Render the Possibilities

SIGGRAPH 2016

Volumetric Global Illumination At Treyarch

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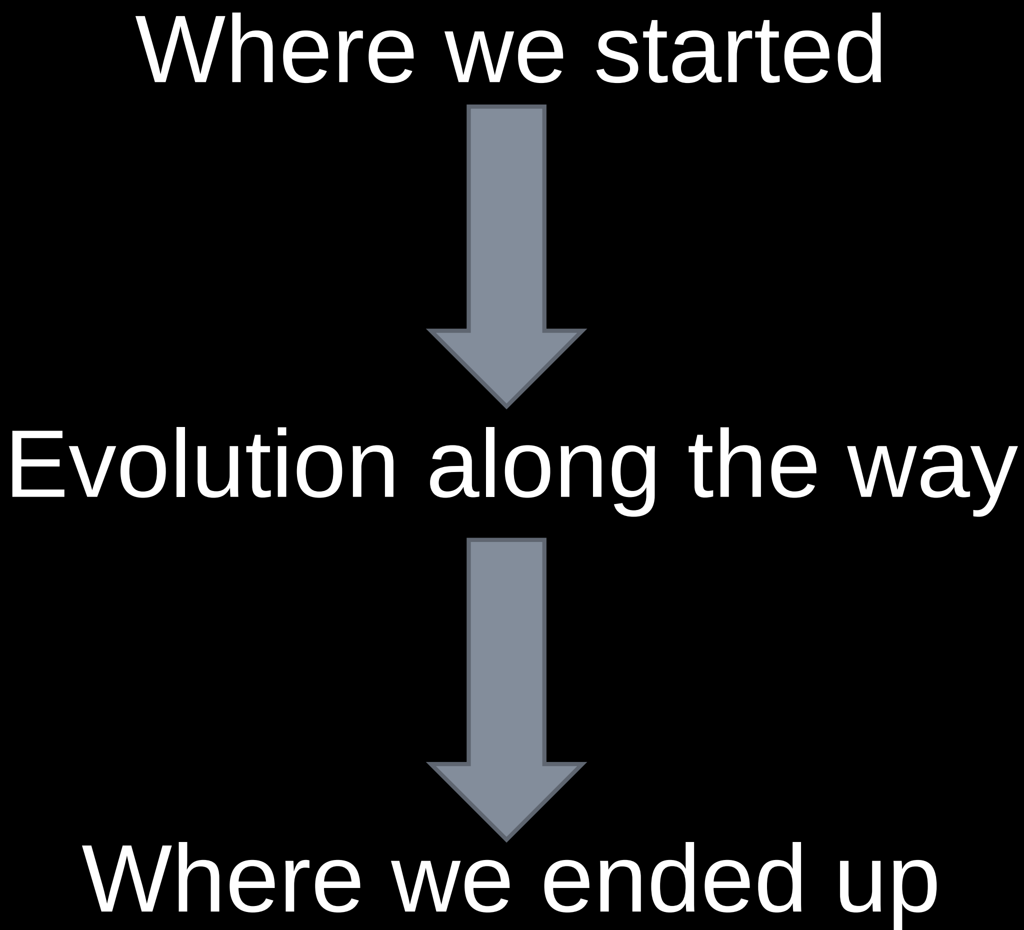
Render the Possibilities
SIGGRAPH2016

Volumetric Global Illumination

- GI in volume texture
- Lean texture data
- IBL baked from probes
- Convex blend shapes

Presentation Order



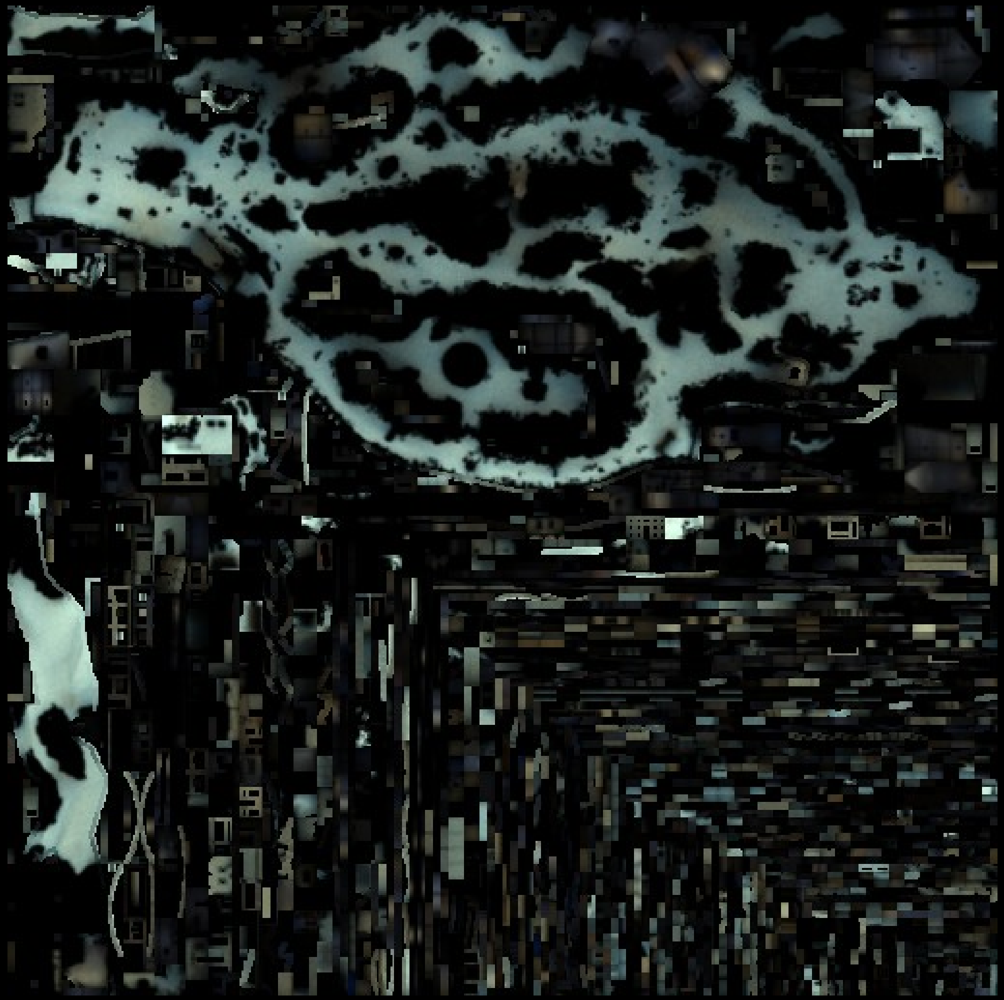
Where we started

Evolution along the way

Where we ended up

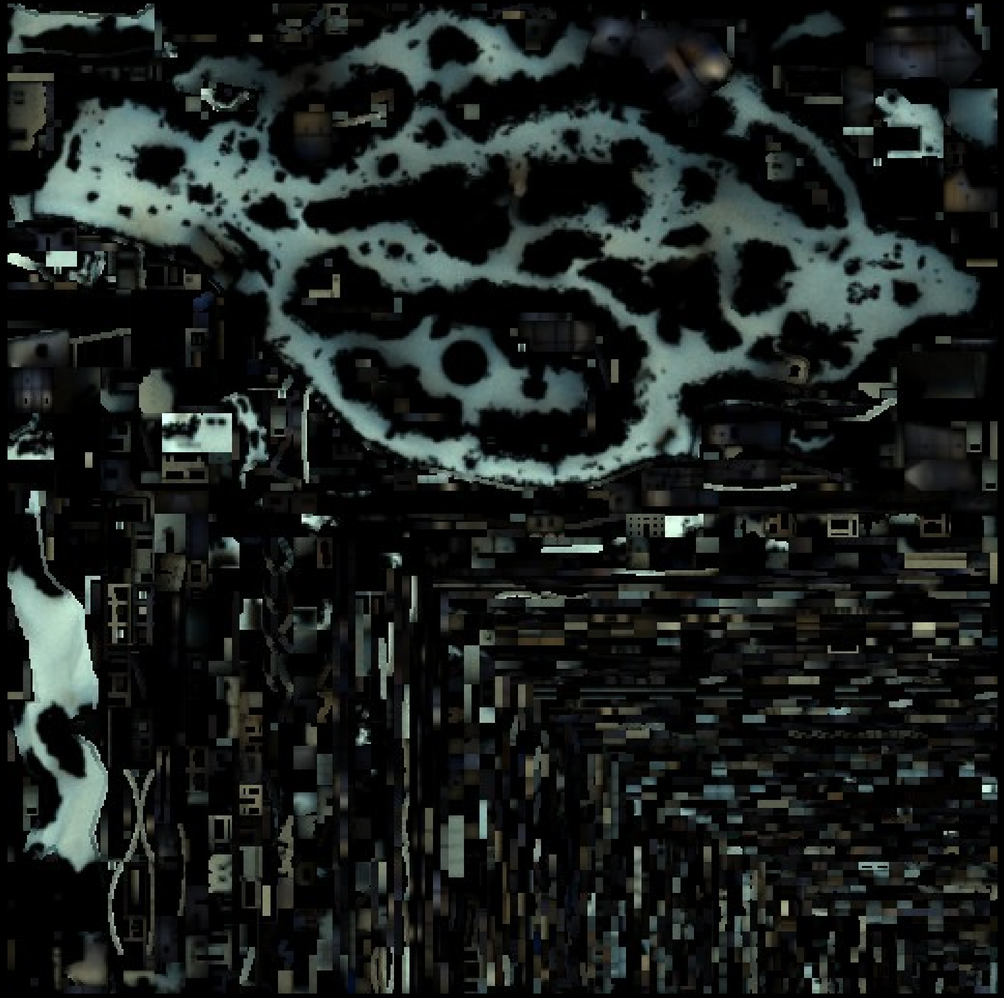
Traditional Approach: Lightmaps

Could be ok, but…



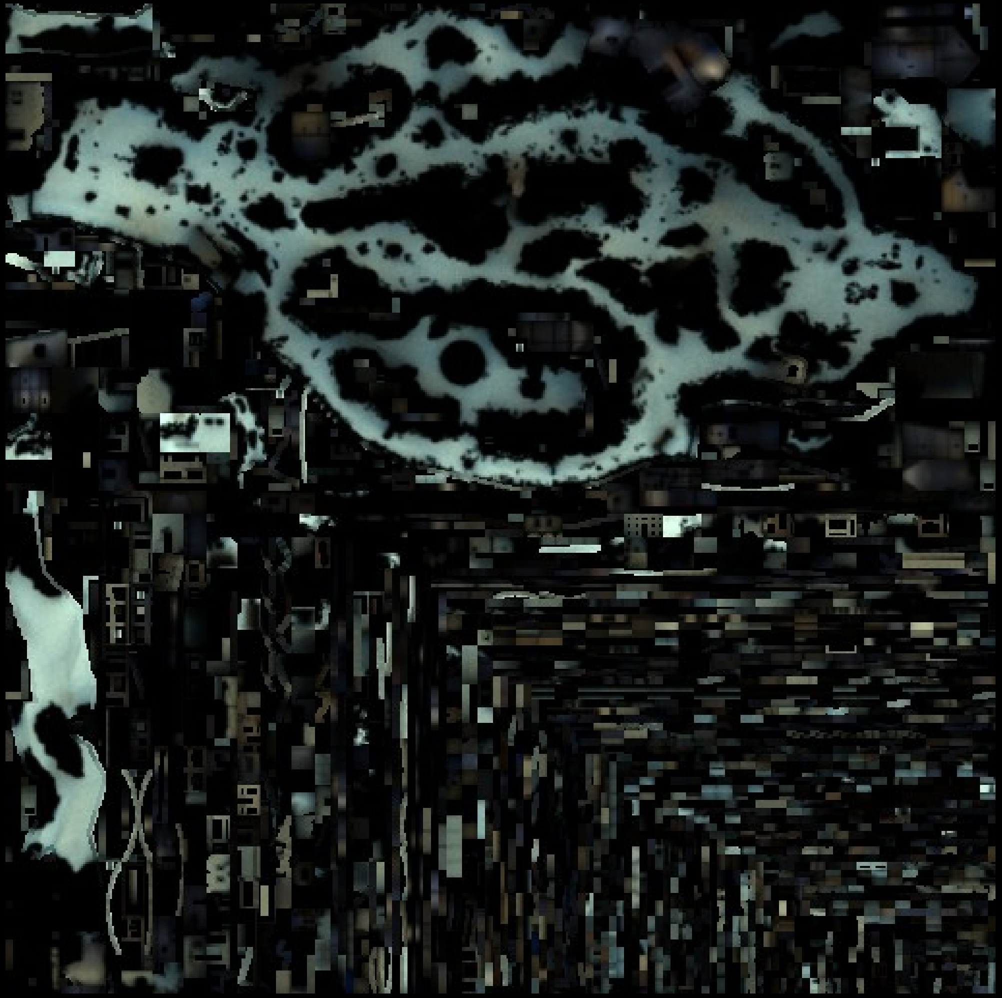
Lightmap Downsides

- Works poorly on detailed or intersecting geometry



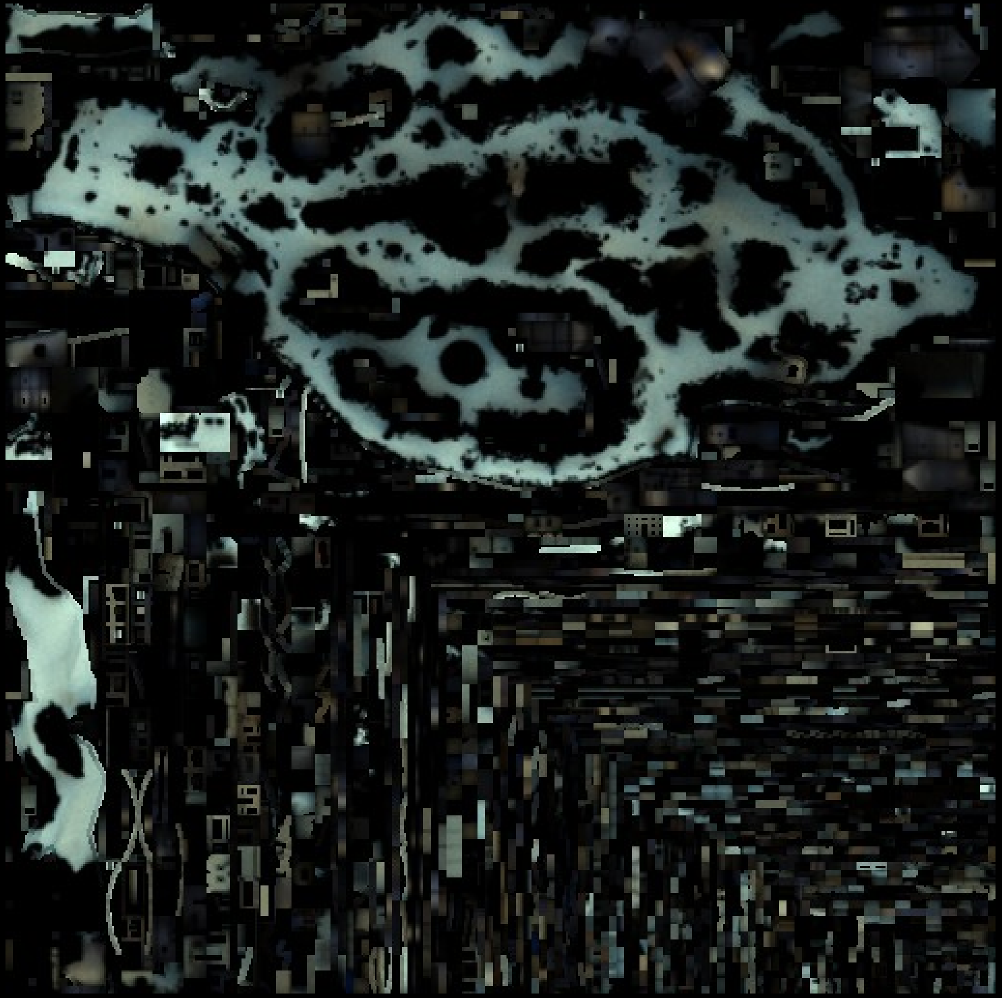
Lightmap Downsides

- Doesn’t work at all on dynamic geometry



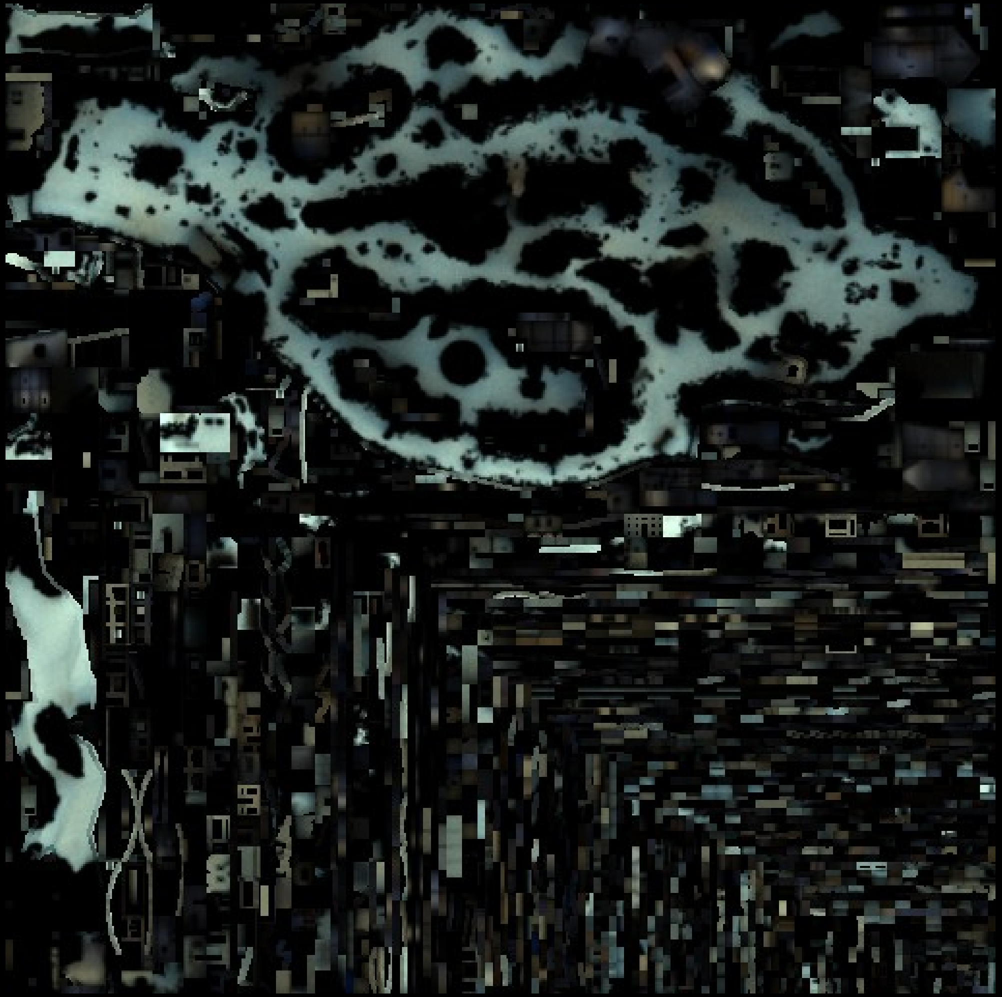
Lightmap Downsides

- Software ray-tracing and shading takes forever



Lightmap Downsides

- Results not visible in world editor



Process of Invention

- Deferred Renderer
- Reflections already present
- So how do we apply deferred GI?

