Interactive Path Tracing and Reconstruction of Sparse Volumes

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Presenter: Chanhyeok Lee

Index

- Introduction
- Renderer
- Denoising
- Evaluation
- Conclusion

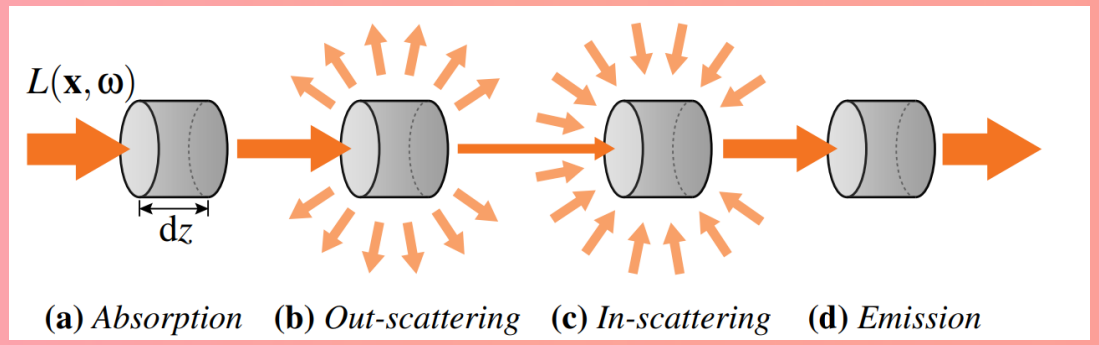
Introduction

- Path tracing is well established and now widely used
- Difficult to leverage graphic hardware with grid a voxel grid
- SOTA rendering + neural denoising

Introduction – Background

- Rendering with Participating Media

$$(\omega \cdot \nabla)L(x,\omega) = \mu_a(x)L(x,\omega) - \mu_s(x)L(x,\omega) + \mu_s(x)L_s(x,\omega) + \mu_a(x)L_e(x,\omega) ,$$

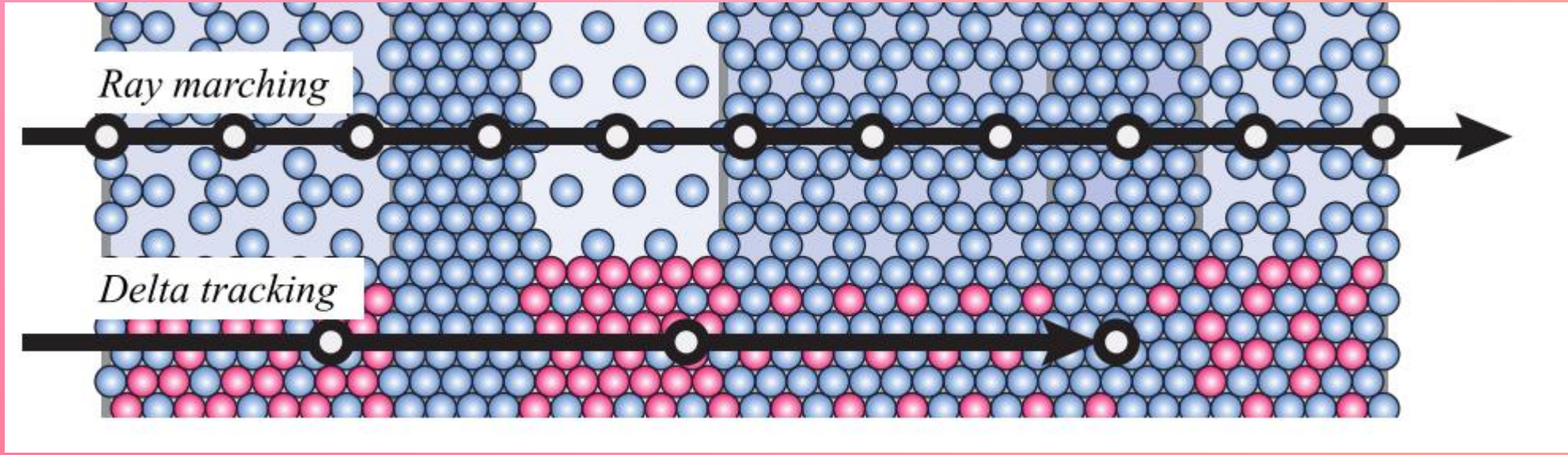


$$L(x,\omega) = \int_0^\infty T(x,y)\left[\mu_a(y)L_e(y,\omega) + \mu_s(y)L_s(y,\omega)\right] dy .$$

