Virtual Spherical Lights for Many-Light Rendering of Glossy Scenes

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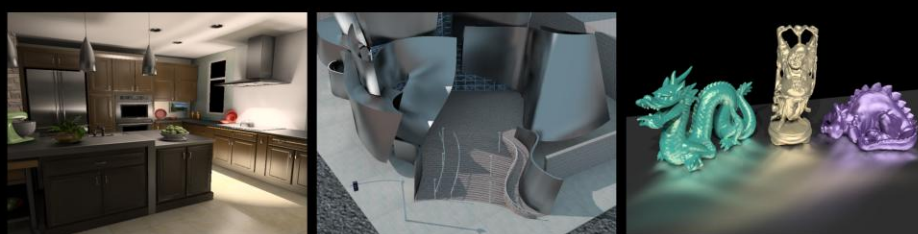
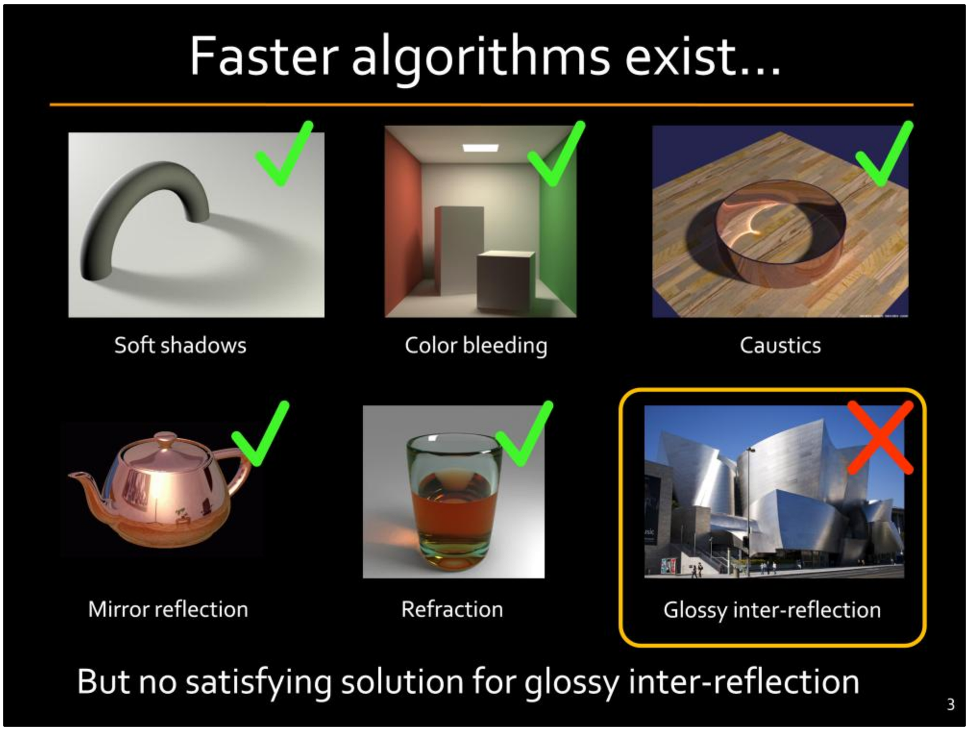
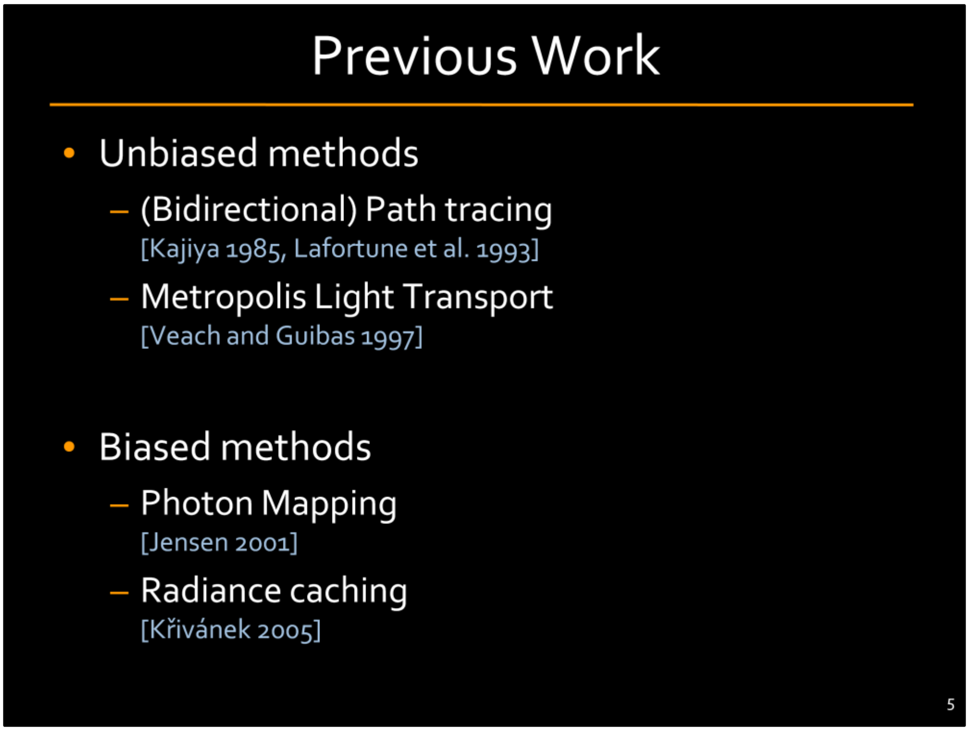


We’re dealing with a long standing problem of CG: computing global illumination efficiently. Depending on the scene properties, GI produces different illumination effects but we’re specifically focusing on light inter-reflections on glossy surfaces. Monte Caro methods, such as PT, are general enough to handle all these effects, but can take long time to converge, especially in the scenes that we’re focusing on.



Some fast specialized algorithms exist but there is no satisfying solution for glossy inter-reflections.

This is the kind of images that we would like to render. Indeed, their appearance is completely dominated by glossy inter-reflections.



Unbiased GI methods converge slowly since they have hard times finding important paths when dealing with glossy scenes.
Photon mapping is the most well known example of an biased GI method. However, it does not perform very well in glossy scene either: huge number of photons is required and final gathering is a bottleneck.
Final gathering can be accelerated with interpolation-based approaches such as radiance caching, but their assumptions about illumination smoothness is often invalid.

