Efficient Simulation of Light Transport in Scenes with Participating Media using Photon Maps

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Overview

- What is participative media?
- Mathematical formulation
- The Photon Map approach
- Results & Discussion

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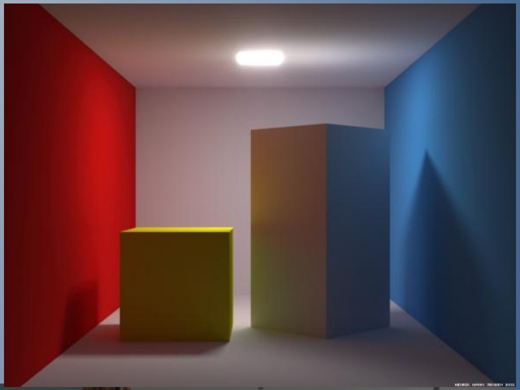
What is participative media?

- Till now
  - Assumption – only objects affect light
  - The medium does not affect light
- What about?
  - Fog
  - Smoke
  - Fire



What is participative media? (2)

- Light *does* interact with the certain media
  - Absorption
  - Scattering
  - Emission

Absorption

- Light can be attenuated while passing through certain media
  - Smoke

Scattering

- Light can scatter when passing through certain media
  - Single scattering – light is scattered once before reaching eye
  - Multiple scattering – light is scattered more than once before reaching eye

Emission

- In some cases the media will emit light
  - Fire
  - Explosions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Mathematical formulation

$$\frac{\partial L(x,\vec{w})}{\partial x} = \alpha(x)L_e(x,\vec{w}) + \sigma(x)L_i(x,\vec{w}) - \alpha(x)L(x,\vec{w}) - \sigma(x)L(x,\vec{w})$$

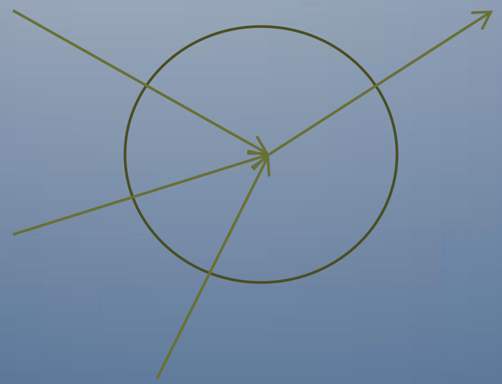
Emitted radiance | In-scattered radiance | Absorption | Out-scattered radiance

- α(x) – Absorption coefficient
- σ(x) – Scattering coefficient
- L_e – Emitted light
- L_i – In-scattered radiance

Mathematical Formulation (2)

$$\frac{\partial L(x,\vec{w})}{\partial x} = \alpha(x) L_e(x,\vec{w}) + \sigma(x) \int_{\Omega} f(x,\vec{w}',\vec{w}) L(x,\vec{w}') \partial w' - \kappa(x) L(x,\vec{w})$$

- κ(x) – Extinction coefficient = α(x) + σ(x)
- f(x,ω′, ω) – Scattering function



Mathematical Formulation (3)

$$\frac{\partial L(x,\vec{w})}{\partial x} = \alpha(x)L_e(x,\vec{w}) + \sigma(x)\int_\Omega f(x,\vec{w}',\vec{w})L(x,\vec{w}')\partial w' - \kappa(x)L(x,\vec{w})$$

- Simply integrating along a path from x_0 to x
- τ(x′,x) – Transmittance along line segment along x′ to x, = $e^{-\int_{x'}^{x}\kappa(\xi)\partial\xi}$

Mathematical formulation (4)

$$\alpha(x)L_e(x,\vec{w}) \Rightarrow \int_{x_0}^{x} \tau(x',x)\alpha(x')L_e(x',\vec{w})\partial x'$$

$$\sigma(x)\int_{\Omega} f(x,\vec{w}',\vec{w})L(x,\vec{w}')\partial w' \Rightarrow \int_{x_0}^{x} \tau(x',x)\sigma(x')\int_{\Omega} f(x,\vec{w}',\vec{w})L(x,\vec{w}')\partial w'\,\partial x'$$

$$L(x,\vec{w}) = \int_{x_0}^{x} \tau(x',x)\alpha(x')L_e(x',\vec{w})\partial x' + \int_{x_0}^{x} \tau(x',x)\sigma(x')\int_{\Omega} f(x,\vec{w}',\vec{w})L(x,\vec{w}')\partial w'\,\partial x' - \tau(x_0,x)L(x_0,\vec{w})$$

$$\tau(x,x') = e^{-\int_{x'}^{x}\kappa(\xi)\partial\xi}$$

And we're done with the math!

