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Hybrid Computational Voxelization using the Graphics Pipeline

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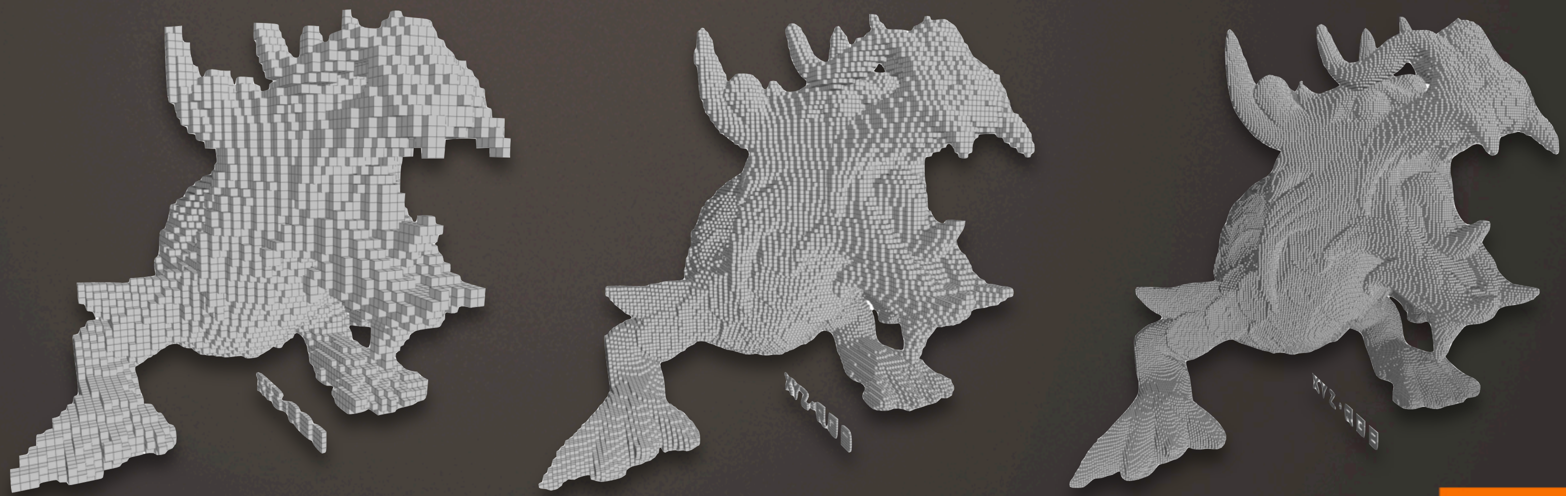
Voxelization

- Conversion of input geometry (triangles) into a regular 3D discretized representation (voxels)
- Analogous to rasterization in 3D



Original Image

Motivation

- Voxels are useful in many applications (global illumination, collision detection, fluid sim, etc...)
- Voxelization can enable these effects for traditional triangle based scenes
- Fast voxelization can enable these effects for dynamic scenes

Triangle vs Fragment Parallel

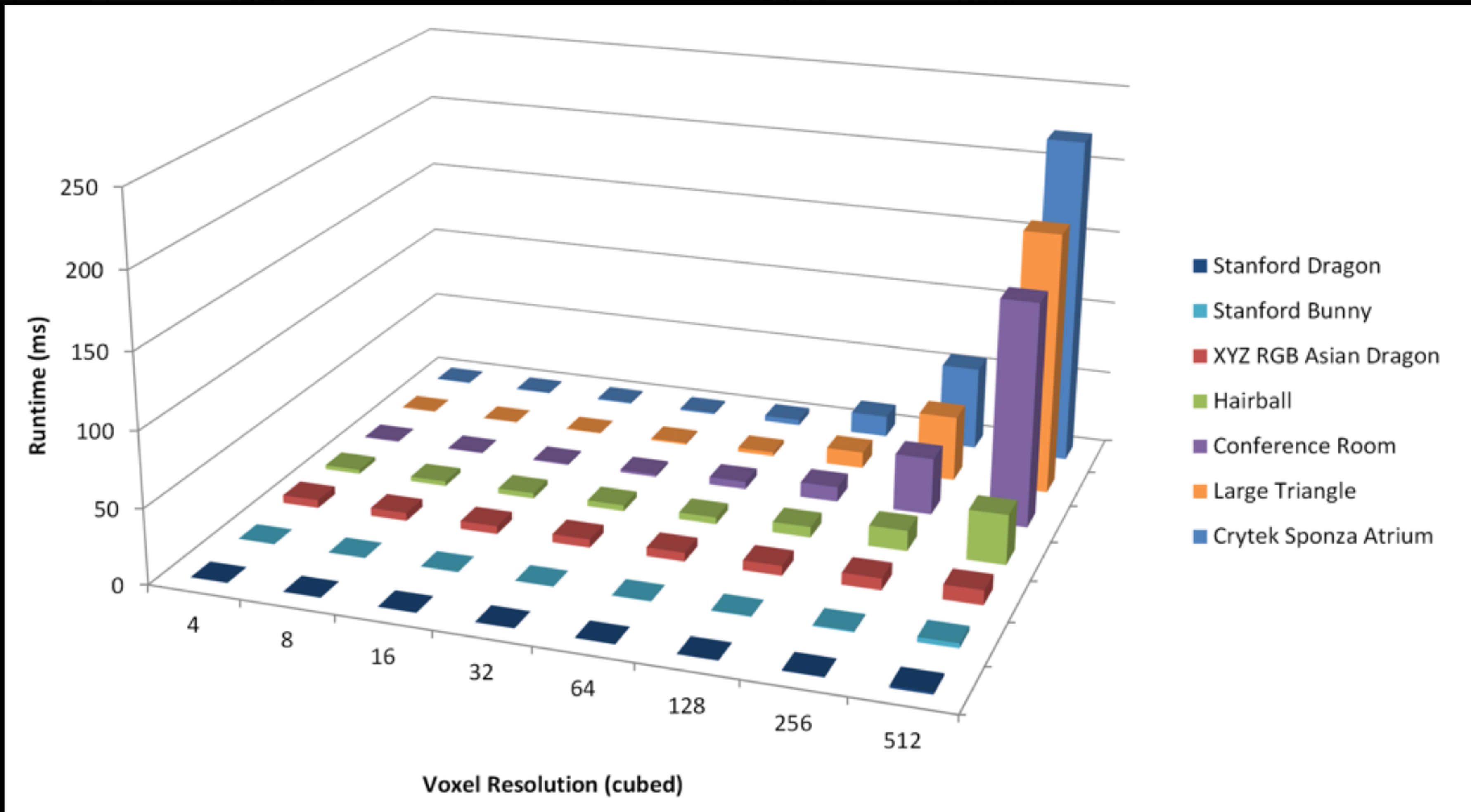
Triangle Parallel

- Threads per triangle
- Can suffer from uneven triangle size distributions

Fragment Parallel

- Threads per triangle fragment
- Can suffer from oversubscription and poor thread utilization

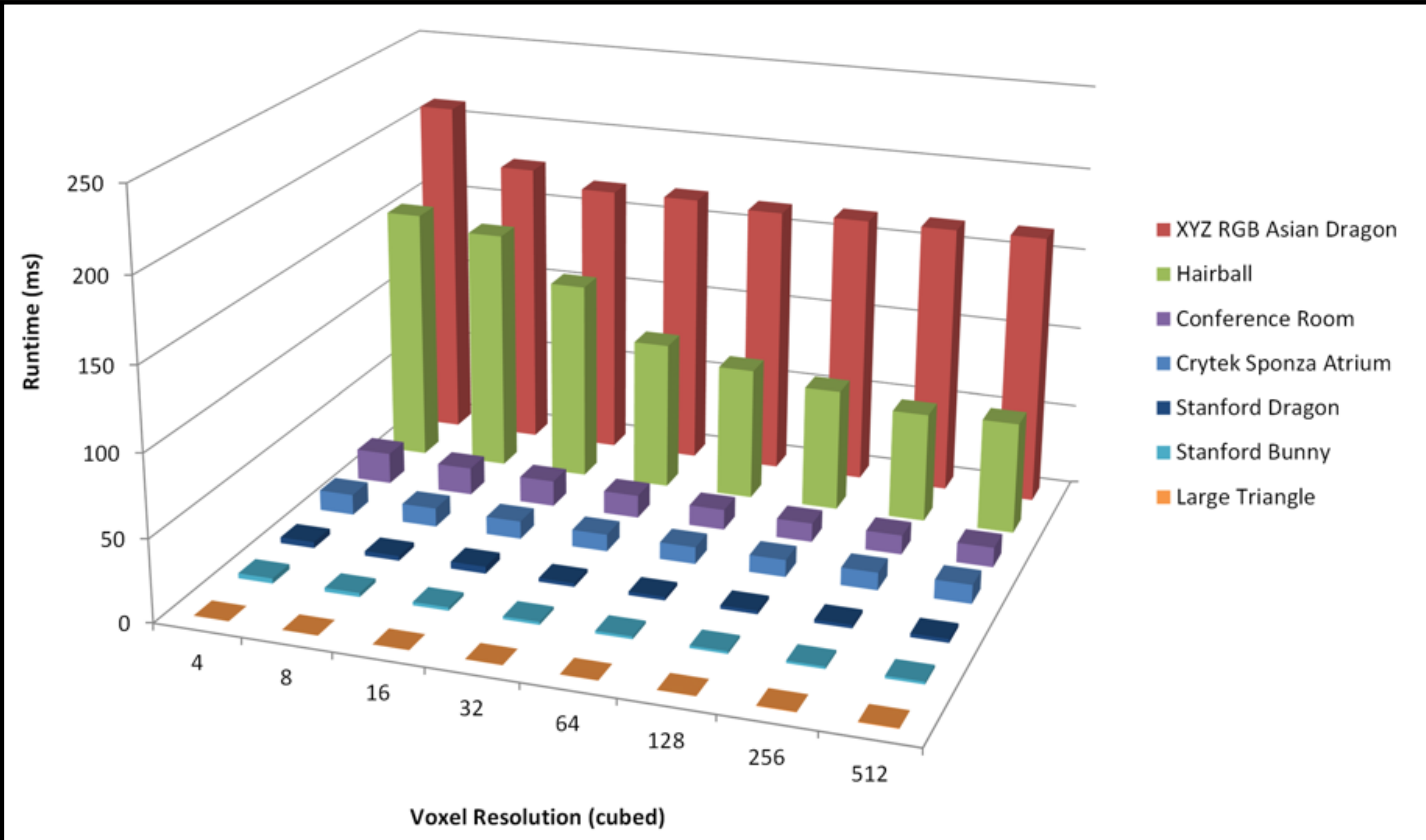
Triangle-Parallel Performance



Triangle-Parallel Analysis

- Performs well on scenes with many small evenly sized triangles
- Performs poorly on any scene with large triangles
- Performance degrades as voxel resolution increases

Fragment-Parallel Performance



Fragment-Parallel Analysis

- Performs well on scenes with large triangles
- Performs poorly on scenes with many small triangles
- Performance degrades as voxel resolution decreases
- Poor “quad-utilization” on small triangles

