Hierarchical Image-Space Radiosity for Interactive Global Illumination

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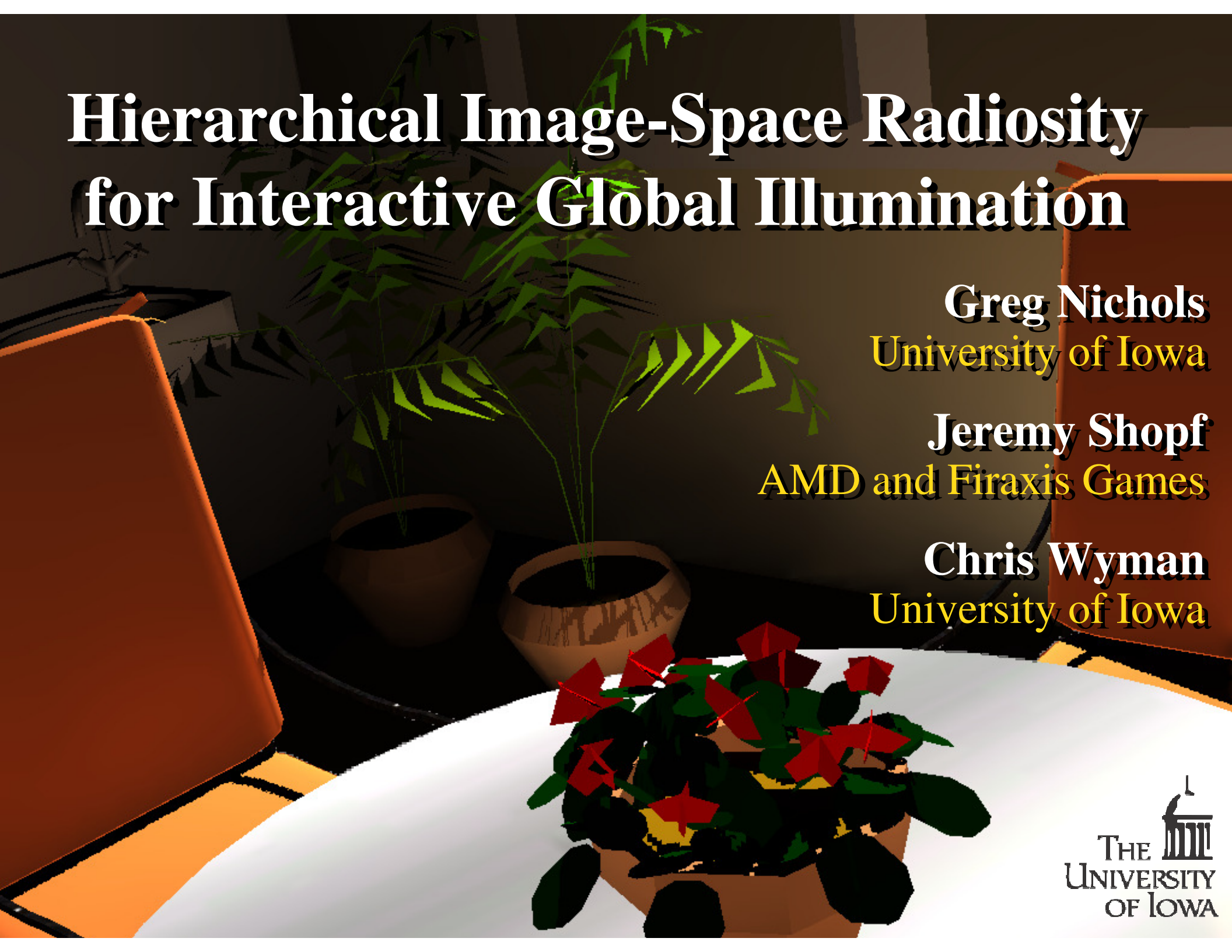

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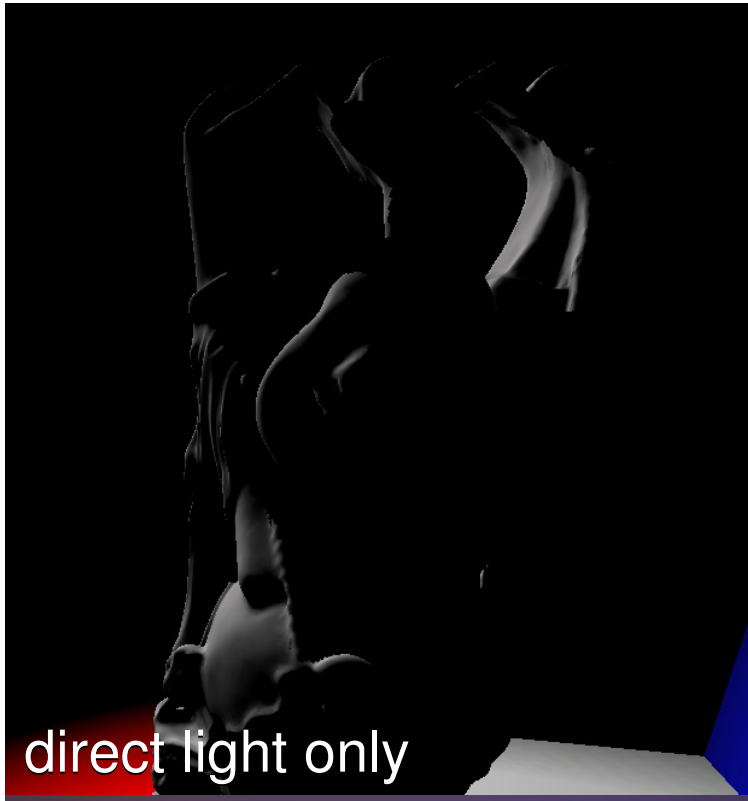
Interactive Global Illumination

