

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    - Store N fragment per pixel (z, $\partial z/\partial x$, $\partial z/\partial y$, color, coverage)
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- Analytic methods
  - Render scene using conservative rasterization
  - Build per-pixel spatial subdivision structure using primitive edges (per-pixel BSP? ☺)
  - Compute fragment weights from fraction of pixel area covered by leaf cells and resolve

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- Prefer inserting the synchronization point in the second half of the shader
  - Increase likelihood of concurrently shading fragments that map to the same pixel
  - Corollary: use HW z-test when possible for better performance (Hi-Z is fast!)

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- DX11+ extension available now (download demos), OpenGL extension in development.

Q&A

- Acknowledgements
  - The ART team
  - Tom Piazza, Chuck Lingle, Tomasz Janczak , Prasoon Surti, Mike Dwyer, Andy Dayton, Mike Apodaca, Aaron Lefohn, Larry Seiler, Leigh Davies, Filip Strugar, Matthew Fife, Steve Hughes, Axel Mamode, Richard Huddy and many others

- Source code
  - Programmable Blending: bit.ly/pixelsync_pb
  - Order-Independent Transparency: bit.ly/pixelsync_oit
  - Adaptive Volumetric Shadow Maps: bit.ly/pixelsync_avsm

- Contacts
  - e-mail: marco.salvi@intel.com
  - twitter: @marcosalvi