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EXPLORING RAYTRACED FUTURE IN METRO EXODUS

"My old dream was to see global illumination in an interactive application, which doesn't depend on any precomputation and works with 100% dynamic lighting conditions and a similarly dynamic environment."

Oles Shyshkovtsov, 4A Games (GPU Gems 2, 2005)

AGENDA

1. Introduction
2. Implementation
3. Denosing
4. Artist point of view

INTRODUCTION

The Quest for the Holy Grail

MOTIVATION

RTX OFF

MOTIVATION

RTX ON

THE QUEST BEGINS

Know what you want to achieve

Everything?

Ok, fine. Global Illumination!

Ok, fine. A hybrid, indirect first-bounce, diffuse, Global Illumination and Deferred rendering pipeline.

Right. Off you go.

A CUTTING EDGE ENGINE

Legacy version

GBuffer / Deffer
- Albedo / AO
  Normals
  Materials
  Depth

Lighting Buffers
- Shadows and SSAO
- RSM / Voxel Global Illumination
- Volumetric Atmospheric Integration

Lighting Accumulation
- Sun, Clustered Lights / IBLs, SSR, GI
- Forward Effects, Access To L-Clusters

TAA / Post-Process
- Distortions, TAA, Motion Blur, Tone-Mapping and Post Effects

A standard deferred renderer

Calculate G-Buffer and lighting buffers, accumulate light and effects, TAA, post-process

Relies heavily on stochastic methods followed by TAA to reduce noise

A CUTTING EDGE ENGINE

RTX ON

GBuffer / Deffer	Lighting Buffers			Lighting Accumulation		TAA / Post-Process
Albedo / AO Normals Materials Depth	Perform and Cache Trace SSAO + RT	New RTGI Denoiser Passes	Standard Shadows and VIA	Raytracing Contribution	Standard Lighting and Forward Effects	Distortions, TAA, Motion Blur, Tone-Mapping and Post Effects

The raytraced elements merge nicely with standard deferred renderer

Added buffer to cache raytrace data for use in RTAO and RTGI passes

Stochastic ray generation: Image is figuratively shouting at us, so a good denoiser is critical

STOCHASTIC METHOD

Why do it 1000 times when once will do?

Monte Carlo Integration: the approximation of large data sets with few samples

- Rather than adding up every single ray/photon, pick a few as “representative”
- You may lose some specific details, but will get the big picture
- Desirable for a GI solution
- Results get to the point of diminishing returns at a tiny fraction of the total set

This doesn’t just apply to raytracing

- Shadows, volumetrics, reflections, hair
- Apply to any suitably complex effect

STOCHASTIC METHOD

The importance of samples

Beware of noise and aliasing, both are issues, aliasing is worse

You are going to produce a noisy data set, and you will run denoisers

Jitter, Importance sampling and Probability Density Function (PDF) provide leverage over sample distribution

Output data is buffered for analysis, filtering and use later on

Produces good general purpose (input agnostic) data on scene illumination

If your image is still noisy at the end of the frame (it will be) add TAA

STOCHASTIC METHOD

Know your noise

Noise breaks up patterns when sampling below input frequency

Must be repeatable, it is used later for re-construction of the hit location from stored distance value

Temporally and spatially uniform to avoid “clumping” and “swimming”

Sample small blue noise texture across the screen, oscillate across frames

```
// Sample noise from screen position and frame index
float2 uv          = t_blue_noise_64.Load(uint4(
     (pixID.xy+32*(frmID&1))&63, frmID&63, 0)).xy;

// Generate ray on hemisphere
float3 vRay        = HemisphereSample(uv);

// Transform to local space of the surface using
// surface normal
float3 T, B;       BasisFromDirection(N, T, B);
return             normalize(FromLocal(ray, T, B, N));
```

RTAO
Why?

AO is a poor-man replacement for GI. We are doing real GI already so why bother?

We are running hybrid pipeline, which is smoothly blended into “old” pipeline

- 250m transition from foreground RTGI to “regular” pipeline

Regular pipeline expects AO available at different stages

- All image-based lighting (light-probes) are directly multiplied by AO
- Some “fake” lights use AO as their shadow approximation. Shame on us :)
- Even sun shadow-map blends into AO at some distance
- Searching for usage in shader-code finds 79 places...

Also, it’s cheap and helps guide the denoiser! :)

SSAO TO RTAO

Reuse and Improve

SSAO
Captures nearby details

RTAO
Recognise enclosed space

SSAO
Misses interior occlusion

RTAO
Progressively darkens

VOXEL-BASED GI TO RTGI

Night vs Day

Voxel GI
Broad directional light, insufficient detail for shadows

RTGI
Light bounce and contact shadows from nearby objects

Voxel GI
No sense of depth

RTGI
Gradual self-occlusion on object interiors


RTX OFF
RTAO PASS
RTGI PASS
RTX ON


RTX OFF
RTAO PASS
RTGI PASS
RTX ON


RTX OFF
RTAO PASS
RTGI PASS
RTX ON


RTX OFF
RTAO PASS
RTGI PASS
RTX ON

PUTTING IT ALL TOGETHER

Ok. Now it works. Just...

- RTX fitted in well with 4A engine
- The game was balanced for the traditional pipeline, but RTX walked in made it its own
- We want more “rays”: We generate as few as possible for performance, but we can always find as use for more them
- Lots of options for the future...

IMPLEMENTATION

It WILL just work, if you work at it

IMPLEMENTATION (1)

Remove unnecessary pipeline stages

RSM rendering (replaced with cheaper depth-only shadow-map rendering)

Geometric ESM-AO (approximation of 16 rays)

SH-voxel-grid computation/gather

SH-voxel-grid temporal blending

SH-voxel-grid screen-space resolve

IMPLEMENTATION (2)

Modify some pipeline stages

SSAO-pass now computes accumulation weights and accumulates raytraced AO

- Velocity, depth disocclusion, etc.
- Weights used for both AO accumulation and GI

AO-filter pass

- Before:
  - SSAO filtering, geometric ESM-AO sampling
  - Blending with terrain AO, precomputed AO maps, per-vertex AO
- Now:
  - Denoising and RTAO accumulation

IMPLEMENTATION (3)

Add new pipeline stages

Raytracing😊 + screen-space pre-tracing

Geometry skinning and animation

Albedo updates/management

BLAS updates

TLAS rebuilds

Deferred shading of hit-positions

Denoising & accumulation

RT MODULE

Separate mini-engine from the rest of the pipeline

Handles skinning and geometric animation

Handles all BLAS updates/TLAS rebuilds

Separate instance-culling (expanded frustum, contribution)

Instance transforms, logical/game visibility

Separate memory manager

Separate command lists

Just 3 .cpp files, ~1500 lines DXR API, ~1100 lines logic, ~200 lines “glue”

BVH MANAGEMENT

Recipe

BLAS = update only for skinned/animated instances; **TLAS = rebuild only** from scratch

- TLAS quality and compactness is extremely important
- TLAS selects those which are inside expanded frustum (+logical visibility, + contribution culling)
- Usually we have more than 100k potentially active instances; less than 5k will survive the culling

Relatively fast, but each update/rebuild is multi-pass, under utilizes GPU

Hide with async-compute!

- We hide it with pre-trace CS and SSR CS
- Alternatively run it from compute queue parallel to the gbuffer rendering
- We have both modes implemented, statistically insignificant perf difference

BLAS UPDATE THROTTLING

Skinned and animated vertices processing

Every entity update increases priority of RT-instances

- Visible = higher priority, small and/or distant = lower priority

Sort instances based on accumulated (across frames) priority

Select a few (16 in our case) with highest priority

Select a few (4 in our case) randomly from the remaining set with non-zero priorities

- High priority objects should not block other stuff updating!
- Shrinks queue to "balanced" state in a matter of seconds
- "Balanced" state is just 5k-6k instances "outdated" :) out of 20k+

Additionally limit the vertex count as well

- Necessary to avoids rare "spikes" in processing

METRO IS EXTREMELY GEOMETRY HEAVY

20,000,000 polygons is a lot to render just for the sun shadow

Depth impostor cache / Simplified IB (separate position-only VB if shader allows)

Reuse those simplified "shadow" meshes for RT!

Result: BLAS meshes are about 4x smaller than the “real” geometry

- There are scenes where it translates into 30% perf gain in raytracing
- All vertex animation and skinning become cheaper
- Memory usage: ~1GB instead of ~4GB
- Zero or close to it difference in quality!

RAYTRACED GI

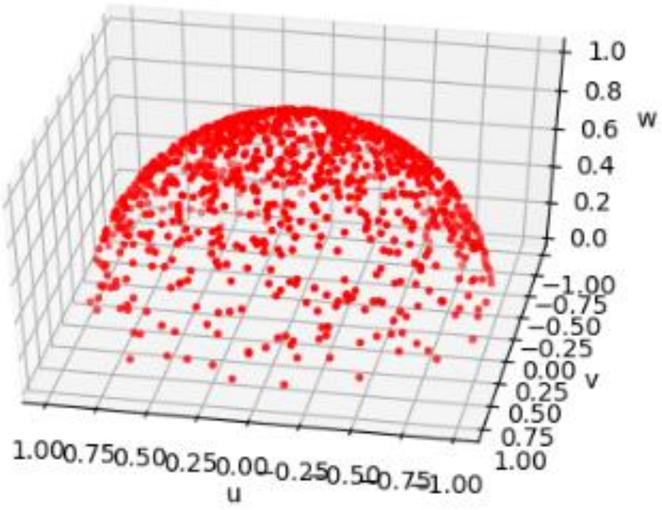
Basic idea

Shoot rays at every pixel in all directions (ok, according to BRDF lobe)

Gather lighting at the contact point; multiplied by albedo of that point

Accumulate that!

Hit distance gives us "free" RTAO



PIPELINE STAGES

Raytracing Specific GPU Pipeline

RAYTRACING !!