Jan Novák, Iliyan Georgiev, Johannes Hanika, and Wojciech Jarosz. 2018. Monte Carlo methods for volumetric light transport simulation. In Computer Graphics Forum, Vol. 37. Wiley Online Library, 551–576.

Introduction – Background

- Null Collision Algorithm



Jan Novák, Andrew Selle, and Wojciech Jarosz. 2014. Residual ratio tracking for estimating attenuation in participating media. ACM Trans. Graph. 33, 6 (2014), 179–1.

Introduction – Background

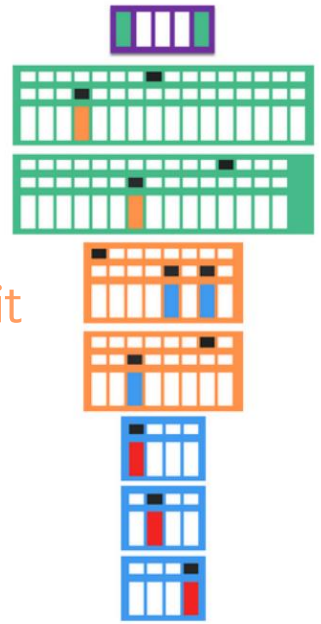
- Denoising
- Many samples: high quality, long time
- Trade-off: Quality vs. time
- Less samples + Neural Denoiser ➔ high quality, short time

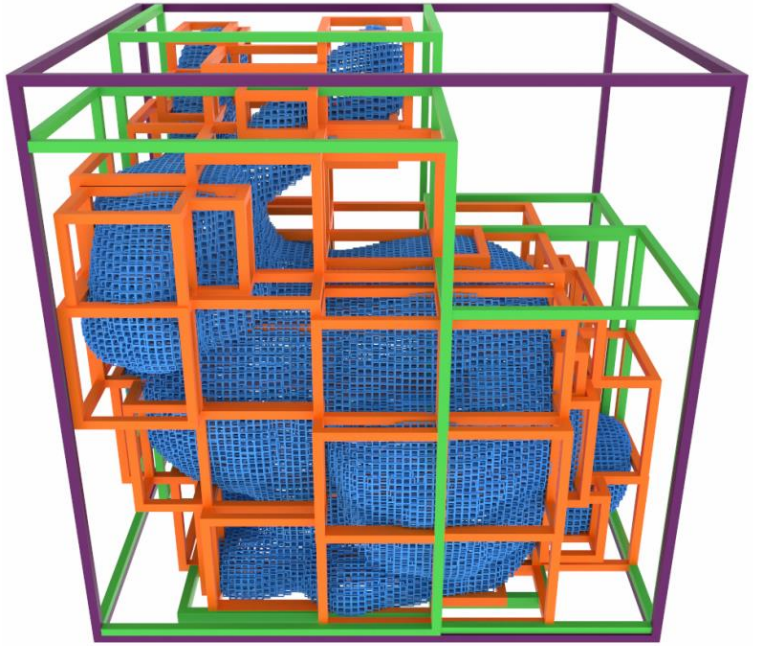
Renderer

- Path Tracer
  - Multiple importance sampling

    Important sampled shadow ray + Accidental light probe hit
  - Sparse voxel Tree

    more time to traverse; memory efficient





Renderer

Volume Filtering

- The volume is a discrete girds

  ➔ Blocky structure

- Interpolation is costly

  ➔ Monte Carlo Integration!!!

