Tessellated Voxelization for Global Illumination using Voxel Cone Tracing

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Outline

1. Introduction
2. Background
3. Implementation
4. Results and Conclusions

Outline

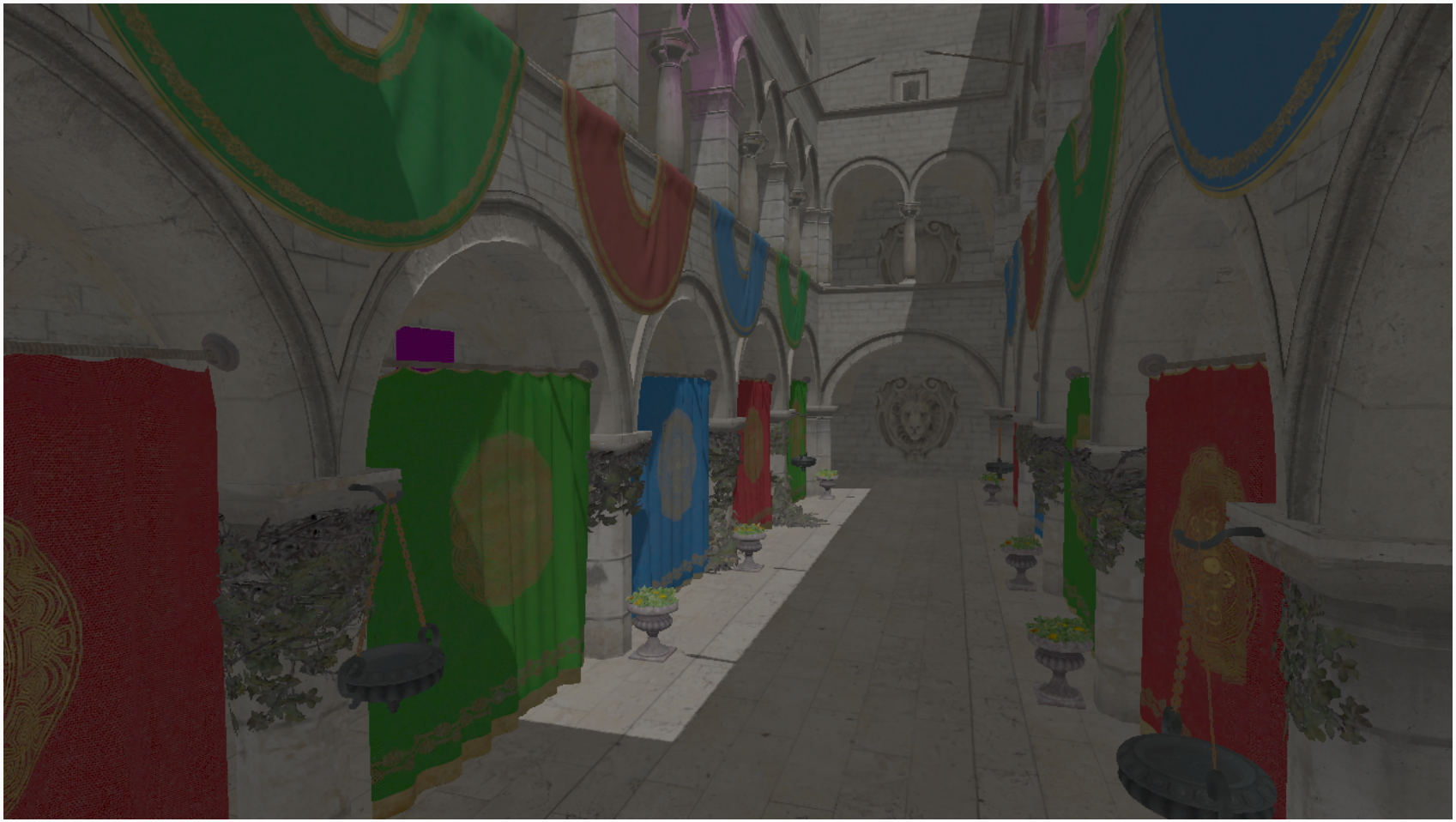
Introduction

Computer Graphics

How can we simulate light in a virtual world?

Physically accurate lighting is too complex for real-time—approximate!

Motivations



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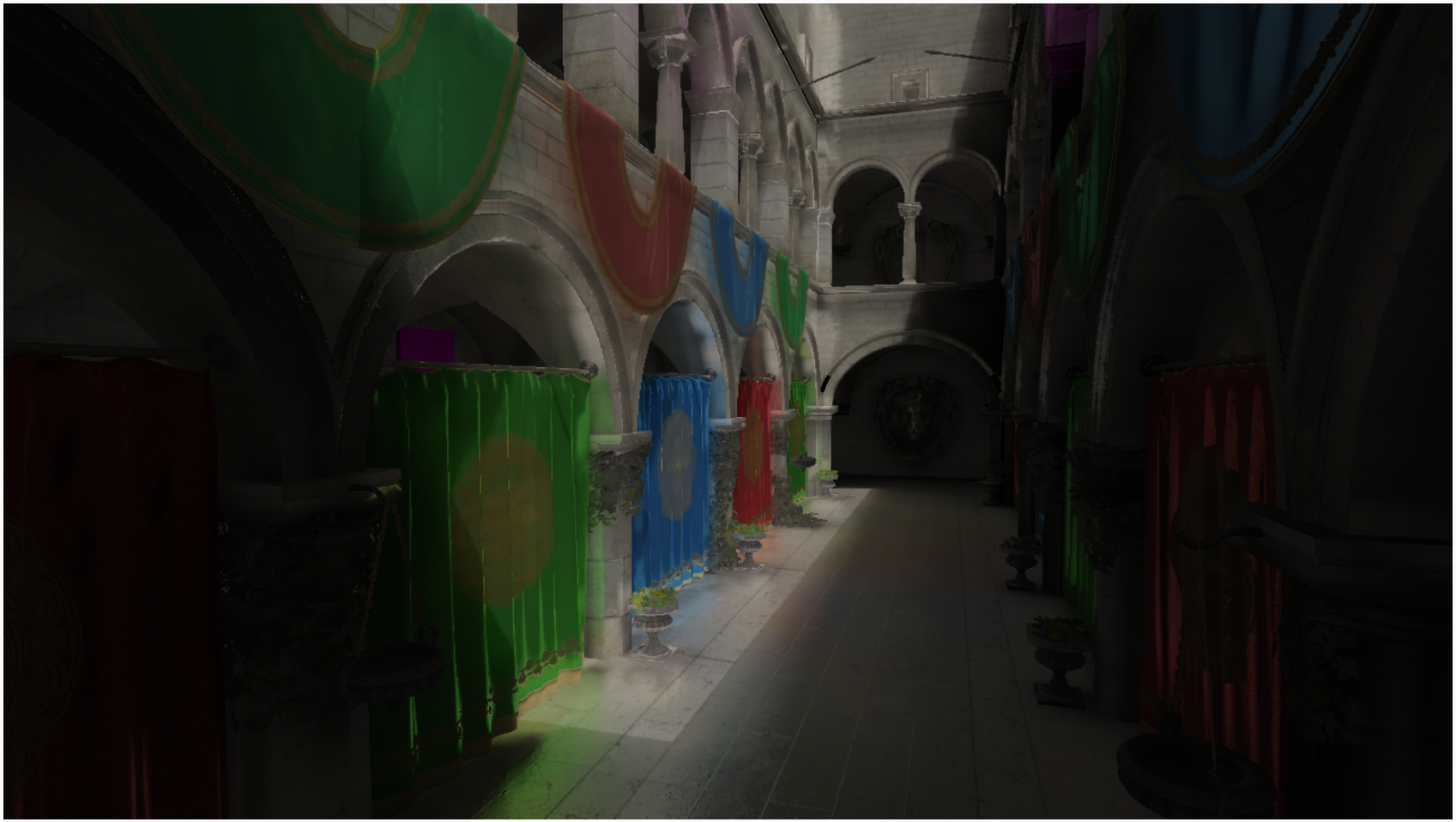
Motivations



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Motivations

1. Real-time global illumination is difficult
    - Approximations need to be as fast and accurate as possible
    - Many steps and stuff to keep track of
2. Limited reference material
    - Not much public code
    - Demo or engine code

Motivations

1. Real-time global illumination is difficult
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    - Many steps and stuff to keep track of
2. Limited reference material
    - Not much public code
    - Demo or engine code
3. It’s cool

Contributions

- Open-source, cross-platform implementation of real-time global illumination (using voxel cone tracing)
- Comparison of two different methods of scene voxelization (rasterization vs. tessellation)
- Investigation into warped (nonuniform size) voxels

Outline

Computer Graphics Primer

Goal

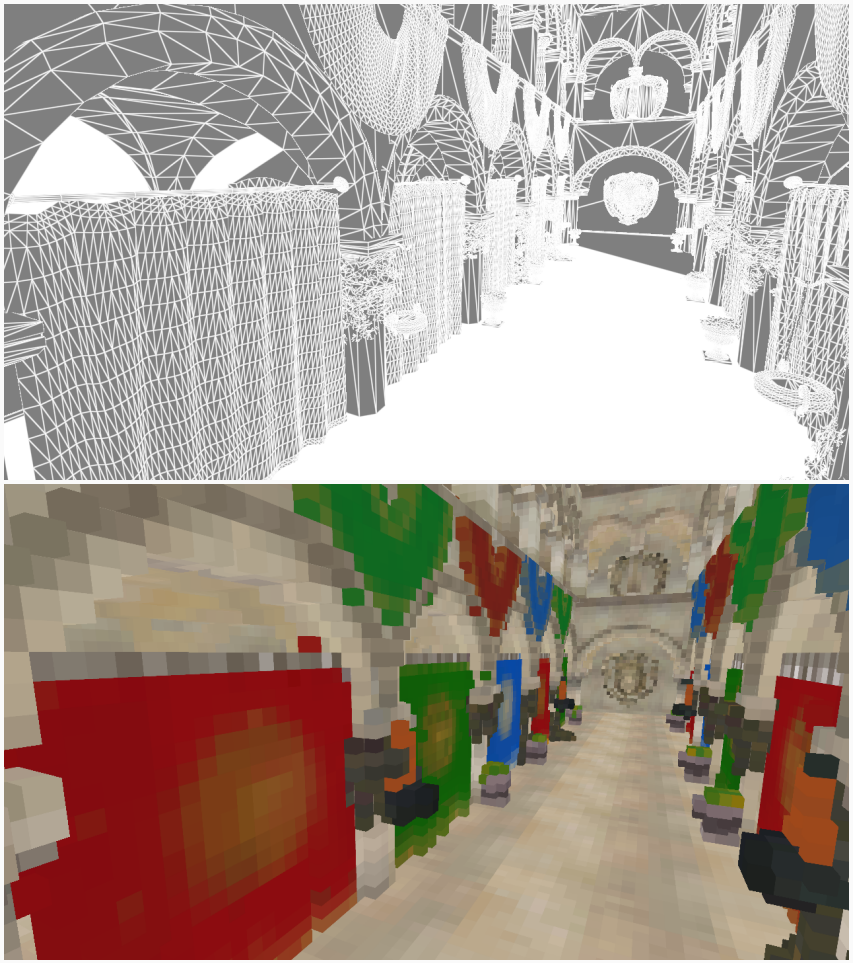
Given a virtual description of a scene, render an image.

Big Issues

1. How do we represent a scene? What information is required?
2. How is a 3D scene represented as a 2D image?
3. How do we render—how is the final pixel color computed?

How do we represent a scene?

- Geometry: triangles, voxels
- Materials: colors and other properties
- Lights: positions, colors, etc.



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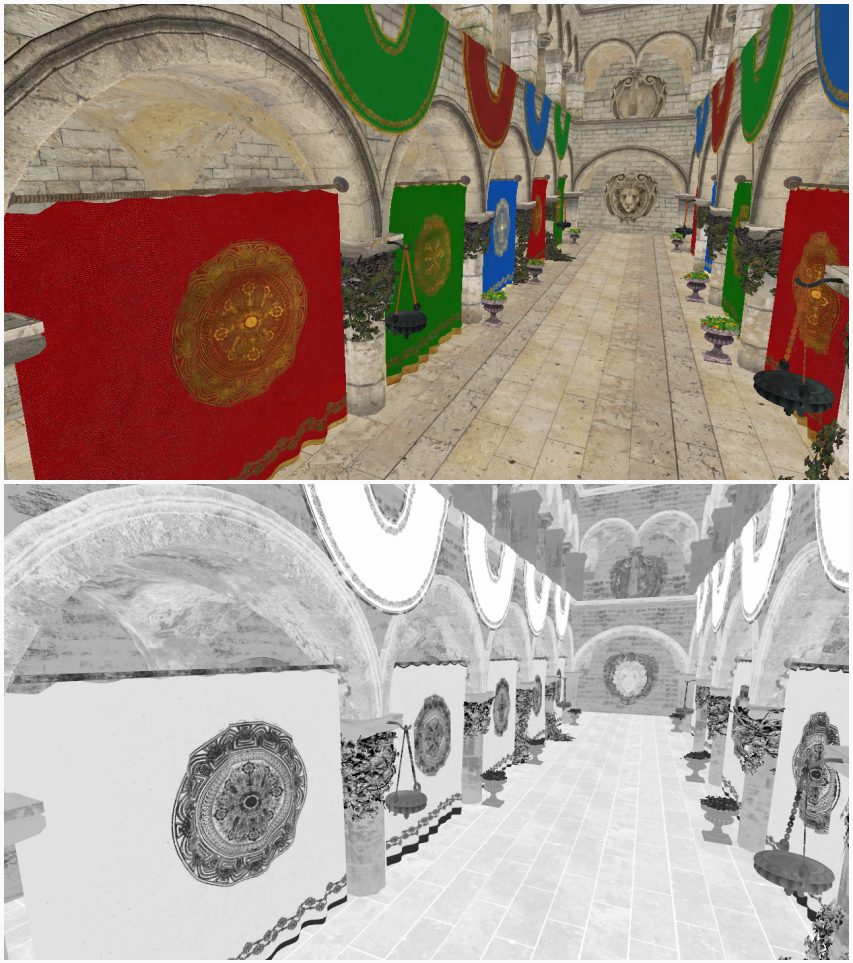

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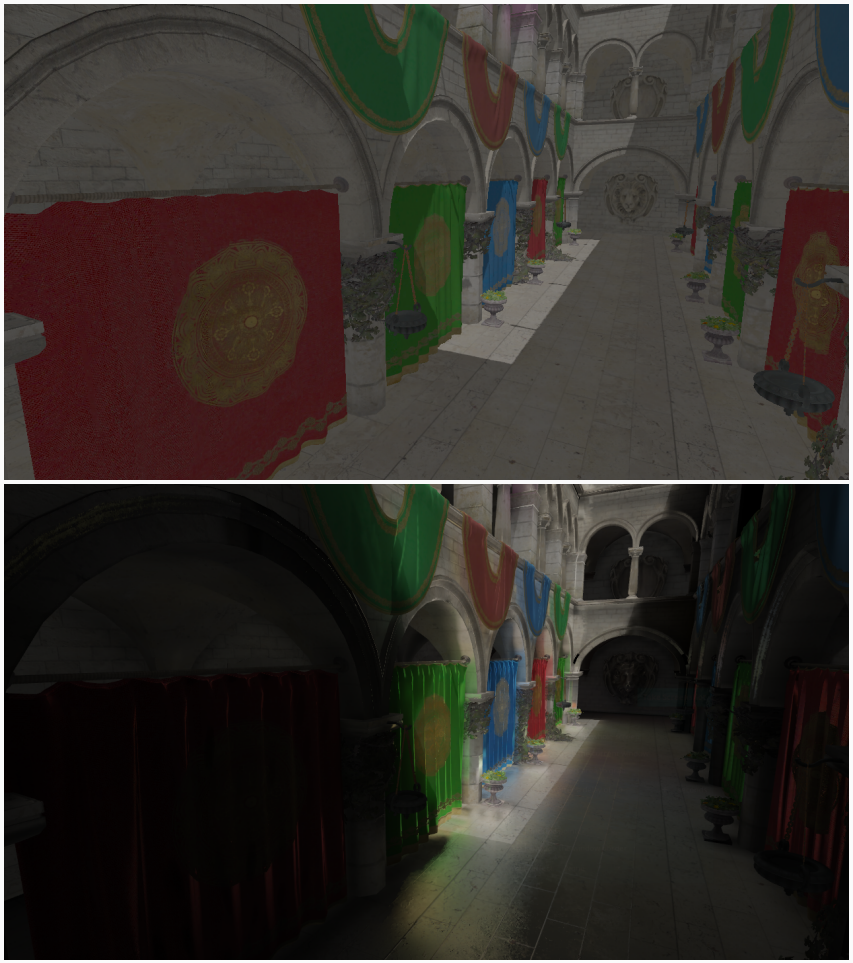


How is a 3D scene represented as a 2D image?

Math!

All coordinates are transformed multiple times before ending up at their appropriate place on the screen.

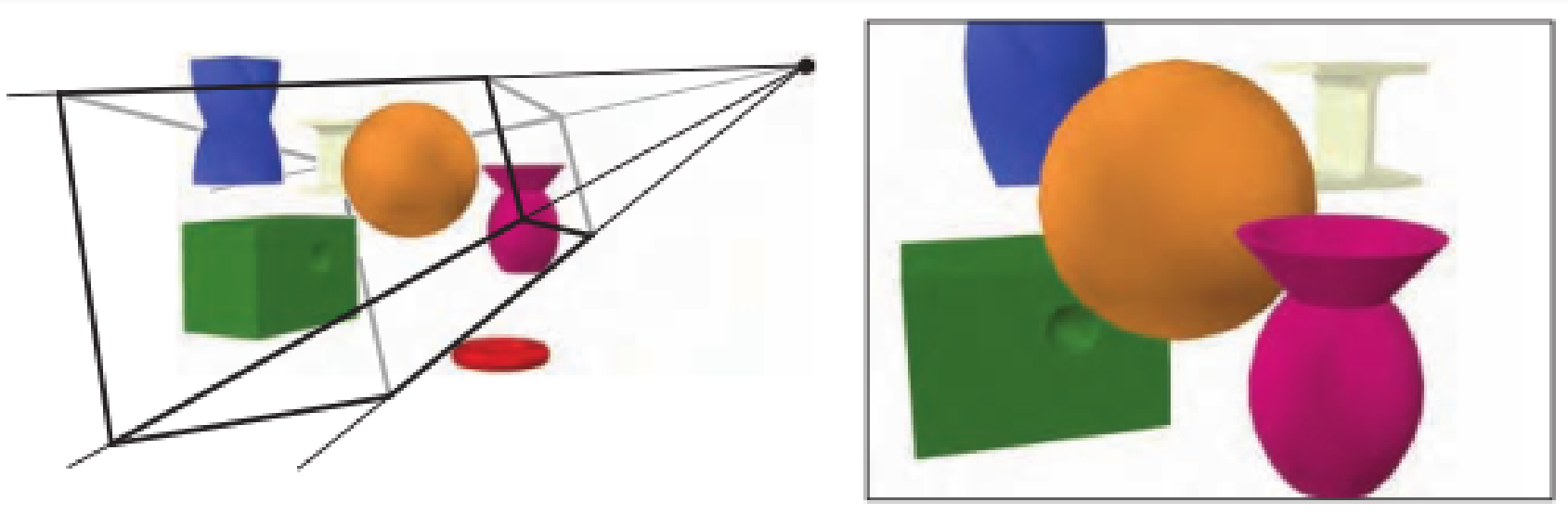
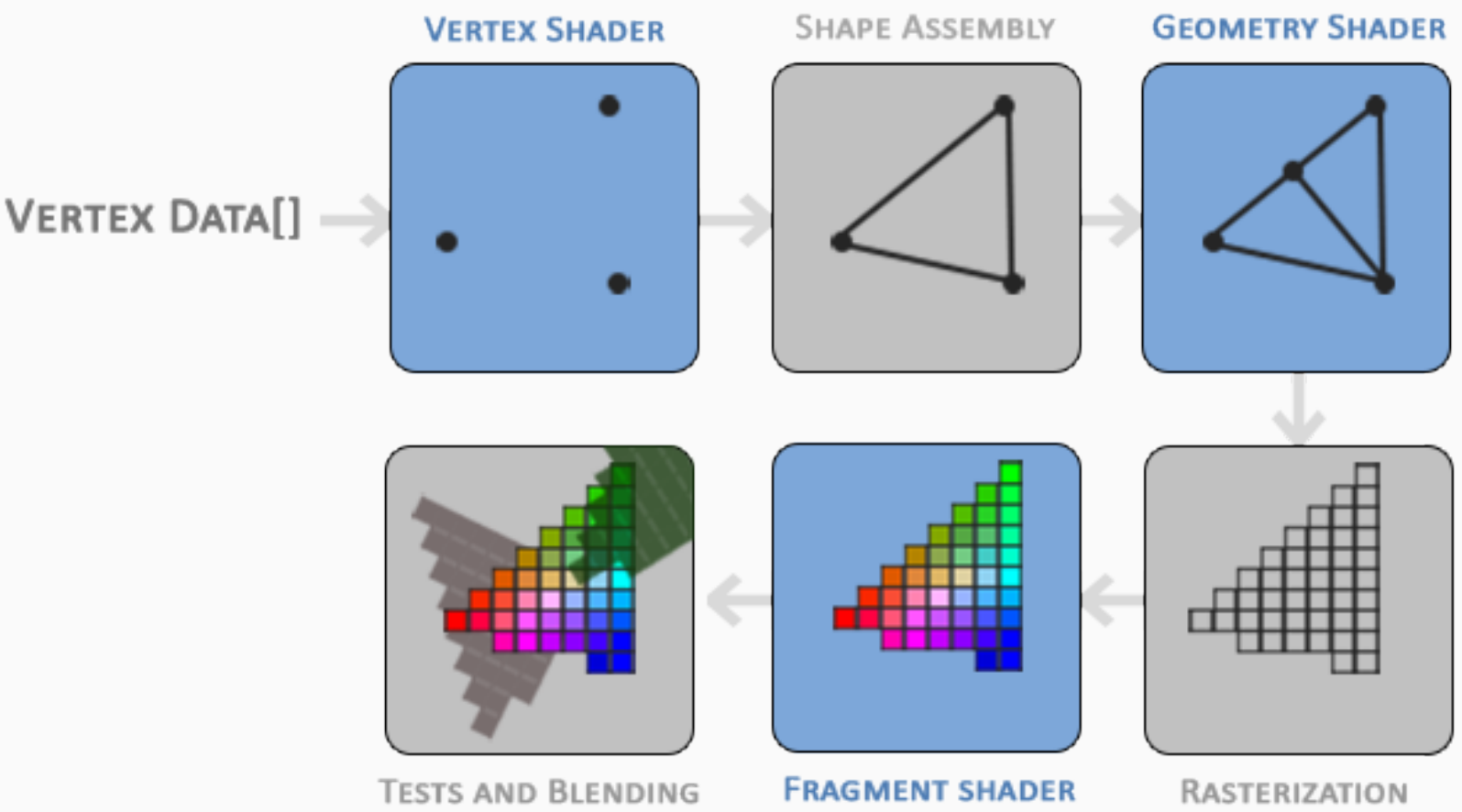


