AMD

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DEVELOPER SUMMIT

AMD Fusion12 DEVELOPER SUMMIT

GLOBAL ILLUMINATION USING RAY-BUNDLE TRACING

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AGENDA

- Global Illumination
- Ray-Bundle Tracing
- GI Prebaking
  - Method
  - In-House Tool
- Interactive GI
  - Instant Radiosity
  - Bidirectional Sampling with Ray-Bundles
- Summary

GLOBAL ILLUMINATION

- Improve visual realism of interactive applications
- Paths of light are ***randomly*** sampled according to a probability distribution function (PDF)
  – Path tracing [Kajiya 1986], photon mapping [Jensen 1996], instant radiosity [Keller 1997]
- Computationally expensive
  – Accuracy is dependent on the number of samples
- Efficient tracing techniques are desired

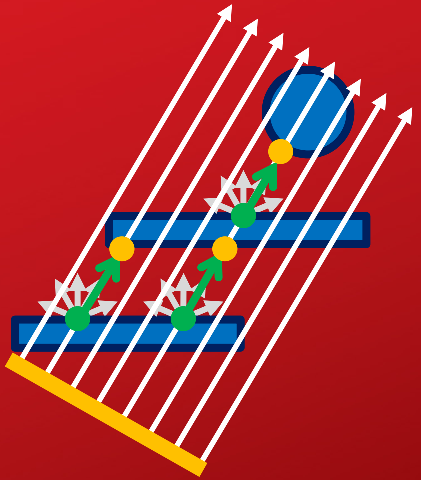

1.6 secs


6 secs


76 secs

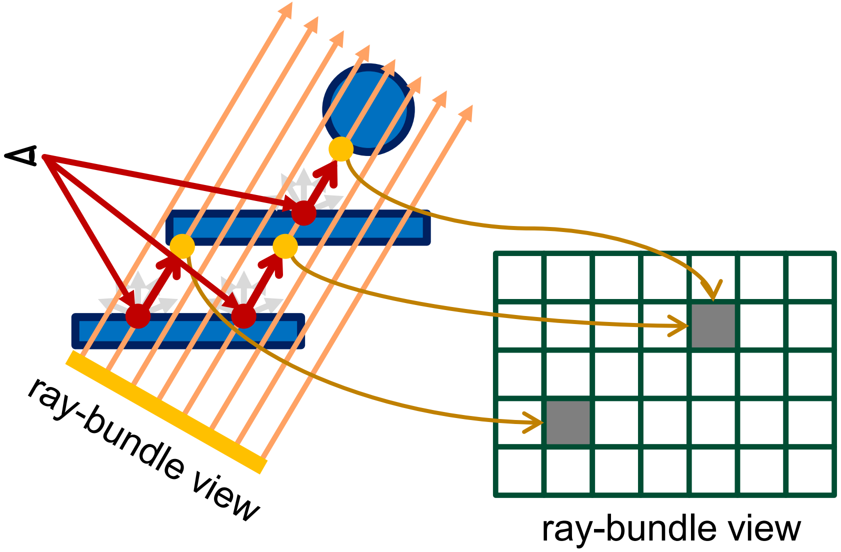
Path tracing on a CPU (480x270 pixels)

RAY-BUNDLE TRACING



RAY-BUNDLE TRACING | BASIC ALGORITHM

- Set of parallel rays
- Visibility test is accelerated with hardware rasterization
  - Focus on a single global direction
  - Rasterize for all fragments in parallel
  - Issue: **how to handle multiple fragments in a single pixel?**



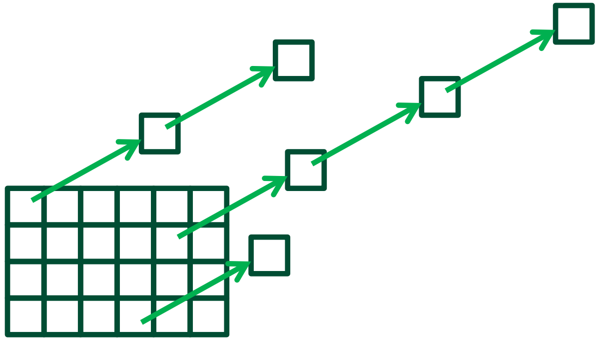
RAY-BUNDLE TRACING | RELATED WORK

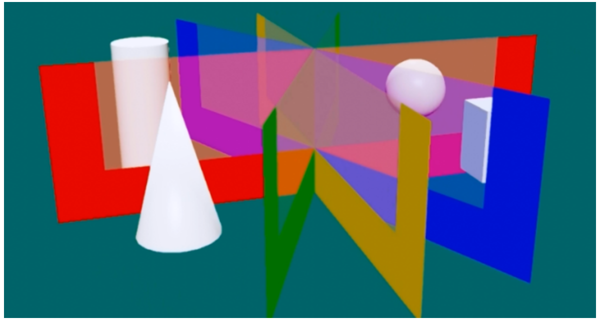
- Depth peeling [Hachisuka 2005; Niessner et al. 2010]
  - ☹ Multi-pass
- *K*-buffer [Hermes et al. 2010]
  - ☺ Single-pass
  - ☹ Limited storage per pixel
- Stochastic depth buffering [Thomsen and Nielsen 2011]
  - ☺ Single-pass
  - ☹ Approximate solution

Final gathering using depth peeling [Hachisuka 2005]

RAY-BUNDLE TRACING | OUR APPROACH

- Per pixel linked-list on DX11 GPU [Yang et al. 2010]
  - ☺ Single-pass
  - ☺ Unlimited storage per pixel
  - ☺ No need to sort for GI (opaque objects)
  - ☹ Unpredictable memory usage
    - Excessive memory has to be allocated to avoid overflow

