Taking KILLZONE® SHADOW FALL

Image Quality into the Next Generation

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Outline

- Look back at the development of Killzone Shadow Fall
- What is the Next-Gen look?
- Key techniques
- Image quality and stability

Killzone Shadow Fall Background

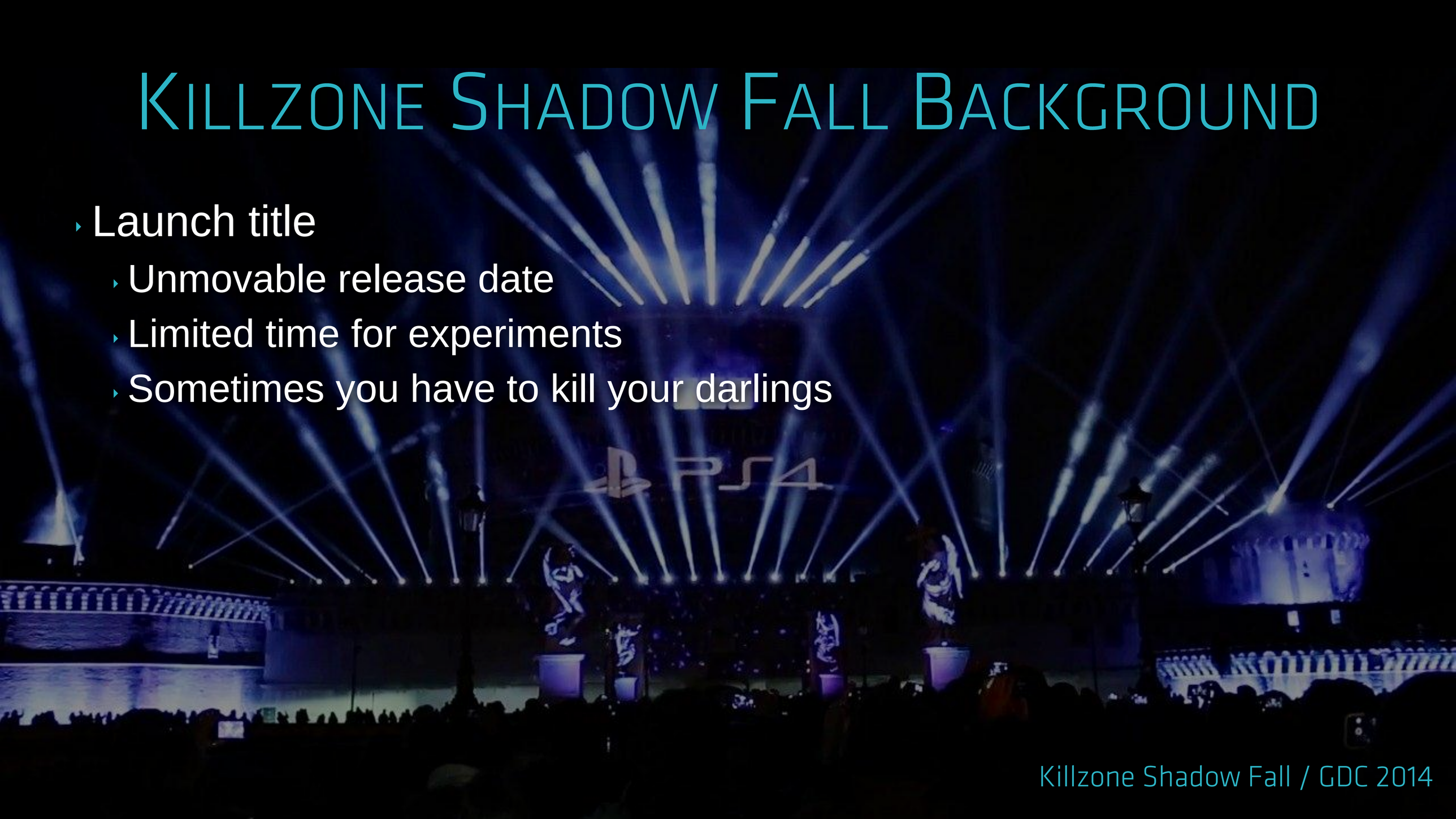
- Early development started in April 2011
- The goal was platform defining, true next-gen, Killzone
  - New game direction
  - Fresh look for a divided world
  - Beautiful environments full of detail and contrasts

Killzone Shadow Fall Background

- New platform
  - Hardware under development
  - Difficult to define scope of the game
  - No PC fallback for the engine
  - Features in development throughout production

Killzone Shadow Fall Background

- Launch title
  - Unmovable release date
  - Limited time for experiments
  - Sometimes you have to kill your darlings



Early 2012 - Owl Experience / Internal Vision Demo

The Patriot / Announcement Demo Timeline

April 2012 - The Patriot / Mockup

Time: T-10 months

July 2012 - The Patriot / Mockup

Time: T-7 months

October 2012 - The Patriot / First Pass Art

Time: T-4 months

Guerrillas Iterating...

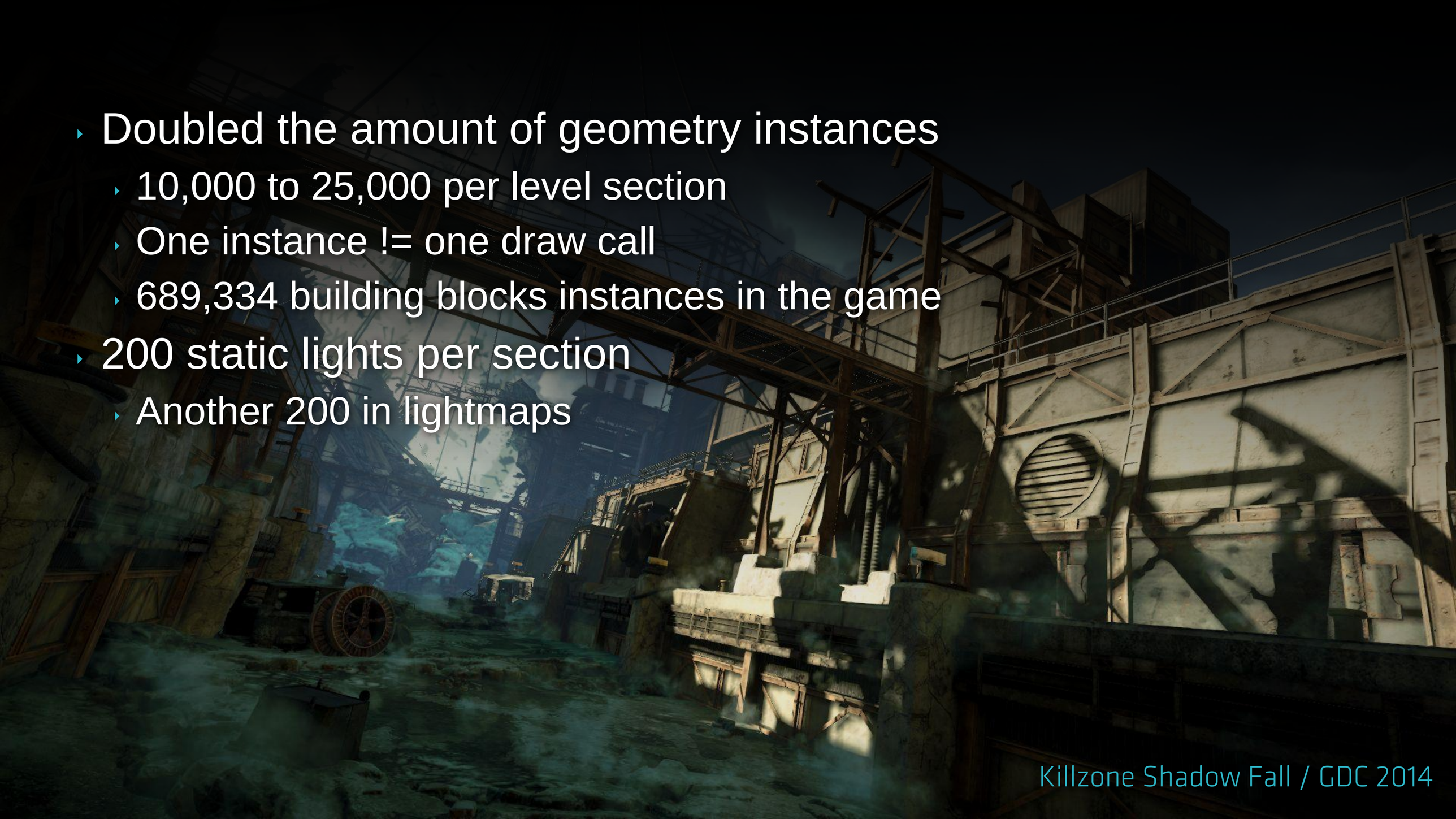
February 2013 - The Patriot / Announcement Demo

Liftoff

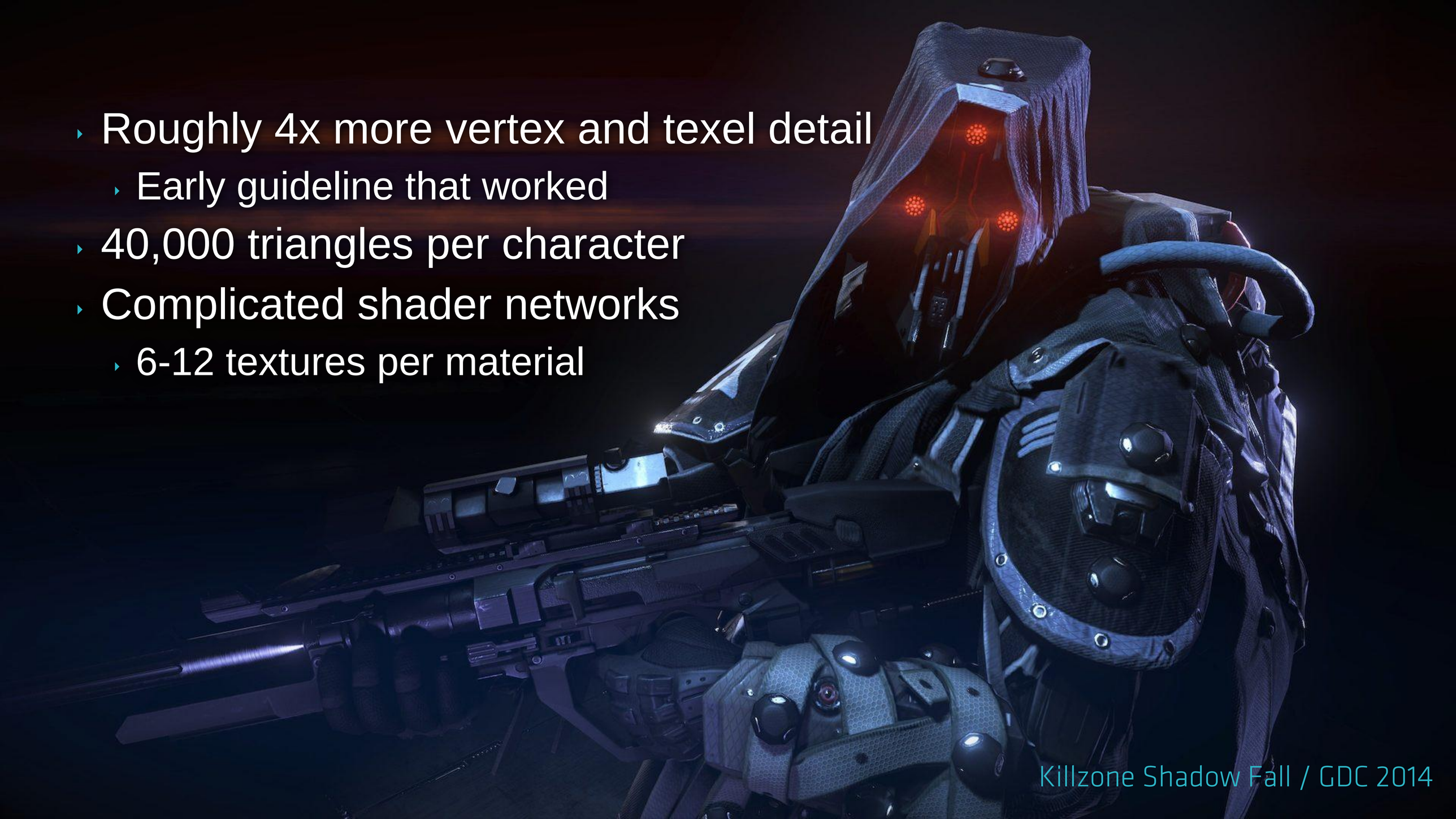
Killzone Shadow Fall In Numbers

Our Levels Grew Bigger (Again)

- Levels 10 to 100 times larger than in Killzone 3
  - Largest map is almost 8km long
  - We don’t have open world engine
  - First time we ran into precision issues



- Doubled the amount of geometry instances
  - 10,000 to 25,000 per level section
  - One instance != one draw call
  - 689,334 building blocks instances in the game
- 200 static lights per section
  - Another 200 in lightmaps



- Roughly 4x more vertex and texel detail
  - Early guideline that worked
- 40,000 triangles per character
- Complicated shader networks
  - 6-12 textures per material

ENGINE 4.0

Goals for PS4 Generation

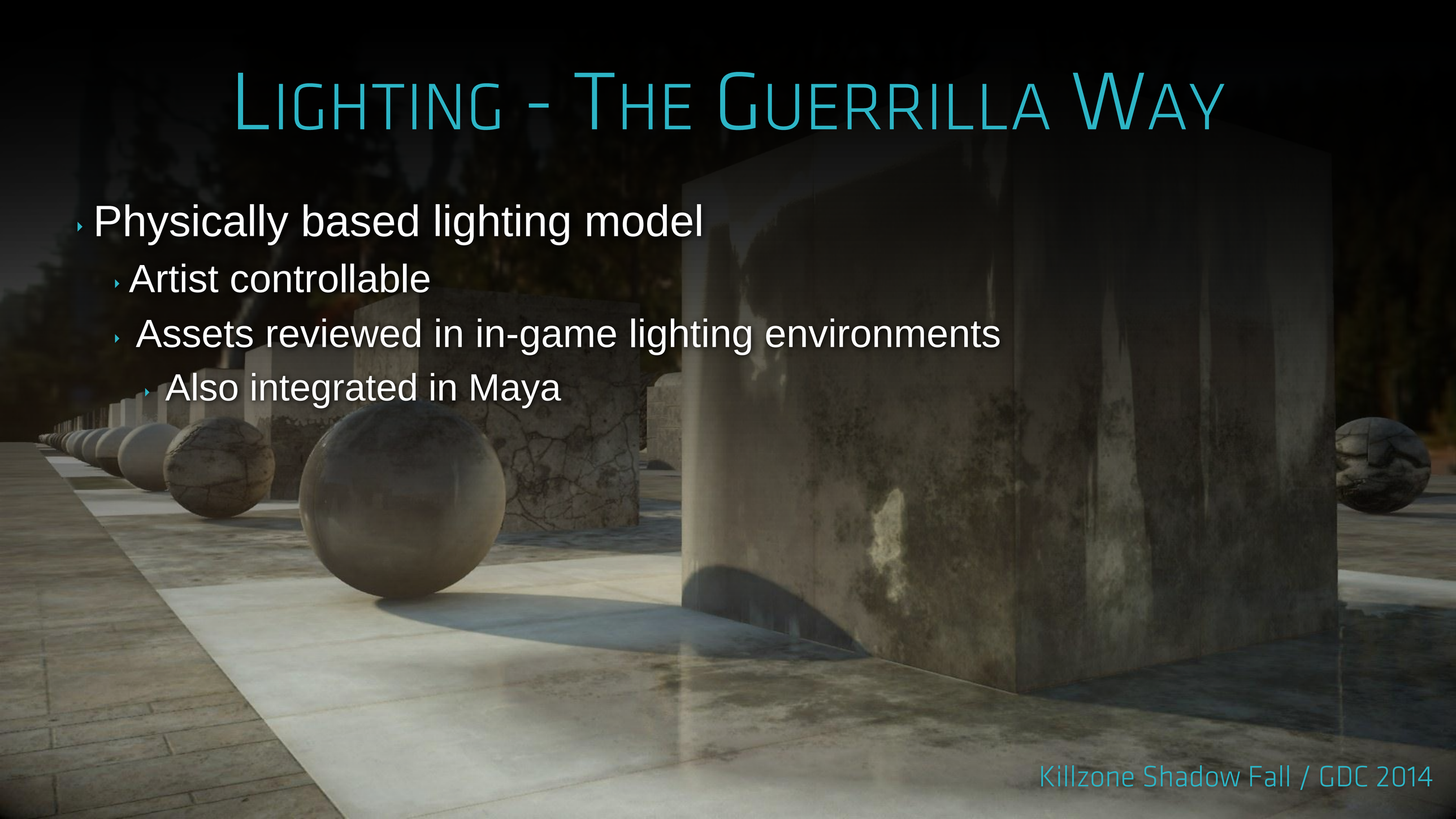
- Killzone Shadow Fall defining tech features
  - Lighting
  - Shading
  - Reflections
  - Effects
- Image fidelity and temporal stability
- Scalability with the amount of content
  - Everything done with jobs

