GPU TECHNOLOGY CONFERENCE

NVIDIA VXGI

DYNAMIC GLOBAL ILLUMINATION FOR GAMES

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OUTLINE

- What is VXGI
- Algorithm Overview
- Engine Integration
- VXGI in UE4
- Quality and Performance
- Ambient Occlusion Mode
- Q&A

"Voxel Global Illumination (VXGI) is a ***stunning advancement****, delivering* ***incredibly realistic lighting****, shading and reflections to next-generation games and game engines."*

Geforce.com

WHAT VXGI REALLY IS

- A software library that computes approximate indirect illumination
  - Works on any DX11 GPU, faster on Maxwell
  - Has to be integrated into rendering engines
  - UE4 integration available
  - One bounce of indirect illumination
- An algorithm inspired by SVOGI
  - Voxel cone tracing
  - Clip-map instead of an octree
  - Handles large and dynamic scenes well, no preprocessing

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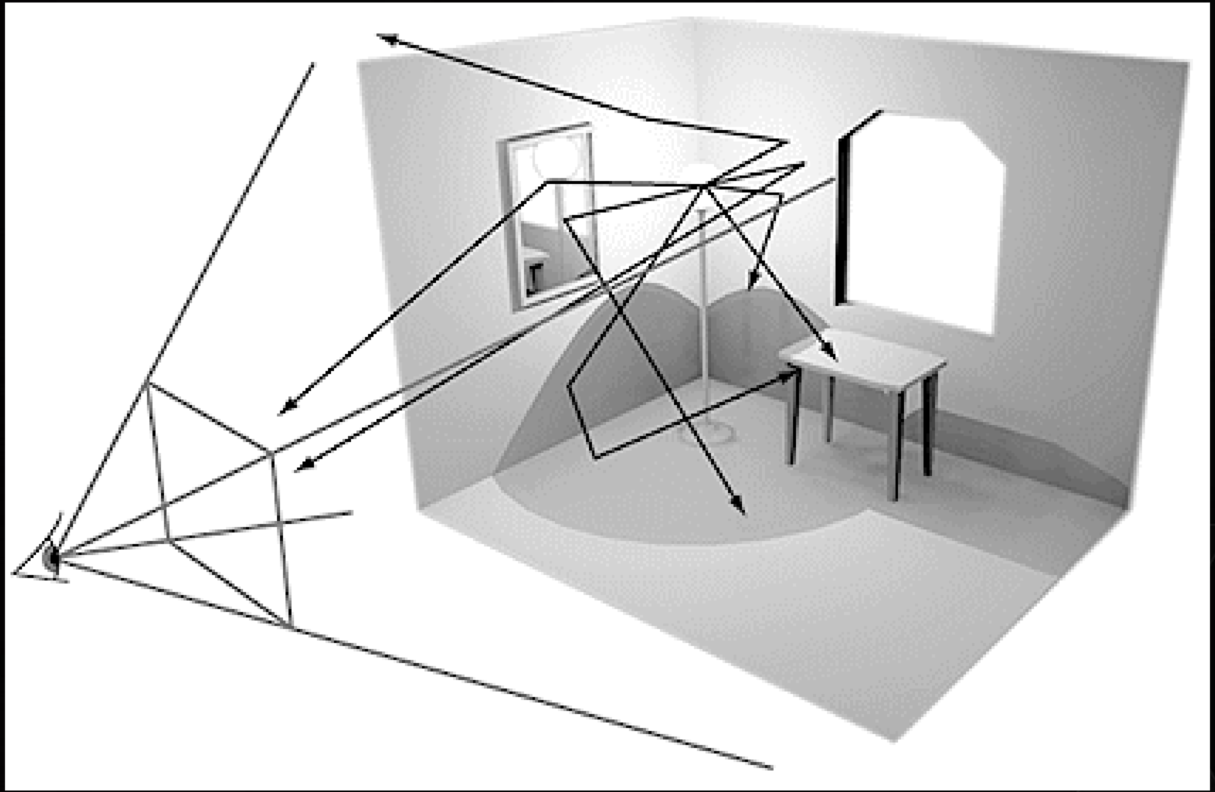
WHY COMPUTING GI IS HARD

1 of 5



A photon can take one of many paths between the light and the observer.

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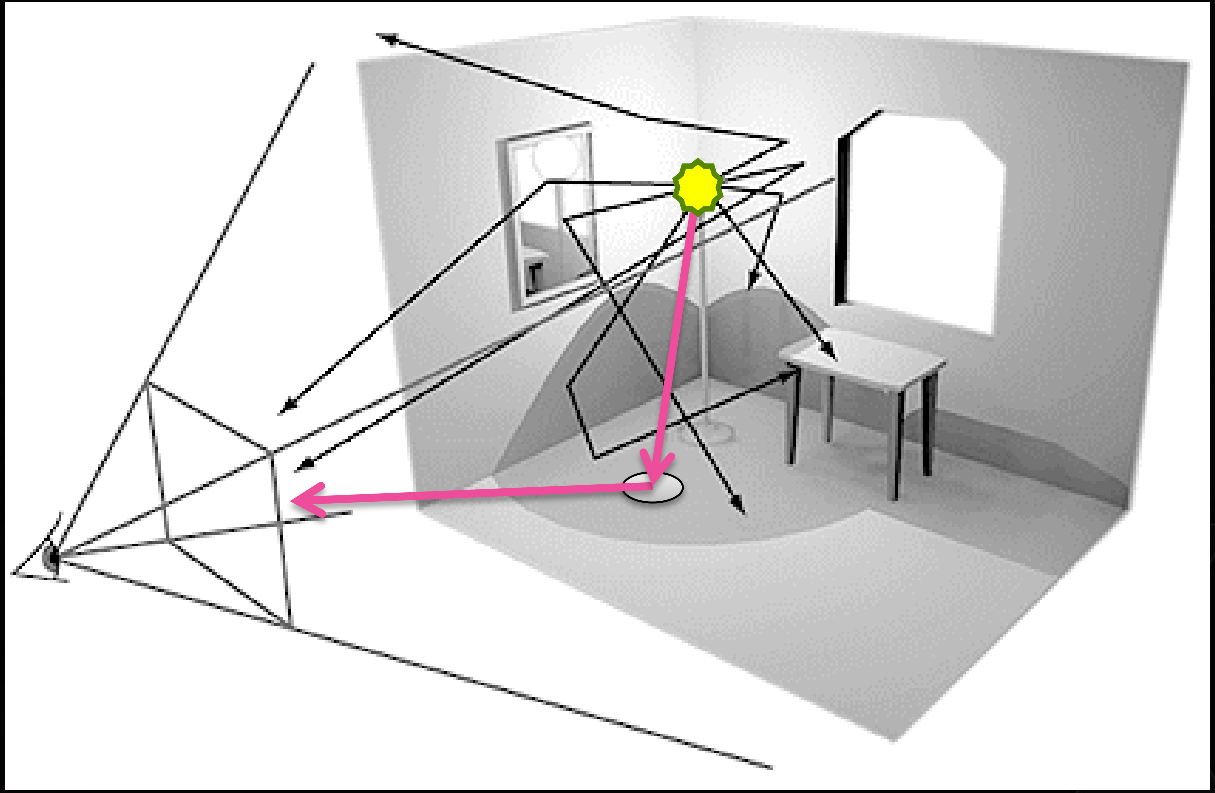
WHY COMPUTING GI IS HARD

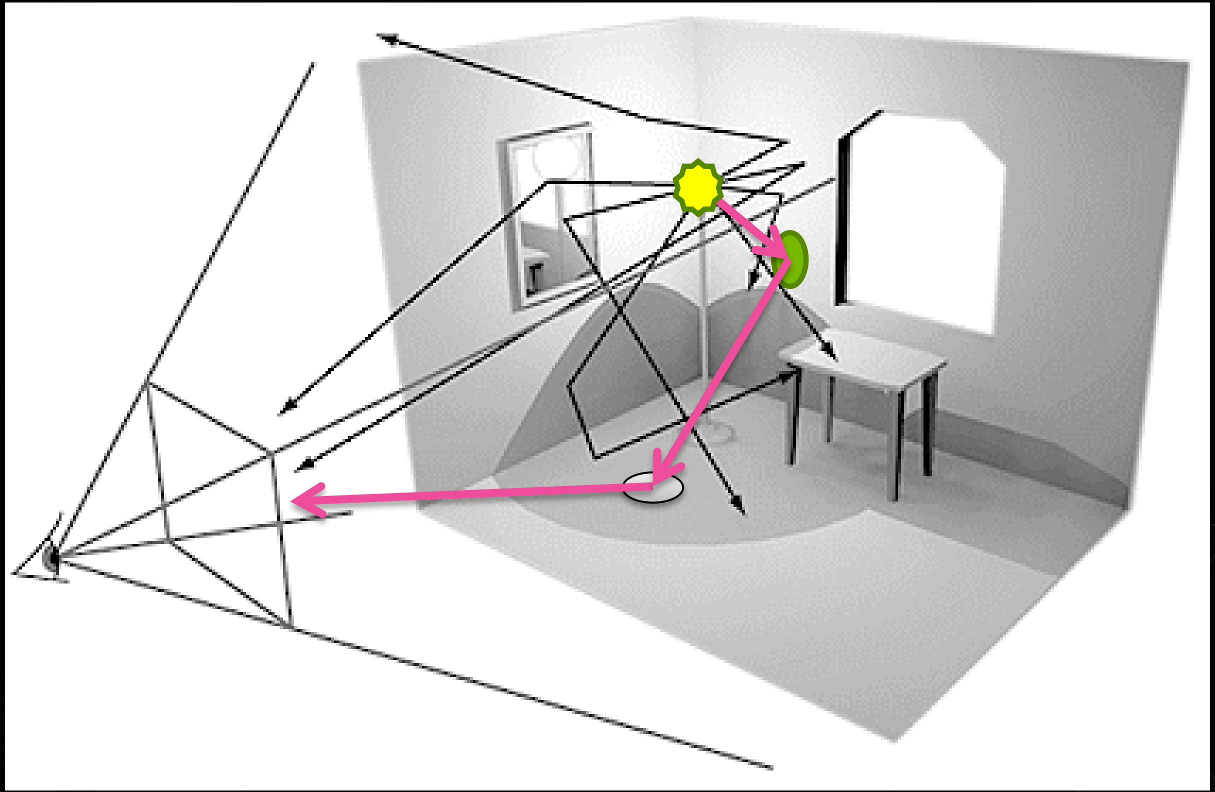
2 of 5



Direct illumination – a single possible path for every visible point on a surface.

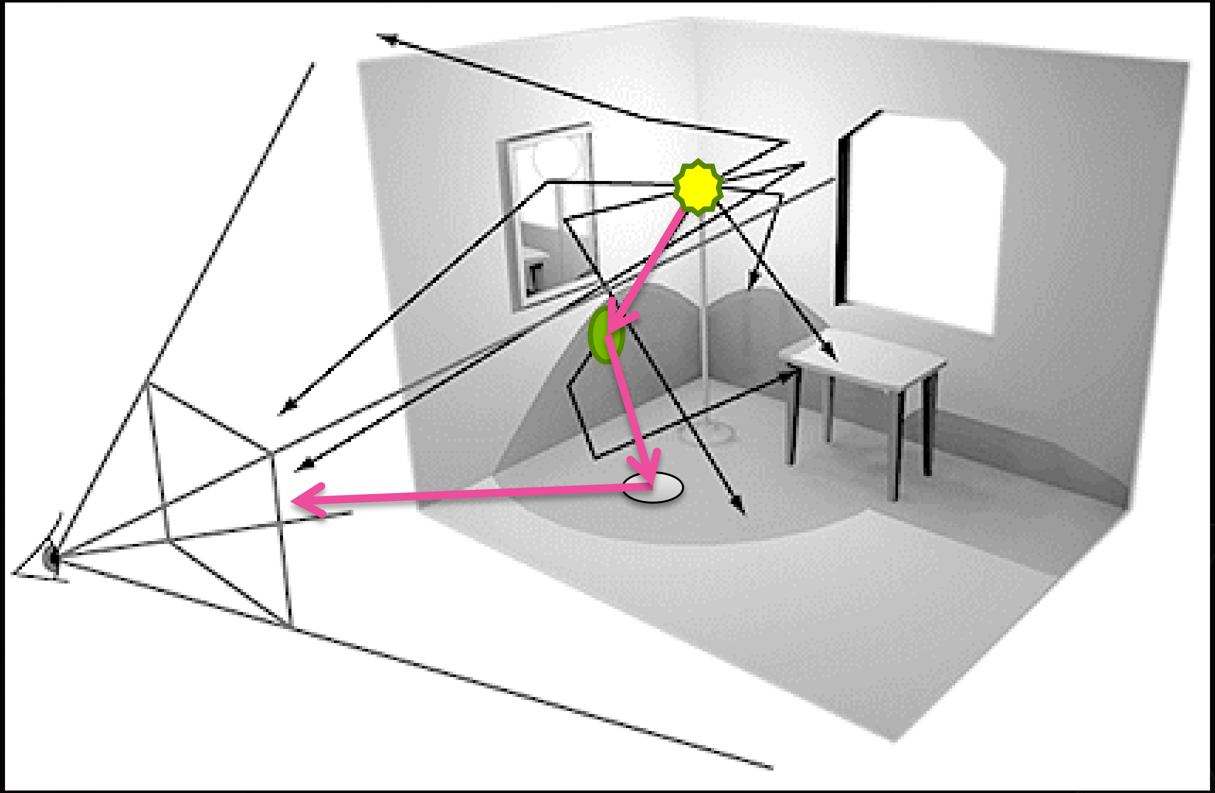
WHY COMPUTING GI IS HARD

3 of 5



One bounce indirect illumination for the same point – one of the many paths…

WHY COMPUTING GI IS HARD



Another path for the same visible point.