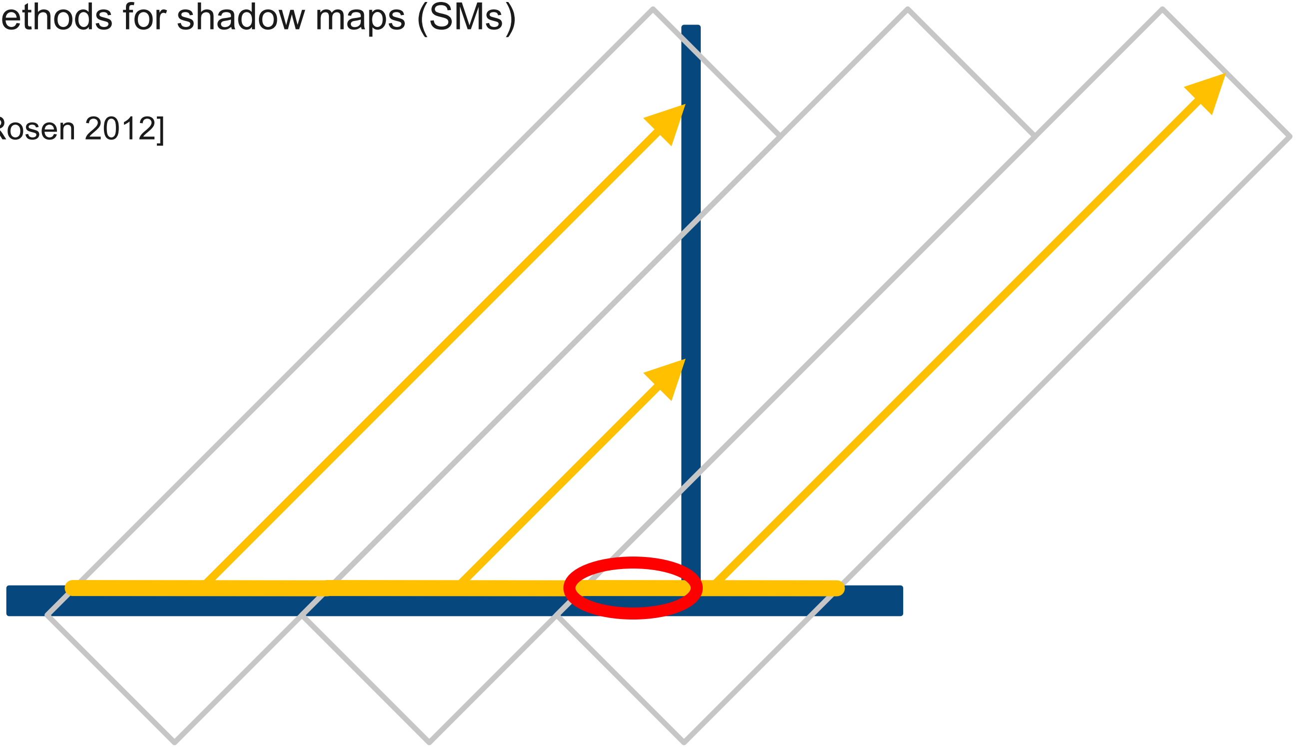




Order independent transparency (OIT)

RAY-BUNDLE TRACING | LIMITATIONS

- Light leaking
  - Reduced by anti-aliasing methods for shadow maps (SMs)
    - Cascade [Lloyd et al. 2006]
    - Rectilinear texture warping [Rosen 2012]



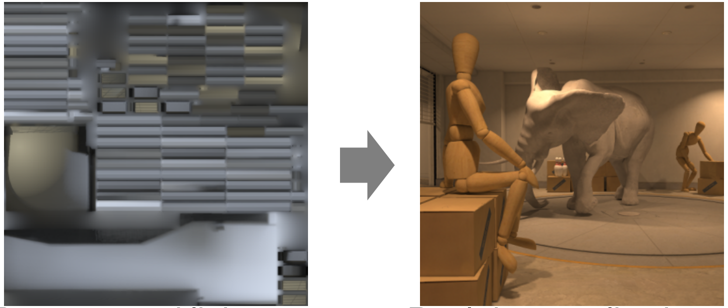
RAY-BUNDLE TRACING | APPLICATIONS

GI prebaking
for static scenes

Robust interactive GI
for dynamic scenes

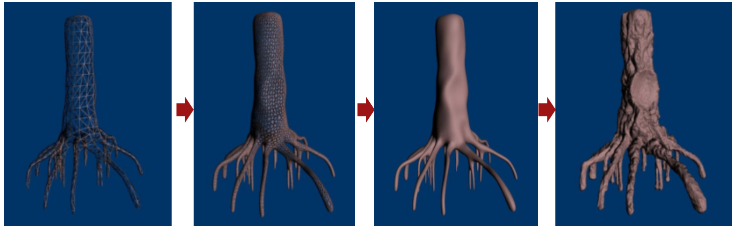
GI PREBAKING
METHOD

- Light maps
  - ☺ Easy to improve realism in real-time applications
  - ☹ Long precomputation time



Precomputed light maps　　Real-time applications

- Tessellation
  - DX11 GPUs support tessellation for real-time rendering
    - Arbitrary displacements by the domain shader
    - Easy to implement
    - Memory efficient
  - Baking system must support the same tessellation
  - This is difficult for off-line CPU rendering



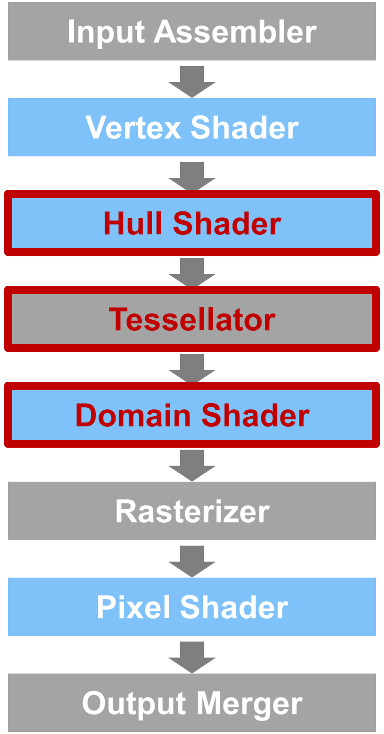
On-the-fly tessellation

GI PRE-BAKING | APPROACHES

- Pretessellation
  - ☹ Memory consuming
- Direct ray tracing with on-the-fly tessellation [Smits et al. 2000]
  - ☺ Accurate
  - ☹ Computationally expensive
  - ☹ Difficult to implement for arbitrary displacements

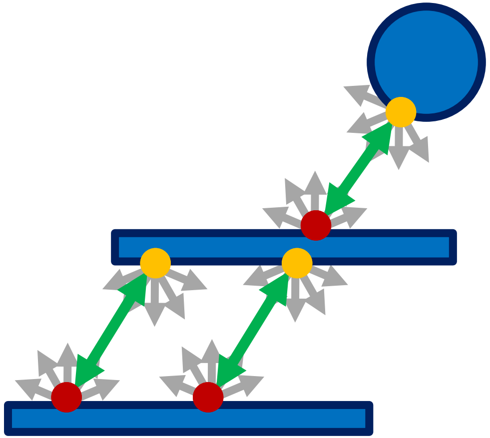
- Ray-bundle tracing on the GPU
  - Simply utilize the tessellator stage
  - The domain shader can be shared with real-time rendering

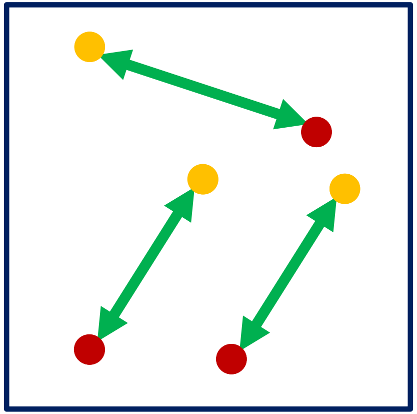
The same displacement as real-time rendering



