30 JULY – 3 AUGUST Los Angeles
SIGGRAPH 2017

A Certain Slant of Light:
Past, Present and Future Challenges of Global Illumination in Games

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Who Am I?

- Senior Rendering Engineer at SEED – Electronic Arts
  - Cross-disciplinary team working on cutting-edge, industry-leading future graphics technologies and creative experiences
  - *Offices in Stockholm, Los Angeles and Montréal*
  - *www.ea.com/SEED*
  - *@SEED*
- Previously
  - Technical Director at WB Games' Montréal
  - Rendering Engineer at EA Montréal and DICE

Agenda

- State of The Union *(≈10 mins)*
- Current Challenges *(≈ 15 min)*
- The Future *(≈ 10 mins)*
- Questions *(≈ 5 mins)*

What's In It For You?

Because you want to know about…

For Researchers:

- How GI in academia compares to the state of the art in games
- Latest art, engineering, pipelines and production challenges in games
- Fundamental issues that artists & programmers have with current approaches
- Unsolved GI problems in the games industry, and how it can orient future research

For Gamedevs:

- The state of GI in your field! ☺
- How academia can help you achieve your goals
- What you can do to improve & create collaboration opportunities
- Where is GI heading for future games

Before We Begin

- Thanks to everyone who contacted me and helped me gather content!
- I’ve done my best to summarize the state of the art of GI in shipped games
- Feel like I’ve missed a thing or two? Please contact me!
- All references at the end of the talk

Disclaimer - Storage vs Data

Storage can be independent of format & encoding

2D Storage	3D Storage	4D Storage
Per-Texel	Probes	Time
Per-Vertex	Voxels (Point/Aniso)	States
Per-Face	Surfels	Story Chapters
Per-Object	Cubemaps	…
…	Polycube maps	…
…	…	…

Encoding
Spherical Harmonics
Spherical Gaussians
Octahedron
Ambient Dice
Custom Basis (RNM, H, …)
…

Format
Raw
Compressed
Quantized
Palletized
Chroma Subsampled
…

Can often be mixed-and-matched

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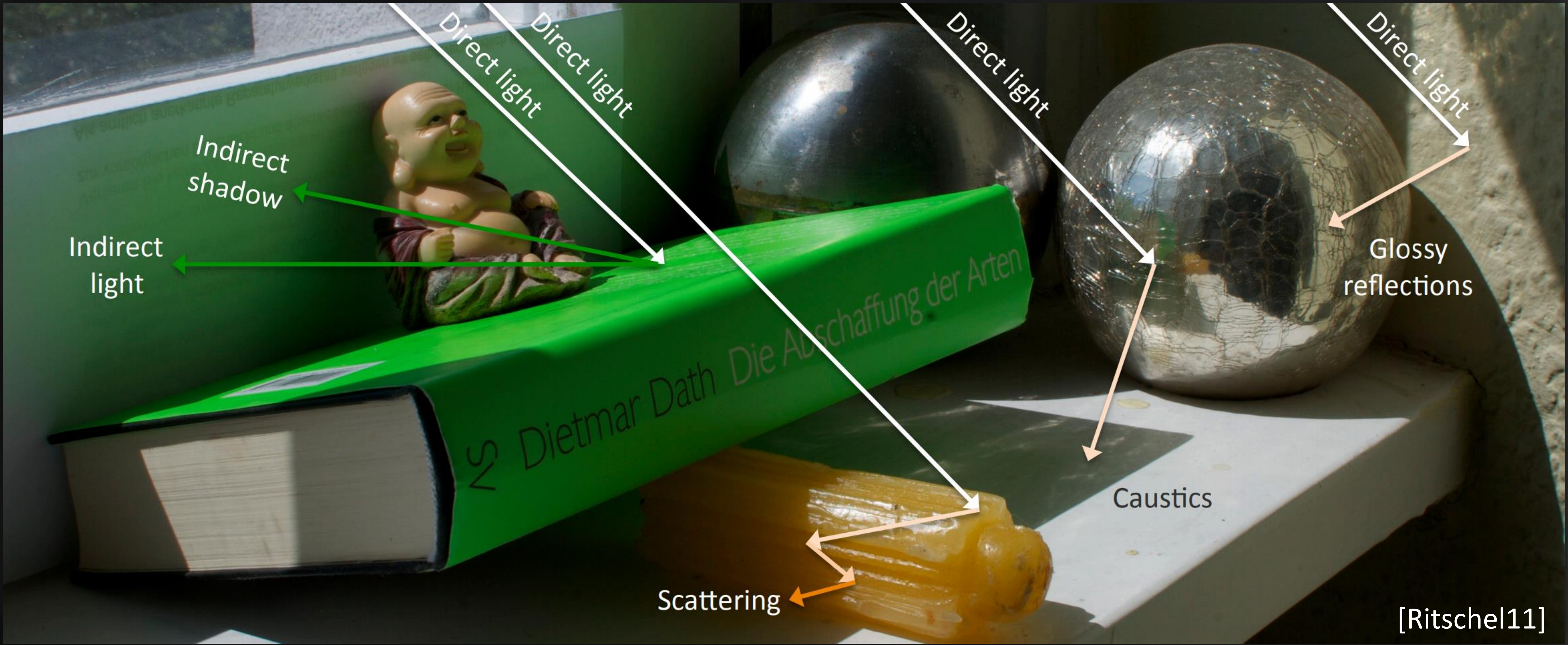
Games' Global Illumination (GI)?

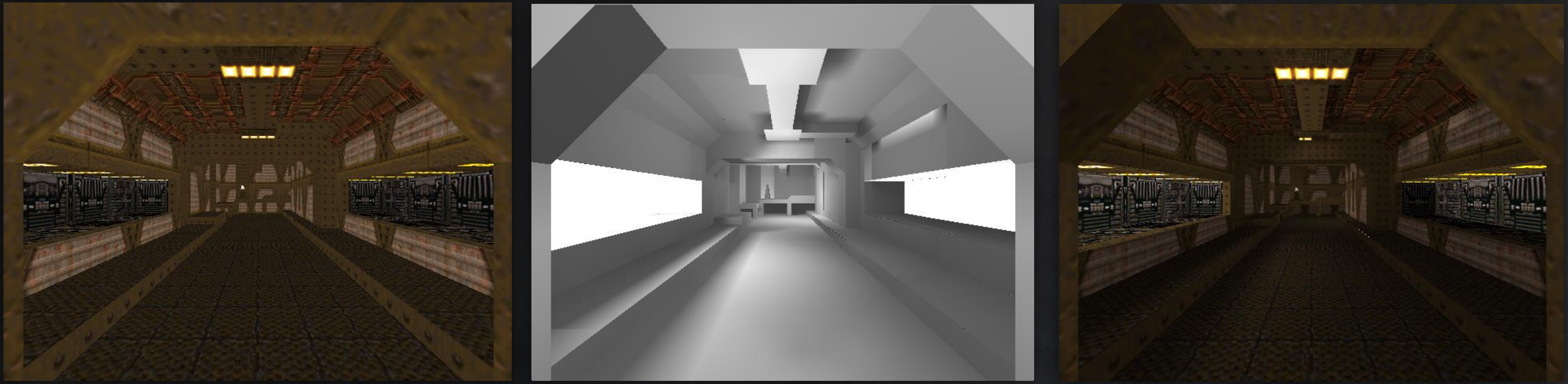


[Ritschel11]

BSDF = BRDF + BTDF…

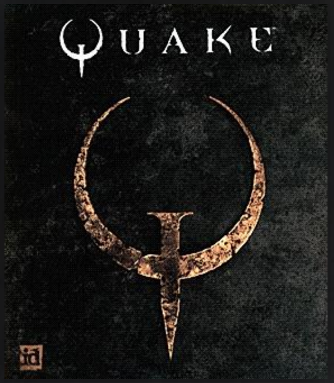
State of the Union

Surface Caching



Quake [Abrash2000]

- The beginning of global illumination in games…
- One of the first games to store precomputed irradiance
- Better sense of space, volume, and tension!
- Single 8-bit value for all lights affecting a vertex/texel
- Later colored (Quake2)

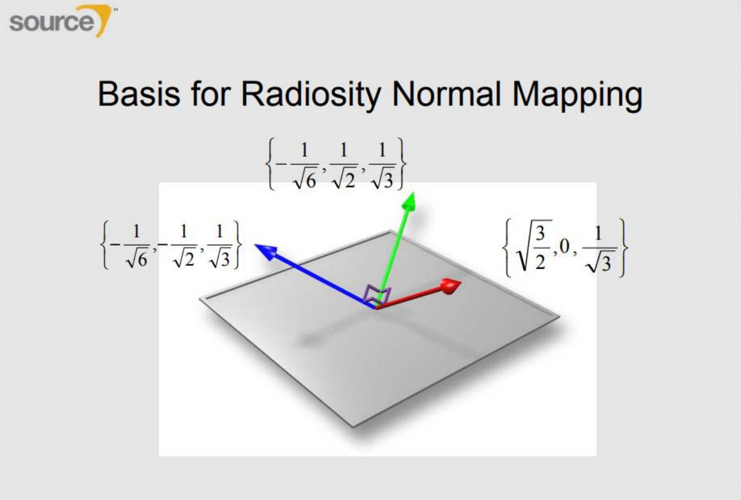


[Images from Bush15]

Radiosity Normal Mapping

- As seen in Half-Life 2 [McTaggart04]
- Avoids flat ambient
- Three full RGB lighting values, in three directions
- Blending based on the *cos(NormalMap, BasisDirections)*
- Can approximate specular
  - When view direction aligns with basis
  - “okay” with rough specular, not with low roughness
- Used in many games/engines!

[McTaggart04]



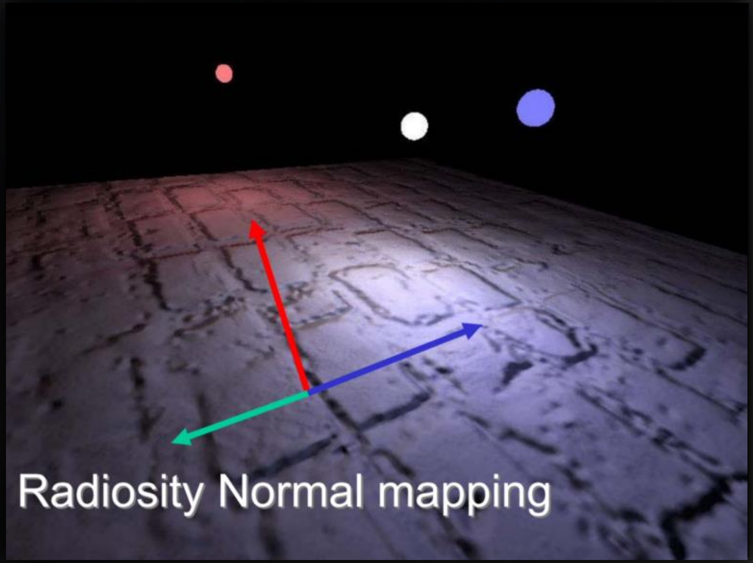
source

Basis for Radiosity Normal Mapping

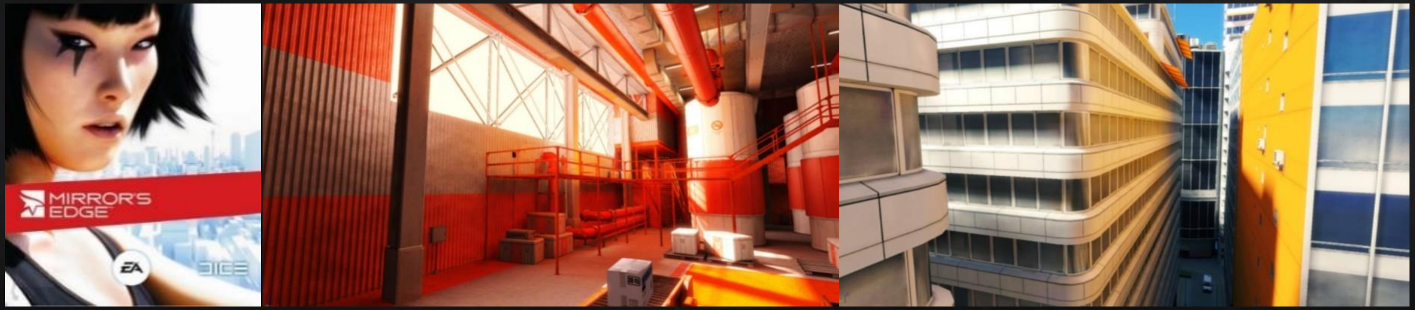
$$\left\{-\frac{1}{\sqrt{6}}, \frac{1}{\sqrt{2}}, \frac{1}{\sqrt{3}}\right\}$$

$$\left\{-\frac{1}{\sqrt{6}}, -\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{3}}\right\}$$

