X39RSO/A4M39RSO Ambient Occlusion Image Based Lighting

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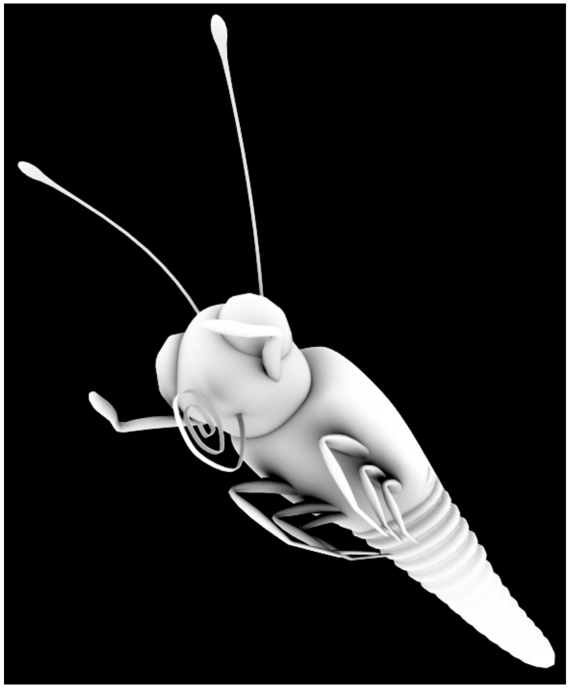
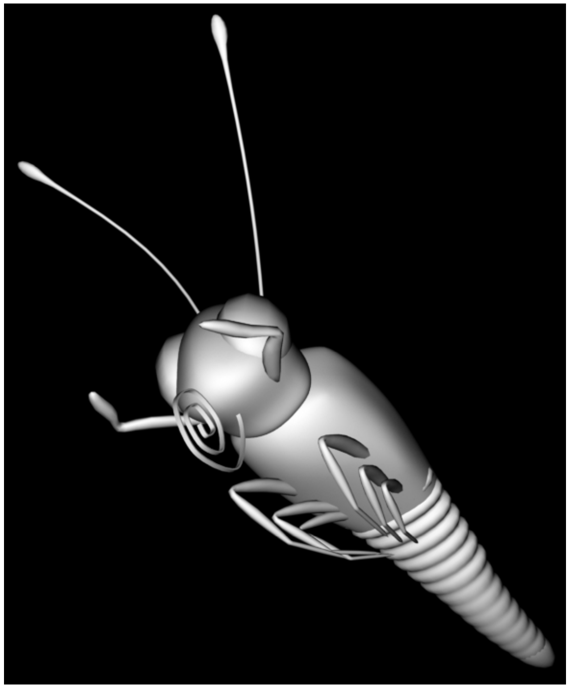
Verze 2012

Ambient Occlusion (year 1999)

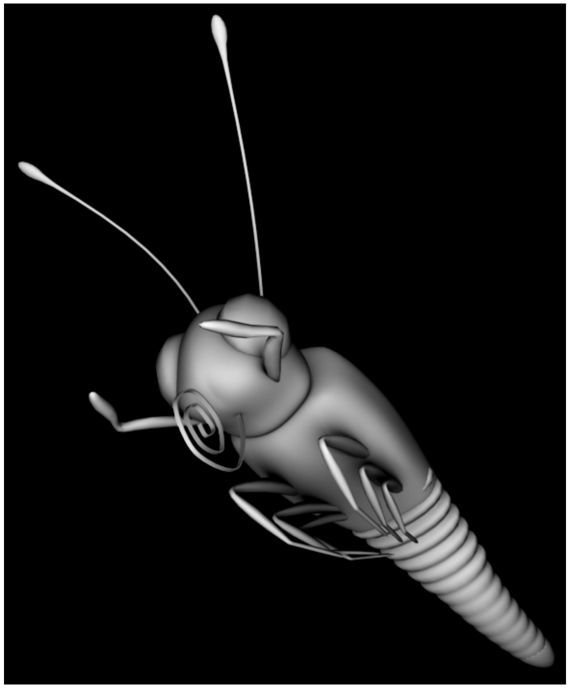
Ambient Occlusion



Ambient occlusion



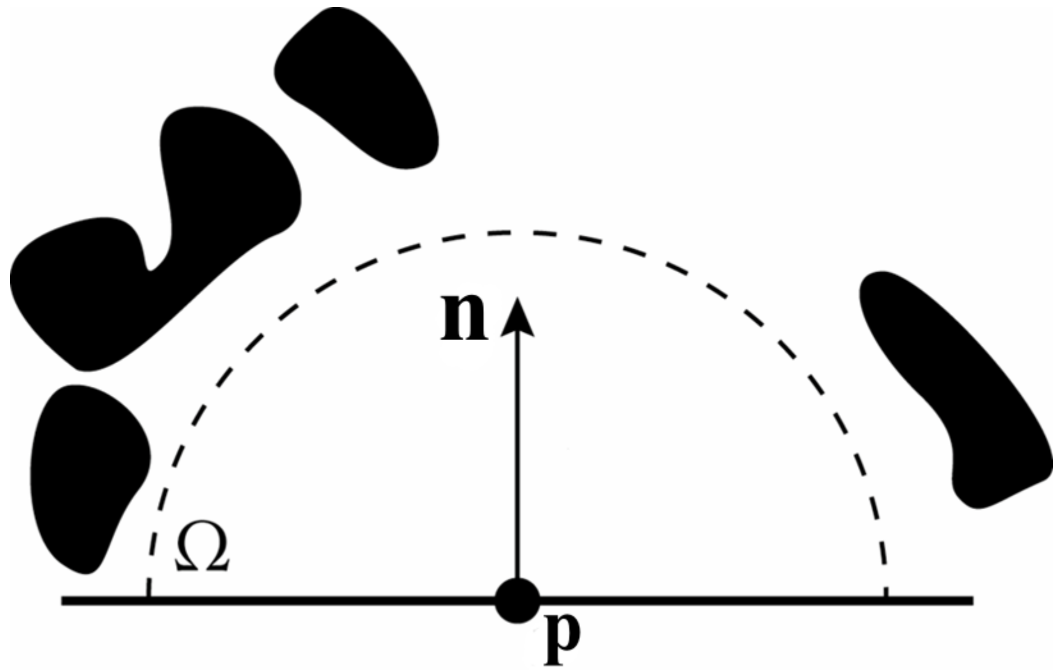
Diffuse shading



Ambient * Diffuse

- Cheap, global illumination-like effect

Ambient Occlusion



Wikipedia

$$A(\mathbf{p}) = \frac{1}{\pi} \int_{\Omega} V(\mathbf{p}, \omega)\,(\mathbf{n} \cdot \omega)\,\mathrm{d}\omega$$

- Ambient occlusion = irradiance for constant, unit L_i
- Percentage of unoccluded hemisphere

Ambient Occlusion

Money grinder with ambient occlusion.

