

Fast Triangle Reordering for Vertex Locality and Reduced Overdraw



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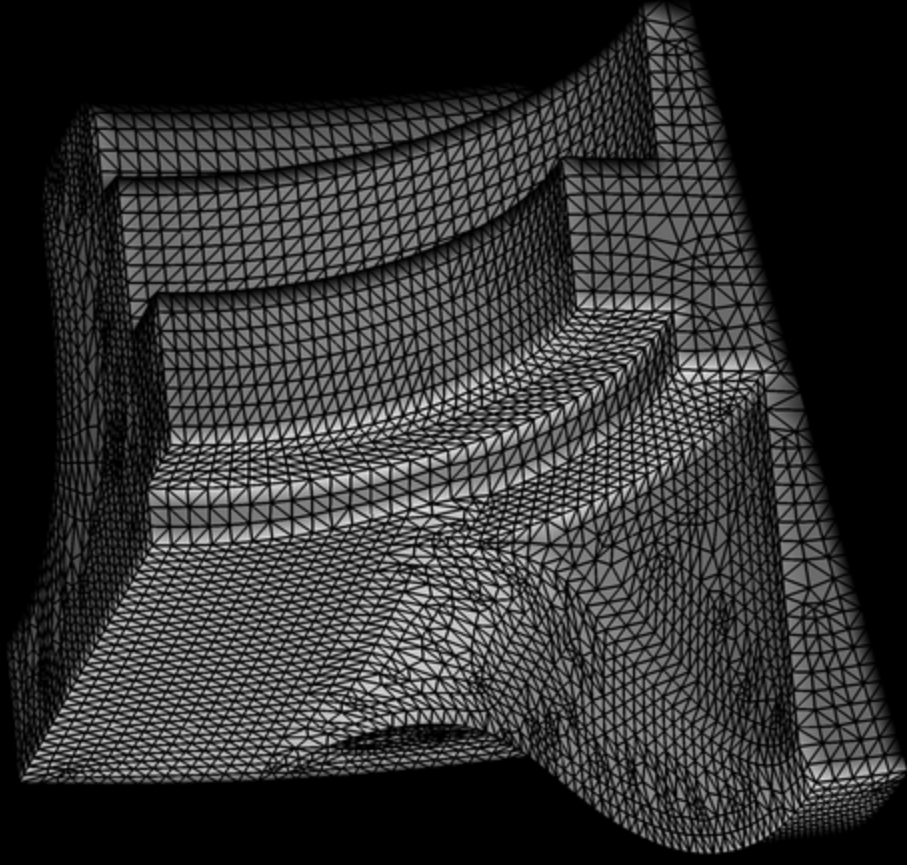


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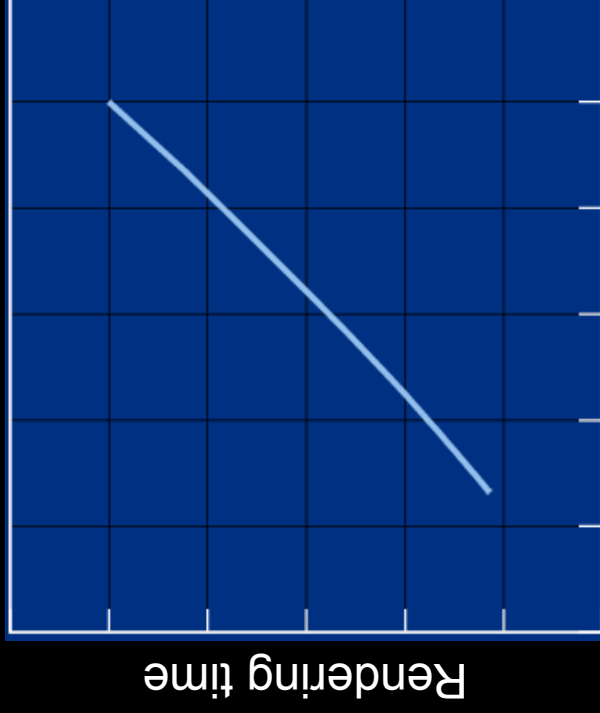
Triangle order optimization



Objective: Reorder triangles to render meshes faster

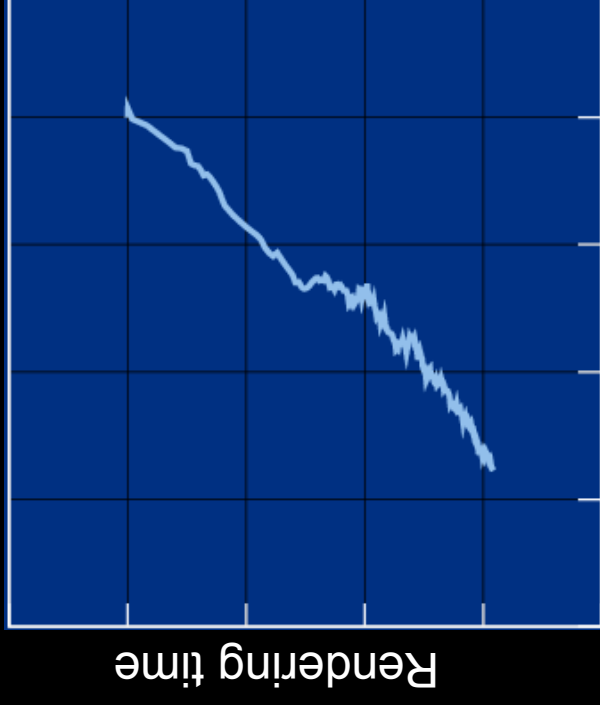
Motivation: Rendering time dependency

Vertex-bound scene



vertices processed

Pixel-bound scene



pixels processed

Reduce!
(transparently)

Goal

- Render faster
 - Two key hardware optimizations
 - Vertex caching (vertex processing)
 - Early-Z culling (pixel processing)
 - Reorder triangles efficiently at run-time
 - No changes in rendering loop
 - Improves rendering speed transparently

Algorithm overview

- Part I: Vertex cache optimization
- Part II: Overdraw minimization

Part I: The Post-Transform Vertex cache

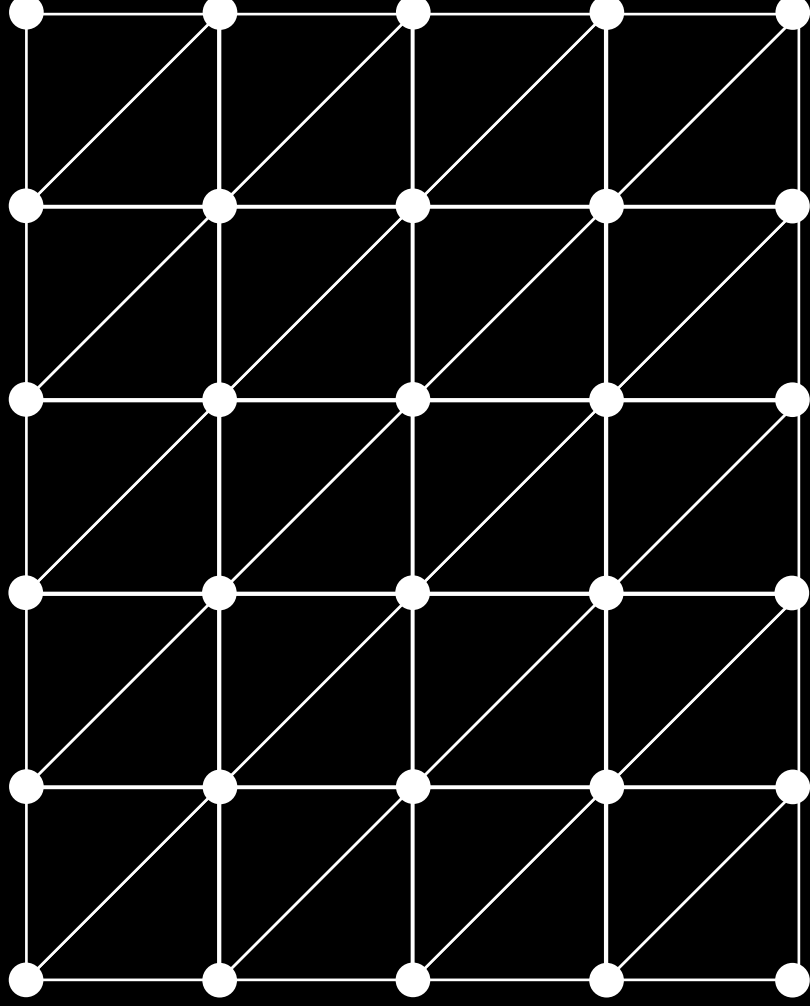
- Transforming vertices can be costly
- Hardware optimization:
 - Cache transformed vertices (FIFO)
- Software strategy:
 - Reorder triangles for vertex locality
- Average Cache Miss Ratio (ACMR)
 - # transformed vertices / # triangles
 - varies within [0.5–3]

ACMR Minimization

- NP-Complete problem
 - GAREY et. al [1976]
- Heuristics reach near-optimal results [0.6–0.7]
 - Hardware cache sizes range within [4–64]
- *Substantial* impact on rendering cost
 - From 3 to 0.6 !
 - Everybody does it

Parallel short strips

Very close to optimal!