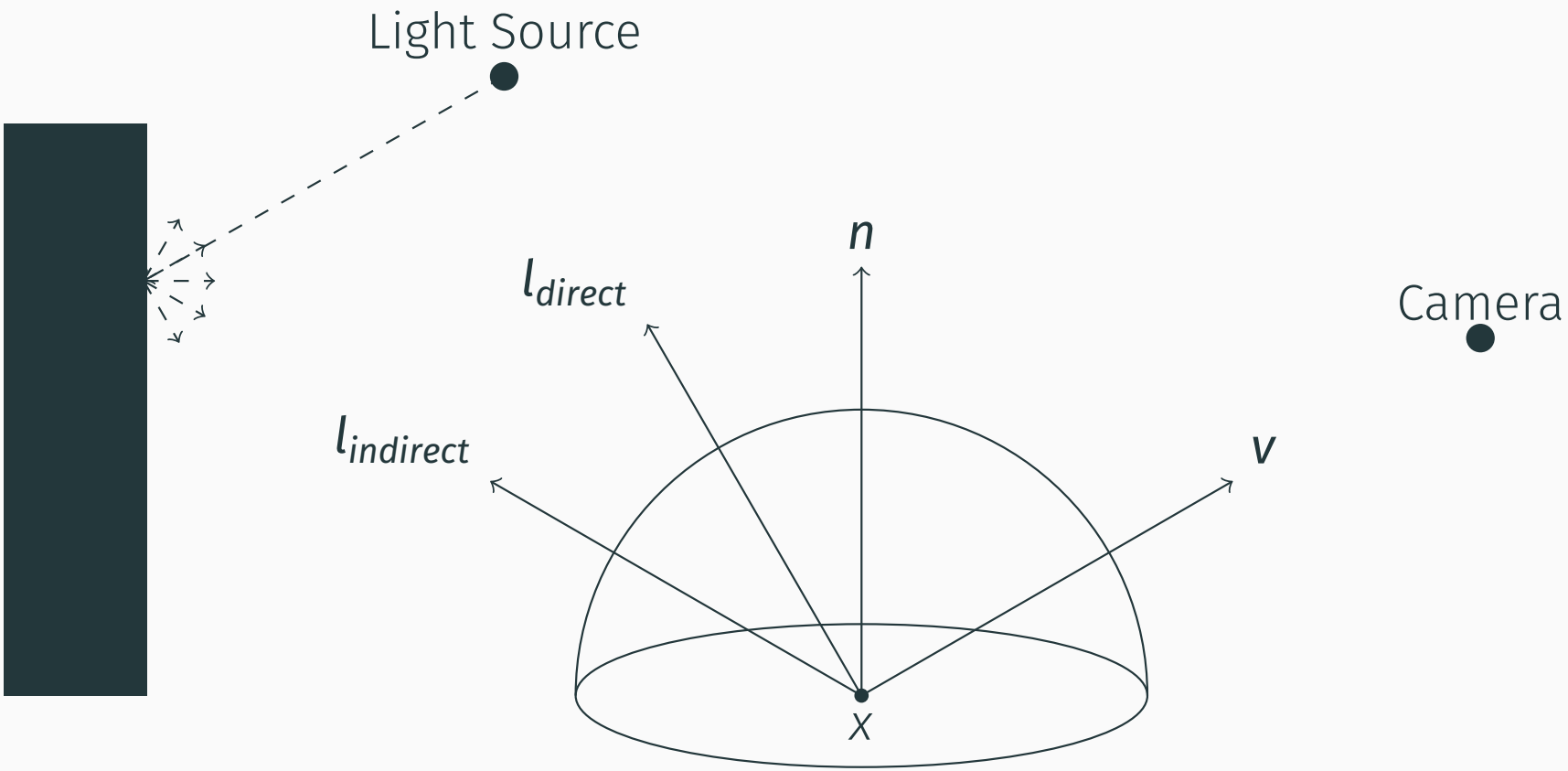
image from Real-Time Rendering

The Graphics Pipeline



How do we render?

Light Theory



Real-Time Global Illumination

Various approaches to approximating indirect light.

Constant Fixed fraction of ambient light

Partial Ambient occlusion, soft shadows, screen space reflections

Static Baked lighting, light probes

Dynamic Reflective Shadowmaps, Light Propagation Volumes, Voxel Cone Tracing

Real-Time Global Illumination

Most dynamic global illumination algorithms follow a few main steps:

1. Construct representation of the scene
2. Calculate indirect lighting information
3. Collect indirect lighting when rendering

What am I doing?

1. Comparing two approaches for scene voxelization
2. Investigating continuous voxel sizes

Outline

Overview of Renderer

Main Steps

1. Setup (load scene, create textures, compile shaders)
2. Voxelize Scene
3. Create Shadowmap
4. Inject Radiance
5. Filter Radiance
6. Shading

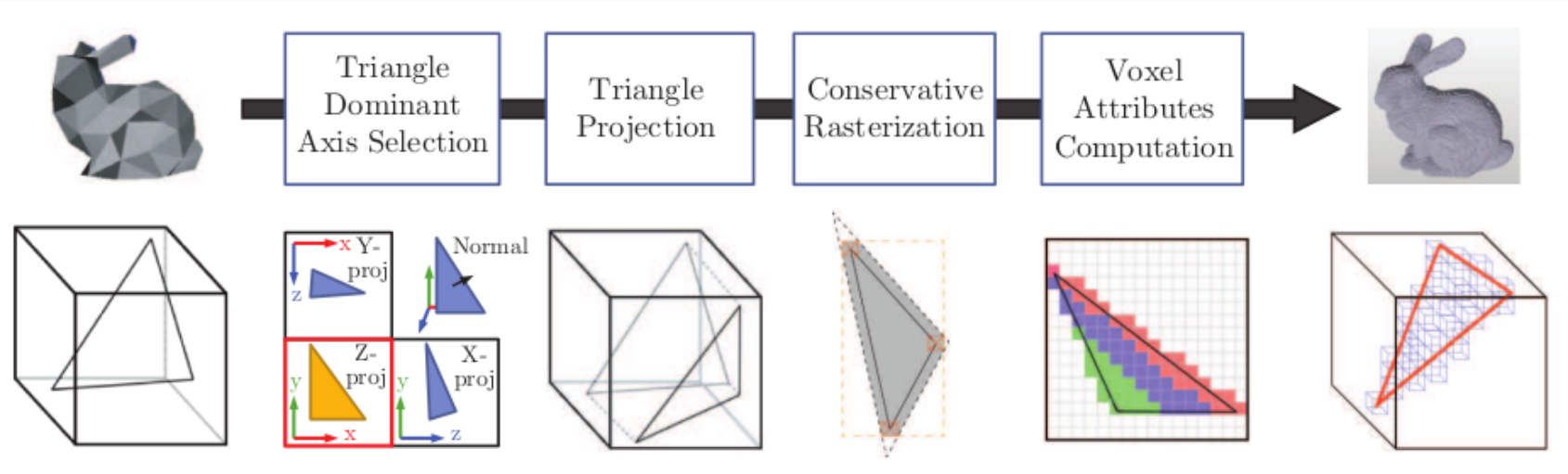
Important Data

1. Scene (meshes, materials, lights)
2. Camera (position, direction)
3. Shadowmap
4. Voxel Textures (color + opacity, normals, radiance)

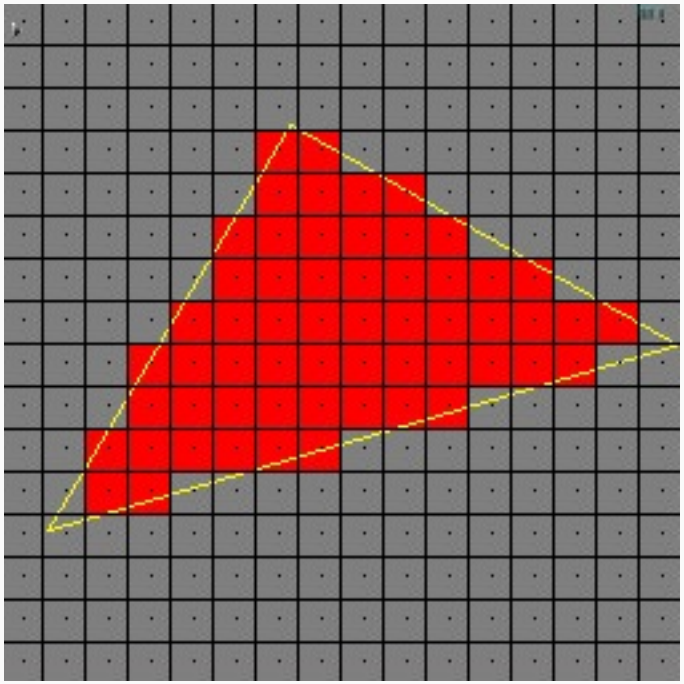
Outline

Voxelization with Rasterizer

Each fragment corresponds to a voxel



Conservative Rasterization



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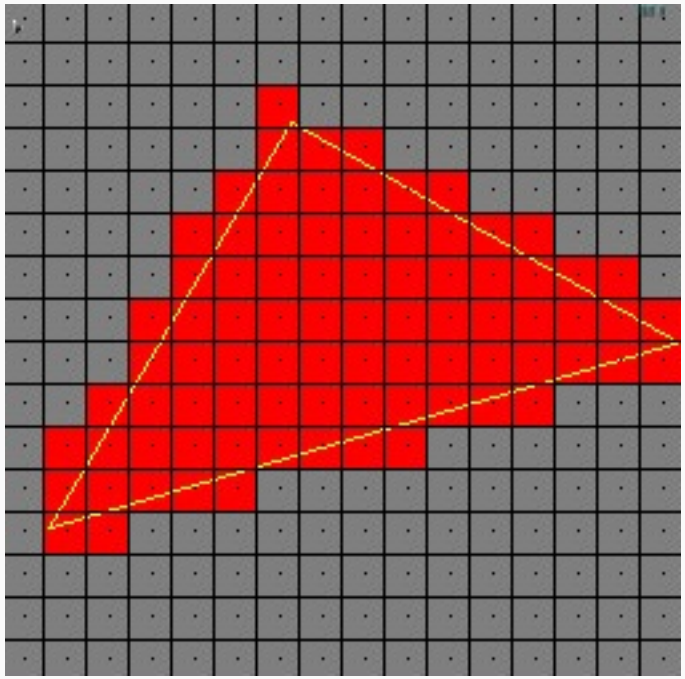


On

Conservative Rasterization

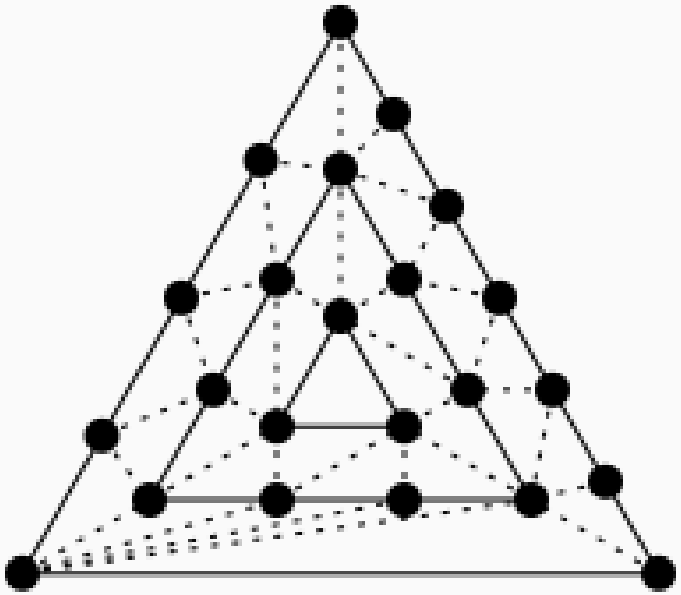
Without conservative rasterization

Conservative Rasterization

With conservative rasterization

Voxelization with Tessellator

Idea: Generate a *vertex* for each voxel instead of a fragment



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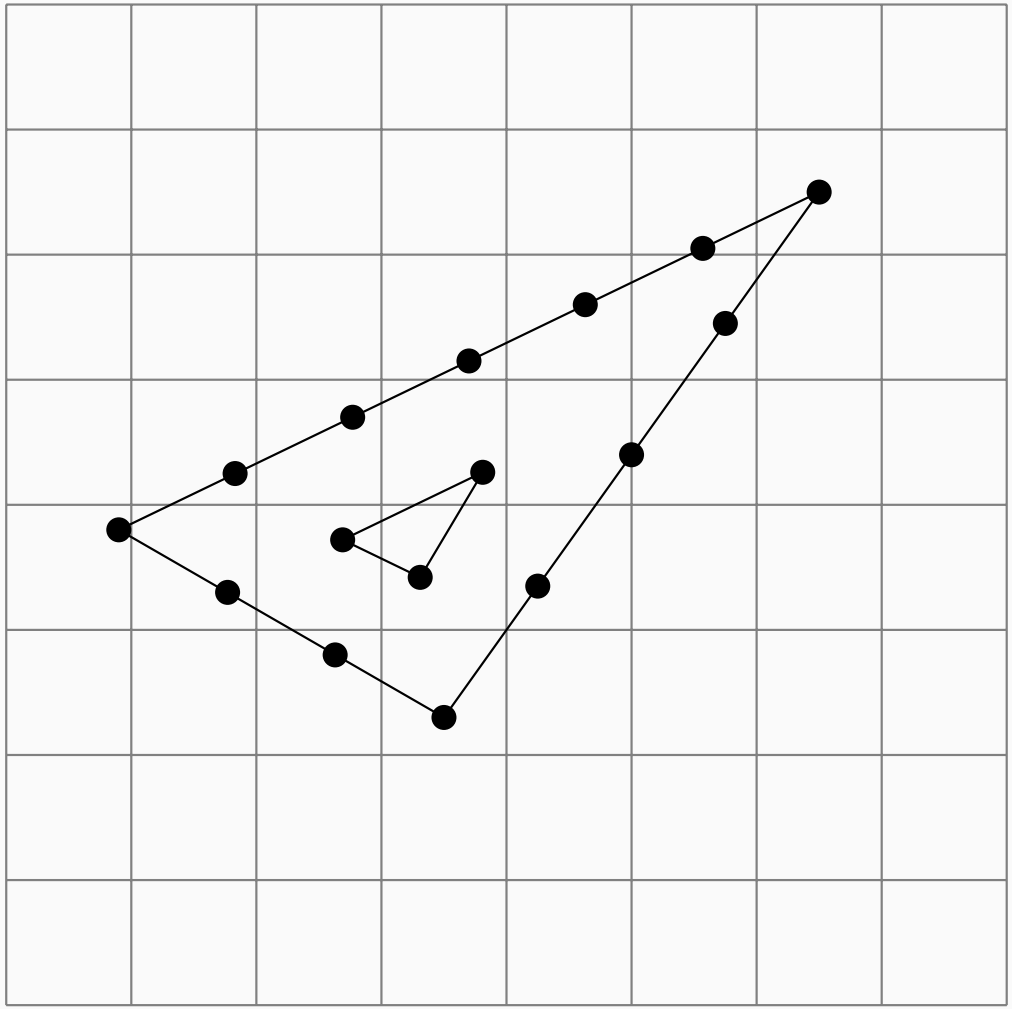
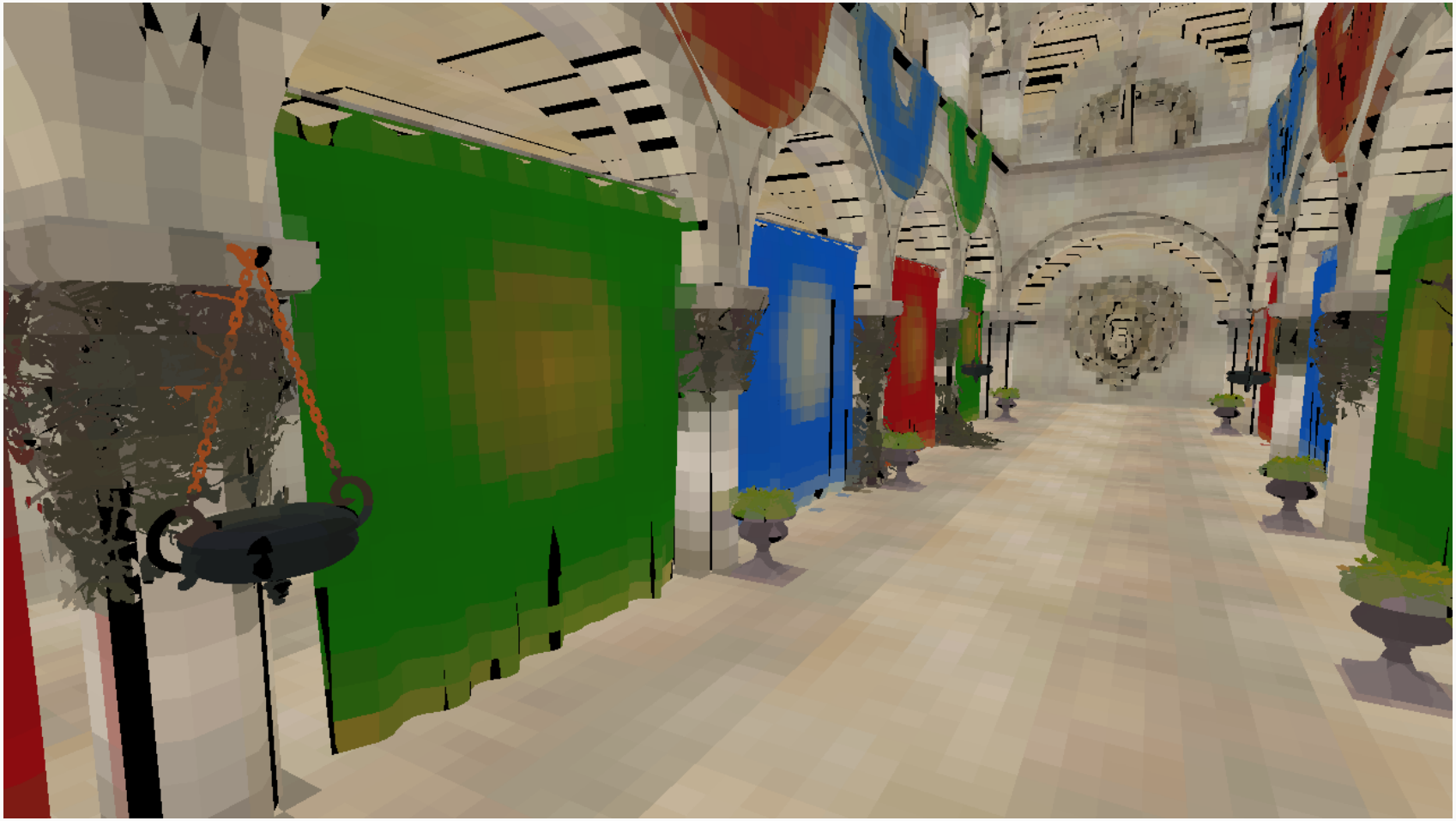
Determining Tessellation Levels

