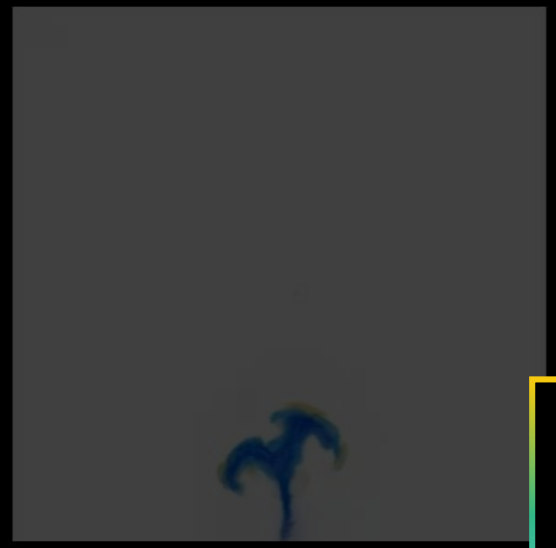
Transport-Based Neural Style Transfer for Smoke Simulations

Byungsoo Kim Vinicius C. Azevedo Markus Gross Barbara Solenthaler

ETH zürich cgl computer graphics laboratory

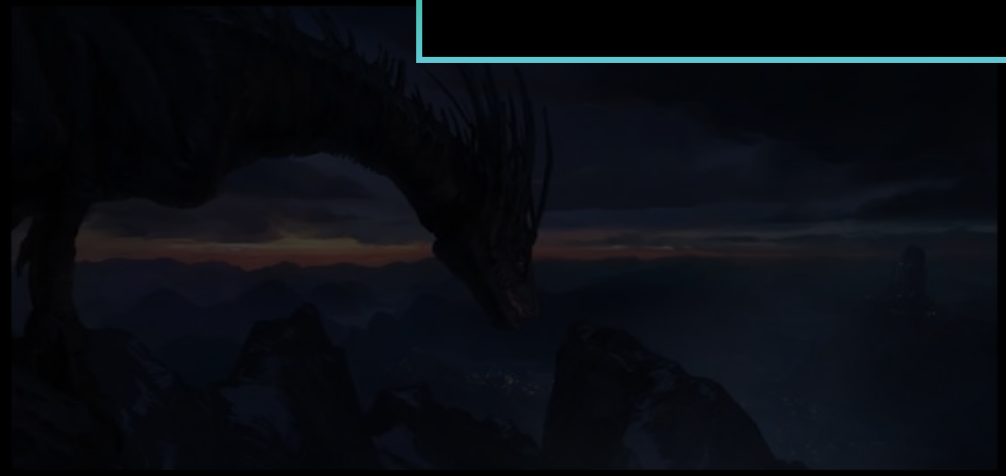
Artistic Control of Smoke Simulations



[Browning et al. 2014]

[Kim et al. 2008]

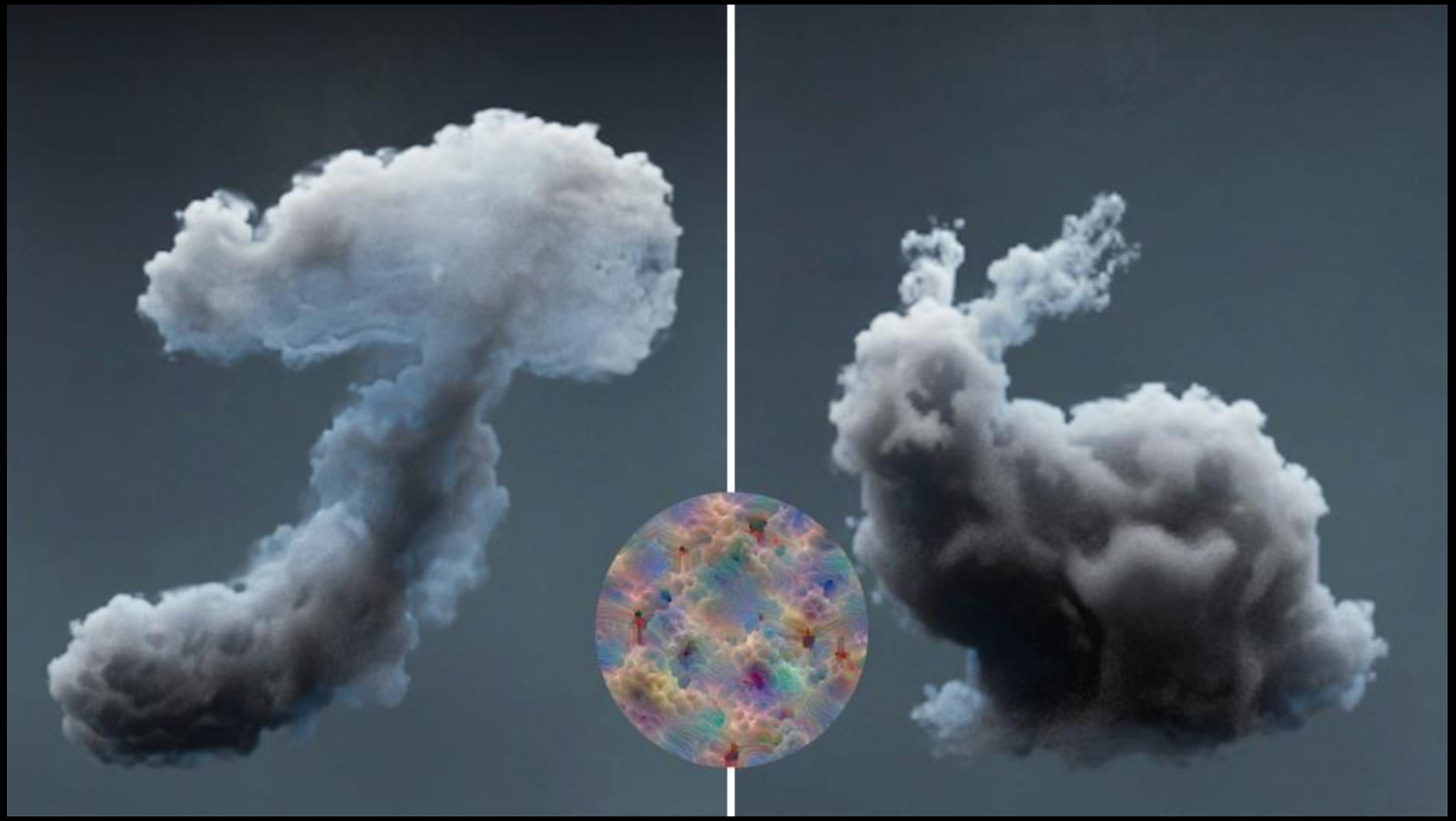
General Artistic Control?



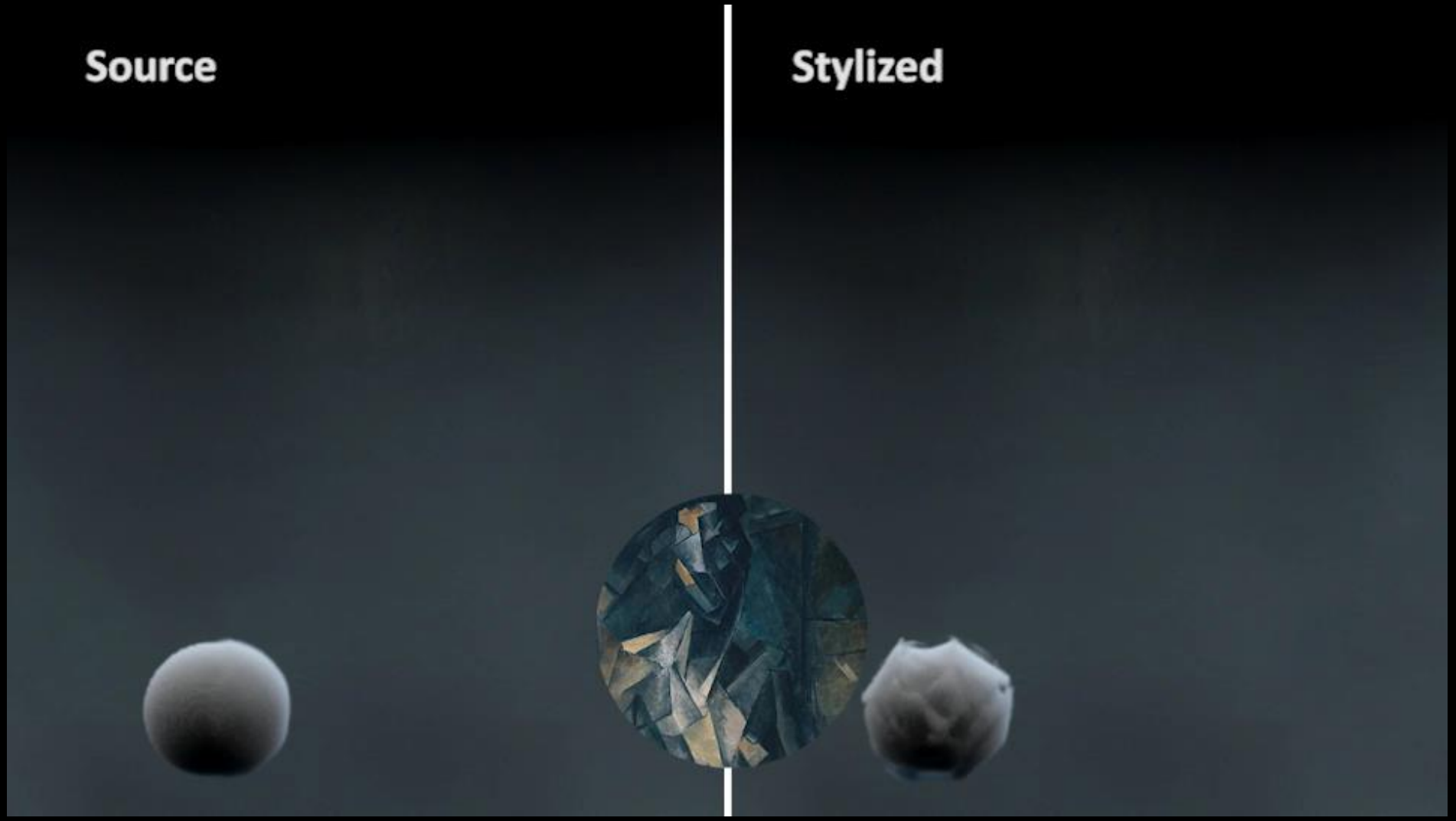
[Jamriška et al. 2015]

[Xie et al. 2018]

Transport-Based Neural Style Transfer

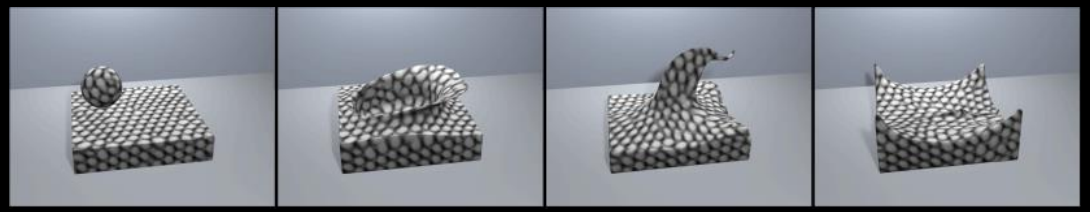


Transport-Based Neural Style Transfer

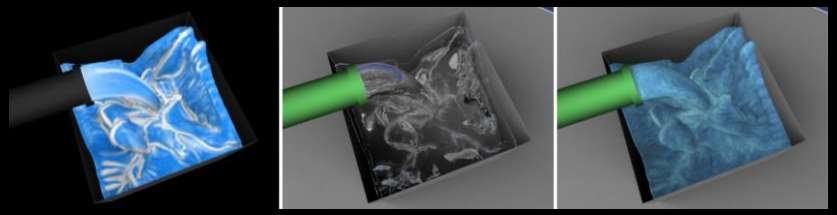


Related Work

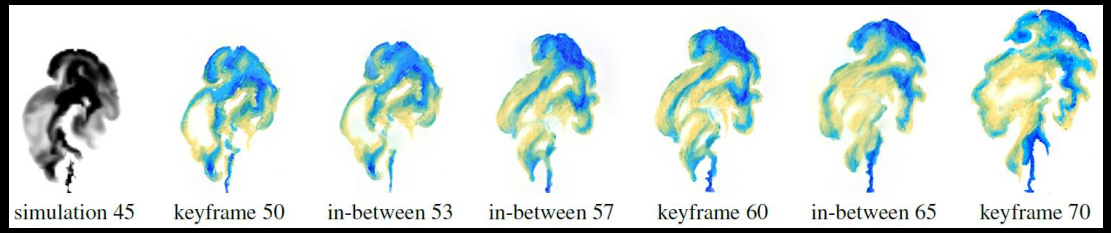
- Appearance Transfer
  - Patch-based Texture Synthesis in 2D