~ 0.5 ACMR

Previous work

- Algorithms sensitive to cache size
 - MeshReorder and D3DXMesh [HOPPE 1999]
 - K-Cache-Reorder [LIN and YU 2006]
 - Many others...
 - Recent independent work [CHHUGANI and KUMAR 2007]

Previous work

- Algorithms oblivious to cache size
 - dfsrendseq [BOGOMJAKOV et al. 2001]
 - OpenCCL [YOON and LINDSTROM 2006]
- Based on space filling curves
- Asymptotically optimal
 - Not as good as cache-specific methods
 - Long running time
- Do not help with CAD/CAM

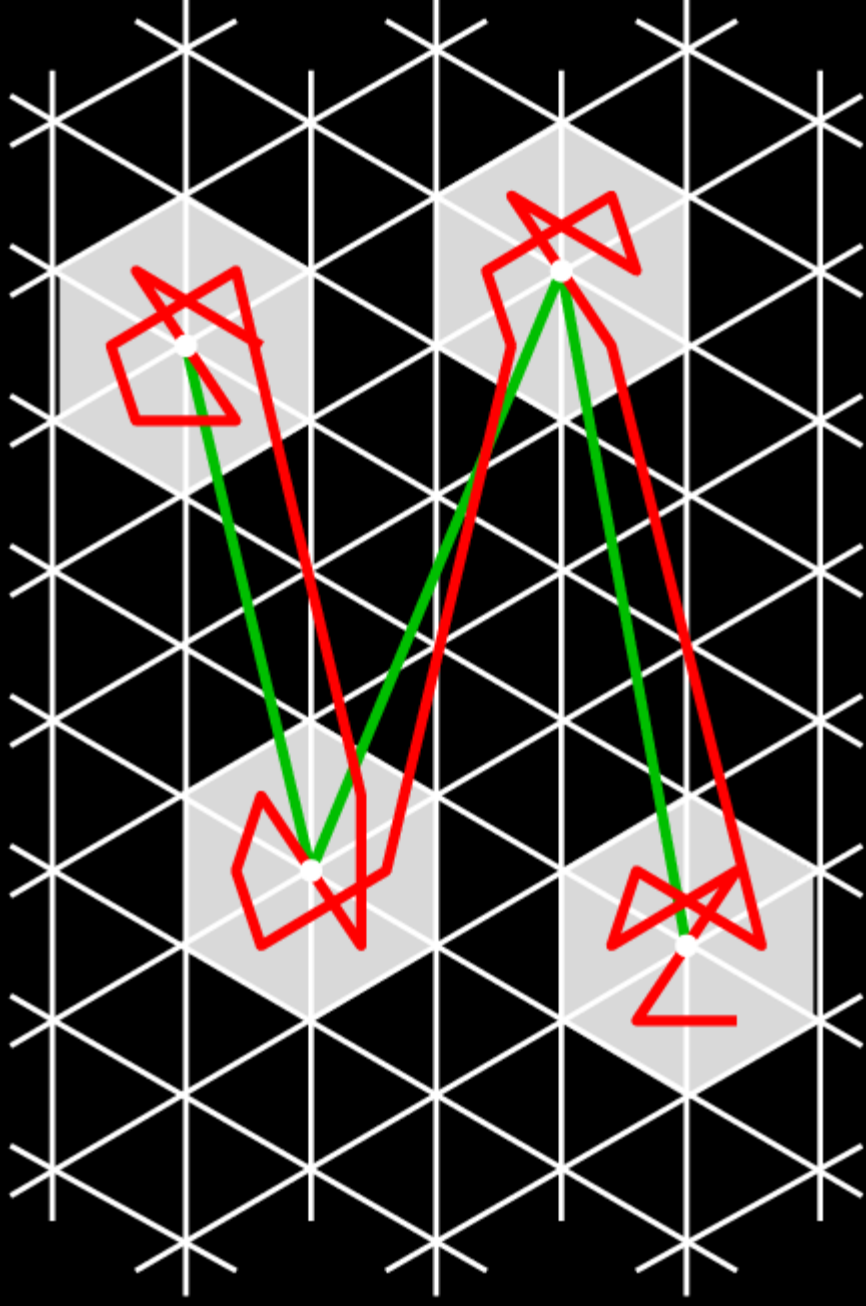
Our objective

- Optimize at run-time
 - We even have access to the *exact* cache size
- Faster than previous methods, i.e., $O(t)$
 - Must *not* depend on cache-size
- Should be easy to integrate
 - Run directly on index buffers
- Should be general
 - Run transparently on non-manifolds

“Triangle-triangle” adjacency unnecessary

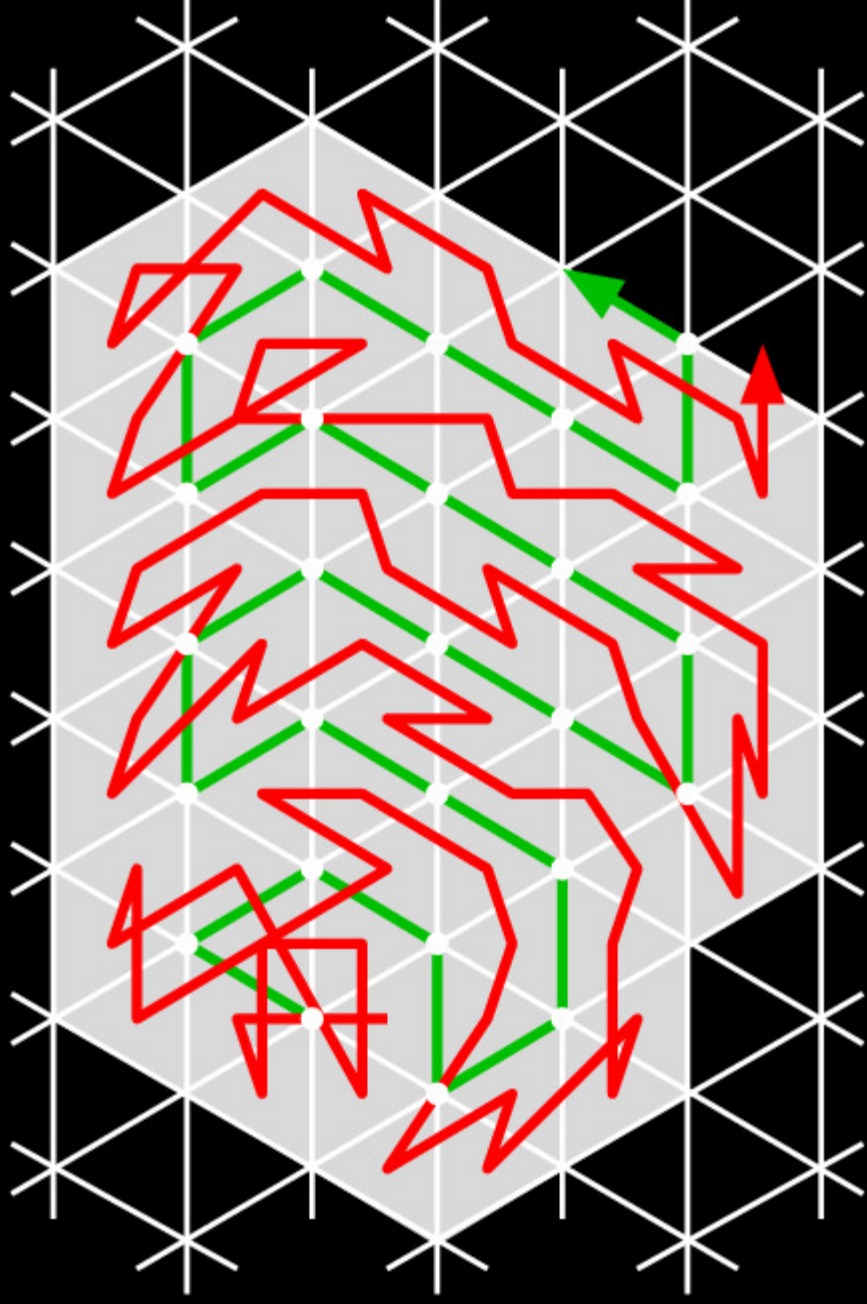
- Awkward to maintain on non-manifolds
- By the time this is computed, we should be *done*
- Use “vertex-triangle” adjacency instead
- Computed with 3 trivial linear passes

Simply output vertex adjacency lists



Tipsy (locally random) fans

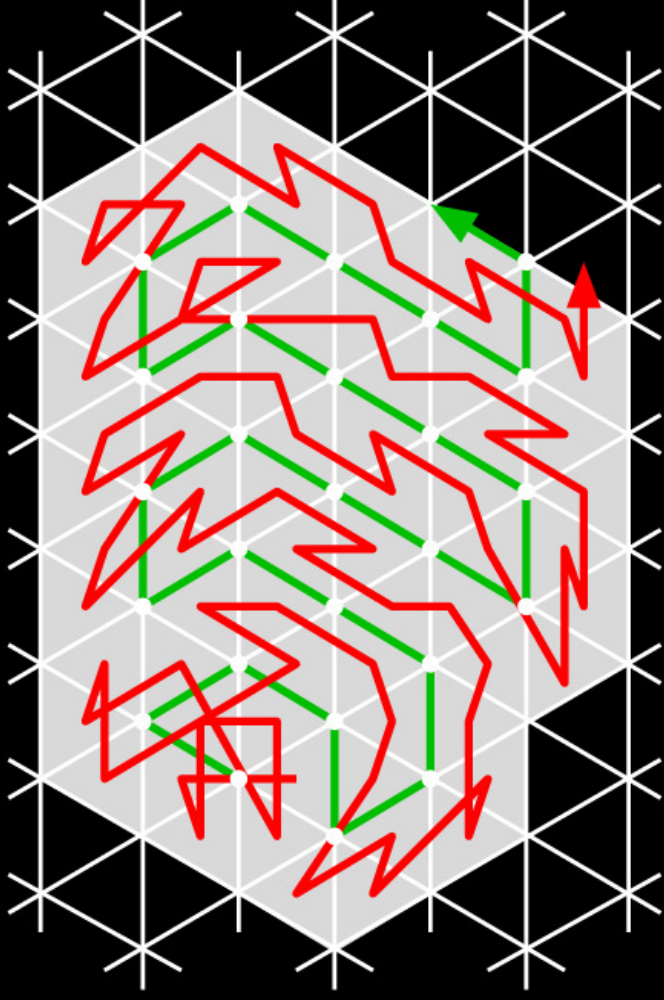
Choosing a better sequence



Tipsy strips

Selecting the next fanning vertex

- Must be a constant time operation
 - Select next vertex from 1-ring of previous
 - If none available, pick latest referenced
 - If none available, pick next in input order



