Introduction to Photon Mapping

*RADIANCE Workshop 2010 – Course Advanced Fenestration*

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Motivation: Caustics

Light transport from specular surfaces gives rise to *caustics* on diffuse surfaces.
Motivation: Caustics

RADIANCE traces rays “backwards”
[viewer → objects → sources] ⇒ inefficient and noisy.
Motivation: Caustics

Supplement RADIANCE with forward raytracer!
[sources $\rightarrow$ objects $\leftarrow$ viewer]
Overview

- Two-pass method based on Monte Carlo (light) particle transport simulation [Wann Jensen 1995]

**Forward pass** emits photons from light sources, scatters/absorbs at objects, deposits on diffuse surfaces $\Rightarrow$ mkpmap.

**Backward pass** evaluates irradiance from photons using RADIANCE’s ambient calculation $\Rightarrow$ rpict/rtrace/rvu.

- Photometrically validated [Schregle/Wienold 2004]
Forward Pass

- Photons emitted from light sources, scattered at surfaces according to material properties until absorbed (*russian roulette*).

- Indirect photon hits on diffuse surfaces stored in kd-tree along with position $\vec{x}$, flux $\Phi$, normal $\vec{N}$.

- **global** photons stored on every indirect [diffuse$\rightarrow$specular $\rightarrow$ diffuse] hit.

- **caustic** photons stored on every indirect [specular $\rightarrow$ diffuse] hit.

- **volume** photons stored in participating media (mist).
Forward Pass

→ Global → Caustic
Forward Pass

→ Global  → Caustic
**mkpmap**

*mkpmap* performs forward pass and generates photon maps, e.g.

```
mkpmap -apg scene.gpm 10k -apc scene.cpm 50k -apv scene.vpm 100k -t 60 scene.oct
```

generates global, caustic, and volume photon map files scene.{gpm,cpm,gpm} of approx. 10k, 50k, and 100k photons resp, with progress report every 60s.
Backward Pass

- Global photon irradiance after single ambient bounce
- Caustic photon irradiance at primary hitpoint
Density Estimation

Irradiance $\hat{f}$ is estimated from photon density:

- Find nearest $N$ photons at $\vec{x}$ in kd-tree
Density Estimation

Irradiance $\hat{f}$ is estimated from photon density:

- Find nearest $N$ photons at $\vec{x}$ in kd-tree
- Sum photon flux $\Phi_i$ weighted by normalised kernel $K$:

$$\hat{f}(\vec{x}) = \sum_{i=1}^{N} K(|\vec{x} - \vec{x}_i|) \Phi_i$$
rpict / rtrace / rvu

rpict et al. performs backward pass using photon maps, e.g.

```
 rpict -ab 1 -apg scene.gpm 50 -apc scene.cpm 50 -apv scene.vpm 50 ... scene.oct
```

Loads global, caustic, and volume photon maps and computes irradiance using 50 photons per density estimate each.

Photon maps may be reused for multiple viewpoints!
-\texttt{ab} has nonstandard behaviour:

- \texttt{ab} > 0: global photon irradiance via \textit{one} ambient bounce (regardless of actual -\texttt{ab})

- \texttt{ab} < 0: no ambient bounce, global photon irradiance at primary hitpoint

- \texttt{ab} = 0: no ambient component at all, caustics at primary hitpoint
Optimisations: Final Gather

Precompute and store irradiance for a fraction of global photons after forward pass [Christensen 2000]

- **PRO:** only look up single closest photon during backward pass and use precomputed irradiance directly
- **CON:** inaccurate with nonuniform ambient illum
Optimisations: Final Gather

Precomp. global photons rendered with -ab < 0
Optimisations: Final Gather

\[
\text{mkpmap} \ -\text{app} \ \text{scene.pgpm} \ 40k \ 50 \ -\text{apf} \ 0.25 \ \text{scene.oct}
\]

distributes 40k global photons, precomputes irradiance for \(0.25 \times 40k = 10k\) (discarding rest) using 50 photons / density estimate, and outputs them to photon map file.