Renderer

Emission Sampling

- Another Grid for temperature
- Collision while delta tracking ➔ Temperature lookup
- TF: $(r, g, b) = (t, t^2, t^4)^2$

Work Load Balancing

- Random sampling + multiple scattering ➔ high variance of paths ➔ inappropriate with GPU
- Two-step rendering: Queue a ray corresponding each pixel, then dequeuer all rays and trace

Renderer

Adaptive Sampling

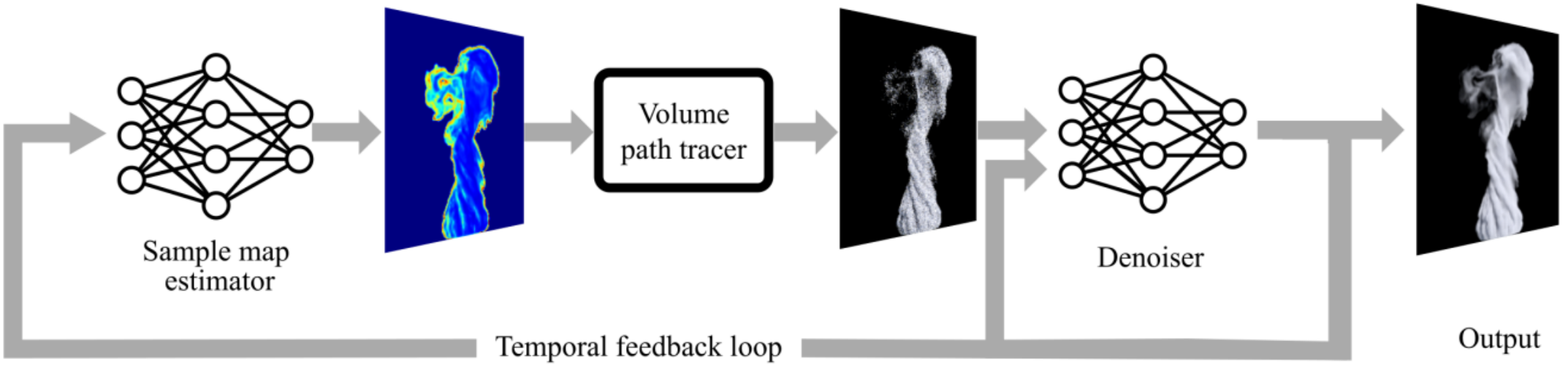
- At global queuing

Empty Space Skipping

- Leveraged by hierarchical bounding boxes
- Delta tracking within a volume until a real collision volume bound escape

