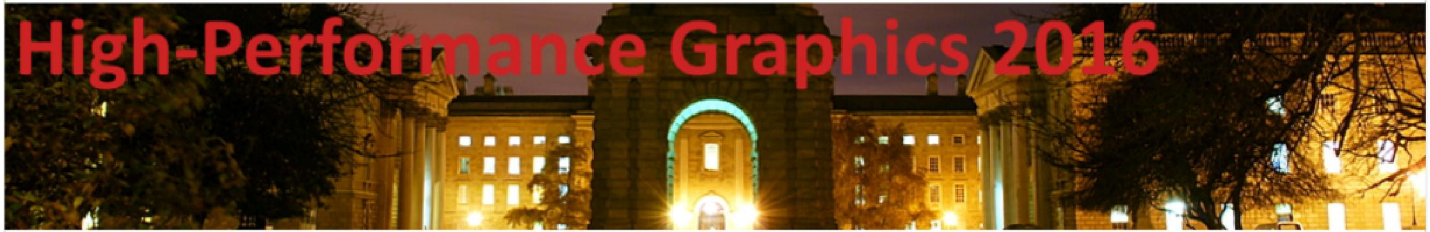


Masked Software Occlusion Culling

Jon Hasselgren
Magnus Andersson
Tomas Akenine-Möller

intel

Background

- **Potentially Visible Sets**
  - Precomputed – very efficient
  - Scene (occluders) must be static
  - Difficult to handle general scenes

Quake 2

Half-Life 2

Background

- **Dynamic occlusion culling increasingly popular**
  - Modern games have more complex and dynamic worlds
  - Simpler content pipeline, no complex pre-computation

Battlefield 4

Assasin's Creed Unity

Dynamic Occlusion Culling

- **Hardware occlusion queries**
  - GPU is extremely efficient at rasterization
  - Long pipeline delay, takes long to get the result of a query
  - May require sending result back to CPU
- **Software occlusion culling**
  - Short delay, no readback → easier to integrate with scene traversal
  - Software rasterization not as efficient as GPU

Hierarchical Z Buffer (HiZ) [Greene93]

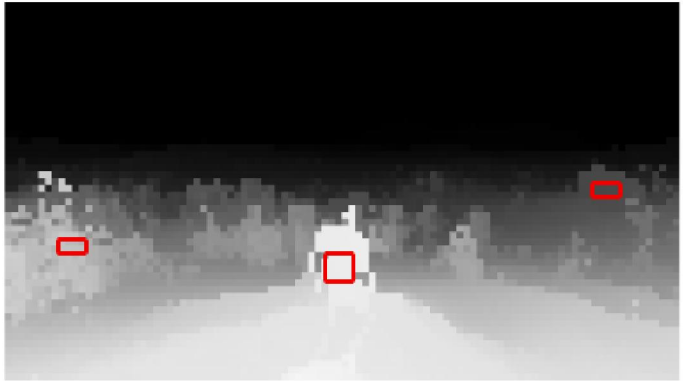
- Rasterize occluders to full resolution z buffer

Hierarchical Z Buffer (HiZ) [Greene93]

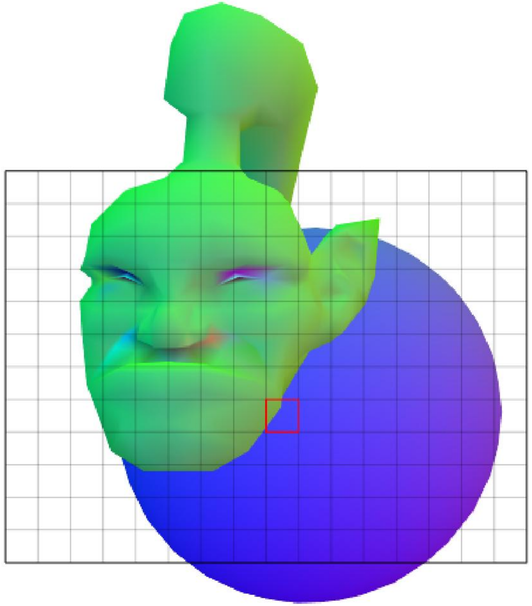
- Rasterize occluders to full resolution z buffer
- Create hierarchical z buffer
  - Find the maximum z in each 8x8 tile

Hierarchical Z Buffer (HiZ) [Greene93]

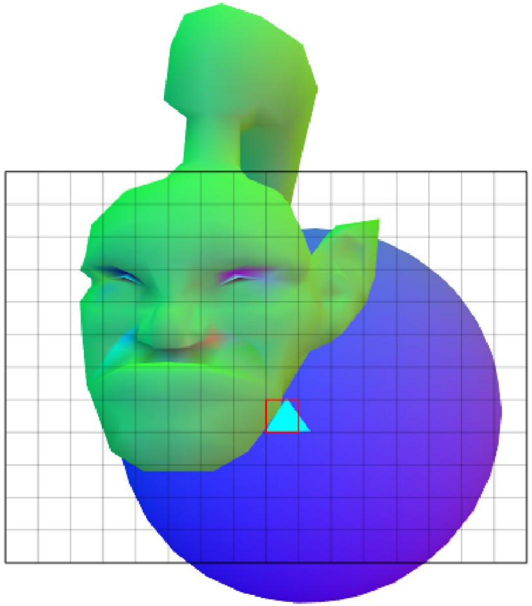
- Rasterize occluders to full resolution z buffer
- Create hierarchical z buffer
  - Find the maximum z in each 8x8 tile
- Perform occlusion queries with hierarchical z buffer

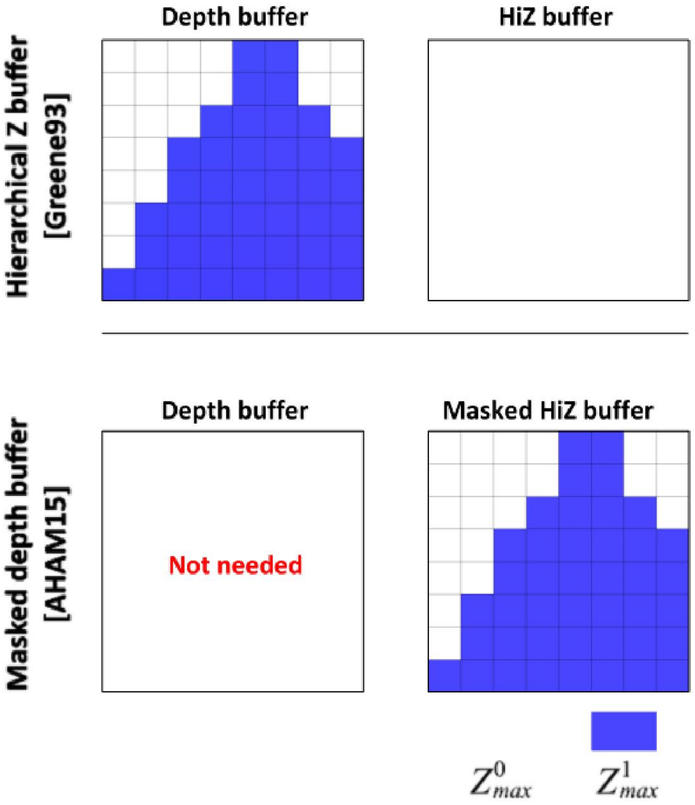


Masked Depth Culling [AHAM15]