- Global illumination is important
- Global illumination is *expensive!*
  - Light at every surface can affect light at every other surface
- **Goal:** interactive global illumination; *completely* dynamic scenes
  - can move geometry, light source, camera without restriction
  - no precomputation



Previous Work

Lots of previous work in this area!

Precomputed radiance transport

[SKS02, KTHS06, NRH03, KAMJ05, IDYN07, SGNS07]

Required precomputation can limit interactivity

Illumination caching

[GKBP05, GSHG98, LZT*08]

Dependent on sampling - changes can “fade in”

Ray-based techniques

[WKB*02, STK08, ZHWG08]

Memory coherency issues can limit scaleability

Image-space approximations

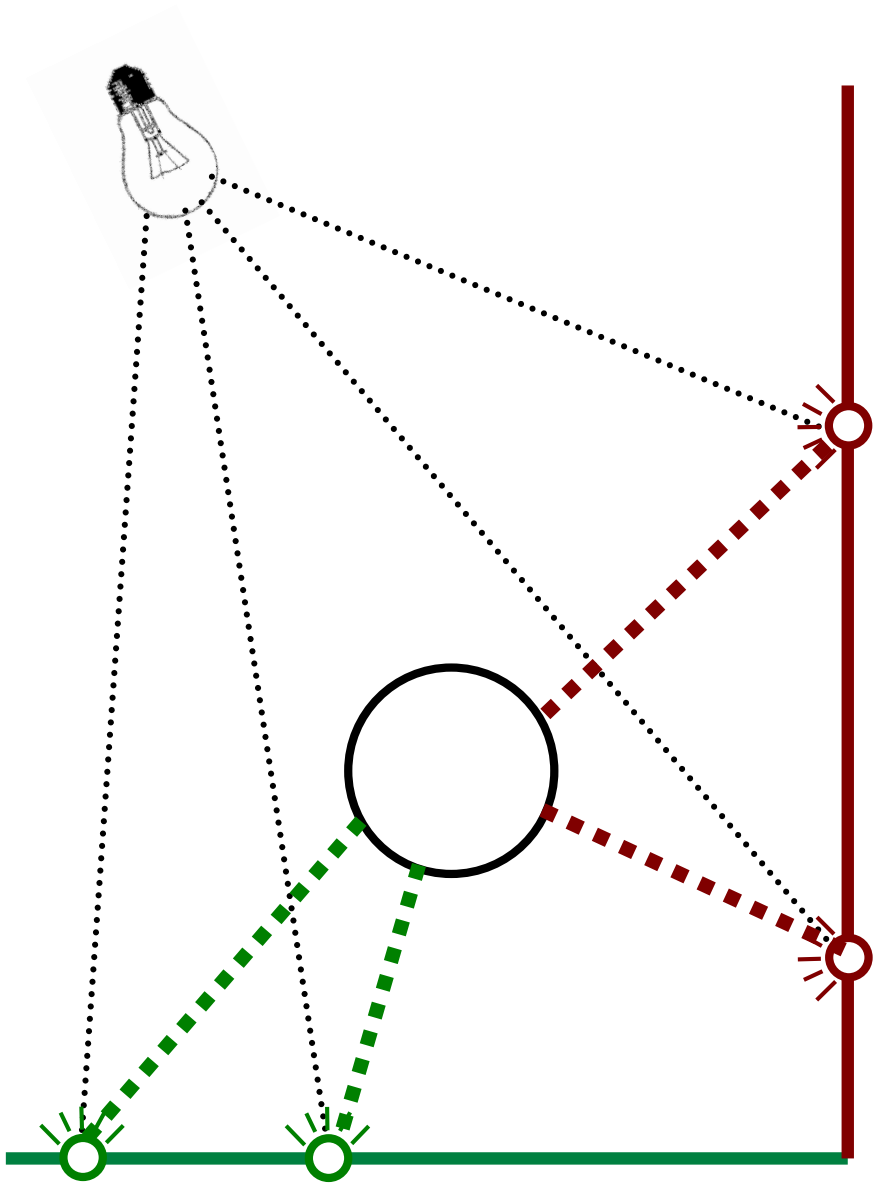
[ZIK98, Bun05, BS09]

Coarse approximations may not always suffice

Instant Radiosity

[Keller 97]

