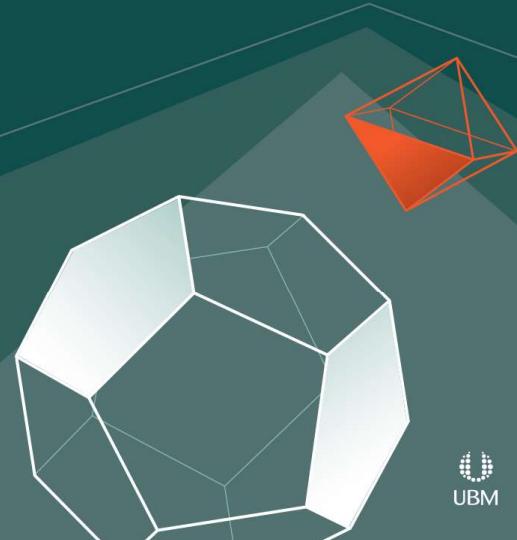
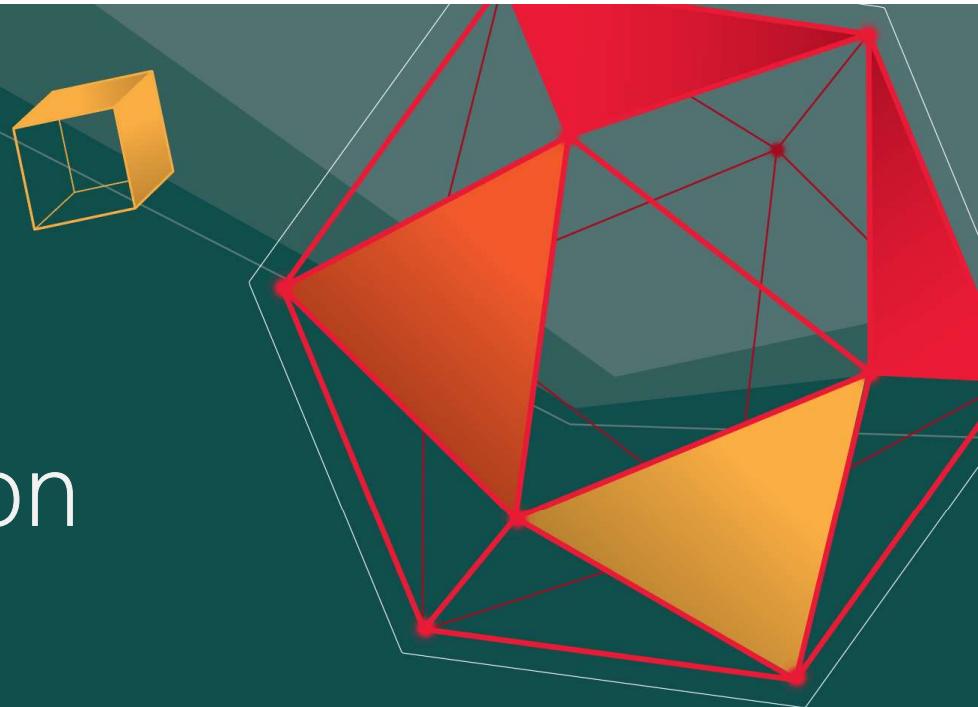


# GDC®

## Real-Time Raytracing for Interactive Global Illumination Workflows in Frostbite

**Sébastien Hillaire**  
Sr Rendering Engineer    EA/Frostbite

GAME DEVELOPERS CONFERENCE® | MARCH 19–23, 2018 | EXPO: MARCH 21–23, 2018 #GDC18



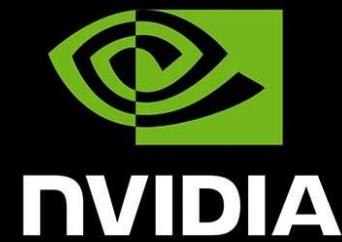
# Outline

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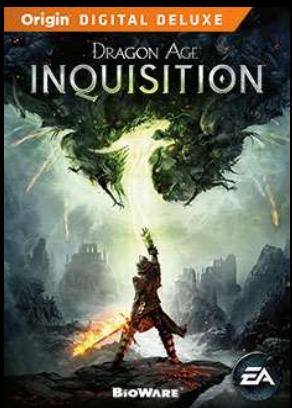
Context & current workflows

GI Live preview tech

DX12 + DXR APIs implementation on NVIDIA RTX technology



# Frostbite: EA game engine



# Global illumination in EA games

## Geomerics Enlighten [Martin10]

- Supports dynamic GI updates
- Time of day
- Weather updates
- Moving lights
- Destruction



## Frostbite Flux path tracer

- Fully precomputed lighting
- Focus on density, quality & performance



# Flux path tracer

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## CPU Baking process

- Intel Embree
- Incredibuild

See Yuriy's talk for more details [O'Donnell18]

Thursday, March 22, 4pm  
Room 3020, West Hall



# Flux in Madden

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# Flux in FIFA dusk

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# Flux in Star Wars Battlefront II

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# Flux in Star Wars Battlefront II

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# Flux in Star Wars Battlefront II

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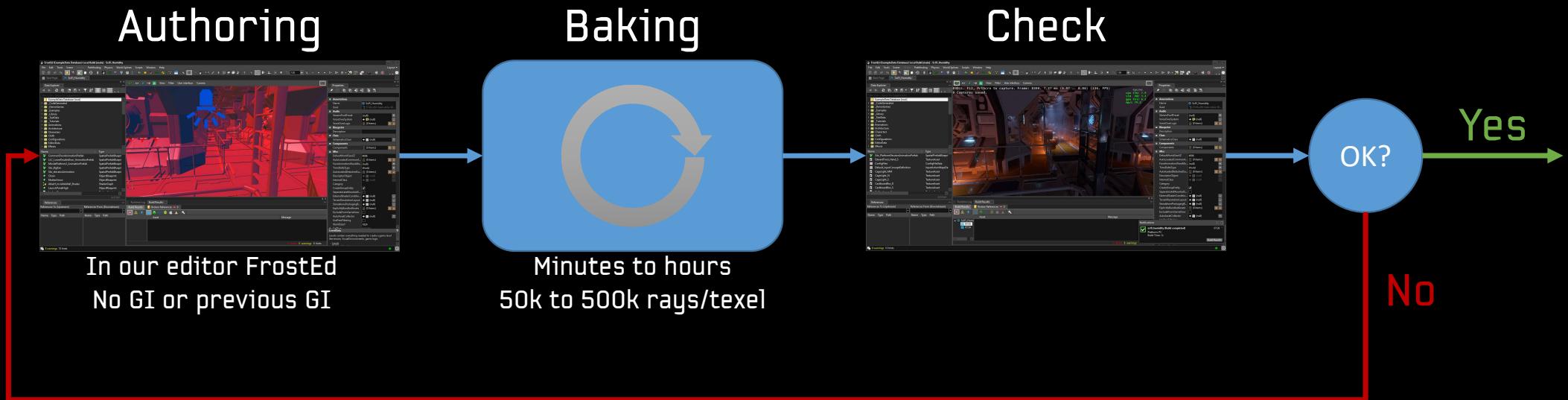


# Flux in Star Wars Battlefront II

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# Flux workflow



CPU GI preview too slow for our constraints



# Path tracing

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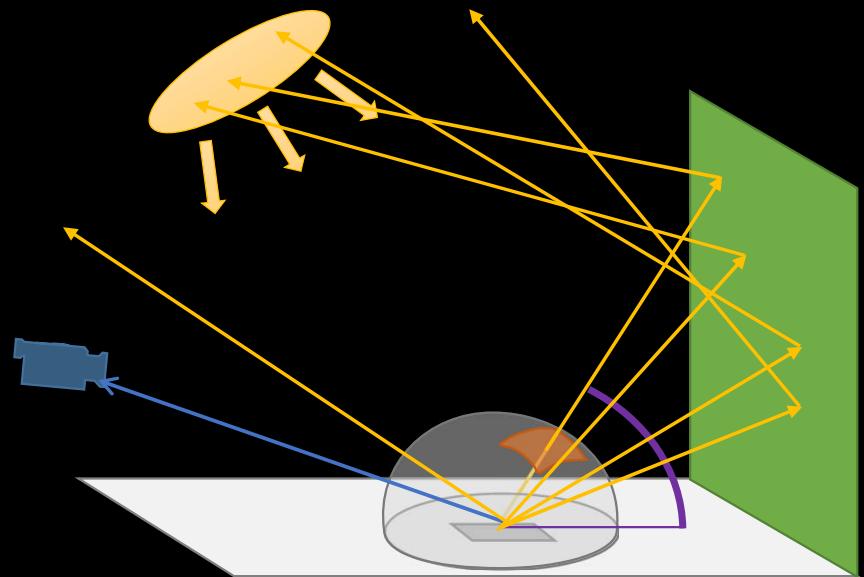
$$L_o = L_e + \int_{\Omega} L_i \cdot f_r \cdot \cos(\theta) \cdot d\omega_i$$