Best next fanning vertex within 1-ring

- Consider vertices referenced by emitted triangles
- Furthest in FIFO that would *remain* in cache



s cache time stamp

how far is u in the cache? $s - C'[u]$

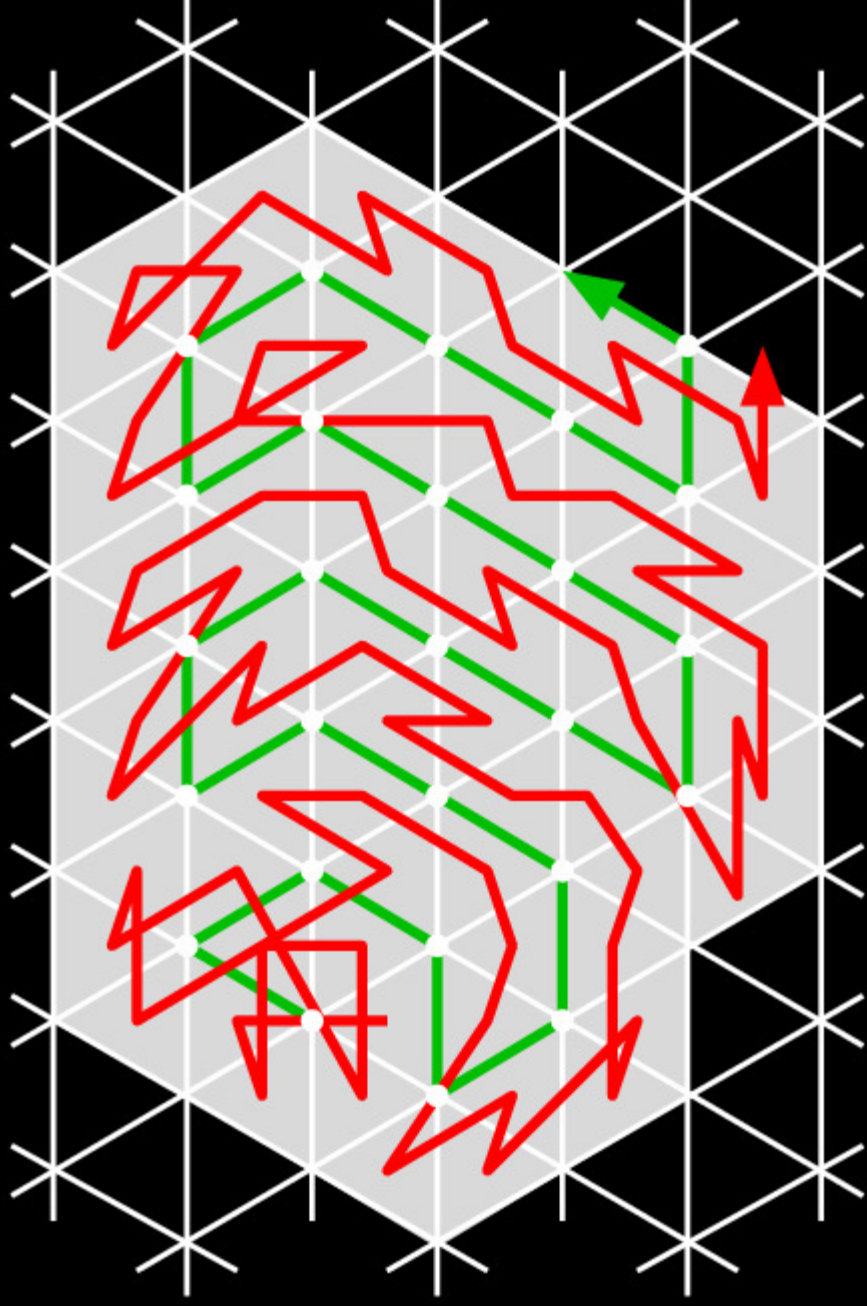
$C[u]$ caching time stamp of u

is u still in the cache? $s - C'[u] \leq k$

$L[u]$ # of live triangles in u

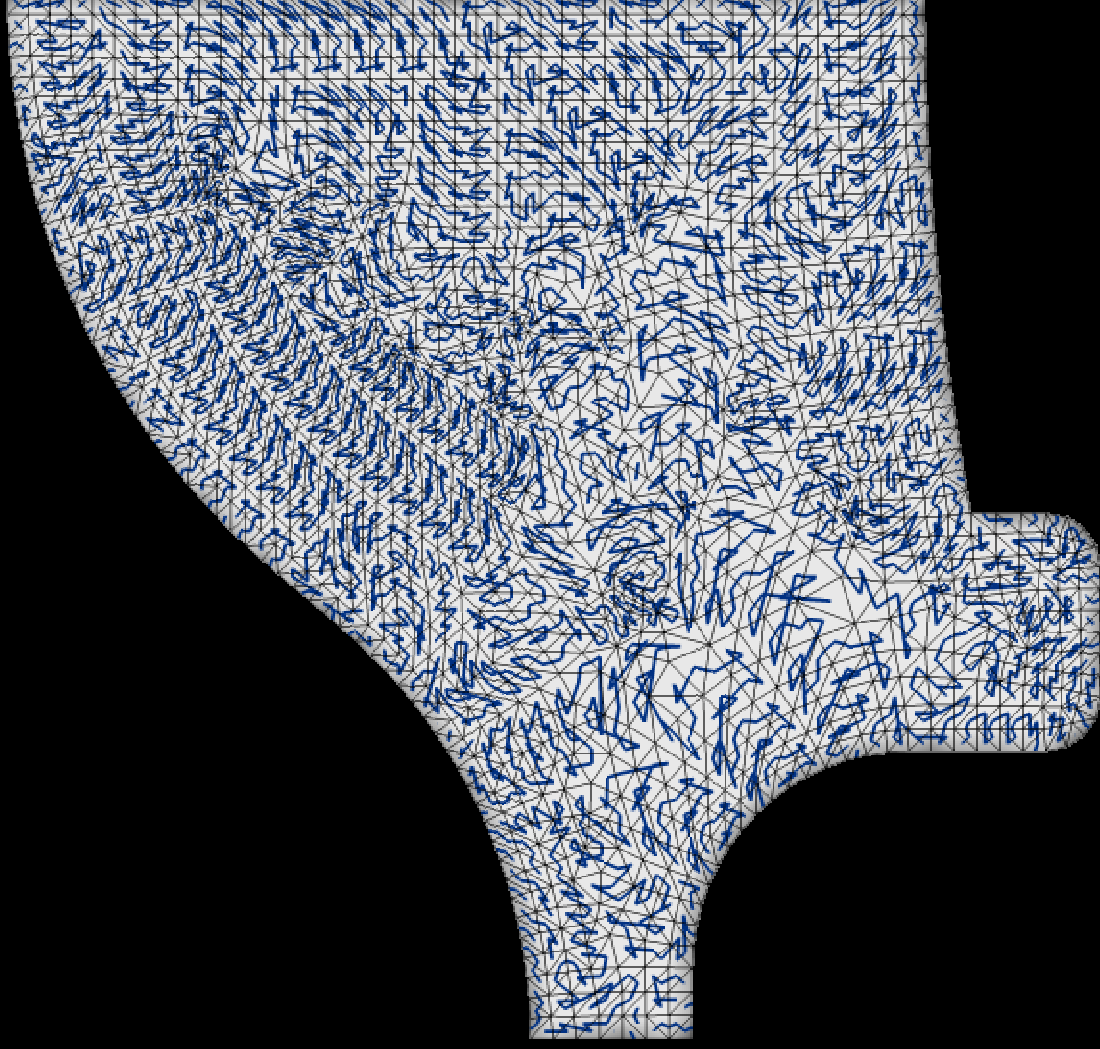
would u remain in cache? $s - C'[u] - 2L[u] \leq k$