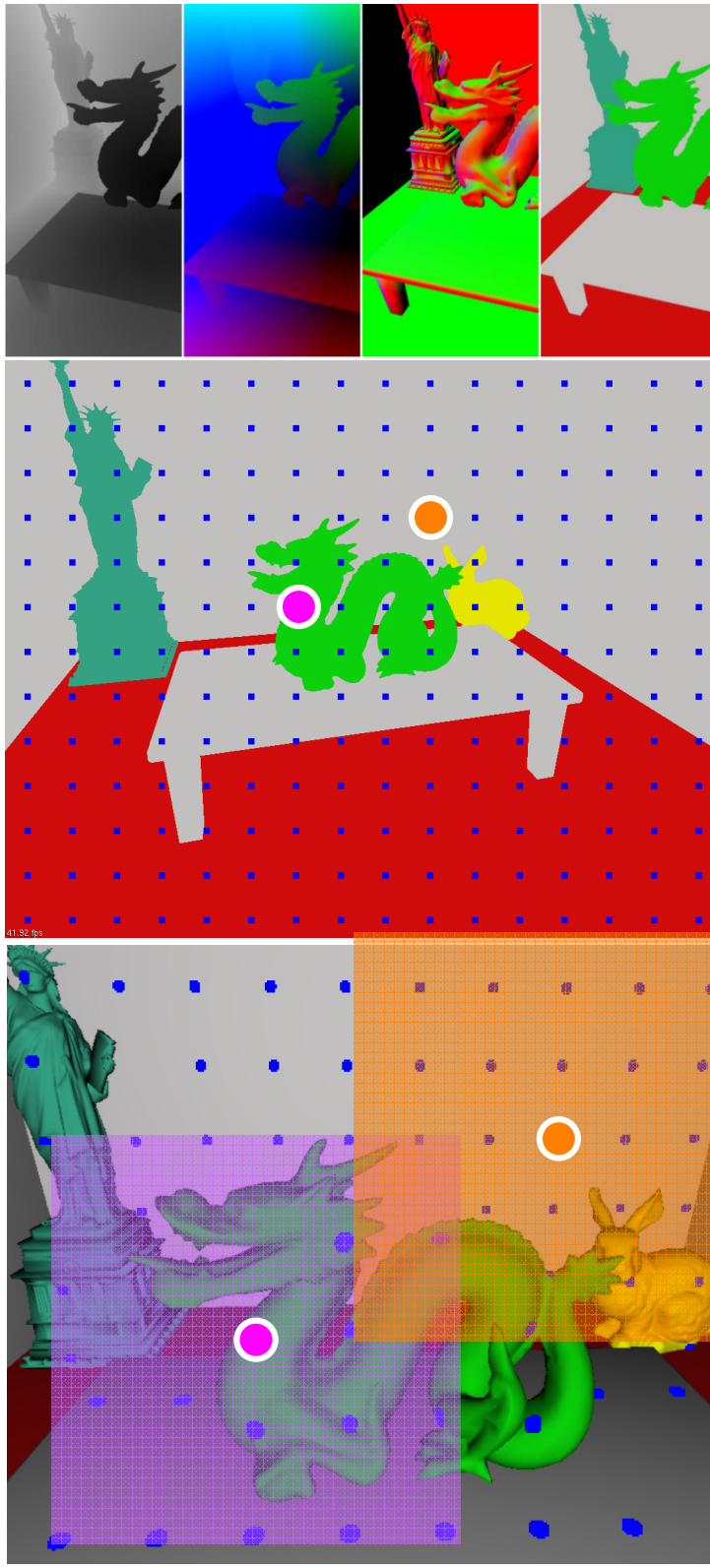
- Trace paths from the light source
- Place *Virtual Point Lights* (VPLs) at reflection points
- Each VPL contributes light to the scene
- Sum of all VPL contributions approximates global illumination



Reflective Shadow Maps (RSMs)

[Dachsbacher and Stamminger 2005, 2006]

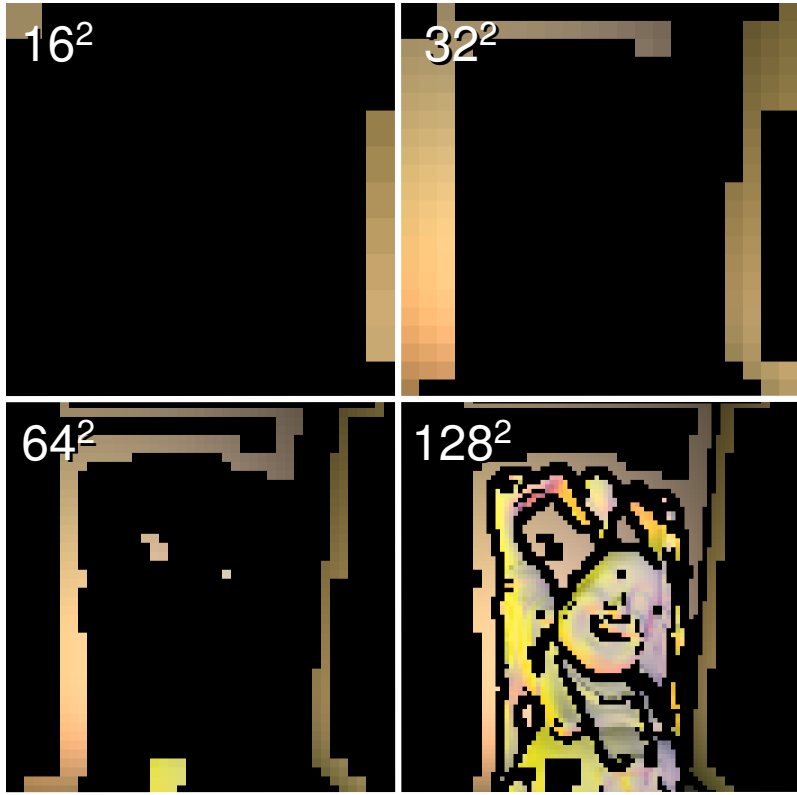
- Instant Radiosity in image space
- Augmented shadow maps sampled to create VPLs
- Splat a quad for each VPL using deferred shading
- Problems:
  - Lots of overdraw
  - Restricted splat sizes