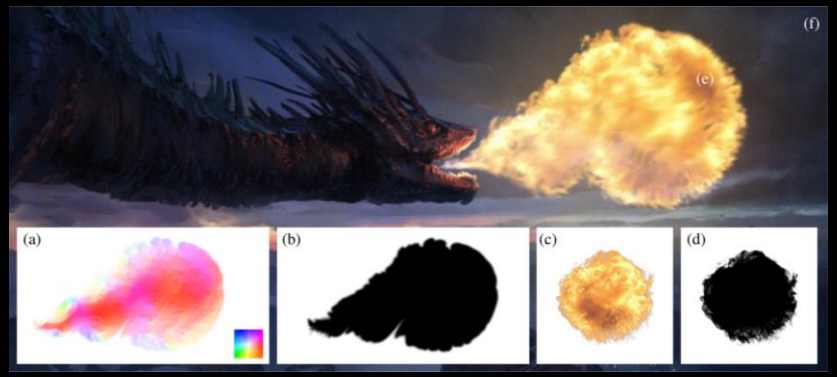
[Bargteil et al. 2006]



[Narain et al. 2007]



[Browning et al. 2014]

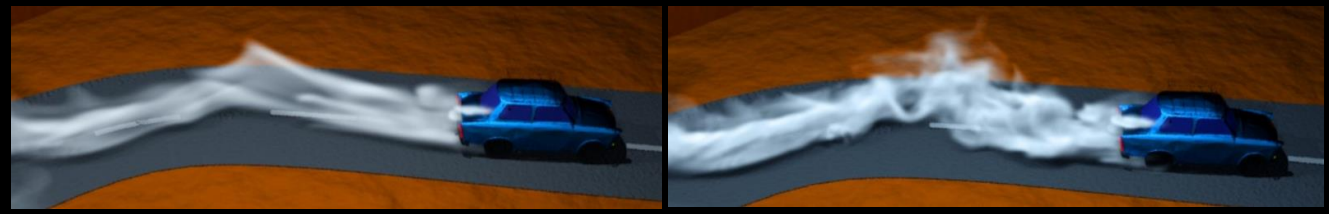


[Jamriška et al. 2015]

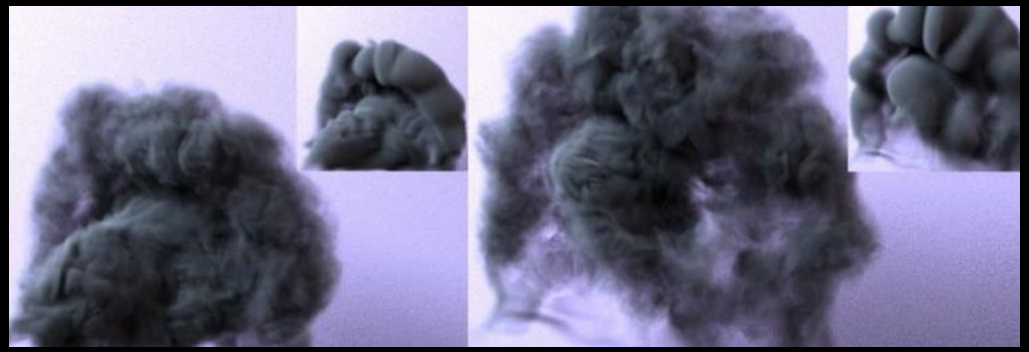
Related Work

- Turbulence Transfer
  - Velocity Synthesis in Sub-scale

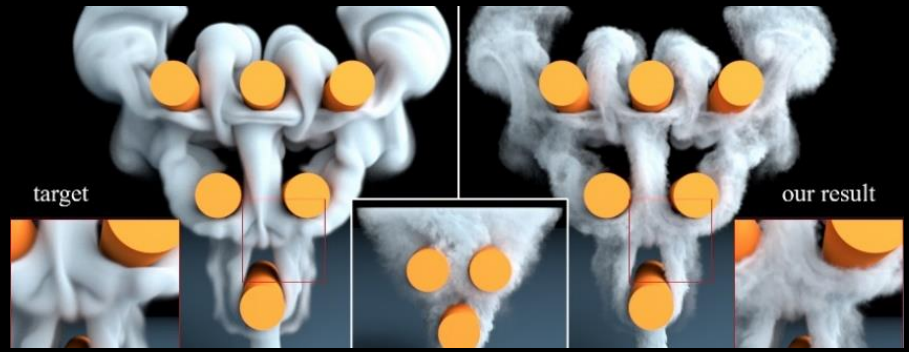
[Kim et al. 2008]



[Pfaff et al. 2009]



[Chu and Thuerey 2017]

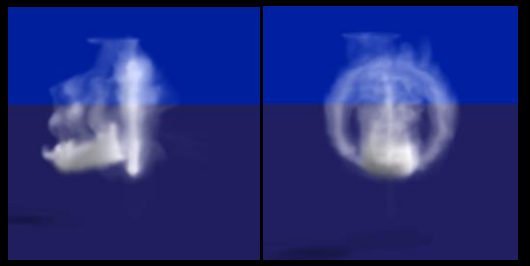


[Sato et al. 2018]

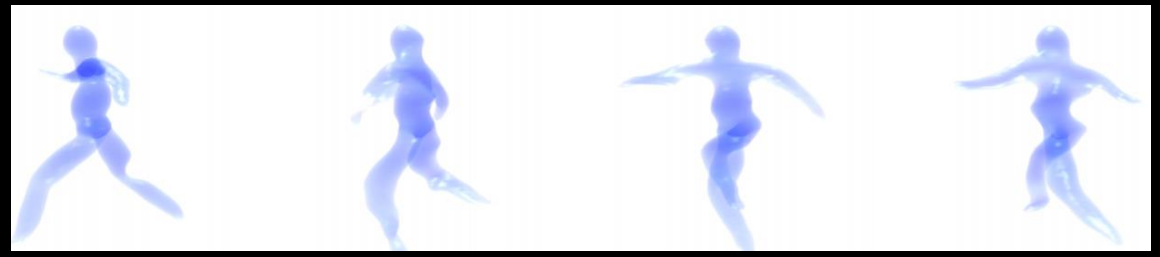
Related Work

- Guided Simulation Control
  - Optimization for User-specified Target Shape / Image

[Treuille et al. 2003]



[Fattal and Lichinski 2004]

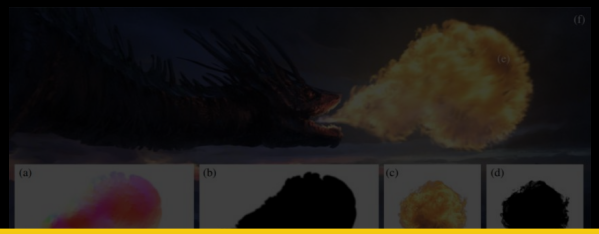


[McNamara et al. 2004]

[Pan and Manocha 2017]

Related Work

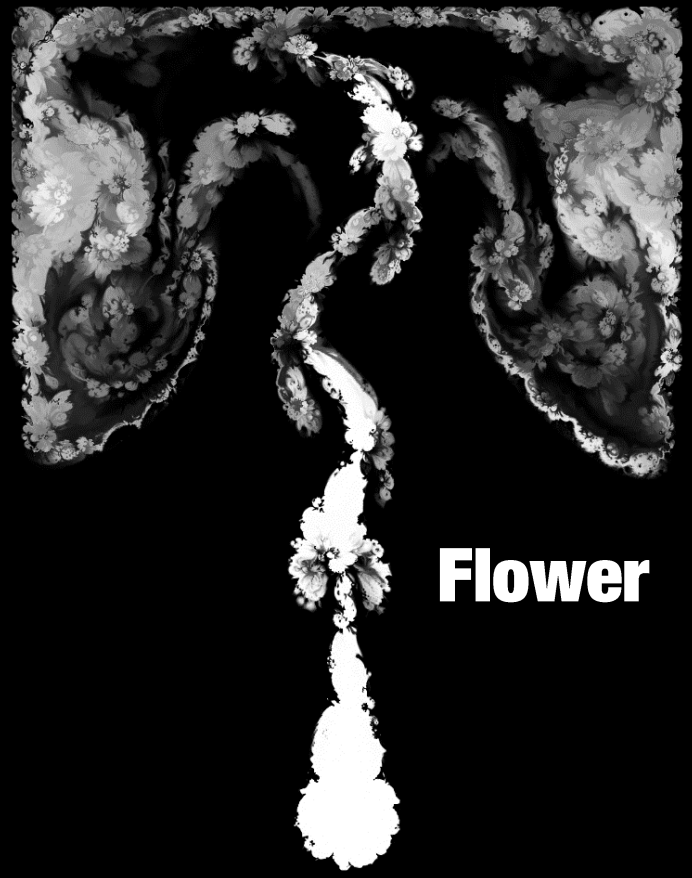
- Appearance Transfer
  - Limited to 2D only
- Turbulence Transfer
  - High Frequency Details only
- Guided Simulation Control
  - Requires Specified Target Shapes



