

Tessellated Voxelization for Global Illumination using Voxel Cone Tracing

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Outline

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

Introduction

Computer Graphics

How can we simulate light in a virtual world?

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

Motivations



:)

Motivations



:)

Motivations

1. Real-time global illumination is difficult
2. Limited reference material

Contributions

- Open-source, cross-platform implementation of real-time global illumination
- Comparison of two different methods of scene voxelization
- Investigation into warped (nonuniform size) voxels

Computer Graphics Primer

Goal

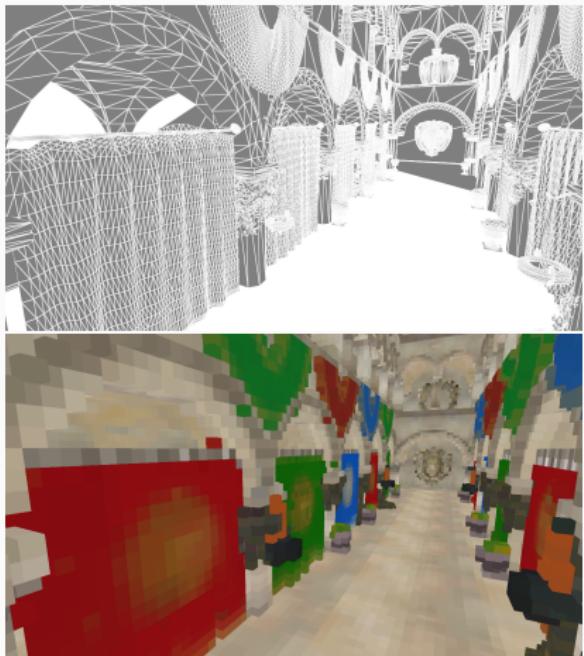
Given a virtual description of a scene, render an image.

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?

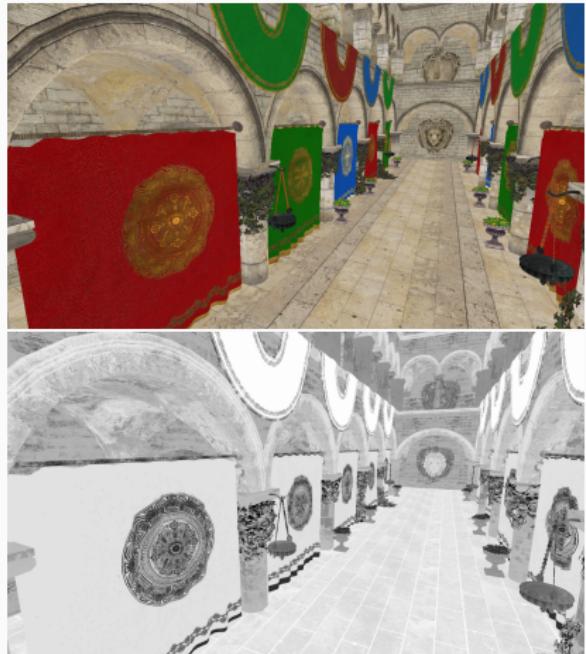
How do we represent a scene?

Geometry triangles, voxels



How do we represent a scene?

Materials colors and other properties



How do we represent a scene?

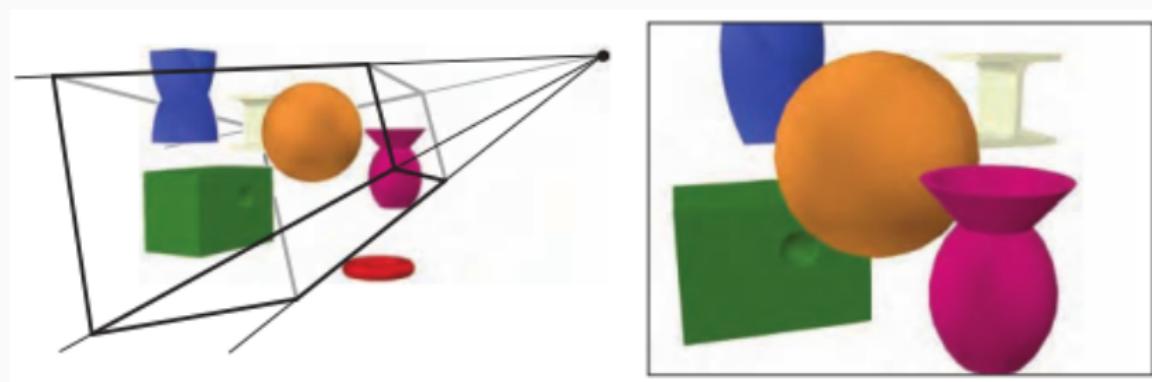
Lights positions, colors,
etc.



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

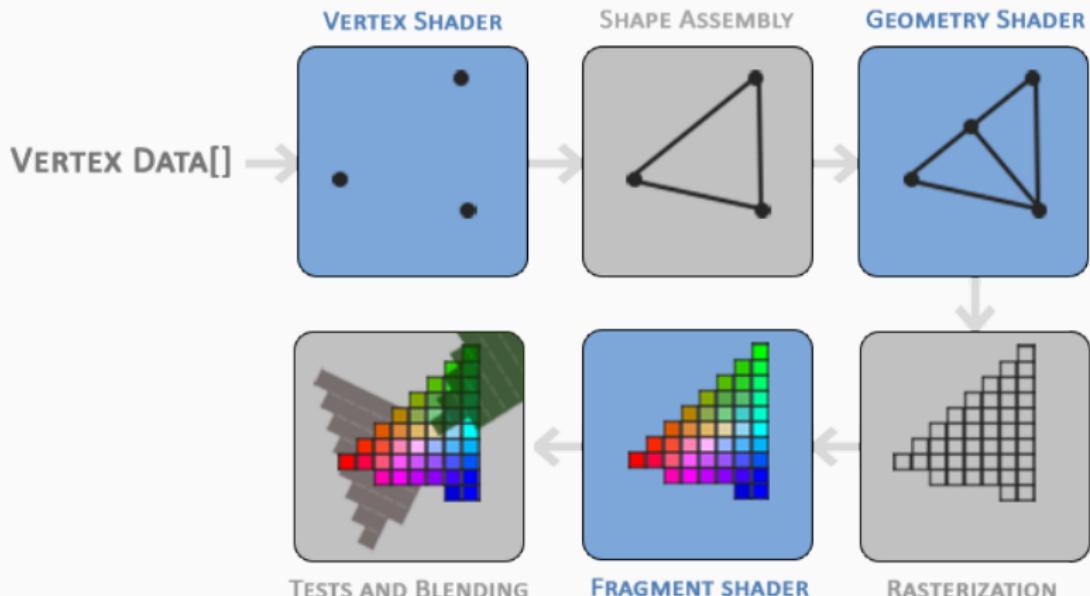
Math!

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



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

The Graphics Pipeline



How do we render?