## Tracing is parallel

- Each lightmap texel is independent
- Each path is independent
- Perfect for GPUs

## Monte Carlo integration

- Incremental refinement
- Perfect for preview



→ Perfect for GPU based interactive GI preview

# Path tracing on GPU

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Flux live preview functional prototype



Using new DXR API

- See Microsoft presentation for API details



GPUs with NVIDIA RTX technology

- Since access to early drivers



# Live authoring of a scene

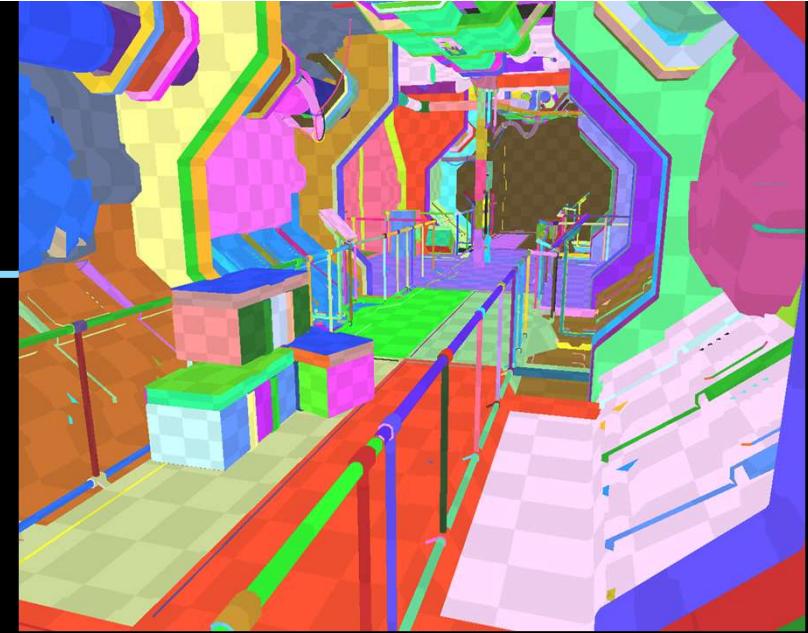
Credits: Evermotion - Granary



# Flux DXR - input

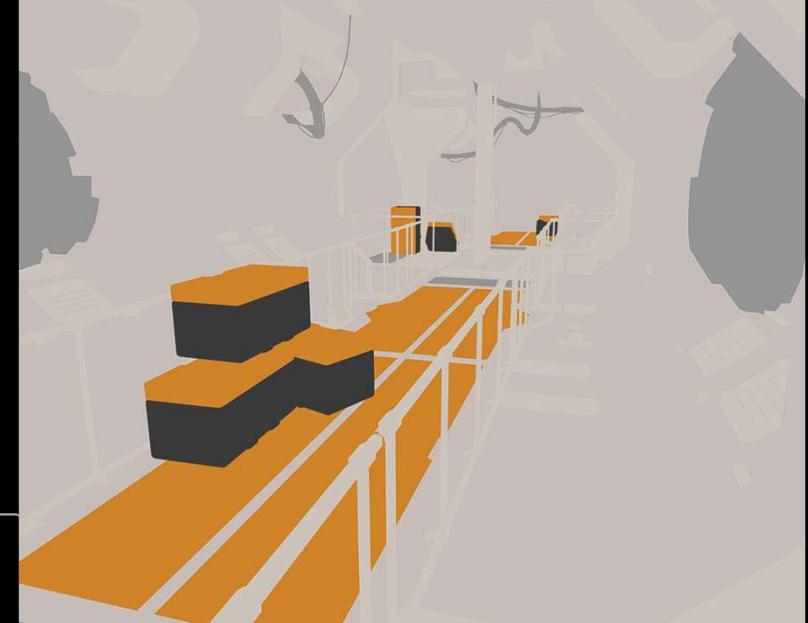
## Meshes

- Triangles
- Lightmap UVs



## Material

- Albedo
- Translucency
- Emissive



Every light type and sky in Frostbite

[Lagarde14] [Hillaire16]



# Flux DXR - output

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## Lightmaps

- Irradiance (bounce light)
- Dominant indirect light direction



## Irradiance volumes

- Irradiance as SH L2



## Same result as real baking

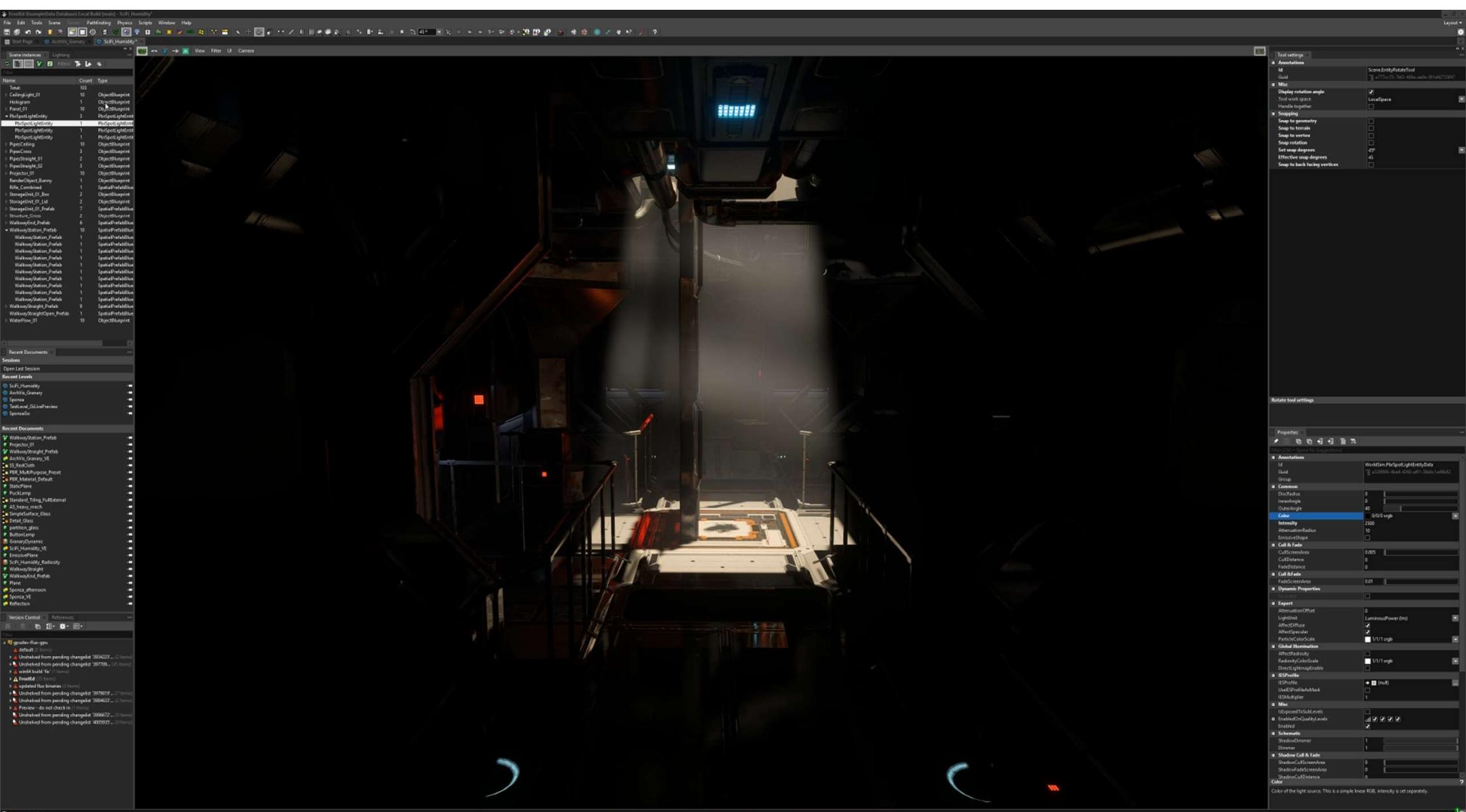
- Not a different algorithm
- Live visualization of in-progress bake
- With acceleration techniques