$$\left\{\sqrt{\frac{3}{2}}, 0, \frac{1}{\sqrt{3}}\right\}$$

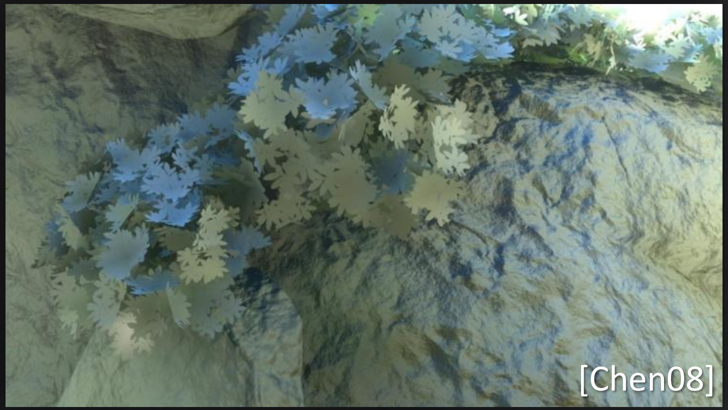


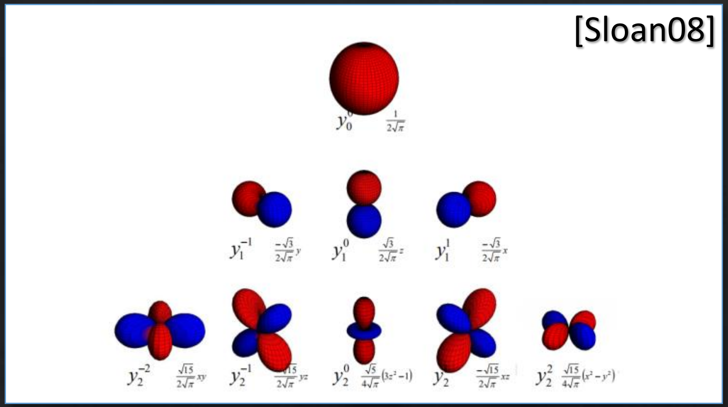
[Halén09]



Spherical Harmonics Lightmaps

[Chen08]


[Chen08]

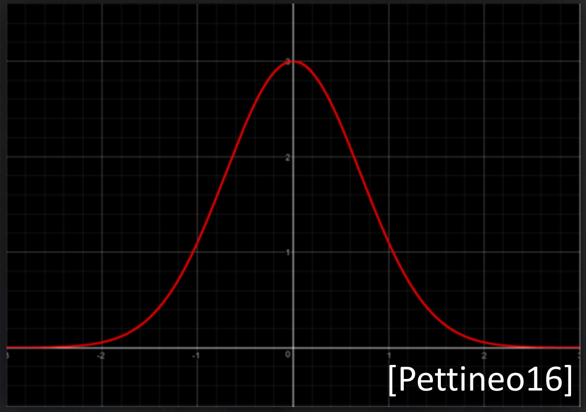

[Sloan08]

y_0^0 $\frac{1}{2\sqrt{\pi}}$
y_1^{-1} $\frac{-\sqrt{3}}{2\sqrt{\pi}}y$
y_1^0 $\frac{\sqrt{3}}{2\sqrt{\pi}}z$
y_1^1 $\frac{-\sqrt{3}}{2\sqrt{\pi}}x$
y_2^{-2} $\frac{\sqrt{15}}{2\sqrt{\pi}}xy$
y_2^{-1} $\frac{-\sqrt{15}}{2\sqrt{\pi}}yz$
y_2^0 $\frac{\sqrt{5}}{4\sqrt{\pi}}(3z^2-1)$
y_2 $\frac{-\sqrt{15}}{2\sqrt{\pi}}xz$
y_2^2 $\frac{\sqrt{15}}{4\sqrt{\pi}}(x^2-y^2)$

- Another step towards “global” improved fidelity
- Spherical harmonics (SH2) from offline photon mapper
- Texel has the irradiance at surface point, as a continuous function on a sphere
- Probes for dynamic objects also stored as SHs
- SH: Great for diffuse, but specular…

Spherical Gaussians Lightmaps

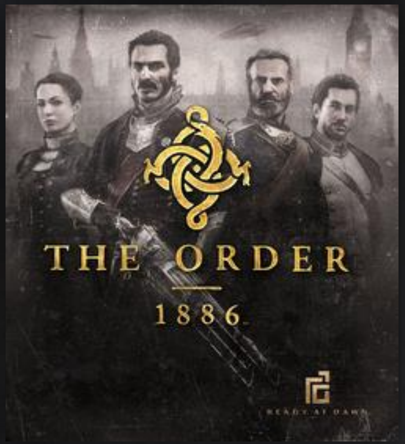
[Neubelt14]



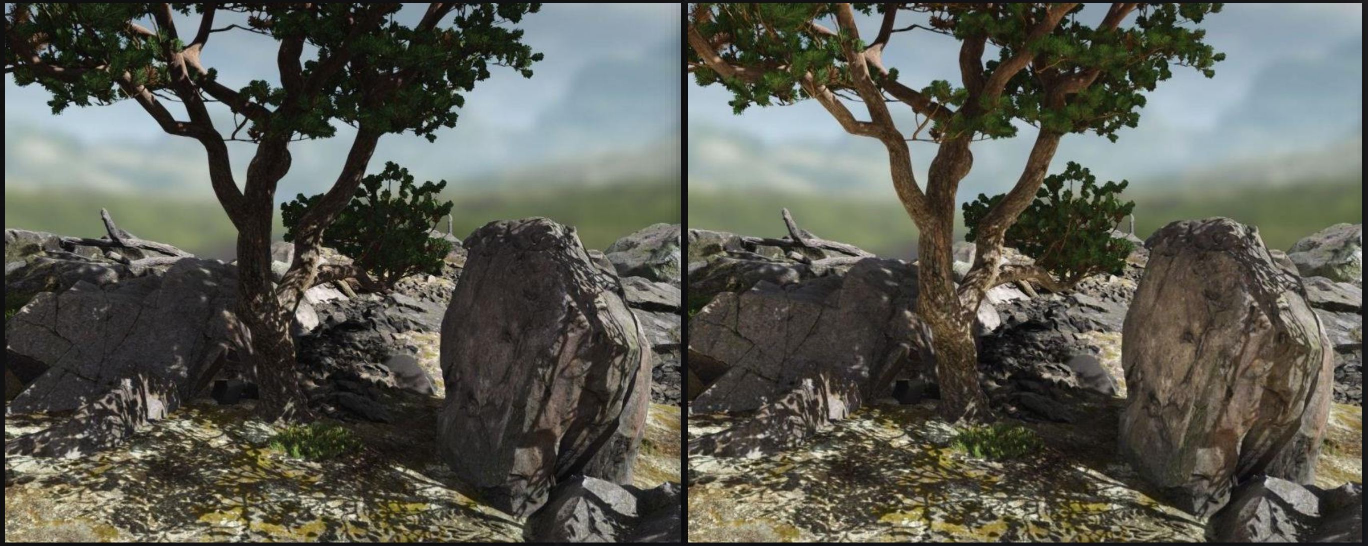
[Pettineo16]

The Order: 1886 [Neubelt14]

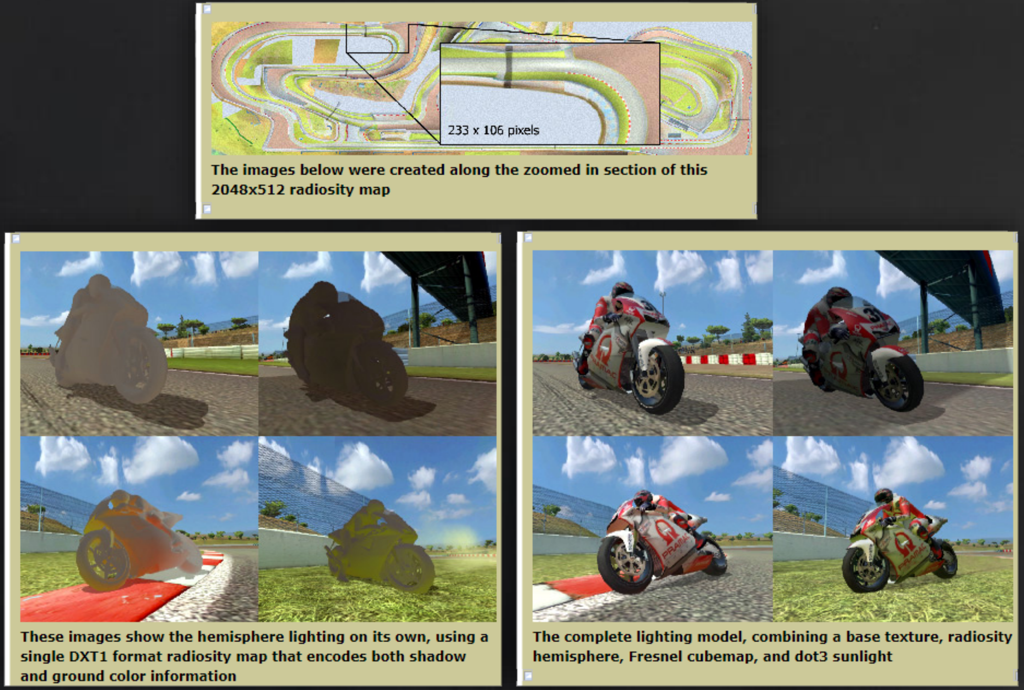
- Approximate incoming radiance using spherical gaussians
- Intuitive & compact representation for diffuse and specular
- Probes for dynamic objects also stored as SGs
- **Extensive** implementation details on Matt’s blog [Pettineo16]



Heightfield GI



UE4 Kite Demo – Without (Left) and With Heightfield GI (Right) [Seymour15]



The images below were created along the zoomed in section of this 2048x512 radiosity map

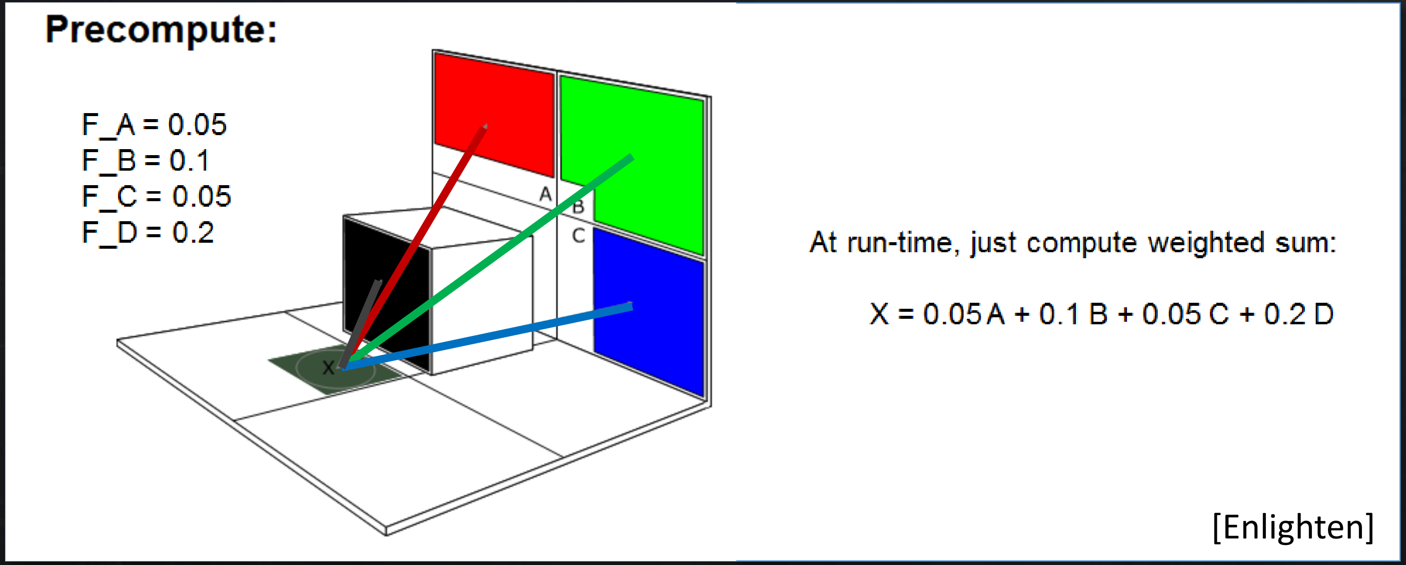
These images show the hemisphere lighting on its own, using a single DXT1 format radiosity map that encodes both shadow and ground color information

The complete lighting model, combining a base texture, radiosity hemisphere, Fresnel cubemap, and dot3 sunlight

Static Terrain Radiosity Maps in MotoGP [Hargreaves03]