(From SIGGRAPH 2003 Course 9, Copyright: Peter Crowther Associates)

Ambient Occlusion

$$A(\mathbf{p}) = \frac{1}{\pi} \int_{\Omega} V(\mathbf{p}, \omega)\, (\mathbf{n} \cdot \omega)\, \mathrm{d}\omega$$

- Evaluated by MC hemisphere sampling
  - Trace cosine-proportional rays, A(p) = 1 - #hits / #total
- In production (offline) rendering
  - Accelerated by interpolation (similar to irradiance caching)
- In real-time rendering
  - Pre-computed for each vertex
  - Real-time approximations also possible
    - Dynamic Ambient Occlusion and Indirect Lighting, GPU Gems 2, http://download.nvidia.com/developer/GPU_Gems_2/GPU_Gems2_ch14.pdf

Artistic Options in RenderMan

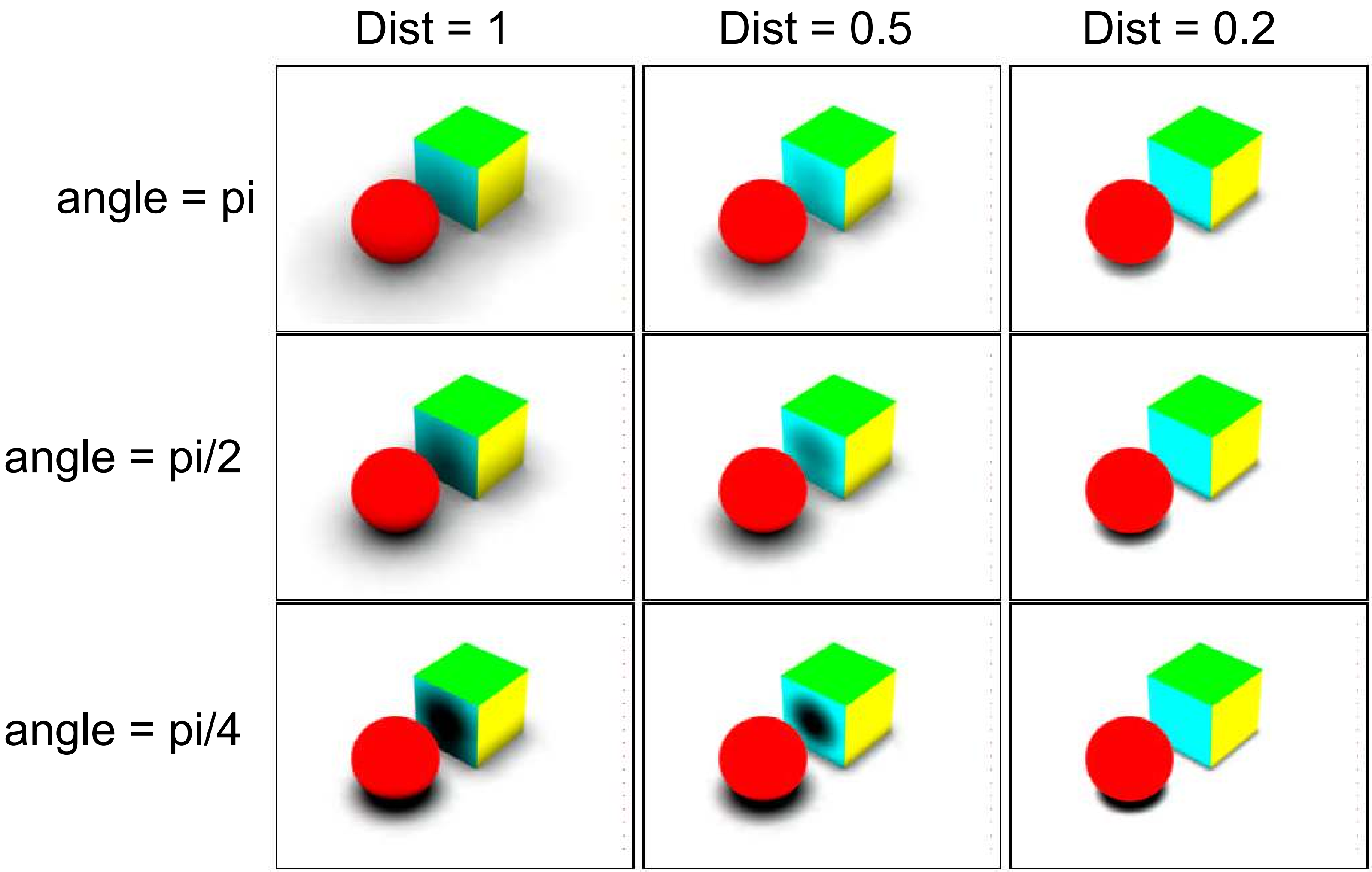


Figure 3.3: Ambient occlusion with different values for coneangle and maxdist. Upper row: coneangle π; middle row: coneangle $\pi/2$; bottom row: coneangle $\pi/4$. Left column: maxdist 1; middle column: maxdist 0.5; right column: maxdist 0.2.

