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UNREAL
TECHNOLOGY

Implementing Distributed Global Illumination in Unreal Engine 3

Derek Cornish
Senior Engine Programmer
Epic Games, Inc.

Epic Games

- Founded 20+ years ago by CEO Tim Sweeney
- About 120 employees (mostly) in Raleigh, NC
- External studios in Utah, Warsaw, Shanghai
- Developer of state-of-the-art, best-selling games
  - Early success with *Jill of the Jungle*, *Epic Pinball*
  - *Unreal* and *Unreal Tournament* series
  - *Gears of War* series
- Licensing *Unreal Engine* since 1996
  - Hundreds of shipped games using it
  - *Unreal Engine 3* is the most widely licensed engine this console generation, continues to grow

Derek Cornish

- Senior Engine Programmer at Epic Games
  - *Unreal Engine 3, Gears of War 2*
- Previously worked at NVIDIA
  - OpenGL drivers for multiple GPU generations
  - Direct3D performance analysis tools
  - *NVIDIA PerfKit, PerfHUD*
- Previous life in middleware

Global Illumination Origins

- *The rendering equation*, James T. Kajiya

$$L_0(x,\omega,\lambda,t) = L_e(x,\omega,\lambda,t) + \int_\Omega f_r(x,\omega',\omega,\lambda,t) L_i(x,\omega',\lambda,t)(-\omega' \cdot n) d\omega'$$

  - Describes the total amount of light emitted from a point along a particular viewing direction, given a function for incoming light and a BRDF
  - Implicitly encompasses virtually all light phenomena
  - Nearly all realistic rendering techniques in computer graphics attempt to solve this one equation
  - Global Illumination describes the general field

Global Illumination Approaches

- Many, many approaches to global illumination
  - Radiosity, Recursive Ray Tracing, Photon Mapping, Bi-directional Path Tracing, etc…

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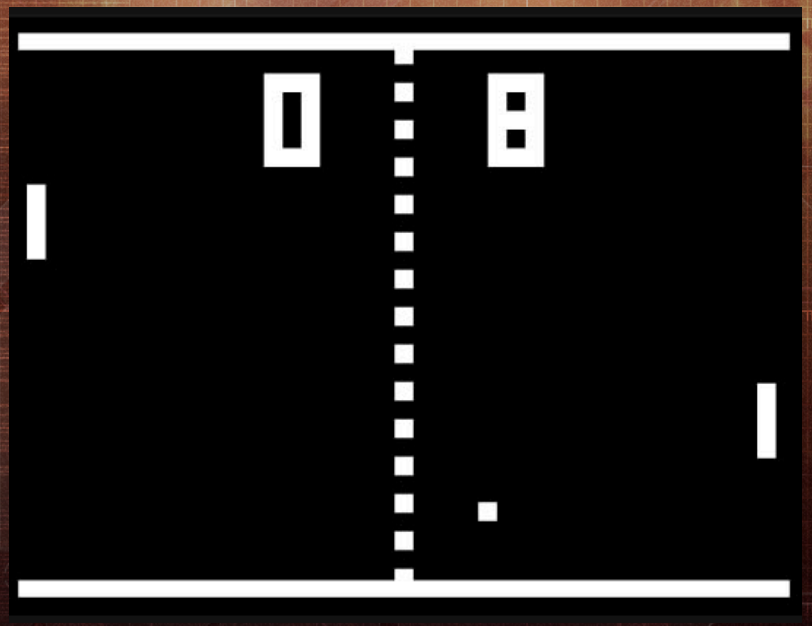
Global Illumination Approaches



- Many, many approaches to global illumination
  - Radiosity, Recursive Ray Tracing, Photon Mapping, Bi-directional Path Tracing, etc…
- Many refinements to each of these techniques

Global Illumination Tradeoffs



vs.

Virtually all of them involve significant tradeoffs

The key to building any good system:

Balance

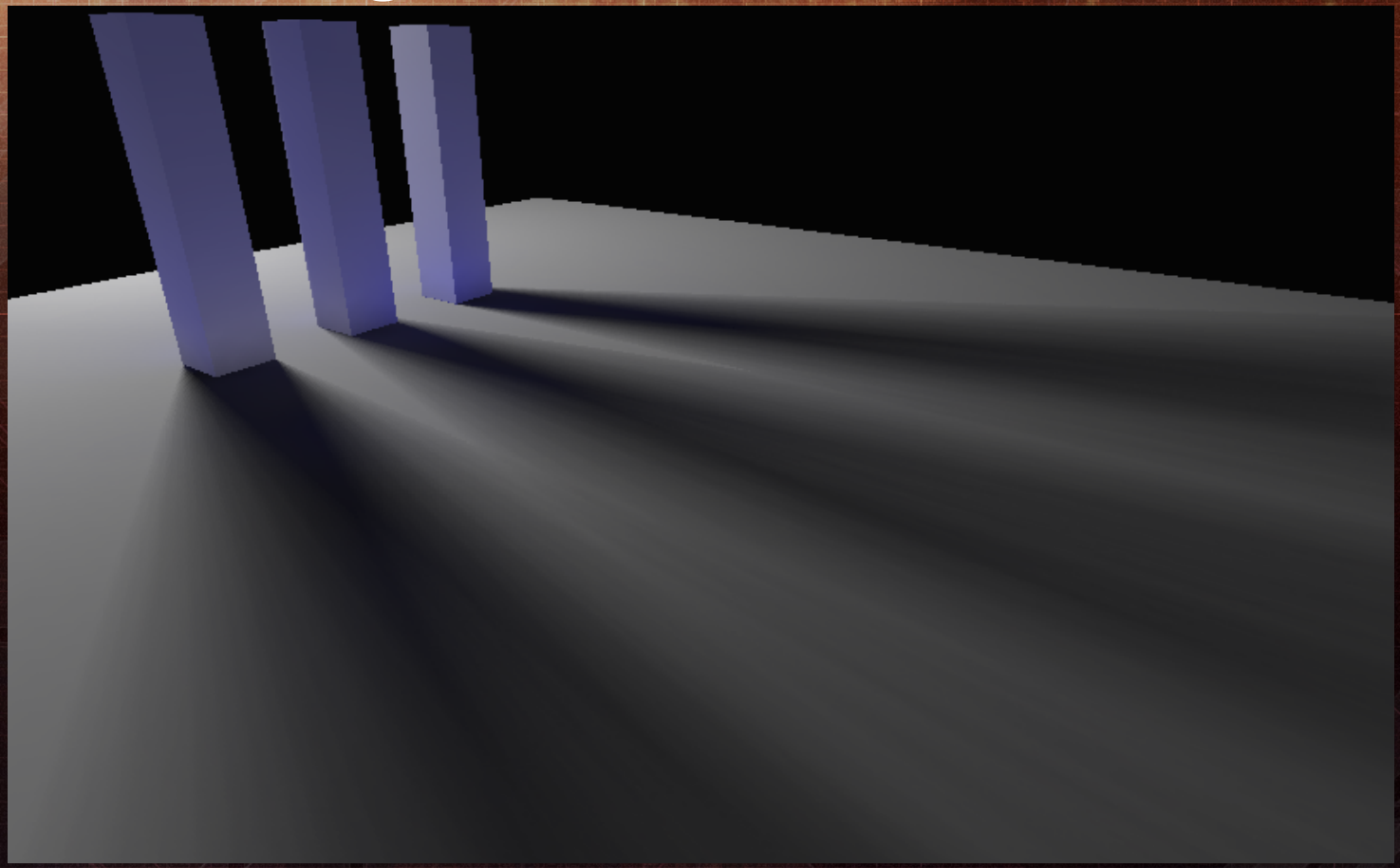
Unreal Lightmass

- In-house global illumination solver for UE3
  - High-quality static lighting with next-generation effects
  - Uses a combination of GI techniques, optimizations
  - Careful balance of features and performance
- Lightmass is feature-rich and highly-optimized
  - Arbitrary light and primitive combinations
  - Arbitrary lights from emissive texels on meshes
  - Soft shadows from area lights with accurate penumbrae
  - Complex diffuse inter-reflection
  - Masked and translucent shadows
  - Character and environment lighting
  - Large level support, highly multithreaded
  - Much more…

Unreal Lightmass Features

Accurate soft shadows from area lights

Unreal Lightmass Features



Accurate soft shadows from area lights

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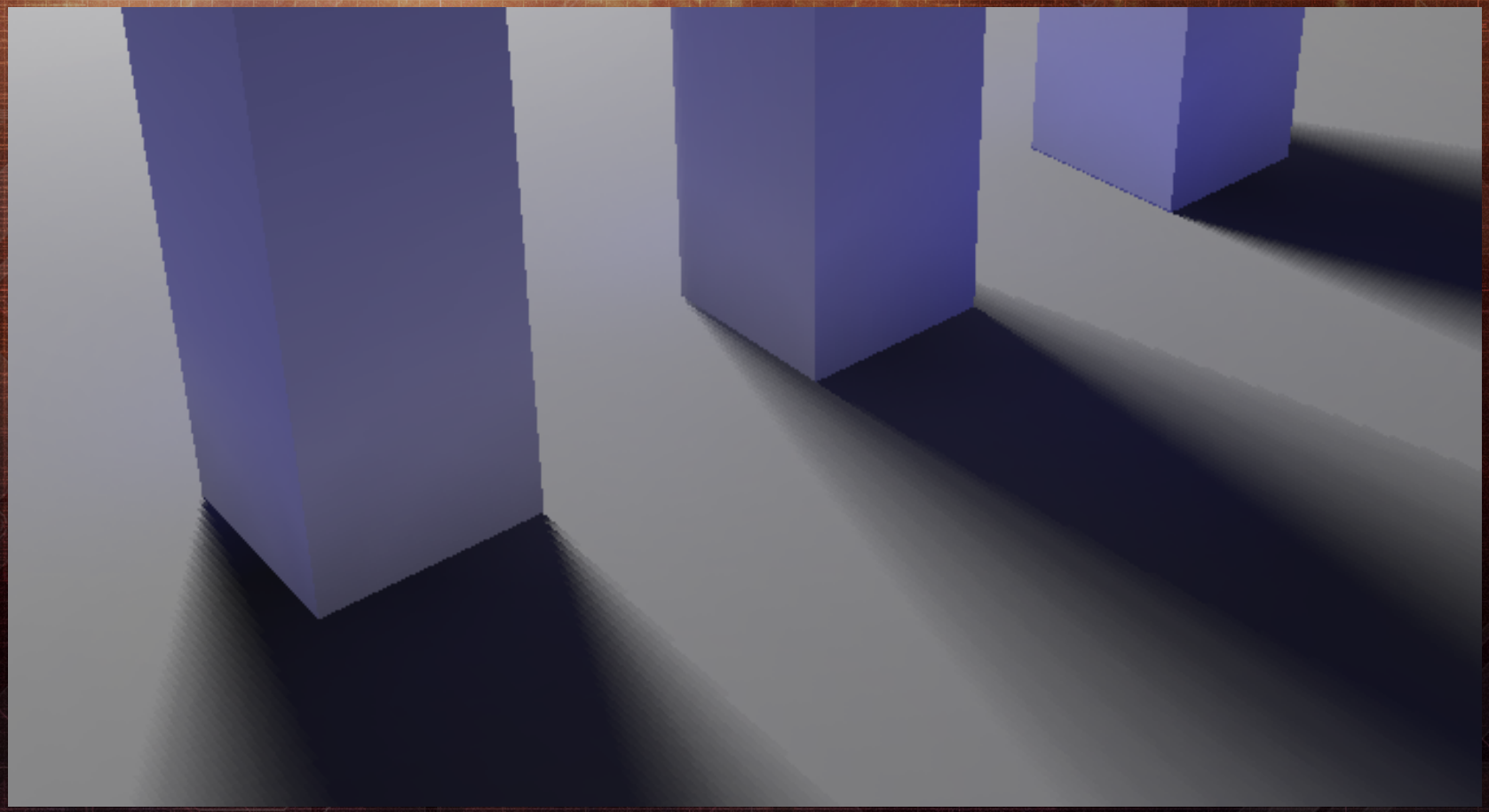


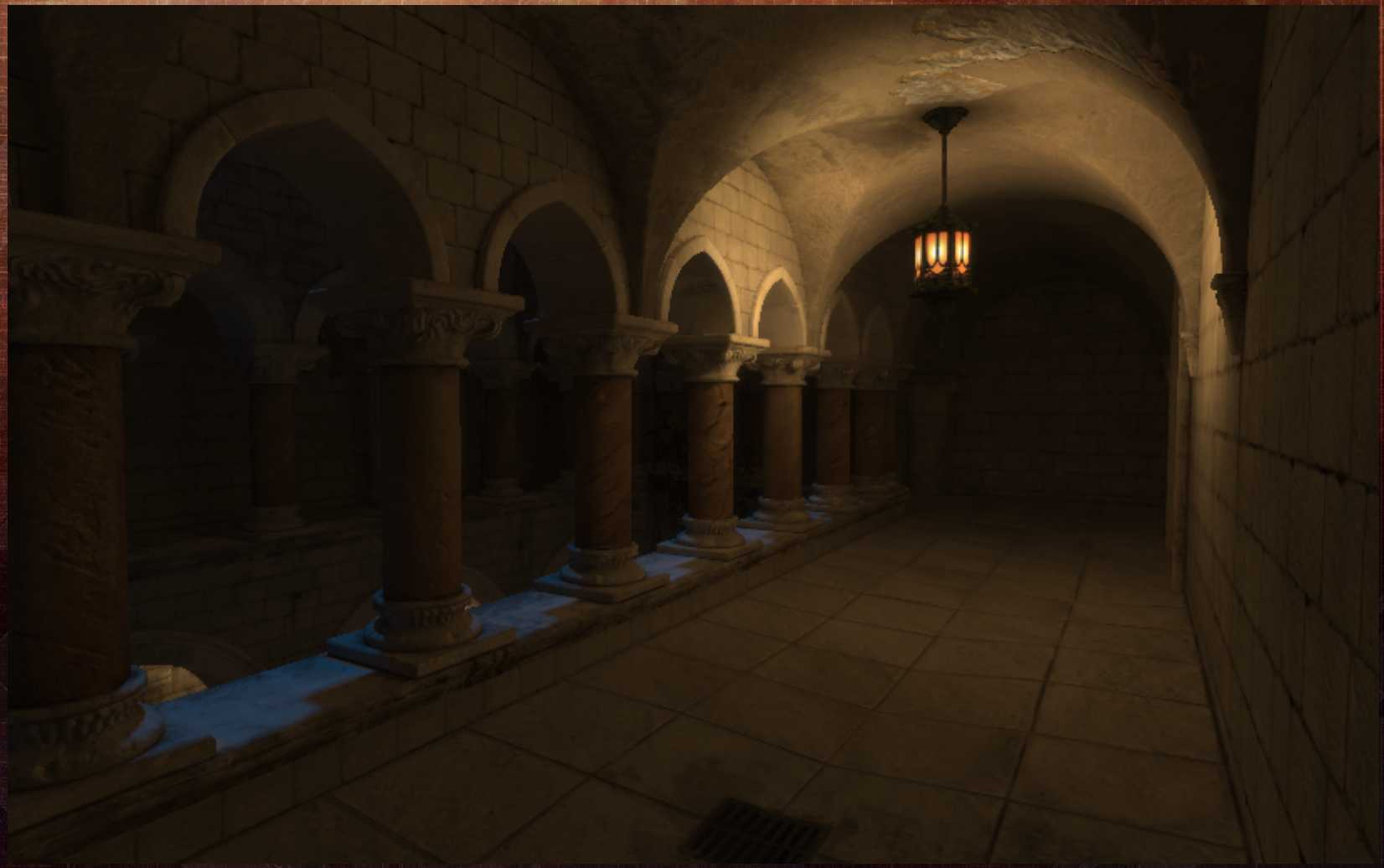
Accurate soft shadows from area lights

Flexible and artist configurable penumbrae

Unreal Lightmass Features

Arbitrary lights from emissive materials on meshes

Unreal Lightmass Features



Arbitrary lights from emissive materials on meshes

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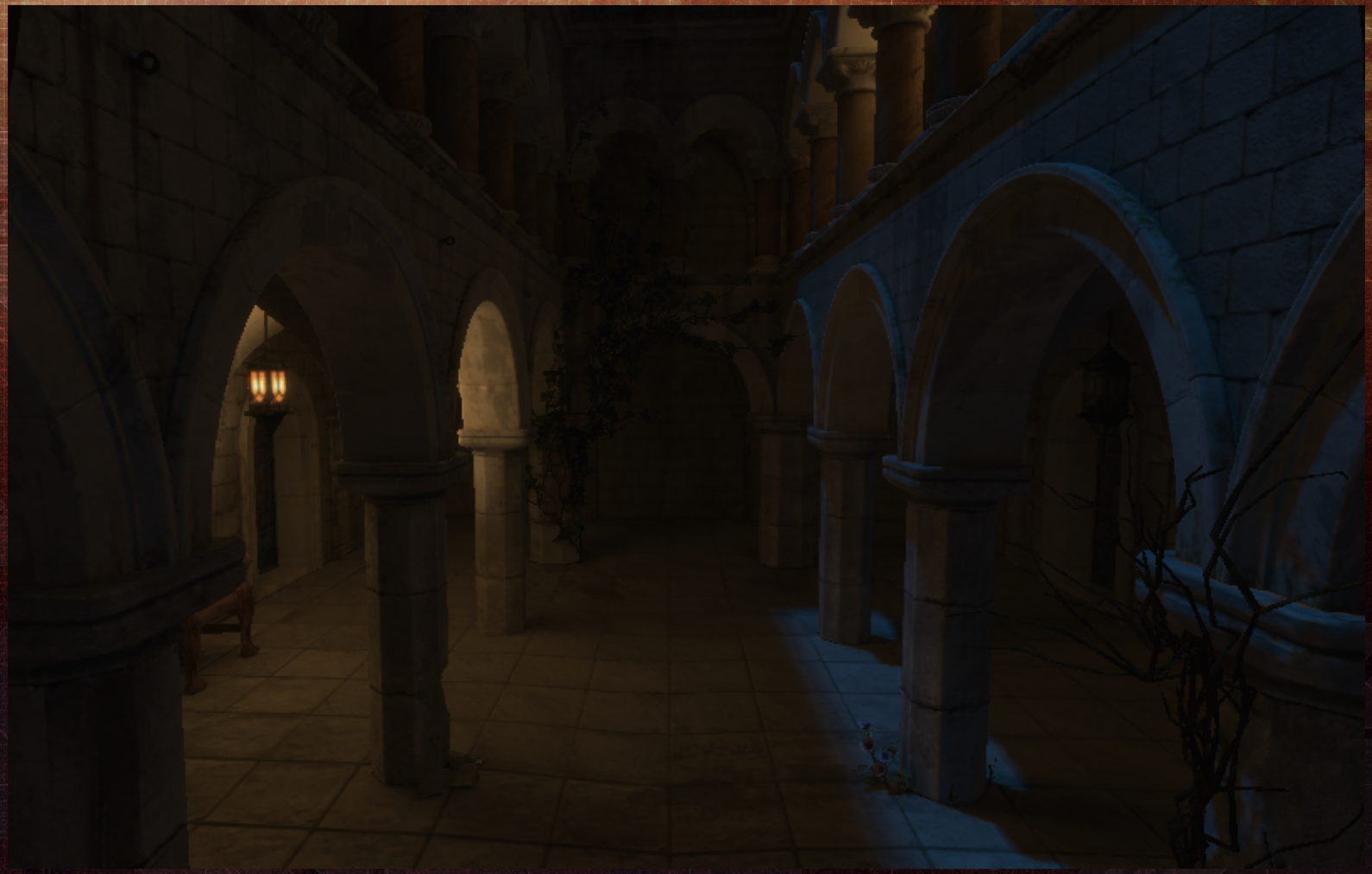

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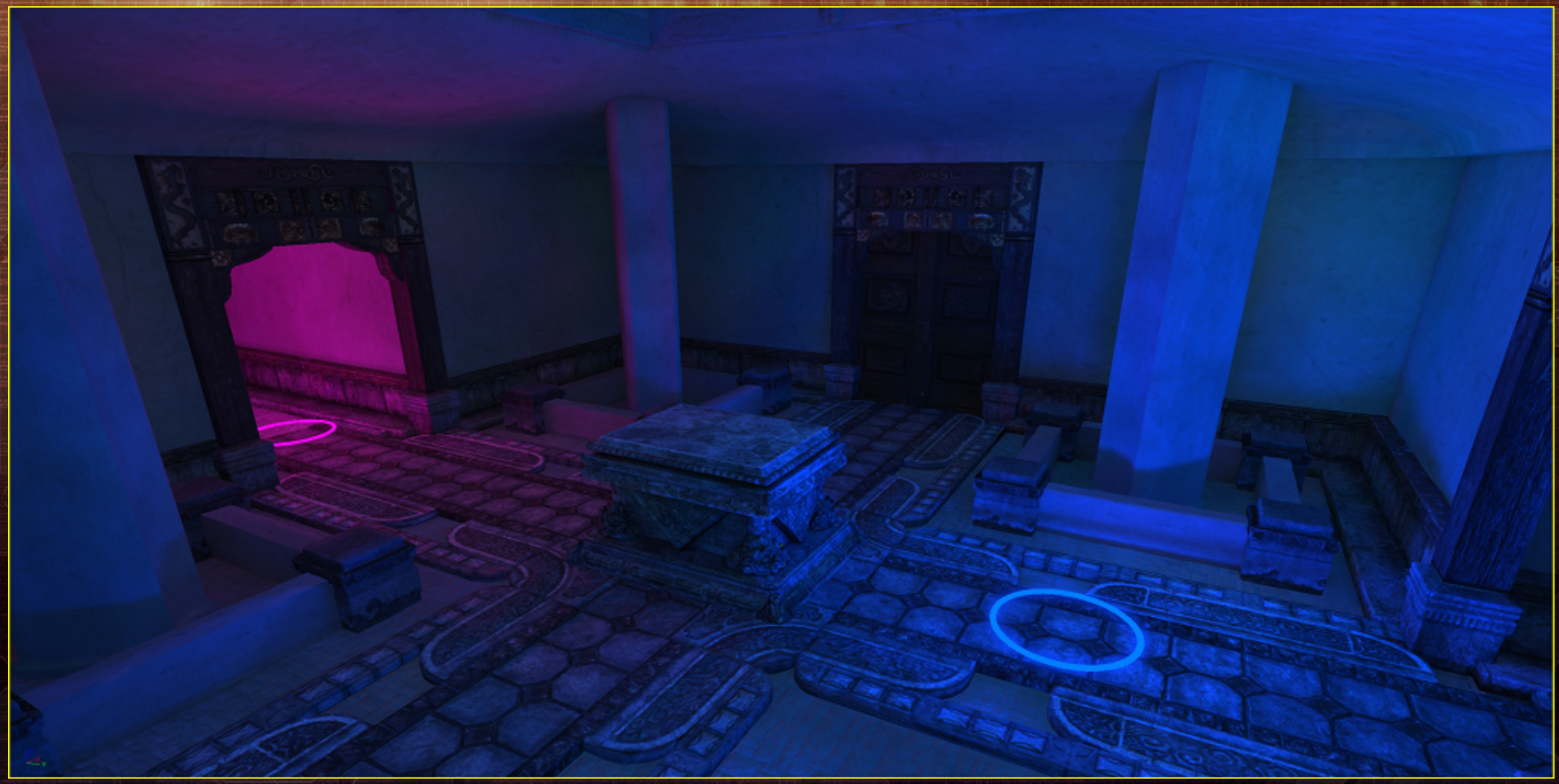