Lighting - The Guerrilla Way

- All aspects of lighting complement each other
  - BRDF
  - Assets
  - Lights
  - Volumetrics
  - Reflections

KILLZONE SHADOW FALL

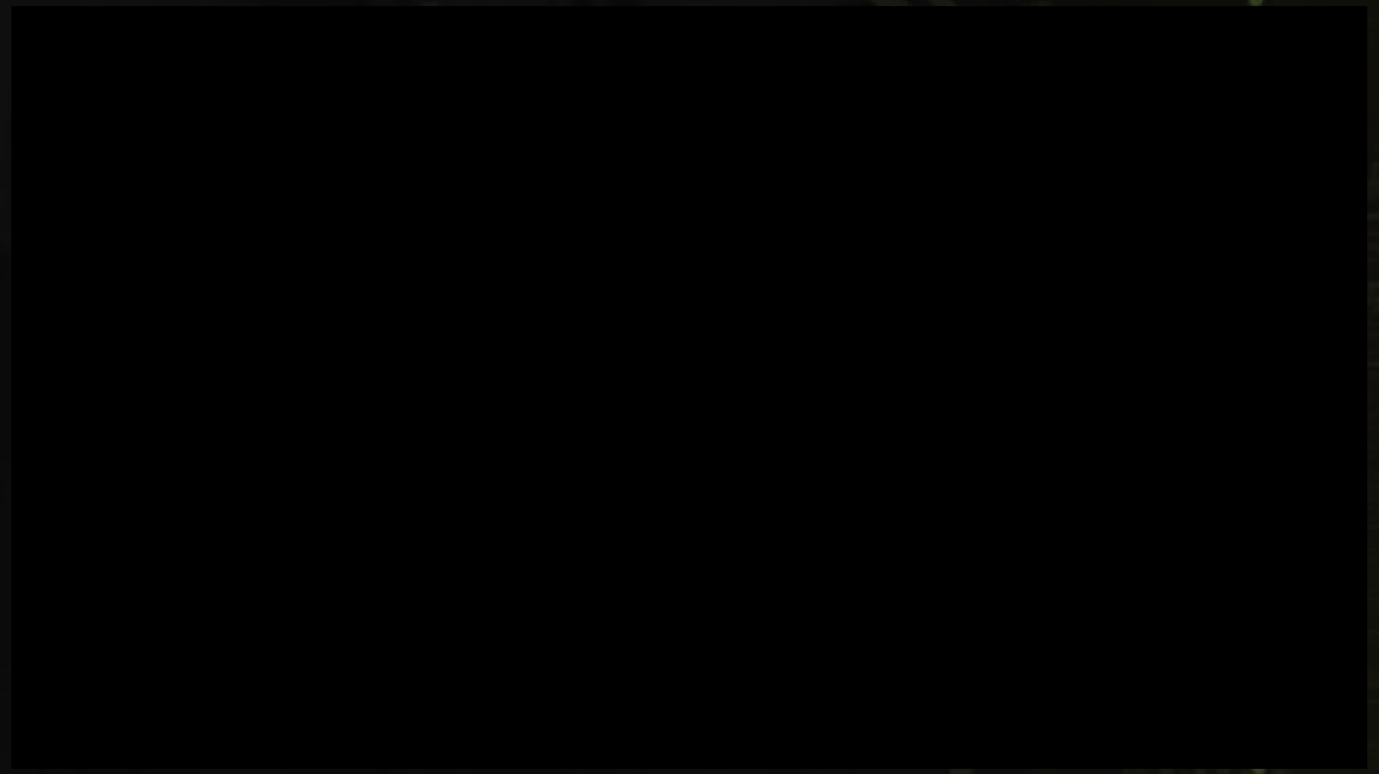
Lighting - The Guerrilla Way



- Physically based lighting model
  - Artist controllable
  - Assets reviewed in in-game lighting environments
    - Also integrated in Maya

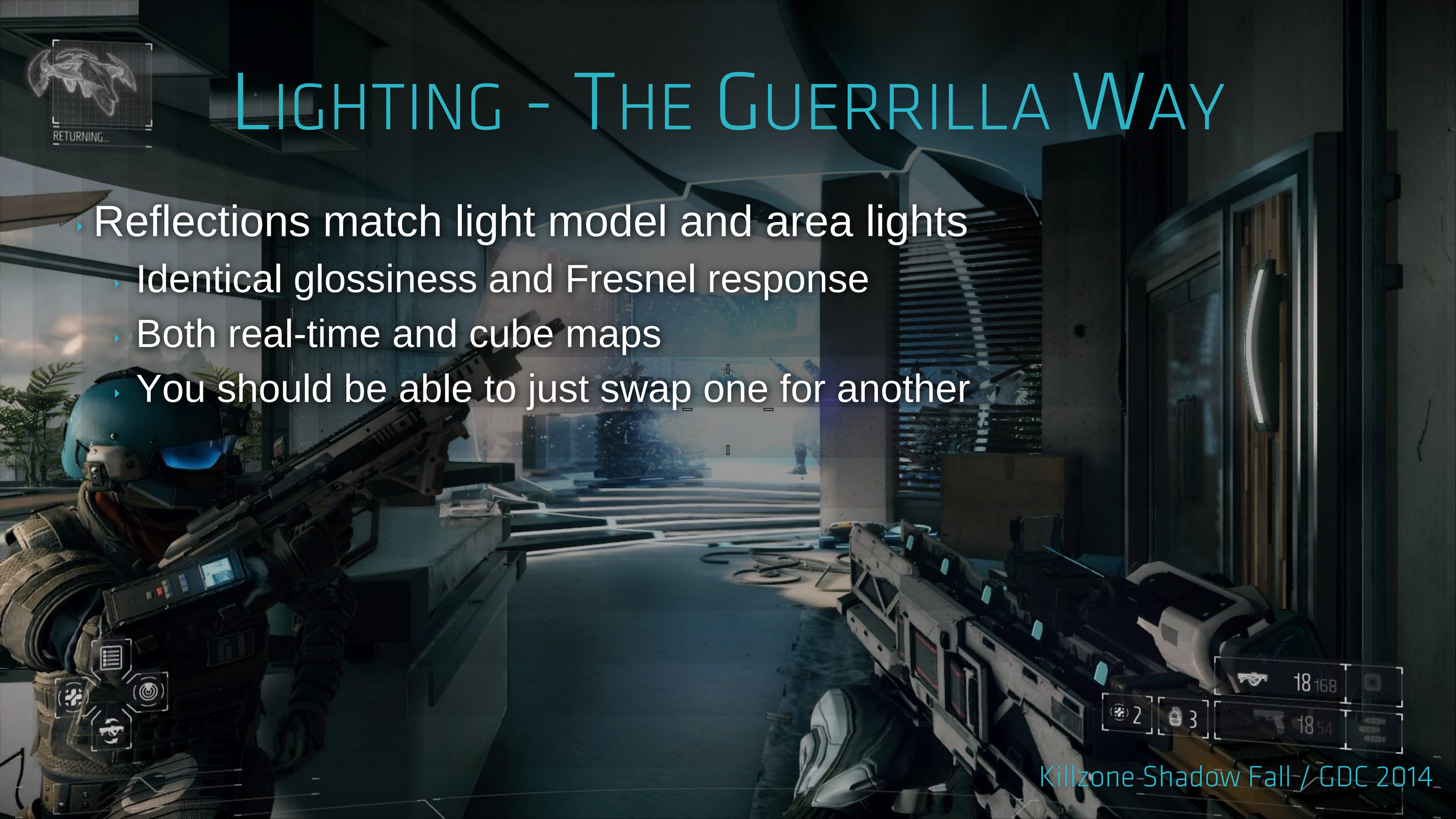
Lighting - The Guerrilla Way

- All lights are area lights
  - Including textured lights
  - Consistent specular response
  - Sunlight
  - Volumetric
  - More details in GPU Pro 5



Lighting - The Guerrilla Way

- Reflections match light model and area lights
  - Identical glossiness and Fresnel response
  - Both real-time and cube maps
  - You should be able to just swap one for another

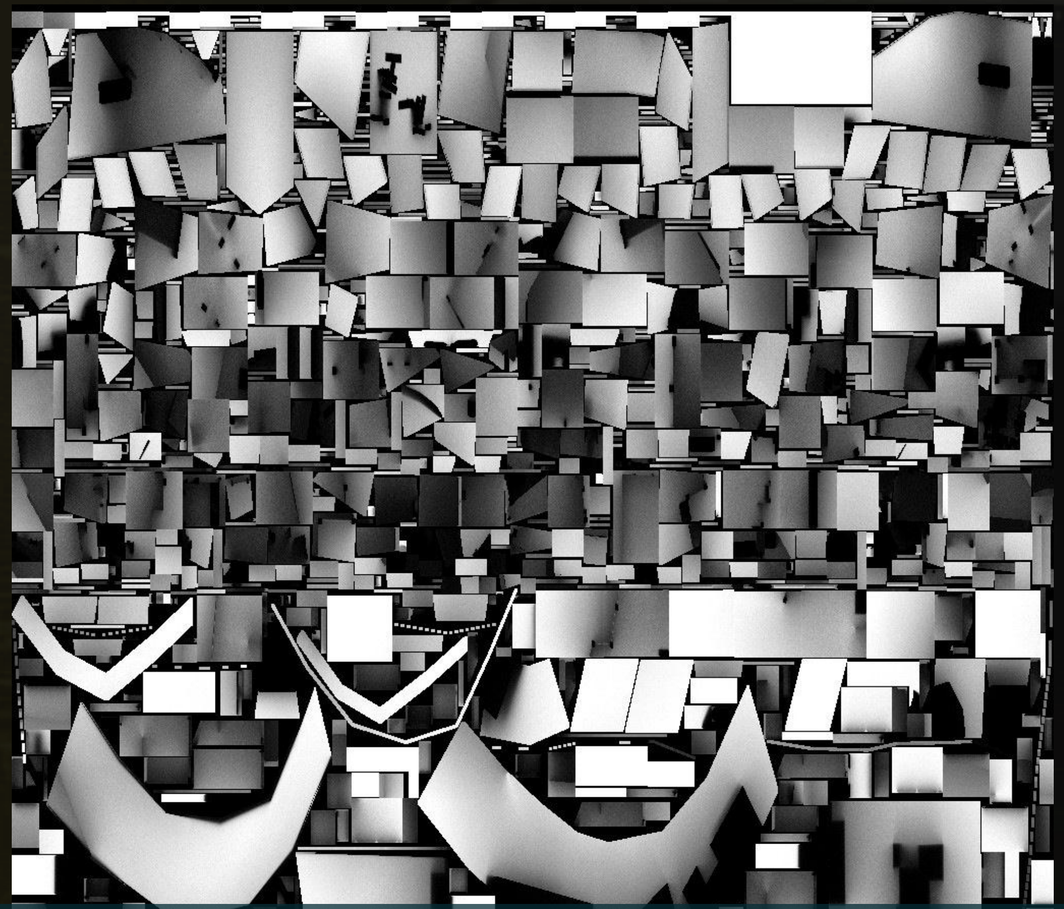


Indirect Lighting

Indirect lighting in Killzone 3

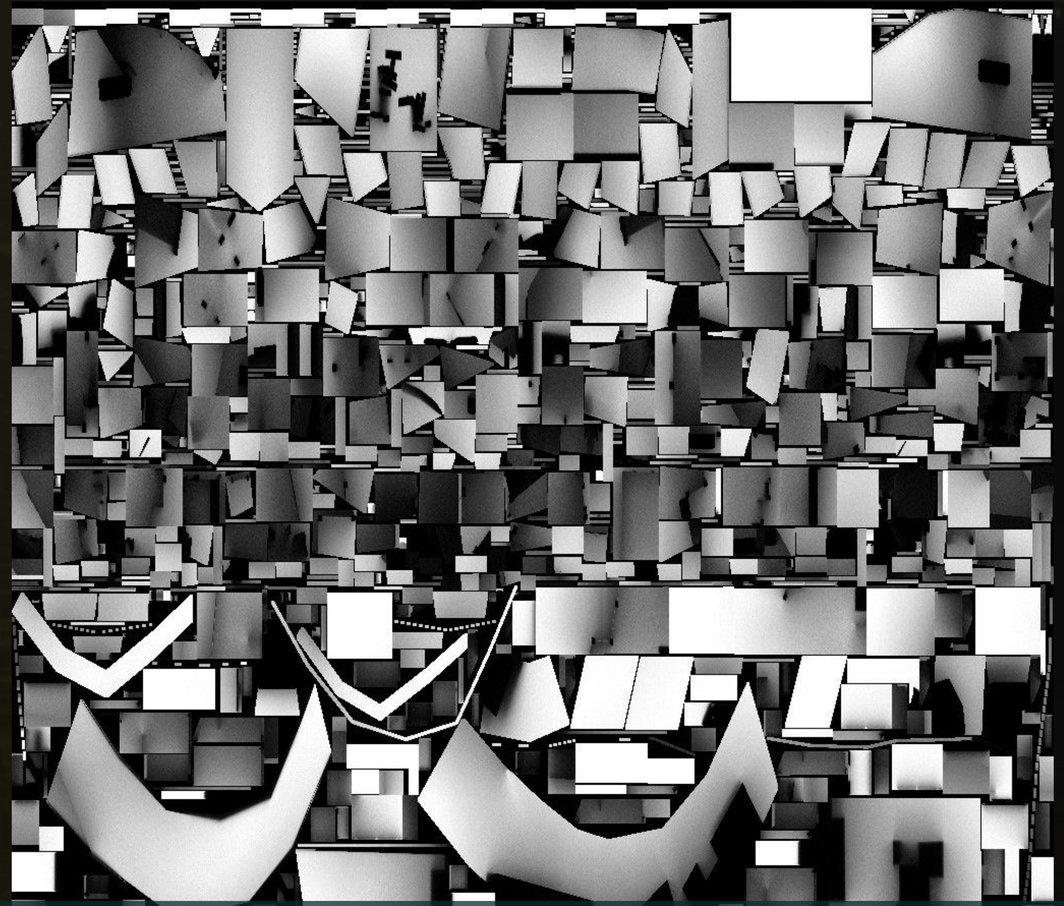
- Per-object light probes
- Lightmaps
  - Need nice unwrapped Us
  - Static objects only
  - Level changes break lighting
  - Wasteful
- We measured render times in days