- SSAO and SSR Pre-trace
  Ray Culling
- Perform Raytracing!
  Store Results

Ambient Occlusion

- RT-AO
- RT-AO Filtering

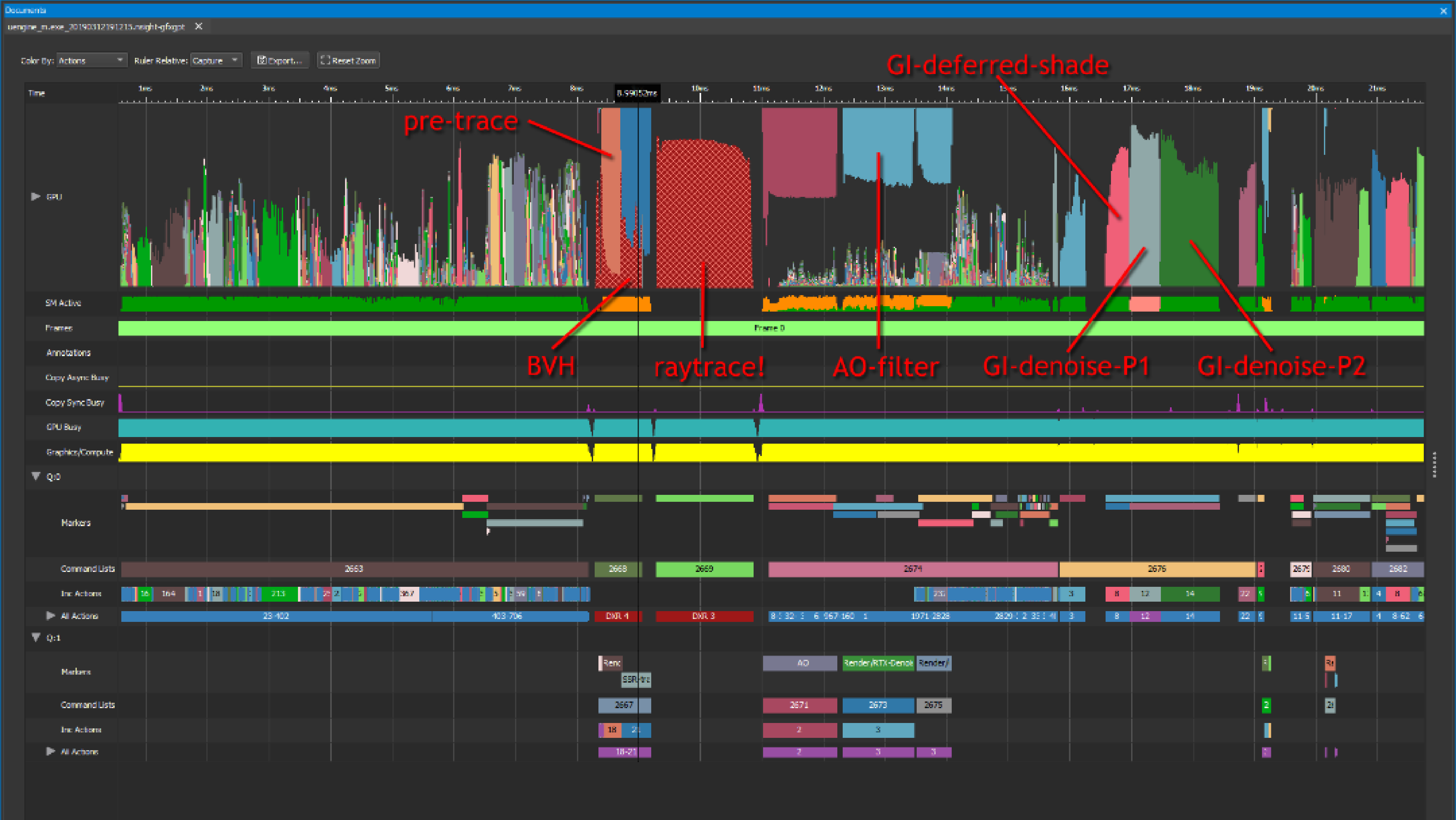
Global Illumination

- Deferred Lighting for RT-GI
- RT-GI First Denoising Pass
- RT-GI Second Denoising Pass

Screen-space pre-trace + all actual raytracing

Ambient Occlusion + Filtering

Global Illumination + Two pass denoiser



GI-deferred-shade
pre-trace
BVH
raytrace!
AO-filter
GI-denoise-P1
GI-denoise-P2

PRE-TRACE

Ray tracing in screen space

Exactly the same ray-generation as the real raytrace

Ray-march against depth buffer

Runs as async-compute, parallel to BVH updates/rebuilds

Fixes missing "alpha-tested" geometry in most cases

- We aggressively filter it out whenever we can

Almost constant distance in screen-space (cache-friendly)

Outputs into UAV hit-distance and albedo (from g-buffer)

RAYTRACING

Real rays!

Only spawn the real ray if pre-trace failed to find intersection

- Leads to a small perf-boost

Ray-marches terrain's heightmap inside the "raygen" shader

- Limit ray distance if intersection is found
- Almost free here (if done carefully) due to GPU latency hiding

Extremely simple pipeline config

- Only [shader("closesthit")] is necessary for us to get hit results
- Payload is a single UINT

Outputs to the same UAV, distance + albedo (packed into a single UINT)

- Needs to be careful with precision and tolerances
- Floating point precision hit us several times

DEFERRED LIGHTING

Hit-positions processing

Run exactly the same ray generation as in main trace

Reconstruct hit position (or indication of "miss") and albedo

MISS = sample skybox HIT = compute lighting

Encode information, more on that later

Accumulate with history

DEFERRED LIGHTING

Why only the sun/moon and sky?

Tech stabilized quite late in the development cycle (late Q4/2018)

Content was mostly done and locked in at the time

Implemented 1st bounce contribution from all lights, out of curiosity

- Lighting already computed in a deferred way? use it
- In frustum, but occluded? Use precomputed lighting from atmosphere
- Out of frustum - run real computation

Extremely cheap (~0.2ms on an RTX 2080ti), could be a big perf-boost if we managed to remove AO/IBL, but...

- It conflicts with hand-crafted lighting and visuals :(
- It breaks the game, especially the stealth mechanic

Simply put: we were out of time to fix current content across the huge game

COLOR TRANSPORT

Where to get albedo for hit results?

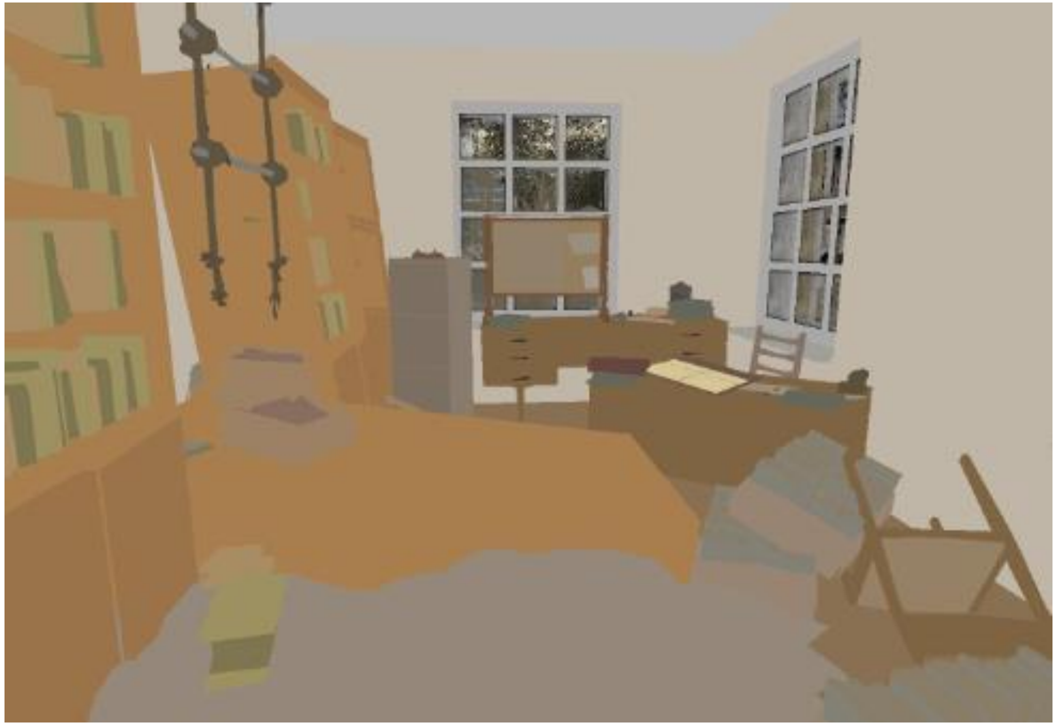
- Color bleeding is mostly visible on close to contact surfaces
  - Usually those are found by initial screen space pre-trace
  - Just sample albedo from gbuffer
- Integration across the whole hemisphere is a low-pass filter in essence
- It is a good idea to pre-filter signal to lower denoiser's input noise level
- We do that pre-filtering extremely aggressively - we store average albedo per-instance :)
  - Low input noise and extremely fast :)

COLOR TRANSPORT

Where to get albedo for hit results?

G-buffer (the pre-trace samples this)

Per-instance albedo (raytracing samples this)



COLOR TRANSPORT

A few problems

Usually average albedo color pre-calculated per-texture suffices

What to do with metals? Theirs albedo is essentially zero…

- Solution: Albedo * (1 - F0) + F0

What if complex shading changes visible albedo?

- Or maybe it is texture-atlas and average doesn't make sense?
- Solution: pre-render that exact combination of mesh-shader-textures-params!
- Then average visible albedo from 6 directions
- Store into sparse database/hash table

Still allow artists to “override” it

Database shipped in the first “hotfix”

Color bleeding - RTX ON

IRRADIANCE STORAGE & ENCODING

Directional color space

Decompose HDR-RGB into Y and CoCg

Encode Y as L1 spherical harmonics (world space), leave CoCg as scalars

- Human eye more sensitive to intensity, not color
- 4xFP16 for Y
- 2xFP16 for CoCg
- 96 bits per pixel in total

All the accumulation and denoising happens in this space

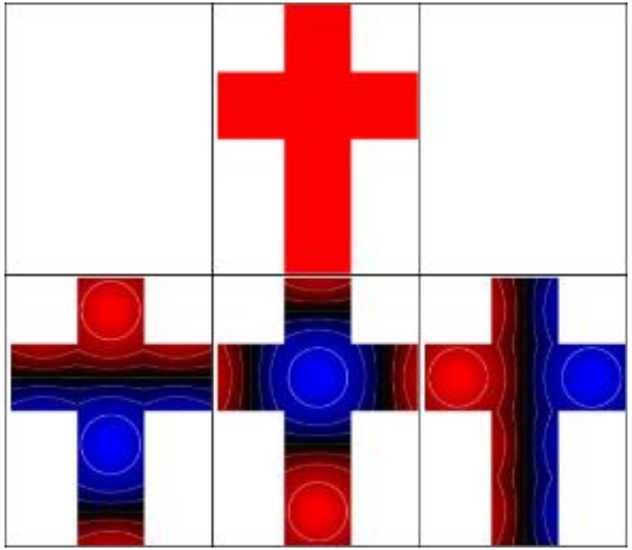


Illustration from paper “Stupid Spherical Harmonics (SH) Tricks” by Peter-Pike Sloan

WHY NOT JUST COLOR?

would R11G11B10 be enough?

Denoisers could go really wide under certain conditions

- Loss of normal-map details
- Loss of "contact" details and general blurriness
- Loss of denoising quality if we weight heavily against normals of samples, less information could be "reused"

96 bits? Why not less?

