King Abdullah University of Science and Technology KAUST

CS 247 – Scientific Visualization
Lecture 16: Volume Visualization, Pt. 3

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Reading Assignment #8 (until Mar 26)

Read (required):

- Real-Time Volume Graphics, Chapter 4 (Transfer Functions) until Sec. 4.4 (inclusive)
- Paper:

  Jens Krüger and Rüdiger Westermann,
  Acceleration Techniques for GPU-based Volume Rendering,
  IEEE Visualization 2003,
  `http://dl.acm.org/citation.cfm?id=1081482`

Quiz #2: Apr 2

Organization

- First 30 min of lecture
- No material (book, notes, ...) allowed

Content of questions

- Lectures (both actual lectures and slides)
- Reading assignments (except optional ones)
- Programming assignments (algorithms, methods)
- Solve short practical examples

Volume Rendering

Volume Rendering Integral Summary

Volume rendering integral
for *Emission Absorption* model

$$I(s) = I(s_0)\, e^{-\tau(s_0,s)} + \int_{s_0}^{s} q(\tilde{s})\, e^{-\tau(\tilde{s},s)}\, \mathrm{d}\tilde{s}$$

$$\tau(s_1, s_2) = \int_{s_1}^{s_2} \kappa(s)\, ds.$$

Iterative/recursive numerical solutions:

Back-to-front compositing

$$C'_i = C_i + (1 - A_i) C'_{i-1}$$

Front-to-back compositing

$$C'_i = C'_{i+1} + (1 - A'_{i+1}) C_i$$

$$A'_i = A'_{i+1} + (1 - A'_{i+1}) A_i$$

here, all colors are *associated* colors!

Opacity Correction

Opacity Correction

Simple compositing only works as far as the opacity values are correct… and they depend on the sample distance!

$$T_i = e^{-\int_{s_i}^{s_i+\Delta t} \kappa(t)\,dt} \approx e^{-\kappa(s_i)\Delta t} = e^{-\kappa_i \Delta t}$$

$$A_i = 1 - e^{-\kappa_i \Delta t}$$

$$\tilde{T}_i = T_i^{\left(\frac{\Delta \tilde{t}}{\Delta t}\right)}$$

$$\tilde{A}_i = 1 - (1 - A_i)^{\left(\frac{\Delta \tilde{t}}{\Delta t}\right)}$$

opacity correction formula

beware that usually this is done *for each different scalar value* (every transfer function entry), not actually at spatial positions/intervals *i*

Associated Colors

Associated (or *"opacity-weighted"* colors) are often used in compositing equations

Every color is *pre-multiplied* by its corresponding opacity

$$\begin{bmatrix} R \\ G \\ B \\ A \end{bmatrix} \Rightarrow \begin{pmatrix} R*A \\ G*A \\ B*A \\ A \end{pmatrix}$$

Our compositing equations assume associated colors!

Important: After opacity correction (updating all opacities accordingly), all *associated colors* must also be updated accordingly! (or combined/multiplied correctly on-the-fly!)

Interlude: “Self-Absorption” (1)

Our previous derivation of the discretization of the volume rendering integral skipped over a small but important detail:

Emission and absorption combine in the same segment (interval)!

$$I(s_n) = I_0 \, e^{-\int_{s_0}^{s_n} \kappa(t)\,\mathrm{d}t} + \sum_{i=0}^{n-1} I(s_i, s_{i+1}) \, e^{-\int_{s_{i+1}}^{s_n} \kappa(t)\,\mathrm{d}t} .$$

$$I(s_i, s_{i+1}) = \int_{s_i}^{s_{i+1}} q(s) \, e^{-\int_{s}^{s_{i+1}} \kappa(t)\,\mathrm{d}t} \,\mathrm{d}s,$$

Interlude: "Self-Absorption" (2)