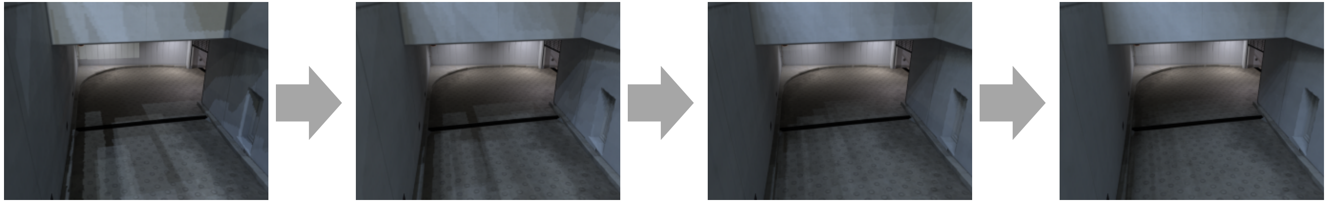
GI PRE-BAKING | RADIANCE EXCHANGE

- [Hermes et al. 2010]'s updating scheme





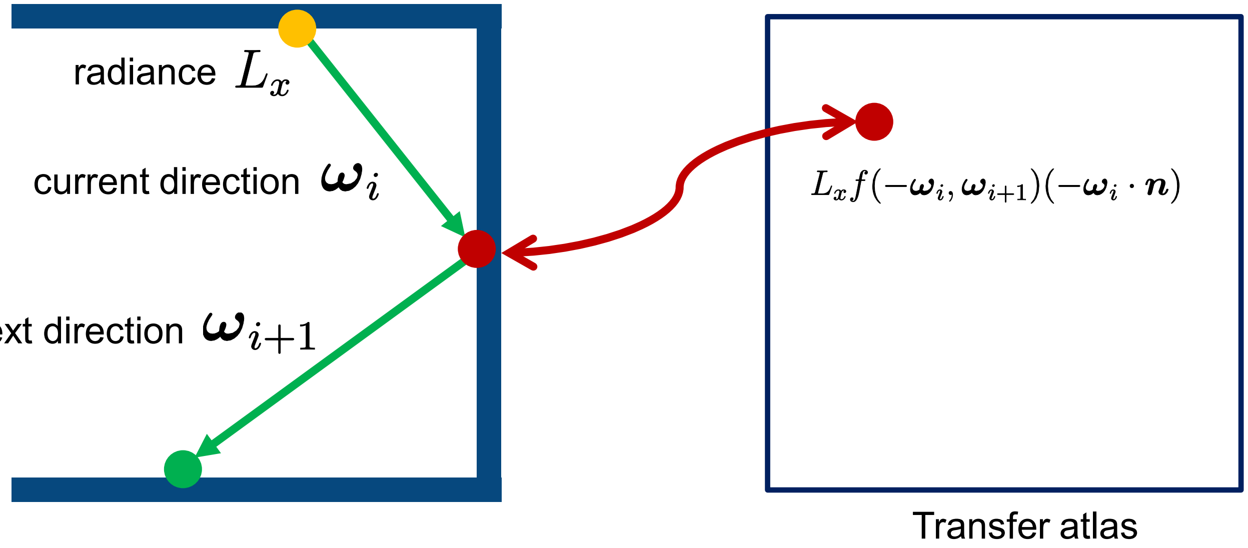
Texture atlas (light maps)



100 directions 200 directions 400 directions 800 directions

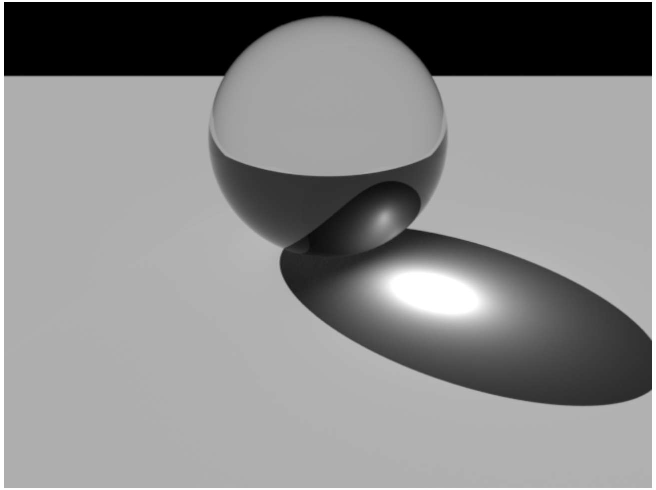
GI PRE-BAKING | RADIANCE EXCHANGE

- Arbitrary BRDFs
  - Use an additional texture atlas



GI PRE-BAKING | LIMITATIONS

- Limited by memory capacity
  - All resources must be in device memory
    - Ray-bundles, scene data, texture atlases, etc.
  - Vast scenes must be split
  - Tessellated scenes are recommended to save memory
- Weak in highly glossy surfaces
  - Cannot render caustics from perfectly specular surfaces



Caustics

GI PREBAKING

IN-HOUSE TOOL

GI PREBAKING | SHOWCASE

GI PREBAKING | SHOWCASE

GI PREBAKING | SHOWCASE

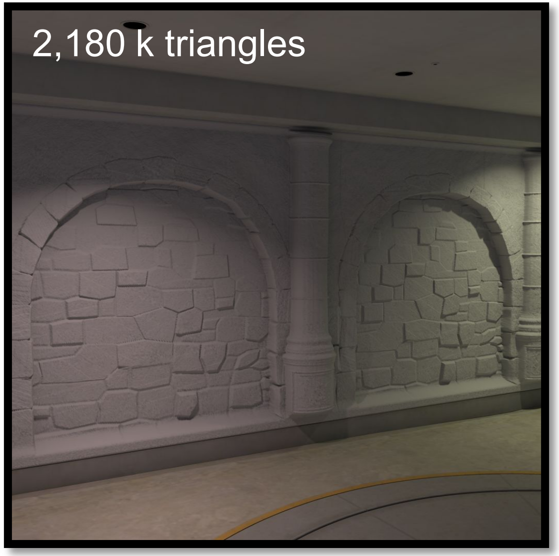
GI PREBAKING | SHOWCASE

GI PREBAKING | SHOWCASE

GI PREBAKING | SHOWCASE

GI PREBAKING | TESSELLATION

Displacement mapping



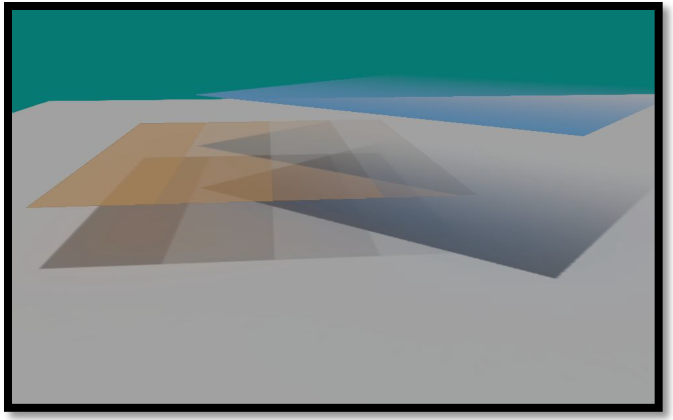
	Vertex Buffer	Height Maps
Pretessellation	178.8MB	0 MB
GPU tessellation	12.3 MB	1 MB