- For large area and environmental lights on height fields. Can be dynamic [Nowrouzezahrai09]
- Many improvements since MotoGP's precomputed radiosity map (2003) [Hargreaves03]
- Pros: Neat solution for height-based worlds
- Cons: Height-field only. Doesn't work for interiors

Precomputed Form Factors



Precompute:

F_A = 0.05
F_B = 0.1
F_C = 0.05
F_D = 0.2

At run-time, just compute weighted sum:

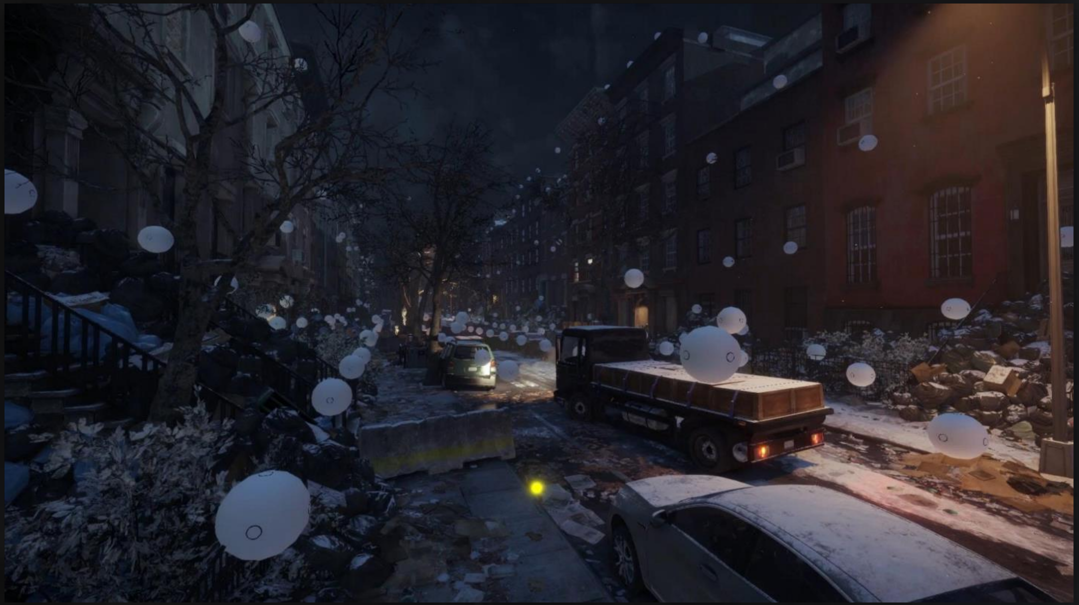
$X = 0.05\,A + 0.1\,B + 0.05\,C + 0.2\,D$

[Enlighten]

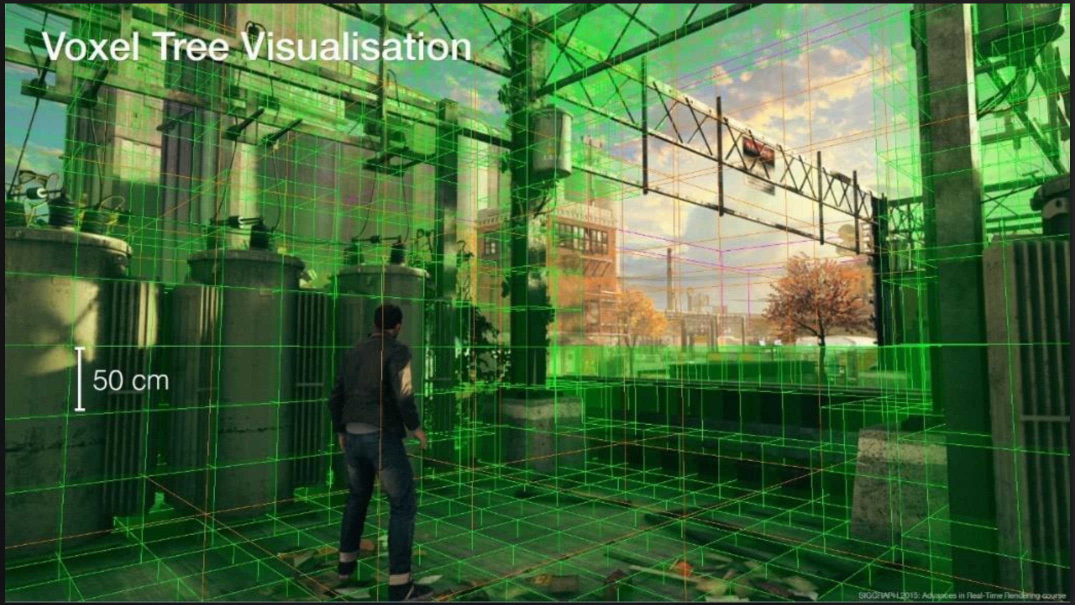
- Subdivide scene into finite elements
- Precompute visibility between elements
- Transfer function used at run-time for diffuse GI, for many *dynamic* lights
- Stored in lightmaps & probes
- Has to be recomputed if geometry (visibility) changes

ENLIGHTEN™

Probe-only Approaches



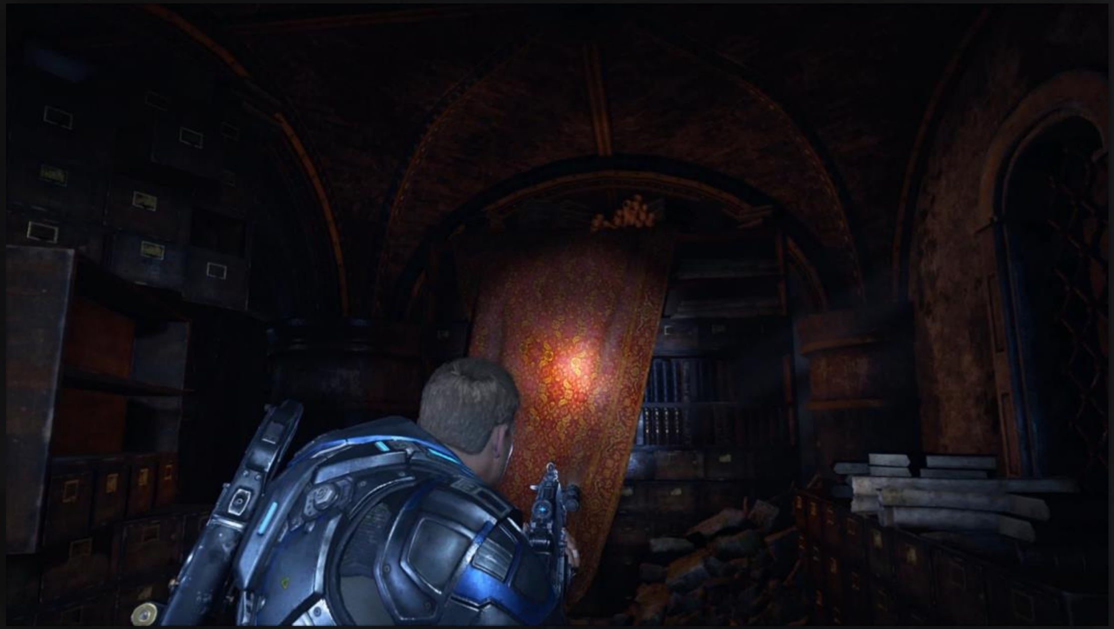
Tom Clancy's The Division [Stefanov15]



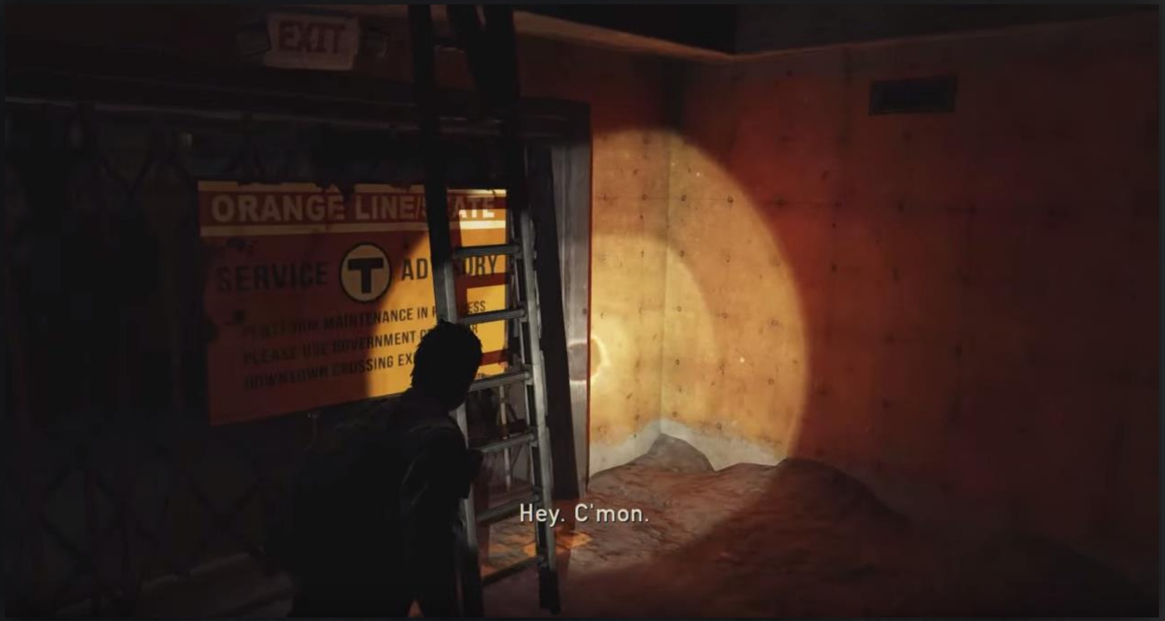
Quantum Break [Silvennoinen15]

- PRT (Farcry / Division), irradiance volumes (Quantum Break) in probes (offline / voxelization)
- Various Unified, CPU/GPU, console friendly approximations to global illumination:
  - *FC4*: CPU probes cells streaming to GPU page table (radiance xfer, clipmap injection and sampling) [McAuley15]
  - *The Division*: Surfels-to-probe, with surfel sharing (G-Buffer Cubemaps) [Stefanov15]
  - Quantum Break: Adaptive Irradiance Volume via octree [Silvennoinen15]
- Pros: Dynamic and static objects lit by same data. Volumetric!
- Cons: No HQ indirect specular. Specular from IBL & SSR

Virtual Point Lights



Gears of War 4 [Malmros17]

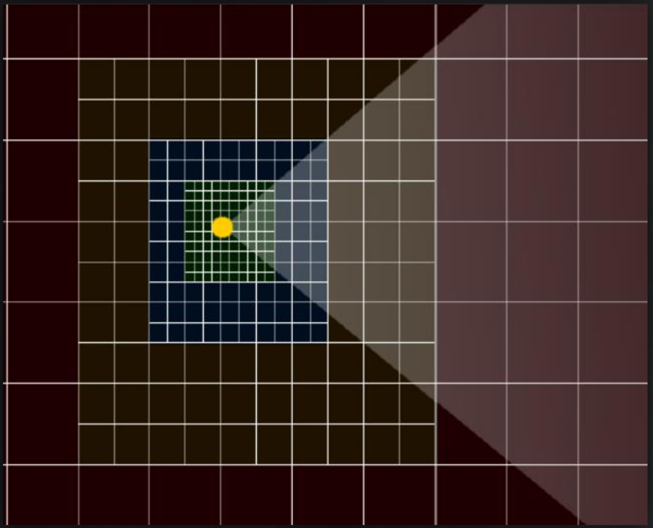


The Last of Us

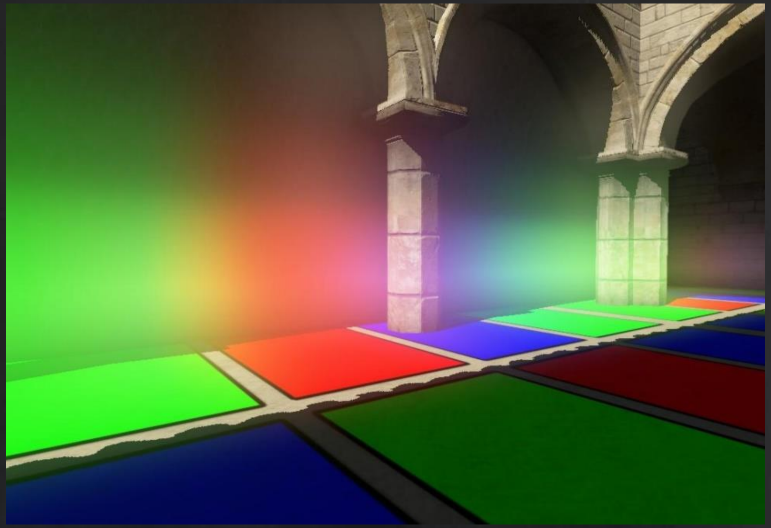
- Generate Virtual Point Lights (VPLs) from Reflective Shadow Maps (RSMs) [Dachsbacher04]
- For the player's flashlight, but also for other spotlights of interest
- Pros: Cheap point lights that approximate bounce. Can be quite convincing!
- Cons: Can be unstable (VPL selection). Localized solution. Precision can be a concern

Light Propagation Volumes

Cascaded Light Propagation Volumes in Fable [Woodhouse14]



Clipmap



Crytek's Light Propagation Volumes [Kaplanyan09]

- Render scene into RSMs, inject VPLs in volume, propagate and apply [Kaplanyan09]
- Cascaded with clipmap: detail up close, consistent in the distance
- Pros: No preprocessing. Console hardware friendly, and volumetric!
- Cons: Grid misalignment leads to bleeding. Stability issues because of VPL aliasing

Voxel Cone Tracing

Sparse Voxel Octree Cone Tracing [Crassin11]

GAME DEVELOPERS CONFERENCE® 2015

MARCH 2-6, 2015 GDCONF.COM

Voxel Cascades

The Tomorrow Children's Cascaded Voxel Cone Tracing [McLaren15]

- Original idea from [Crassin11], with sparse voxel octree
- Clipmap by [Pantaleev15], more GPU-friendly compared to octree [Mittring12]
- Pros: Diffuse and specular GI, and mid-to-large scale AO from voxels [Crytek16]
- Cons: Some leaking of GI, low roughness specular cone cost is significant, clipmap transitions

Ambient Occlusion?