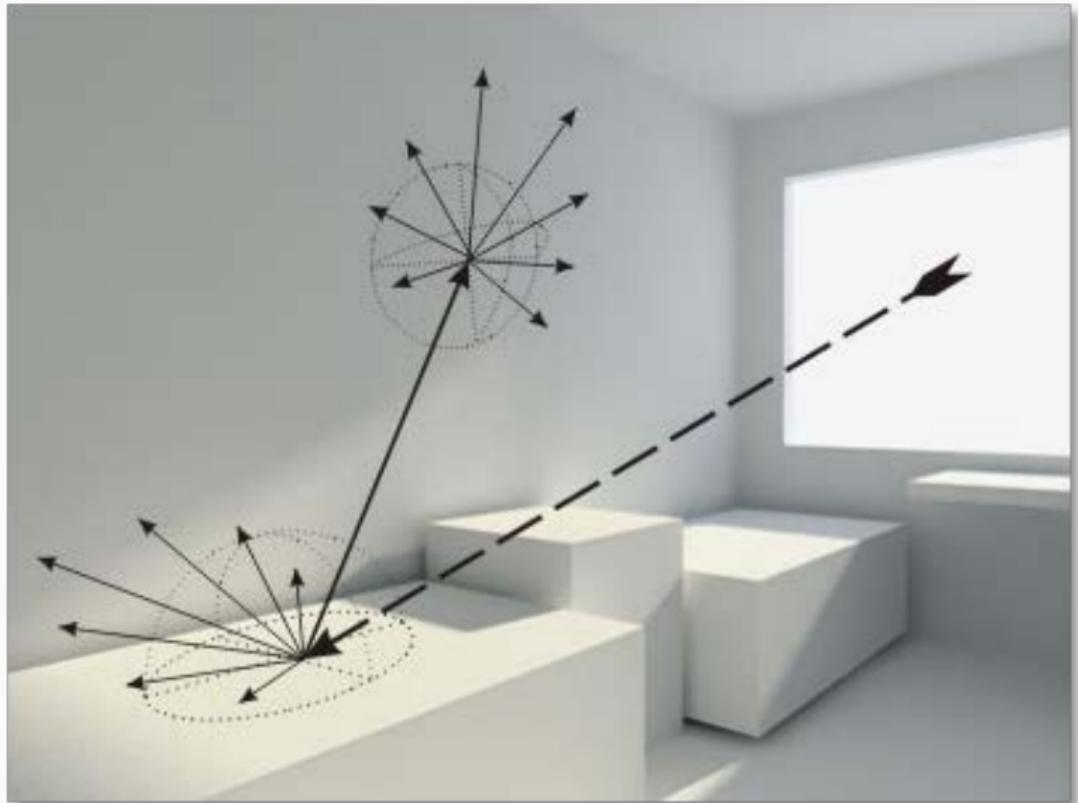
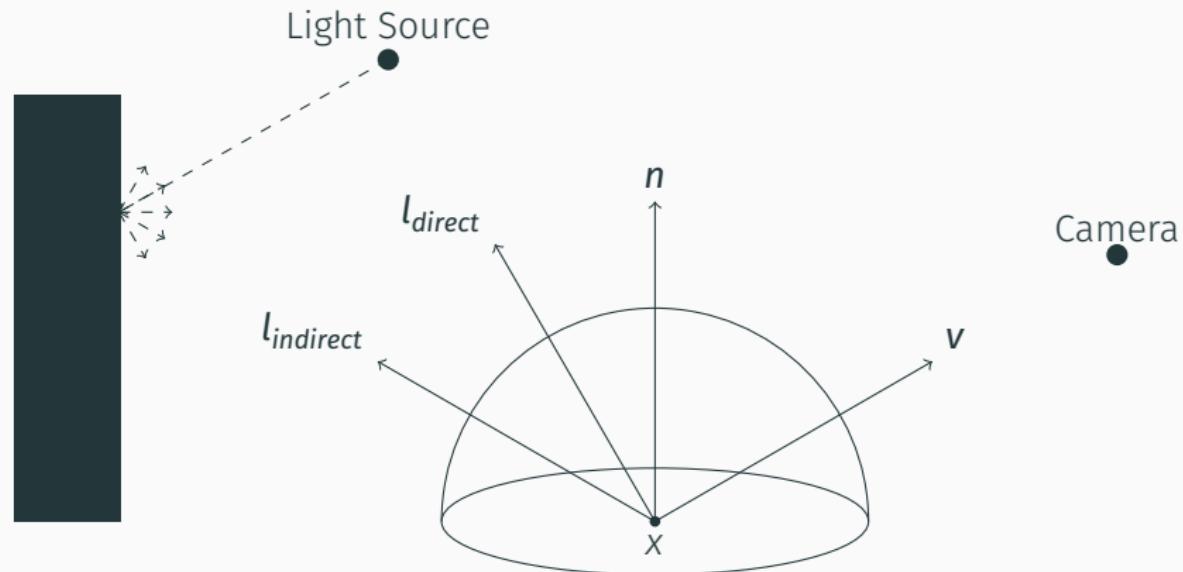


image from VCT and SVO for Real-time Global Illumination by Cyril Crassin

Light Theory



Real-Time Global Illumination

Various approaches to approximating indirect light.