Piecewise constant approximation, *but* correct integration

$$I(s_i, s_{i+1}) = \int_{s_i}^{s_{i+1}} q(s)\, e^{-\int_{s}^{s_{i+1}} \kappa(t)\,\mathrm{d}t}\, \mathrm{d}s,$$

not piecewise constant q, κ

$$\bar{I}(s_i, s_{i+1}) = \int_{s_i}^{s_{i+1}} q_i\, e^{-\kappa_i \cdot (s_{i+1} - s)}\, \mathrm{d}s,$$

piecewise constant q, κ

$$q(s) = q_i \quad \forall s \in [s_i, s_{i+1})$$

$$\kappa(s) = \kappa_i \quad \forall s \in [s_i, s_{i+1})$$

$$I(s_i, s_{i+1}) \approx \bar{I}(s_i, s_{i+1})$$

Interlude: "Self-Absorption" (3)

Piecewise constant approximation, *but* correct integration

$$\bar{I}(s_i, s_{i+1}) = q_i e^{-\kappa_i s_{i+1}} \int_{s_i}^{s_{i+1}} e^{\kappa_i s} \, \mathrm{d}s.$$

$$= q_i e^{-\kappa_i s_{i+1}} \left(\frac{1}{\kappa_i} e^{\kappa_i s_{i+1}} - \frac{1}{\kappa_i} e^{\kappa_i s_i} \right)$$

$$= \frac{q_i}{\kappa_i} \left(1 - e^{-\kappa_i \cdot (s_{i+1} - s_i)} \right),$$

$$= \frac{q_i}{\kappa_i} \left(1 - e^{-\kappa_i \Delta t} \right).$$

Associated Colors in Volume Rendering

Standard emission-absorption optical model

- Only *one kind of particle*: the same particles that absorb light, emit light
- Aha! Therefore lower absorption means lower emission as well

Light observed from (in front of) segment *i* (without any light behind it):

$$C_i = \frac{q_i}{\kappa_i}\left(1 - e^{-\kappa_i \Delta t}\right) = \hat{C}_i A_i$$

$$q_i := \hat{C}_i \kappa_i$$

$$A_i := 1 - e^{-\kappa_i \Delta t}$$

$$\lim_{\kappa_i \to 0} q_i \frac{\left(1 - e^{-\kappa_i \Delta t}\right)}{\kappa_i} = \lim_{\kappa_i \to 0} \hat{C}_i \left(1 - e^{-\kappa_i \Delta t}\right) = 0$$

$$\lim_{\kappa_i \to \infty} q_i \frac{\left(1 - e^{-\kappa_i \Delta t}\right)}{\kappa_i} = \lim_{\kappa_i \to \infty} \hat{C}_i \left(1 - e^{-\kappa_i \Delta t}\right) = \hat{C}_i$$

hold $\hat{C}_i$ fixed! (as a fixed ratio)

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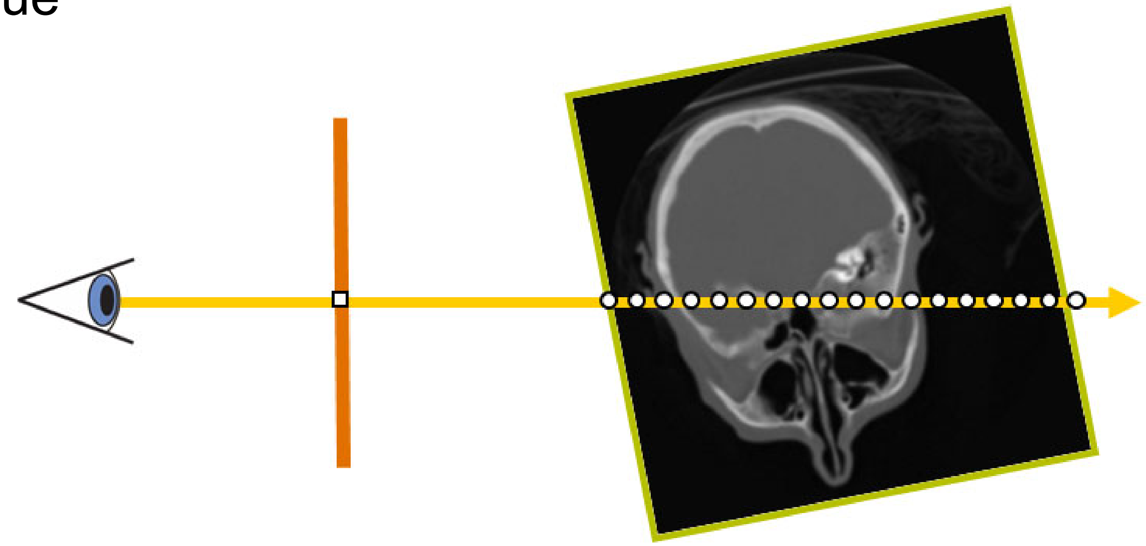
Implementation

