Realistic fire rendering

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Overview

Outline

Introduction

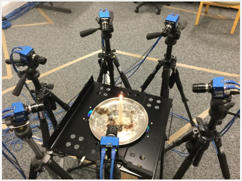
- Manipulate fire in virtual scenes
  - Create
  - Edit
  - Visualize

Real fire with paper as fuel, image courtesy of FireImg1 (2015).

Pipeline

Capture

Raw data



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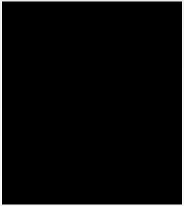
Processing

Refined data



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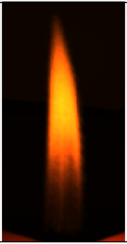
Visualization

Image



Volume rendering area

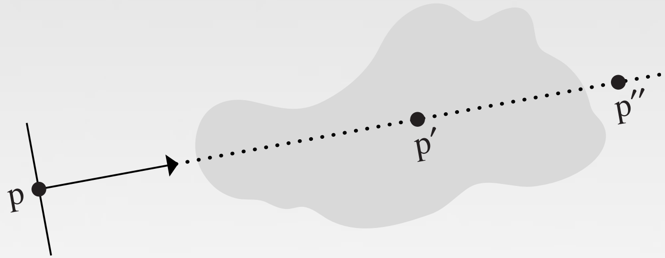


Diagram of light observed at p, image courtesy of Pharr and Humphreys (2004)

The problem

- Render fire realistically
  - Participating media
  - Emission cannot be ignored
  - Varied fuel types

Real fire with paper as fuel, image courtesy of FireImg1 (2015).

Outline

Previous work

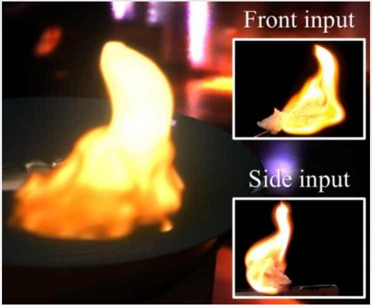
- Ray-tracing-based
  - Physically based
  - Accurate
  - Slow

- Raster-based
  - 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).

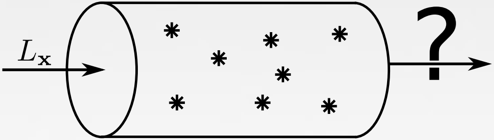
The model: RTE

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

The model: RTE

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

Differential of radiance over a segment



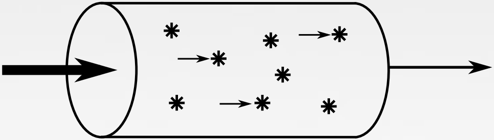
$$(\nabla)L_{\mathbf{x}} = \boxed{-\sigma_a L_{\mathbf{x}}} + \sigma_a L_e - \sigma_s L_{\mathbf{x}} + \sigma_s \int L_i \Phi d\omega_i$$