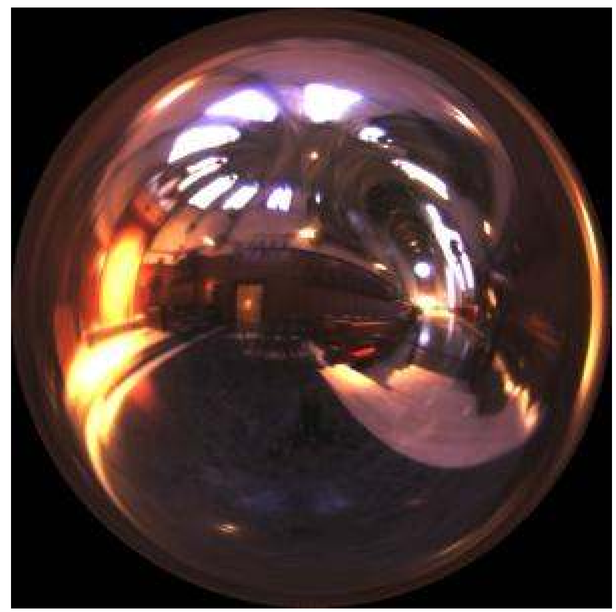
From SIGGRAPH 2003 Course 9

Image-Based Lighting

Image-Based Lighting

- Light source = real environment
- Must be high dynamic range (HDR)
- Capture – photographing a reflective sphere

St. Peter's Basilica, Rome

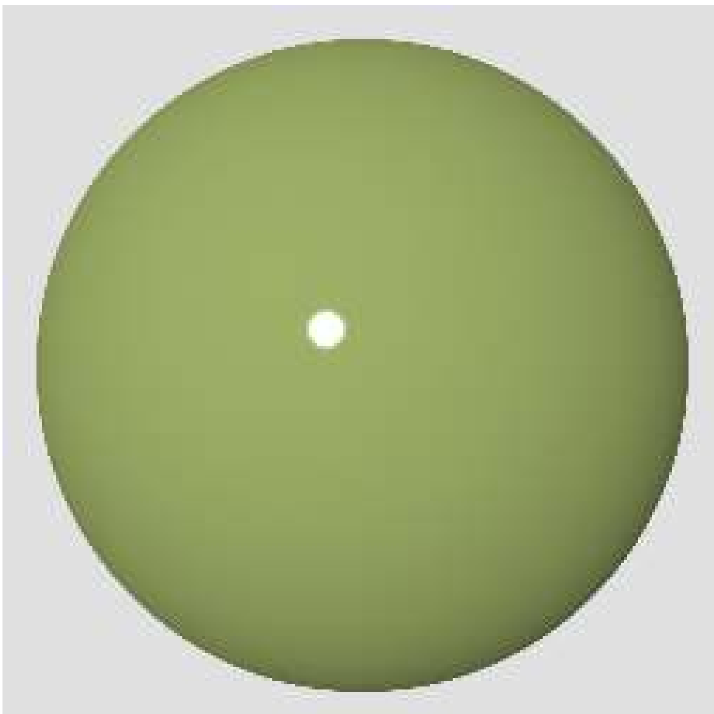


Grace Cathedral, San Francisco

Image-Based Lighting

Rationale: People perceive materials and shapes more easily under *natural illumination* than under simplified illumination.

The BRDF is the same



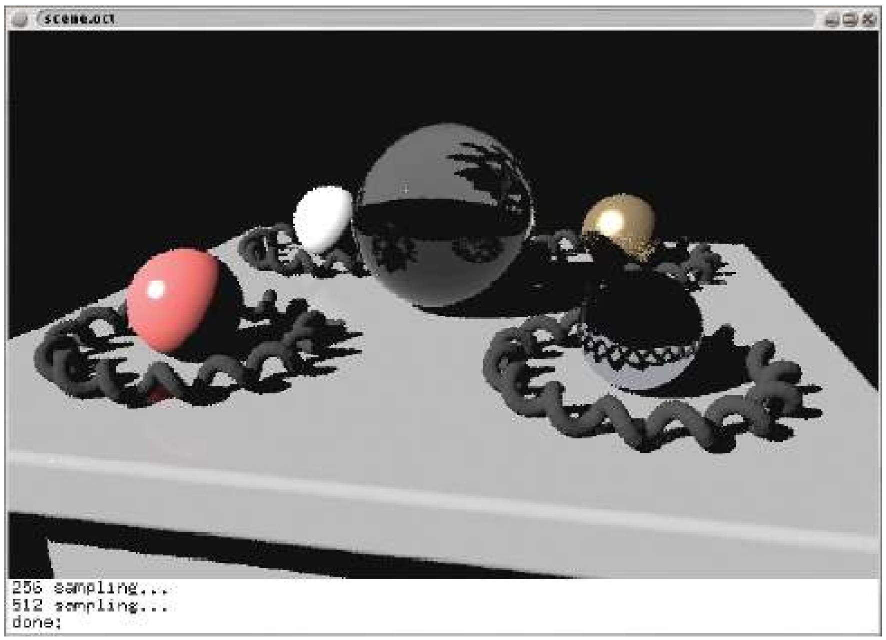
Point light

Captured natural environment

Images Ron Dror and Ted Adelson

Image-Based Lighting (IBL)

- Demo: **Rendering with Natural Light** by Paul Debevec
- http://www.debevec.org/RNL/



Point light source

HDR environment map

Image-Based Lighting

- More demos by Paul Debevec (http://www.debevec.org/)
  - **Fiat Lux**
  - **Parthenon**
  - **Image-based Lighting**

Image-Based Lighting on the CPU

- IBL = evaluate the illumination integral

$$L_o(\omega_o) = \int L_i(\omega_i) V(\omega_i) f_r(\omega_i, \omega_o) \cos\theta_i d\omega_i$$

visibility (self occlusion)

HDR environment map

- Evaluation = sampling
  - One sample = one shadow ray

a) Sample the BRDF
  - hemisphere sampling

b) Sample the environment map
  - Replace environment maps with point lights

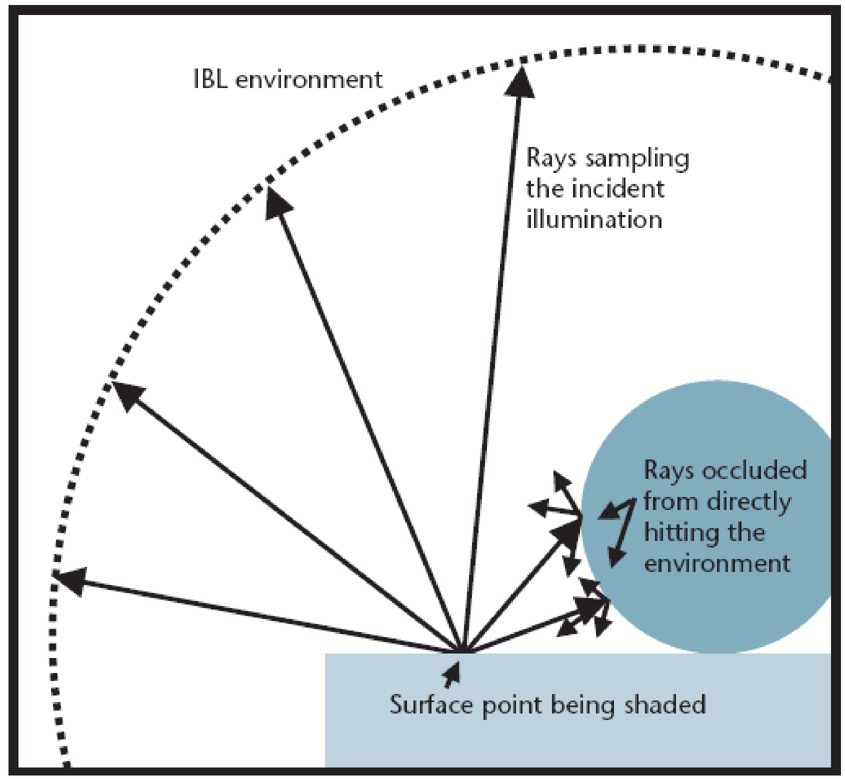
c) Sample the product BRDF x environment