Reflection Probes as Diffuse Data

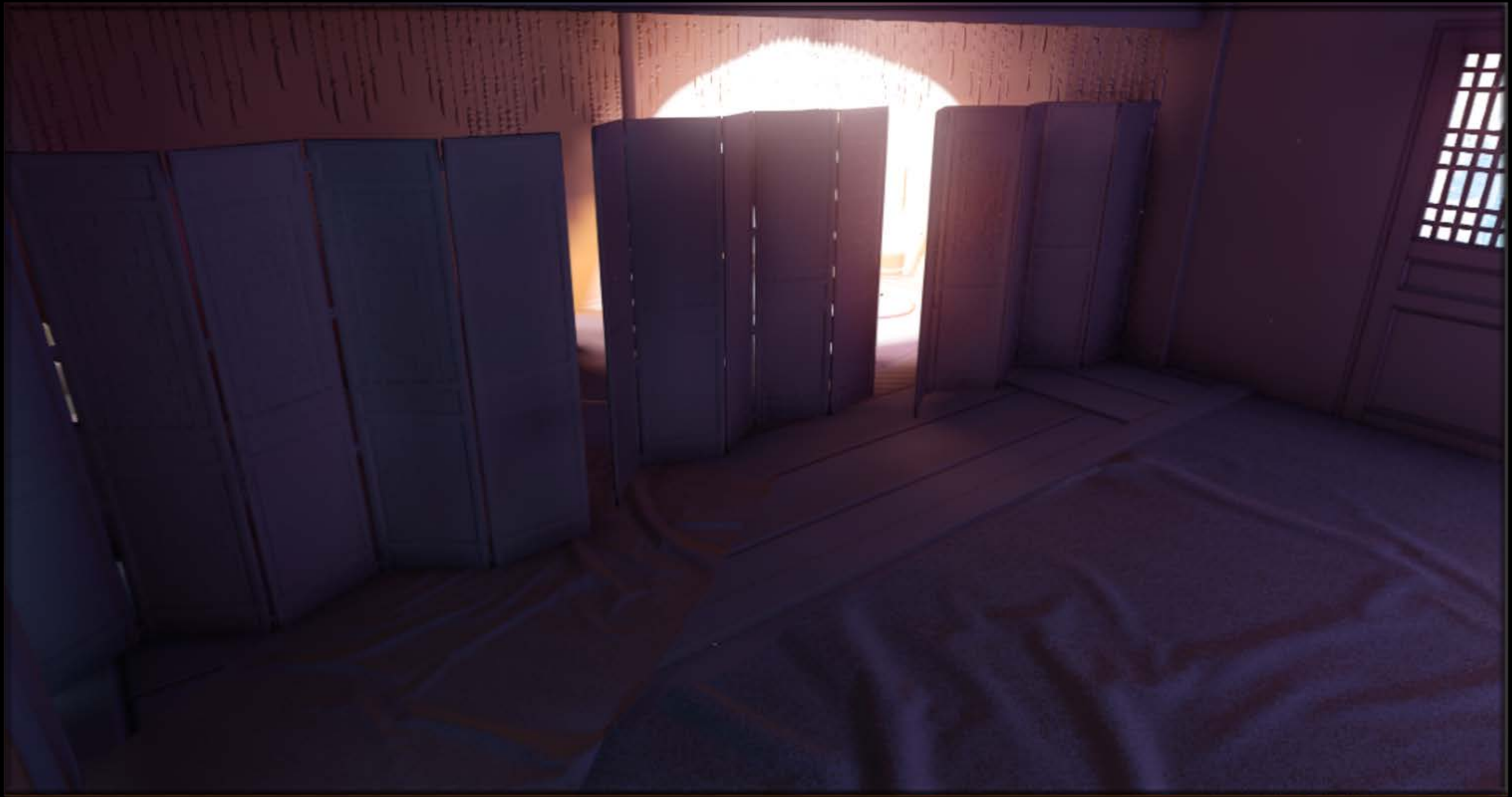
- Higher Mips:
  convolved specular

  [DROBOT13]

- Lowest Mip:
  diffuse irradiance

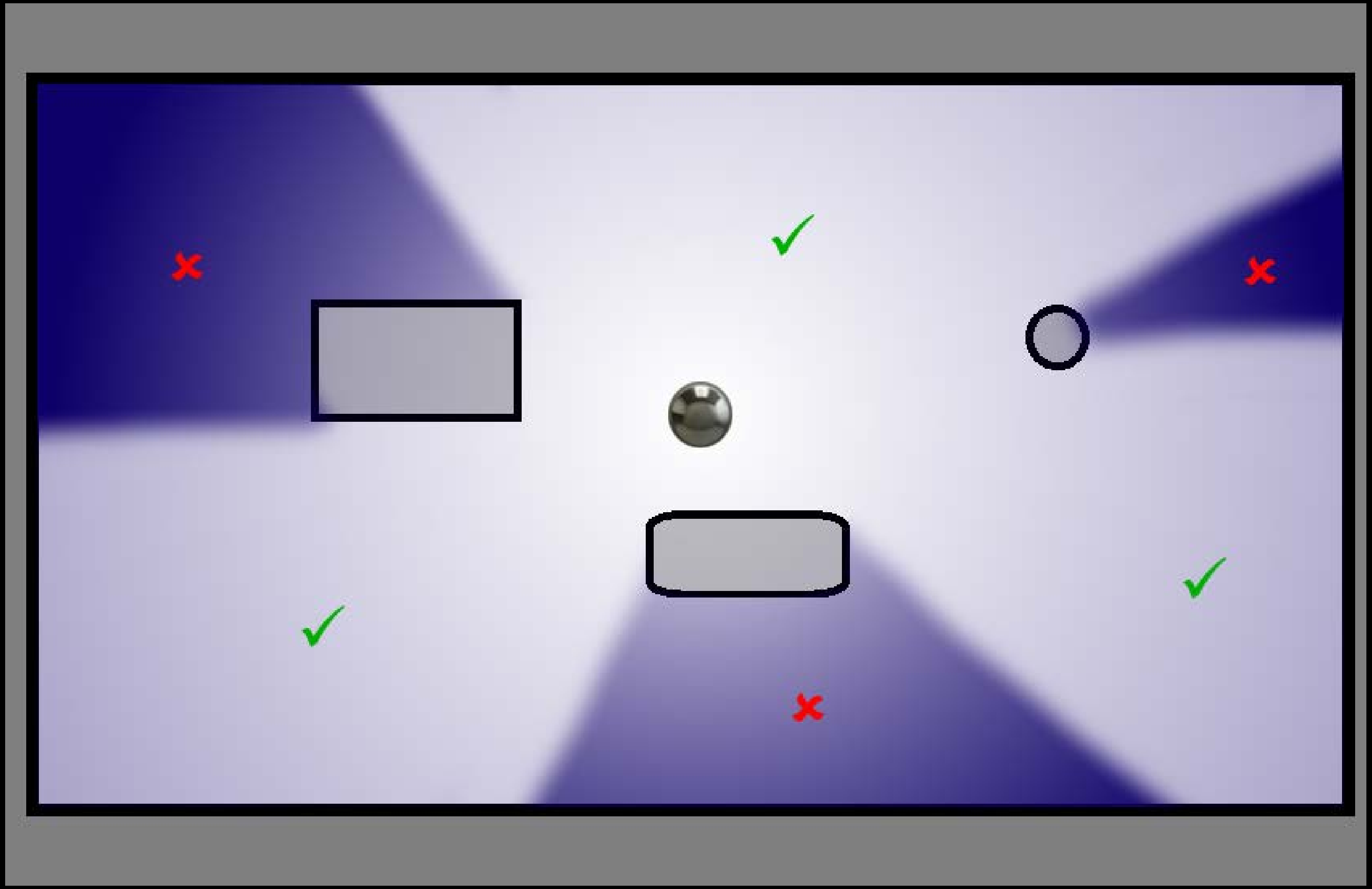
- Real time IBL

Occlusion Is A Problem

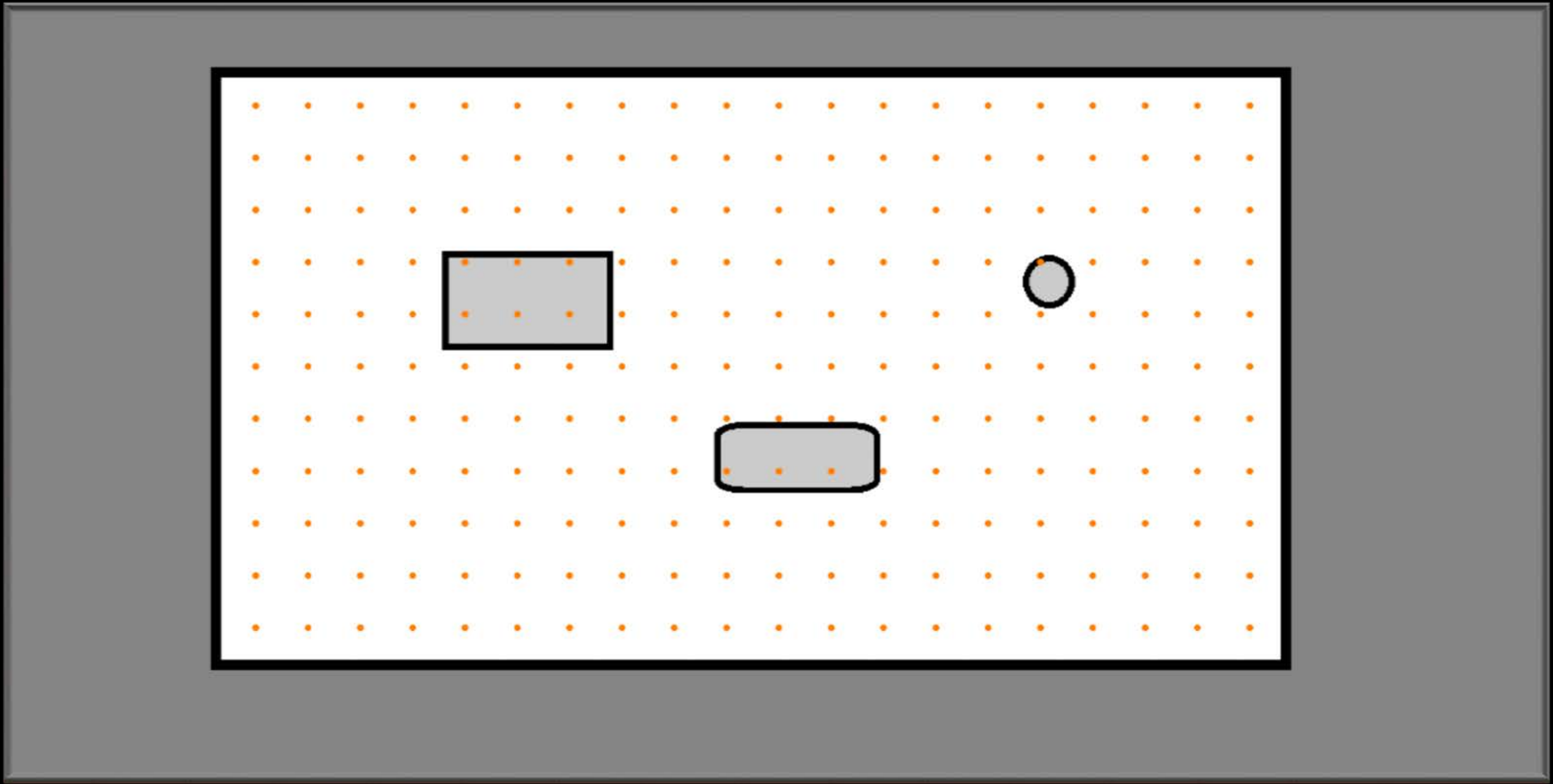


Visibility Is A Problem

- Where the probe doesn't see
- Looks like shadows



Irradiance Volume [TATARCHUK05]



Render a Reflection Probe Per Voxel?

138 Volumes × 40^3 Voxels × 6 Faces

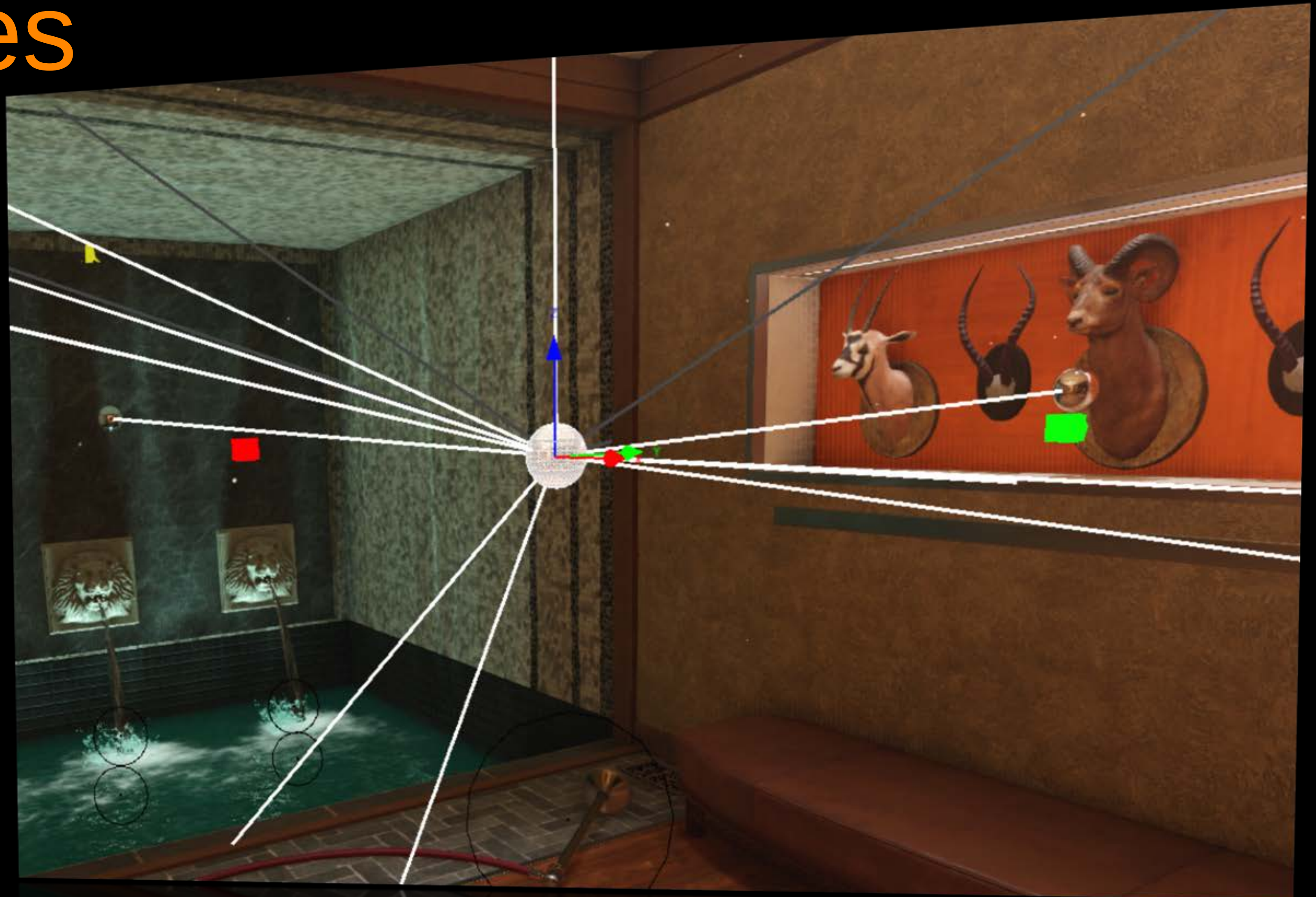
÷ 60 FPS ÷ 60 Seconds

= 14,720 Minutes (≈ *10 Days*)

Collect Colors From Reflection Probes

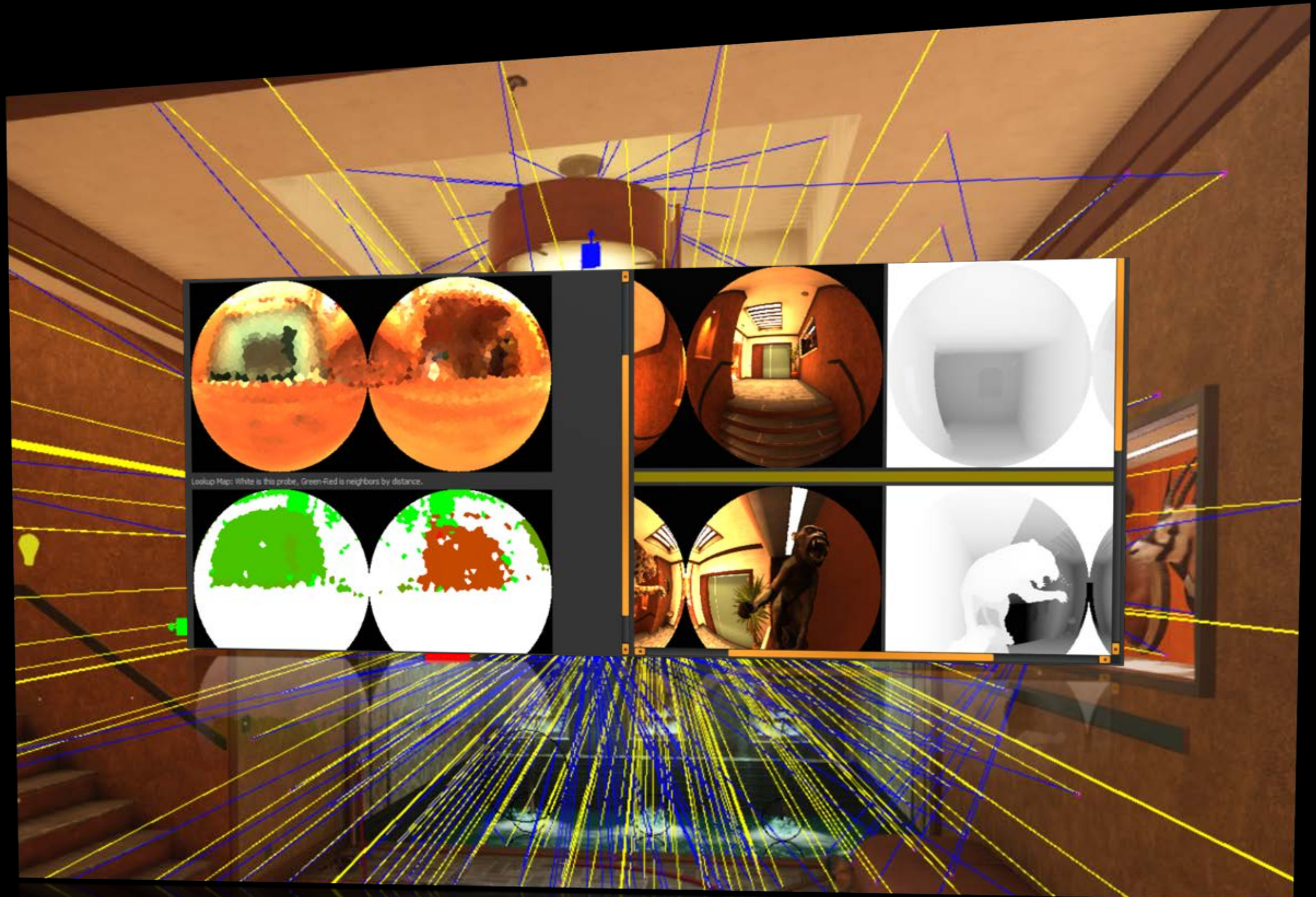
- Re-project cube maps
- Combine to fill holes

[BUEHLER01]

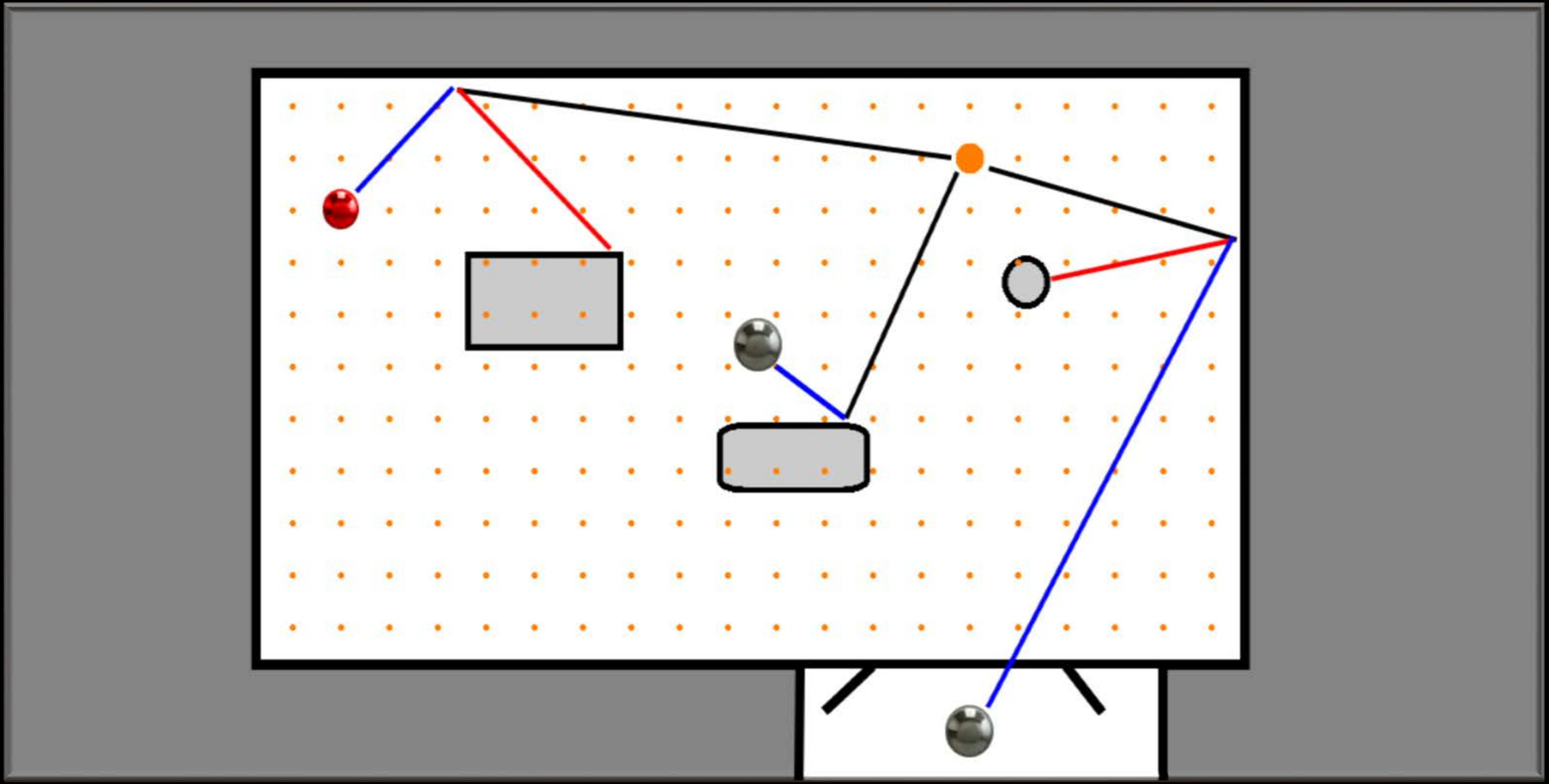


In Practice

- 4096 rays per voxel
- 15 neighbors considered
- Missed rays are in-painted


Lookup Map: White is this probe., Green-Red is neighbors by distance.