Tipsy pattern



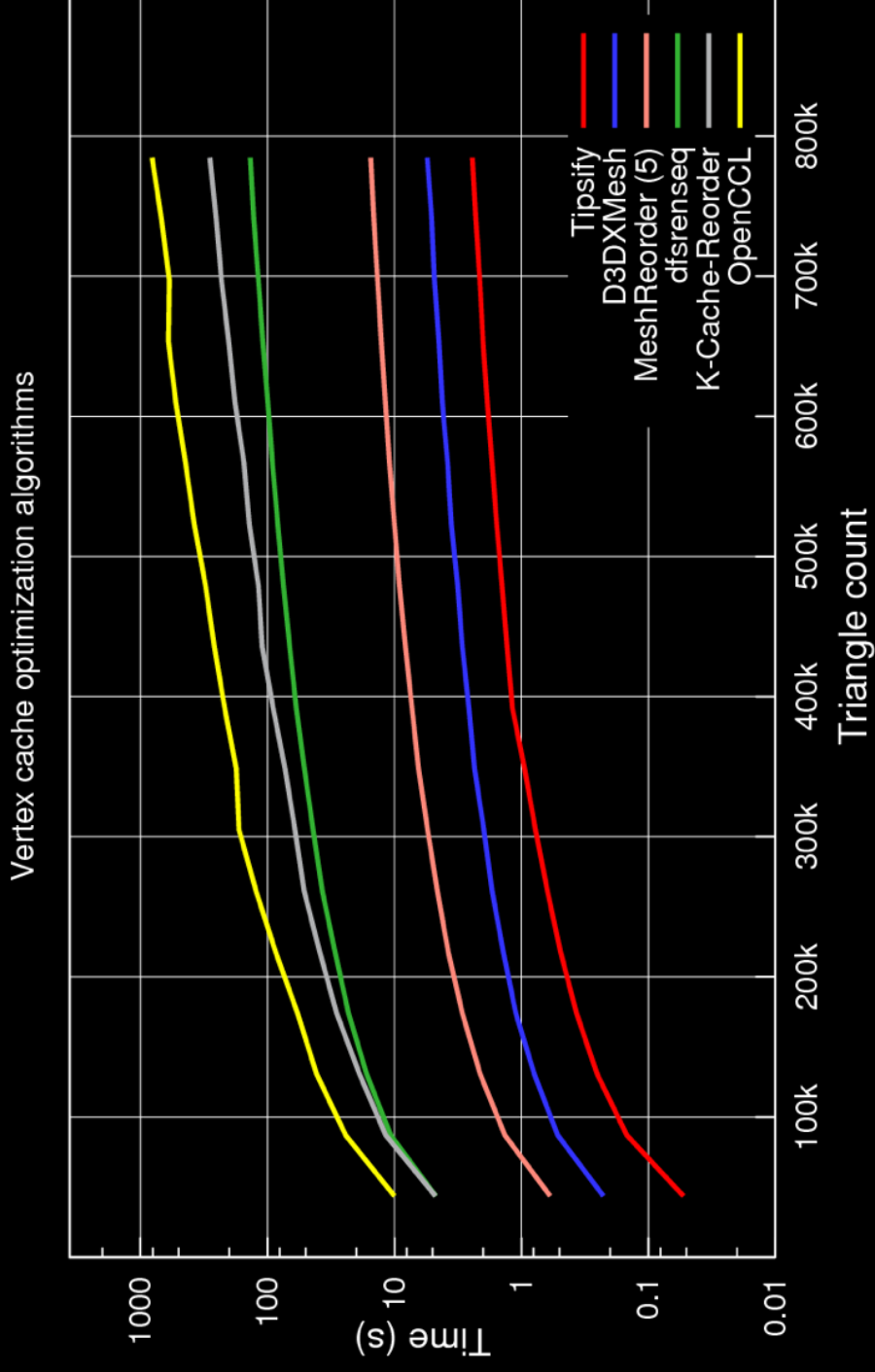
Tipsy strips

Tipsy pattern



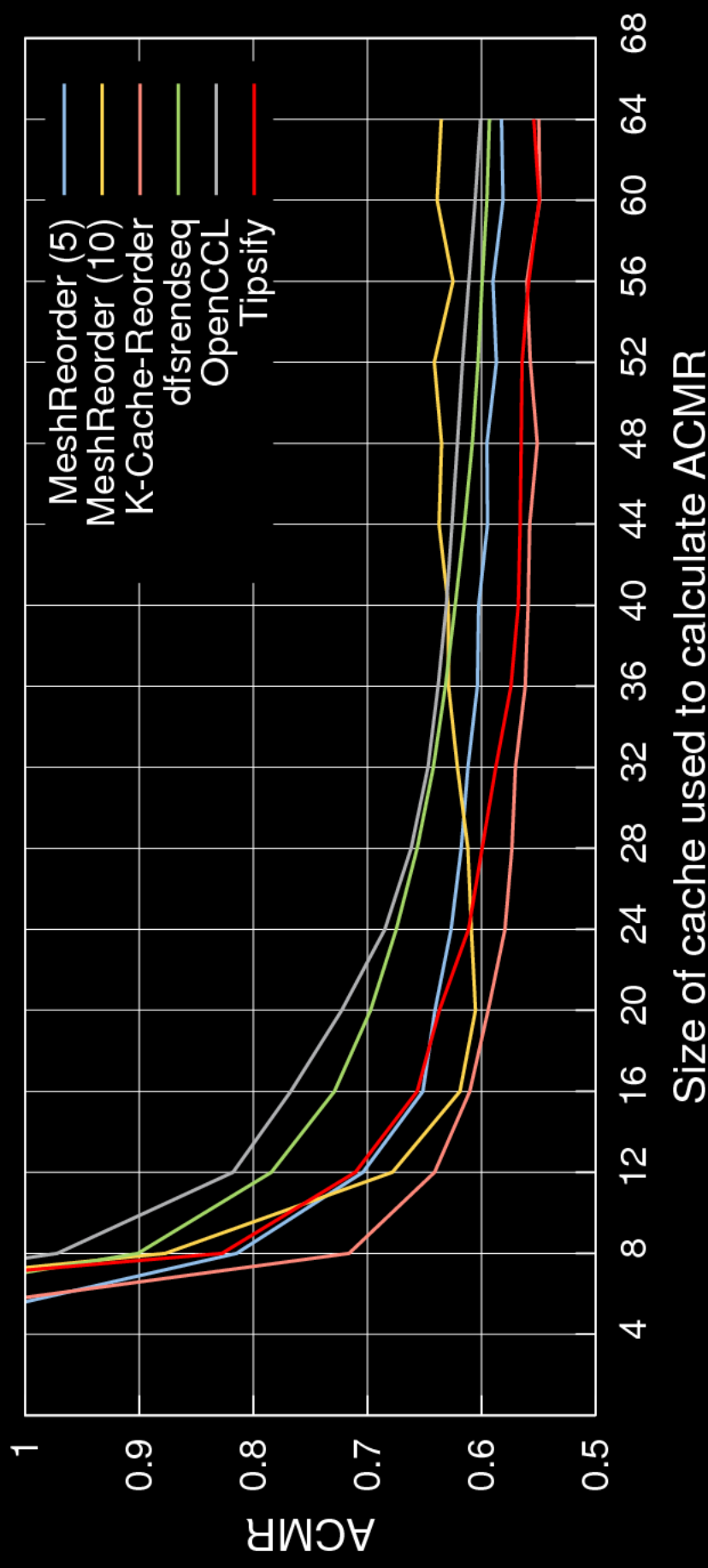
Tipsify

Typical running times



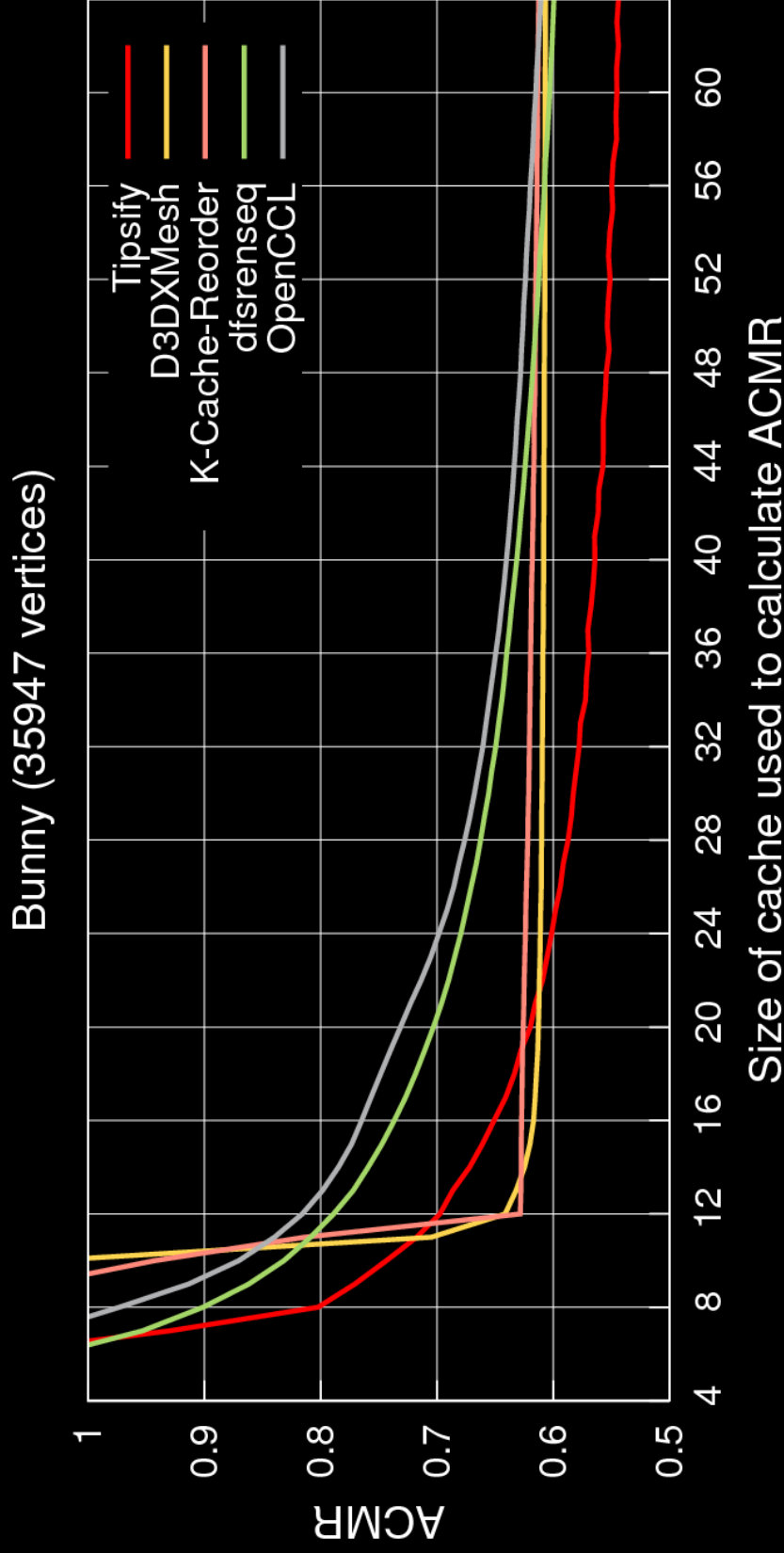
Preprocessing comparison

All with correct cache size



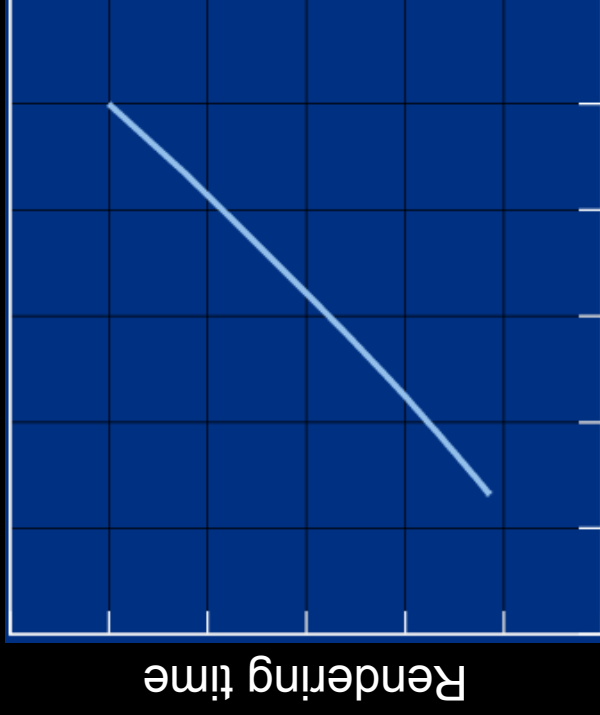
Typical ACMR comparison

Cache size of 12



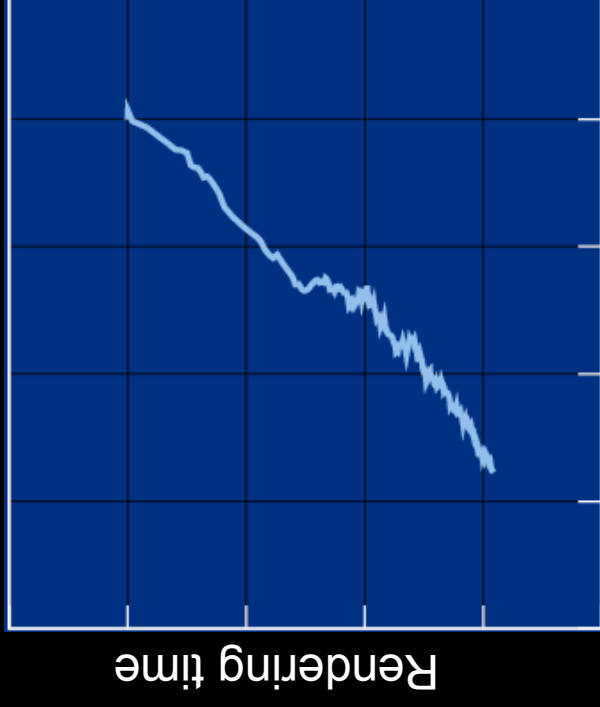
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vertices processed