Previous Work – Instant Radiosity

- Virtual Point Lights (VPLs)
- Very efficient in mostly diffuse scenes
  - Real-time global illumination
    [Wald et al. 2002, Segovia et al. 2006, 2007, Laine et al. 2007, Ritschel et al. 2008, Dong et al. 2009]
- Scalability to many lights
  [Walter et al. 2005, 2006, Hašan et al. 2007]

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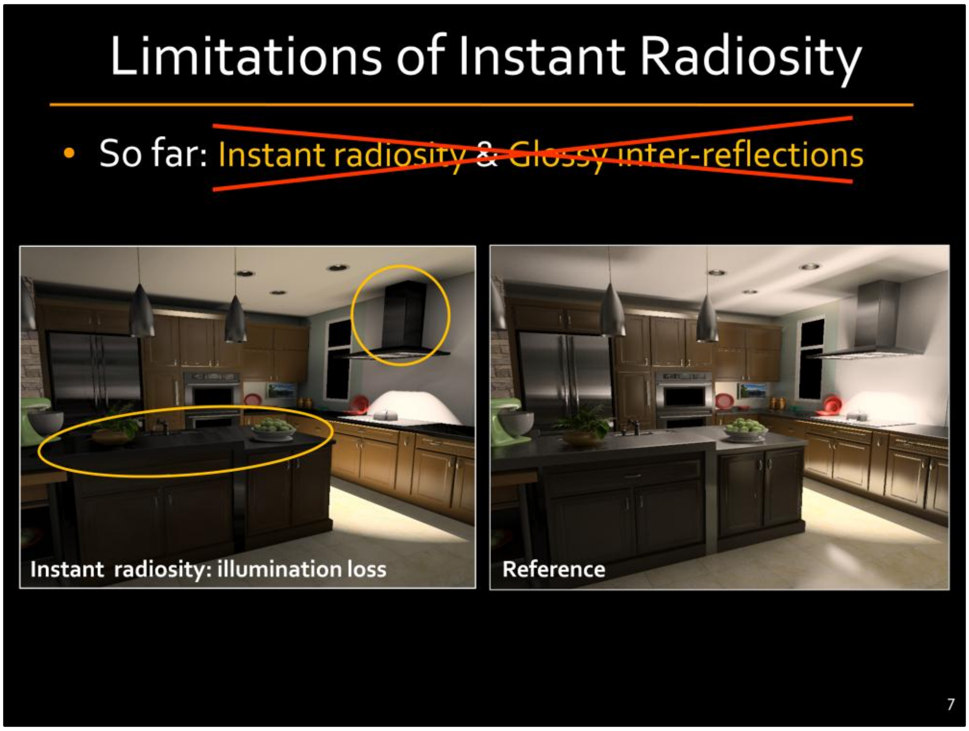
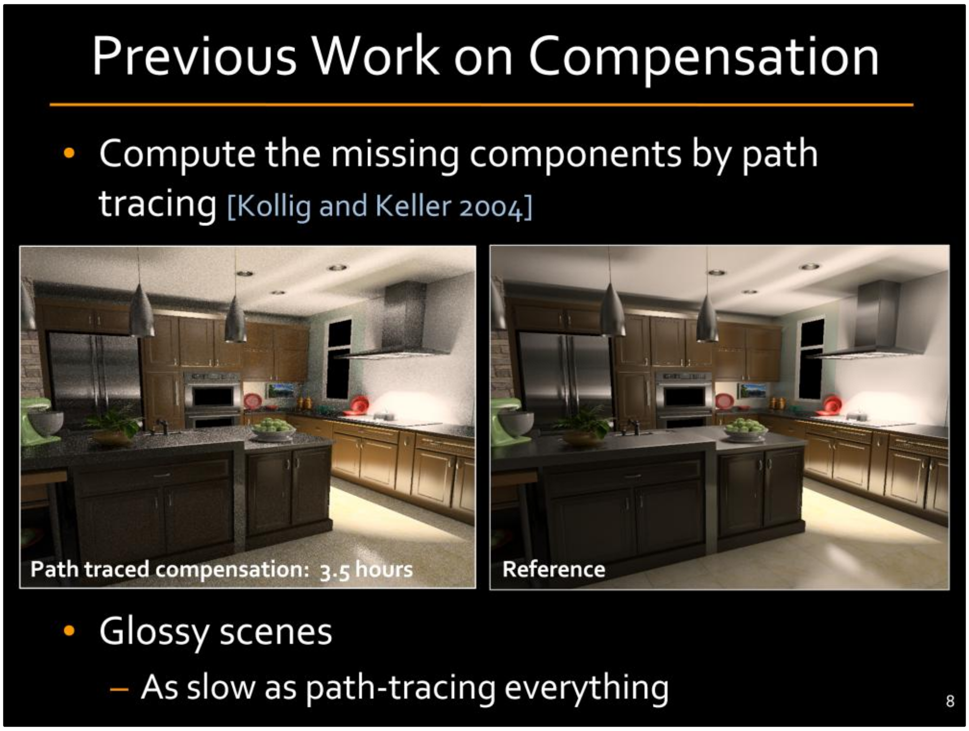
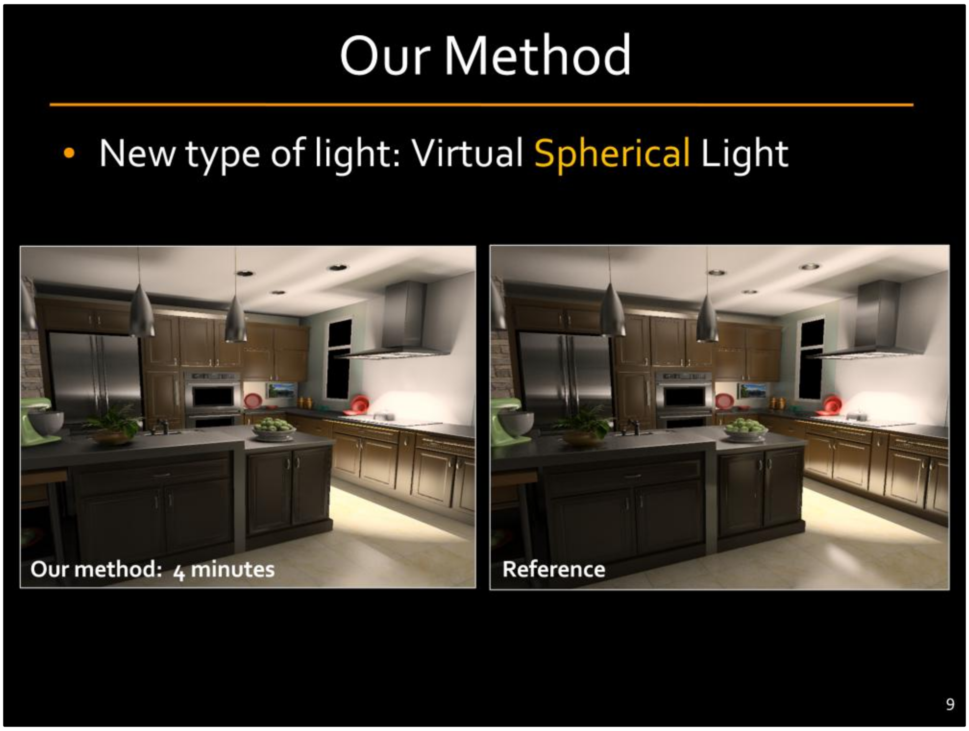
Instant radiosity is a GI method that has gained a lot of attention recently. The idea is to convert all the illumination into a set of VPLs. Since only a few VPLs are sufficient to get a believable approximation of GI, this algorithm has been the basis of many recent real-time GI methods.
On the other hand, with many VPLs, instant radiosity can produce very high quality images – that's why some work has addressed the problem of scalability with many lights.
Due to it's efficiency, we chose IR as the basis of our approach to the glossy inter-reflection problem.