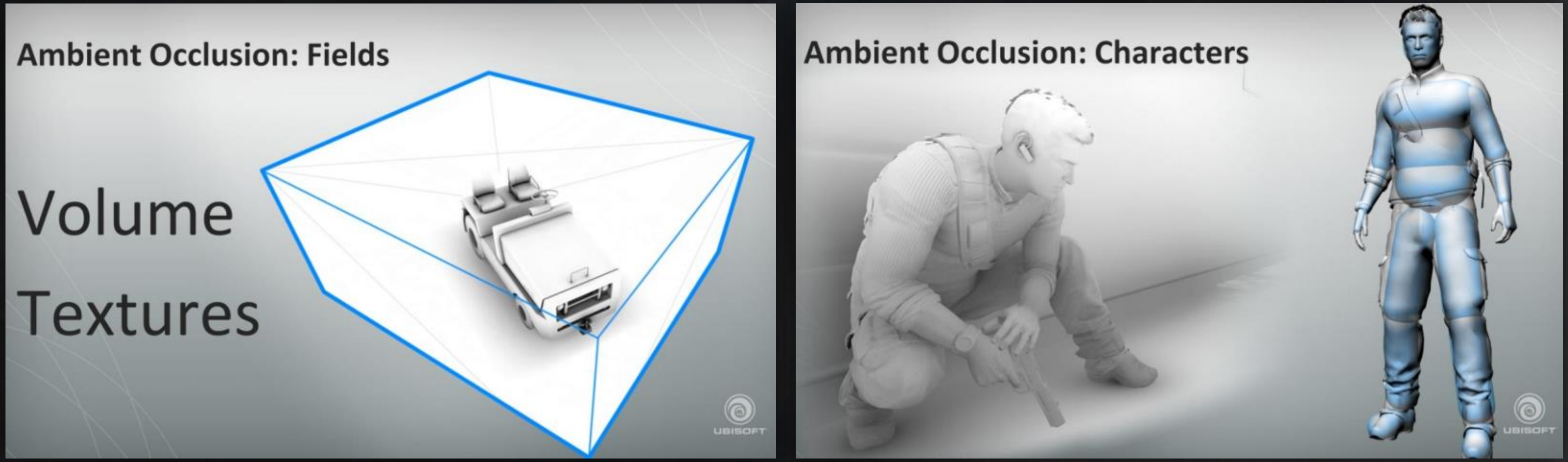
Multiple frequencies

- Near-field: vertex/lightmap, cavity or screen space (SSAO) [Mittring07]
- Mid-field: vertex/lightmap, SSAO, volumes or capsules [Hill10]
- Far-field: [Sloan16], height-based [McAuley15], distance-fields (UE4) [Wright15]

BUNGiE
DESTINY

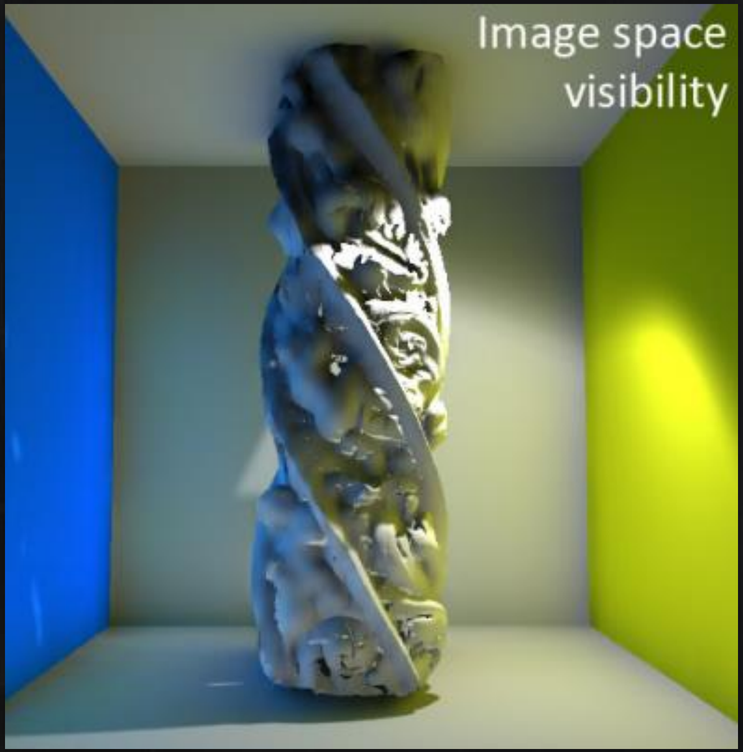
Ambient Obscurance Baking on the GPU [Sloan16]

SH Sky Occlusion [McAuley15]



AO Fields and AO Capsules [Hill10]

Screen Space GI?



SSDO [Ritschel09]

Screen-Space Diffuse
SIGGRAPH 2015: Advances in Real-Time Rendering course

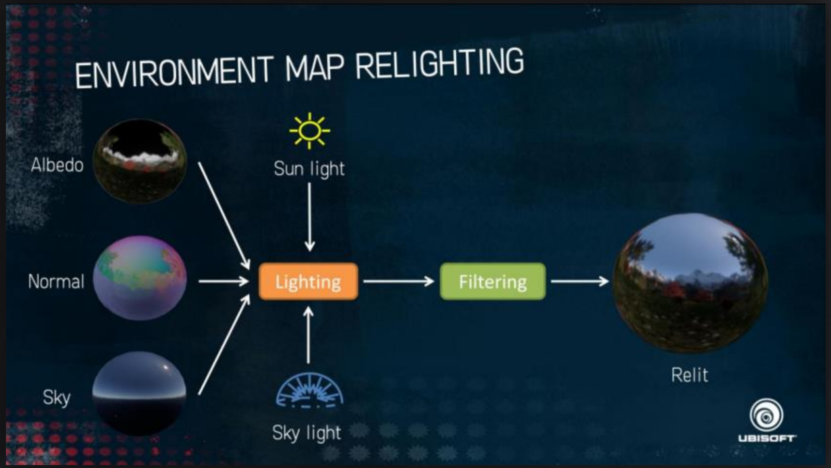
Quantum Break [Silvennoinen15]

Additional near-field local diffuse GI via screen-space

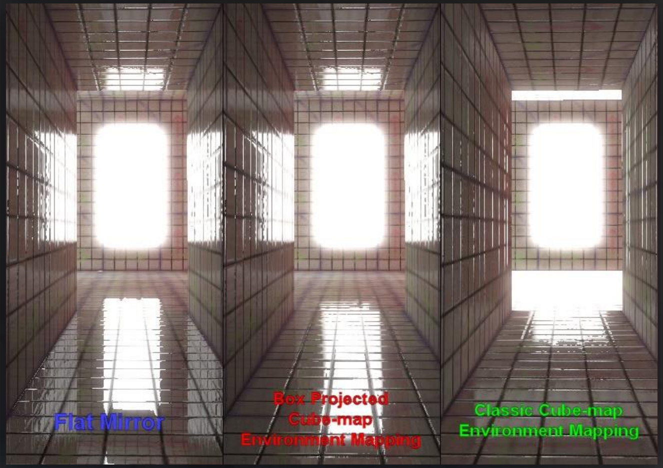
- Screen-Space Diffuse Lighting [Silvennoinen15]
- Inspired by first bounce approximation from SSDO [Ritschel09]

Specular GI?

Stochastic SSR [Stachowiak14]



Cubemap Relighting [McAuley15]


Flat Mirror
Box Projected Cube-map Environment Mapping
Classic Cube-map Environment Mapping

Box Projected Cube Maps [Bech10]

Mostly approximated via:

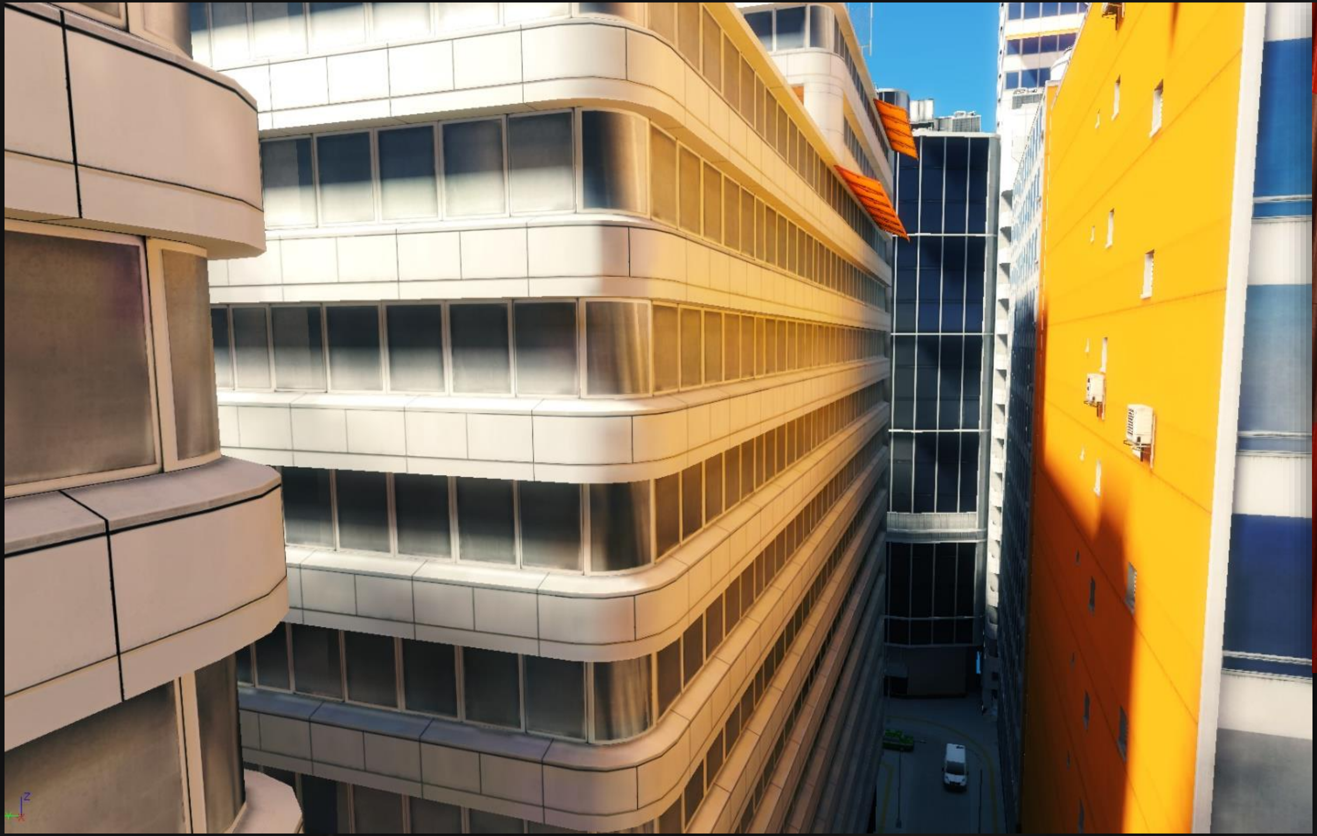
- Parallax-Corrected Cubemaps [Bech10] [Lagarde12]
- Screen-Space Reflections (SSR) [Sousa11] [Stachowiak14]
- Cubemap relighting [Stachowiak14] [McAuley15]
- Extract dominant color from 2nd order SH
- Specular for SG [Neubelt14]

Most games don’t do specular to specular light transport

Art, Engineering, Pipeline & Production Challenges

aka Gamedev Table Flipping… (╯°□°）╯︵ ┻━┻

Visual Consistency



[Halén09]

Visually-plausible representation of light transport (8 years ago)

- Color bleeding, global shadows, colored transparency, …
- Clever combination of art direction and technology to maximize visual consistency

When Visual Consistency Fails

Various points in the process with where visual consistency can break

- Simplified representation ≠ visual representation
  - Hand-authored mesh proxies [Martin10]
- Over-simplified representation of PBR parameters for GI
  - Simplified albedo color
  - Not handling metallic surfaces
  - Not handling roughness properly
  - Not storing enough post-computation info to reconstruct view-dependent results
- Resolution issues
  - Vertex/surface/detail normal to texel/voxel/probe ratio
- Not properly handling shadow casting lights for GI and custom filters (Gobos / Gels / Cookies)
- Per-object / per-light custom parameters
- Lighting channels and negative lights…

(╯°□°) ╯︵┻━┻

When Iteration Fails

Long precompute that requires whole game world re-evaluated is a huge problem!