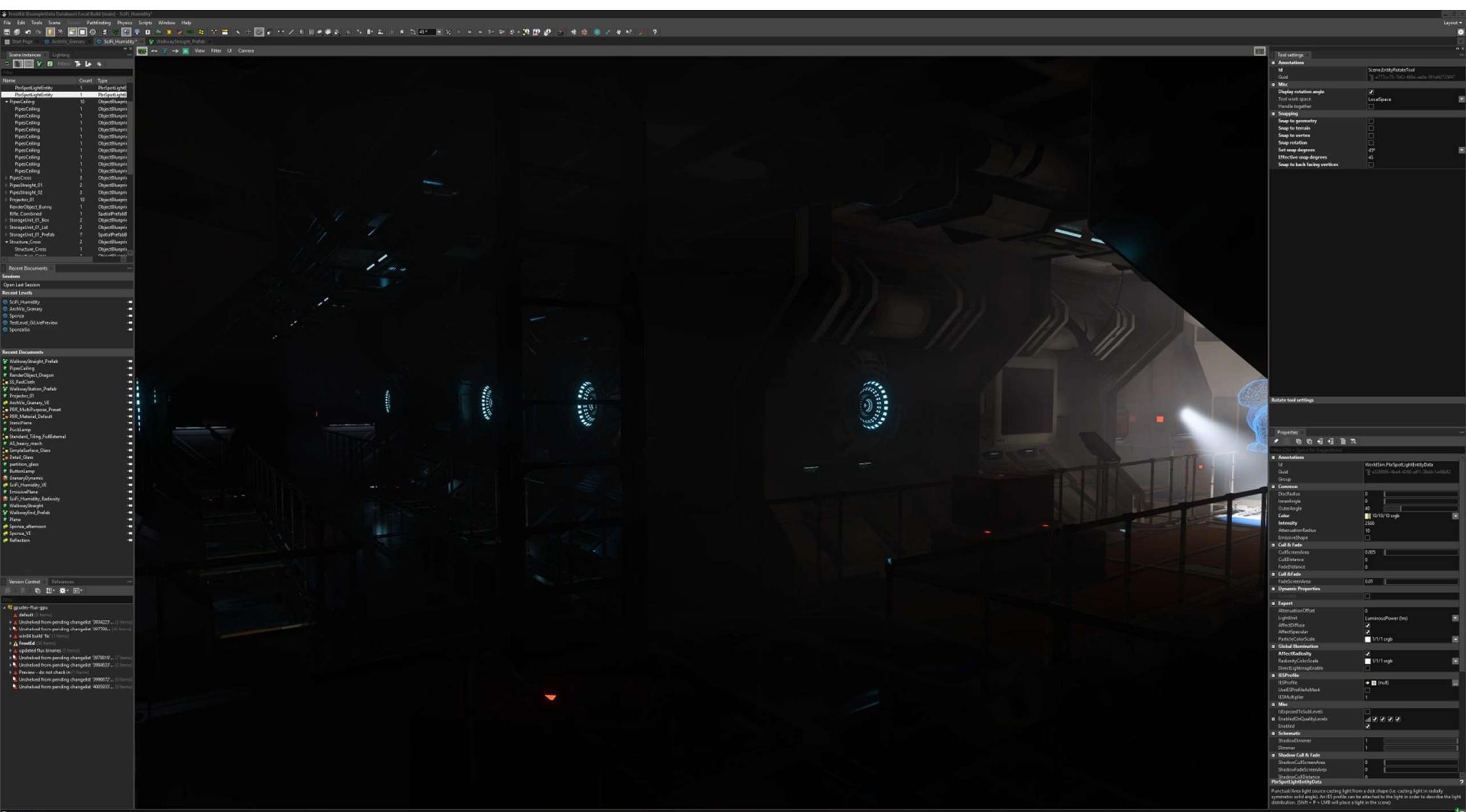


# Flux DXR - Final output

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# DXR - setup

## Single GPU works

- But Frostbite and Flux compete for it  
(adapt tracing budget based on frame rate)