Lightmaps



Expectation

Lightmaps



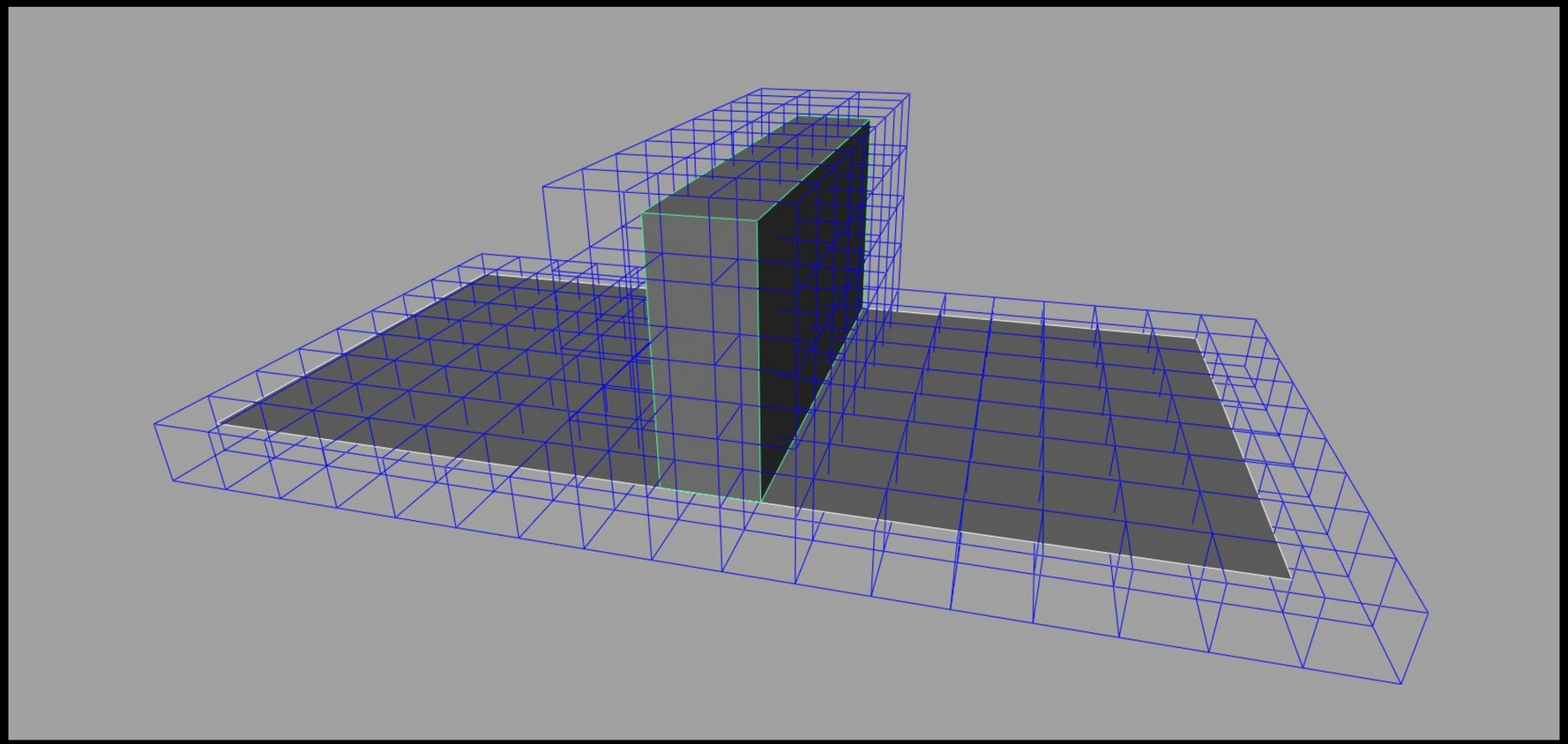
Expectation

Reality

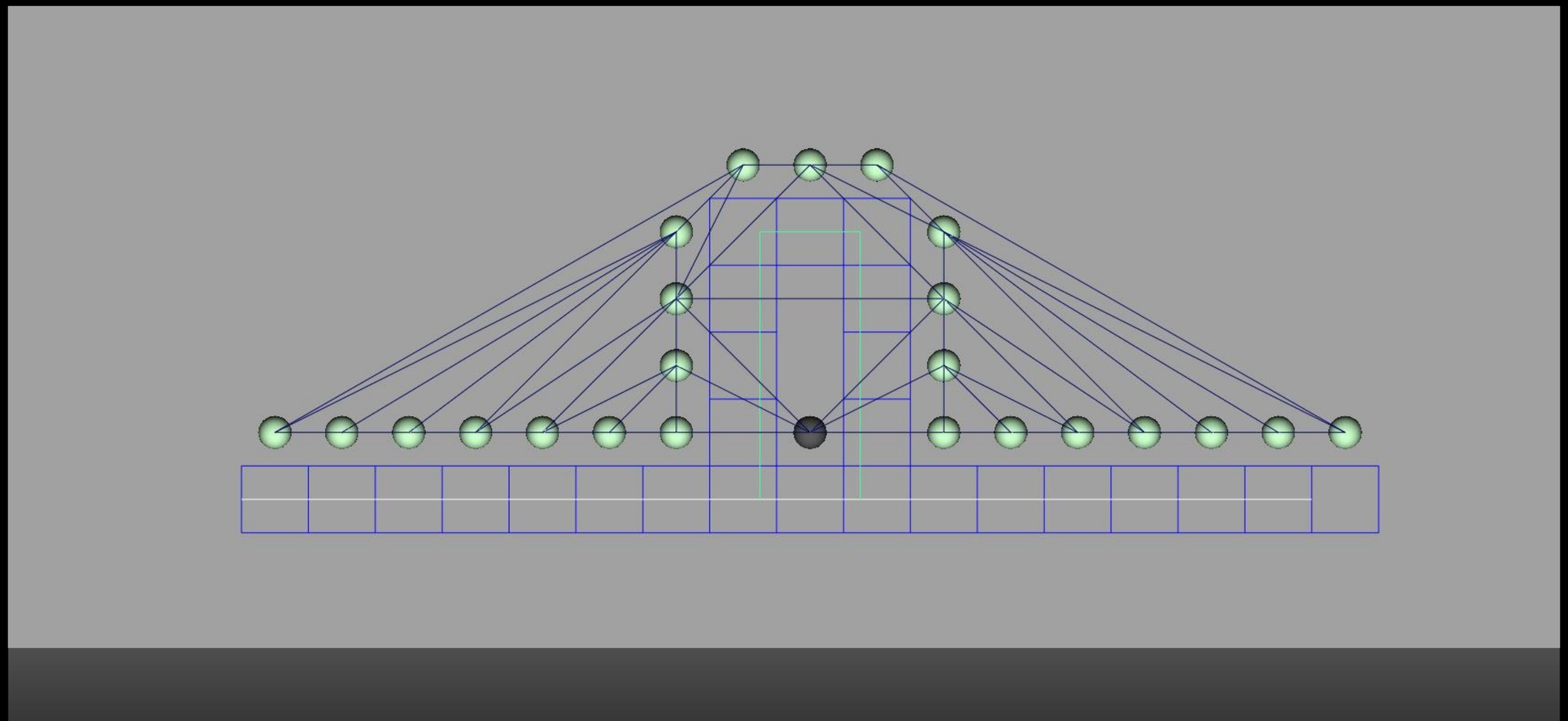
Indirect lighting in KZ:SF

- Decided to use light probes
  - Static and dynamic geometry supported
  - Works after level changes
  - Scalable
- Applied per pixel
  - Deferred pass
  - Works on large objects
  - Uniform look for static and dynamic objects

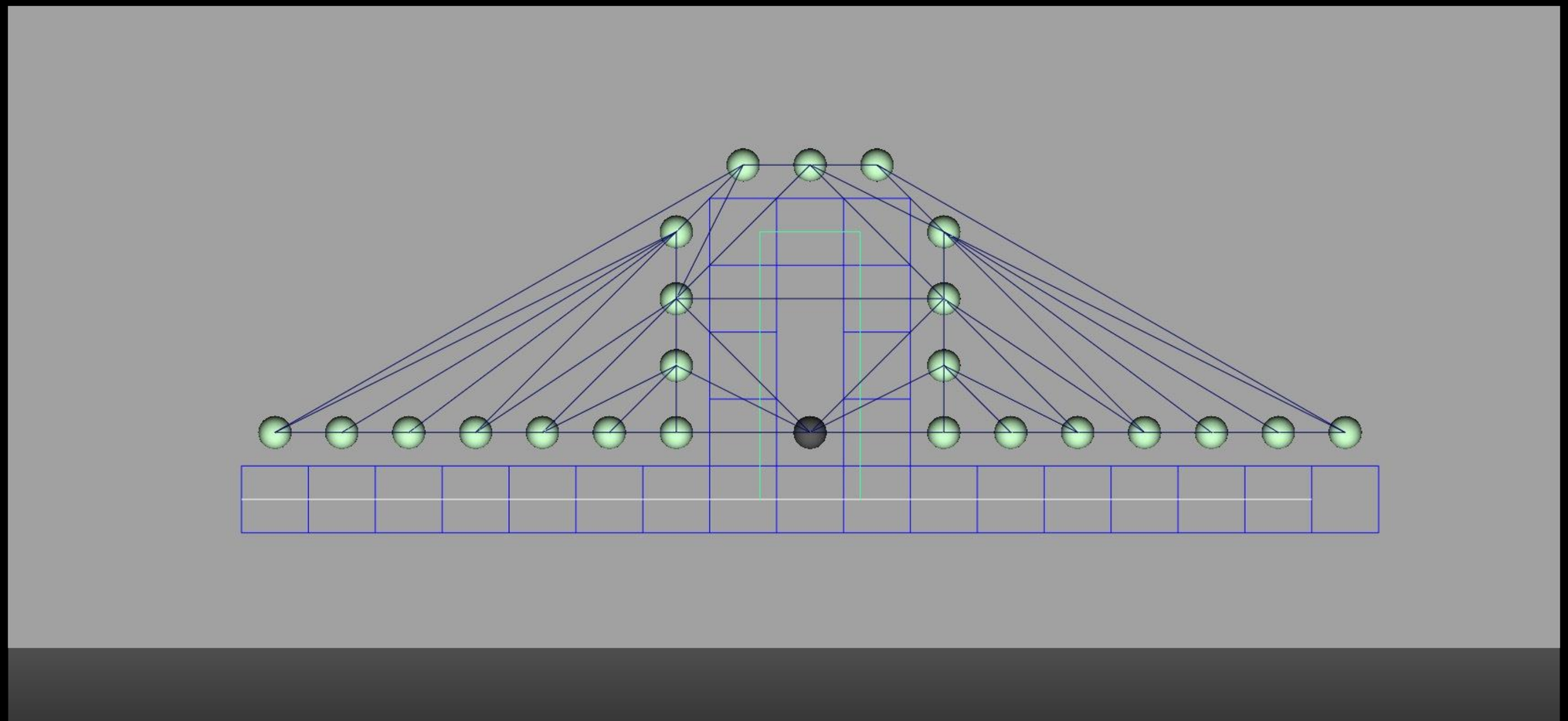
- Voxelize the scene
  - 1-2m in gameplay areas
  - 10m in background



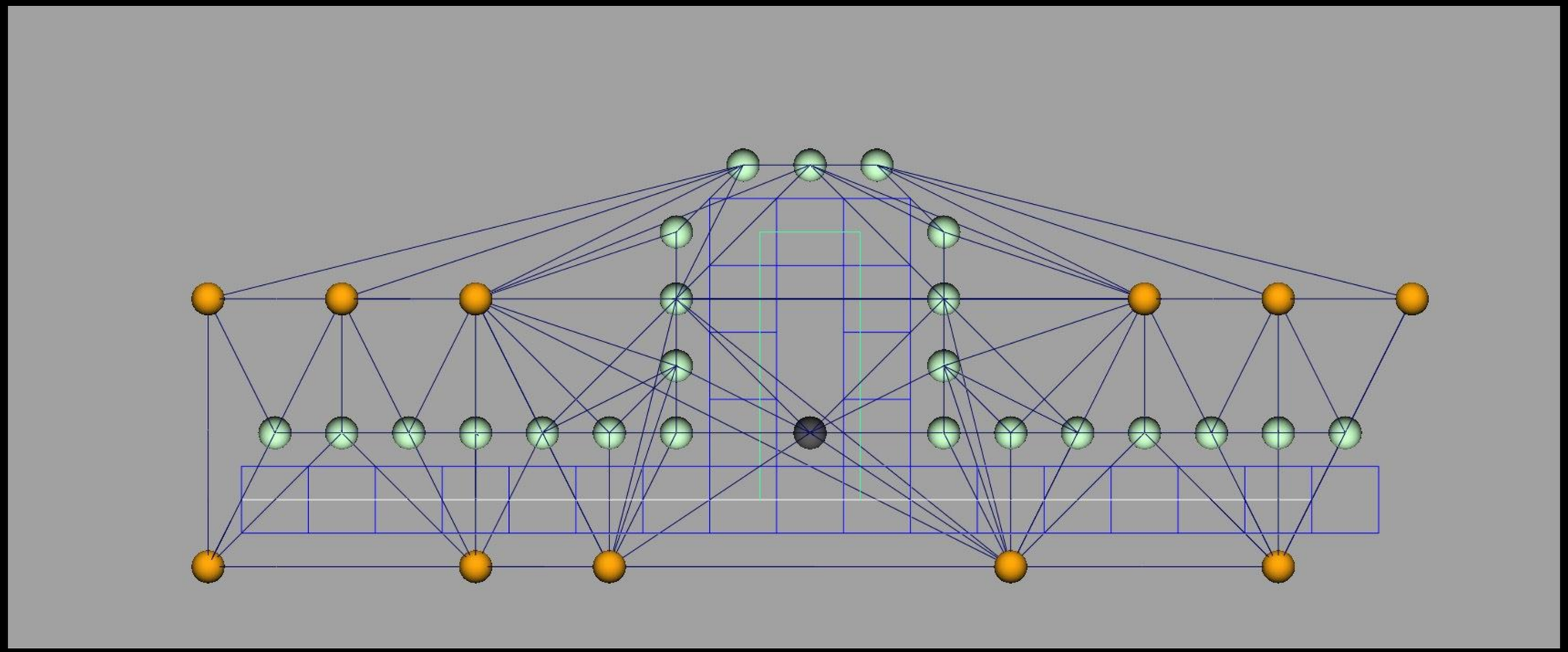
- Place light probes
  - In empty voxels
  - Next to features