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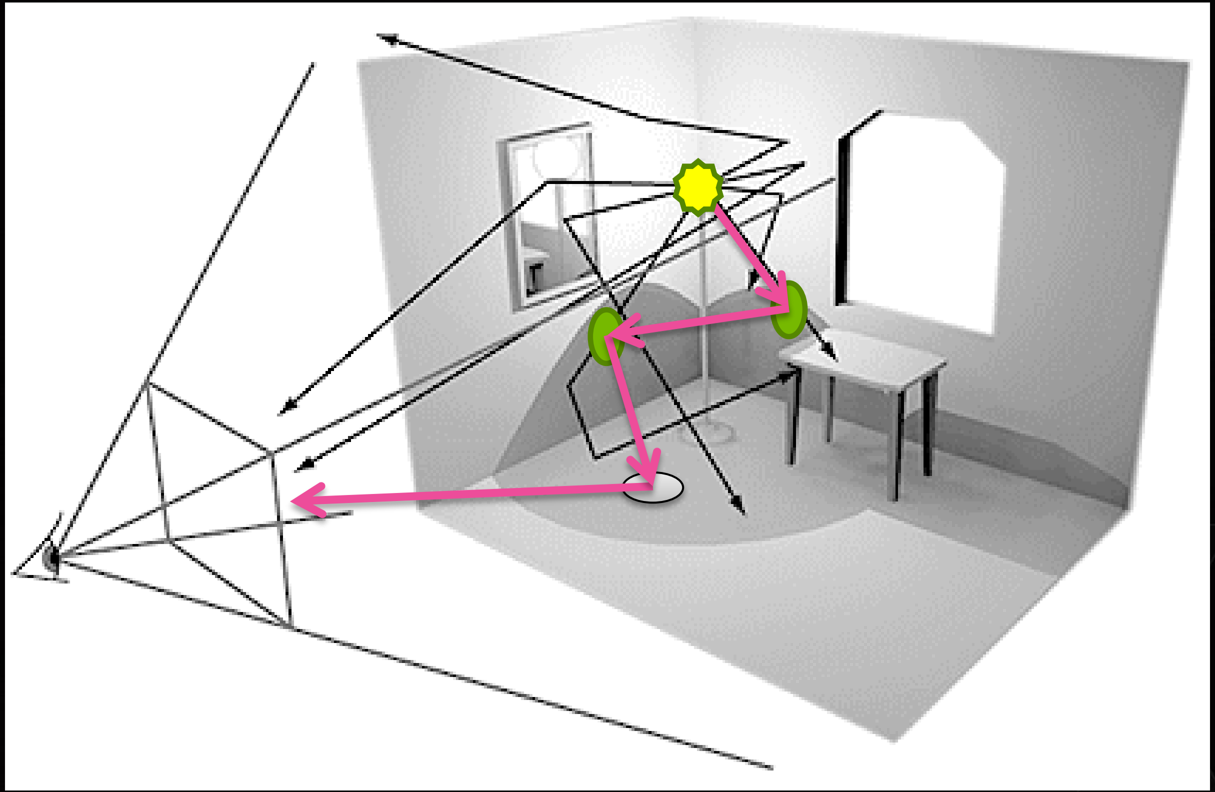
WHY COMPUTING GI IS HARD

5 of 5



This path is also possible – it’s two bounce indirect illumination.

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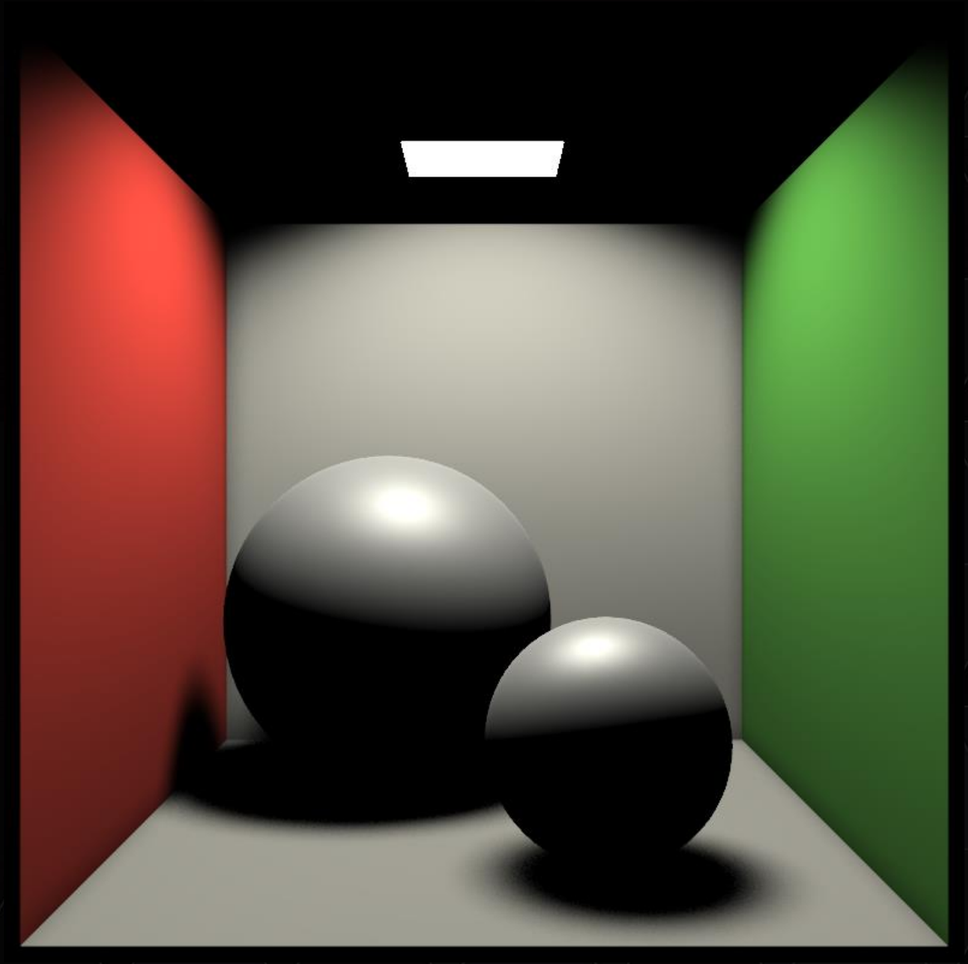
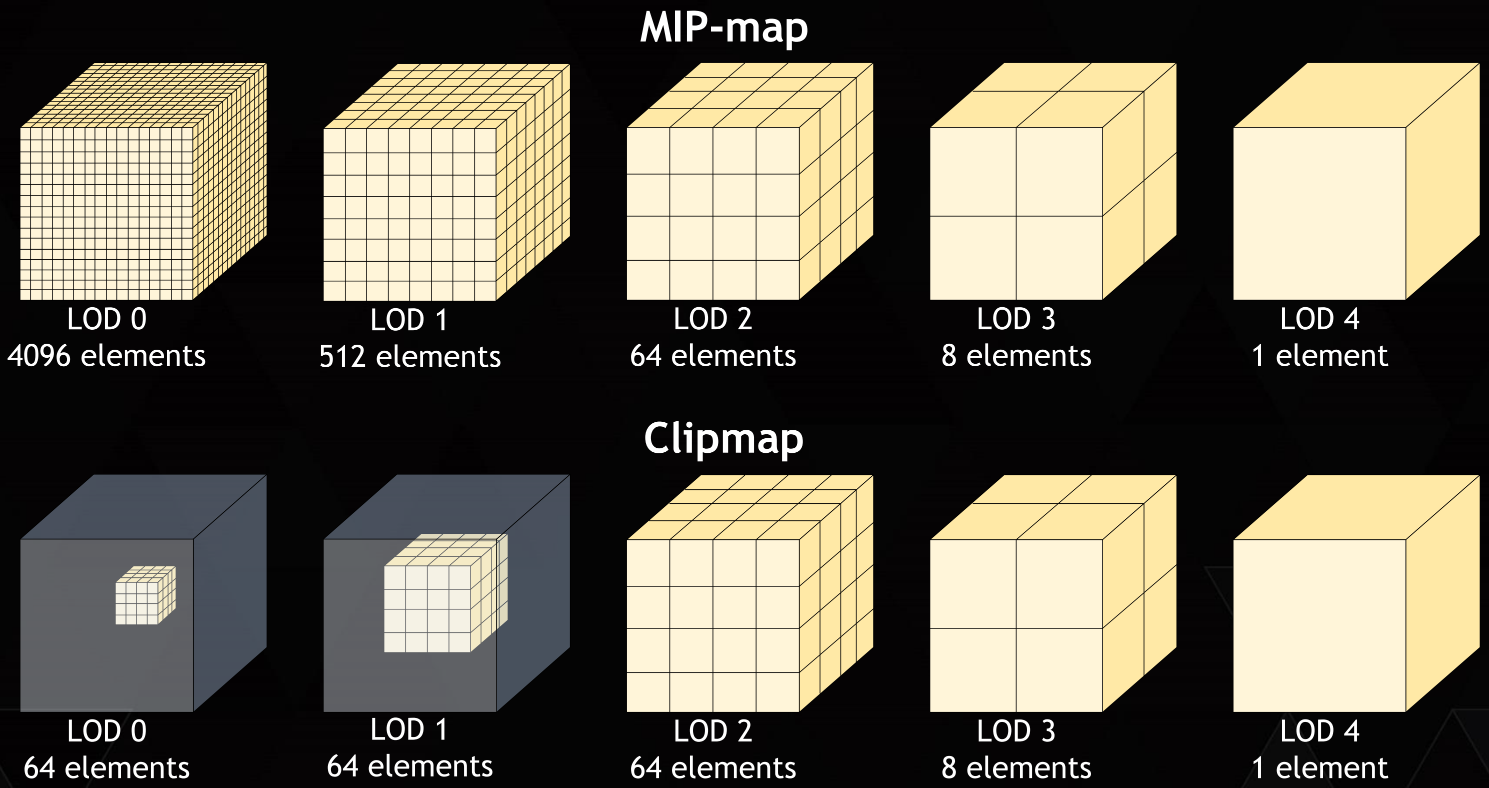
VXGI ALGORITHM OVERVIEW

- Step 1: Opacity Voxelization
- Step 2: Emittance Voxelization
- Step 3: Cone Tracing

- Use Cornell Box as an example



VOXEL STORAGE: 3D CLIP-MAP



MIP-map

LOD 0
4096 elements

LOD 1
512 elements

LOD 2
64 elements

LOD 3
8 elements

LOD 4
1 element

Clipmap

LOD 0
64 elements

LOD 1
64 elements

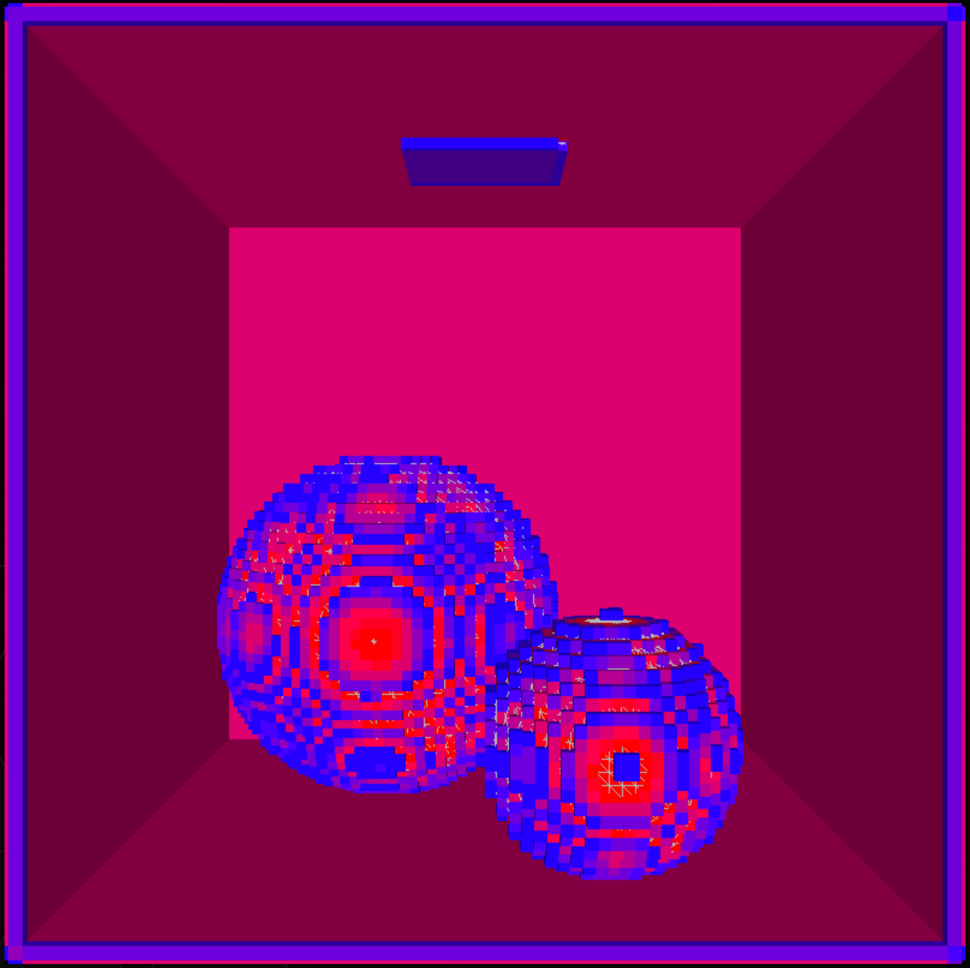
LOD 2
64 elements

LOD 3
8 elements

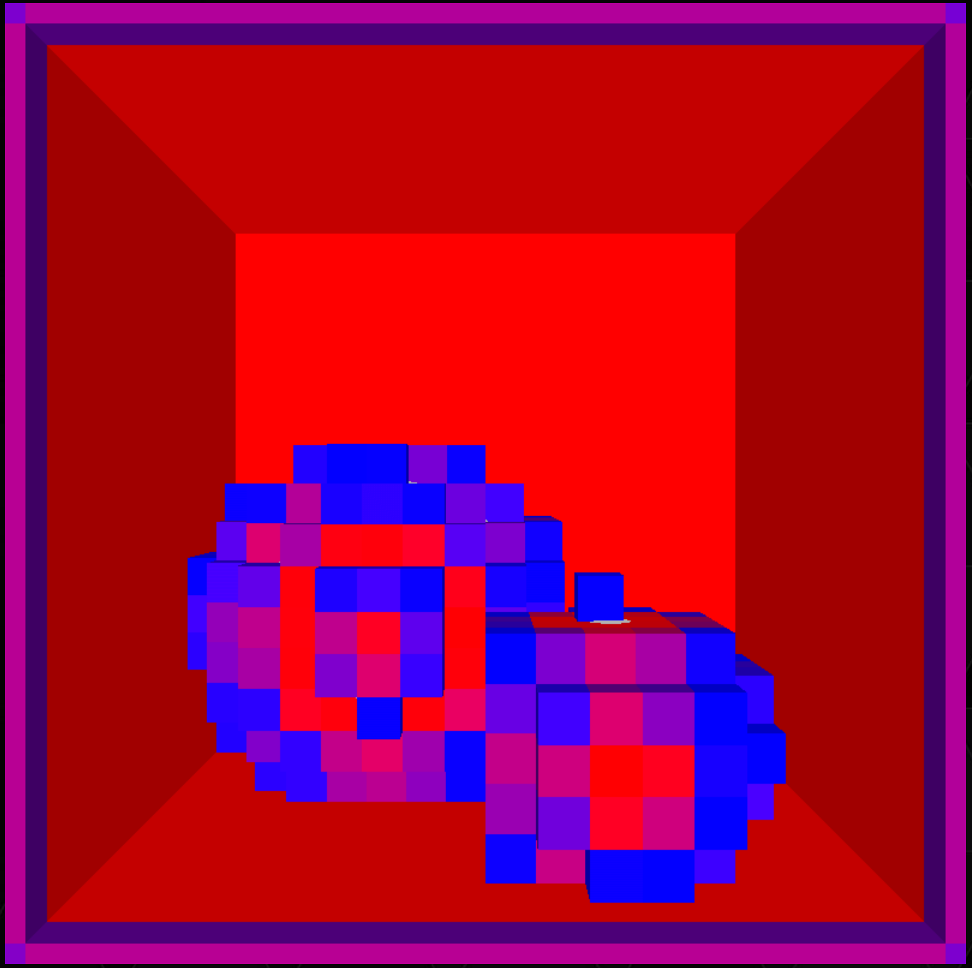
LOD 4
1 element

- Hardware addressing => much faster than SVO
- Scalable: $(32\ldots256)^3$ with 3…5 LODs, 16…56 bytes per voxel
  => 1.5 MB … 4.5 GB VRAM