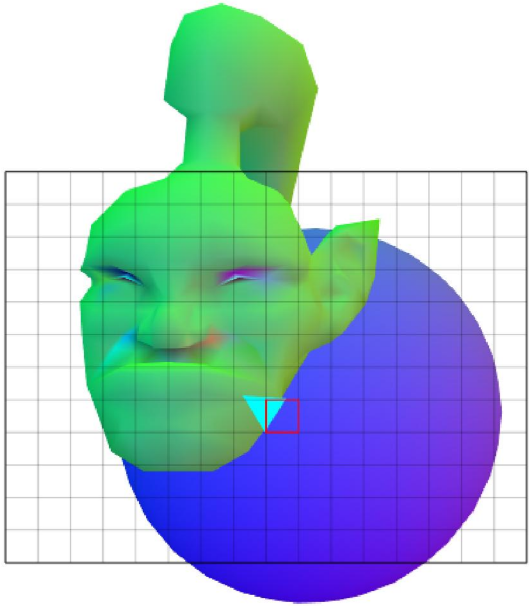


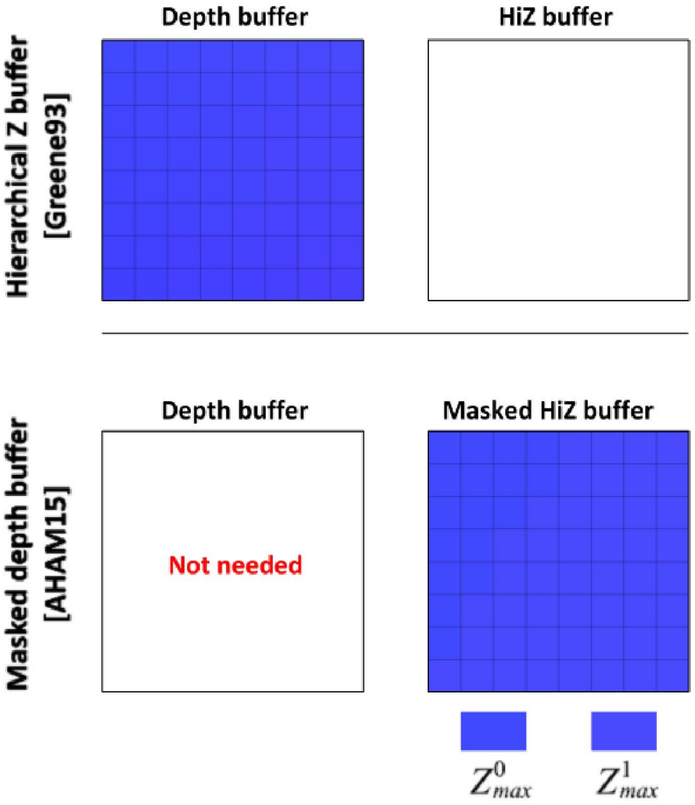
Masked Depth Culling [AHAM15]



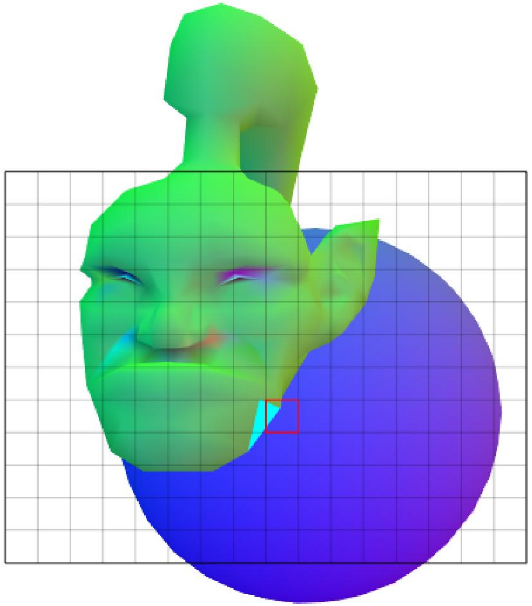


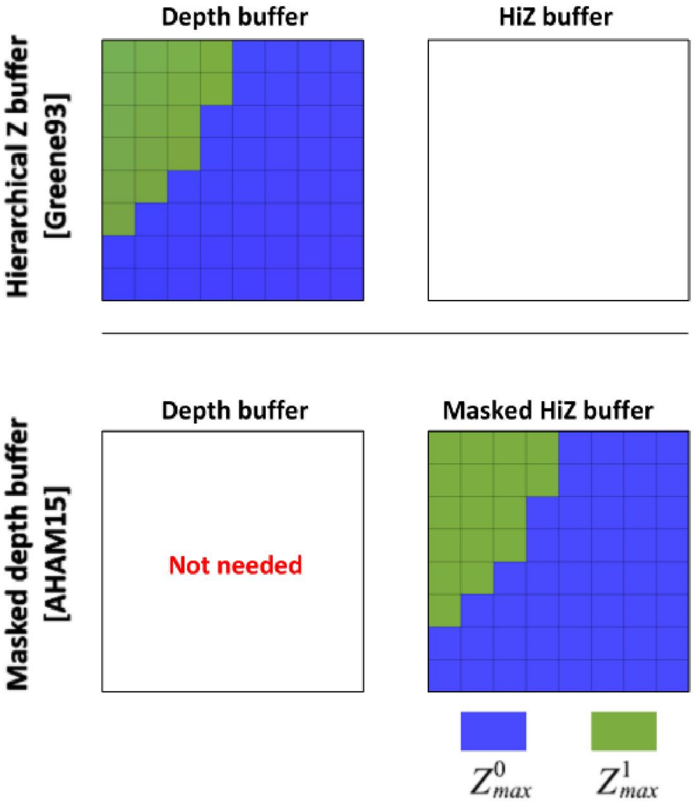
Masked Depth Culling [AHAM15]





Masked Depth Culling [AHAM15]