However, it has been a common knowledge that instant radiosity does not work well in glossy scenes. The reason is that in order to prevent image artifacts, instant radiosity completely ignores some complex parts of light transport, which results in serious illumination loss on glossy surfaces, as you can see on the range hood or the counter.



The illumination loss problem hasn't been extensively discussed in previous work with the exception of the paper by Kollig and Keller, who propose to compensate for the missing energy by path tracing. Unfortunately, in glossy scenes, their compensation methods is nearly as expensive as path tracing the entire image.



Our idea, on the other hand, is to prevent the illumination loss in the first place, rather than trying t compensate for it. We achieve this by introducing a new type of light, the VSL, that overcomes some of the problems of VPLs.
With this new type of light, we are able to render images very similar to the reference yet in much shorter time.

Outline

- Problems with Virtual Point Lights (VPLs)
- Our solution: Virtual Spherical Lights (VSLs)
- Implementation
- Results

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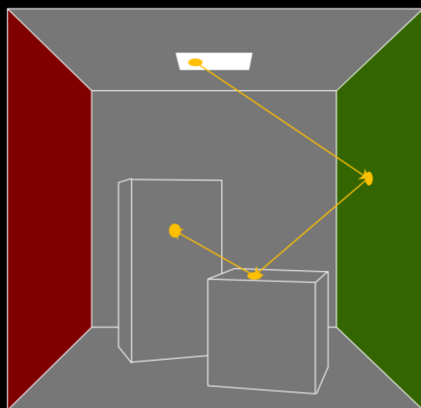
Instant Radiosity



- **STEP 1**
  - Trace paths from the light

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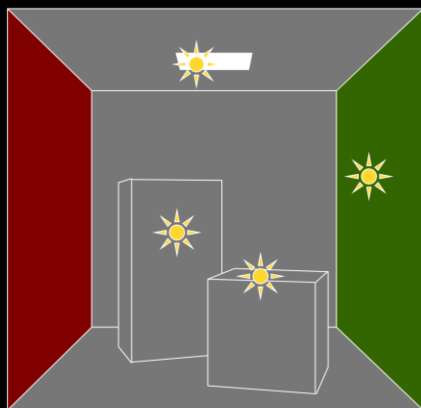
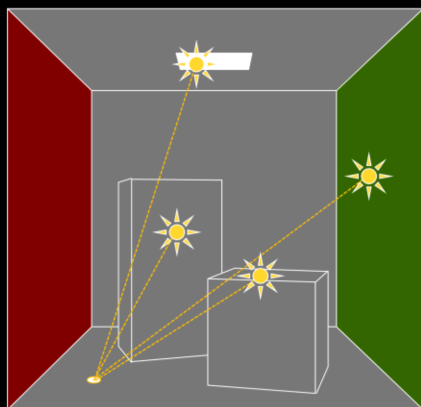
Instant Radiosity



- **STEP 1**
  - Trace paths from the light
  - Treat path vertices as Virtual Point Lights (VPLs)

Instant Radiosity



- **STEP 1**
  - Trace paths from the light
  - Treat path vertices as Virtual Point Lights (VPLs)
- STEP 2
  - Render scene with VPLs

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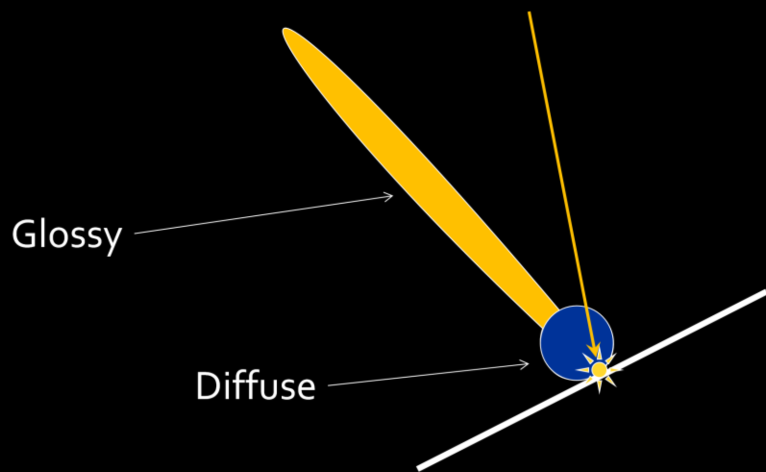
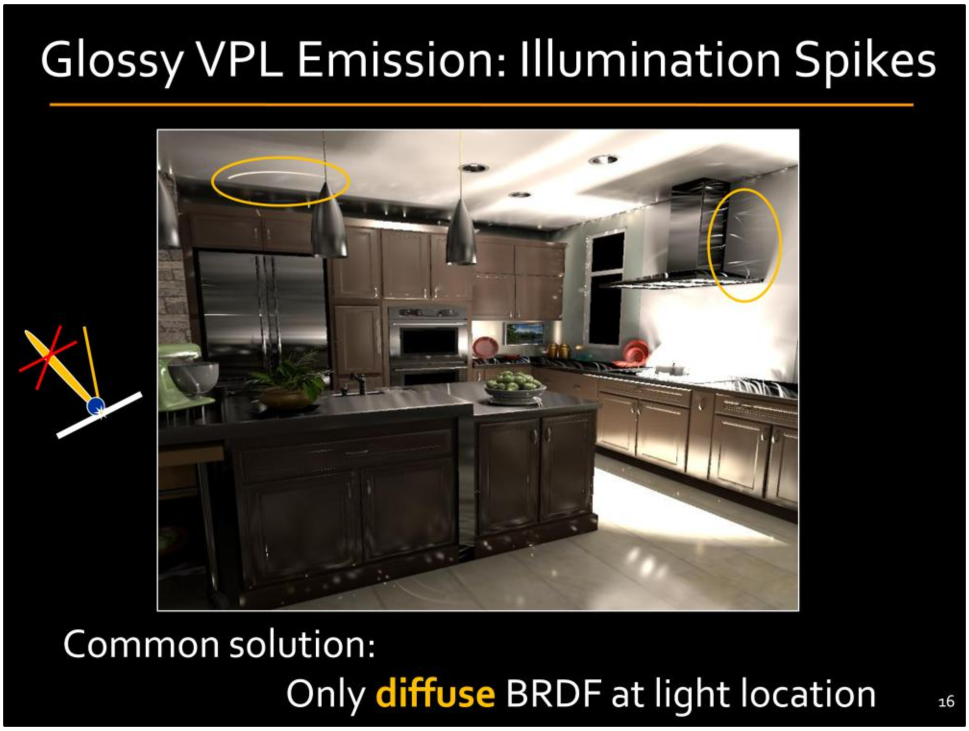
Emission Distribution of a VPL

