Realistic fire rendering

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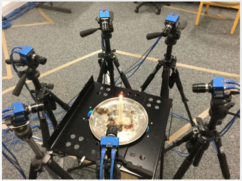
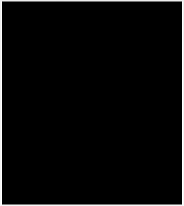
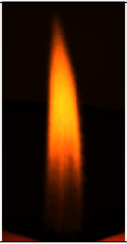
Overview

Outline

- Create, edit and visualize fire in virtual scenes
  - Common phenomena: candles, stoves, camp fires, ...
  - Widely used in VFX, safety and engineering simulations, ...
  - Dangerous and expensive, difficult reproducibility

Fire scene the film industry, image courtesy of ILM[1].

Pipeline

Capture		Processing		Visualization
Raw data		Refined data		Image
	→		→	

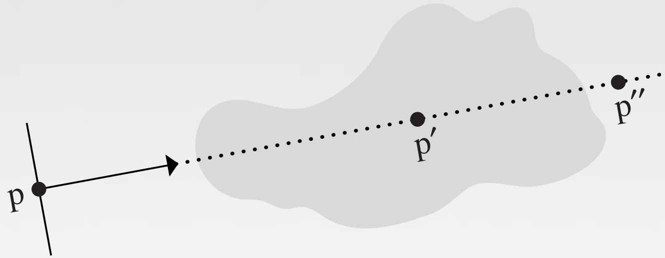


Diagram of light observed at p, image courtesy of Pharr and Humphreys (2004)

The problem

- Render fire realistically
  - Emission cannot be ignored
  - Heat transport
  - Multiphase flow
  - Chemical reactions
    - Fuel type

Real fire with paper as fuel, image courtesy of FireImage[2].

Outline

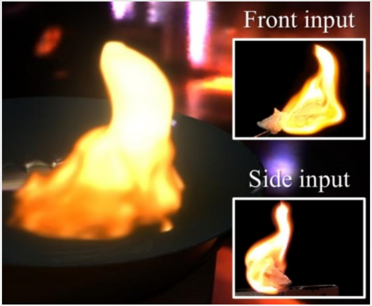
Previous work

- Ray-tracing-based
  - Physically based
  - Accurate
  - Slow
- Raster-based
  - Alpha blending
  - Many artefacts
  - Fast

Previous work: Results 1

Left, methane fire pool Pegoraro and Parker (2006); right, a dragon emits a flame Hong et al. (2007).

Previous work: Results 2



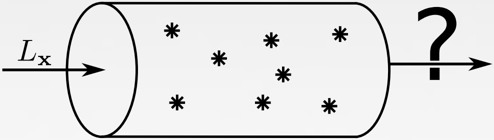
Left, a dragon emits a flame Jamriška et al. (2015); right, sparse flame reconstruction Okabe et al. (2015).

Outline

The model: Radiative Transport Equation

$$\boxed{(\nabla)L_{\mathbf{x}}} = -\sigma_a L_{\mathbf{x}} + \sigma_a L_e - \sigma_s L_{\mathbf{x}} + \sigma_s \int L_i \Phi d\omega_i$$

Differential of radiance
over a segment
for a wave number λ

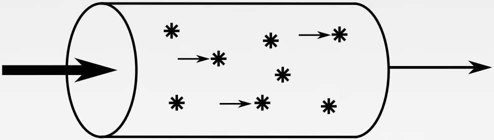


The model: Radiative Transport Equation

$$(\nabla)L_{\mathbf{x}} = \boxed{-\sigma_a L_{\mathbf{x}}} + \sigma_a L_e - \sigma_s L_{\mathbf{x}} + \sigma_s \int L_i \Phi d\omega_i$$

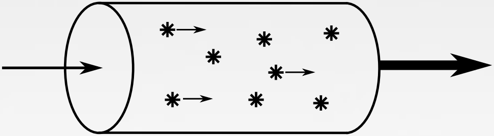
Absorption,

where σ_a is an absorption coefficient



$$(\nabla)L_{\mathbf{x}} = -\sigma_a L_{\mathbf{x}} + \boxed{\sigma_a L_e} - \sigma_s L_{\mathbf{x}} + \sigma_s \int L_i \Phi d\omega_i$$