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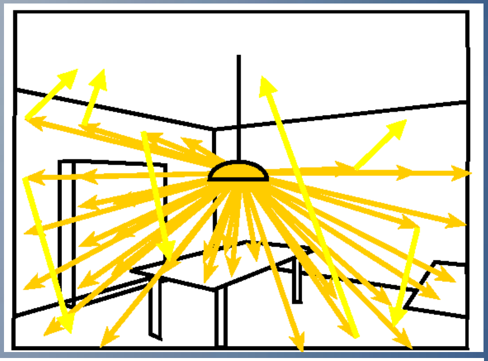
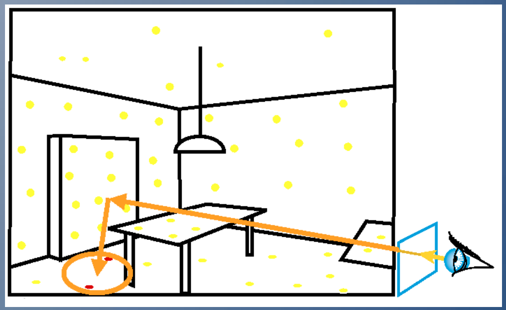
Photon Map review

- 2 pass algorithm
  - Pass 1: Trace photons through the scene
  - Pass 2: Use photons in ray tracing to get indirect illumination estimate
- Store in 2 k-D trees
  - Caustic Map (LS^+D)
  - Global/Indirect Illumination Map ($L(S|D)^+D$)