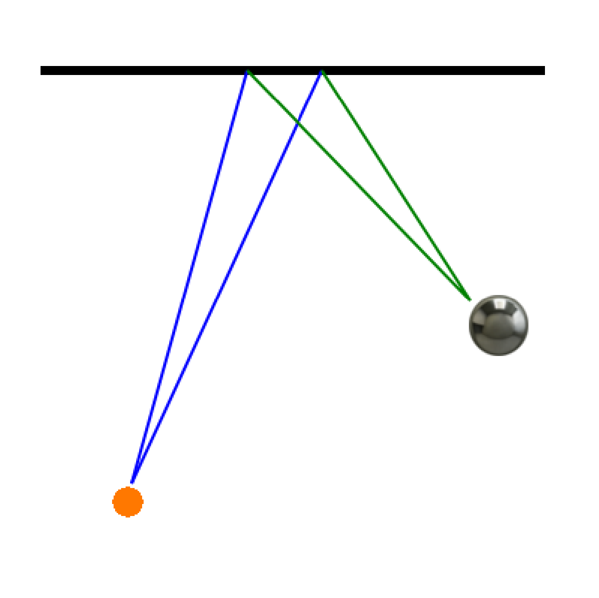
Re-Project From Existing Probes



Reprojection

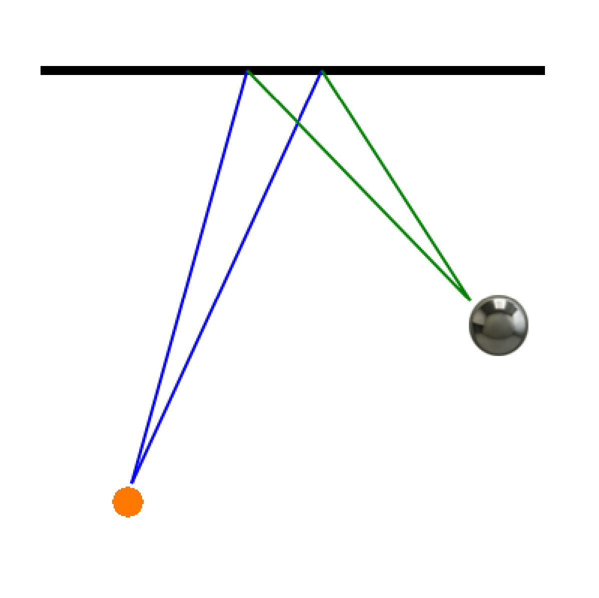
- Neighbor candidates sorted based on distance

- What about spec?



Reprojection

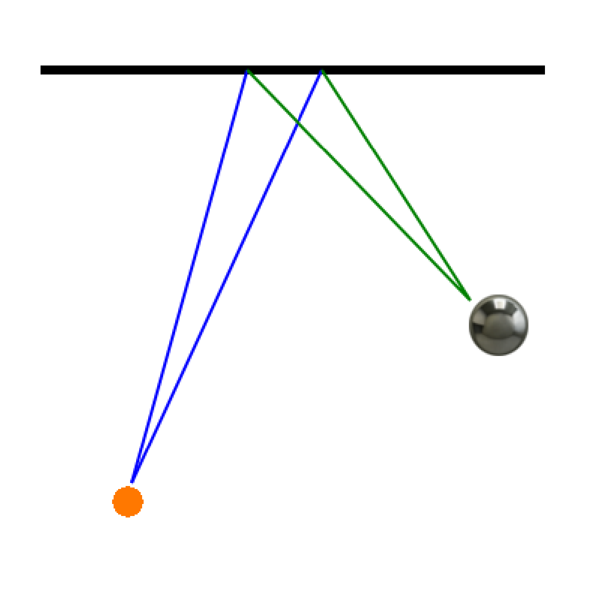
- Angle and distance to surface defines a solid angle in the cube map



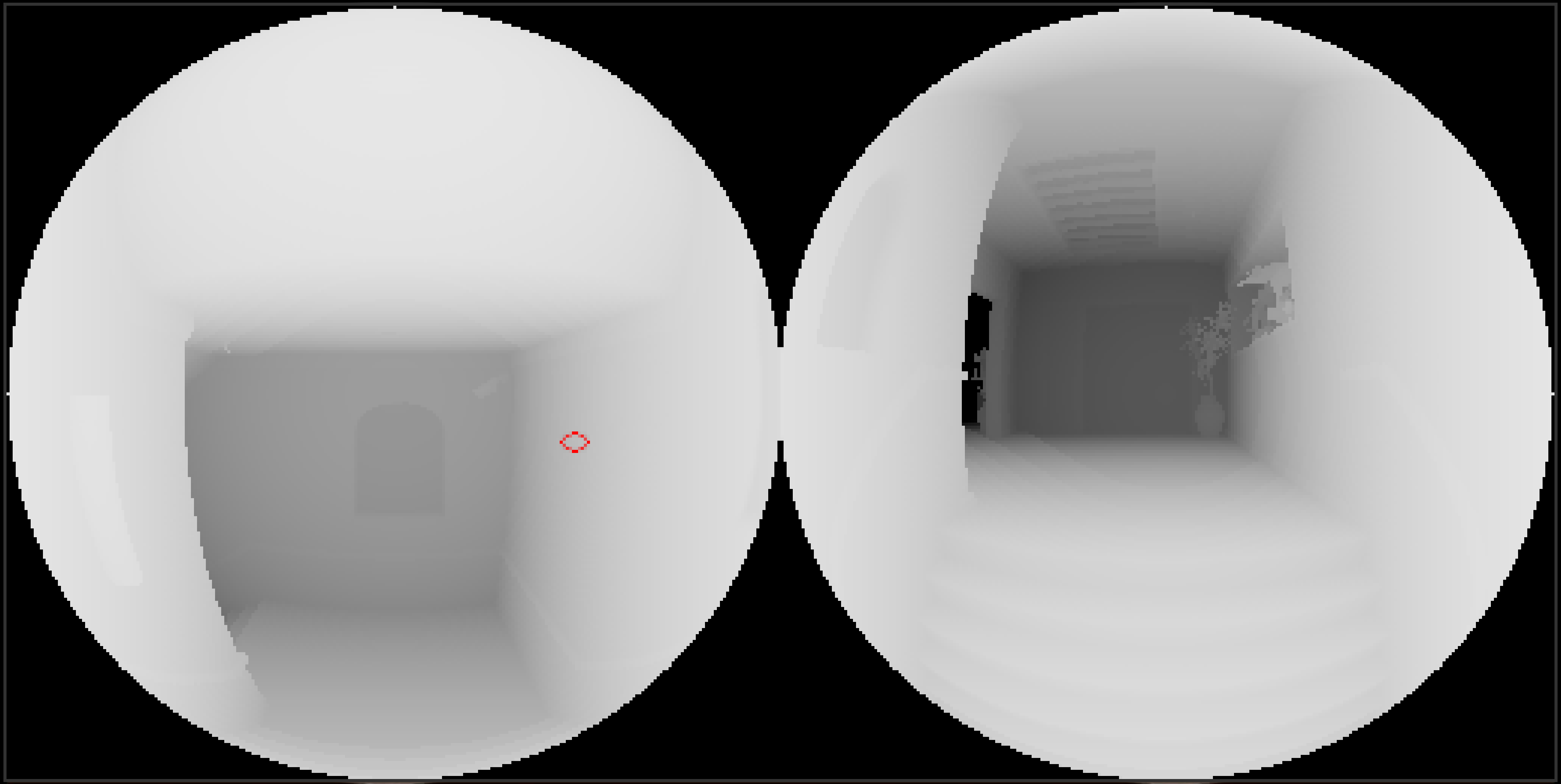
Reprojection

- Sample area validated against depth pyramid

- If visible
  appropriate mip sampled



Reprojection Caluclation



Reprojection Calculation

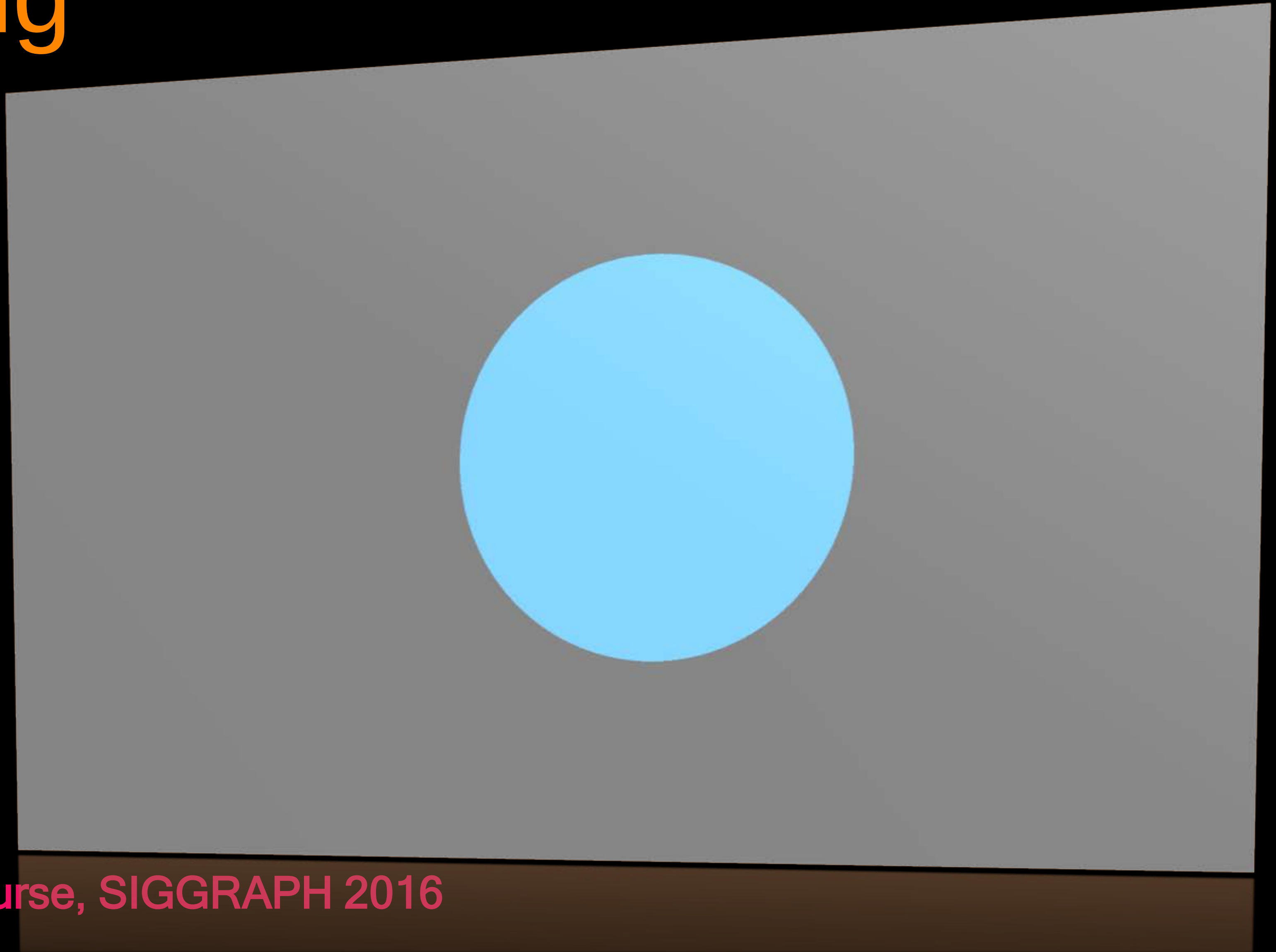
```
distFromUnitCube = √( 1 + u² + v² ); // Compensation for cube-map shape.
angleOfVoxel = 4 * PI / numSamples; // Solid angle from voxel.
inSqrt = 1 + distFromVoxel² * angleOfVoxel * ( angleOfVoxel – 4PI ) / ( 4 * PI² * distFromProbe² );
angleOfProbe = 2PI * ( 1 – √inSqrt ); // Solid angle from reflection probe.
cubeRes = 1.0f / √( angleOfProbe * distFromUnitCube³ ); // Resolution needed for sample.
mipLevel = clamp( mipCount – log2( cubeRes ), 0, mipCount ); // Mip level to use.

return mipLevel;
```

Biggest Benefit

- Hardware rendering
- Re-render to get bounces
- Only have to ray-trace and re-project once

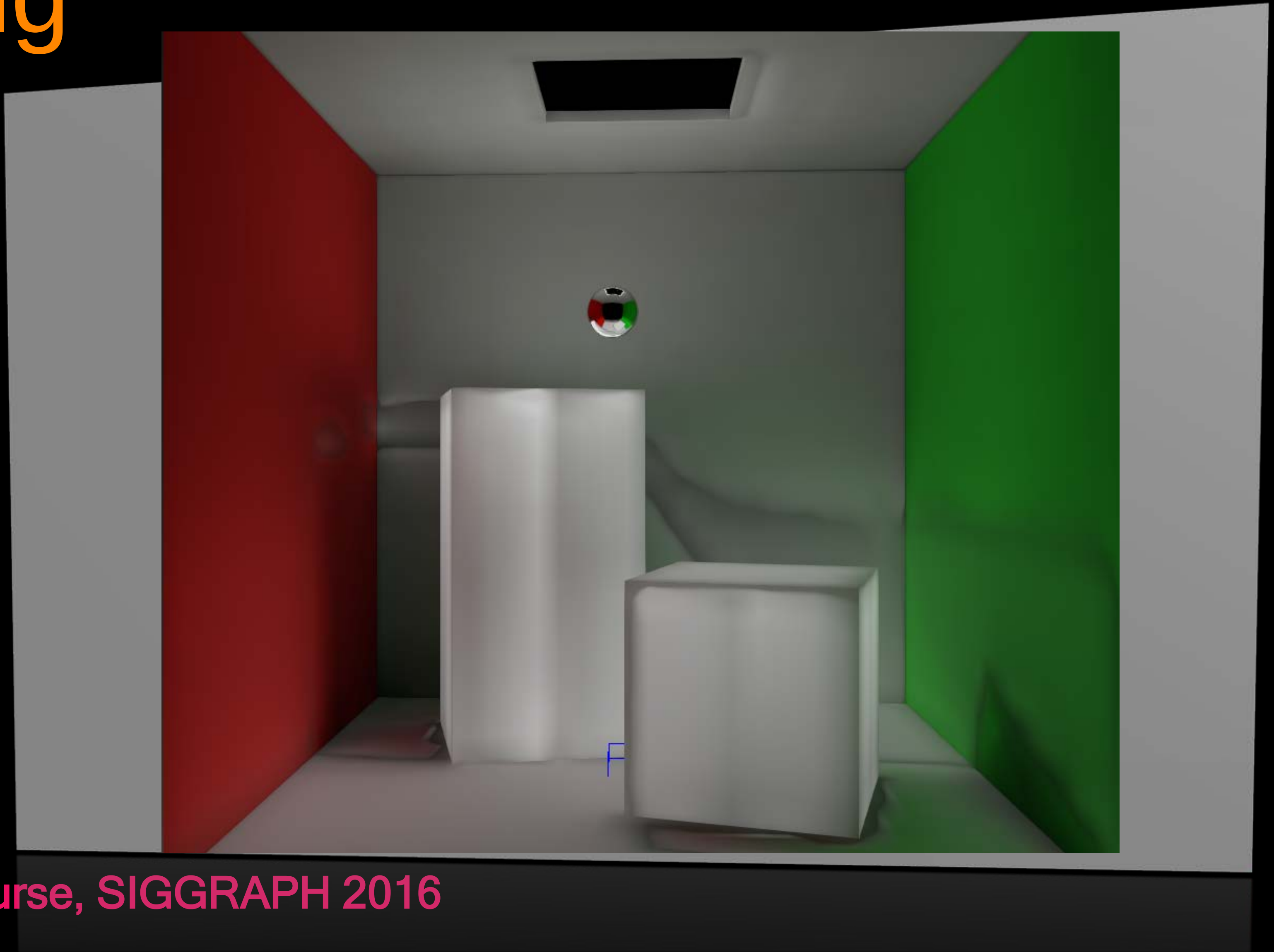
Texture Encoding

- Flat Color?



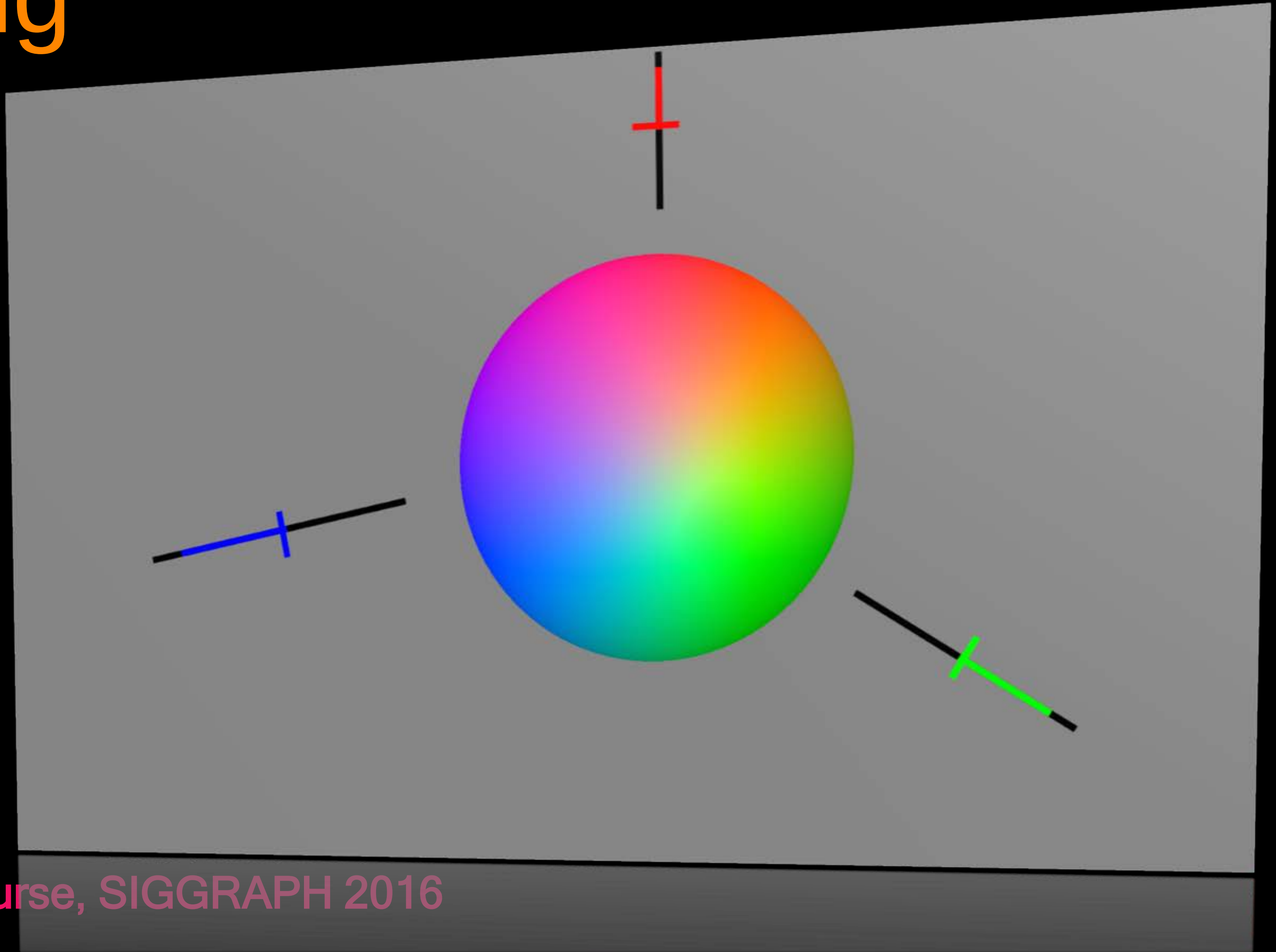
Texture Encoding

- Ambient / Highlight / Direction?