Light maps: 1024^2 pixels x 15
Ray-bundle: 2048^2 pixels
Directions: 3000

GI PREBAKING | ORDER INDEPENDENT TRANSPARENCY

- Sort fragments in a ray-bundle [Yang et al 2010]
  - ☺ Perfect solution
  - ☹ More complex implementation
    - Divide rasterization pass for opaque objects and transparent objects
    - Need for sorting pass
  - ☹ Increased computation time

- Stochastic approach [Enderton et al. 2010]
  - ☺ Simple implementation
  - ☺ Memory efficient
    - Node is stochastically stored according to the opacity
  - ☹ Increased variance
    - Need many samples



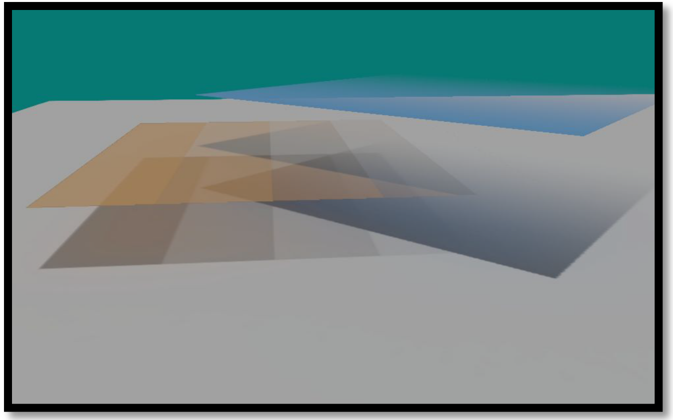
GI with transparent objects

GI PREBAKING | ORDER INDEPENDENT TRANSPARENCY

- Sort fragments in a ray-bundle [Yang et al 2010]
  - ☺ Perfect solution
  - ☹ More complex implementation
    - Divide rasterization pass for opaque objects and transparent objects
    - Need for sorting pass
  - ☹ Increased computation time

Not so computationally expensive for our background objects (almost opaque)

- Stochastic approach [Enderton et al. 2010]
  - ☺ Simple implementation
  - ☺ Memory efficient
    - Node is stochastically stored according to the opacity
  - ☹ Increased variance
    - Need many samples



GI with transparent objects

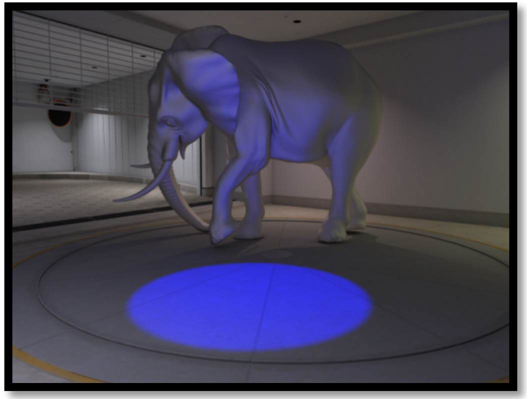
GI PREBAKING | LIGHT MAPS FOR GLOSSY MATERIALS

- Spherical harmonics
  - Used for rough glossy surfaces with 4-9 base coefficients

$$Y_l^m(\theta,\varphi) = \begin{cases} \sqrt{2}K_l^m \cos(m\varphi)P_l^m(\cos\theta), & m > 0 \\ \sqrt{2}K_l^m \sin(-m\varphi)P_l^{-m}(\cos\theta), & m < 0 \\ K_l^0 P_l^0(\cos\theta), & m = 0 \end{cases}$$

$$K_l^m = \sqrt{\frac{(2l+1)}{4\pi}\frac{(l-|m|)!}{(l+|m|)!}}$$

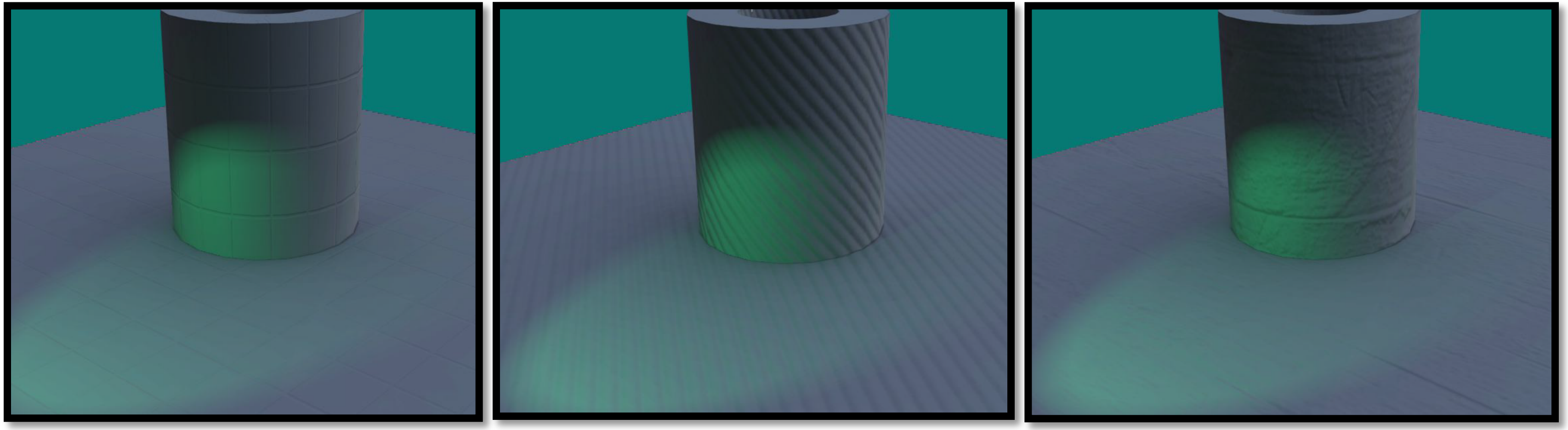
P_l^m : Associated Legendre polynomials



Light maps: 1024^2 pixels x 16
Ray-bundle: 2048^2 pixels
Directions: 3000
SH Basis: 9