Semantic & Style Transfer for 3D Smoke Simulations

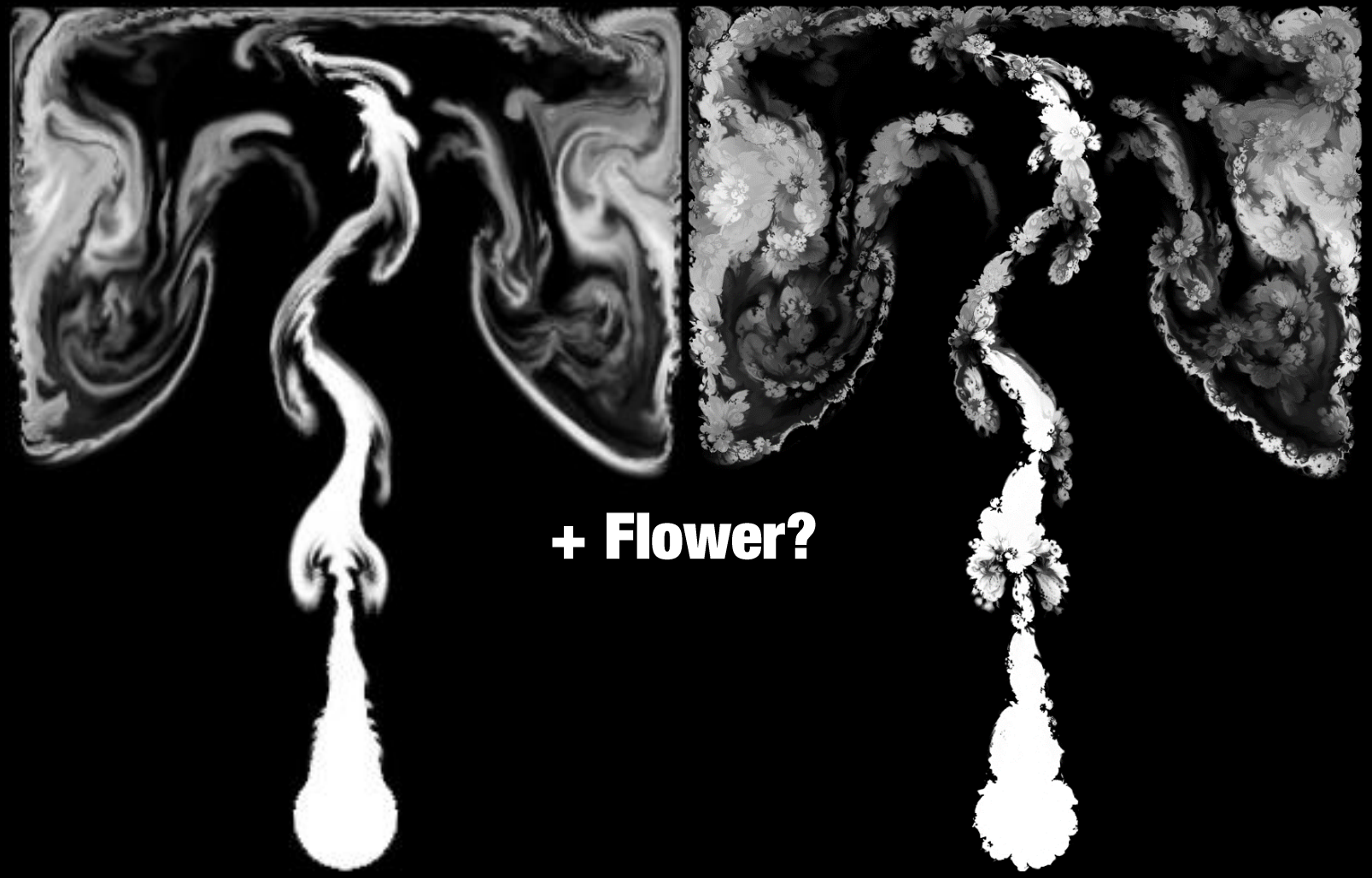
Semantic & Style Transfer for Smoke Simulations

- Semantic Transfer



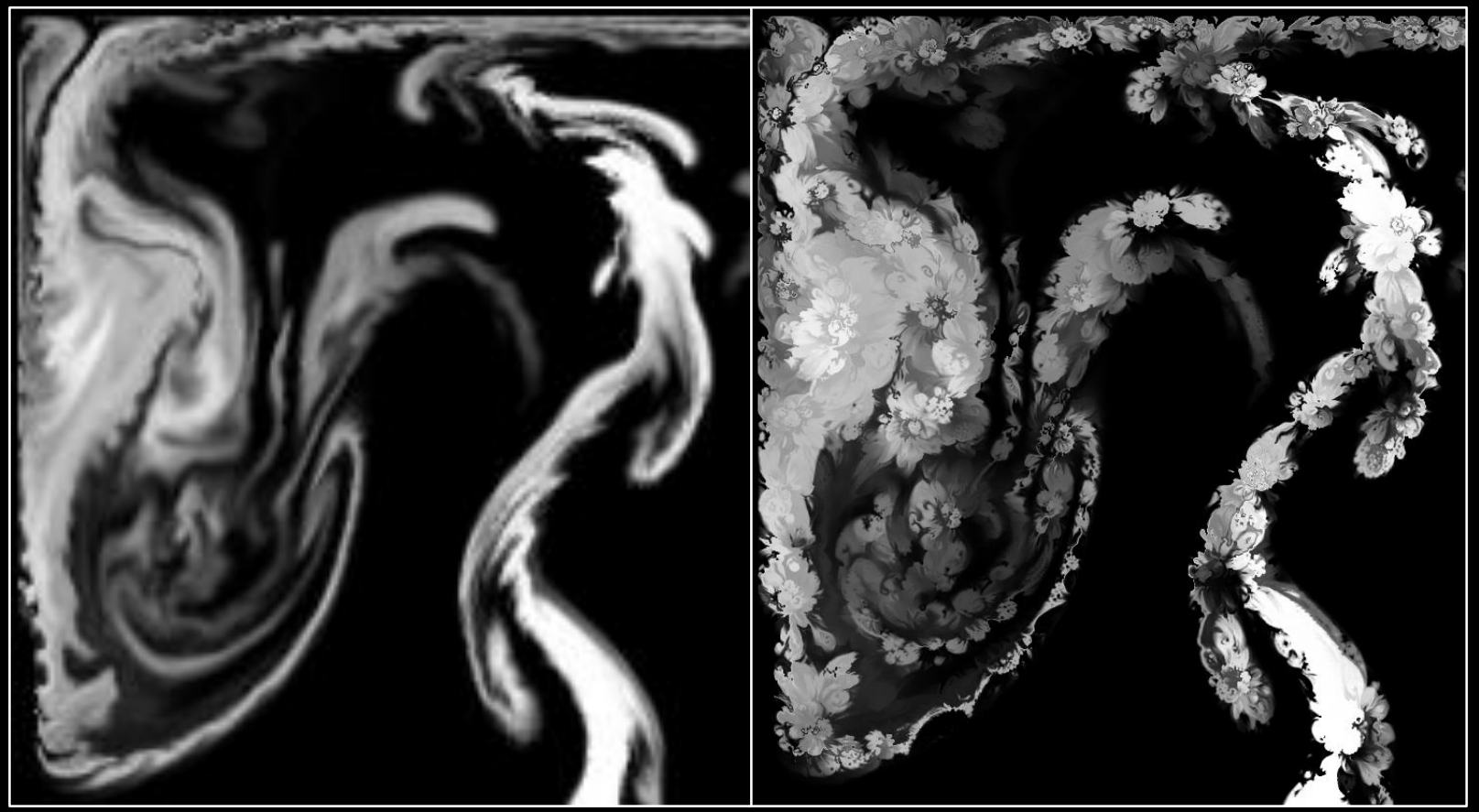
- Style Transfer

Semantic Transfer for Smoke Simulations

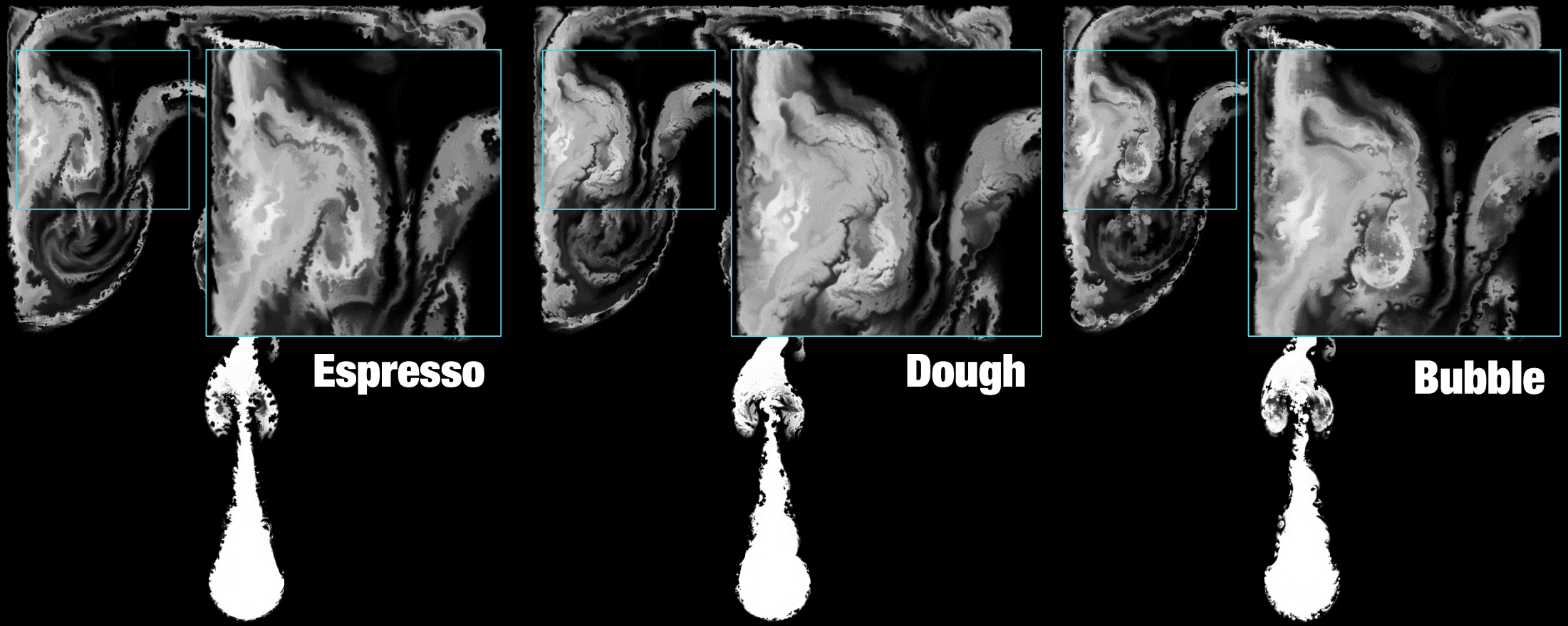


Semantic Transfer for Smoke Simulations

- "Flowery" Smoke = $\arg\min_{smoke} \mathcal{L}(smoke, "flower")$



Semantic Transfer for Smoke Simulations



Style Transfer for Smoke Simulations

+

Fire examplar ©Bunzellisa via pixabay

- Stylized Smoke = $\arg\min_{smoke} \mathcal{L}(smoke, \text{"Style"}\ of\ given\ image)$

Semantic & Style [Gatys et al. 2015]