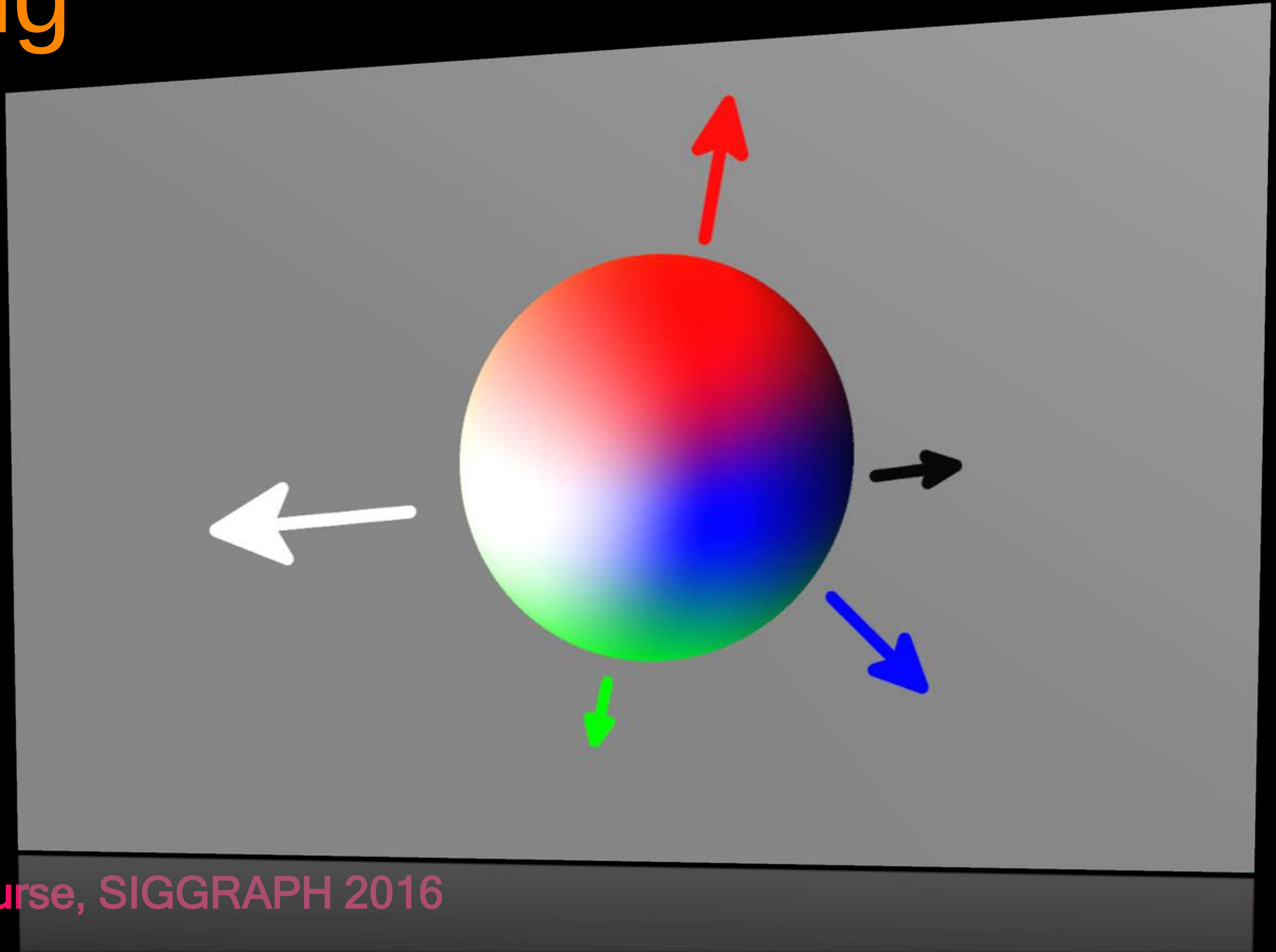
Texture Encoding

- Second Order Spherical Harmonic?

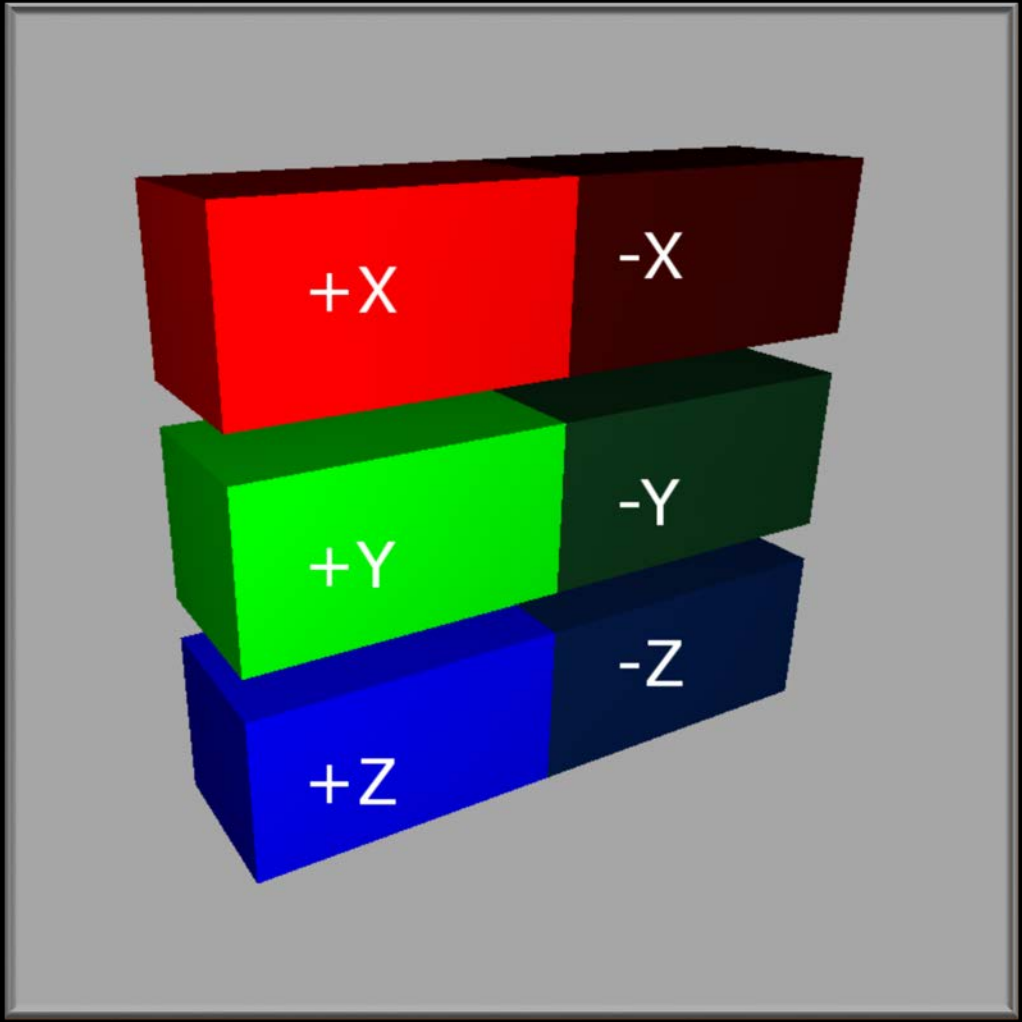


Texture Encoding

- Ambient Cube! [MCTAGGART04]
  - BC6H Compressed

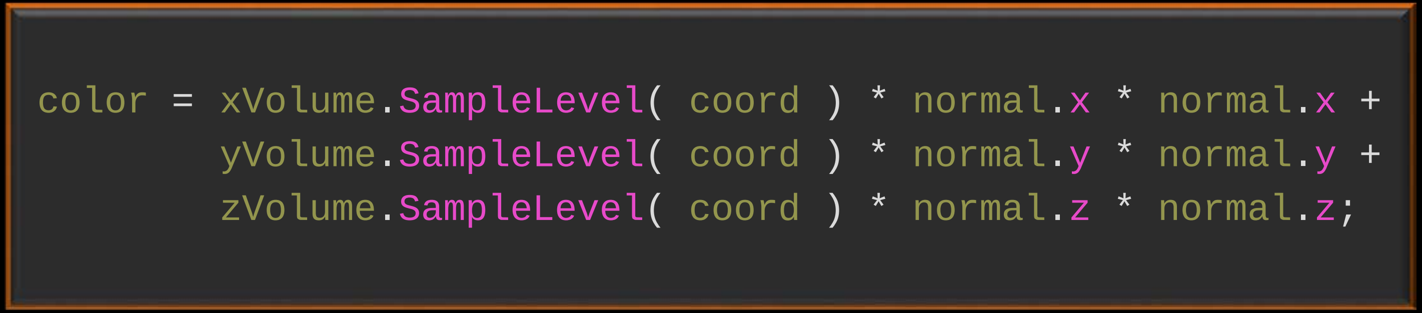


Volume Texture Layout



Performance Benefits

- Only 3 samples



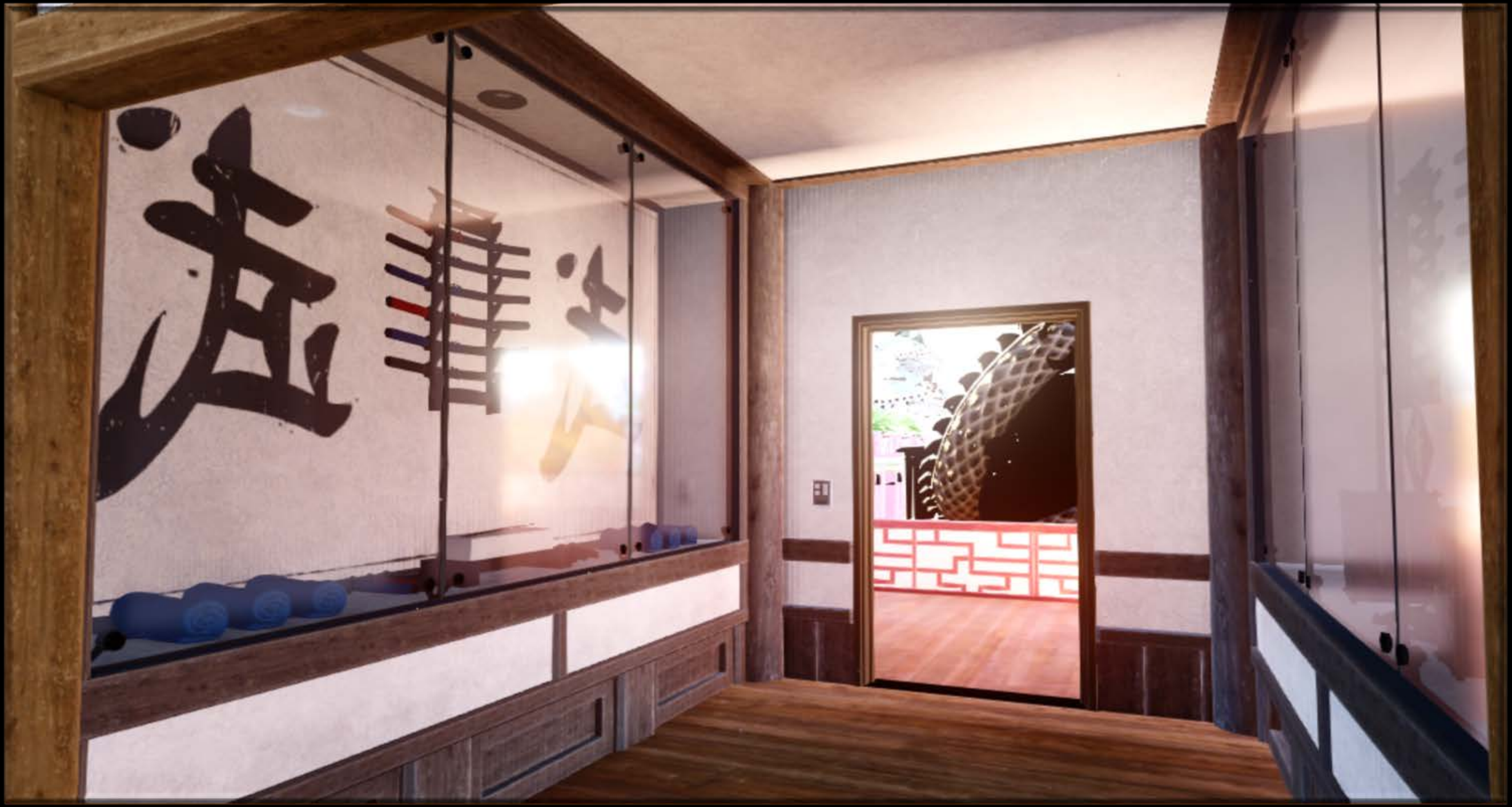
```
color = xVolume.SampleLevel( coord ) * normal.x * normal.x +
        yVolume.SampleLevel( coord ) * normal.y * normal.y +
        zVolume.SampleLevel( coord ) * normal.z * normal.z;
```

- Hardware trilinear filtering

- Evaluation:

color[n] = normal^2 · float3(Xsample[n], Ysample[n], Zsample[n])

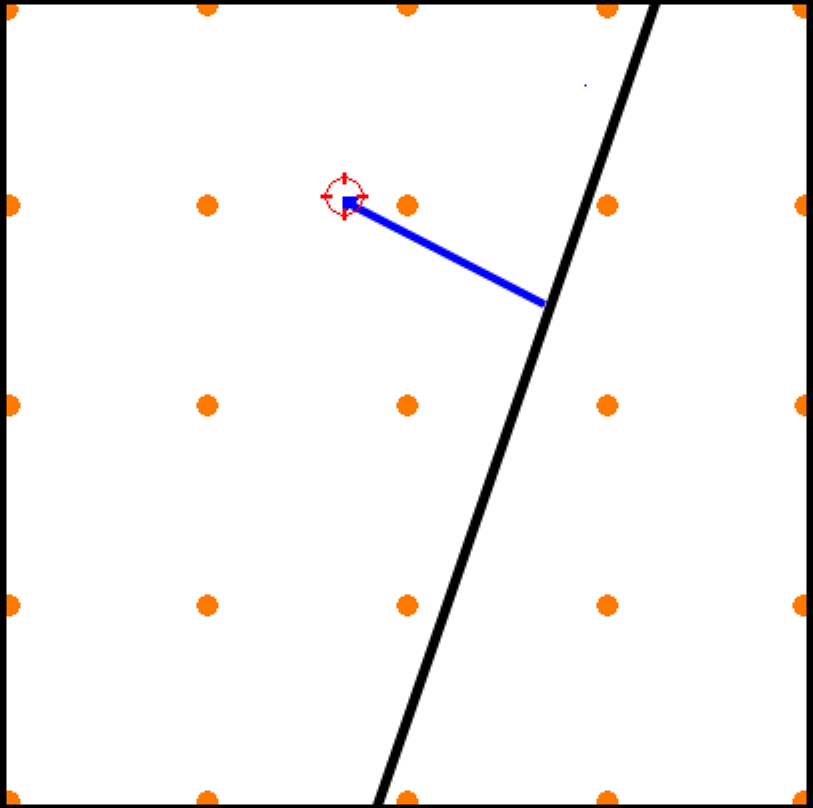
Light Leaking Is A Problem



Common Approach

- Adjust trilinear Based on normal [SILVENNOINEN15]

- Our approach needs to be more reliable



More Voxel Data

- Planes
- Signed distance field
- Bad artifacts

Solve With Shaping

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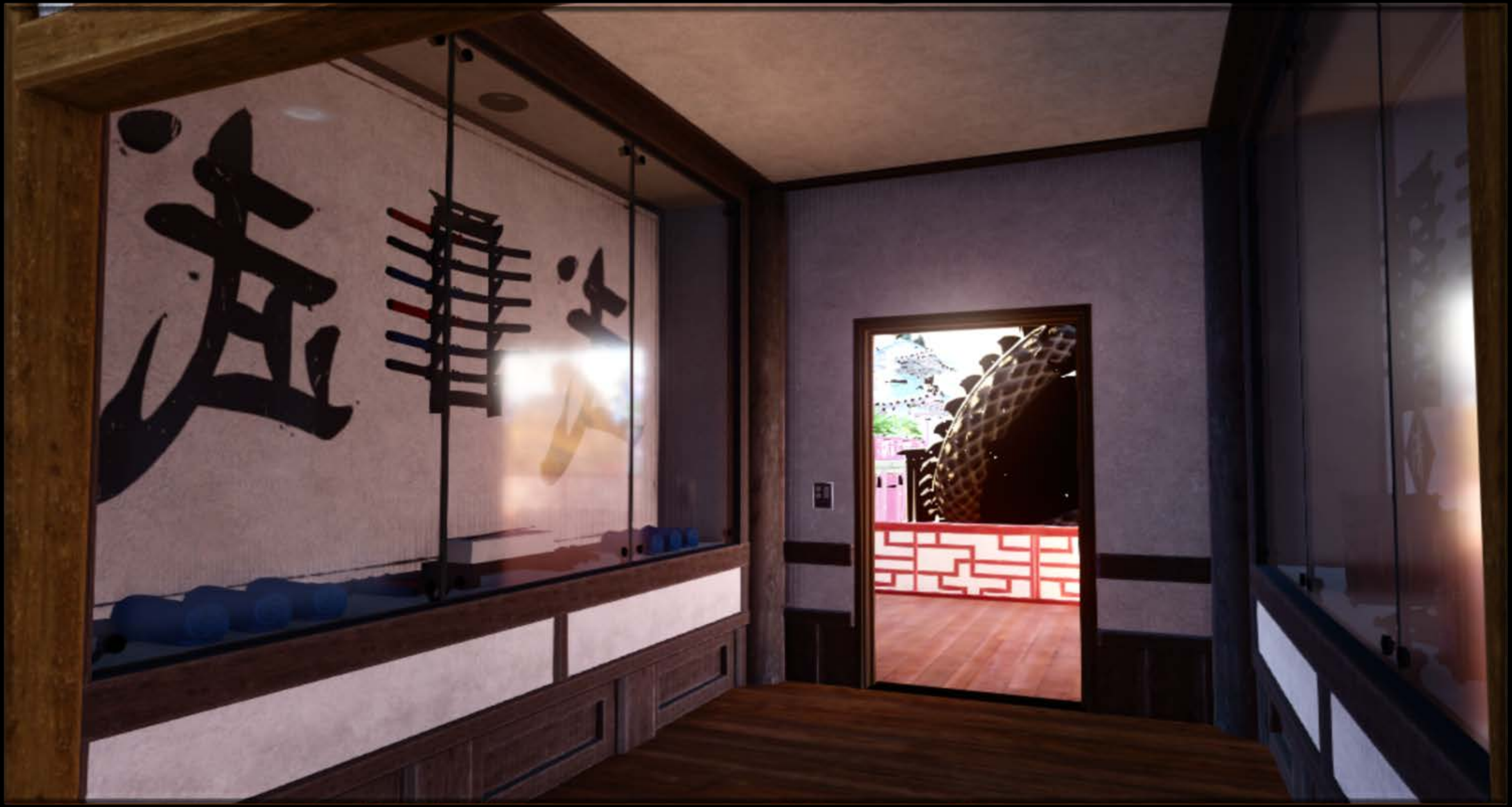
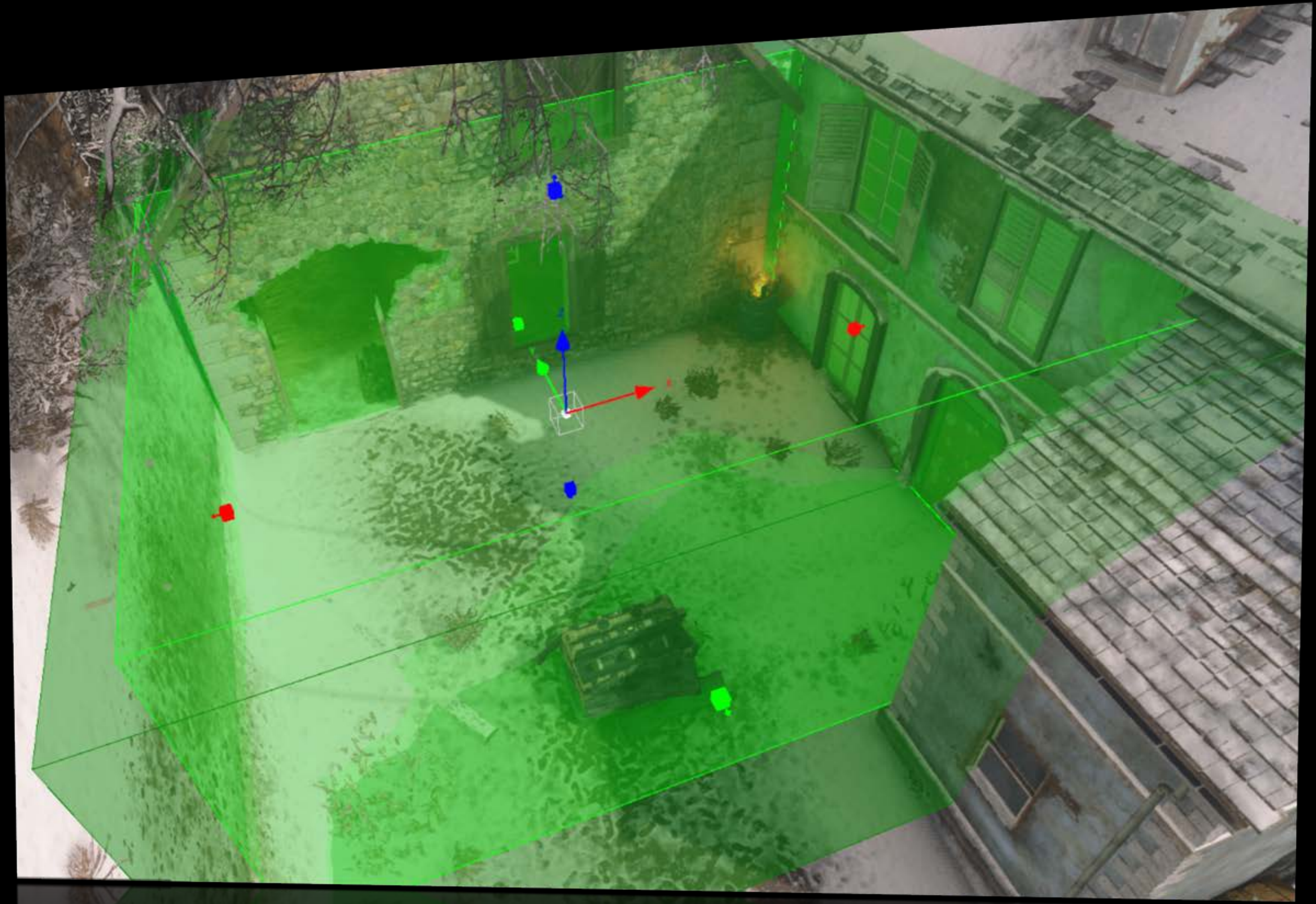
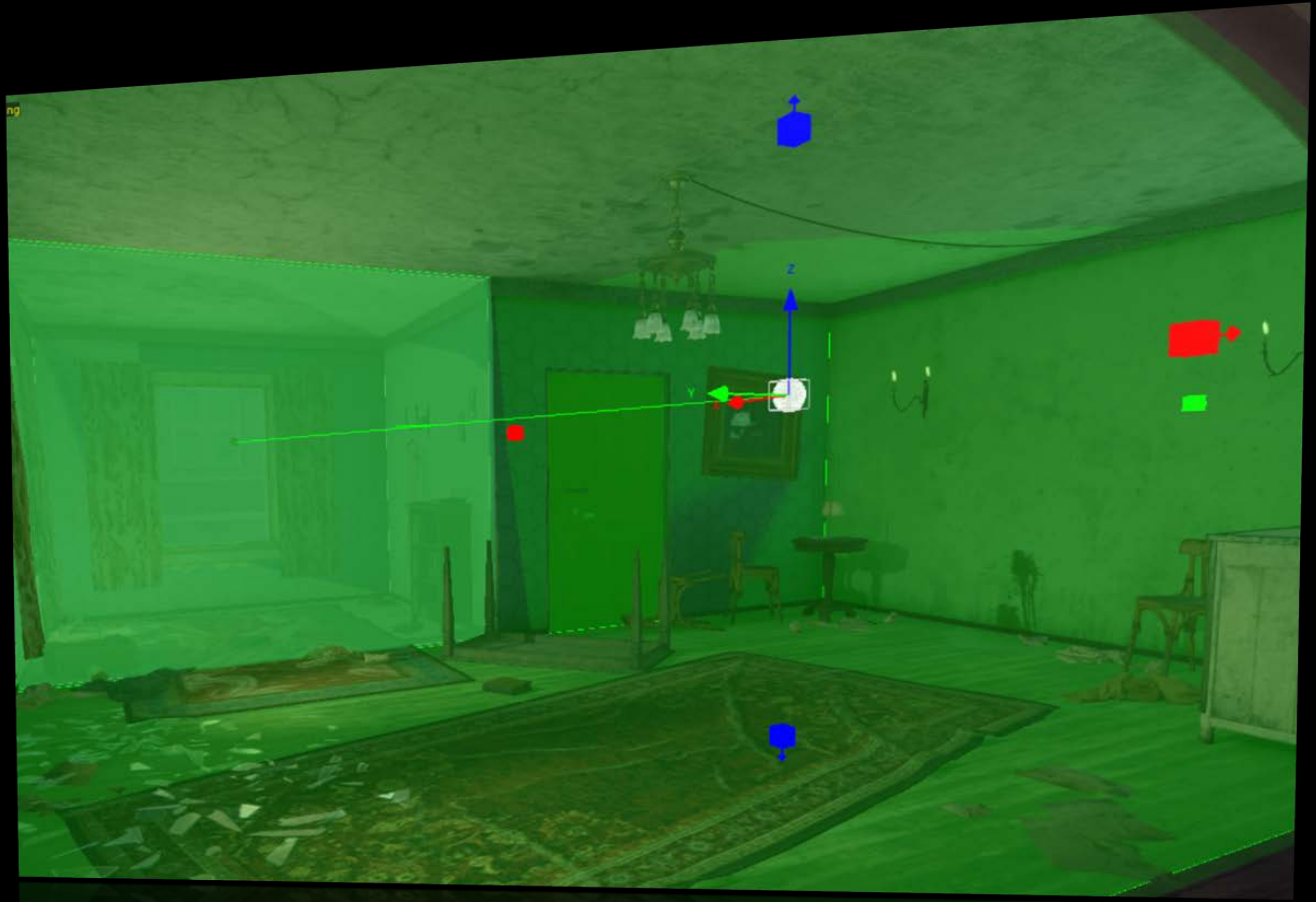