- Tried to reduce it down to 64 bits - failed
- Mostly because of "recurrent" nature of denoisers which could be extremely aggressive on temporal accumulation and thus precision
- In case of LDR, Y would be in range of [0..1] and CoCg in [-1..1], in our case it is actually in [0..HDR] and [-HDR..+HDR]

SPECULAR!

Important for PBR materials consistency

This encoding is actually a low order approximation of cubemap

But at each individual pixel!

This allows us to reconstruct indirect specular!

Crucial for metals where albedo is zero or close to it

(Illustration from paper “Stupid Spherical Harmonics (SH) Tricks” by Peter-Pike Sloan)

DECODING IRRADIANCE

Details

Resolve SH as usual against pixel's BRDF to get diffuse

Extract dominant direction out of SH

Compute SH degradation into non-directional/ambient SH

- If SH is non-directional - it means incoming light is uniform over hemisphere
- And if it is uniform - that’s the same as if material is "rough" -> recompute new roughness

Run regular GGX with (extracted_direction, recomputed_roughness)

SPECULAR GI OFF

Booooooooo

SPECULAR GI ON!

Yay \(•□•)/

THE POWER OF PIPELINE

Details

The BRDF importance sampling doesn't care what to integrate at all, it is "unbiased" in that sense

- Be it 1st, 2nd or 3rd bounce indirect lighting or "direct" lighting or whatever

What if we put something emissive in the scene?

DEMO TIME!

POLYGONAL LIGHTS

Details

Yes, that's arbitrary shaped and textured polygonal lights

- I saw a lot of research on that...
- But nobody does shadows, right? 😝

It is free!

WRAPPING THINGS UP

“Holy Grail” cracked!

Game-scale realtime 1st bounce indirect lighting from any analytic light

- Not limited to 1st bounce at all, but… Xms trace Yms light per bounce
- Even 2nd bounce gives diminishing returns compared to cost

Direct lighting and shadowing from arbitrary shaped polygonal area lights

- Or sky, or whatever… Artistic freedom...

Computes both diffuse BRDF (Disney) and specular BRDF (GGX)

Everything is fully dynamic, both the geometry and lighting (no precomputation!)

- In fact 4A-Engine doesn’t really have a concept of something static (prebaked)

Massive scenes

- ~150 000 000 triangles on a typical Metro level in TLAS before culling

DENOISING

Trapping the beast in 15 mins

DENOISING

What is it?

Denoising (or noise reduction) is the process of removing noise from a signal

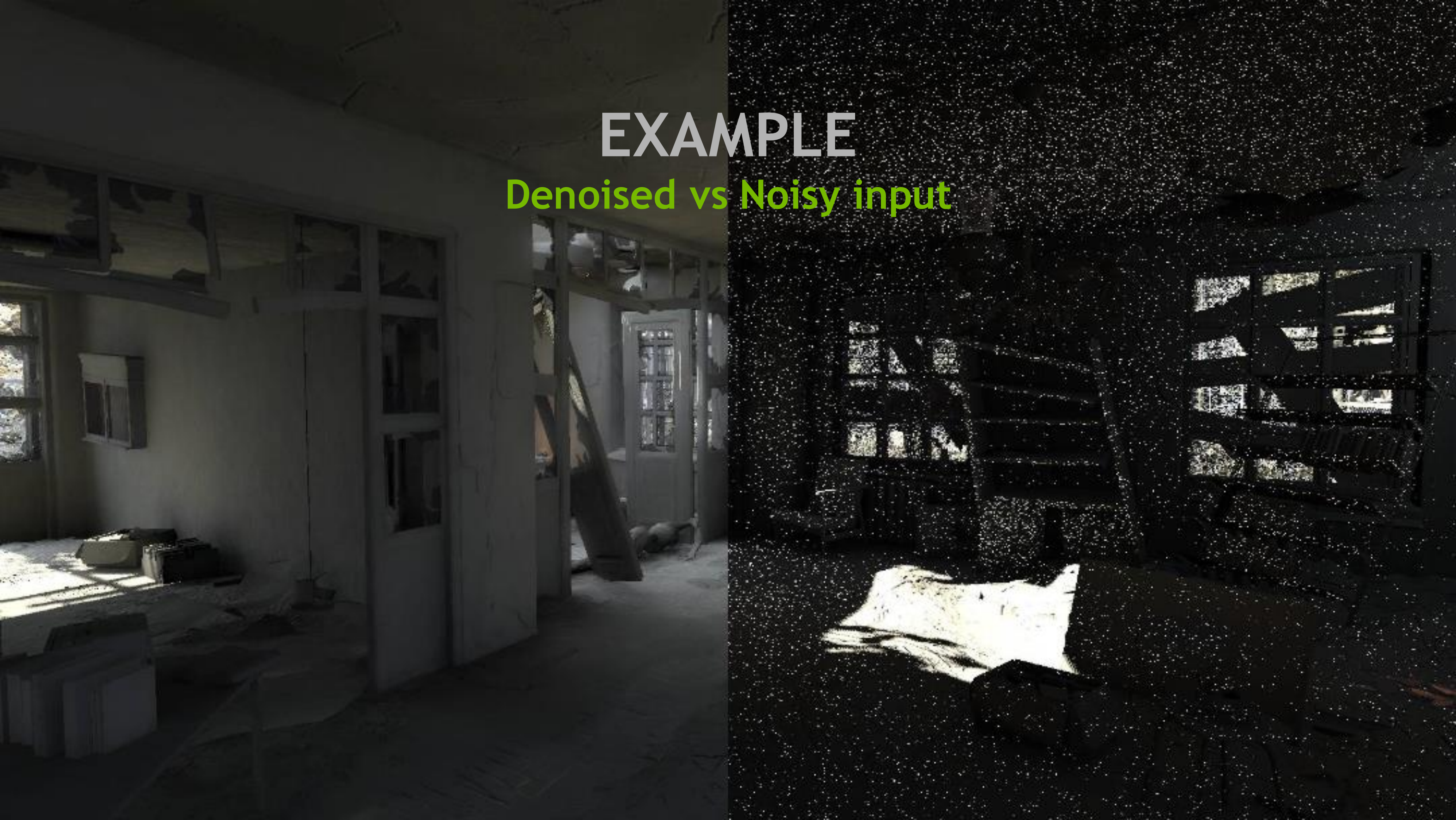
Can be convolution or Deep Learning based

DL-based solution is barely explored in real-time graphics

Our approach is convolution-based and has **spatial** and **temporal** components

EXAMPLE

Denoised vs Noisy input



EXAMPLE

Noisy input vs Denoised

DENOISING IS NOT A FUN...

...but casting rays is :)

Keeps you sad - IQ is always lower than it needs to be

Friendship is very fragile - a small change can ruin IQ completely

Small gifts don't help – tiny tunings here and there turn the algorithm into Frankenstein's creature

Demands too much of attention – single pass denoising works badly or inefficiently

DENOISING

Problem decomposition

Spatial component:

- Sampling space, distribution and radius?
- Sample weight?
- Number of samples?

Temporal component:

- Feedback link or links?
- Feedback strength and ghosting?

DENOISING: SPATIAL COMPONENT (1)

As a single-pass blur

Take a lot of samples around current pixel

Accumulate weighted sum

The weight depends on the signal type (AO or GI, reflections, shadows)

Same as Monte Carlo integration:

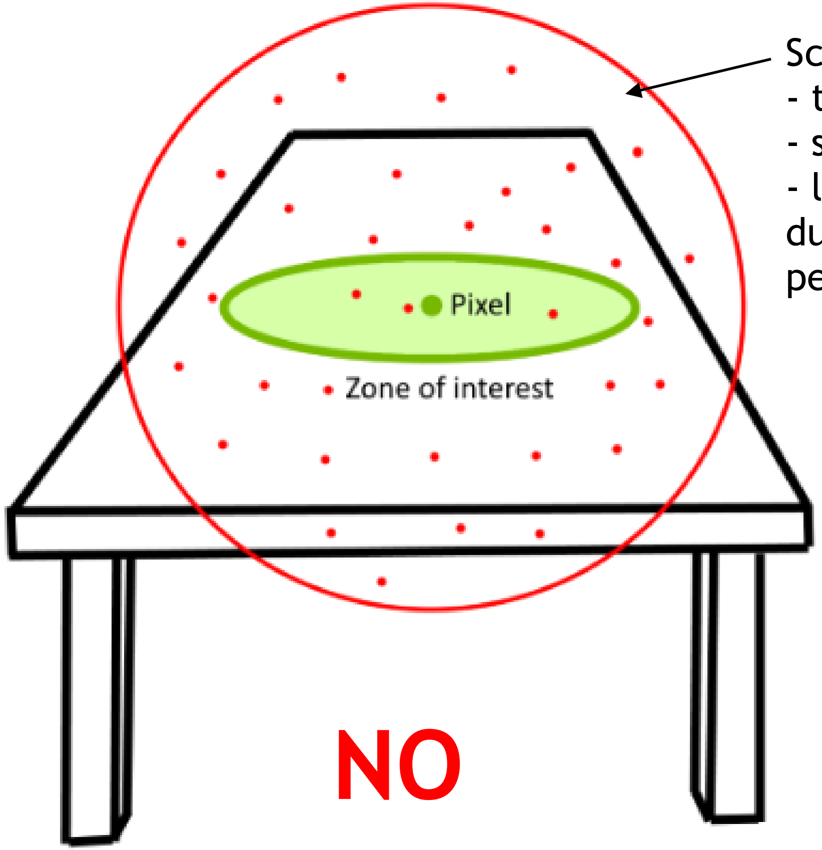
$$\int f(x)dx \approx \frac{1}{N} \sum_{n=1}^{N} f(x_i)$$

Final reconstructed signal
(GI, AO)