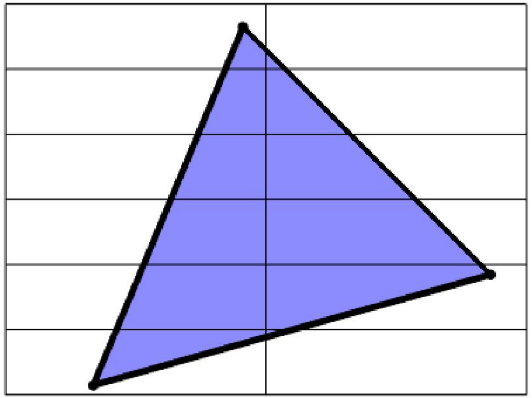
Masked Software Occlusion Culling

- Masked Depth Culling [AHAM15]
  - Was originally intended for graphics hardware
  - Directly update hierarchical z buffer without computing full res z buffer
  - Decouples coverage sampling (rasterization) and depth computation
- Could it be really fast for software?
  - Much less memory to read/write than full resolution z buffer
  - Updates use bitmasks, can process 256 pixels in parallel using AVX

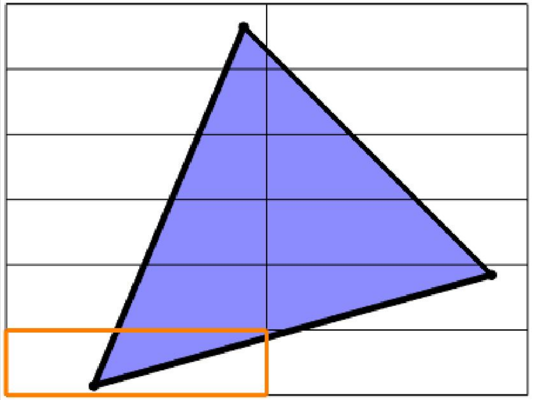
Algorithm

Compute Bounding Box

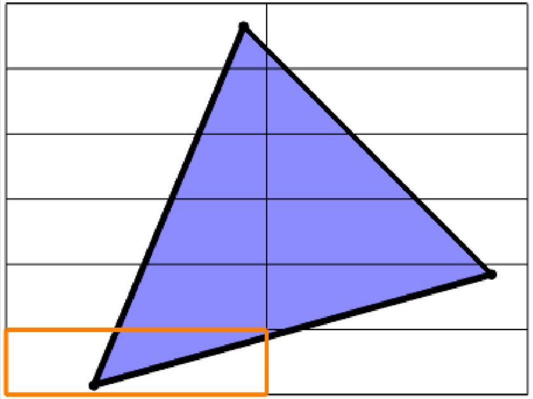
- Padded to 32x8 pixel supertiles

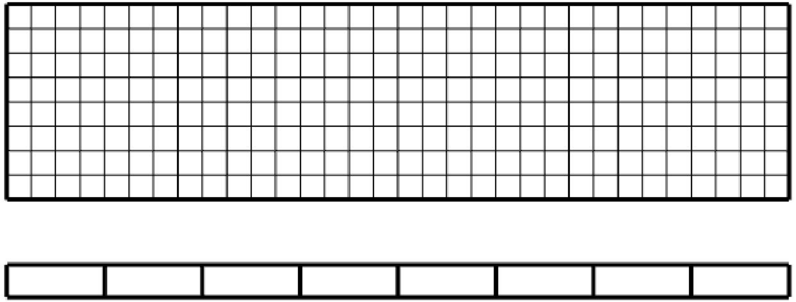


Traverse Supertiles



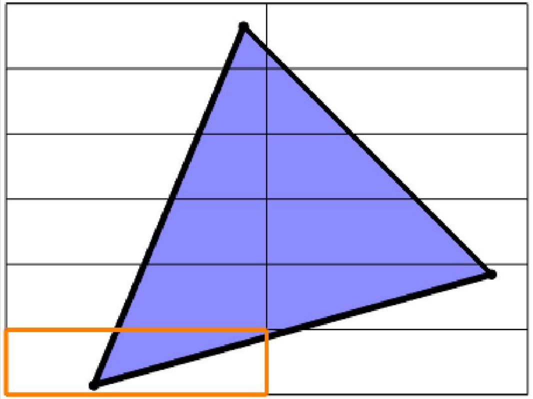
Traverse Supertiles

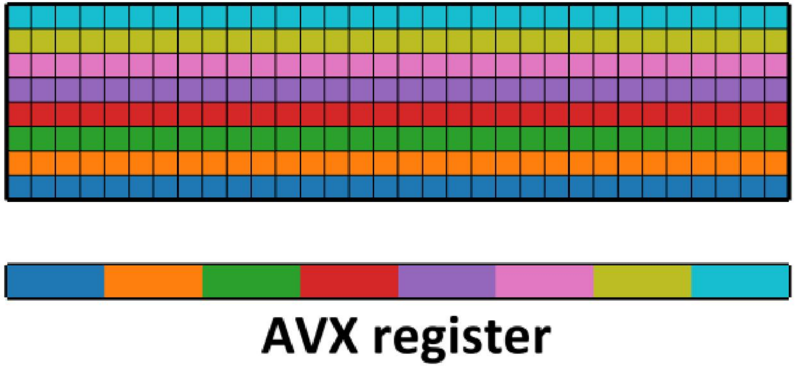




AVX Register Layout

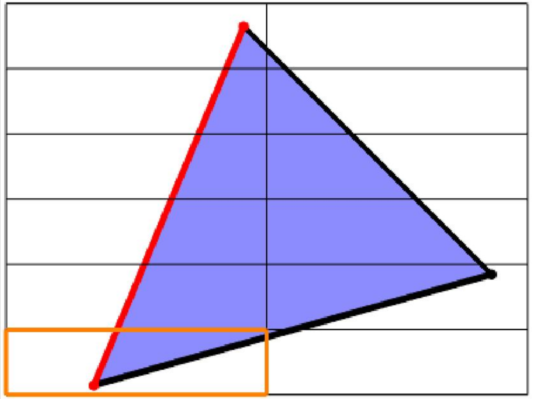
- One Scanline per SIMD-lane

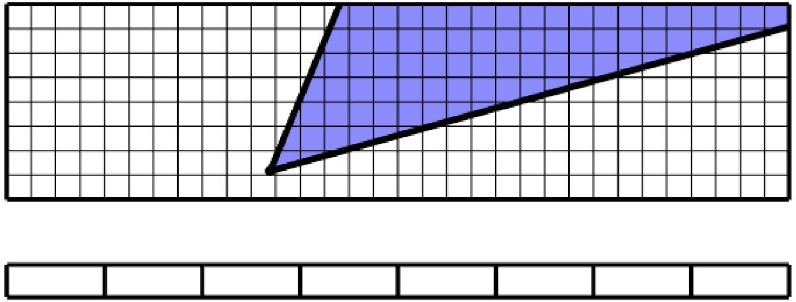




Edge Slopes

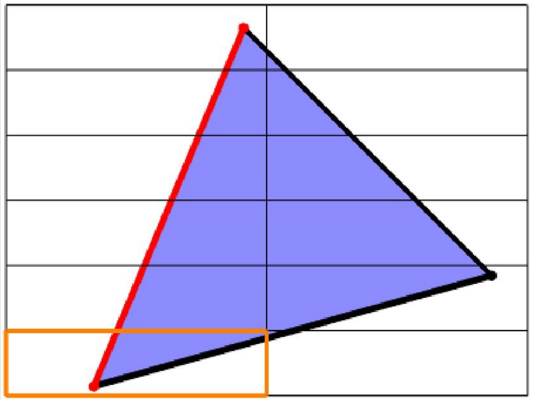
- **Compute slopes (Δy/Δx) during triangle setup**
  - Similar to regular scanline rasterizers
  - Some precision caveats due to tile size