Click To Size Boxes

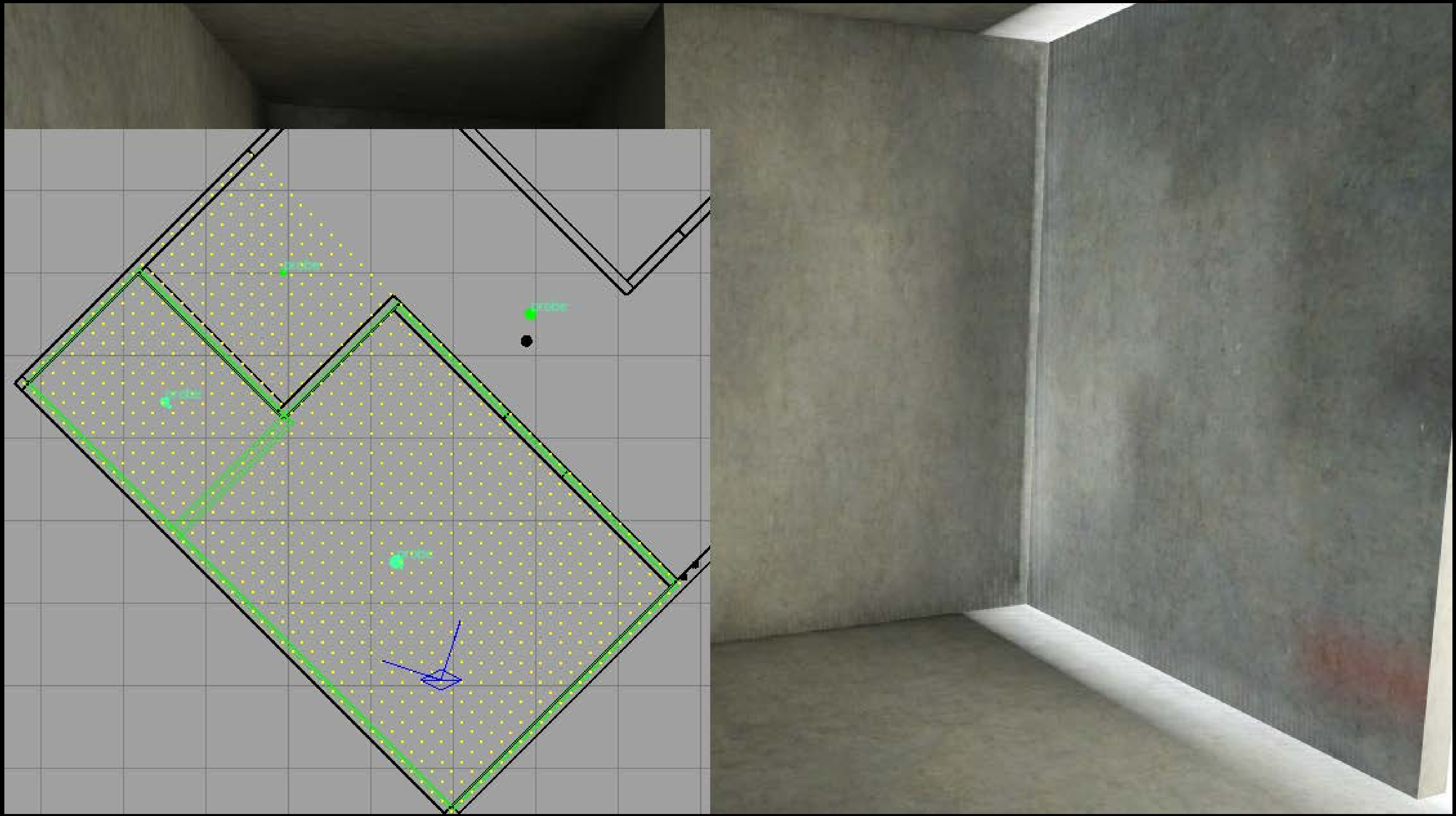


Click To Add Boxes

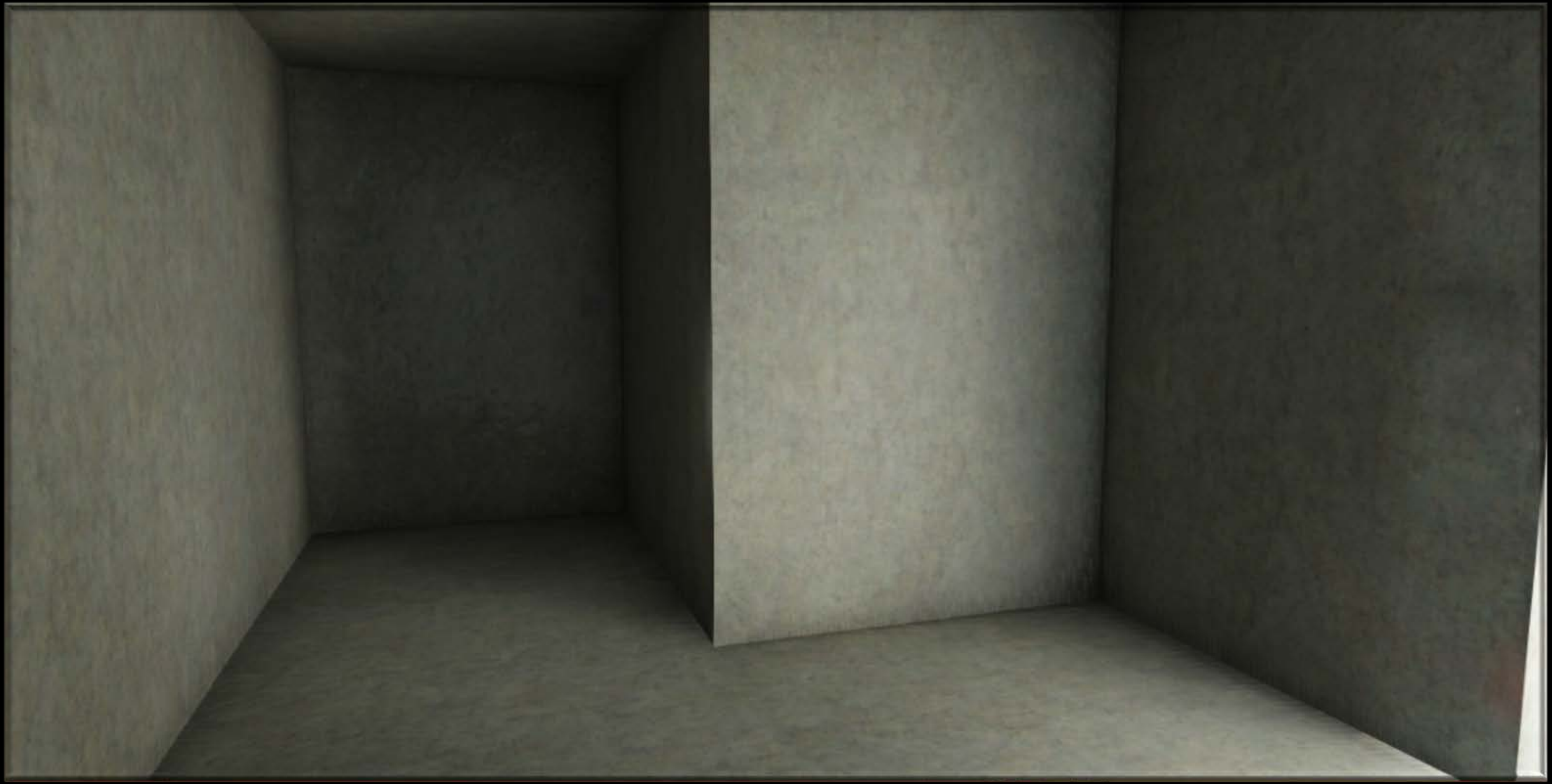
Auto-parent on creation



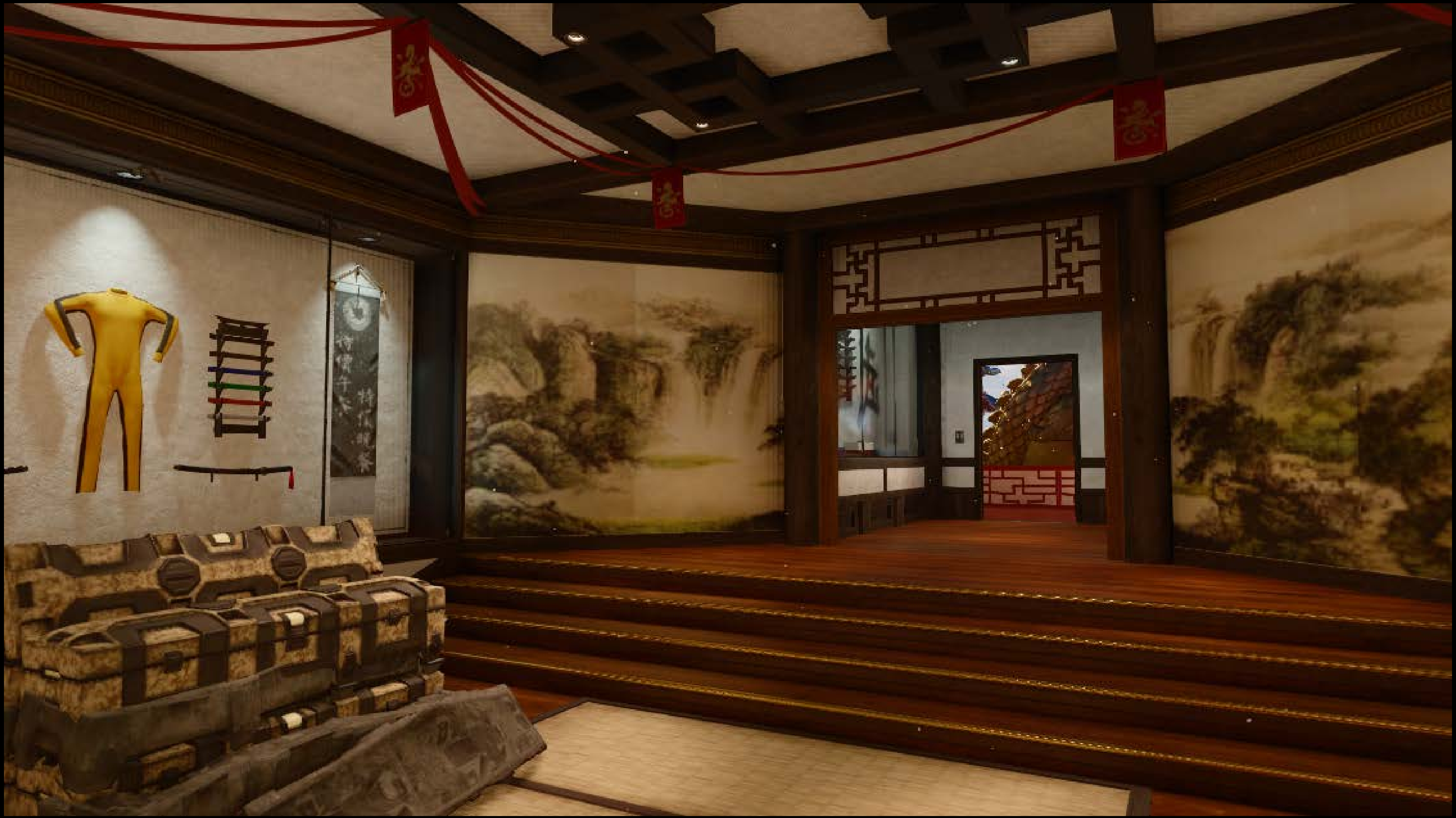
Voxels Near Walls



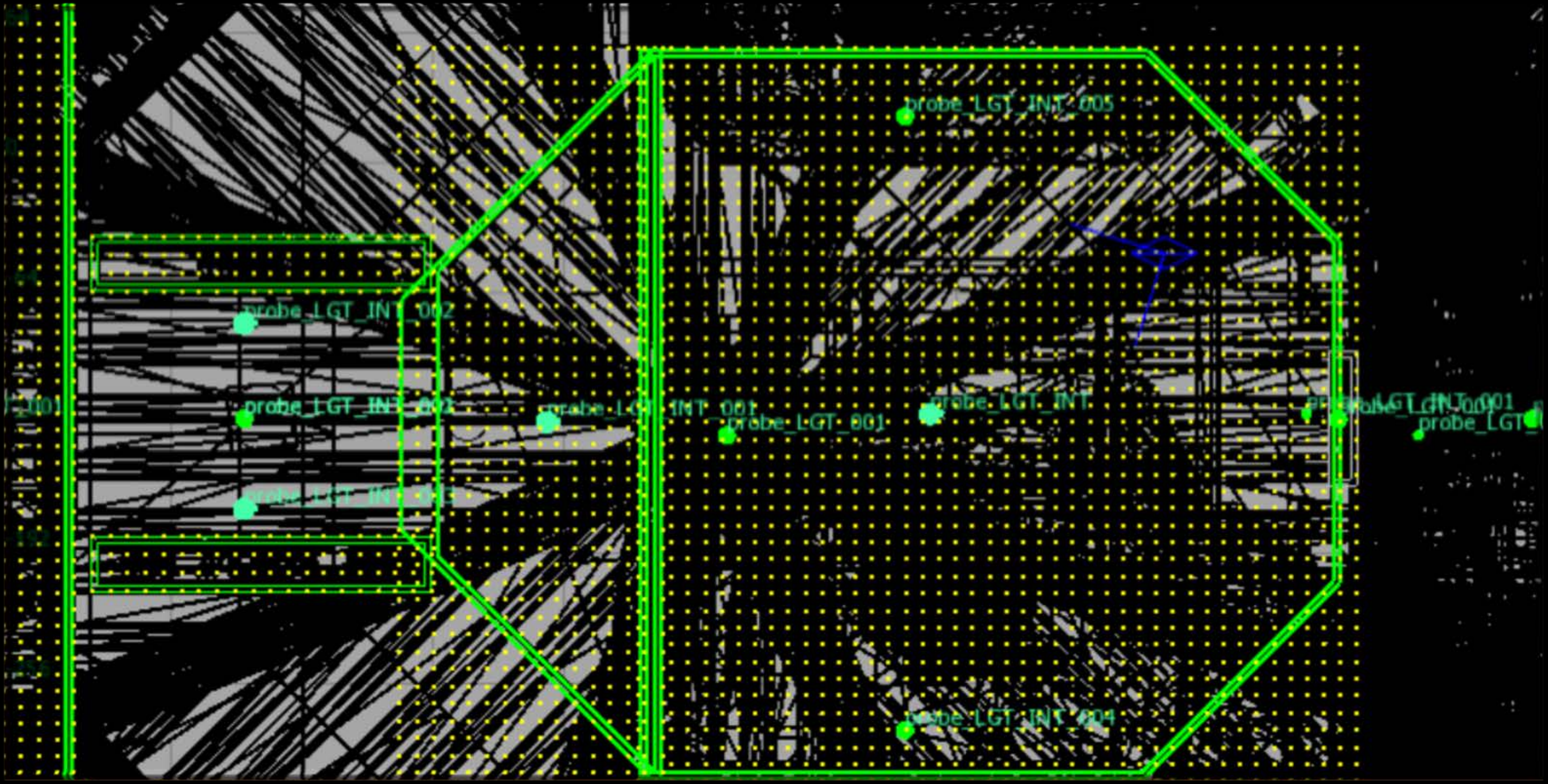
Consider Backfaces



Complex Room Shapes



Solution: Convex Shapes

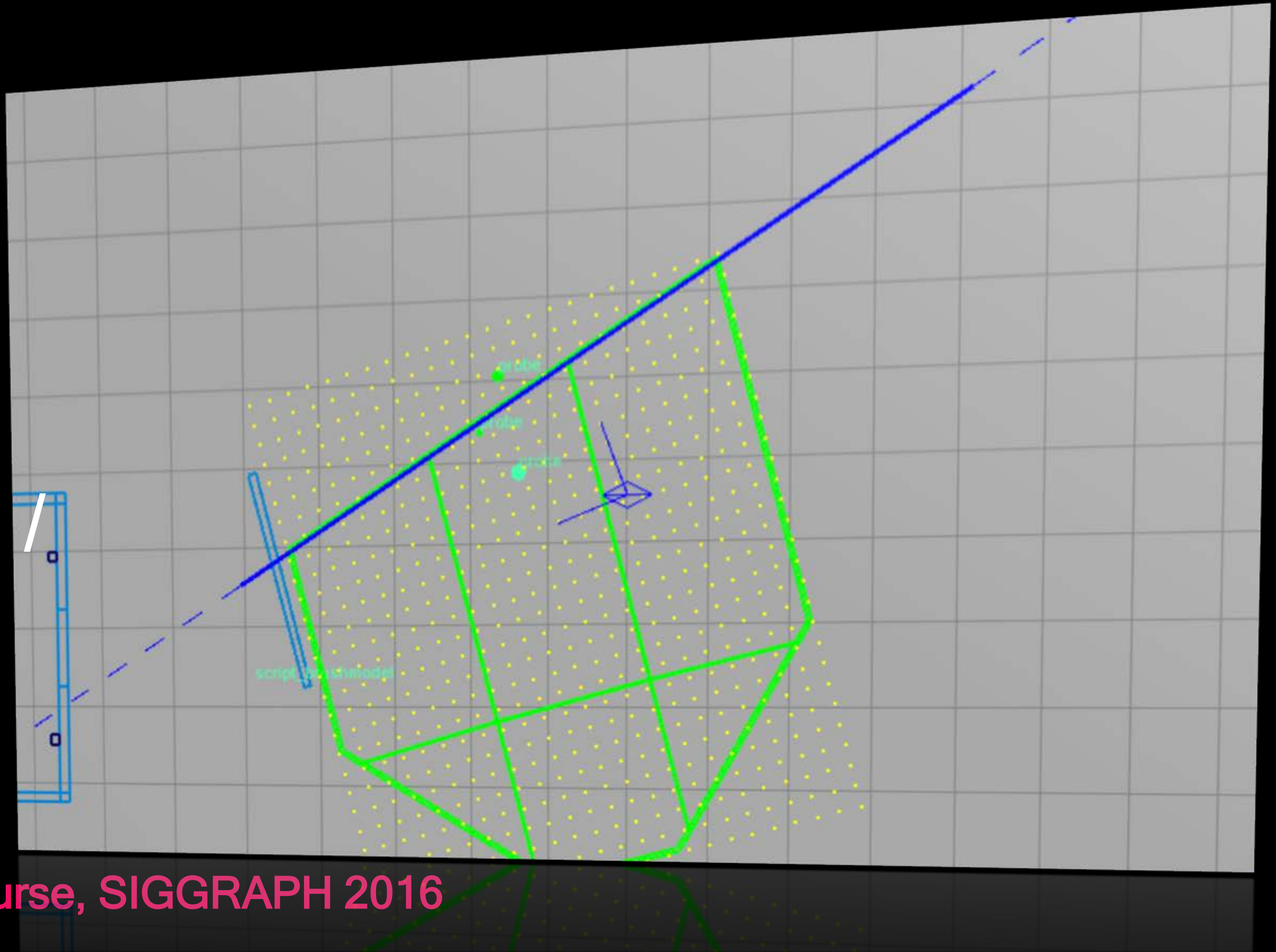


Multiface Volumes

Click to add and remove faces.

Multiface Volume Editing

Drag / Cut / Slice / Rotate



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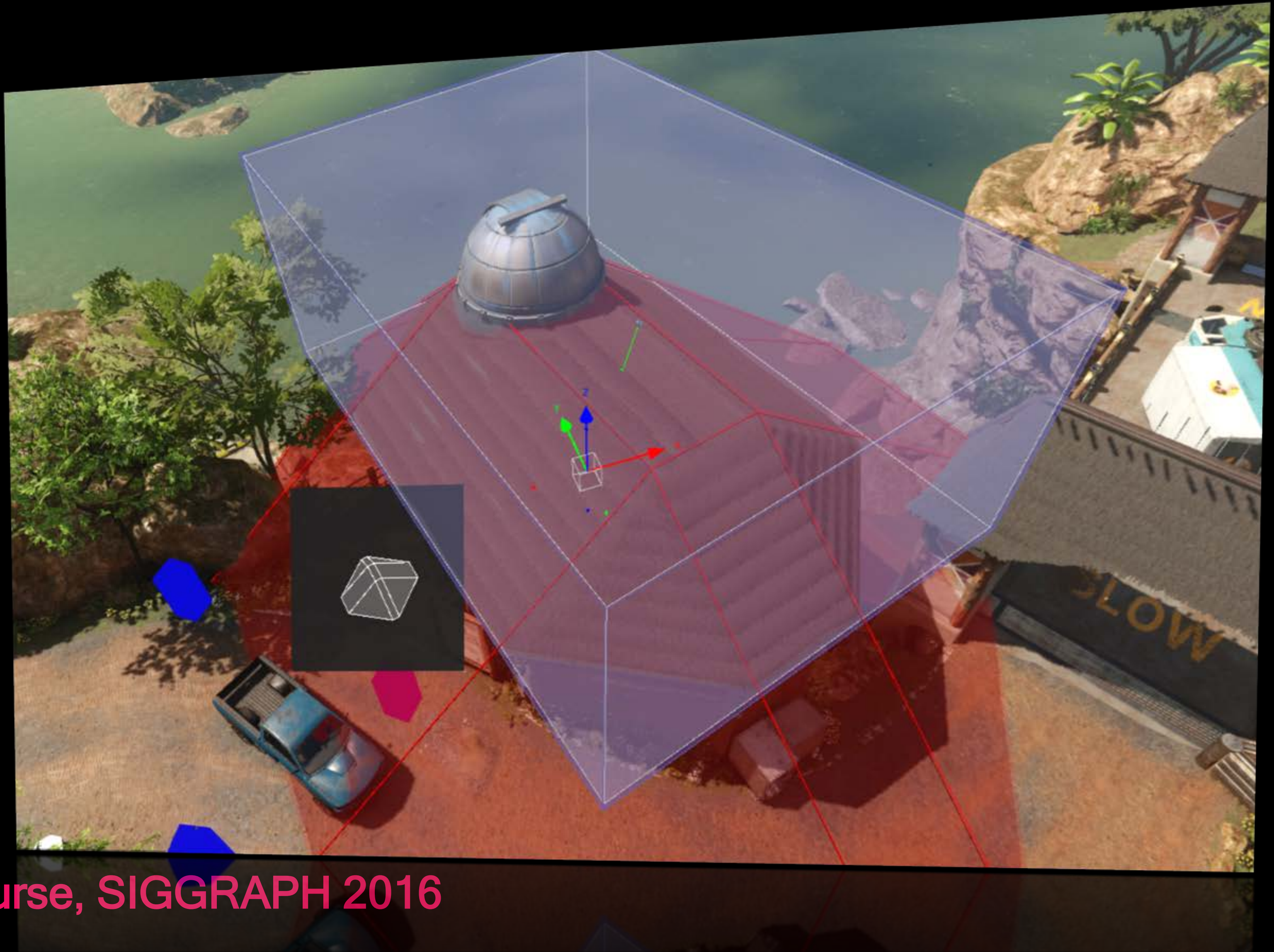
Subtract Shapes

CSG add

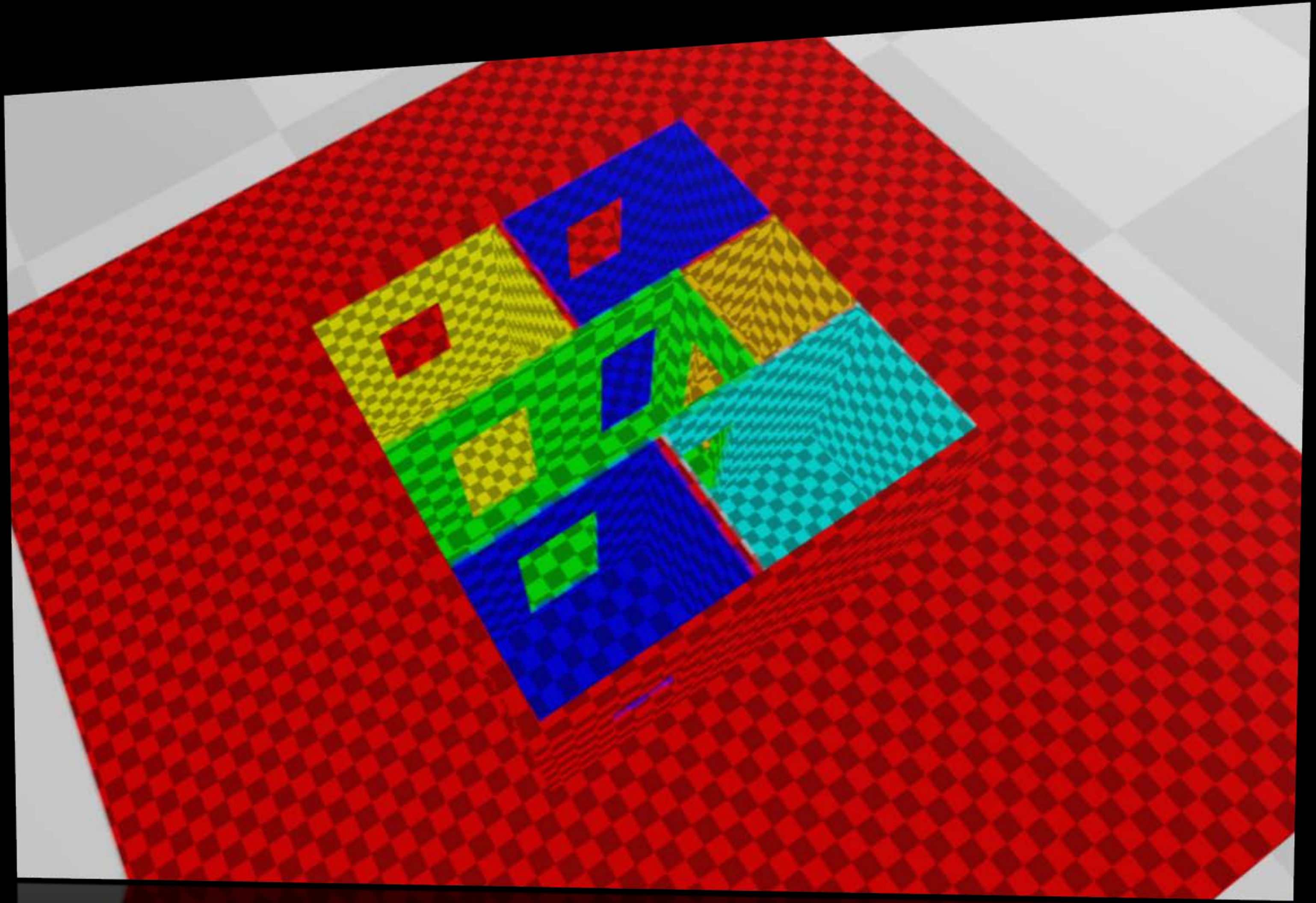
Then subtract



Override Volumes

Like priority

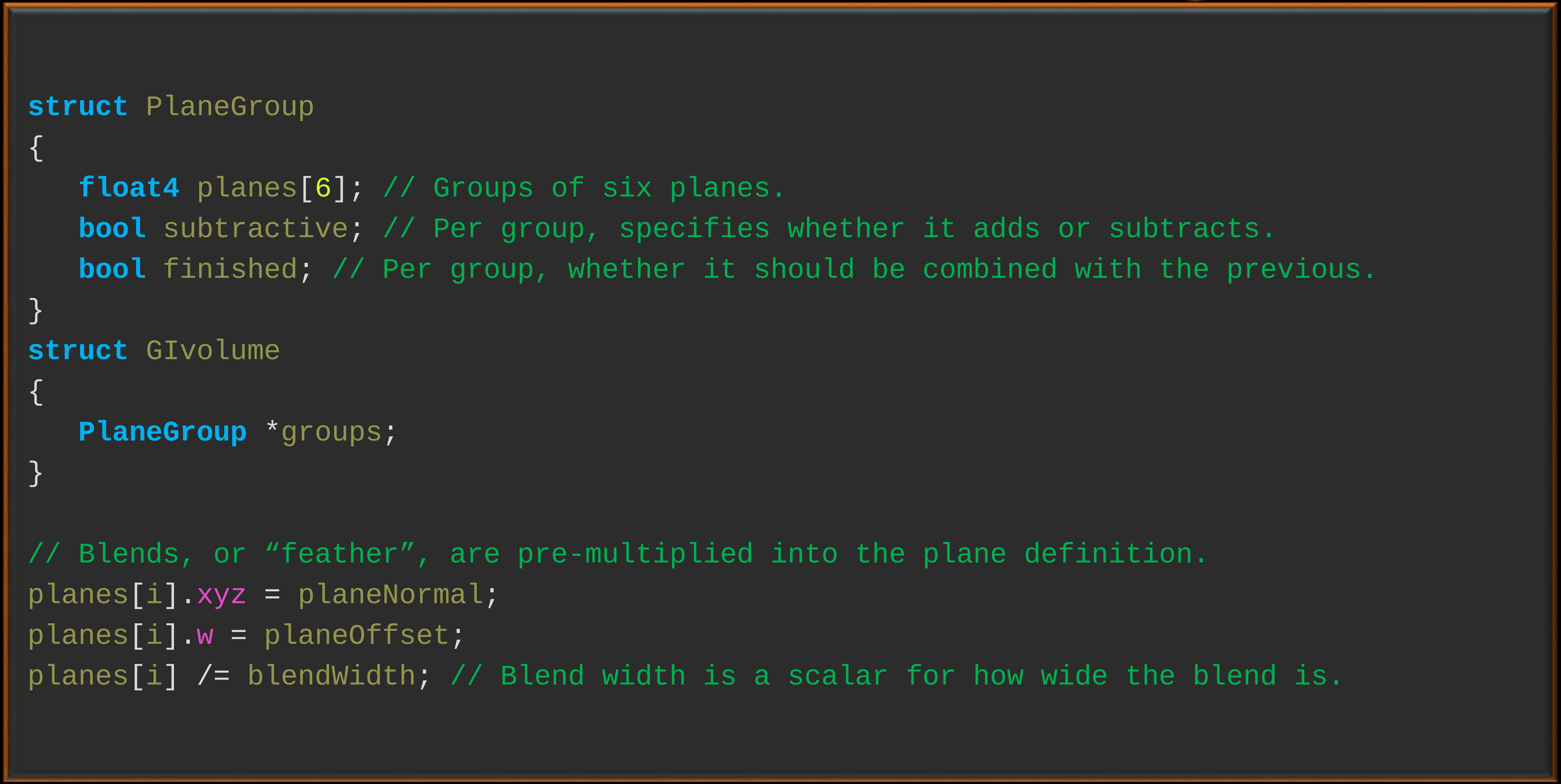
Only two levels.



Runtime Implementation

1. Cull against volume AABB’s to build a list of volumes
2. Per pixel calculate attenuation on visible volumes
   - Convex hull CSG
   - Groups of six planes either extended, combined or subtracted

Example GI Volume



```
struct PlaneGroup
{
   float4 planes[6]; // Groups of six planes.
   bool subtractive; // Per group, specifies whether it adds or subtracts.
   bool finished; // Per group, whether it should be combined with the previous.
}
struct GIvolume
{
   PlaneGroup *groups;