a) Sample the BRDF

- Paul Debevec. **A Tutorial on Image-Based Lighting**, In IEEE Computer Graphics and Applications, Jan/Feb 2002. http://www.debevec.org/CGAIBL2/ibl-tutorial-cga2002.pdf

- Irradiance caching for the diffuse term
- BRDF-proportional importance sampling for the glossy/specular term

- Advantage: includes indirect illumination



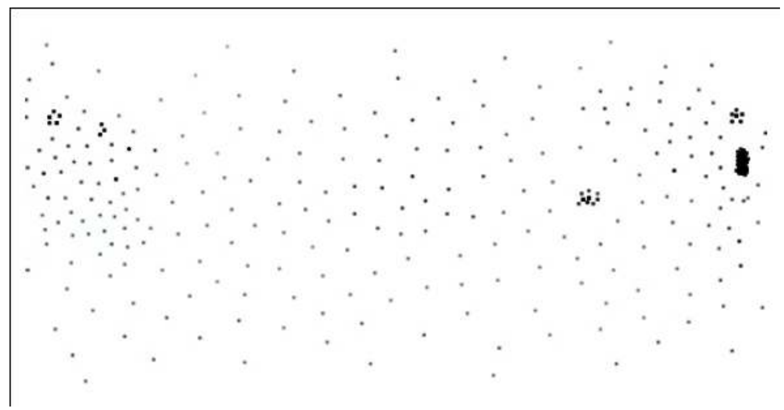
7 How Radiance traces rays to determine the incident illumination on a surface from an IBL environment.

b) Sample the Environment Map

- Replace environment map by a number of light sources
- Agarwal et al. **Structured Importance Sampling**
  http://vision.ucsd.edu/~sagarwal/structured/

SEE VIDEO

Environment map



Point light sources

Importance w/ 300 samples

Importance w/ 3000 samples

Structured importance w/ 300 samples

Structured importance w/ 4.7 rays/pixel

b) Sample the Environment Map

- Kollig & Keller, **Efficient Illumination by High Dynamic Range Images**, EGSR 2003, http://graphics.uni-ulm.de/

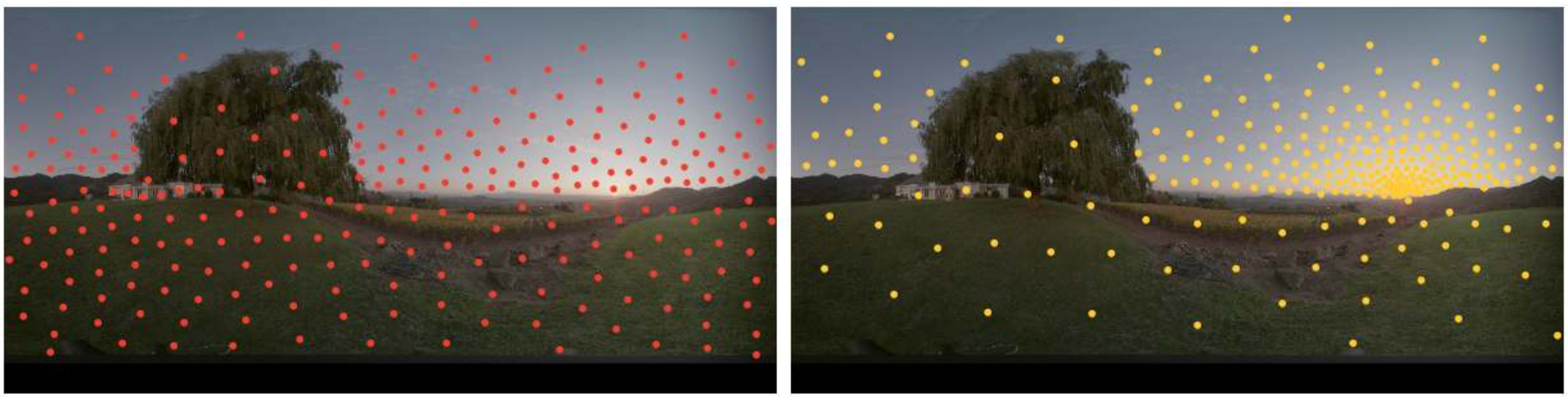


Figure 1: *The $N = 256$ colored points in each image indicate the directions ω_i generated by Lloyd's relaxation algorithm on the left and our improved scheme on the right. For convenience the spherical images are displayed as 2:1 lattitude/longitude maps. Obviously the new approach captures the light distribution much more precisely resulting in a smaller integration error during rendering. Both images have been tone mapped for display.*