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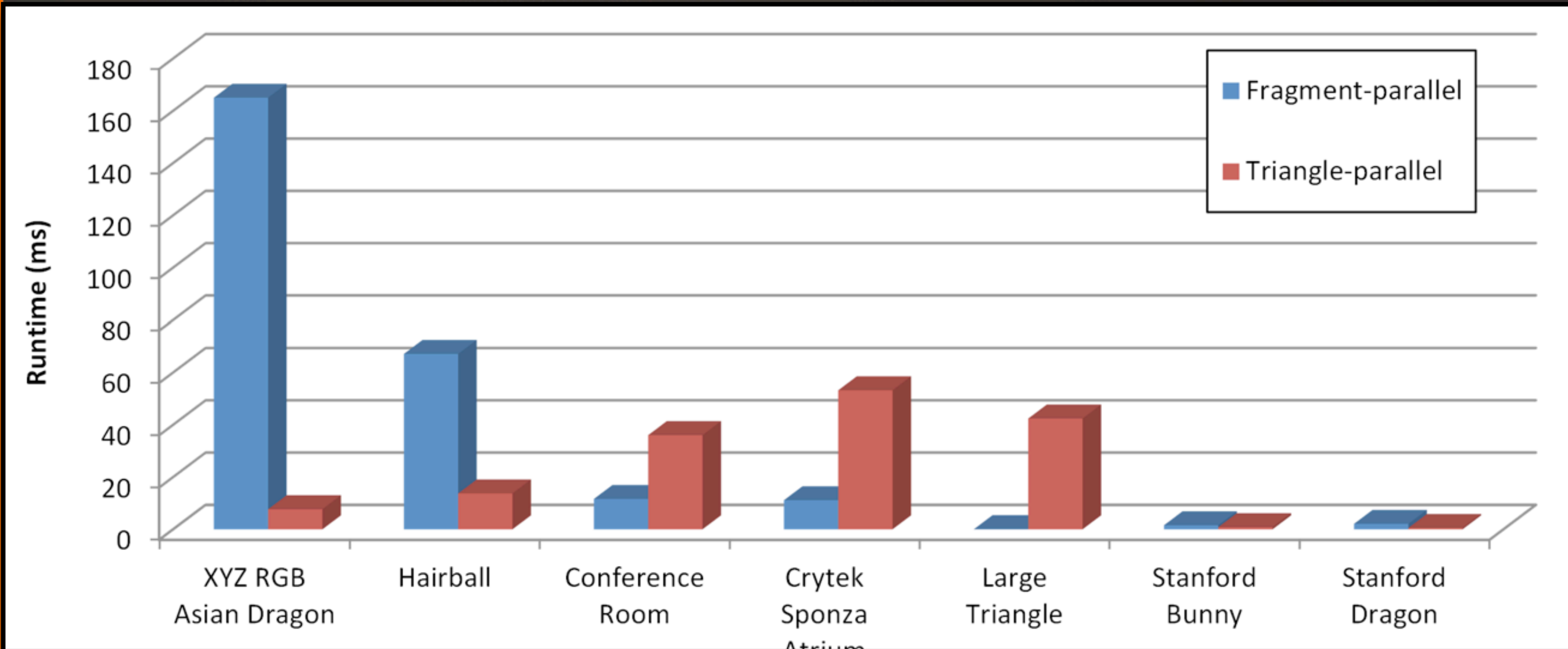
Fragment vs Triangle parallel @256^3



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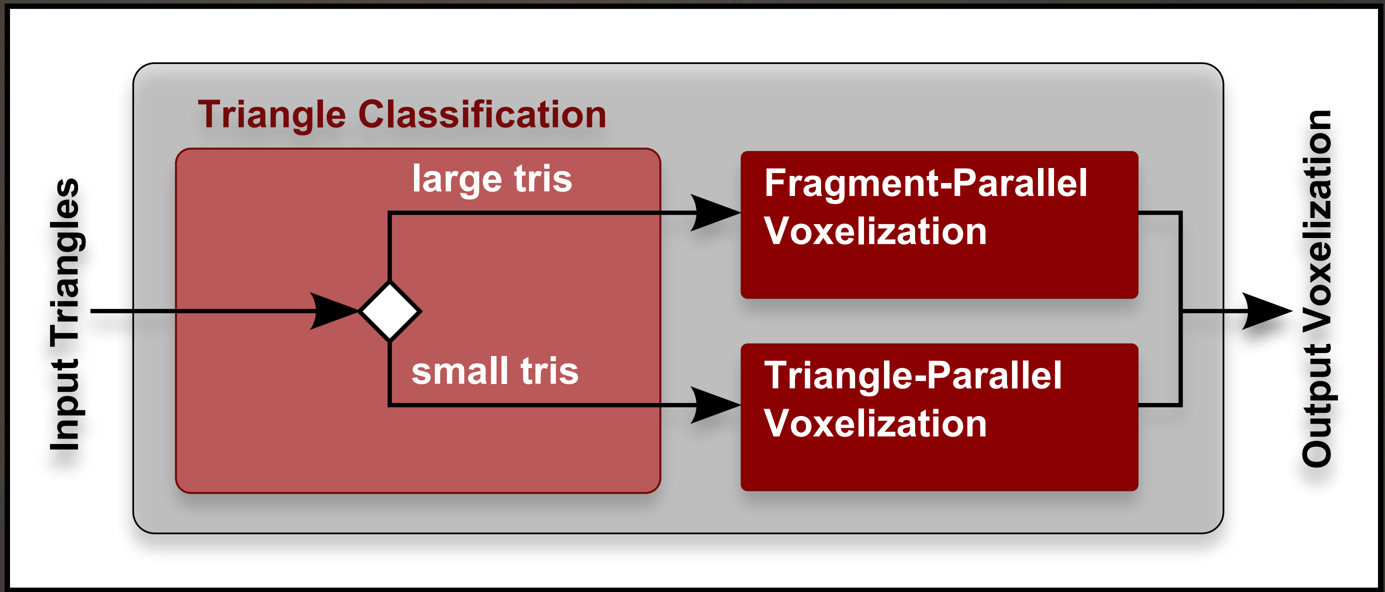
Hybrid Voxelization

- Introduce a hybrid pipeline that splits the workload between "small" and "large" triangles

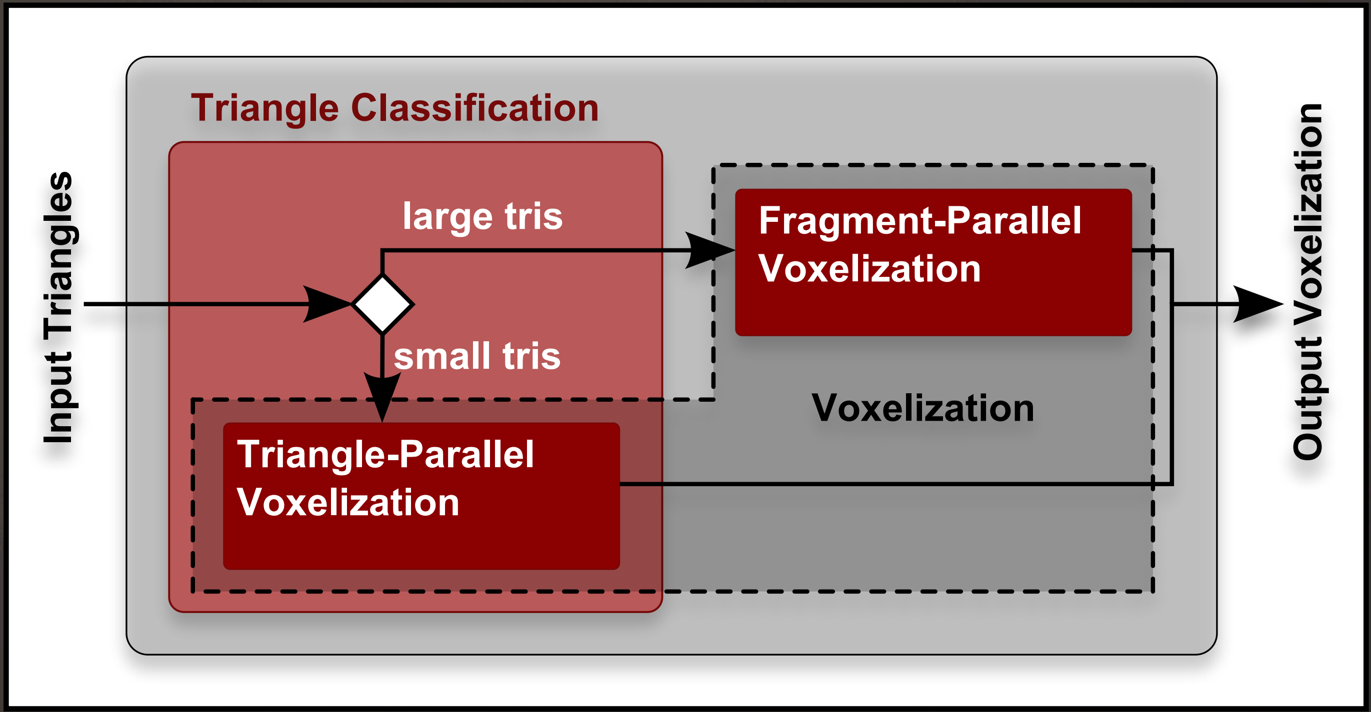


Details

- Creates a “two-pass” approach
- Avoids poor thread utilization and oversubscription caused by rasterizing small triangles
- Avoids idle threads waiting on large triangles
- Effectively classified scenes take longer

Optimized Hybrid Voxelization

- Immediately voxelize small triangles, defer only large triangles



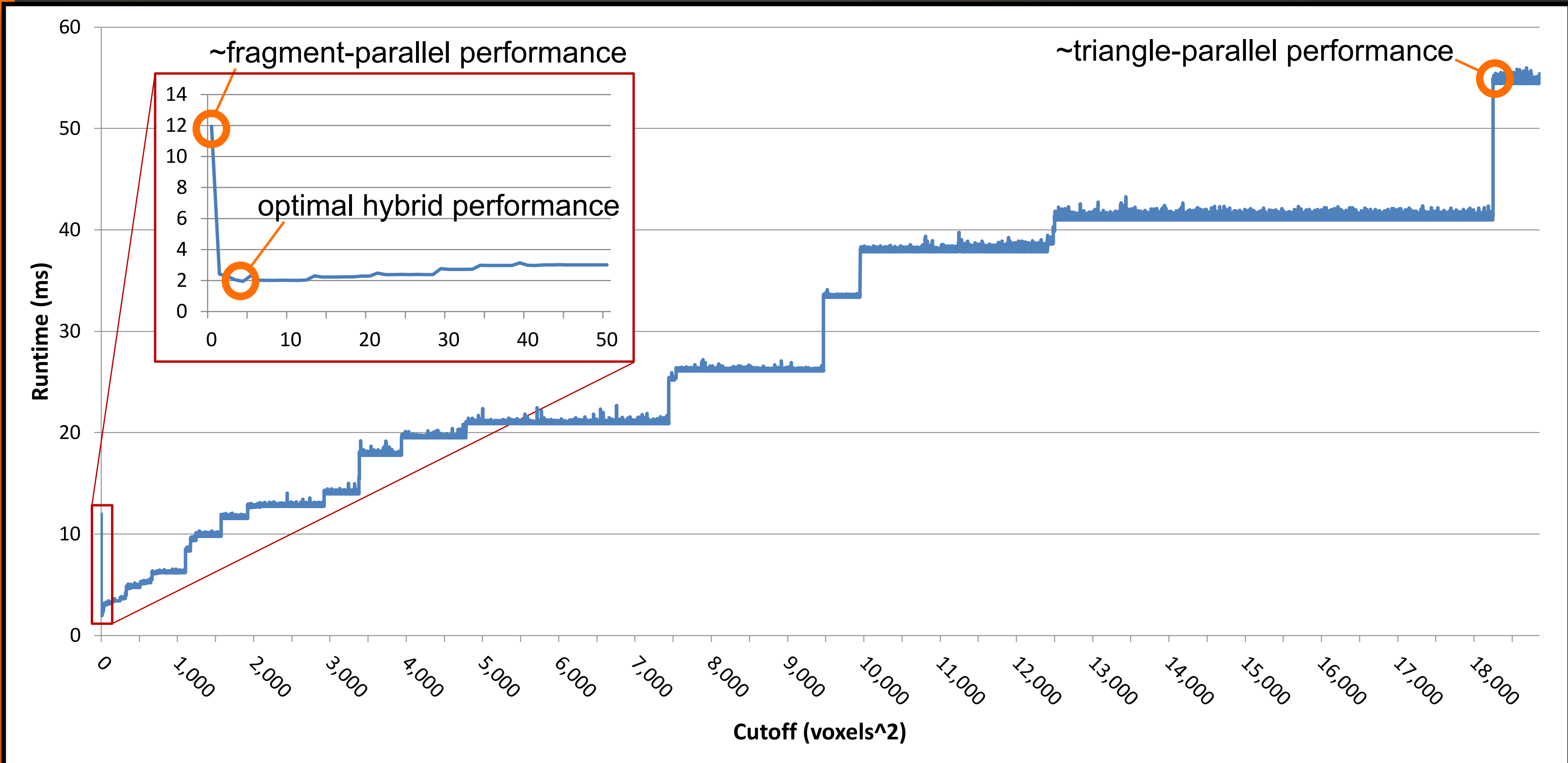
Benefits

- Less overhead for small triangle voxelization
- Reduce under-utilized threads
- Reduces output of classification stage
- More of a “just over one-pass” approach, as typically only a small subset of triangles are processed twice