Pixel-bound scene

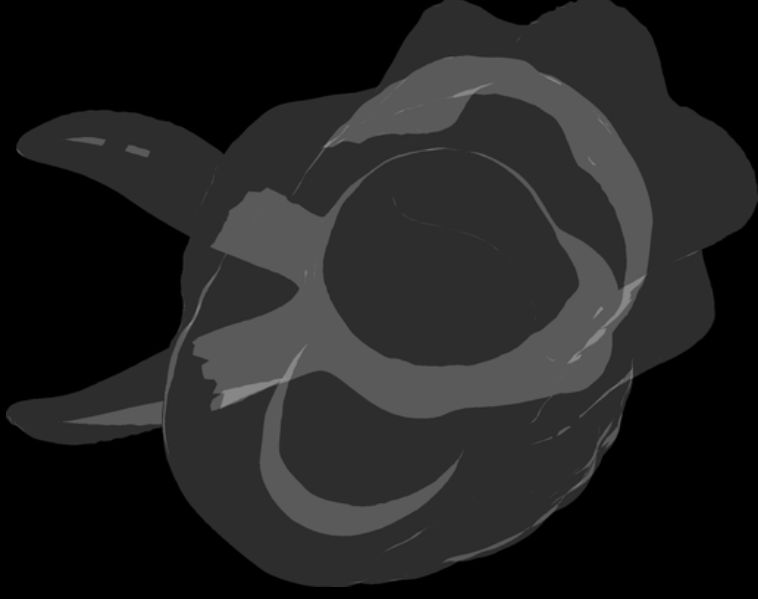
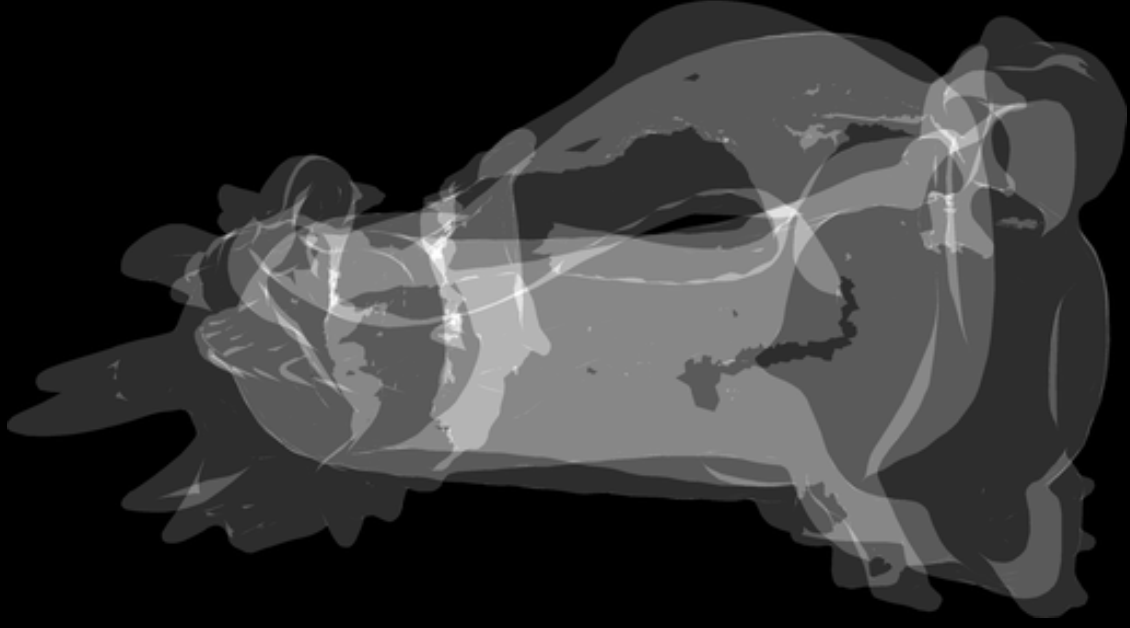


pixels processed

Reduce!
(transparently)

Part 2: Overdraw

- Expensive pixel shaders
- High overdraw
- Use early-z culling



Options

- Dynamic depth-sort
 - Can be too expensive
 - Destroys mesh locality
- Z-buffer priming
 - Can be too expensive
- Sorting per object
 - E.g. GOVINDARAJU et al. 2005
 - Does not eliminate intra-object overdraw
 - Not transparent to application
 - Requires CPU work
 - Orthogonal method

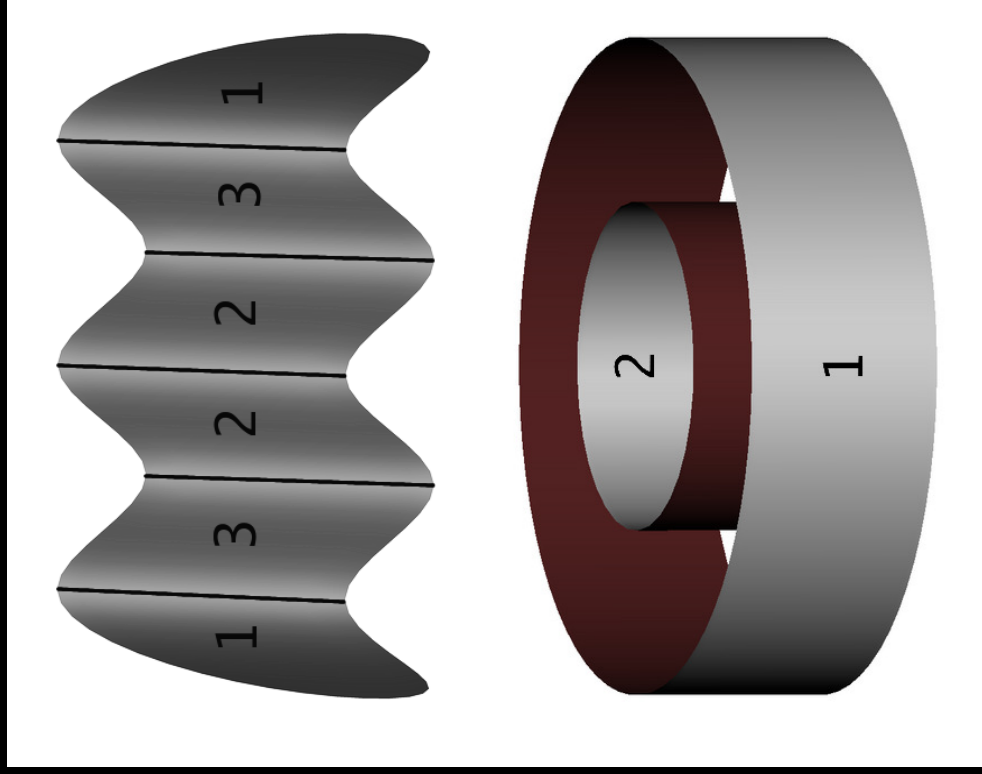
Objective

- Simple solution
- Single draw call
- Transparent to application
- Good in both vertex and pixel bound scenarios
- Fast to optimize

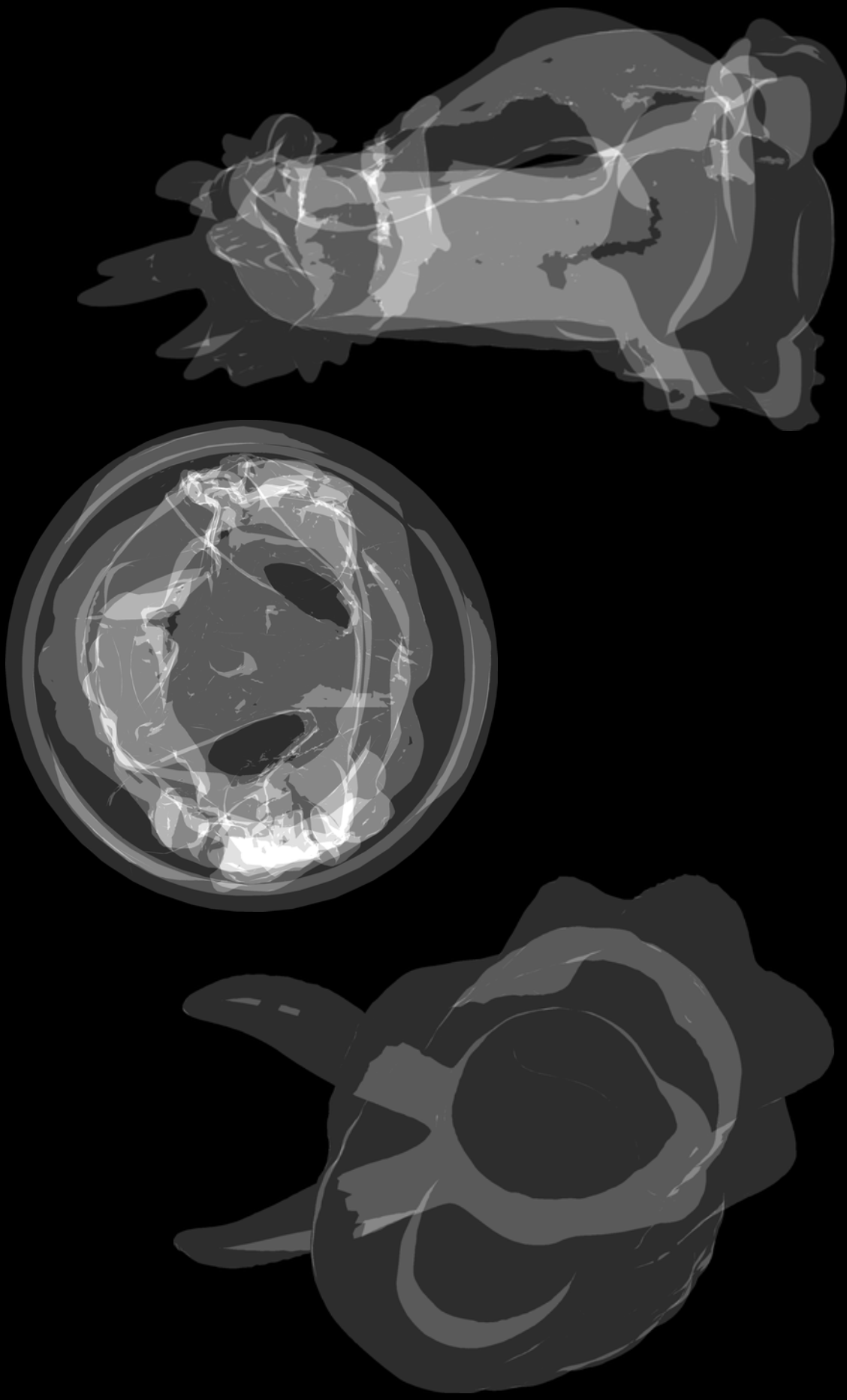
Insight: View Independent Ordering

[Nehab et al. 06]