}

// Blends, or “feather”, are pre-multiplied into the plane definition.
planes[i].xyz = planeNormal;
planes[i].w = planeOffset;
planes[i] /= blendWidth; // Blend width is a scalar for how wide the blend is.
```

Group Size?

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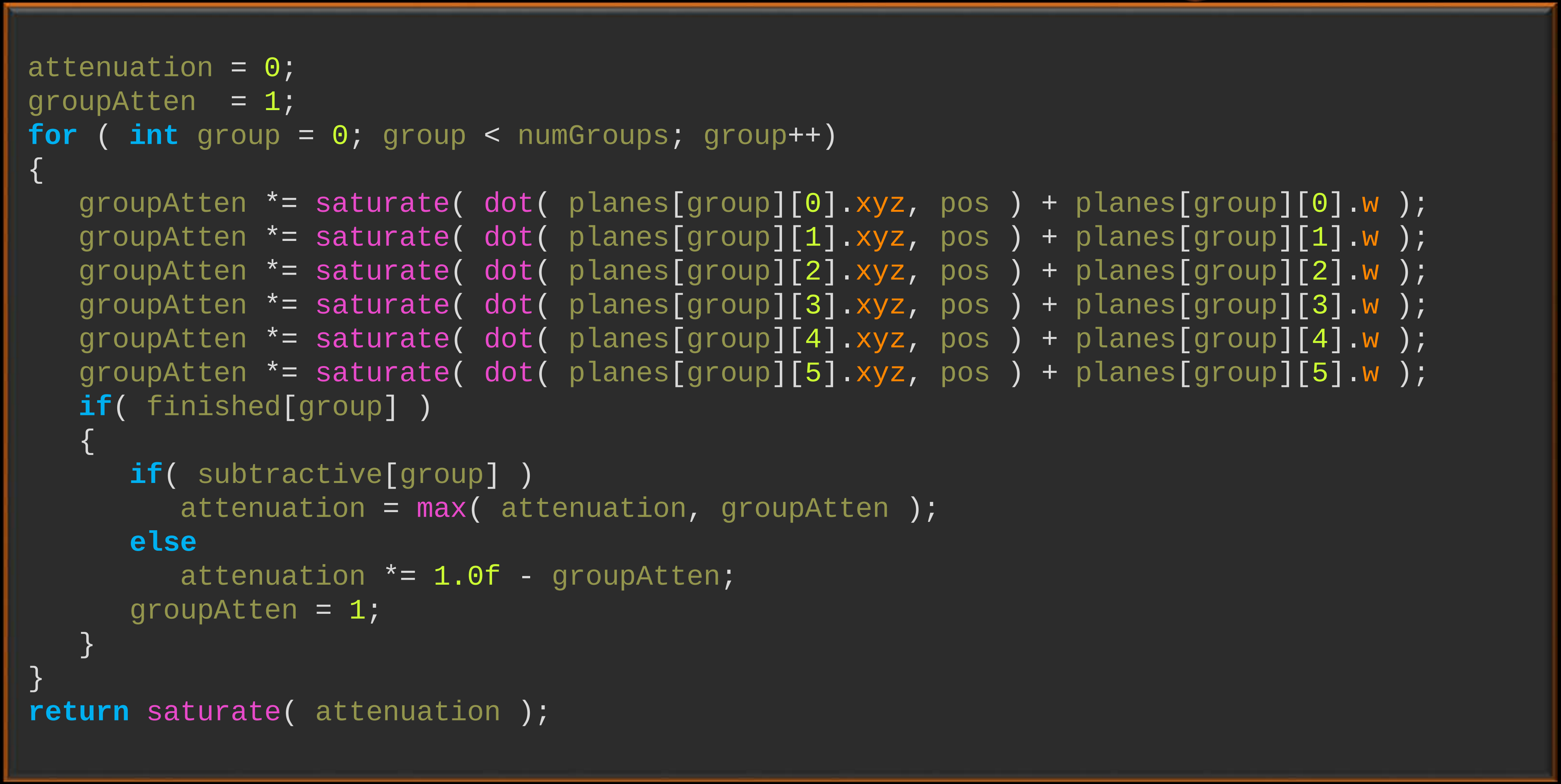
[6]+[6+6+…?

[6]+[4+4+...?

[4]+[4+4+…?

[8]+[2+2+…?

Shader Example



```
attenuation = 0;
groupAtten  = 1;
for ( int group = 0; group < numGroups; group++)
{
   groupAtten *= saturate( dot( planes[group][0].xyz, pos ) + planes[group][0].w );
   groupAtten *= saturate( dot( planes[group][1].xyz, pos ) + planes[group][1].w );
   groupAtten *= saturate( dot( planes[group][2].xyz, pos ) + planes[group][2].w );
   groupAtten *= saturate( dot( planes[group][3].xyz, pos ) + planes[group][3].w );
   groupAtten *= saturate( dot( planes[group][4].xyz, pos ) + planes[group][4].w );
   groupAtten *= saturate( dot( planes[group][5].xyz, pos ) + planes[group][5].w );
   if( finished[group] )
   {
      if( subtractive[group] )
         attenuation = max( attenuation, groupAtten );
      else
         attenuation *= 1.0f - groupAtten;
      groupAtten = 1;
   }
}
return saturate( attenuation );
```

Why Not K-DOPs?