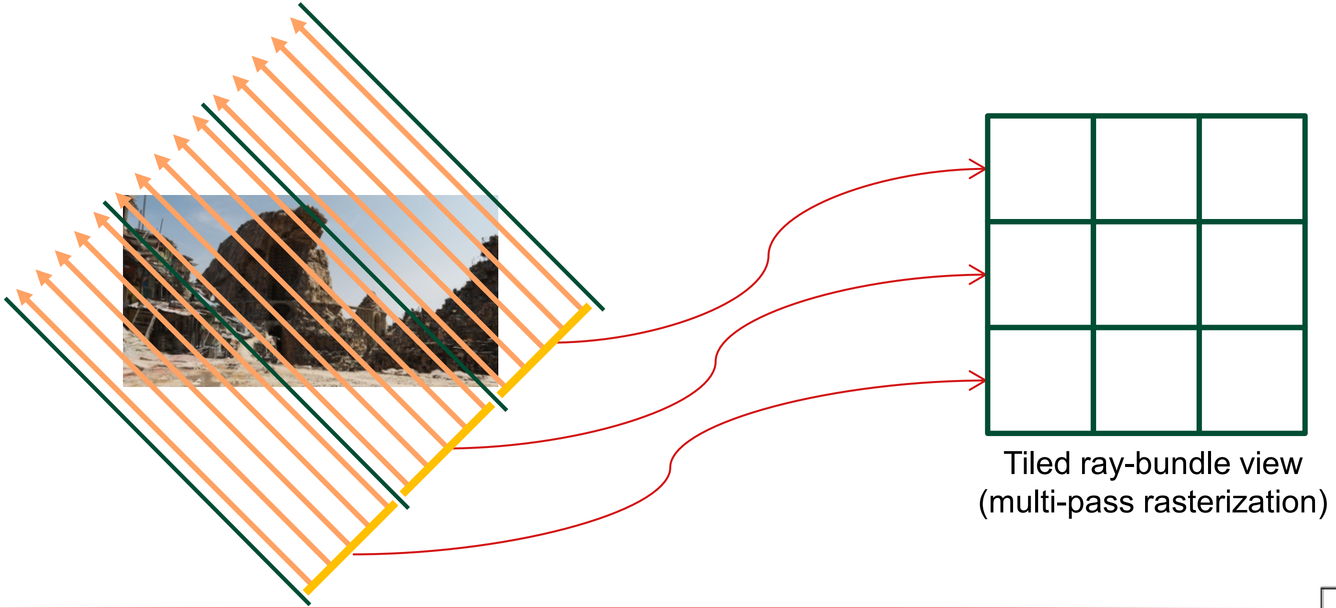
GI PREBAKING | DYNAMIC BUMP MAPPING

- Our system evaluates SH light maps using the runtime normal vector
- For changing surface details
  - E.g. dynamic bump mapping
  - Neglecting global light transport, but plausible



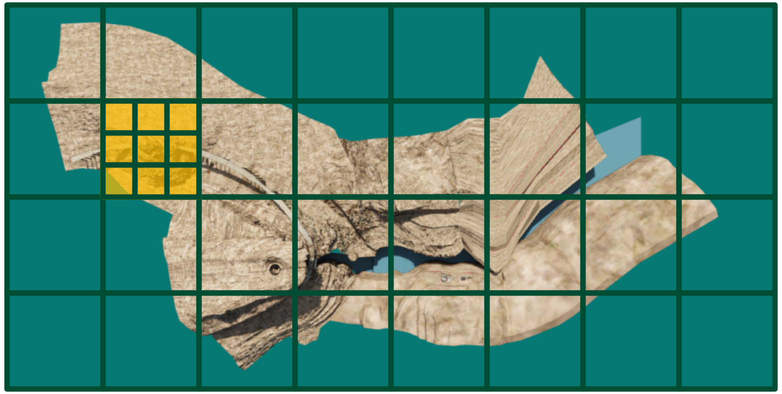
GI PREBAKING | TILING FOR VAST SCENES

- Ray-bundle resolution is limited by memory capacity
- Solved by tiling [Thibieroz 2011]
  - Multi-pass
  - Arbitrary resolution by sacrificing time



GI PREBAKING | ADAPTIVE SOLUTION FOR VAST SCENES

- Light map resolution is limited by memory capacity
- Split the scene
  - Generate light maps for each area
  - Currently focused area:
    - High-resolution light maps (output)
    - Dense ray-bundles
  - Others:
    - Low-resolution texture atlas (temporary)
    - Sparse ray-bundles

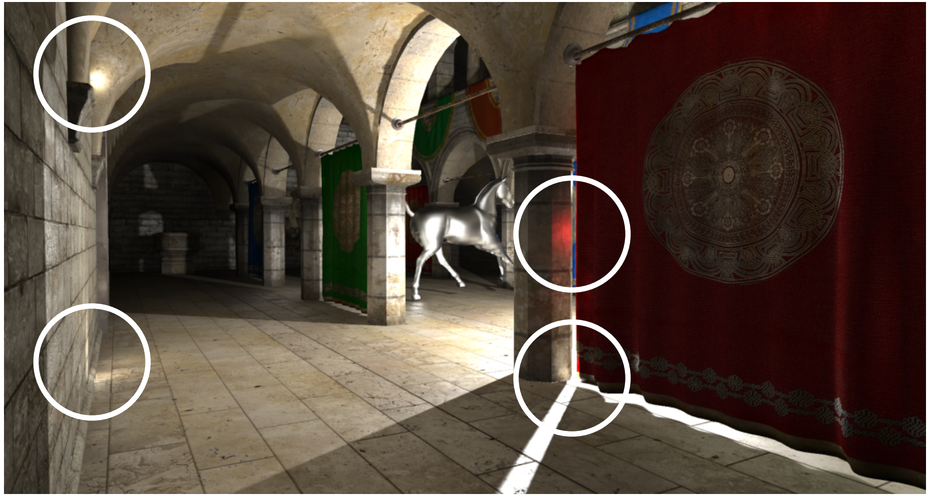


INTERACTIVE GI

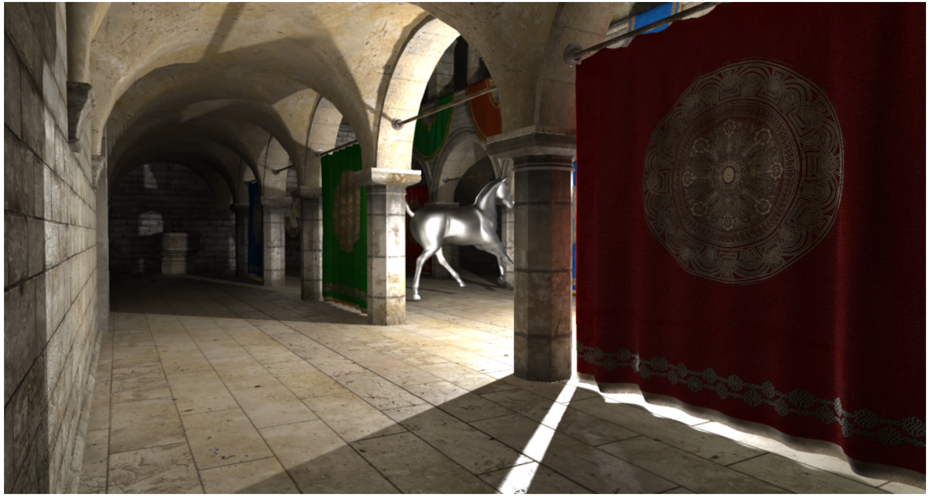
INTERACTIVE GI | OUR CONTRIBUTION

- Classic instant radiosity suffers from a large numerical error
- Ray-bundles reduce the error