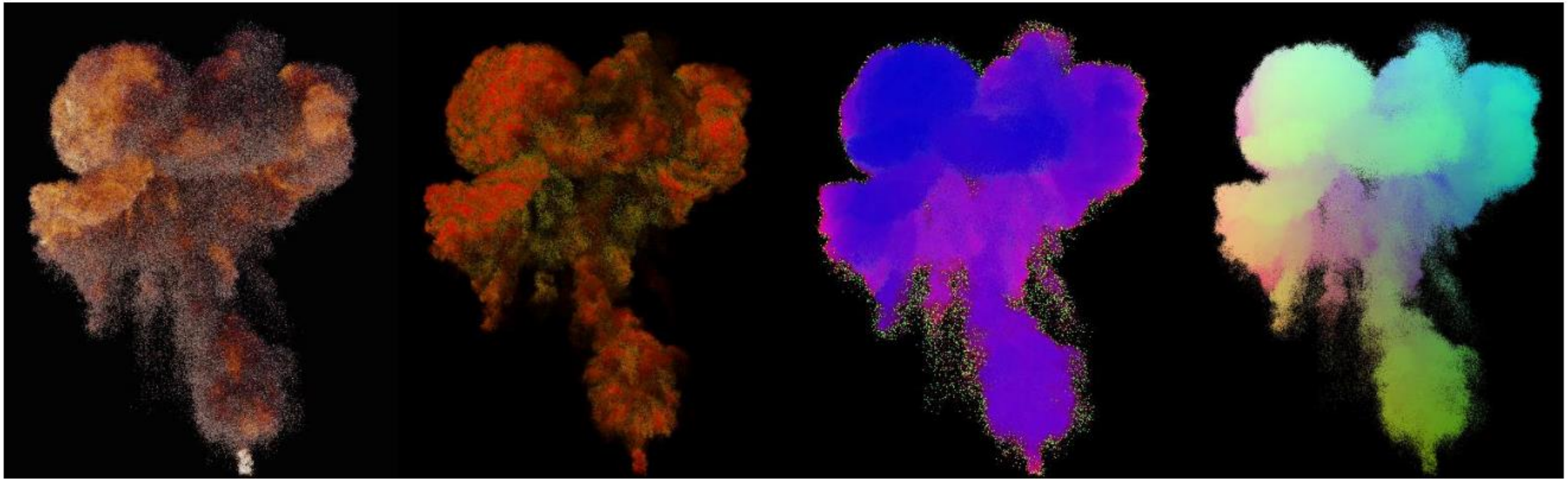
Denoising – Network Architecture

- Data flow

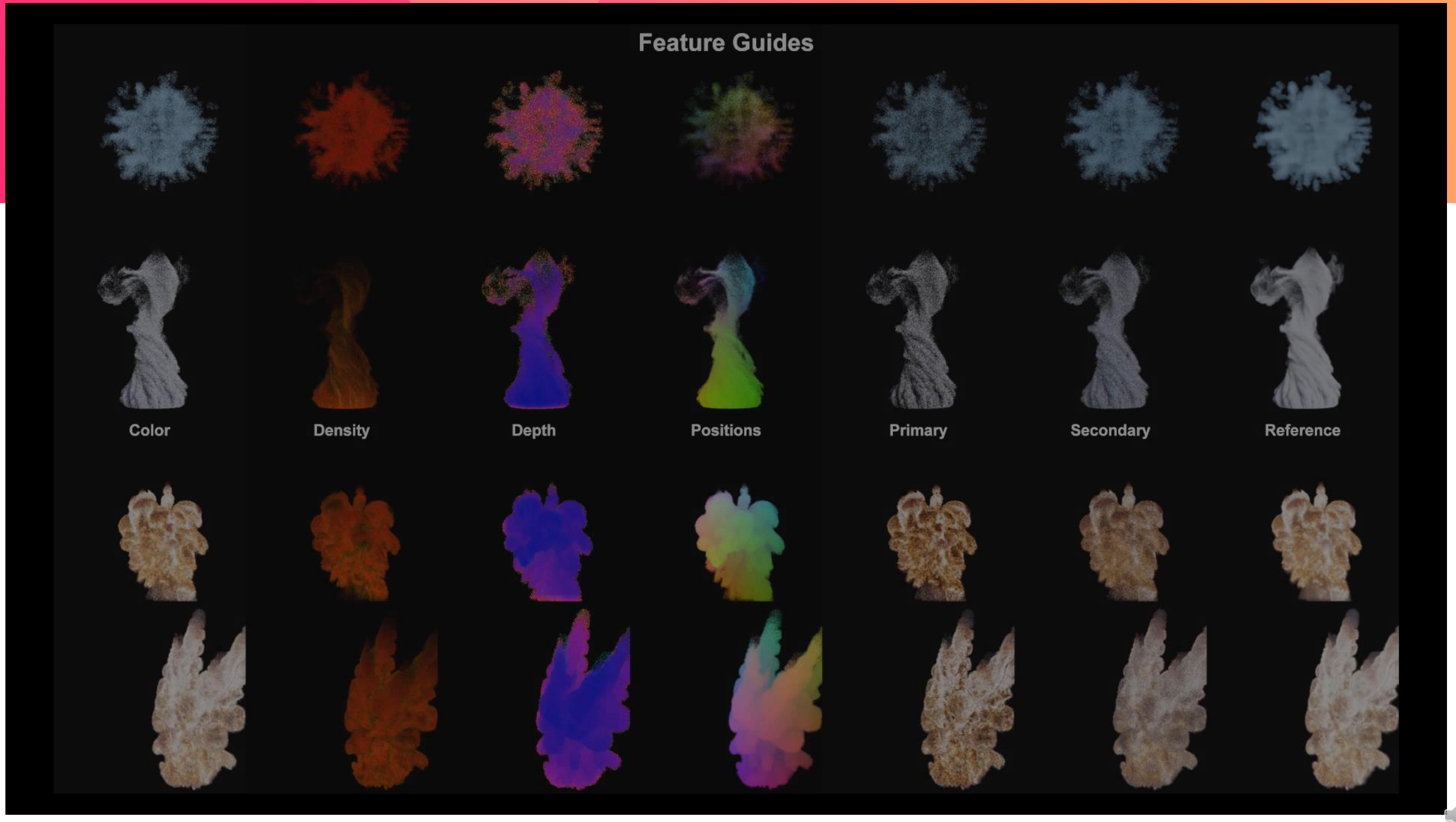


Denoising – Network Architecture

- Network inputs



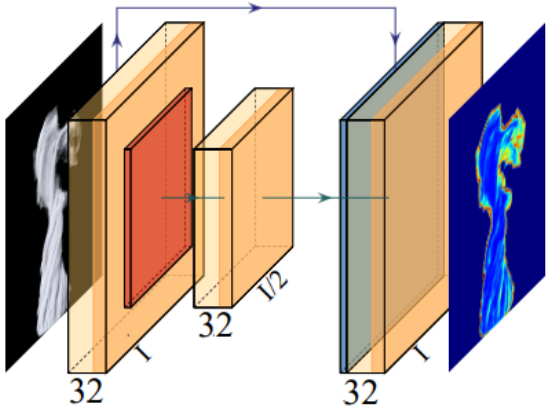
color density depth position

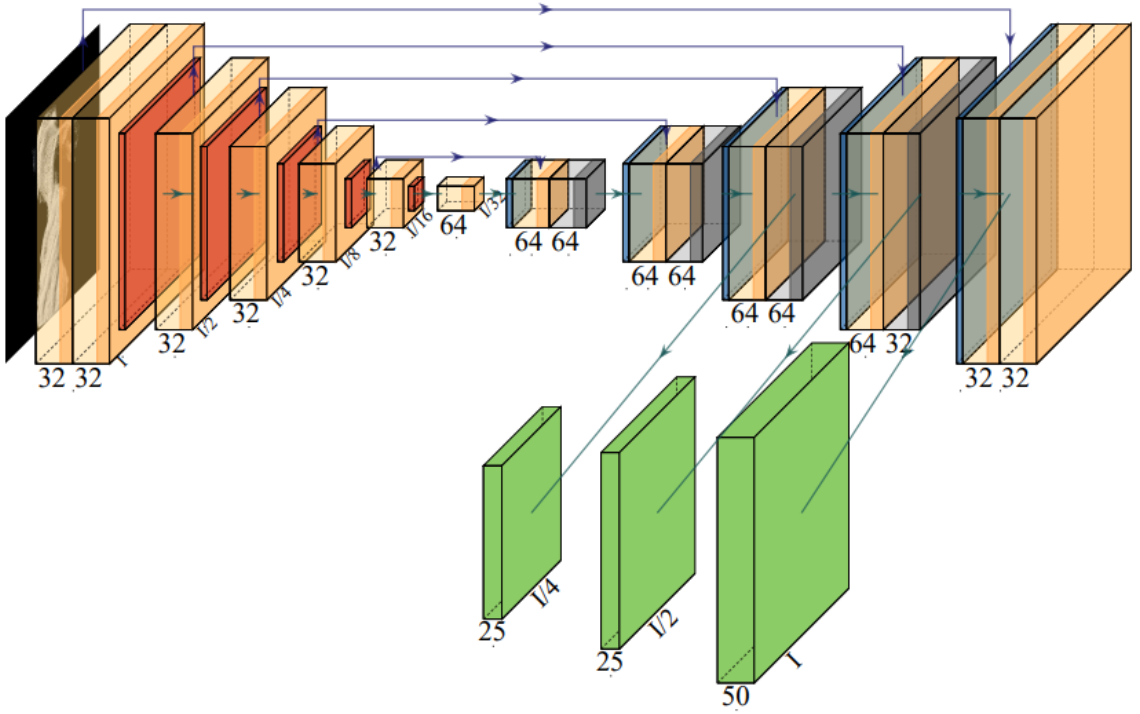


https://research.nvidia.com/publication/2021-03_Interactive-Path-Tracing

Denoising – Network Architecture

- Network architecture





Denoising – Training and Dataset

- 1000 clips from a set of volumes
- Input: path tracing result with 1-32 spp
- Target: path tracing result with 4096 spp
- Objective function