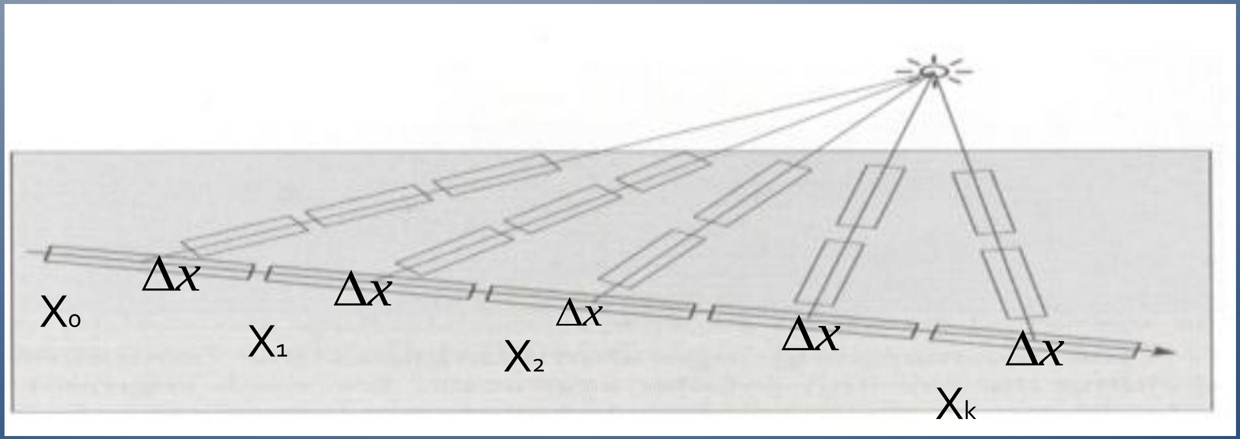


The Photon Map approach

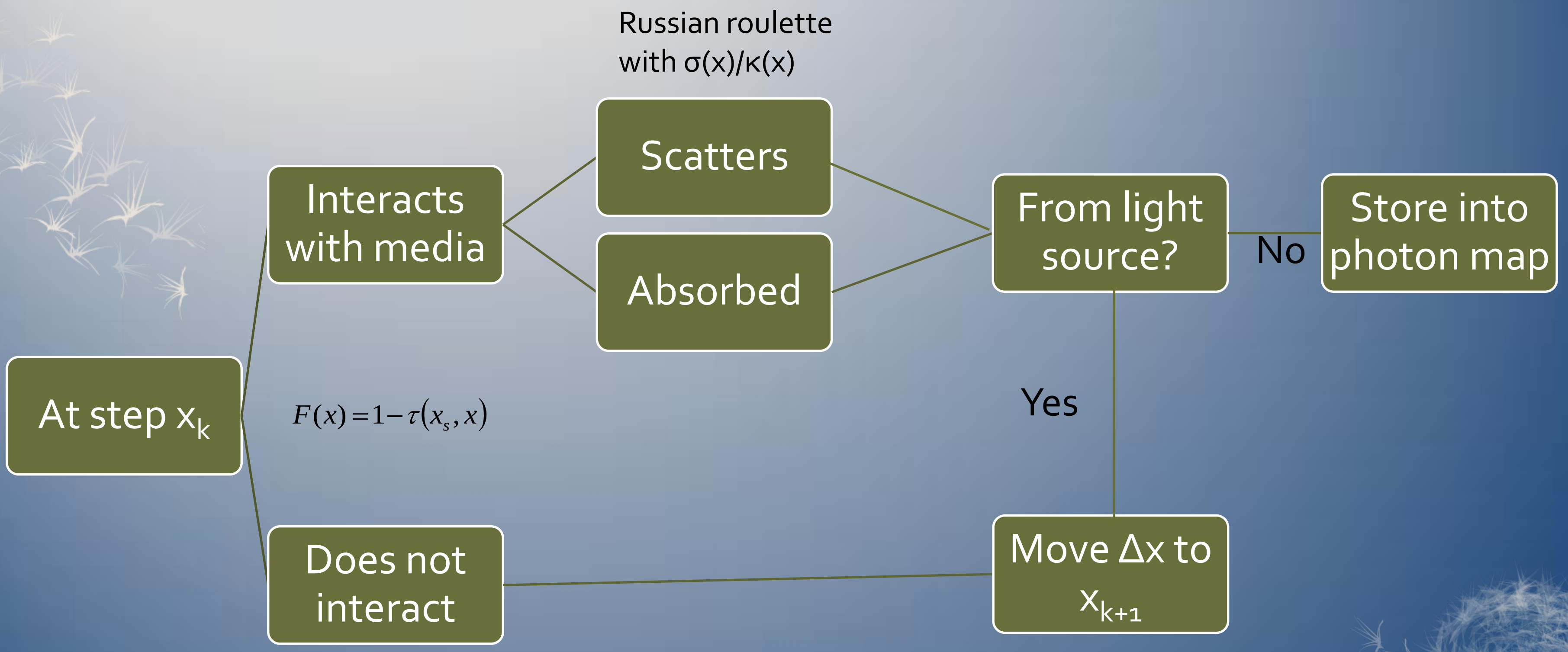
- Extend previous surface photon map approach
- Changes
  - Define a "volume photon map"
  - Photon data structure needs to be augmented with direction
- Justification for using k-D tree for storing photons! – 3-D storage data structure required
- Only indirect illumination – only store photons which
  - Have reflected or transmitted off an object before interaction with media ($L(S|D)^{+}M$)
  - Have been scattered at least once by media (LM^{+})

Ray Marching

- Integration scheme
- Move through a region with some step Δx
  - Integrate function with sampling at x_k
  - Used extensively for volume integration



Photon Map algorithm for participating media (Pass 1)



Rendering pass (Pass 2)