- CNNs for Object Recognition

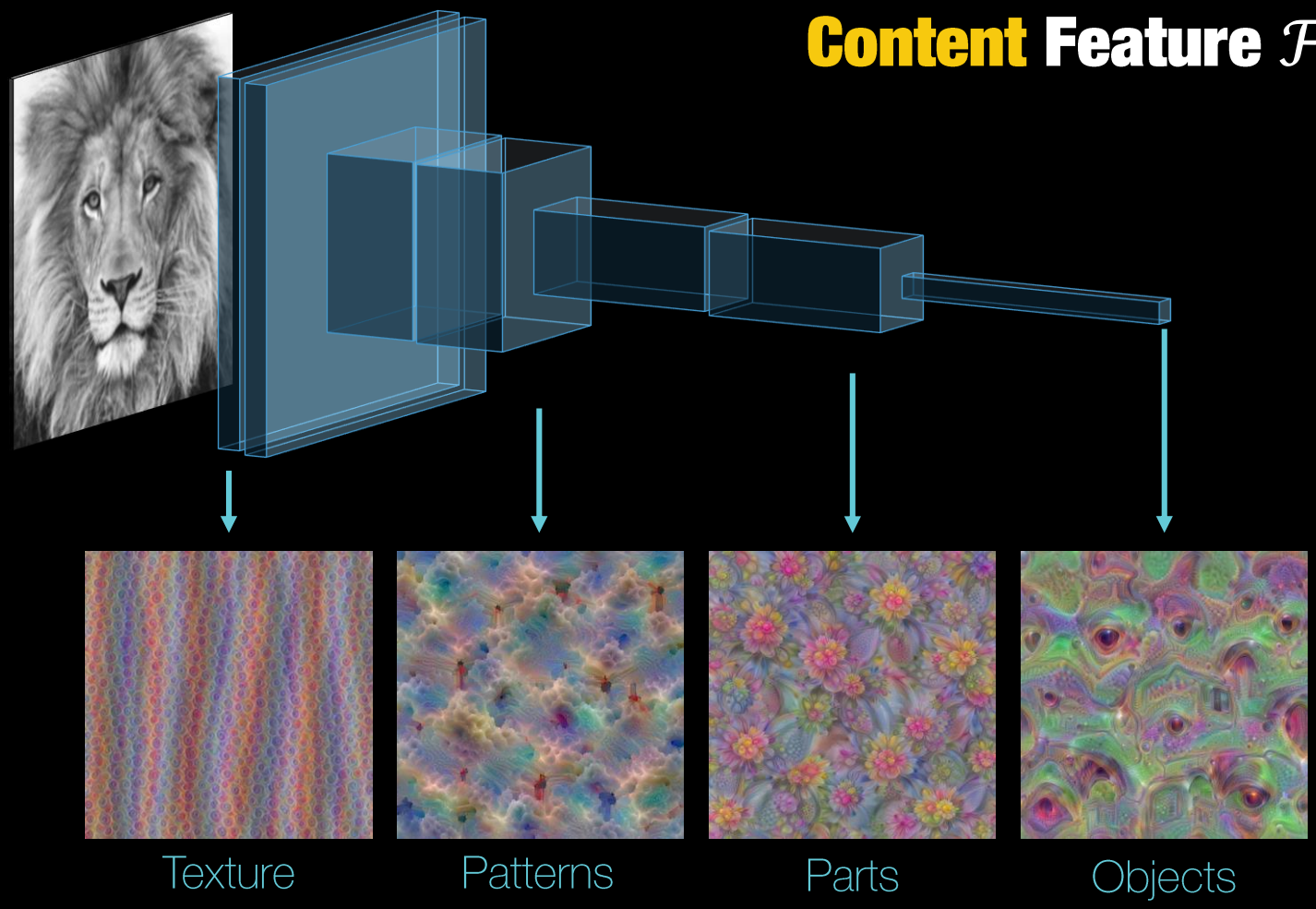
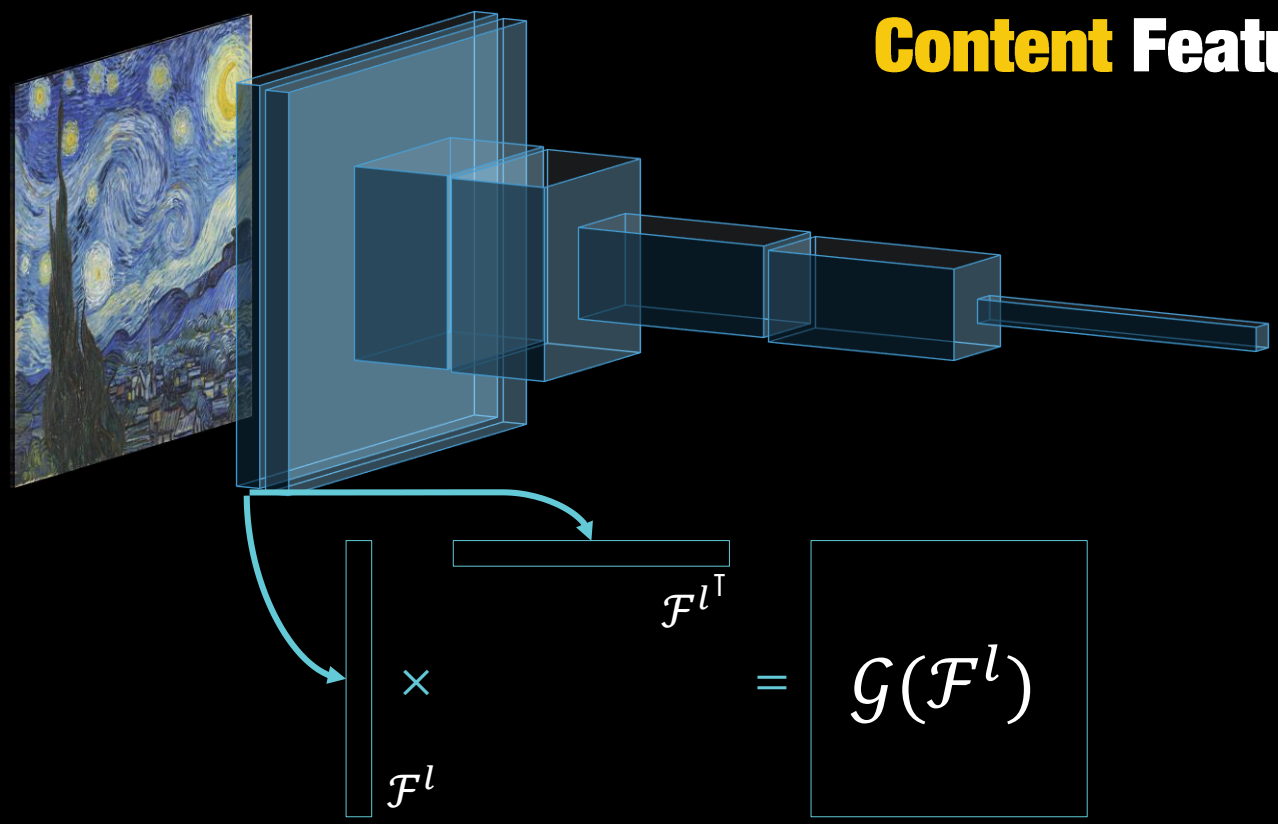


Image source ©cysmith via github Feature visualization by deepdream ©google

Semantic & Style [Gatys et al. 2015]

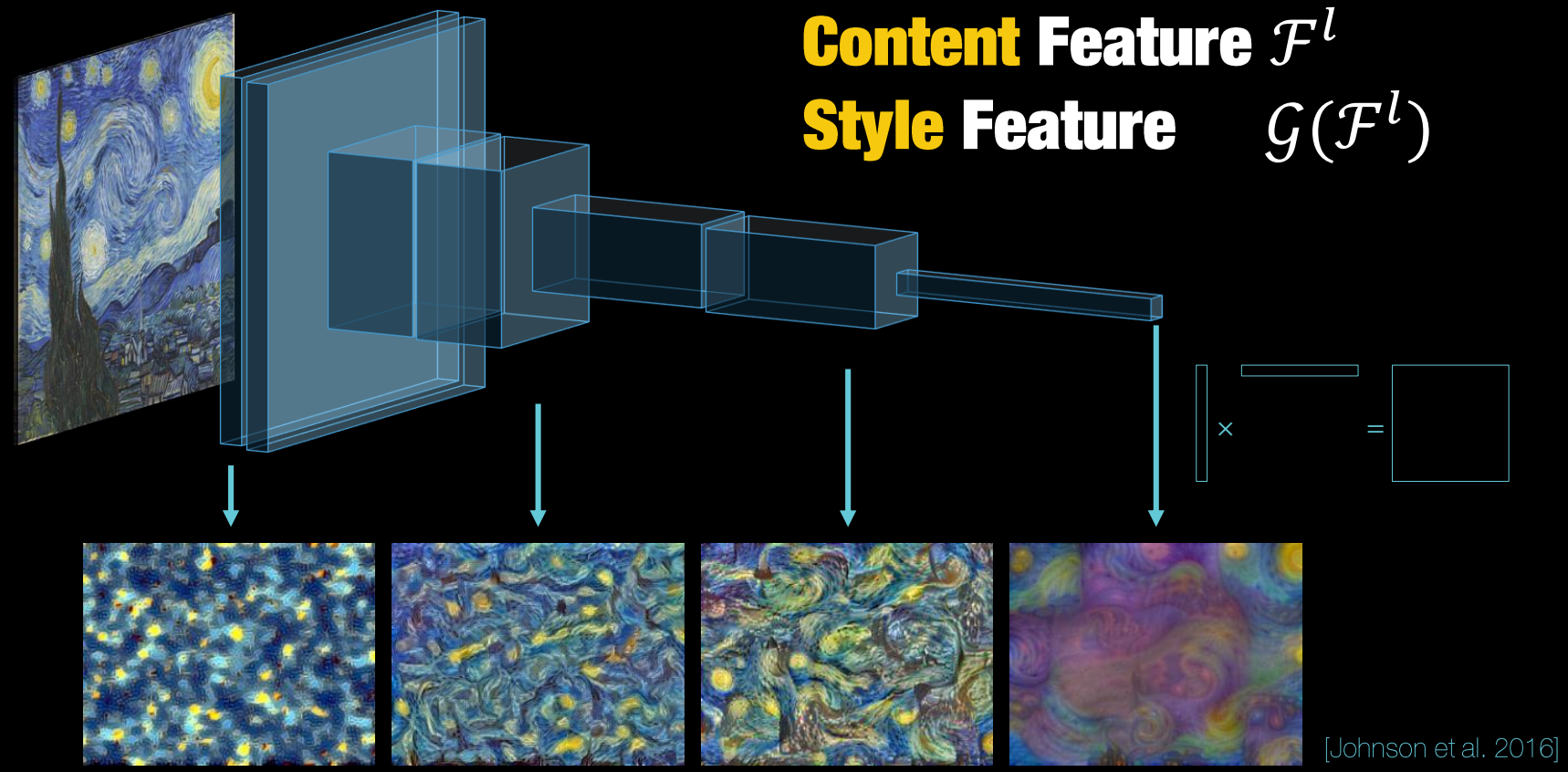
- CNNs for Object Recognition



Cross-Correlation between Content Feature Maps

Semantic & Style [Gatys et al. 2015]

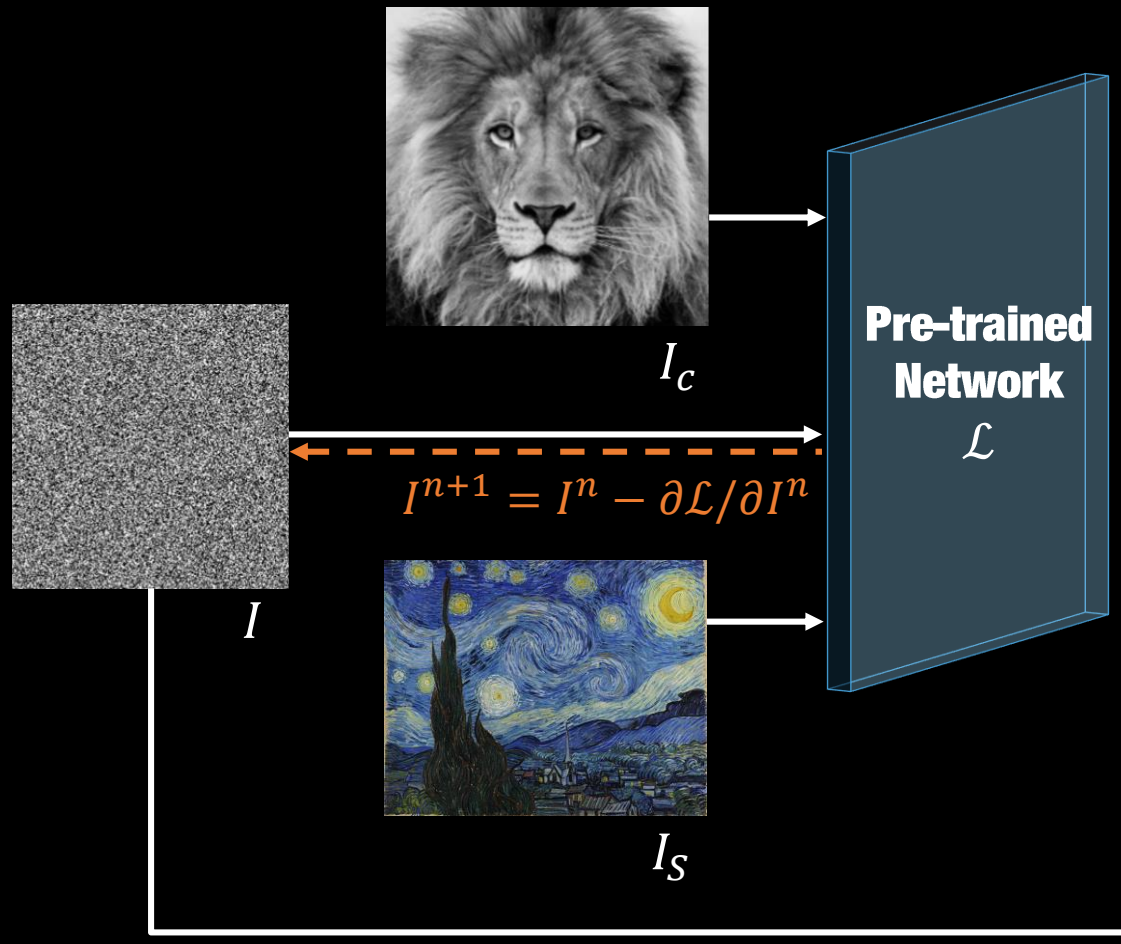
- CNNs for Object Recognition



[Johnson et al. 2016]