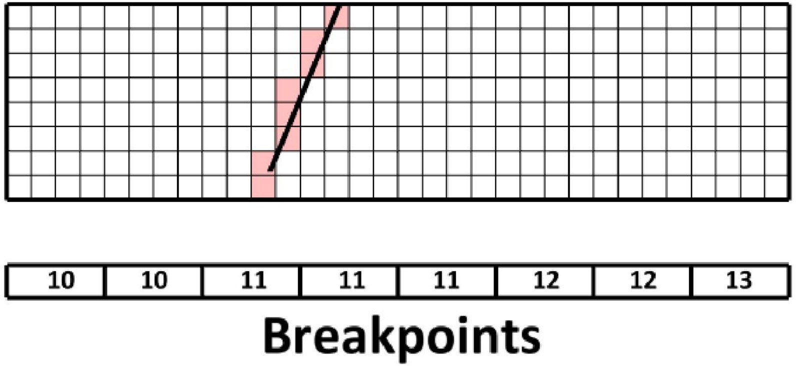




Compute Break Points

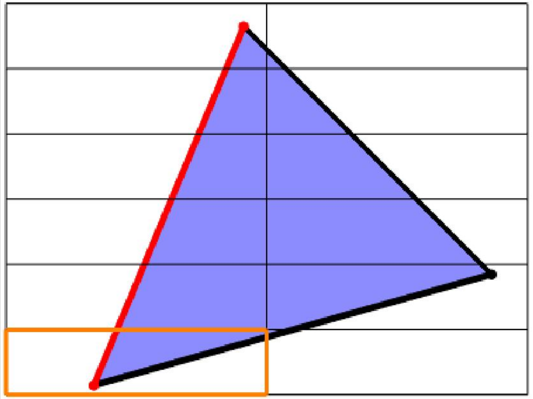
- **Compute break point for each scanline**
  - Eight scanlines in parallel using AVX



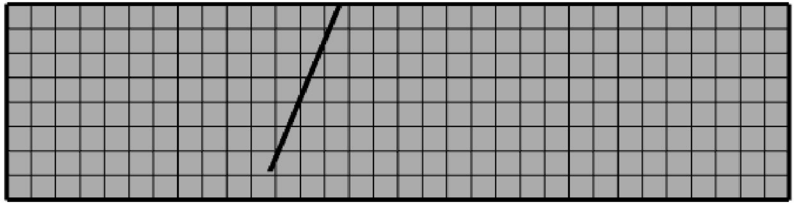


Compute Coverage Mask

- **Start with full coverage mask**



Coverage mask

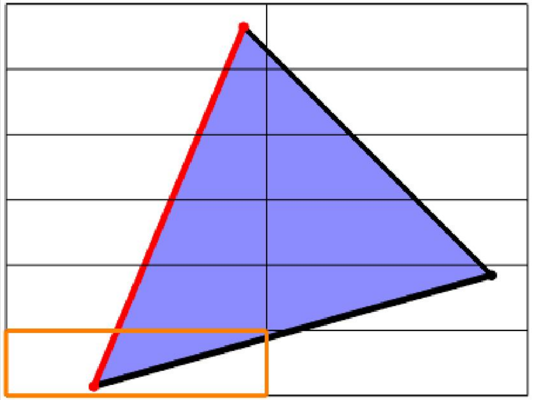


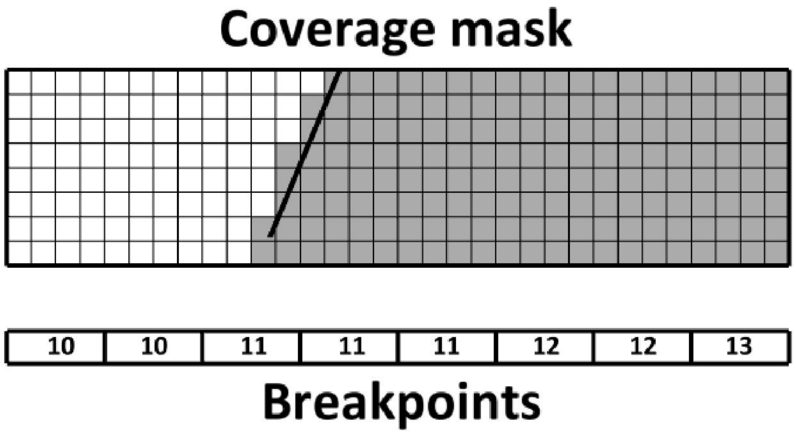
10	10	11	11	11	12	12	13

Breakpoints

Compute Coverage Mask

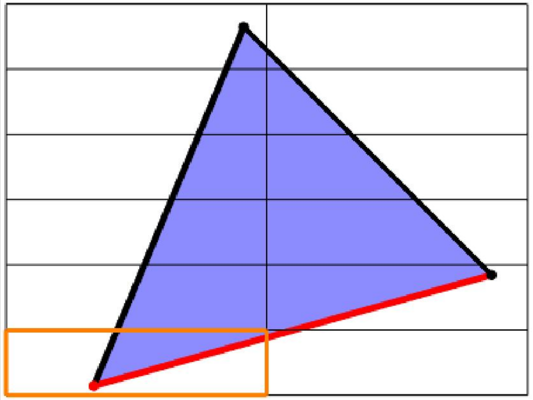
- **Start with full coverage mask**
  - Shift each lane (scan line) to break point
  - AVX2 and later support per-lane shift