Outer levels determined from respective edge lengths

Inner level determined from maximum triangle altitude length

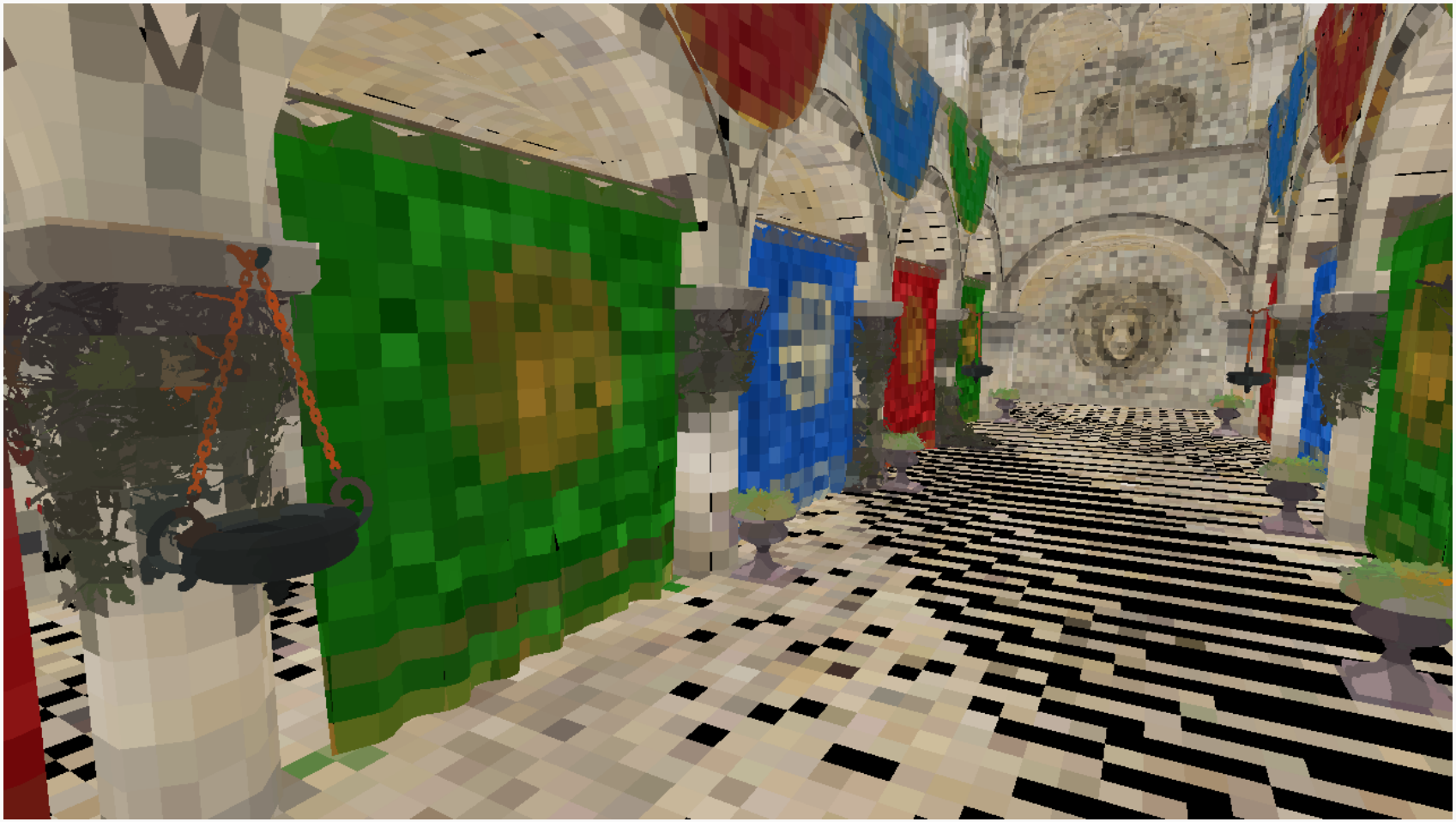


Voxelized Scene



Scene colored with rasterized voxels

Voxelized Scene



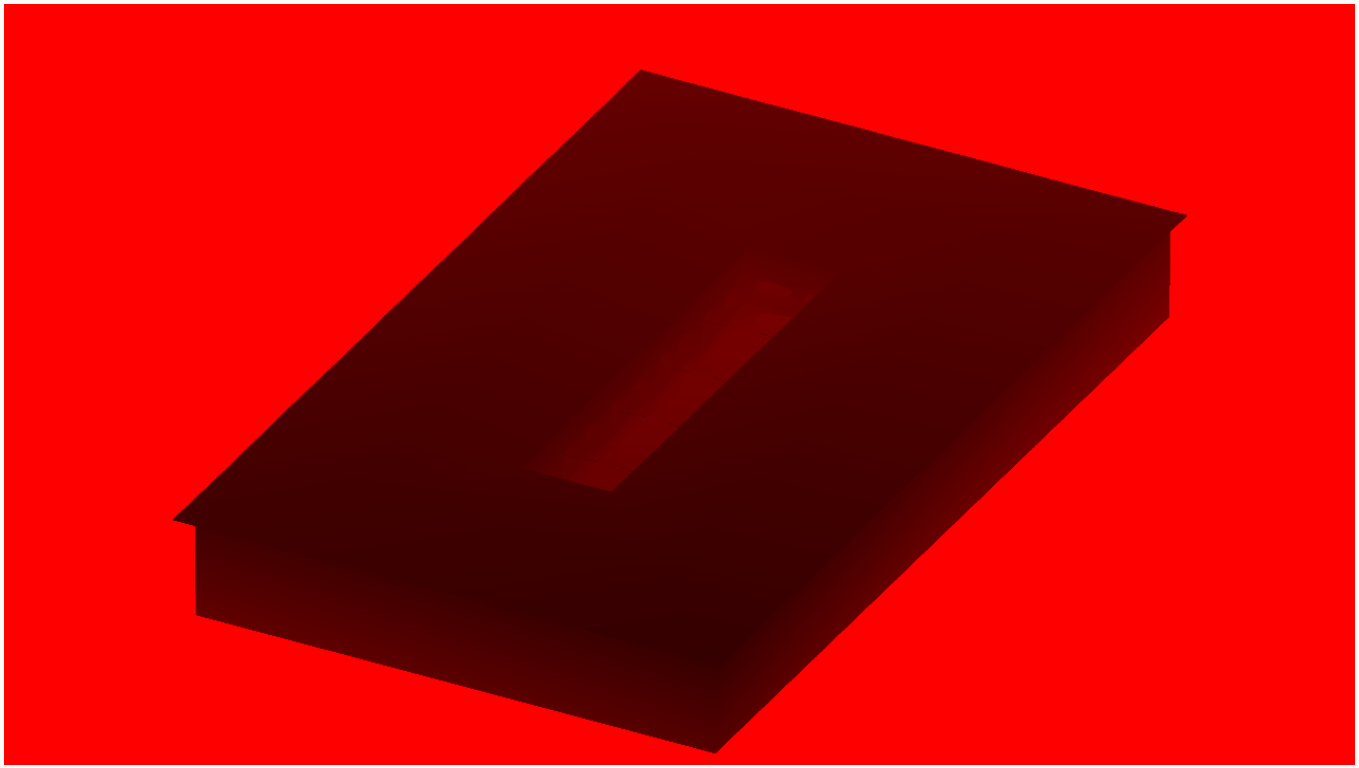
Scene colored with tessellated voxels

Outline

Radiance Injection—Shadow Mapping

To determine where the virtual point lights (indirect light sources) should be, we use a **shadowmap**.

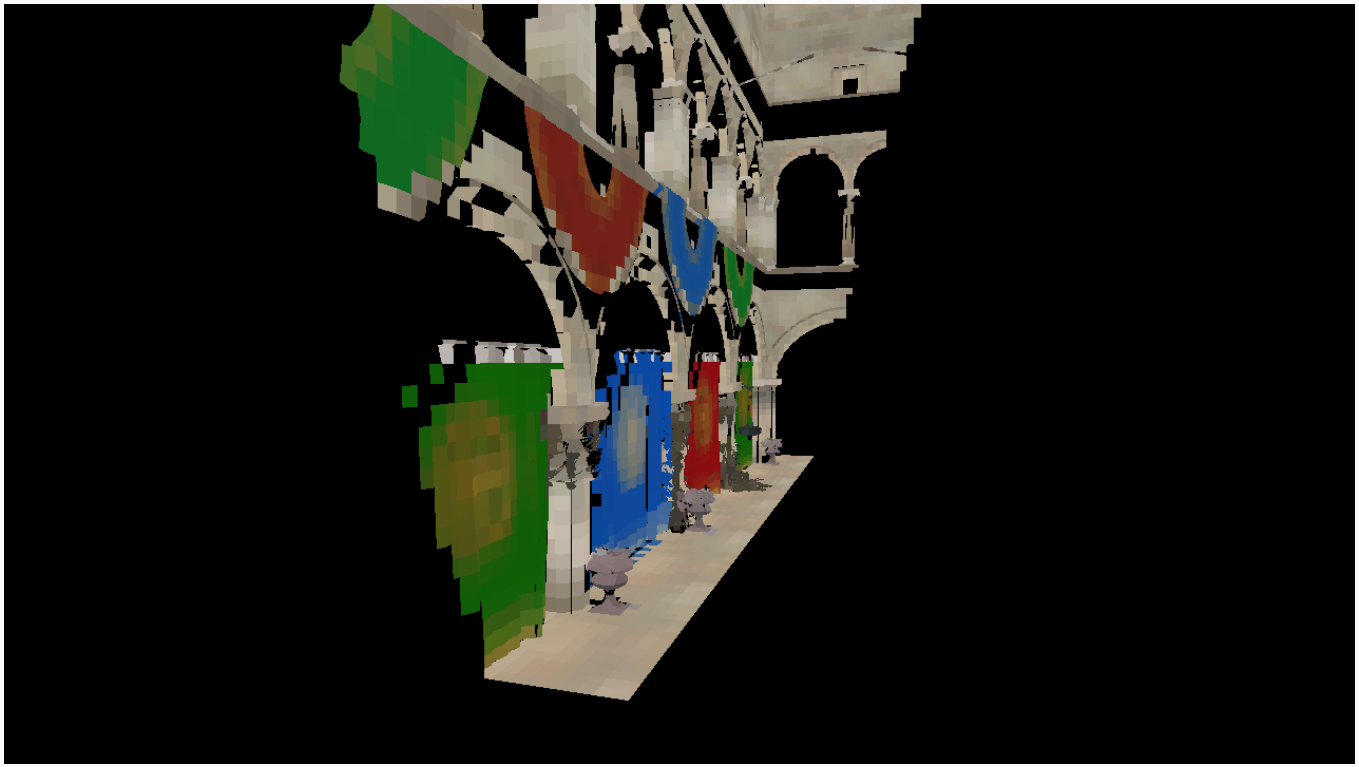
Render the scene from the *light*'s point of view.



Radiance Injection—Injecting VPLs

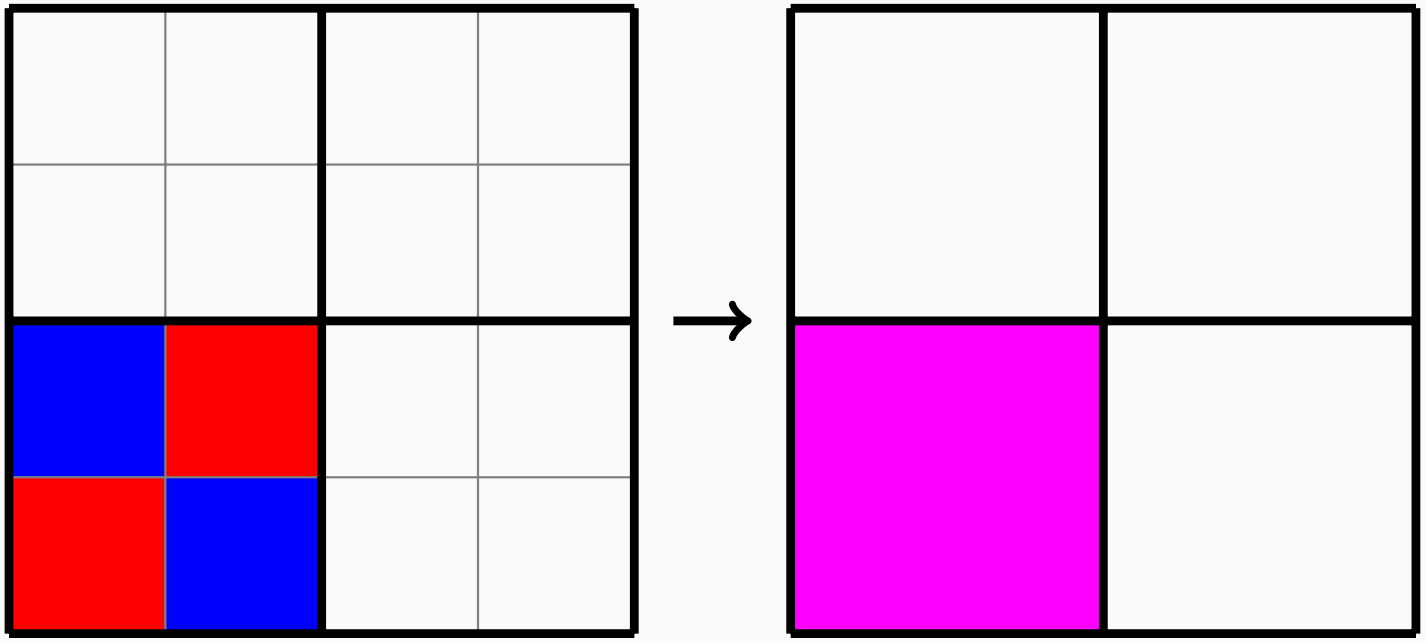
For each pixel in the shadowmap, find it's voxel index and insert the corresponding color into the radiance texture.

Using the light matrix and stored depth value, we compute the point's world space position.

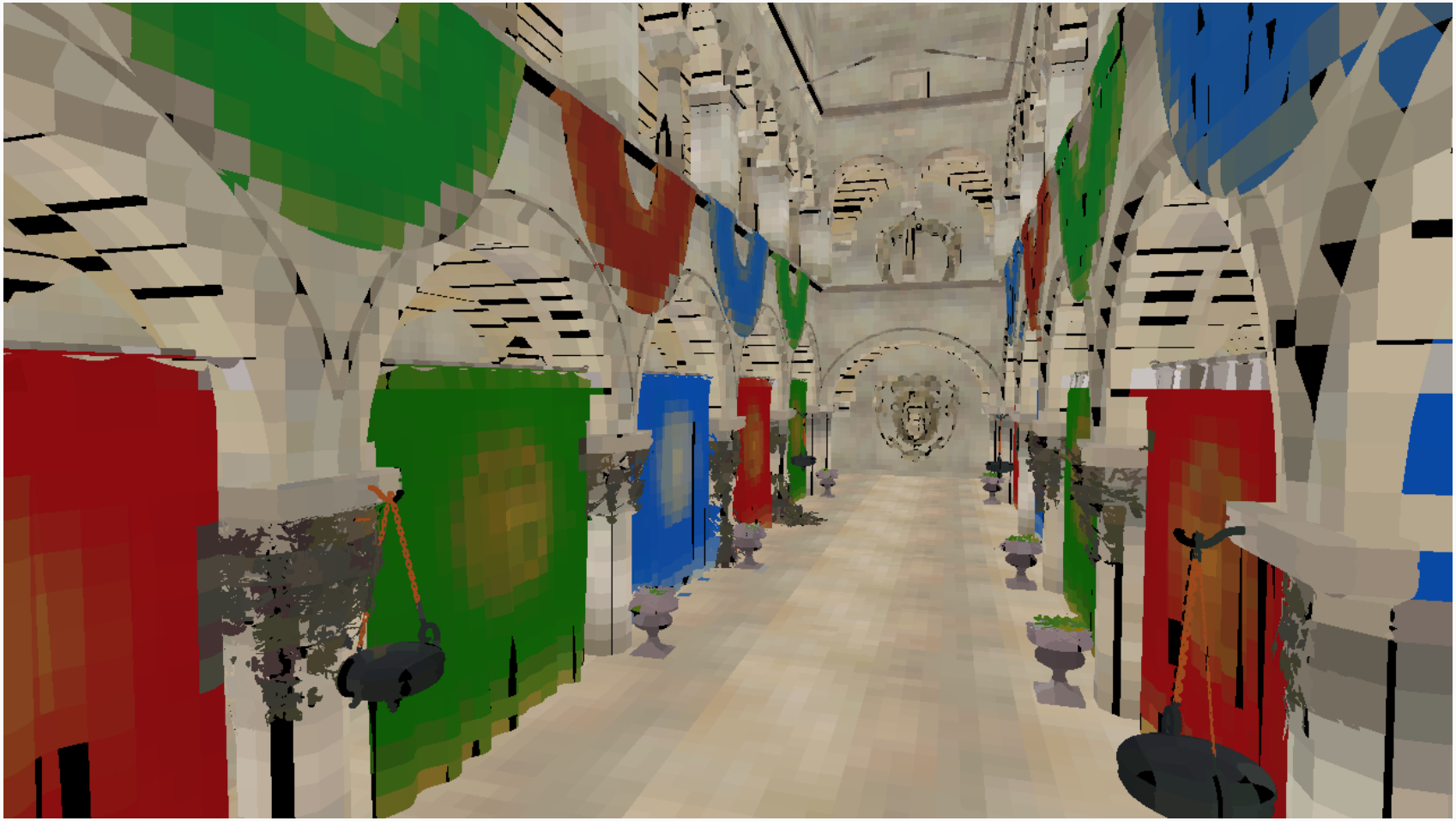


Radiance Filtering

- Multiple **levels** (mipmaps)
- Each level is half the size of the previous
- Computing the next level is a 2x2x2 average