OPACITY VOXELIZATION



Finest level of detail (LOD 0)



4x coarser representation (LOD 2)

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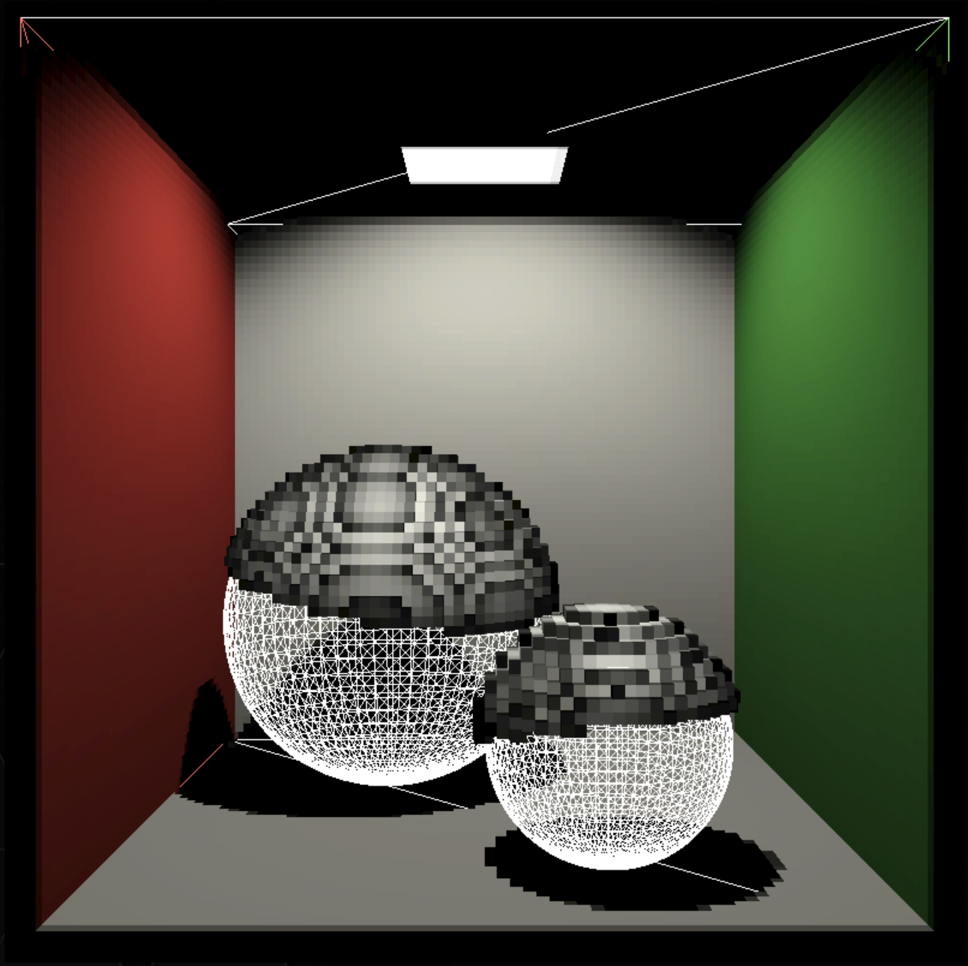
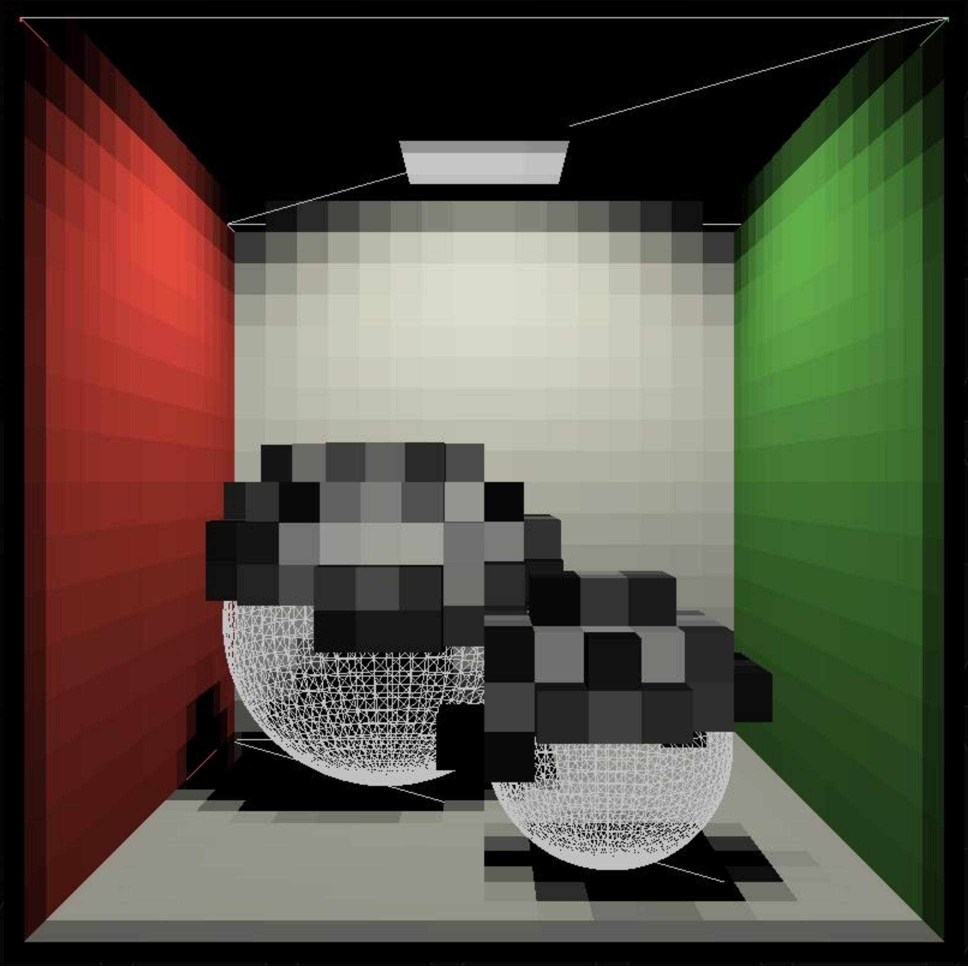
EMITTANCE VOXELIZATION



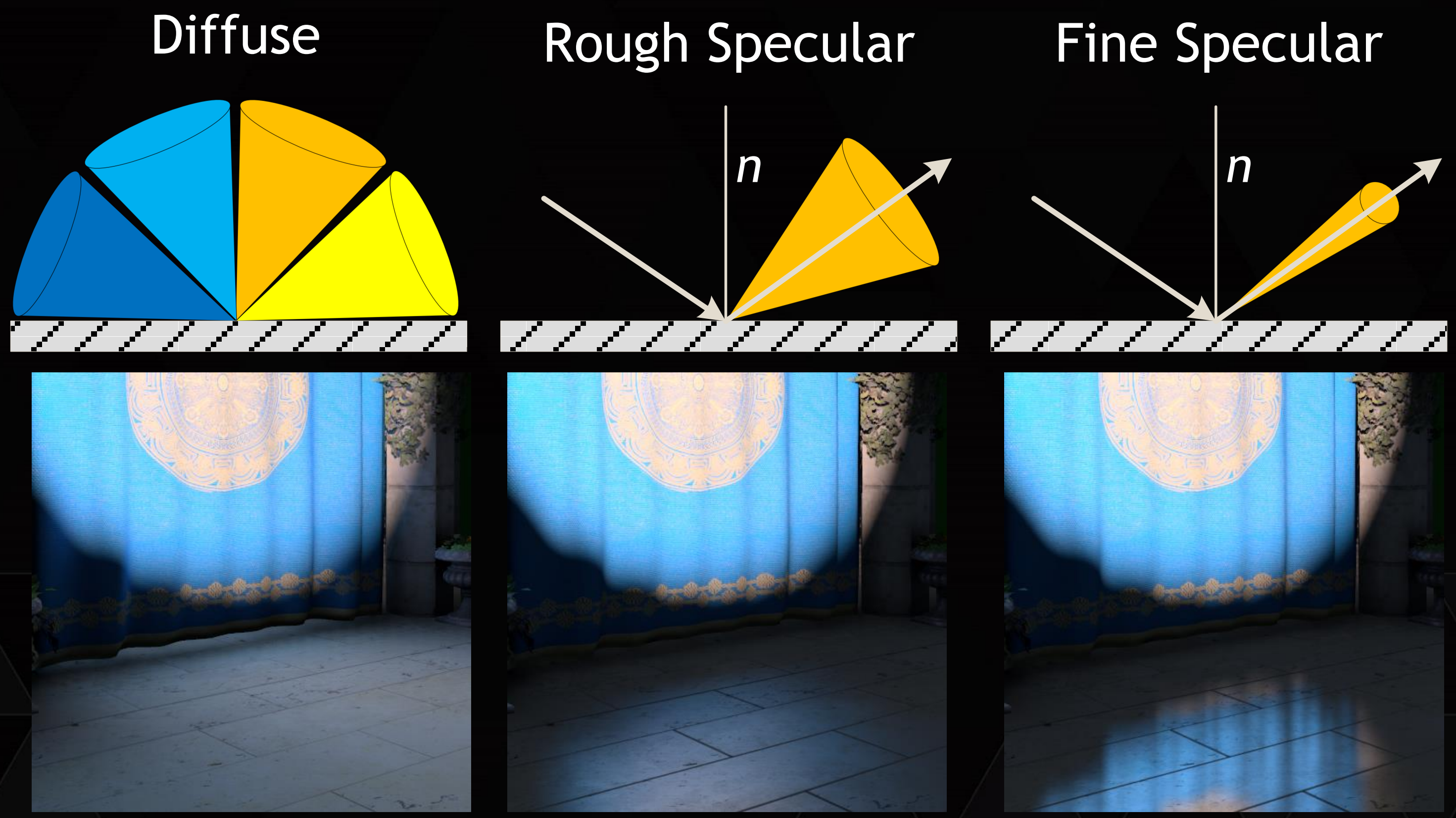
Finest level of detail (LOD 0)



4x coarser representation (LOD 2)

CONE TRACING

$$Irradiance = \sum Emittance_i \left(\frac{ConeFactor}{SampleSize}\right)^2 \prod_0^i (1 - Opacity_k)^{tStep \times OpacityCorrectionFactor}$$