Cross-Correlation between Content Feature Maps

Neural Style Transfer [Gatys et al. 2015]



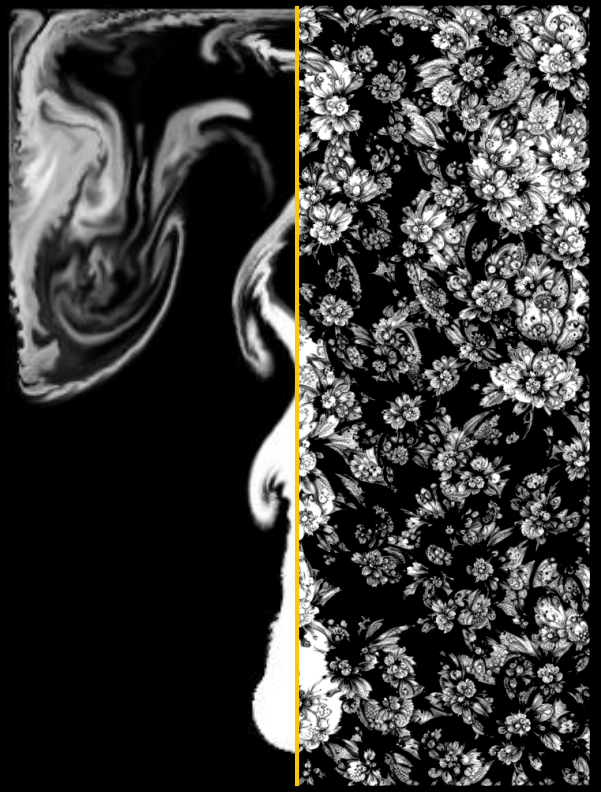
$$\mathcal{L} = \alpha\mathcal{L}_c(I, I_c) + \beta\mathcal{L}_s(I, I_s)$$

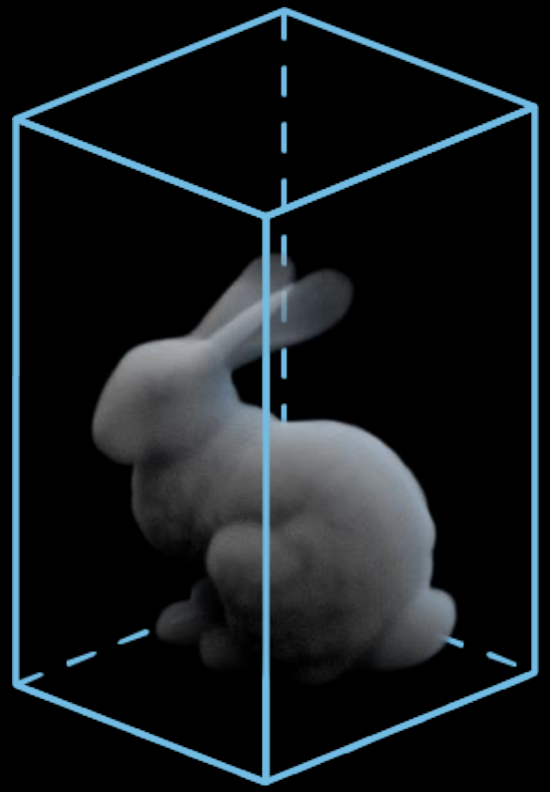
Content **Style**

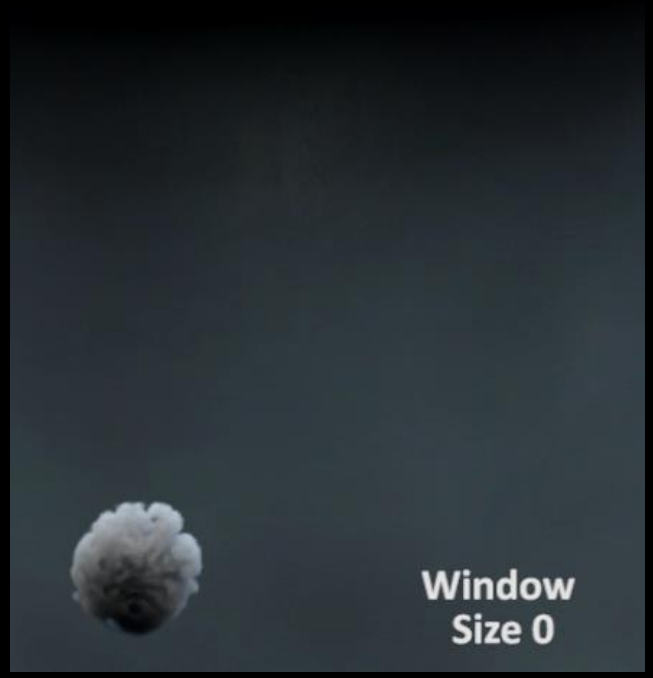
$$I^* = \arg\min_I \mathcal{L}(I, I_c, I_s)$$

Image source ©cysmith via github

Challenges

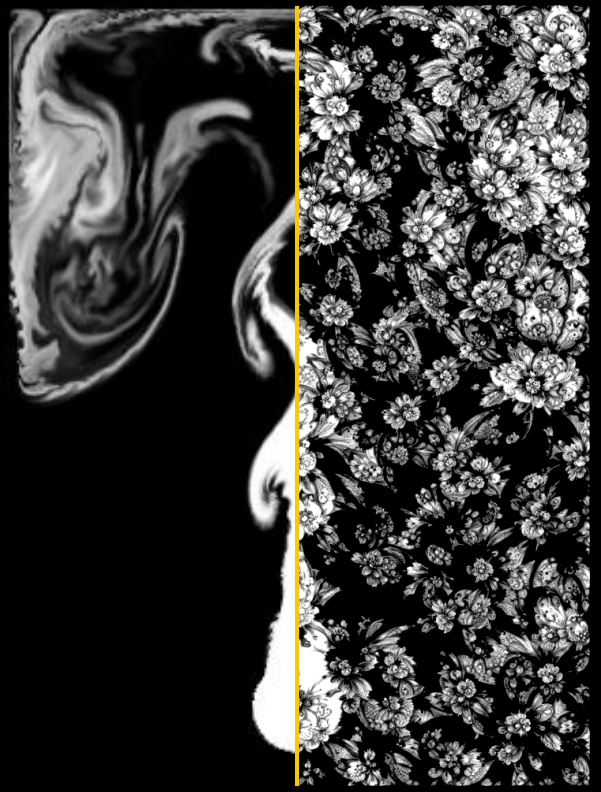


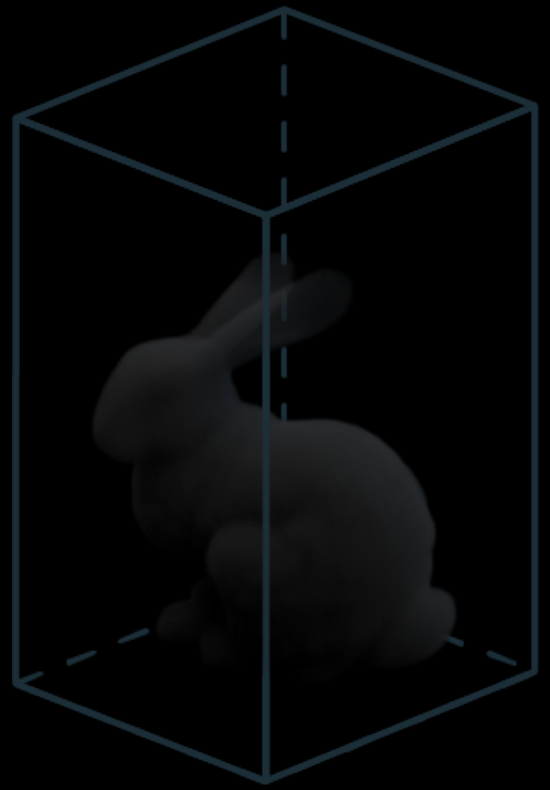




1. Density Source/Sink Control
2. 3D Smoke Volume with 2D Feature Extractor
3. Temporal Coherency

Challenges





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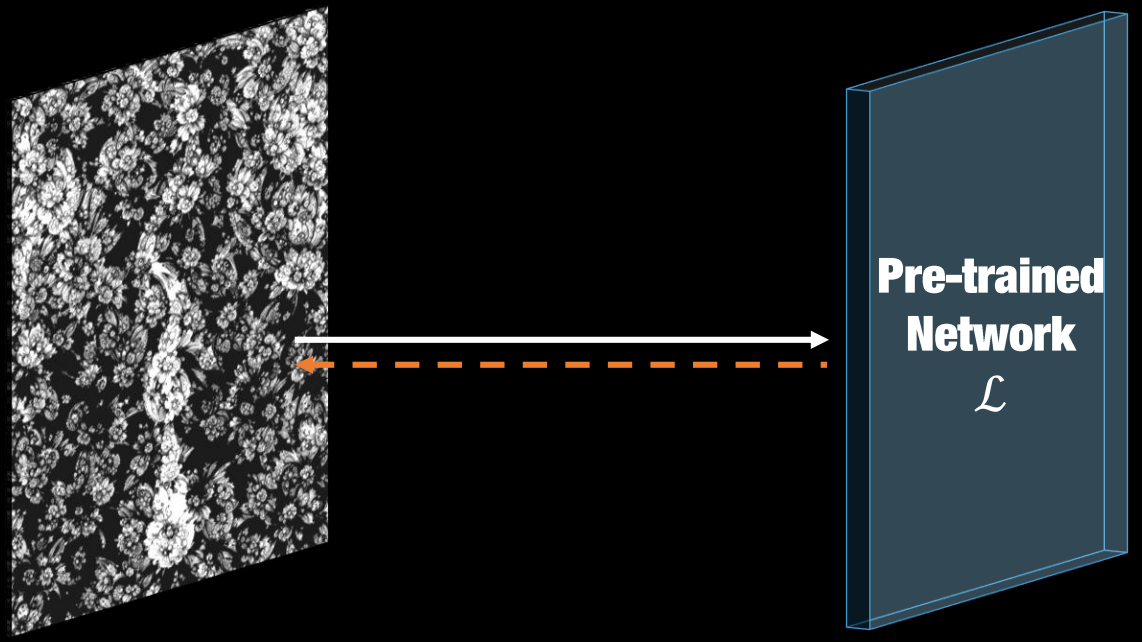
Neural Style Transfer