Implementation

Ray setup

Loop over ray

- Resample scalar value
- Classification
- Shading
- Compositing



Implementation

Ray setup

Loop over ray

- Resample scalar value
- Classification
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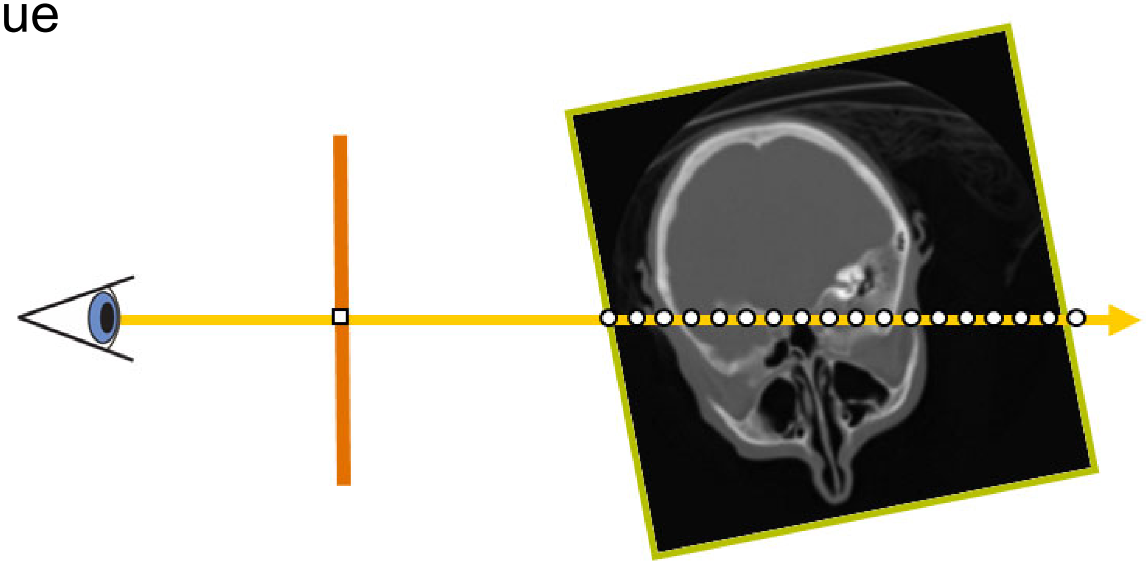
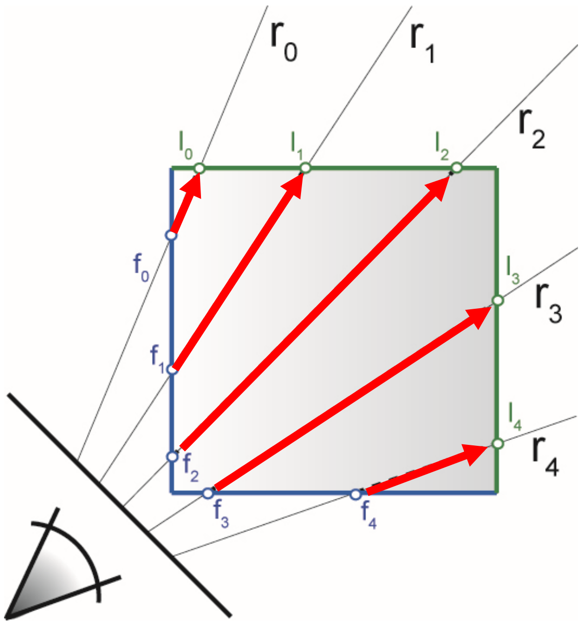
- Compositing



Ray Setup

Two main approaches:

- Procedural ray/box intersection [Röttger et al., 2003], [Green, 2004]
- Rasterize bounding box [Krüger and Westermann, 2003]