Diffuse

Rough Specular

Fine Specular

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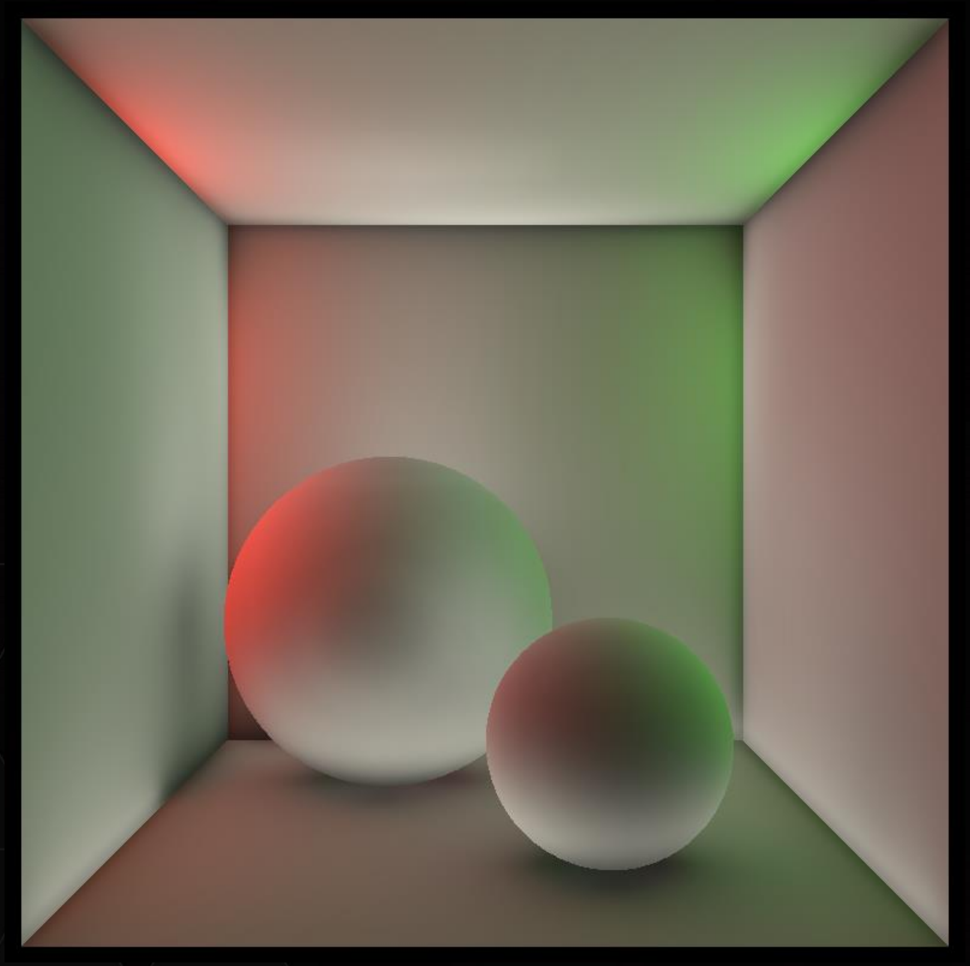
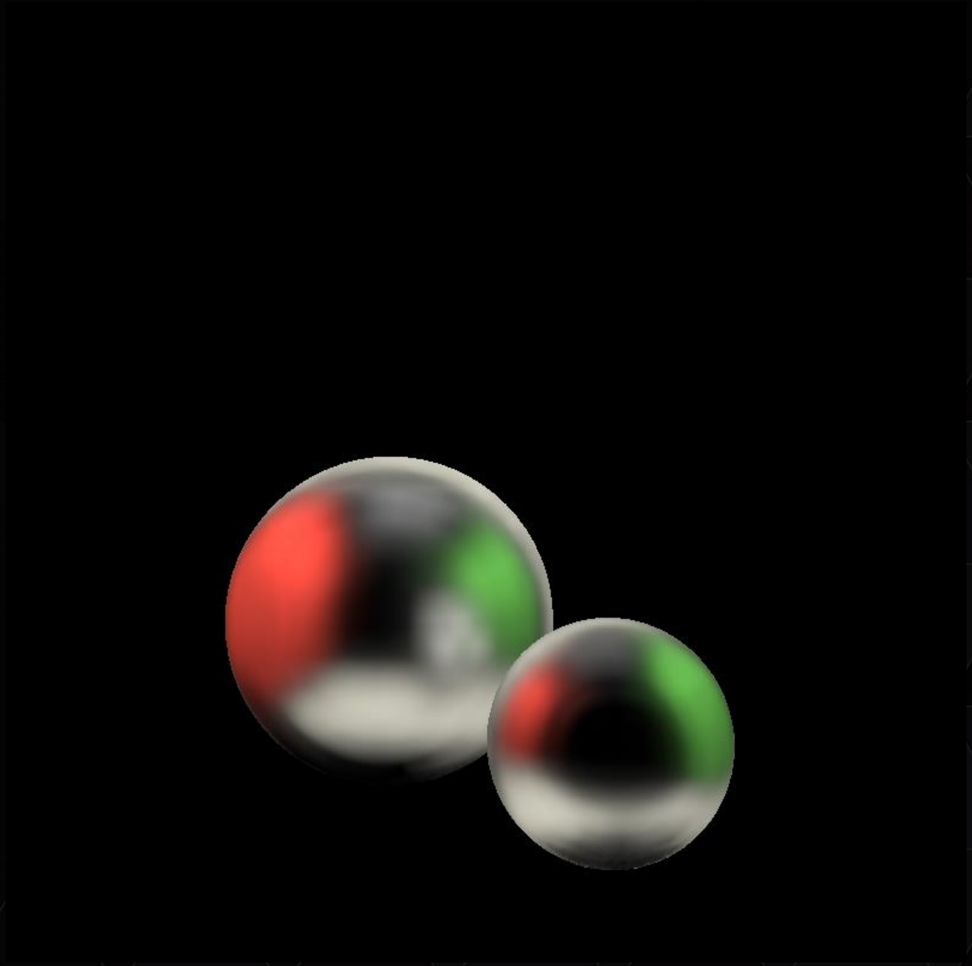
RESULTS OF CONE TRACING

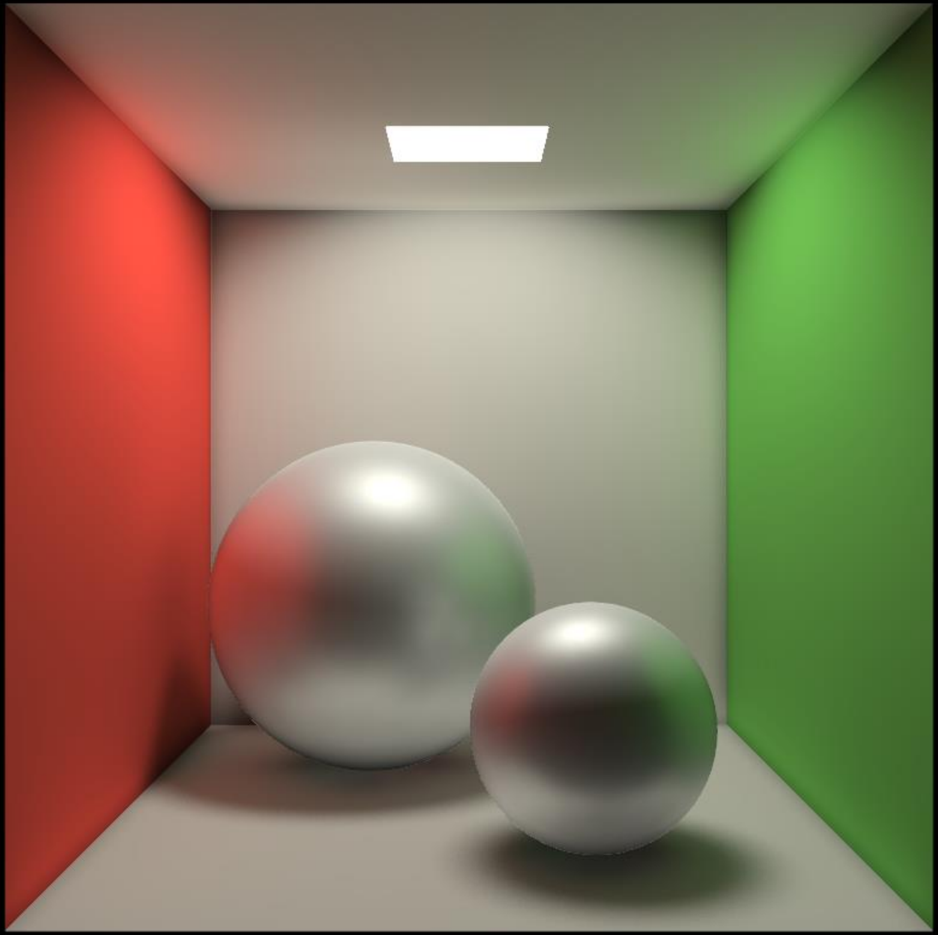


Indirect diffuse lighting

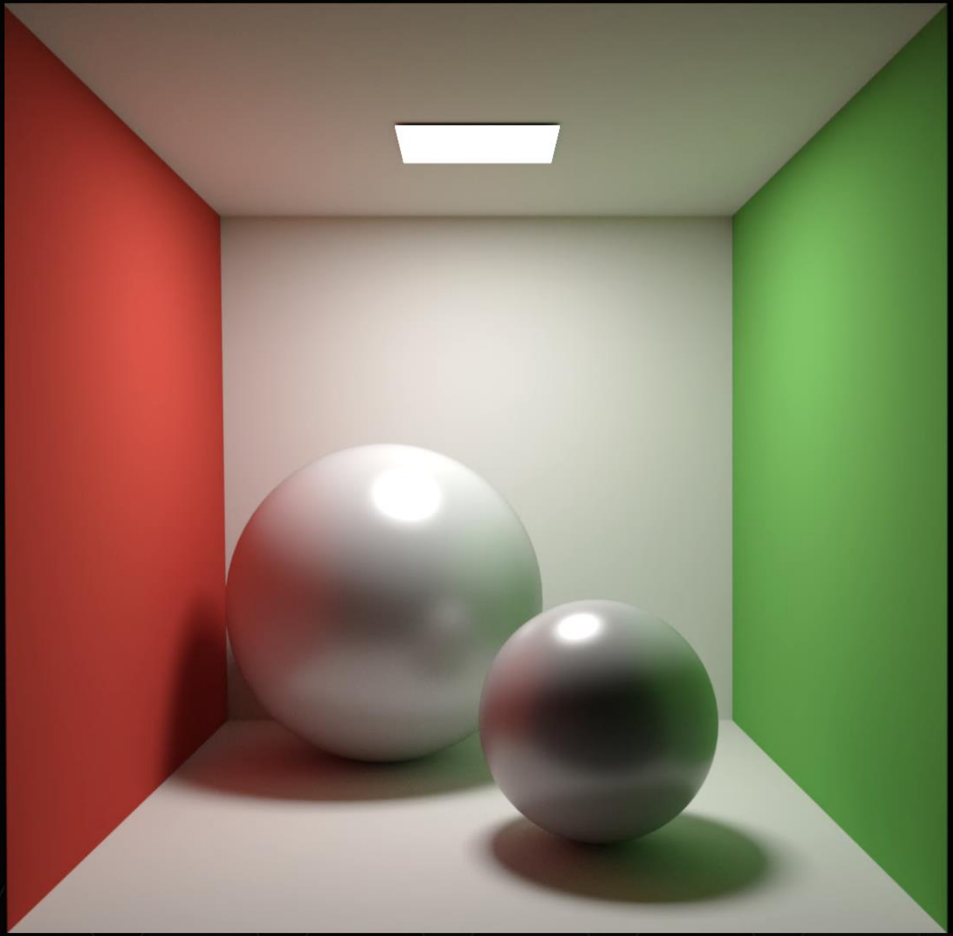


Indirect specular reflections

FINAL RESULT



Direct and VXGI Indirect combined



Reference rendering with NVIDIA Iray

DEMO: SAN MIGUEL

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VXGI INTEGRATION OVERVIEW

1. Implement or copy and adapt the RHI backend
2. Initialize a GI object
3. Test voxelization and debug visualization
4. Implement app specific voxelization
5. Compute indirect illumination using a G-buffer

STEP 1. RHI BACKEND

- VXGI API is based on C++ classes
- VXGI works with the rendering APIs through RHI abstraction
  - RHI = Rendering Hardware Interface
  - Supports Direct3D 11 now
  - Will support OpenGL 4.4 soon
- The application implements the RHI backend
  - We provide a reference implementation of the DX11 backend
- The interface is stateless, consists of methods like these:
  - TextureHandle createTexture(const TextureDesc& d, const void* data);
  - void writeConstantBuffer(ConstantBufferHandle b, const void* data, size_t dataSize);
  - void dispatchCompute(const DispatchState& state, const Vector3u& groupCount);

STEP 2 & 3. INITIALIZATION

- Call VFX_VXGI_CreateGIObject(const GIParameters& params, …) supplying:
  - Voxelization parameters: clipmap geometry, quality options
  - Reference to the RHI backend
  - Custom memory allocator, error callback function, perf monitor interface

- Test voxelization using a built-in cube scene:

```
pGI->prepareForOpacityVoxelization(…)
pGI->voxelizeTestScene(position, size)
pGI->prepareForEmittanceVoxelization()
pGI->voxelizeTestScene(position, size)
pGI->finalizeVoxelization()
pGI->renderDebug(mode, viewMatrix, …)
```

STEP 4. VOXELIZATION

- Create the voxelization shaders once:
  - pGI->createVoxelizationGeometryShaderFromVS(…const void* binary…);
  - pGI->createVoxelizationPixelShader(…const char* source…);
- Voxelize scene geometry on every frame:
  - pGI->prepareForOpacityVoxelization(const UpdateVoxelizationParameters& params, …);

    ```
    VXGI::MaterialInfo info = /* your code describing the material */;
    VXGI::DrawCallState state;
    pGI->getVoxelizationState(info, state);
    pRHIBackend->applyState(state);
    pD3DContext->DrawIndexed(…);
    pD3DContext->DrawIndexed(…);
    ```
  - pGI->prepareForEmittanceVoxelization(…);

    Repeat the same sequence…
  - pGI->finalizeVoxelization();

STEP 5. TRACING

- Create a tracer once:
  - pGI->createNewTracer(&pTracer);

- Call pTracer->setInputBuffers(…) on every frame
  - gbufferDepth
  - gbufferNormal with roughness in .a
  - gbufferGeoNormal – a smoother normal channel, optional
  - environmentMap – a far-away environment map, optional

- Compute indirect illumination channels:
  - computeDiffuseChannel(const DiffuseTracingParameters& params…)
  - computeSpecularChannel(const SpecularTracingParameters& params…)

- Composite indirect lighting with your direct lighting

VOXELIZATION SHADERS

- Voxelization PS is combined from your code and our code (in HLSL)

- Your part of the shader evaluates material parameters
  - Generate any attributes in the VS and we'll get them through the GS
  - Bind any textures or other resources in the PS, just let us know where
- Your part of the shader computes emitted and reflected radiance
  - Use any lighting models, sample shadow maps, whatever
  - You can trace opacity cones when voxelizing for emittance
- Our part of the shader takes care of updating the voxel data

```
void main(MyPSInput IN)
{
    float3 color = ComputeReflectedColor(IN);
    VXGI::StoreVoxelizationData(IN.vxgiData, color);
};
```