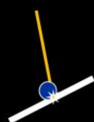
- Cosine-weighted BRDF lobe at the VPL location





If you render the scene with VPLs defined this way your will get an image with a lot of splotches. Each splotch corresponds to the spike in the emission distribution of a single VPL. For example, the streak on the ceiling is caused by a VPL located on a highly anisotropic glossy surface.
The common solution in instant radiosity is to ignore the glossy component of the BRDF at the light location which produces VPLs with very uniform emission distribution.

Remaining Spikes



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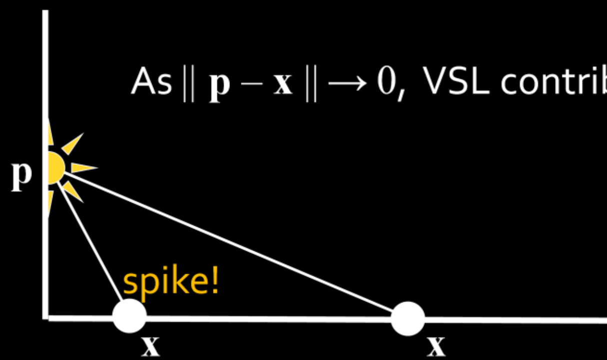
Remaining Spikes

- VPL contribution =

As $\| \mathbf{p} - \mathbf{x} \| \rightarrow 0,$ VSL contribution $\rightarrow \infty$



- Common solution: **Clamp** VPL contributions

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Instant Radiosity: The Practical Version

Clamping and diffuse-only VPLs:

Illumination is lost!

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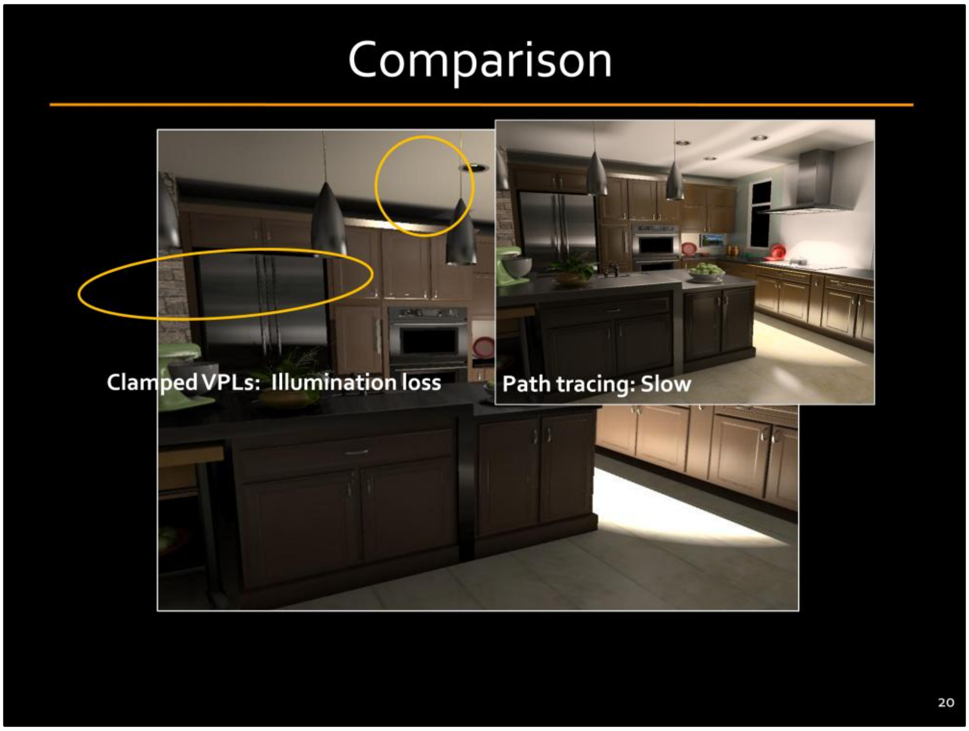
Comparison
Clamped VPLs: Illumination loss
Path tracing: Slow
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Motivation

- VPLs: image splotches due to
  - Spikes in the VPL emission distibution
  - $1 / \| \mathbf{p} - \mathbf{x} \|$ term
- Idea
  - Spread VPL energy over a finite surface
  - Compute contribution as solid angle integral