\[
\text{rpict} \ -\text{ab} \ 1 \ -\text{app} \ \text{scene.pgpm} \ ... \\
\text{scene.oct}
\]

renders using closest precomputed global photon
Optimisations: Bias Compensation

Density estimation is inherently biased; photon irradiance $\hat{f}$ converges to actual irradiance $f$ convolved with $K$ rather than $f$ proper:

$$E \left[ \hat{f} (\vec{x}) \right] = \int_{\{ \vec{y} : \|\vec{x} - \vec{y}\| \leq r(N) \}} K (\|\vec{x} - \vec{y}\|) f (\vec{y}) d\vec{y}$$

Bias visible as blur, esp. in caustics and with large $N$

**BUT...** reducing $N$ increases noise!
Optimisations: Bias Compensation

Bias/noise tradeoff depends on photons/estimate $N$

$N=2000$

$N=20$
Optimisations: Bias Compensation

⇒ Dynamically adapt $N$ according to estimated bias in given interval $[N_{min}, N_{max}]$!
Optimisations: Bias Compensation

Bias Compensation adapts photons/density estimate $N$ to minimise bias and noise [Schregle 2003]
- Maintains running mean and variance of density estimates to estimate bias
- Increases $N$ until probable bias is detected

```
rpict ... -apcb scene.cpm 50 500
... scene.oct
```

renders caustics with bias compensation using 50..500 photons/density estimate.
Optimisations: Bias Compensation

$N = 50$ caustic/estimate  

$N = 500$ caustic/estimate
Optimisations: Bias Compensation

Bias compensated, 50..500 caustic/estimate
Optimisations: Photon Ports

Few photons emitted from source reach viewer (slow)
Optimisations: Photon Ports

⇒ Emit photons directly from window!
Optimisations: Photon Ports

- Ports define apertures as part of regular scene geometry for photon emission from sources.
- Flux incident from sources and occlusion taken into account.
- Photons emitted directly from port object.

Ports are specified by modifier, e.g.

```
mkpmap -apg scene.gpm 100k -apo windowMat scene.oct
```

distributes photons from all objects using the windowMat material in scene.oct.
Optimisations: Photon Ports

62k precomp. global
250k caustic
Port at pipe aperture
(antimatter material)
Utilities: pmapinfo

`pmapinfo <pmapFile>` gives following info on a photon map:

- photon map type (global, caustic, volume, etc)
- `mkpmap` command line used in forward pass
- Number of photons in map
- Average spectral photon flux
Utilities: pmapdump

pmapdump <radius> <pmapFile>...<pmapFile>
generates scene description of photons as spheres for visualisation of distribution in original scene, e.g.

% oconv scene.rad > scene.oct
% mkpmap -apg pmap.gpm -apc pmap.cpm scene.oct
% pmapdump 0.01 pmap.gpm pmap.cpm | oconv -n 16 - scene.rad > scene-distr.oct

Useful for debugging with small number of photons.
Utilities: pmapdump

5k global, 10k caustic dump
Example: Y-Glass

RADIANCE, 12 pm

-ab 10 -ad 4096 -aa 0.05 -ar 64
Example: Y-Glass

25k precomp. global, 100k caustic, ports at window
Example: CPC

0° incidence

45° incidence
Example: Volume Caustics

97k caustic photons
Limitations

- Not part of official distribution – requires patching and recompiling stock RADIANCE code
- (Still) no support for user defined BRDFs (brtdfunct, transfunc, transdata, etc)
- Suitable parametrisation requires some experience
- Slow with complex or pathological (e.g. “leaky” or highly absorbant) scene geometry
- Inaccurate density estimates on curved surfaces or outside plane
- Bias/noise tradeoff
Acknowledgements

Contributors: Peter Apian-Bennewitz, Jan Wienold, Christian Reetz, Carsten Bauer

Daylight Simulation with Photon Maps:
www.ganjatron.net/pmap/schregle-daylight_simulation_with_photon_maps.pdf

Official website: www.ise.fhg.de/radiance