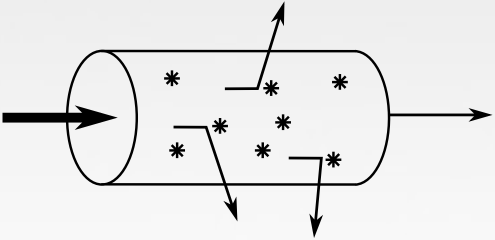
Emission



The model: Radiative Transport Equation

$$(\nabla)L_{\mathbf{x}} = -\sigma_a L_{\mathbf{x}} + \sigma_a L_e \boxed{-\sigma_s L_{\mathbf{x}}} + \sigma_s \int L_i \Phi d\omega_i$$

Out-scattering

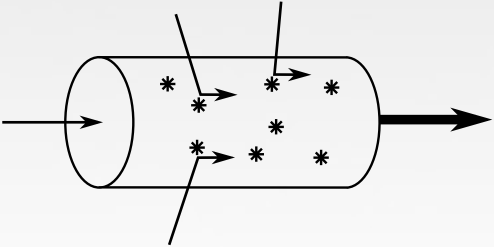


The model: Radiative Transport Equation

$$(\nabla)L_{\mathbf{x}} = -\sigma_a L_{\mathbf{x}} + \sigma_a L_e - \sigma_s L_{\mathbf{x}} + \boxed{\sigma_s \int L_i \Phi d\omega_i}$$

In-scattering,

where σ_s is a scattering coefficient, Φ a scattering function and ω_i is a incoming direction

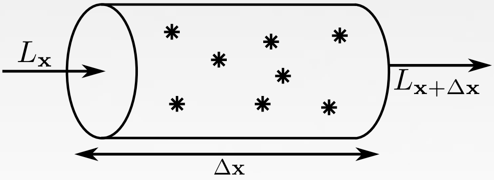


Analytical solution

$$L_{\mathbf{x}} = e^{-\sigma_t \|\Delta\mathbf{x}\|} L_{\mathbf{x}+\Delta\mathbf{x}} + \left(1 - e^{-\sigma_t \|\Delta\mathbf{x}\|}\right) \frac{\sigma_a L_e + \sigma_s \int L_i \Phi d\omega_i}{\sigma_t}$$

$$\sigma_t = \sigma_a + \sigma_s$$

Segment increment $\Delta\mathbf{x}$



The model: Important quantities

- Fuel type $\Rightarrow \sigma_a(\mathbf{x}, \lambda)$, $\sigma_s(\mathbf{x}, \lambda)$
  - Burning soot emission (Propane, Methane, ...)
  - Exotic chemicals (Copper, Lithium, ...)
- Black Body radiation $\Rightarrow L_e$
- Visual Adaptation $\Rightarrow L_{\mathbf{x}}$
- Refraction $\Rightarrow \Delta\mathbf{x}$
- Scattering function $\Rightarrow \Phi$

Outline

Prior simplifications

$$L_{\mathbf{x}} = e^{-\sigma_t \|\Delta \mathbf{x}\|} L_{\mathbf{x}+\Delta \mathbf{x}} + \left(1 - e^{-\sigma_t \|\Delta \mathbf{x}\|}\right) \frac{\sigma_a L_e + \sigma_s \int L_i \Phi d\omega_i}{\sigma_t}$$

Prior simplifications

$$L_{\mathbf{x}} = e^{-\sigma_t \|\Delta \mathbf{x}\|} L_{\mathbf{x}+\Delta \mathbf{x}} + \left(1 - e^{-\sigma_t \|\Delta \mathbf{x}\|}\right) \frac{\sigma_a L_e + \sigma_s \int L_i \Phi d\omega_i}{\sigma_t}$$

$$\sigma_s = 0.$$

Prior simplifications

$$\sigma_t = \sigma_a + \cancel{\sigma_s}$$

$$L_{\mathbf{x}} = e^{-\sigma_t \|\Delta \mathbf{x}\|} L_{\mathbf{x}+\Delta \mathbf{x}} + \left(1 - e^{-\sigma_t \|\Delta \mathbf{x}\|}\right) \frac{\cancel{\sigma_a} L_e + \cancel{\sigma_s \int L_i \Phi d\omega_i}}{\cancel{\sigma_t}}$$

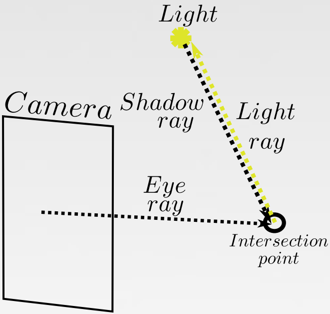
Prior simplifications

$$L_{\mathbf{x}} = e^{-\sigma_a \|\Delta \mathbf{x}\|} L_{\mathbf{x}+\Delta\mathbf{x}} + \left(1 - e^{-\sigma_a \|\Delta \mathbf{x}\|}\right) L_e$$