$$\mathrm{SMAPE}(\mathbf{r}, \mathbf{d}) = \frac{1}{3N} \sum_{p \in N} \sum_{c \in C} \frac{|\mathbf{d}_{p,c} - \mathbf{r}_{p,c}|}{|\mathbf{d}_{p,c}| + |\mathbf{r}_{p,c}| + \epsilon}.$$

$$\mathrm{tSMAPE}(\Delta_r, \Delta_d, \mathbf{r}, \mathbf{d}) = \frac{1}{3N} \sum_{p \in N} \sum_{c \in C} \frac{|\Delta_{\mathbf{d}p,c} - \Delta_{\mathbf{r}p,c}|}{|\mathbf{d}_{p,c}| + |\mathbf{r}_{p,c}| + \epsilon}.$$

Evaluation – Runtime Performance

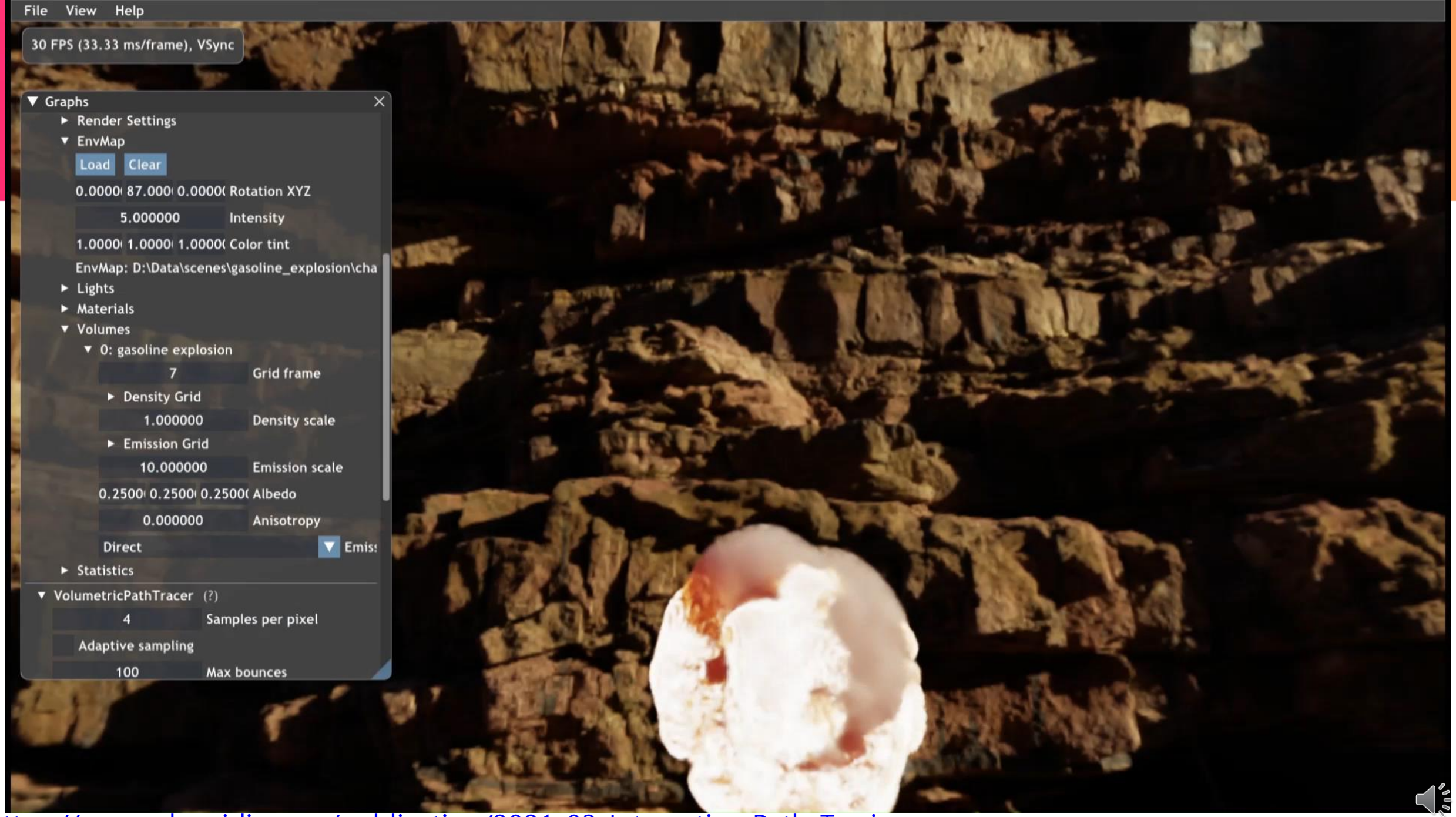
	4 spp uniform					
Scene	**#Voxels**	**#Paths**	**Render**	**Denoise**	**∑**	**FPS**
Dust Devil	2.5M	1.4M	8.6	7.3	15.9	63
Gasoline Explosion	3.6M	1.6M	8.9	7.3	16.2	61
Building Implosion	4.0M	2.8M	8.4	7.3	15.7	64
Midair Explosion	5.4M	2.7M	16.5	7.3	23.8	42
Smoke Plume	11.4M	1.6M	20.1	7.3	27.4	36
Disney Cloud	188.4M	5.3M	53.4	7.3	60.7	16