CONE TRACING SHADERS

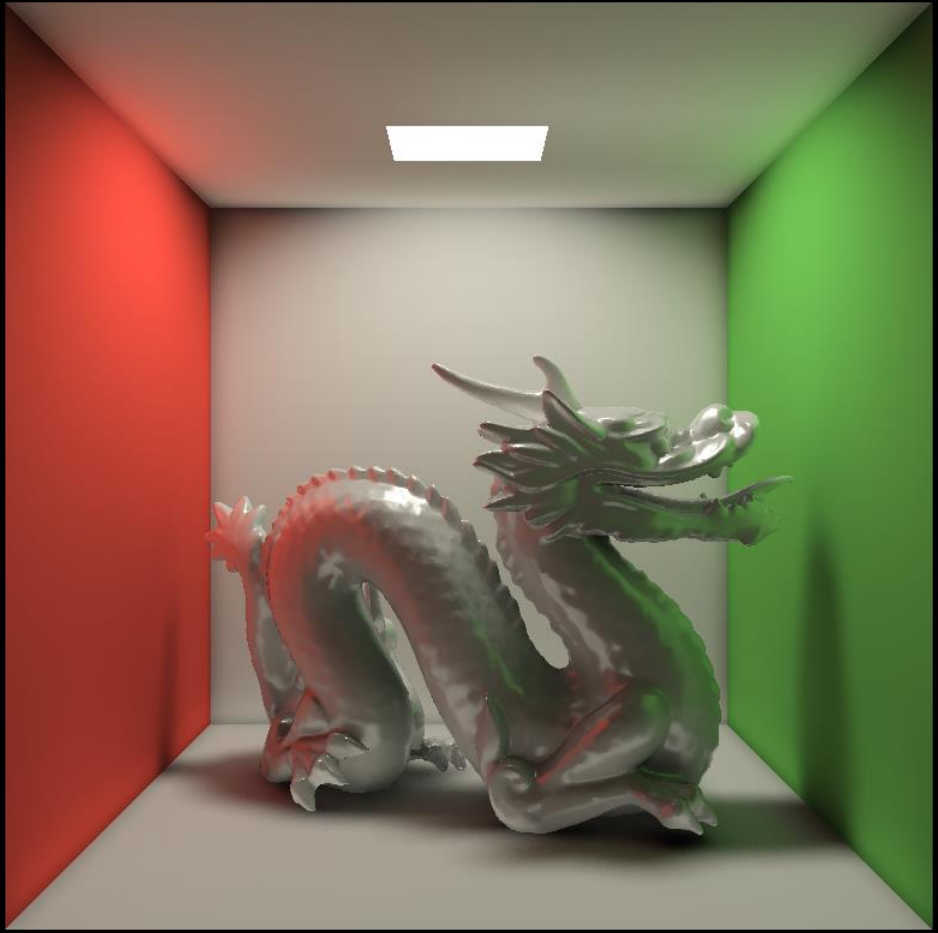
- You can create arbitrary shaders that call our cone tracing function

```
VXGI::ConeTracingArguments args = VXGI::DefaultConeTracingArguments();
    args.coneFactor = …;
    args.direction = …;
    args.firstSamplePosition = …;
VXGI::ConeTracingResults cone = VXGI::TraceCone(args);
```

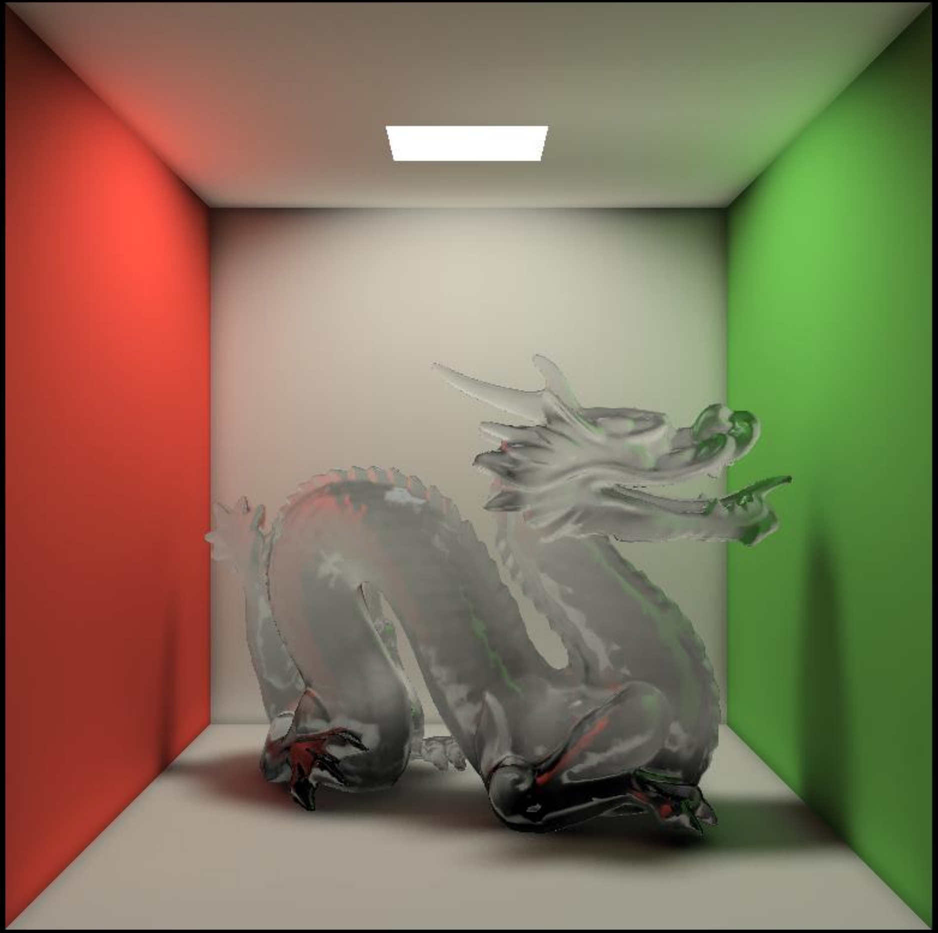
Use cone.**irradiance**, cone.ambient, cone.finalOpacity

- Use it for…
  - Advanced material effects: **refraction**, anisotropic reflection
  - Building **light maps** or reflection probes quickly
  - Implementing other diffuse illumination algorithms using our data

REFRACTIVE MATERIAL EXAMPLE



Regular VXGI diffuse + specular



Custom refraction + reflection material

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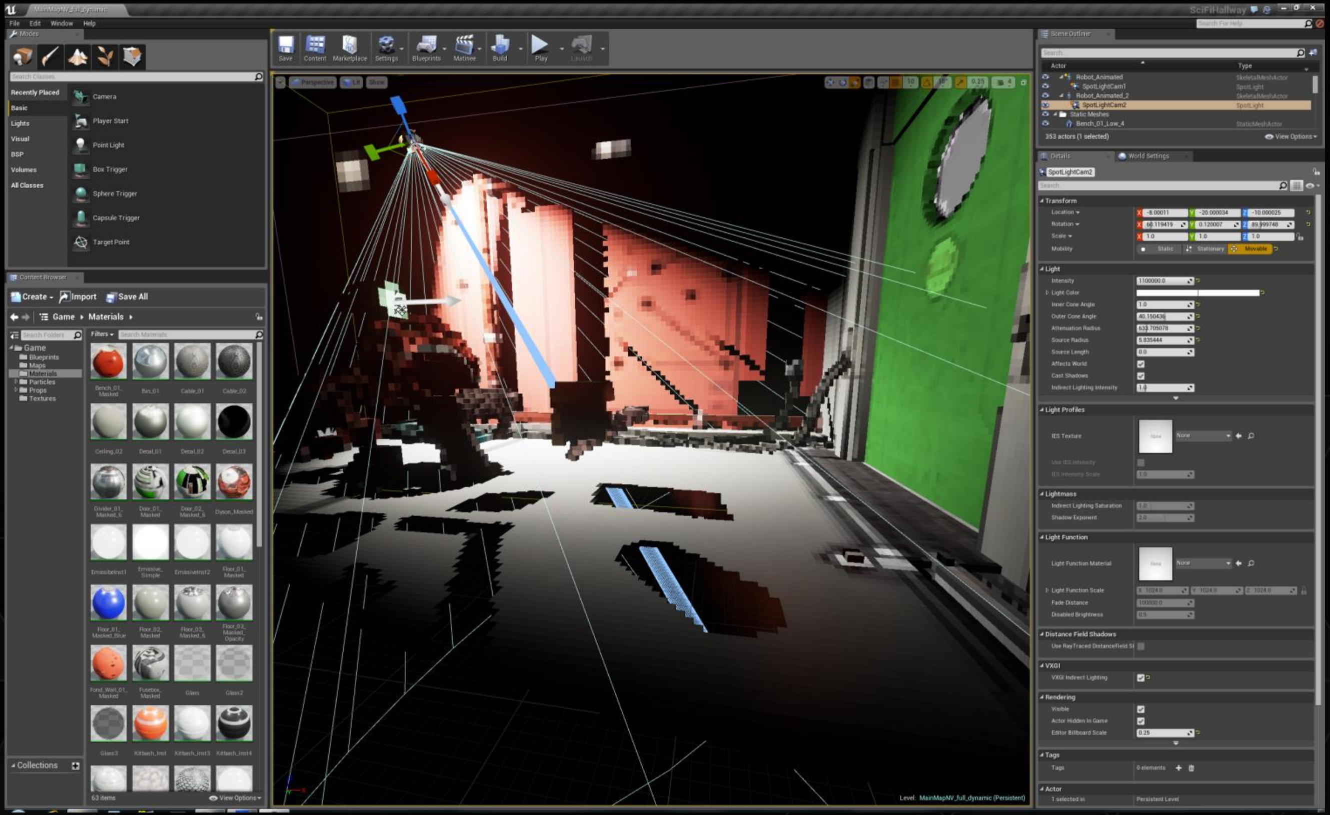
VXGI IN UE4

- https://github.com/NvPhysX/UnrealEngine
  - VXGI branch, requires a UE4 account to access



Actor	Type
Robot_Animated	SkeletalMeshActor
SpotLightCam1	SpotLight
Robot_Animated_2	SkeletalMeshActor
SpotLightCam2	SpotLight
Static Meshes	
Bench_01_Low_4	StaticMeshActor

353 actors (1 selected)

SpotLightCam2

Transform

- Location: X -8.00011, Y -20.000034, Z -10.000025
- Rotation: X 60.119419, Y 0.120007, Z 89.999748
- Scale: X 1.0, Y 1.0, Z 1.0
- Mobility: Static, Stationary, Movable

Light

- Intensity: 1100000.0
- Light Color
- Inner Cone Angle: 1.0
- Outer Cone Angle: 40.150436
- Attenuation Radius: 633.705078
- Source Radius: 5.835444
- Source Length: 0.0
- Affects World: ☑
- Cast Shadows: ☑
- Indirect Lighting Intensity: 1.0

Light Profiles

- IES Texture: None
- Use IES Intensity: □
- IES Intensity Scale: 1.0

Lightmass

- Indirect Lighting Saturation: 1.0
- Shadow Exponent: 2.0

Light Function

- Light Function Material: None
- Light Function Scale: X 1024.0, Y 1024.0, Z 1024.0
- Fade Distance: 100000.0
- Disabled Brightness: 0.5

Distance Field Shadows

- Use RayTraced DistanceField Sl: □

VXGI

- VXGI Indirect Lighting: ☑

Rendering

- Visible: ☑
- Actor Hidden In Game: ☑
- Editor Billboard Scale: 0.25

Tags

- Tags: 0 elements

Actor

- 1 selected in: Persistent Level

Level: MainMapNV_full_dynamic (Persistent)

63 items

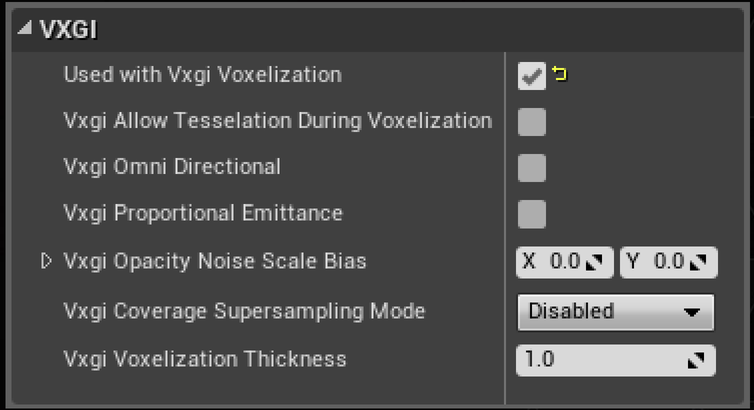
ENABLING VXGI IN A MAP

- Materials: check **Used With VXGI Voxelization**
- Lights: check **VXGI Indirect Lighting**

- **r.VXGIDebugMode 2** : opacity visualization
- **r.VXGIDebugMode 3** : emittance visualization
- **r.VXGIDebugMode 0** : regular shading

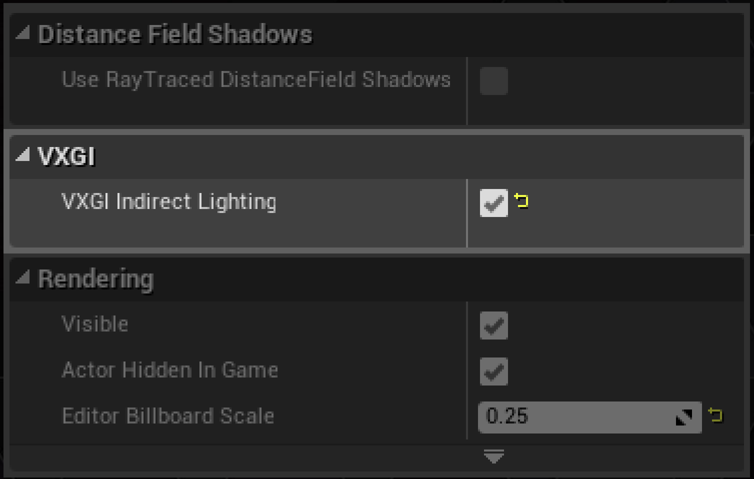
- **r.VXGI.DiffuseTracingEnable 1**
  - VXGI Diffuse is added to the UE HDR lighting

- **r.VXGI.SpecularTracingEnable 1**
  - VXGI Specular replaces UE SSR



VXGI

Used with Vxgi Voxelization	☑
Vxgi Allow Tesselation During Voxelization	□
Vxgi Omni Directional	□
Vxgi Proportional Emittance	□
Vxgi Opacity Noise Scale Bias	X 0.0 Y 0.0
Vxgi Coverage Supersampling Mode	Disabled
Vxgi Voxelization Thickness	1.0



Distance Field Shadows

Use RayTraced DistanceField Shadows	□

VXGI

VXGI Indirect Lighting	☑

Rendering

Visible	☑
Actor Hidden In Game	☑
Editor Billboard Scale	0.25

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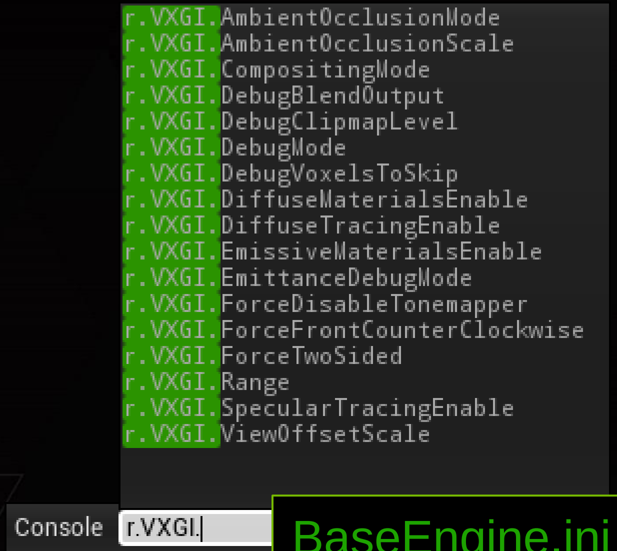
OTHER VXGI PARAMETERS