Constant refraction indices

Implementation overview

- MentalRay shader in Maya
  - Ray marching divides the RTE into
    - Light Ray $\rightarrow L_e$
    - Shadow Ray $\rightarrow e^{-\sigma_a \|\Delta \mathbf{x}\|} L_{\mathbf{x}+\Delta \mathbf{x}}$
    - Eye Ray $\rightarrow L_{\mathbf{x}} = e^{-\sigma_a \|\Delta \mathbf{x}\|} L_{\mathbf{x}+\Delta \mathbf{x}} + L_e$
  - Light shader
  - Volume/Shadow shader
  - Utility scripts

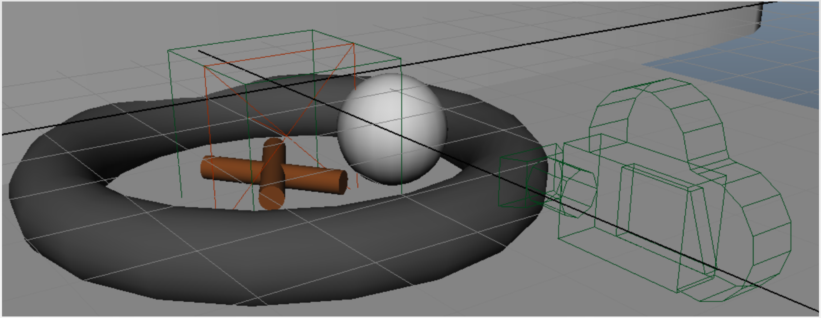


Rays diagram for a sample intersection point.

Other details

- Large memory footprint
  - Sparse voxel dataset library OpenVDB
- Validation with more data
  - Uintah simulation framework
- Different fuel types
  - NIST atomic emission spectra database

Results I

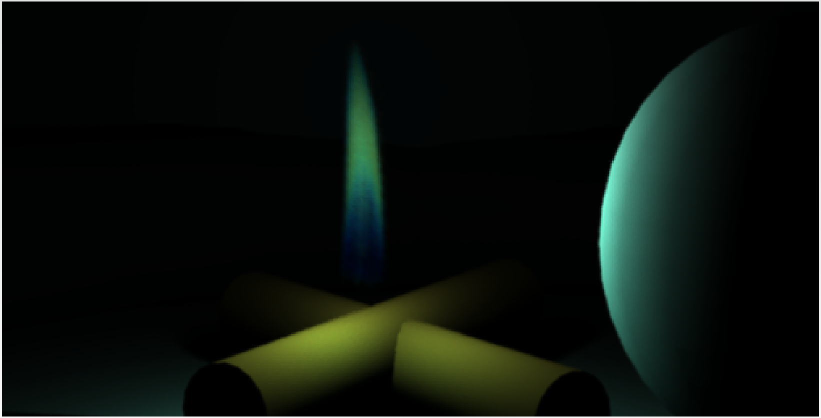


The test scene.

Results II

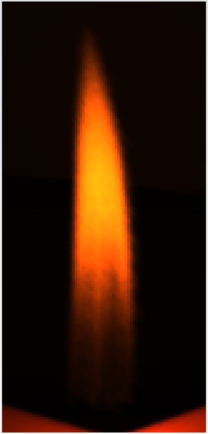
Propane flame, left raw data.

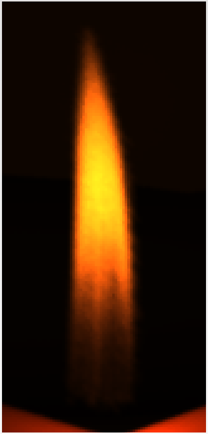
Results III



Flame with copper fuel.

Results IV





Visual adaptation to the flame; left, no adaptation, right, fully adapted.

Results V

A complex scene with several flames.

Conclusions and Future Work

- Limitations
  - Difficult parametrization
  - Relies on tabulated data
  - Computationally intensive
  - Spherical particles
- Future work
  - Importance sampling, Mizutani and Iwasaki (2014); Wang et al. (2014)
  - Automatic parameter estimation

Parameter Estimation

- Image differencing
  - Search in the physical parameters
  - Gradient descent
  - Previous work Dobashi et al. (2012)
- Spectrum reconstruction
  - Under constrained
  - Prior knowledge: Camera spectral sensitivity
  - Previous work Smits (1999); Sun et al. (2001); Drew and Finlayson (2003)

Thank you

Questions?

References I

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[1] http://www.ilm.com/
[2] https://en.wikipedia.org/wiki/File:Fire.JPG