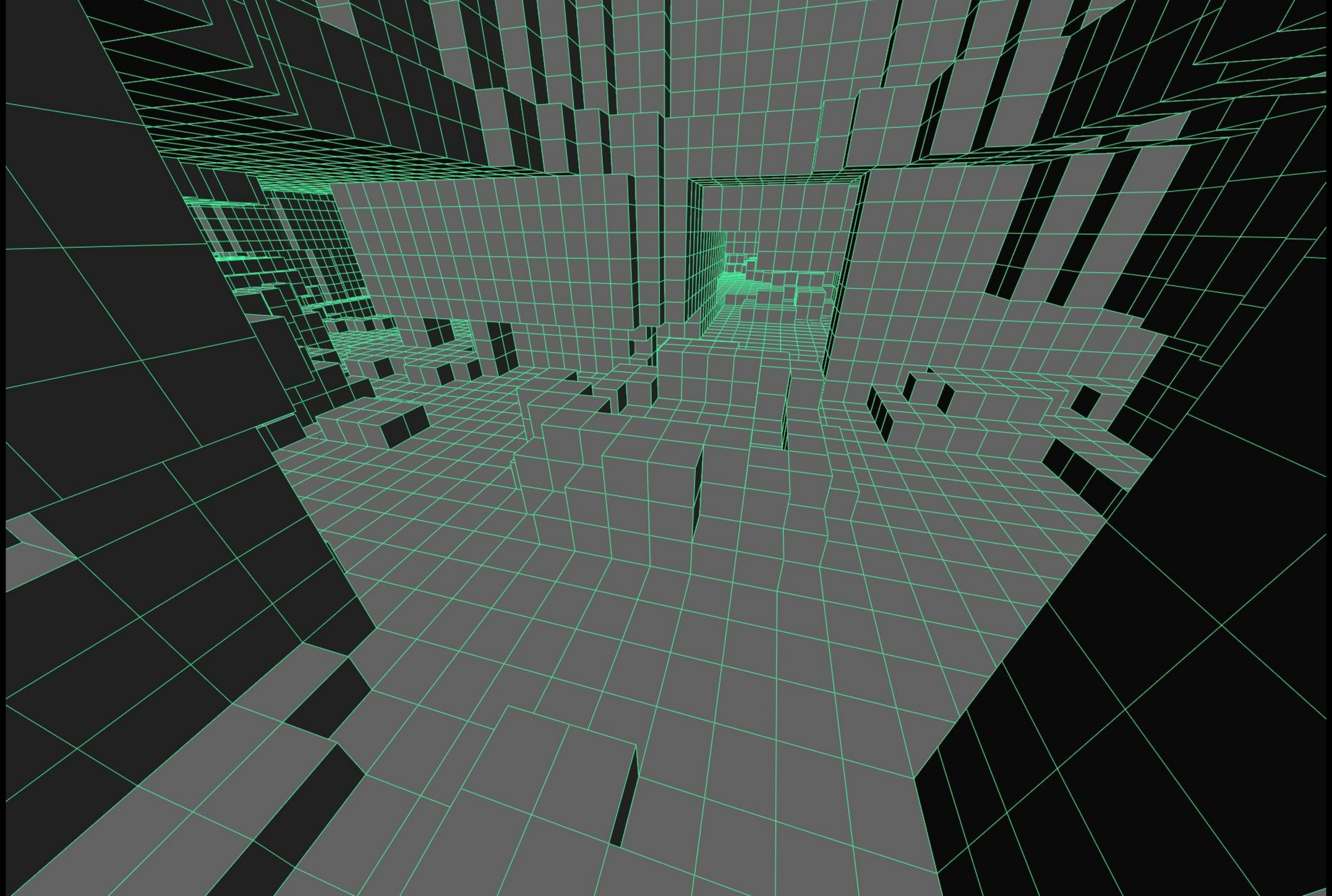


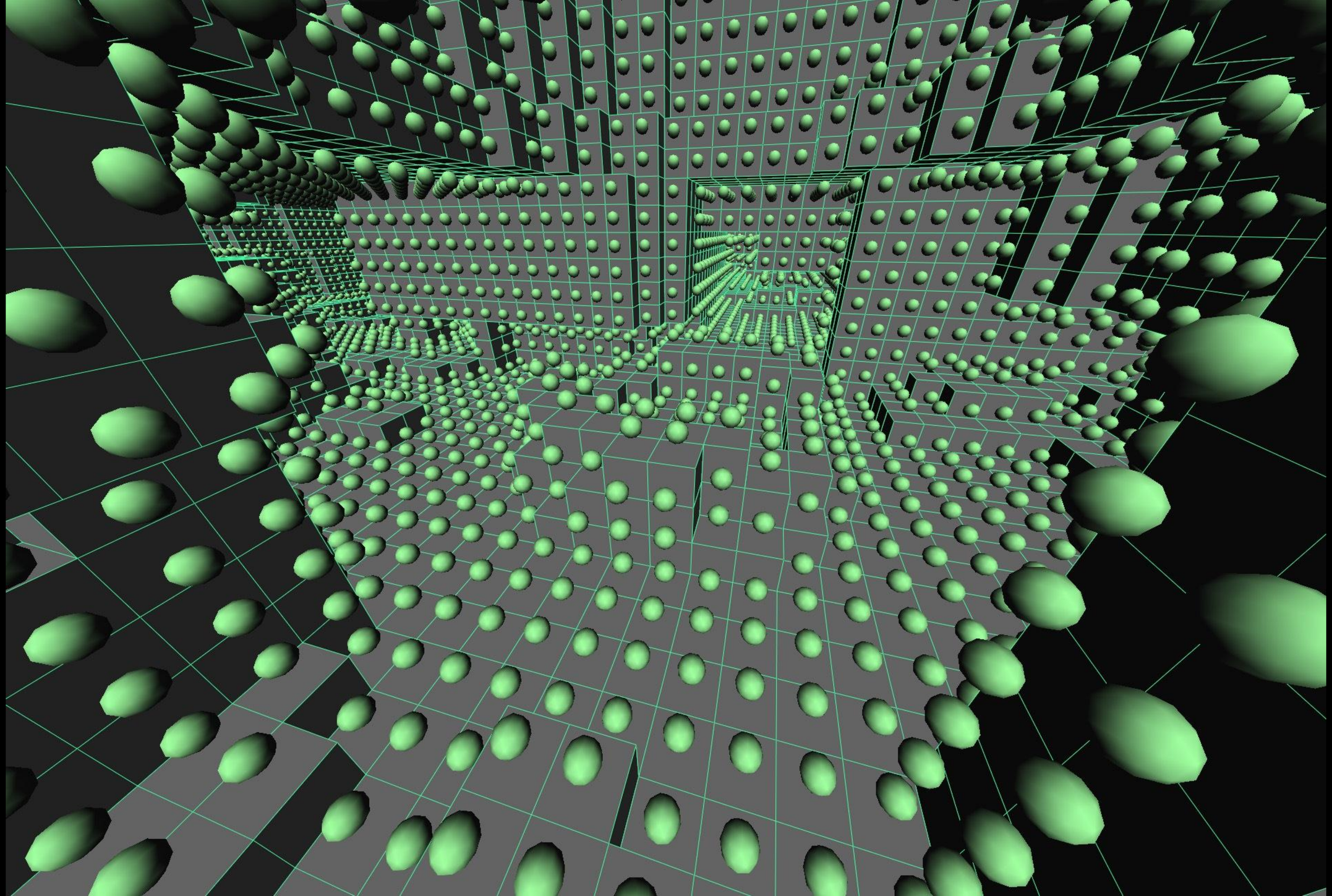
- Build tetrahedron structure
  - ‘*Light probe interpolation using tetrahedral tessellations*’
  - Tends to generate “slivers”

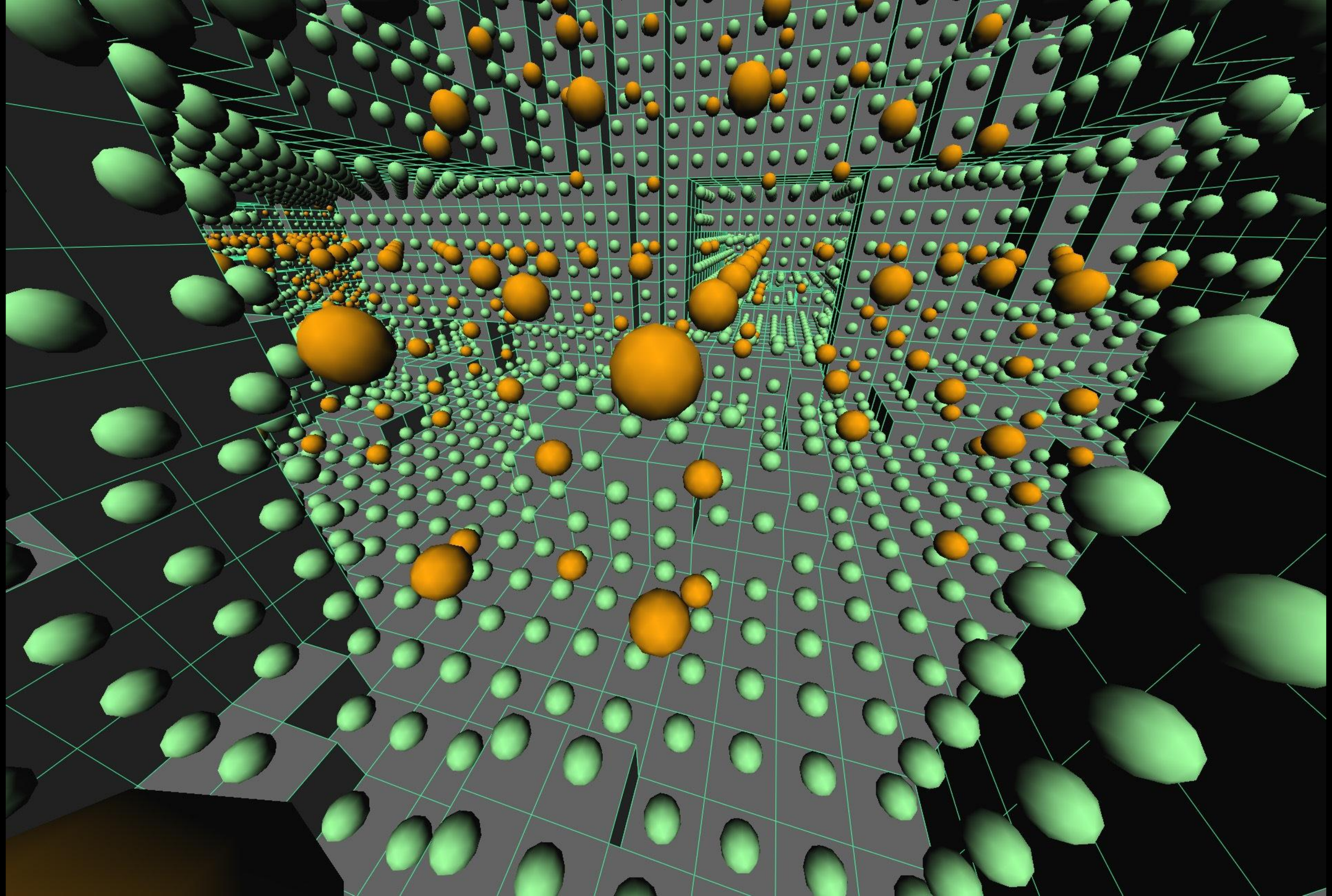


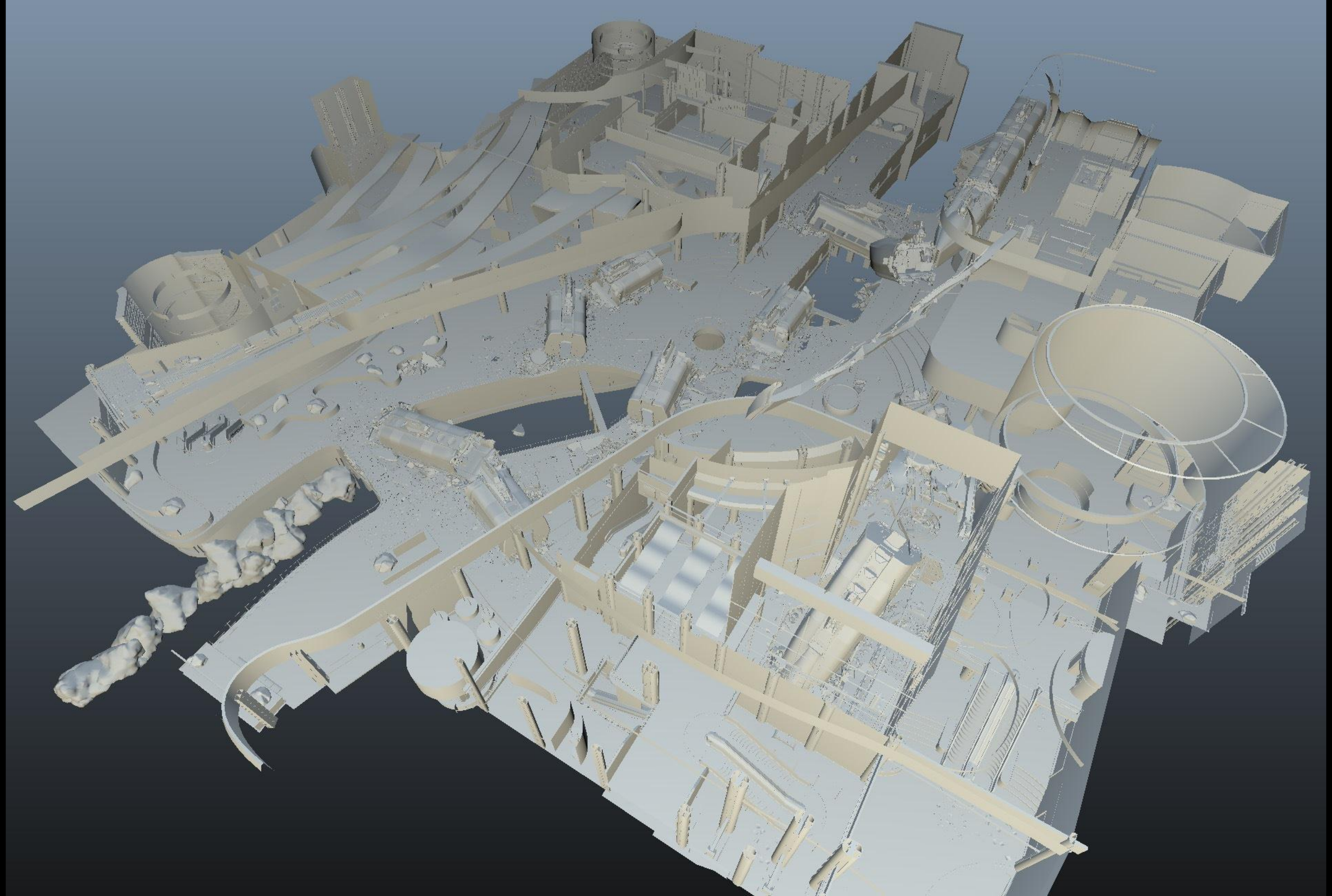
- Add fill probes
  - In empty space
  - Lower frequency
  - More uniform tetrahedrons