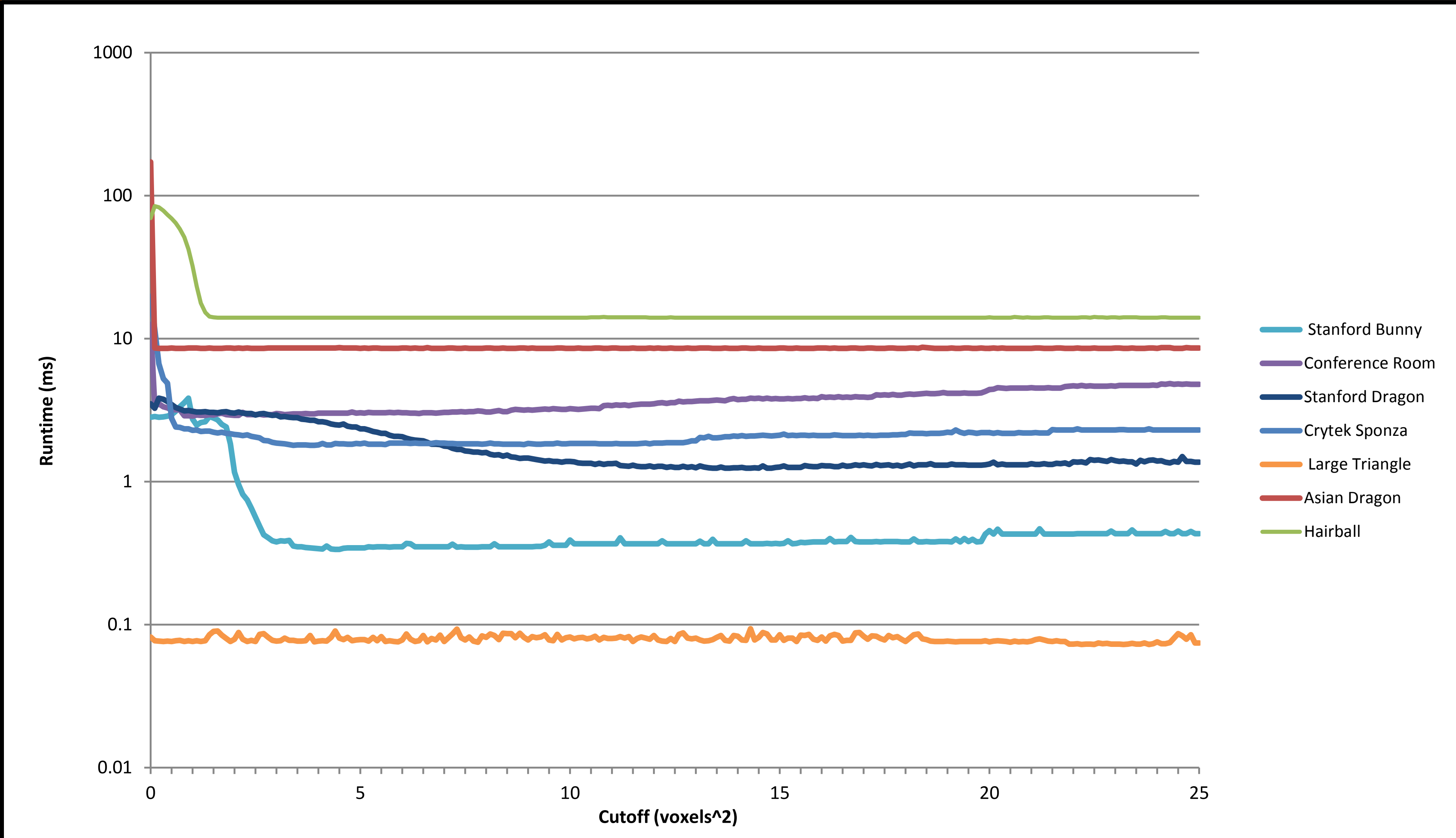
“Small” vs “Large” Triangles

- Classify triangles based on the maximal 2D projected area of triangle in voxel units
- Triangles are classified as large or small according to a cutoff value

Hybrid Performance (Sponza)



Hybrid Performance (zoomed)

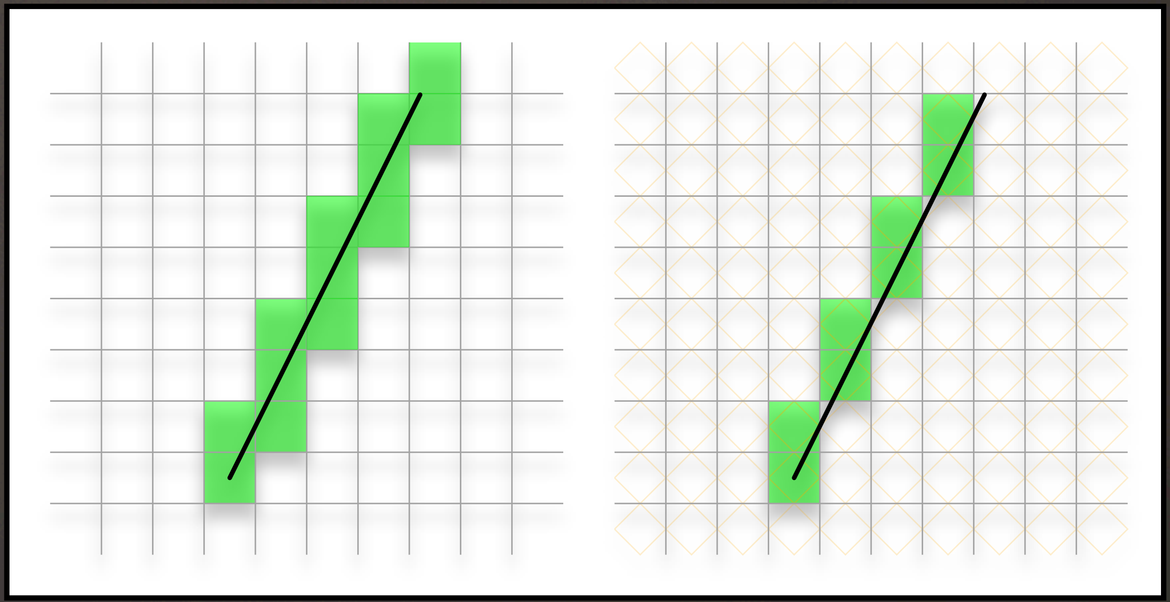


Implementation Details

- Surface Voxelization
- OpenGL 4.2
- Computational Intersection

Surface Voxelization

- Conservative voxelization (26-separable)
- Thin voxelization (6-separable)

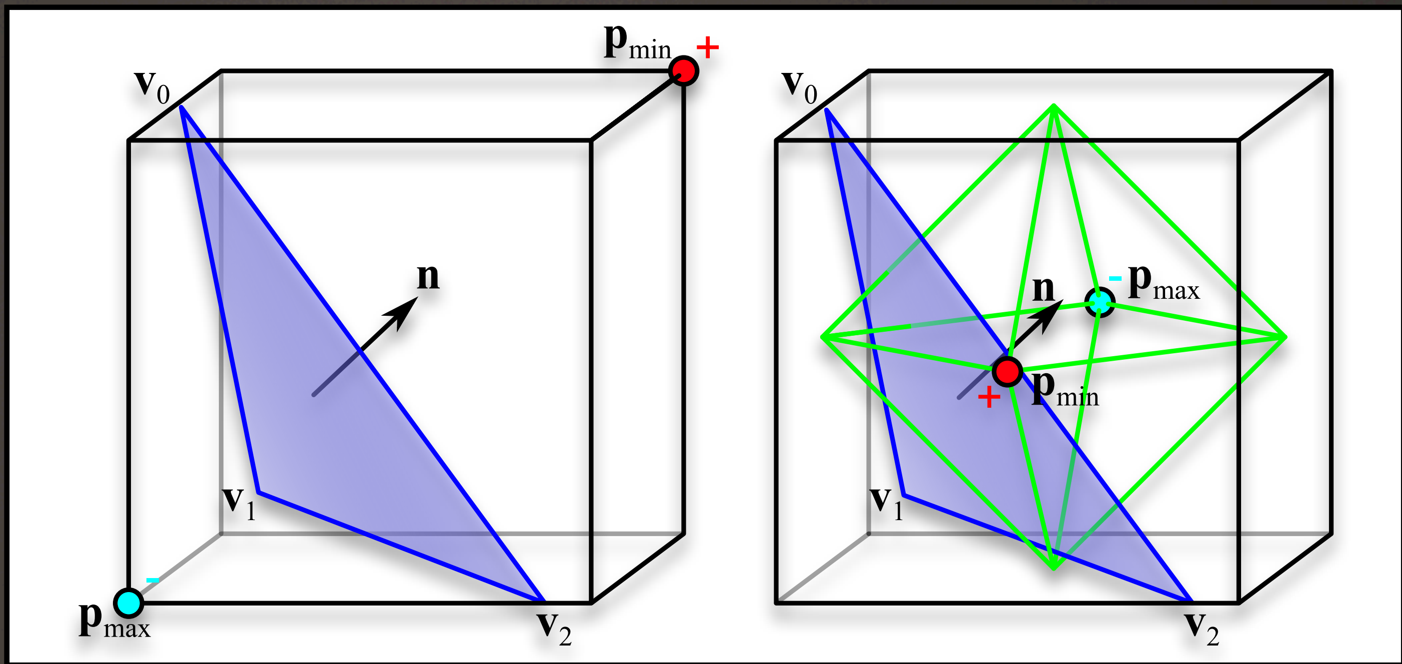


Conservative Thin

Triangle/Voxel Overlap

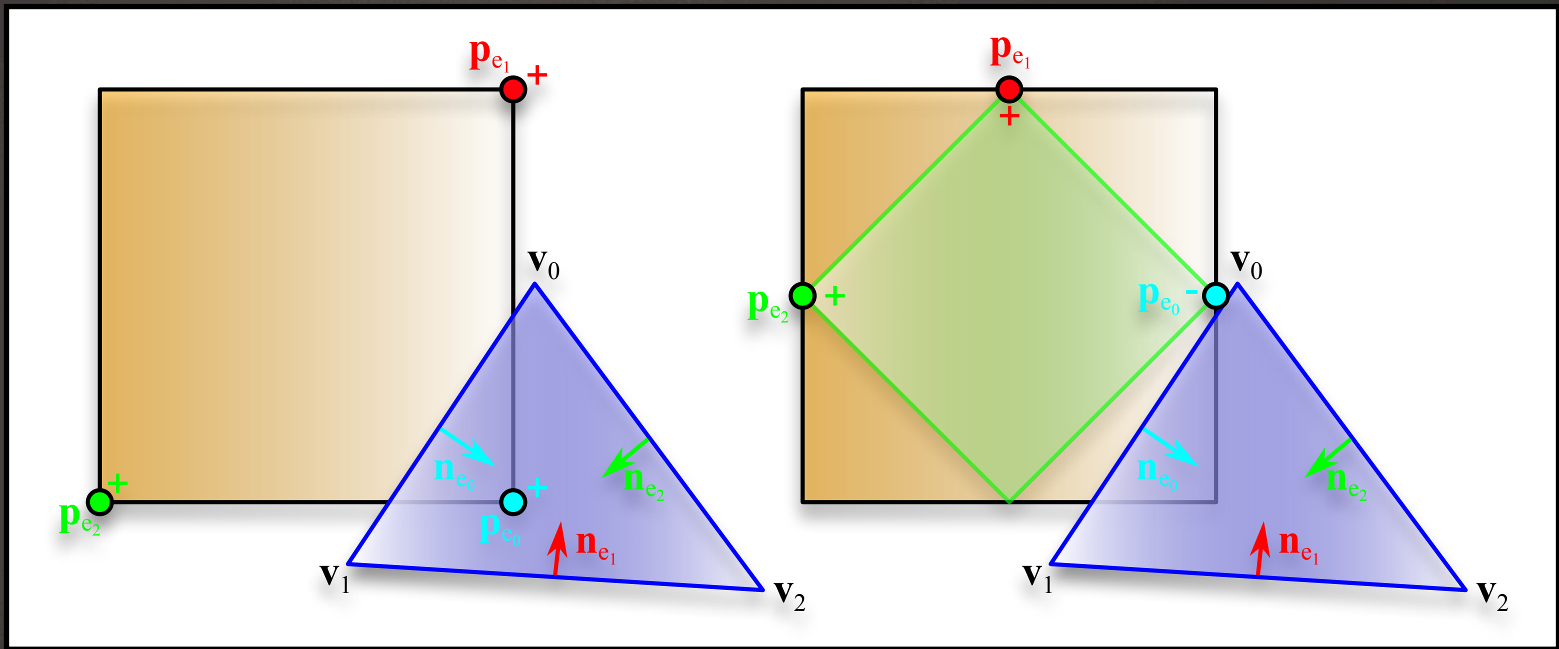
- Reduce the set of potential voxel intersections to only those that overlap the axis-aligned bounding volume of the triangle
- Iterate over this reduced set of voxels and discard any that do not intersect the triangle's plane
- If the triangle plane divides the voxels test all three of its 2D planar projections to confirm overlap