Absorption,

where σ_a is

an absorption

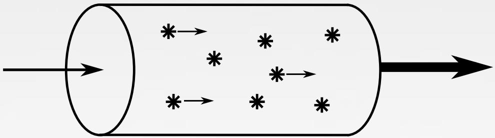
coefficient



The model: RTE

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

Emission

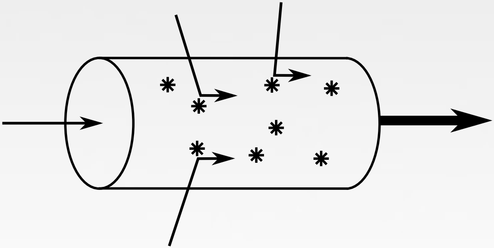


The model: RTE

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

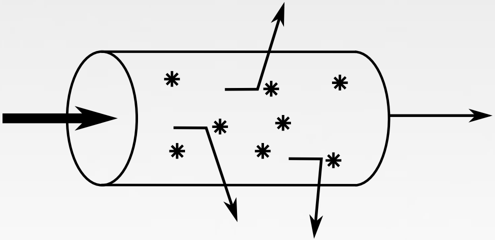
In-scattering,

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



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

Out-scattering



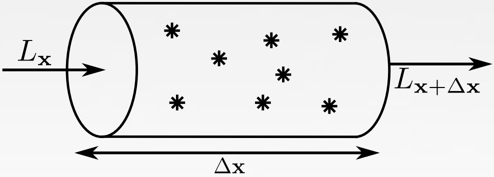
The model: RTE

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

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

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

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

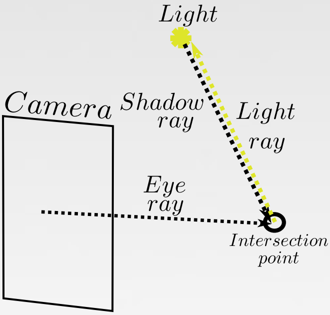
Prior simplifications

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

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



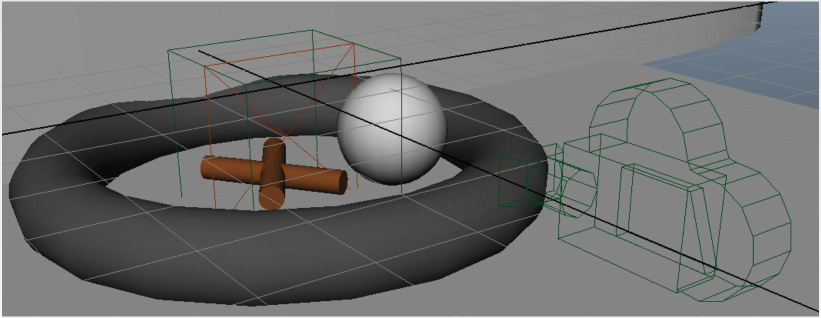
Rays diagram for a sample intersection point.

Other details

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

Outline

Results I

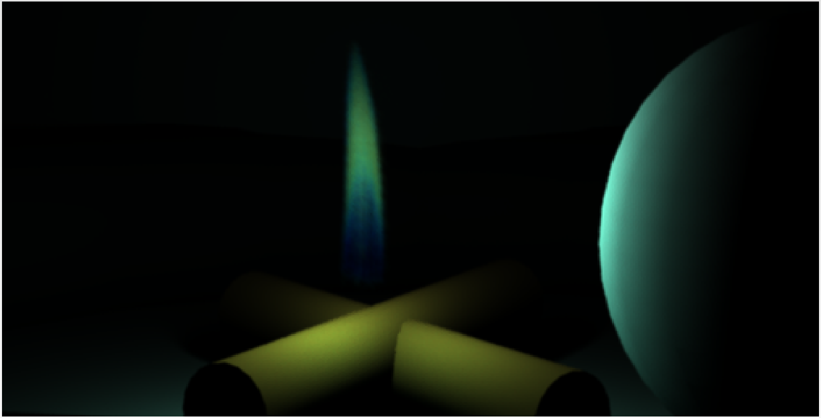


The test scene.

Results II

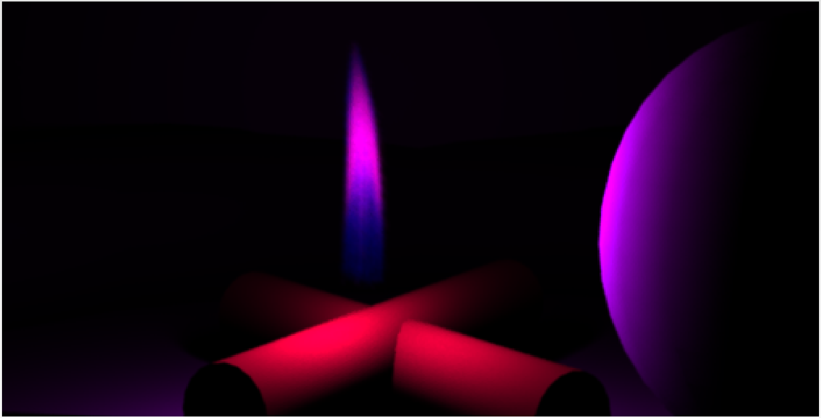
Propane flame.

Results III



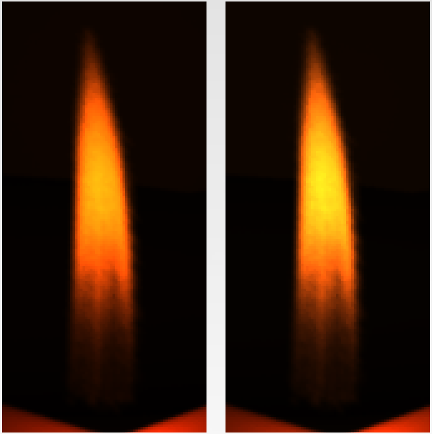
Flame with copper fuel.

Results IV



Flame with sulfur fuel.

Results V



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

Conclusions and Future Work

- Limitations
  - Difficult parametrization
  - Relies on tabulated data
  - Computationally intensive
  - Spherical particles
- Future work
  - Importance sampling
  - Automatic parameter estimation

Parameter Estimation

- Spectrum reconstruction
- Under constrained
- Prior knowledge
  - Camera sensitivity
- Previous work, Smits (1999), Sun et al. (2001), Drew and Finlayson (2003)

Thank you

Questions?

References I

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