Volume Scattering Probability Guiding

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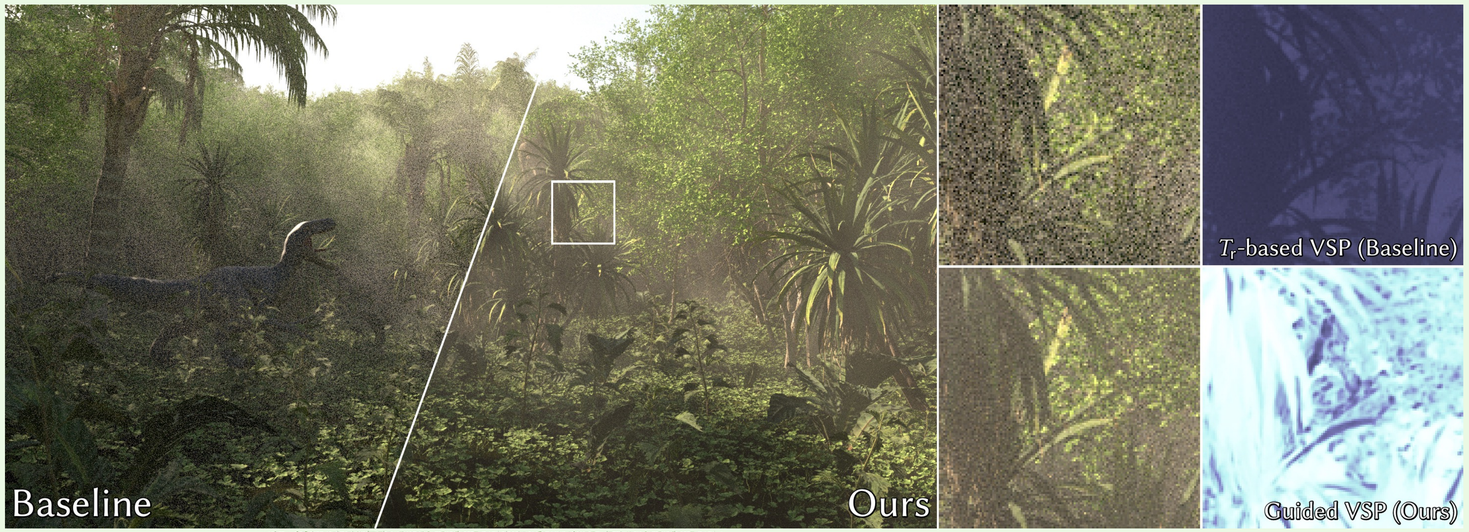
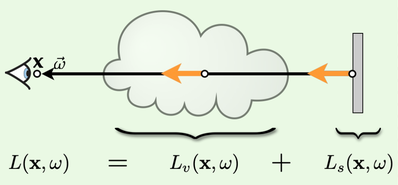


Motivation

P_{vol} = **Volume Scattering Probability** = **Vol-Surf (Sample) Ratio**

Volume Rendering Equation

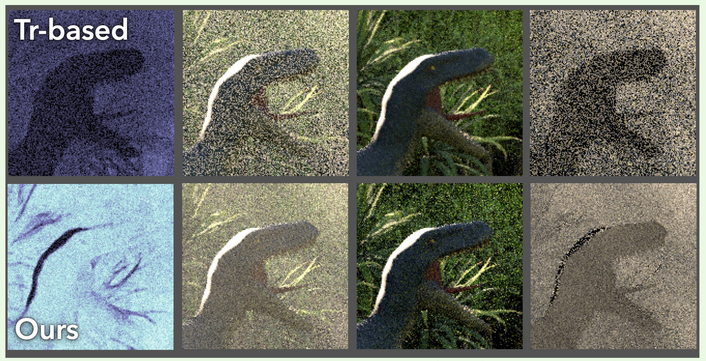


$$L(\mathbf{x},\omega) = L_v(\mathbf{x},\omega) + L_s(\mathbf{x},\omega)$$

Monte Carlo Estimator

$$\langle L(\mathbf{x},\omega)\rangle = \begin{cases} \frac{1}{P_{\text{vol}}}\langle L_v(\mathbf{x},\omega)\rangle \\ \frac{1}{1-P_{\text{vol}}}\langle L_s(\mathbf{x},\omega)\rangle \end{cases}$$