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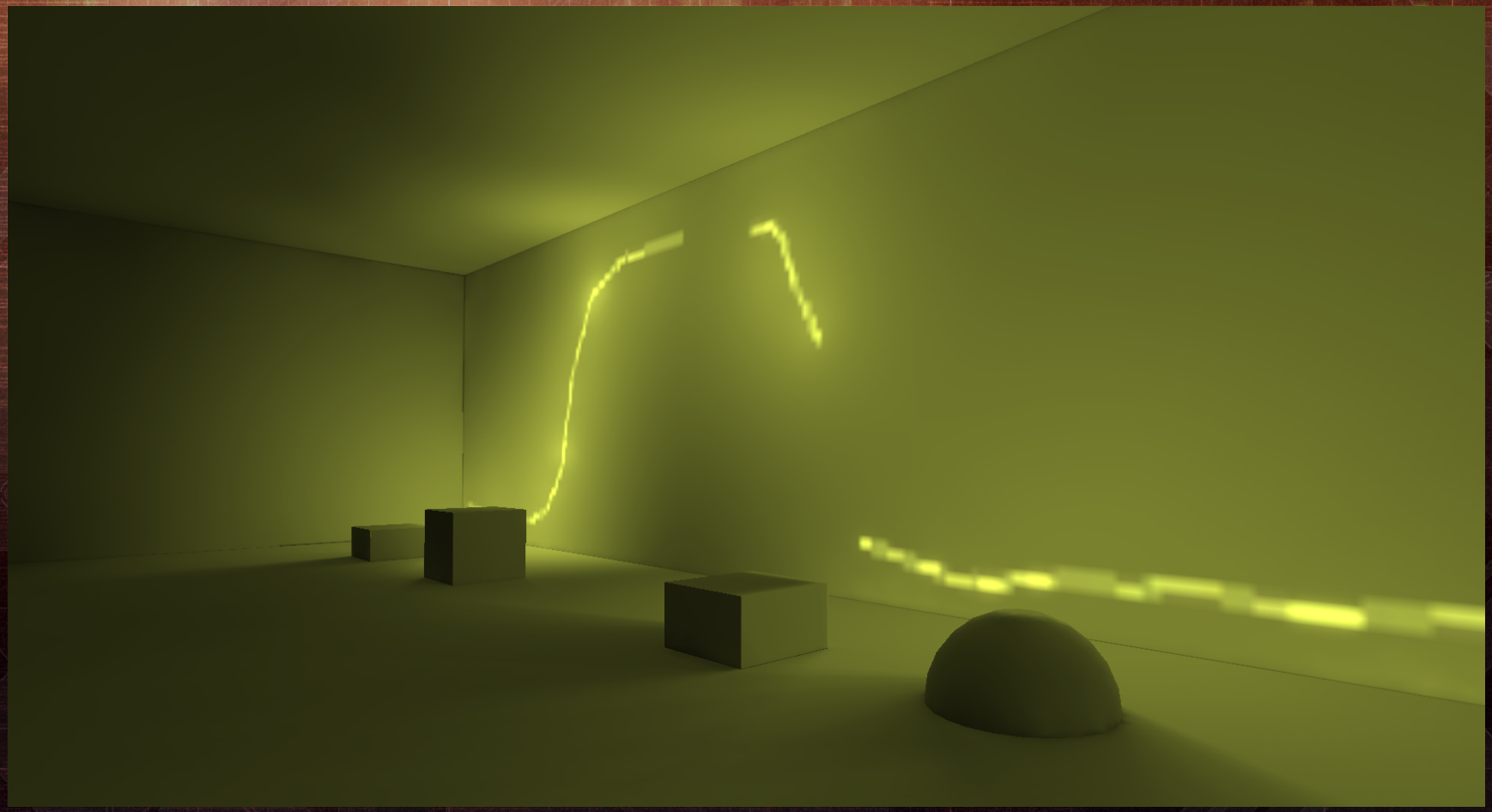
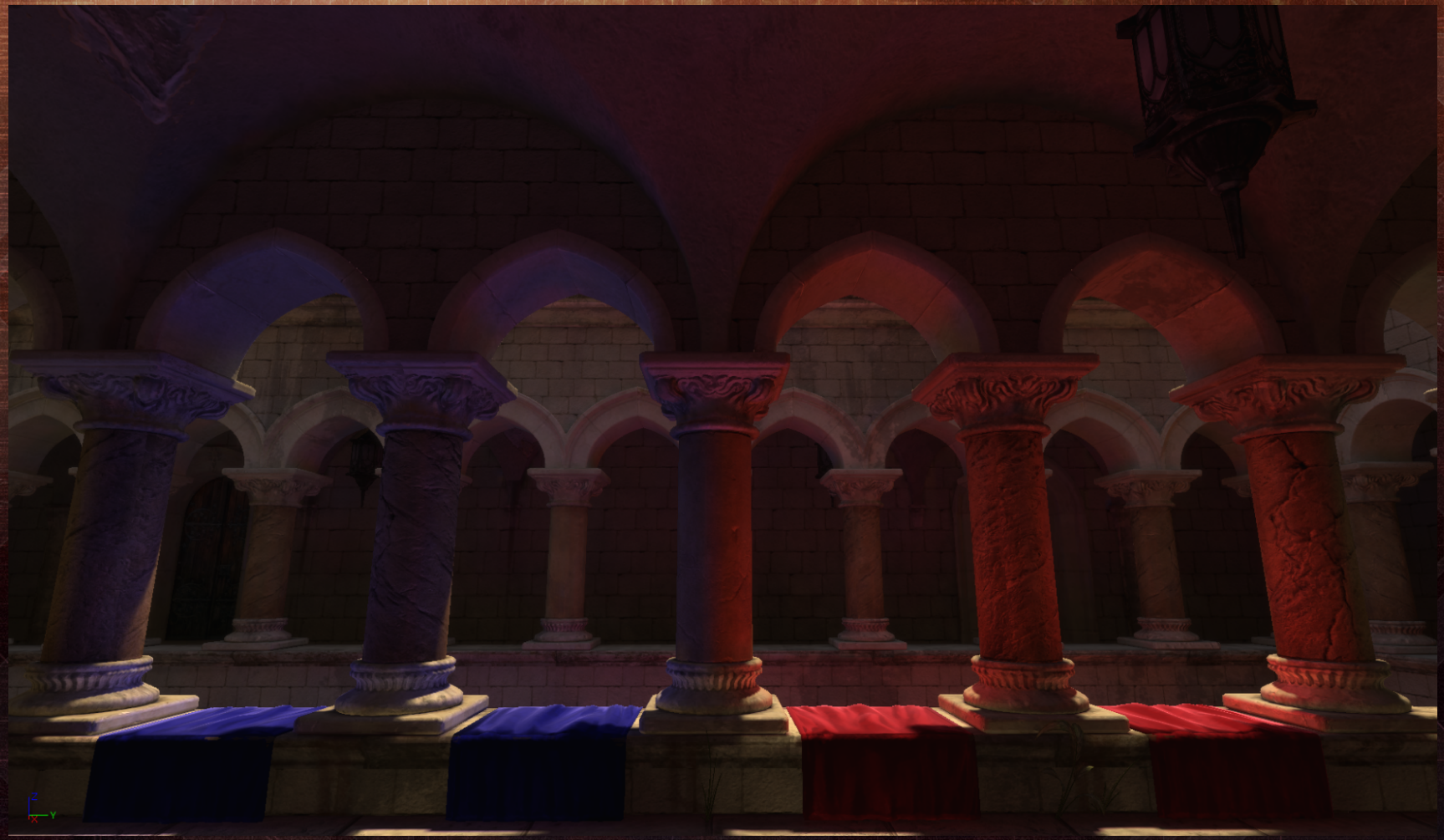


Arbitrary lights from emissive materials on meshes

Unreal Lightmass Features

Complex diffuse inter-reflection (Color bleed)

Unreal Lightmass Features



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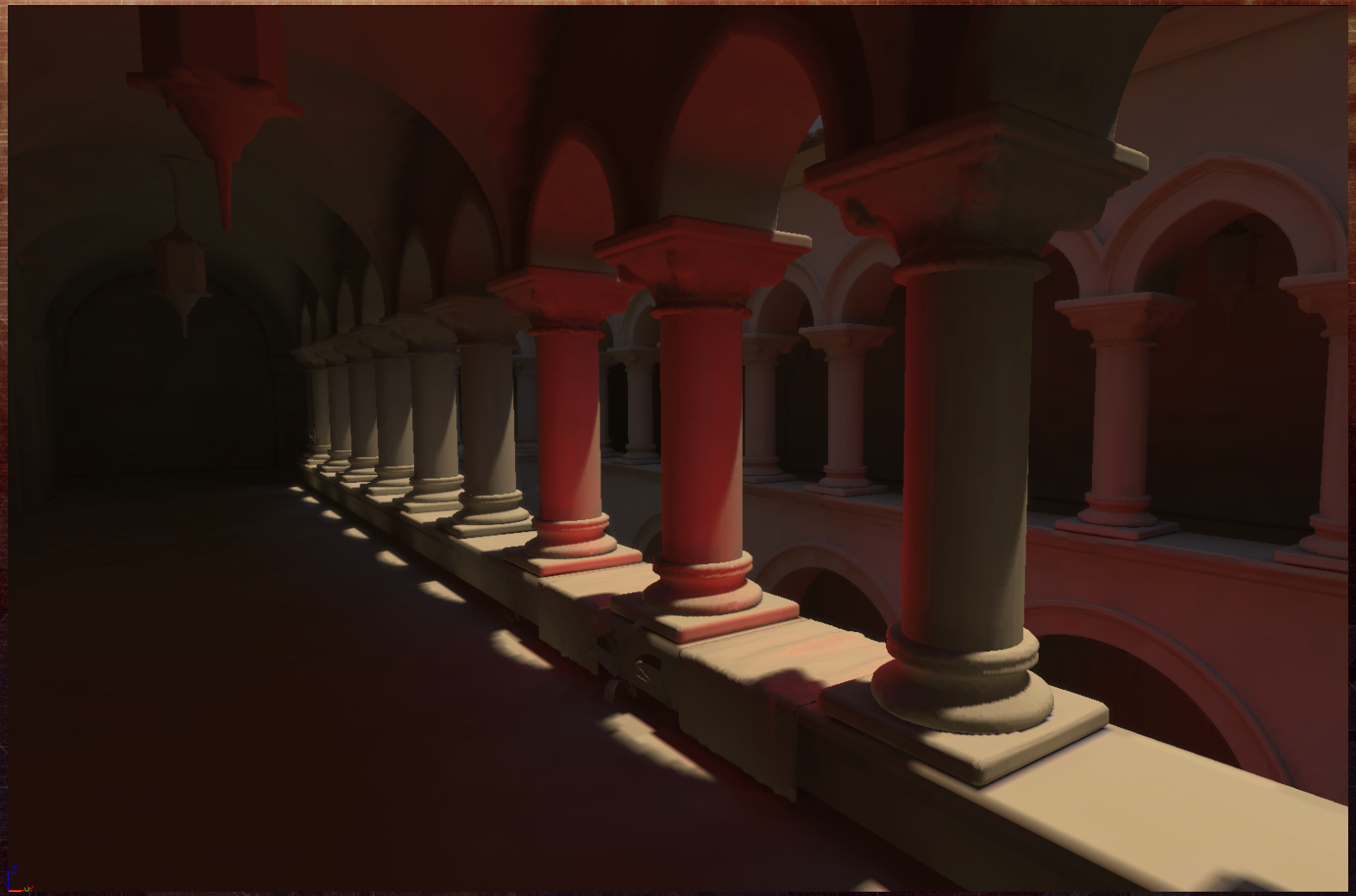

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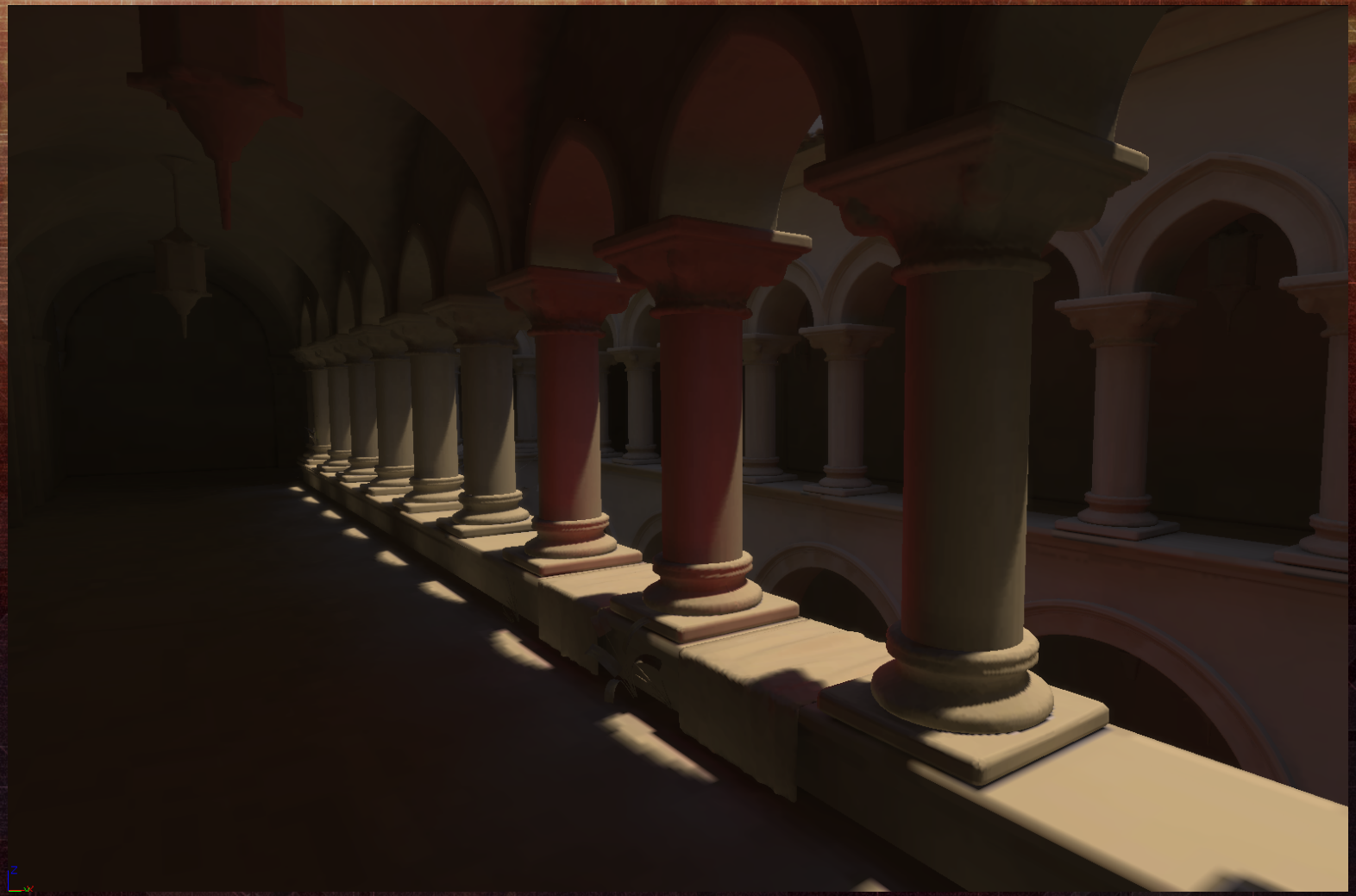


Complex diffuse inter-reflection (Color bleed)