Console Variables



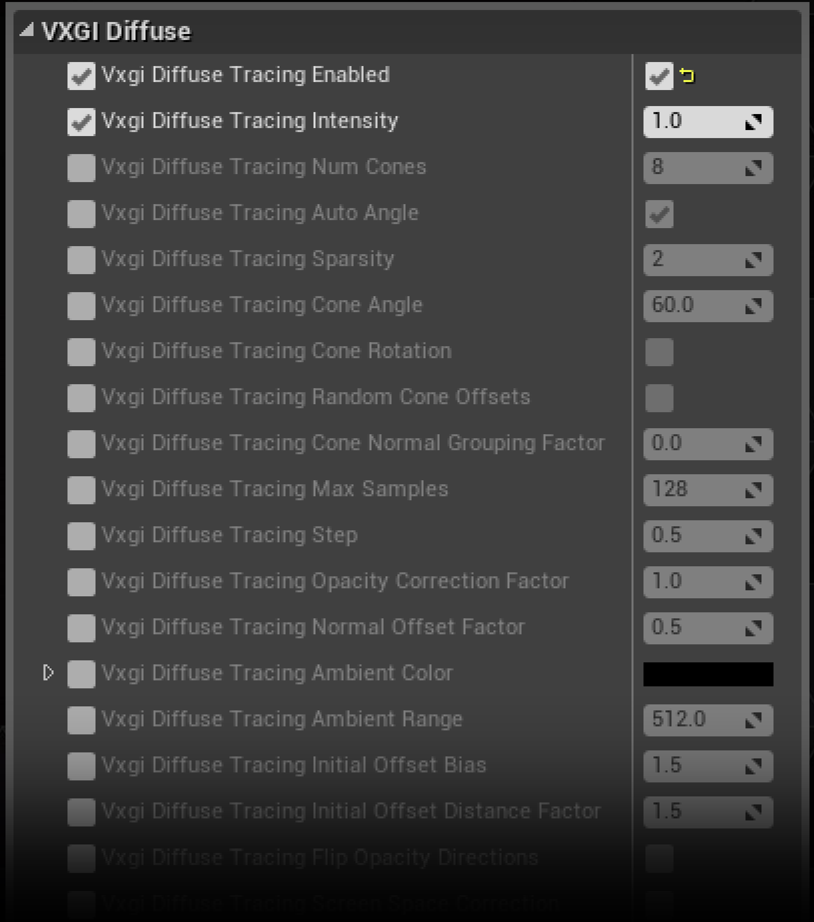
```
r.VXGI.AmbientOcclusionMode
r.VXGI.AmbientOcclusionScale
r.VXGI.CompositingMode
r.VXGI.DebugBlendOutput
r.VXGI.DebugClipmapLevel
r.VXGI.DebugMode
r.VXGI.DebugVoxelsToSkip
r.VXGI.DiffuseMaterialsEnable
r.VXGI.DiffuseTracingEnable
r.VXGI.EmissiveMaterialsEnable
r.VXGI.EmittanceDebugMode
r.VXGI.ForceDisableTonemapper
r.VXGI.ForceFrontCounterClockwise
r.VXGI.ForceTwoSided
r.VXGI.Range
r.VXGI.SpecularTracingEnable
r.VXGI.ViewOffsetScale
```

Console r.VXGI.

BaseEngine.ini

```
VxgiMapSize=128
VxgiStackLevels=5
bVxgiOpacityDirectionCount6D=true
bVxgiAmbientOcclusionMode=false
bVxgiNvidiaExtensions=true
bVxgiStoreEmittanceInFP16=false
VxgiEmittanceStorageScale=1.0
```

Cone Tracing Parameters in Post-Process Volume

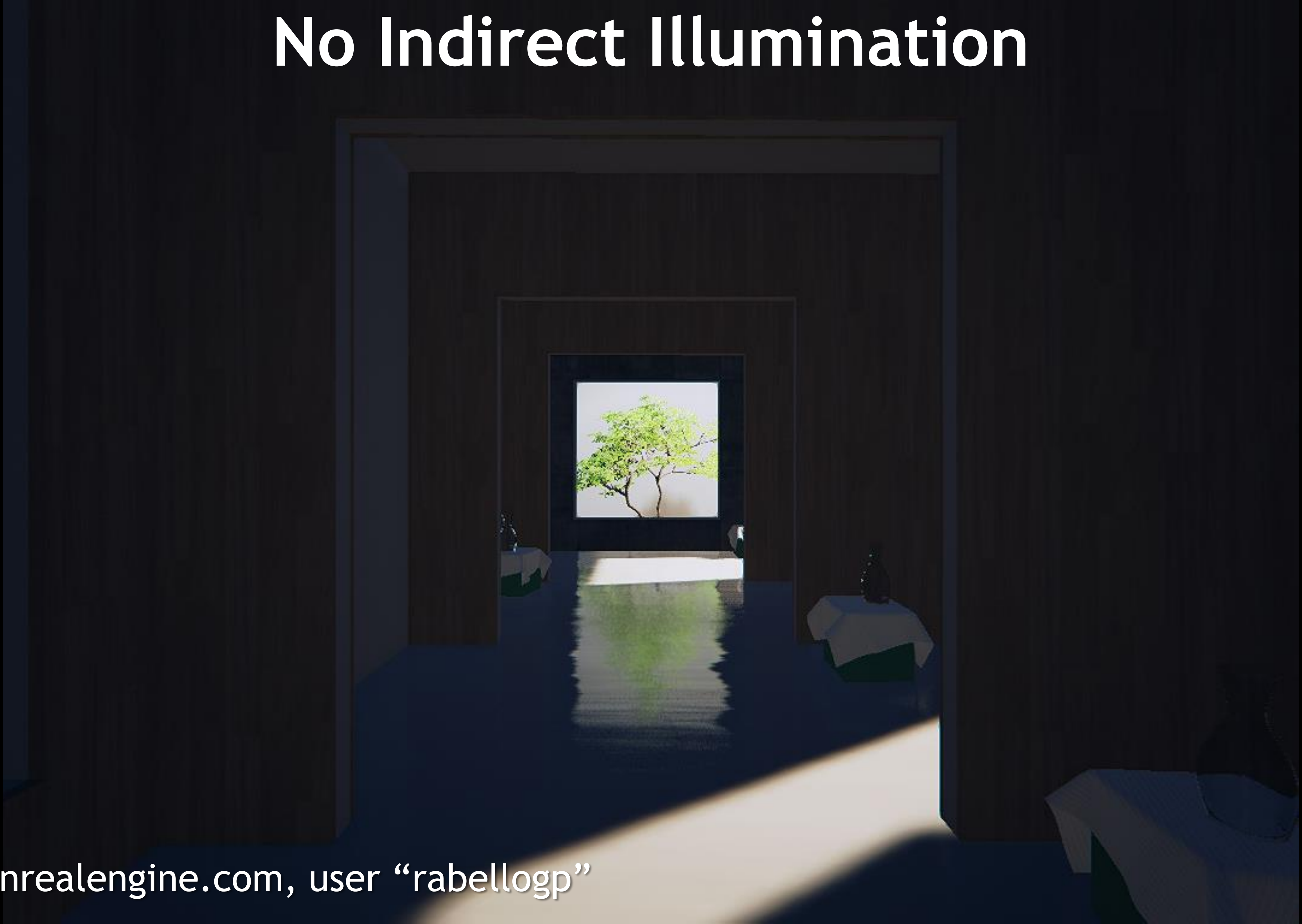


VXGI Diffuse

☑ Vxgi Diffuse Tracing Enabled	☑
☑ Vxgi Diffuse Tracing Intensity	1.0
□ Vxgi Diffuse Tracing Num Cones	8
□ Vxgi Diffuse Tracing Auto Angle	☑
□ Vxgi Diffuse Tracing Sparsity	2
□ Vxgi Diffuse Tracing Cone Angle	60.0
□ Vxgi Diffuse Tracing Cone Rotation	□
□ Vxgi Diffuse Tracing Random Cone Offsets	□
□ Vxgi Diffuse Tracing Cone Normal Grouping Factor	0.0
□ Vxgi Diffuse Tracing Max Samples	128
□ Vxgi Diffuse Tracing Step	0.5
□ Vxgi Diffuse Tracing Opacity Correction Factor	1.0
□ Vxgi Diffuse Tracing Normal Offset Factor	0.5
□ Vxgi Diffuse Tracing Ambient Color	■
□ Vxgi Diffuse Tracing Ambient Range	512.0
□ Vxgi Diffuse Tracing Initial Offset Bias	1.5
□ Vxgi Diffuse Tracing Initial Offset Distance Factor	1.5
□ Vxgi Diffuse Tracing Flip Opacity Directions	□
□ Vxgi Diffuse Tracing Screen Space Correction	□