GPU: Radeon HD 6990



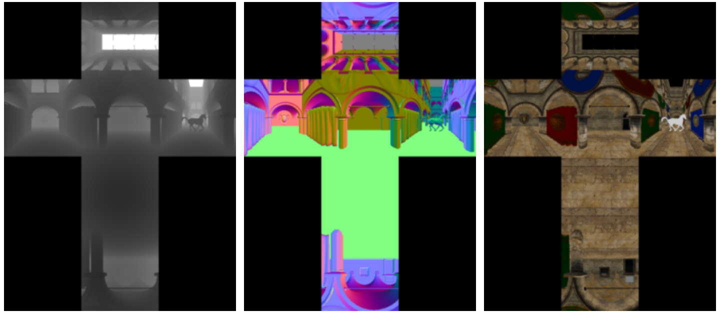
Only VPLs
(Spike artifacts and flickering)
32 ms



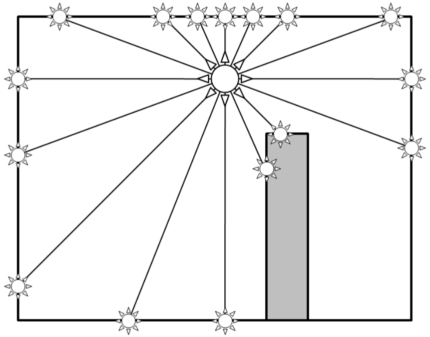
Bidirectional approach
(Artifacts are reduced)
44 ms

INTERACTIVE GI | INSTANT RADIOSITY

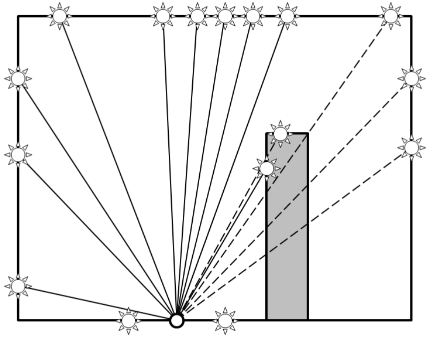
- Virtual point lights (VPLs) are emitted from light sources
- Visibility can be resolved by rasterization
  - Render reflective shadow maps (RSMs) [Dachsbacher and Stamminger 2005]
  - Sample VPLs from RSMs stochastically
  - Render SM for each VPL
  - Shading from VPLs



Cube RSM of a point light



Sample VPLs



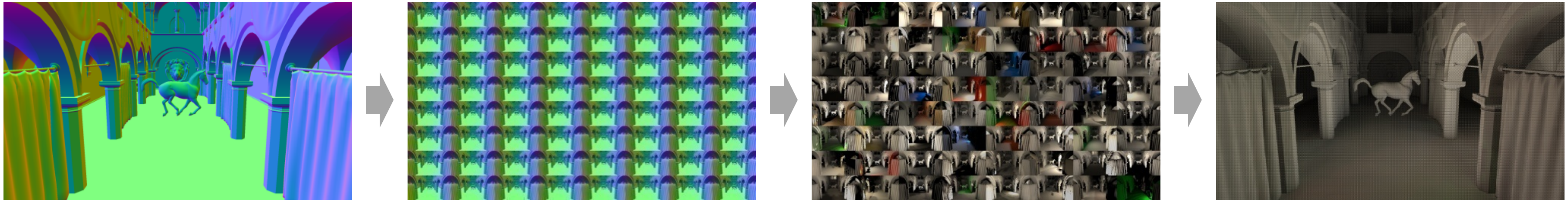
Shading

INTERACTIVE GI | INTERLEAVED SAMPLING

- Interleaved sampling reduces the shading cost
- High-frequency noise is removed by geometry-aware filtering
- Indirect illumination is low-frequency

(256 VPLs) / (8x8 interleave) = 4 VPLs / pixel

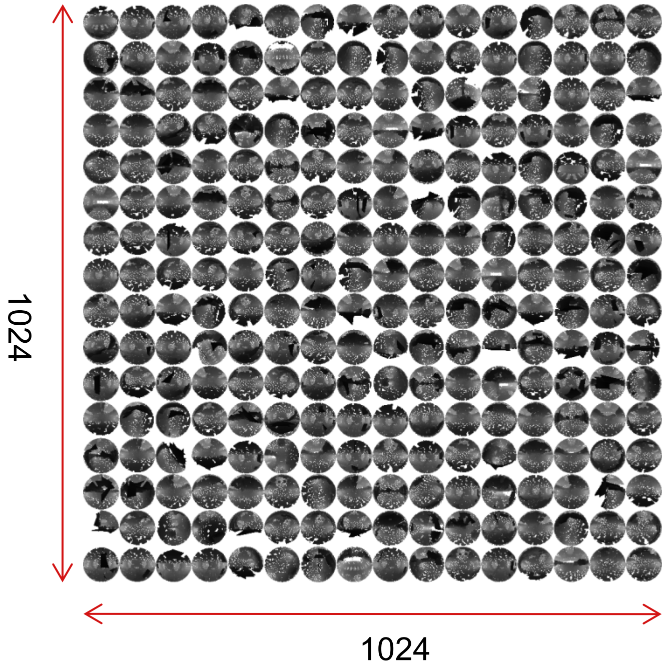
- G-buffer splitting [Segovia et al. 2006]
  - Exploit computation coherency for interleaved sampling



Split a G-buffer into small sub-buffers | Shade each small sub-buffer (coherent computation) | Gather the resulting sub-buffers

INTERACTIVE GI | IMPERFECT SHADOW MAPS [Ritschel et al. 2008; 2011]

- Low-resolution SMs for many lights (e.g., VPLs)
  - Single-pass
  - An arbitrary number of lights
  - Efficient non-linear rasterization
- Point based approximated visibility (= imperfect)
  - Holes
  - Higher bias
  - But fast!