Constant Fixed fraction of ambient light

Partial Ambient occlusion, 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

Overview of Renderer



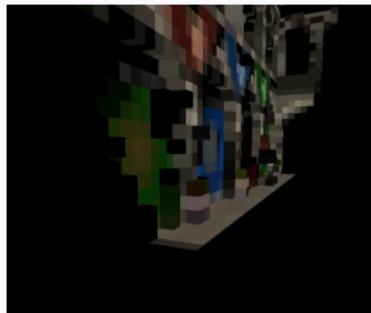
(1) Voxelize



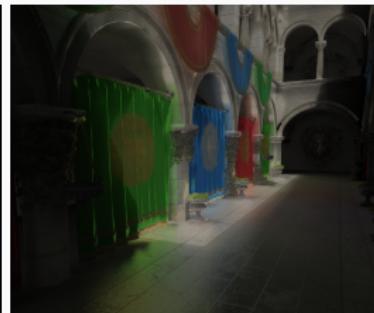
(2) Direct lighting



(3) Inject direct lighting
into voxels



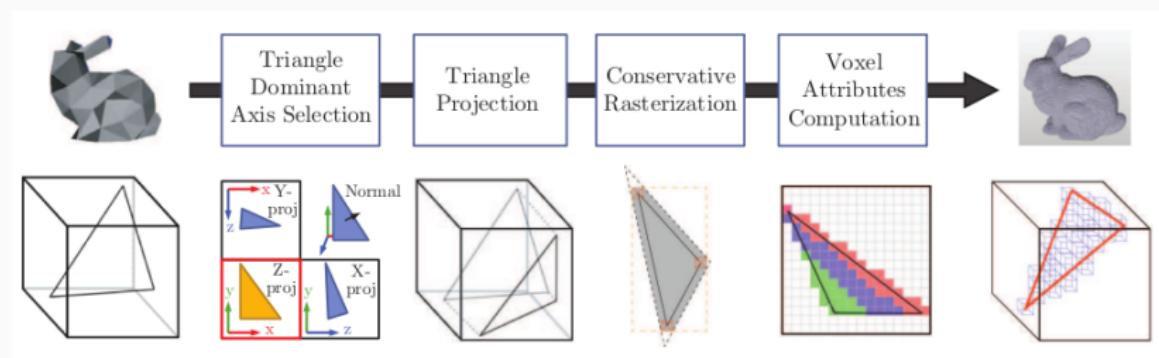
(4) Filter voxels



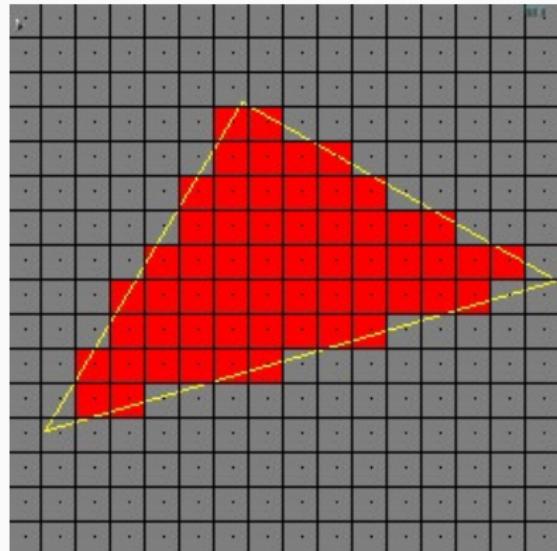
(5) Sample using voxel
cone tracing

Voxelization with Rasterizer

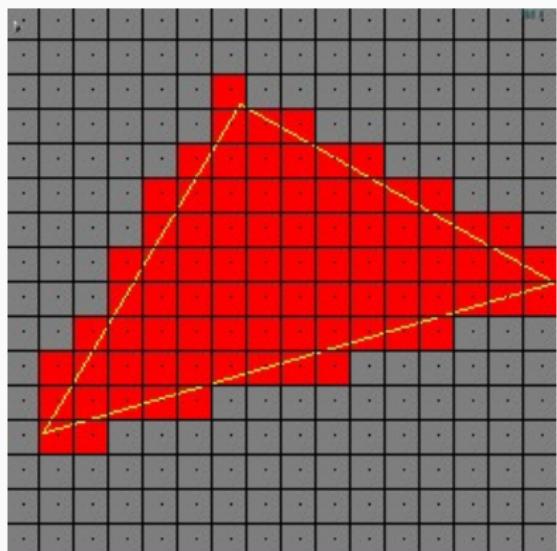
Each fragment corresponds to a voxel



Conservative Rasterization



Off



On

Conservative Rasterization



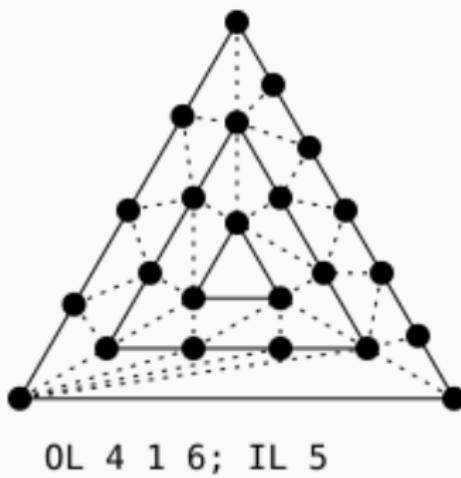
Off



On

Voxelization with Tessellator

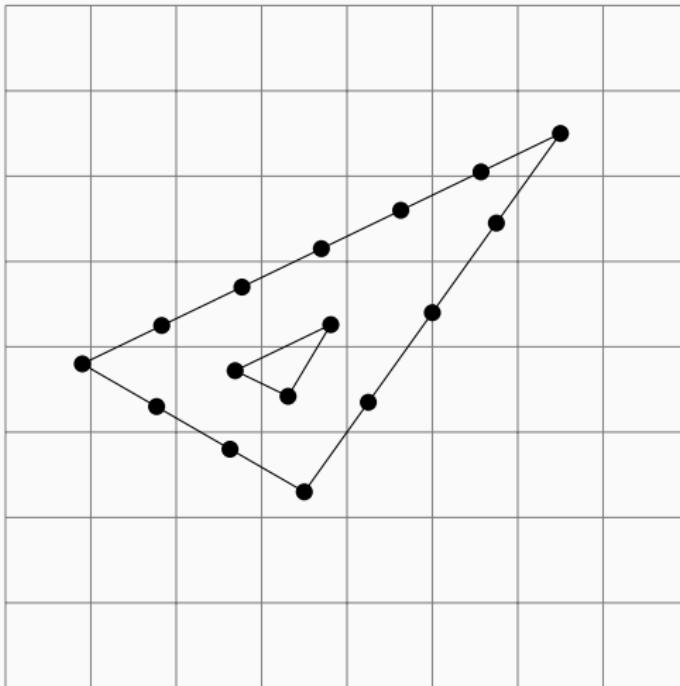
Idea: Generate a *vertex* for each voxel instead of a fragment



Determining Tessellation Levels

Outer levels determined from respective edge lengths

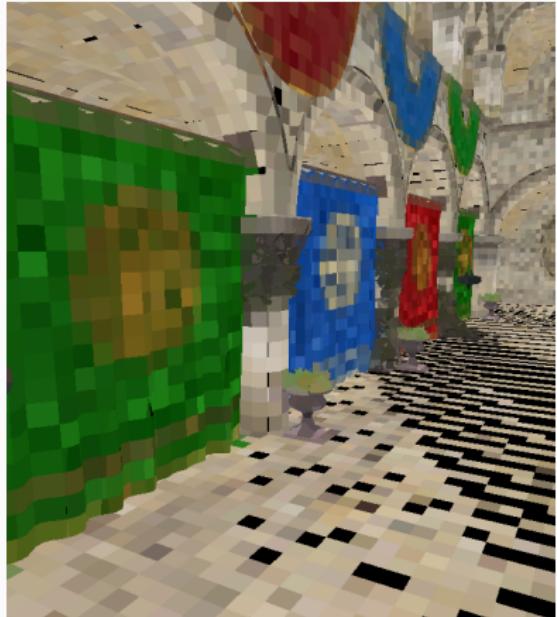
Inner level determined from maximum triangle altitude length



Voxelized Scene



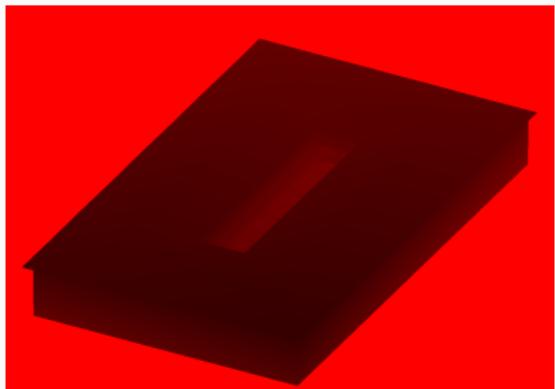
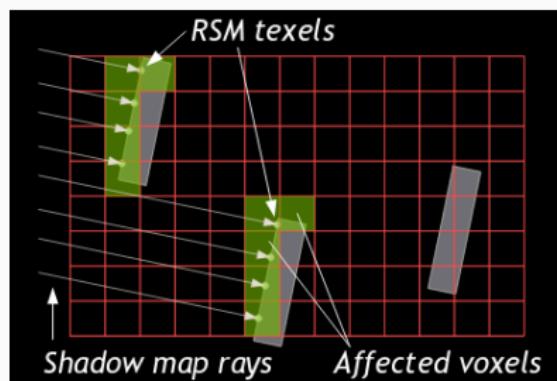
Rasterized voxels



Tessellated voxels

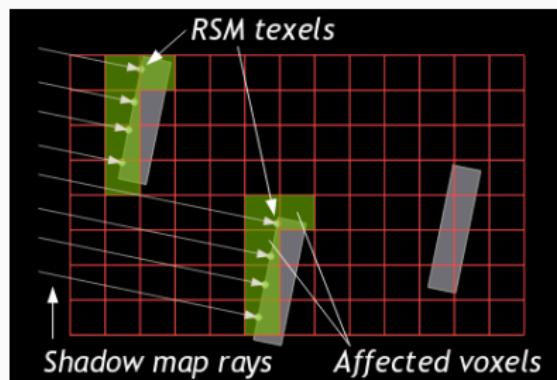
Radiance Injection

Use **shadowmap** to determine where direct light hits voxels



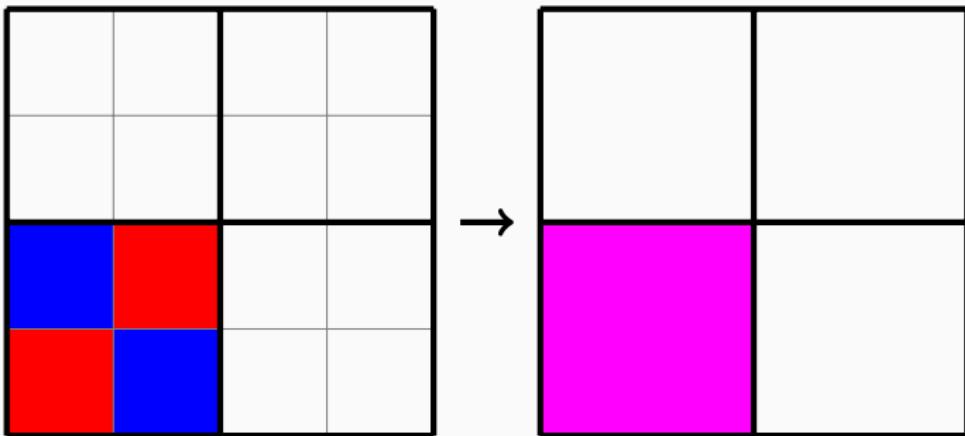
Radiance Injection

Use **shadowmap** to determine where direct light hits voxels

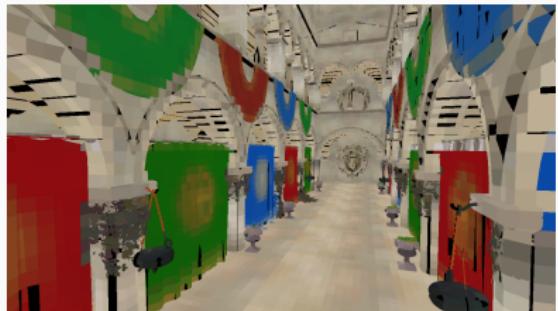


Radiance Filtering

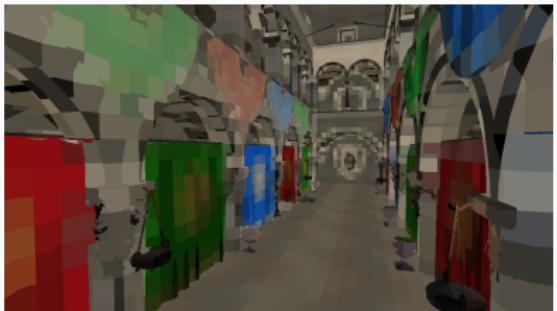
- Multiple **levels** (mipmaps)
- Each level is half the size of the previous
- Computing the next level is a 2x2x2 average