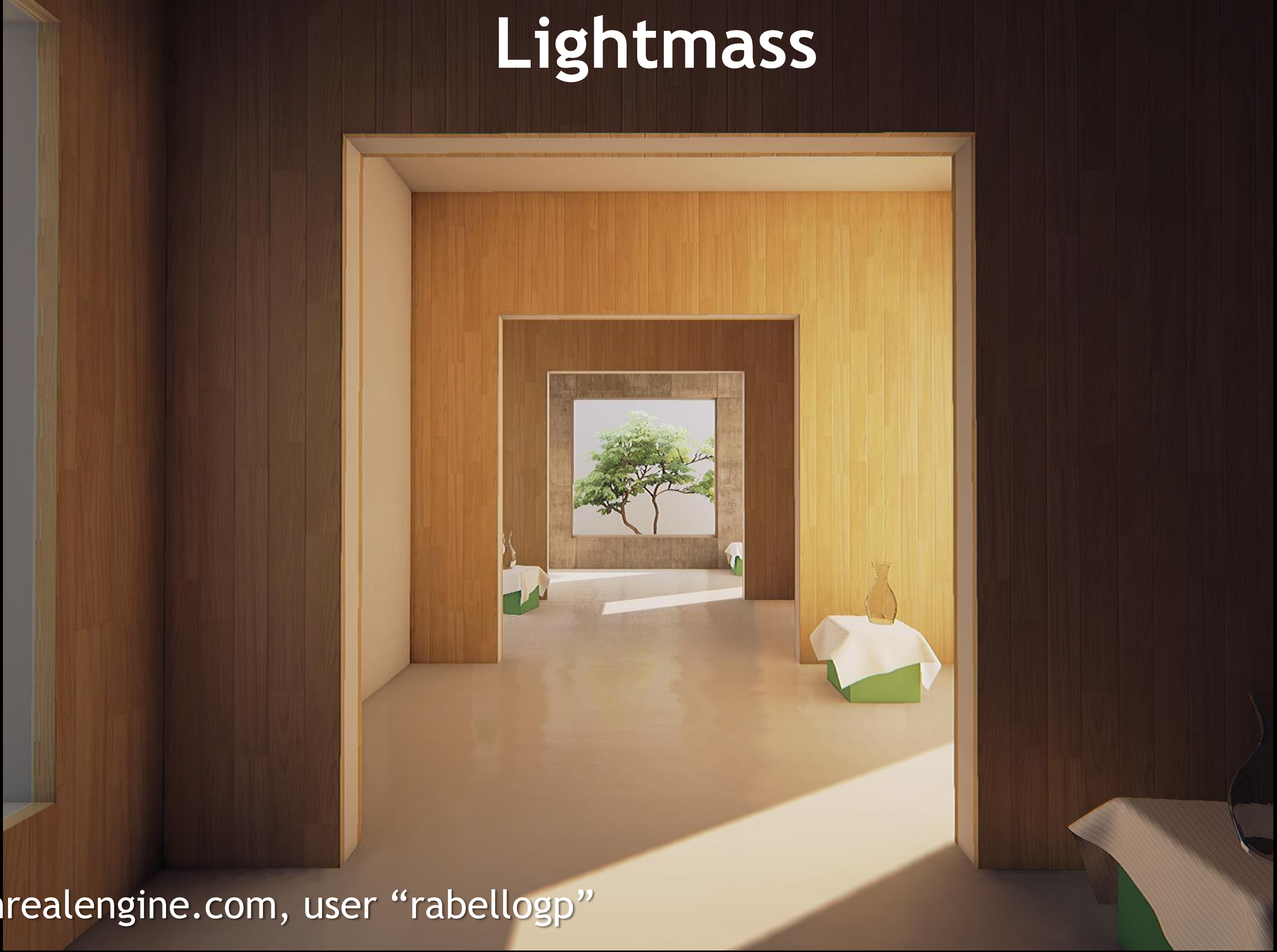
DEMO: UE4 EDITOR

No Indirect Illumination



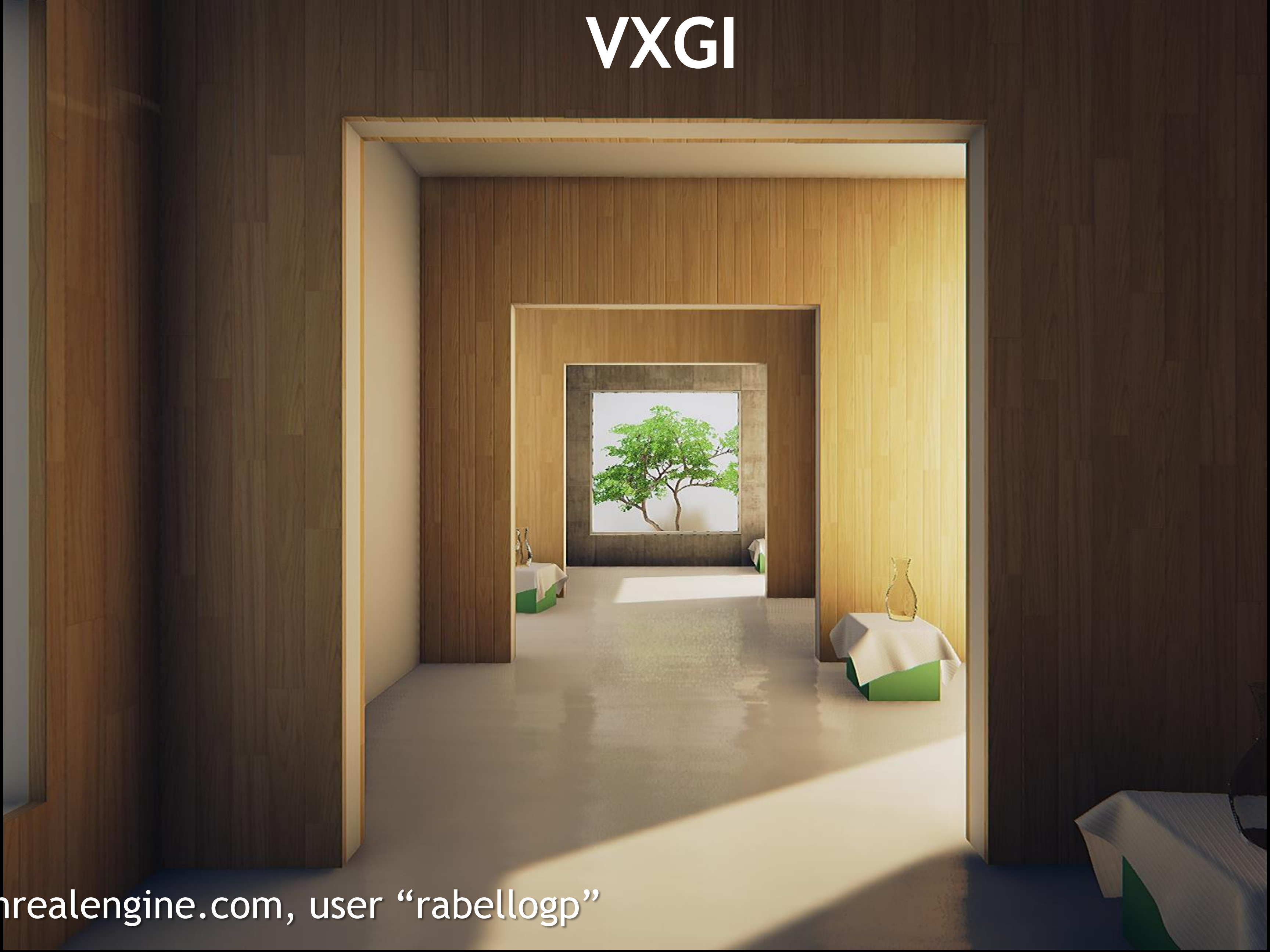
forums.unrealengine.com, user “rabellogp”

Lightmass



forums.unrealengine.com, user “rabellogp”

VXGI



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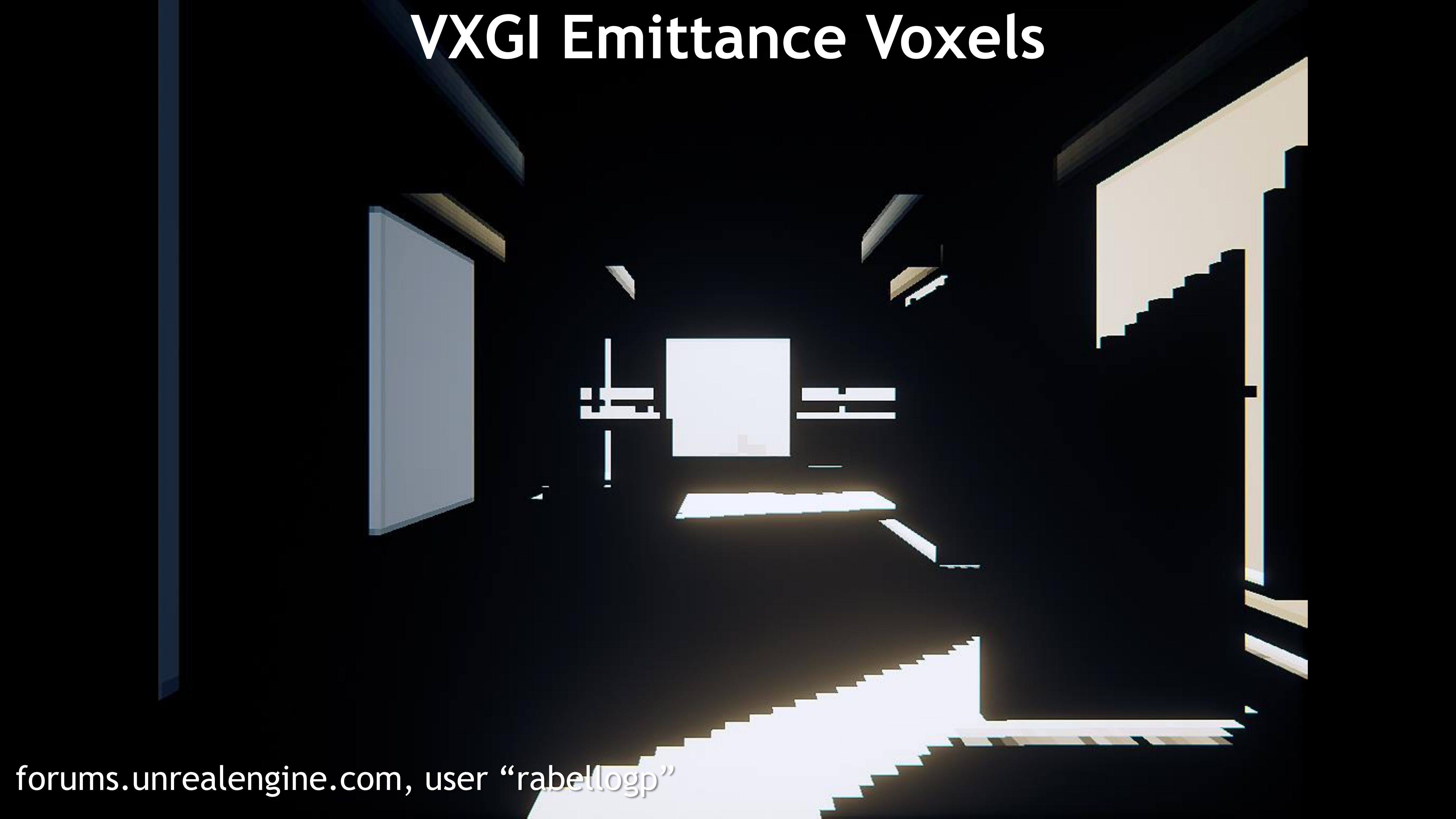
VXGI Emittance Voxels



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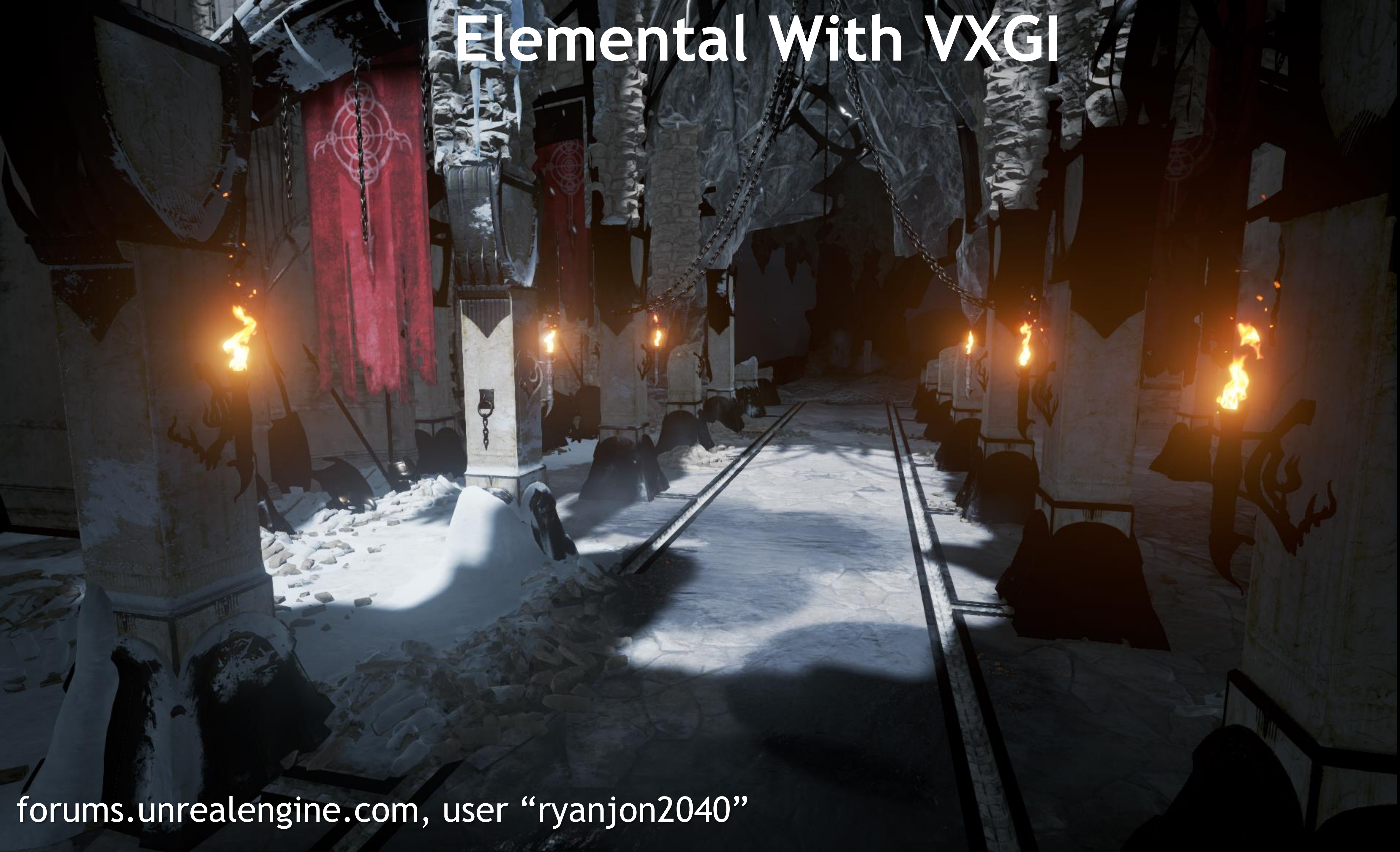
Elemental With VXGI



forums.unrealengine.com, user “ryanjon2040”

Effects Cave

forums.unrealengine.com, user “Ad3ViLl”

Effects Cave With VXGI

forums.unrealengine.com, user “Ad3ViLl”

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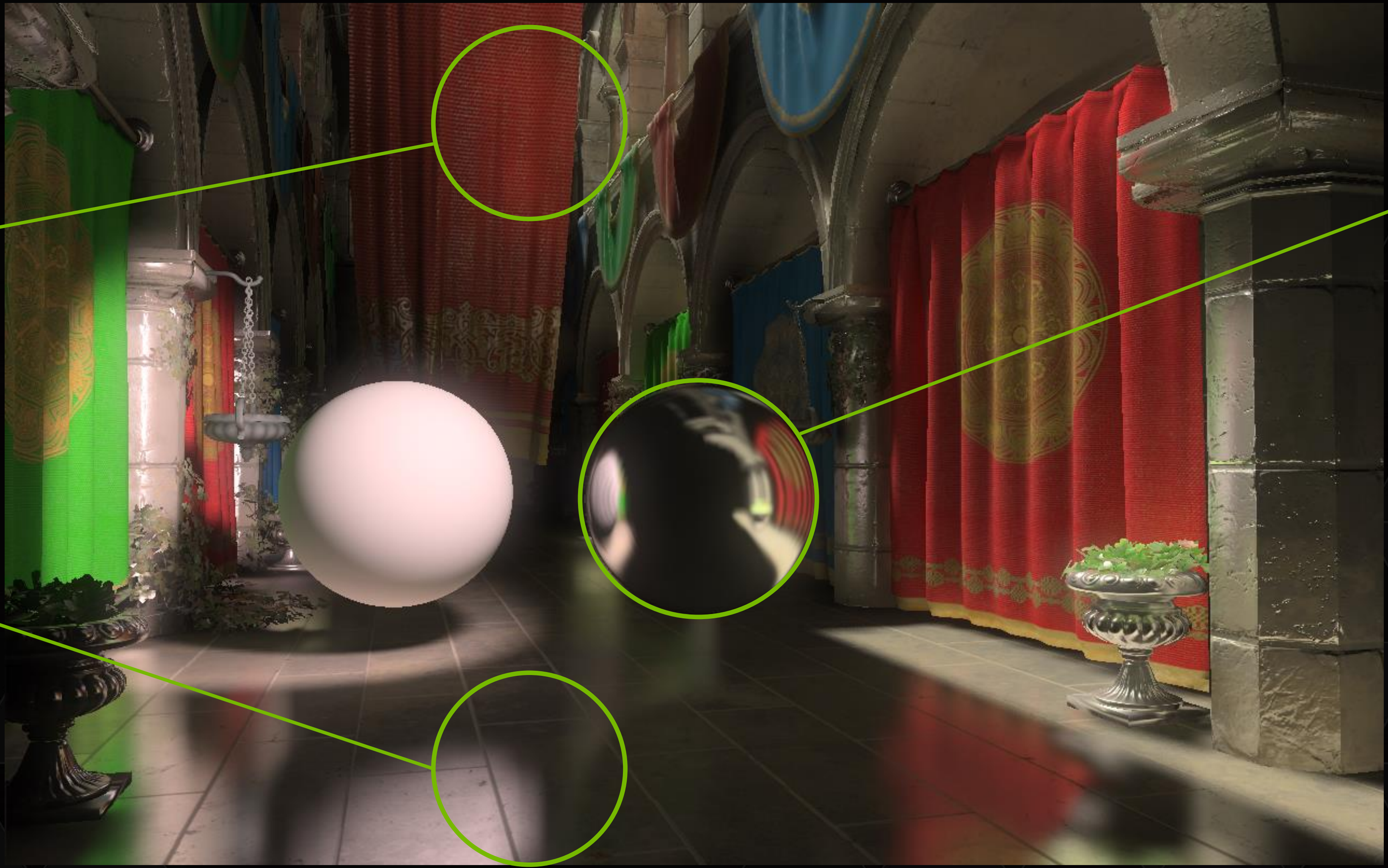
VOXELIZATION QUALITY ISSUES