b) Sample the Environment Map

- Kollig & Keller
  - Notice image artifacts due to low sample count

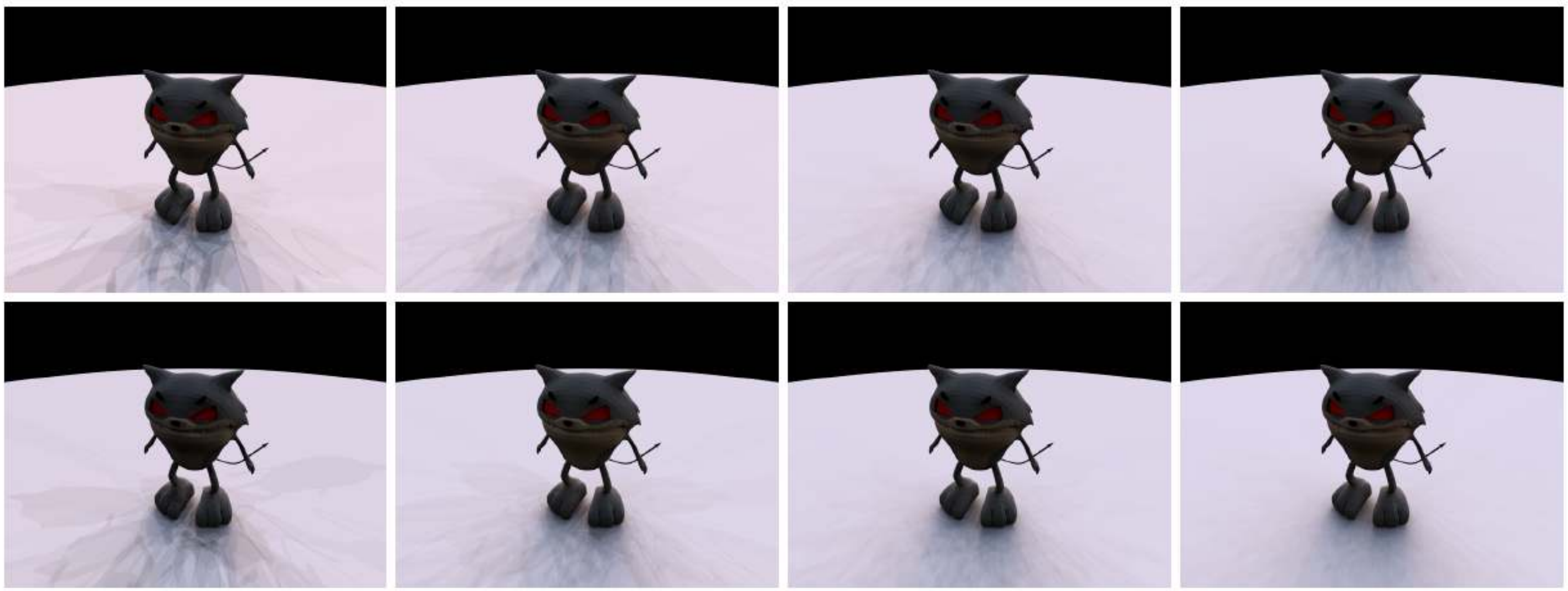


Figure 2: *Images rendered using the quadrature rules generated by Lloyd's relaxation algorithm (top row) and our improved scheme (bottom row) as illustrated in figure 1. The number of light sources is* $N = 32, 64, 128, 256$ *(from left to right). The shadow boundary artifacts caused by the directional light sources vanish much faster with our new scheme, clearly indicating the faster decay of the integration error due to the more equalized and consequently smaller weights of the quadrature rule.*

b) Sample the Environment Map
Penrose Tiling

- Ostromoukhov et al. **Penrose Tiling**, SIGGRAPH 2004, http://www.iro.umontreal.ca/~ostrom/publications/abstracts.html

SEE VIDEO

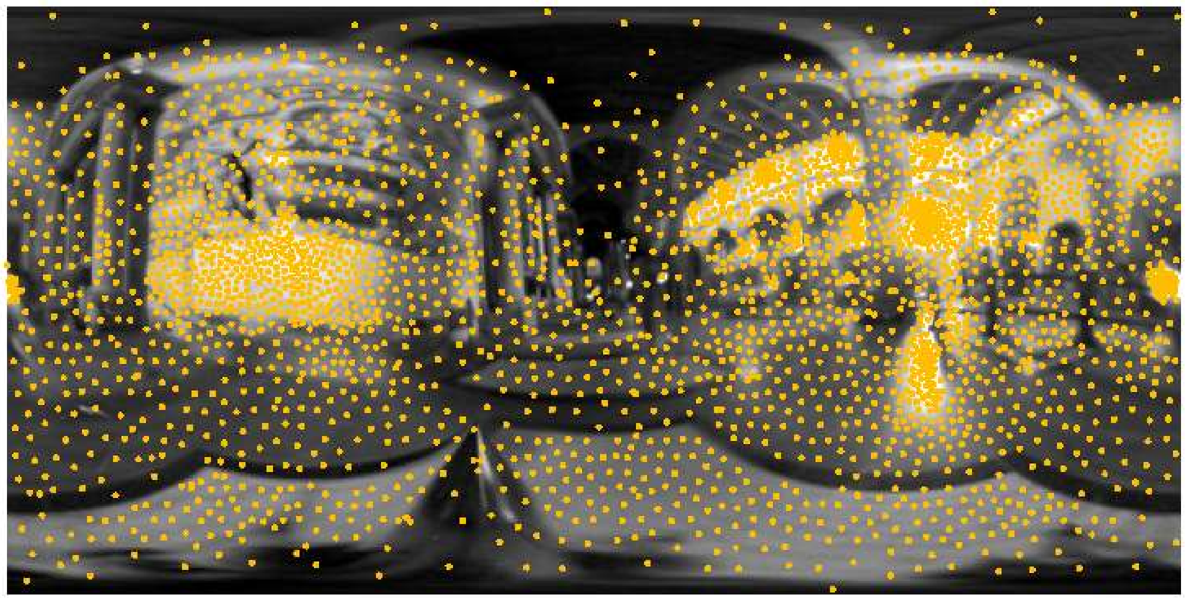
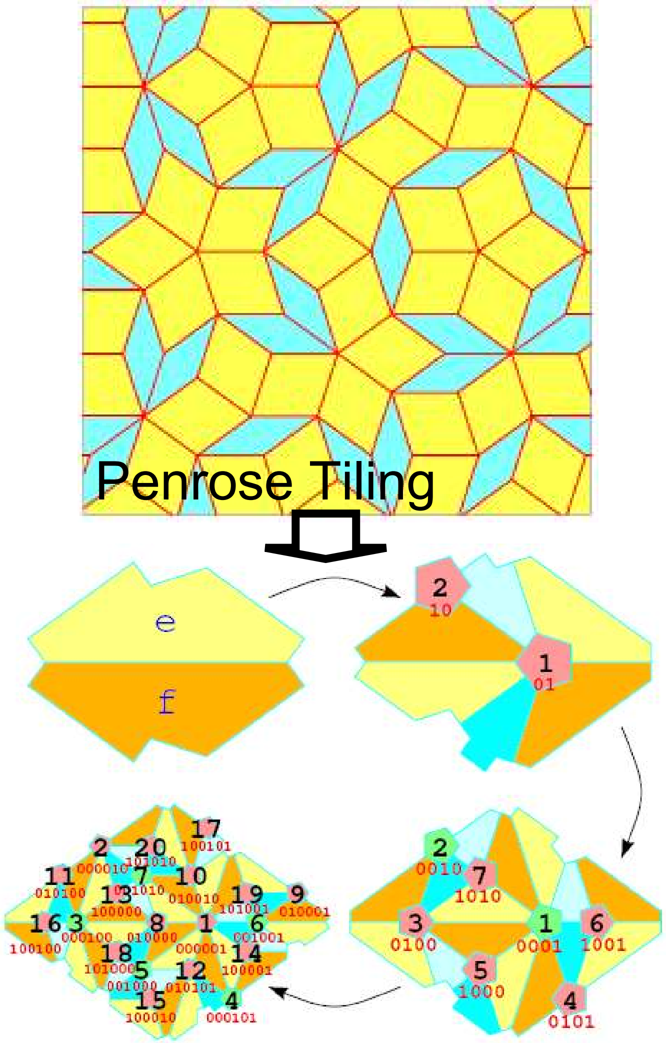