Multiresolution Splatting

[Nichols and Wyman 2009]

- Not everything needs to be rendered at high resolution!
- Render each patch of the imag at lowest resolution possible
  - Low frequences at low res
  - High frequencies at high res
  - Check for depth/normal discontinuities



Algorithm: Multiresolution Splatting

Create RSM → Sample VPLs → Coarsely sample patches at low res

Adaptively refine patches

Render patches to illumination buffer

Upsample and interpolate → Combine with direct light

Performance Issues

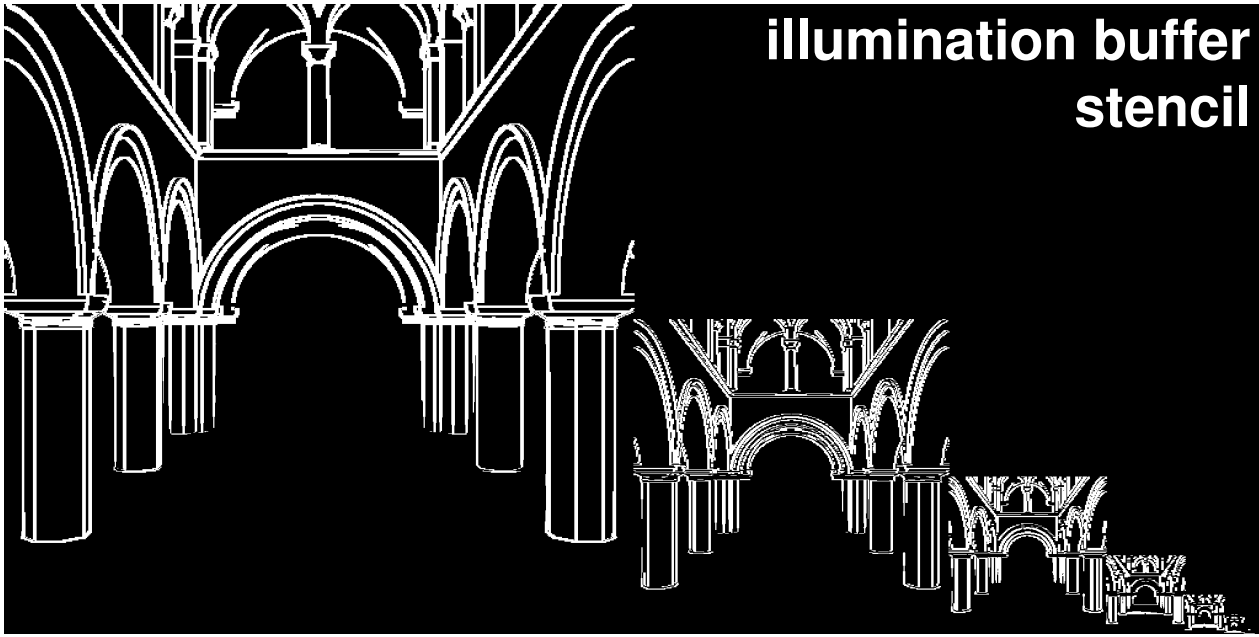
- Performance of multiresolution splatting - not ideal
- ~50,000 image space patches per frame
- Slow ***refining:***
  - multiple geometry shader passes
- Slow ***rendering:***
  - vertex and fragment processing for each patch/VPL
  - ~13 million per frame!
- **Total time to produce indirect light:** 50 - 125 ms

One Pass Stenciled Refinement

- Refinement can be done in *parallel*
- For each fragment in the illumination buffer: does a patch belong at this resolution?
- Create a stencil for the illumination buffer
- Single pass; constant speed
- Replaces multiple geometry shader passes