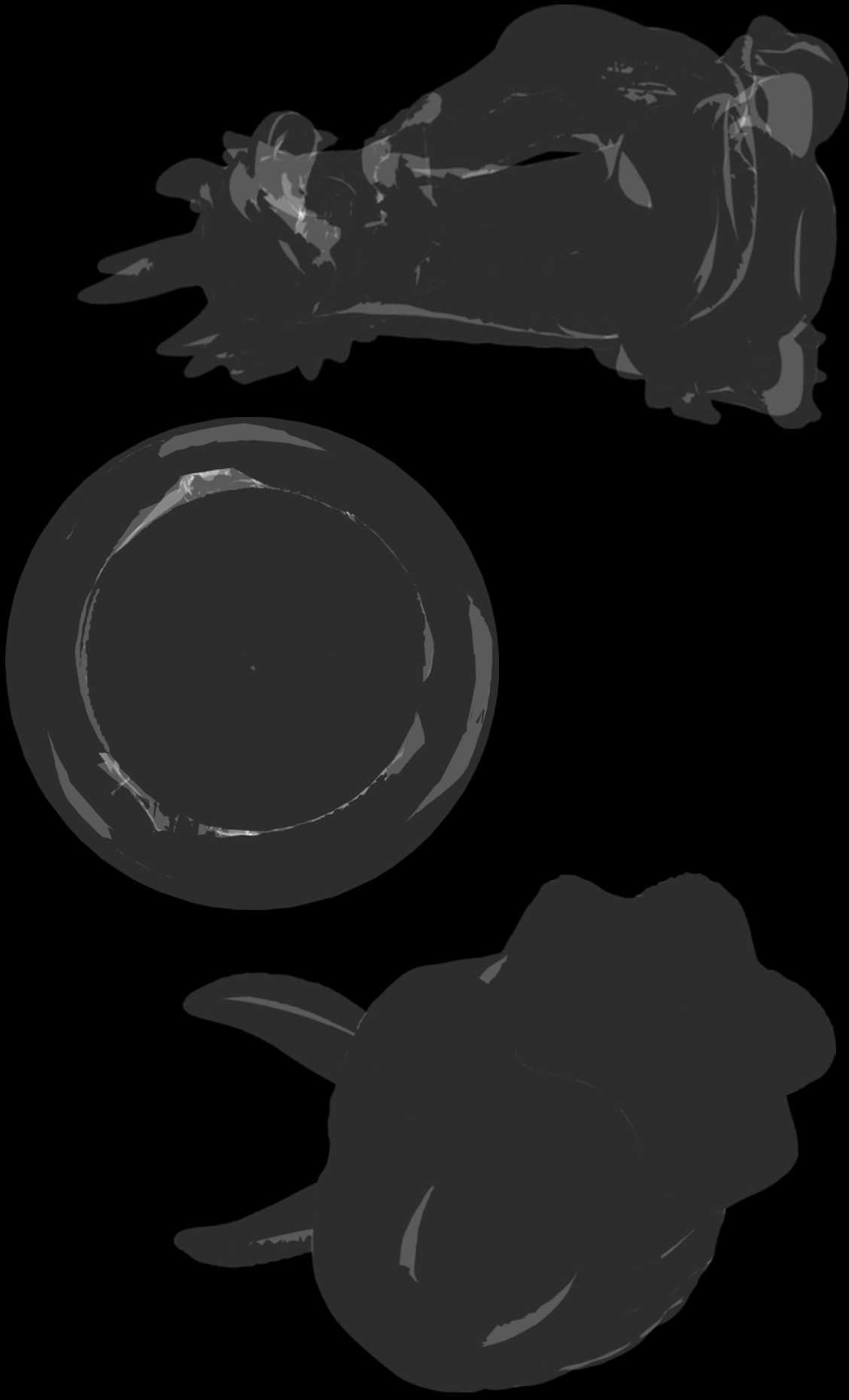
- Back-face culling is often used
- Convex objects have *no* overdraw, regardless of viewpoint
- Might be possible even for concave objects!



Overdraw (before)



Overdraw (after)



Our algorithm

- Can we do it at load-time or interactively?
- Yes! 😊 (order of milliseconds)
 - Quality on par with previous method
 - Can be immediately executed after vertex cache optimization (Part 1)
 - Like tipsy, operates on vertex and index buffers

Algorithm overview

1. Vertex cache optimization
 - Optimize for vertex cache *first* (Tipsify)
2. Linear clustering
 - Segment the index buffer into clusters
3. Overdraw sorting
 - Sort clusters to minimize overdraw

2. Linear clustering

During tipsy optimization:

- Maintaining the current ACMR
- Insert cluster boundary when:
 - A cache flush is detected
 - The ACMR reaches above a particular threshold λ

Threshold λ trades off

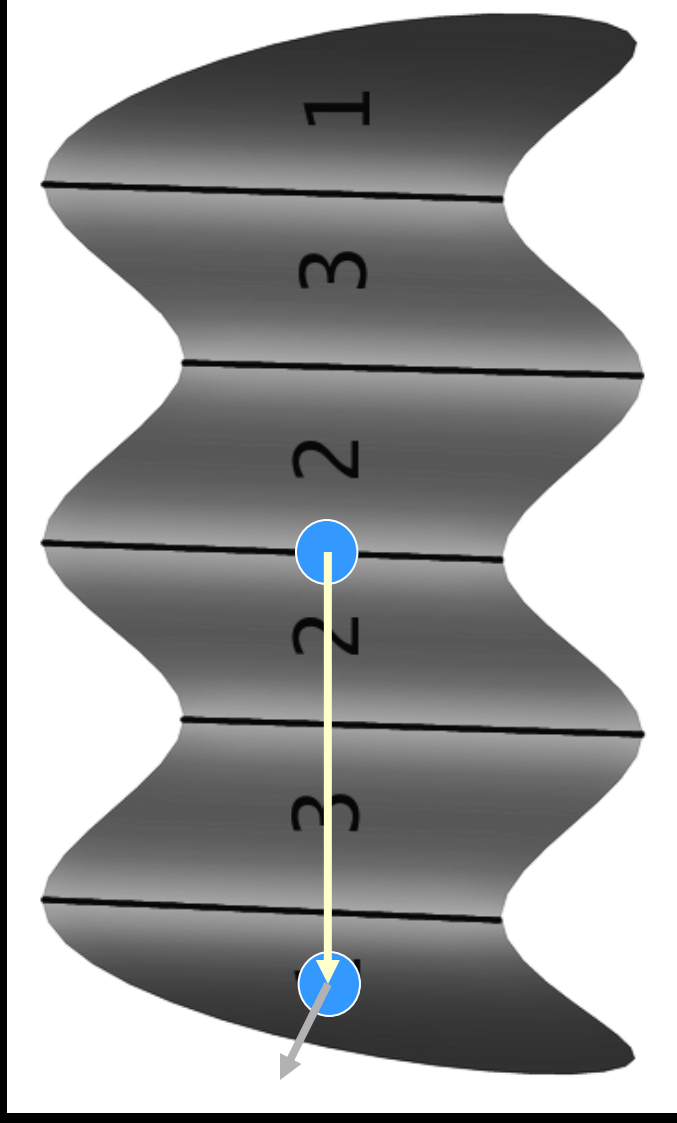
cache efficiency vs. ***overdraw***

If we care about both, use $\lambda = 0.75$ on all meshes

- Good enough vertex cache gains
- More than enough clusters to reduce overdraw

3. Sorting: The DotRule

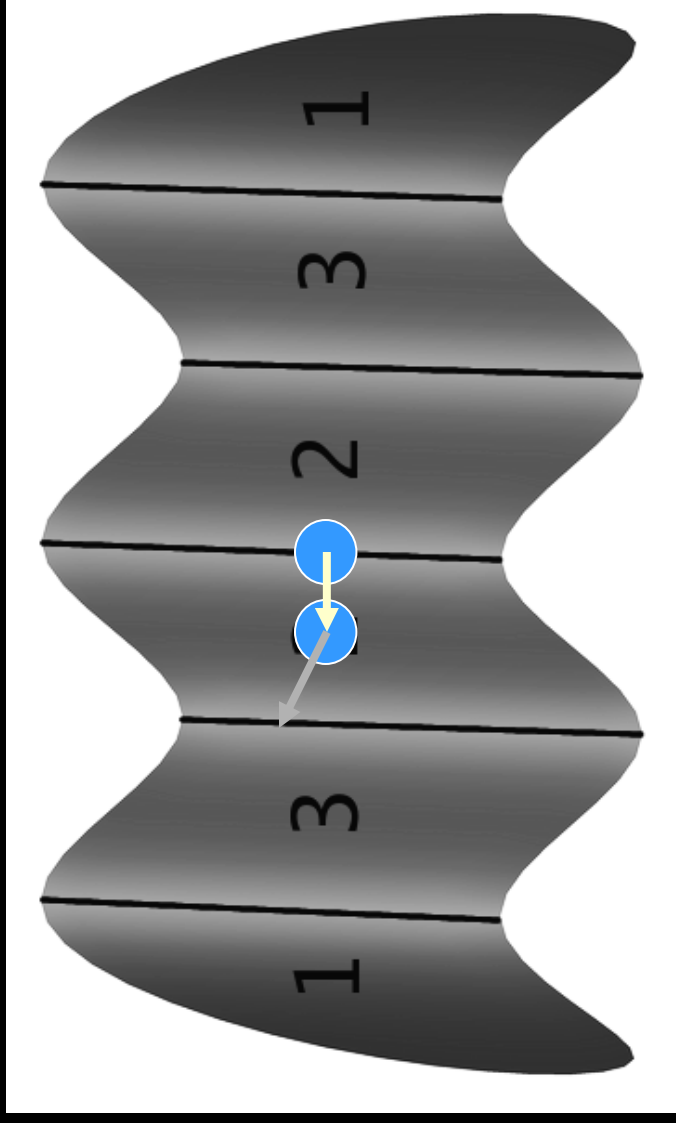
- How do we sort the clusters?
- Intuition: Clusters *facing out* have a higher *occluder potential*