- Ray march through volume
- At each step

$$L(x_k,\vec{\omega}) = \alpha(x_k)L_e(x_k,\vec{\omega})\Delta x_k + \sigma(x_k)L_i(x_k,\vec{\omega})\Delta x_k + e^{-\kappa(x_k)\Delta x_k} L(x_{k-1},\vec{\omega})$$

$$L_i(x,\vec{\omega}) = L_{i,d}(x,\vec{\omega}) + \frac{\sigma(x)}{\kappa(x)} L_{i,i}(x,\vec{\omega})$$

- Δx_k is the step – can be recursively halved if radiance changes by too much
- Step size is also jittered to avoid aliasing

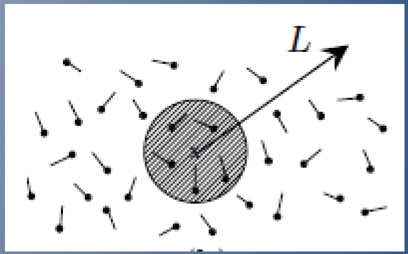
Finding In-scattered radiance

$$L(x,\vec{\omega}) = \frac{d^2\Phi(x,\vec{\omega})}{\sigma(x)\,d\omega\,dV}$$

$$L_i(x,\vec{\omega}) = \int_\Omega f(x,\vec{\omega}',\vec{\omega})L(x,\vec{\omega}')\,d\omega'$$

$$L_i(x,\vec{\omega}) = \frac{1}{\sigma(x)}\int_\Omega f(x,\vec{\omega}',\vec{\omega})\frac{d^2\Phi(x,\vec{\omega})}{dV}$$

$$L_i(x,\vec{\omega}) \approx \frac{1}{\sigma(x)}\sum_{p=1}^{n} f(x,\vec{\omega}_p',\vec{\omega})\frac{\Delta\Phi_p(x,\vec{\omega}_p')}{\frac{4}{3}\pi r^3}$$



- Gather n nearest photons and use their flux $\Delta\Phi$ to collect radiance
- In this step we only use indirect illumination, hence only those photons having indirect illumination are used

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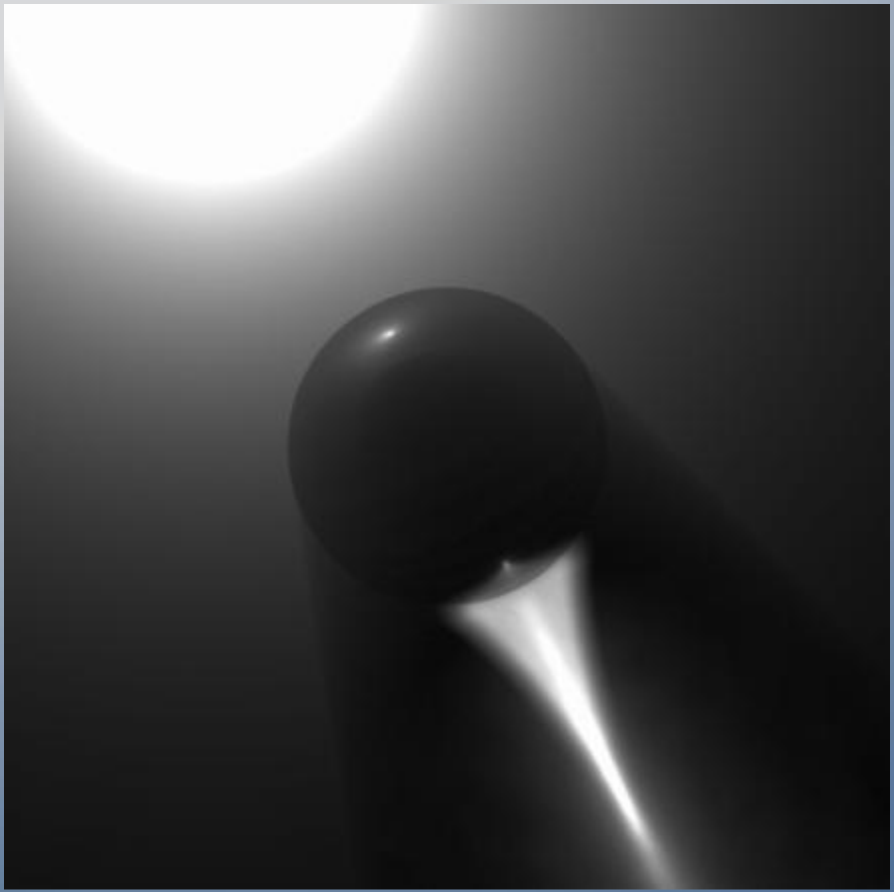
Results



Volume caustics!