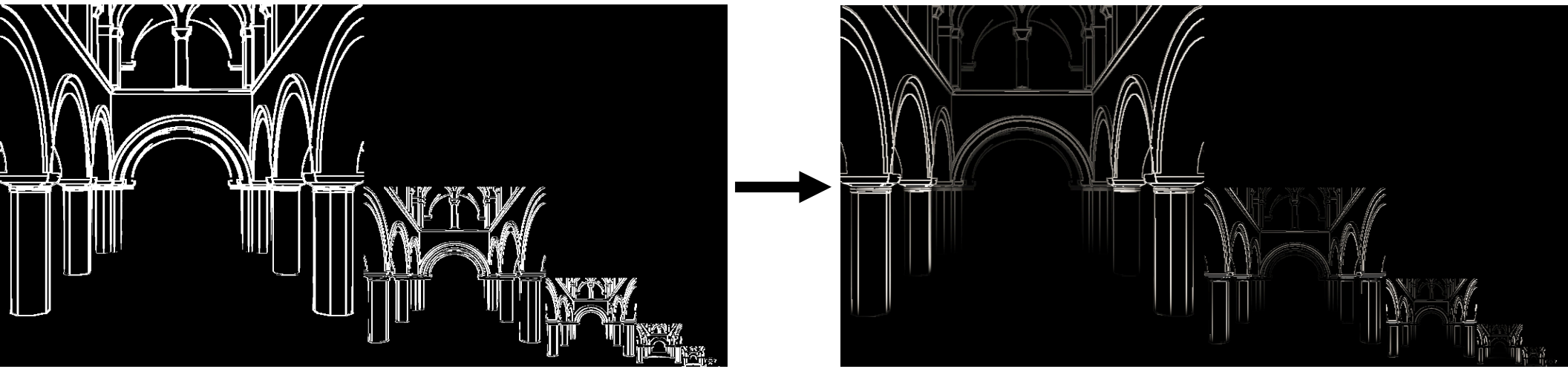
Draw Patch Here If:

- This patch does not need subdividing
- Next coarser patch **does** need subdividing

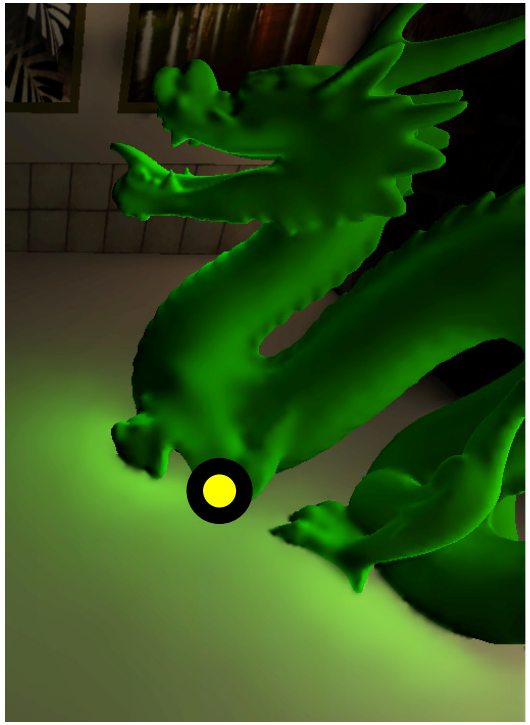


Stenciled Rendering

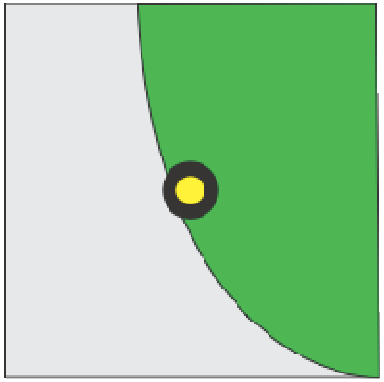
- Reorganize using *gathering* instead of *splatting*
- Render illumination buffer *one time*
- Very few fragments pass stencil test!
  - Most fragments are efficiently discarded using hierarchical processing on modern GPUs
- Nearly 10x speed boost for indirect illumination!



Temporal Coherence



- VPLs jump between surfaces in animation
- Flickering / popping artifacts
- **Problem:** poor light space patch selection
  - One patch can contain multiple surfaces!
- Increasing VPL resolution is slow



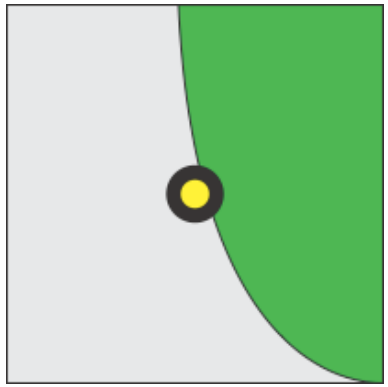
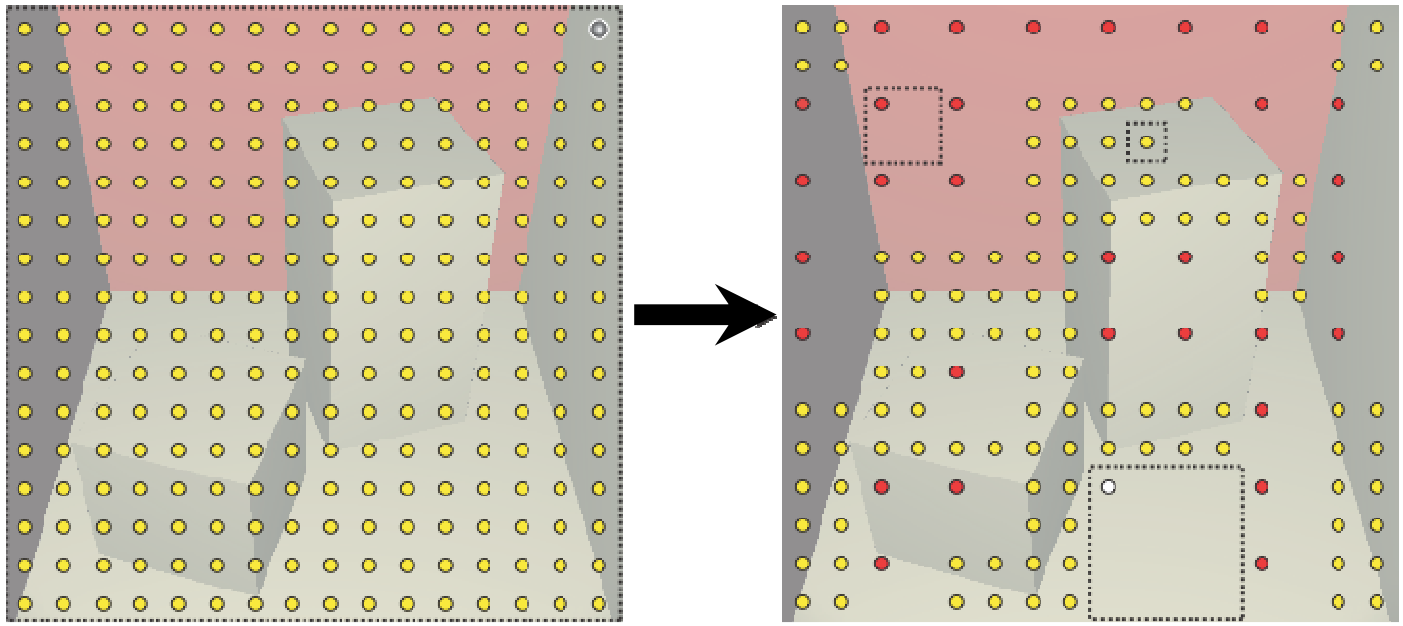