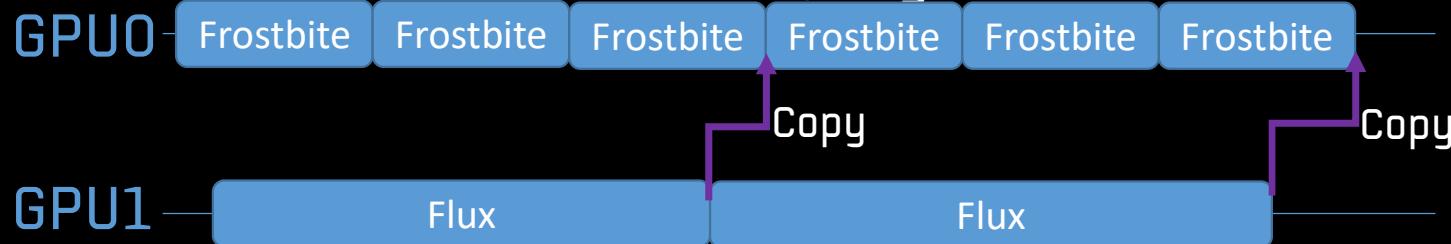
## 1+1 GPUs

- Frostbite on one GPU
- Flux side GPU

## 1080 GTX Ti + Titan V

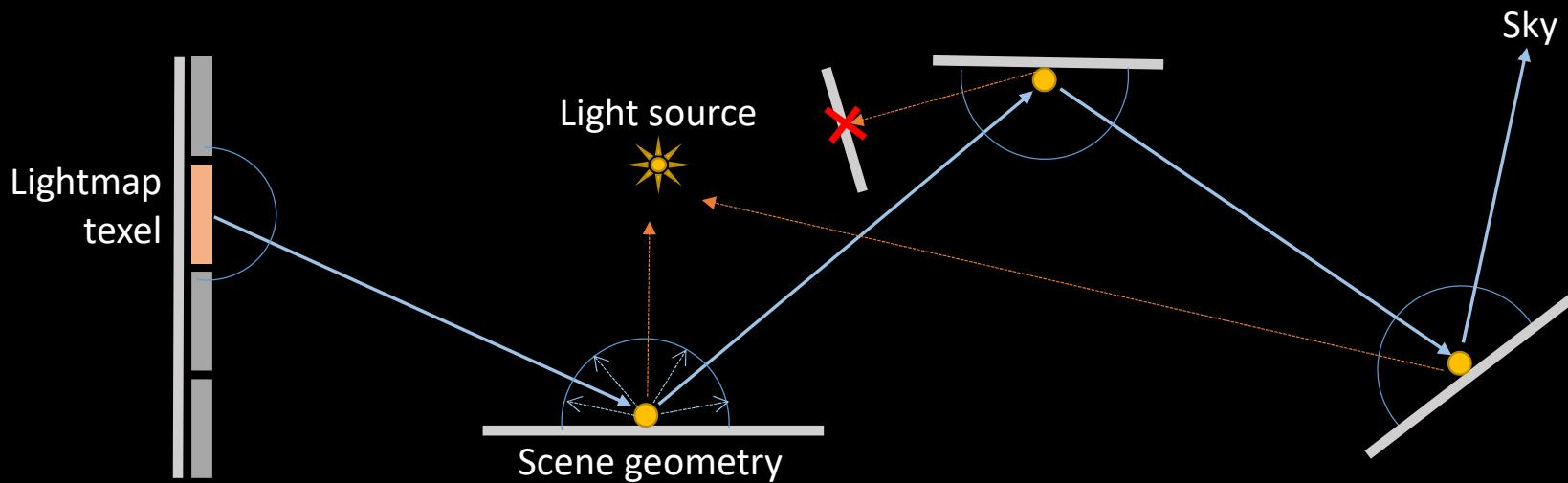


## DX12 multi-adapter mode, asynchronous



# Tracing lightmap texel (1/3)

Naïve forward path tracer kernel with next event estimation

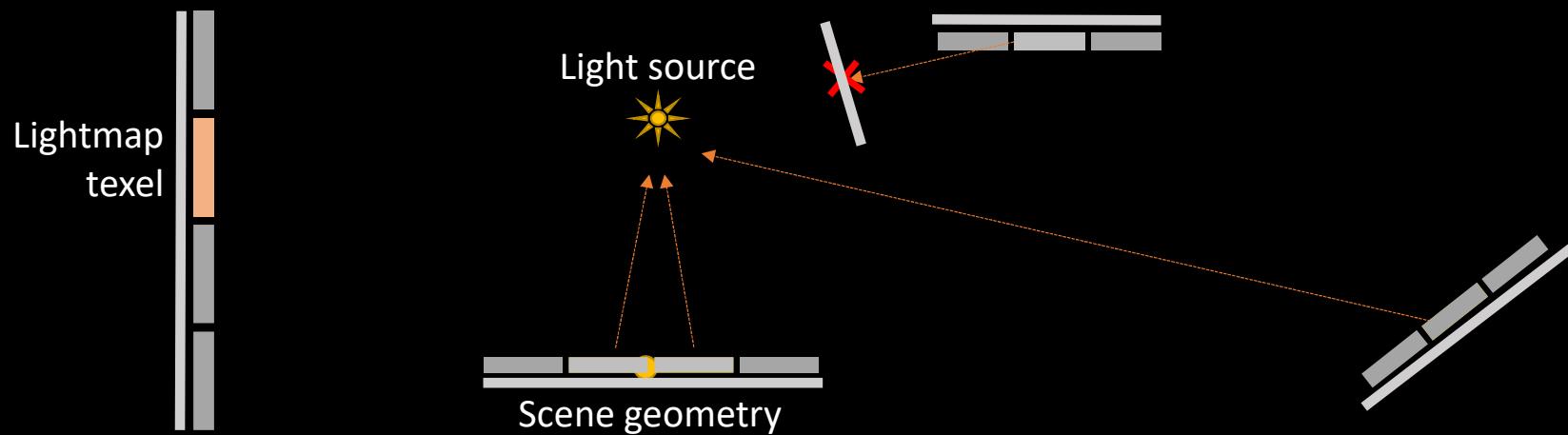


Accumulate over time / reset when lighting/object/material changed

Secondary shadow rays are **incoherent** and thus more expensive

# Tracing lightmap texel (2/3)

Use (naïve) **irradiance cache** for direct light (sun, local light, emissive)

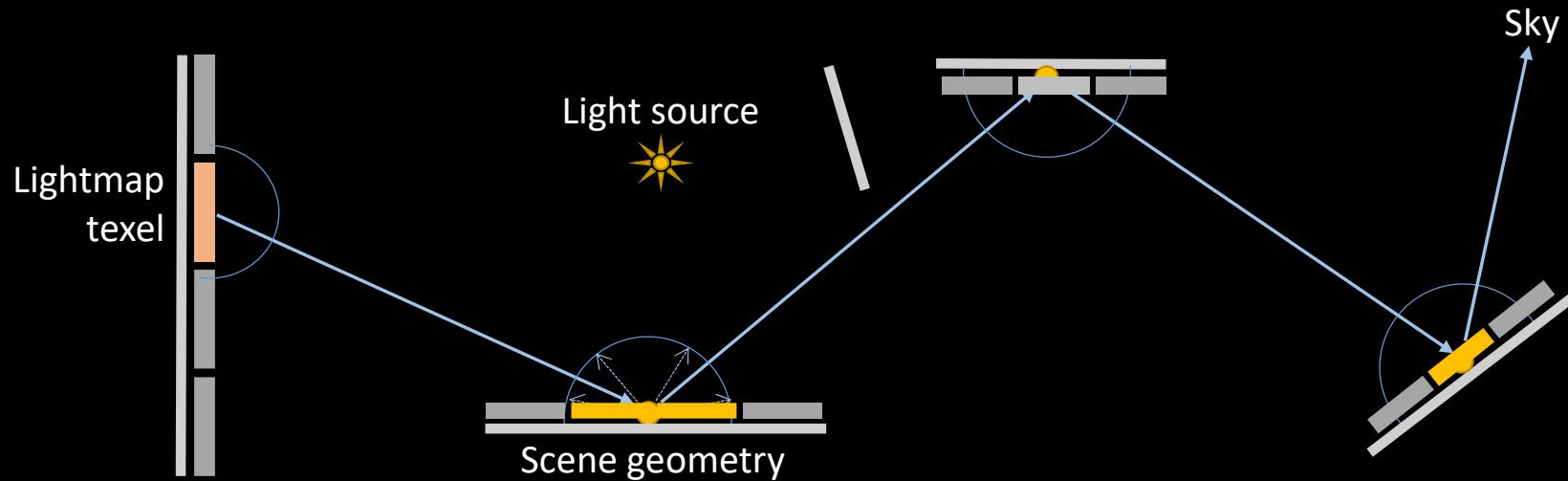


Cache filled in **over multiple frames** when lighting condition changed

Sampling next event along the path becomes a **simple texture fetch**.

# Tracing lightmap texel (2/3)

Use (naïve) **irradiance cache** for direct light (sun, local light, emissive)

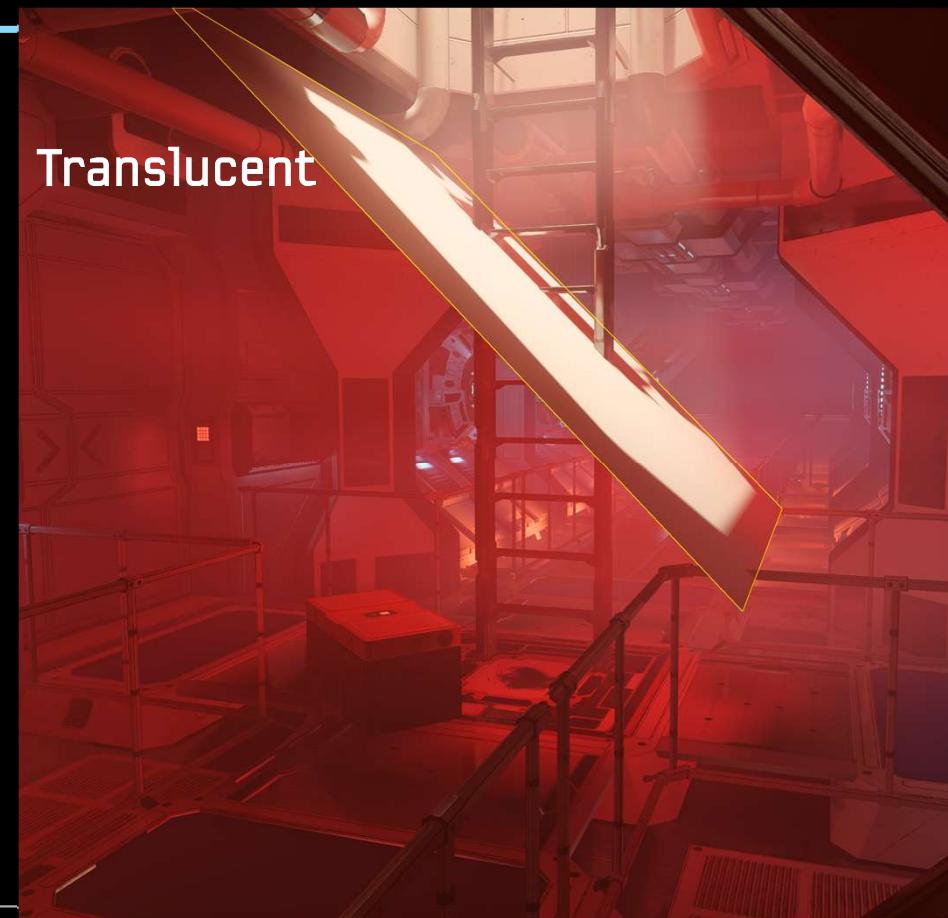
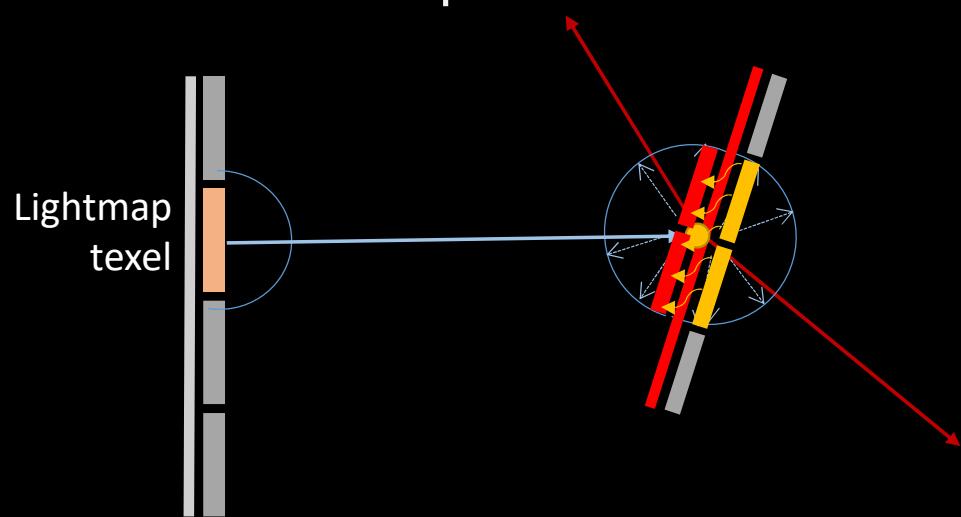