$$(C_p - M_p) \cdot C_n$$

3. Sorting: The DotRule

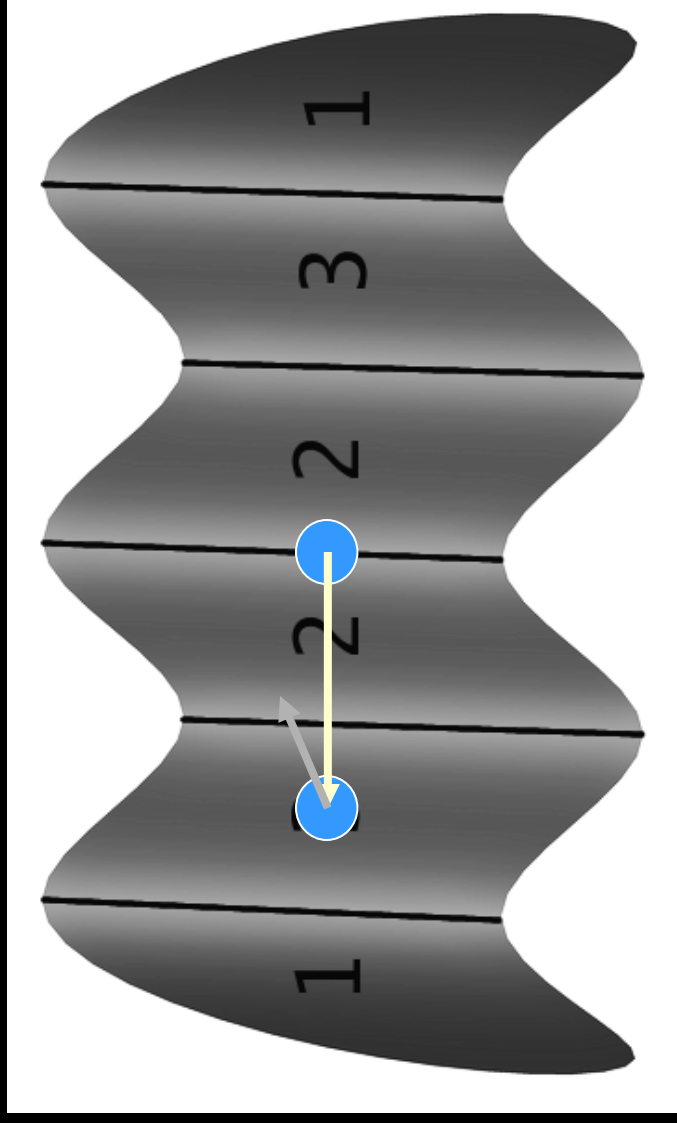
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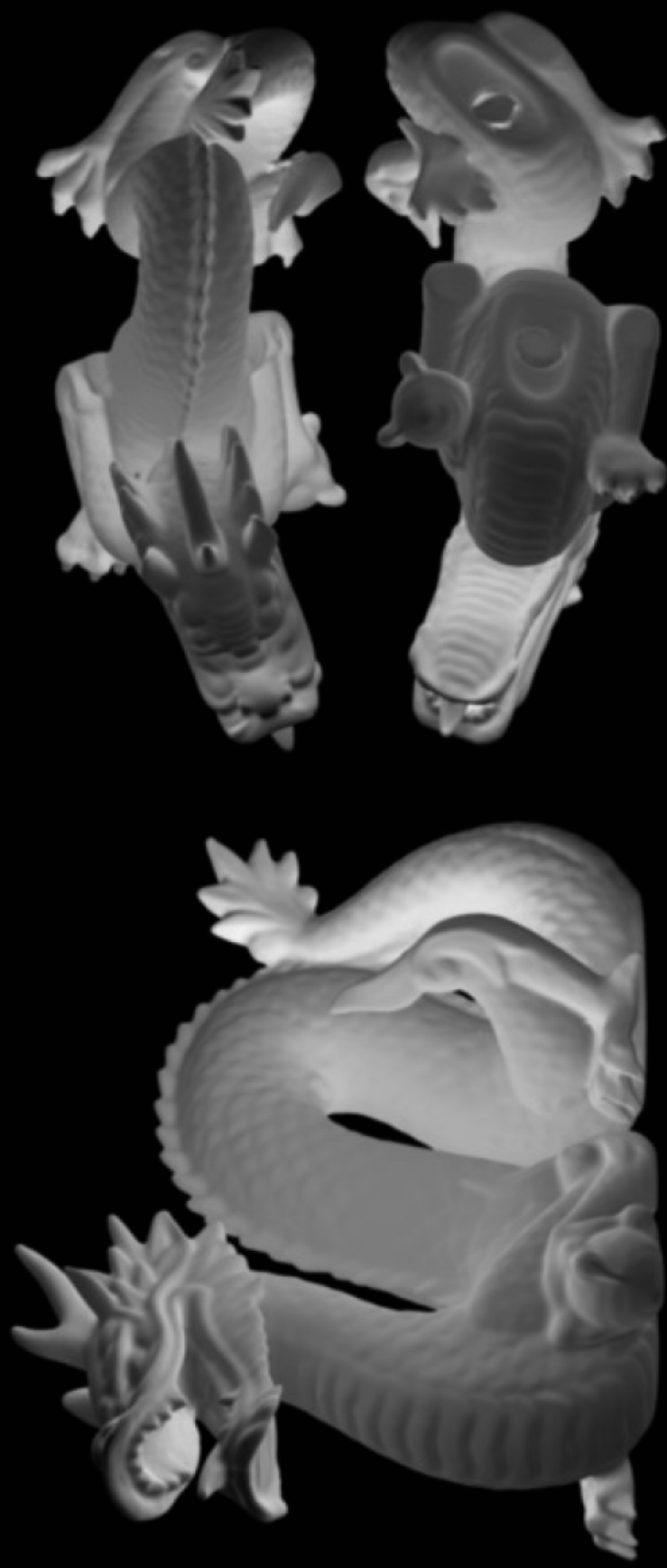
3. Sorting: The DotRule

- How do we sort the clusters?
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$$(C_p - M_p) \cdot C_n$$

Sorted triangles



Sorted triangles



Sorted clusters



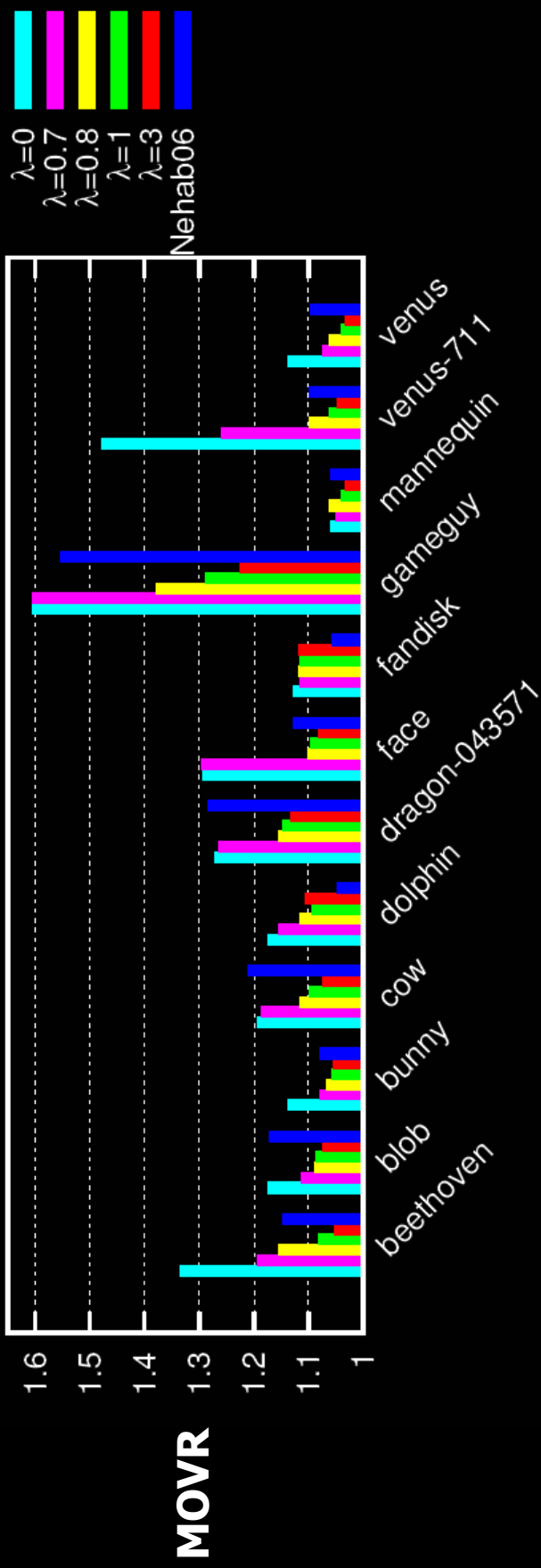
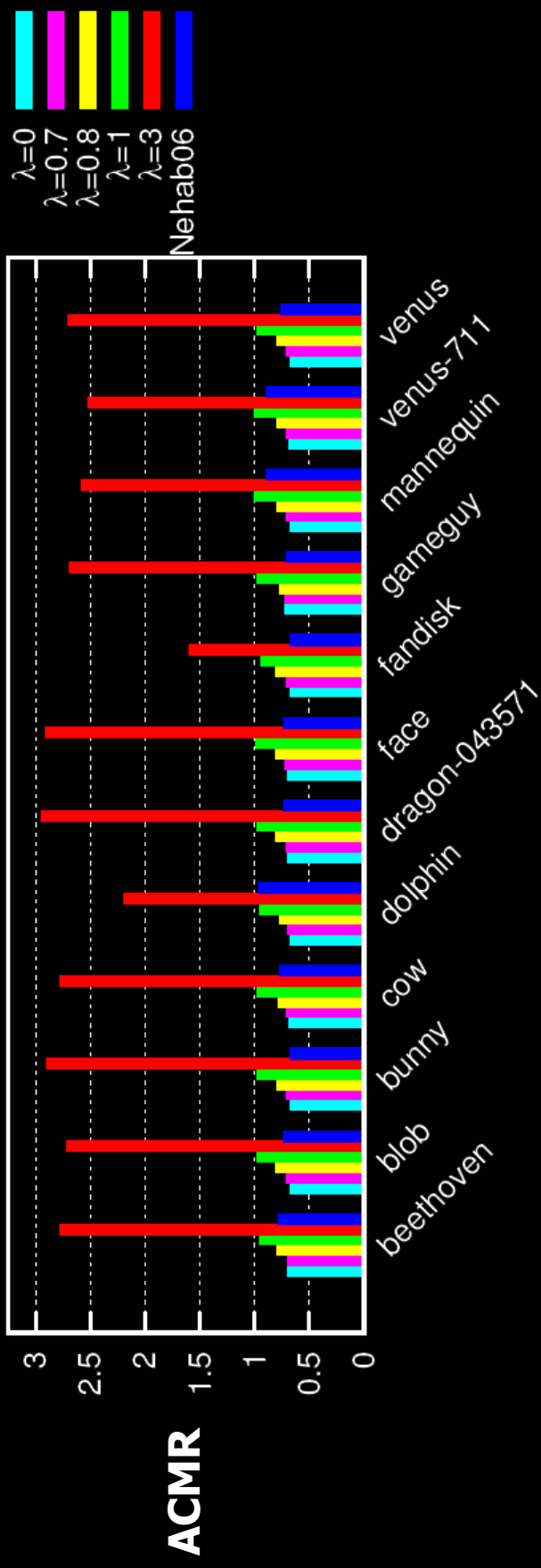
Comparison to Nehab et al. 06