Radiance Filtering



Level 0



Level 1



Level 2

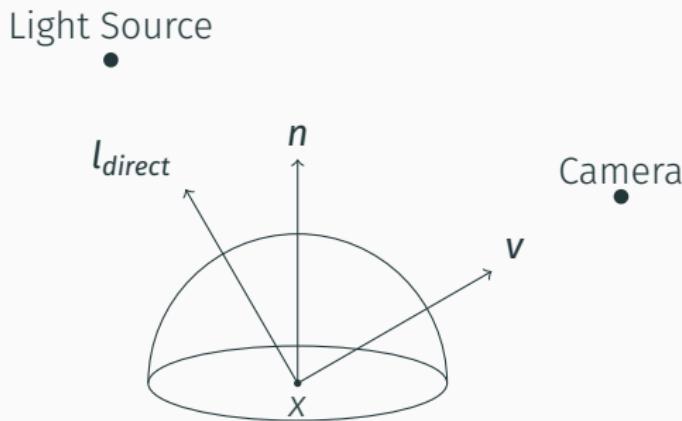


Level 3

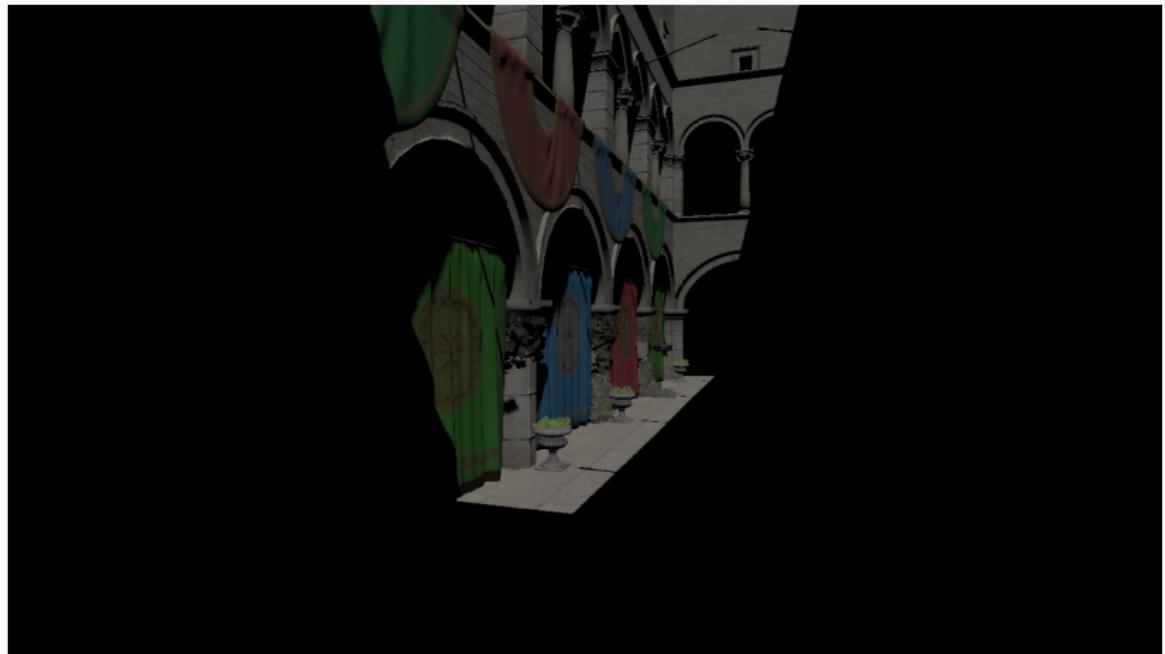
Mipmaps

Direct Lighting

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



Direct Lighting

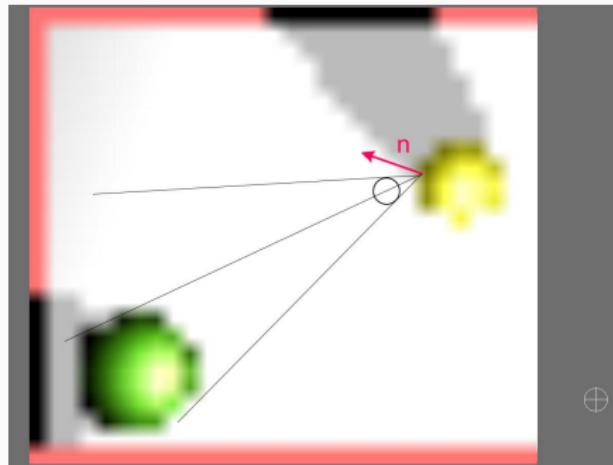


Direct Lighting

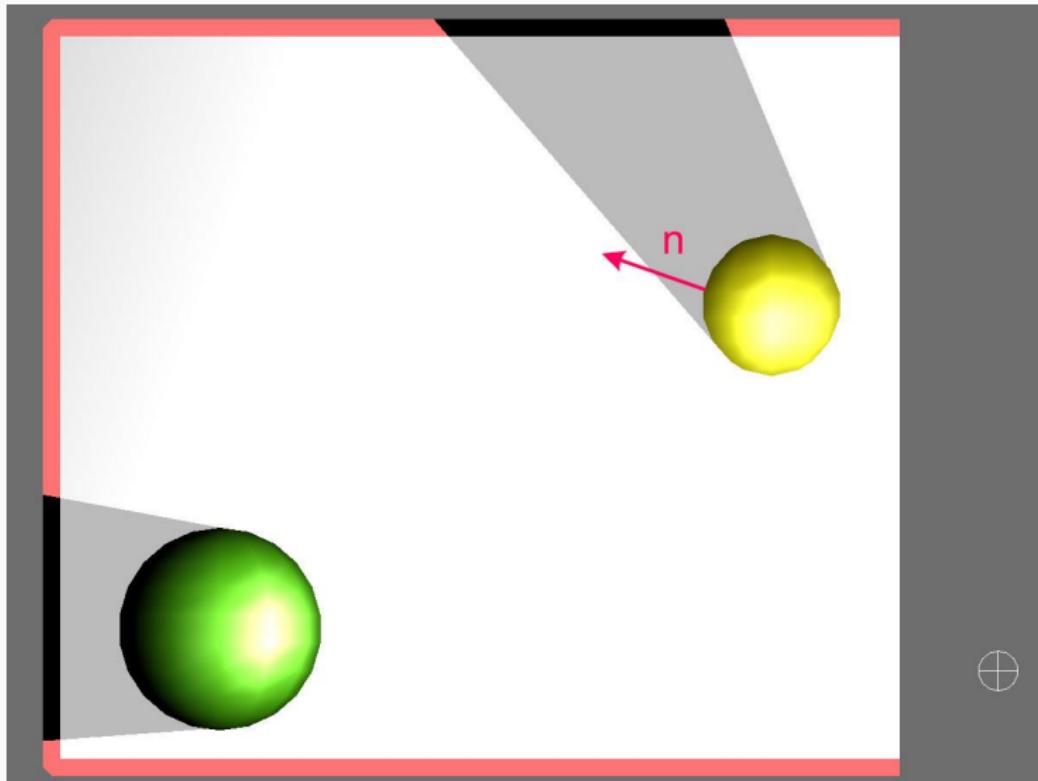
Indirect Lighting—Voxel Cone Tracing

Voxel Cone Tracing

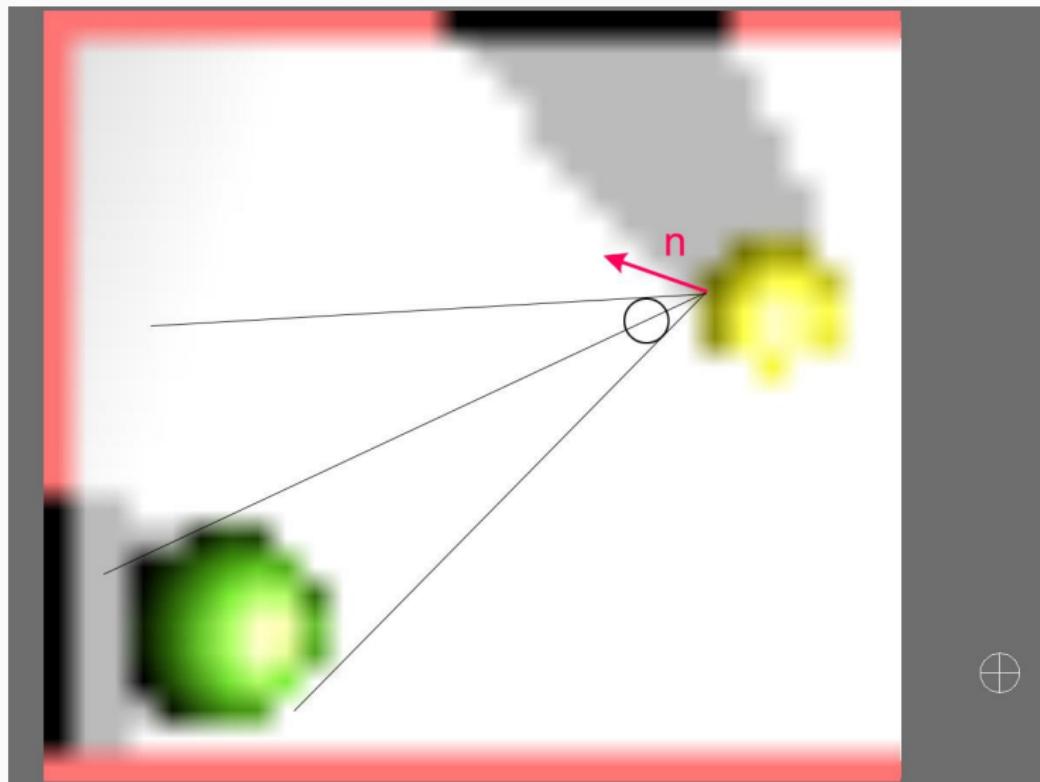
1. Sample light and occlusion from the radiance texture along a particular direction
2. Adjust level of detail as we get farther from sample point