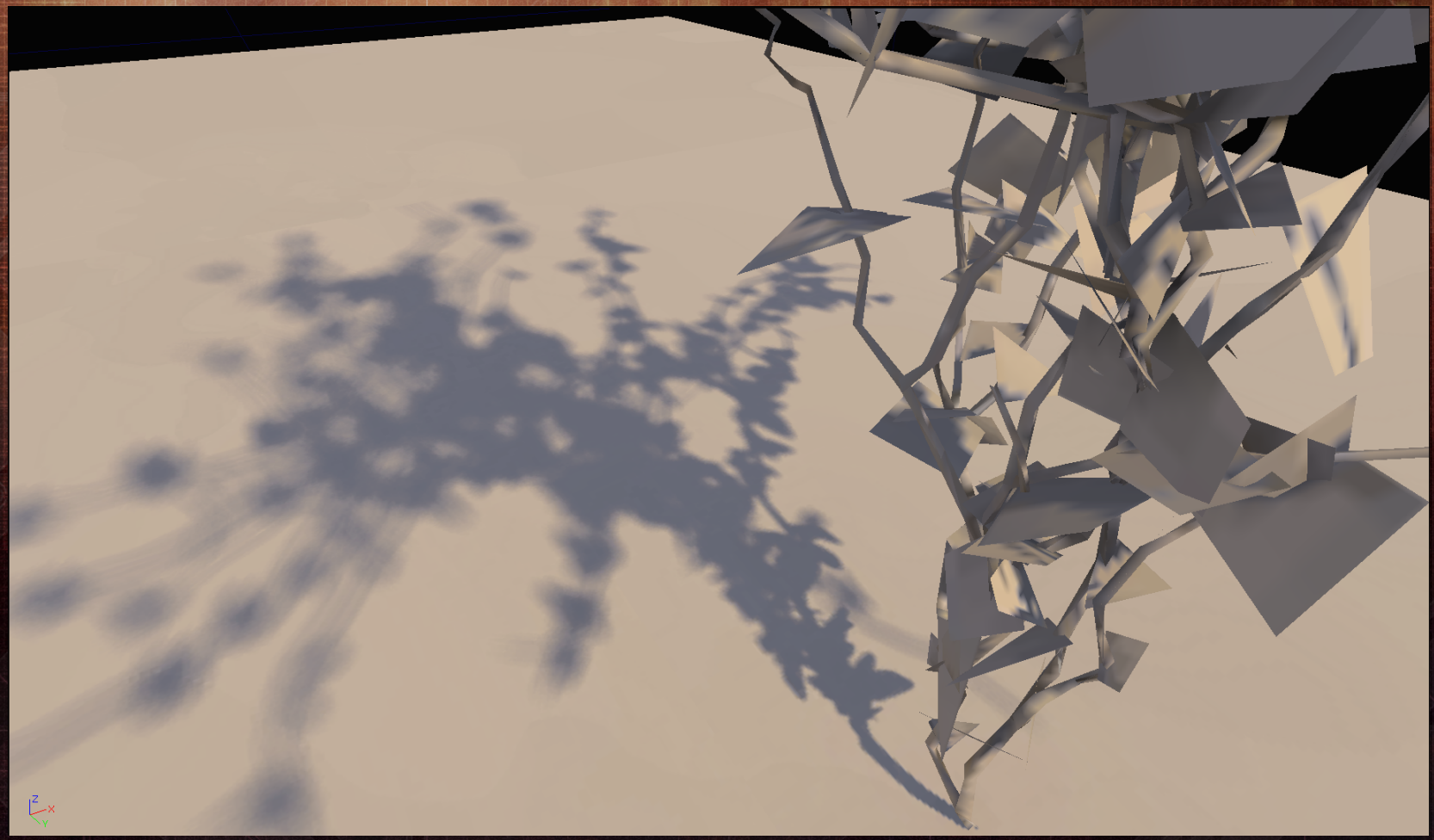
Unreal Lightmass Features

Masked and translucent shadows

Unreal Lightmass Features

Masked shadows

Unreal Lightmass Features

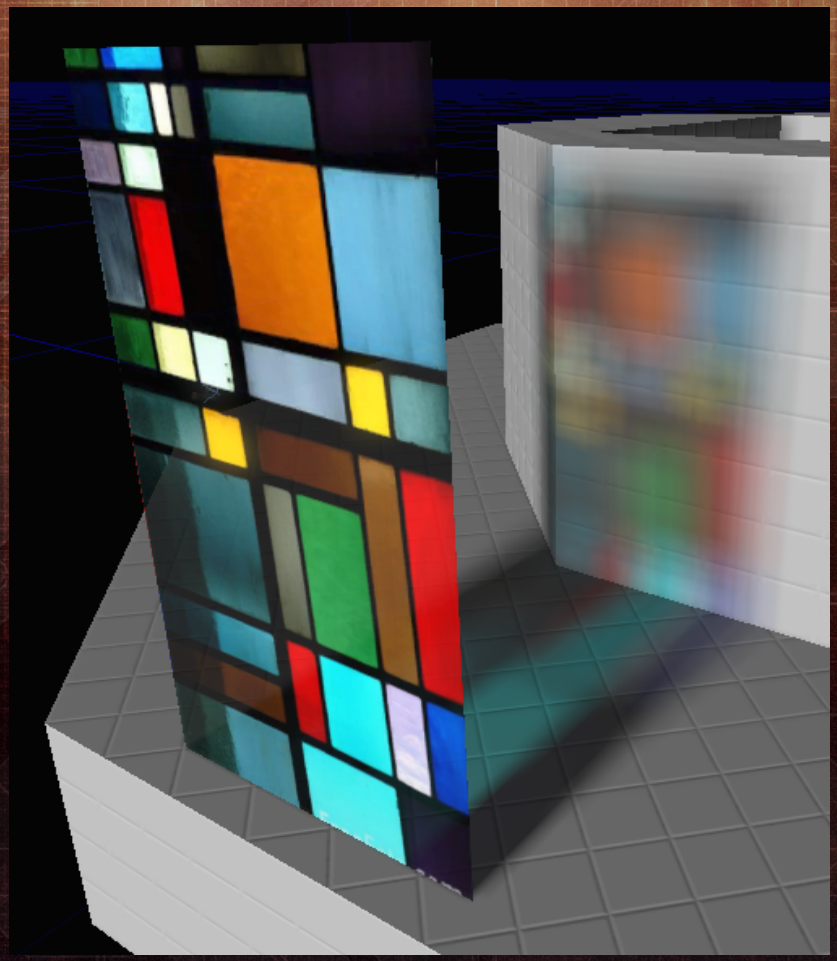


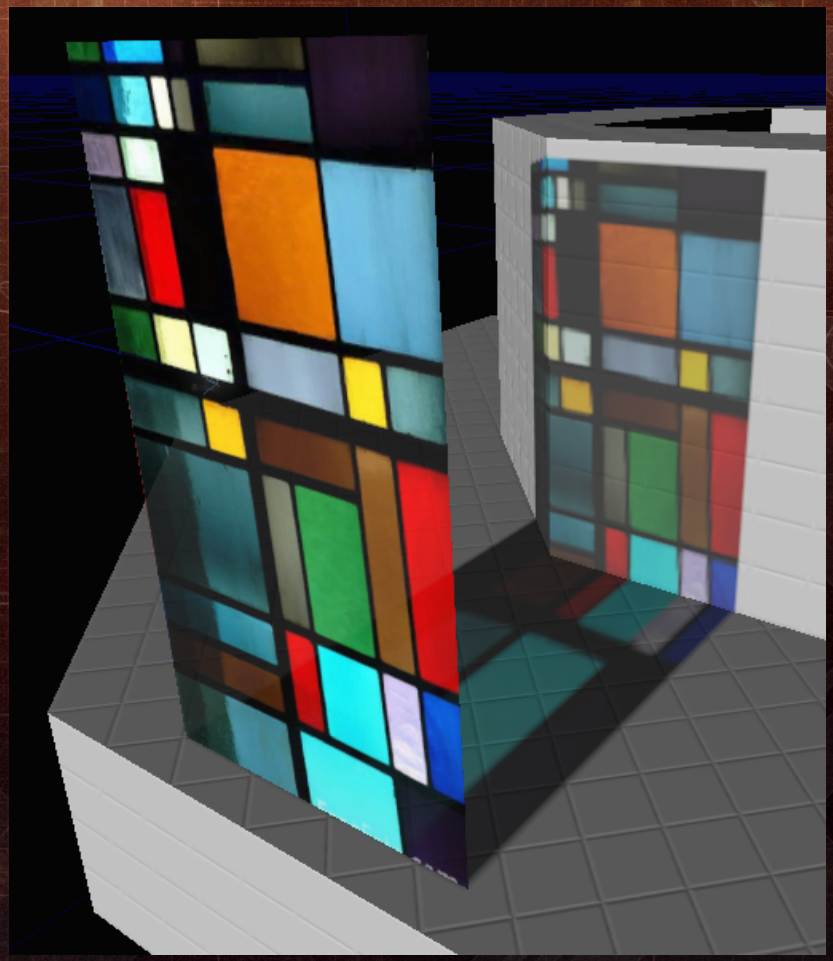
Masked shadows

Unreal Lightmass Features

Masked shadows with color bleeding

Unreal Lightmass Features



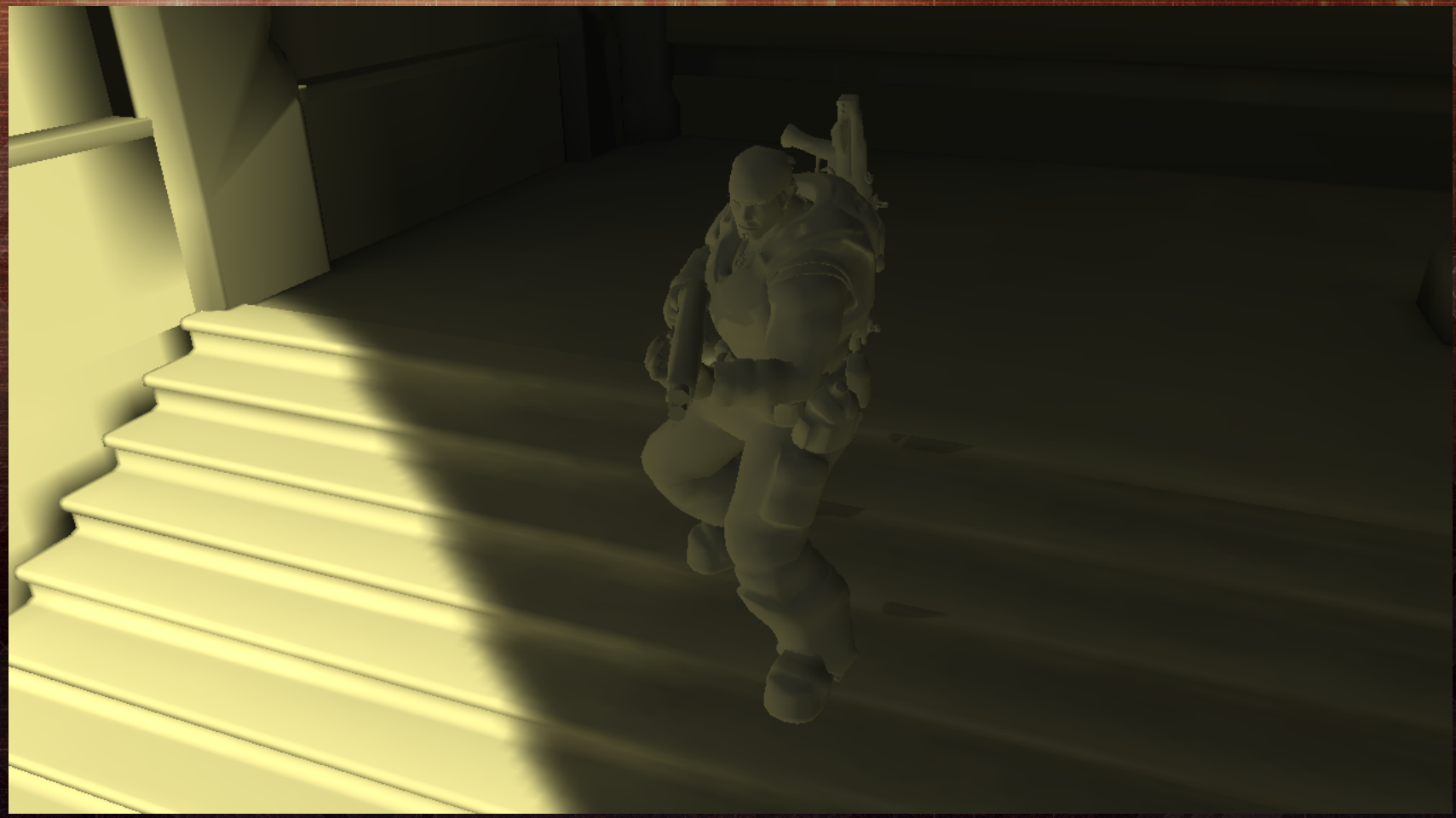


Translucent shadows

Unreal Lightmass Features

Character and environment lighting

Unreal Lightmass Features



Character and environment lighting

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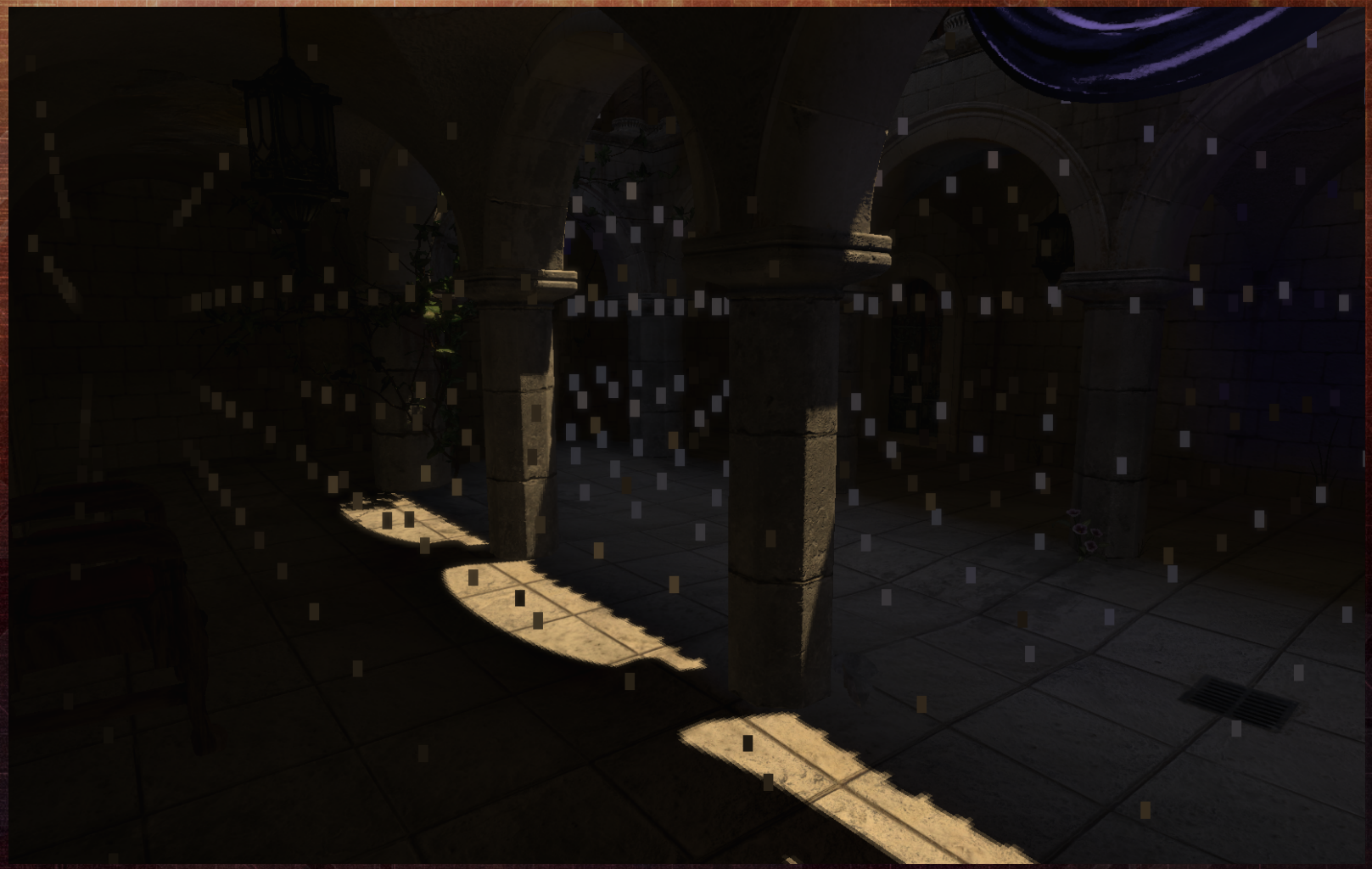

Character and environment lighting

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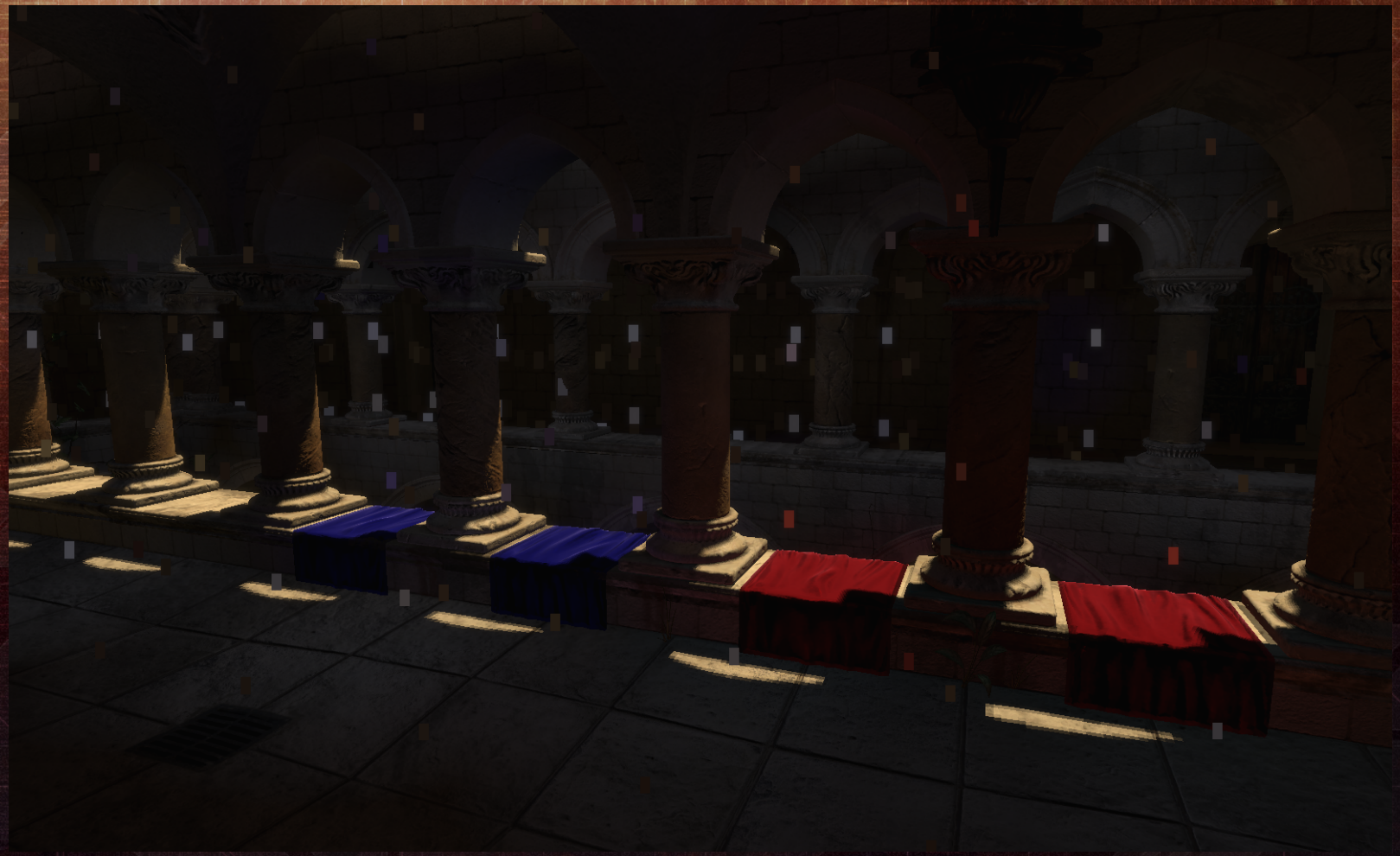


Character and environment lighting

Unreal Lightmass Features

Character lighting with distance field shadows

Unreal Lightmass Features

Character lighting with distance field shadows

Building Unreal Lightmass

How did we build Lightmass?

Planning

Consistent execution

Building Unreal Lightmass

- Consistent goals throughout development
  - Dramatically improve visual quality and feature set
  - Maintain existing workflow as much as possible

Standard UE3 Lighting Pipeline

Standard UE3 Lighting Pipeline

- Gather scene geometry and lights
  - Invalidate any lightmap or shadow map references
  - Determine what objects need to be updated

Standard UE3 Lighting Pipeline

- Generate new lightmaps and shadow maps
  - Relatively straightforward
  - Direct lighting only

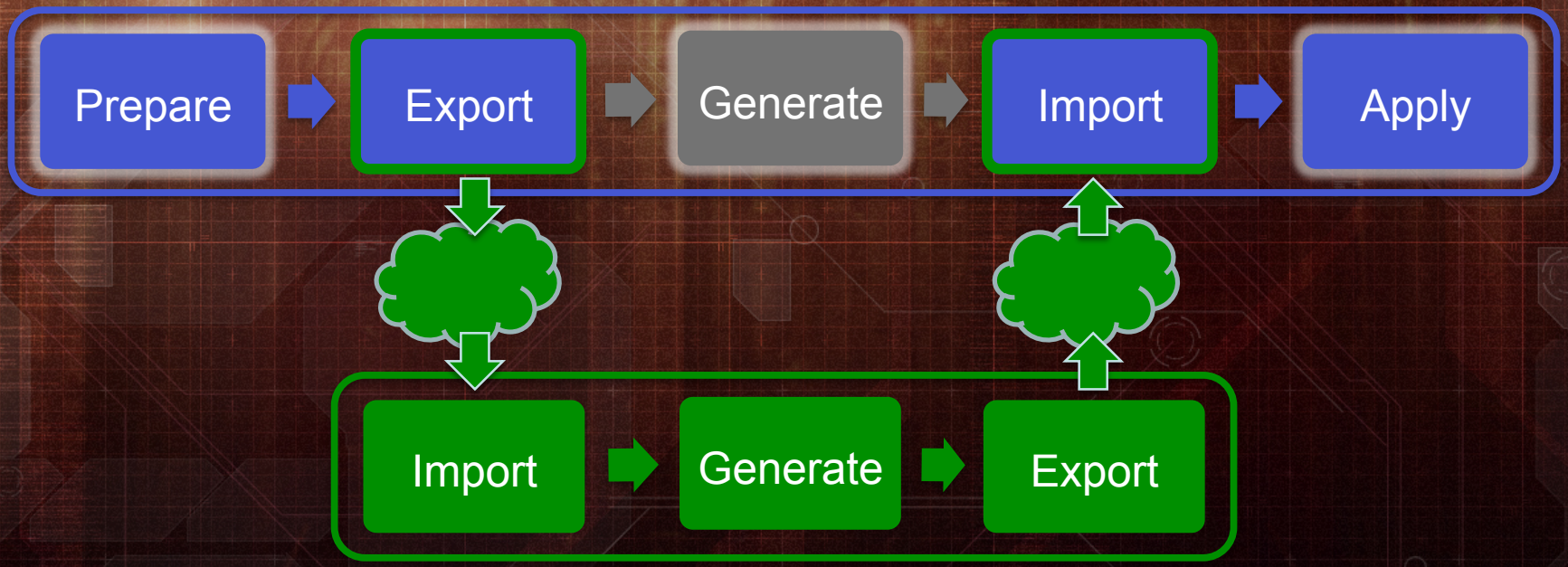
Standard UE3 Lighting Pipeline

- Apply to geometry and lights
  - Lightmap atlases generated, compressed
  - Update objects with new lightmap references

What does Lightmass replace?

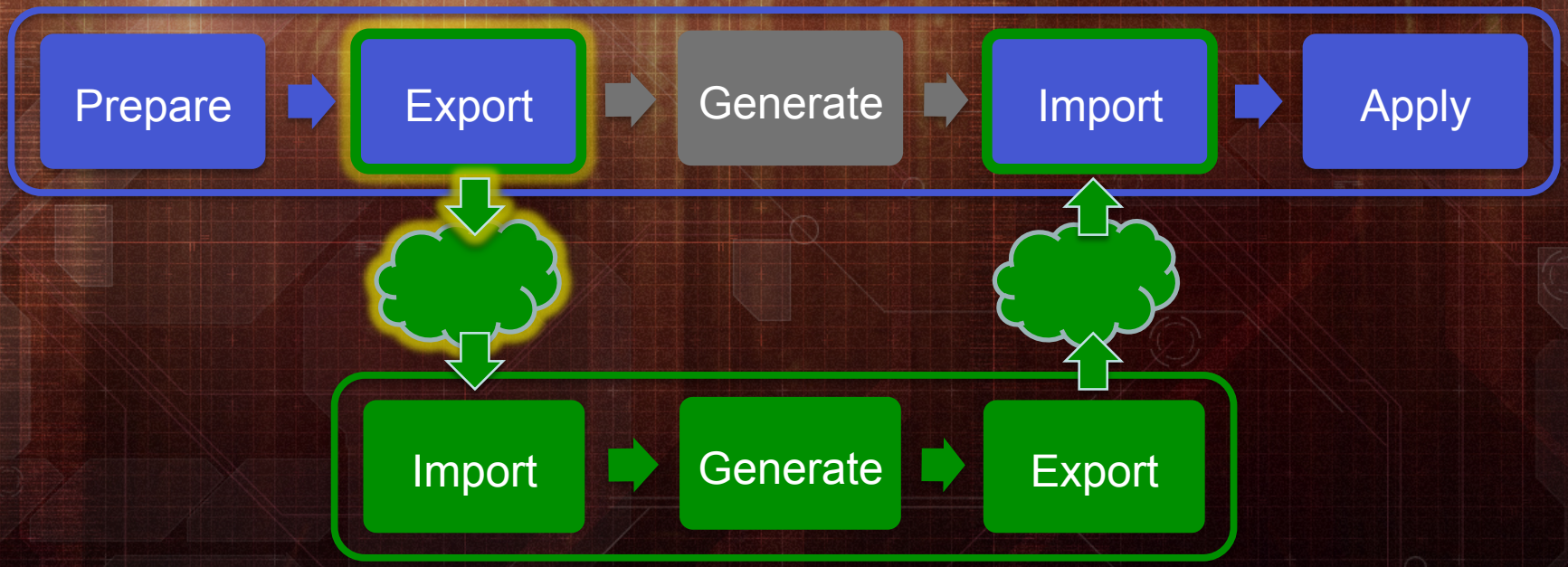
- Goal is to modify workflow as little as possible

What does Lightmass replace?



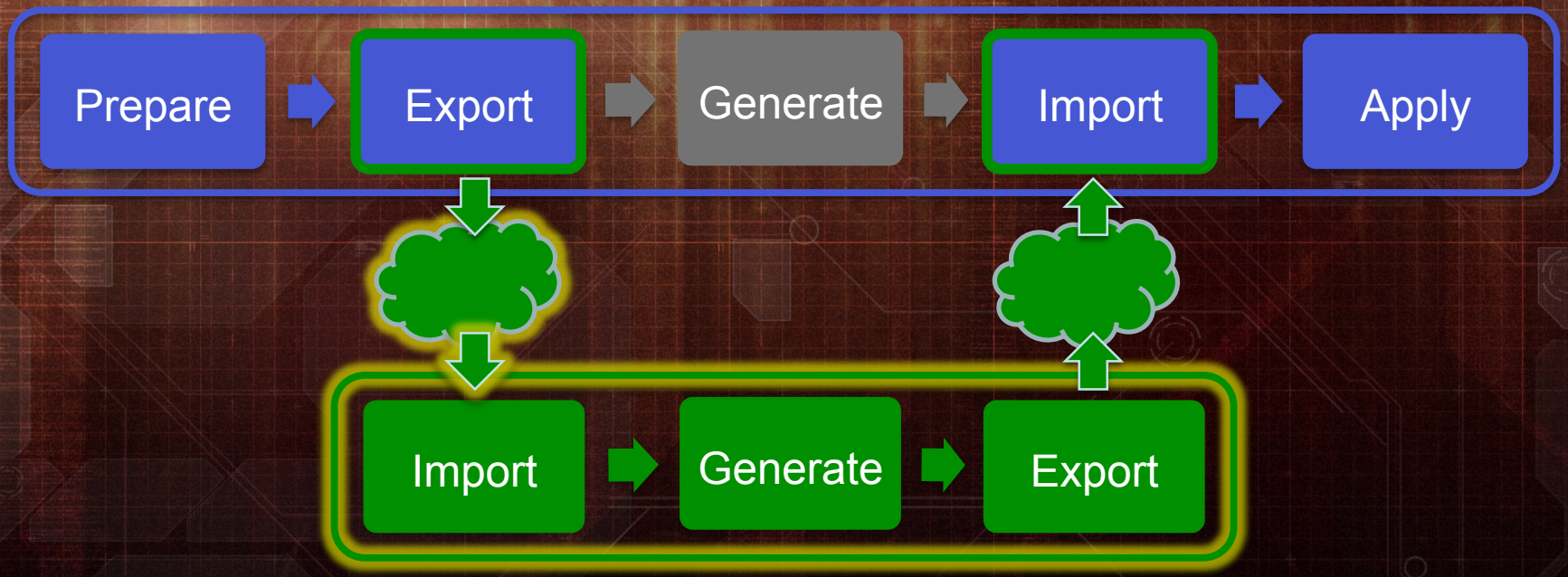
- Goal is to modify workflow as little as possible
- Replaces only the lightmap and shadow map generation stage, with slight additions

Lightmass Lighting Pipeline



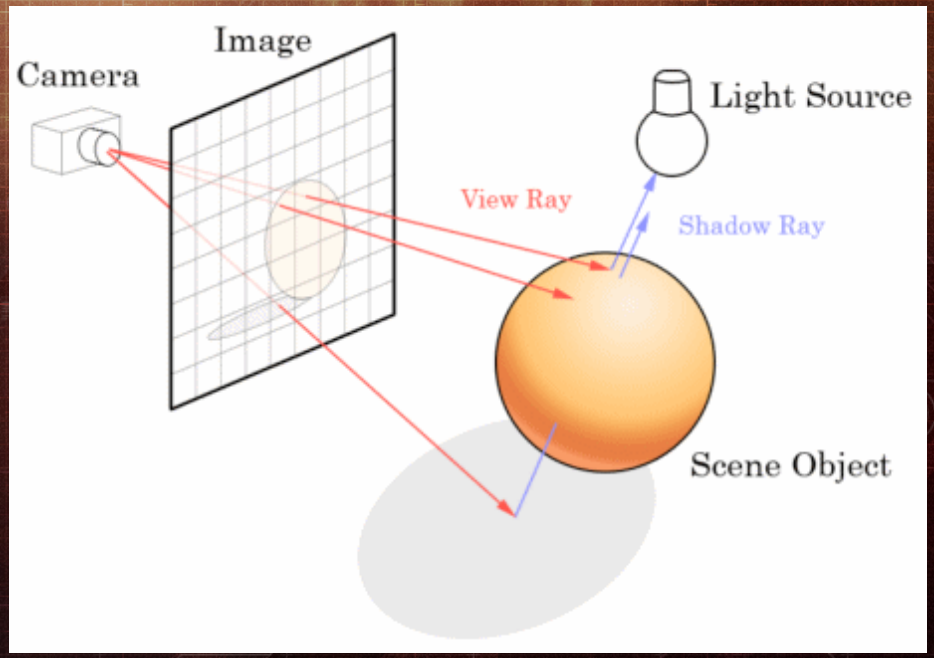
- Export “heavy, static” elements
  - Meshes, materials, terrain, etc.
  - Objects which change infrequently
- Export overall scene description file

Lightmass Lighting Pipeline



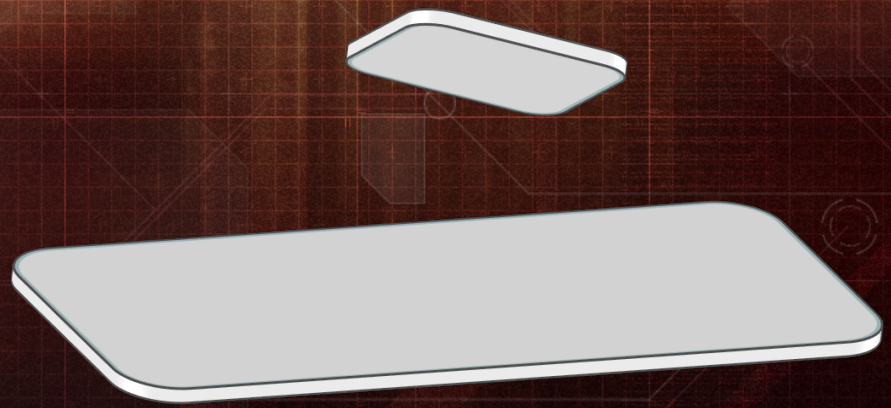
- Collect all dependencies for Lightmass
- Launch the Lightmass executable

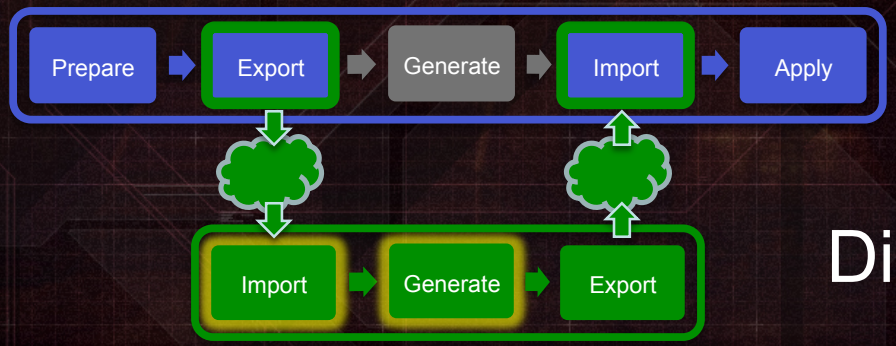
Unreal Lightmass



- Ray tracing selected as central technology
  - Many highly-desired visual features fall out naturally
  - Highly parallelizable and scalable
  - Large selection of optimizations to meet our needs

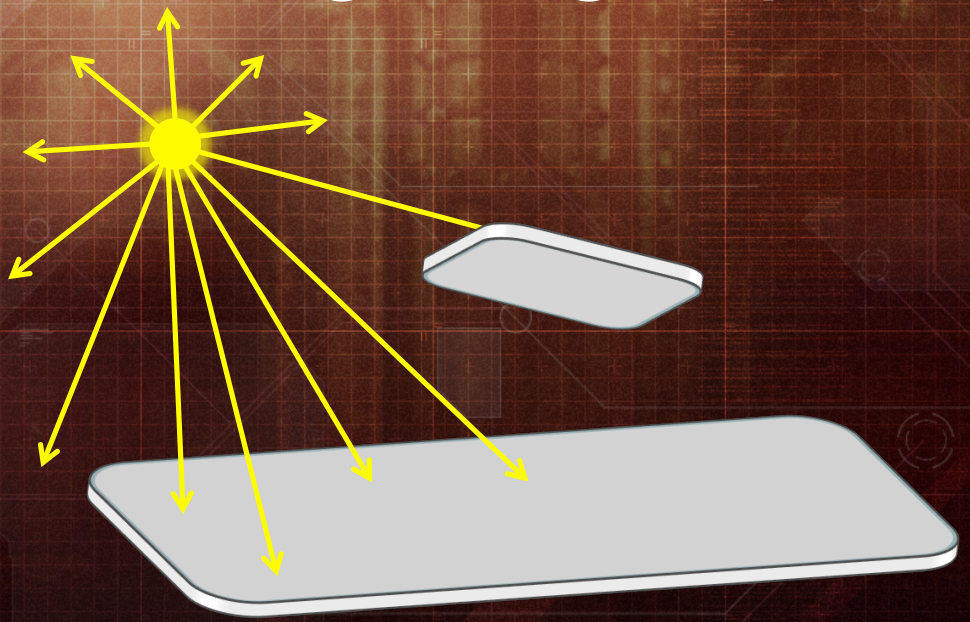
Lightmass Lighting Pipeline

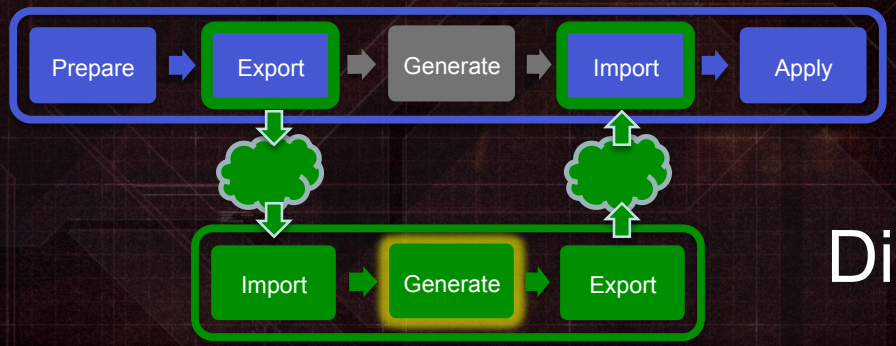




Direct Photon Emission

Lightmass Lighting Pipeline





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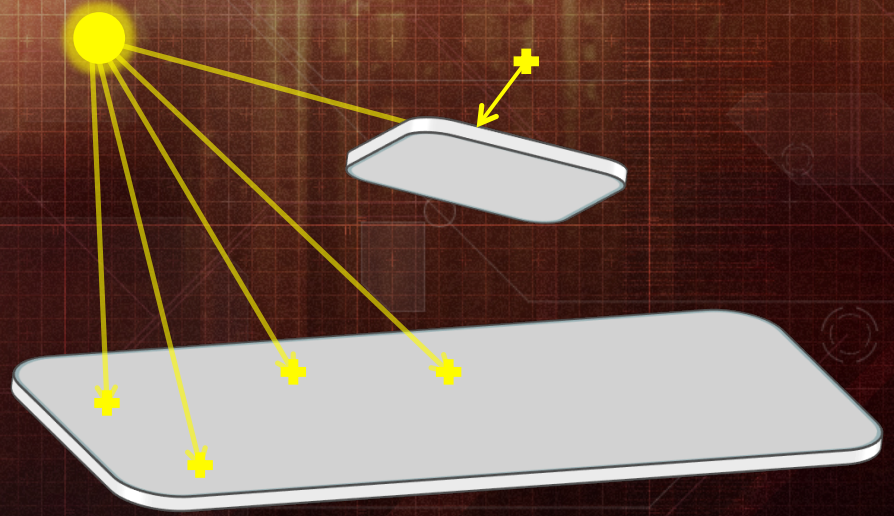