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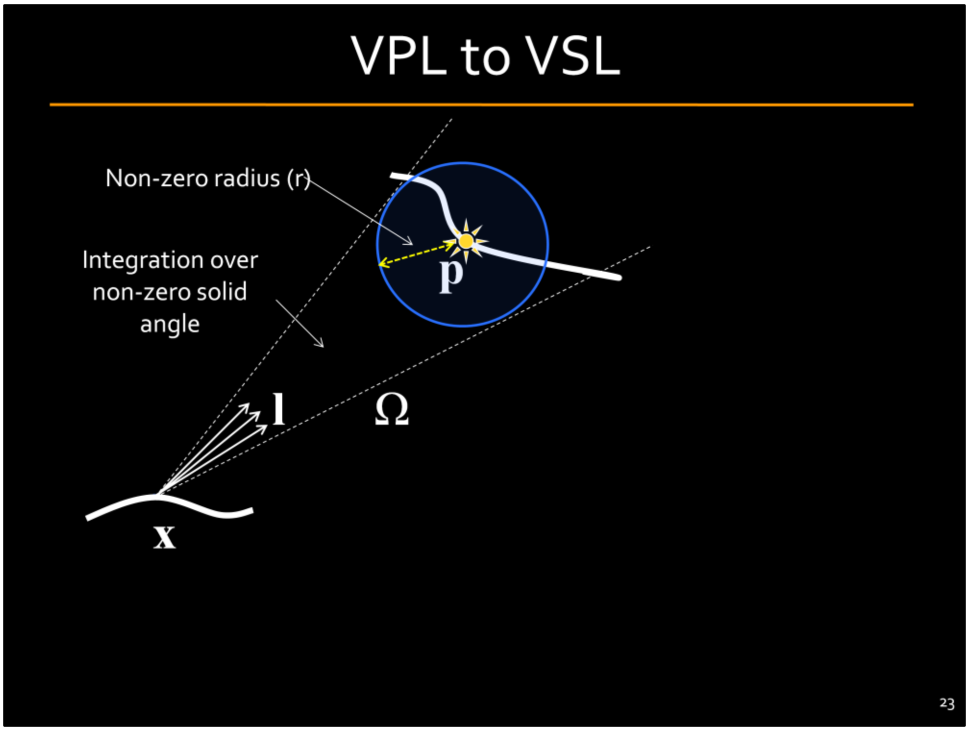
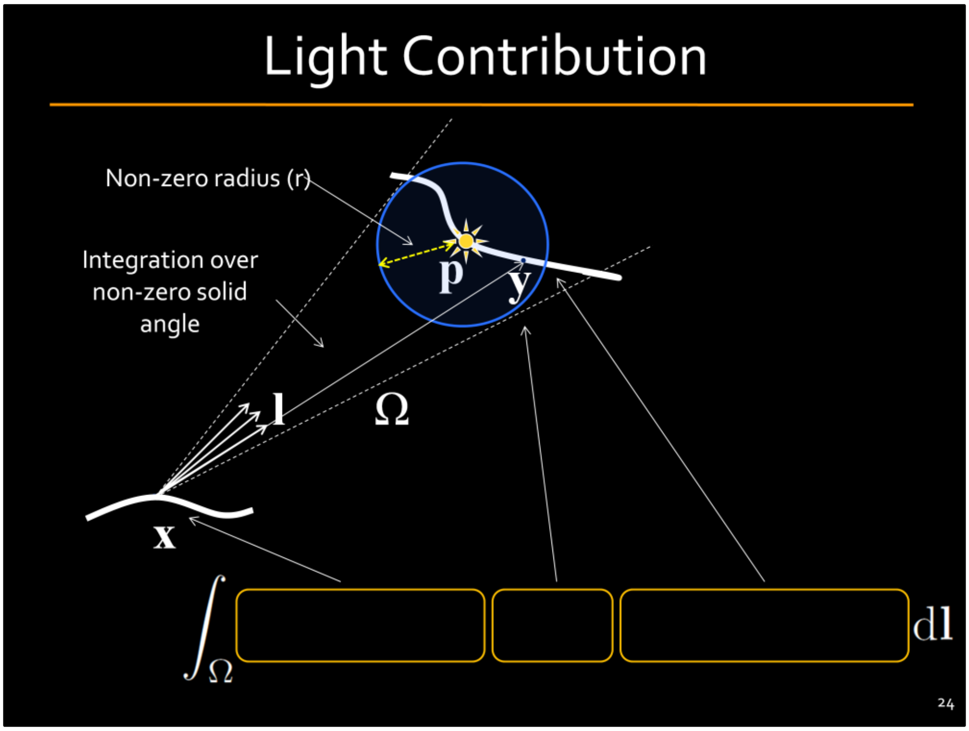
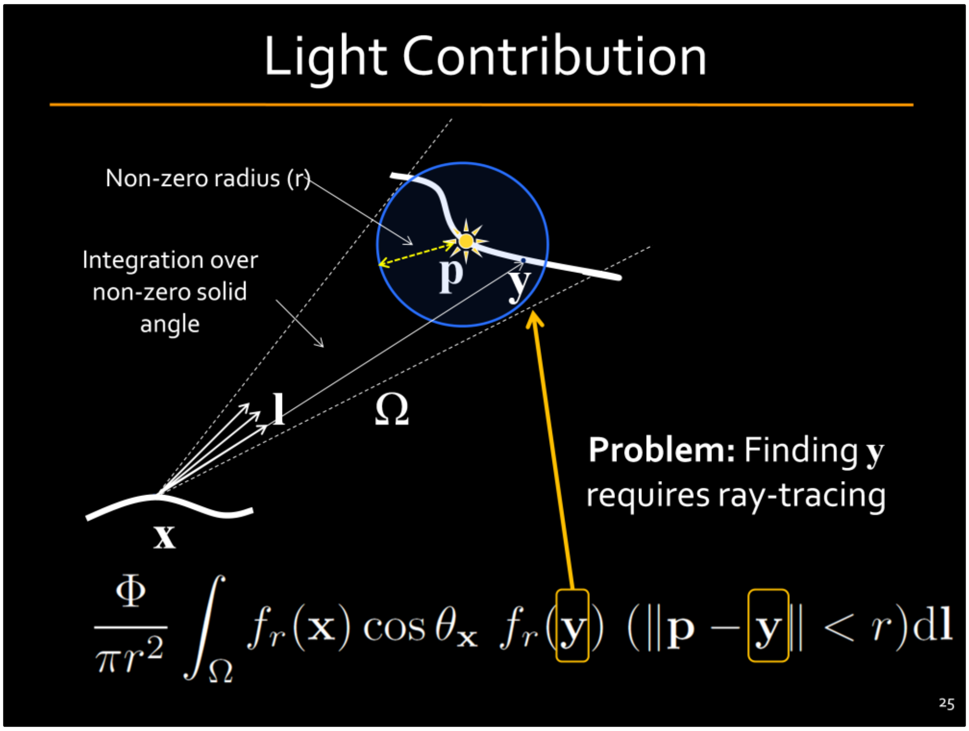


More specifically, we well spread the light energy over the surfaces inside the sphere of radius r centered at the light position p. And the contribution of the light will be computed as an integral over the solid angle subtended by the sphere.