- We optimize for vertex cache first
- Allows for *significantly* more clusters
- Clusters not as planar, but we can afford more
- New heuristic to sort clusters very fast
- Tradeoff vertex vs. pixel processing at runtime

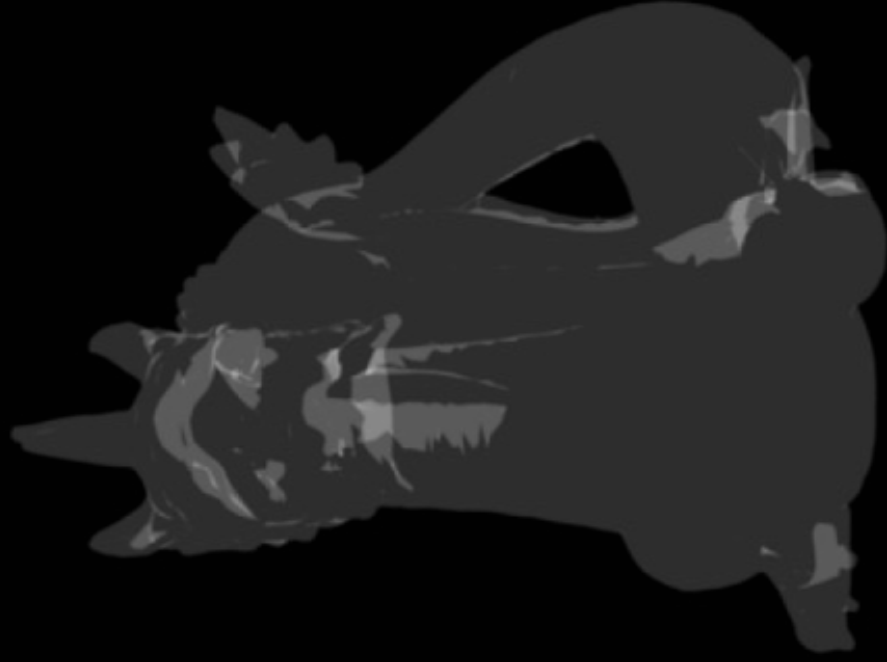
Timing comparisons

Mesh	Sander 07 (s)	New:Nehab 06
beethoven.m	0.0030	2712x
blob.m	0.0125	1359x
bunny.m	0.0749	321x
cow.m	0.0047	641x
dolphin.m	0.0003	10054x
dragon-043571.m	0.0434	253x
face.m	0.0199	251x
fandisk.m	0.0098	1024x
gameguy.m	0.0424	354x
mannequin.m	0.0007	13699x
venus.m	0.0033	1529x
Average		3129x

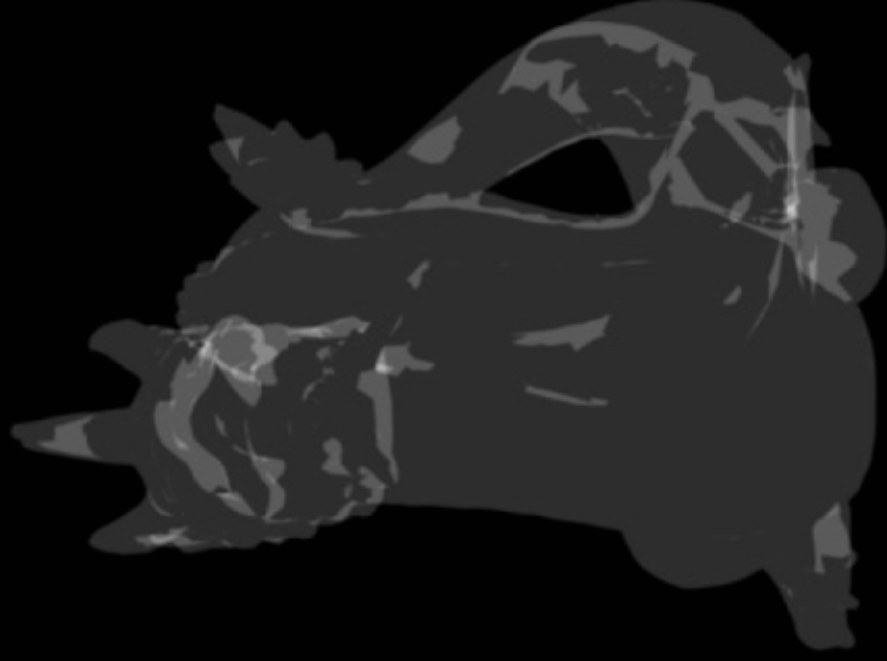
Overdraw comparison



Comparison



Nehab et al. 06
40sec



Tipsy + DotRule
0.076sec

Summary

- Run-time vertex cache optimization
- Run-time overdraw reduction
- Operates on vertex and index buffers directly
- Works on non-manifolds
- Orders of magnitude faster
- Allows for varying cache sizes and animated models
- Quality comparable with previous methods
- About 500 lines of code!
- Extremely easy to incorporate in a rendering pipeline
- Expect most game rendering pipelines will incorporate such an algorithm
- Expect CAD applications to use and re-compute ordering interactively as geometry changes

```

void OverdrawOrder(int *piIndexBufferIn,
int *piIndexBufferOut,
int iNumFaces,
float *pvVertexPositionsIn,
int iNumVertices,
int *piClustersIn,
int iNumClusters,
int *piScratch,
int *piRemap = NULL)
{
    int i, j;
    int c=0, cstart=0;
    int cnext=piClustersIn[1];
    int *p = piIndexBufferIn;
    Vector *pvVertexPositionsIn = (Vector *)pvVertexPositionsIn;
    Vector *vMeshPositions = Vector(0,0,0);
    float fMArea = 0.f;

    int *piScratchBase = piScratch;
    Vector *pvClusterPositions = (Vector *)piScratch;
    piScratch += iNumClusters * 3;

    Vector *pvClusterNormals = (Vector *)piScratch;
    piScratch += iNumClusters * 3;

    ClusterSort *cs = (ClusterSort *)piScratch;
    piScratch += iNumClusters * 2;

    for(i = 0; i < iNumClusters; i++)
    {
        pvClusterPositions[i] = Vector(0,0,0);
        pvClusterNormals[i] = Vector(0,0,0);
    }

    float fMArea = 0.f;
    for(i = 0; i <= iNumFaces; i++)
    {
        if(i == cnext)
        {
            pvClusterPositions[c] /= fMArea * 3.f;
            pvClusterNormals[c].normalize();
            c++;
            if(c == iNumClusters)
                break;
            cstart = i;
            cnext = piClustersIn[c+1];
            fMArea = 0.f;
        }

        Vector vNormal = cross(pvVertexPositionsIn[p[i]] -
            pvVertexPositionsIn[p[0]],
            pvVertexPositionsIn[p[1]] -
            pvVertexPositionsIn[p[0]]);
        float fArea = vNormal.length();
        if(fArea > 0.f)

```

```

        {
            vNormal /= fArea;
        }
        else
        {
            fArea = 0.f;
            vNormal = Vector(0,0,0);
        }

        for(j = 0; j < 3; j++)
        {
            Vector *vp = (Vector *)pvVertexPositionsIn[(i * 3) + j];
            vMeshPositions += *vp * fArea;
            pvClusterPositions[c] += *vp * fArea;
            p++;
        }
        pvClusterNormals[c] += vNormal;

        fMArea += fArea;
        fMArea += fArea;

        vMeshPositions /= fMArea * 3.f;

        for(i = 0; i < iNumClusters; i++)
        {
            cs[i].dp = dot(pvClusterPositions[i] - vMeshPositions,
                pvClusterNormals[i]);
            if(cs[i].dp < -2e20 || cs[i].dp > 2e20)
            {
                cs[i].dp = 0.f;
            }
            cs[i].i = i;
        }

        std::sort(cs, cs+iNumClusters, sortfunc);

        int jj=0;
        for(i = 0; i < iNumClusters; i++)
        {
            for(j = piClustersIn[cs[i].i]*3; j < piClustersIn[cs[i].i+1]*3; j++)
                piIndexBufferOut[jj++] = piIndexBufferIn[j];
        }

        if(piRemap != NULL)
        {
            for(i = 0; i < iNumClusters; i++)
            {
                piRemap[i] = cs[i].i;
            }
        }

        memset(piScratchBase, 0, (piScratch - piScratchBase) * sizeof(int));
    }
}

```

Summary

- Run-time triangle order optimization
- Run-time overdraw reduction
- Operates on vertex and index buffers directly
- Works on non-manifolds
- Allows for varying cache sizes and animated models
- Orders of magnitude faster
- Quality comparable with state of the art
- About 500 lines of code!
- Extremely easy to incorporate in a rendering pipeline
- Hope game rendering pipelines will incorporate such an algorithm
- Hope CAD applications to use and re-compute ordering interactively as geometry changes

Thanks

- Phil Rogers, AMD
- 3D Application Research Group, AMD

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