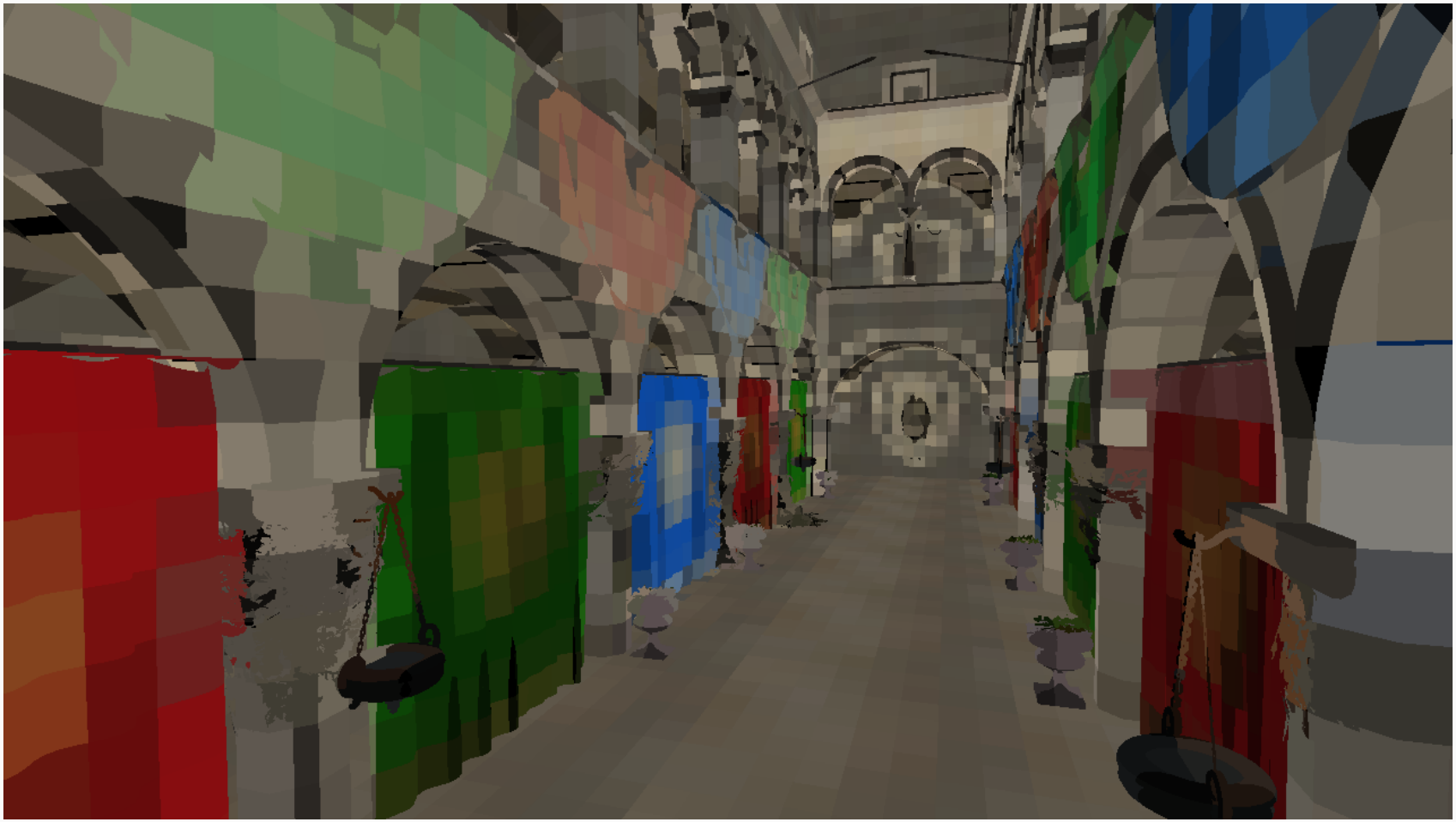


Radiance Filtering



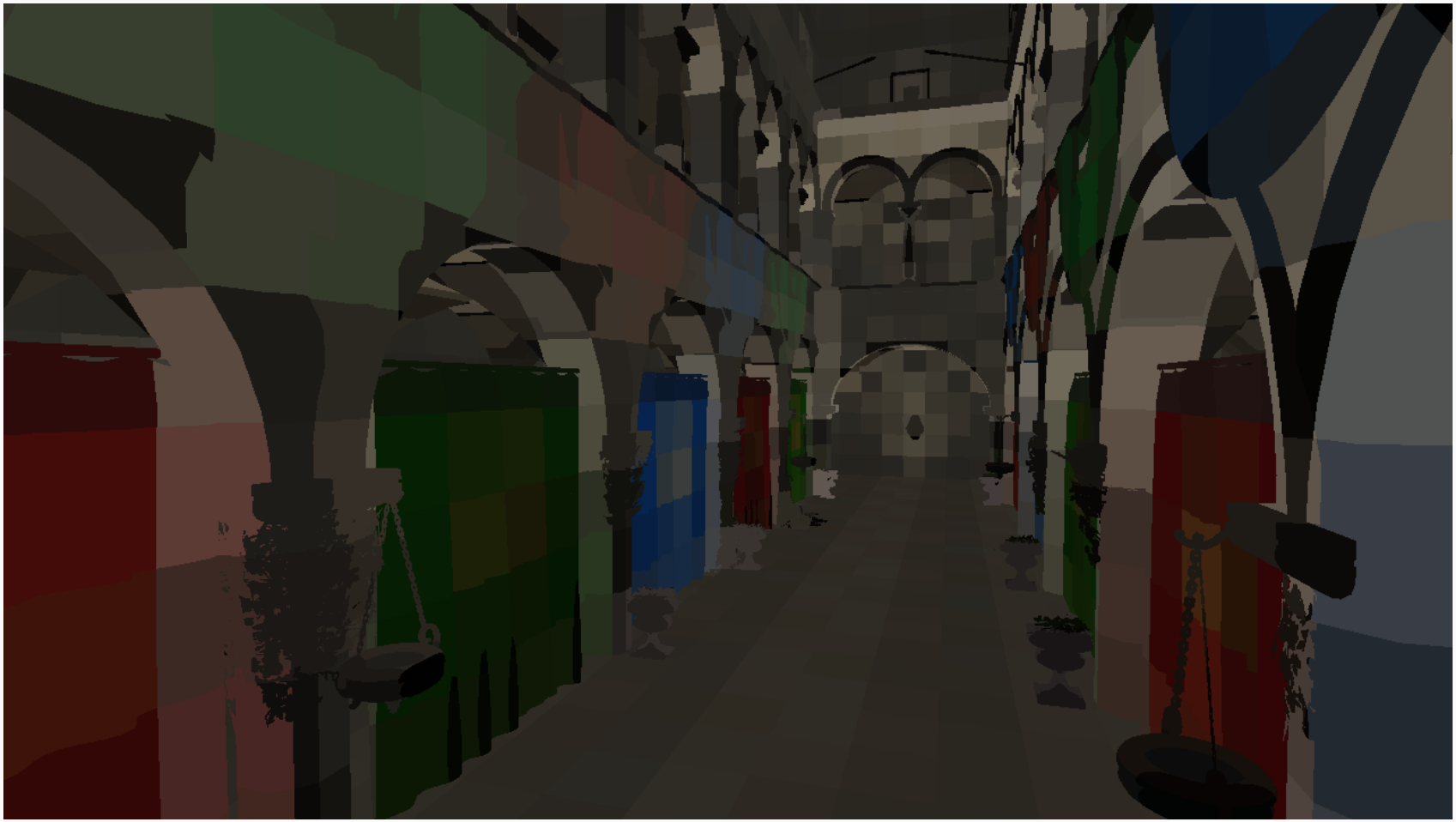
Mipmap level 0

Radiance Filtering



Mipmap level 1

Radiance Filtering



Mipmap level 2

Radiance Filtering

Mipmap level 3

Outline

Final Shading

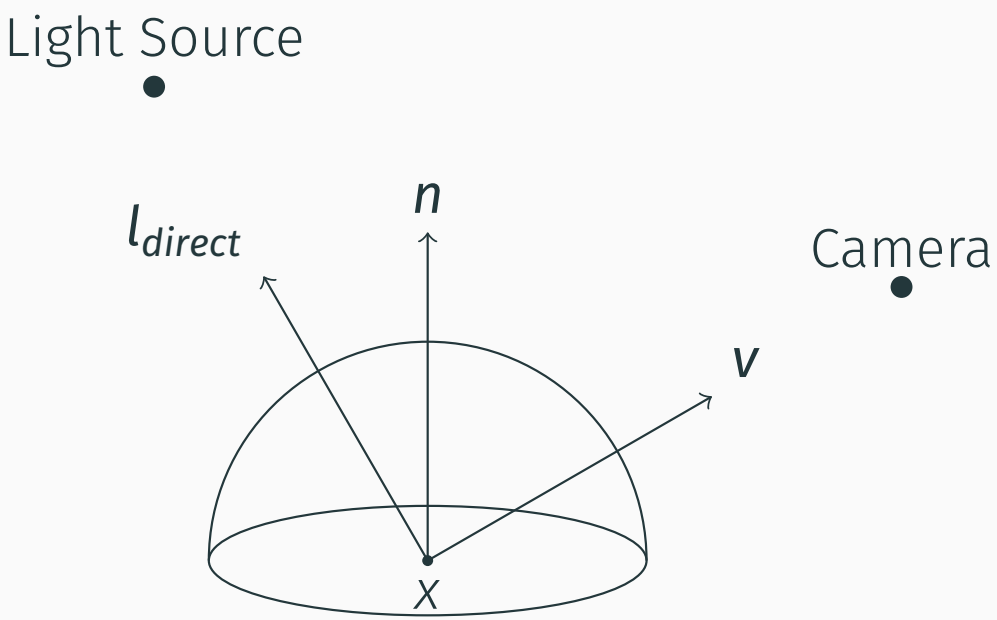
Direct Lighting sum light contributions using Cook-Torrance shading model

Indirect Lighting voxel cone tracing

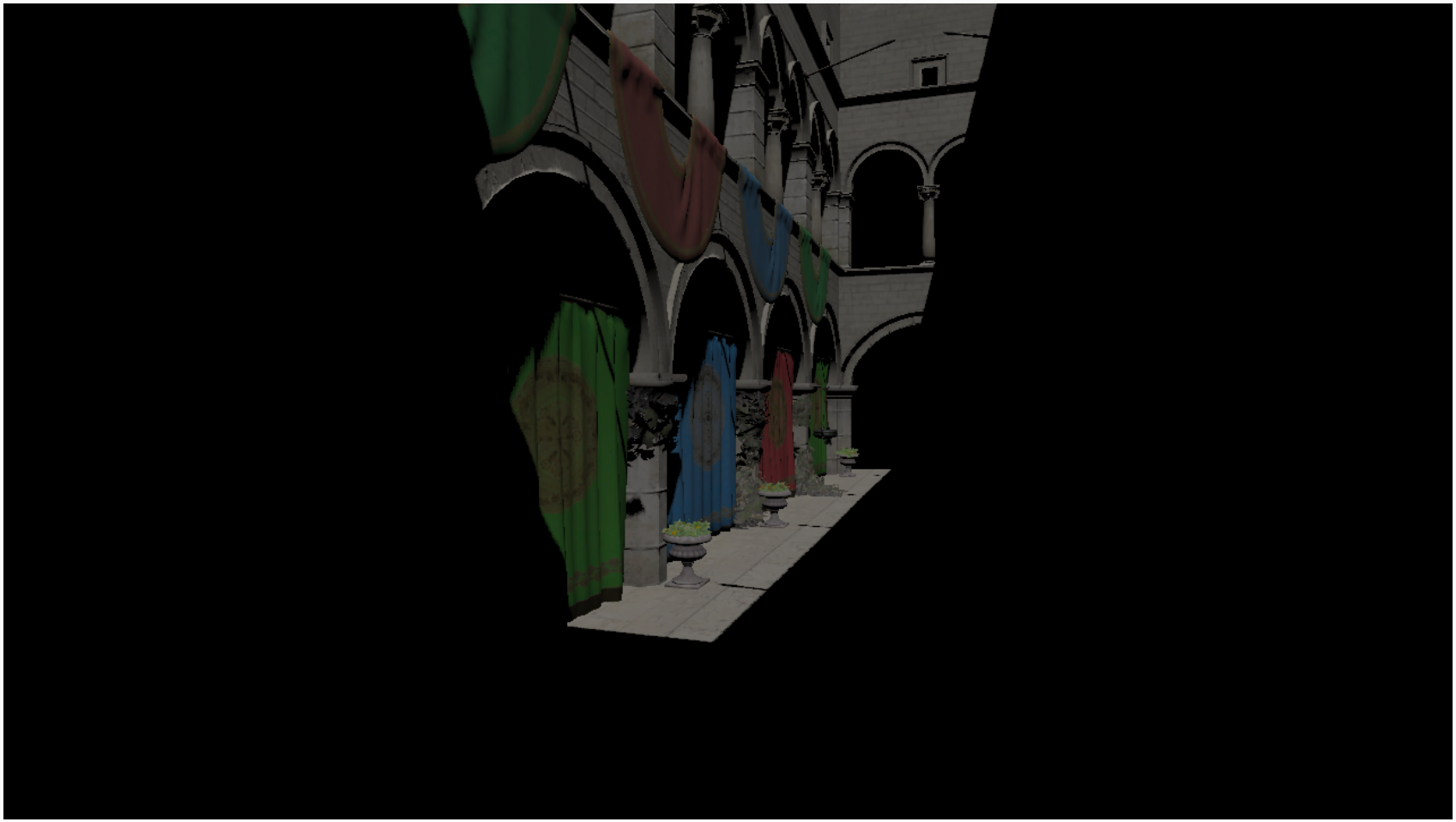
Post Processing tone mapping and gamma correction

Direct Lighting

```
color = 0
for each light in the scene do
    if not in shadow then
        color += computeLighting()
    end if
end for
```



Direct Lighting

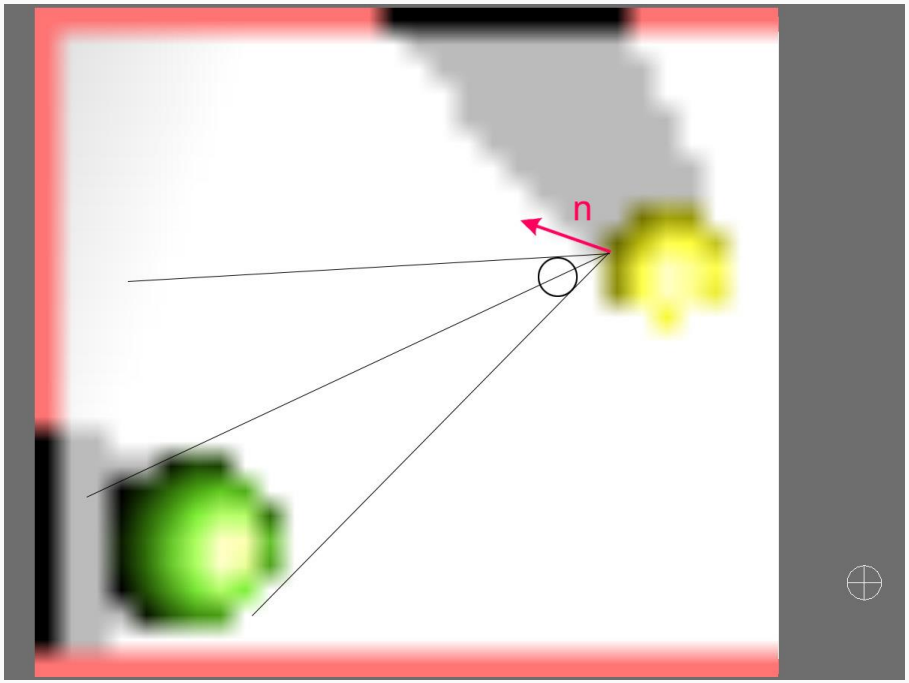


Direct Lighting

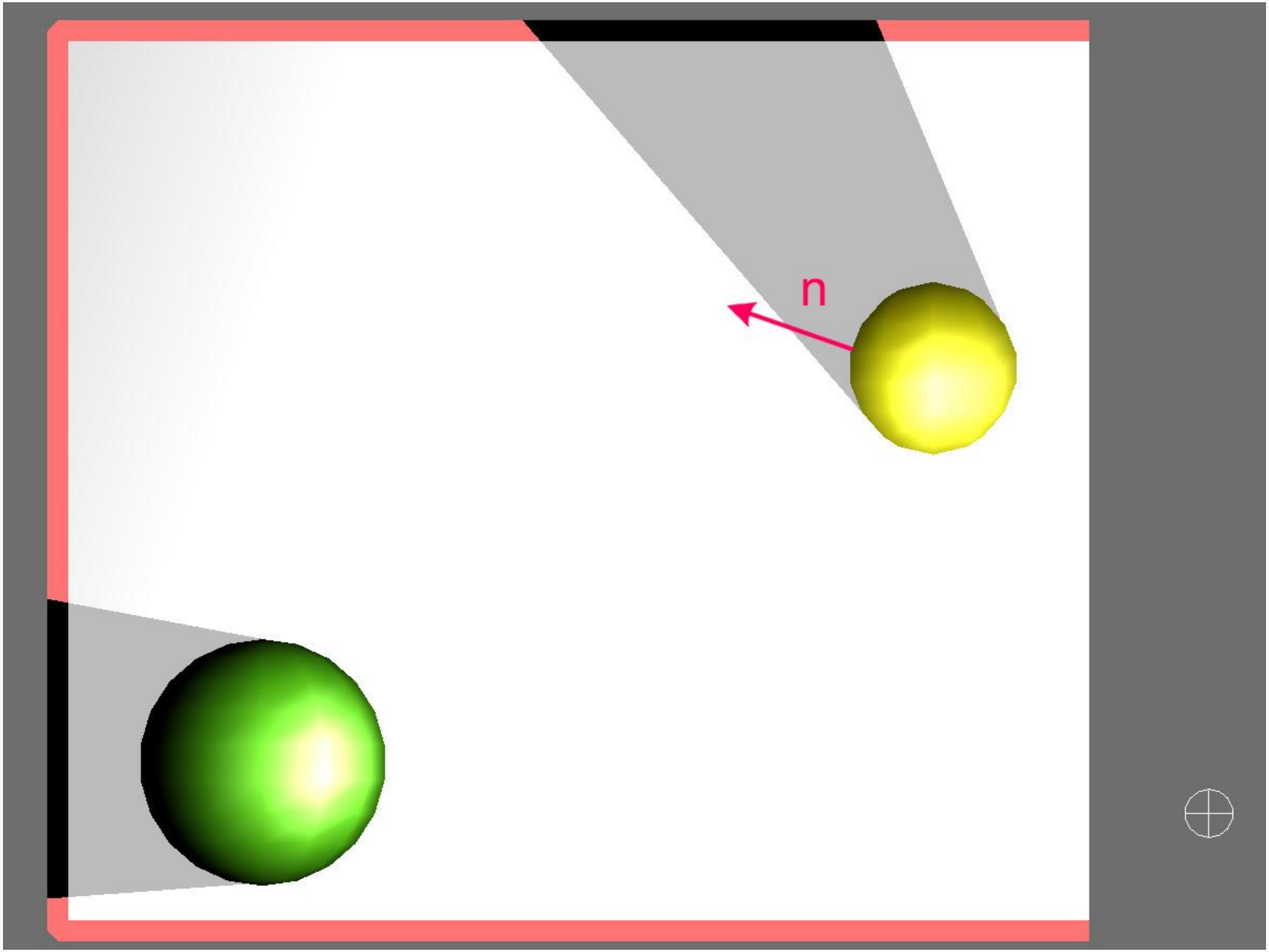
Indirect Lighting

Voxel Cone Tracing

1. Sample light from the radiance texture along a particular direction
2. Adjust level of detail as we get farther from sample point



Voxel Cone Tracing



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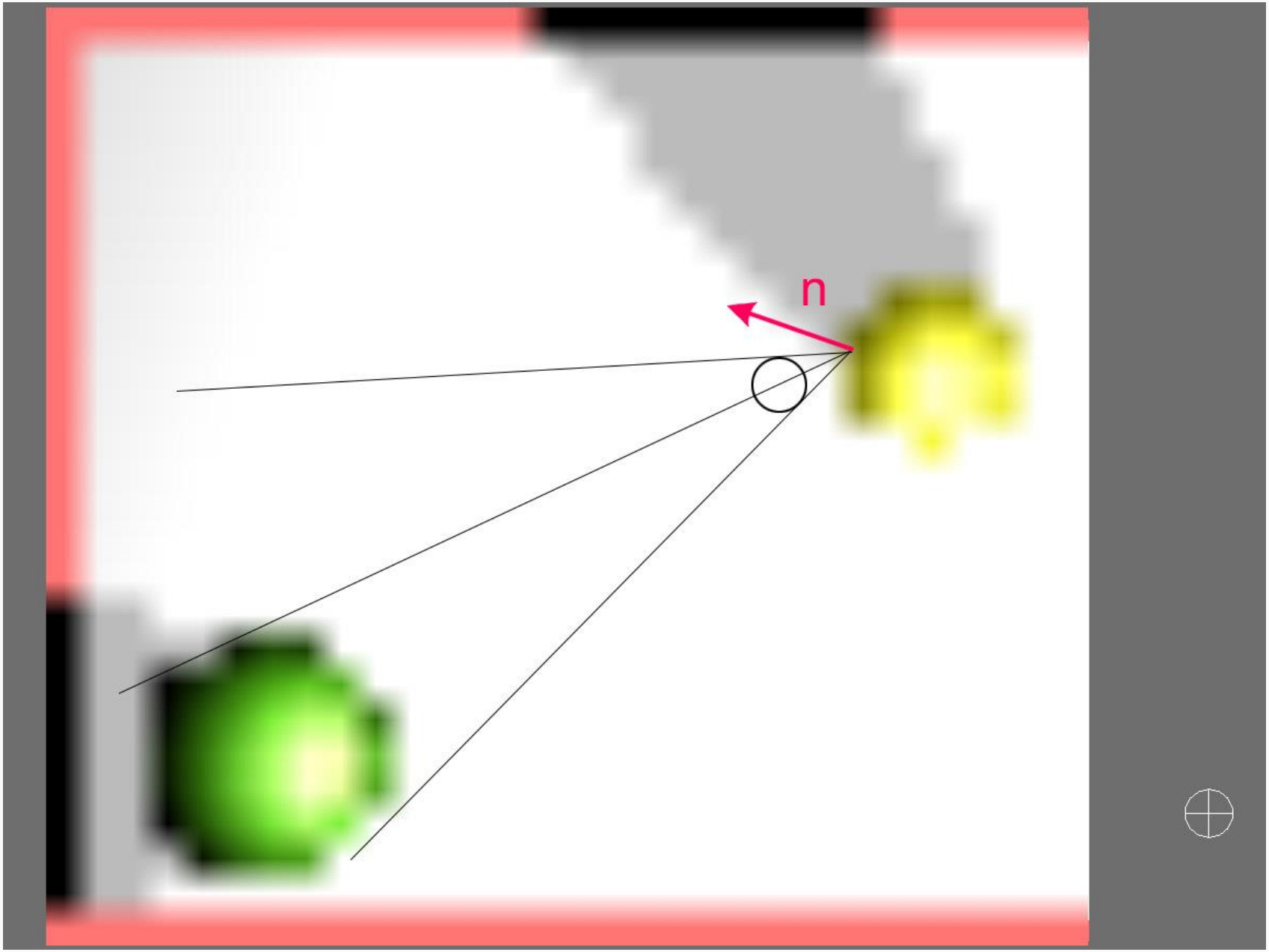