Cache filled in **over multiple frames** when lighting condition changed

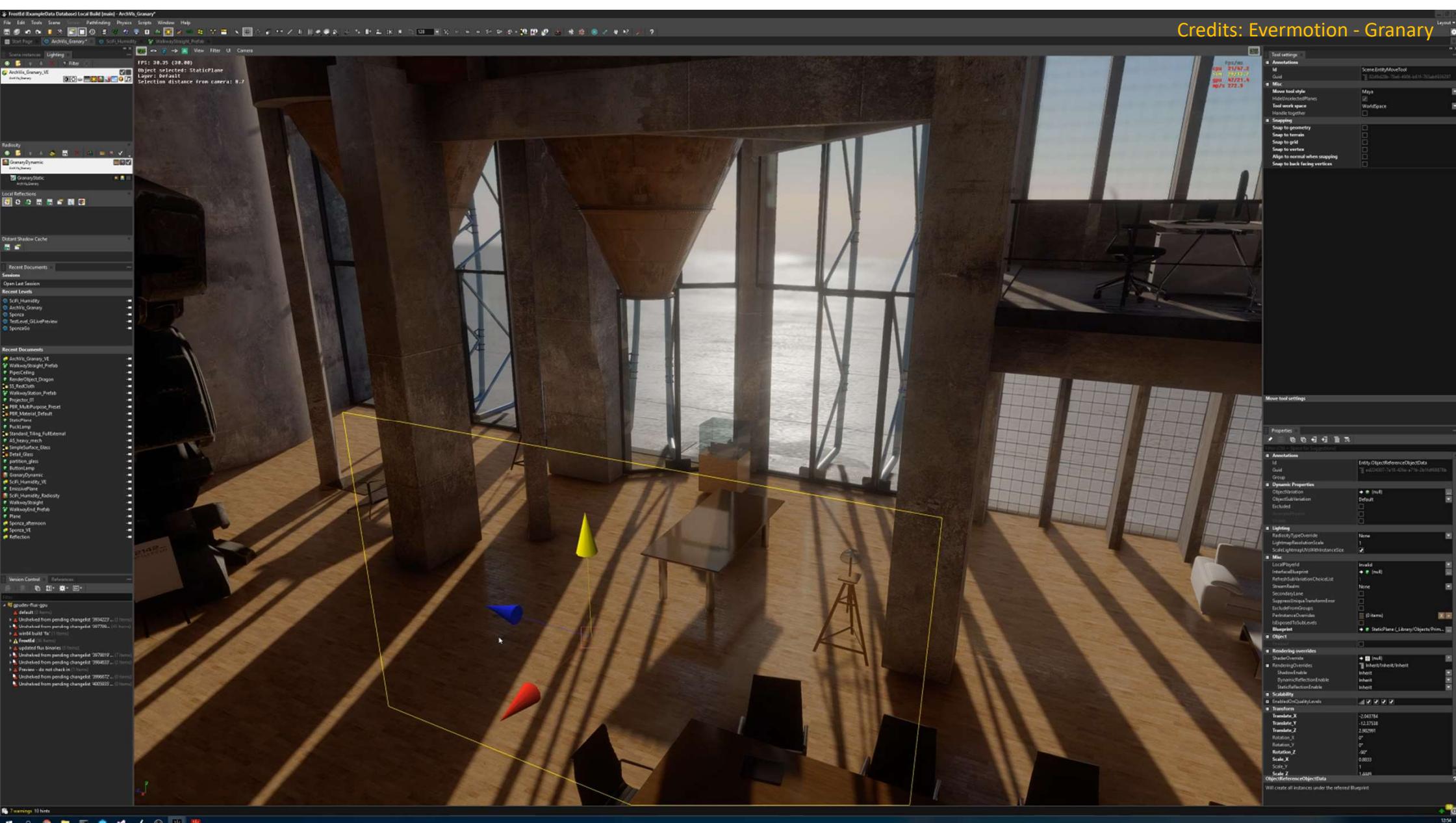
Sampling next event along the path becomes a **simple texture fetch**.

# Tracing lightmap texel (3/3)

Translucency support on thin surfaces becomes cheap



Credits: Evermotion - Granary



# View Prioritization

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- Tracing is **expensive**: preview only what is **visible**
- Render/update **only visible texels**:
  - Trace rays from camera to scene
  - Schedule hit texels
    - **Fast**: 1.3M paths scheduled in 0.15ms  
(**Titan V**)