3D Voxel Overlap



Conservative Thin

2D Box Overlap



Conservative Thin

Optimization

- Pre-compute all per-triangle variables
- Determine the dominant normal direction
  - select the orthogonal plane of maximal projection (XY, YZ, or ZX)
  - iterate over the component axes
- Test the 2D projected overlap with the orthogonal plane of maximal projection first
- Depth intersection test to determine the minimal necessary range to iterate over
- Test the remaining two planar projections for overlap

Pseudocode

function conservativeVoxelize($\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\text{min}}, \mathbf{b}_{\text{max}}, \mathit{unswizzle}$)

  $\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\text{mod}3} - \mathbf{v}_i$

  $\mathbf{n} \leftarrow \text{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

  $\mathbf{n}_{\mathbf{e}_i}^{\text{XY}} \leftarrow \text{sign}\left(\mathbf{n}_{\text{z}}\right) \cdot \left(-\mathbf{e}_{i,\text{y}}, \mathbf{e}_{i,\text{x}}\right)^{\text{T}}$

  $\mathbf{n}_{\mathbf{e}_i}^{\text{YZ}} \leftarrow \text{sign}\left(\mathbf{n}_{\text{x}}\right) \cdot \left(-\mathbf{e}_{i,\text{z}}, \mathbf{e}_{i,\text{y}}\right)^{\text{T}}$

  $\mathbf{n}_{\mathbf{e}_i}^{\text{ZX}} \leftarrow \text{sign}\left(\mathbf{n}_{\text{y}}\right) \cdot \left(-\mathbf{e}_{i,\text{x}}, \mathbf{e}_{i,\text{z}}\right)^{\text{T}}$

  $d_{\mathbf{e}_i}^{\text{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\text{XY}}, \mathbf{v}_{i,\text{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\text{x}}^{\text{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\text{y}}^{\text{XY}}\right)$

  $d_{\mathbf{e}_i}^{\text{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\text{YZ}}, \mathbf{v}_{i,\text{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\text{x}}^{\text{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\text{y}}^{\text{YZ}}\right)$

  $d_{\mathbf{e}_i}^{\text{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\text{ZX}}, \mathbf{v}_{i,\text{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\text{x}}^{\text{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\text{y}}^{\text{ZX}}\right)$

  $\mathbf{n} \leftarrow \text{sign}\left(\mathbf{n}_{\text{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\text{min}} < z_{\text{max}}$

  $d_{\text{min}} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\text{x}}) - \max(0, \mathbf{n}_{\text{y}})$

  $d_{\text{max}} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\text{x}}) - \min(0, \mathbf{n}_{\text{y}})$

  for $\mathbf{p}_{\text{x}} \leftarrow \mathbf{b}_{\text{min,x}}, \ldots, \mathbf{b}_{\text{max,x}}$ **do**

    for $\mathbf{p}_{\text{y}} \leftarrow \mathbf{b}_{\text{min,y}}, \ldots, \mathbf{b}_{\text{max,y}}$ **do**

      if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\text{XY}}, \mathbf{p}_{\text{xy}} \right\rangle + d_{\mathbf{e}_i}^{\text{XY}} \geq 0\right)$ **then**

        $z_{\text{min}} \leftarrow \max\left(\mathbf{b}_{\text{min,z}}, \left\lfloor \left(-\left\langle \mathbf{n}_{\text{xy}}, \mathbf{p}_{\text{xy}} \right\rangle + d_{\text{min}}\right) \frac{1}{\mathbf{n}_{\text{z}}} \right\rfloor\right)$

        $z_{\text{max}} \leftarrow \min\left(\mathbf{b}_{\text{max,z}}, \left\lceil \left(-\left\langle \mathbf{n}_{\text{xy}}, \mathbf{p}_{\text{xy}} \right\rangle + d_{\text{max}}\right) \frac{1}{\mathbf{n}_{\text{z}}} \right\rceil\right)$

        for $\mathbf{p}_{\text{z}} \leftarrow z_{\text{min}}, \ldots, z_{\text{max}}$ **do**

          if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\text{YZ}}, \mathbf{p}_{\text{xy}} \right\rangle + d_{\mathbf{e}_i}^{\text{YZ}} \geq 0 \wedge \left\langle \mathbf{n}_{\mathbf{e}_i}^{\text{ZX}}, \mathbf{p}_{\text{xy}} \right\rangle + d_{\mathbf{e}_i}^{\text{ZX}} \geq 0\right)$ **then**

            $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

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Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

- $\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\bmod 3} - \mathbf{v}_i$
- $\mathbf{n} \leftarrow \text{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$
- $\mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$
- $\mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$
- $\mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$
- $d^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{y}}\right)$
- $d^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{y}}\right)$
- $d^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{y}}\right)$
- $\mathbf{n} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$
- $d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$
- $d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$
- **for** $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**
  - **for** $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**
    - **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{XY}}_{\mathbf{e}_i} \geq 0\right)$ **then**
      - $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$
      - $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$
      - **for** $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**
        - **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{ZX}}_{\mathbf{e}_i} \geq 0\right)$ **then**
          - $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Precompute Variables

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Pseudocode

function conservativeVoxelize($\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle}$)

  $\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\bmod 3} - \mathbf{v}_i$

  $\mathbf{n} \leftarrow \text{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

  $\mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

  $\mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

  $\mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

  $d_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{XY}}\right)$

  $d_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{YZ}}\right)$

  $d_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{ZX}}\right)$

  $\mathbf{n} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

  $d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

  $d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

  for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

    for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

      if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{XY}} \geq 0\right)$ **then**

        $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

        $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

          for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

            if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{YZ}} \geq 0 \wedge \left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{ZX}} \geq 0\right)$ **then**

              $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

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Pseudocode

function conservativeVoxelize($\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle}$)

  $\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\bmod 3} - \mathbf{v}_i$

  $\mathbf{n} \leftarrow \text{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

  $\mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

  $\mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

  $\mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

  $d^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{y}}\right)$

  $d^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{y}}\right)$

  $d^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{y}}\right)$

  $\mathbf{n} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

  $d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

  $d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

  for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

    for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

      if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{XY}}_{\mathbf{e}_i} \geq 0\right)$ **then**

        $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

        $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

          for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

            if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{ZX}}_{\mathbf{e}_i} \geq 0\right)$ **then**

              $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Iterate over maximal plane

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

$\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1) \bmod 3} - \mathbf{v}_i$

$\mathbf{n} \leftarrow \text{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

$d_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{XY}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{YZ}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{ZX}}\right)$

$\mathbf{n} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

  for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

    if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{XY}} \geq 0 \right)$ **then**

      $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

      $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

      for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

        if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{YZ}} \geq 0 \land \left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{ZX}} \geq 0 \right)$ **then**

          $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

  $\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\mathrm{mod}3} - \mathbf{v}_i$

  $\mathbf{n} \leftarrow \mathrm{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

  $\mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

  $\mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

  $\mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

  $d_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{XY}}\right)$

  $d_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{YZ}}\right)$

  $d_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{ZX}}\right)$

  $\mathbf{n} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

  $d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

  $d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

  for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

    for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

      if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{XY}} \geq 0 \right)$ **then**

        $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor \right)$

        $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil \right)$

        for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

          if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{YZ}} \geq 0 \land \left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{ZX}} \geq 0 \right)$ **then**

            $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

maximal plane test

Pseudocode

function conservativeVoxelize($\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle}$)

$\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\mathrm{mod}3} - \mathbf{v}_i$

$\mathbf{n} \leftarrow \mathrm{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

$d_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{XY}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{YZ}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{ZX}}\right)$

$\mathbf{n} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

  for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

    if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{XY}} \geq 0 \right)$ **then**

      $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

      $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

        for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

          if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{YZ}} \geq 0 \wedge \left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{ZX}} \geq 0 \right)$ **then**

            $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Pseudocode

function conservativeVoxelize($\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, unswizzle$)

$\quad \mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\mathrm{mod}3} - \mathbf{v}_i$

$\quad \mathbf{n} \leftarrow \mathrm{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

$\quad \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

$\quad \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

$\quad \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

$\quad d_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{XY}}\right)$

$\quad d_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{YZ}}\right)$

$\quad d_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{ZX}}\right)$

$\quad \mathbf{n} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$\quad d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$\quad d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

$\quad$ **for** $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

$\qquad$ **for** $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

$\qquad\quad$ **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{XY}} \geq 0 \right)$ **then**

$\qquad\qquad z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

$\qquad\qquad z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

$\qquad\qquad$ **for** $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

$\qquad\qquad\quad$ **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{YZ}} \geq 0 \wedge \left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{ZX}} \geq 0 \right)$ **then**

$\qquad\qquad\qquad V\left[unswizzle \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Z-range calc and iterate

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\text{min}}, \mathbf{b}_{\text{max}}, unswizzle)$

$\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\text{mod}3} - \mathbf{v}_i$

$\mathbf{n} \leftarrow \text{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

$\mathbf{n}^{\text{XY}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\text{z}}\right) \cdot \left(-\mathbf{e}_{i,\text{y}}, \mathbf{e}_{i,\text{x}}\right)^{\text{T}}$

$\mathbf{n}^{\text{YZ}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\text{x}}\right) \cdot \left(-\mathbf{e}_{i,\text{z}}, \mathbf{e}_{i,\text{y}}\right)^{\text{T}}$

$\mathbf{n}^{\text{ZX}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\text{y}}\right) \cdot \left(-\mathbf{e}_{i,\text{x}}, \mathbf{e}_{i,\text{z}}\right)^{\text{T}}$

$d^{\text{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\text{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\text{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\text{XY}}_{\mathbf{e}_i,\text{x}}\right) + \max\left(0, \mathbf{n}^{\text{XY}}_{\mathbf{e}_i,\text{y}}\right)$

$d^{\text{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\text{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\text{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\text{YZ}}_{\mathbf{e}_i,\text{x}}\right) + \max\left(0, \mathbf{n}^{\text{YZ}}_{\mathbf{e}_i,\text{y}}\right)$

$d^{\text{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\text{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\text{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\text{ZX}}_{\mathbf{e}_i,\text{x}}\right) + \max\left(0, \mathbf{n}^{\text{ZX}}_{\mathbf{e}_i,\text{y}}\right)$

$\mathbf{n} \leftarrow \text{sign}\left(\mathbf{n}_{\text{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\text{min}} < z_{\text{max}}$

$d_{\text{min}} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\text{x}}) - \max(0, \mathbf{n}_{\text{y}})$

$d_{\text{max}} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\text{x}}) - \min(0, \mathbf{n}_{\text{y}})$

for $\mathbf{p}_{\text{x}} \leftarrow \mathbf{b}_{\text{min,x}}, \ldots, \mathbf{b}_{\text{max,x}}$ **do**

for $\mathbf{p}_{\text{y}} \leftarrow \mathbf{b}_{\text{min,y}}, \ldots, \mathbf{b}_{\text{max,y}}$ **do**

if $\forall^2_{i=0} \left(\left\langle \mathbf{n}^{\text{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\text{xy}} \right\rangle + d^{\text{XY}}_{\mathbf{e}_i} \geq 0\right)$ **then**

$z_{\text{min}} \leftarrow \max\left(\mathbf{b}_{\text{min,z}}, \left\lfloor \left(-\left\langle \mathbf{n}_{\text{xy}}, \mathbf{p}_{\text{xy}} \right\rangle + d_{\text{min}}\right) \frac{1}{\mathbf{n}_{\text{z}}} \right\rfloor\right)$