KDOP – *k*-sided Discrete Oriented Polytope

Pairs of planes or slabs
Instead of individual planes

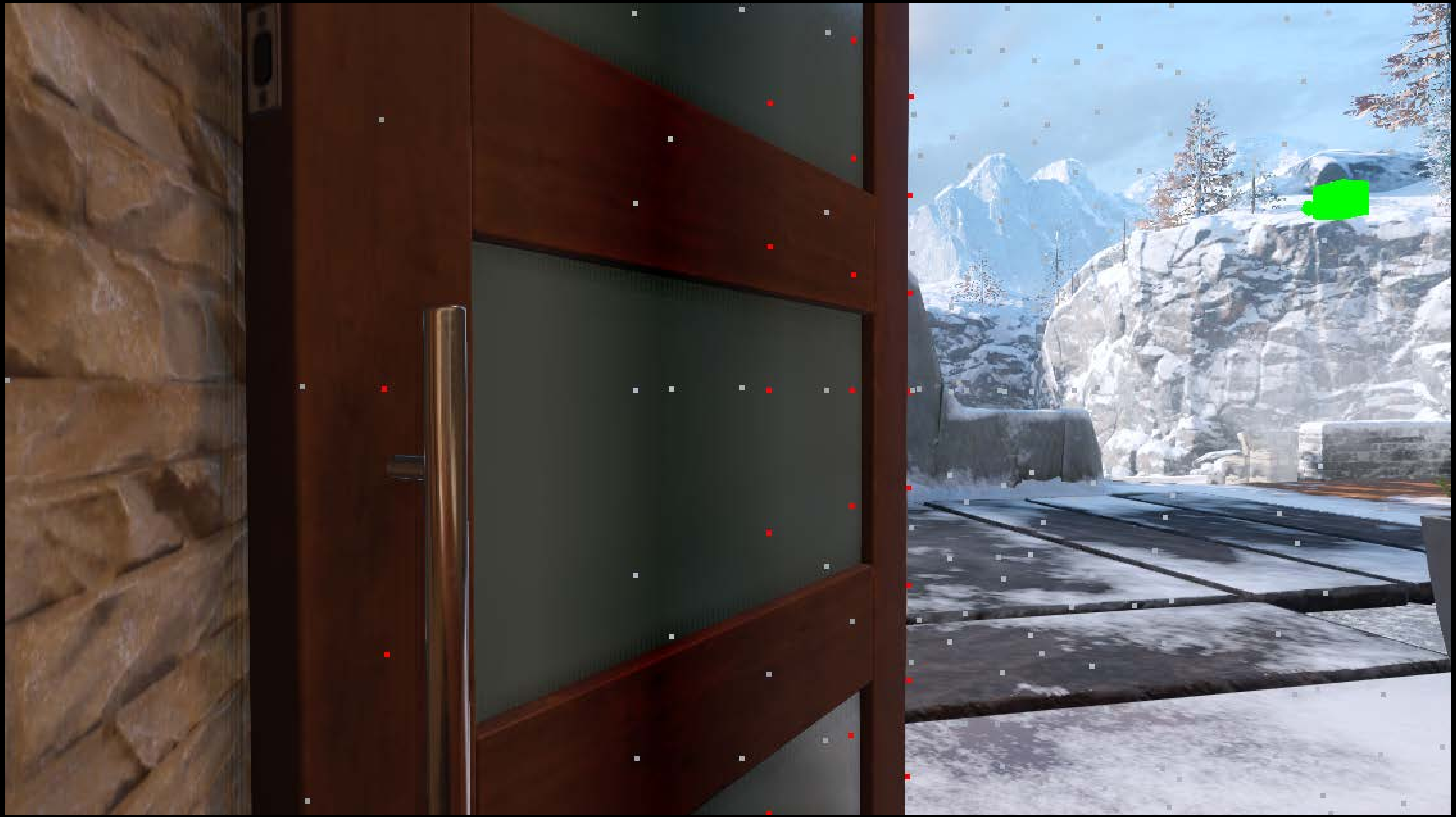
Runtime Implementation

3. Sample three ambient cube values depending on normal

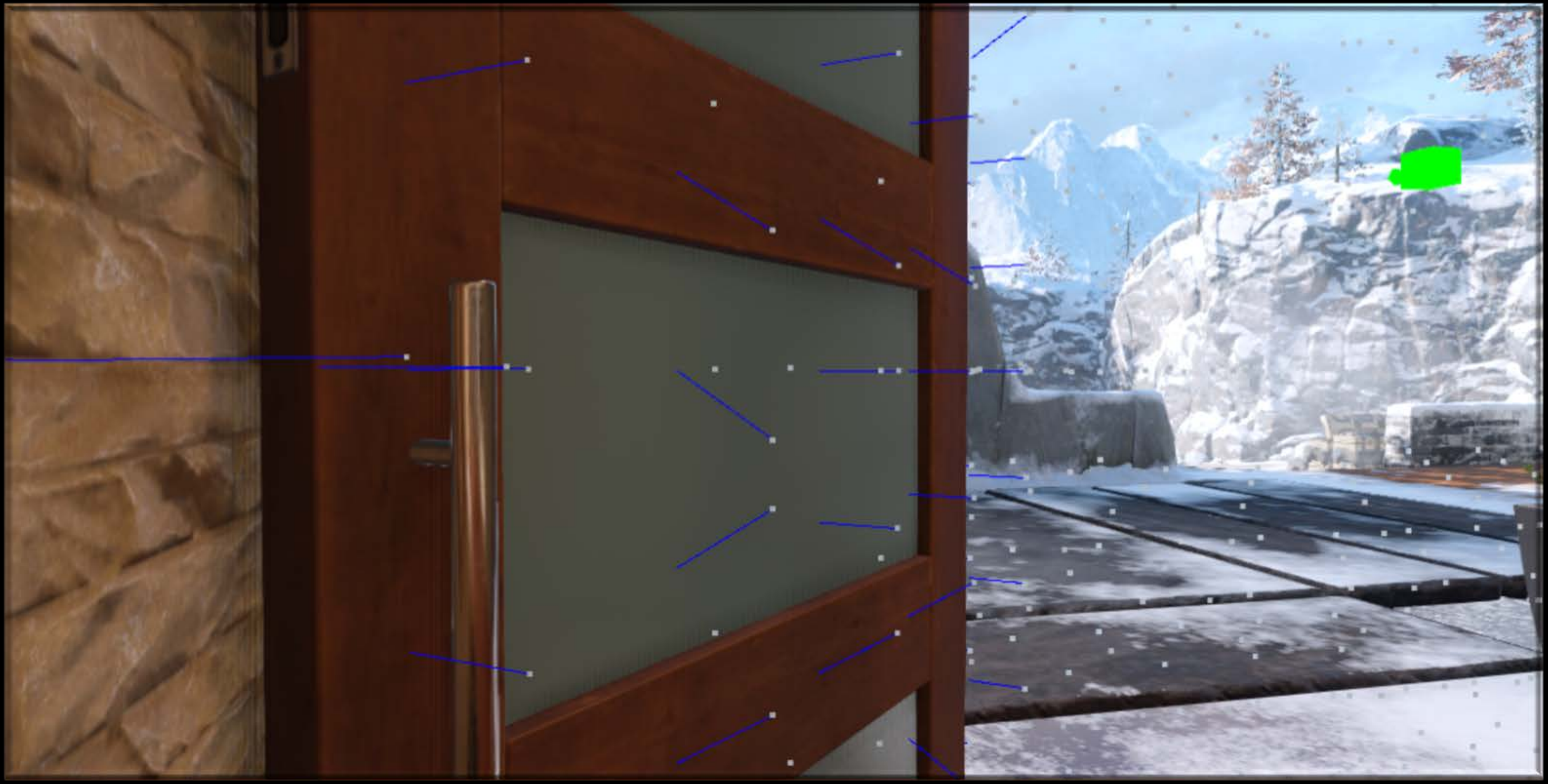
4. Blend results between all volumes

Challenges

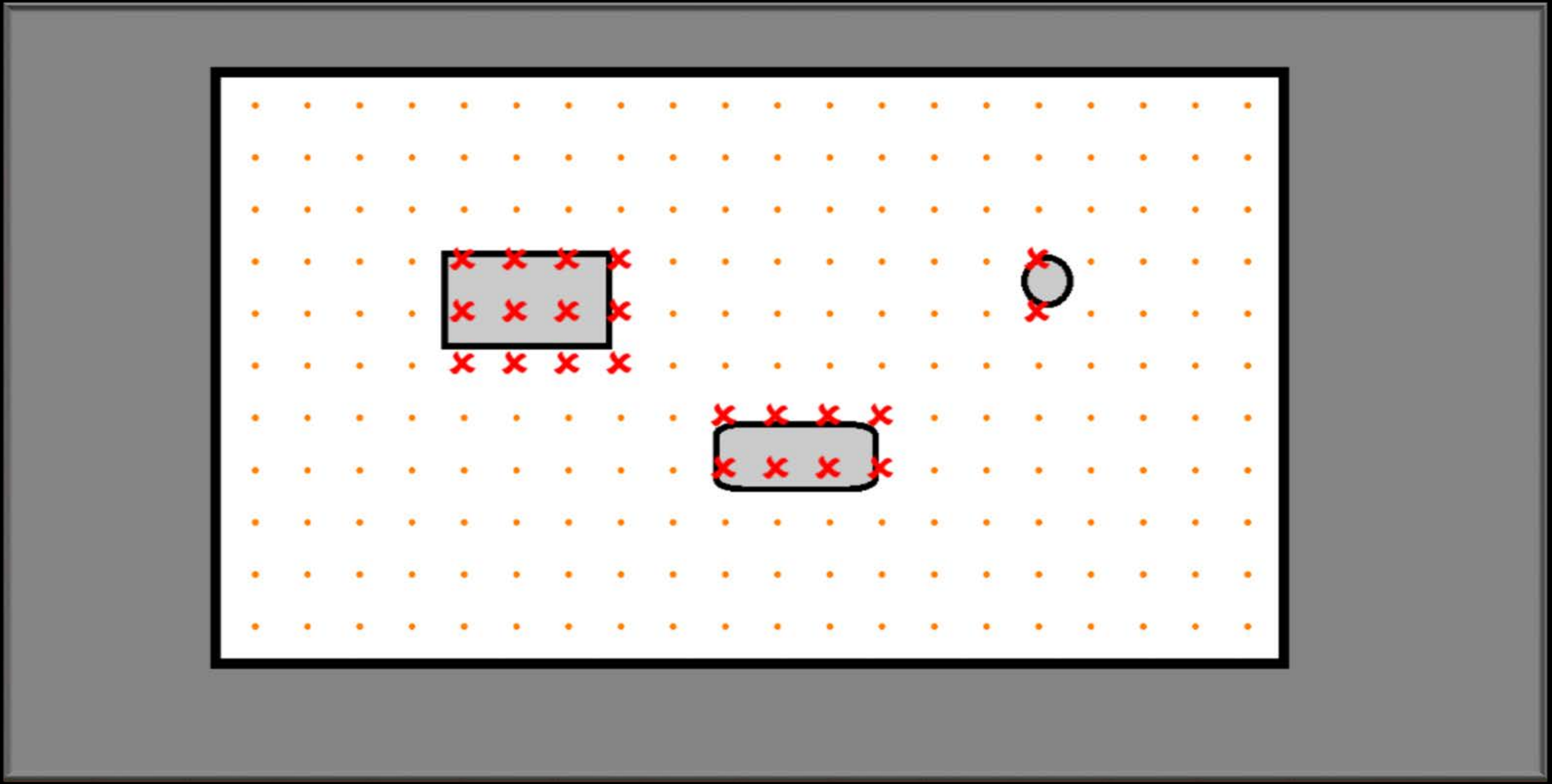
Problem: Geo Within Voxels



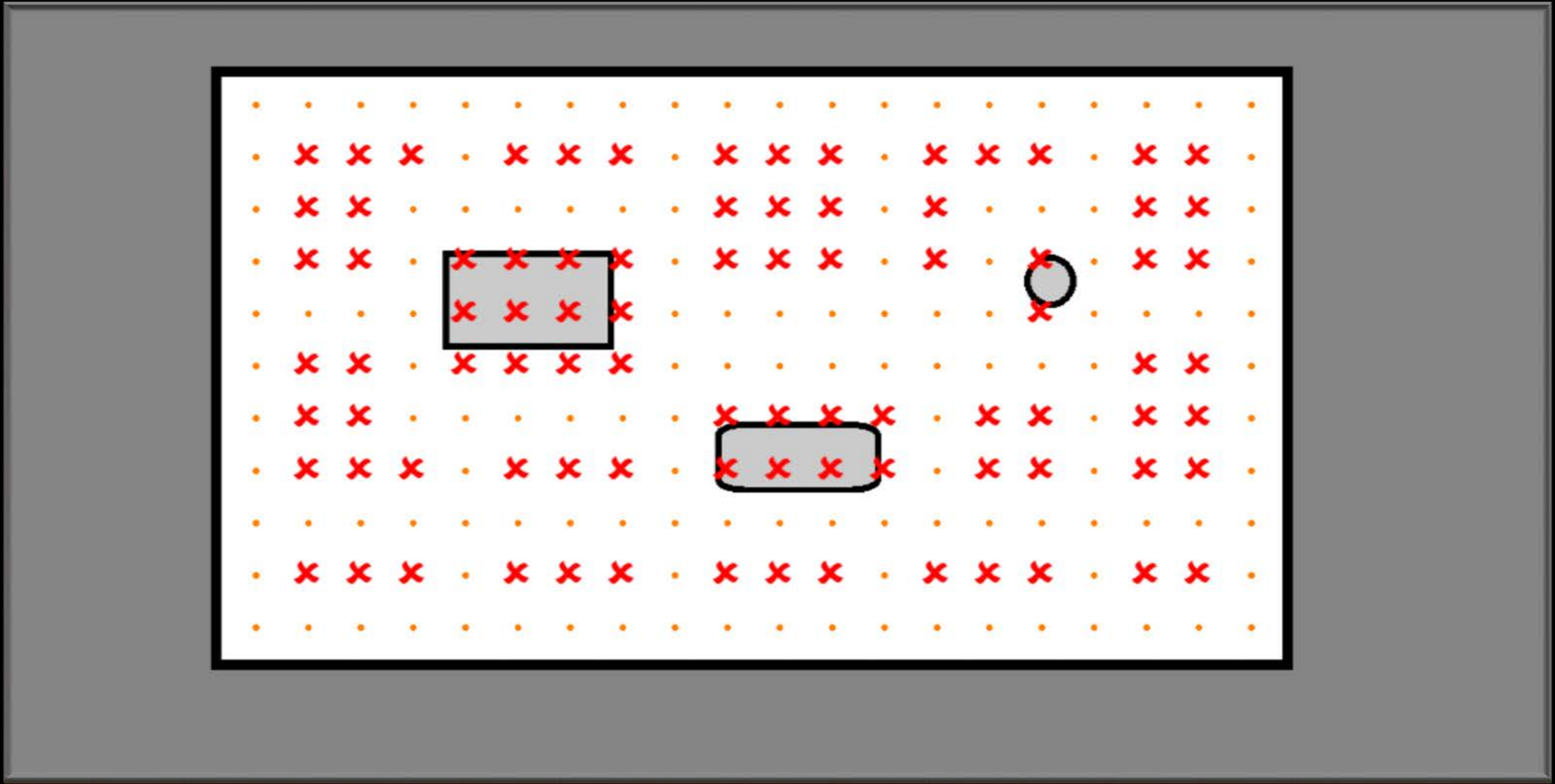
Solution: Smart Centers



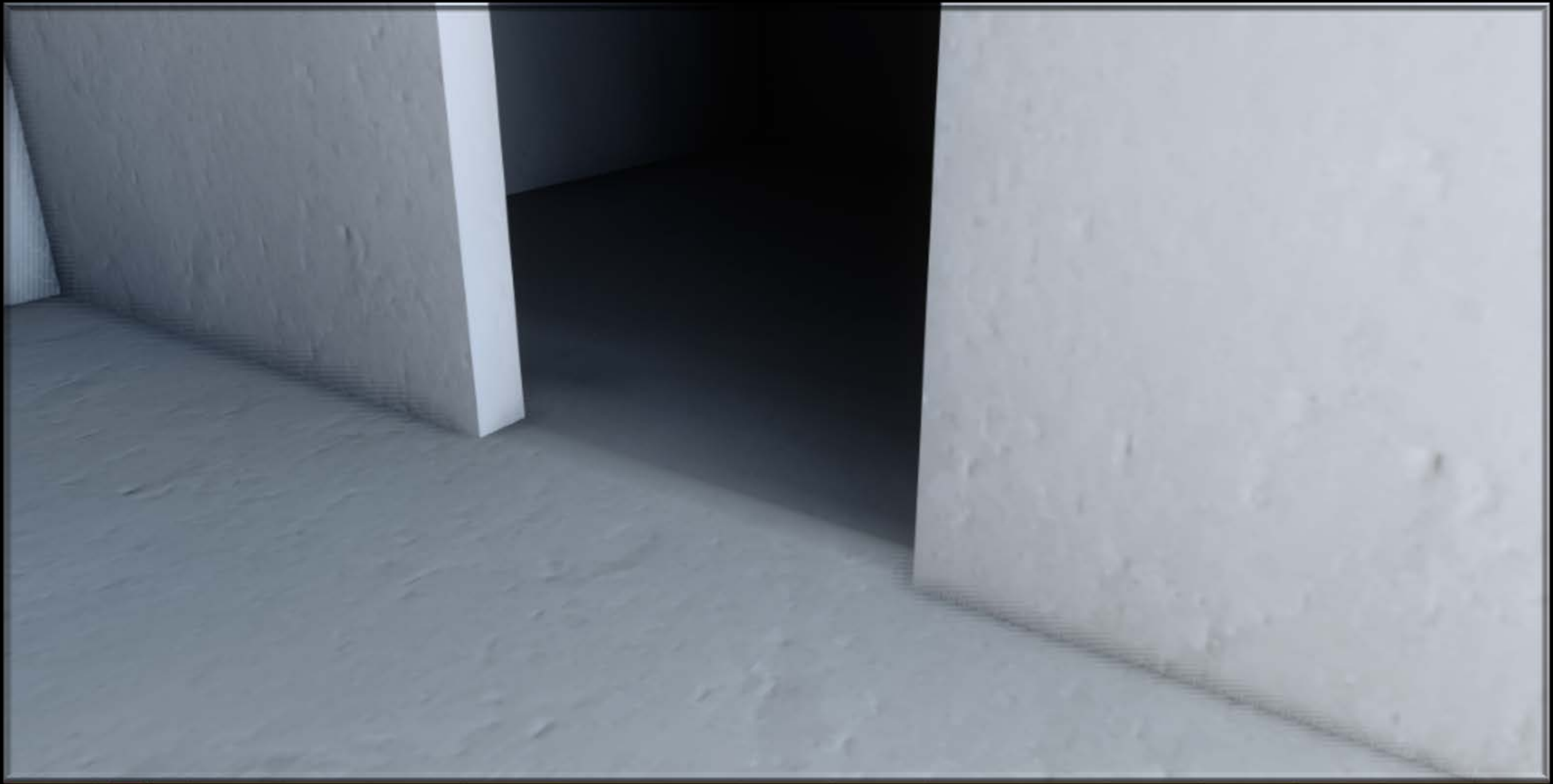
Invalidate Near Geometry



Empty Space Skip



Problem: Seams



Solution: Volume Smoothing

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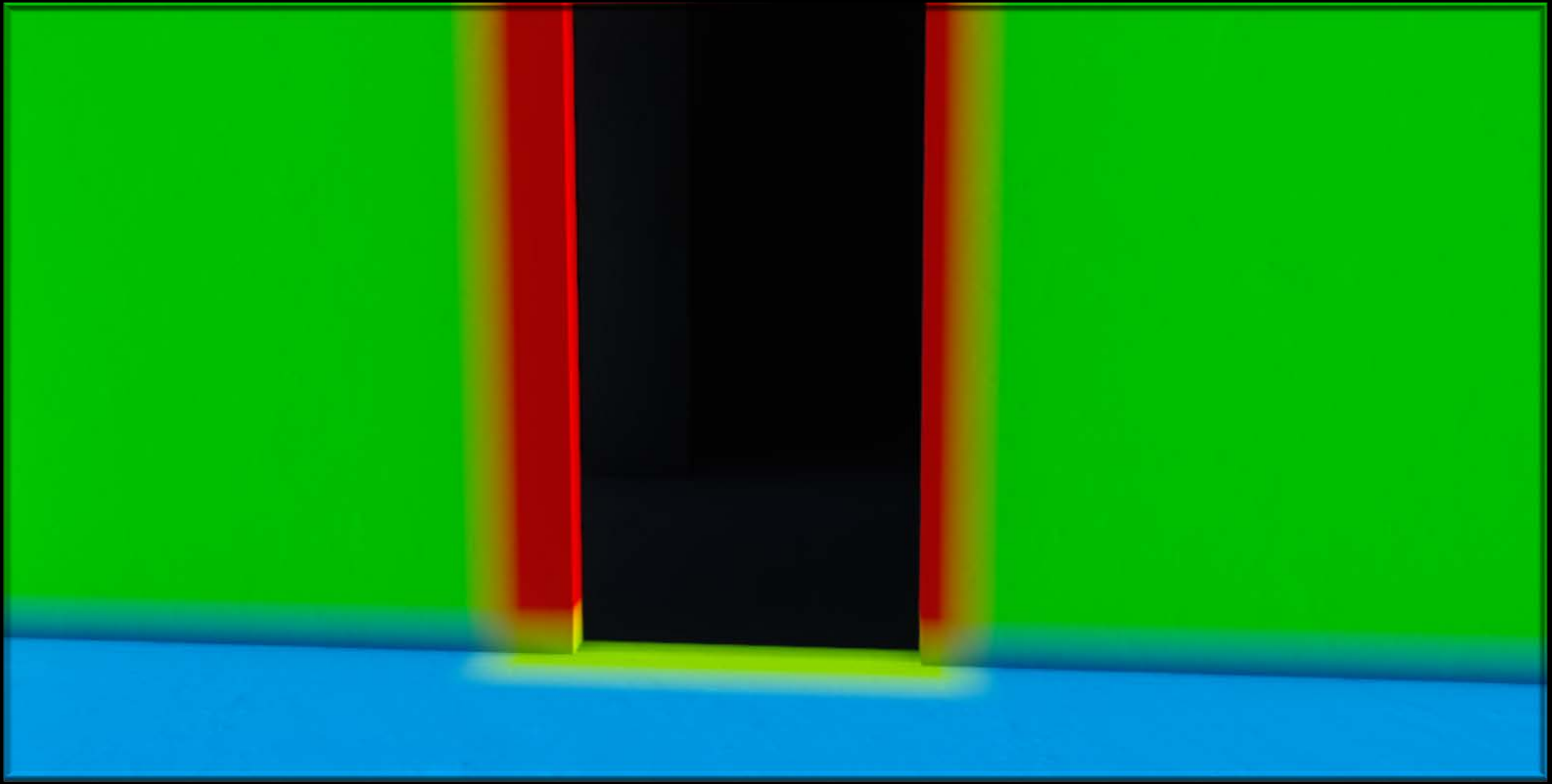