Slowed down by a LOT  
for demo purposes

# Battling Noise (1/3)

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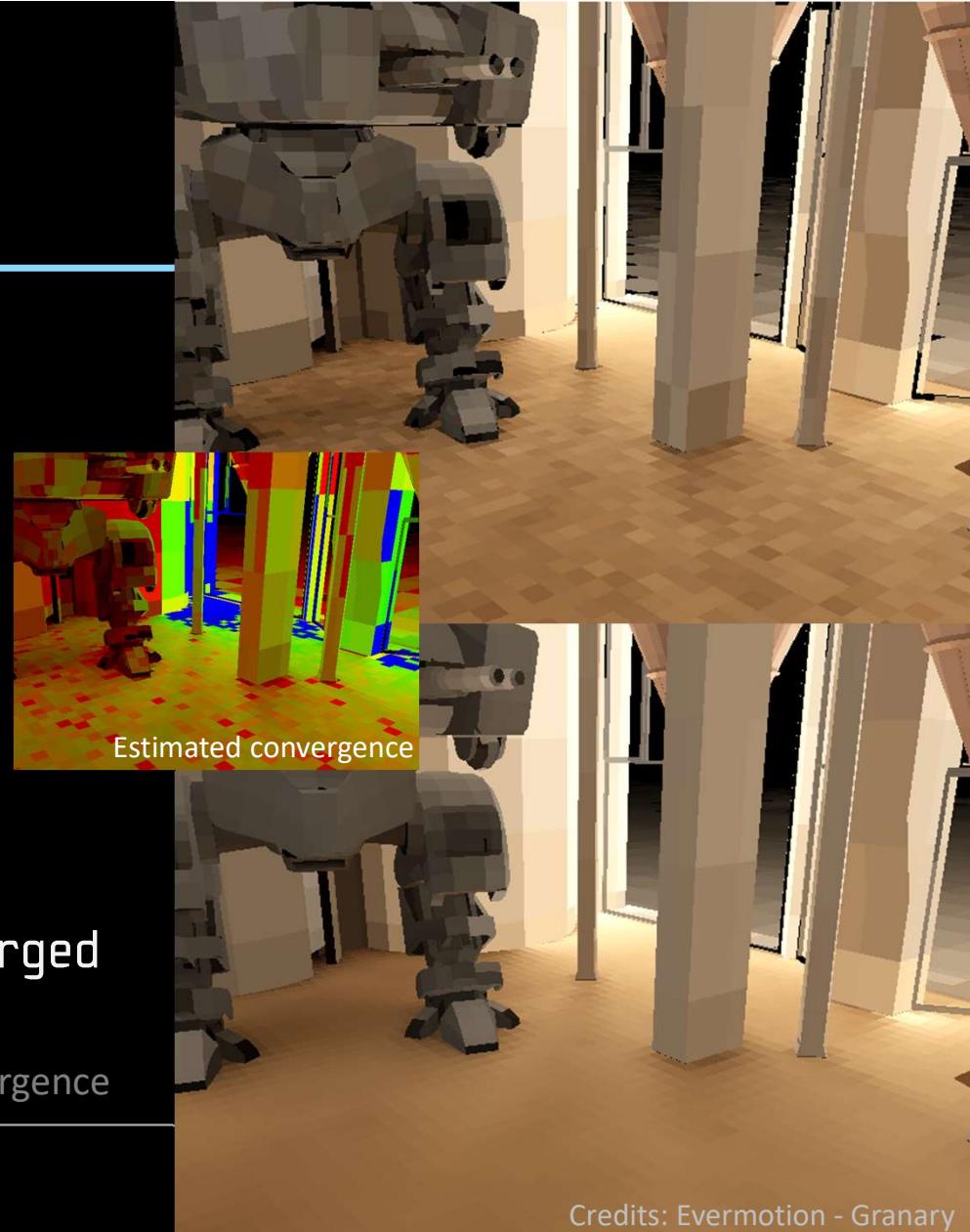
- Forward path tracer has a lot of **noise** (variance)
- Track **(running) variance per texel** in order to know when a **texel has converged**. This is used for:
  - **Balancing tracing budget** where it matters in the frame (do not schedule converged texels)
  - **Denoising** lightmap



# Battling Noise (2/3)

## Denoising lightmap

- Use a **hierarchical A-Trous filter** in lightmap space [Schied17]
- Applied every frame on the lightmap\* before presented to the user
- Denoising is faded out as texel converged



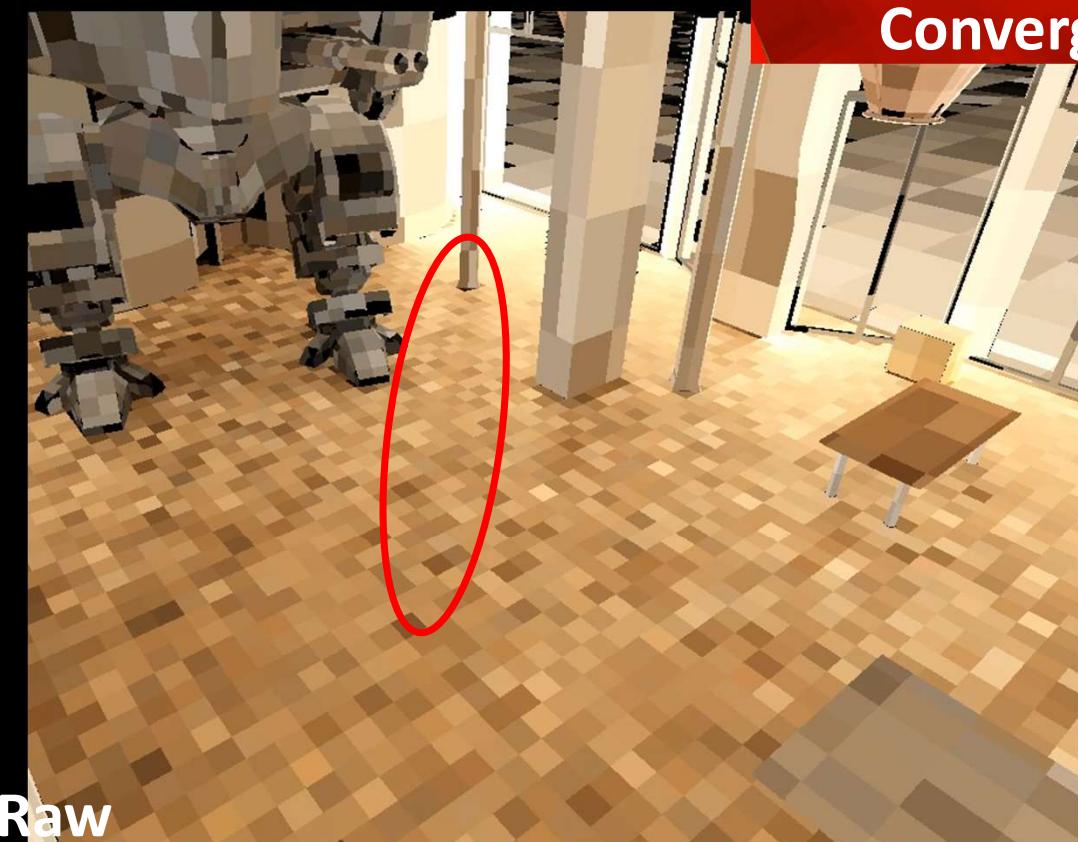
\* The actual lightmap is kept untouched for not biasing the convergence