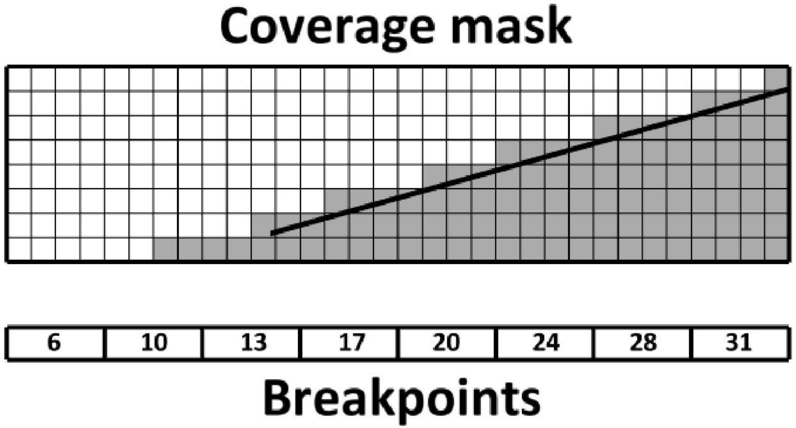




Repeat for Next Edge

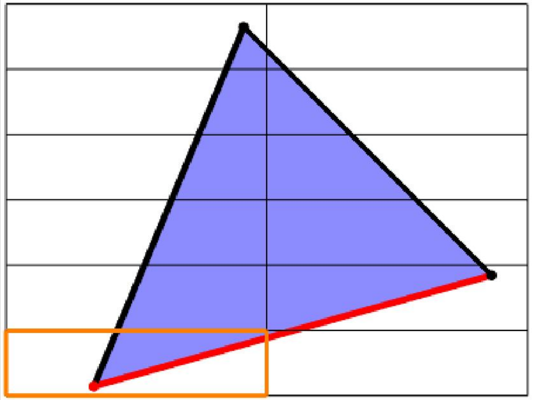
- Repeat the same process for next edge



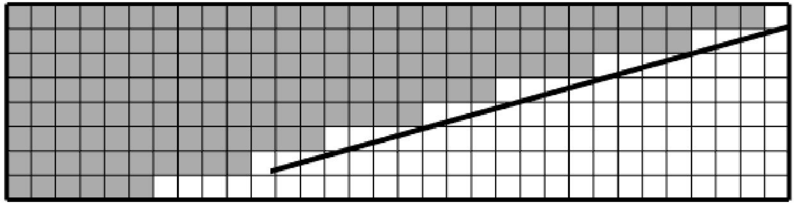


Repeat for Next Edge

- **Repeat the same process for next edge**
  - Edge is facing right → invert mask



Coverage mask

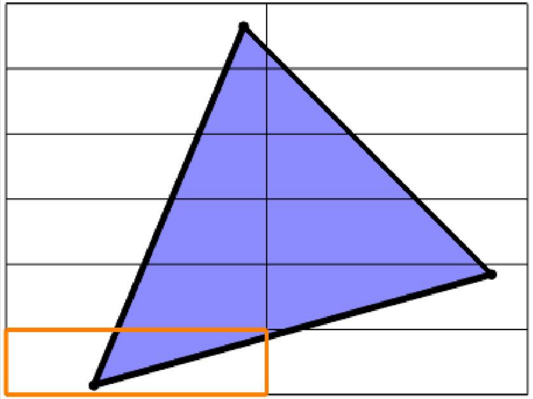


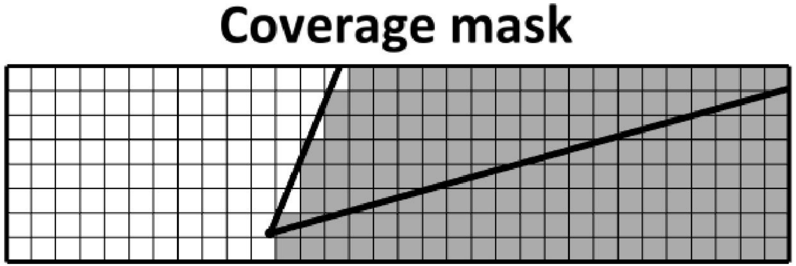
6	10	13	17	20	24	28	31

Breakpoints

Combine Masks

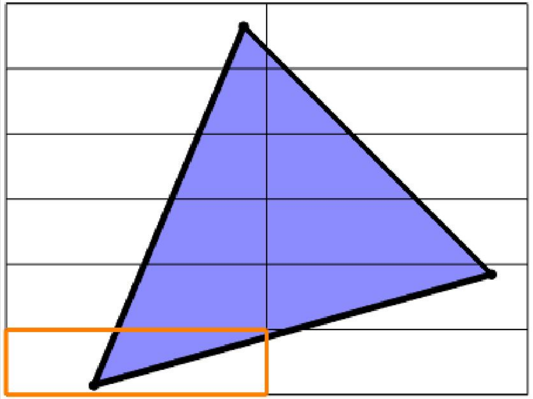
- Combine mask of all overlapping edges

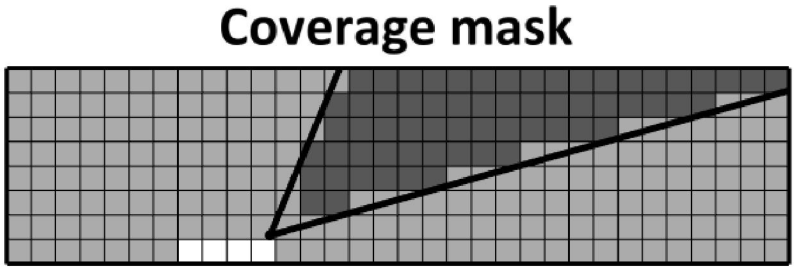




Combine Masks

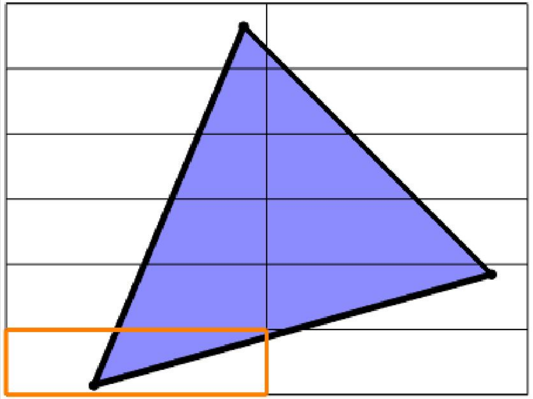
- Combine mask of all overlapping edges
  - Using bitwise AND

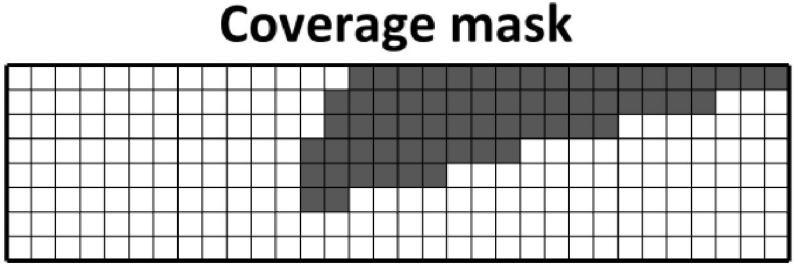




Resulting Coverage Mask

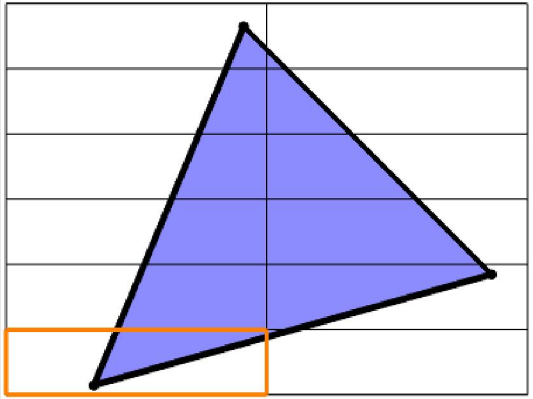
- Combine mask of all overlapping edges
  - Using bitwise AND