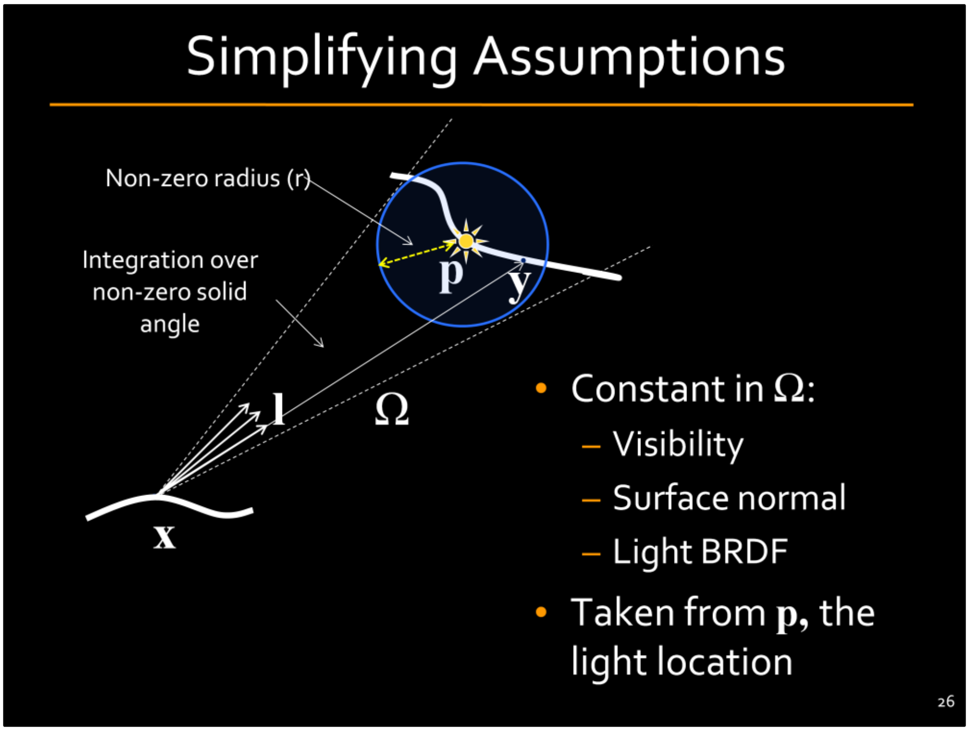


Let's write down the formula for the contribution of such a light to the surface point x. We have the integration over the solid angle. The integrand is a product of the following terms: the cosine weighted BRDF at the surface, next, the BRDF at the point y n the vicinity of the light location. Finally, we have an indicator term that is zero for all the directions that correspond to surface point y outside the sphere. We normalize the integration by the expected surface area inside the sphere, pi*r^2, and multiply by the light flux.

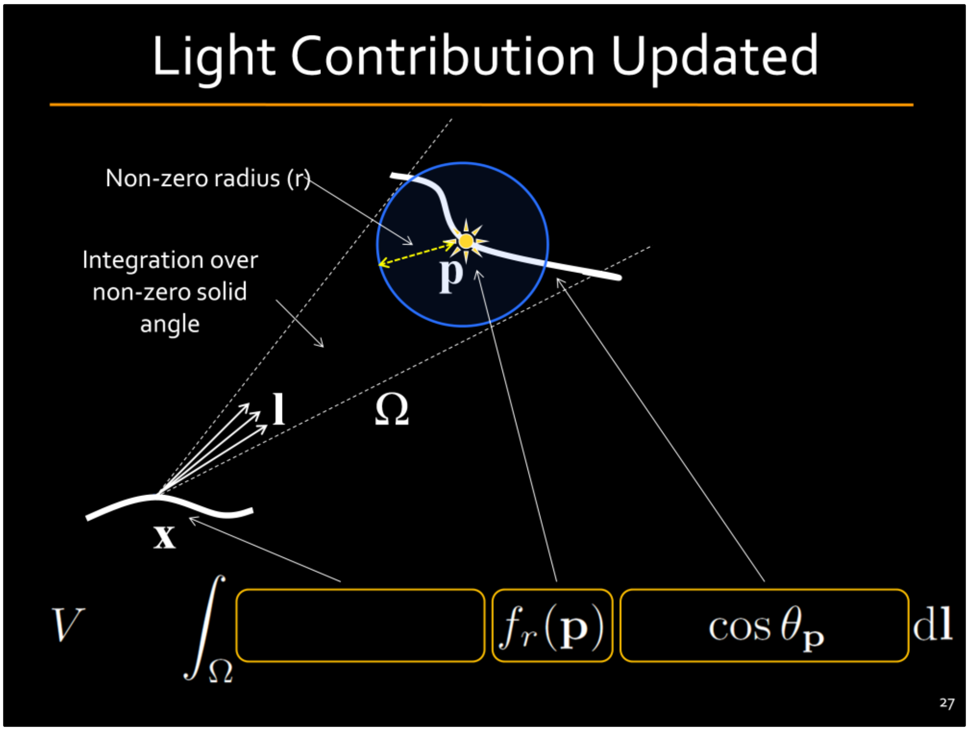
To avoid this indicator term, we could define the light contribution as an integral over a disk area. Unfortunately, doing that re-introduces the infamous 1/dist^2 term and produces bad results (we tried it).



Unfortunately, this formulation requires finding the point y for all directions l inside the cone, which required ray tracing. This is clearly not feasible.



To produce a computationally convenient approximation to the previous formula, we make the following simplifying assumptions. We assume that the visibility, the surface normal and the BRDF are constant inside the sphere. And we take them from the light location p.