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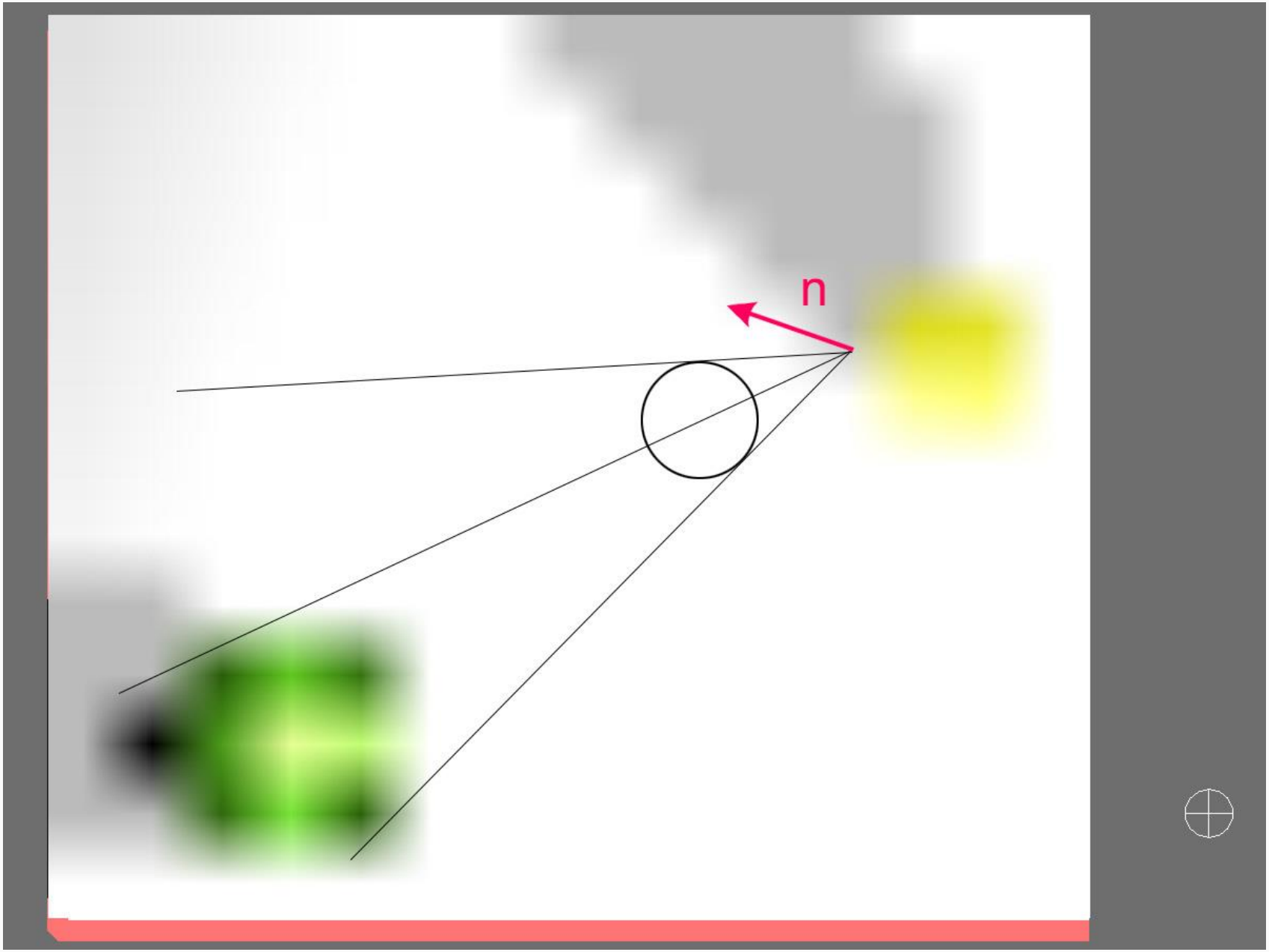

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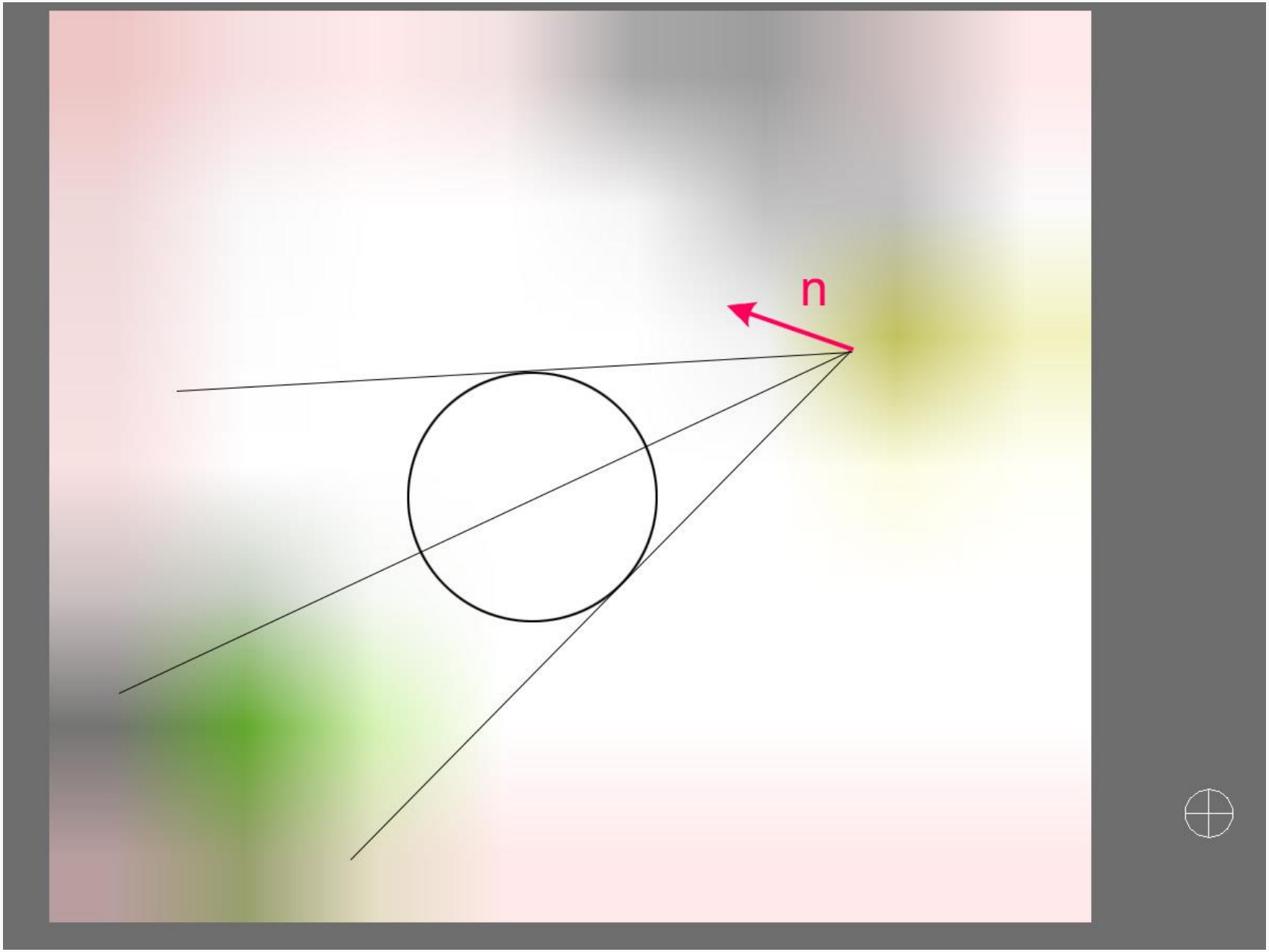

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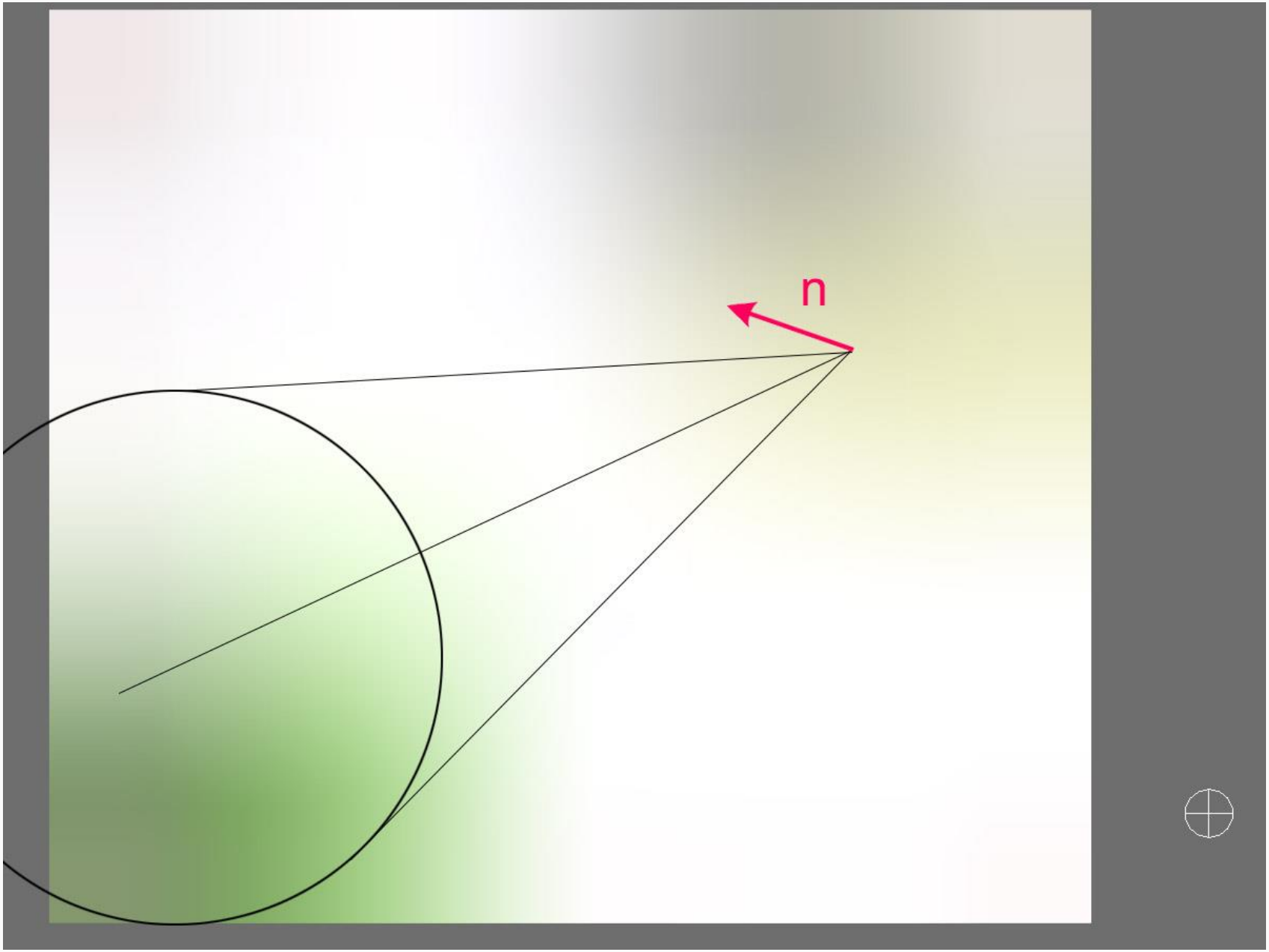
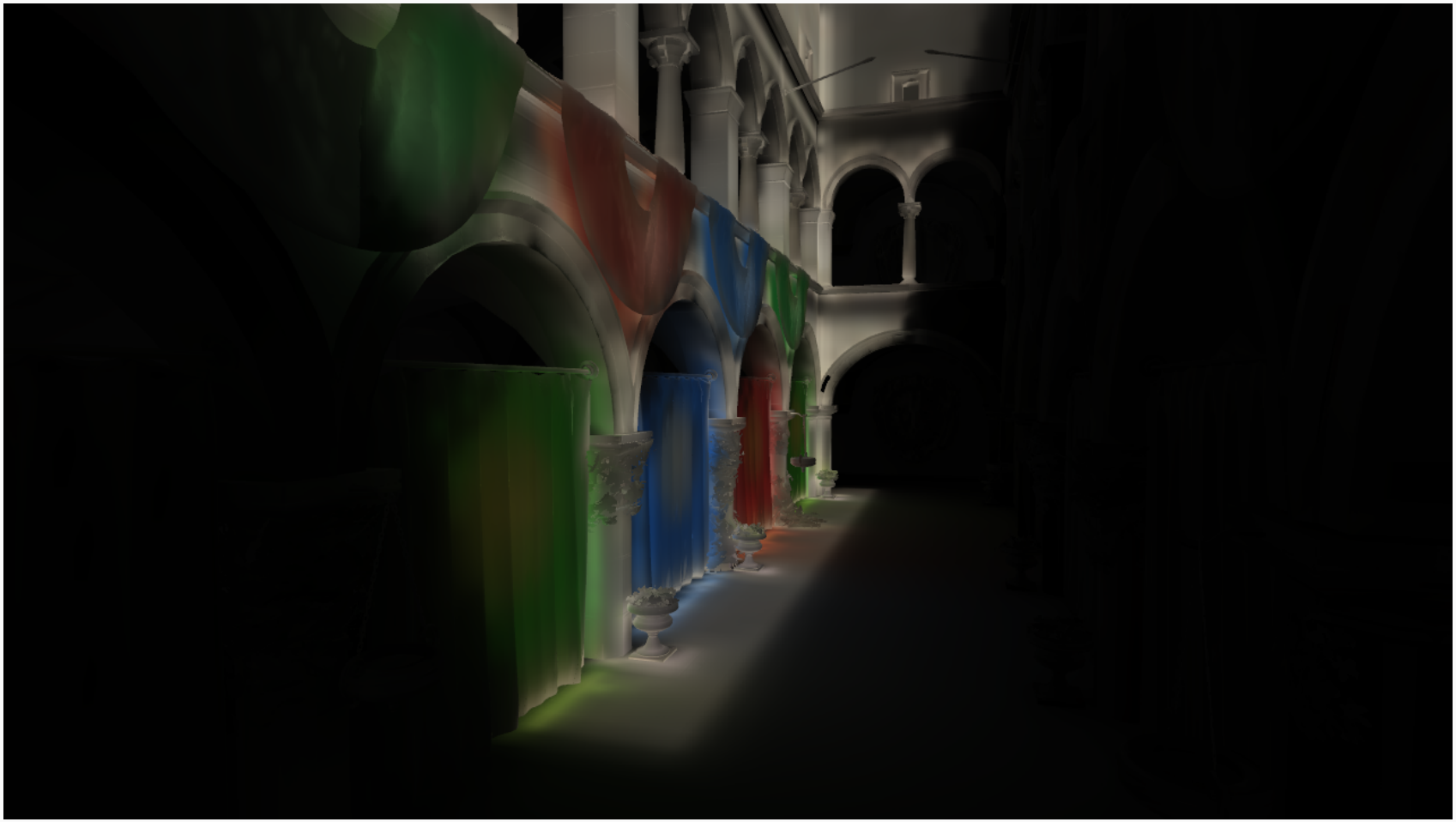


Indirect Lighting



Diffuse Indirect (no occlusion)

Indirect Lighting

Specular Indirect (no occlusion)

Indirect Lighting

Occlusion

Outline

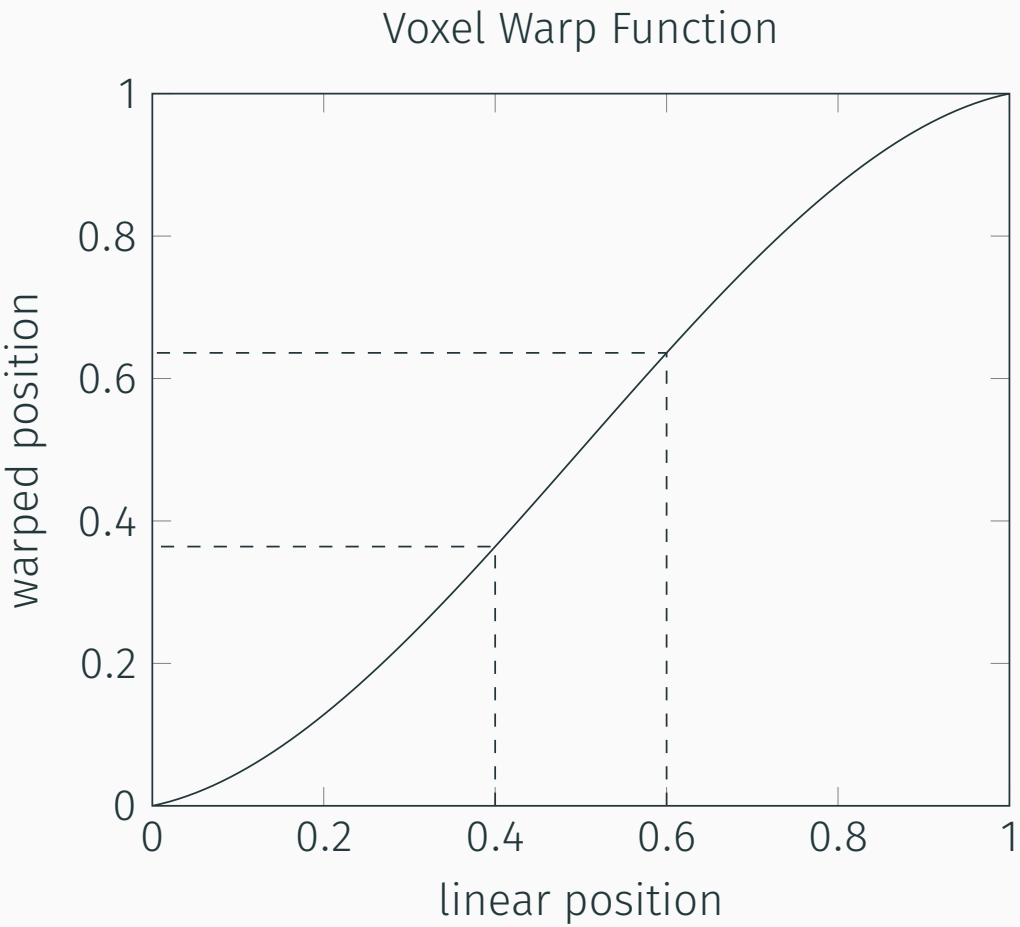
Voxel Warping

- Voxels are usually restricted to discrete sizes
- What if the size is not restricted?
    1. Vary with distance from camera
    2. Vary based on perspective

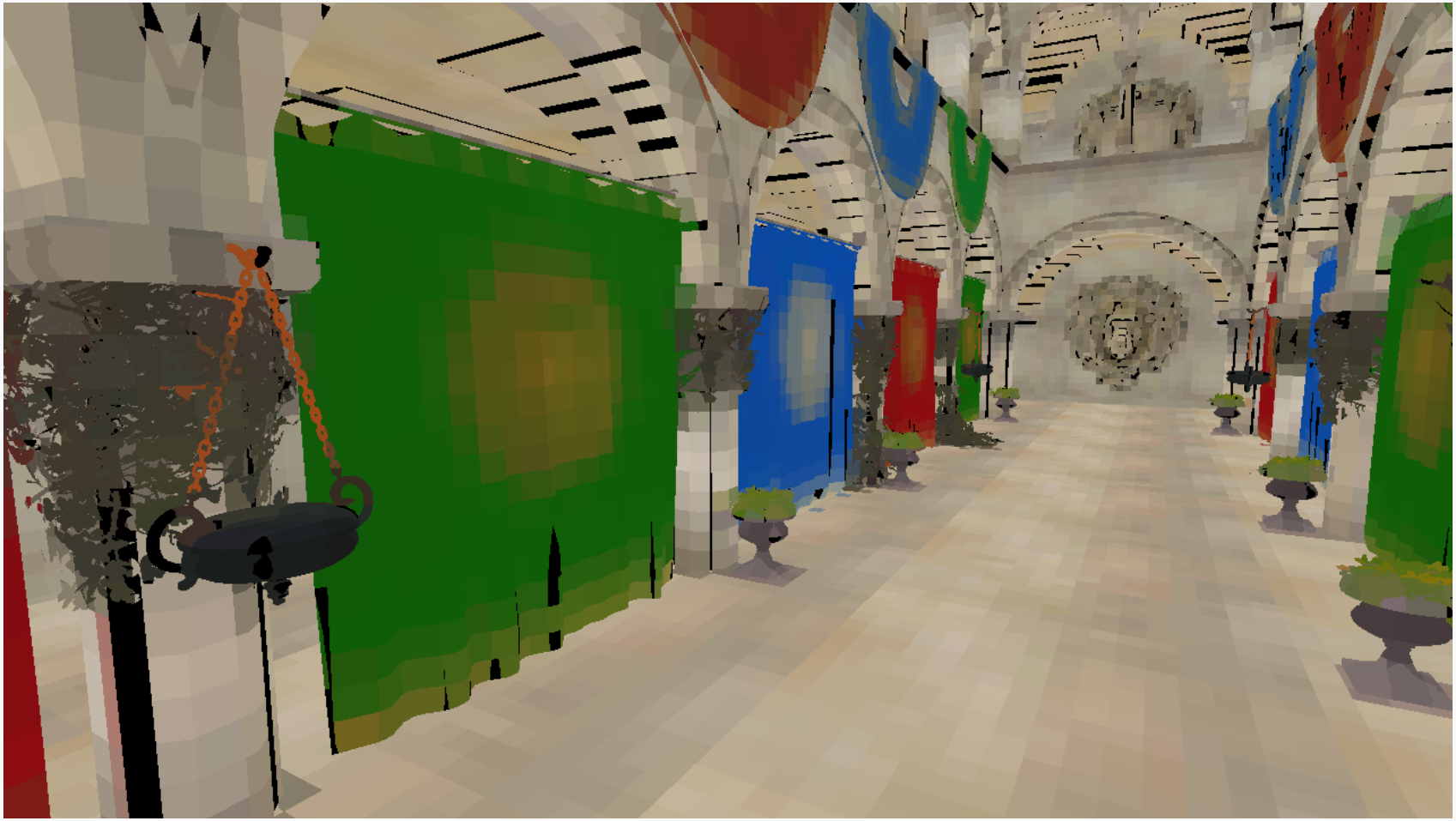
Vary with distance from camera

1. Find voxel position normalized to $[0, 1]$
2. Apply 'warping' function $w : [0, 1] \to [0, 1]$

The camera is in the middle ($x = 0.5$)