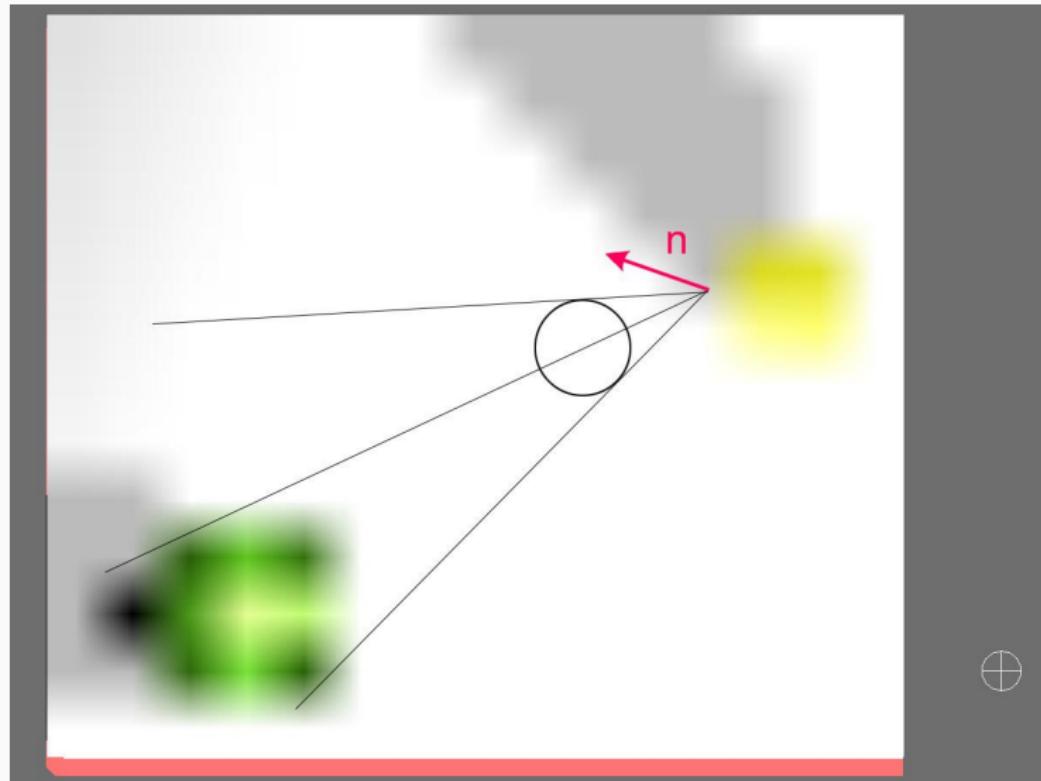
Indirect Lighting—Voxel Cone Tracing



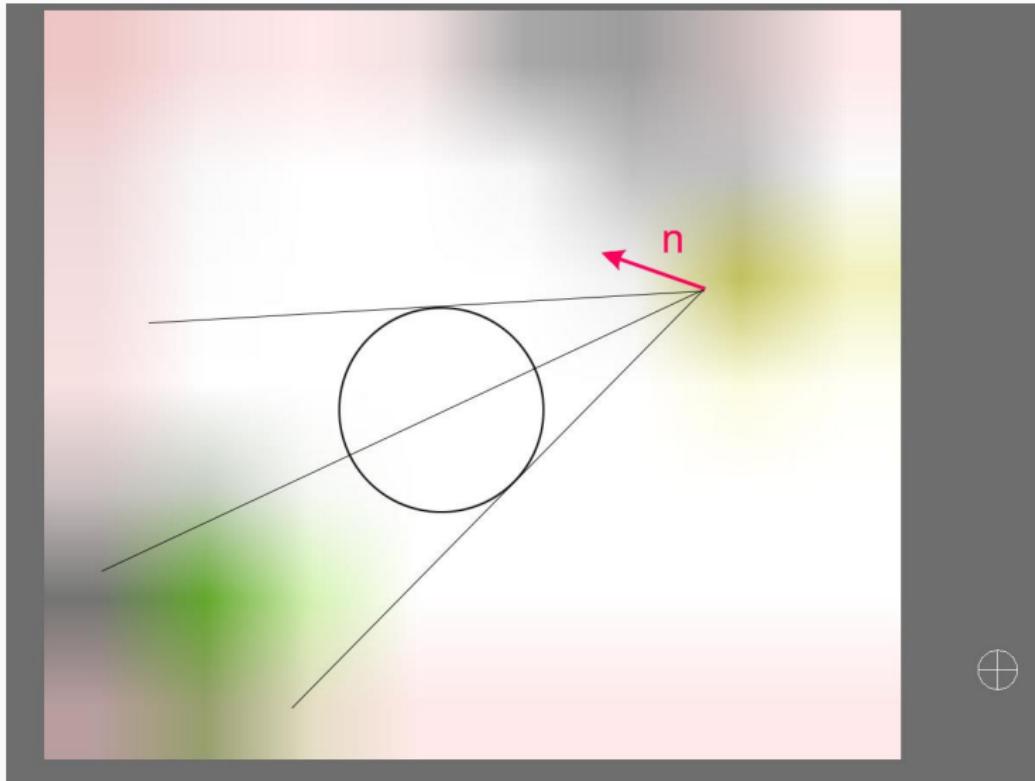
Indirect Lighting—Voxel Cone Tracing



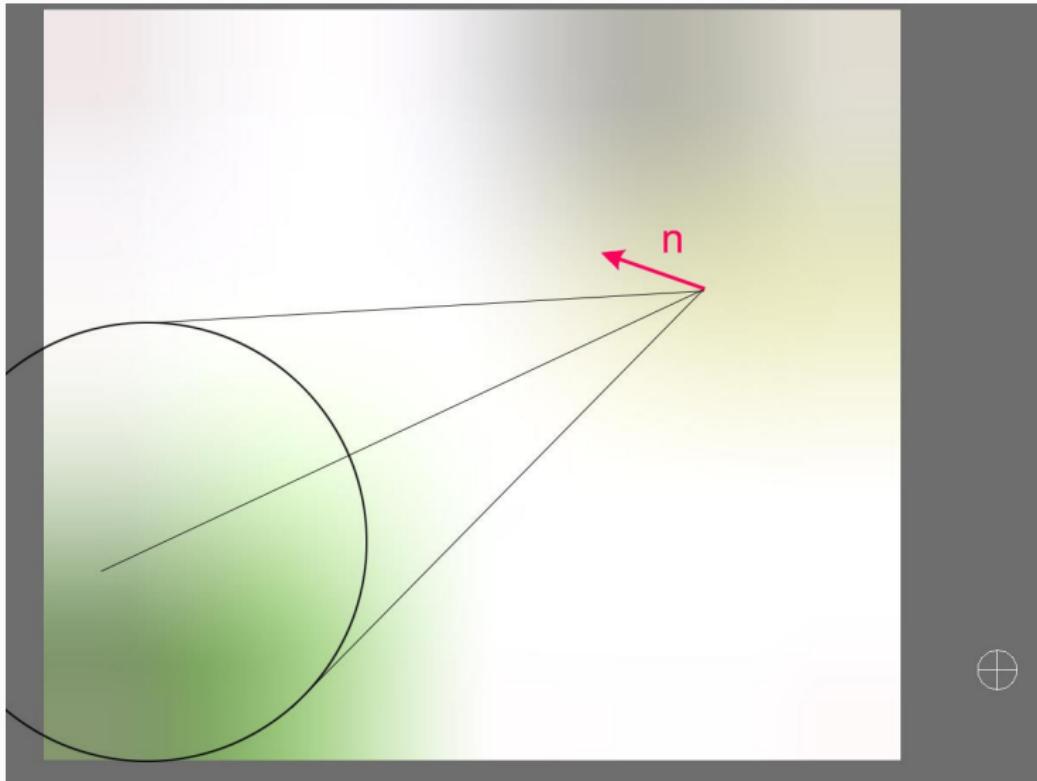
Indirect Lighting—Voxel Cone Tracing



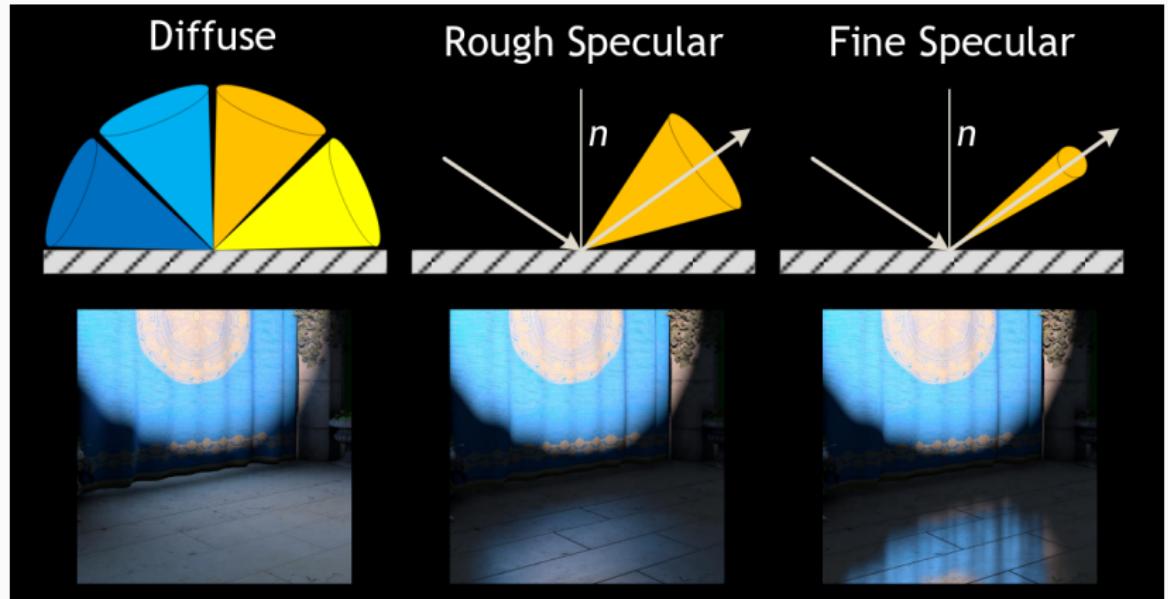
Indirect Lighting—Voxel Cone Tracing



Indirect Lighting—Voxel Cone Tracing



Indirect Lighting—Voxel Cone Tracing

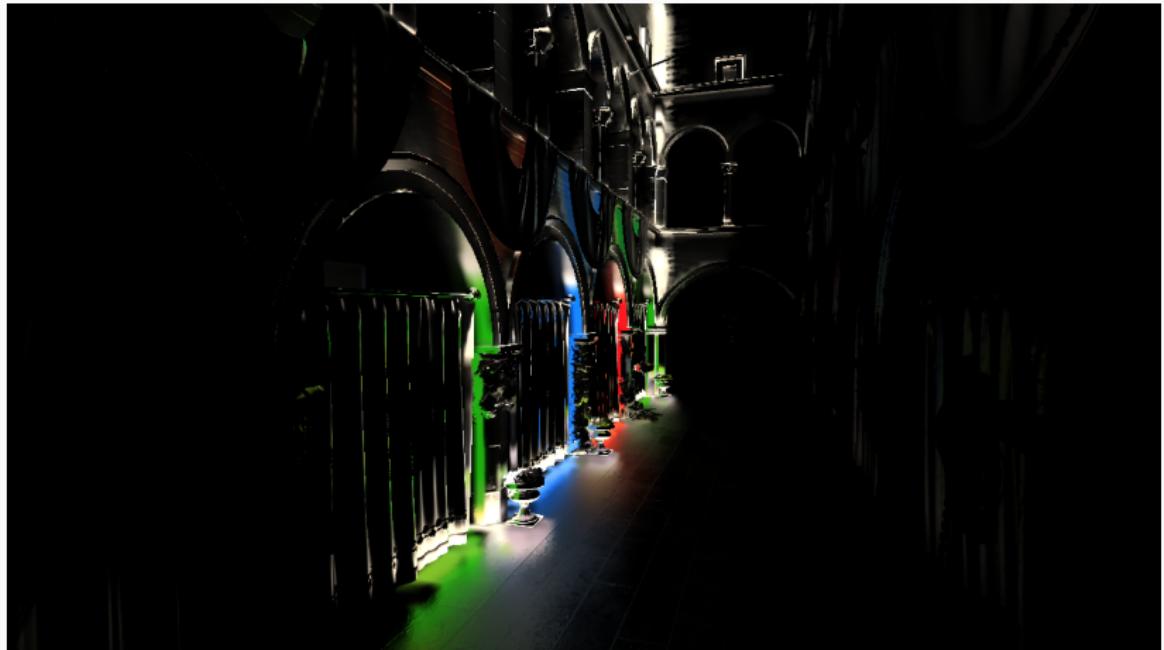