Image Space Radiosity

- Similar to hierarchical radiosity, but using image space patches
- Multiresolution splatting:
  - Hierarchy of patches in eye space
  - *Fixed* patches in light space
- We add *light space* hierarchical patch selection
- Two methods:
  - Basic Image Space Radiosity
  - Hierarchical Image Space Radiosity

Basic Image Space Radiosity

- Start with initial, dense sampling of VPLs
- Cluster them in areas without discontinuities
- All fragments gather from resulting patch set
- Single reject-only geometry shader pass

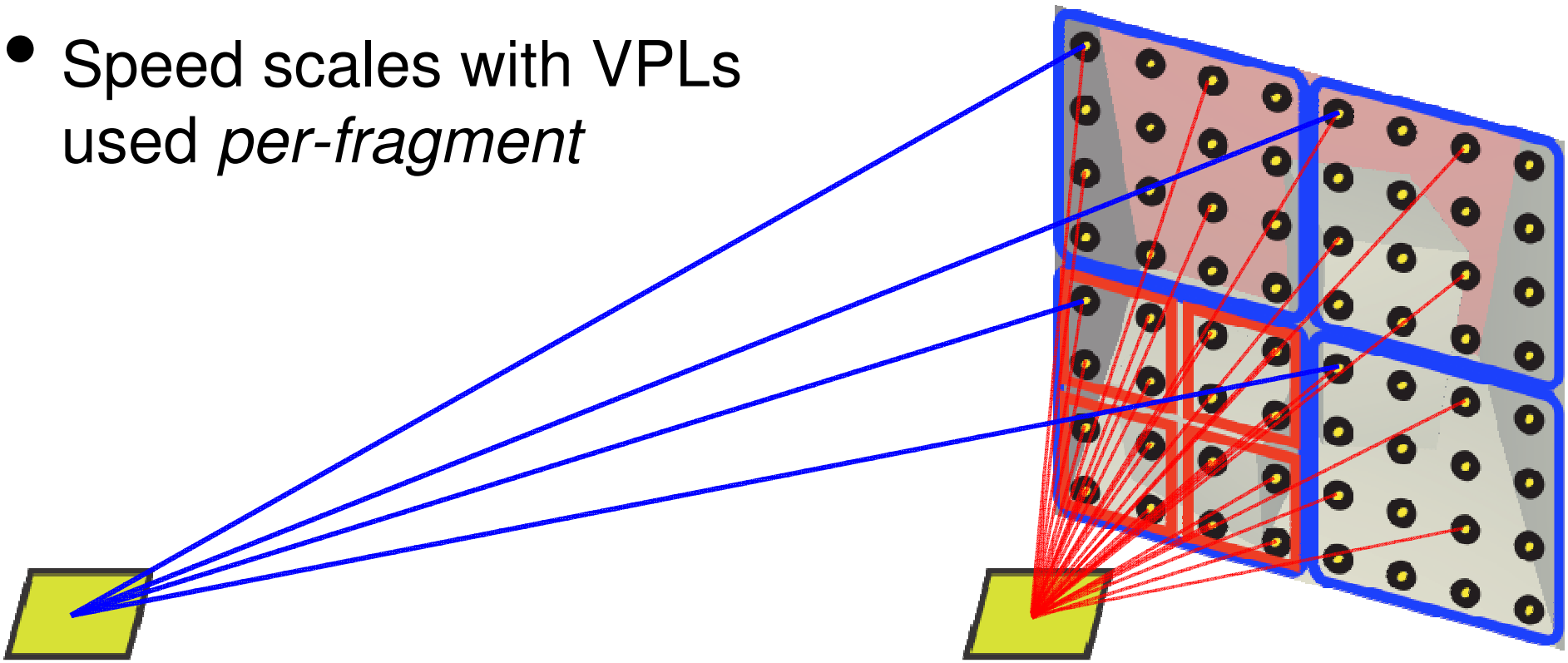


Patch Importance

- *All* light space patches contributing to *all* eye-space patches: overkill
- Patches that are far away do often not need finely divided light space patches