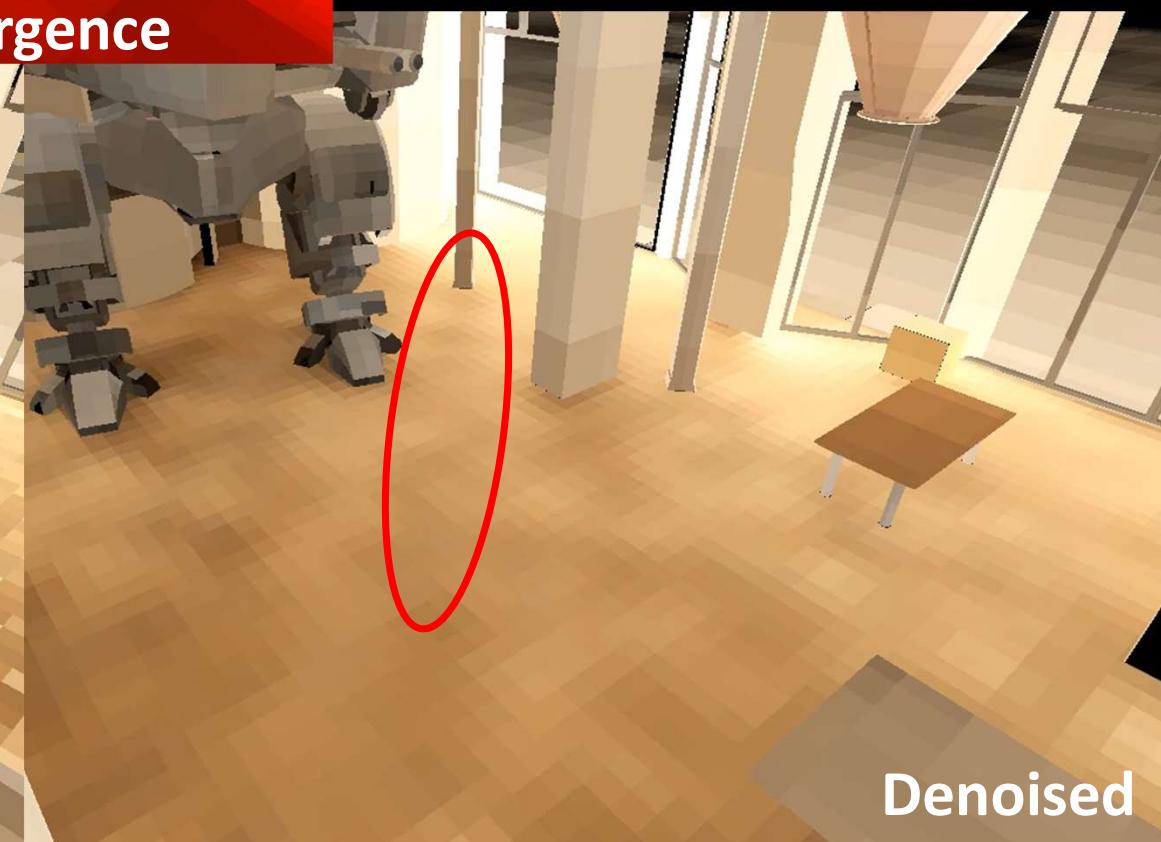
Credits: Evermotion - Granary

Credits: Evermotion - Granary

Convergence



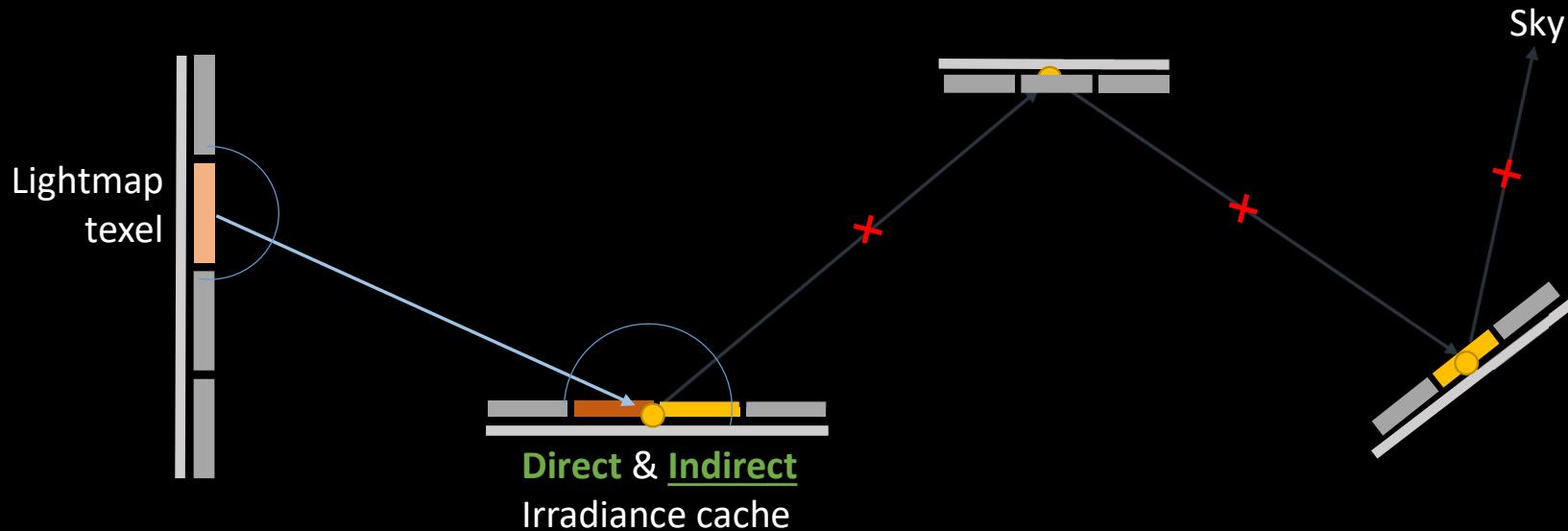
Denoised



# Battling Noise (3/3)

## Future

- Mix **image & lightmap space** denoiser for reducing light leaks
- Add converged texel to an **indirect irradiance** in order to shorten path



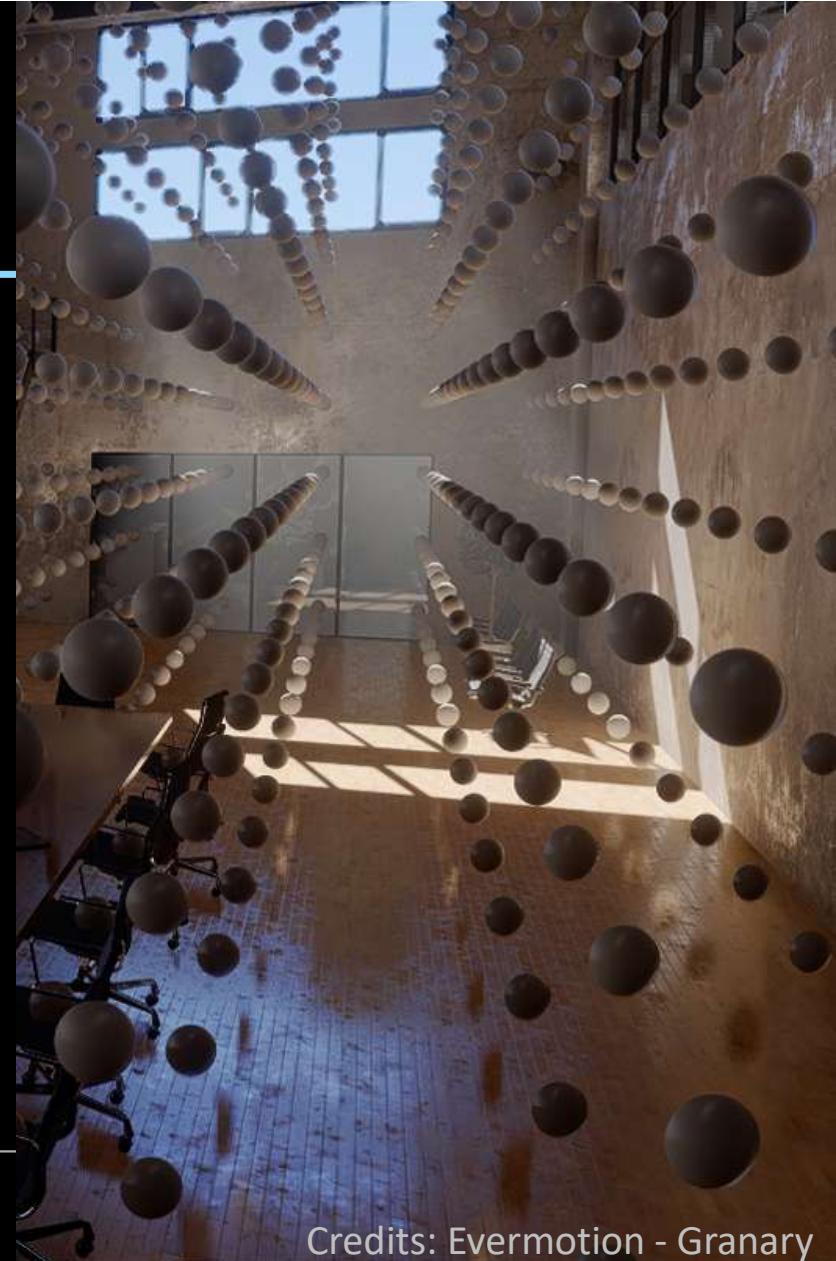
# Irradiance volumes

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Trace probe irradiance of **visible** volumes