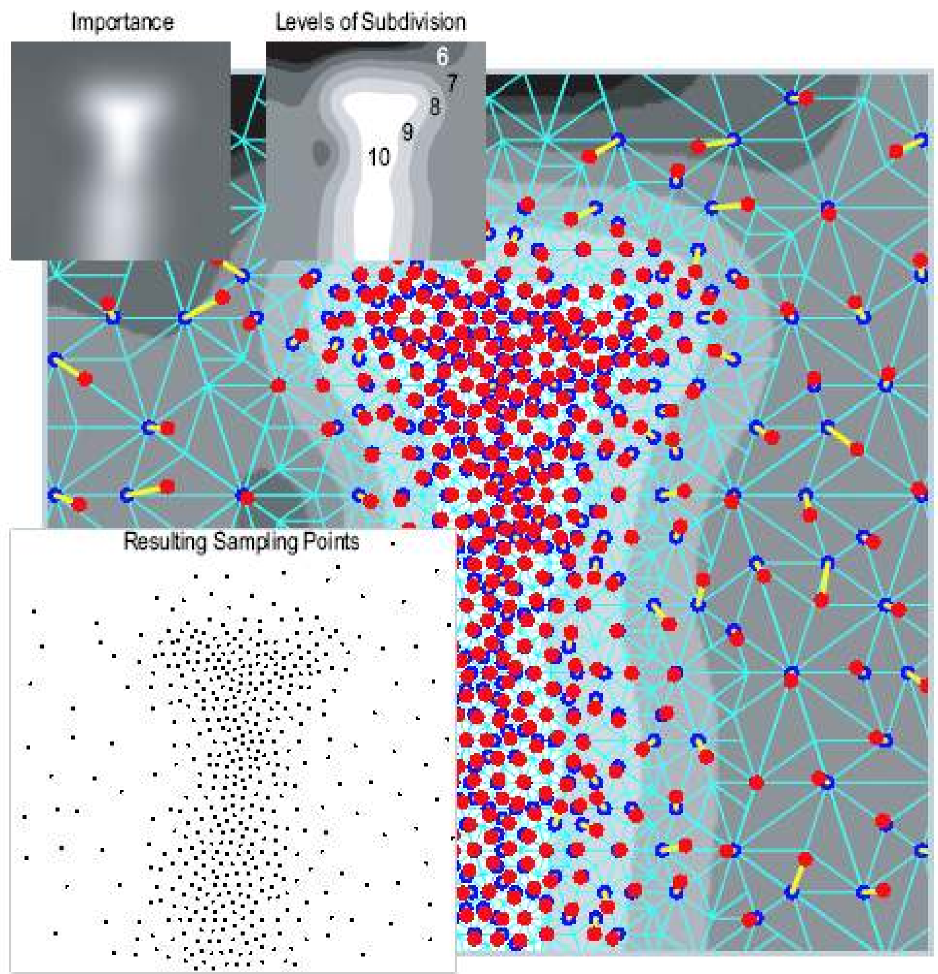
Figure 1: A high dynamic range 1024×512 environment map [Debevec 98] sampled with 3000 point lights. In this image, importance density is represented by the lightness of the background. It took 0.064 seconds on a 2.6 GHz P4 to generate this point set. Similar results using a hardware accelerated Lloyd relaxation [Hoff et al. 1999] required 1 second, while *Structured Importance Sampling* [Agarwal et al. 2003] took 1393 seconds.

b) Sample the Environment Map

Penrose Tiling



Subdivision



Hierarchical Sampling

Video Environment Maps Havran et al. 2005

- Dynamic environment map (changing in time)
- The environment map acquisition in real time using HDR camera with fish eye lens
- Precomputing the environment map to directional light sources for each frame with using importance sampling in real time.
- Rendering images on a GPU with shadow maps
- Further information:

  http://www.mpi-inf.mpg.de/resources/hdr/vem/

and Tomas Nikodym, Master Thesis, May 2012.

c) Sample the Product BRDF x Env. Map

- For sharp glossy BRDF and environment maps with concentrated light sources, sole BRDF sampling or environment map sampling cannot give a good results

1. Multiple Importance Sampling
   - Interesting, but not really useful for IBL
2. Sample / Resample
3. Wavelet Importance Sampling

   … and other papers

c) Sample the Product BRDF x Env. Map: Multiple Importance Sampling

- Veach & Guibas, SIGGRAPH 95, http://graphics.stanford.edu/papers/combine/
- Importance sampling of function *f* using several PDFs p_i ("sampling techniques")

$$F = \sum_{i=1}^{n} \frac{1}{n_i} \sum_{j=1}^{n_i} w_i(X_{i,j}) \frac{f(X_{i,j})}{p_i(X_{i,j})} \qquad \sum_i w_i(x) = 1$$

c) Sample the Product BRDF x Env. Map: <u>Multiple Importance Sampling</u>

- **Q:** How to combine the samples together to get the least variance? (i.e. how to choose weights w_i ?)
- **A:** Balance heuristic is a very good choice