Results (2)

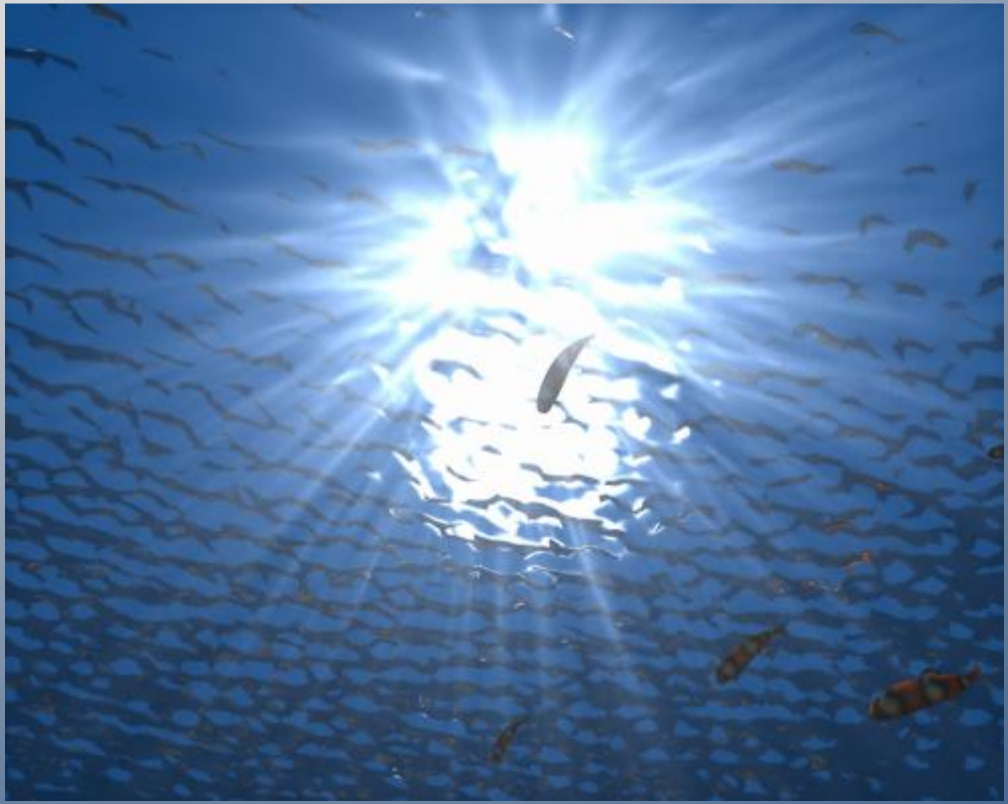
Scattering and absorption in an anisotropic heterogeneous media

Results (3)

Volume caustics for water

Results (4)

Results (5)



God (or crepuscular) rays

Advantages/Pitfalls

- Advantages
  - Claimed to be faster than Monte-Carlo methods
  - Better image quality
- Pitfalls
  - Large number of photons may be required – memory requirement
  - Doesn't scale to large scenes too well – people usually put it in future work
  - Still need light sources to model emissive media – no heuristic for naturally emitting media

References

- Efficient Simulation of Light Transport in Scenes with Participating Media using Photon Maps – Henrik Wann Jensen, Per H. Christensen
- Smoke simulation for Large Scale Media – Fedkiw et al.
- Per H. Christensen - http://www.seanet.com/~myandper/per.htm
- Henrik Wann Jensen - http://graphics.ucsd.edu/~henrik/
- Certain images from presentation by Jen-Yuan Chiang on the same paper (http://www.csie.ntu.edu.tw/~cyy/courses/rendering/05fall/assignments/pres/slides/volume.ppt)