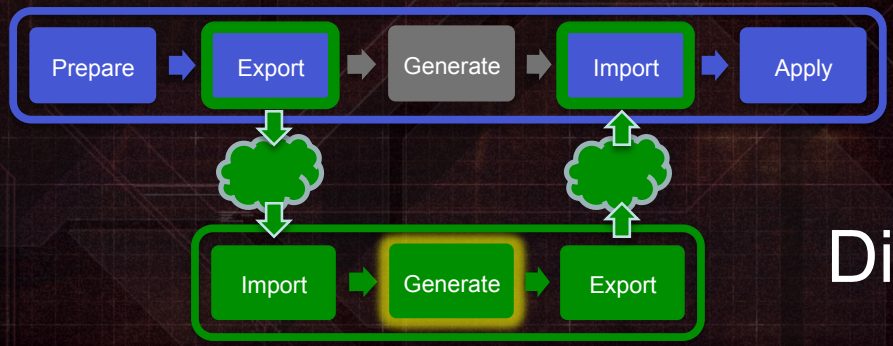

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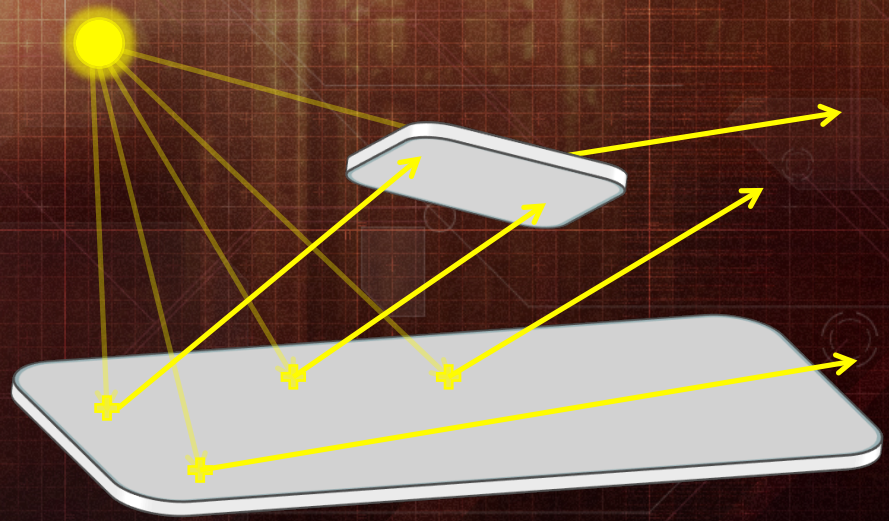

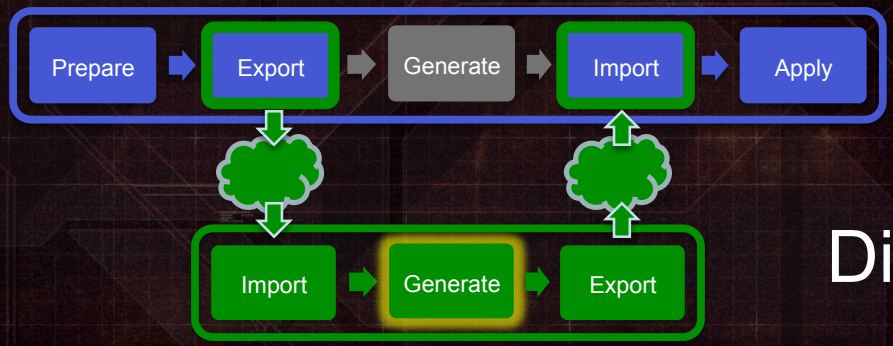

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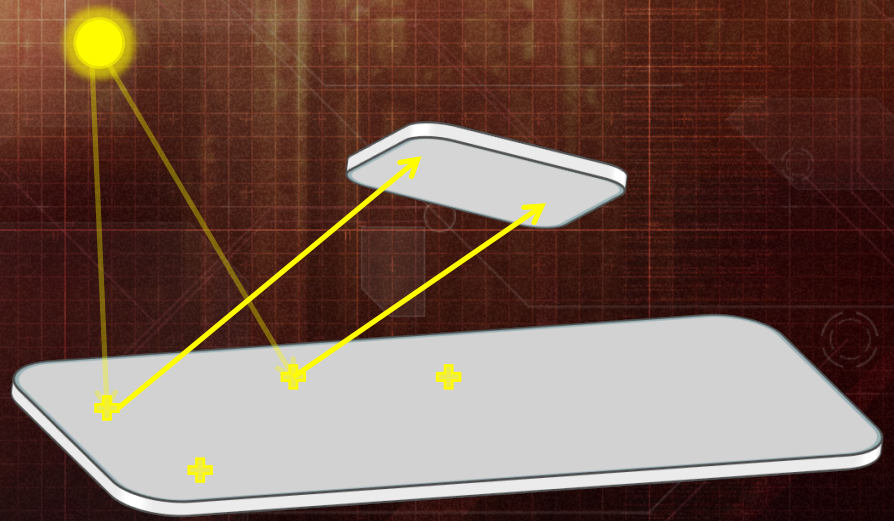

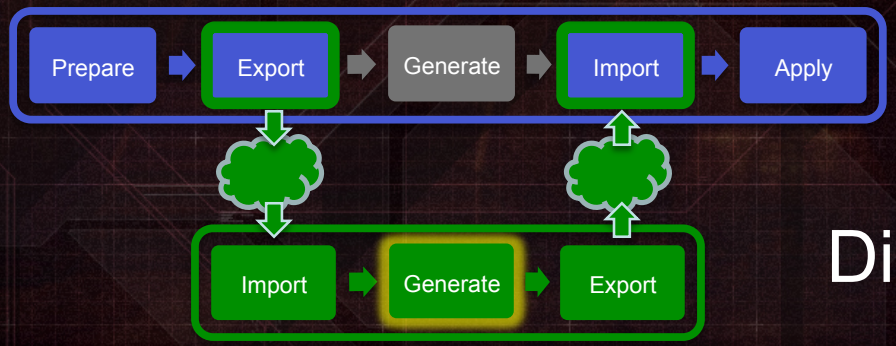

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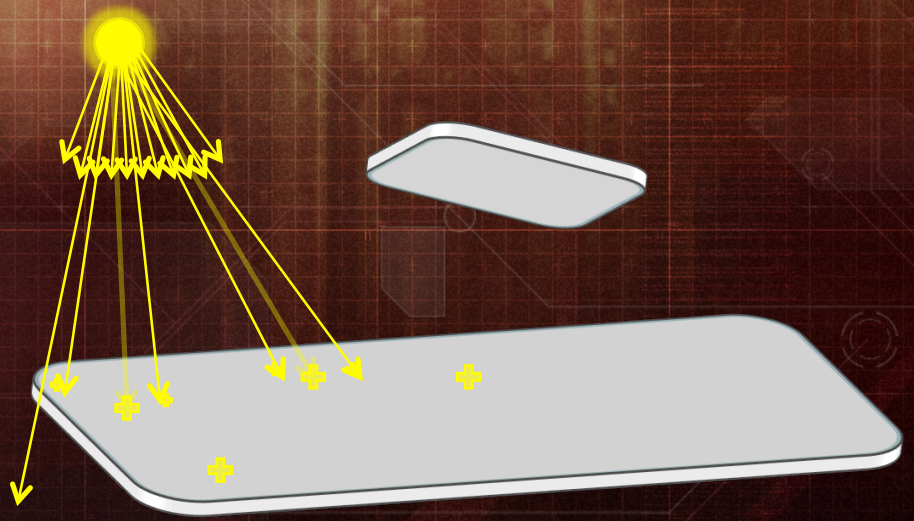

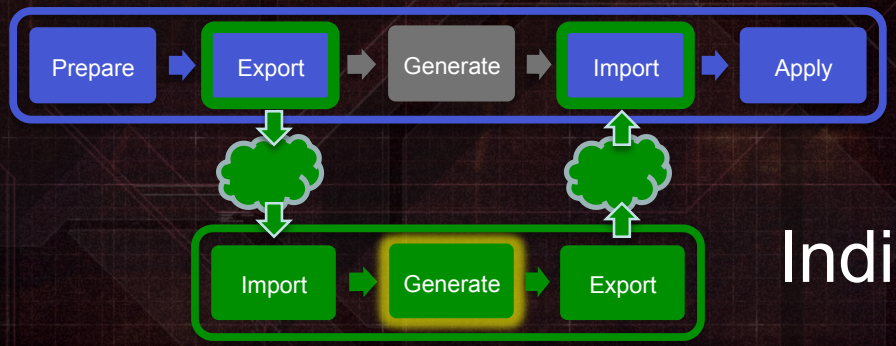

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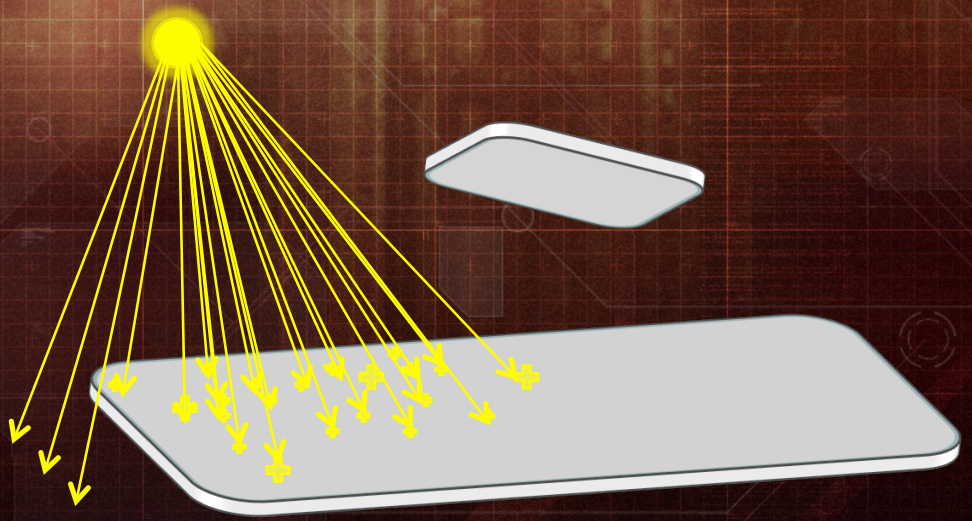

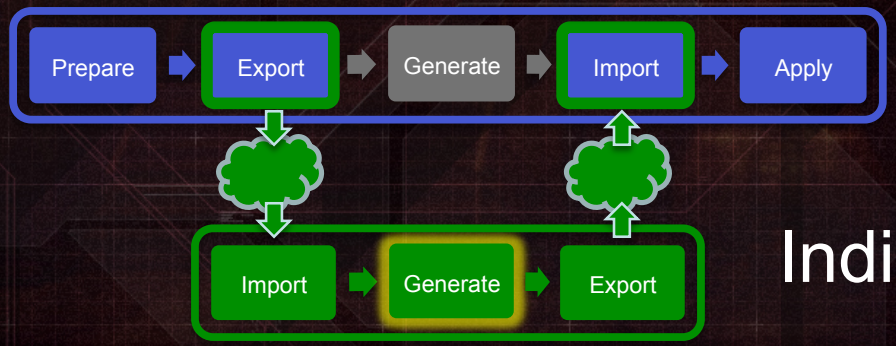

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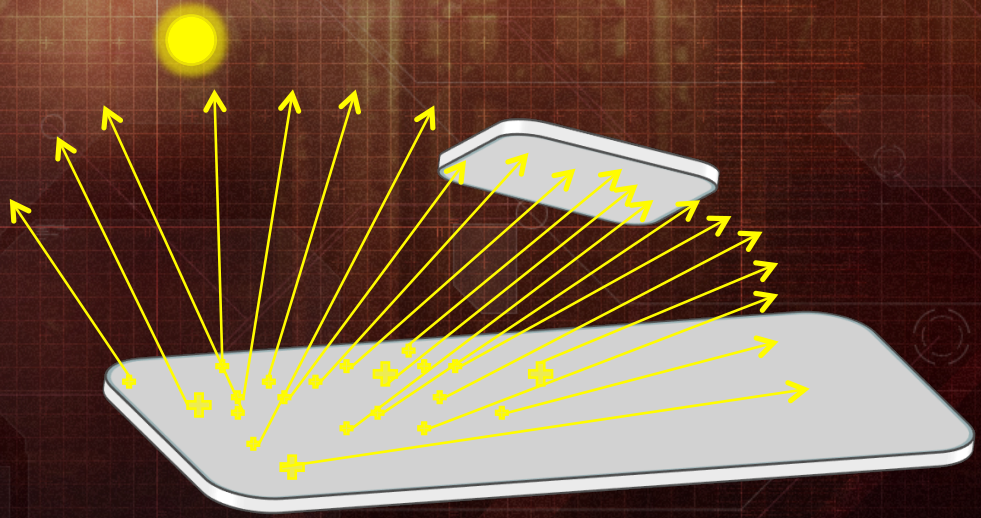

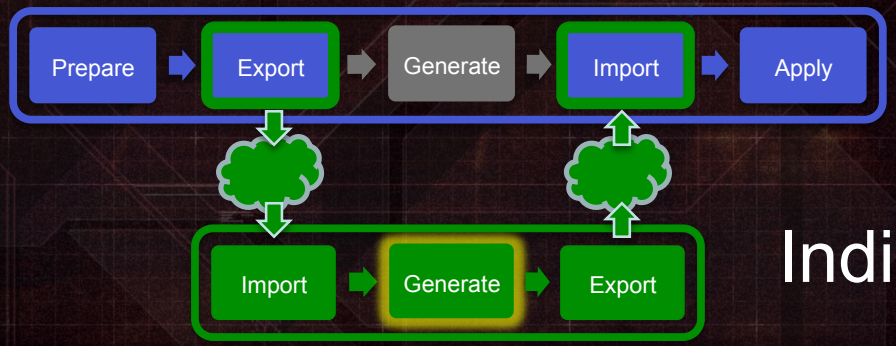

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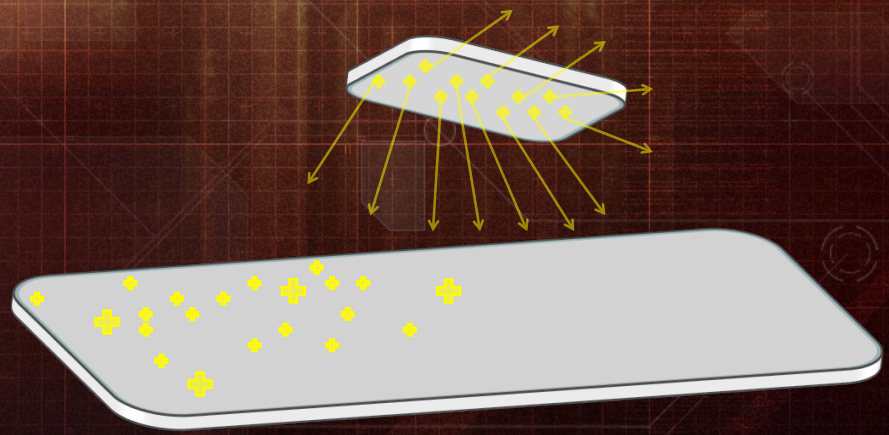

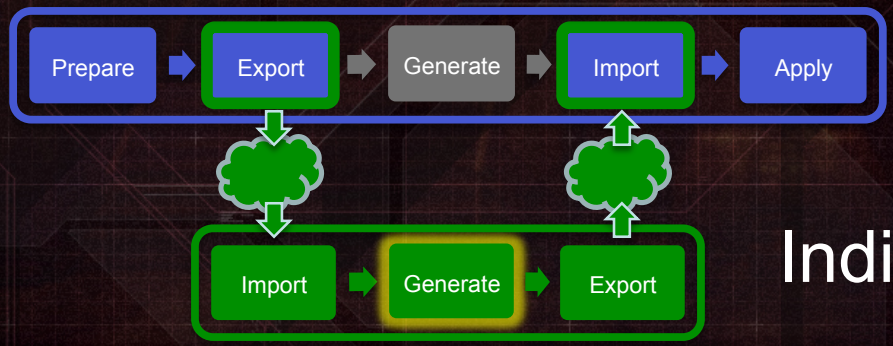

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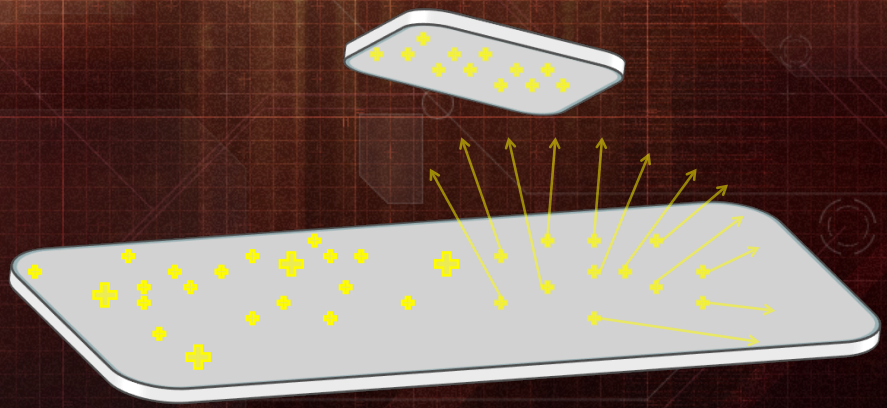

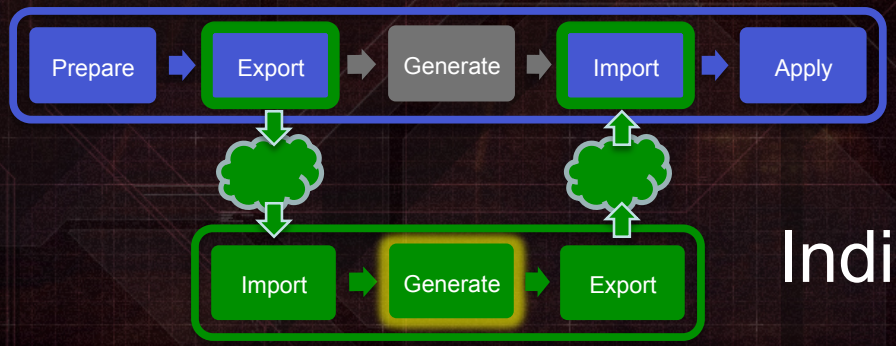

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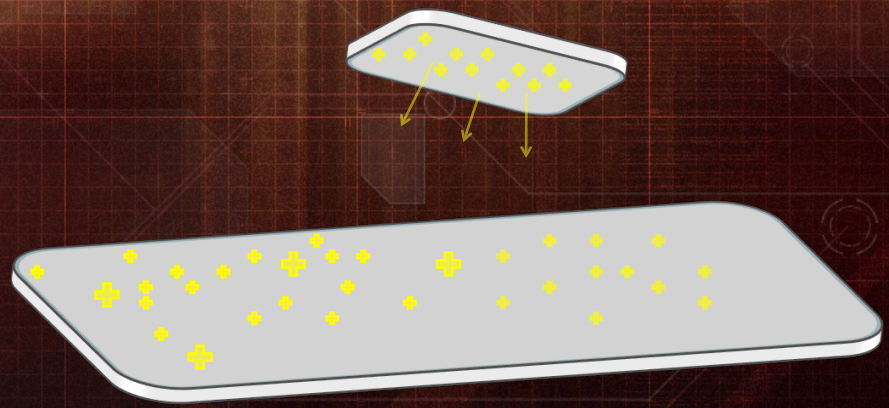

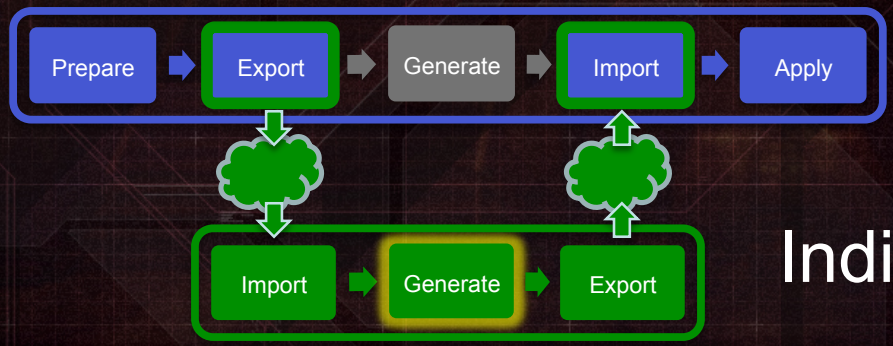

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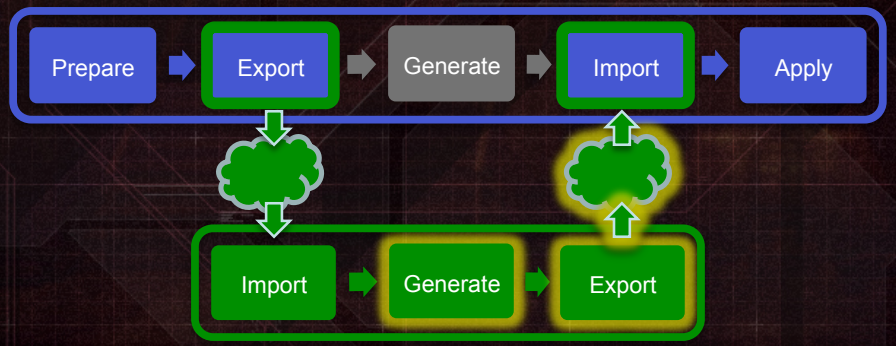
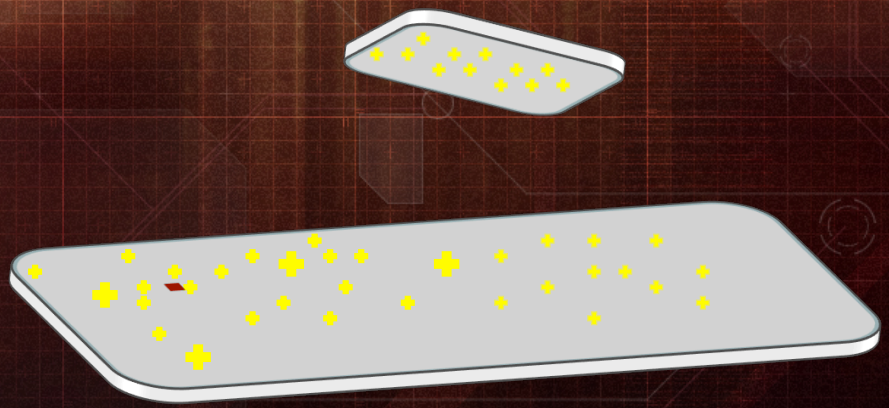
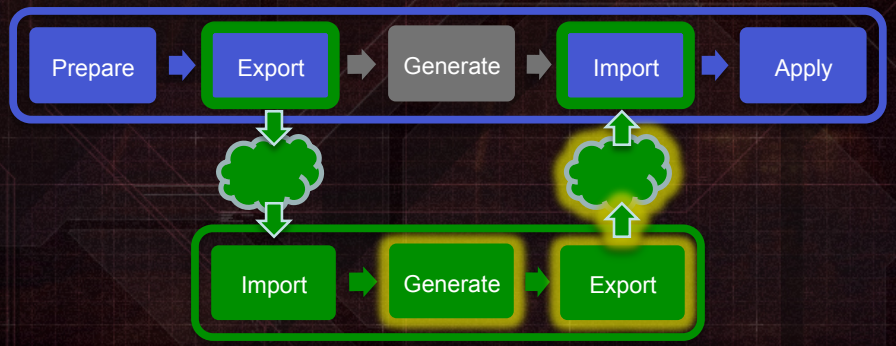


Final Gather (Direct)