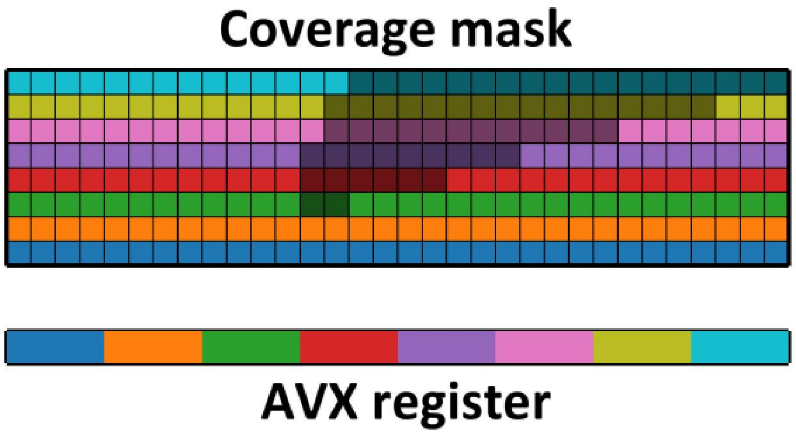




Shuffle mask

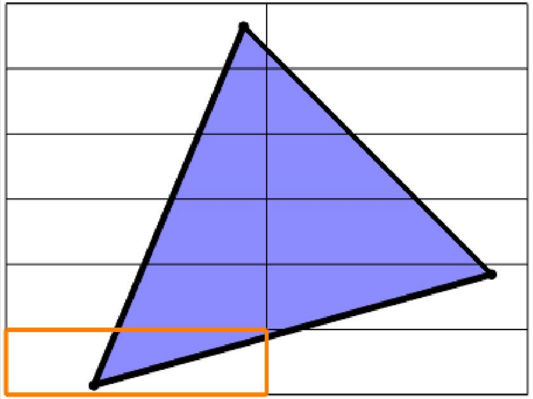
- **Shuffle mask to form better shaped tiles**
  - Before: each SIMD-lane is a scanline

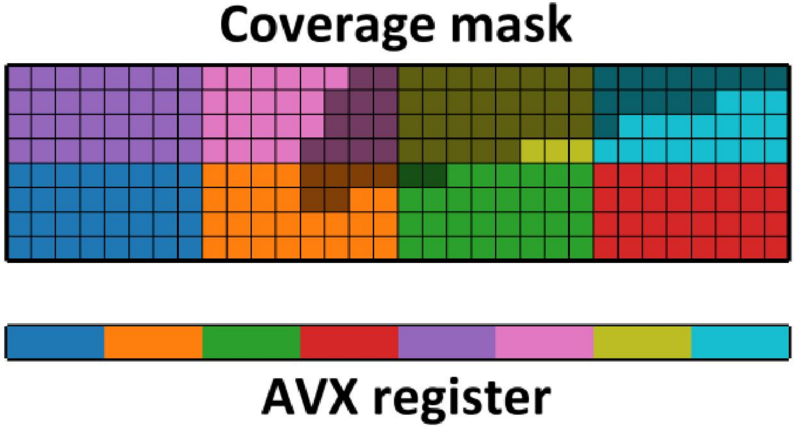




Shuffle mask

- **Shuffle mask to form better shaped tiles**
  - Before: each SIMD-lane is a scanline
  - After: each SIMD-lane is a 8x4 tile

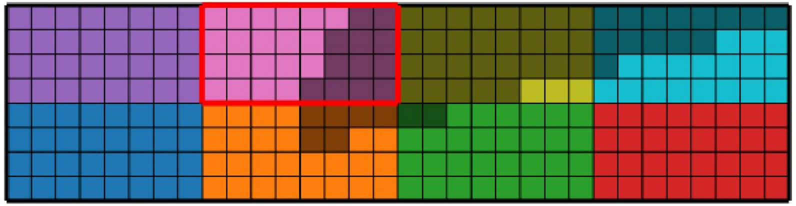


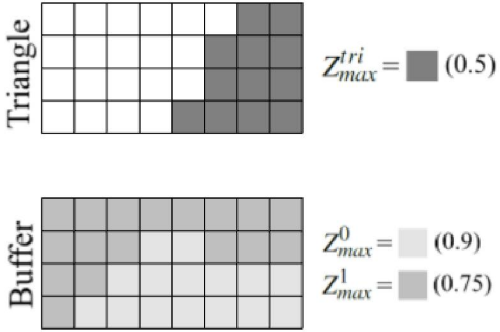


Masked Depth Buffer Update

- **Masked z update similar to previous work [AHAM15]**
  - Optimized for AVX and software implementation
  - Less accurate than original, more dependent on render order
  - Easier to control render order than for HW culling

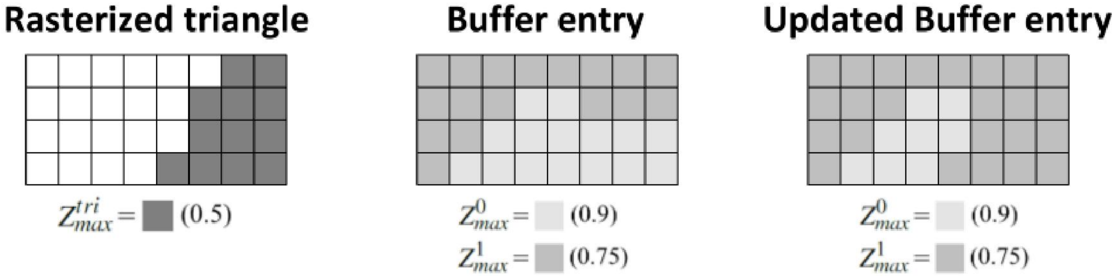
- **Input for an 8x4 tile**
  - Tri: Coverage mask (32b) + Zmax value (32b float)
  - Buffer: Selection mask (32b) + 2 Zmax values (2x32b float)