$z_{\text{max}} \leftarrow \min\left(\mathbf{b}_{\text{max,z}}, \left\lceil \left(-\left\langle \mathbf{n}_{\text{xy}}, \mathbf{p}_{\text{xy}} \right\rangle + d_{\text{max}}\right) \frac{1}{\mathbf{n}_{\text{z}}} \right\rceil\right)$

for $\mathbf{p}_{\text{z}} \leftarrow z_{\text{min}}, \ldots, z_{\text{max}}$ **do**

if $\forall^2_{i=0} \left(\left\langle \mathbf{n}^{\text{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\text{xy}} \right\rangle + d^{\text{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\text{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\text{xy}} \right\rangle + d^{\text{ZX}}_{\mathbf{e}_i} \geq 0\right)$ **then**

$V\left[unswizzle \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

$\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\bmod 3} - \mathbf{v}_i$

$\mathbf{n} \leftarrow \operatorname{cross}(\mathbf{e}_0, \mathbf{e}_1)$

$\mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow \operatorname{sign}(\mathbf{n}_{\mathrm{z}}) \cdot (-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}})^{\mathrm{T}}$

$\mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow \operatorname{sign}(\mathbf{n}_{\mathrm{x}}) \cdot (-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}})^{\mathrm{T}}$

$\mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow \operatorname{sign}(\mathbf{n}_{\mathrm{y}}) \cdot (-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}})^{\mathrm{T}}$

$d^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$d^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$d^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$\mathbf{n} \leftarrow \operatorname{sign}(\mathbf{n}_{\mathrm{z}}) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{XY}}_{\mathbf{e}_i} \geq 0 \right)$ **then**

$z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

$z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{ZX}}_{\mathbf{e}_i} \geq 0 \right)$ **then**

$V[\mathit{unswizzle} \cdot \mathbf{p}] \leftarrow$ **true**

end function

remaining plane tests

Pseudocode

function conservativeVoxelize($\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle}$)

  $\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\bmod 3} - \mathbf{v}_i$

  $\mathbf{n} \leftarrow \operatorname{cross}(\mathbf{e}_0, \mathbf{e}_1)$

  $\mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow \operatorname{sign}(\mathbf{n}_{\mathrm{z}}) \cdot (-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}})^{\mathrm{T}}$

  $\mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow \operatorname{sign}(\mathbf{n}_{\mathrm{x}}) \cdot (-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}})^{\mathrm{T}}$

  $\mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow \operatorname{sign}(\mathbf{n}_{\mathrm{y}}) \cdot (-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}})^{\mathrm{T}}$

  $d^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{y}}\right)$

  $d^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{y}}\right)$

  $d^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{y}}\right)$

  $\mathbf{n} \leftarrow \operatorname{sign}(\mathbf{n}_{\mathrm{z}}) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

  $d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

  $d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

  for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

    for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

      if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{XY}}_{\mathbf{e}_i} \geq 0 \right)$ **then**

        $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

        $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

          for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

            if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{ZX}}_{\mathbf{e}_i} \geq 0 \right)$ **then**

              $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

$\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\mathrm{mod}3} - \mathbf{v}_i$

$\mathbf{n} \leftarrow \mathrm{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

$\mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

$\mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

$\mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

$d^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$d^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$d^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$\mathbf{n} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

  for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

    if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{XY}}_{\mathbf{e}_i} \geq 0\right)$ **then**

      $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

      $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

      for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

        if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{ZX}}_{\mathbf{e}_i} \geq 0\right)$ **then**

          $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

unswizzle and store

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

$\quad \mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\mathrm{mod}3} - \mathbf{v}_i$

$\quad \mathbf{n} \leftarrow \mathrm{cross}\,(\mathbf{e}_0, \mathbf{e}_1)$

$\quad \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow \mathrm{sign}\,(\mathbf{n}_{\mathrm{z}}) \cdot (-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}})^{\mathrm{T}}$

$\quad \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow \mathrm{sign}\,(\mathbf{n}_{\mathrm{x}}) \cdot (-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}})^{\mathrm{T}}$

$\quad \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow \mathrm{sign}\,(\mathbf{n}_{\mathrm{y}}) \cdot (-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}})^{\mathrm{T}}$

$\quad d^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$\quad d^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$\quad d^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$\quad \mathbf{n} \leftarrow \mathrm{sign}\,(\mathbf{n}_{\mathrm{z}}) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$\quad d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$\quad d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

$\quad$ **for** $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

$\qquad$ **for** $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

$\qquad\quad$ **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{XY}}_{\mathbf{e}_i} \geq 0\right)$ **then**

$\qquad\qquad z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

$\qquad\qquad z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

$\qquad\qquad$ **for** $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

$\qquad\qquad\quad$ **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{ZX}}_{\mathbf{e}_i} \geq 0\right)$ **then**

$\qquad\qquad\qquad V\,[\mathit{unswizzle} \cdot \mathbf{p}] \leftarrow$ **true**

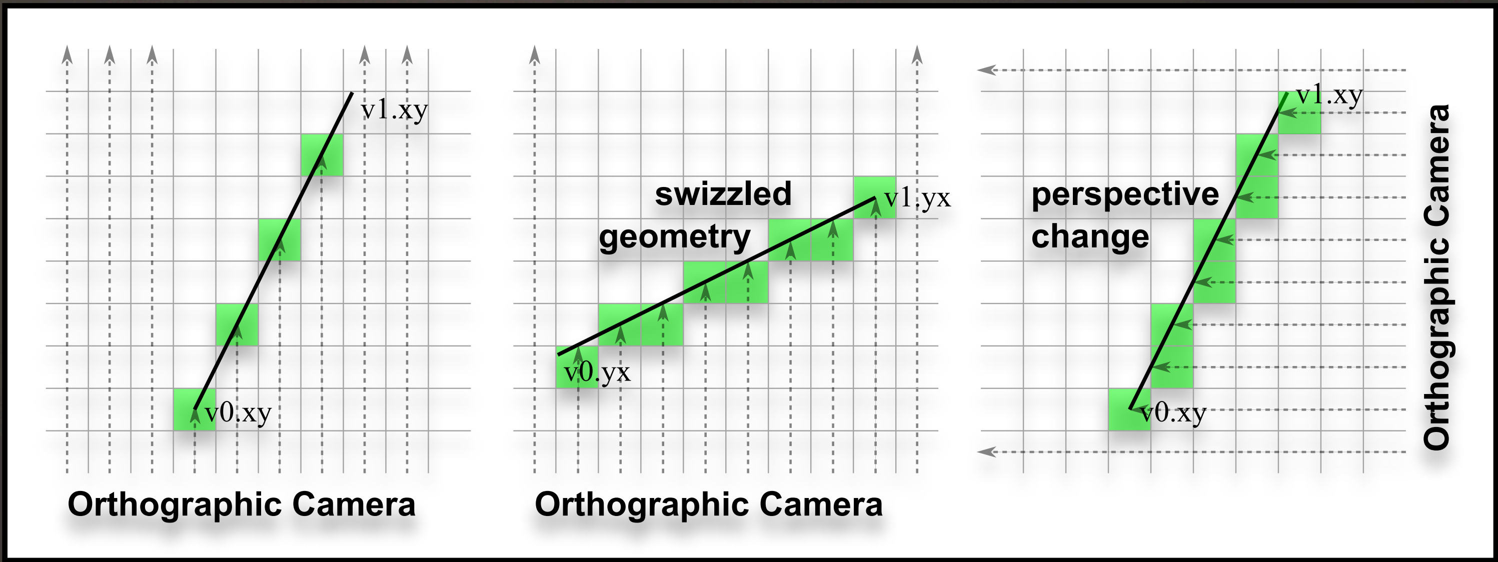
end function

Fragment-Parallel Voxelization

- Improve parallelism by breaking up large triangles
- Use the existing rasterization based pipeline to accomplish this
- 2 potential problems to overcome
  1) Gaps within triangles caused by an overly oblique camera angle
  2) Gaps between triangles caused OpenGL’s rasterization rules

(1) Projection

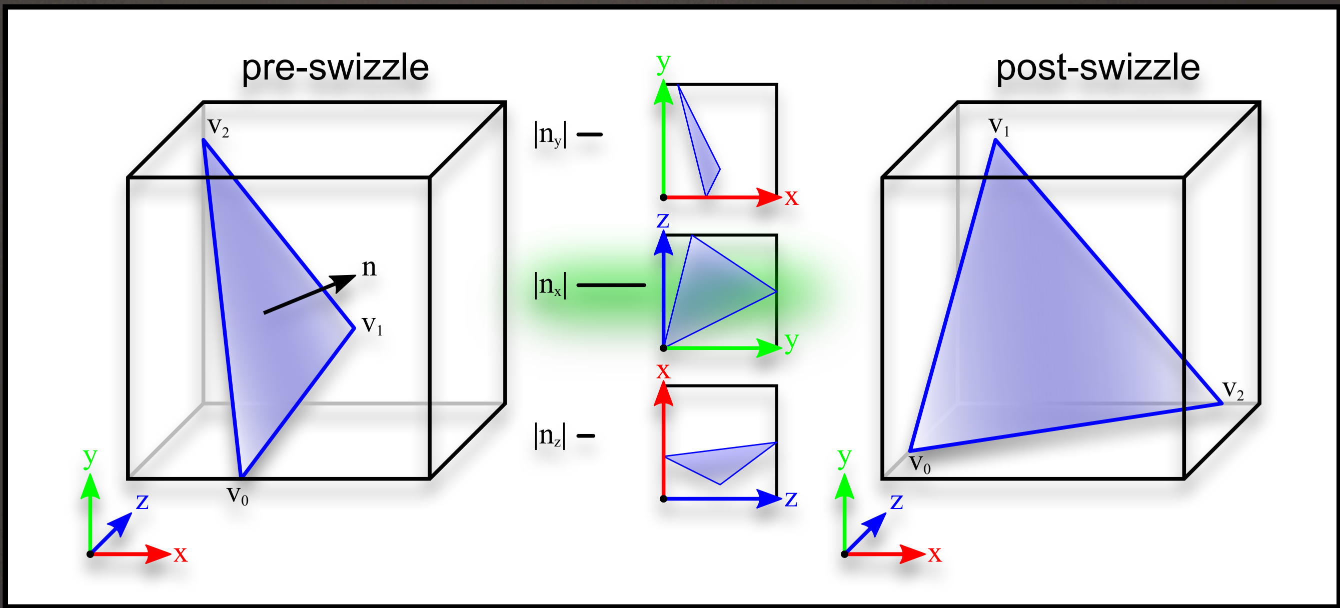
- Can solve the first problem by projecting the input geometry onto the dominant plane



Oregon State University

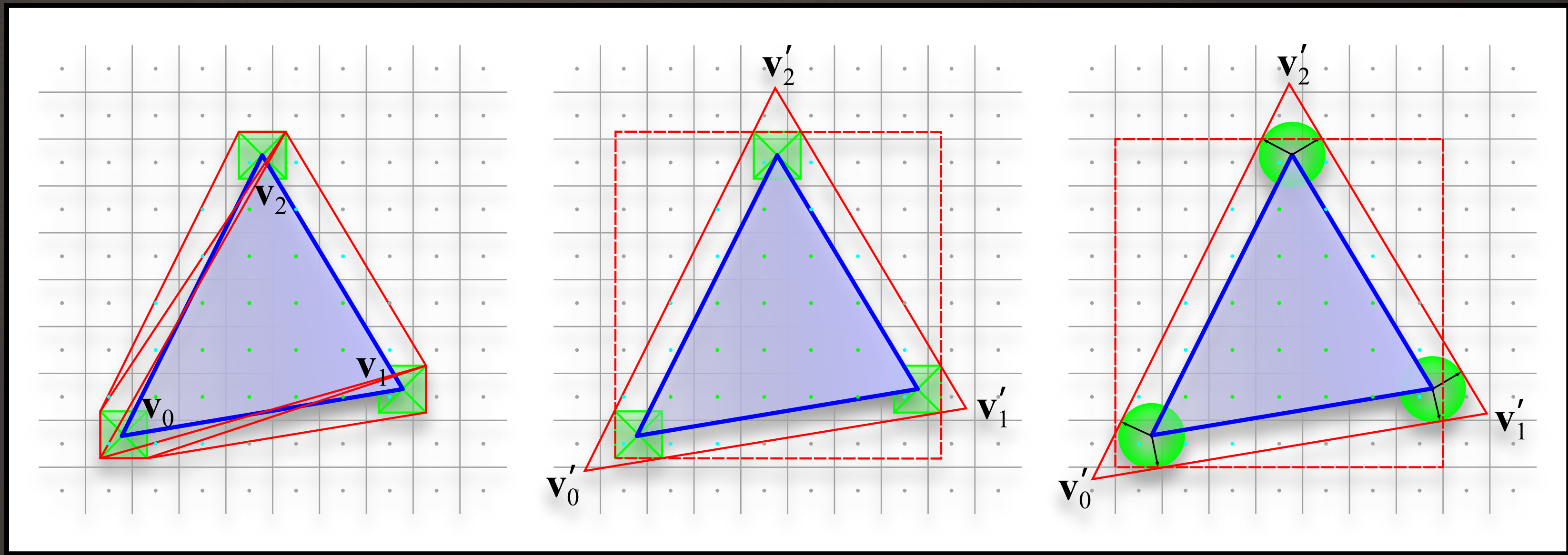
3D Projection

- The appropriate projection plane is selected by the dominant normal direction



(2) Conservative Rasterization

- Can solve the second problem with “conservative rasterization”



Hasselgren (A) Hasselgren (B) Hertel et al.