Lightmass Lighting Pipeline





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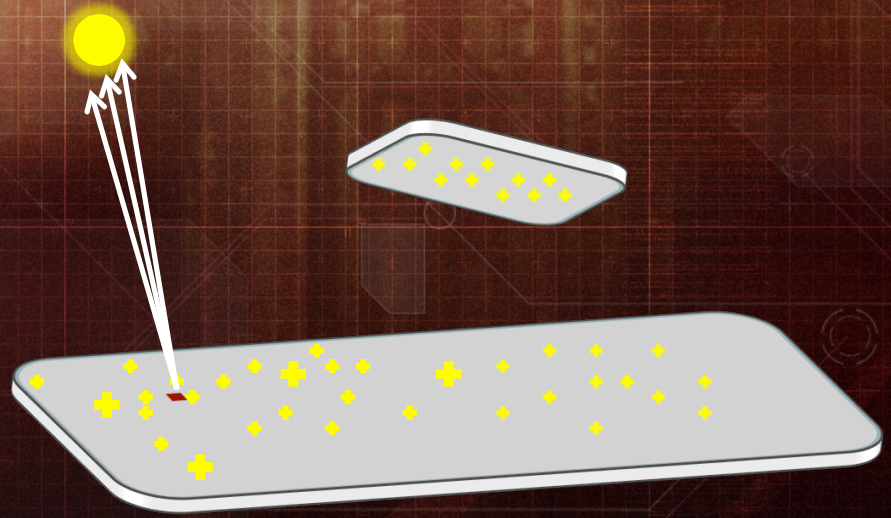

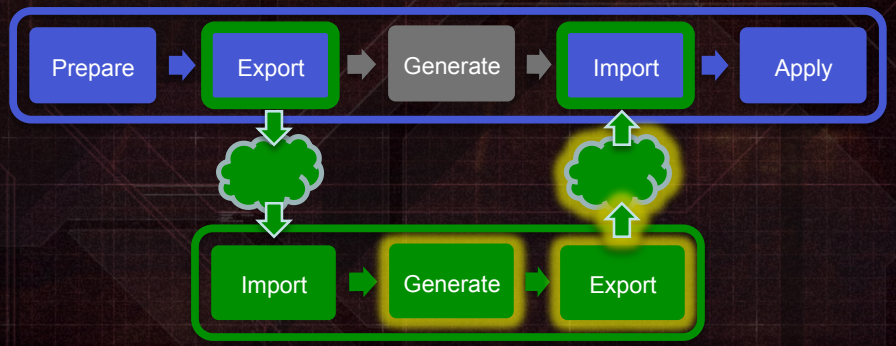

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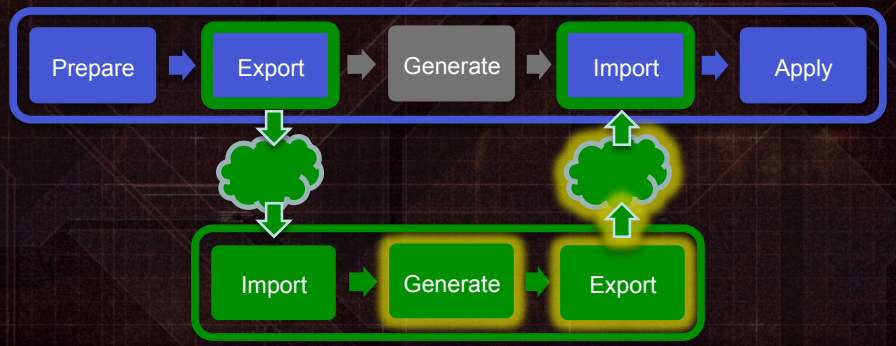

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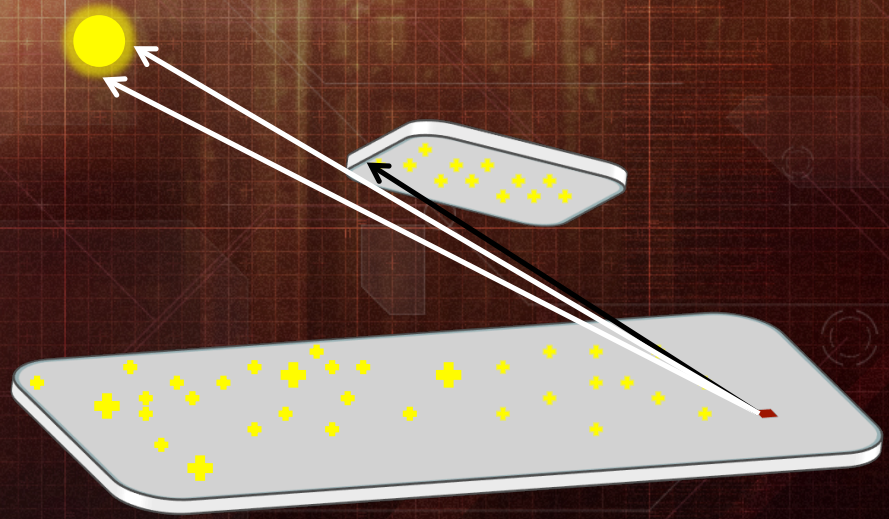
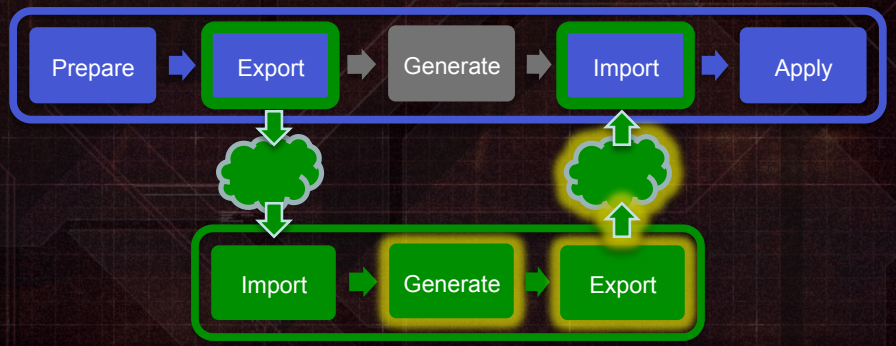
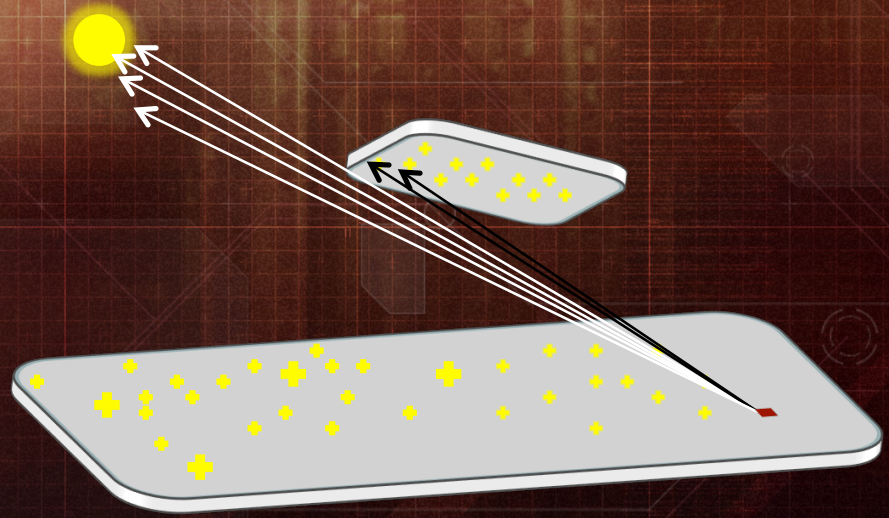
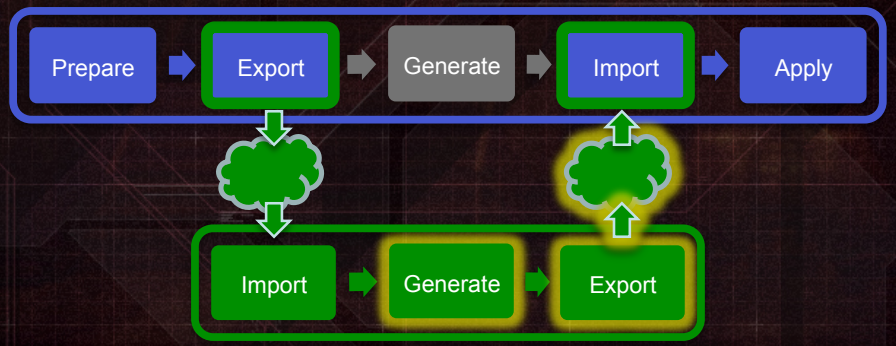




Final Gather (Direct)

Lightmass Lighting Pipeline





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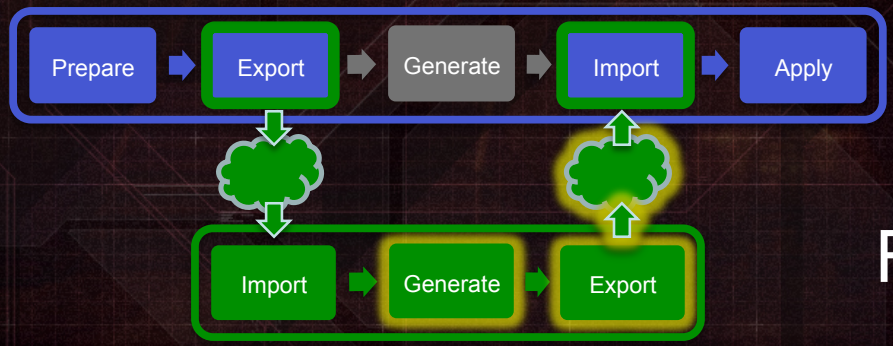

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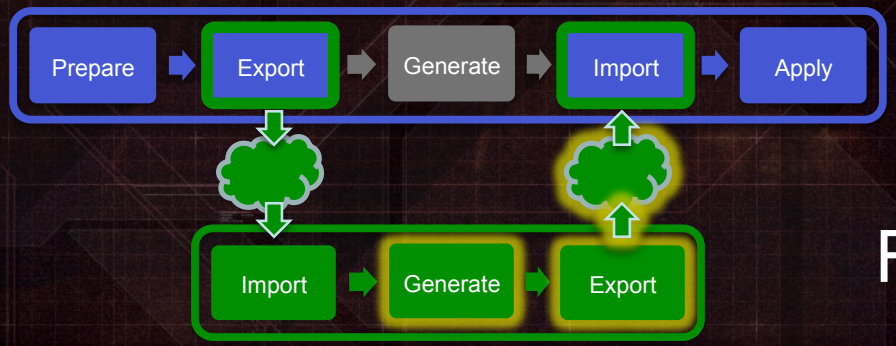

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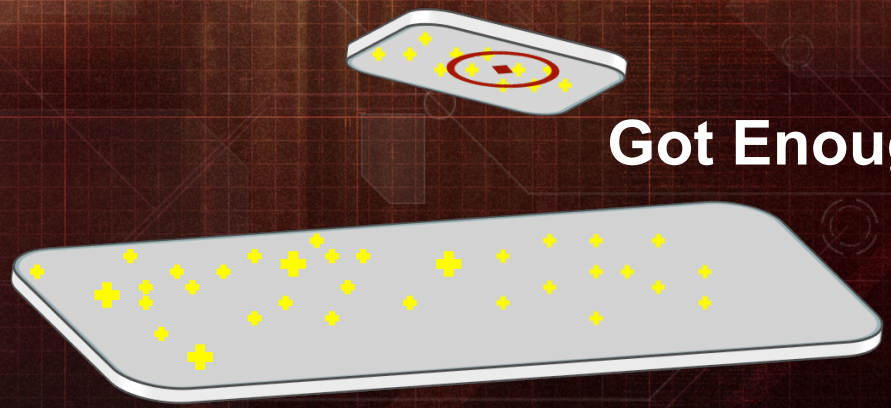

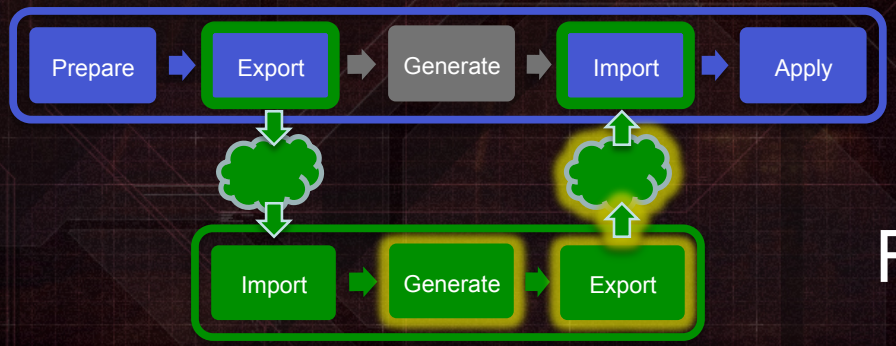

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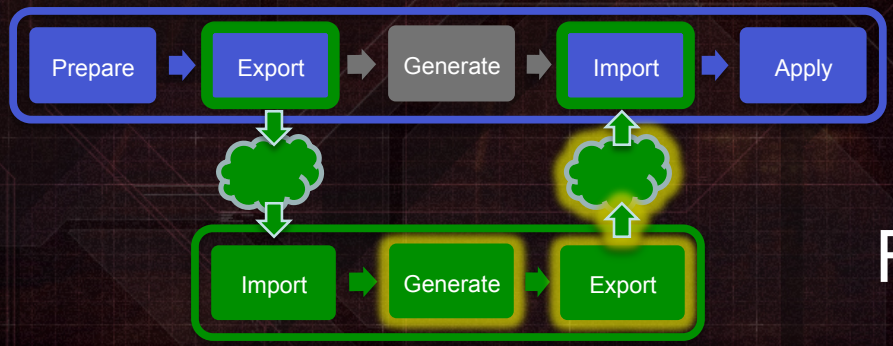

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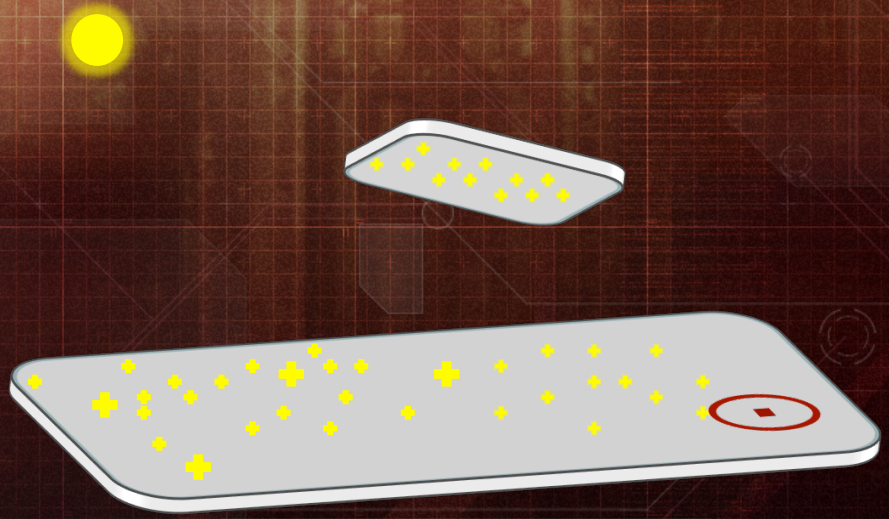
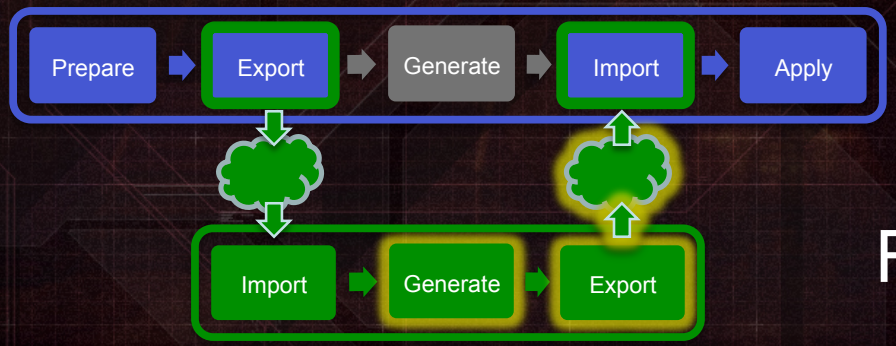


Not Enough!



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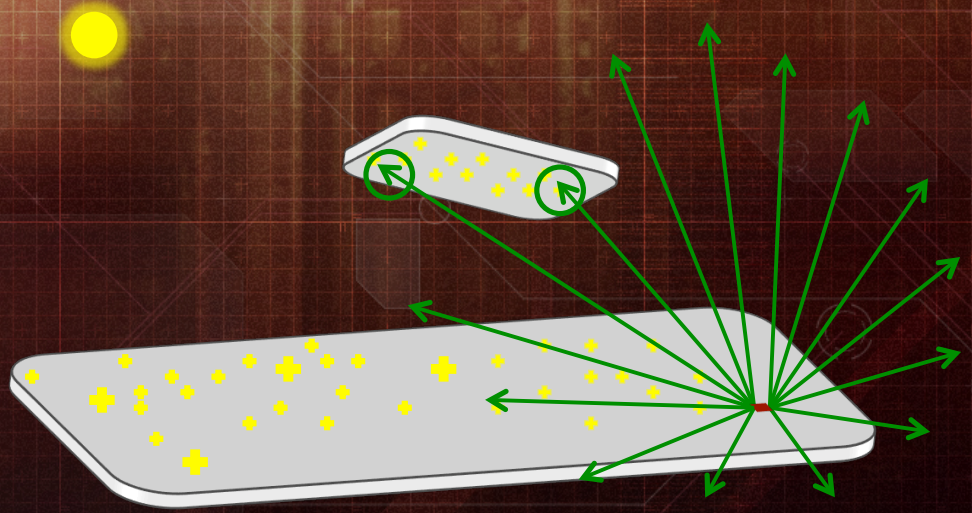

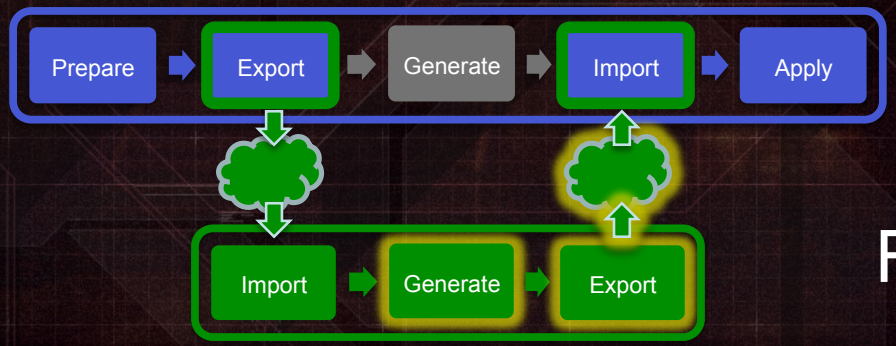

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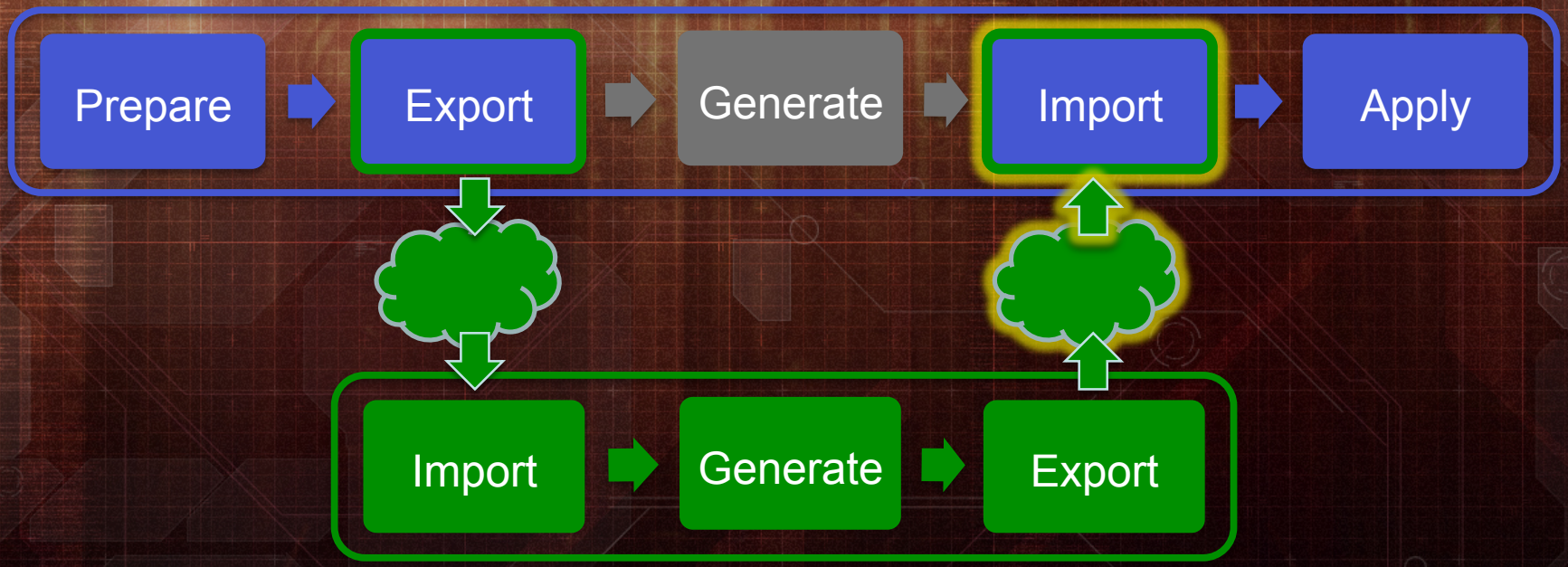
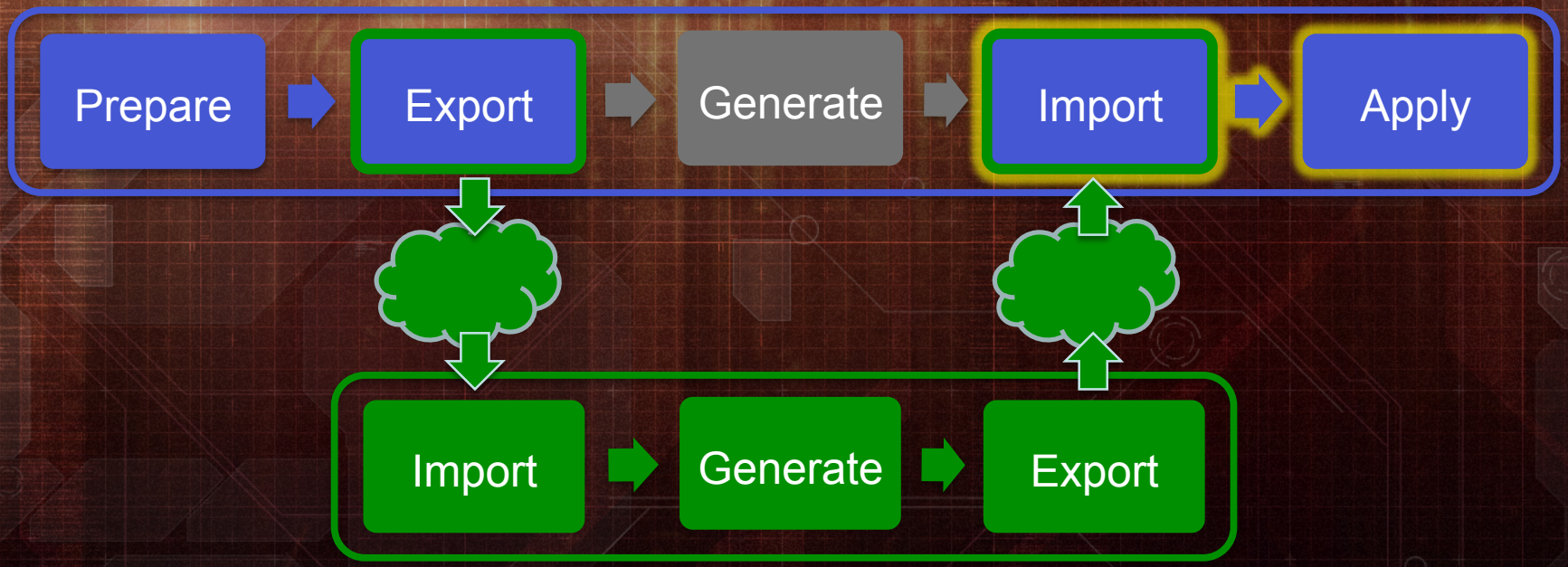