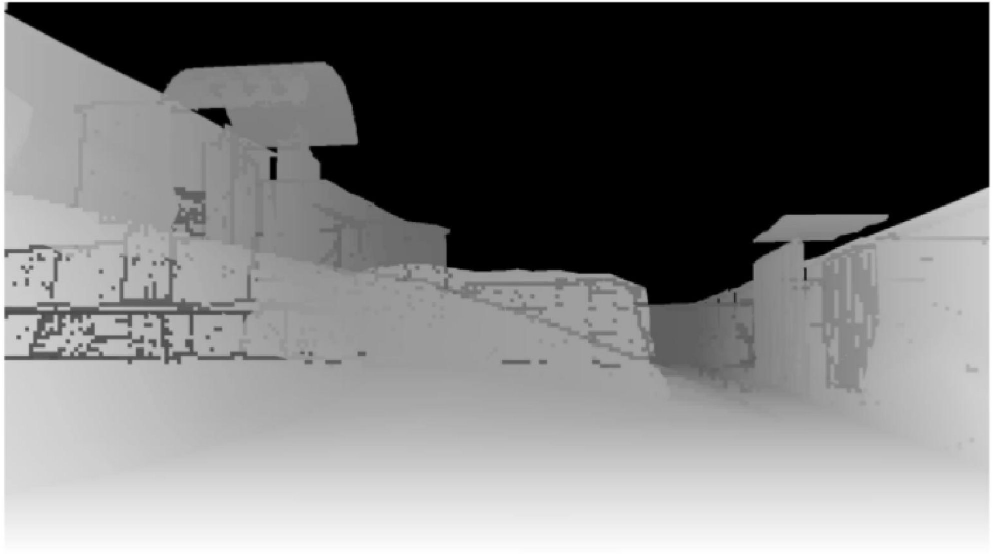
Masked Depth Buffer Update

- Z^1_{max} is the working layer
  - Updated as: $\max\left(Z^1_{max}, Z^{tri}_{max}\right)$
  - Mask is updated using bitwise or
- Z^0_{max} is the reference layer
  - Whenever working layer mask is full, overwrite reference layer
  - Clear working layer



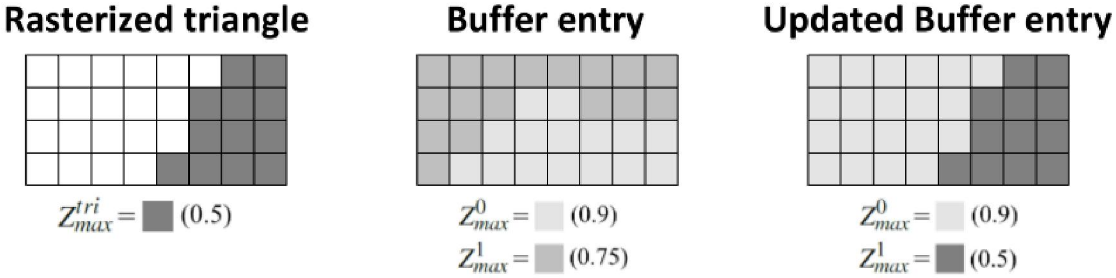
Update Heuristic Results

- **Silhouettes can leak through geometry**
  - Reason: partial working layer contaminates foreground layer, which would otherwise completely overwrite the tile

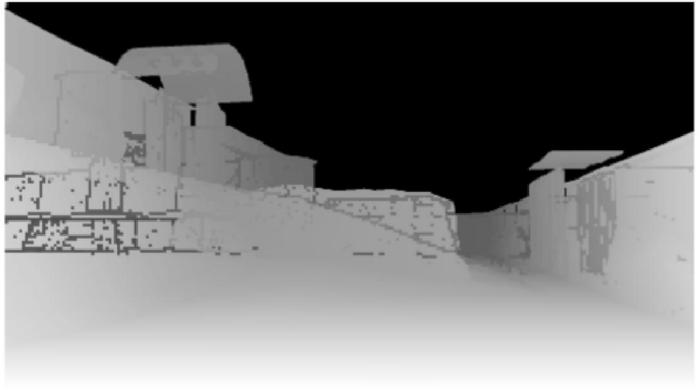


Revised Update

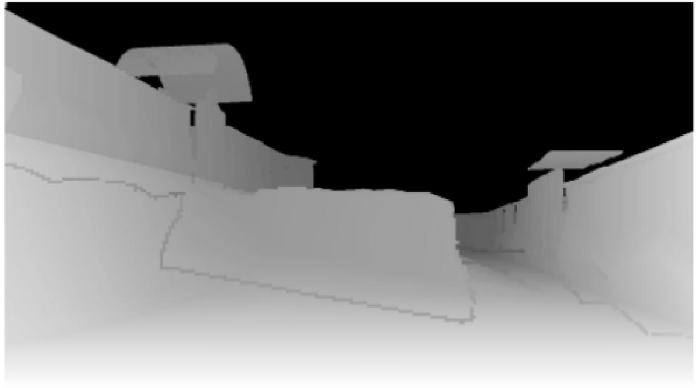
- **Discard working layer if drawing a new object**
  - Throw away partial data avoid contaminating layers in front
  - How to know if we begin drawing a new object?
- **Discard heuristic**
  - If Z^1_{max}-Z^{tri}_{max} > Z^0_{max}-Z^1_{max} , discard working layer
  - Avoids fixed threshold value



Update Heuristic Results



No discard

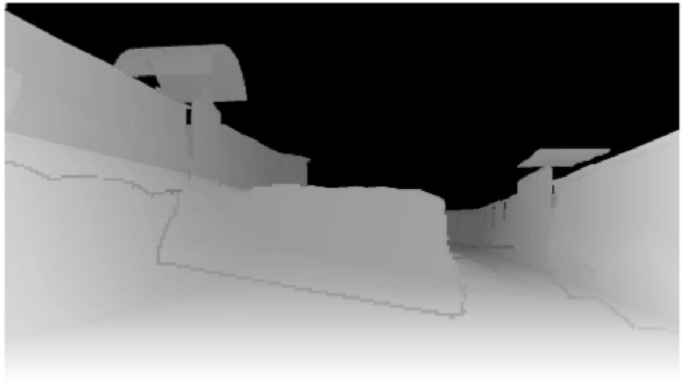


Discard heuristic

Results

Results
Intel Occlusion Culling Sample

- Integrated in Intel occlusion culling sample
  - Uses low-poly occluder meshes
  - Two pass occlusion culling (rasterize occluders, perform queries)
  - Contains an AVX2 optimized version of the HiZ algorithm
  - Integrated our algorithm making minimal changes