- Lighting is always “wrong" during development
- Destroys iteration, can create serious dependencies in review & approval process, and ultimately ruin reviews
  - i.e.: Build made two revisions before lighting was “generated”, hard to judge art!
  - i.e.: Lighting done late in the level authoring process, after sign-off
- “Global” = move a pillar, have to relight the whole level instead of proximity
- Preview modes that take 5+ minutes where one can’t use their computer

Example Scenario: Nightly build of GI for open world map (8+ hours)

1. Artist submits everything in time for automated process to start
2. Process runs all night
3. Artist arrives at work in the morning, syncs and opens editor, notices something is visually broken
4. Fixes it, submits, waits (next day, or several hours)
5. Rinse-and-repeat

Such process leads to very static game worlds

(╯°□°) ╯︵ ┻━┻

When Authoring Fails

Relying on hand-tweaks to compensate for lack of robustness

- GI-only lights for when lack of convincing propagation
- Per-object GI parameters, hand-tweaked to make objects artificially “pop”
- Fixing leaks with override volumes & planes (interiors/exteriors) [Hooker16] [Stefannov15]
- Negative lights to remove GI [Schulz14]

Grunt Work: I doubt any artist out there likes doing the following tasks

- Unwrapping lightmap UVs
- Building simplified geometry for GI
- Any other task imposed on artists that was “a-ok” to do back then, but that doesn’t scale today

(╯°□°)╯︵ ┻━┻

The (<n) ms Threshold

Game & platform-specific cut-off at which a technique can make it into game

- We tend to keep our frames pretty busy
- Unless significant change to aesthetics, something else will have to go
- Has to be implemented early in production

30hz Games: [0 – **10%**] → [0…**3.0 ms**]

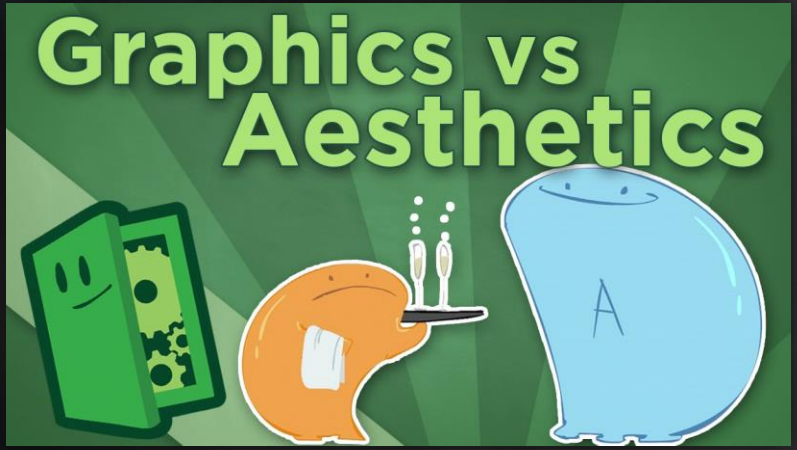
60hz Games: [0 – **10%**] → [0…**1.5 ms**]

0-frame-drop-allowed-60hz Competitive Games & VR:

- 16ms @ 60hz… but really it's less than that
- MK / Injustice: 12-13 ms frame times [Greenberg05], FIFA

Consider non highest-end GPUs (TFLOPS) [Wikipedia]

- PS4: 1.8, PS4Pro: 4.2, XB1: 1.3, XB1X: 6
- TitanX: 11, Vega: 13.1



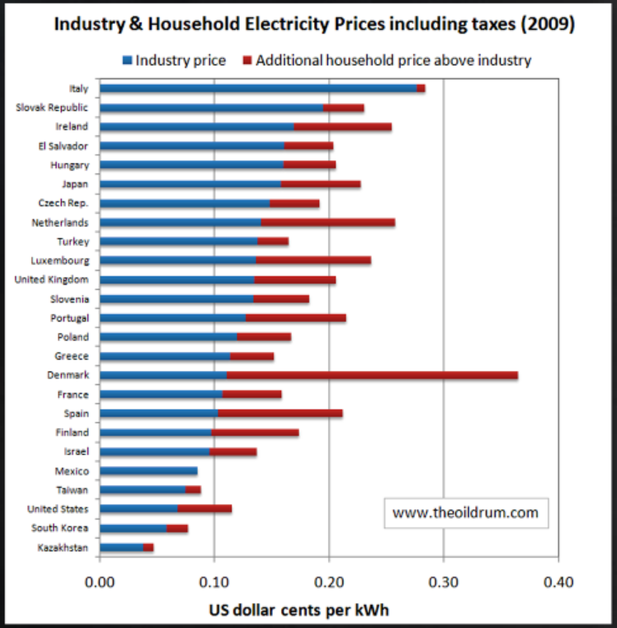
Graphics vs. Aesthetics

The Power Cost ($)

The cost of power for precomputing (parts/full) lighting for a modern large world might be non-trivial

- Beefy Machines / Server Setups
  - CoD: 48 GB RAM and 12 GB VRAM machines [Hooker16]
  - Halo 3: 256 servers, 456 Processors, 1GB memory [Chen08][Villegas08]
  - SNDBS/Incredibuild: pool of GPUs running all night (650W+ PSUs)
  - Consider additional costs (i.e.: cooling, hardware failure, …)
- Cloud computing might be cheaper in the long run
  - Even with reduced cost of electricity (Industrial vs Household)

[Chen08]



The Open World Beast

GI solutions for open world games is non-trivial

Handles scale

- Massive world dimensions, at quality
  - ACU: scalable quality (DVD space), up to 21+ GB of GI
  - Significant team decision, and it was worth it!
- High entity count
  - Wildlands [Werle2017]: 839 862 trees, 3 449 638 bushes, 775 288 rocks

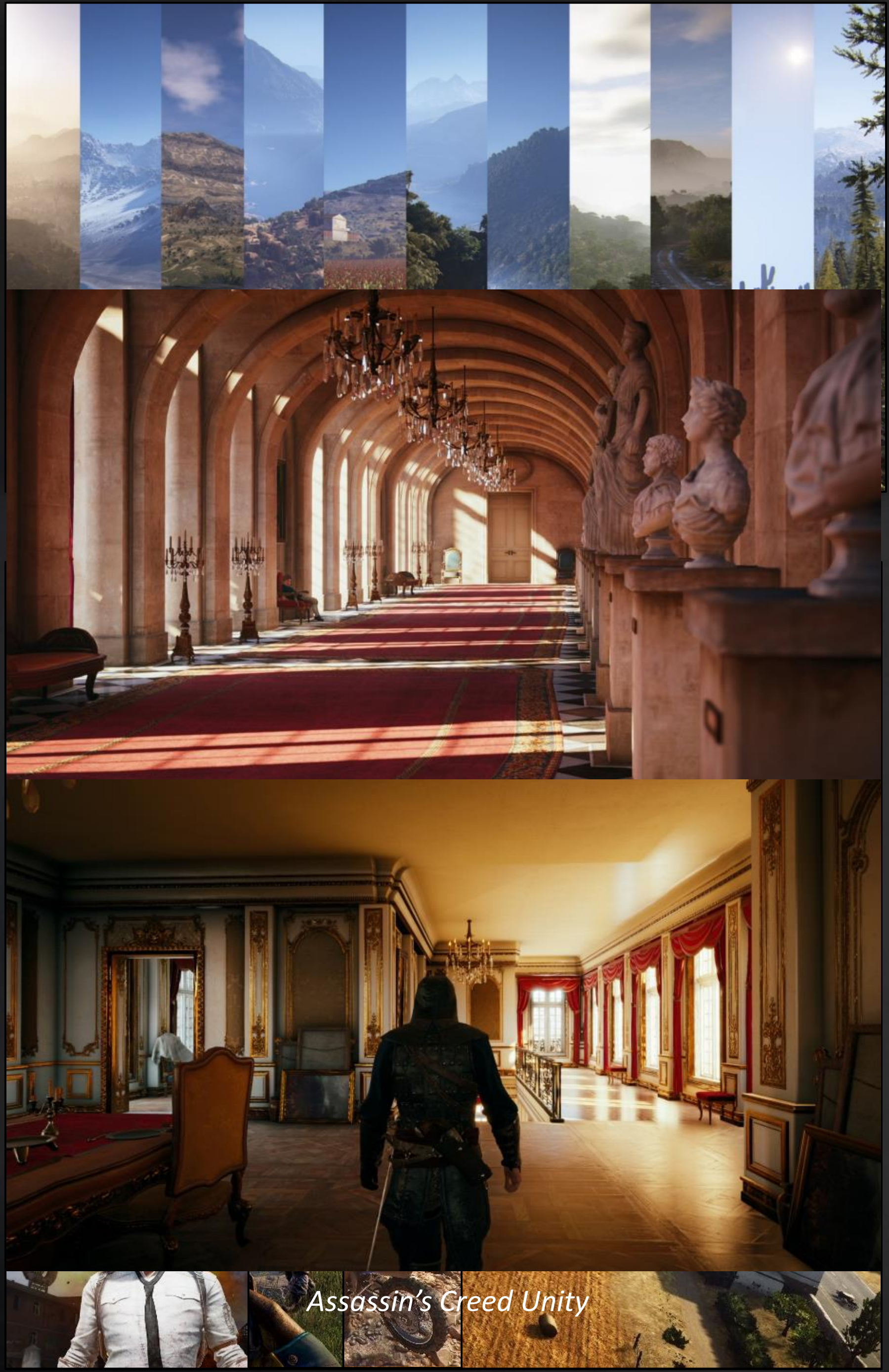
Holds on console memory, handles streaming

Handles interiors & exteriors (without leaks)

Often handles time-of-day, weather

Authoring content as such scale requires:

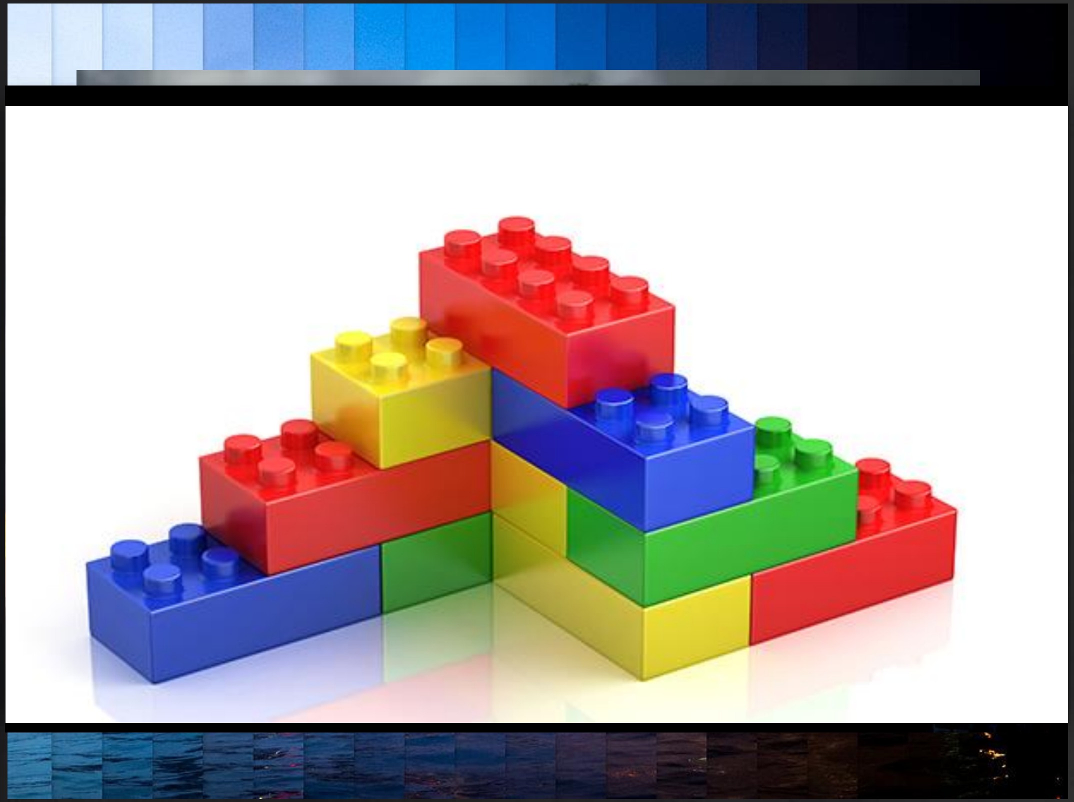
- Robust and distributed process
- Easy of authoring/updating, production-manageable