No Density Control

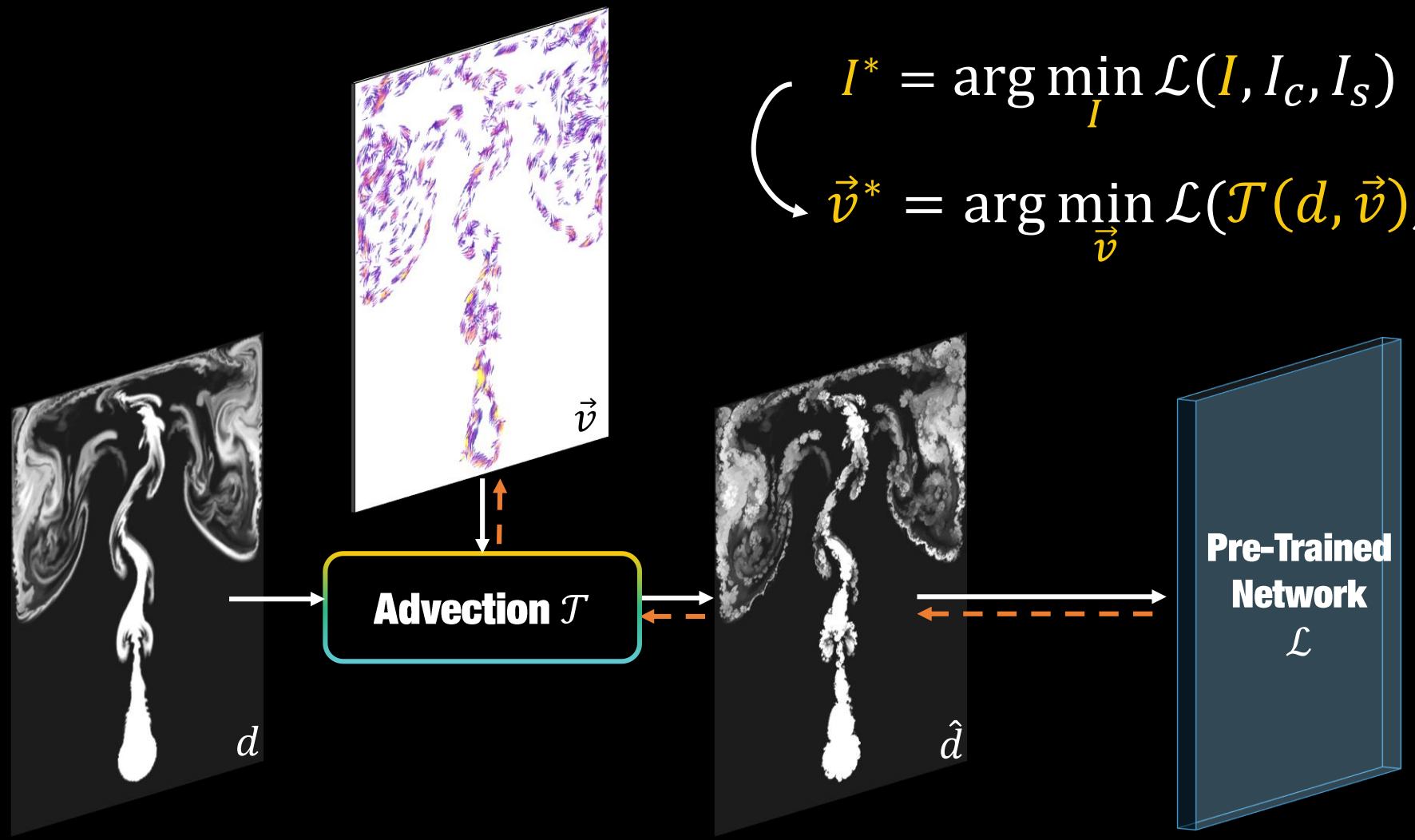


$$I^* = \arg\min_I \mathcal{L}(I, I_c, I_s)$$ [Gatys et al. 2015]

Transport-Based Neural Style Transfer

$$I^* = \arg\min_I \mathcal{L}(I, I_c, I_s)$$ [Gatys et al. 2015]

$$\vec{v}^* = \arg\min_{\vec{v}} \mathcal{L}(\mathcal{T}(d, \vec{v}), I_c, I_s)$$

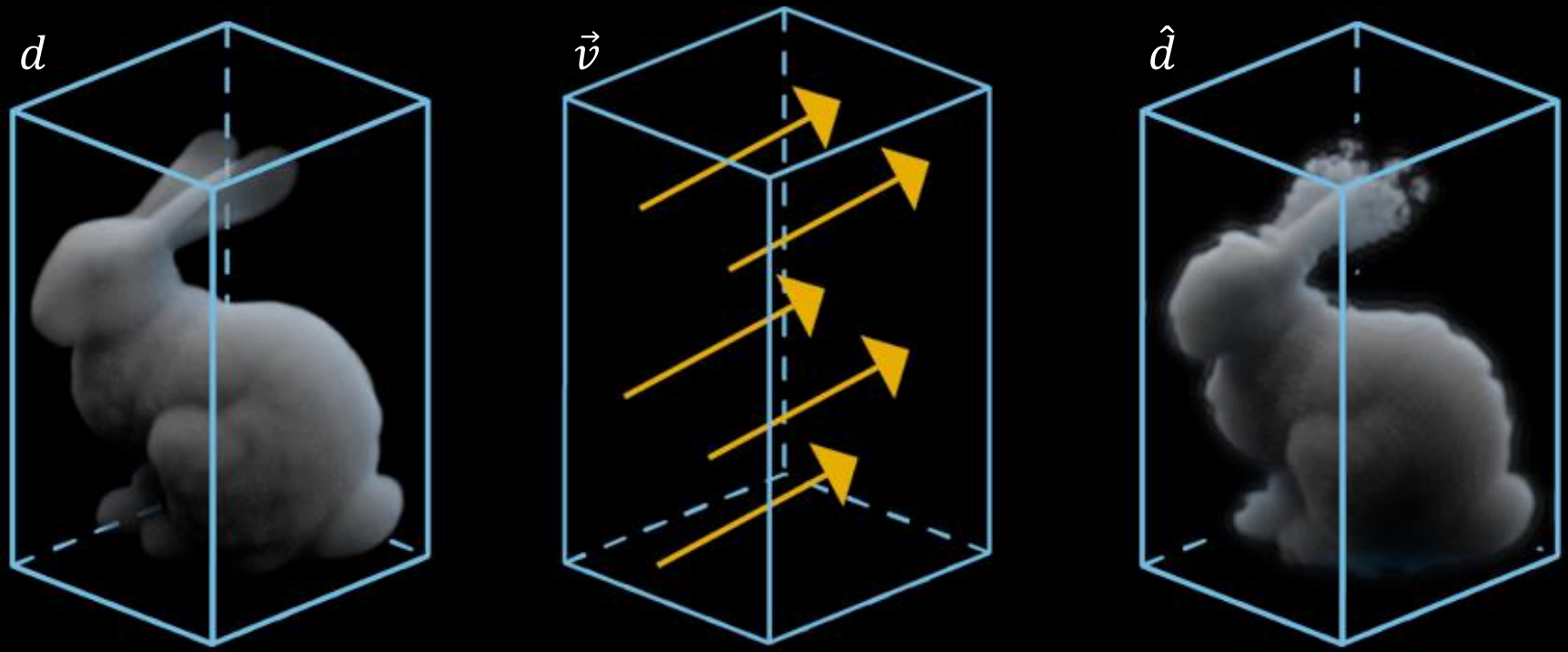


Transport-Based Neural Style Transfer

- Stylized density $\hat{d}$ is advected from d towards stylization with

$$\hat{d} = \mathcal{T}(d, \vec{v})$$

MacCormack Method [Selle et al. 2008]



Transport-Based Neural Style Transfer

- Stylized density $\hat{d}$ is advected from d towards stylization with

$$\hat{d} = \mathcal{T}(d, \vec{v})$$

MacCormack Method [Selle et al. 2008]

- The stylization velocity field $\vec{v}$ combines irrotational and incompressible parts

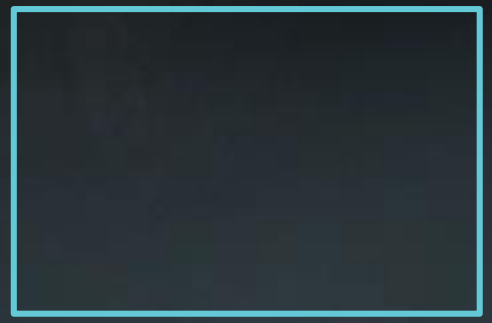
$$\vec{v} = \lambda \nabla \phi + (1 - \lambda) \nabla \times \vec{\psi}$$

Irrotational $\nabla \times \nabla \phi = 0$ Incompressible $\nabla \cdot \nabla \times \vec{\psi} = 0$

- Using velocity field for stylization minimizes the creation of smoke sources and sinks

Incompressible

$$\nabla \cdot \nabla \times \vec{\psi} = 0$$



Lambda = 0.5

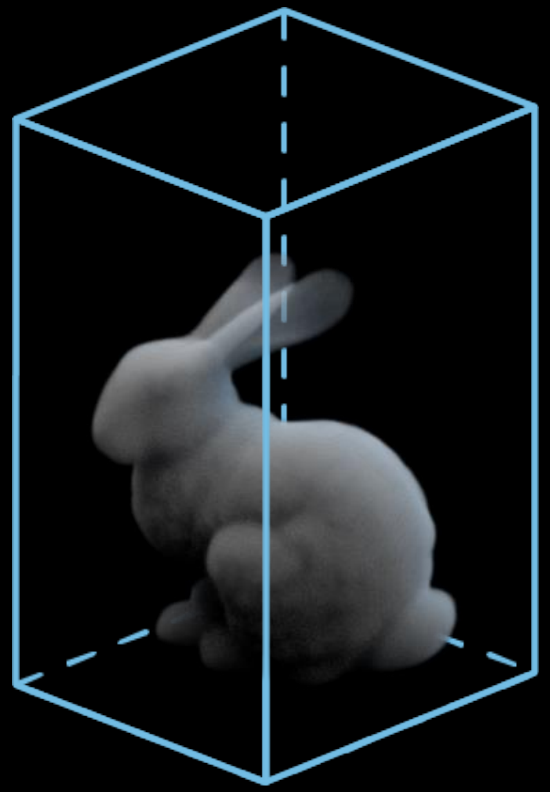
$$\vec{v} = \lambda \nabla \phi + (1 - \lambda) \nabla \times \vec{\psi}$$