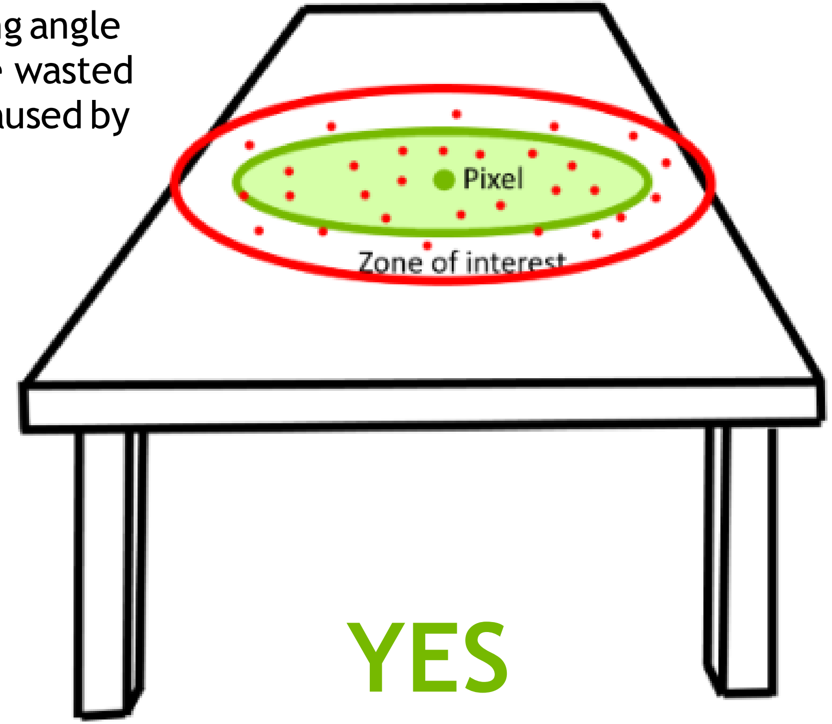
Weighted sum (N samples)
f(x) - noisy input

DENOISING: SPATIAL COMPONENT (2)

Screen- vs world- space sampling



Screen space problems:
- thin objects
- surfaces at glancing angle
- lots of samples are wasted due to anisotropy caused by perspective



DENOISING: SPATIAL COMPONENT (3)

Importance sampling

$$\int f(x)dx \approx \frac{1}{N}\sum_{n=1}^{N}\frac{f(x_i)}{p(x_i)}$$

Final reconstructed signal (GI, AO)

Weighted sum (N samples)
f(x) - noisy input

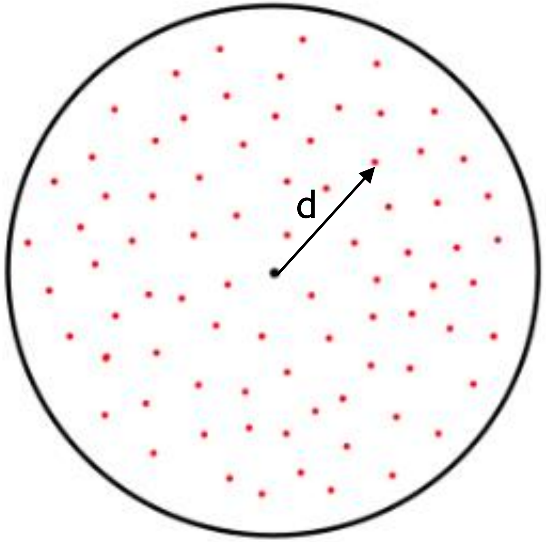
p(x) - Probability Distribution Function (PDF) allows to replace uniform distribution with something more relevant…

DENOISING: SPATIAL COMPONENT (4)

Sampling distribution & distance weight

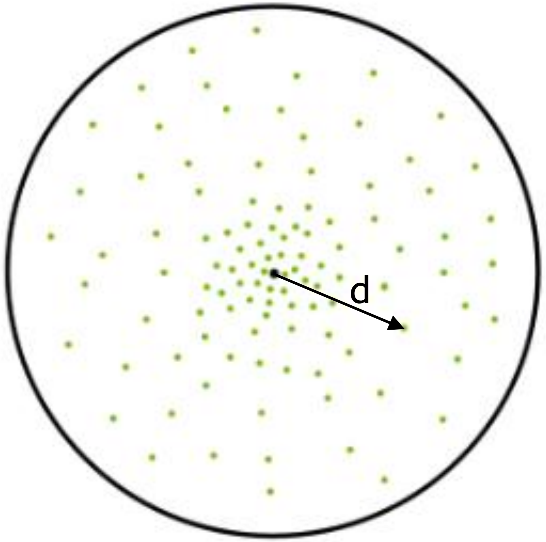
NO

Uniform



Weight = non_linear_F(d)

Quadratic



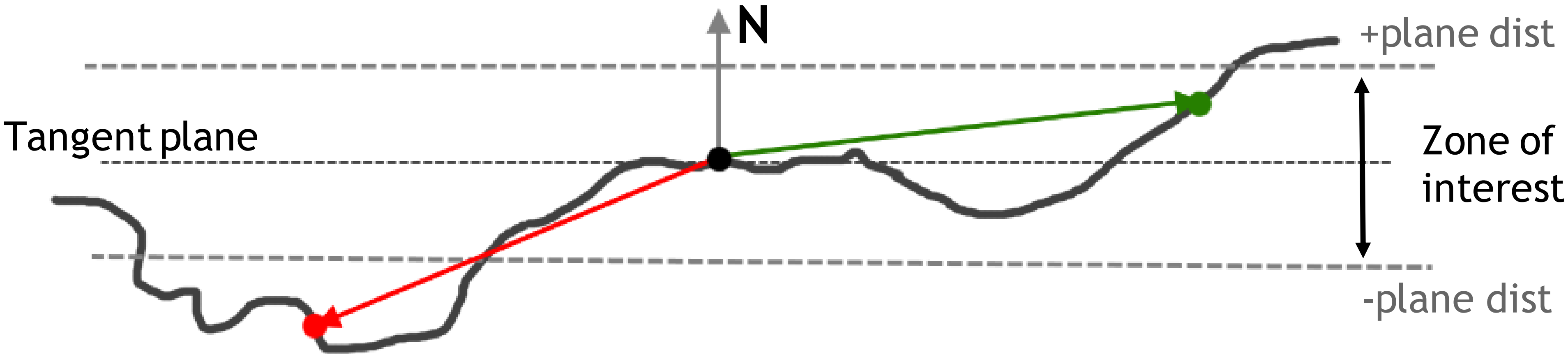
Weight = linear_F(d) or step(d, R)

YES

Moving distance falloff math to the distribution and simplifying weight calculation to “step” function leads to output noise reduction!

DENOISING: SPATIAL COMPONENT (5)

Distance weight



Most important samples are on tangent plane

Use plane distance to calculate falloff

Use absolute value, otherwise denoising will skip all rounded objects

DENOISING: SPATIAL COMPONENT (6)

Normal weight

Using ***pow* is incorrect** because it explicitly contradicts lighting theory

It makes your result very oriented

Using ***x*** instead of ***pow(x, 8)*** is a good idea

```
// Please, don't use 'pow'!
float NormalWeight(float3 Ncenter, float3 Nsample)
{
        float f = dot(Ncenter, Nsample);

        return pow(saturate(f), 8.0);
}
```

DENOISING: SPATIAL COMPONENT (7)

Per pixel kernel rotations

NO!

Leads to 2x-5x slowdown!

Input signal is already noisy (applying noise on top of noise isn’t worth it)

Use **per frame random rotation** to improve quality of temporal accumulation!

DENOISING: SPATIAL COMPONENT (8)

Radius of denoising

Needs to be large, but can be scaled with distance

Compute **variance** of the input signal, blur less if variance is small

Blur less in “dark corners”, i.e. multiply by AO

Signal-to-noise ratio - blur less where direct lighting is strong

$$R = BaseRadius \cdot F(viewZ) \cdot F(variance) \cdot F(AO)$$

DENOISING: SPATIAL COMPONENT (8)

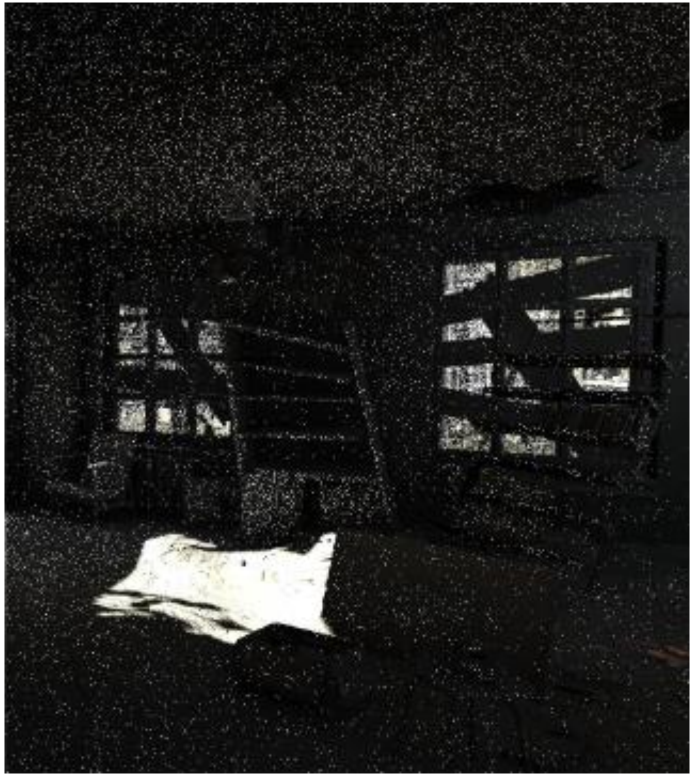
Number of samples

A lot of samples are required! 32? 64? 128? (depending on number of passes)

Compute variance of the input signal, adaptively reduce number of samples if variance of the input signal is small...