- Editor imports the next result from Lightmass

Lightmass Lighting Pipeline

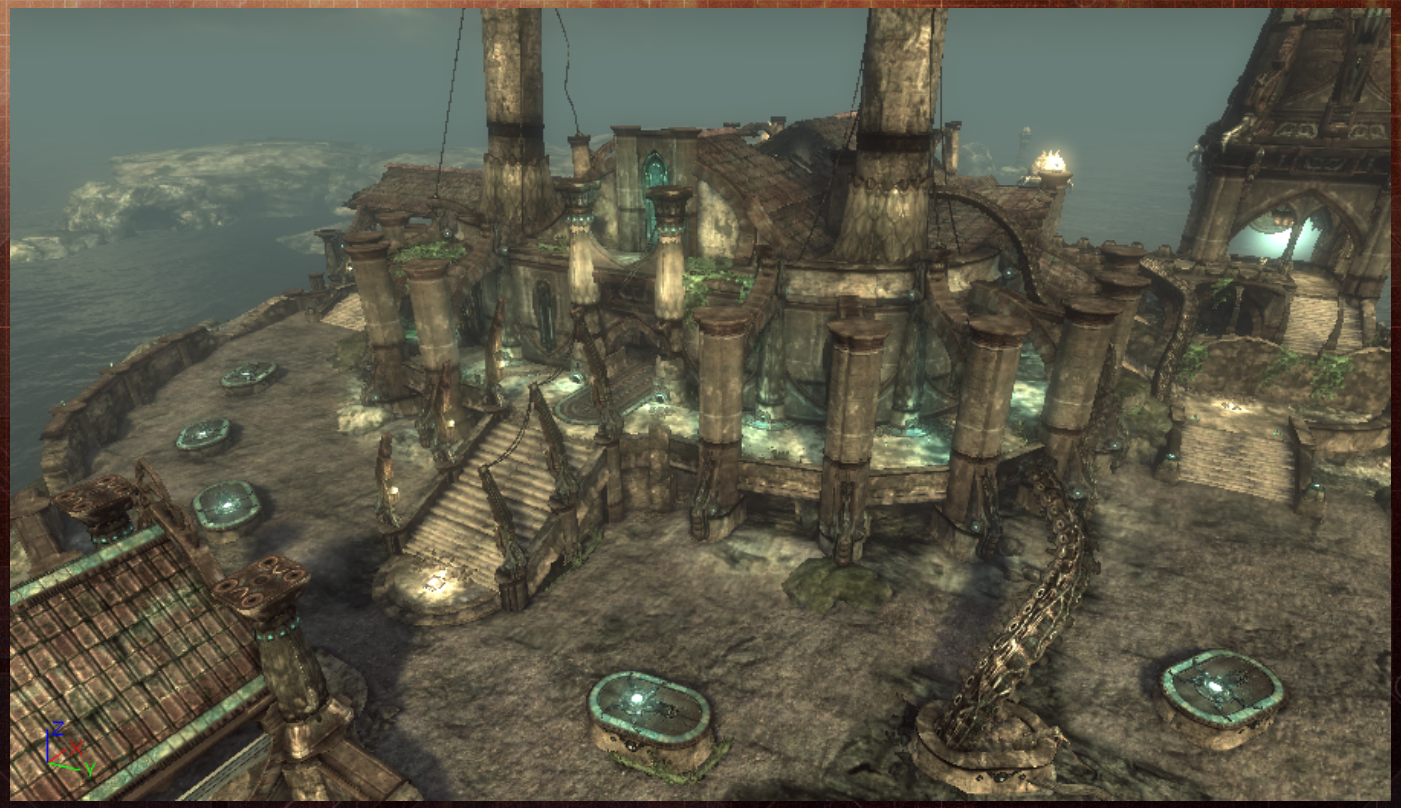


- Apply updated lightmaps to geometry and lights

Workflow Adjustments

- To take full advantage of the new lighting model, minor changes to our content were necessary
- Old lighting encouraged artists to create lighting effects with textures and hundreds of fill lights

Workflow Adjustments



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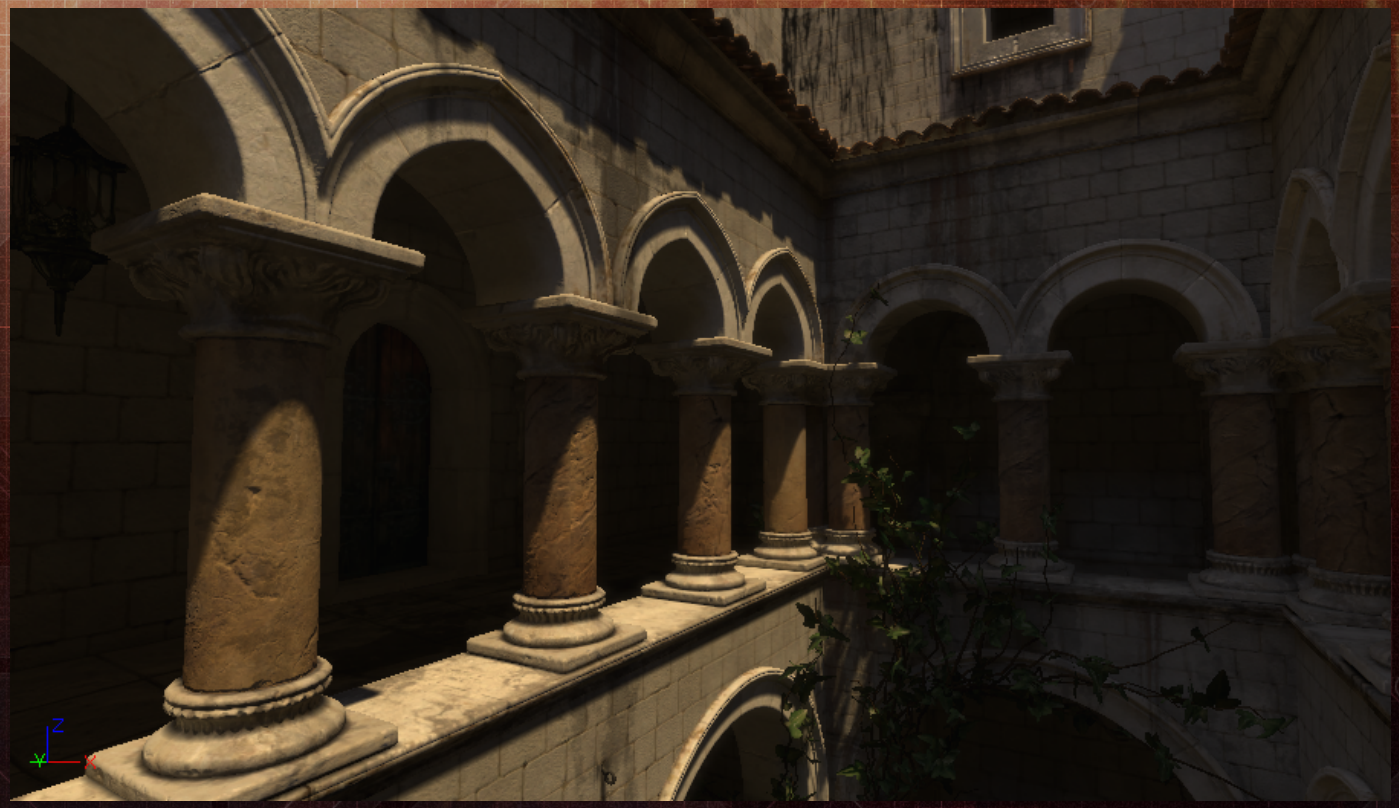
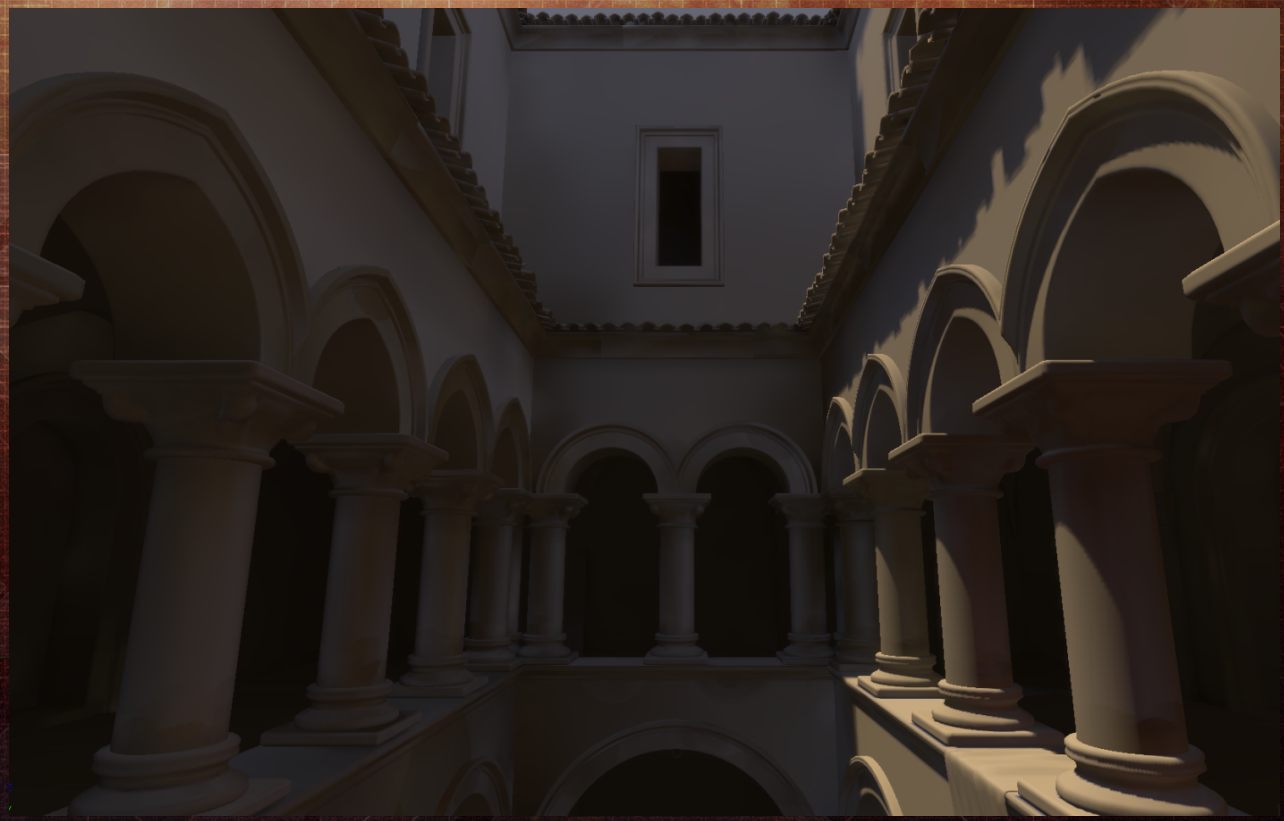


- Brighten textures, allow light to do the lighting
- No need for hundreds of fill lights anymore
- New content being built with Lightmass in mind

Workflow Adjustments

- Lighting rebuilds can be long-running
  - Even longer now with global illumination
  - Potentially conflicts with our goal to maintain workflow
  - We developed multiple solutions to this challenge!

Workflow Adjustments



Preview
Lighting Time
1:04 min

- Lightmass core technology scales!
  - Preview, Medium, High, Production quality levels
  - Preview used to iterate quickly, Production used for shipping quality but still has reasonable build times

Workflow Adjustments

Medium
Lighting Time
1:50 min

- Lightmass core technology scales!
  - Preview, Medium, High, Production quality levels
  - Preview used to iterate quickly, Production used for shipping quality but still has reasonable build times

Workflow Adjustments

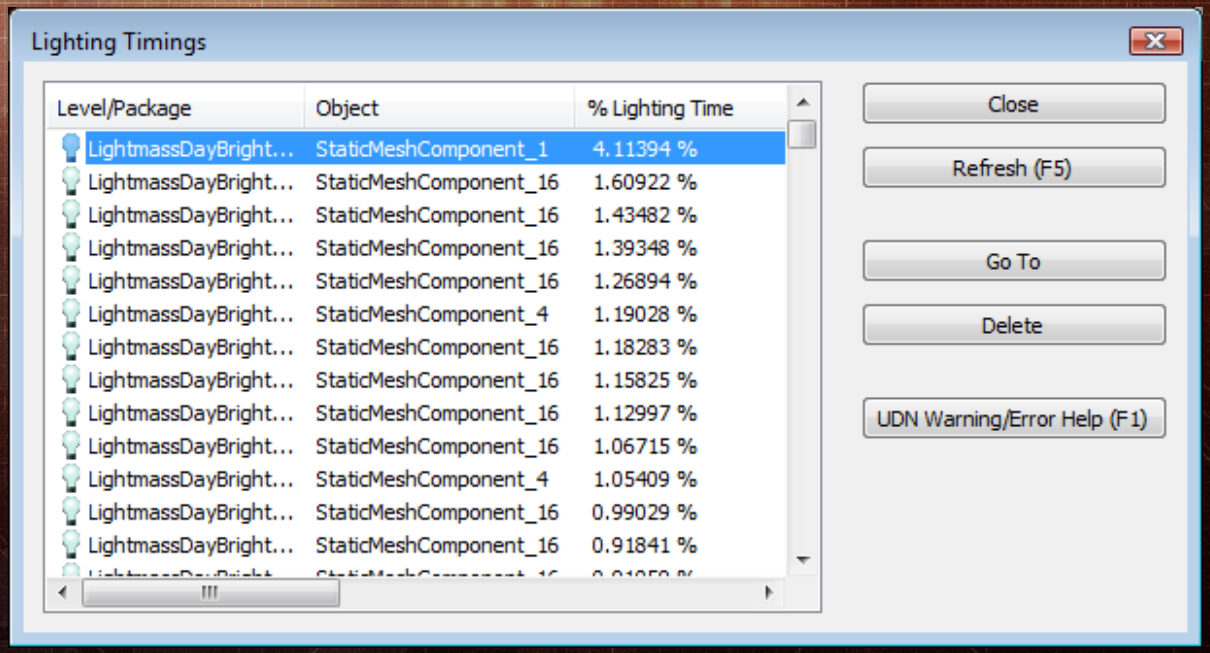
Production Lighting Time 9:46 min

- Lightmass core technology scales!
  - Preview, Medium, High, Production quality levels
  - Preview used to iterate quickly, Production used for shipping quality but still has reasonable build times

Workflow Adjustments

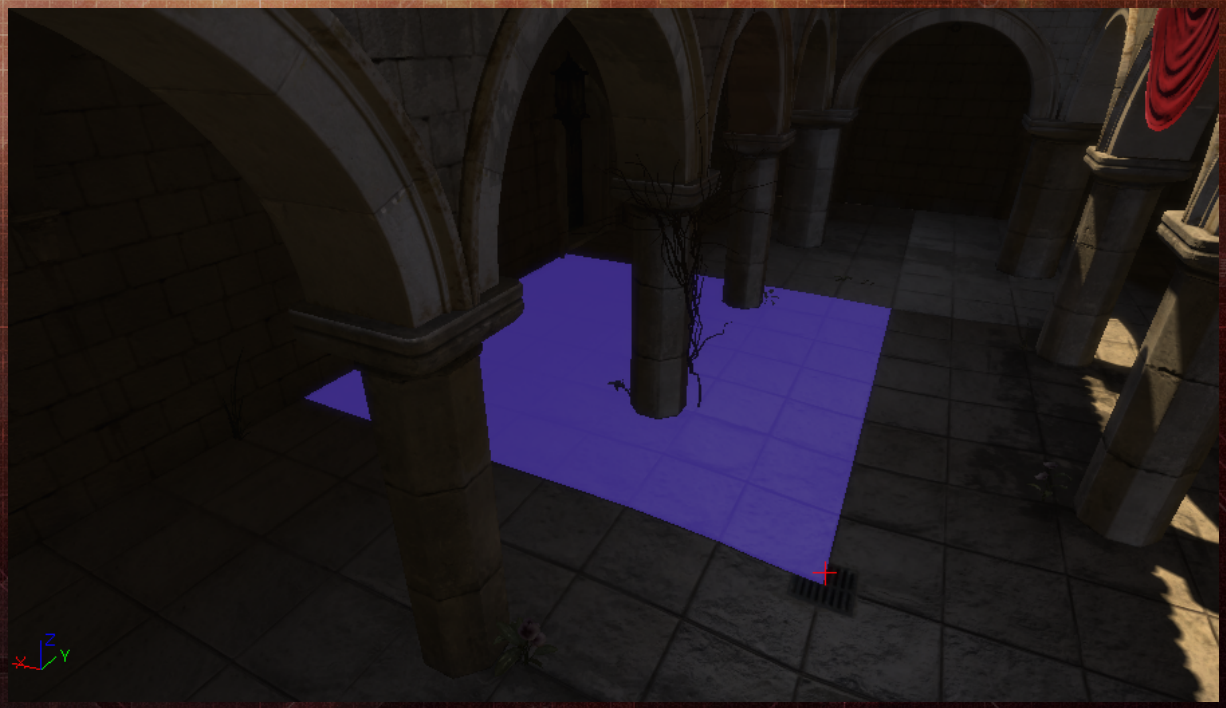
- Lightmass has now shifted burden for long build times from programmers to content creators
- Engine team has provided tools to avoid pitfalls

Workflow Adjustments



- Lighting timings dialog
  - Timings for each completed mapping are provided
  - Help tune performance, find potential outliers

Workflow Adjustments



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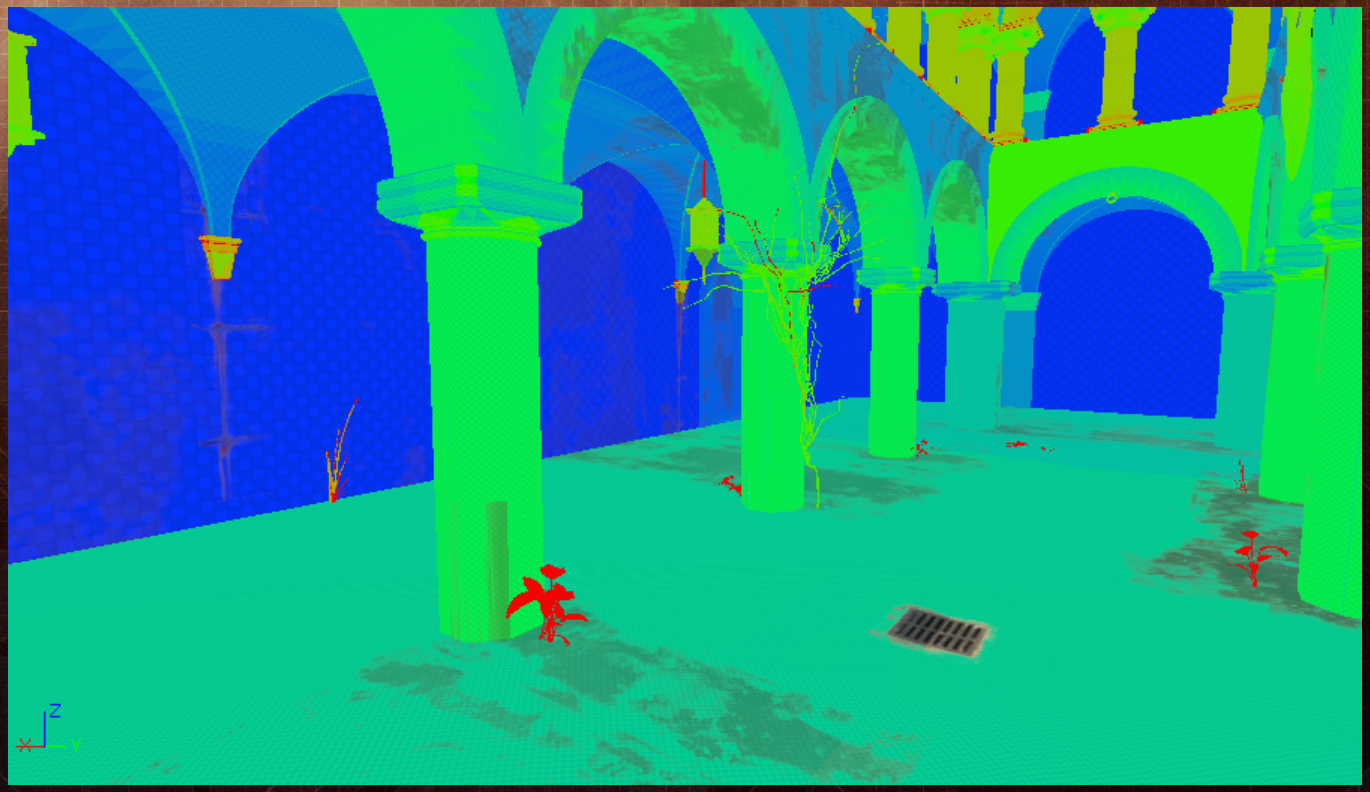
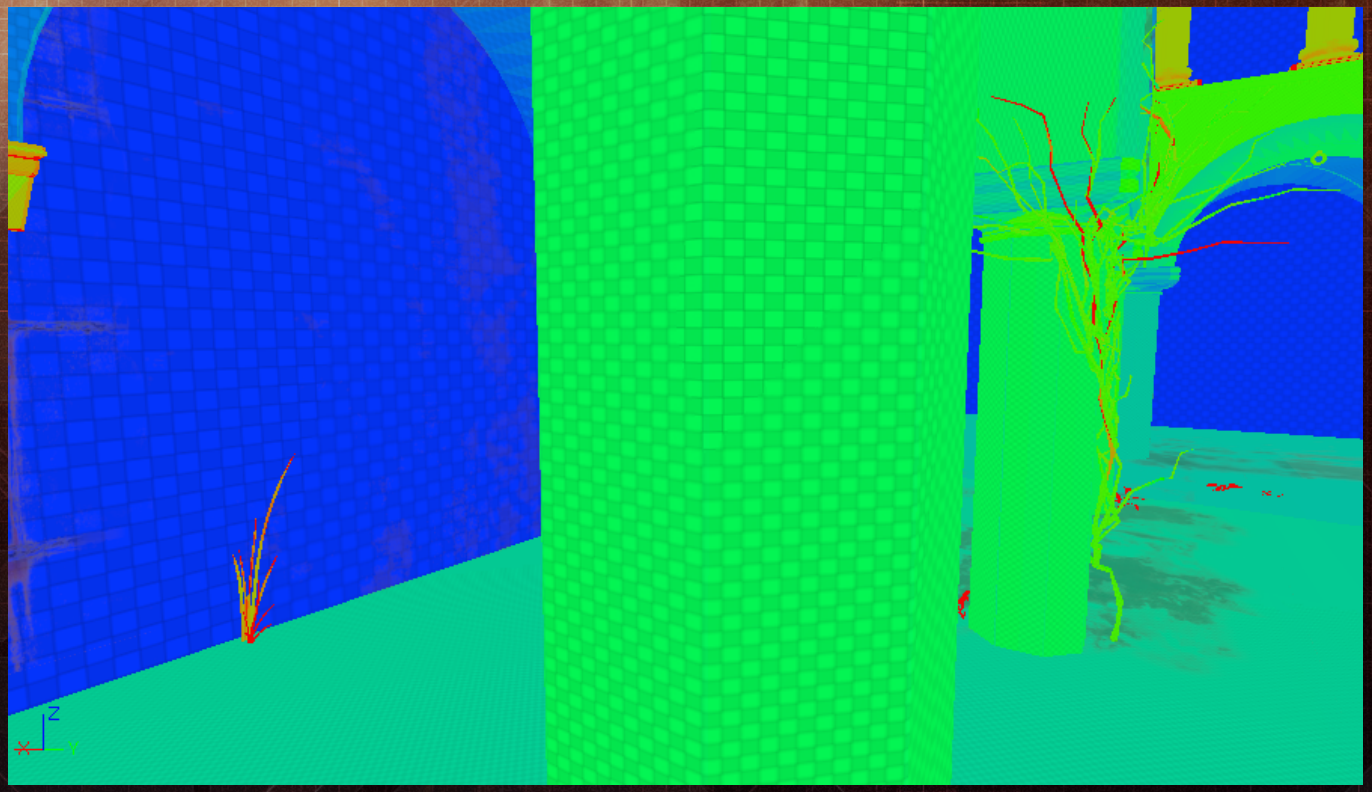


- Lightmap density visualizer
  - Color-coded to provide a visual guide to hotspots
  - Configurable to allow custom densities on-the-fly

Workflow Adjustments



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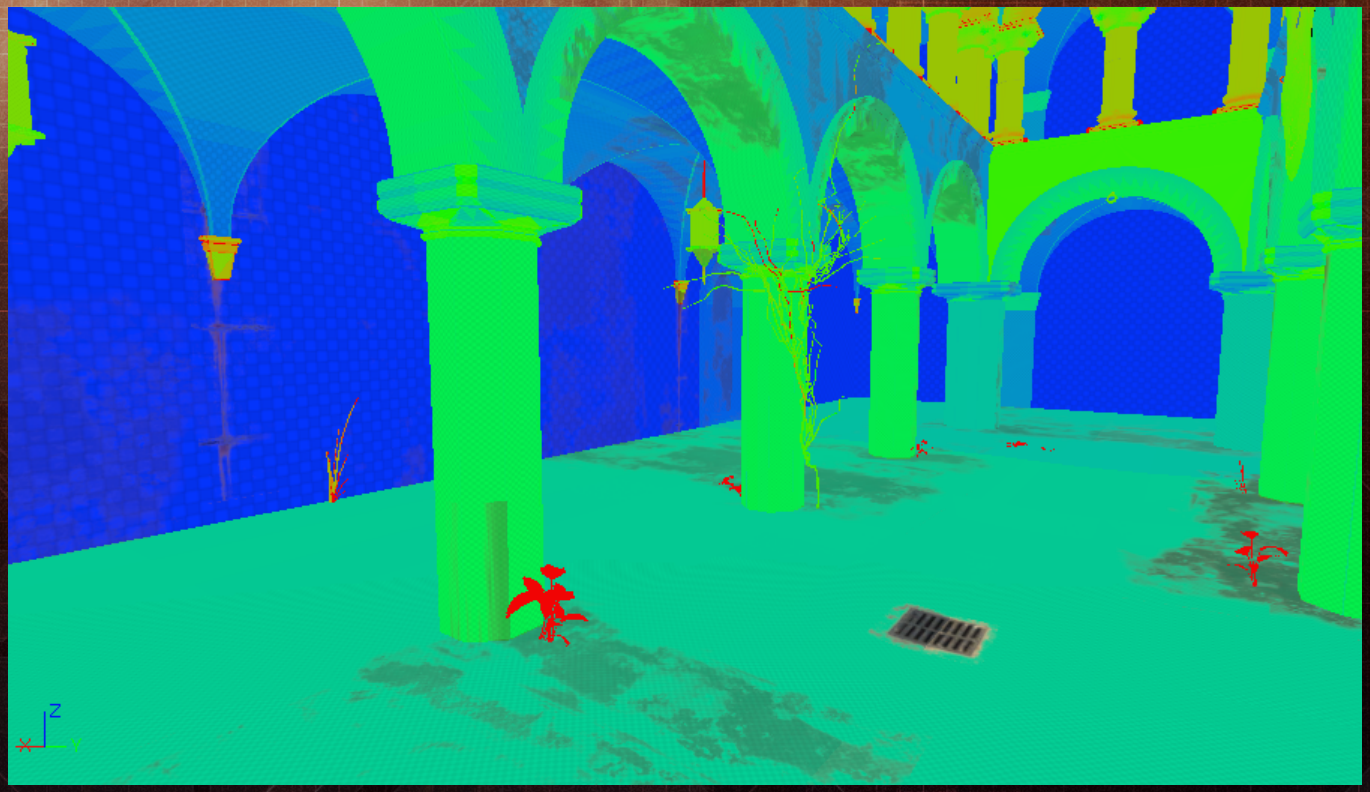