Conservative Rasterization

- Conservative rasterization dilates the input triangles such that if any part of a pixel is covered by the original triangle the pixel center is covered by the dilated triangle

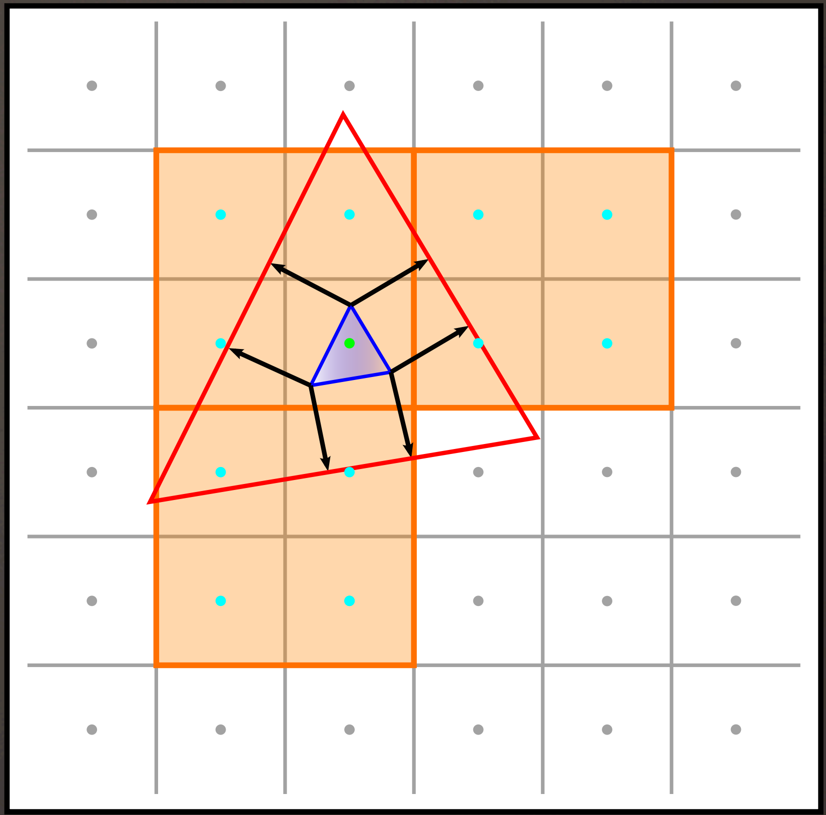
$$\mathbf{v}'_i = \mathbf{v}_i + l\left(\frac{\mathbf{e}_{i-1}}{\mathbf{e}_{i-1}\cdot\mathbf{n}_{\mathbf{e}_i}} + \frac{\mathbf{e}_i}{\mathbf{e}_i\cdot\mathbf{n}_{\mathbf{e}_{i-1}}}\right)$$

Quad Utilization

- Pixels actually processed in batches of 2x2 “quads” to provide derivative information
- A sub-voxel sized triangle may utilize only 25% of threads allocated
- Worse when triangle dilation is taken into account

Dilated Triangle Utilization

- This triangle exhibits only 8.33% thread utilization



Pseudocode

function conservativeVoxelize($\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle}$)

$\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\mathrm{mod}3} - \mathbf{v}_i$

$\mathbf{n} \leftarrow \mathrm{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

$d_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{XY}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{YZ}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{ZX}}\right)$

$\mathbf{n} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

  for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

    if $\forall_{i=0}^{2}\left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{XY}} \geq 0\right)$ **then**

      $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

      $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

      for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

        if $\forall_{i=0}^{2}\left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{YZ}} \geq 0 \wedge \left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{ZX}} \geq 0\right)$ **then**

          $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

  $\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\bmod 3} - \mathbf{v}_i$

  $\mathbf{n} \leftarrow \mathrm{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

  $\mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

  $\mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

  $\mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

  $d^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{y}}\right)$

  $d^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{y}}\right)$

  $d^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{y}}\right)$

  $\mathbf{n} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

  $d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

  $d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

  for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

    for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

      if $\forall^{2}_{i=0} \left(\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{XY}}_{\mathbf{e}_i} \geq 0\right)$ **then**

        $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

        $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

        for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

          if $\forall^{2}_{i=0} \left(\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{ZX}}_{\mathbf{e}_i} \geq 0\right)$ **then**

            $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Geometry Shader

`flat ->`

fragment shader

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

$\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\mathrm{mod}3} - \mathbf{v}_i$

$\mathbf{n} \leftarrow \mathrm{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

$d_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{XY}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{YZ}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{ZX}}\right)$

$\mathbf{n} \leftarrow \mathrm{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

  for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

    if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{XY}} \geq 0\right)$ **then**

      $z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

      $z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

      for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

        if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{YZ}} \geq 0 \wedge \left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{ZX}} \geq 0\right)$ **then**

          $V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

$\quad \mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\bmod 3} - \mathbf{v}_i$

$\quad \mathbf{n} \leftarrow \text{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

$\quad \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

$\quad \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

$\quad \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

$\quad d^{\mathrm{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$\quad d^{\mathrm{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$\quad d^{\mathrm{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{x}}\right) + \max\left(0, \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i,\mathrm{y}}\right)$

$\quad \mathbf{n} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$\quad d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$\quad d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

$\quad$ **for** $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

$\quad\quad$ **for** $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

handled implicitly

$\quad\quad\quad$ **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{XY}}_{\mathbf{e}_i} \geq 0\right)$ **then**

$\quad\quad\quad\quad z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

$\quad\quad\quad\quad z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

$\quad\quad\quad\quad$ **for** $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

$\quad\quad\quad\quad\quad$ **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}^{\mathrm{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\mathrm{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d^{\mathrm{ZX}}_{\mathbf{e}_i} \geq 0\right)$ **then**

$\quad\quad\quad\quad\quad\quad V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Pseudocode

function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$

$\quad \mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\mathrm{mod}3} - \mathbf{v}_i$

$\quad \mathbf{n} \leftarrow \mathrm{cross}\,(\mathbf{e}_0, \mathbf{e}_1)$

$\quad \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow \mathrm{sign}\,(\mathbf{n}_{\mathrm{z}}) \cdot (-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}})^{\mathrm{T}}$

$\quad \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow \mathrm{sign}\,(\mathbf{n}_{\mathrm{x}}) \cdot (-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}})^{\mathrm{T}}$

$\quad \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow \mathrm{sign}\,(\mathbf{n}_{\mathrm{y}}) \cdot (-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}})^{\mathrm{T}}$

$\quad d_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{XY}}\right)$

$\quad d_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{YZ}}\right)$

$\quad d_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{ZX}}\right)$

$\quad \mathbf{n} \leftarrow \mathrm{sign}\,(\mathbf{n}_{\mathrm{z}}) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$\quad d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$\quad d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

$\quad$ **for** $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

$\qquad$ **for** $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

$\qquad\quad$ **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{XY}} \geq 0 \right)$ **then**

$\qquad\qquad z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

$\qquad\qquad z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

$\qquad\qquad$ **for** $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

$\qquad\qquad\quad$ **if** $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{YZ}} \geq 0 \wedge \left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{ZX}} \geq 0 \right)$ **then**

$\qquad\qquad\qquad V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

Pseudocode

function conservativeVoxelize($\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle}$)

$\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\bmod 3} - \mathbf{v}_i$

$\mathbf{n} \leftarrow \text{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{y}}, \mathbf{e}_{i,\mathrm{x}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{x}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{z}}, \mathbf{e}_{i,\mathrm{y}}\right)^{\mathrm{T}}$

$\mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{y}}\right) \cdot \left(-\mathbf{e}_{i,\mathrm{x}}, \mathbf{e}_{i,\mathrm{z}}\right)^{\mathrm{T}}$

$d_{\mathbf{e}_i}^{\mathrm{XY}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{v}_{i,\mathrm{xy}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{XY}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{XY}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{YZ}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{v}_{i,\mathrm{yz}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{YZ}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{YZ}}\right)$

$d_{\mathbf{e}_i}^{\mathrm{ZX}} \leftarrow -\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{v}_{i,\mathrm{zx}} \right\rangle + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{x}}^{\mathrm{ZX}}\right) + \max\left(0, \mathbf{n}_{\mathbf{e}_i,\mathrm{y}}^{\mathrm{ZX}}\right)$

$\mathbf{n} \leftarrow \text{sign}\left(\mathbf{n}_{\mathrm{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$

$d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\mathrm{x}}) - \max(0, \mathbf{n}_{\mathrm{y}})$

$d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\mathrm{x}}) - \min(0, \mathbf{n}_{\mathrm{y}})$

for $\mathbf{p}_{\mathrm{x}} \leftarrow \mathbf{b}_{\min,\mathrm{x}}, \ldots, \mathbf{b}_{\max,\mathrm{x}}$ **do**

for $\mathbf{p}_{\mathrm{y}} \leftarrow \mathbf{b}_{\min,\mathrm{y}}, \ldots, \mathbf{b}_{\max,\mathrm{y}}$ **do**

if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{XY}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{XY}} \geq 0\right)$ **then**

$z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\mathrm{z}}, \left\lfloor \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\min}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rfloor\right)$

$z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\mathrm{z}}, \left\lceil \left(-\left\langle \mathbf{n}_{\mathrm{xy}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\max}\right) \frac{1}{\mathbf{n}_{\mathrm{z}}} \right\rceil\right)$

for $\mathbf{p}_{\mathrm{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**

if $\forall_{i=0}^{2} \left(\left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{YZ}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{YZ}} \geq 0 \wedge \left\langle \mathbf{n}_{\mathbf{e}_i}^{\mathrm{ZX}}, \mathbf{p}_{\mathrm{xy}} \right\rangle + d_{\mathbf{e}_i}^{\mathrm{ZX}} \geq 0\right)$ **then**