Store irradiance into **Spherical Harmonic L2**

Use the same **integrator** as for texels

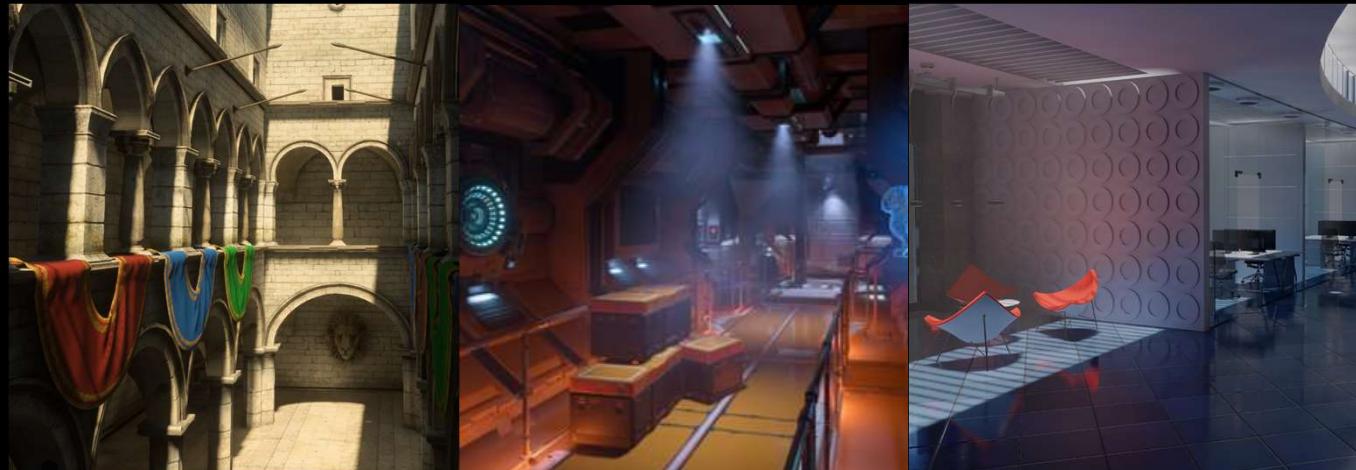


Credits: Evermotion - Granary



# Performance on Titan V

1. Only Sun
2. Many Lights
3. Sun + Sky



Credits: Dabrovic D. & Meinl F.

Credits: Evermotion - Granary

	Sponza	SciFi	ArchVis
Default	150	70	135
+ View Prioritization	220	100	280
+ Irradiance Cache	250	300	320

Performance in million ray / seconds



# Future thoughts

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## Path tracing improvement

Bi-directional tracing

Better irradiance cache representation,

Path guiding for long paths [Vorba14]

## 1+N GPUs

Different random seeds per GPUs

## GPU farm

High quality bakes

Shared on-demand bake resources



# Conclusion

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Interactive GI preview implemented using DXR API

## Benefits

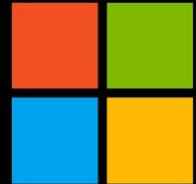
- Faster iterations, interactive, a matter of seconds
- More time for artists to produce high quality scenes



RAY TRACING IS  
BACK FROM THE FUTURE?

# Questions?

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## Frostbite

- Diede Apers
- Charles de Rousiers
- Per Einarsson
- Sebastien Hillaire
- Yuriy O'Donnell
- Alban Wood

## DICE

- Oscar Carlen
- Tilmann Milde

## EA Sports

- Michael Day
- Joe Warren
- Philip Zborovsky



# Other EA talks

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Thursday, 10:00am

**Real Player Motion Tech in 'EA Sports UFC 3**

Geoff Harrower

Thursday, 11:30am

**Deep Learning: Beyond the Hype**

Magnus Nordin

Thursday, 3:00pm

**Cloth Self Collision with Predictive Contacts**

Chris Lewin

Thursday, 4:00pm

**Precomputed Global Illumination in Frostbite**

Yuriy O'Donnell

Friday, 10:00am

**Frostbite GPU Emitter Graph System**

Sebastien Hillaire & Anders Egleus



# Previous work

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[Hillaire16] Sébastien Hillaire, [Physically Based Sky, Atmosphere & Cloud Rendering](#), SIGGRAPH 2015

[Lagarde14] Sébastien Lagarde and Charles de Rousiers, [Moving Frostbite to Physically based rendering](#), SIGGRAPH 2014

[Martin10] Sam Martin and Per Einarsson, [A Real Time Radiosity Architecture for Video Games](#), SIGGRAPH 2010

[O'Donnell18] Yuriy O'Donnell, [Precomputed Global Illumination in Frostbite](#), GDC 2018

[Vorba14] Jiri Vorba *et al.*, [On-line learning of parametric mixture models for light transport simulation](#), ACM TOG 2014



# Bonus

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# Adapt tracing budget

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- Tracing cost can vary a lot between frames (paths length/coherence)
  - On single GPU machine
    - Cap tracing under a fixed budget (e.g.16ms)
    - Adapt the number of texels/samples based on previous frame timers. This allows to keep frame rate smoother
  - On multi-GPU machine
    - 1 GPU is allocated to FB, the other GPUs are allocated to the GI preview. The "GI" GPUs work in async and thus tracing budget is uncapped (in order to provide valid result as fast as possible).

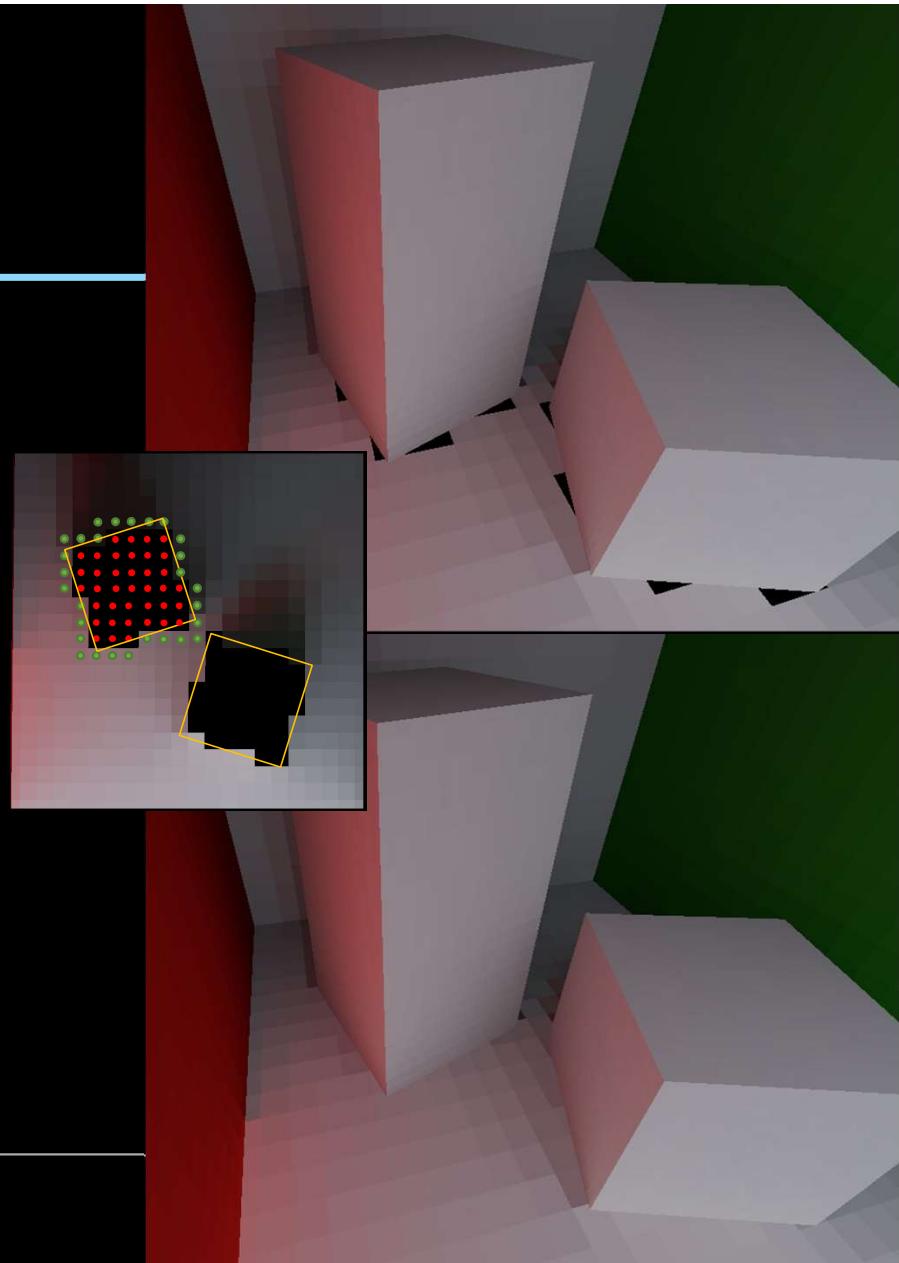


# Filter invalid texels

Lightmap can contain invalid texel data  
(samples within geometry)

Use **dilation** with lightmap chart for filling  
invalid pixels

Applied at every lightmap iteration



# Flux in FIFA night time

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