1 render target
1 draw call
64x64 ISMs for 256 VPLs

INTERACTIVE GI | TEMPORAL REPROJECTION

- Reverse reprojection caching [Nehab et al. 2007]
  - Improve indirect illumination quality
  - Temporal anti-aliasing
  - Reduce flickering

Temporal coherence

w/o reprojection

with reprojection

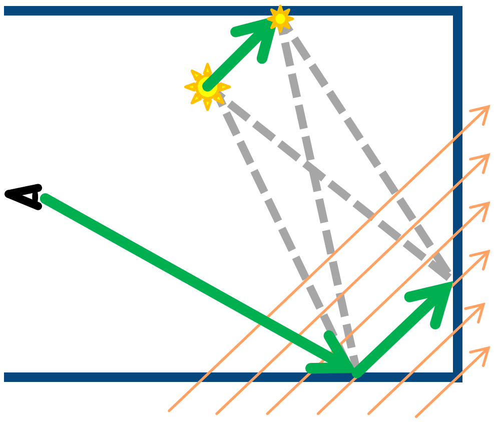
INTERACTIVE GI | FAILURE OF SAMPLING STRATEGY

- Only sample light subpaths (VPLs)
  - Singularities near VPLs
  - Temporal flickering
    - Reduced by temporal reprojection (but insufficient)

Singularities near VPLs

INTERACTIVE GI | OUR BIDIRECTIONAL APPROACH

- Bidirectional path tracing [Lafortune et al. 1993; Veach et al.1994]
  – Robust algorithm for off-line rendering
  – Generating light subpaths & eye subpaths using ray tracing
  – They are connected by shadow rays

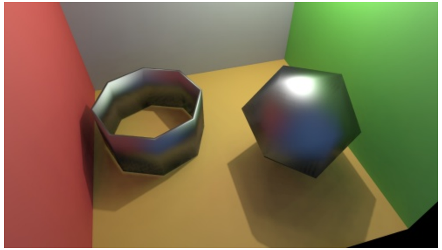


- We employ ***ray-bundles*** for eye subpaths
  – Eye subpaths: G-buffer & ray-bundles
  – Light subpaths: VPLs via RSMs
  – Connecting edges: SMs or ISMs for VPLs

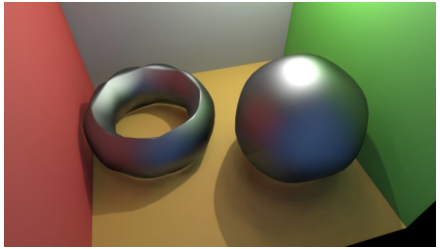
Only Rasterization!

  – Easy to implement
  – Support for GPU tessellation

GPU: Radeon HD 6990



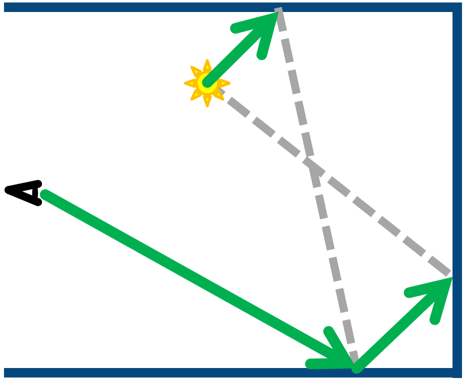
w/o tessellation
29 ms



Phong tessellation
31 ms

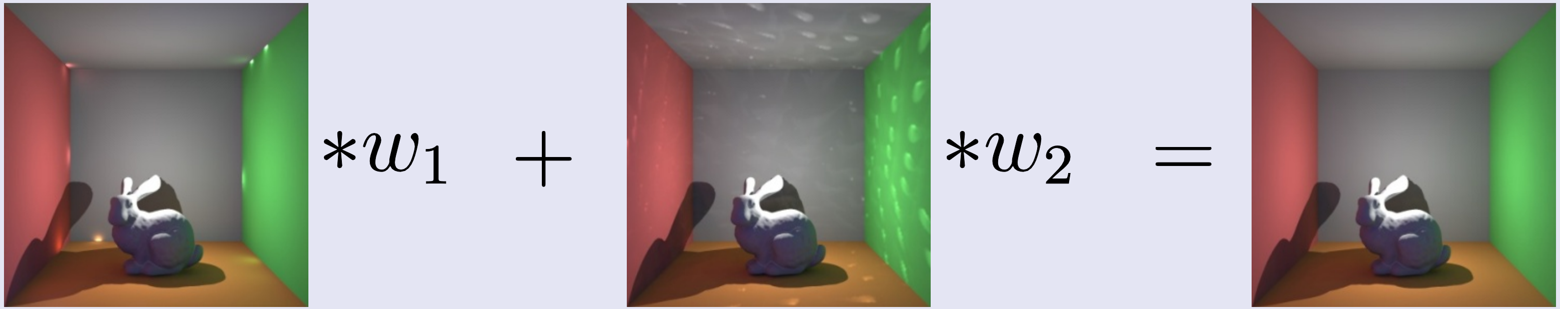
INTERACTIVE GI | MULTIPLE IMPORTANCE SAMPLING [Veach and Guibas1995]

- Combine several paths with a ***weighting function***
- Accurate results with fewer artifacts



Weighting function: $w_i(\bar{\boldsymbol{x}}) = \frac{N_i p_i(\bar{\boldsymbol{x}})}{\sum_j N_j p_j(\bar{\boldsymbol{x}})}$