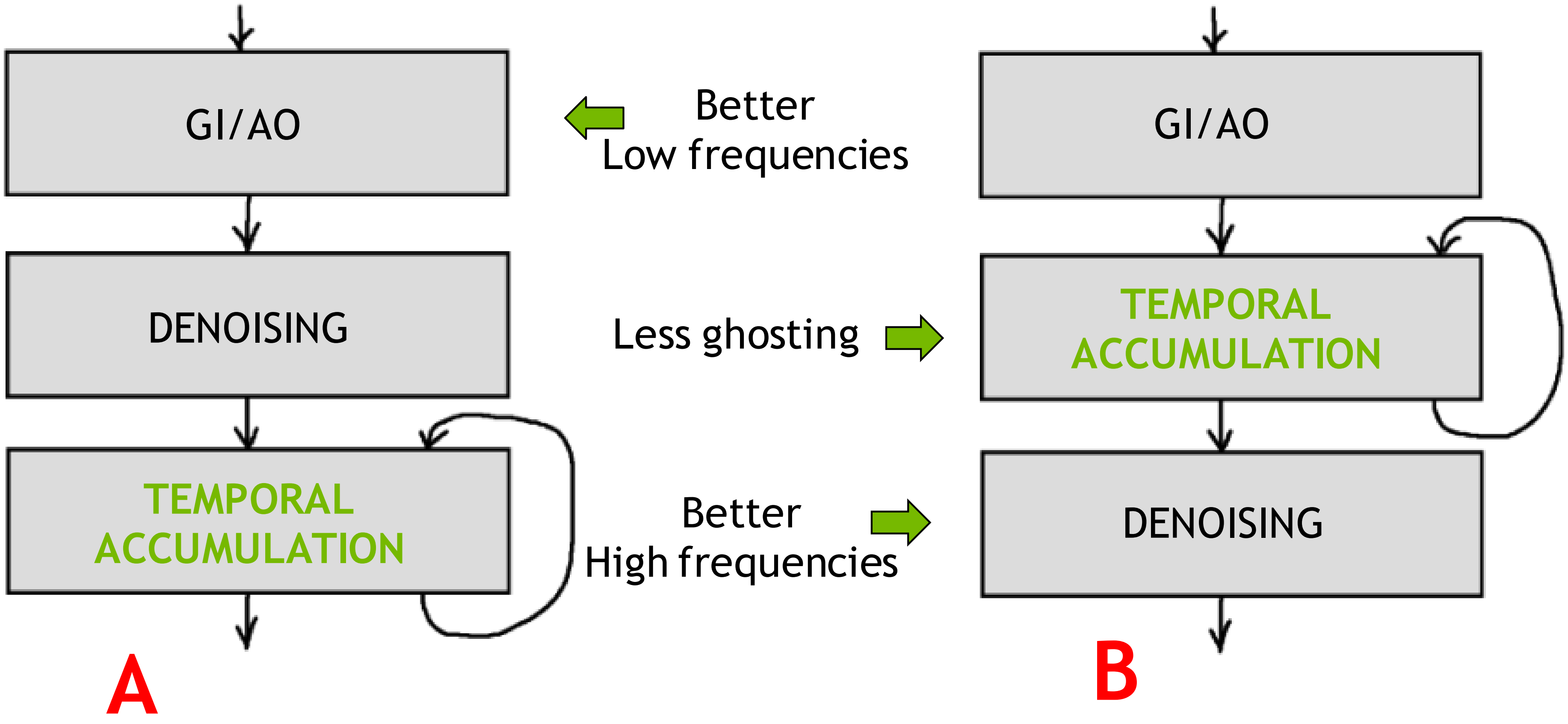
...but variance computed for the current frame is always big! Solution - add temporal component \O/

Obviously, accumulated signal will get less and less variance over time!



DENOISING: TEMPORAL COMPONENT (1)

Common ideas



DENOISING: TEMPORAL COMPONENT (2)

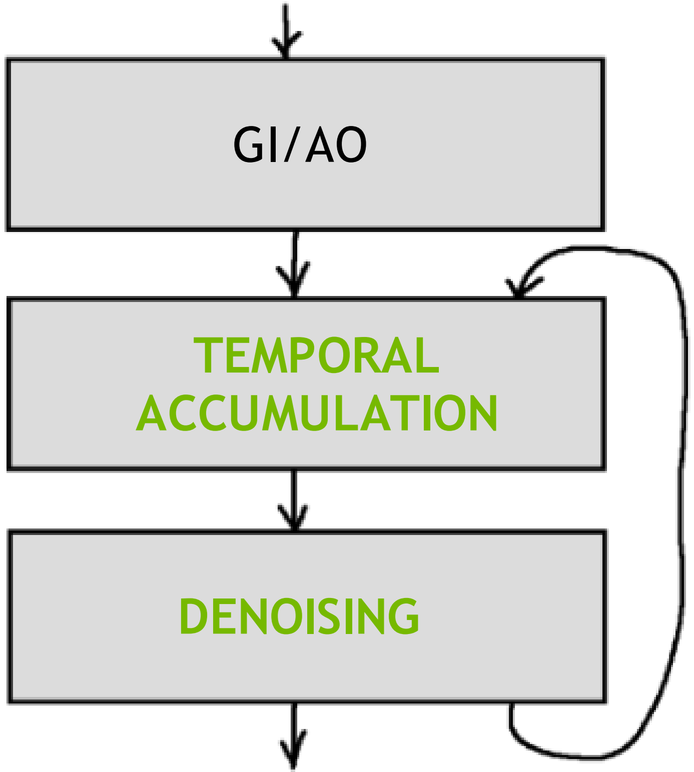
Our idea

More frequencies over time (mixture of low and high)

Requires less samples per frame

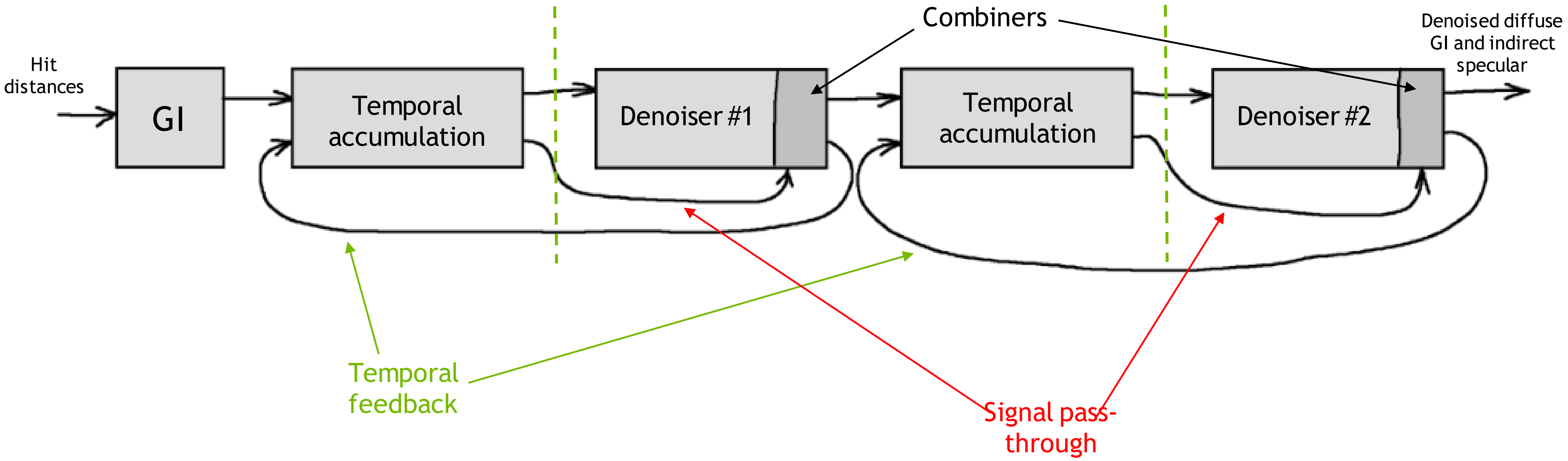
Less ghosting (denoising smoothes out reprojection artefacts)

(**AO denoising** uses this scheme, adaptive sampling with up to 64 samples, processes 2 pixels per thread sharing results between them if no edges)



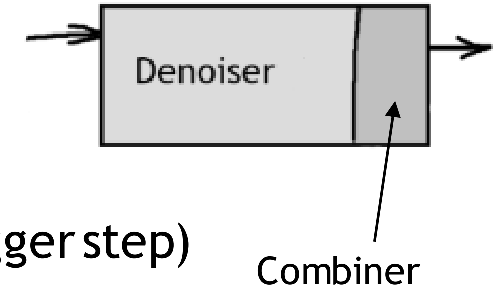
DENOISING: LITTLE MONSTER (1)

GI denoiser



DENOISING: LITTLE MONSTER (2)

Denoiser block



Computes variance of the input signal (3x3 pixels)

Computes radius scale as “F(viewZ) · F(variance) · F(AO)”

Computes adaptive step N = F(scaleRadius) (small radius = bigger step)

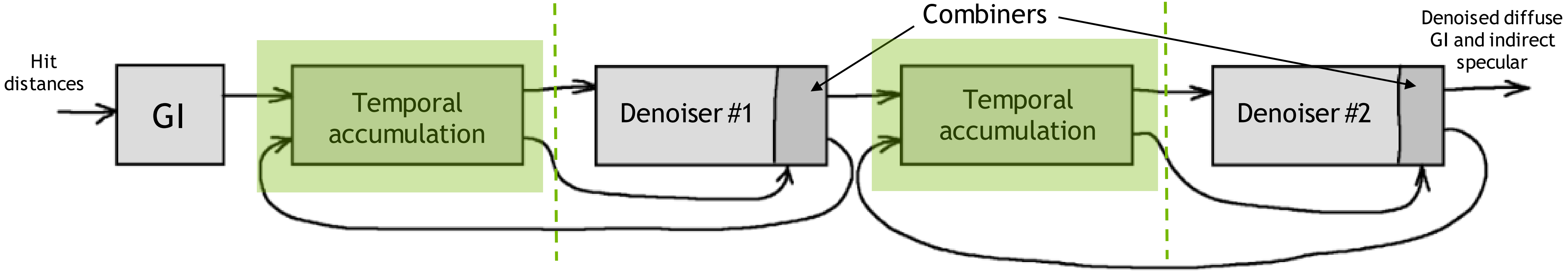
Processes each Nth sample from a poisson disk (up to 32 samples per pass)

The combiner just mixes up denoised and noisy input signals as:

Combiner = lerp(denoisedSignal, inputSignal, 0.5 * accumSpeed) (accumSpeed = 0.93 if no motion)

DENOISING: LITTLE MONSTER (3)

GI denoiser

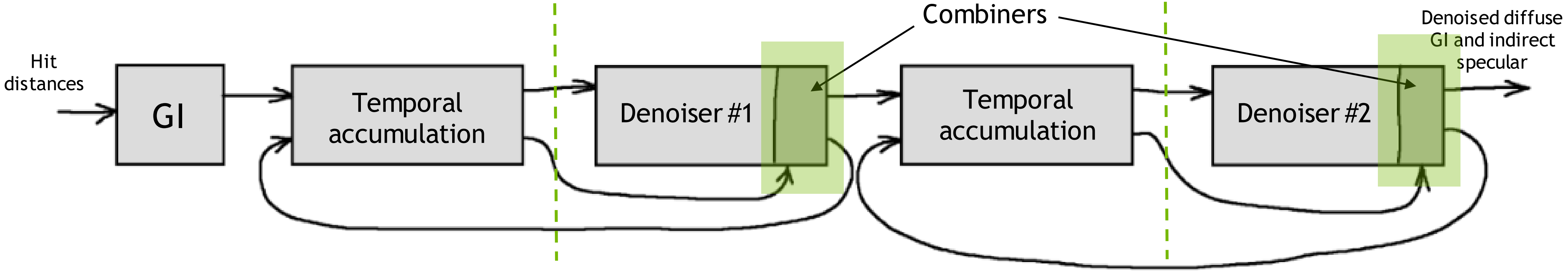


Temporal accumulation always happens **before denoising** to eliminate ghosting and reprojection artefacts

History is always rejected if out-of-screen sampling or z-occlusion are detected

DENOISING: LITTLE MONSTER (4)

GI denoiser

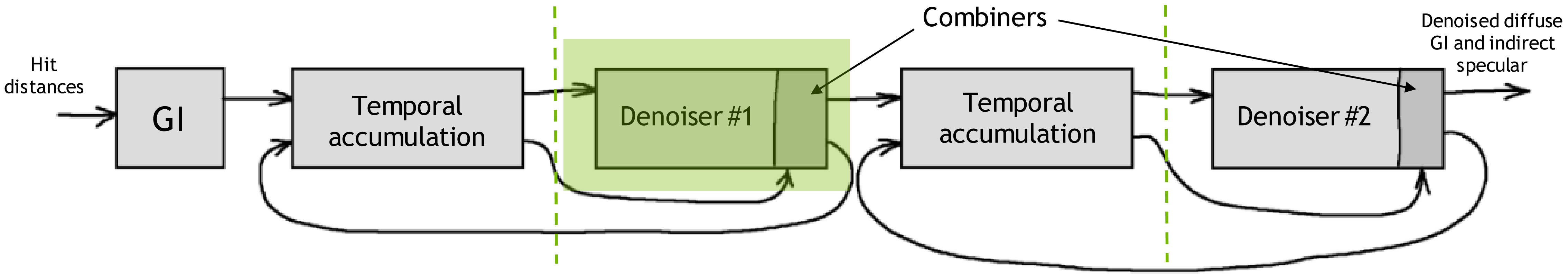


The output of each denoiser is always a combination of denoised and noisy input signals!