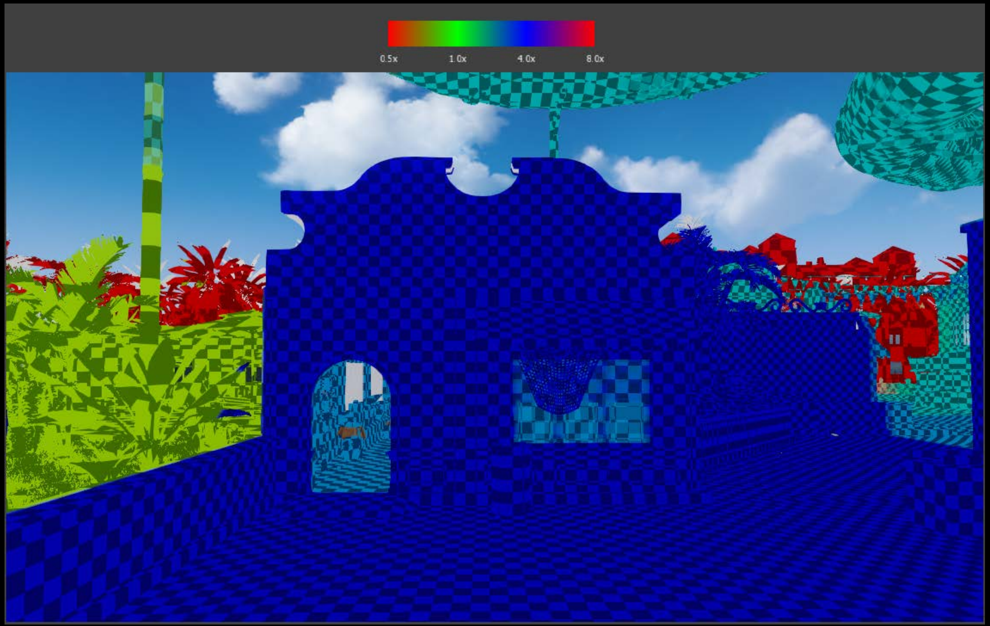
Careful Lighting Artistry

Auto Volumes?

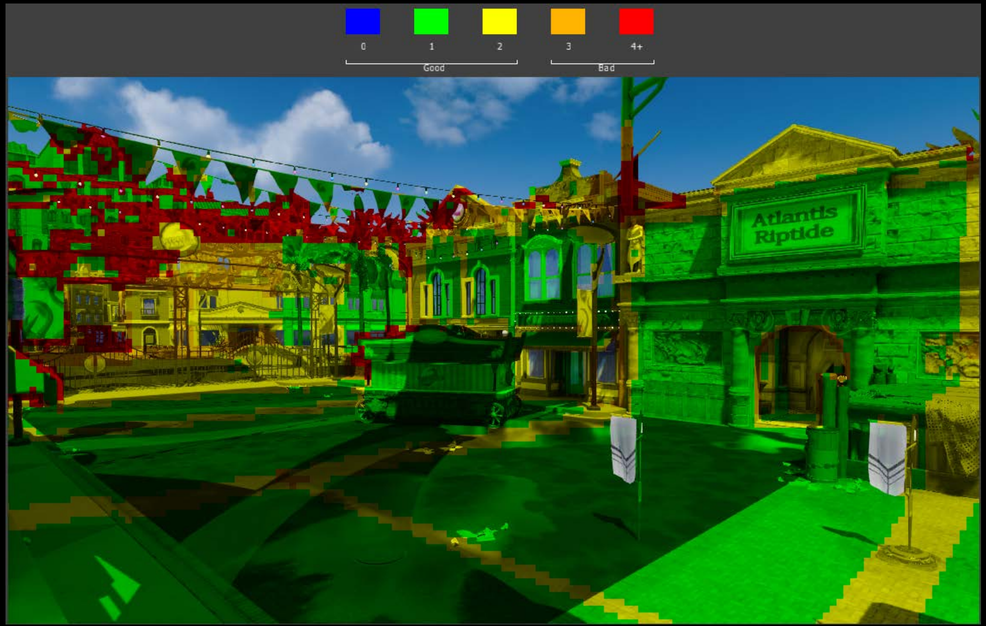
"Do-Everything Button"

Debug Tools

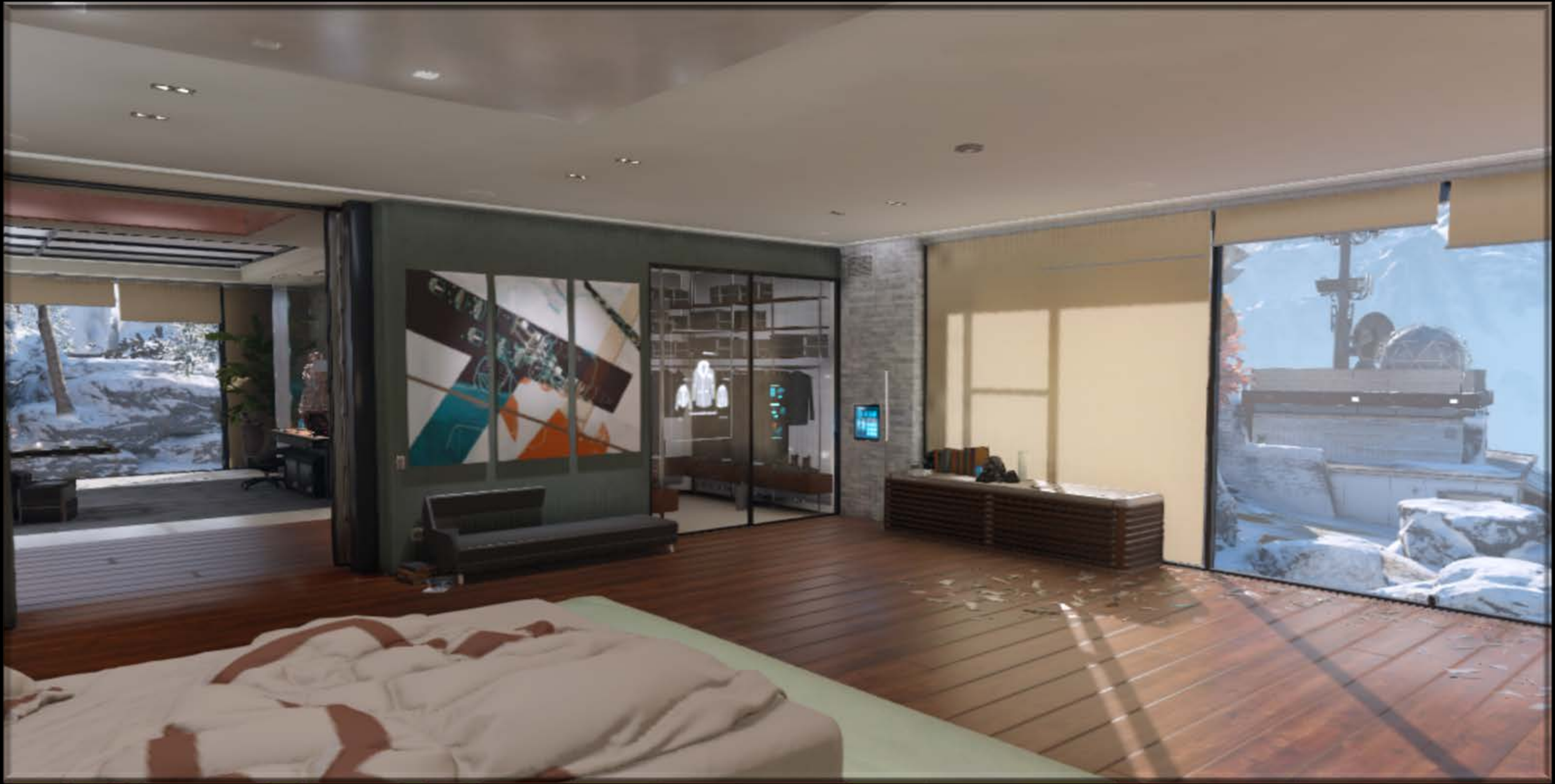
Volume Blending And Density



Volume Overdraw Per Tile



Reflections



Reflection Planes [LAGARDE12]

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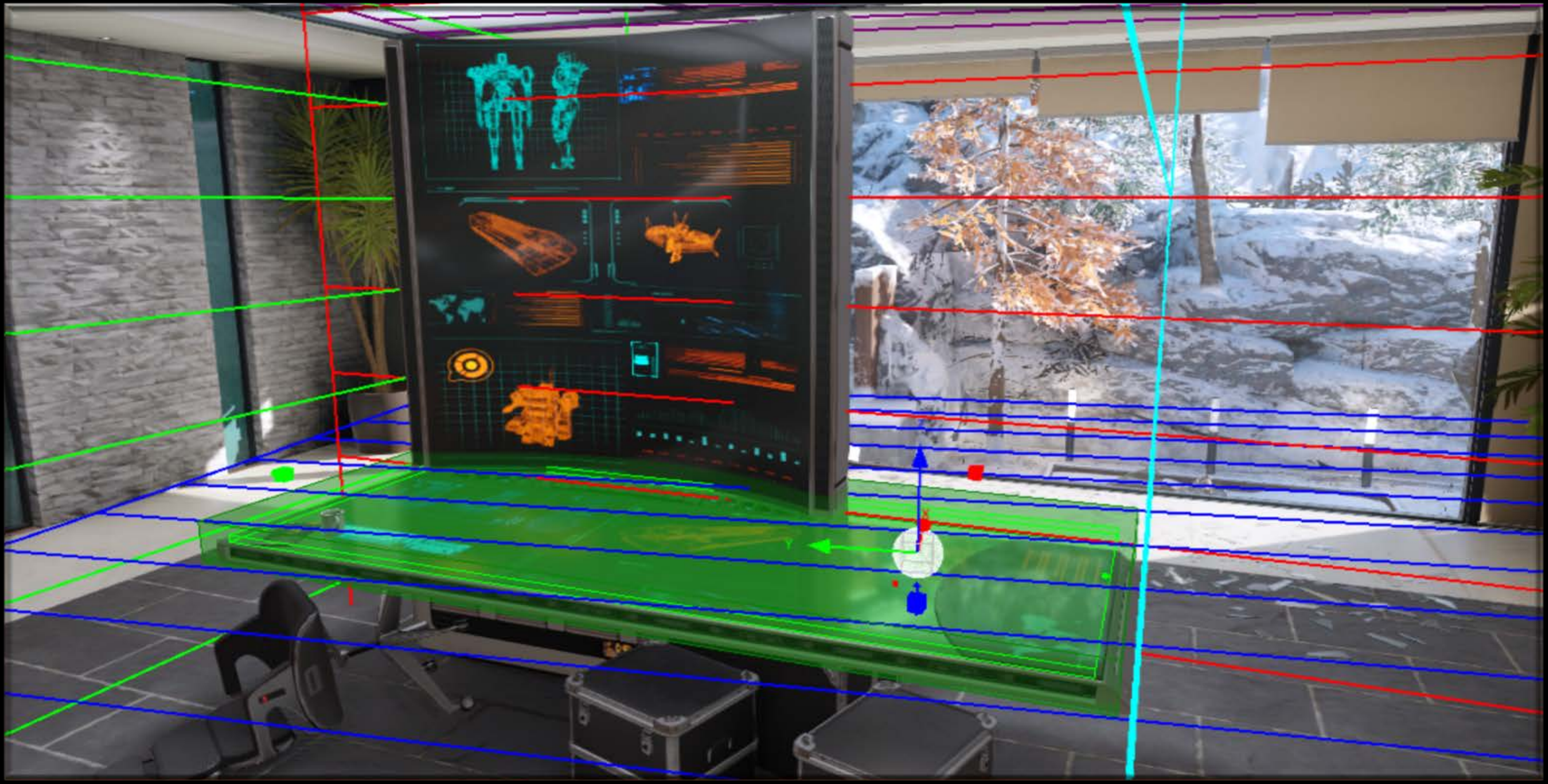
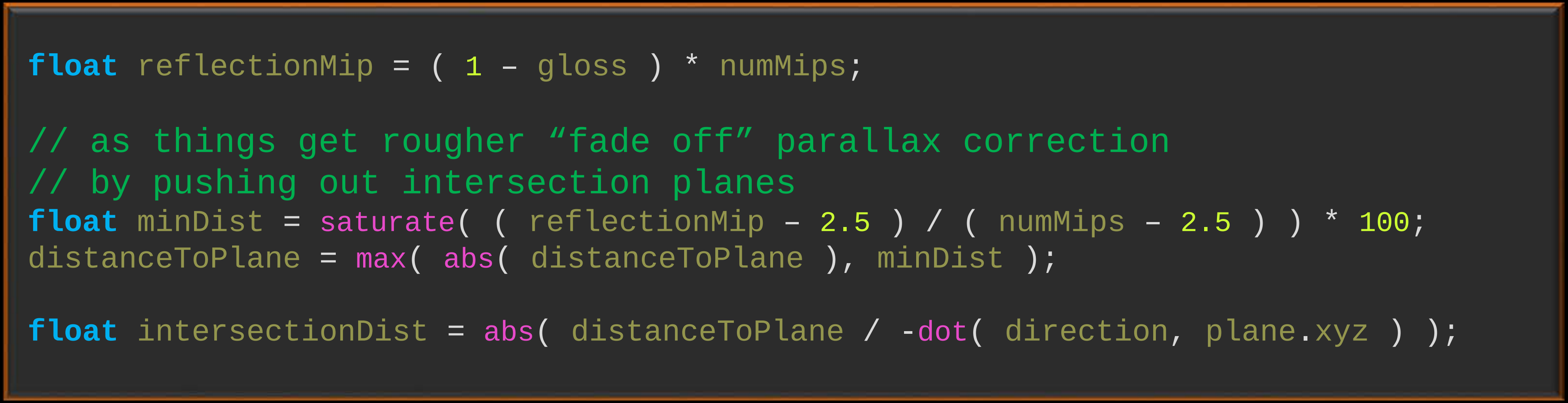


Clever Artistry

DIE ES
MÖGEN

Reflection Plane Parallax

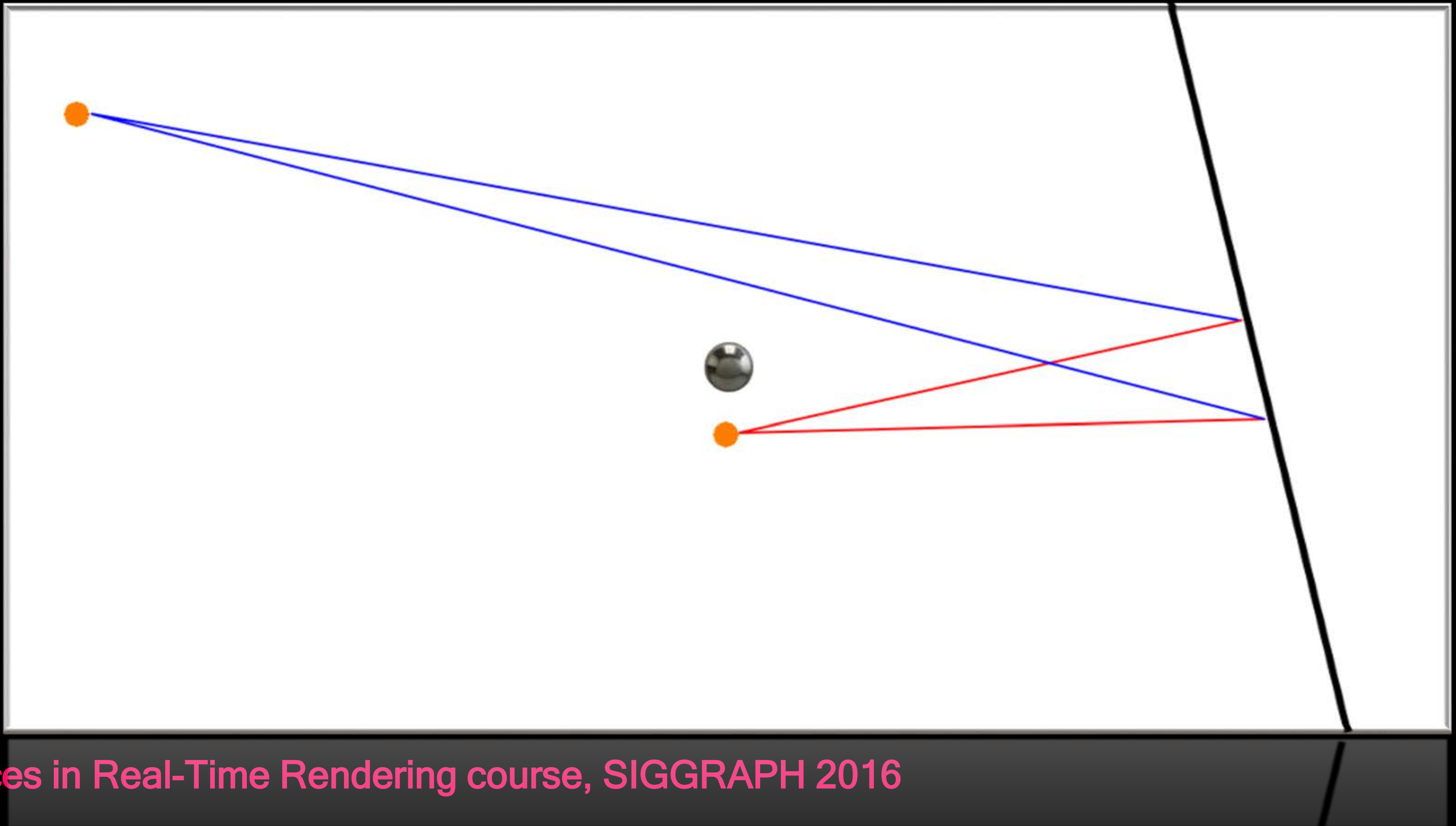


```
float reflectionMip = ( 1 – gloss ) * numMips;

// as things get rougher “fade off” parallax correction
// by pushing out intersection planes
float minDist = saturate( ( reflectionMip – 2.5 ) / ( numMips – 2.5 ) ) * 100;
distanceToPlane = max( abs( distanceToPlane ), minDist );

float intersectionDist = abs( distanceToPlane / -dot( direction, plane.xyz ) );
```

Parallax Fade Out



Reflection Brightness Correction

[LAZAROV13]

Reflection Brightness Correction

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Brightness Correction

```
float maximumSpecValue = max3( 1.26816,
   9.13681 * exp2( 6.85741 - 2 * mip ) * nDotV,
   9.70809 * exp2( 7.085 - mip - 0.403181 * mip^2) * nDotV );
```

```
float adjustedMaxSpec = diffuseGILum * maximumSpecValue;
float3 specLum = luminance( cubeMapSample );
float3 reflection = cubeMapSample *
   adjustedMaxSpec / ( adjustedMaxSpec + speculum );
```

Pros:

1. As good or better quality than light maps

Pros:

2. Less than 2ms for reflections and GI

Pros:

3. Works on all geometry

Pros:

4. Less baking time with incremental baking

Pros:

5. Baking is done in editor

Pros:

6. Moving and changing GI

Pros:

7. Loose connection between light and geo

Cons:

1. Takes set up time

Cons:

2. Training is hard

Cons:

3. Either lower resolution

   or more memory use in game

Cons:

4. Need beefy dev machines

   (48Gb RAM and 12Gb VRAM)

Cons:

5. Development challenges

Special Thanks

Treyarch:

Dimitar Lazarov – Original Idea

Kevin Myers – Baking Code

Everyone Else at Treyarch

Activision Central Tech:

Peter-Pike Sloan – Lots of Math

Josiah Manson – Light Bake Features

Angelo Pesce – Reflection Solutions

References

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