Hierarchical Image Space Radiosity

- Ideal: gather from **best** set of light patches
- Subdivide light space patches as needed *per-fragment* (based on distance)
- Speed scales with VPLs used *per-fragment*



Adaptive Patch Subdivision

- **Question:** How do we decide which light space patches to use?
- For fragment i and light space patch j: when to subdivide j into smaller patches?
- **Goal:** minimize image space error
- Subdivide when $C_{j \to i}$ exceeds user threshold τ

$$C_{j \to i} = \rho_i \rho_j I_j \left(\frac{A_j (\vec{N}_i \cdot \vec{V}_{ij})(\vec{N}_j \cdot \vec{V}_{ji})}{\pi \|\vec{V}_{ij}\|^2 + A_j} \right)$$

- Need cheap, conservative estimate!

Bounding $C_{j \to i}$

- $C_{j \to i}$ can be bounded:

$$C_{j \to i} \leq \frac{2I\|V_j\|^2}{3 \cdot \mathrm{RSM}_{res}^2 \|\vec{V}_{ij}\|^2 + 2\|V_j\|^2}$$

- per-fragment terms are $\|\vec{V}_{ij}\|^2$ and $\|V_j\|^2$ (distance from j to i, and from j to light)
- Subdivide j when:

$$\|\vec{V}_{ij}\|^2 \leq \boxed{\frac{2(I-\tau)}{3\tau \cdot \mathrm{RSM}_{res}^2}} \|V_j\|^2 \equiv T\|V_j\|^2,$$

Constant for each frame

Performance

Interactive speeds (20 - 50 fps)

Speed depends on:

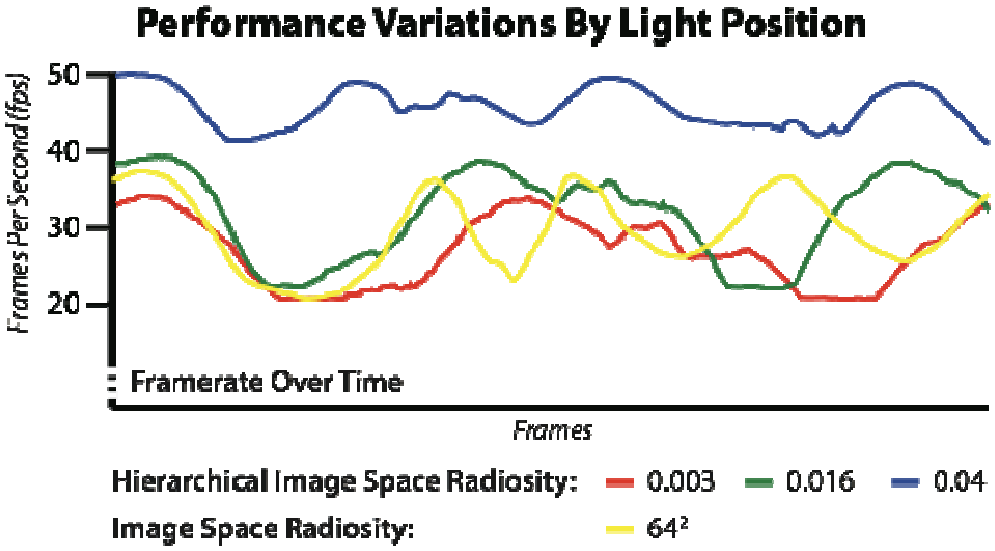
- Eye-space refinement thresholds
- Visual complexity in eye space

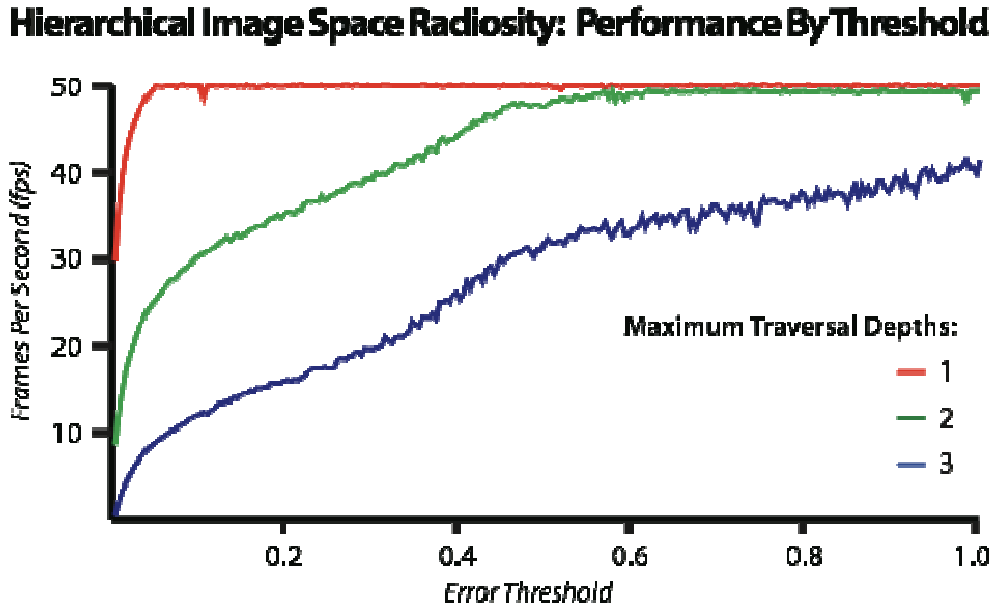
Basic Image Space Radiosity:

- Visual complexity in light space
- VPL sampling resolution

Hierarchical Image Space Radiosity:

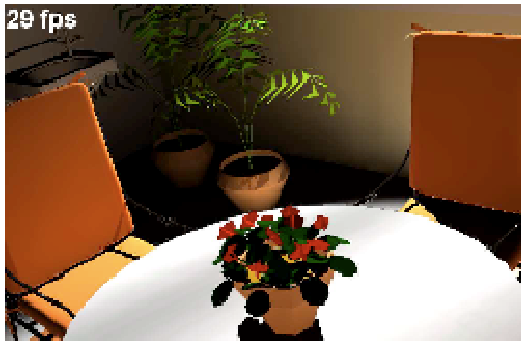
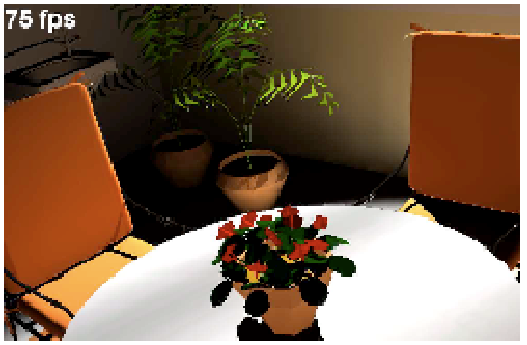
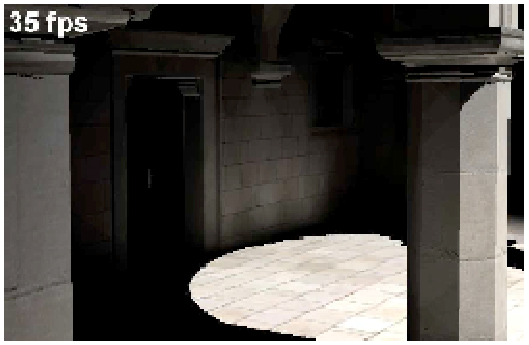
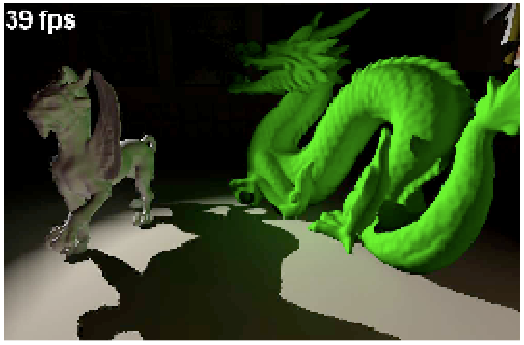
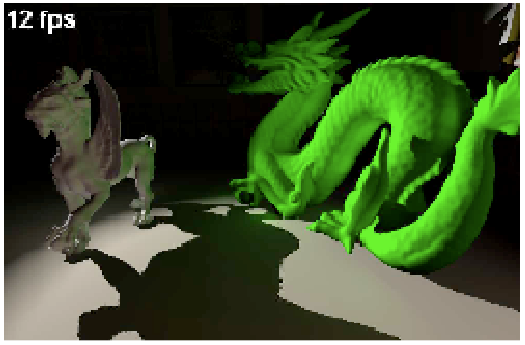
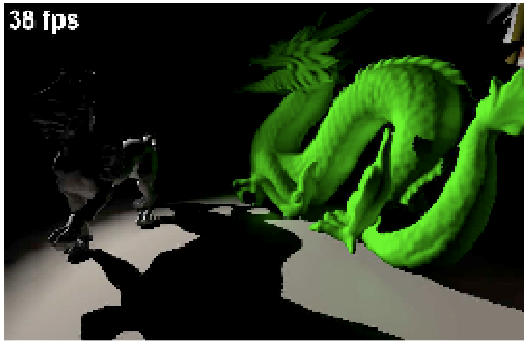
- Light-space error threshold
- Max traversal depth
- Light position relative to geometry





Comparison Images

Comparison Images

Hierarchical Image Space Radiosity	Multiresolution Gathering (256 VPLs)	Full Screen RSM Splats (256 VPLs)	Restricted RSM Splats (256 VPLs)
			
			
			

Video

Summary

- Huge performance increase over multires splatting
- Two different methods of choosing light space patches:
- **Basic image space radiosity**
  - Choose patches per-frame
- **Hierarchical image space radiosity**
  - Choose patches per-fragment
  - Scales with number of VPLs per fragment

Future Work

- Visibility approximation (indirect shadows, etc)
- Non-diffuse materials
- Multiple bounce approximations

Questions?

Acknowledgments

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