With these assumptions, we can write a formula for the contribution of a VSL:

Virtual Spherical Light

- All inputs taken from $\mathbf{x}$ and $\mathbf{p}$
  - Local computation
- Same interface as any other light
  - Can be implemented in a GPU shader
- Visibility factored from the integration
  - Can use shadow maps

$$V \frac{\Phi}{\pi r^2} \int_\Omega f_r(\mathbf{x}) \cos\theta_{\mathbf{x}} \; f_r(\mathbf{p}) \; \cos\theta_{\mathbf{p}} \; \mathrm{d}\mathbf{l}$$

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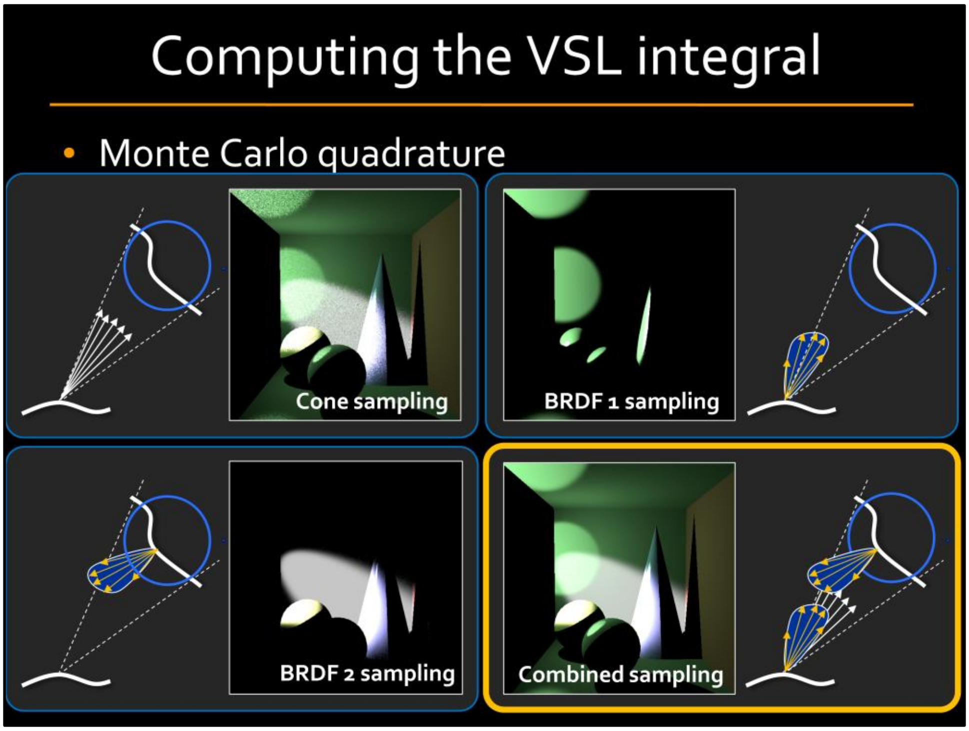
Computing the VSL integral
Monte Carlo quadrature
Cone sampling
BRDF 1 sampling
BRDF 2 sampling
Combined sampling

Implementation

- Matrix row-column sampling [Hašan et al. 2007]
  - Shadow mapping for visibility
  - VSL integral evaluated in a GPU shader
- Need more lights than in diffuse scenes
- VSL radius proportional to local VSL density
  - determined by k-NN queries

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Results: Kitchen

- Most of the scene lit indirectly
- Many materials glossy and anisotropic

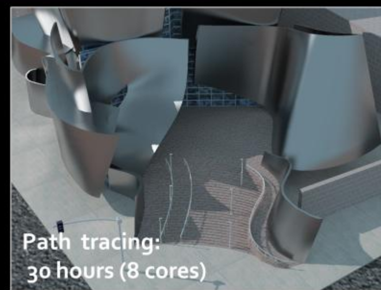

Path tracing:
316 hours (8 cores)

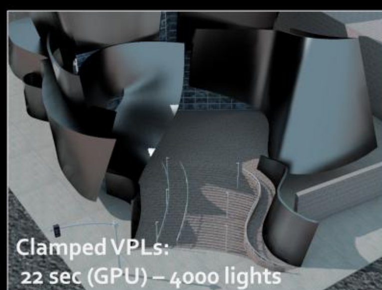

Clamped VPLs
34 sec (GPU) – 2000 lights


New VSLs:
4 min 4 sec (GPU) – 10000 lights

Results: Disney Concert Hall

- Curved walls with no diffuse component
- Standard VPLs cannot capture any reflection from walls


Path tracing:
30 hours (8 cores)


Clamped VPLs:
22 sec (GPU) – 4000 lights


New VSLs:
1 min 26 sec (GPU) – 15000 lights

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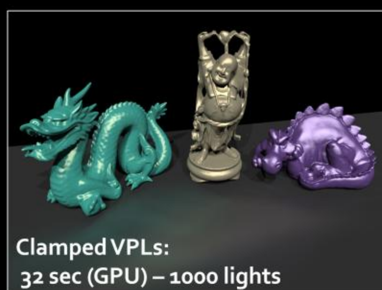
Results: Anisotropic Tableau

- Difficult case
- Standard VPLs capture almost no indirect illumination

Path tracing:
2.2 hours (8 cores)



Clamped VPLs:
32 sec (GPU) – 1000 lights

New VSLs:
1 min 44 sec (GPU) – 5000 lights

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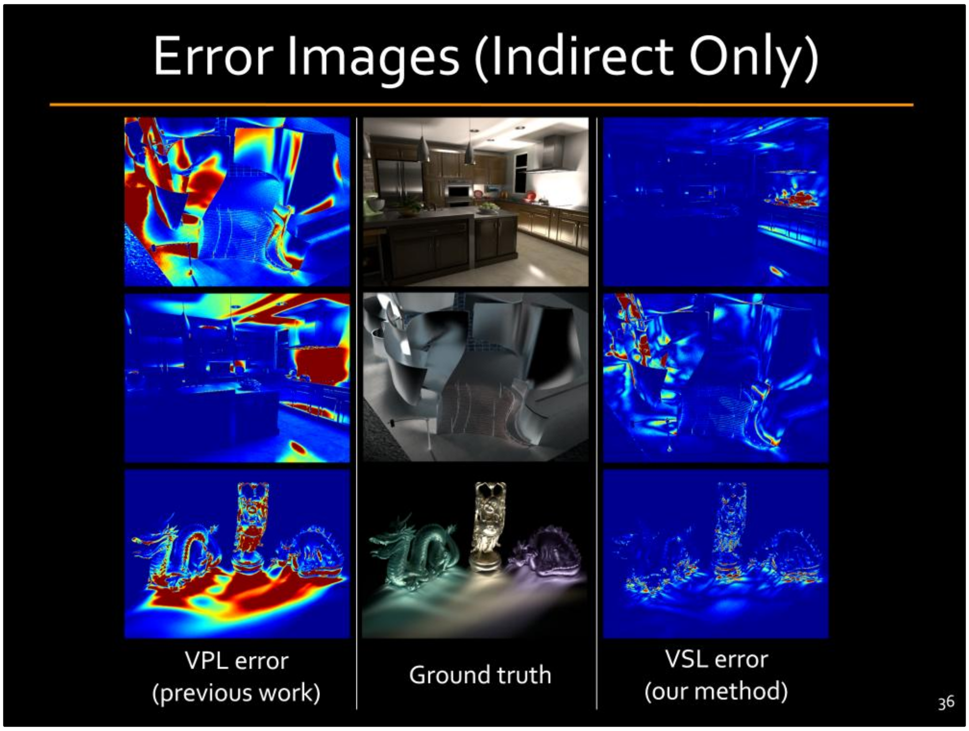
Error Images (Indirect Only)
VPL error
(previous work)
Ground truth
VSL error
(our method)
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Limitations: Blurring