$V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**

end function

fragment shader

Pseudocode

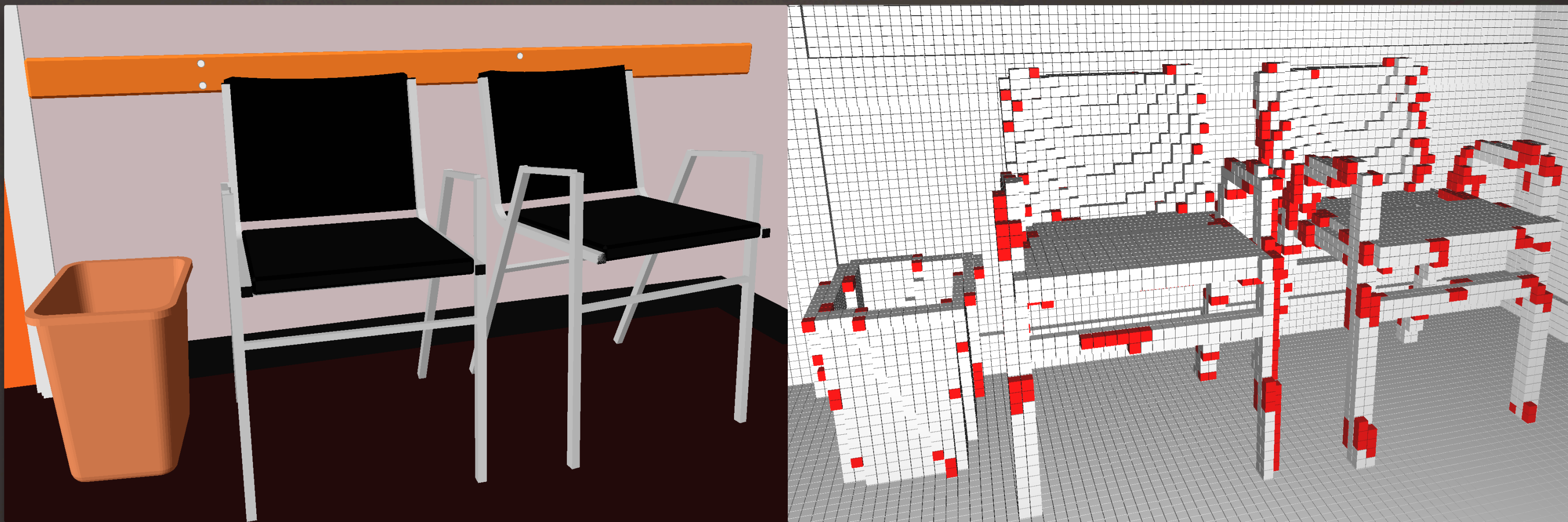
function conservativeVoxelize$(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2, \mathbf{b}_{\min}, \mathbf{b}_{\max}, \mathit{unswizzle})$
$\mathbf{e}_i \leftarrow \mathbf{v}_{(i+1)\bmod 3} - \mathbf{v}_i$
$\mathbf{n} \leftarrow \text{cross}\left(\mathbf{e}_0, \mathbf{e}_1\right)$
$\mathbf{n}^{\text{XY}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\text{z}}\right) \cdot \left(-\mathbf{e}_{i,\text{y}}, \mathbf{e}_{i,\text{x}}\right)^{\text{T}}$
$\mathbf{n}^{\text{YZ}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\text{x}}\right) \cdot \left(-\mathbf{e}_{i,\text{z}}, \mathbf{e}_{i,\text{y}}\right)^{\text{T}}$
$\mathbf{n}^{\text{ZX}}_{\mathbf{e}_i} \leftarrow \text{sign}\left(\mathbf{n}_{\text{y}}\right) \cdot \left(-\mathbf{e}_{i,\text{x}}, \mathbf{e}_{i,\text{z}}\right)^{\text{T}}$
$d^{\text{XY}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\text{XY}}_{\mathbf{e}_i}, \mathbf{v}_{i,\text{xy}} \right\rangle + \max\left(0, \mathbf{n}^{\text{XY}}_{\mathbf{e}_i,\text{x}}\right) + \max\left(0, \mathbf{n}^{\text{XY}}_{\mathbf{e}_i,\text{y}}\right)$
$d^{\text{YZ}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\text{YZ}}_{\mathbf{e}_i}, \mathbf{v}_{i,\text{yz}} \right\rangle + \max\left(0, \mathbf{n}^{\text{YZ}}_{\mathbf{e}_i,\text{x}}\right) + \max\left(0, \mathbf{n}^{\text{YZ}}_{\mathbf{e}_i,\text{y}}\right)$
$d^{\text{ZX}}_{\mathbf{e}_i} \leftarrow -\left\langle \mathbf{n}^{\text{ZX}}_{\mathbf{e}_i}, \mathbf{v}_{i,\text{zx}} \right\rangle + \max\left(0, \mathbf{n}^{\text{ZX}}_{\mathbf{e}_i,\text{x}}\right) + \max\left(0, \mathbf{n}^{\text{ZX}}_{\mathbf{e}_i,\text{y}}\right)$
$\mathbf{n} \leftarrow \text{sign}\left(\mathbf{n}_{\text{z}}\right) \cdot \mathbf{n}$ // ensures $z_{\min} < z_{\max}$
$d_{\min} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \max(0, \mathbf{n}_{\text{x}}) - \max(0, \mathbf{n}_{\text{y}})$
$d_{\max} \leftarrow \langle \mathbf{n}, \mathbf{v}_0 \rangle - \min(0, \mathbf{n}_{\text{x}}) - \min(0, \mathbf{n}_{\text{y}})$
for $\mathbf{p}_{\text{x}} \leftarrow \mathbf{b}_{\min,\text{x}}, \ldots, \mathbf{b}_{\max,\text{x}}$ **do**
for $\mathbf{p}_{\text{y}} \leftarrow \mathbf{b}_{\min,\text{y}}, \ldots, \mathbf{b}_{\max,\text{y}}$ **do**
if $\forall^2_{i=0} \left(\left\langle \mathbf{n}^{\text{XY}}_{\mathbf{e}_i}, \mathbf{p}_{\text{xy}} \right\rangle + d^{\text{XY}}_{\mathbf{e}_i} \geq 0 \right)$ **then**
$z_{\min} \leftarrow \max\left(\mathbf{b}_{\min,\text{z}}, \left\lfloor \left(-\left\langle \mathbf{n}_{\text{xy}}, \mathbf{p}_{\text{xy}} \right\rangle + d_{\min} \right) \frac{1}{\mathbf{n}_{\text{z}}} \right\rfloor \right)$
$z_{\max} \leftarrow \min\left(\mathbf{b}_{\max,\text{z}}, \left\lceil \left(-\left\langle \mathbf{n}_{\text{xy}}, \mathbf{p}_{\text{xy}} \right\rangle + d_{\max} \right) \frac{1}{\mathbf{n}_{\text{z}}} \right\rceil \right)$
for $\mathbf{p}_{\text{z}} \leftarrow z_{\min}, \ldots, z_{\max}$ **do**
if $\forall^2_{i=0} \left(\left\langle \mathbf{n}^{\text{YZ}}_{\mathbf{e}_i}, \mathbf{p}_{\text{xy}} \right\rangle + d^{\text{YZ}}_{\mathbf{e}_i} \geq 0 \wedge \left\langle \mathbf{n}^{\text{ZX}}_{\mathbf{e}_i}, \mathbf{p}_{\text{xy}} \right\rangle + d^{\text{ZX}}_{\mathbf{e}_i} \geq 0 \right)$ **then**
$V\left[\mathit{unswizzle} \cdot \mathbf{p}\right] \leftarrow$ **true**
end function

Computational v. Raster Intersection

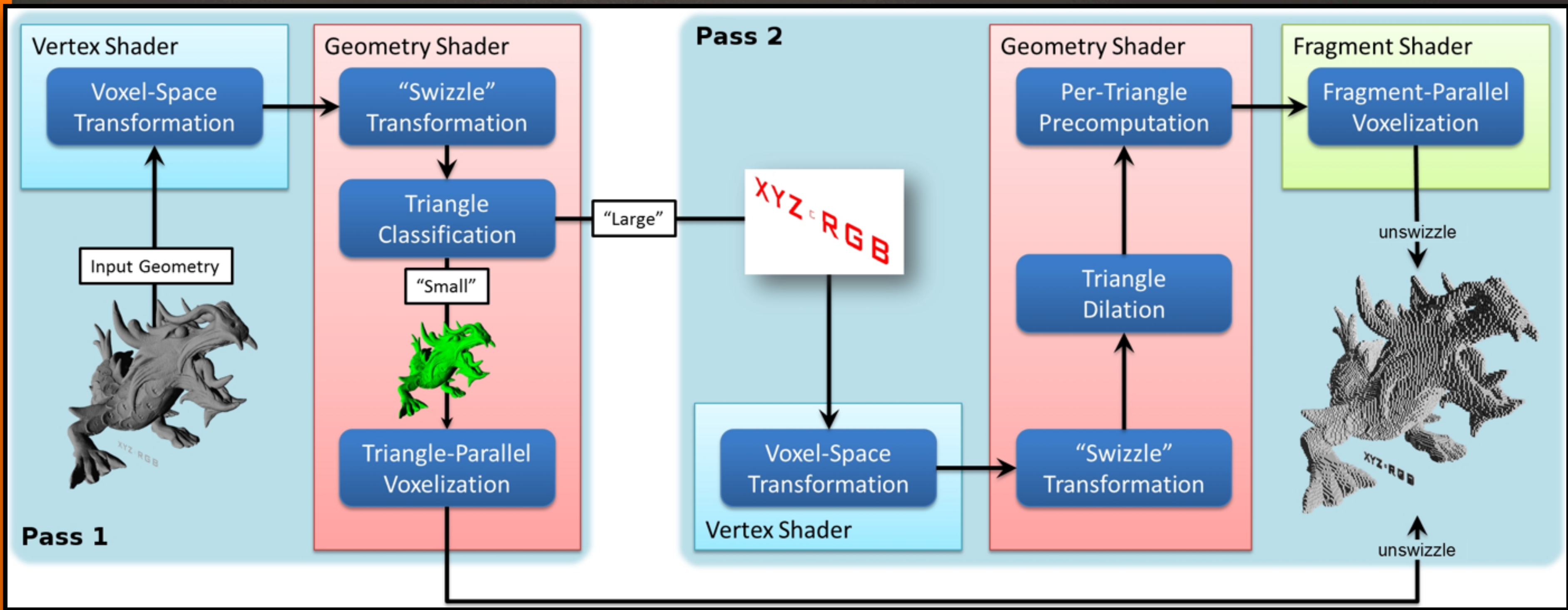
- Triangle dilation can produce overly conservative results leading to false positives during voxelization
- Maintaining a computational intersection test eliminates false positives

Computational v. Raster Intersection

- Red voxels indicate false positives



Full Pipeline



Attribute Interpolation

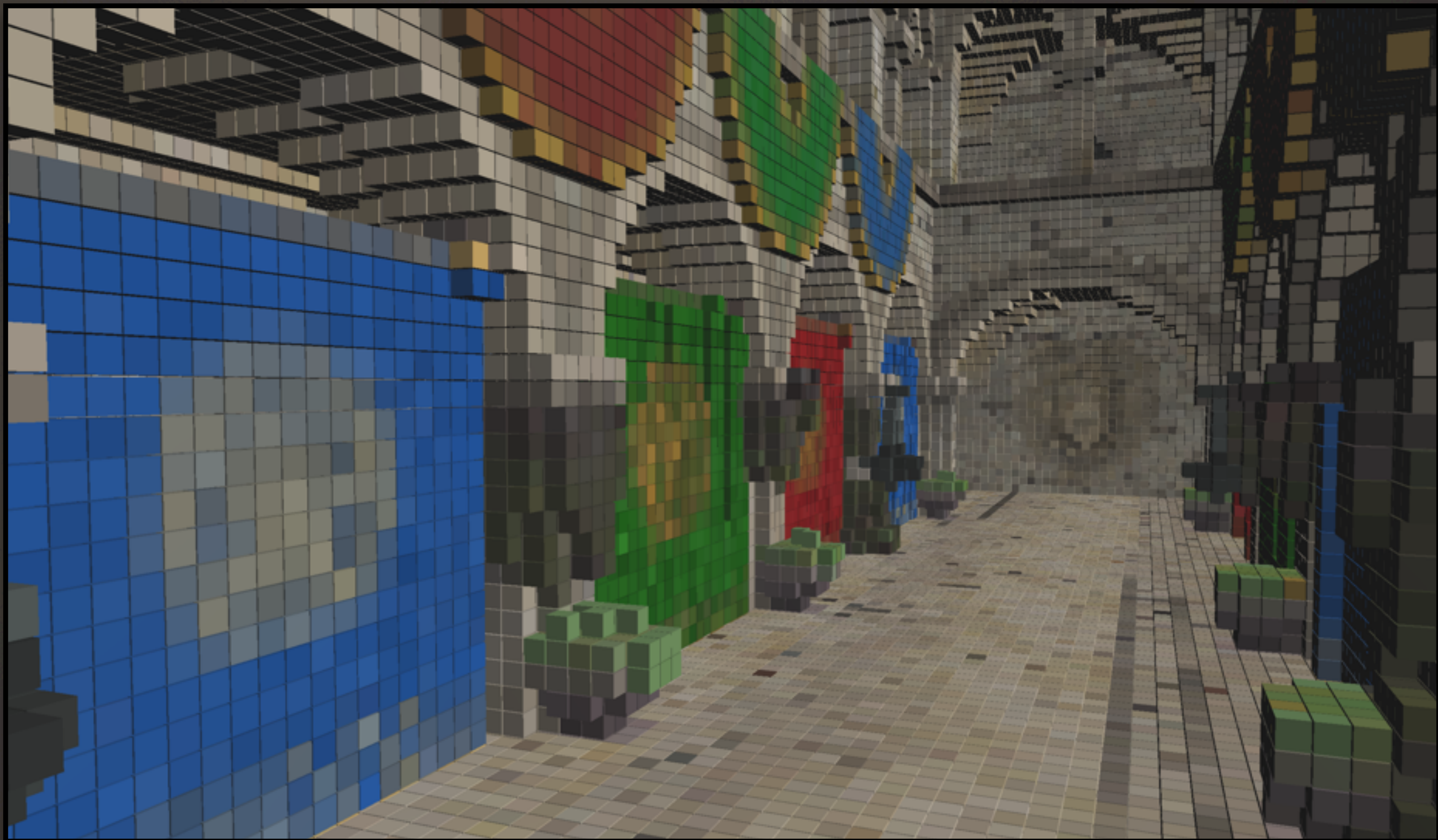
- Calculate barycentric coordinates of dilated triangle

$$\lambda_i\left(\mathbf{v}_i'\right) = \frac{\text{area}\left(\mathbf{v}_i', \mathbf{v}_{i+1}, \mathbf{v}_{i+2}\right)}{\text{area}\left(\mathbf{v}_0, \mathbf{v}_1, \mathbf{v}_2\right)}$$