Indirect Lighting



Diffuse Indirect (no occlusion)

Indirect Lighting



Specular Indirect (no occlusion)

Indirect Lighting



Occlusion

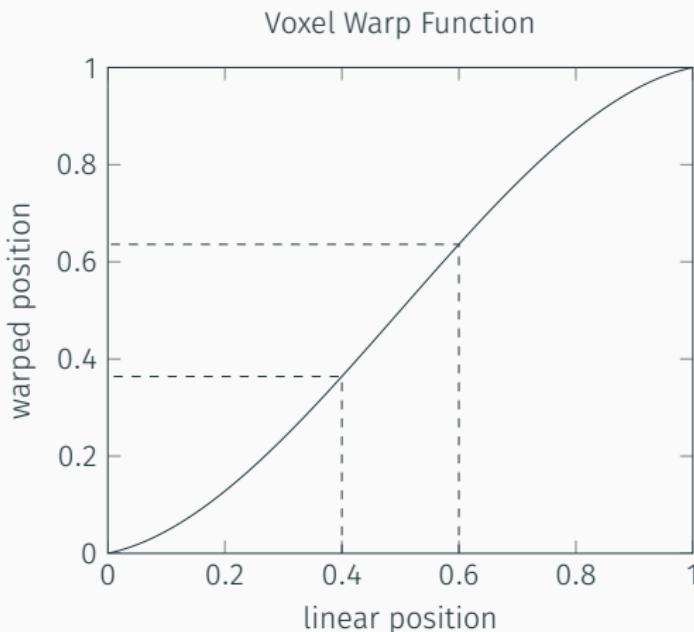
Voxel Warping

- 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

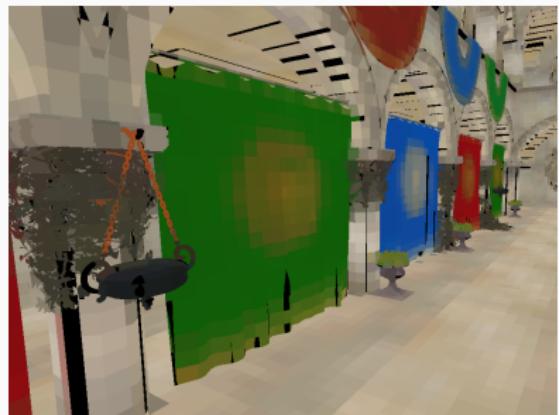
Vary with distance from camera

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

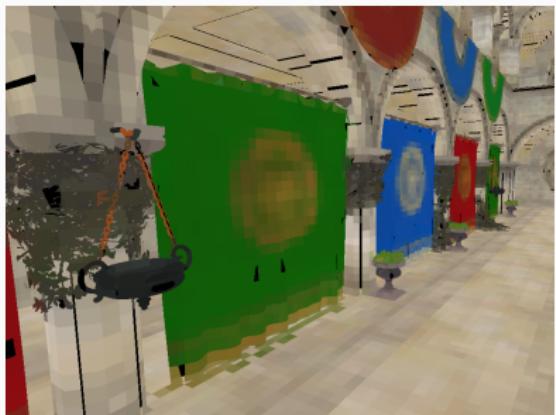
The camera is in the middle ($x = 0.5$)