Irrotational

$$\nabla \times \nabla \phi = 0$$

Challenges

Transport-Based Neural Style Transfer

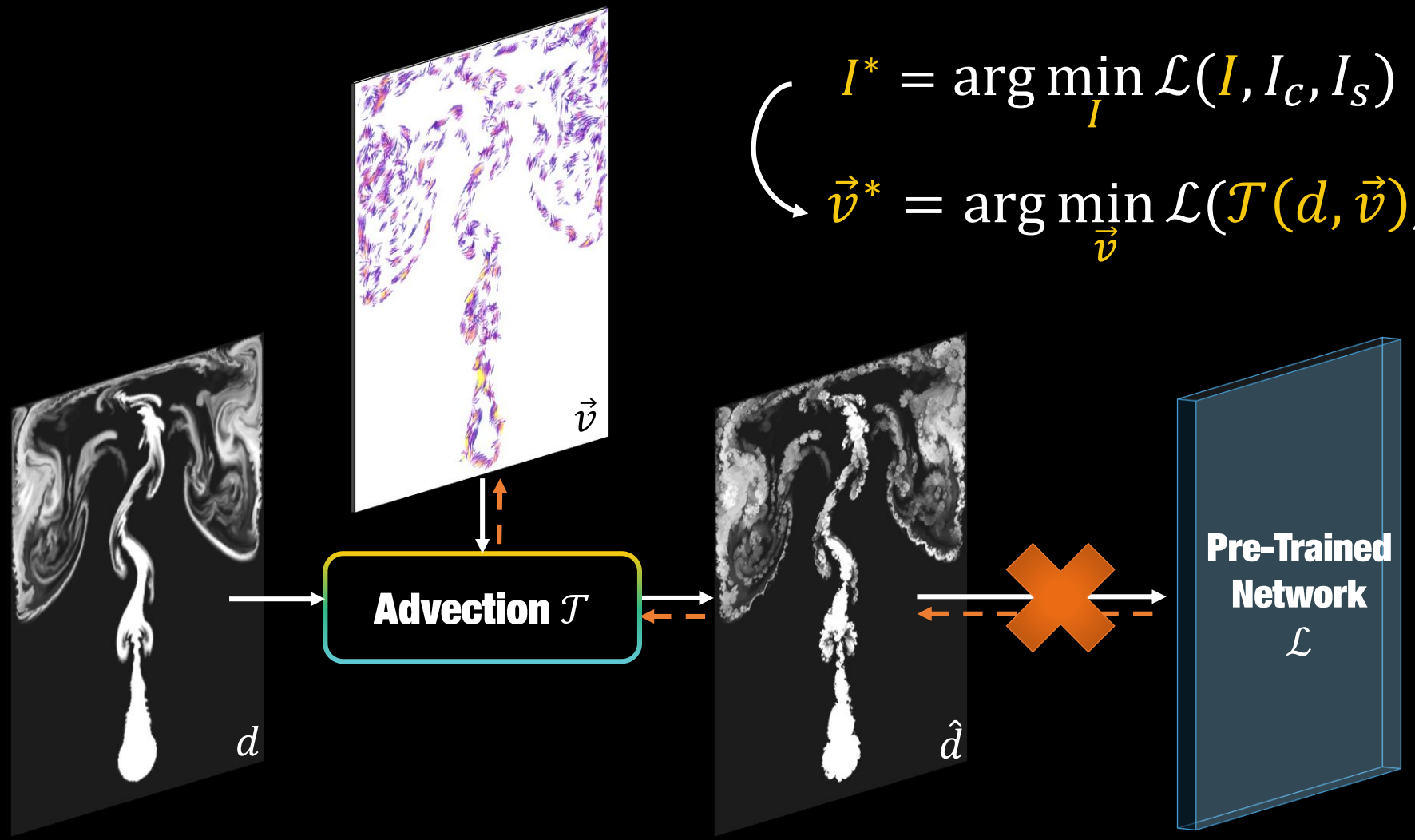


1. Density Source/Sink Control
2. 3D Smoke Volume with 2D Feature Extractor
3. Temporal Coherency

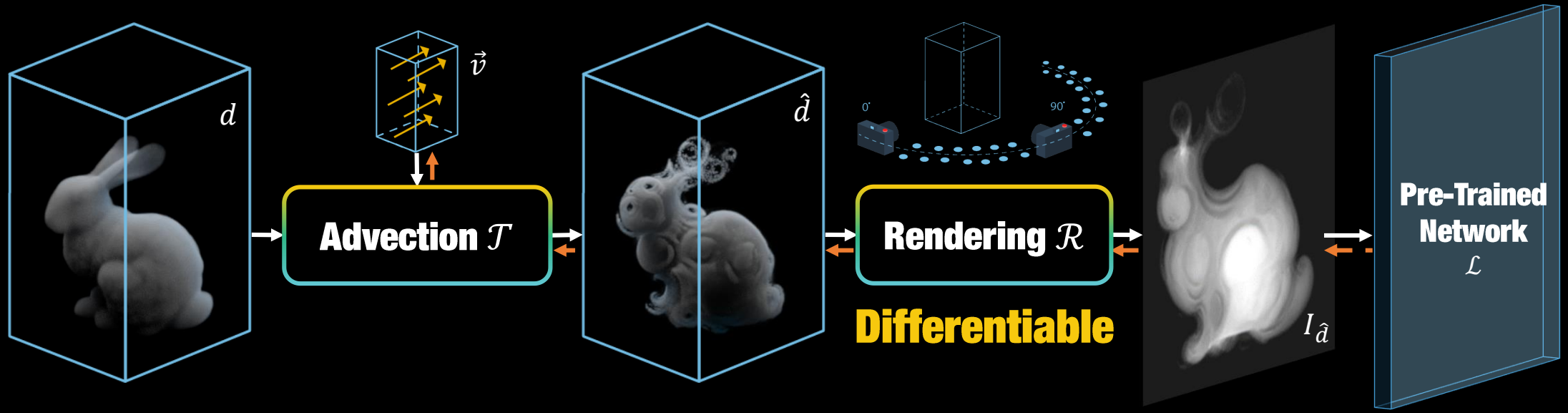
Transport-Based Neural Style Transfer in 2D

$$I^* = \arg\min_I \mathcal{L}(I, I_c, I_s)$$ [Gatys et al. 2015]

$$\vec{v}^* = \arg\min_{\vec{v}} \mathcal{L}(\mathcal{T}(d, \vec{v}), I_c, I_s)$$



Transport-Based Neural Style Transfer in 3D



$$\vec{v}^* = \arg\min_{\vec{v}} \mathcal{L}(\mathcal{T}(d, \vec{v}), I_c, I_s)$$

$$\vec{v}^* = \arg\min_{\vec{v}} \sum_{\theta \in \Theta} \mathcal{L}(\mathcal{R}_\theta(\mathcal{T}(d, \vec{v})), I_c, I_s)$$