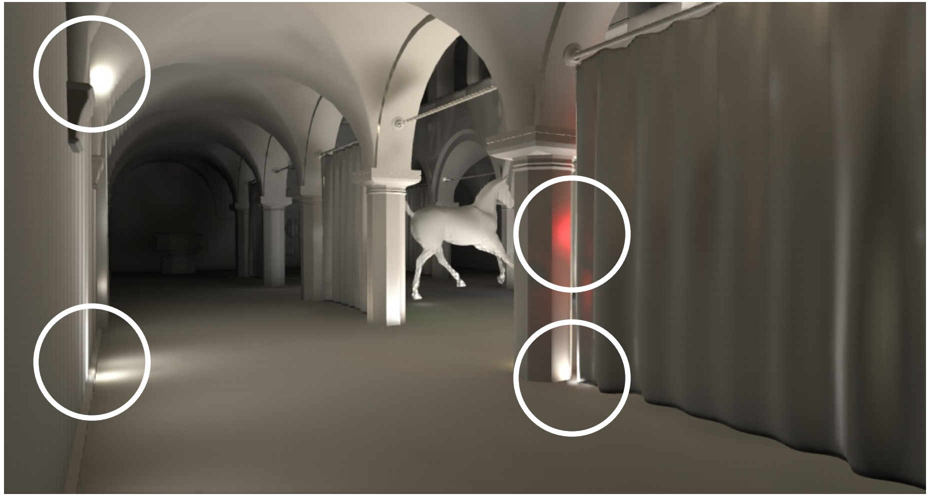
number of samples — PDF



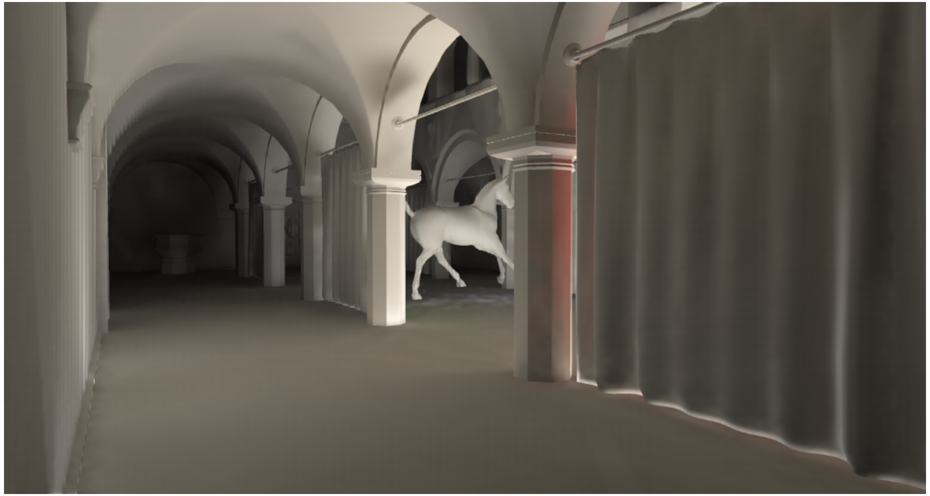
Light path via VPLs

Eye path via ray-bundles

INTERACTIVE GI | RESULTS



Only VPLs
(Spike artifacts and flickering)
32 ms

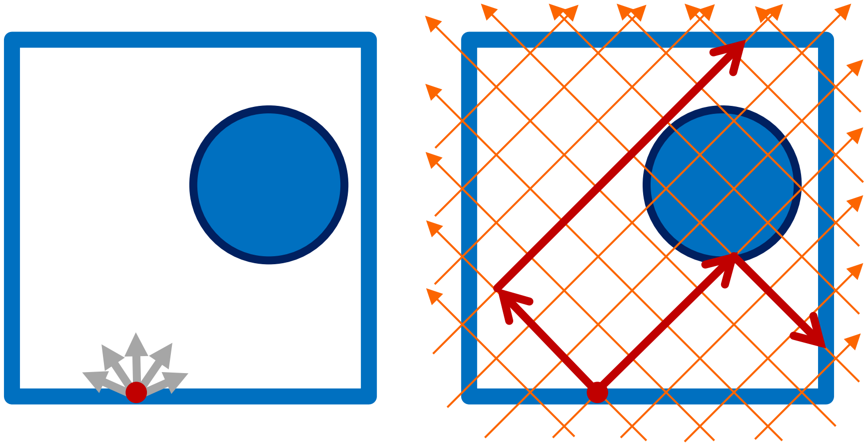


Bidirectional approach
(Artifacts are reduced)
44 ms

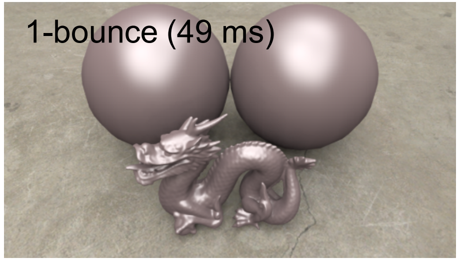
Screen: 1920x1024 resolutions, 2x2 supersampling
ISMs: 64x64 resolution, ***256 VPLs***, 16384 points
Ray-bundles: 256x256 resolution, ***16 samples***
GPU: Radeon HD 6990

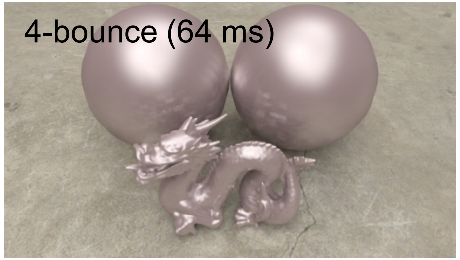
INTERACTIVE GI | MULTI-BOUNCE RENDERING

- All ray-bundles are created preliminary to solve the light transport problem
- Randomly select a single ray-bundle and reuse it for the next bounce
- ☺ No need for additional visibility tests for an arbitrary number of interreflections
- ☹ Memory consuming, only small scenes



GPU: Radeon HD 6990

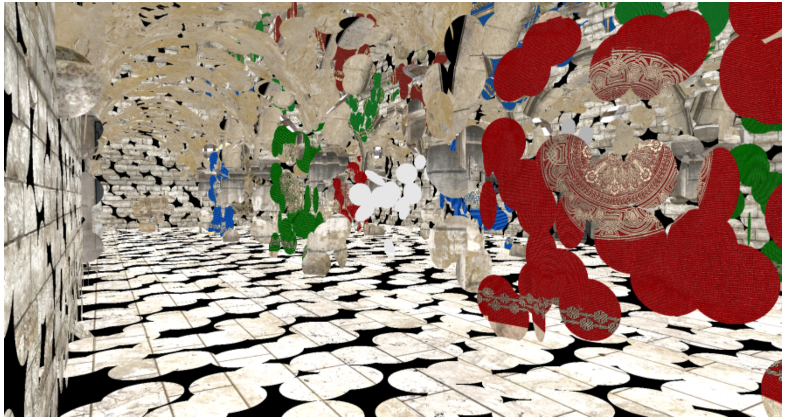




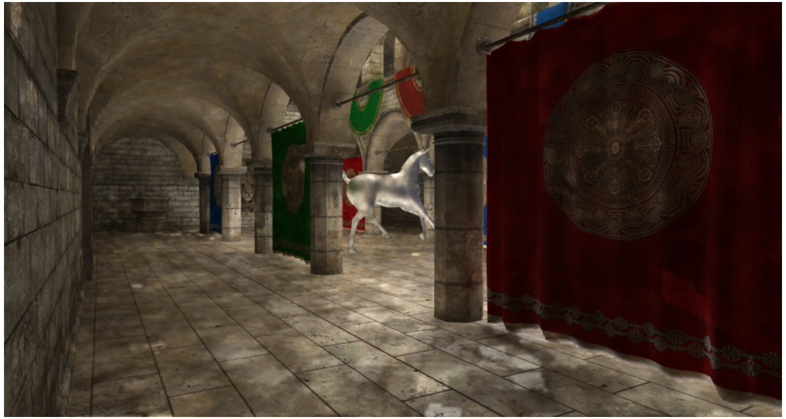
INTERACTIVE GI | IMPERFECT RAY-BUNDLE TRACING

- Point based approximation of scene geometry
- Inherit pros & cons of ISMs

GPU: Radeon HD 6990



Direct visualization of the point splats



Imperfect ray-bundle tracing
(256 directions, 3-bounce eye paths)
89 ms

SUMMARY

- Modern GPUs enable simple & fast ray-bundle tracing
- GI for tessellated scenes is easily computed with ray-bundles
- Bidirectional sampling with ray-bundles reduces the error for interactive GI

GI prebaking
for static scenes

Robust interactive GI
for dynamic scenes

THANK YOU

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