It helps to preserve tiny details

DENOISING: LITTLE MONSTER (5)

GI denoiser

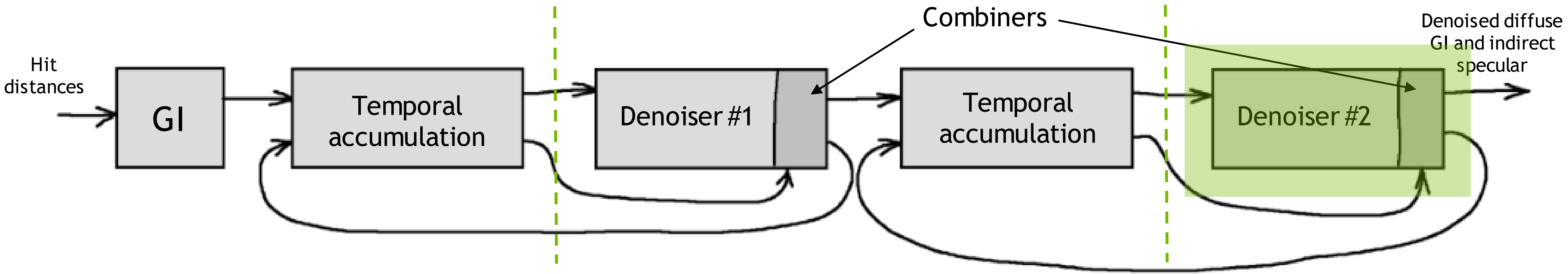


First pass of denoising doesn’t take normals into account

It has wider base radius (6m)

DENOISING: LITTLE MONSTER (6)

GI denoiser



Second pass of denoising takes normals into account

It has smaller base radius (3m)

Physically it's same denoiser which applies "normal weight" on top of geometry weight

DENOISING

Tips & tricks

Use NSIGHT GRAPHICS GPU Trace utility to understand your limiters

Fetch heavy data only if weight is non-zero

TAA is your friend - it’s a free pass of denoising

SH irradiance is your friend - solves “blurriness” problem

Know your noise - perfection in image “cleanness” is not needed

PERFORMANCE

RTX 2080 at 2560x1440

Stage	HIGH	ULTRA
Pretrace	~0.4 ms	~0.8 ms
BLAS/TLAS (completely hidden by async)	~0.5 ms	~0.5 ms
Raytracing	1 to 3 ms	2 to 6 ms
AO Denoising	~0.6 ms	~0.9 ms
GI computation	~0.6 ms	~1.0 ms
GI denoising	~1.6 ms	~2.1 ms
Total Frame Time Overhead (vs RTX OFF)	**~20%**	**~30%**

ARTIST POINT OF VIEW

Just make it work for us

OUR FIRST RTAO SHOT

...Which one is RT ON? 🤔

DEFENDING THE CHOICE OF RTGI

Why not do reflections instead?

There were not many people who believed RTGI was a good direction of research

From audience to stakeholders (oops)

Especially when convincing solutions already exist:

- SSAO and geometric ESM-AO for world space AO
- Super-lazy-realtime grid of probes for GI
- Voxel GI (which we already have nicely integrated with PBR in Exodus)

LIMITATIONS ARE ALSO WELL KNOWN

And we accepted them for years

Reflection probes or lightmaps for GI?

- not a realtime solution

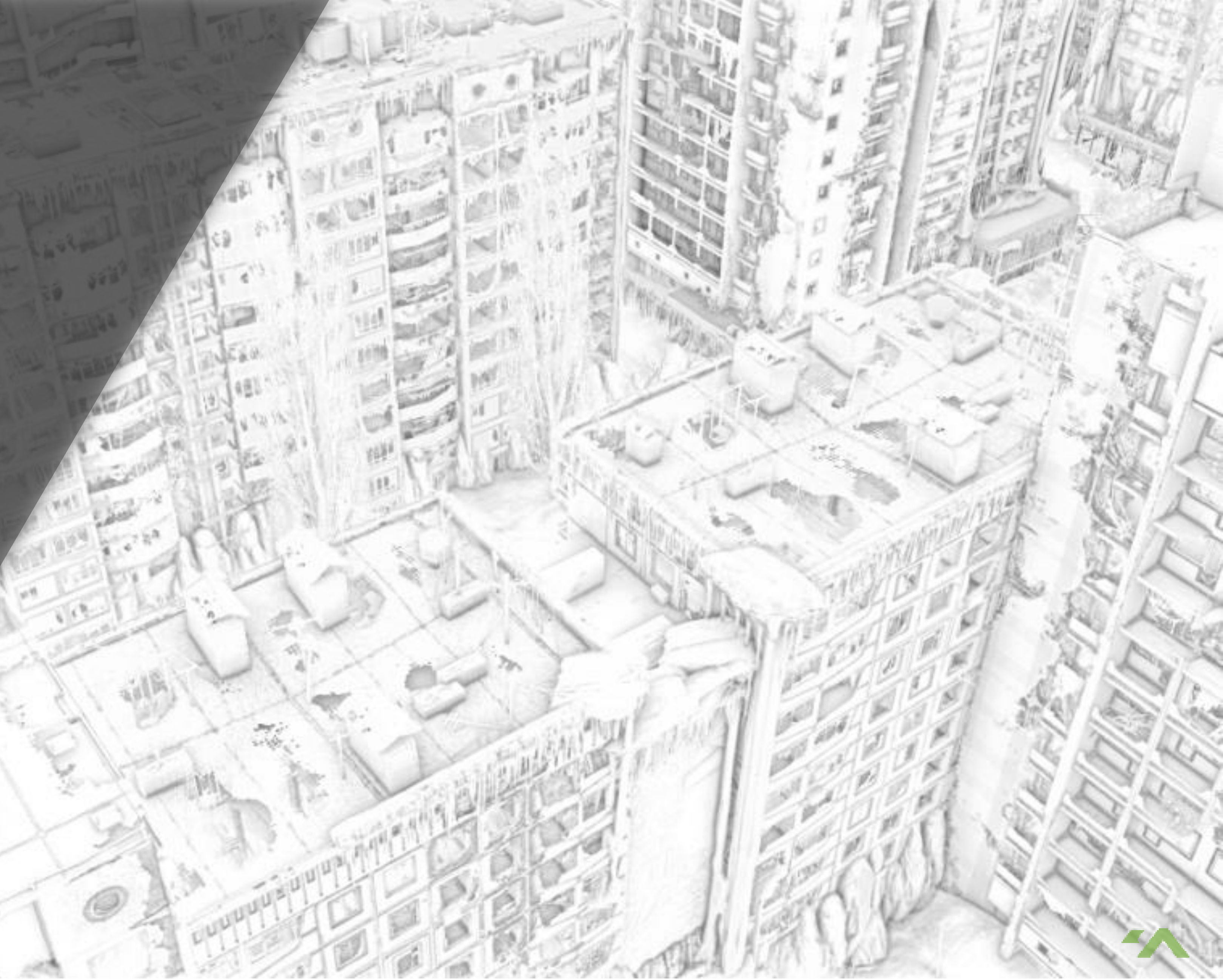
SSAO for AO?

- suffers from its screen-space nature
- limited to 1m tracing (good for features of... <1m in size)

SIZE MATTERS

1m is not enough (°∩°)