Game Features

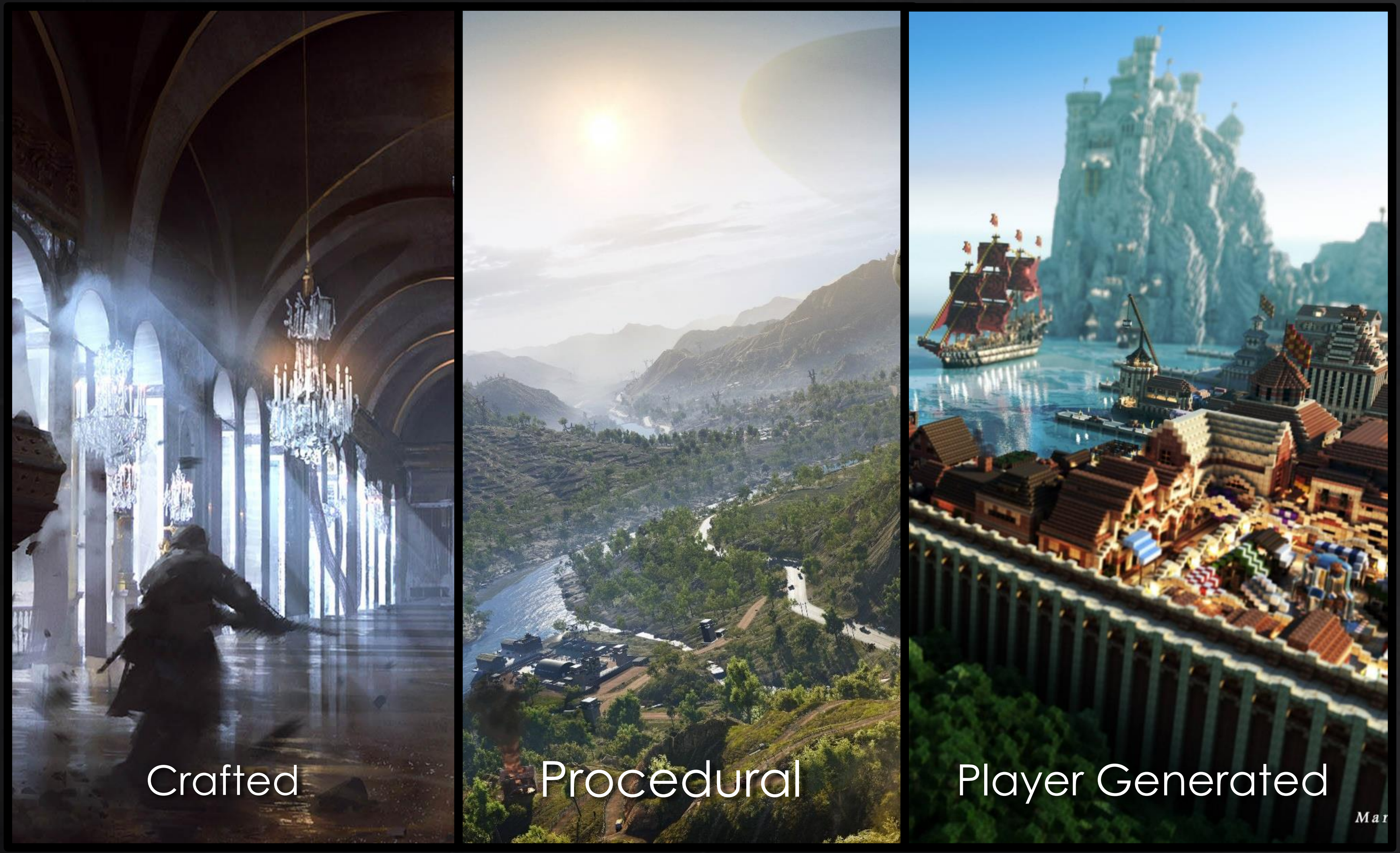
Several features that can make/break GI:

- Wear, tear, destruction
  - A hole in the wall can drastically break GI
  - Handle arbitrary malleable worlds
- Time-of-Day
  - Art-direct key hours, but what about in-betweens?
  - Interpolation doesn't always give best results
- Weather
- User-Generated/Assembled Environments
  - Can't guarantee AAA gamedev artist authoring here, for composition, performance, etc.
  - Generating lightmaps at load time, like Halo 4? Partial recomputation?
- Stuff-that-moves, lights on/off, volumetrics



The Future

GI for Games of The Future



From Left to Right: BF1, Tom Clancy's Ghost Recon Wildlands, Minecraft

GI as a First-Class Citizen

Artists can rely on shadows for gameplay, but not GI

FPS scenario where the firefight actually sets things on fire:

- Continuously burn, affecting lighting and GI
- Lighting from incidental fire could have a big and striking effect on gameplay

Corridor shooter, where another player is around a corner:

- But you can see the bounce of their muzzle flashes
- Audio gives queues of what's ahead. So can GI

Use GI to create better games and experiences

Die Hard 2

Mixed Environments

Inconsistent representation for different geometries

Organic: GI for forests / vegetation is non-trivial

- Trunk / big branches: lightmaps? (maybe…)
- Branches: probes? vertex color?
- Leaves (cards): …

Need a unified solution for organics and artificially-made environments

- Coexist in the same environment
- Hard edges
- Don't want leaks

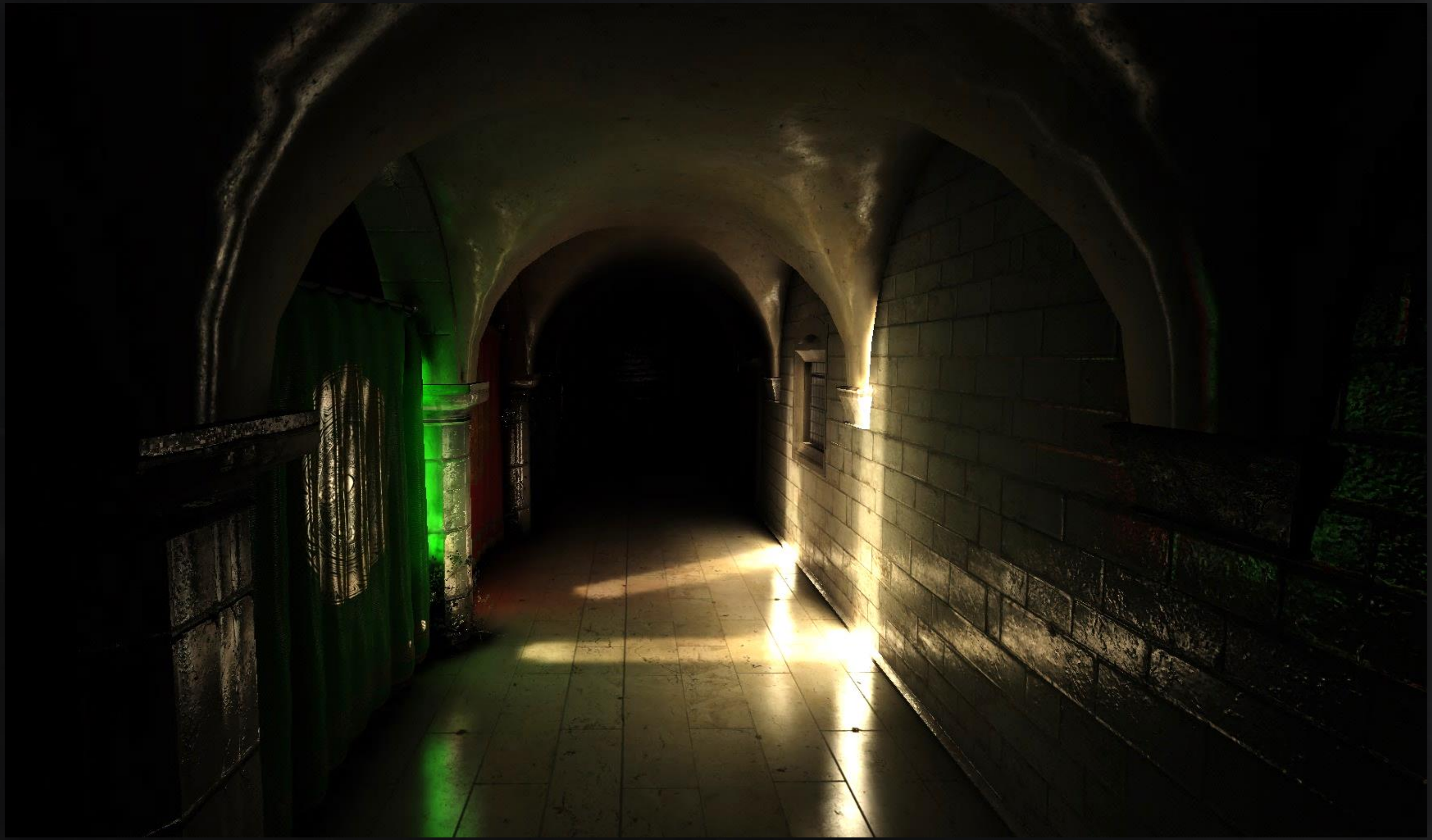
Participating Media

GI for complex participating media is definitely unsolved in games

© Caters News Agency

Lighting the world with physically-based pyroclastic simulations!

The Importance of Specular GI



Indirect Specular with SVOGI [Crassin12]

Player Generated Content

Can’t assume AAA gamedev art & composition from user-generated content

Reconcile (potential) weird assemblage of player made worlds:

- Players can do whatever they want and system has to deal with it
- Handle weird ratios (geometry/materials) and weird composition

Alternative runtime representations as a true equalizer?

- Voxelization?
- Spherical representations?
- Or transform to a common/uniform/compact representation

Need robust solutions that just work ™ (on millions of arbitrary assets)

The Artist Perspective (1/2)

Design GI with our main client in mind: artists and designers!

Big Picture vs Details

- Solve “big picture” GI rapidly, and refine details over time

Progressive feedback with refinement

- Algorithms that support for quick previz, able to slice work over n-frames
- Refinement zones (user, camera-driven) works: *progressive lightmapper* [Unity16]
- Runtime approximation of final quality to unblock people (art reviews, playtest, bugs)
- Drastically improves iteration times, **iteration → quality**
- Less downtime, and bakes always mean downtime

Towards a Zero Grunt Work™ Pipeline

Automatic parametrization & good interfaces!

Let’s get rid of the tedious “non-art” manual steps:

- Unwrapping lightmap UVs
- Building simplified geometry for GI
- Manually placing GI & reflection volumes
- Any other non-artistic step that could be automated

Interface & Tweakables

- Exposing everything doesn't mean the best results
  - Horrible PBR: 75% metals
- Simple and clear, artist and art director friendly params
  - People test stuff by trying extremes: 0-1 mappings
  - Complex behaviours: slider driving 4 sliders. Presets!