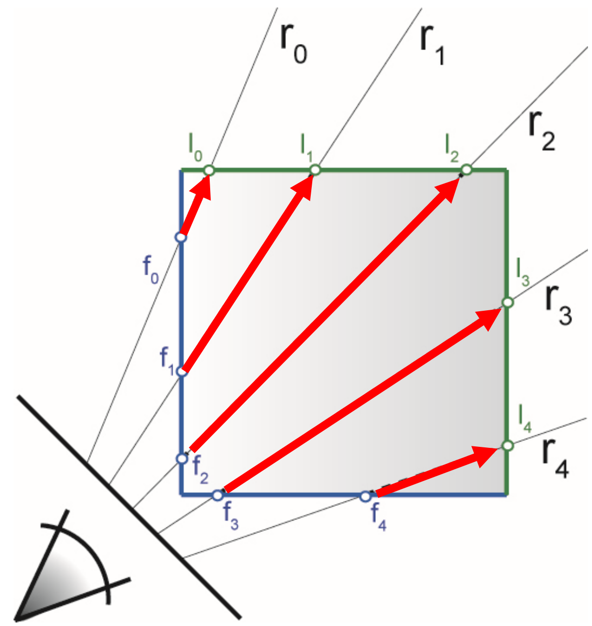


Some possibilities

- Ray start position and exit check
- Ray start position and exit position
- Ray start position and direction vector

Procedural Ray Setup/Termination

- Everything handled in the fragment shader / CUDA kernel
- Procedural ray / bounding box intersection

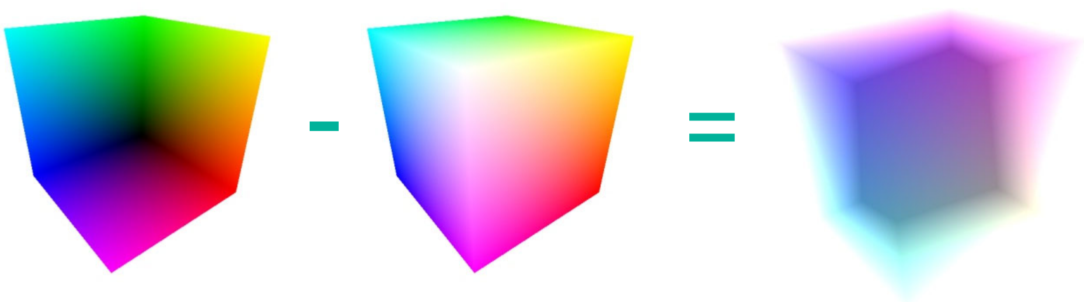


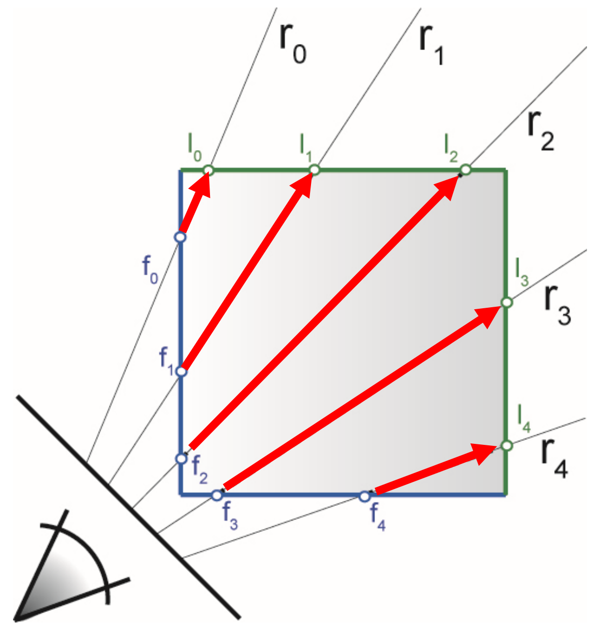
- Ray is given by camera position and volume entry position
- Exit criterion needed

- Pro: simple and self-contained
- Con: full computational load per-pixel/fragment

Rasterization-Based Ray Setup

- Fragment == ray
- Need ray start pos, direction vector
- Rasterize bounding box





- Identical for orthogonal and perspective projection!

Thank you.

Thanks for material

- Helwig Hauser
- Eduard Gröller
- Daniel Weiskopf
- Torsten Möller
- Ronny Peikert
- Philipp Muigg
- Christof Rezk-Salama