Vary with distance from camera



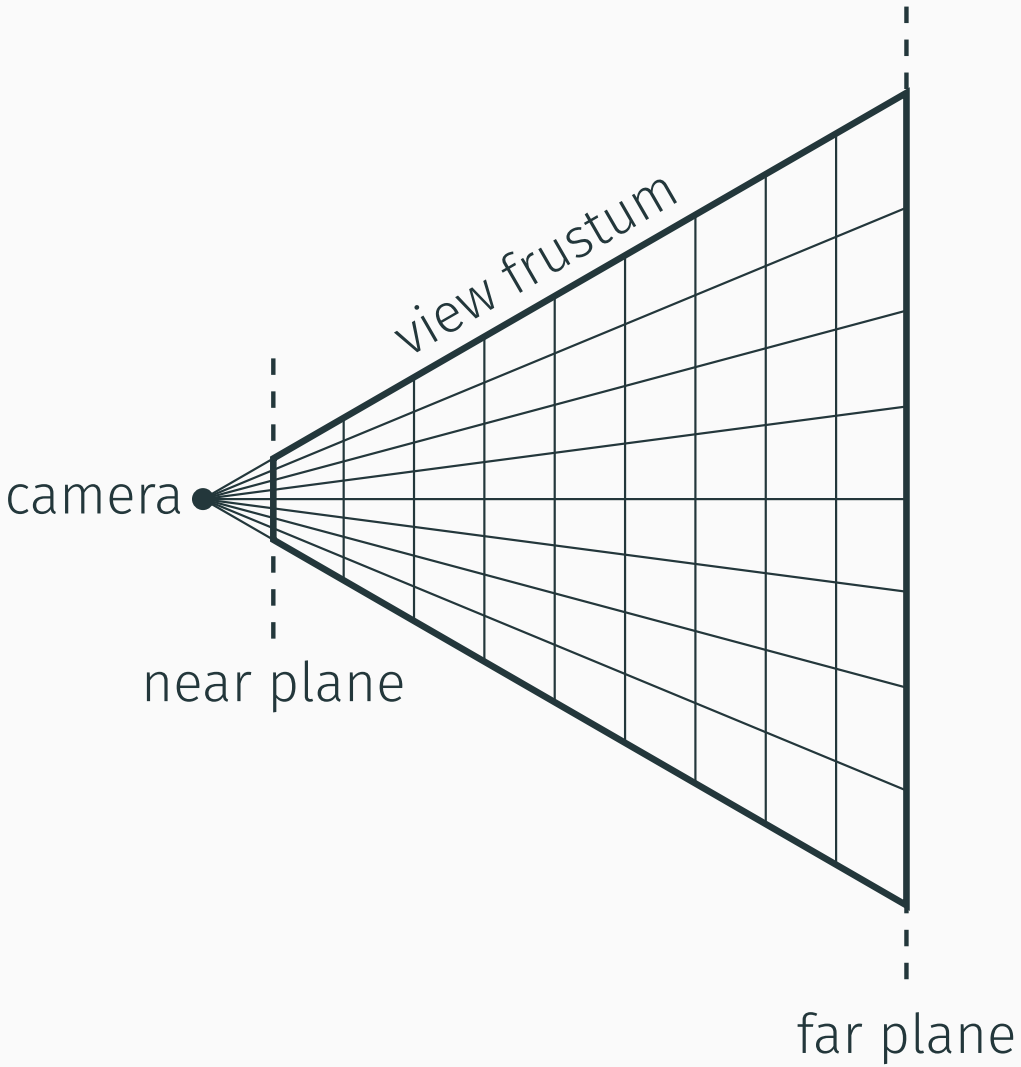
Without warping

Vary with distance from camera

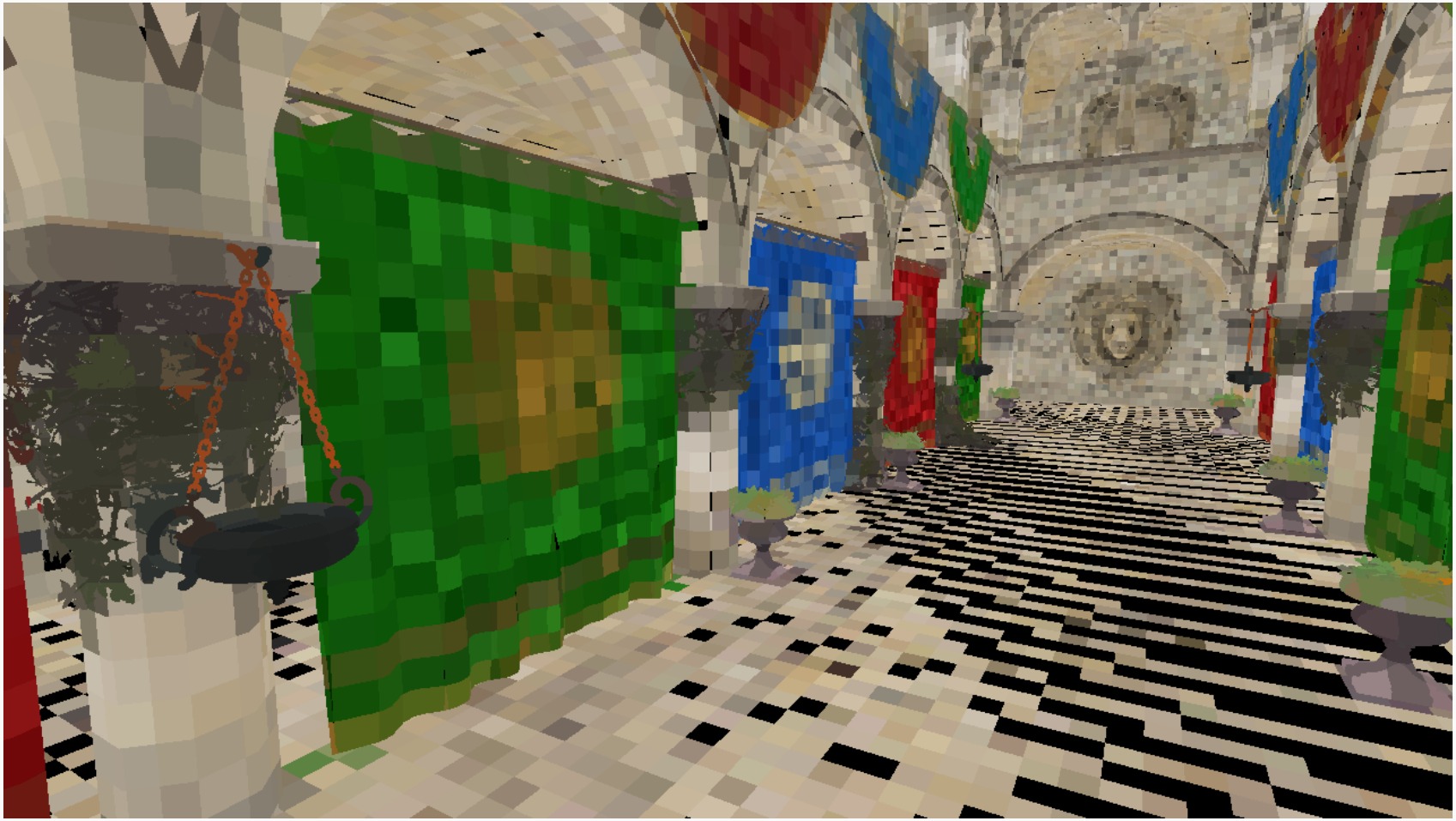
With warping

Vary based on perspective

- Use perspective projection to determine voxel size
- Makes voxel size based on relative size in screen space