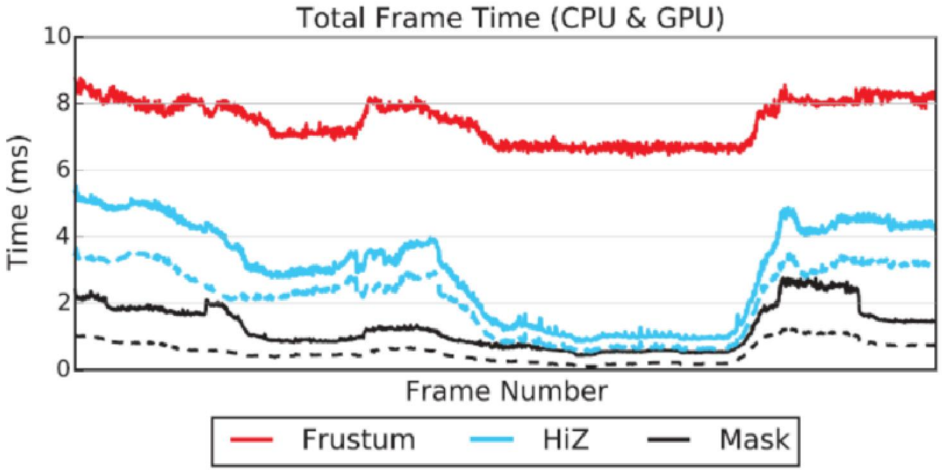
Results
Intel Occlusion Culling Sample

- **Algorithm timing breakdown**
  - Clear: Clearing the depth buffer
  - Geom: Transform & project geometry
  - Rast: Triangle setup & occluder rasterization
  - Gen: Compute hierarchical z buffer from full resolution z buffer
  - Test: Perform occlusion queries

	Clear	Geom	Rast	Gen	Test	Total
HiZ	377	196	2145	509	278	3505
Mask	23	194	584	0	255	1056
	16x		3.7x			

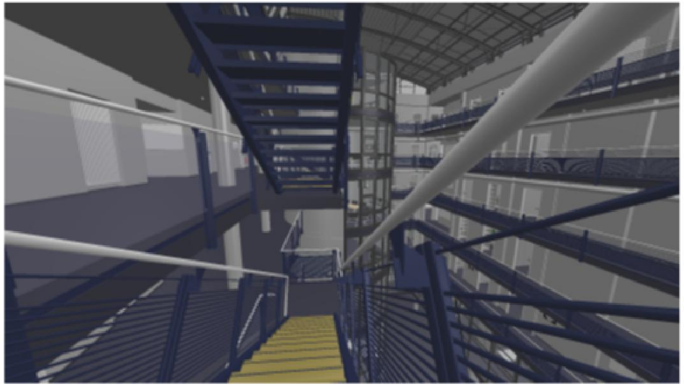
Results
Intel Occlusion Culling Sample

- **Performance comparison for camera animation**

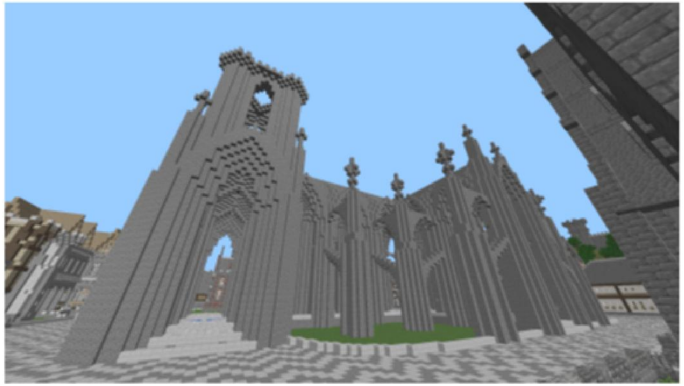


Results
Standalone framework

- Standalone engine tailored for our algorithm
  - One pass: interleaving occluder rasterization and occlusion queries
  - Early exit: don't perform occlusion culling in occluded regions
  - Modified version of the hierarchical z buffer (HiZ) algorithm



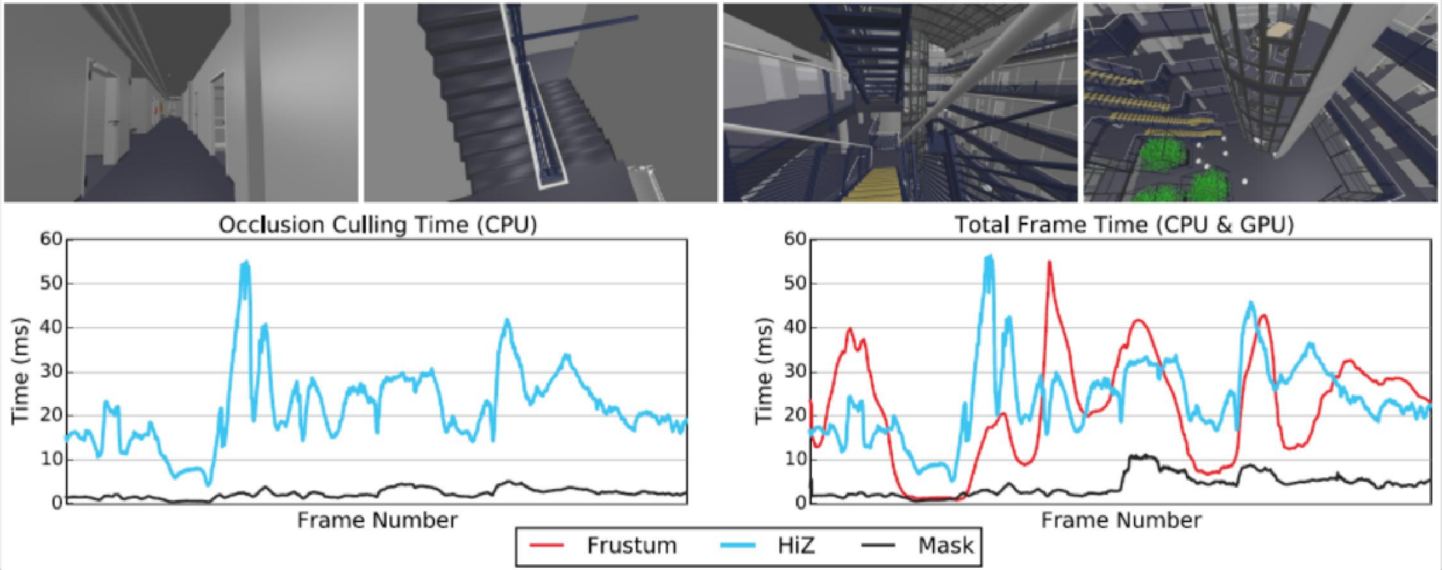
MPI Informatics Building
Mesh: 72 MTris, Occluder: 143 KTris



Rungholt
Mesh: 7 MTris, Occluder: 7 MTris

Results
MPI Informatics Building

- **Performance during camera flythrough**



Rungholt

- Live demo

Conclusion

- **Efficient algorithm for rasterizing occlusion buffers**
  - More than 3x better performance than previous work
  - Can be integrated tightly with traversal algorithm (low latency)
  - Very accurate culls 98% of all triangles culled by hierarchical z buffer
- **Future work**
  - Efficient multi-threading
  - Better update heuristics for masked z buffer
  - GPU implementation

Thank you

- Source code available
  - www.github.com/GameTechDev/MaskedOcclusionCulling
- Questions