In large scenes short rays produce no more than an 'edge trace' effect



NEW INSANE POSSIBILITIES

Literally insane

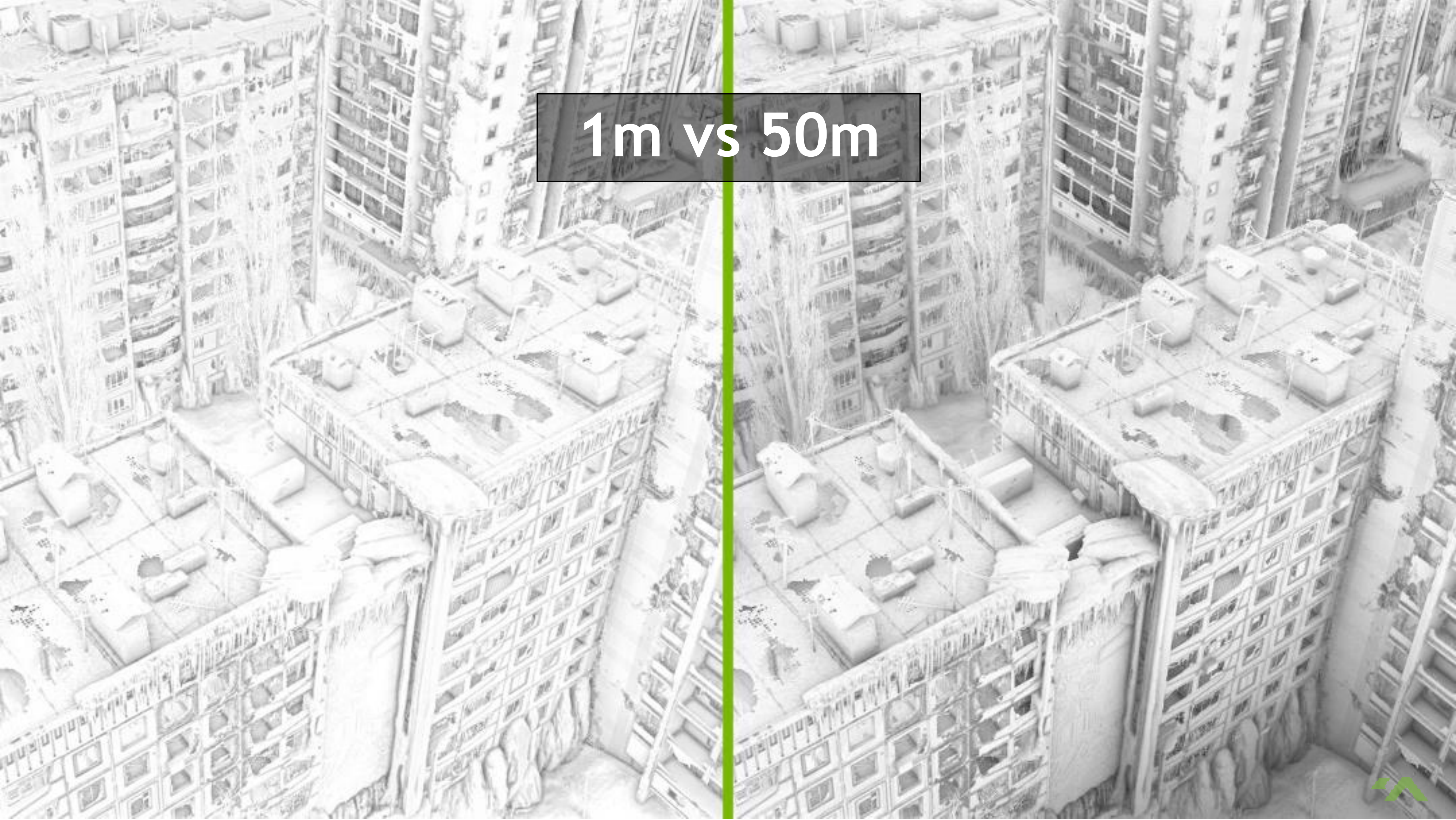
50m ray tracing

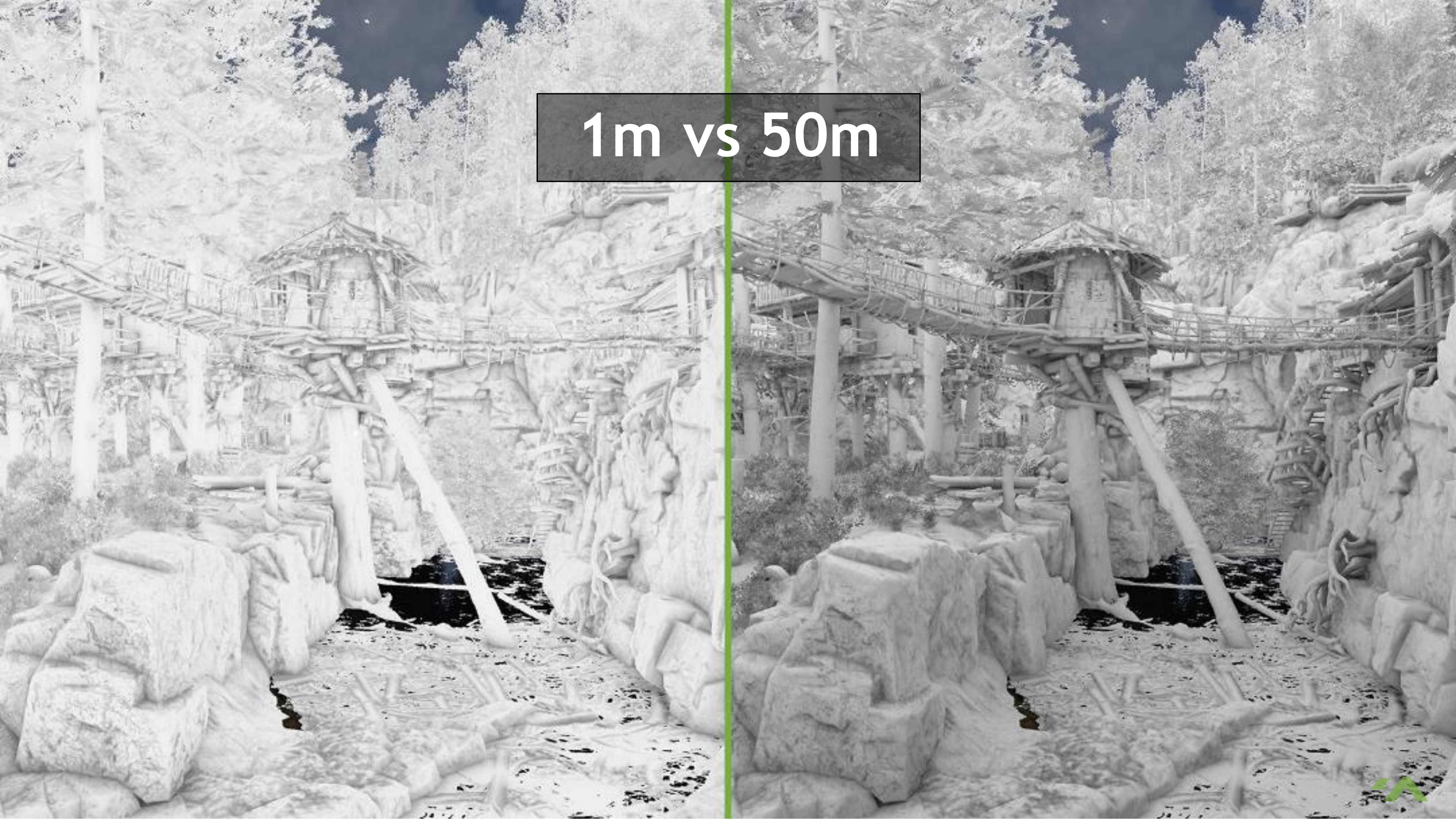
Billions of rays per second

Per-pixel details at any scale:

- pencils on table 1mm scale
- ships 20m scale
- canyons, skyscrapers 100m+ scale

And at no cost!.. Well, almost


1m vs 50m


1m vs 50m

LEGACY AO


RTGI

SSAO NO MORE

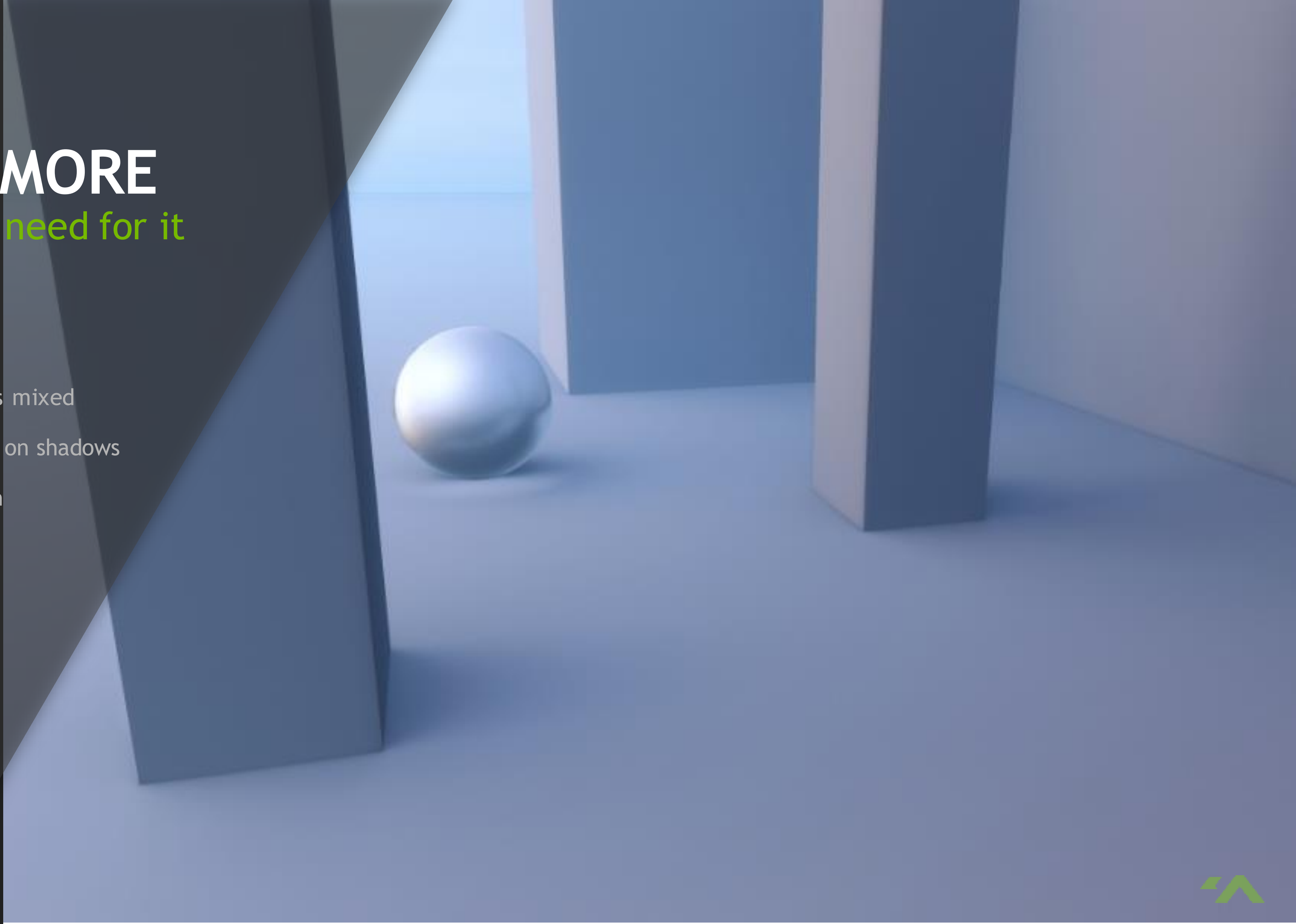
GI replaces the need for it

Legacy AO:

- Tons of AO sources mixed
- Multiplied directly on shadows
- Effectively a patch

RTGI:

- Solves it all



SKYLIGHT SHADOWS

No direct lights involved

Single frame took several minutes of rendering in ‘99

- Mesmerizing to watch

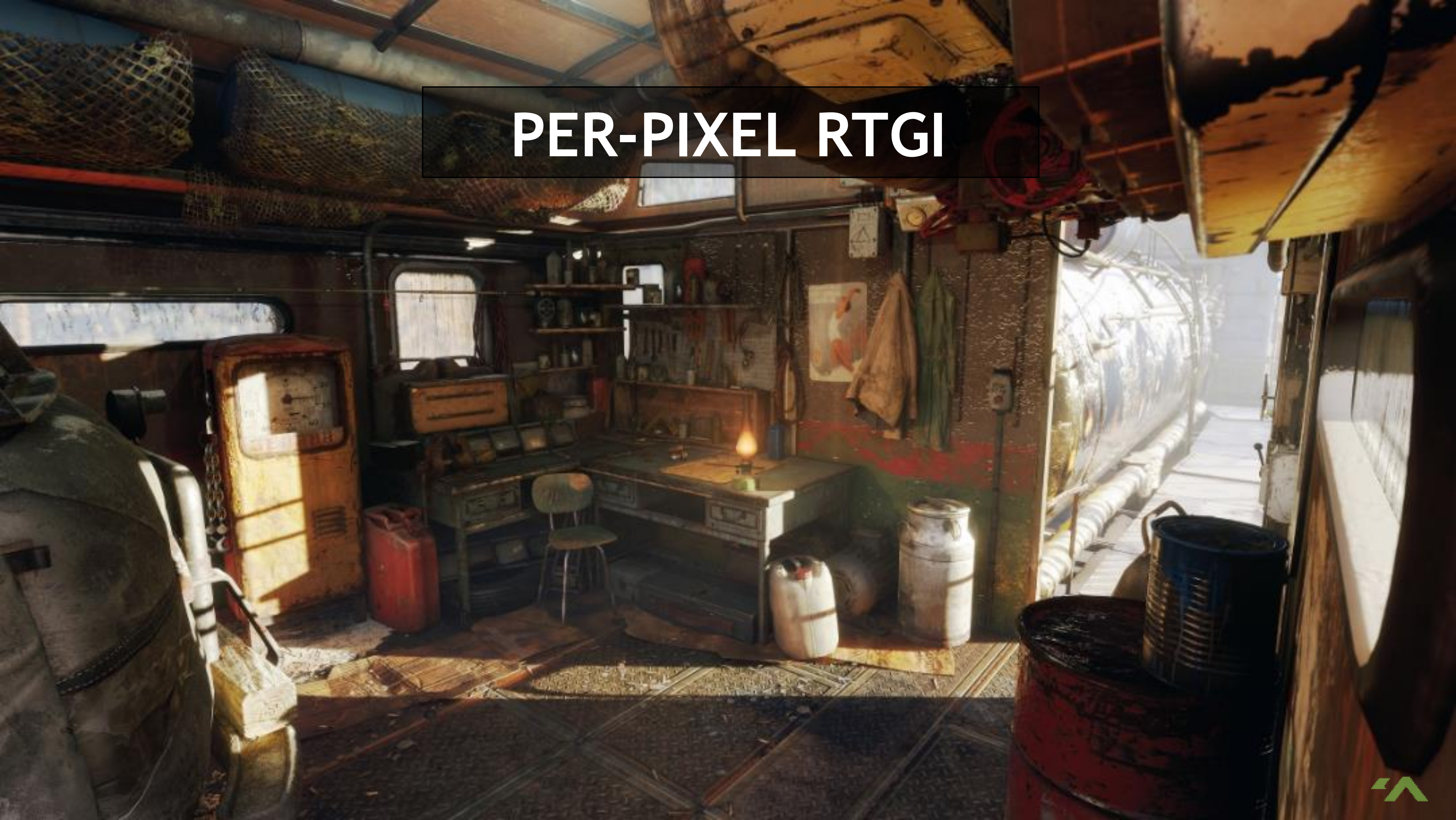
GI FROM LIGHT SOURCES

Interiors fully lit by sun

Пиши умное, э

GI BY LIGHT PROBES

PER-PIXEL RTGI



IMPLEMENTATION CONTINUES...

Still missing something

Specular GI

- Specular lighting contributes up to 50% of light on rough surfaces

Color bleeding

- The most prominent feature in GI


COLOR BLEEDING OFF

COLOR BLEEDING ON

CLOSE TO RELEASE

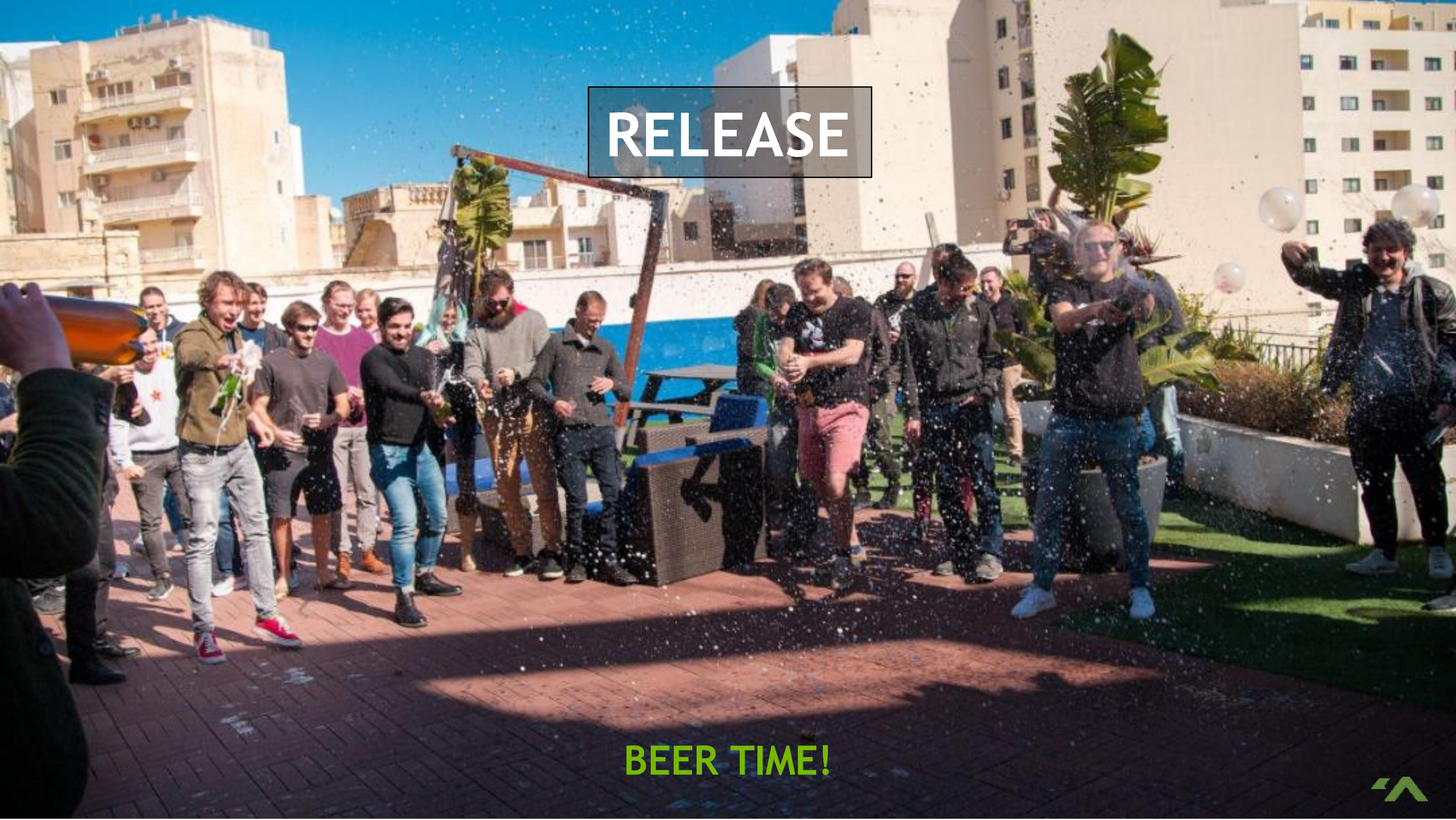
Content fixes and polishing

Making content work well in both modes

- Revert fake artsy lights
- Adjust non-RTX mode content to match RTX in extreme cases

Both versions must look good!

- There cannot be a loser it's Exodus vs Exodus


RELEASE
BEER TIME!

NEW MEASUREMENT OF ‘BETTER’

Enough of concerns

We do not expect RT-lighting to be exactly 'better'

Especially in an art-directed game

Results are clearly different

Mathematically stable solution makes them believable and natural

Or just convincing

RTX ?


RTX ?

HOW RT MAKES US HAPPY

A tool to play with

An achievement

Fully dynamic solution - 4A’s pillar

Lighting reference tool

Emergent results

OUR NEXT DREAMS

What would Oles dream of next?

- AO and GI are nailed
- Area lights with soft shadows
- Caustics. Magic in real life
- Raytracing as one unified solution
  - Light-based gameplay logic
  - Deferred+Forward
  - Volumetrics
- RT on consoles

USEFUL LINKS

https://media.contentapi.ea.com/content/dam/eacom/frostbite/files/gdc2018-precomputedgiobalilluminationinfrostbite.pdf

http://orlandoaguilar.github.io/sh/spherical/harmonics/irradiance/map/2017/02/12/SphericalHarmonics.html

http://cg.ivd.kit.edu/publications/2017/svgf/svgf_preprint.pdf

https://cg.ivd.kit.edu/publications/2018/adaptive_temporal_filtering/adaptive_temporal_filtering.pdf

Спасибо!

Slides at bit.ly/4agames

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BONUS SLIDE!

Color to spherical harmonics

```
float4 ConvertToIrradianceSH(float3 color, float3 dir, out float2 CoCg)
{
    float   Co      = color.r - color.b;
    float   t       = color.b + Co * 0.5;
    float   Cg      = color.g - t;
    float   Y       = max(t + Cg * 0.5, 0.0);

    CoCg = float2(Co, Cg);

    float   L00     = 0.282095;
    float   L1_1    = 0.488603 * dir.y;
    float   L10     = 0.488603 * dir.z;
    float   L11     = 0.488603 * dir.x;
    float4  shY     = float4 (L11, L1_1, L10, L00) * Y;

    return shY;
}
```

BONUS SLIDE!

Spherical harmonics to color (no resolve)

```
float3 GetColorFromIrradianceSH(float4 shY, float2 CoCg)
{
    float   Y       = shY.w / 0.282095;
    float   T       = Y - CoCg.y * 0.5;
    float   G       = CoCg.y + T;
    float   B       = T - CoCg.x * 0.5;
    float   R       = B + CoCg.x;

    return max(float3(R, G, B), 0.0);
}
```

BONUS SLIDE!

Spherical harmonics resolve

```
float3 ResolveIrradianceSHToDiffuse(float4 shY, float2 CoCg, float3 N)
{
    float d = dot(shY.xyz, N);
    float Y = 2.0 * (1.023326 * d + 0.886226 * shY.w);
    Y = max(Y, 0.0);

    // correct color-reproduction
    CoCg *= 0.282095 * Y / (shY.w + 1e-6);

    // YCoCg -> RGB
    float   T       = Y - CoCg.y * 0.5;
    float   G       = CoCg.y + T;
    float   B       = T - CoCg.x * 0.5;
    float   R       = B + CoCg.x;

    return max(float3(R, G, B), 0.0);
}
```