- Apply to the attributes of the original triangle to calculate dilated attributes

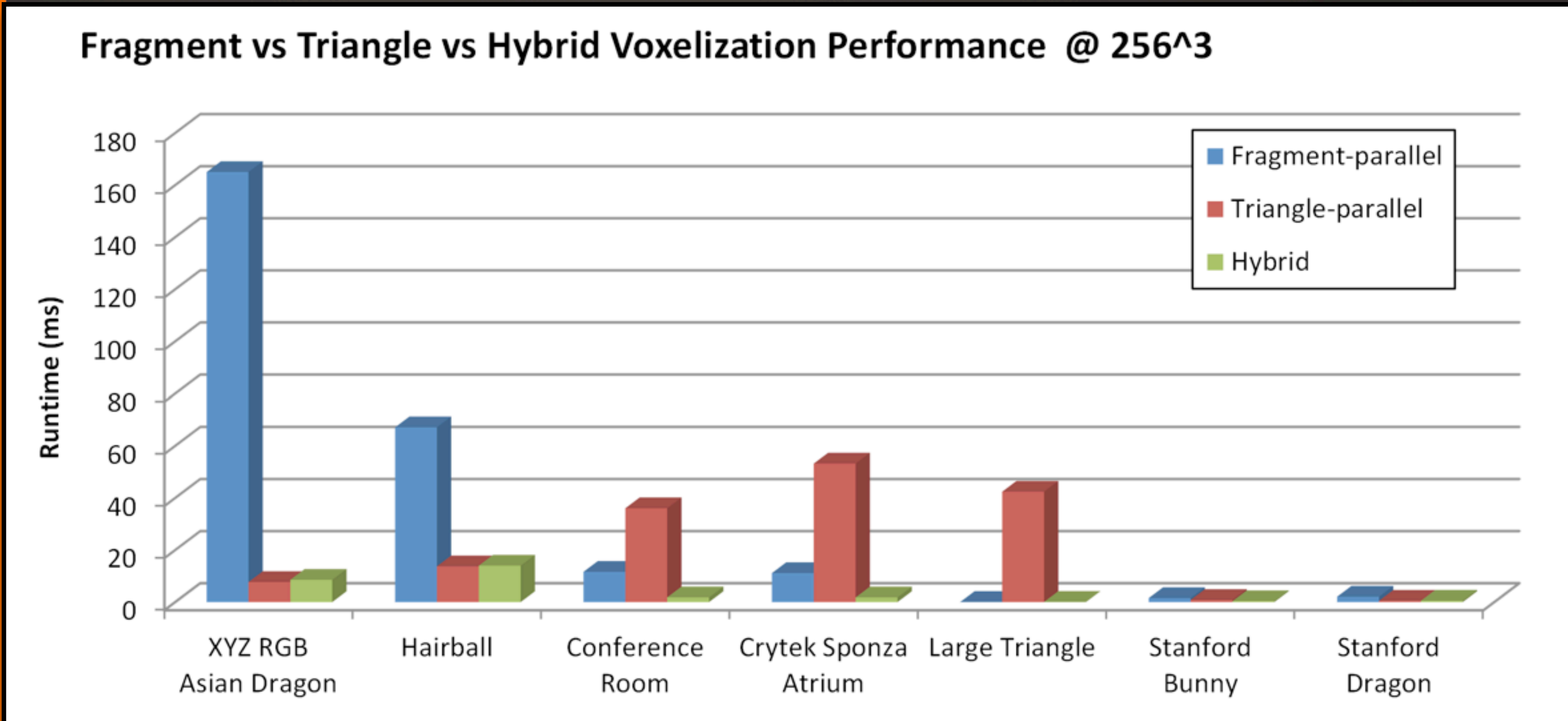
$$\mathbf{a}_i' = \lambda_0\left(\mathbf{v}_i'\right)\mathbf{a}_0 + \lambda_1\left(\mathbf{v}_i'\right)\mathbf{a}_1 + \lambda_2\left(\mathbf{v}_i'\right)\mathbf{a}_2$$

Color Voxelization (Sponza)

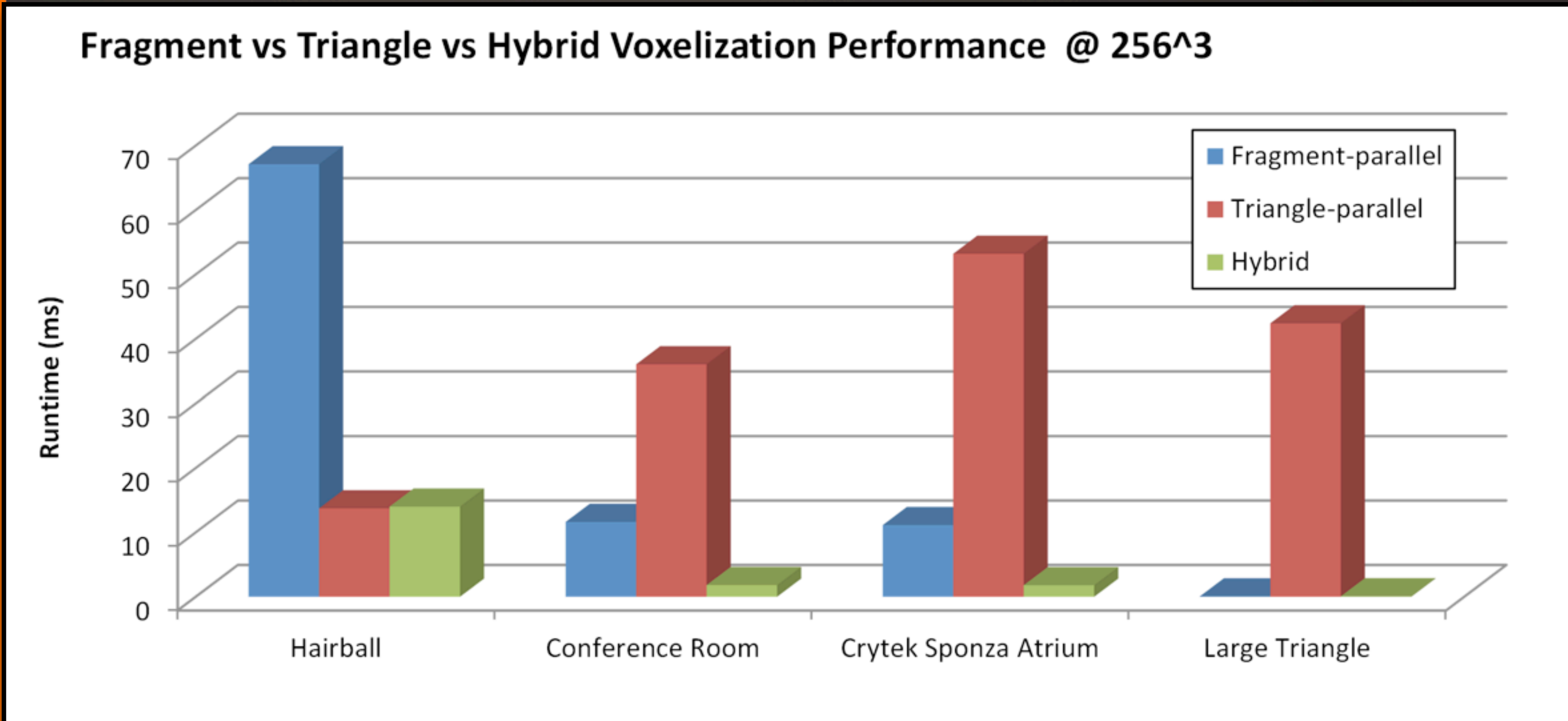


Original Image

Results


Fragment vs Triangle vs Hybrid Voxelization Performance @ 256^3
Runtime (ms)
0
20
40
60
80
100
120
140
160
180
Fragment-parallel
Triangle-parallel
Hybrid
XYZ RGB Asian Dragon
Hairball
Conference Room
Crytek Sponza Atrium
Large Triangle
Stanford Bunny
Stanford Dragon

Results


Fragment vs Triangle vs Hybrid Voxelization Performance @ 256^3
Runtime (ms)
70
60
50
40
30
20
10
0
Hairball
Conference Room
Crytek Sponza Atrium
Large Triangle
Fragment-parallel
Triangle-parallel
Hybrid

Conclusion

- Fastest available voxelization, even on less than state of the art hardware
- Easy to implement in current graphics APIs, avoids complex tiling assignments, sorting stages, and work/load balancing schemes
- Does not sacrifice quality of the voxelization in order to utilize the graphics pipeline, i.e. maintains robust computational intersection at all stages

Questions?

Results

Model	Grid size	6-separating (thin) binary voxelization						
		Triangle-parallel	Fragment-parallel	Hybrid @voxels^2	Pass 1/Pass 2	Schwarz & Seidel	VoxelPipe	Crassin & Greene (680)
large triangle (1 tri)	128^3	10.62	0.03	0.04 @na	36.1%/63.9%			
	256^3	42.4	0.06	0.07 @na	22.1%/77.9%			
	512^3	169.7	0.22	0.19 @na	12.0%/88.0%			
XYZ RGB Asian Dragon (7,219,045 tris)	128^3	6.37	165.2	8.51 @2.0	99.9%/0.1%	11.36	21.2	
	256^3	7.70	165.0	8.57 @1.7	99.7%/0.3%	14.73		
	512^3	9.80	164.6	10.3 @1.4	99.8%/0.2%	16.67	22.0	
Crytek Sponza Atrium (262,267 tris)	128^3	13.4	10.65	1.11 @2.8	87.7%/12.3%			
	256^3	53.2	11.13	1.80 @3.9	71.6%/28.3%			
	512^3	208.7	11.87	3.68 @3.1	52.8%/47.2%			
Conference (331,179 tris)	128^3	9.23	11.47	1.41 @0.5	68.5%/31.5%	3.9	3.3	
	256^3	36.04	11.62	1.82 @1.7	69.2%/30.8%			
	512^3	141.2	11.94	3.01 @0.9	52.2%/47.8%	59.3	4.3	
Stanford Bunny (69,666 tris)	128^3	0.28	1.58	0.19 @1.8	88.1%/11.9%	0.60		
	256^3	0.82	1.55	0.34 @4.5	91.6%/8.4%	0.89		
	512^3	3.12	1.82	1.08 @12.7	93.0%/7.0%	2.35		
Stanford Dragon (100,000 tris)	128^3	0.25	2.13	0.26 @13.3	97.8%/2.2%	3.44	4.8	1.19
	256^3	0.51	2.09	0.52 @5.9	93.4%/6.6%	3.96		
	512^3	1.61	2.25	1.25 @13.7	88.6%/11.4%	4.44	5.0	1.38
Hairball (2,880,000 tris)	128^3	7.09	74.8	7.37 @2.3	99.89%/0.11%	22.8	12.8	
	256^3	13.73	67.1	14.0 @2.4	99.94%/0.06%			
	512^3	33.47	68.4	33.9 @8.0	99.97%/0.03%	95.0	18.3	