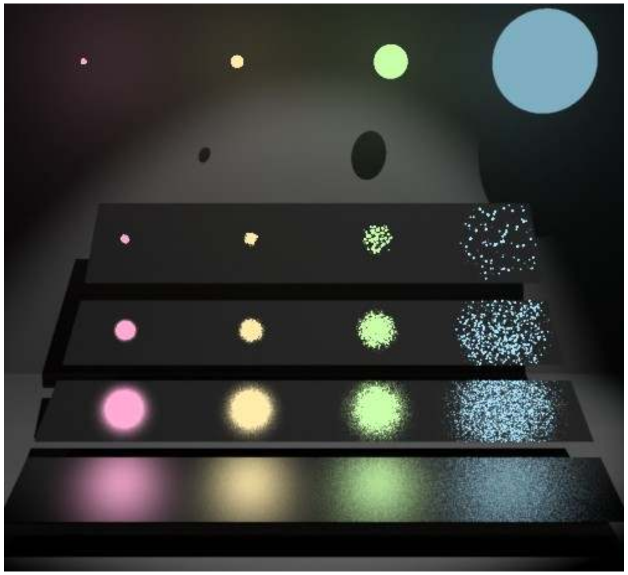
$$\hat{w}_i(x) = \frac{c_i p_i(x)}{\sum_j c_j p_j(x)}$$

c_i … relative number of samples taken from p_i

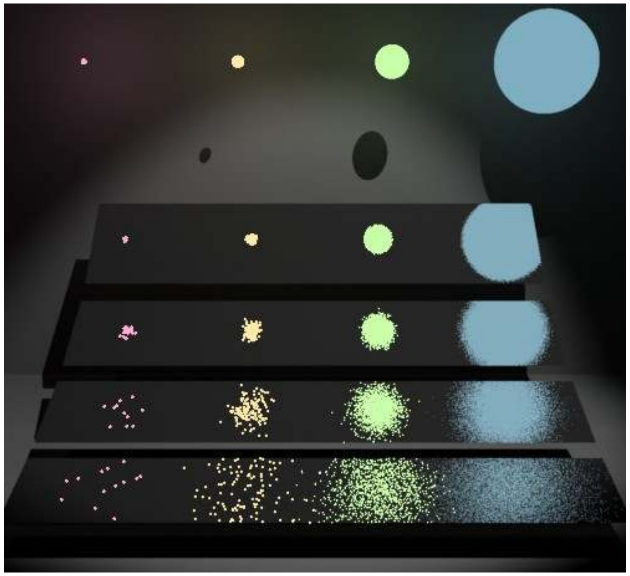
- more weight to more probable samples
- cancels out the importance sampling normalization

c) Sample the Product BRDF x Env. Map: Multiple Importance Sampling

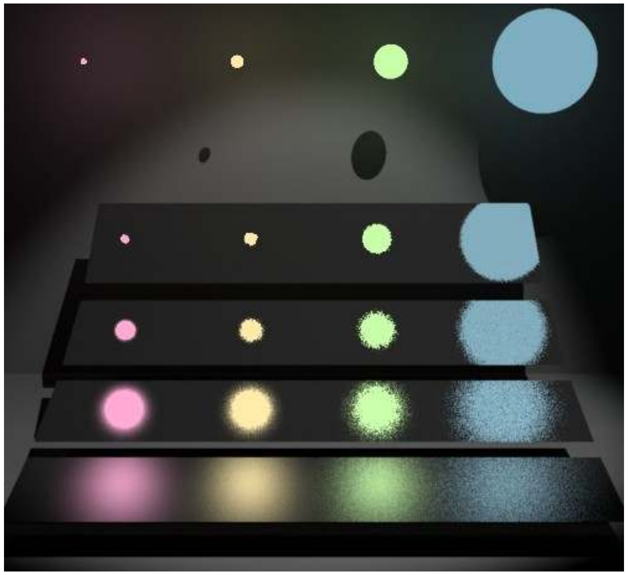
- Spherical light illuminating a glossy surface



Light source sampling



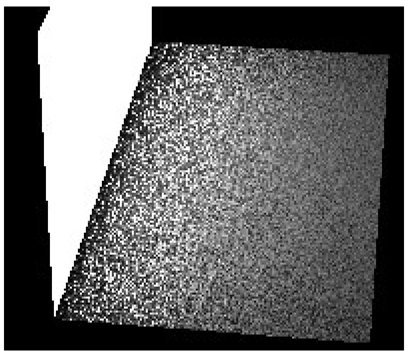
BRDF sampling



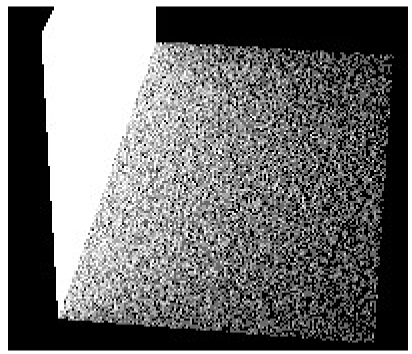
Balance heuristic

c) Sample the Product BRDF x Env. Map: Multiple Importance Sampling

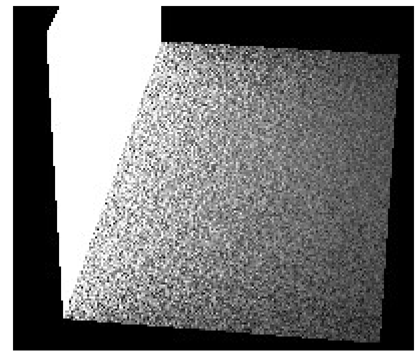
- Area light illuminating an adjacent polygon