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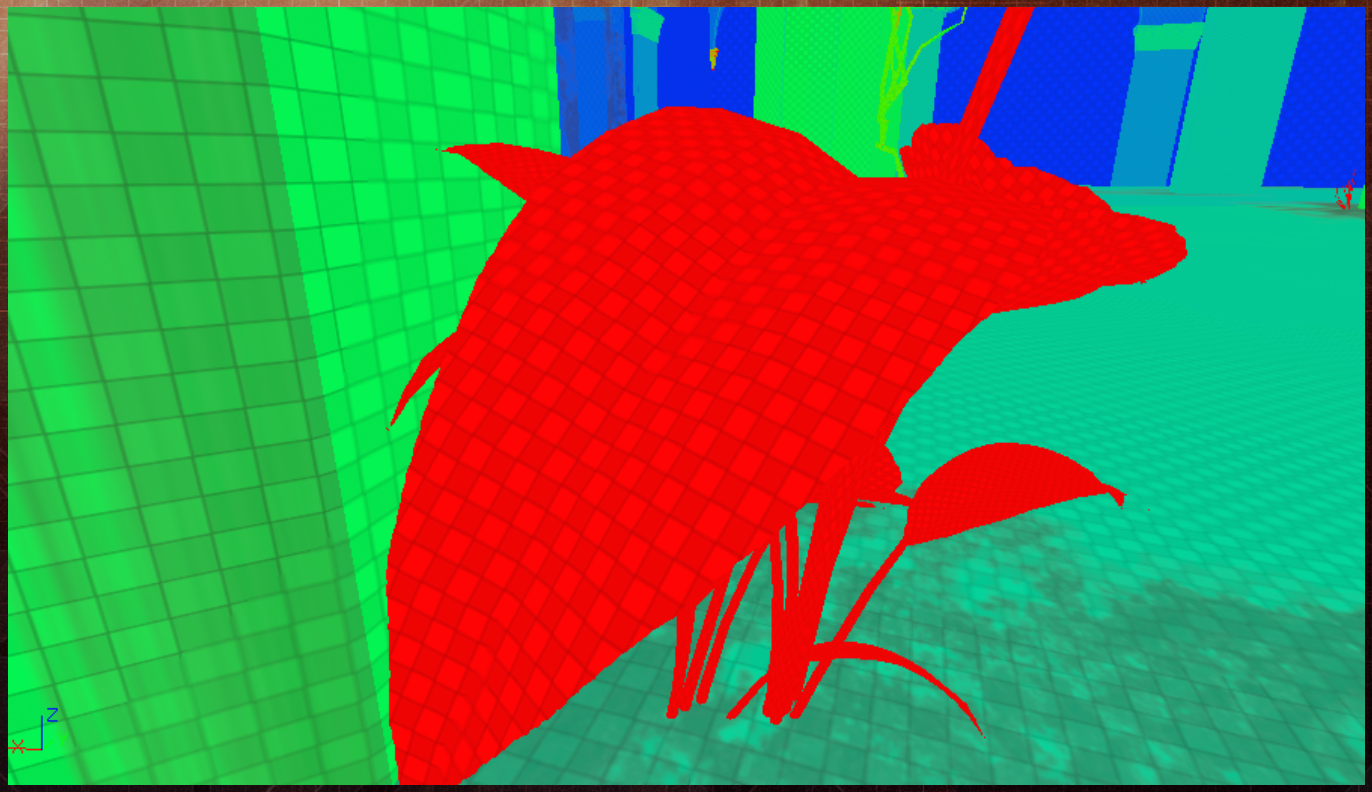

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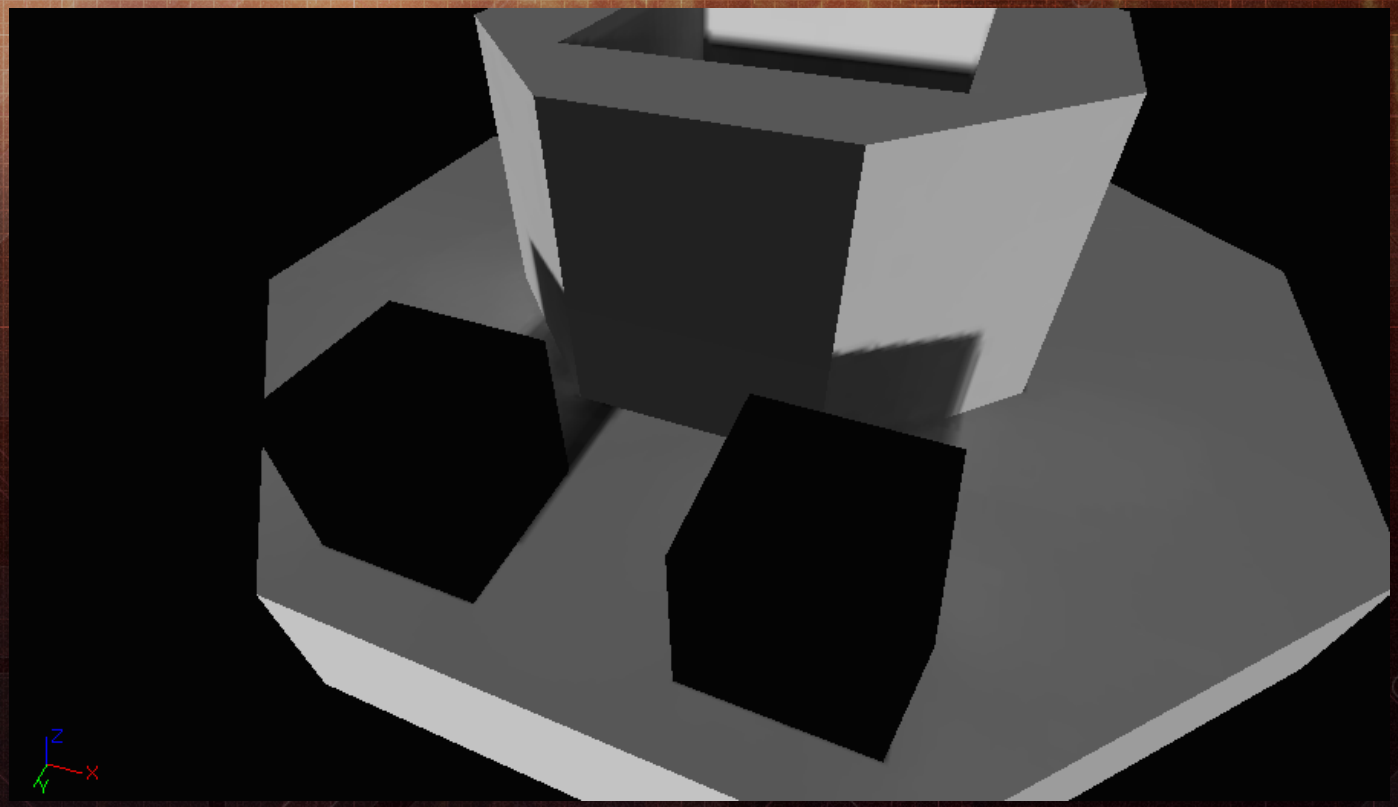
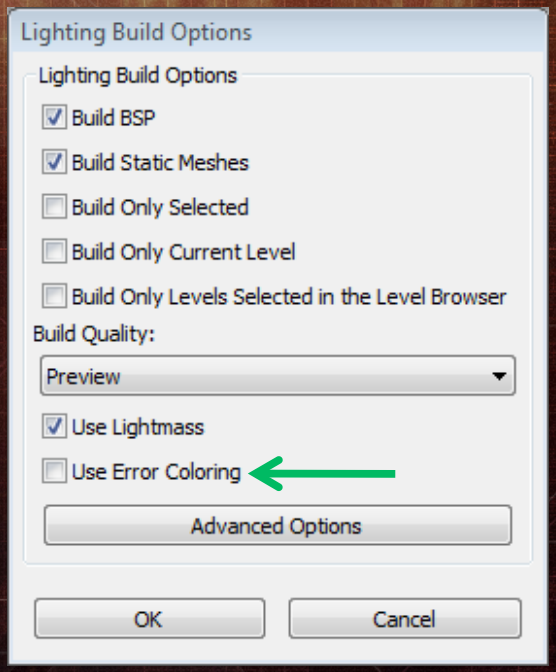


- Errors in content discovered during the lighting build can be embedded in lightmaps themselves

Workflow Adjustments



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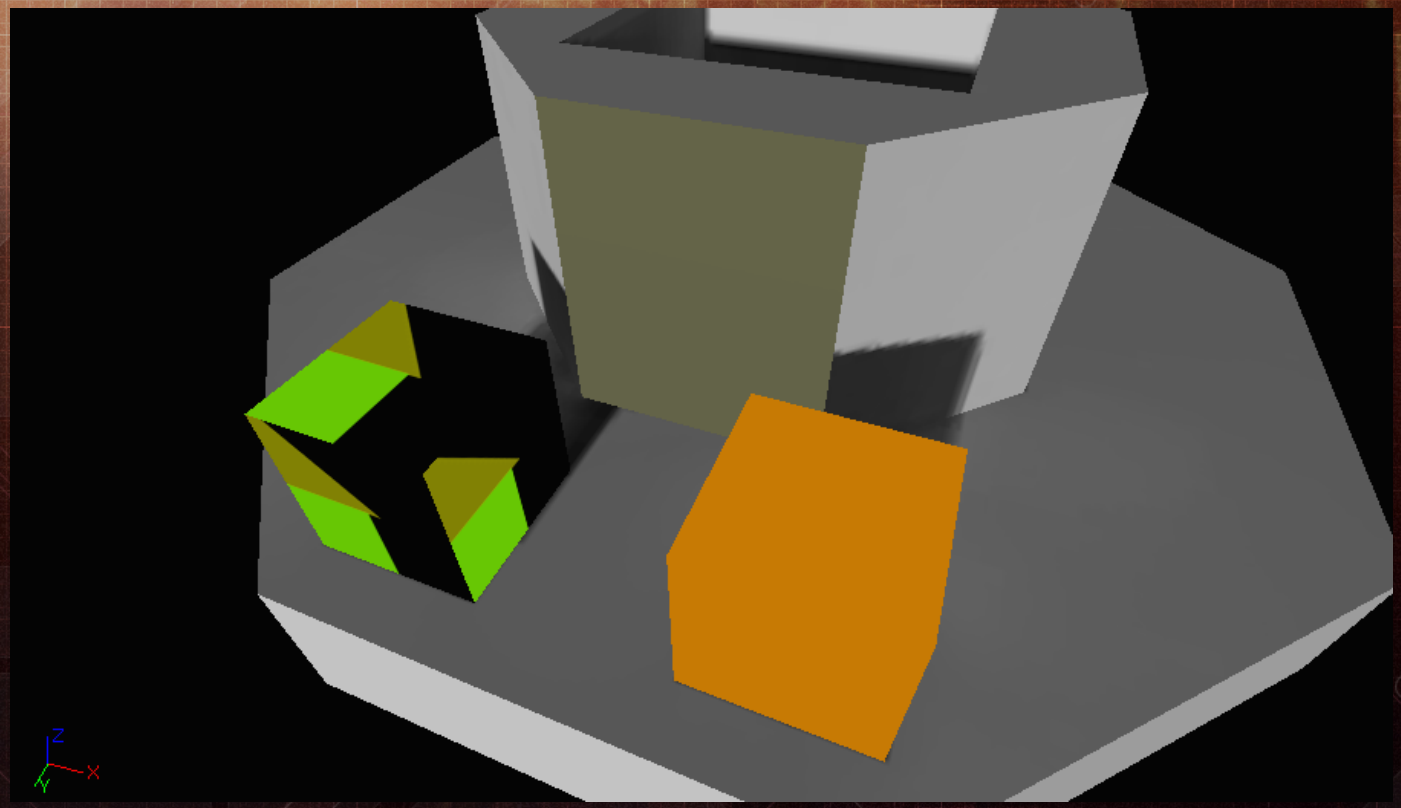

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  - Color-coded by error type, very easy to track down
  - Visuals in Preview builds only, messages always

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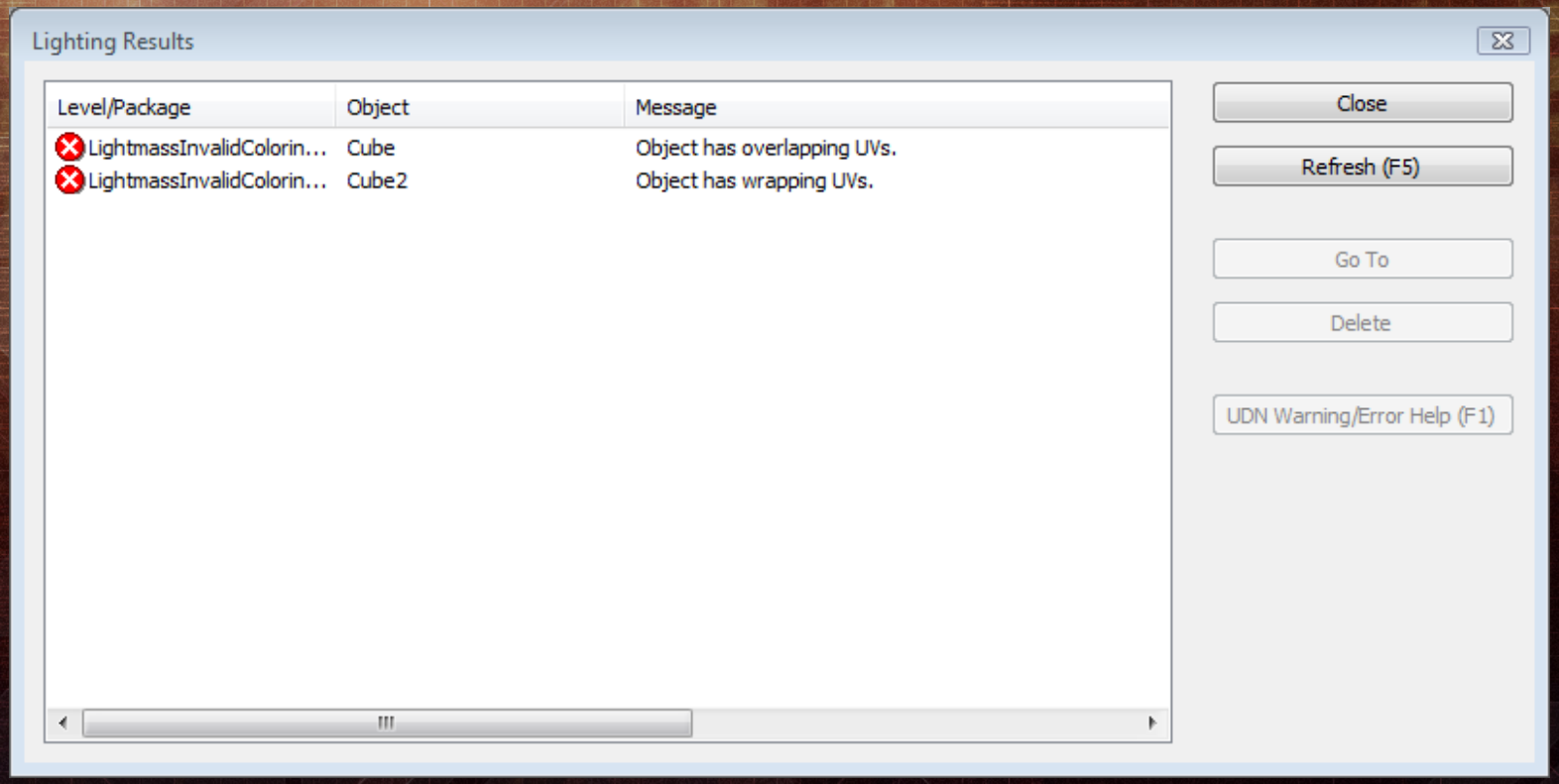

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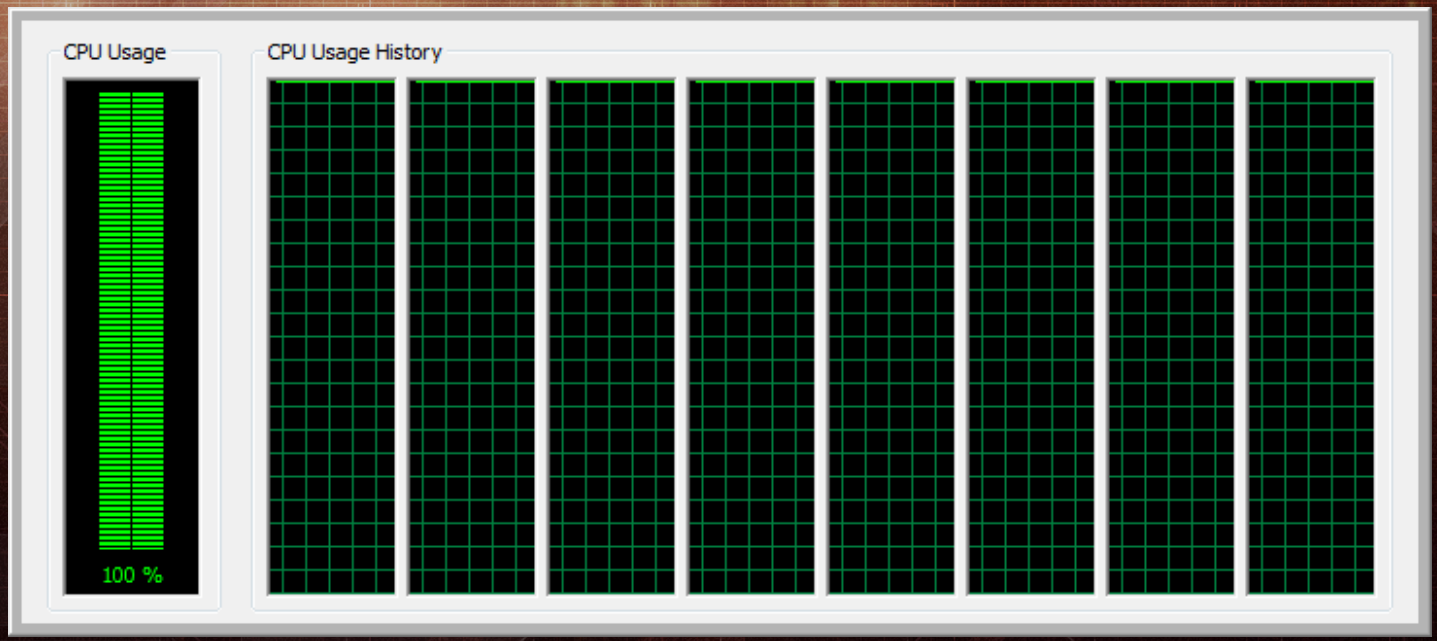
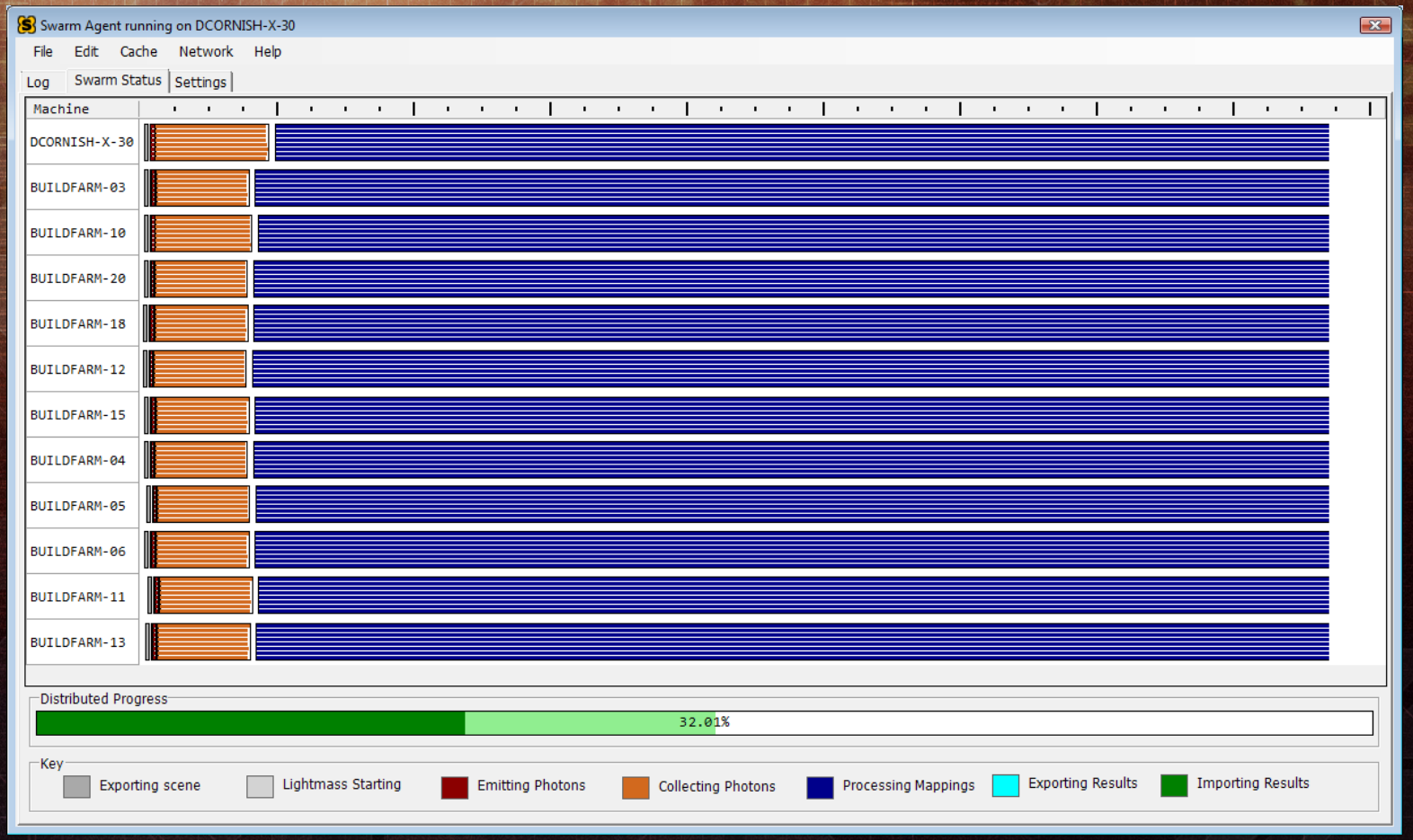
Lightmass Processing



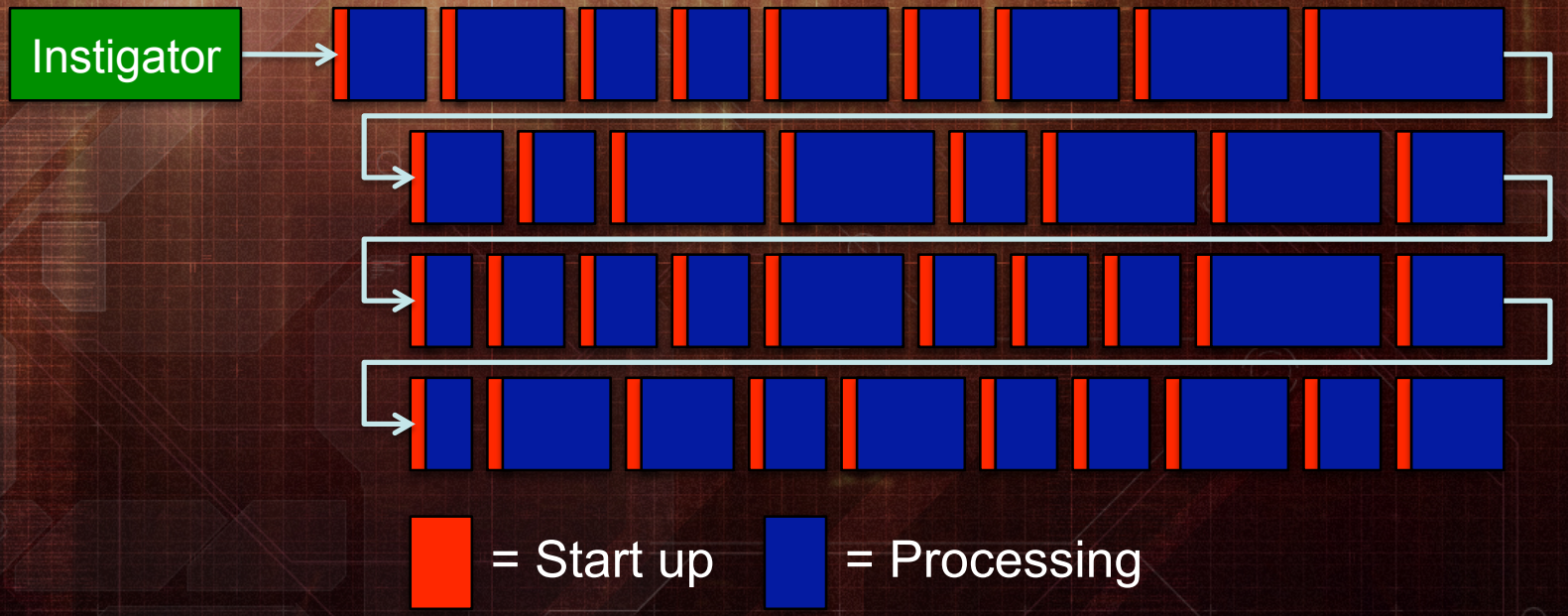
- Amazing new lighting pipeline comes at a price
  - Computational complexity
  - Network distribution is a huge win