P_{vol}: the binary sample distribution between surface and volume



P_{vol} $\quad L(\mathbf{x},\omega) = L_s(\mathbf{x},\omega) + L_v(\mathbf{x},\omega)$

- Many works on optimizing $\langle L_v \rangle$ and $\langle L_s \rangle$
- P_{vol} is an important decision that has been previously ignored
- Bad P_{vol} can be a source of noise

Optimal Vol-Surf Ratio in Theory

- Minimize the variance of the total estimator
- Two criteria: **contribution-based** and **variance-based**
  - Assume the nested estimators have **no variance**

$$P_{\text{vol}}^{\text{1st}} = \frac{\mathbb{E}[\langle L_v(x,\omega)\rangle]}{\mathbb{E}[\langle L_v(x,\omega)\rangle] + \mathbb{E}[\langle L_s(x,\omega)\rangle]}$$

  - Consider the **variance** of the nested estimators

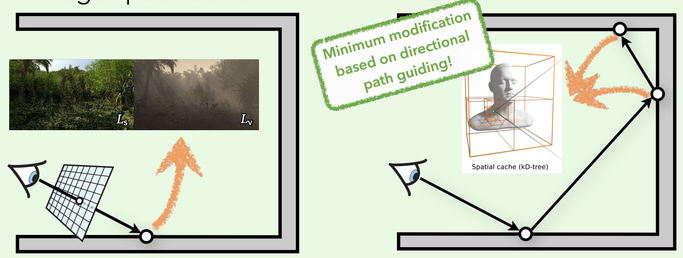
$$P_{\text{vol}}^{\text{2nd}} = \frac{\mathbb{E}[\langle L_v(x,\omega)\rangle^2]}{\mathbb{E}[\langle L_v(x,\omega)\rangle^2] + \mathbb{E}[\langle L_s(x,\omega)\rangle^2]}$$

Optimal Vol-Surf Ratio in Practice

Store Estimates

Primary ray: image space buffer

Secondary ray: 5D spatial-directional



References:

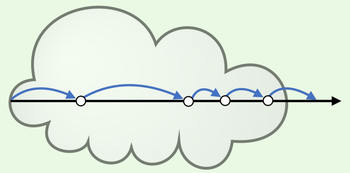
- Efficient Unbiased Rendering of Thin Participating Media. Villemin et al. 2018.
- Product Importance Sampling of the Volume Rendering Equation using Virtual Density Segments. Wrenninge and Villemin. 2020.
- Volume Path Guiding Based on Zero-variance Random Way Theory. Herholz et al. 2019.
- Variance-aware Path Guiding. Rath et al. 2020.

Project Page

Our approach reallocates computational effort between volume and surface components to enhance volume rendering efficiency.

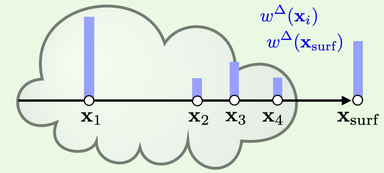
Reach the Optimal Vol-Surf Ratio

1: Delta Tracking as Resampling



Continued distance sampling → **candidate samples**

2: Resampling Weights for Delta Tracking



Computed from local volume properties

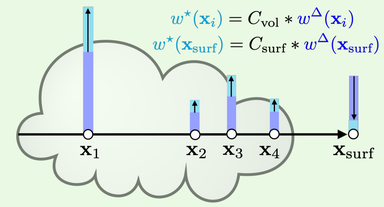
Order

4: Reservoir Sampling

$$\mathbb{P}[\text{Accept } i] = \frac{w_i}{\sum_{j \le i} w_j}$$

No need to store all the candidate samples

3: Resampling Weights for VSP Guiding



Two constants!

Exactly reaches the target P_{vol}

Summary

- **Key insight:** explicitly controlling P_{vol} can improve efficiency
- A practical framework for:
  1. Computing the optimal P_{vol}
  2. Achieve precise control over P_{vol}

✓ Unbiased

✓ Easy to implement & minimal overhead

- Perfect combination with directional guiding!

✓ Fully automatic, no user parameter