	4 spp adaptive					
Scene	**#Voxels**	**#Paths**	**Render**	**Denoise**	**∑**	**FPS**
Dust Devil	2.5M	5.3M	27.8	7.3 + 3.1	38.2	26
Gasoline Explosion	3.6M	6.1M	31.4	7.3 + 3.1	41.8	24
Building Implosion	4.0M	8.3M	22.6	7.3 + 3.1	33.0	30
Midair Explosion	5.4M	8.3M	50.1	7.3 + 3.1	60.5	17
Smoke Plume	11.4M	6.1M	79.5	7.3 + 3.1	89.9	11
Disney Cloud	188.4M	8.5M	86.4	7.3 + 3.1	96.8	10

Evaluation – Runtime Performance

- Contributions to speedup

Disney cloud, 4 spp (ms)	On	Off	Speedup
Next-event estimation	278.0	150.8	×0.54
Stochastic interpolation	87.2	278.0	×3.19
Load balancing	63.2	87.2	×1.38
Empty space skipping	53.4	63.2	×1.18



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Evaluation – Denoiser Ablation Studies

Feature Guides

Influence of guides	relMSE	SMAPE	PSNR
Color	0.0199	0.0238	35.37
Color + guides	0.0185	0.0234	35.48

Network size

Network size	relMSE	SMAPE	PSNR
Color	0.0199	0.0238	35.37
Color 2x weights	0.0185	0.0236	35.47
Color 4x weights	0.0198	0.0238	35.51
Color + guides	0.0185	0.0234	35.48
Color + guides 2x weights	0.0175	0.0228	35.73
Color + guides 4x weights	0.0211	0.0230	35.75

Evaluation – Denoiser Ablation Studies

Adaptive Sampling

Uniform vs. Adaptive	relMSE	SMAPE	PSNR
Uniform 4 spp	0.0186	0.0229	35.28
Uniform 8 spp	0.0123	0.0194	36.75
Adaptive (naive) 2 spp	0.0265	0.0253	35.13
Adaptive (naive) 4 spp	0.0167	0.0201	37.26
Adaptive (ours) 2 spp	0.0180	0.0226	35.68
Adaptive (ours) 4 spp	0.0115	0.0188	37.27

Conclusion

- Unbiased Interactive Volume Rendering in real time!!!!
- Only single volume ➔ full path tracer with light interactions between volumes + meshes
- High computational cost to generate training data
- Further improvement expected