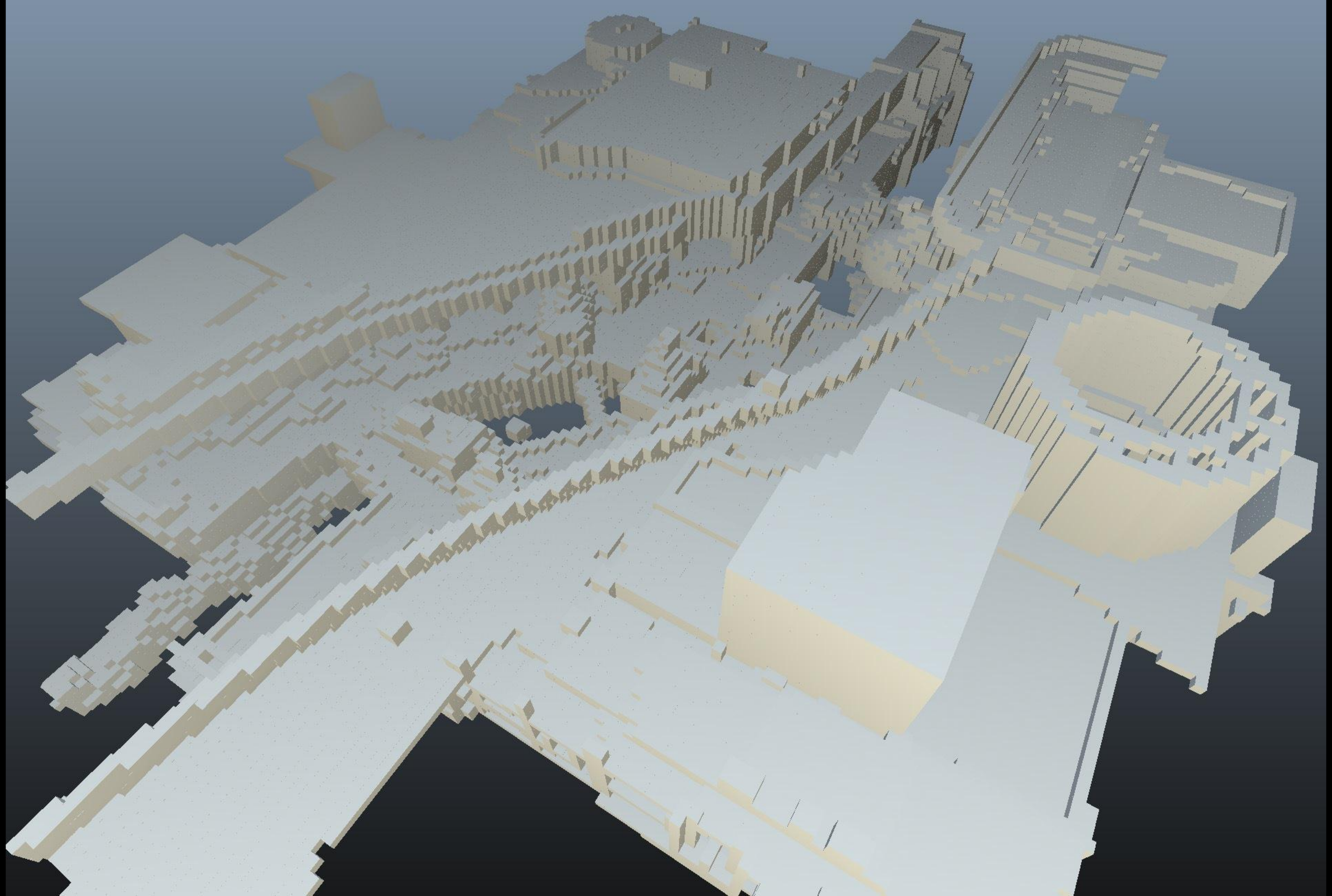


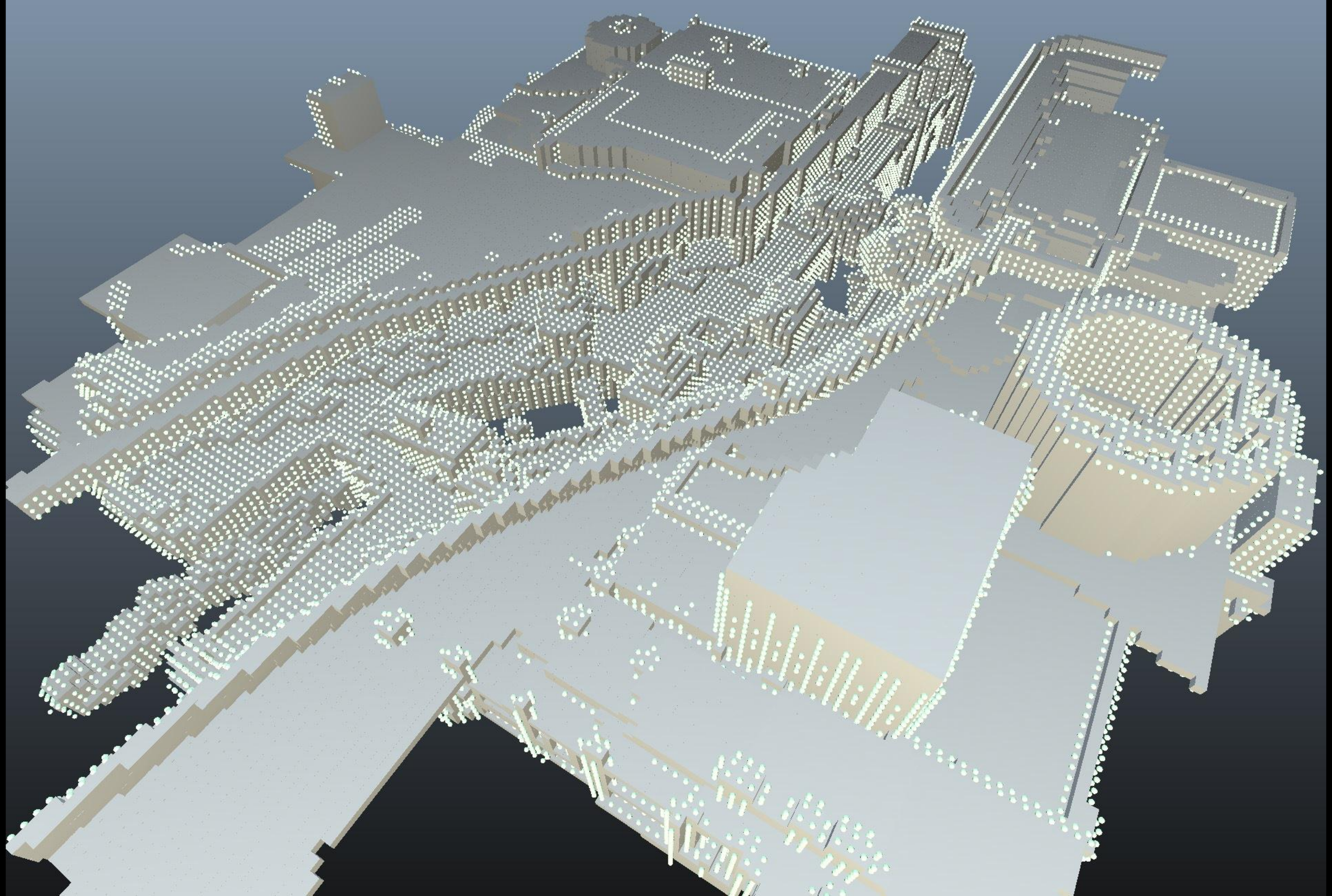


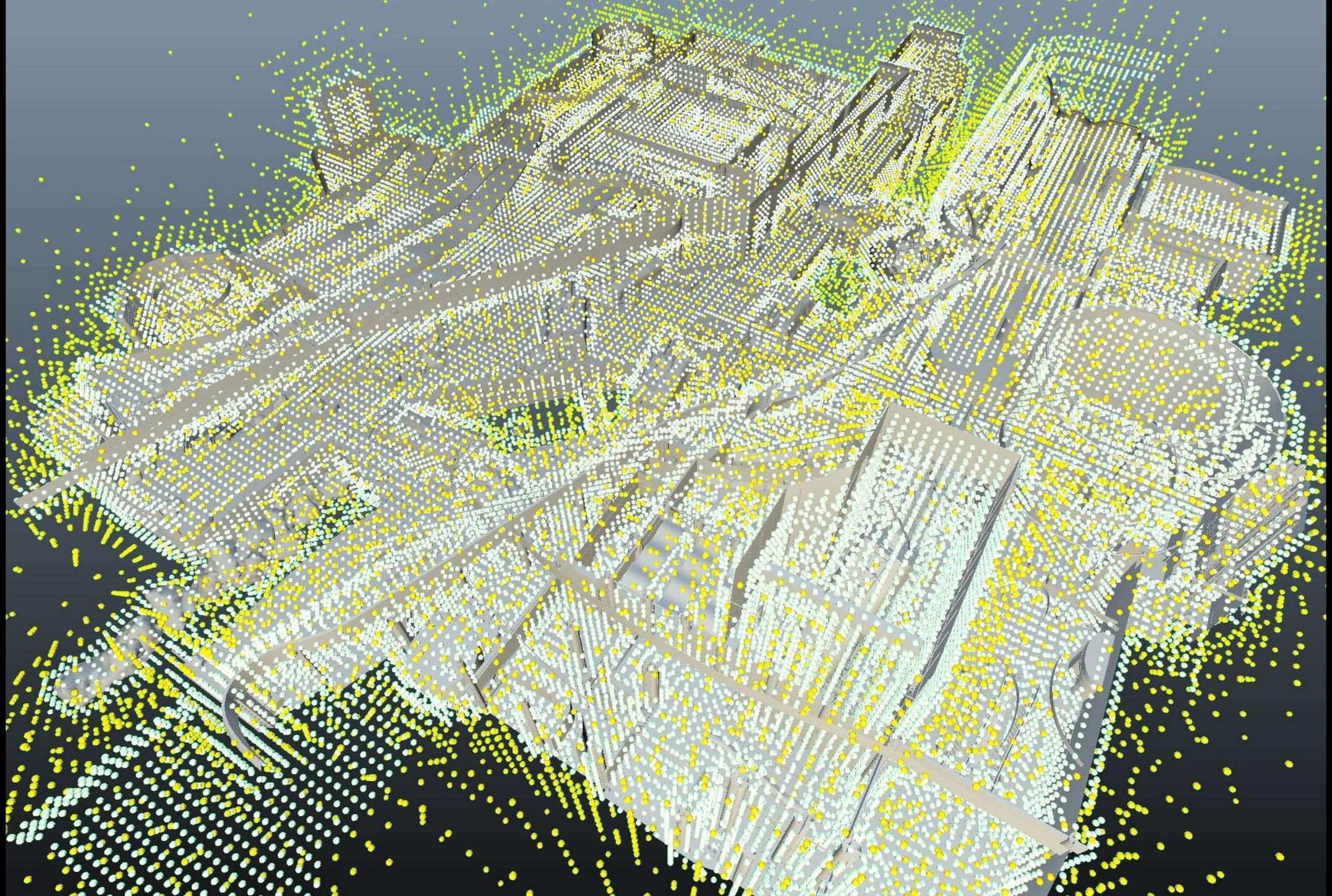










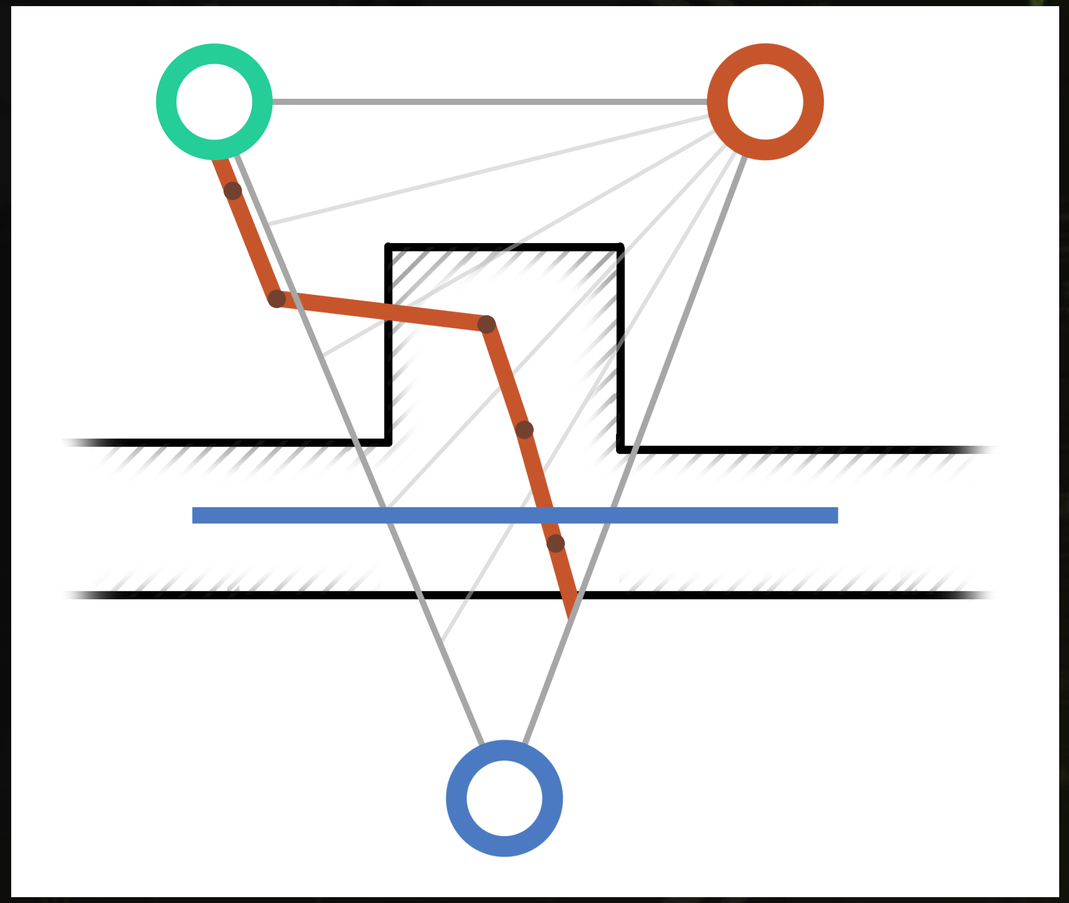


Light Probe System Details

- Few hundred thousand probes per section
- Per pixel search during lighting
- Tetrahedrons partitioned into a sparse grid
  - $16m^3$ per cell
- BSP tree per grid cell

Light probe system details

- Light leaking problematic
- Store optional data in tetrahedrons
- Up to 3 occlusion planes
- Up to 4 occlusion shadow maps
  - One per triangular tetrahedron side
  - 15 samples per map



Results

- Tech became available very late
  - Too risky to switch
- Used for all dynamic objects
- Used outside gameplay areas
  - Saved 500mb per section
- Only few levels lit exclusively by probes
  - Most levels still use light maps
- In use for our next game

Deferred Particle Lighting

Particle lighting

- Particle lighting so far
  - Mostly unlit
  - Forward rendering
  - Performance and feature limitations
- Particles need to fit our environments
  - Lighting matching the rest of geometry
  - Support for all our light types
  - Shadows
- Performance is important