Vary with distance from camera



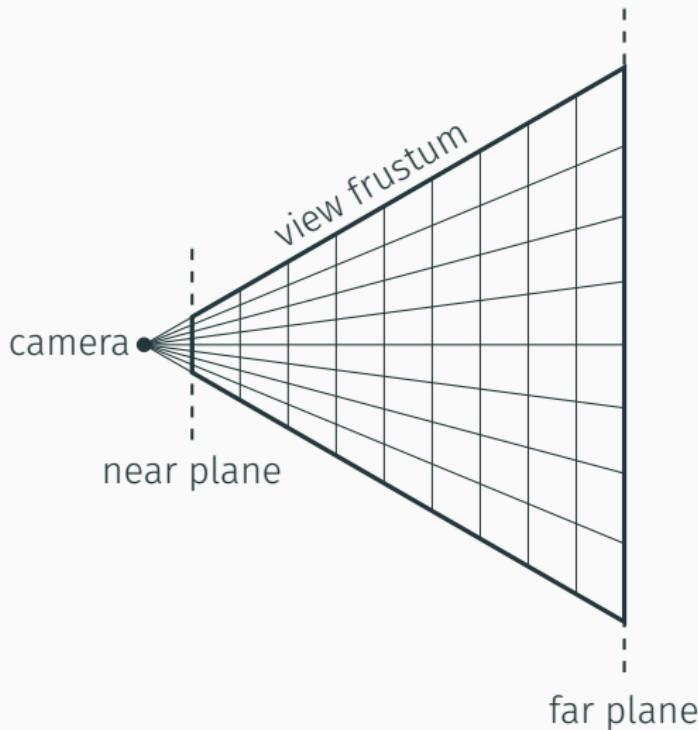
Without warping



With warping

Vary based on perspective

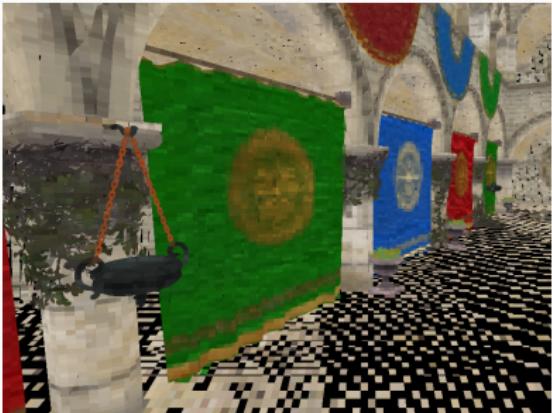
- Use perspective projection to determine voxel size
- Makes voxel size based on relative size in screen space