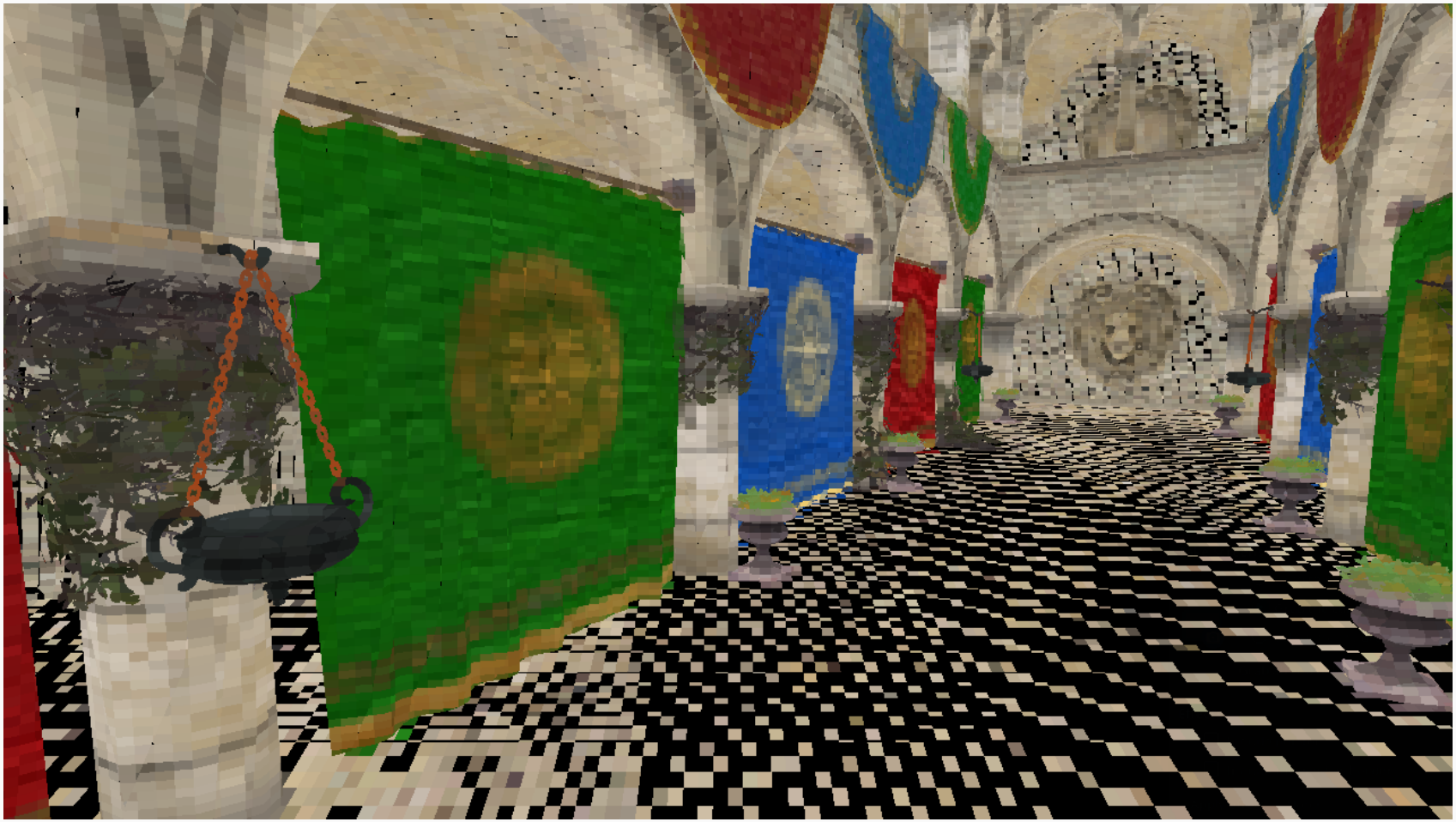


Vary based on perspective



Without warping

Vary based on perspective

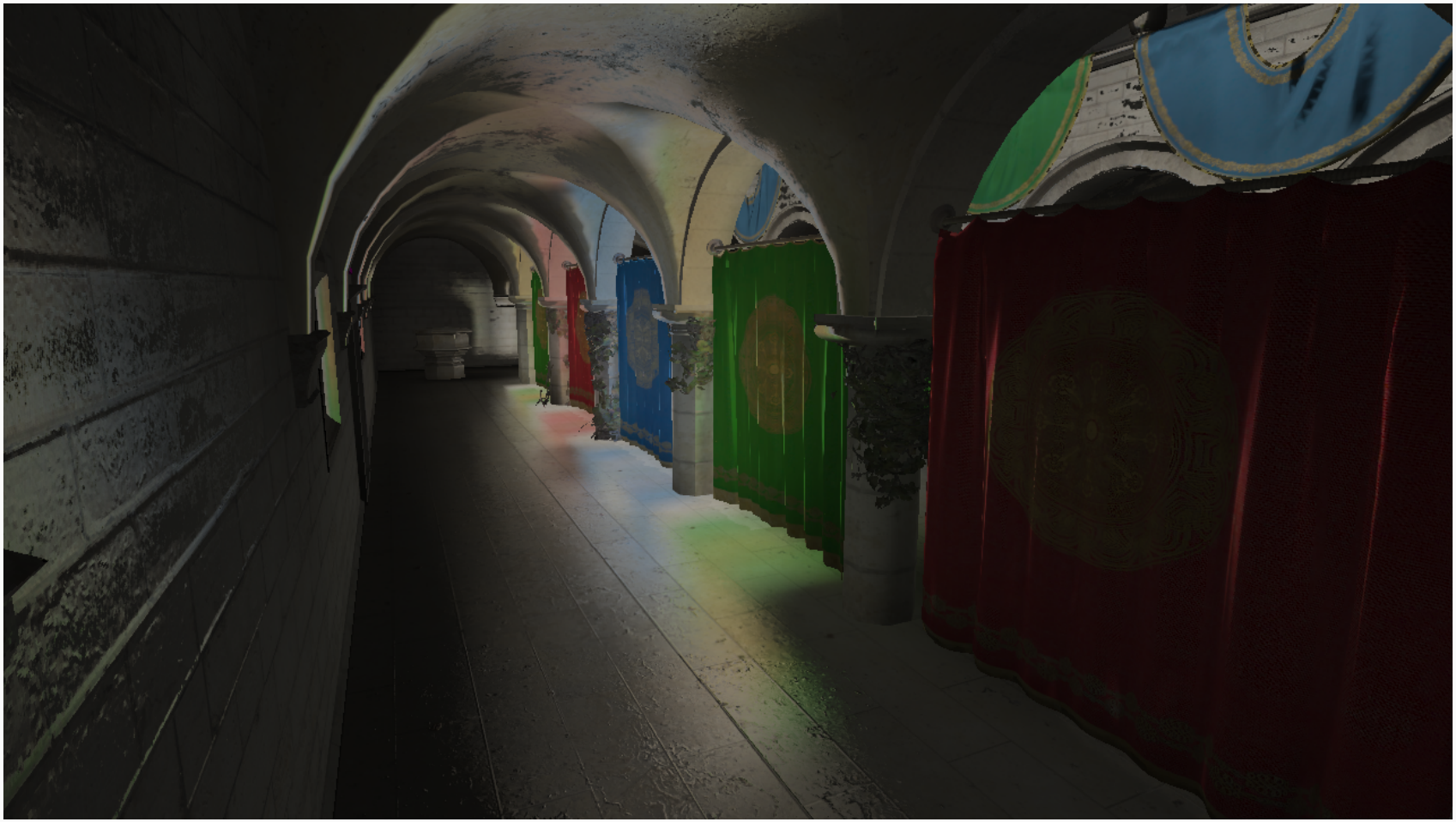


With warping

Outline

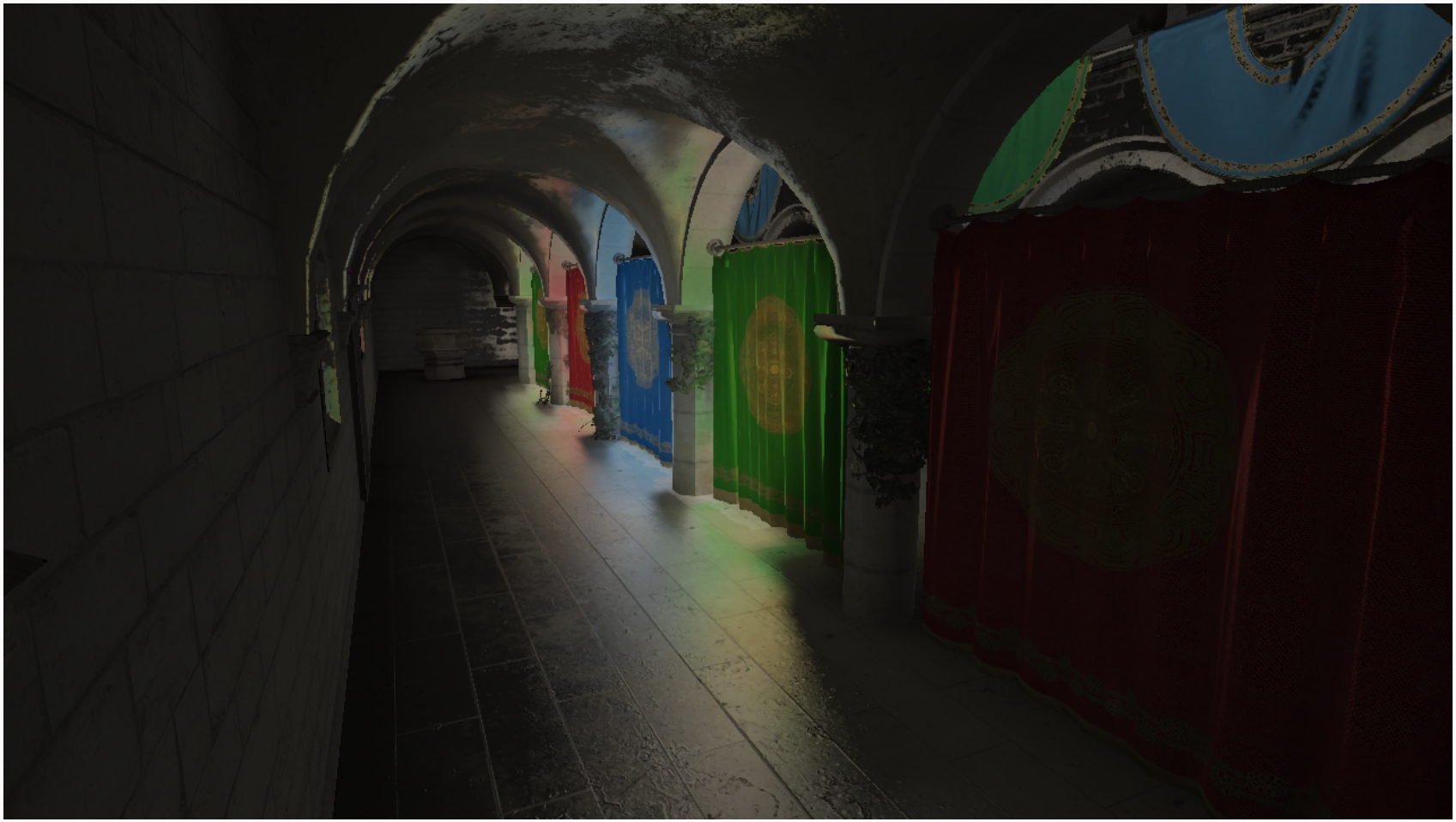
Outline

Performance



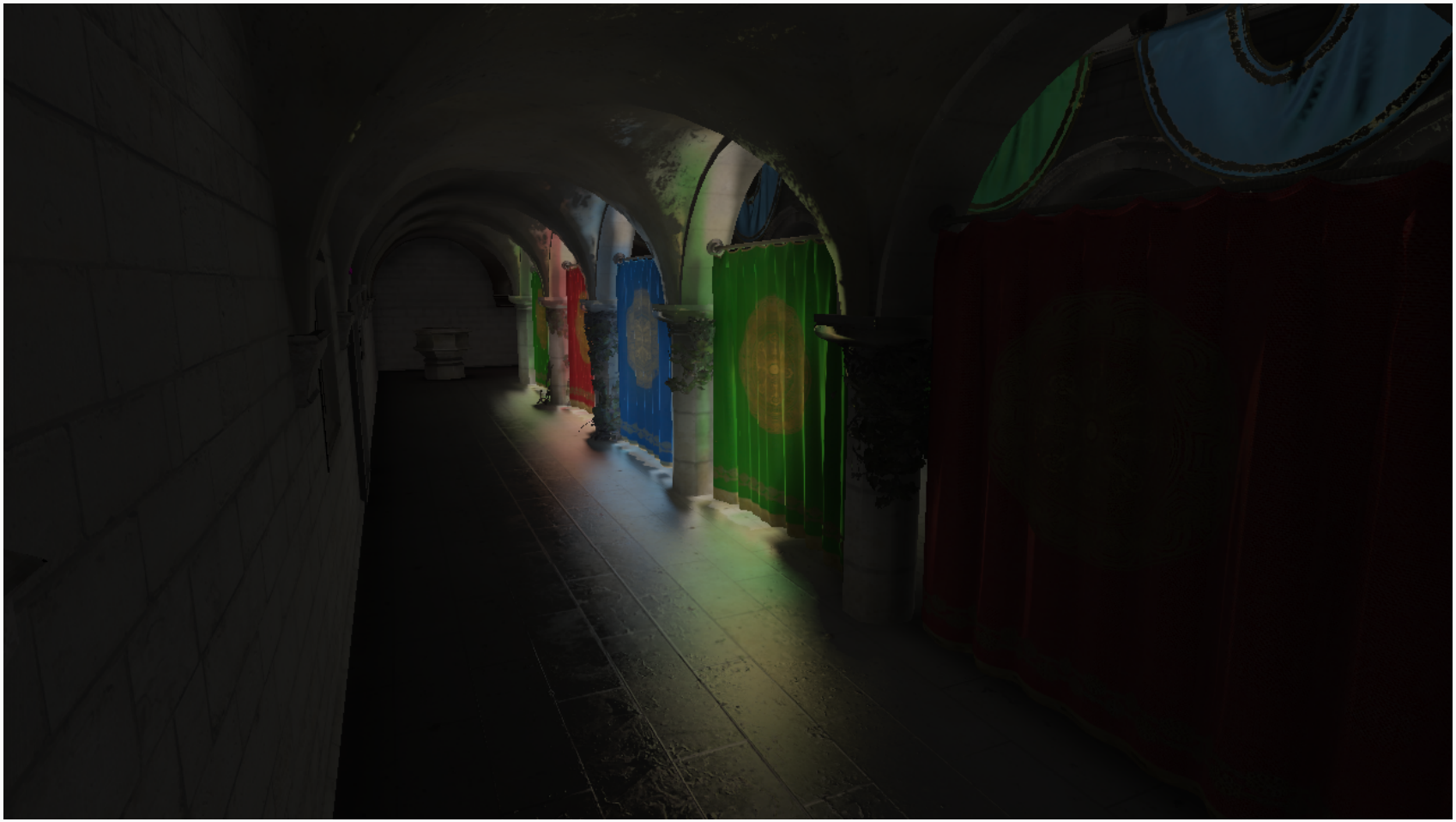
64^3 voxel grid

Performance



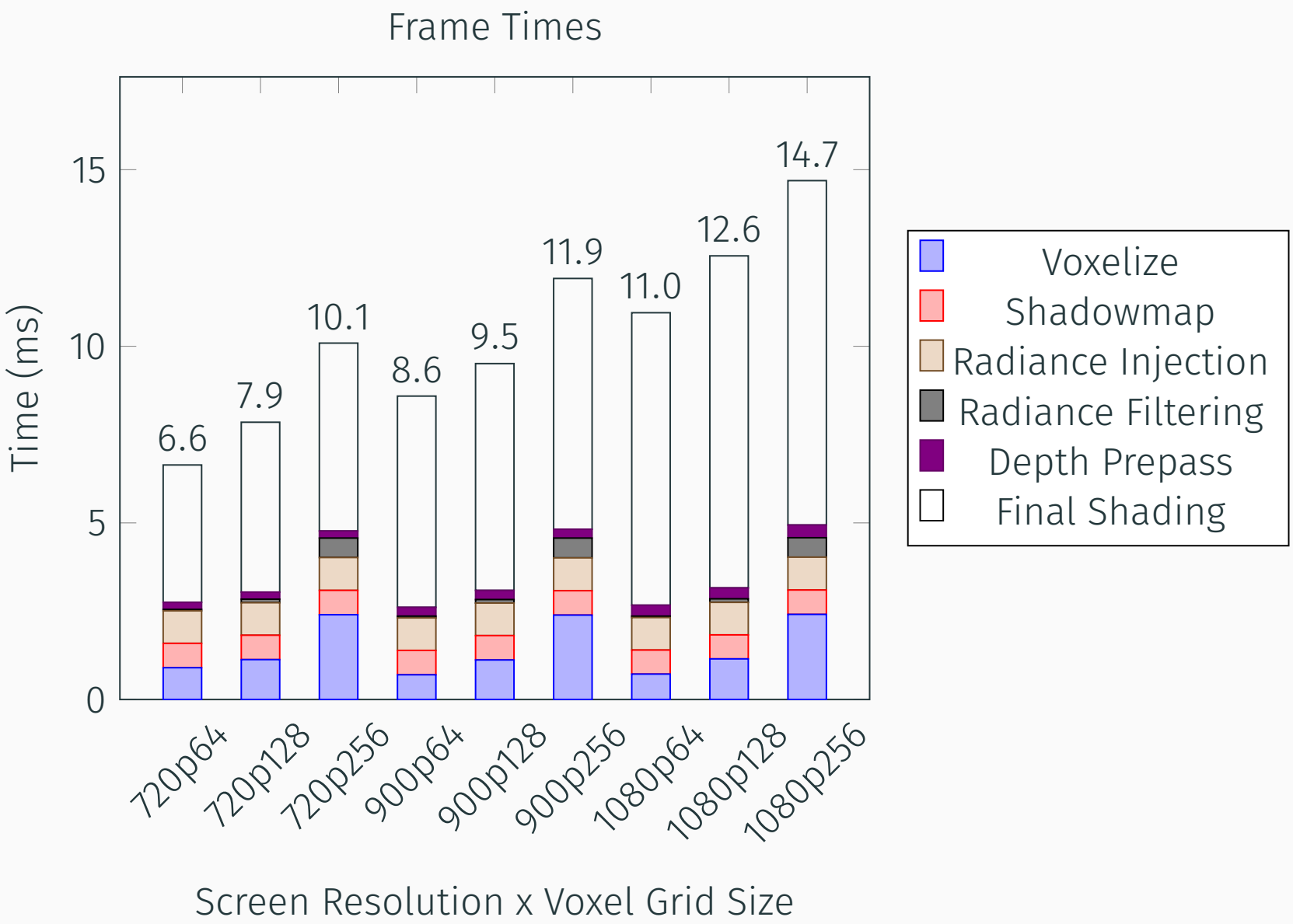
128^3 voxel grid

Performance

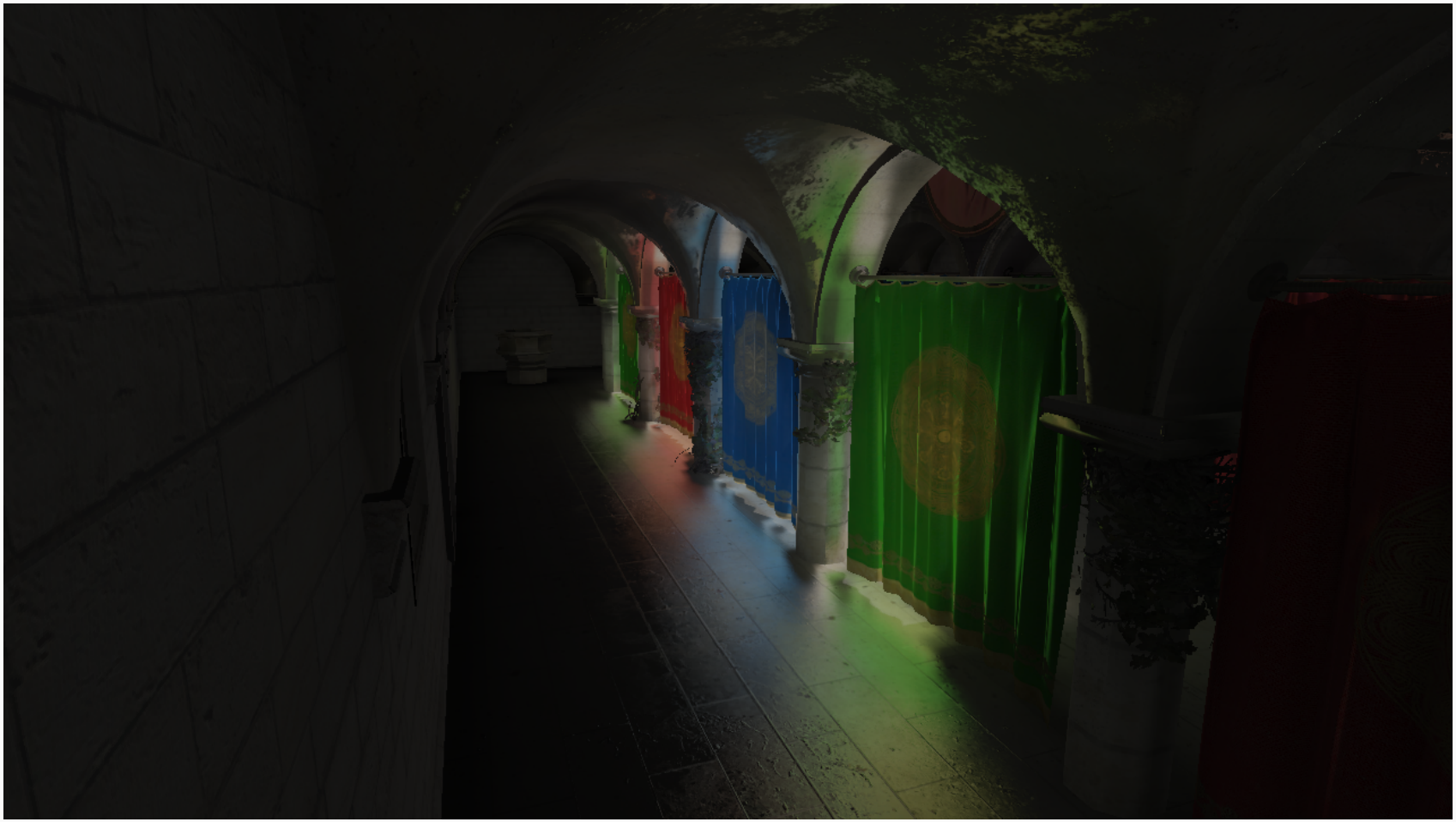


256^3 voxel grid

Performance

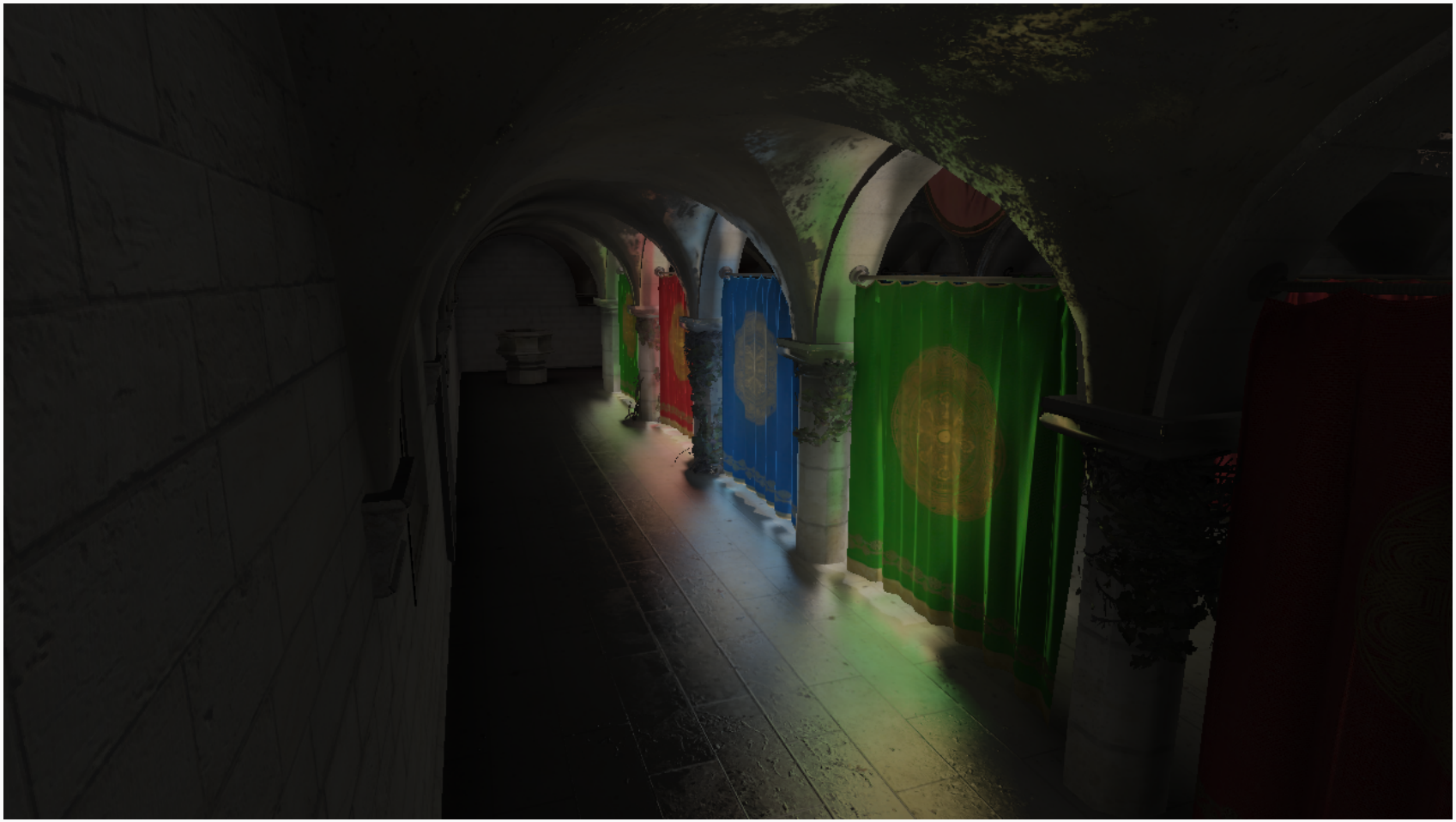


Rasterized vs. Tessellated Voxels



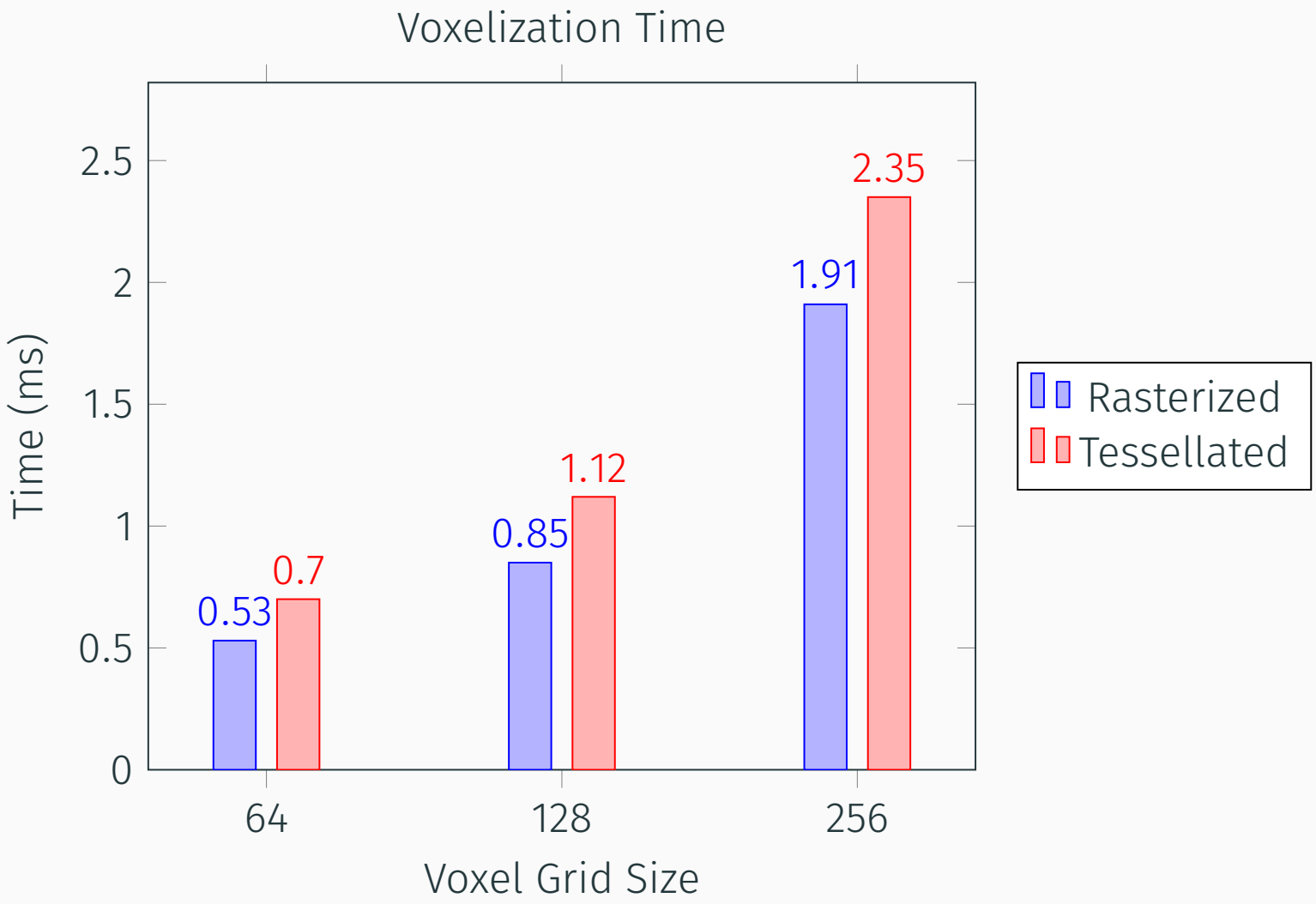
Rasterized voxels

Rasterized vs. Tessellated Voxels



Tessellated voxels

Rasterized vs. Tessellated Voxels



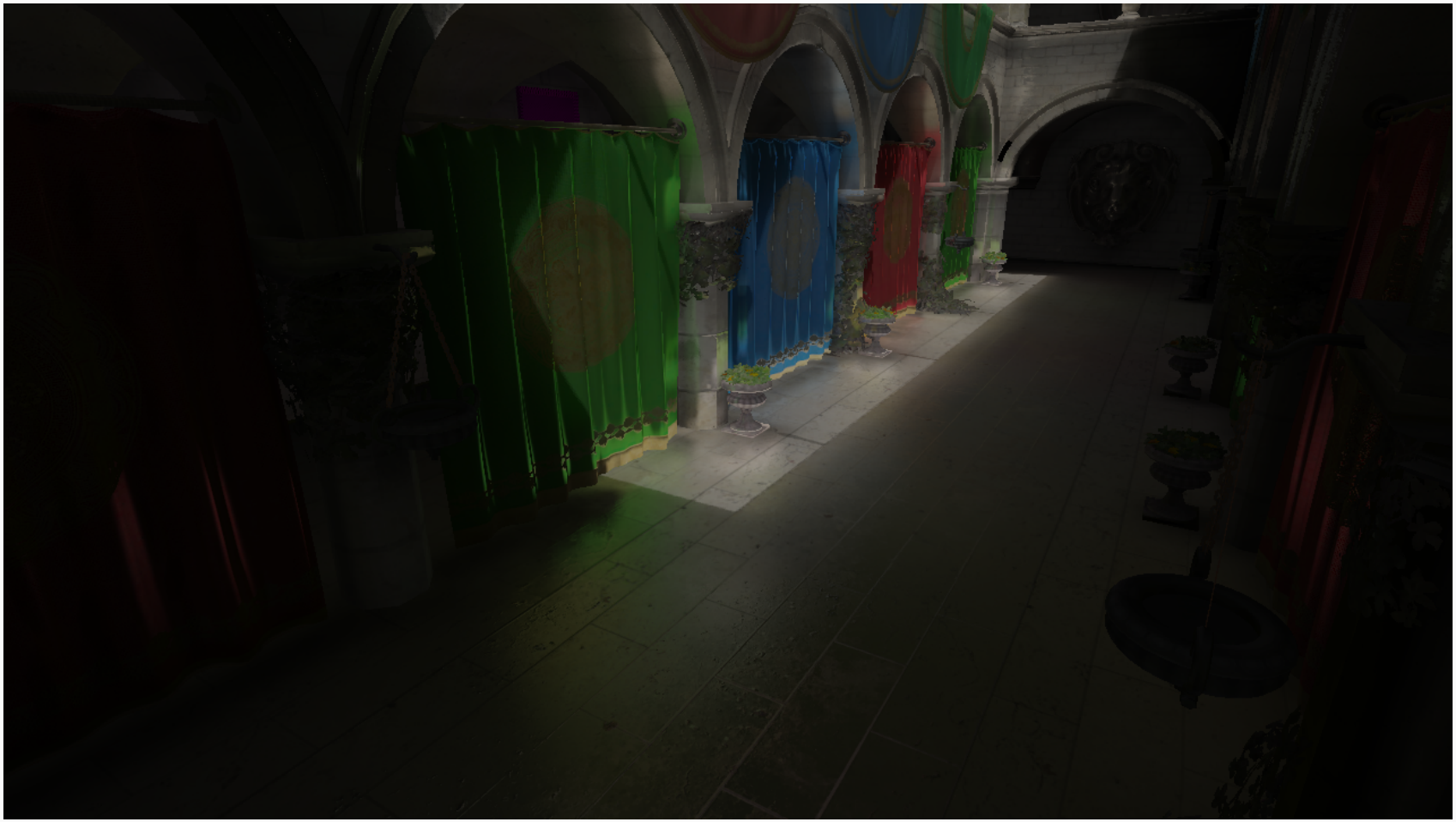
Rasterized vs. Tessellated Voxels

Summary

Rasterized: slightly faster, conservative rasterization, dominant axis projection, precision limited by fragments