Future Light Types

Area lighting is becoming more and more common

Blade Runner

Used in several areas in games [Drobot13] [Lagarde14] [Heitz16]

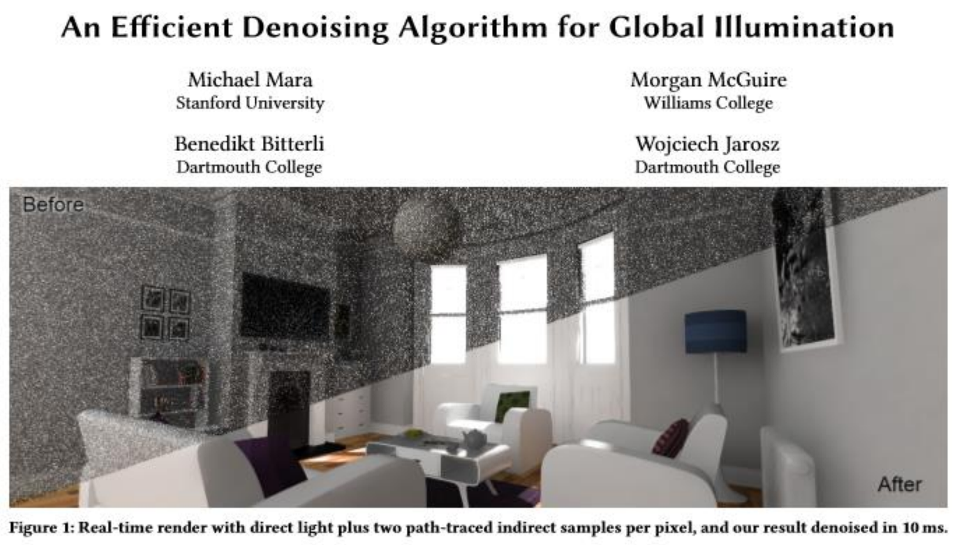
- Runtime (windows, ad panels, light enclosures)
- In-game cinematics (photo-studio lighting, 3+ point lighting)

Need to build GI systems that work for such light types, in real-time

- With diffusers, textured & animated
- Even direct area light shadows are still unfortunately challenging

Denoising / Reconstruction

Denoising becomes relevant when considering path tracing as a solution



An Efficient Denoising Algorithm for Global Illumination

Michael Mara
Stanford University

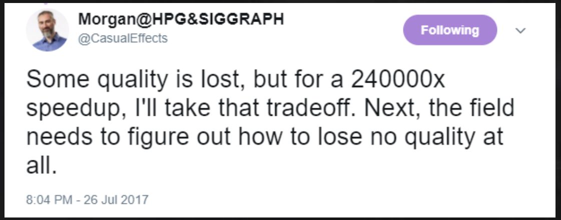
Morgan McGuire
Williams College

Benedikt Bitterli
Dartmouth College

Wojciech Jarosz
Dartmouth College

Figure 1: Real-time render with direct light plus two path-traced indirect samples per pixel, and our result denoised in 10 ms.

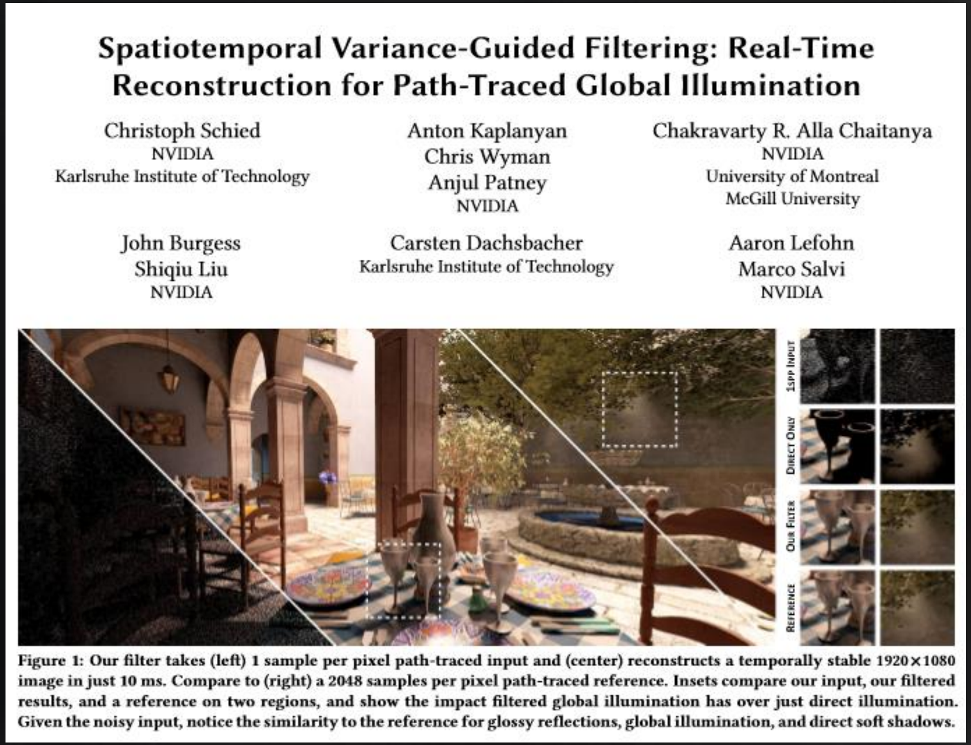
[Mara17]



Morgan@HPG&SIGGRAPH
@CasualEffects

Some quality is lost, but for a 240000x speedup, I'll take that tradeoff. Next, the field needs to figure out how to lose no quality at all.

8:04 PM - 26 Jul 2017



Spatiotemporal Variance-Guided Filtering: Real-Time Reconstruction for Path-Traced Global Illumination

Christoph Schied
NVIDIA
Karlsruhe Institute of Technology

Anton Kaplanyan
Chris Wyman
Anjul Patney
NVIDIA

Chakravarty R. Alla Chaitanya
NVIDIA
University of Montreal
McGill University

John Burgess
Shiqiu Liu
NVIDIA

Carsten Dachsbacher
Karlsruhe Institute of Technology

Aaron Lefohn
Marco Salvi
NVIDIA

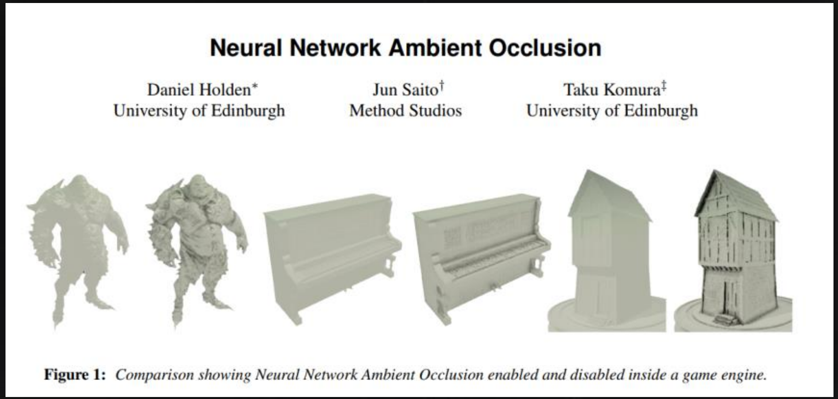
Figure 1: Our filter takes (left) 1 sample per pixel path-traced input and (center) reconstructs a temporally stable 1920×1080 image in just 10 ms. Compare to (right) a 2048 samples per pixel path-traced reference. Insets compare our input, our filtered results, and a reference on two regions, and show the impact filtered global illumination has over just direct illumination. Given the noisy input, notice the similarity to the reference for glossy reflections, global illumination, and direct soft shadows.

[Schied17]

The denoisers in these papers are still too heavy for games today (1-2 spp, 10ms @ TITAN X), <u>but they are far better than film denoisers</u> (100+ spp, seconds-to-minutes). **Huge progress**! ☺

Deep Learning

Deep learning is making its way into rendering as well!

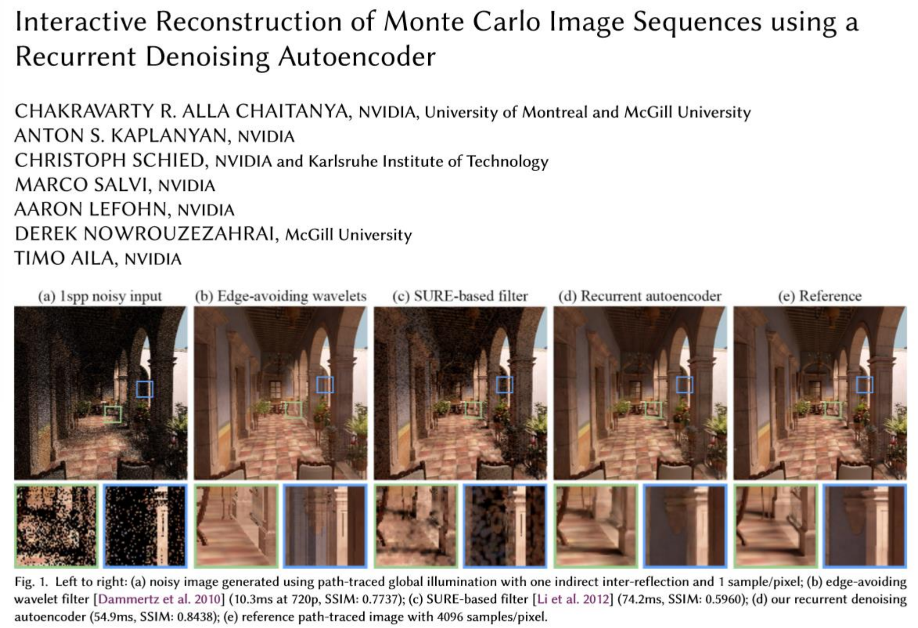


Neural Network Ambient Occlusion

Daniel Holden* University of Edinburgh
Jun Saito† Method Studios
Taku Komura‡ University of Edinburgh

Figure 1: *Comparison showing Neural Network Ambient Occlusion enabled and disabled inside a game engine.*

[Holden16]



Interactive Reconstruction of Monte Carlo Image Sequences using a Recurrent Denoising Autoencoder

CHAKRAVARTY R. ALLA CHAITANYA, NVIDIA, University of Montreal and McGill University
ANTON S. KAPLANYAN, NVIDIA
CHRISTOPH SCHIED, NVIDIA and Karlsruhe Institute of Technology
MARCO SALVI, NVIDIA
AARON LEFOHN, NVIDIA
DEREK NOWROUZEZAHRAI, McGill University
TIMO AILA, NVIDIA

(a) 1spp noisy input (b) Edge-avoiding wavelets (c) SURE-based filter (d) Recurrent autoencoder (e) Reference

Fig. 1. Left to right: (a) noisy image generated using path-traced global illumination with one indirect inter-reflection and 1 sample/pixel; (b) edge-avoiding wavelet filter [Dammertz et al. 2010] (10.3ms at 720p, SSIM: 0.7737); (c) SURE-based filter [Li et al. 2012] (74.2ms, SSIM: 0.5960); (d) our recurrent denoising autoencoder (54.9ms, SSIM: 0.8438); (e) reference path-traced image with 4096 samples/pixel.

[AllaChaitanya17]

More info about DL and rendering in Marco's Talk

"Deep Learning: The Future of Real-Time Rendering?" @ 4:25PM

Open Questions

What is the next big step in a completely unified real-time GI solution?

- Need a unified "solve all BSDF" approach (organics, human-made, volumetrics)?
- Need to solve for fully malleable, deformable and interactive worlds!

Are engines architectures and current art methods preventing us from moving forward with high-quality real-time GI?

- What if we weren't using triangles anymore…
- What if the data representation used for GI was completely different from authoring?
- Real-time denoised path-tracers for future rendering architectures?

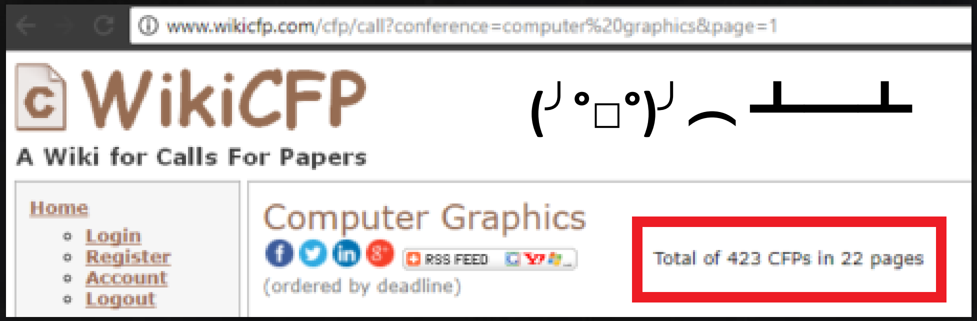
How do we go about solving real-time GI for mobile and VR?

- Mid-to-far-field on the cloud, near-field on the device?