Unreal Swarm



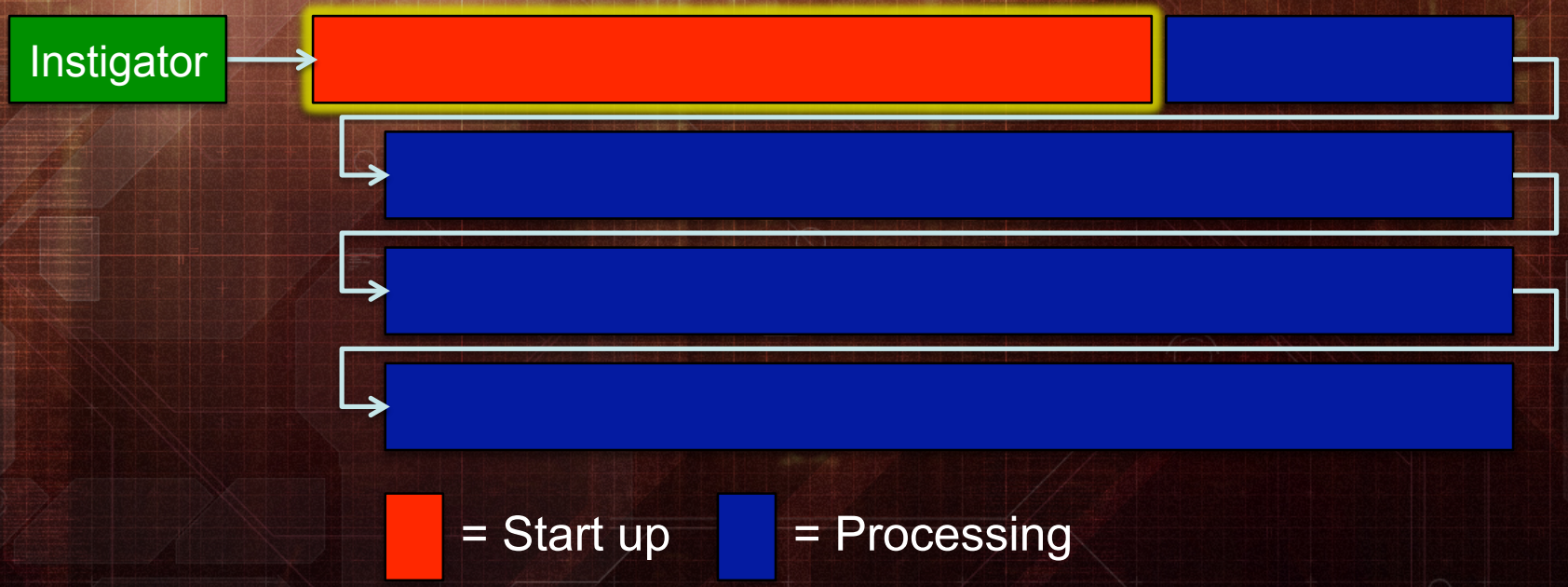
- Distribution system co-developed with Lightmass
  - Designed for network distribution of computation
  - Abstracts I/O, Network, Messaging, Jobs/Tasks

Unreal Swarm Design



- Most systems distribute many small applications
  - Large set of simple applications running in parallel
  - Cloud of clients running isolated tasks and quitting
  - Application lives to only do one thing

Unreal Swarm Design



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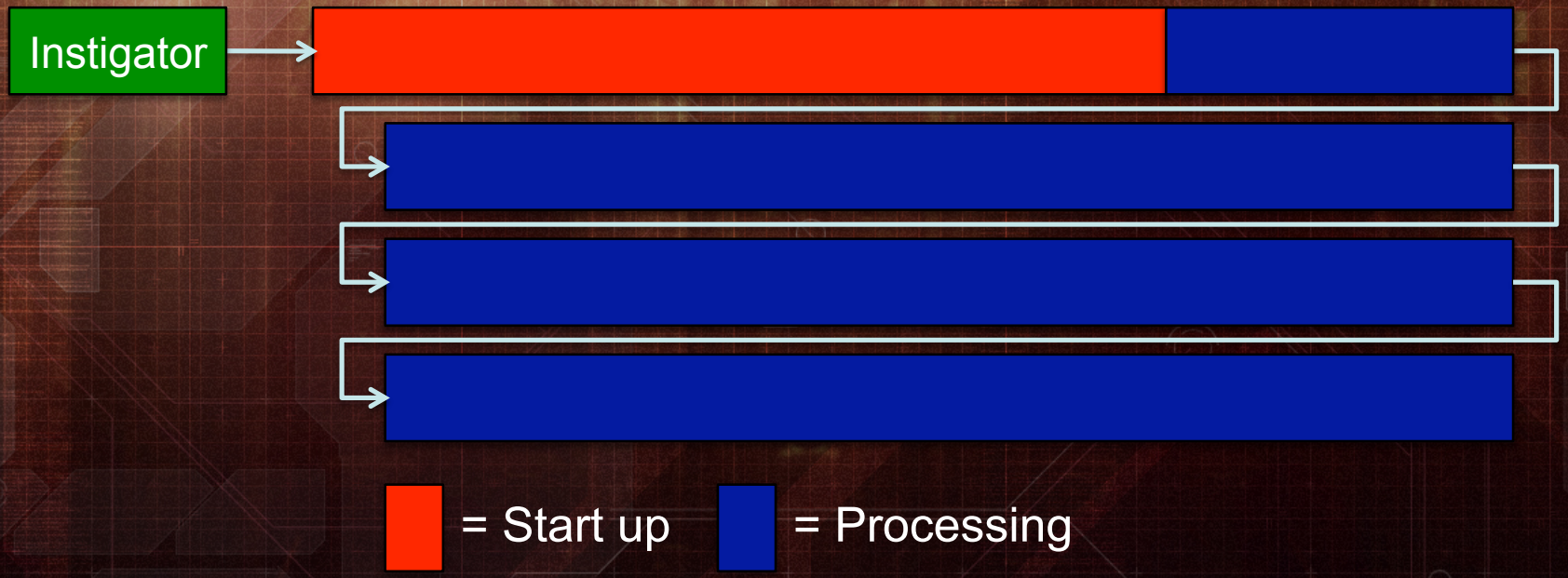
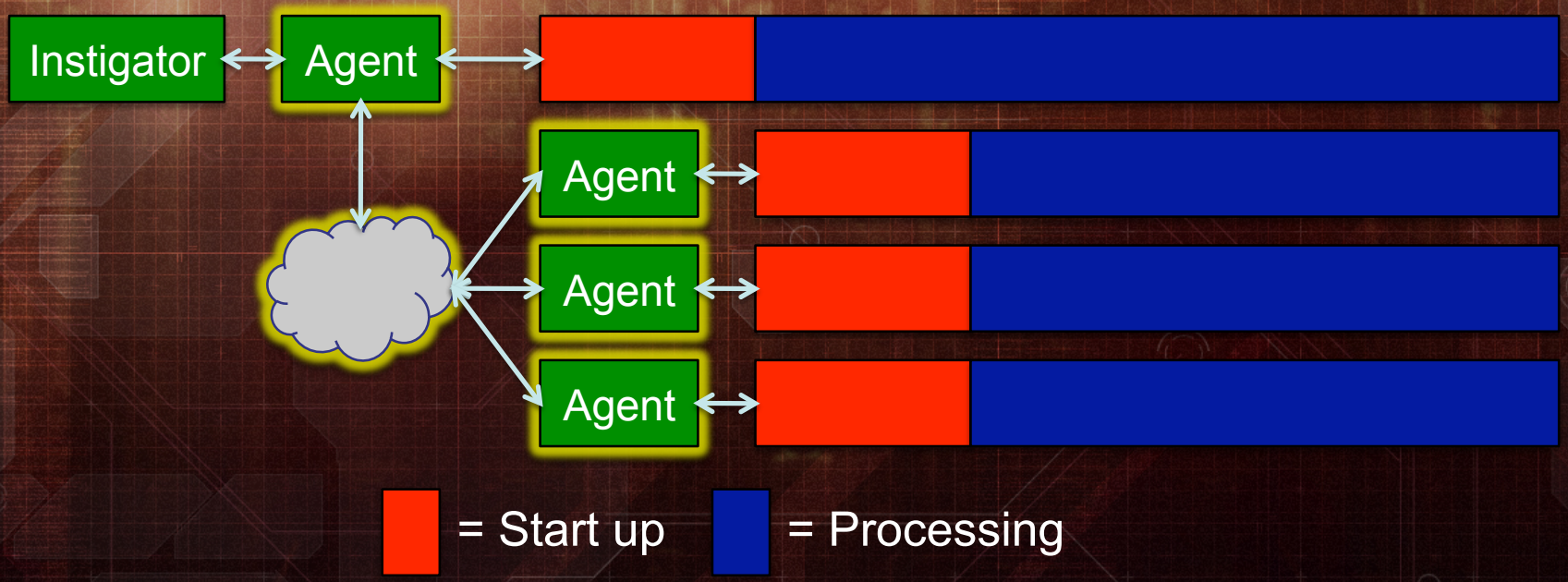


- Swarm manages a single distributed application
  - Identical applications with persistent connections
  - Allows for large start up time and in-memory data sets
  - Application requests work until everything is done

Unreal Swarm Design



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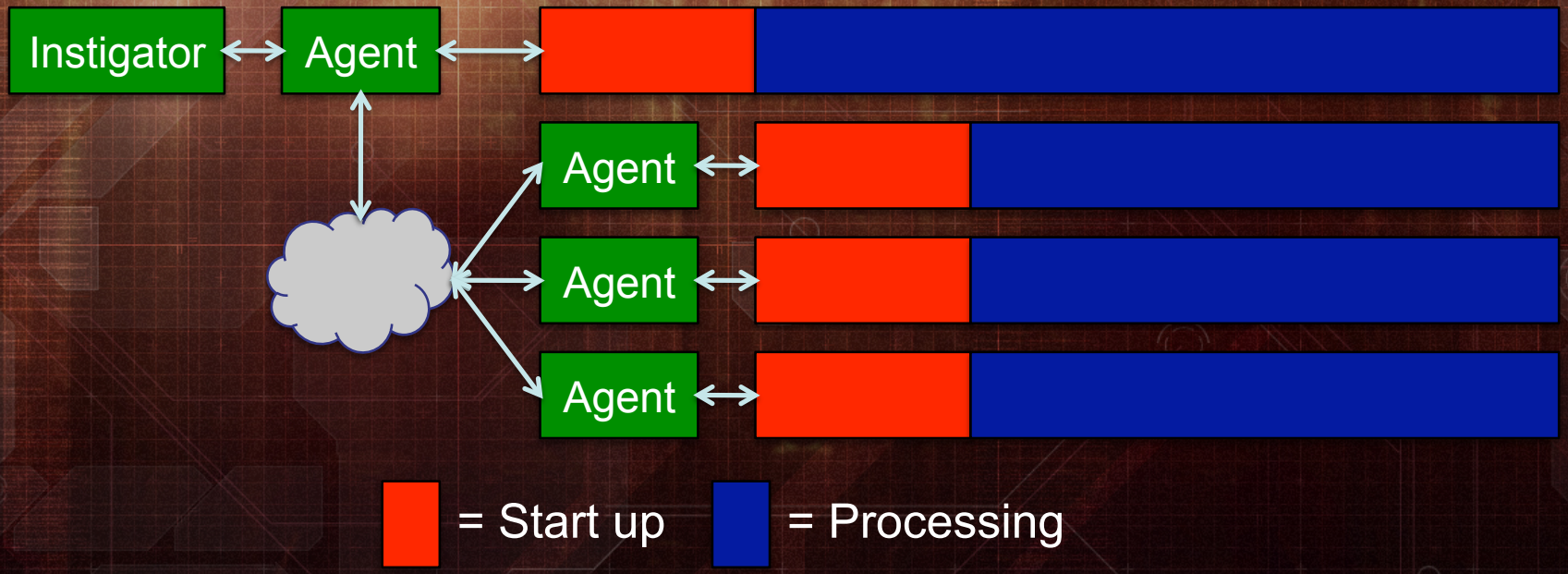

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  - Allows for large start up time and in-memory data sets
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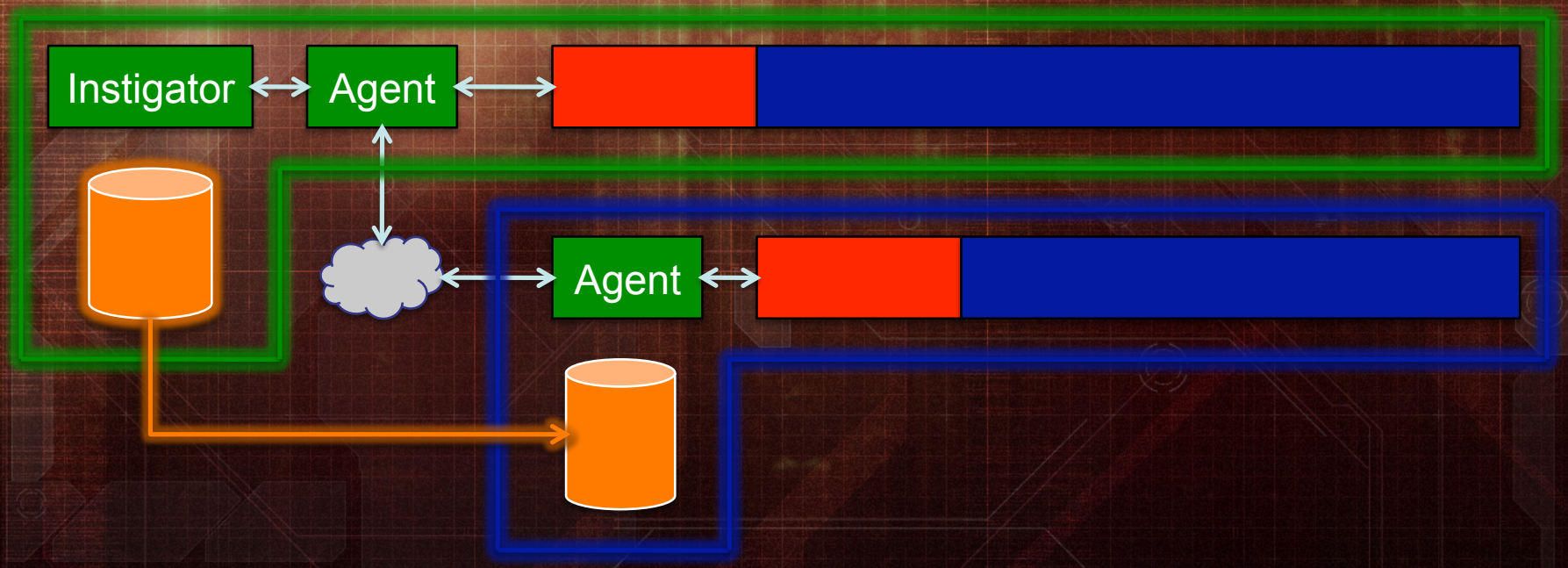
Caching and Distribution

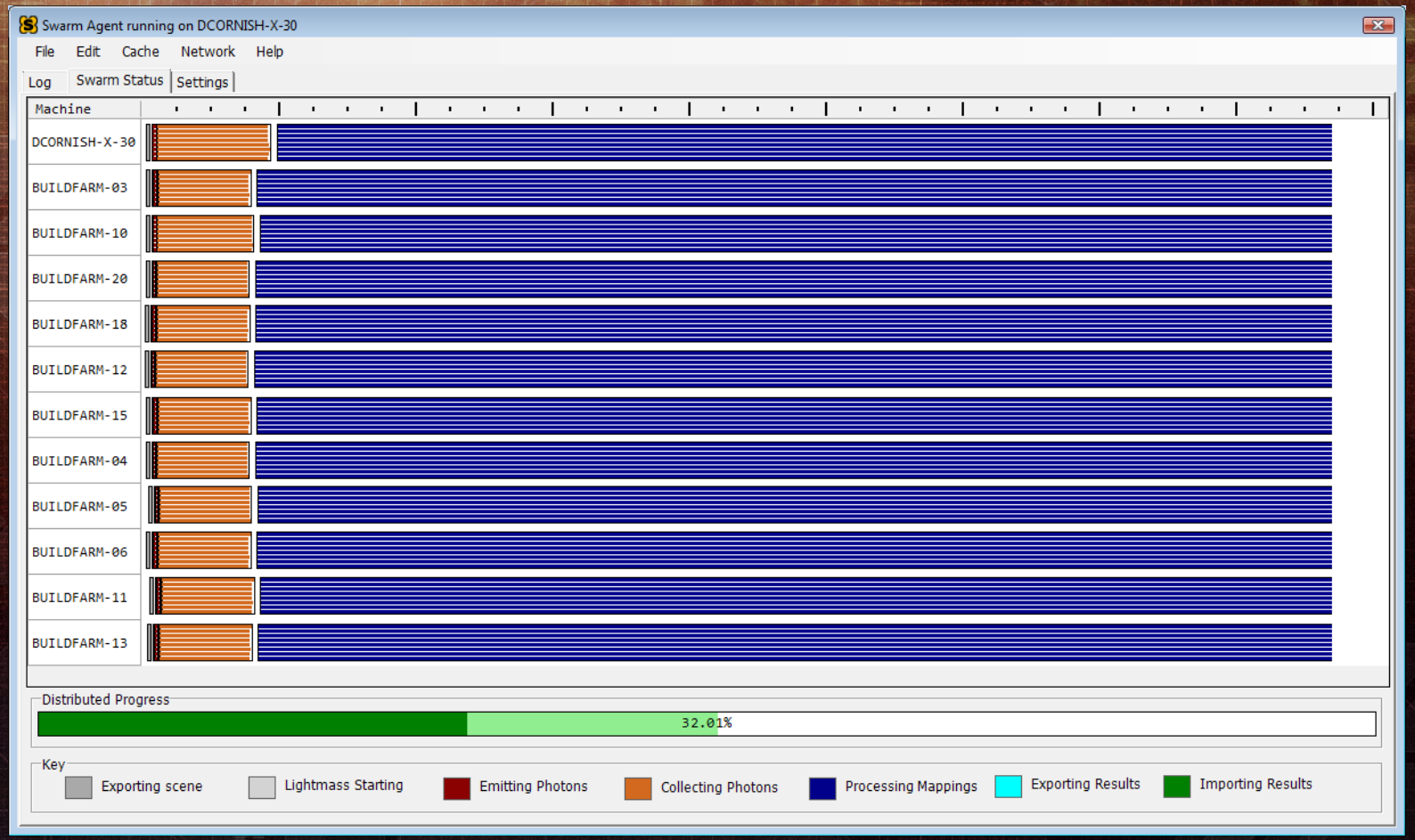
- Swarm maintains a cache of content, binaries
  - All files in the cache have globally unique names
  - Some data is generated directly in the cache

Caching and Distribution



- Swarm manages on-demand cache distribution
- Rely on caching for high performance iteration
  - Size of content is non-trivial, networks not limitless
  - Most raw content rarely changes

Unreal Swarm



Unreal Swarm API

- Swarm Interface API is a simple programming interface to the entire Swarm system
  - Exactly the same API Lightmass and Editor use
  - Designed to be very general for other uses

Conclusions and Future

Rendering equation

Carefully balanced global illumination system

Lightmass pipeline

Workflow improvements

Swarm

What’s next?

Questions?

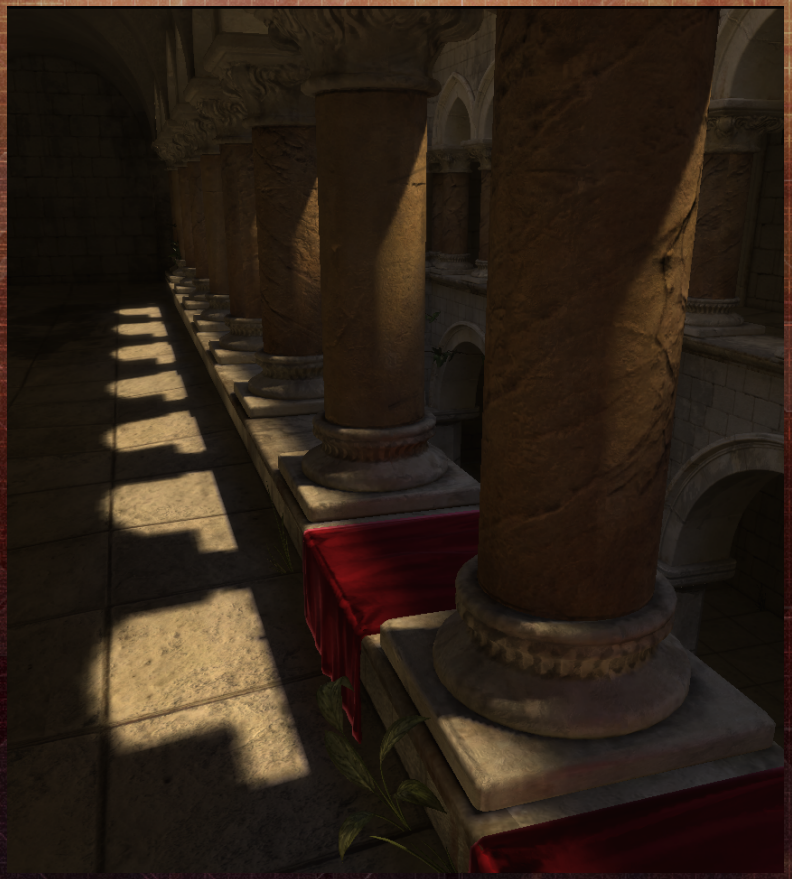
Thank you

Unreal Lightmass Features

Large level support, highly multithreaded

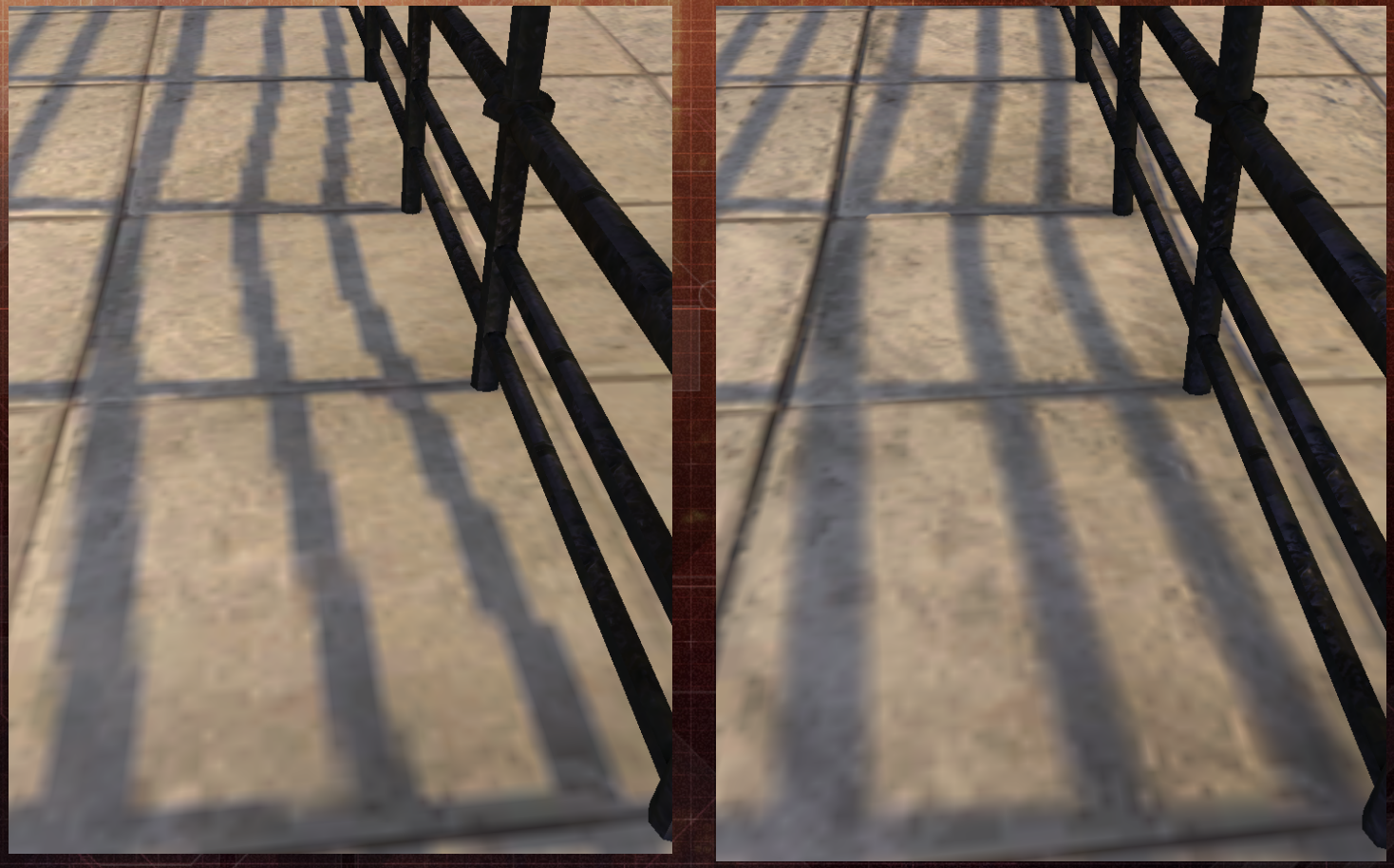
Large level support, highly multithreaded

Unreal Lightmass Features



Dominant light types and distance field shadows

Unreal Lightmass Features



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