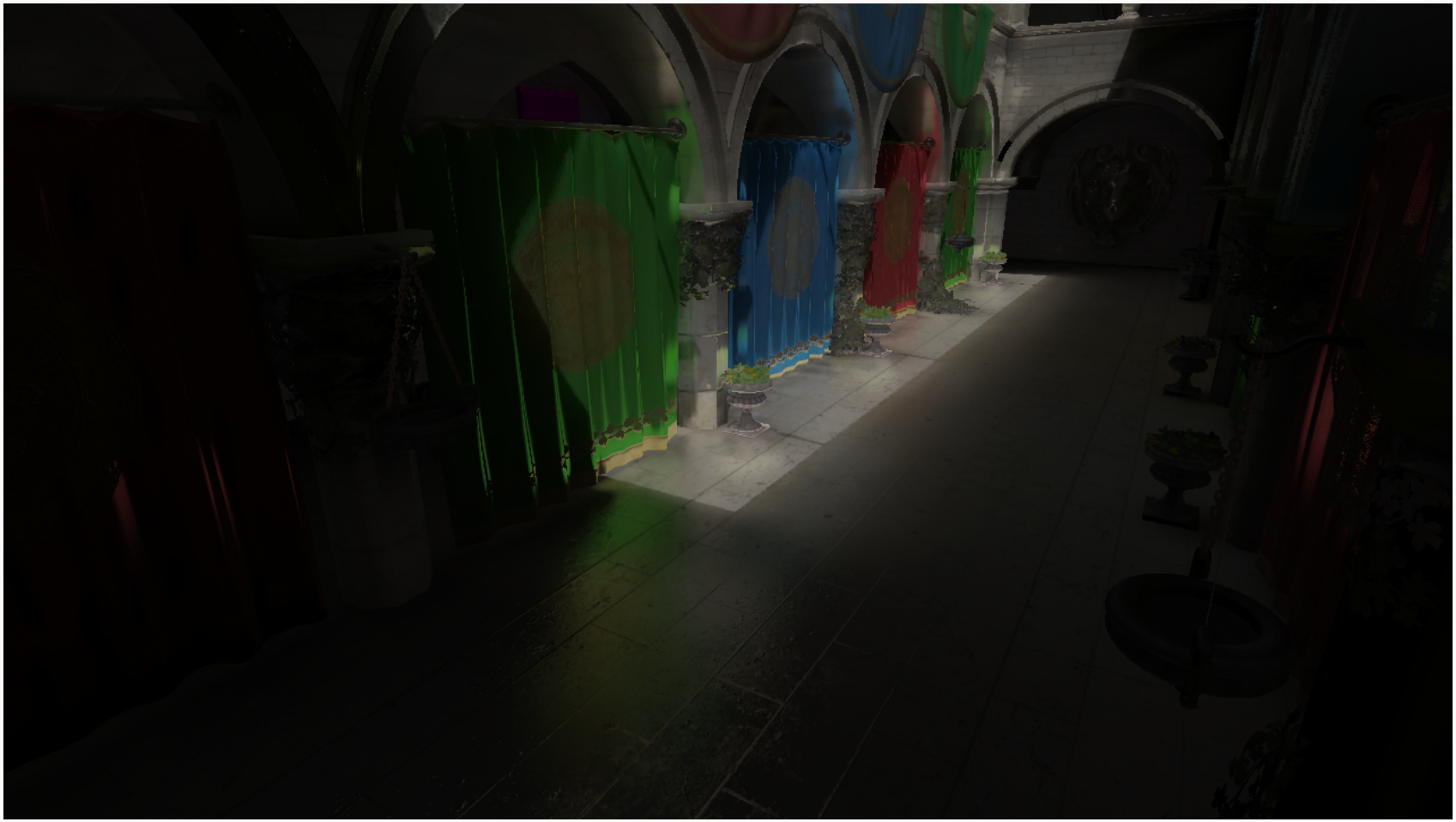
Tessellated: easier to implement, full precision, max triangle size limited by hardware

Voxel Warping



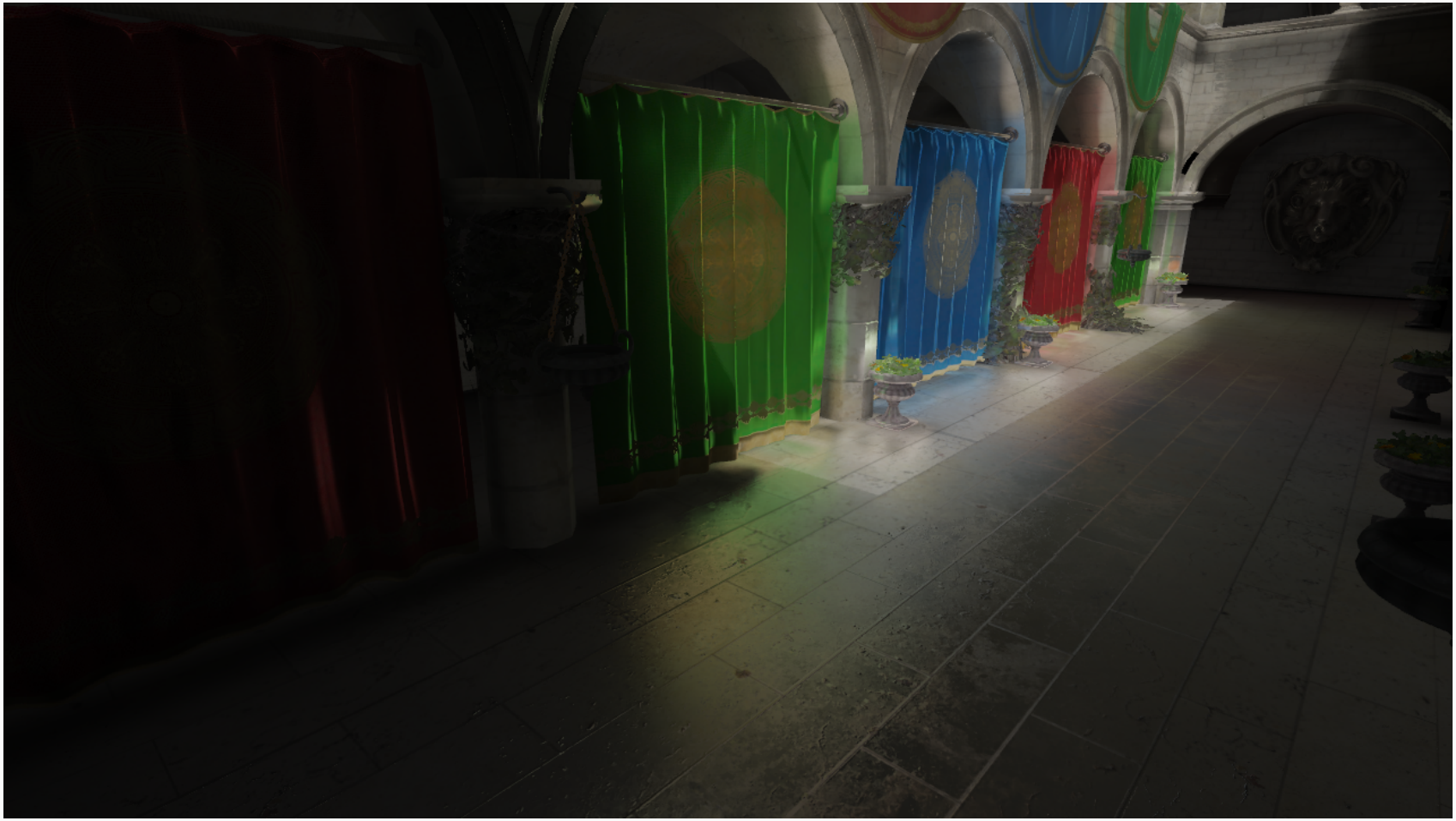
Without voxel warping

Voxel Warping



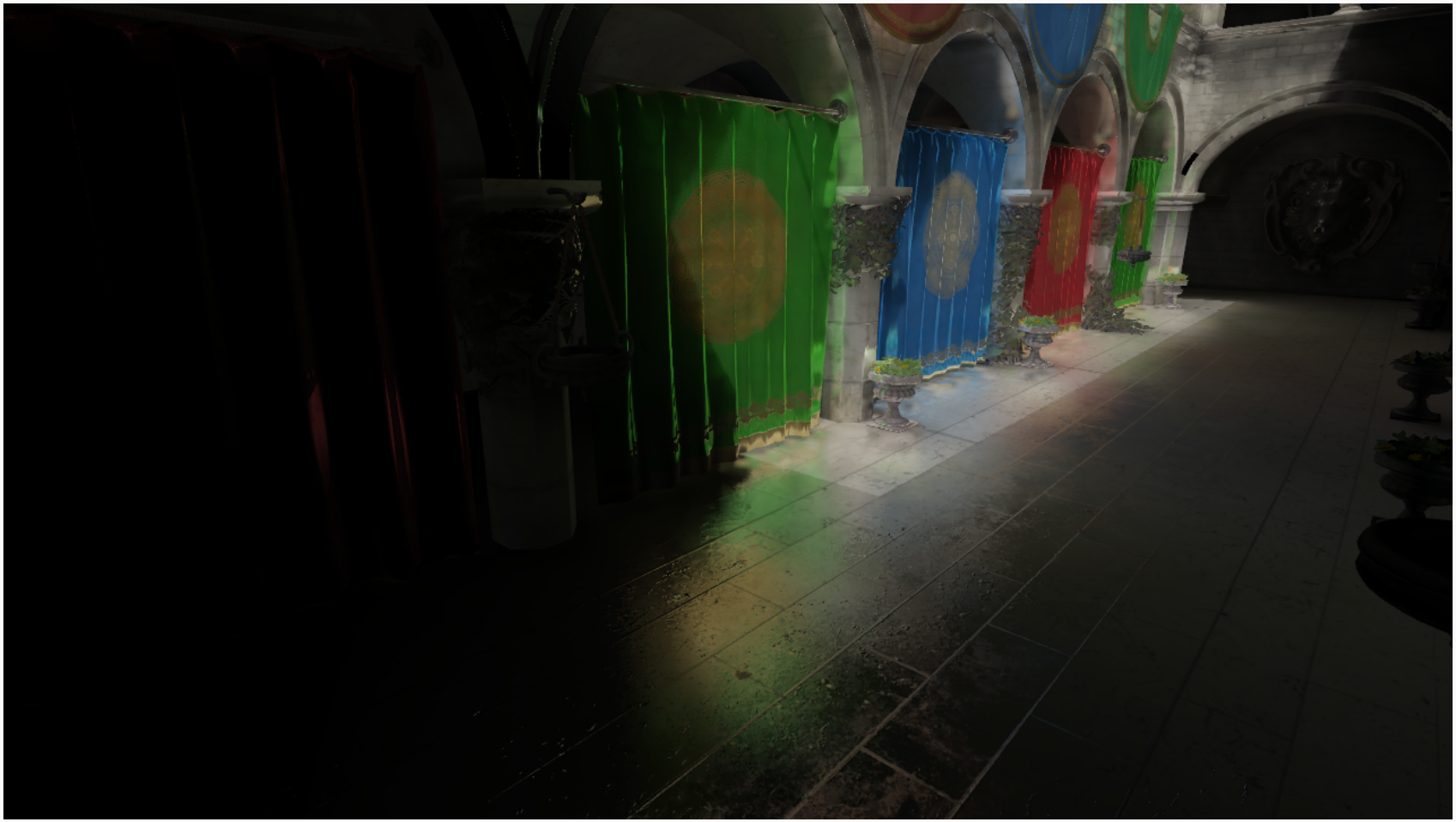
With voxel warping

Perspective Voxel Warping



Without voxel warping

Perspective Voxel Warping



With voxel warping

Outline

Related Work

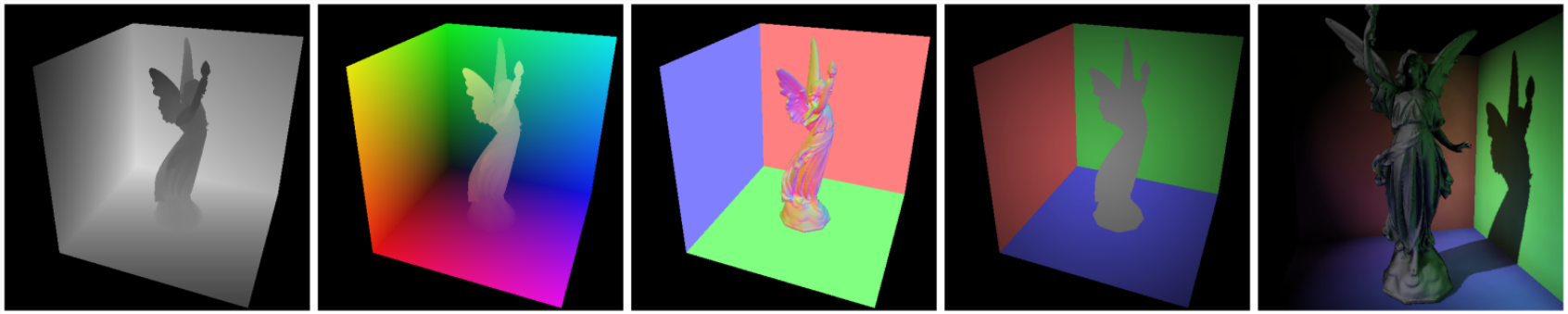
How does it compare with other methods?

Important parts of global illumination algorithms:

1. Scene representation?
2. Light computation?
3. Light sampling?

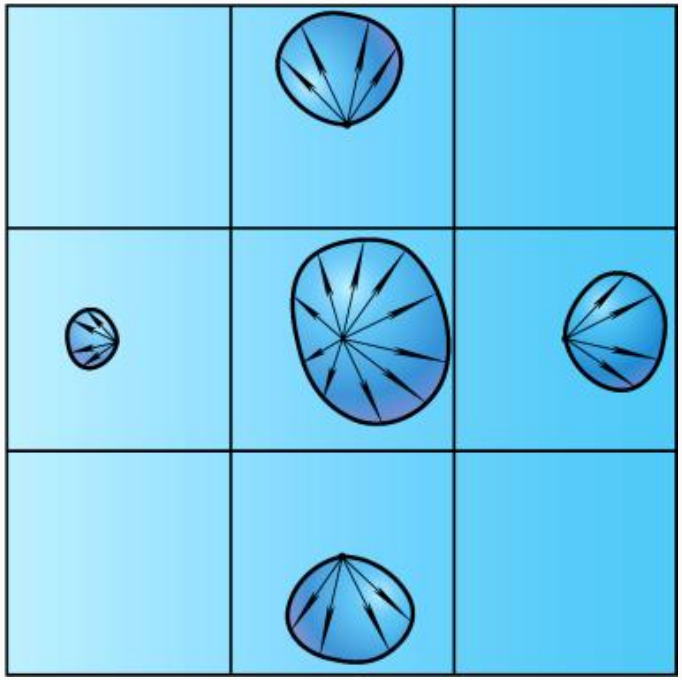
Related Work—Reflective Shadowmaps

1. Scene representation? Reflective shadowmap (RSM)
2. Light computation? None, use color and normal from RSM
3. Light sampling? Sample nearby points in RSM



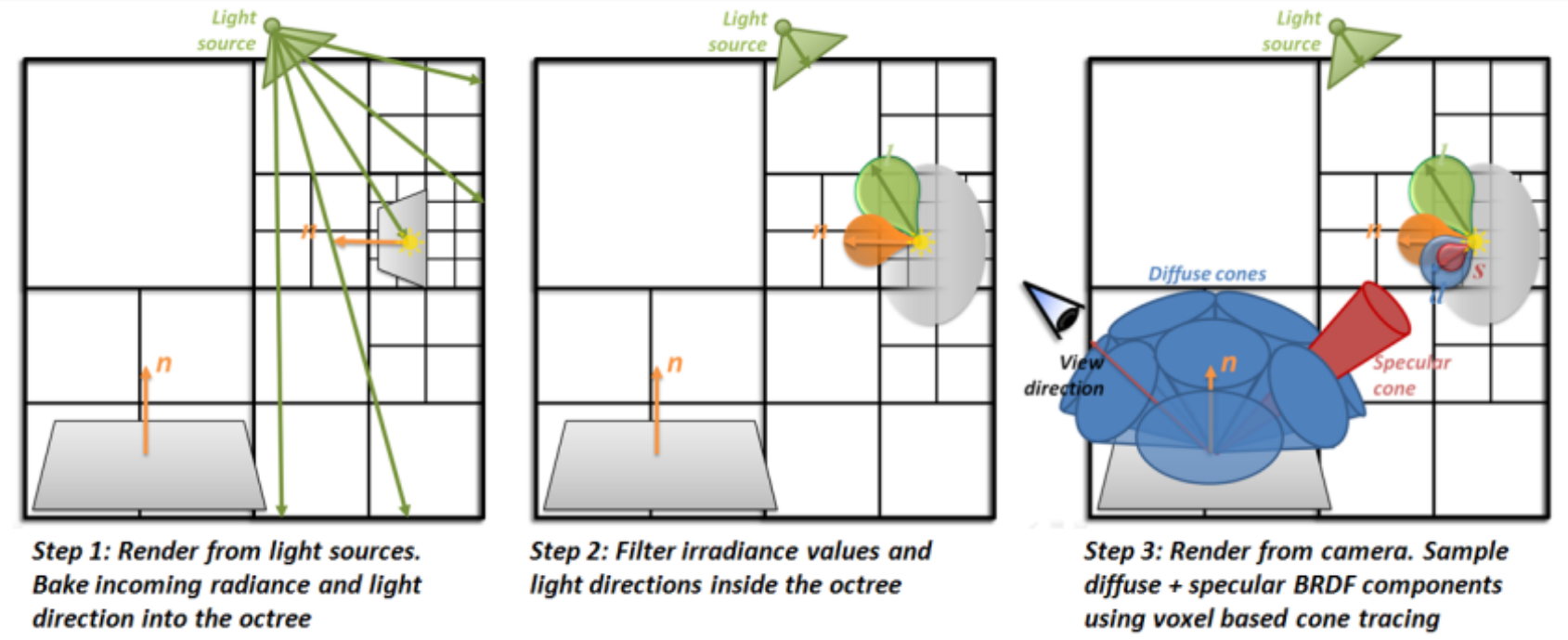
Related Work—Light Propagation Volumes

1. Scene representation? Voxel grid (incomplete)
2. Light computation? Iterative propagation
3. Light sampling? Texture lookup



Related Work—Voxel Cone Tracing

1. Scene representation? Sparse voxel octree (or clipmap)
2. Light computation? Mipmaps
3. Light sampling? Voxel cone tracing



Step 1: Render from light sources. Bake incoming radiance and light direction into the octree

Step 2: Filter irradiance values and light directions inside the octree

Step 3: Render from camera. Sample diffuse + specular BRDF components using voxel based cone tracing

Related Work—Ours

1. Scene representation? Warped voxel grid
2. Light computation? Mipmaps
3. Light sampling? Voxel cone tracing

Outline

Conclusion

- Implementation[1] of real-time global illumination using voxel cone tracing
- Implementation and comparison of two voxelization methods
- Investigation into warped voxels

[1] Find the source here: `github.com/sfreed141/vct`

Future Work

- Cascaded sparse 3D textures
- Take advantage of tessellated voxelization to try to resolve temporal artifacts
- Spherical harmonics, anisotropic filtering, adaptive cone tracing quality, other miscellaneous optimizations

Thank you!

Questions?