Vary based on perspective

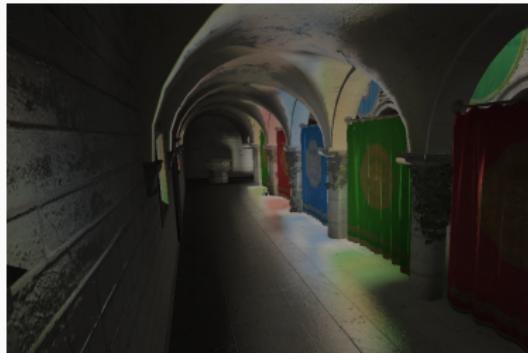


Without warping

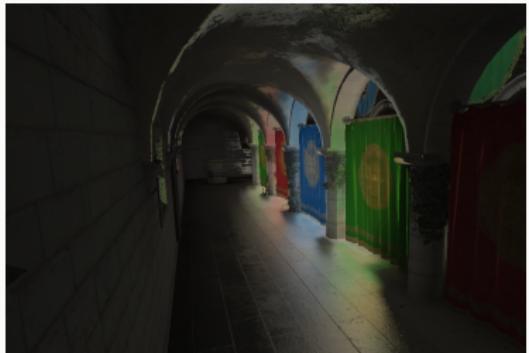


With warping

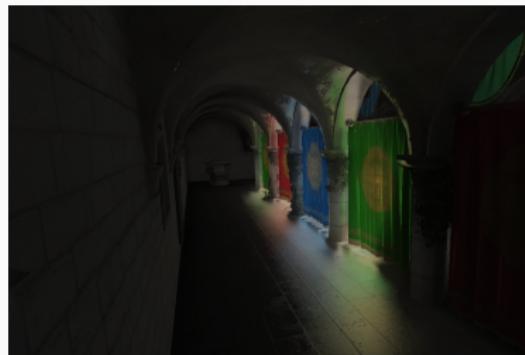
Results



64^3

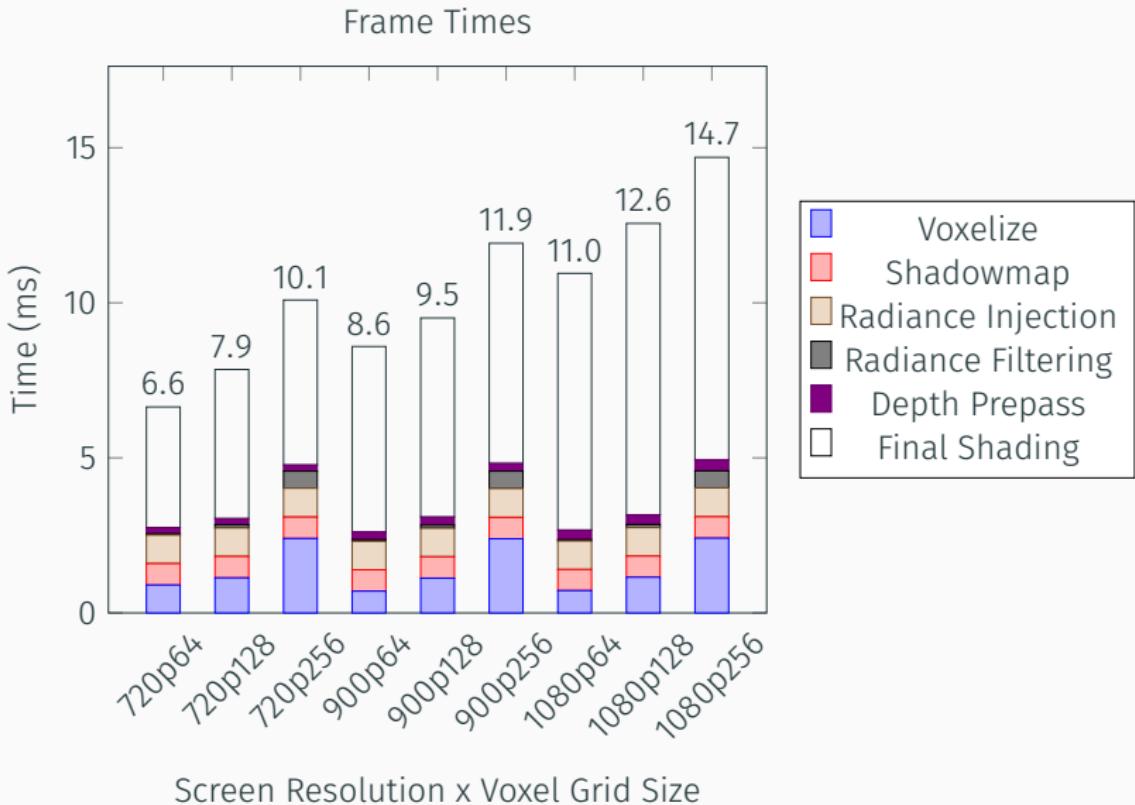


128^3

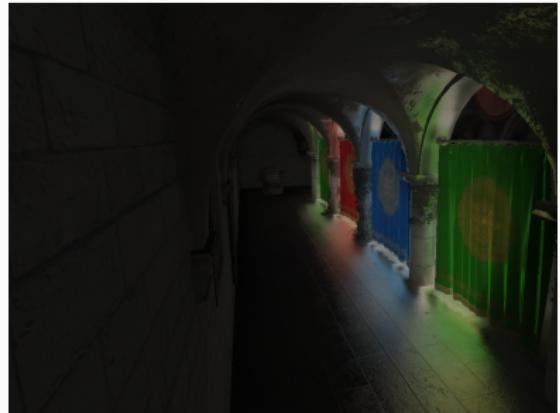


256^3

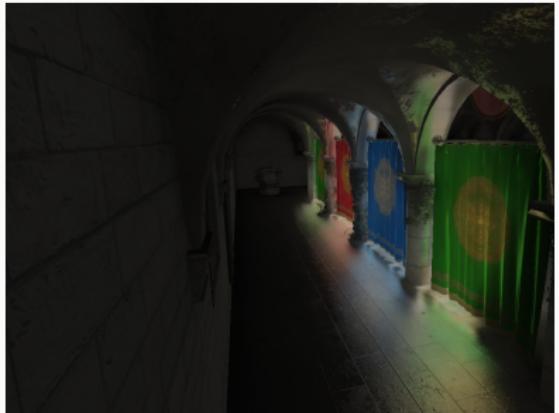
Performance



Rasterized vs. Tessellated Voxels

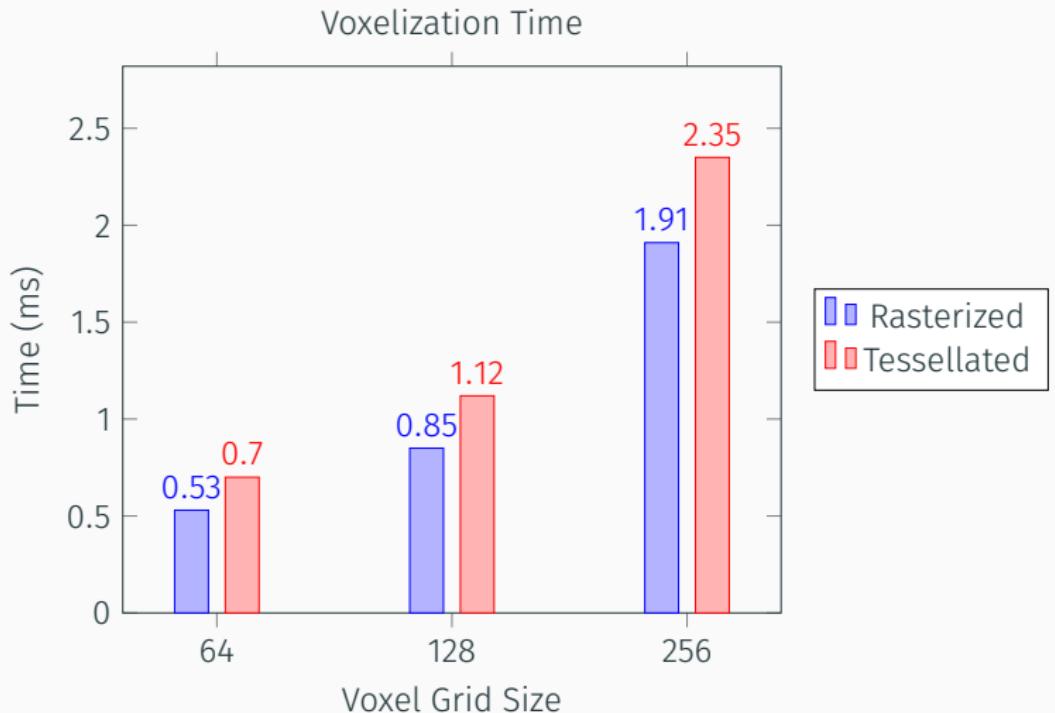


Rasterized voxels



Tessellated voxels

Rasterized vs. Tessellated Voxels



Rasterized vs. Tessellated Voxels

Summary

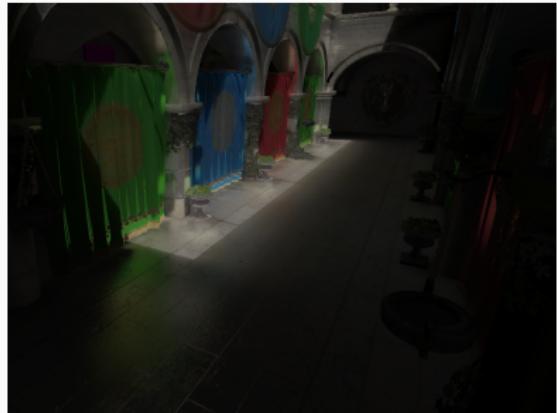
Rasterized: limited by rasterizer, slightly faster

Tessellated: limited by hardware, easier to implement

Voxel Warping

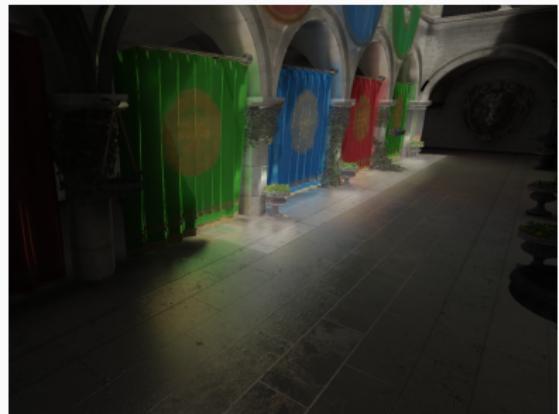


Without voxel warping

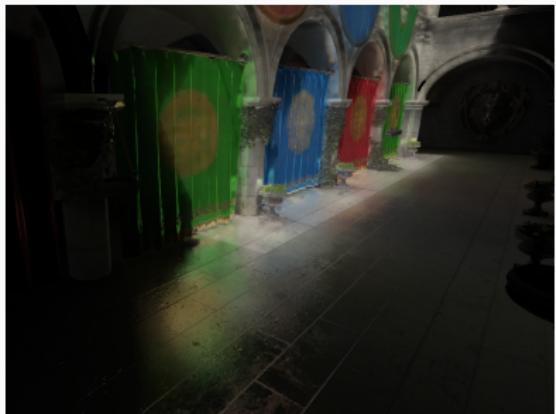


With voxel warping

Perspective Voxel Warping



Without voxel warping



With voxel warping

Related Work

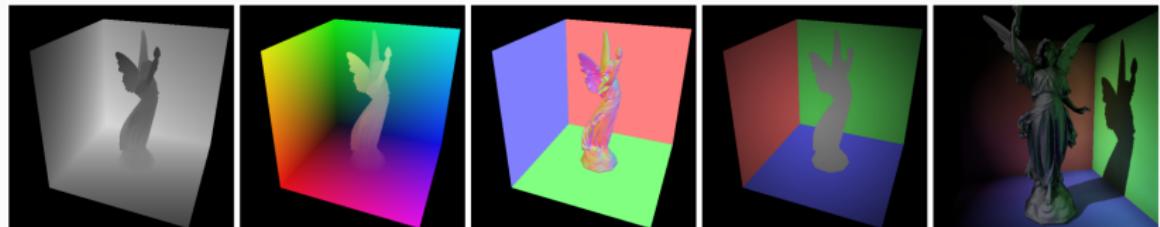
How does it compare with other methods?

Important parts of global illumination algorithms:

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

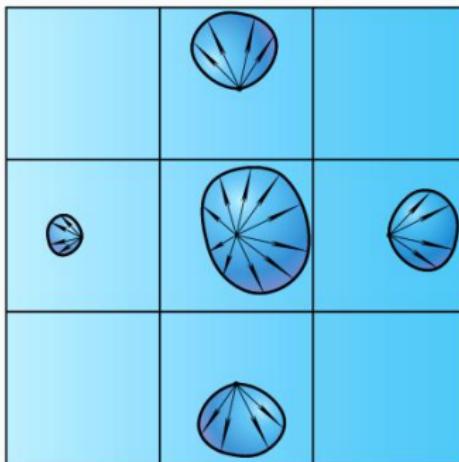
Related Work—Reflective Shadowmaps

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



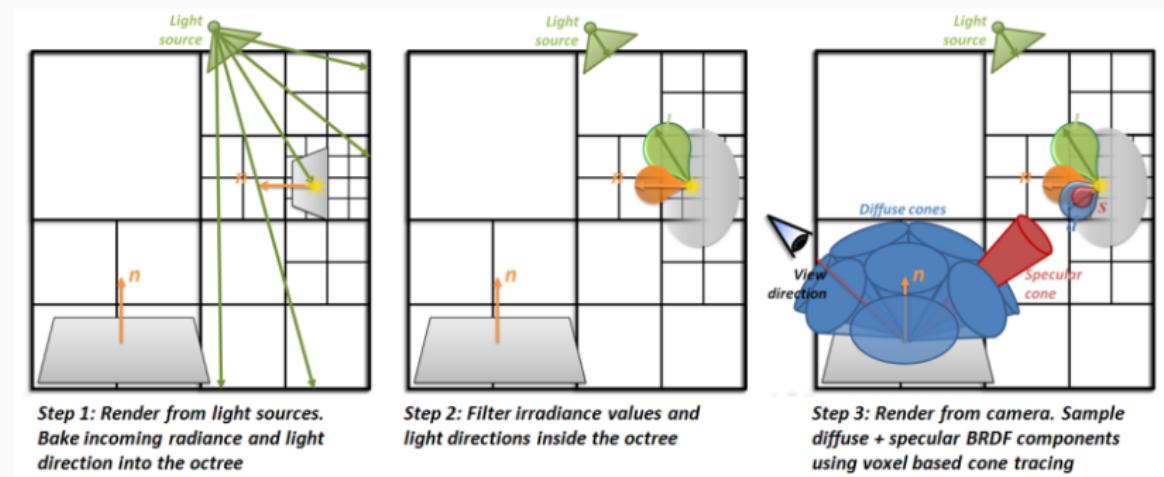
Related Work—Light Propagation Volumes

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**
2. Light computation? **Mipmaps**
3. Light sampling? **Voxel cone tracing**



Conclusion

- Implementation¹ of real-time global illumination using voxel cone tracing
- Implementation and comparison of two voxelization methods
- Investigation into warped voxels

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

Future Work

- Try to alleviate flickering with warped voxels
- Fully implement RSMs, LPVs, and VCT (as described in research paper) for direct comparison
- Cascaded sparse 3D textures
- Spherical harmonics, anisotropic filtering, adaptive cone tracing quality, other miscellaneous optimizations

Thank you!

Questions?