Deferred particle lighting

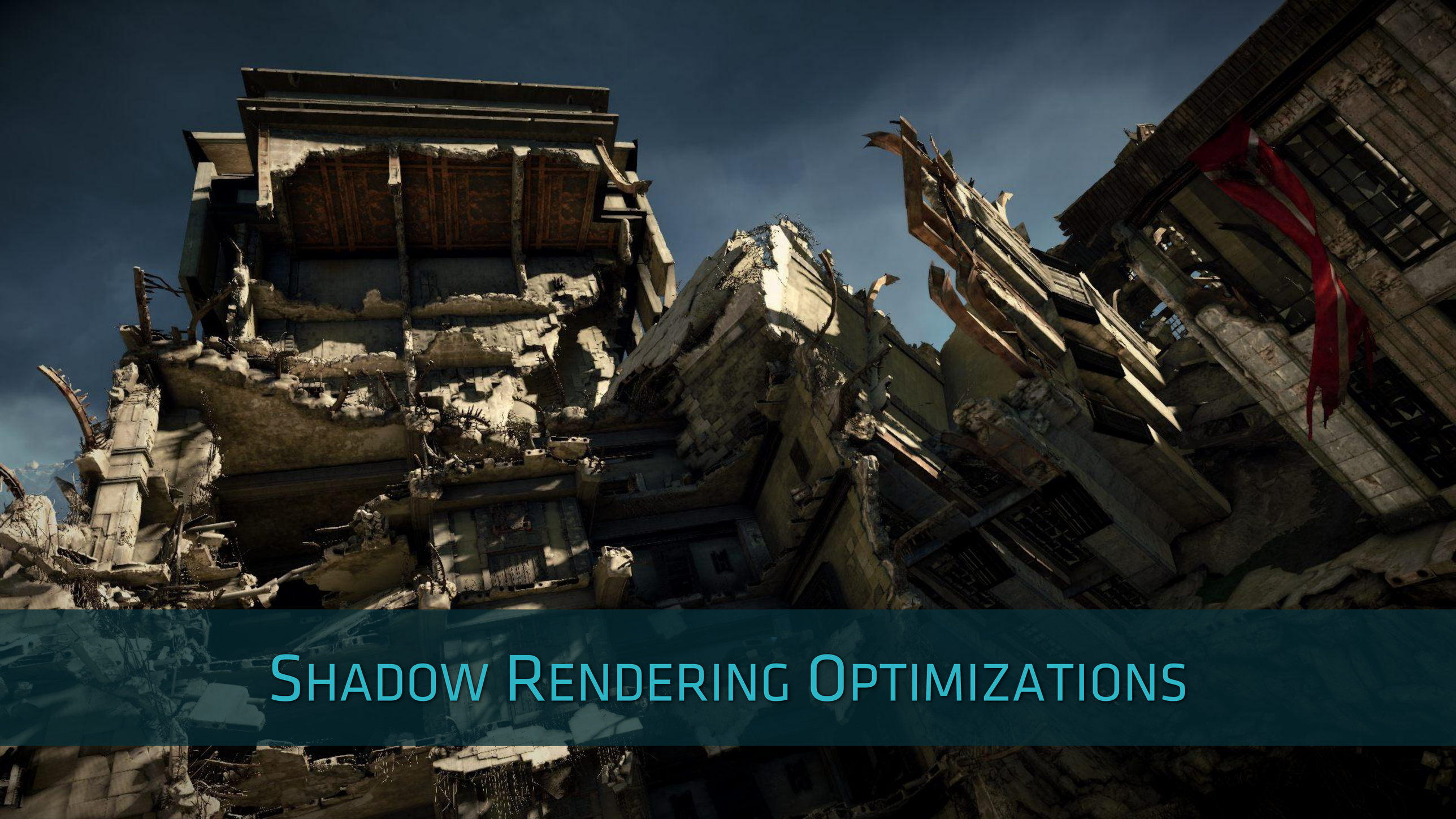
- G-Buffer for particle data
  - Small footprint
  - Position, Normal, Depth, Accumulated lighting
  - Flat data array
- Store several reference points per particle
  - 8x8, 4x4, 2x2 or 1x1
  - Artist chosen based on size
  - Normals bent outwards
  - Initialize with IBL lighting

Deferred particle lighting

- Integrated into regular lighting pass
  - Runs after each on-screen light
  - Allows to reuse shadow maps
- Final lighting available in particle shaders
  - Drive transparency based on lighting
  - Used for fog or dust

Deferred particle lighting

- Pros
  - Generic framework - works for any point in space
  - Builds on strengths of deferred rendering
  - Support all current and future lighting features
- Cons
  - G-Buffer size limits particle count
  - Interpolation can be visible



Shadow Rendering Optimizations

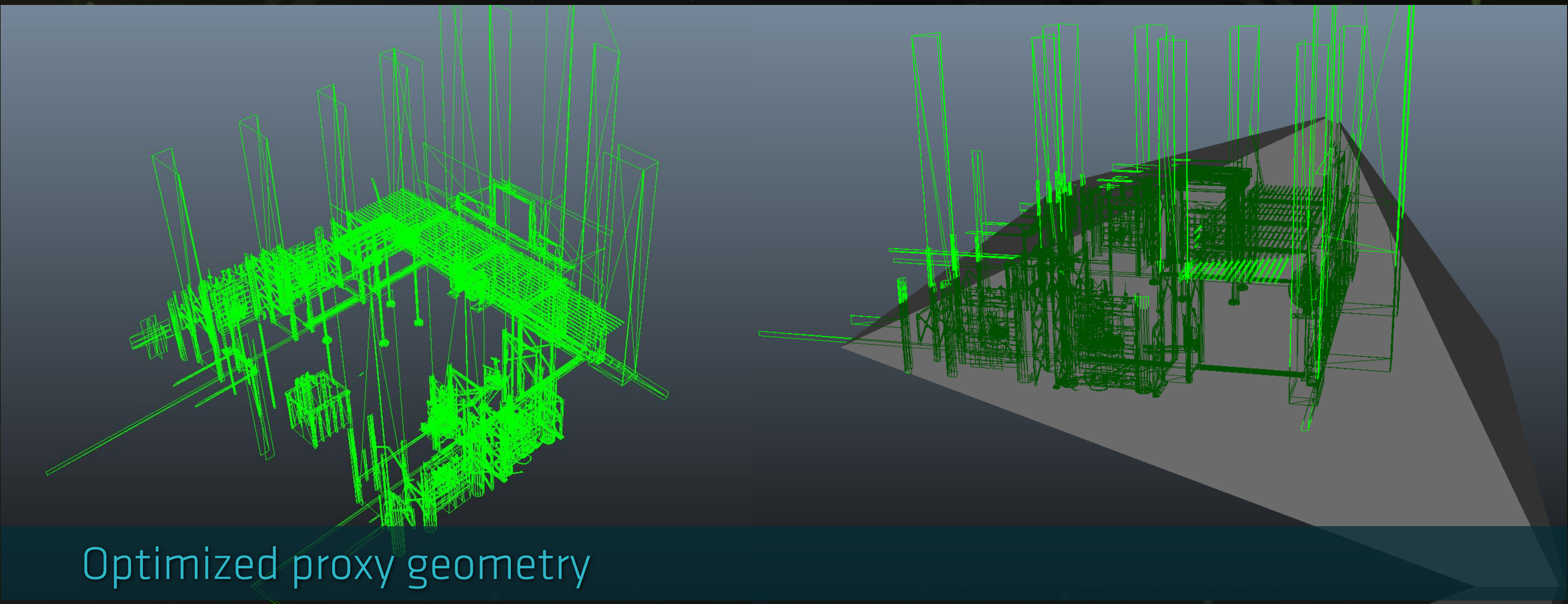
Shadow rendering optimizations

- Shadow map rendering turned out to be slow
  - Up to 60% of lighting budget
  - 5000+ drawcalls, ~3 million triangles
  - Tens of shadow casting lights
  - Four sunlight shadow cascades
- Discovered late in production
  - Cannot optimize art
  - Cannot reduce lighting quality

Local light shadow optimizations

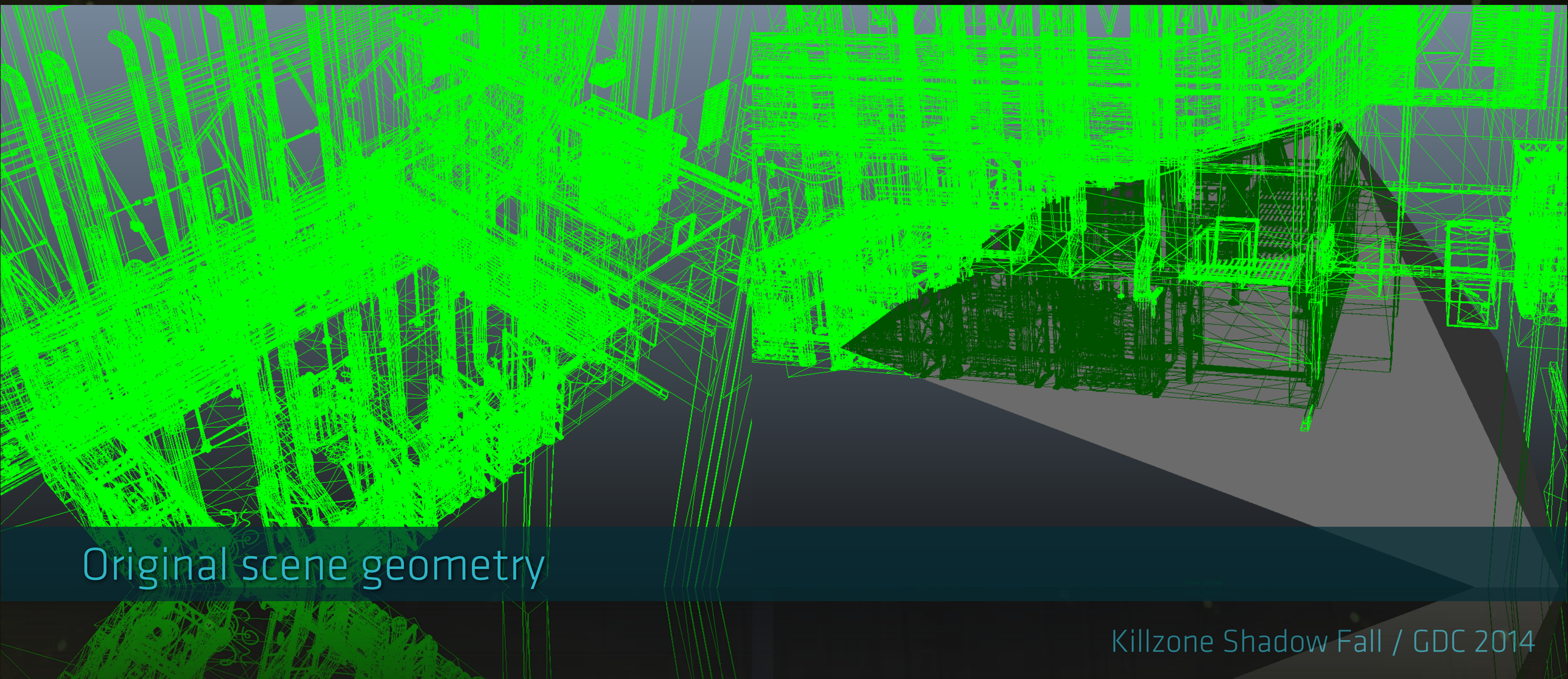
- Offline generated shadow proxies
  - Static lights and geometry
- Only polygons affecting shadow map
  - 60-80% triangle reduction
- Single drawcall per light
- Dynamic objects rendered separately
  - 500k triangles