- VSLs can blur illumination
- Converges as number of lights increases

5,000 lights - blurred

1,000,000 lights - converged

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Other Limitations

- Some remaining corner darkening
- Computation overhead

Conclusion

- Virtual Spherical Lights
  - No spikes, no clamping necessary
  - Address illumination loss
- Many-light methods + VSLs:
  - A step to solve the glossy inter-reflection problem
- Future Work
  - More lights: improve scalability

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The Problem, Numerically

- Recall: Integration over paths, use Monte Carlo

$$\int_{\Omega} f_j(\bar{x})d\mu(\bar{x}) \approx \frac{1}{N}\sum_{i=1}^{N}\frac{f(x_i)}{p(x_i)}$$

- The contribution $f(x_i)$ *contains:*
  - Inverse distance-squared term
  - Material term at surface location
  - Material term at VPL location
- What if $f(x_i)$ becomes locally large?
  - "Spikes"

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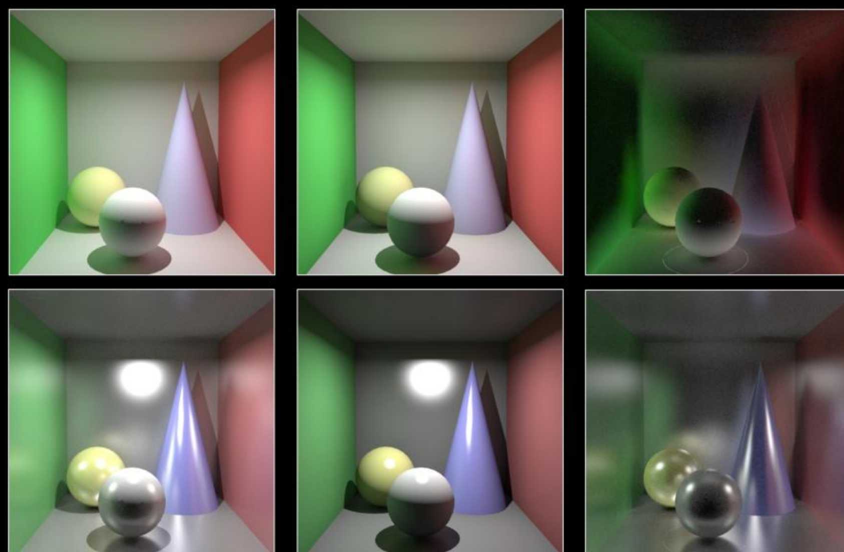
The Problem Revision

Path tracer | Instant radiosity | Difference image



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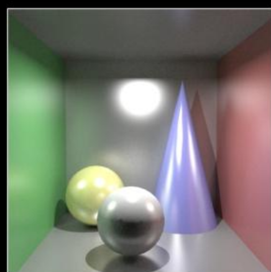
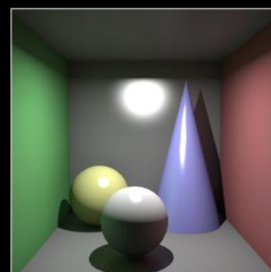
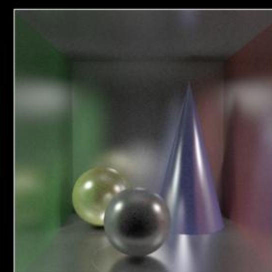
Another Example



Path tracer



Instant radiosity



Difference image

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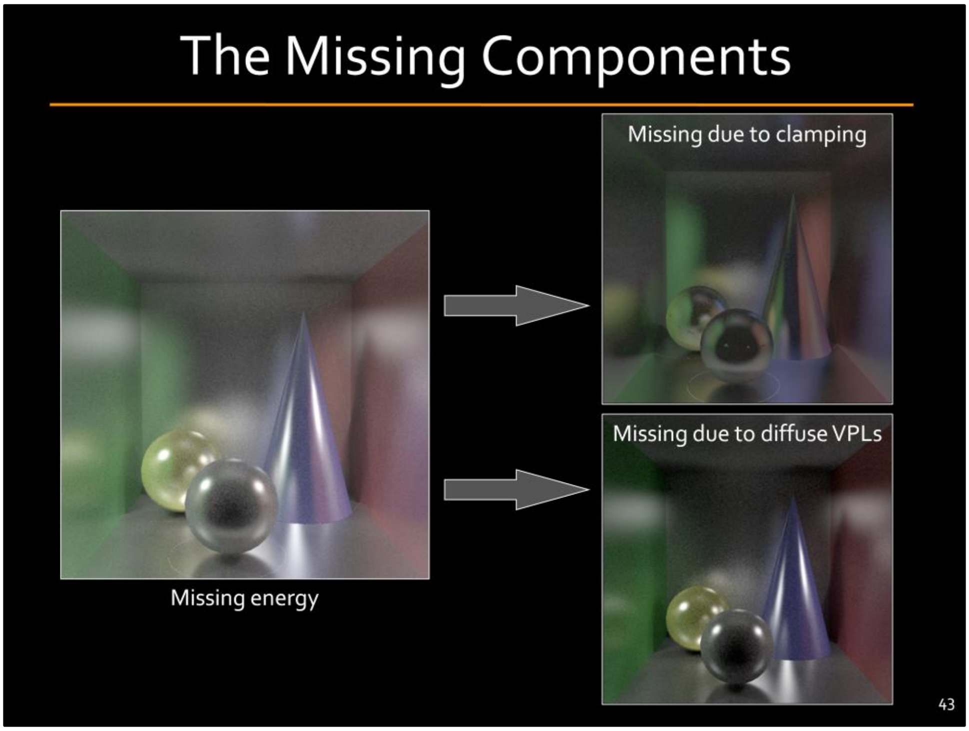
The Missing Components
Missing due to clamping
Missing due to diffuse VPLs
Missing energy
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