- Voxelization aliasing
  - Moving lit objects sometimes flicker
  - Use supersampled emittance voxelization for small objects
  - Use temporal filtering to cancel the flicker
- Light quantization or saturation
  - RGBA8_UNORM emittance is used on non-Maxwell GPUs
  - Insufficient dynamic range to capture HDR lighting
  - Tune VoxelizationParameters::emittanceStorageScale

VOXELIZATION PERFORMANCE TIPS

- Use low-detailed meshes for voxelization
  - Disable tessellation or reduce tessellation factors
- Use a custom culling function with the voxelization GS
  - Cull triangles outside of light frustum or facing away from the light
  - Pass the function code to pGI->createVoxelizationGeometryShaderXX(...)
- Voxelize geometry for several lights at a time
- Only enable emittance supersampling for small moving objects

CONE TRACING QUALITY ISSUES

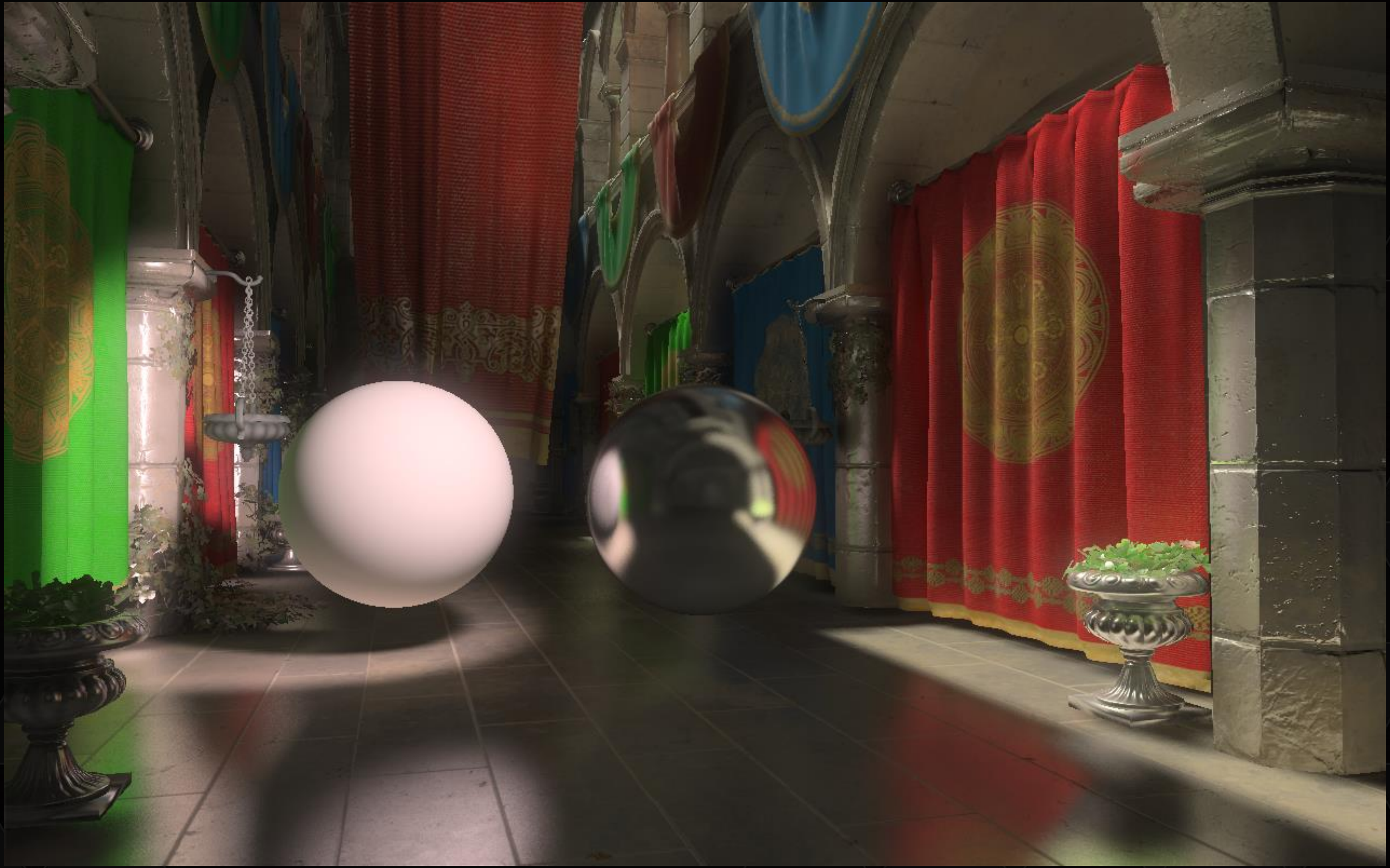


Light leaking

Voxels in reflections

Single bounce specular

IMPROVED TRACING QUALITY



SUMMARY OF TRACING ISSUES

- Light leaking
  - Light comes through walls or looks like SSS
  - Make walls thicker
  - Don’t voxelize light outside of potential visible area
- Visible voxels in specular reflections
  - Insufficient voxel resolution for mirror reflections
  - Make materials more rough or bumpy
  - Enable tangent jitter and temporal filtering
- Specular reflections are single bounce
  - Cone tracing only “sees” directly lit surfaces
  - Add constant ambient when voxelizing for emittance

  - Combine VXGI specular with other techniques

TRACING PERFORMANCE TIPS

- Use fewer diffuse cones and enable cone rotation
  - 4-8 cones is probably enough
- Use temporal filtering for diffuse and specular tracing
- Reduce the number of visible specular pixels
  - No tracing is done when gbufferNormal.a = 0.0
- Use the gbufferGeoNormal channel to speed up diffuse tracing
  - Surface detail will be preserved

PERFORMANCE EXAMPLE

- Scene: San Miguel - **3.0 M triangles**, revoxelized on every frame
- GPU: GeForce GTX 980, pre-release R349 driver

- Opacity voxelization: 6.9 ms + 1.5 ms for post-processing
- Emittance voxelization: 4.7 ms + 3.3 ms for post-processing
  - No supersampling, 1 directional light, FP16

- Diffuse tracing: 7.0 ms + 1.0 ms for interpolation
- -OR- Ambient tracing: 2.5 ms + 1.0 ms for interpolation
  - 1920x1080, 8 cones, trace every 4th pixel

- Specular tracing: 1.8 ms
  - Depends on visible geometry a lot

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BONUS: VOXEL-BASED AO

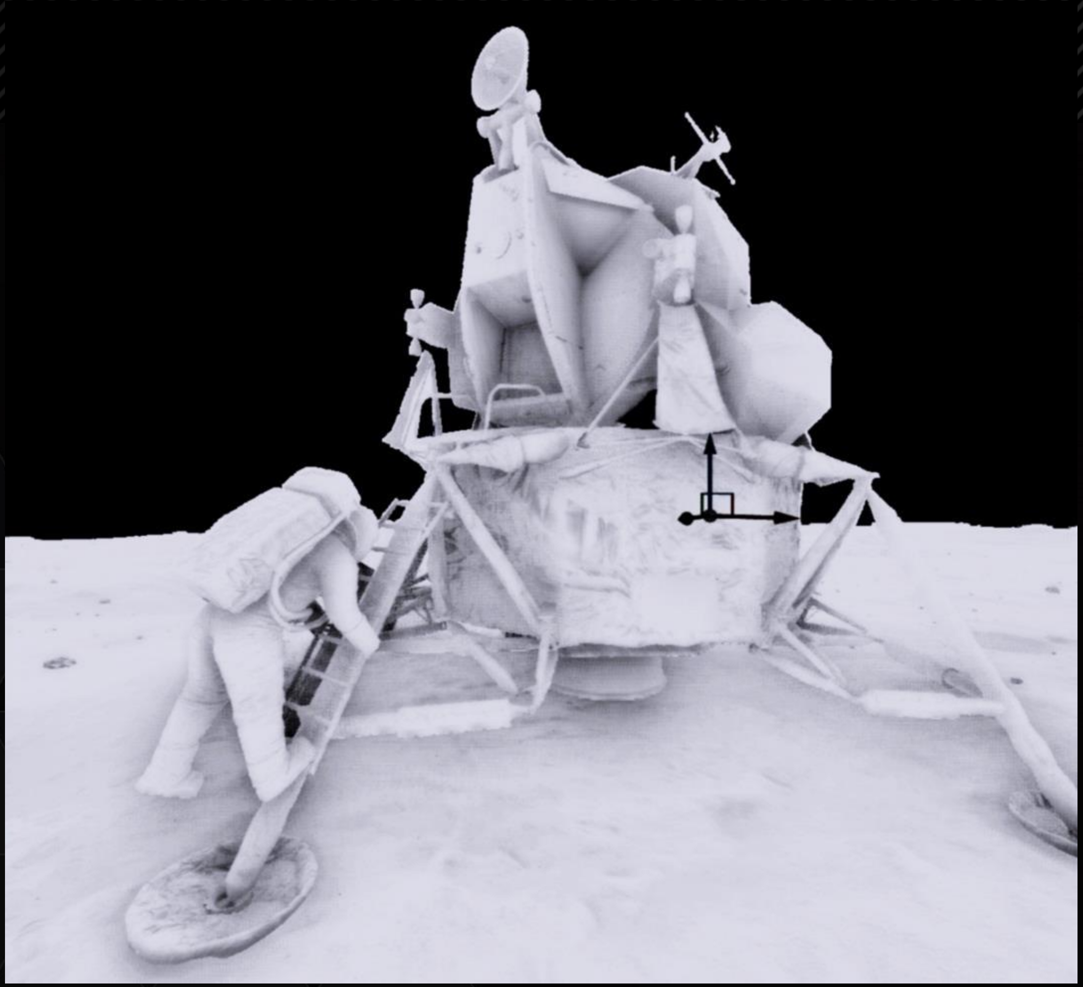
- Remove the emittance voxel textures
  - VoxelizationParameters::emittanceDirectionCount = NONE

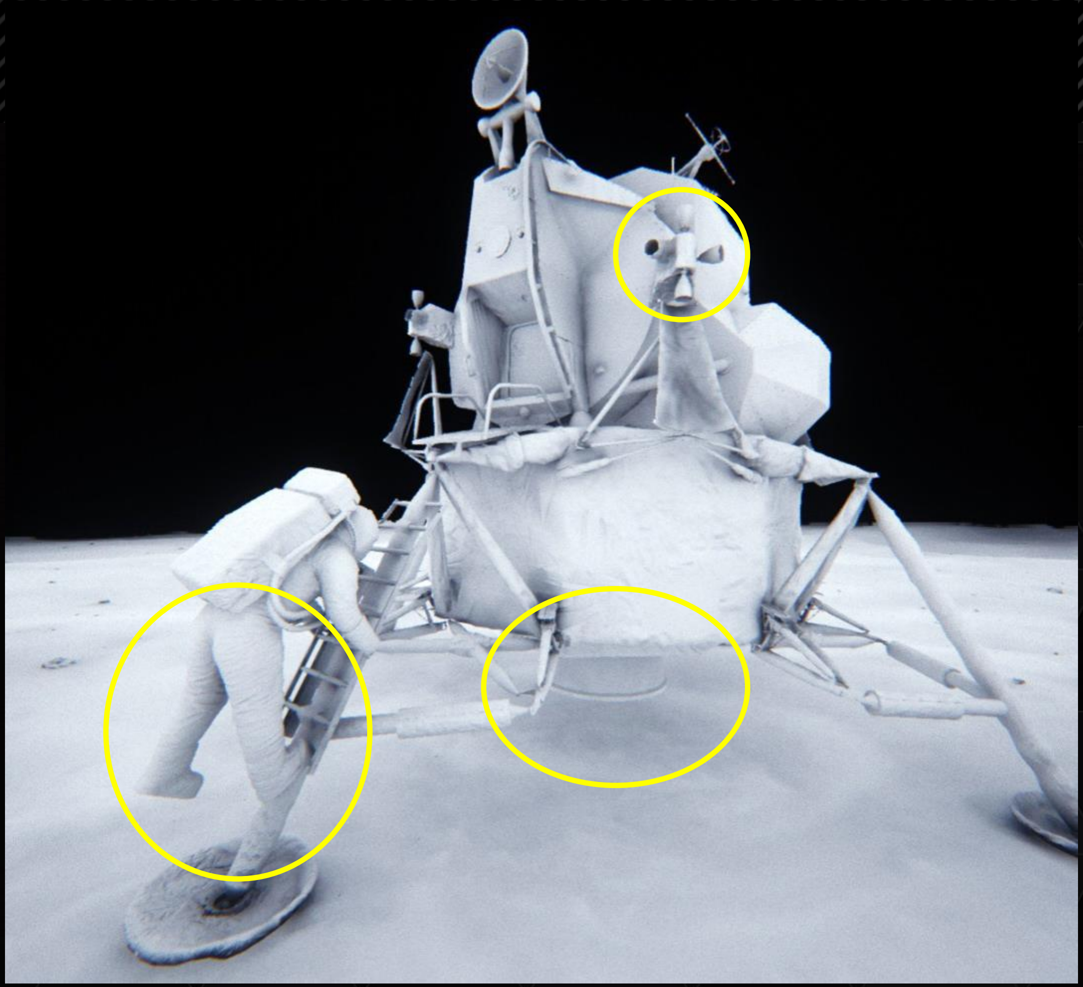
- Skip emittance voxelization and light injection
- Call pTracer->computeDiffuseChannel(…) to get the AO surface
  - DiffuseTracingParameters::ambientRange controls effect locality

- Compared to full GI…
  - Tracing is about 3x cheaper
  - Easier to integrate into apps

- Compared to SSAO…
  - World-space, stable AO effect

SSAO VS. VXGI AO





DEMO: VOXEL-BASED AO

SUMMARY

- VXGI provides an efficient real-time GI solution
  - Tuning is required to mitigate quality issues and make it work fast
- VXGI supports all DX11 GPUs
  - Maxwell produces higher quality results and works faster
- DX11 version and UE4 integration available now
- OpenGL version is being worked on

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OUTLINE

- What is VXGI
- Algorithm Overview
- Engine Integration
- VXGI in UE4
- Quality and Performance
- Ambient Occlusion Mode
- Q&A

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THANK YOU!

JOIN THE CONVERSATION

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