Local light shadow optimizations



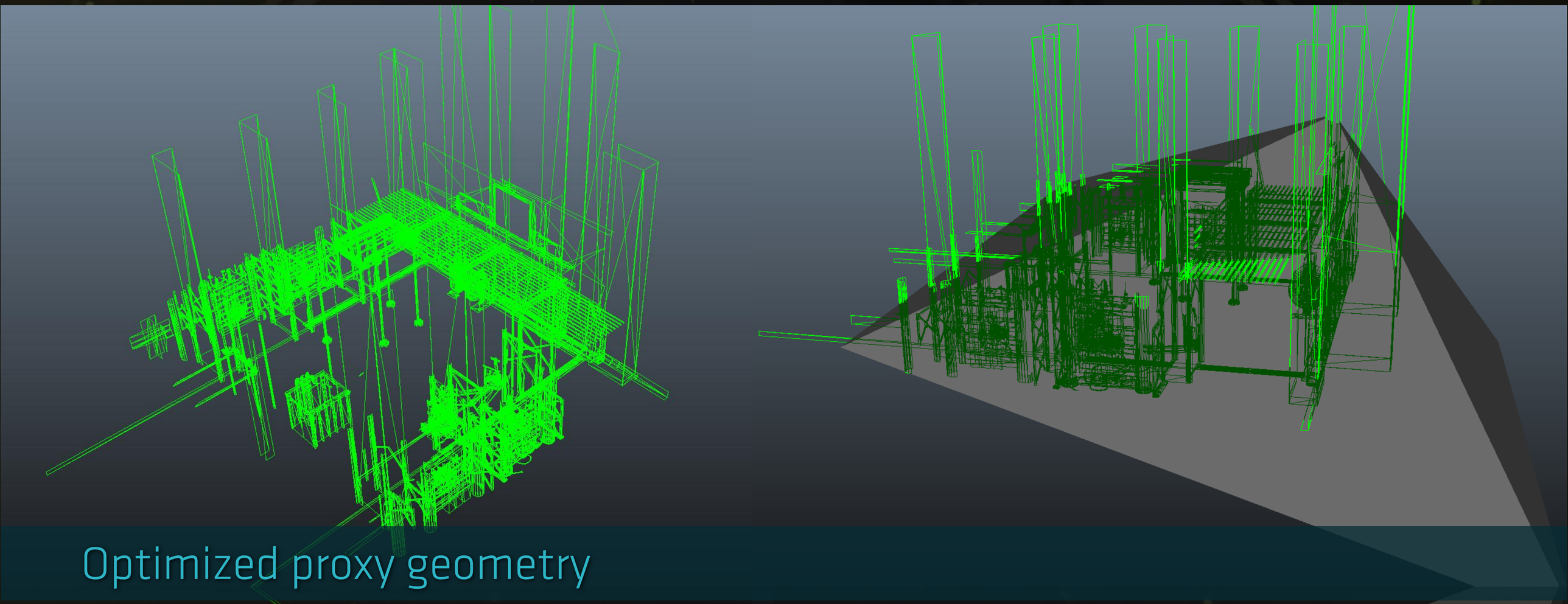
Optimized proxy geometry

Local light shadow optimizations



Original scene geometry

Local light shadow optimizations



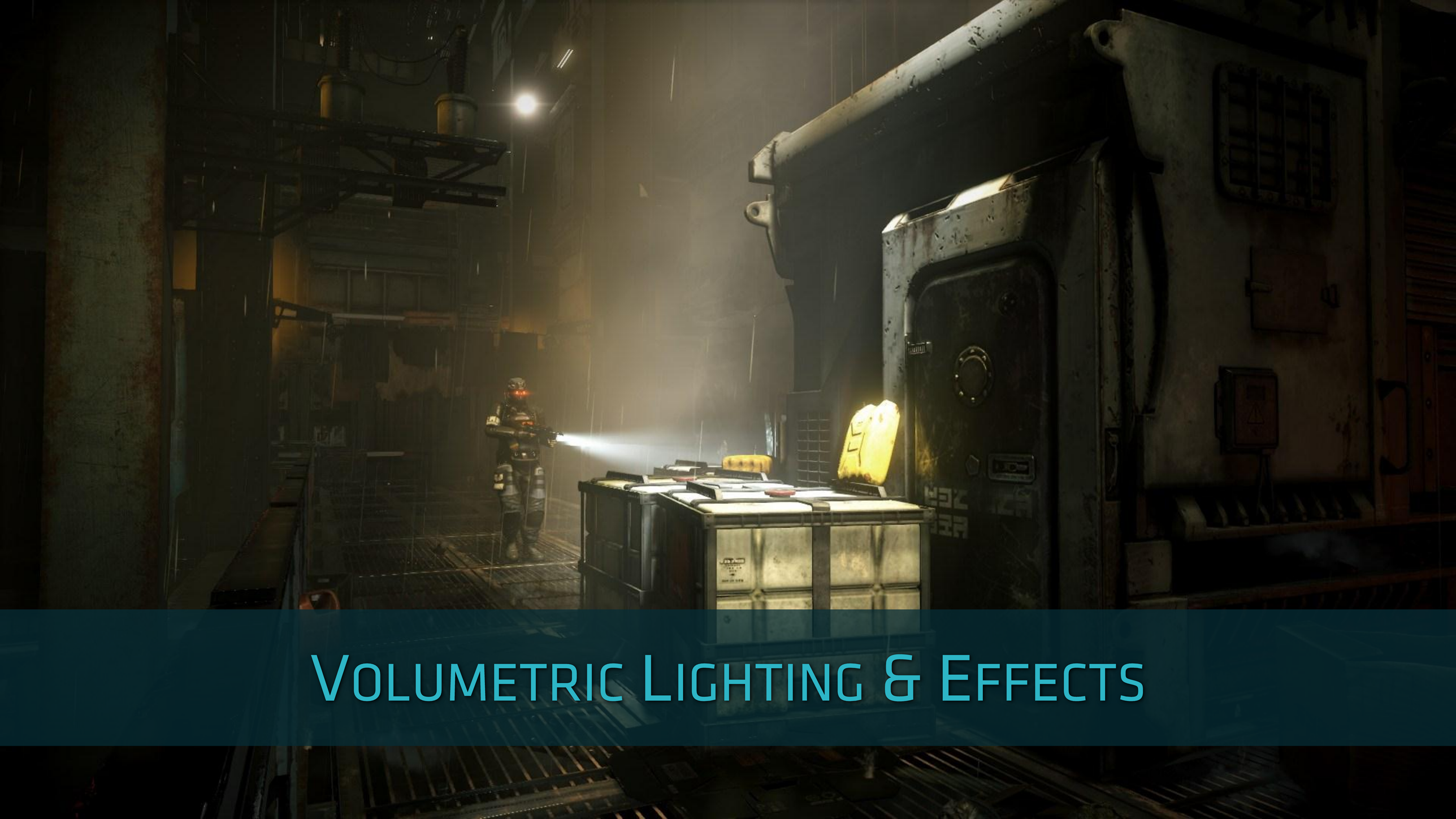
Optimized proxy geometry

Sun shadow optimizations

- Proxy mesh alone does not work for sunlight
  - Too many triangles
  - Too large
- Hybrid approach
  - Baked shadow map
  - Proxy delta mesh

Shadow map optimizations

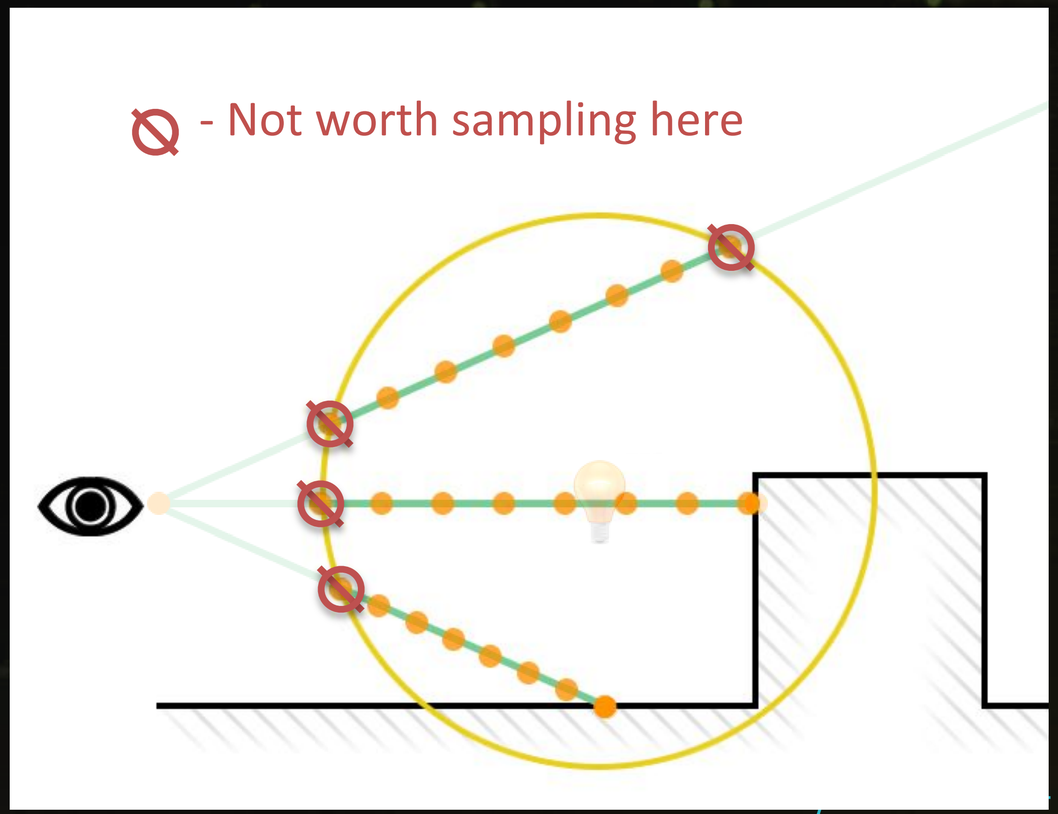
- Pros:
  - Significant CPU and GPU cost reduction
  - Cheap long distance sun shadows
    - 3rd and 4th cascades only use shadow map
- Cons:
  - Memory cost
  - Breaks on level geometry change
  - Offline process costs time



Volumetric Lighting & Effects

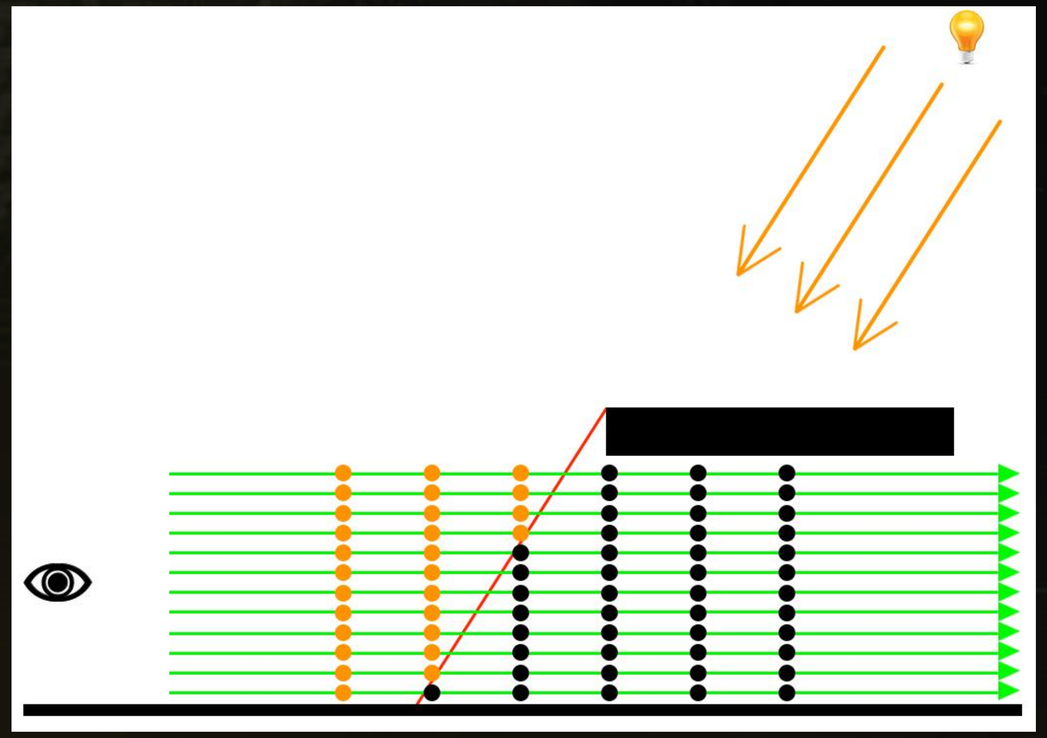
Volumetric lighting

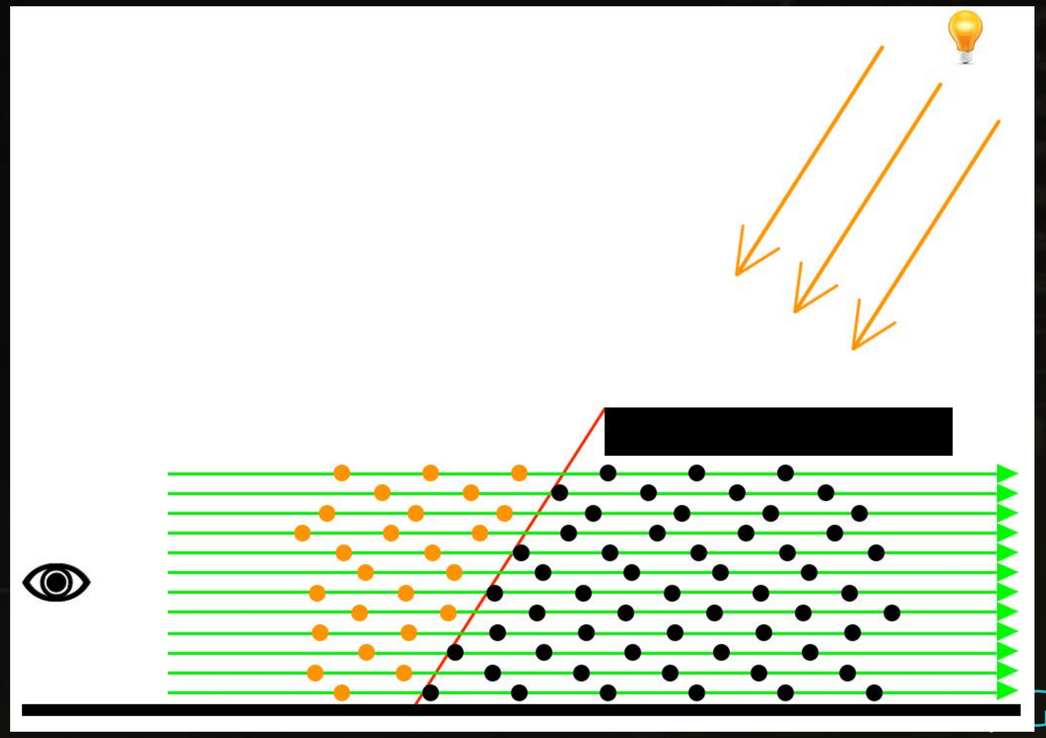
- One of the most important ingredients of KZ:SF look
- Implemented as straightforward view space raymarching
  - Support for all light configurations
  - Easily controllable cost vs. quality
  - Part of deferred lighting pass
- Rendered at half resolution
  - Bilateral upscale to full resolution



Volumetric lighting

- Raymarch step offset by random value
  - Increased perceived quality
  - Bilateral blur removes the dither pattern





Scattering Amount Buffer

- Plain volumetrics look bland
- Particle systems can add structure
  - Complete artist control
  - Reacts to physics, player movement, wind forces
- Particles rendered into 3D Scattering Amount Buffer
  - Affects intensity of raymarch samples
  - $1/8^{th}$ of native resolution, 16 depth slices
  - Camera space, quadratic depth distribution

Scattering Amount Buffer Visualization

Volumetric composing

Incorrect

Correct

Volumetric composing

Incorrect

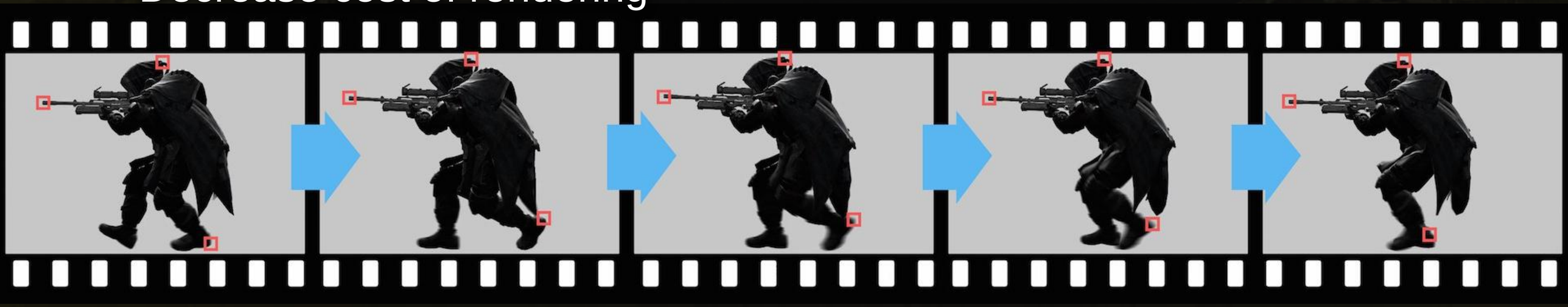
Correct

Volume Light Intensity Buffer

- Composing with transparencies is problematic
- Solved by 3D Volume Light Intensity Buffer
  - Similar idea to Scattering Amount Buffer
  - Half resolution to match volumetrics
  - Amount of visible volumetrics after ray marching
    - Between camera and given depth slice
    - Includes shadows, light attenuation and textures
- GPU Pro 5 - '*Volumetric Light Effects in Killzone Shadow Fall*'

Temporal Reprojection

- Consecutive frames are usually very similar
- Regular rendering is wasteful
  - Render image and throw it away
- Previous frames can improve the next
  - Increase visual quality
  - Decrease cost of rendering



Volumetric Reprojection

- Increased quality without extra raymarch samples
- Reuse previous volumetric buffer
  - Decide on color and depth similarities
  - `result = lerp(current, previous, 0.5*saturate(similarity))`
- Change raymarch offset every frame
  - Alternate between two configurations
  - Effectively doubles the sample count*

* Your mileage may vary, might contain traces of nuts

Temporal stability in post processing

- Post processing benefits from temporal reprojection
  - Mostly rendered at lower resolution
  - Sensitive to undersampling or rasterization artifacts
  - Smoother motion
- Bloom
- Screen Space Ambient Occlusion
- Godrays
- Exposure measurement

Reprojection disabled

Reprojection enabled

Dust and Rain

- Shader effects created by FX artists
  - Designed completely in nodegraph editor
- Fullscreen passes modifying g-buffer
- React to bullet decals or footsteps
  - Decals write to “user” channel of our g-buffer
- Top-down variance shadow map used
  - Limit rain to outdoors