Gamedev vs Research

So many academic sources:

- SIGGRAPH / SIGGRAPH ASIA
- I3D
- HPG
- EGSR
- JCGT
- But also:



www.wikicfp.com/cfp/call?conference=computer%20graphics&page=1

WikiCFP

A Wiki for Calls For Papers

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Computer Graphics

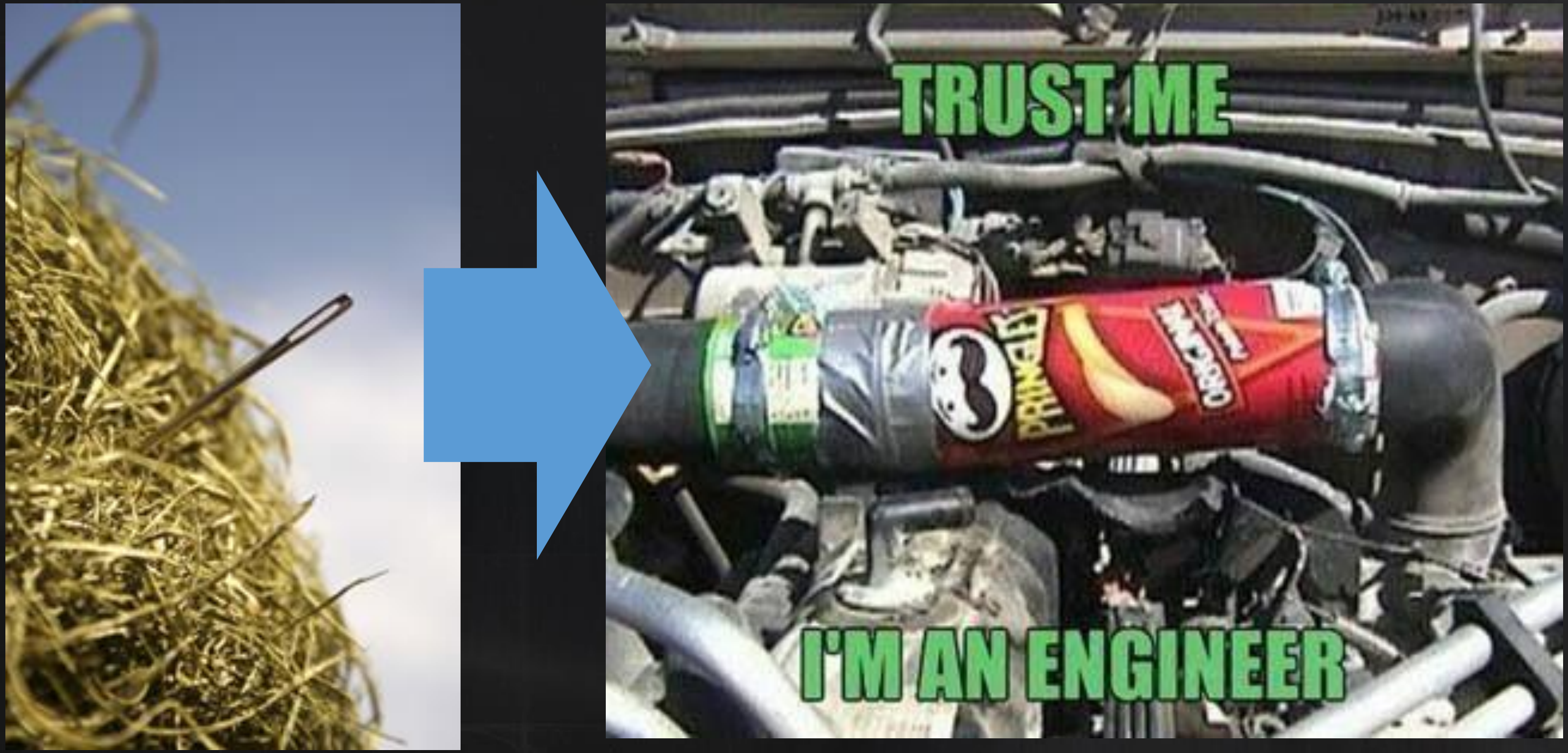
RSS FEED

(ordered by deadline)

Total of 423 CFPs in 22 pages

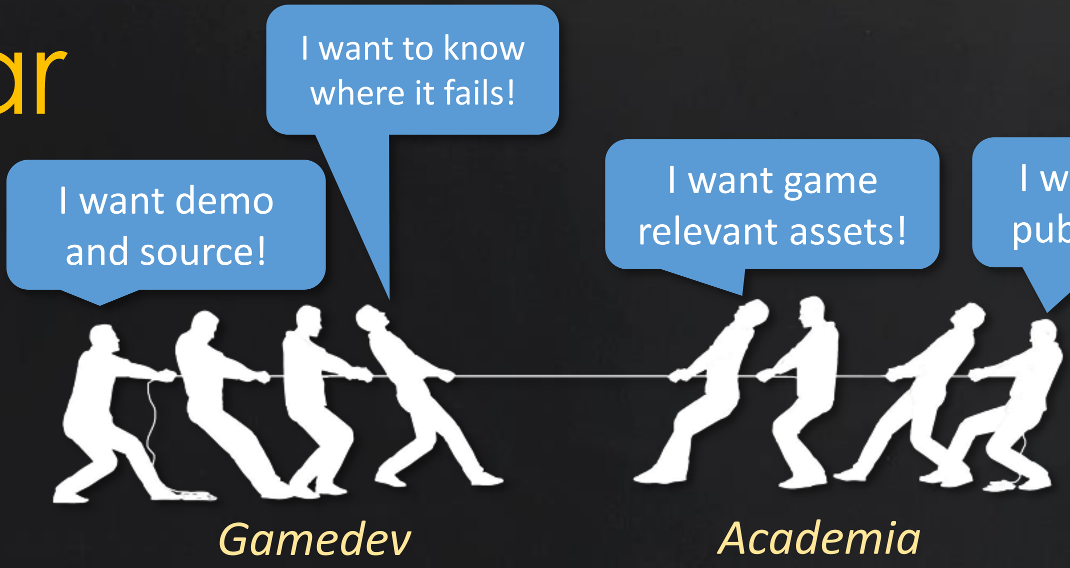
Finding what works for your game may sometimes feel like finding a needle in a haystack

Gamedev vs Research



And once we’ve found it, we might have to duct tape it in the engine…

Tug-of-War


I want demo and source!
I want to know where it fails!
I want game relevant assets!
I want more publications!
Gamedev
Academia

We need to challenge our respective organizations to align for the greater good

Gamedevs:

- Contact academia when you have questions!
- Consider finding different ways to work with them, and share some assets!
- Cite and give credit to academia in your GDC/SIGGRAPH presentations!

Academia:

- When a gamedev contacts you, it means they're interested and want to hear back from you!
- It's not just "implementation details". Consider practicality in addition to citations [Hecker11] [Baker11], augmenting artists [McGuire13]
- You think your technique belongs in a game? Cool! More info in the next slide.

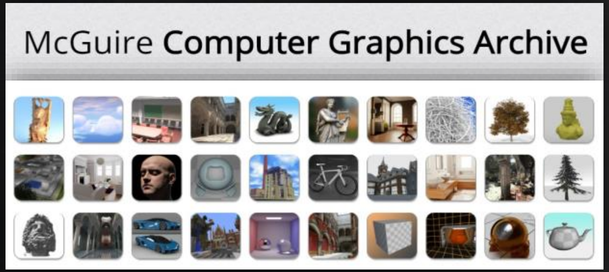
Middle ground: JCGT

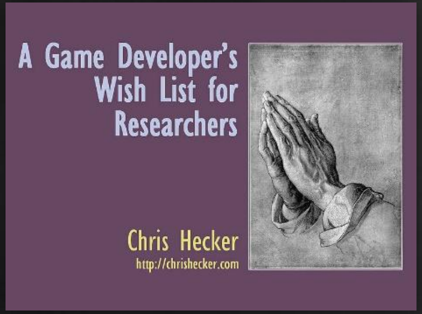
the Journal of
COMPUTER GRAPHICS TECHNIQUES
peer-reviewed, open access, and free to all

Getting Your Technique in Games

If you want your stuff in games, here's how to achieve maximal visibility:

1. HLSL / GLSL / Code in your paper (i.e.: appendix)
   - While many gfx programmers have an extensive math background, yours is most likely more complete
   - Learning from source is easier, and trying out stuff rapidly is great
2. Working Demo with **Source**
   - Github
3. Use Social Media
   - Twitter: lots of devs hang-out there, and retweet papers they find interesting
   - Blog Post to summarize and add extra content (i.e.: summary, where it breaks, etc.)
4. Relevant Art Assets
   - Check out Morgan McGuire's Mesh Database [McGuire17-2]
   - Want something different? Ping artists on art forums!
5. Use *ms* instead of *fps* [Hecker11] [Baker11]
6. Try on non highest-end GPUs ;) (slide 26)
7. **Team up with us and other R&D groups!**


McGuire Computer Graphics Archive


A Game Developer's Wish List for Researchers

Chris Hecker
http://chrishecker.com

Summary

Still have lots of work to do!

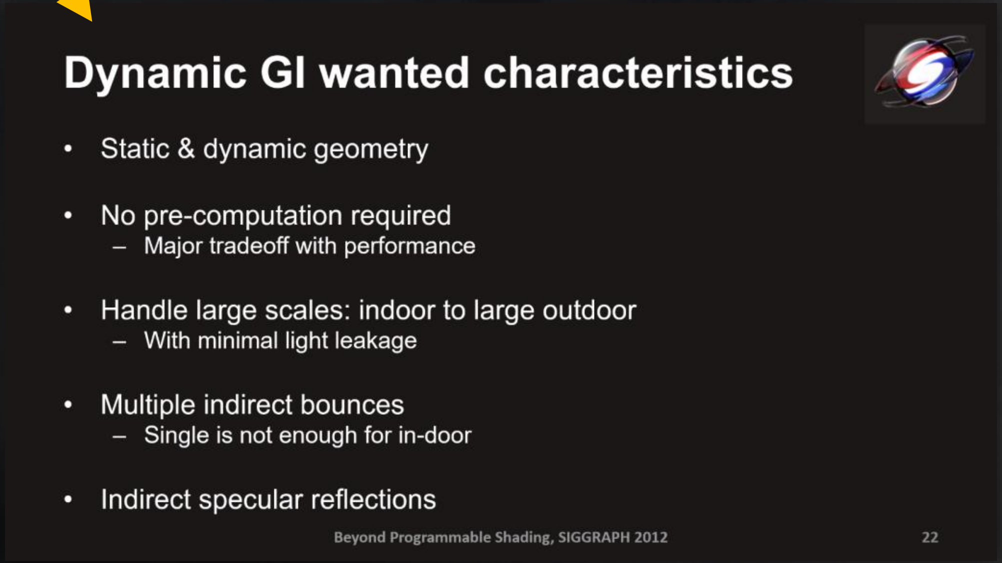
- Need to work towards a unified GI solution for games of the future
- With the latest advances in both academia and gamedev GI, the future is looking promising!
- Need more/strong collaborations between academia and gamedevs, with a model where both parties win!

Beyond Programmable Shading Course
ACM SIGGRAPH 2012

25~~5~~ MAJOR CHALLENGES
IN REAL-TIME RENDERING

Johan Andersson, DICE

Beyond Programmable Shading, SIGGRAPH 2012 3



Dynamic GI wanted characteristics

- Static & dynamic geometry
- No pre-computation required
  – Major tradeoff with performance
- Handle large scales: indoor to large outdoor
  – With minimal light leakage
- Multiple indirect bounces
  – Single is not enough for in-door
- Indirect specular reflections

Beyond Programmable Shading, SIGGRAPH 2012 22

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- Dave Barrett
- Francesco Cifariello
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- John White
- Cyril Crassin
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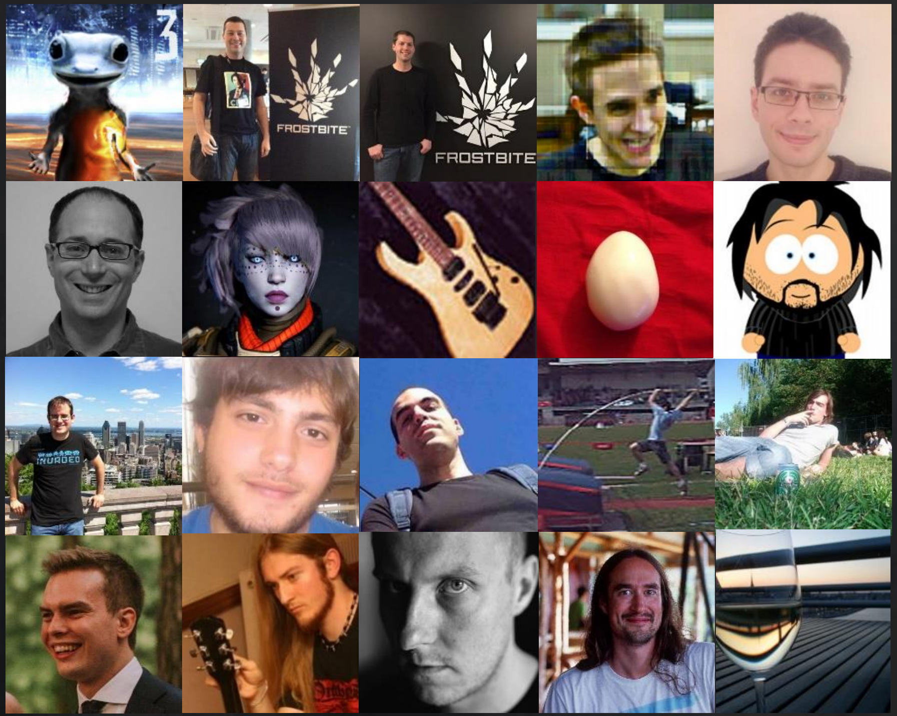

Questions?

SEED // SEARCH FOR EXTRAORDINARY EXPERIENCES DIVISION

www.ea.com/seed We're hiring! @SEED

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