Light source sampling



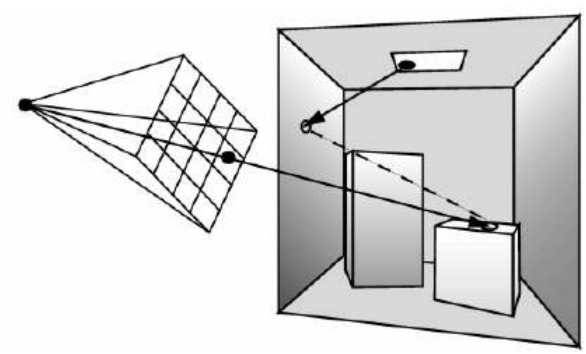
BRDF sampling



Balance heuristic

c) Sample the Product BRDF x Env. Map: Multiple Importance Sampling

- Combining paths in bidirectional path tracing



c) Sample the Product BRDF x Env. Map: Sample / Resample

- Algorithm
  - Propose samples from the environment map
  - Reject them if BRDF is too small for that direction
  - Test visibility (i.e. cast a visibility ray) only is sample not rejected
- Also possible to propose samples from BRDF and reject based on the environment map
- Computationally expensive – most samples are rejected

c) Sample the Product BRDF x Env. Map: Wavelet Importance Sampling

- Clarberg et al., SIGGRAPH 2005, http://graphics.ucsd.edu/papers/wis/

BRDF sampling Env. map sampling Product sampling

- Product cannot be pre-computed
  - different BRDF lobe for each pixel

c) Sample the Product BRDF x Env. Map: <u>Wavelet Importance Sampling</u>

- Pre-process
  - A MIP-map-like hierarchy of the environment map and the BRDF is constructed
- Sampling
  - Product BRDF x EM computed on-the-fly as the hierarchy is traversed
  - Uniform samples are warped according to probabilities in sub-trees

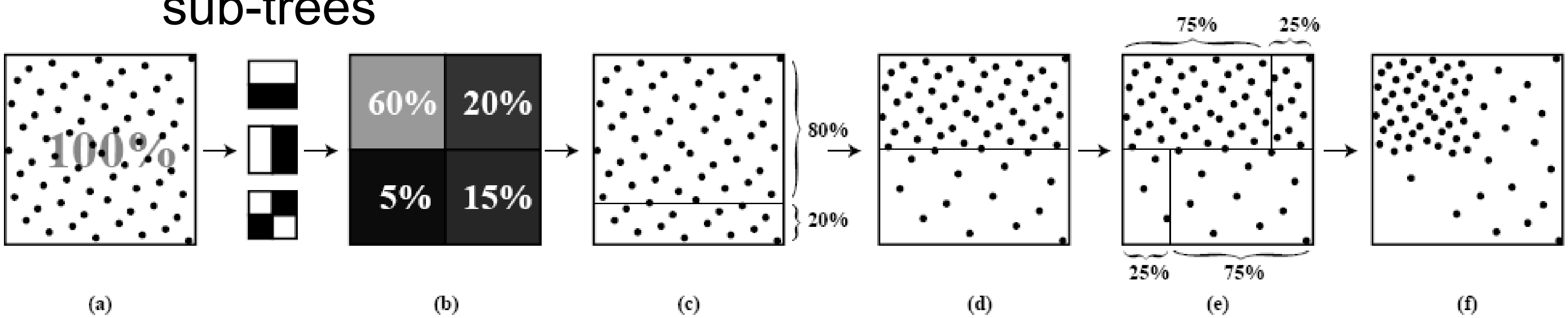


Figure 5: *Warping input points (a) according to one level of a wavelet-compressed importance map where the quadrant percentages (b) are derived from the wavelet coefficients for the current region using Equation 7. The initial point set is first partitioned into two rows with heights determined by their total probabilities (c) and then scaled to fit within the rows (d). Finally, each row is individually divided horizontally according to the probabilities of its child regions (e) and the points are again scaled to fit within the regions to arrive at the warped points for that level (f). The process repeats at step (a) for each child region using its allotted point set as input.*

c) Sample the Product BRDF x Env. Map: Wavelet Importance Sampling

- Good point distributions are preserved by WIS

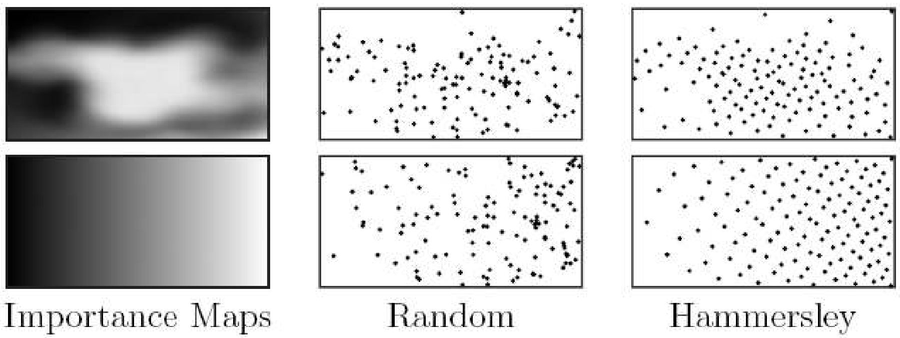


Figure 4: *Two example importance functions and 256 warped samples using uniform random points and Hammersley points. Our warping algorithm is able to preserve the quality of input point set.*

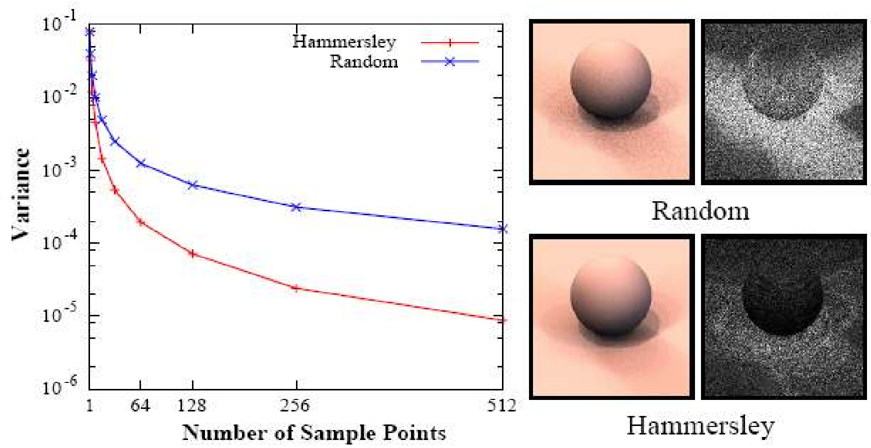


Figure 6: *Variance as a function of the number of samples used for rendering a simple scene illuminated by St. Peters cathedral. On the right are images rendered using 32 samples per pixel and their corresponding variance images. The warping scheme tends to preserve properties of the initial point distribution, hence the variance with Hammersley points is significantly lower than with uniform random points. Using 64 Hammersley points results in less variance than using 512 random points.*

Conclusion

- Image-Based Lighting essential for combining synthetic images with real footage
- Sampling approaches deliver good quality, but rendering is slow (around 300 shadow rays for each pixel)
- Real-time image-based lighting is possible under some restrictions (ignoring self-occlusion, low-frequency lighting etc.)