Raindrops 3D texture

Real-Time Reflections

Reflections Overview

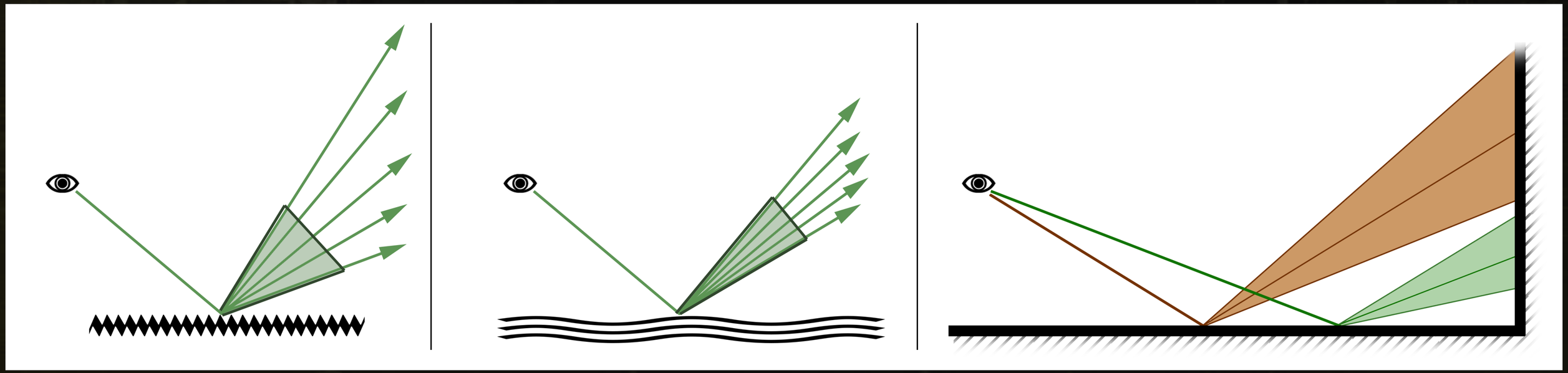
- Real-time raytrace system
  - Dynamic reflections, multiple distances
- Static localized cubemap zones
  - Local reflections
- Static background cubemap
  - Far away reflections
- Each stage falls back to next one on miss

Localized Cubemaps

- The zones are placed by artists
- Two pass cubemap rendering
  - Clean render with reflections disabled
  - Secondary bounces with reflections enabled
  - Rendering takes an hour per section
- Mipmap filtering matches BRDF specular cone
  - ‘*Local Image-based Lighting With Parallax-corrected Cubemap*’

Glossiness

- Driven by surface roughness and reflection ray length
  - Affect reflection cone aperture and radius
- Determines cubemap mip selection



Real-time reflections

- Screen space ray-tracing
- Stages
  - Ray-tracing
  - Filtering and reprojection
  - Composing with cubemaps
- Half resolution
  - Pick different pixel from 2x2 quad every frame
  - Cover full resolution after 4 frames

Ray-trace

- Constant step in screen XY
  - Smoother surfaces have smaller step
  - Reflection vector dependent
- Ray passes under weapon
- Hit depth interpolated from last two depths
- Reproject hit color from last frame
  - Secondary bounces!
- Output - hit color / hit mask / glossiness

Filtering and Reflection

- Generate mip chain from ray-trace results
  - Matches BRDF just like cubemaps
  - Use mask to discard ‘miss’ pixels
  - Not depth aware!
- Build the reflection buffer
  - Use gloss buffer to pick mipmap
  - Mip does match the cone radius

Stabilization and Reprojection

- Alternating samples need stabilization
- Temporal reprojection supersampling filter
  - Blend with history if colors are similar
  - Use reflection neighborhood color range
  - ‘*Real-Time Global Illumination and Reflections in Dust 514*’
- Compose with cubemaps
  - Ray-trace mask used for blending

Anti-Aliasing

KILLZONE® SHADOW FALL

ANTI-ALIASING

- Originally went for MSAA
  - With temporal reprojection for better quality
- Implementation started very late
  - Other features took priority
  - Launch-title ‘noob’ mistake
- Introduced small performance hit
  - Game assets already balanced
  - No time to find extra GPU performance

Temporal Anti-Aliasing

- Temporal reprojection + FXAA
  - No MSAA
  - Better image stability
- Accumulate pixels into history buffer
  - Contains roughly 16 frames worth of data
  - Uses color similarities criteria
- Experimented with sub-pixel jitter

Image by Andrew Selle

Temporal Anti-Aliasing

- Numerical diffusion is a problem
  - Image gets blurry with reprojection
  - Usually invisible with MSAA
- Use back and forth error compensation and correction method
  - '*An Unconditionally Stable MacCormack Method*'

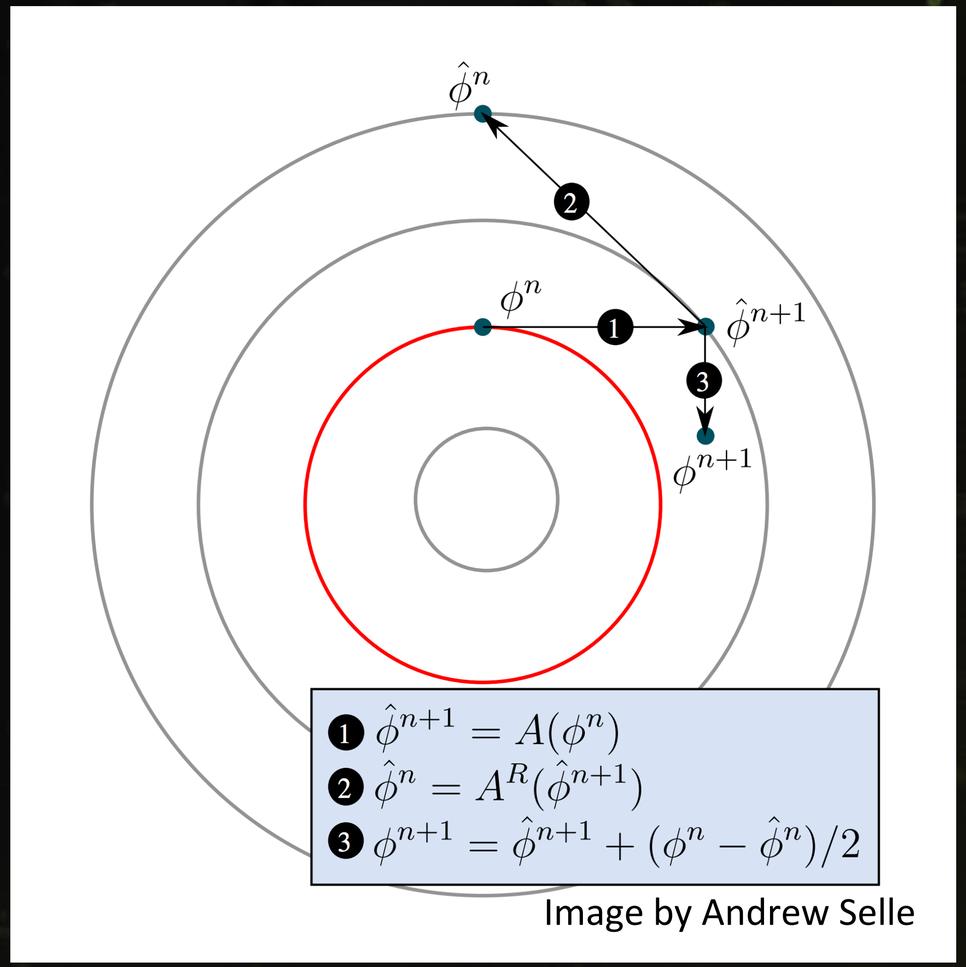


Image by Andrew Selle

Multiplayer Rendering

Temporal 1080p

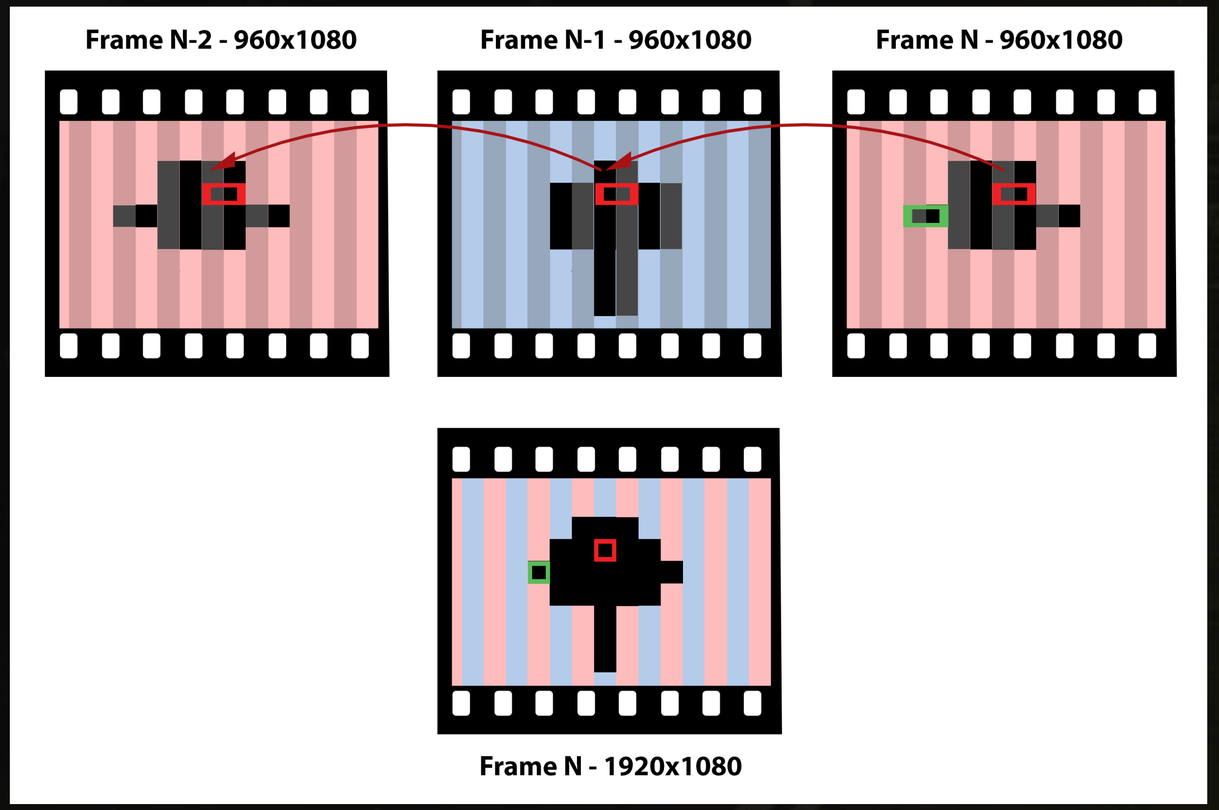
- Single player targets 1080p 30 fps
- Multiplayer targets 1080p 60 fps
  - Faster responses
  - Smoother gameplay
- Did not want to downsize the content
  - Multiplayer needs to look next-gen
  - No time to create optimized assets
- Tech solution needed

Temporal 1080p

- Needed 100% speedup
  - But not lower quality
- Reprojection can help here
  - Render buffers at 960x1080
  - Alternate rendering of odd/even pixels
  - Use reprojection to build 1920x1080 frame
- Results hard to distinguish from 1080p single player
  - Usually 80% performance gain

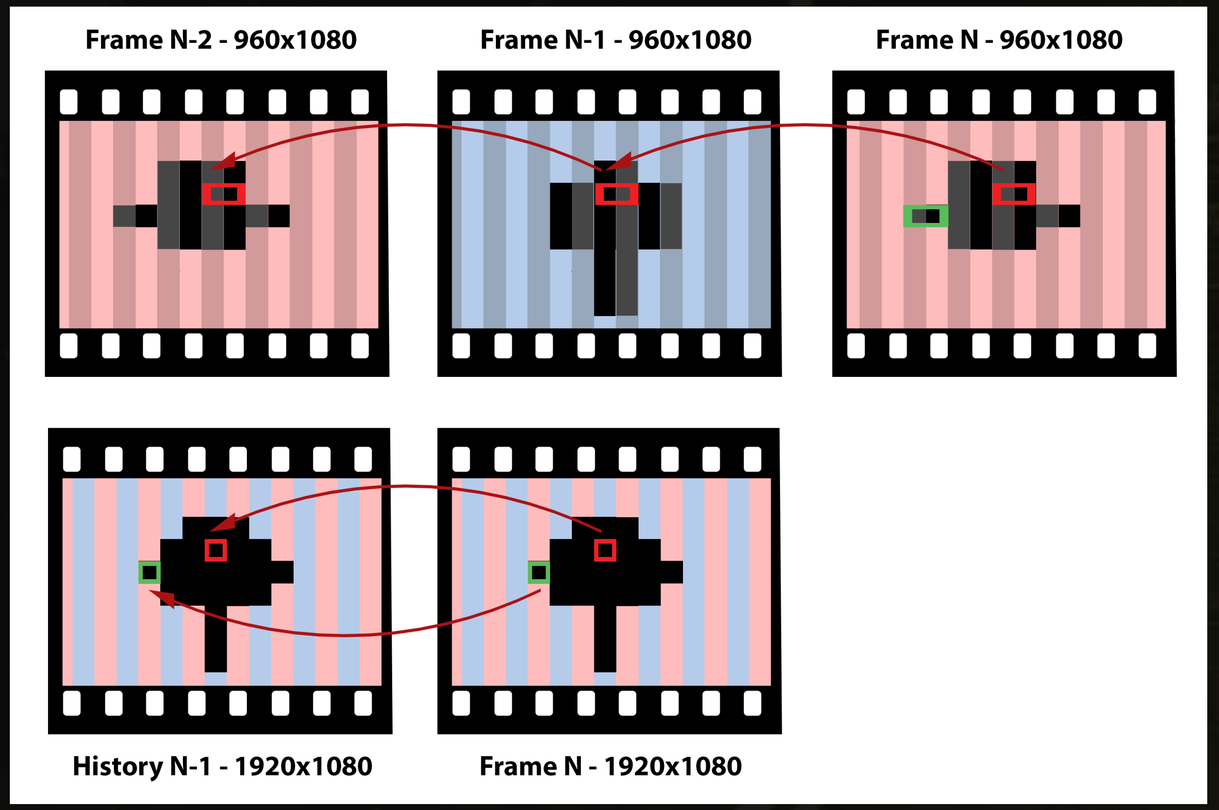
Temporal 1080p

- Keep two previous half-frames
  - Use double reprojection
- Check similarity of N and N-2
  - Color neighborhood similarity
  - Motion continuity
- Accept pixel N-1 for similar frames
  - Otherwise just interpolate from N



Temporal 1080p

- Keep full-resolution history buffer
- Only reproject in safe case
  - Motion is coherent
  - Colors are similar
- Adds extra image stability



The End / Questions?

- Recap:
  - Physically correct lighting is a big step, go the full distance.
  - Don’t let the lightmaps disappoint you, fight back.
  - It is worth investing into particle lighting and volumetrics.
  - Real-time reflections are the next thing.
  - Reproject all the things!

Special thanks: **Andreas Varga** / **Guido de Haan** / **Hugh Malan** / **Jaap van Muijden** / **Jeroen Krebbers** / **Kenzo ter Elst** / **Michal Drobot** / **Michiel van der Leeuw** / **Nathan Vos** / **Will Vale**

Bonus Slides - Forcefields, Texture Streaming

Forcefields

- Art-driven force simulation framework
- Several area affecting primitives
  - Wind box, explosion, vortex
- Statically placed
- Attached to entities or player
- Focus on complete art-direction control
- Affects cloth, particles and shaders

Early forcefields prototype

Forcefields

- Calculation is running as compute job
  - 60,000 points sampled each frame
- Explicit queries return forces for specific points
  - Used for cloth simulation or particles
- Forces cached in grid around the player
  - Grids - 16x16x16x25cm, 32x32x32x1m, 16x16x16x2m
  - Data available in shaders
  - Used for foliage, tarps or water surface
  - Includes spring solver with few elasticity presets

Forcefields visualization

Forcefields+Particles+Sprites=Crowd

Texture Streaming

- Killzone 3 prioritized streaming with bounding boxes
  - Does not work inside buildings
- Shadow fall needs 10+GB RAM without streaming
  - Have to stream almost all mipmaps
- PS4 GPU can report mipmap usage
  - No change to shaders needed
  - Precise estimation for texture streaming
  - Works well with complicated shaders