Viewpoints

Differentiable Smoke Renderer

- Lightweight Volume Renderer

Transmittance

$$\tau(x, \vec{r}) = e^{-\gamma \int_x^0 d(r_z)\, dr_z}$$

Extinction Factor

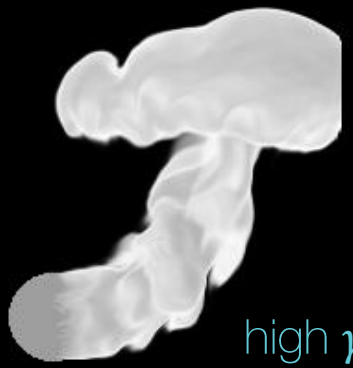
Radiance

$$I_{ij} = \int_D^0 d(x)\tau(x, \vec{r})\, dx$$

Ray-Tracing Renderer

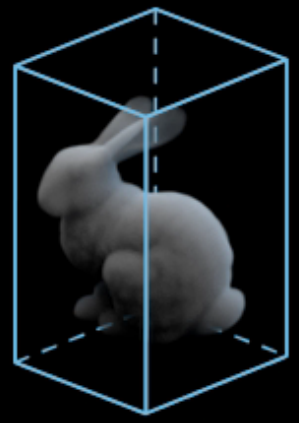
Ours

low γ



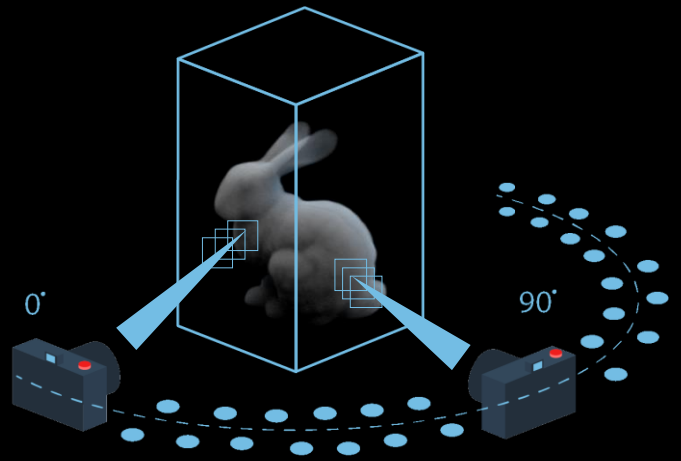
high γ

Multi-View Rendering



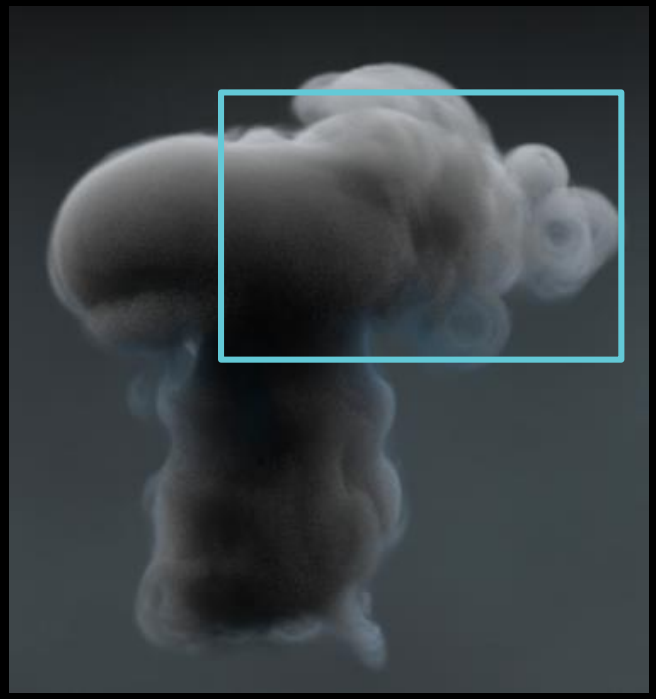
Multi-View Rendering

- Poisson-Sampling to Avoid Bias



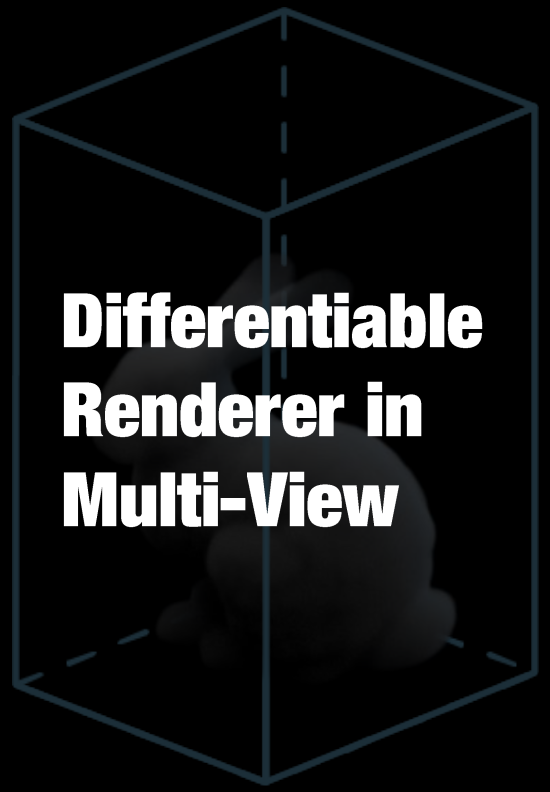
Fixed-View

Multi-View

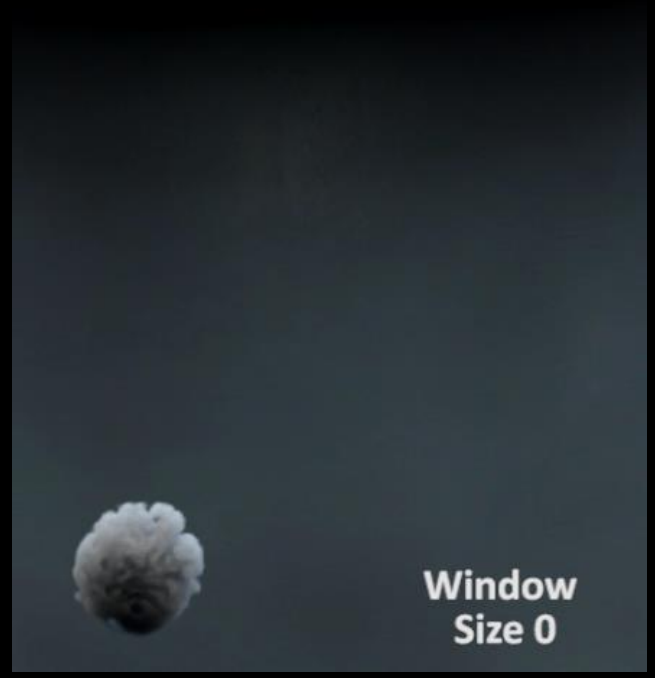


Challenges

Transport-Based Neural Style Transfer



Differentiable Renderer in Multi-View



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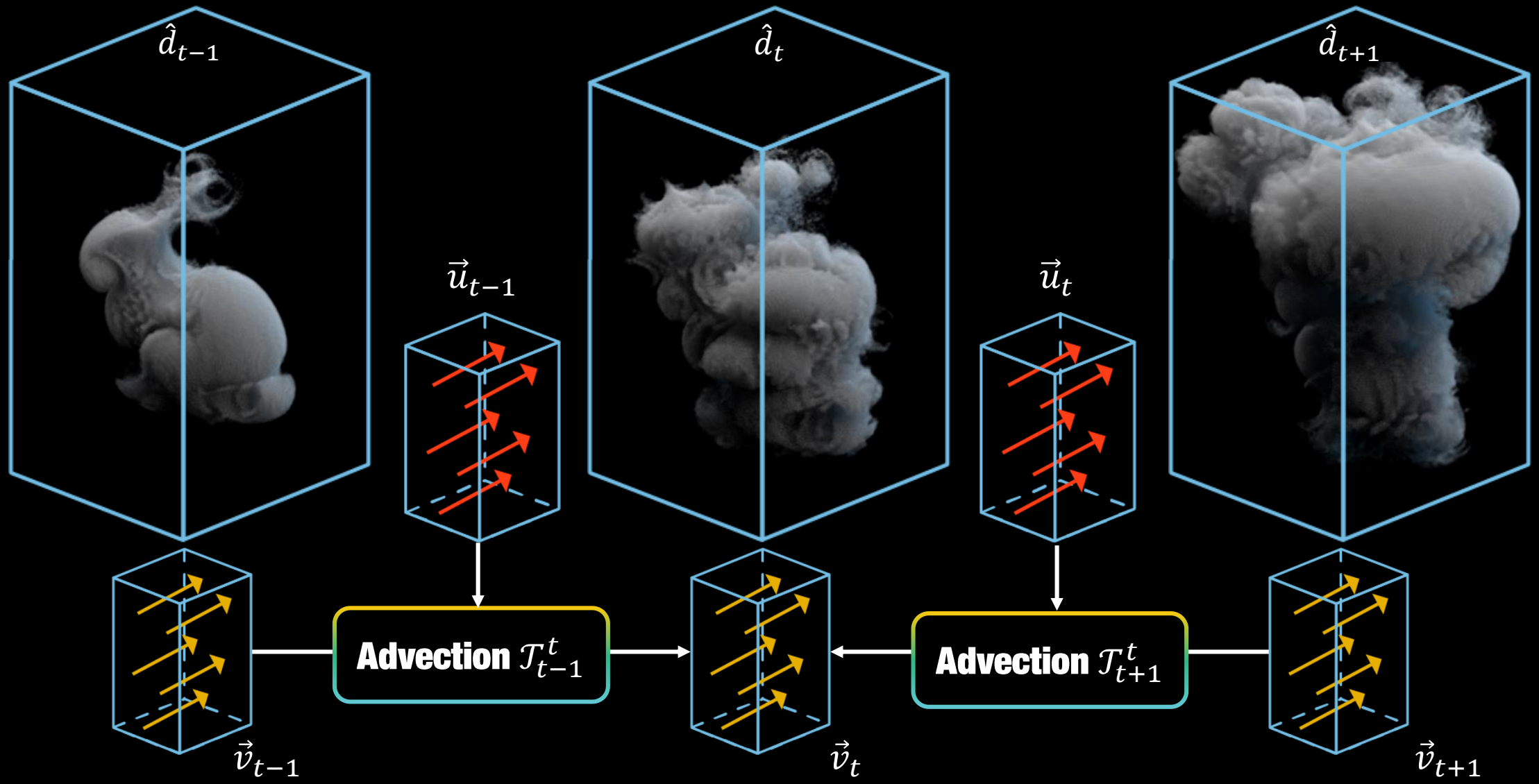
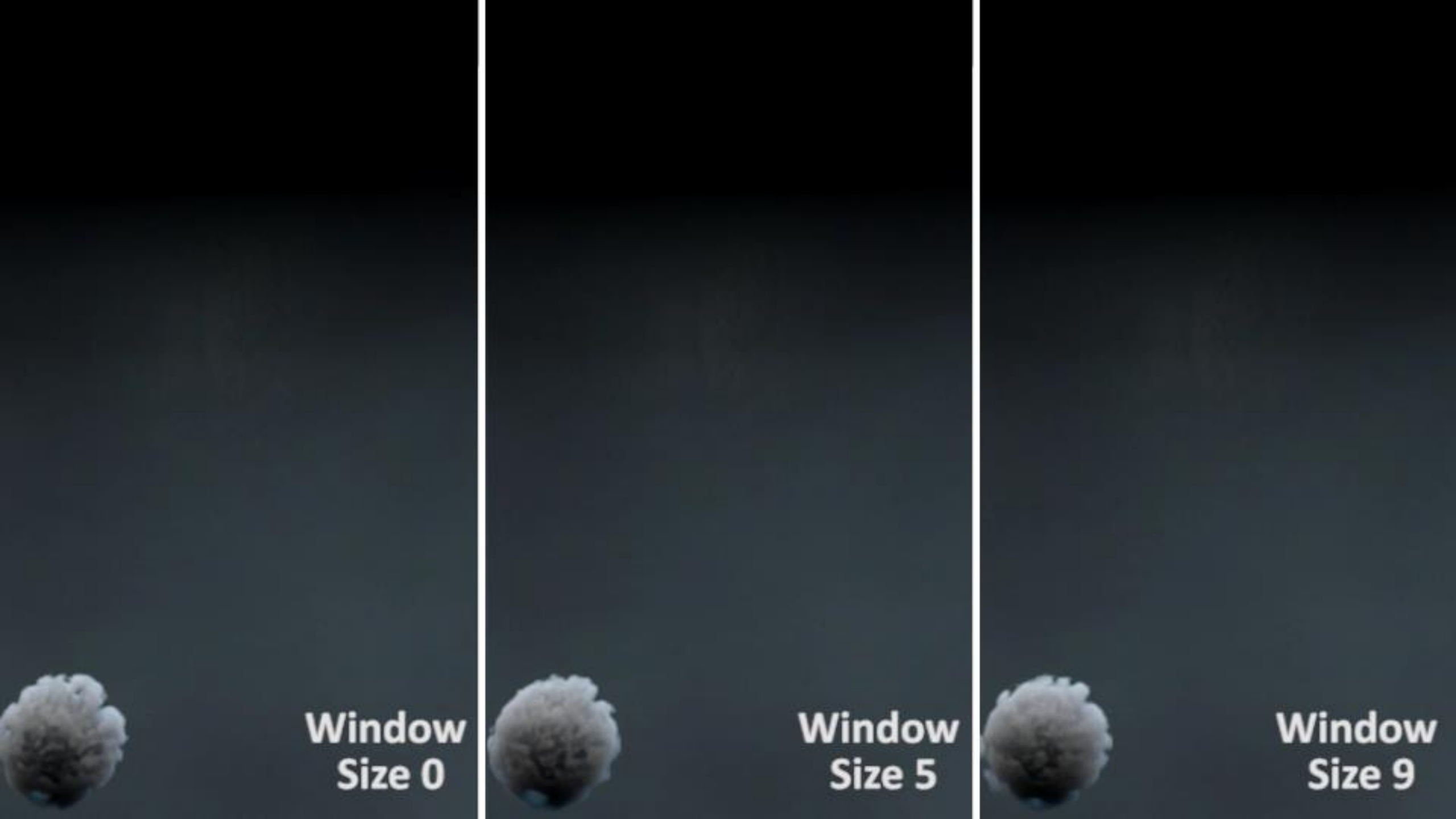
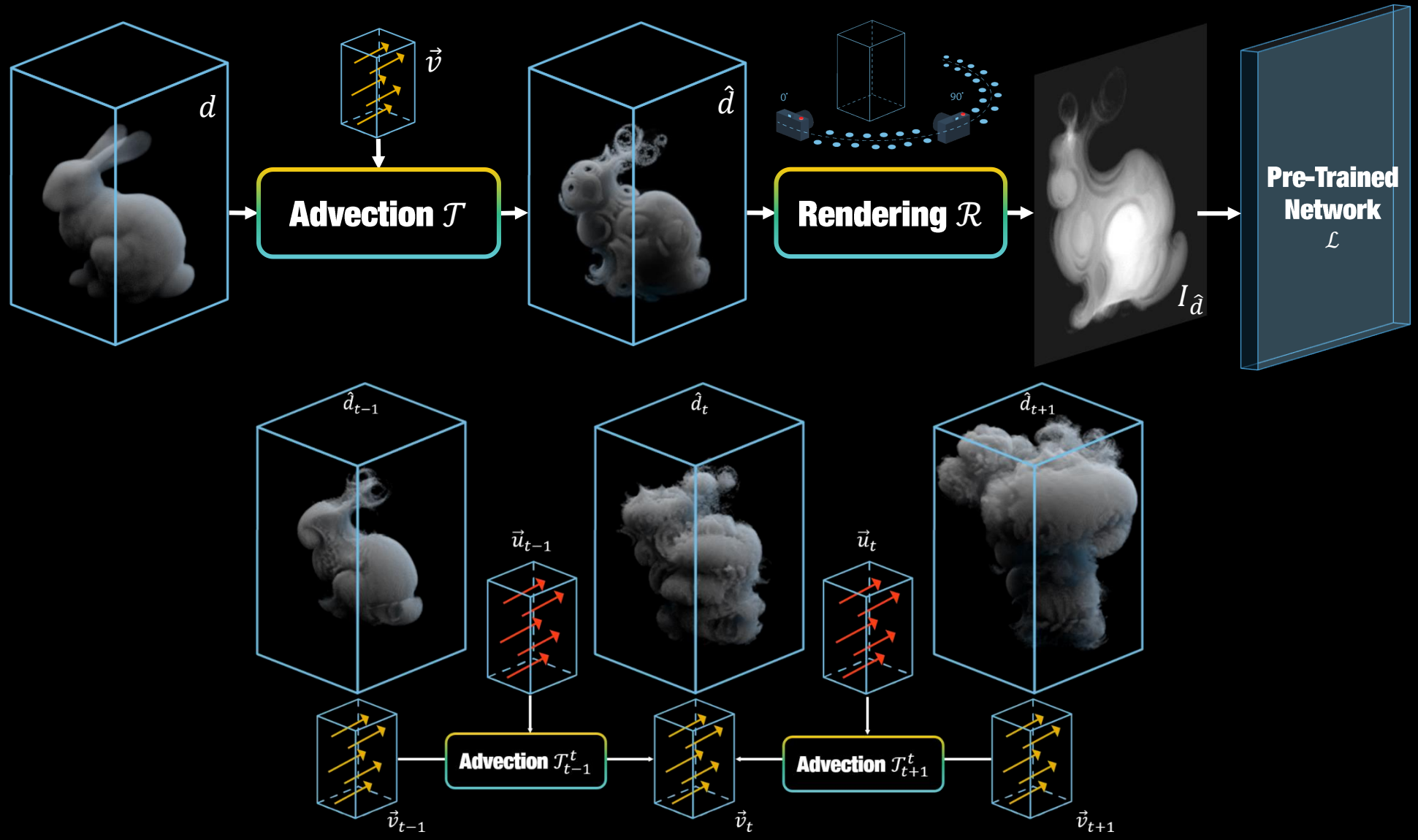
Time-Coherent Stylization




Window
Size 0
Window
Size 5
Window
Size 9

Transport-Based Neural Style Transfer



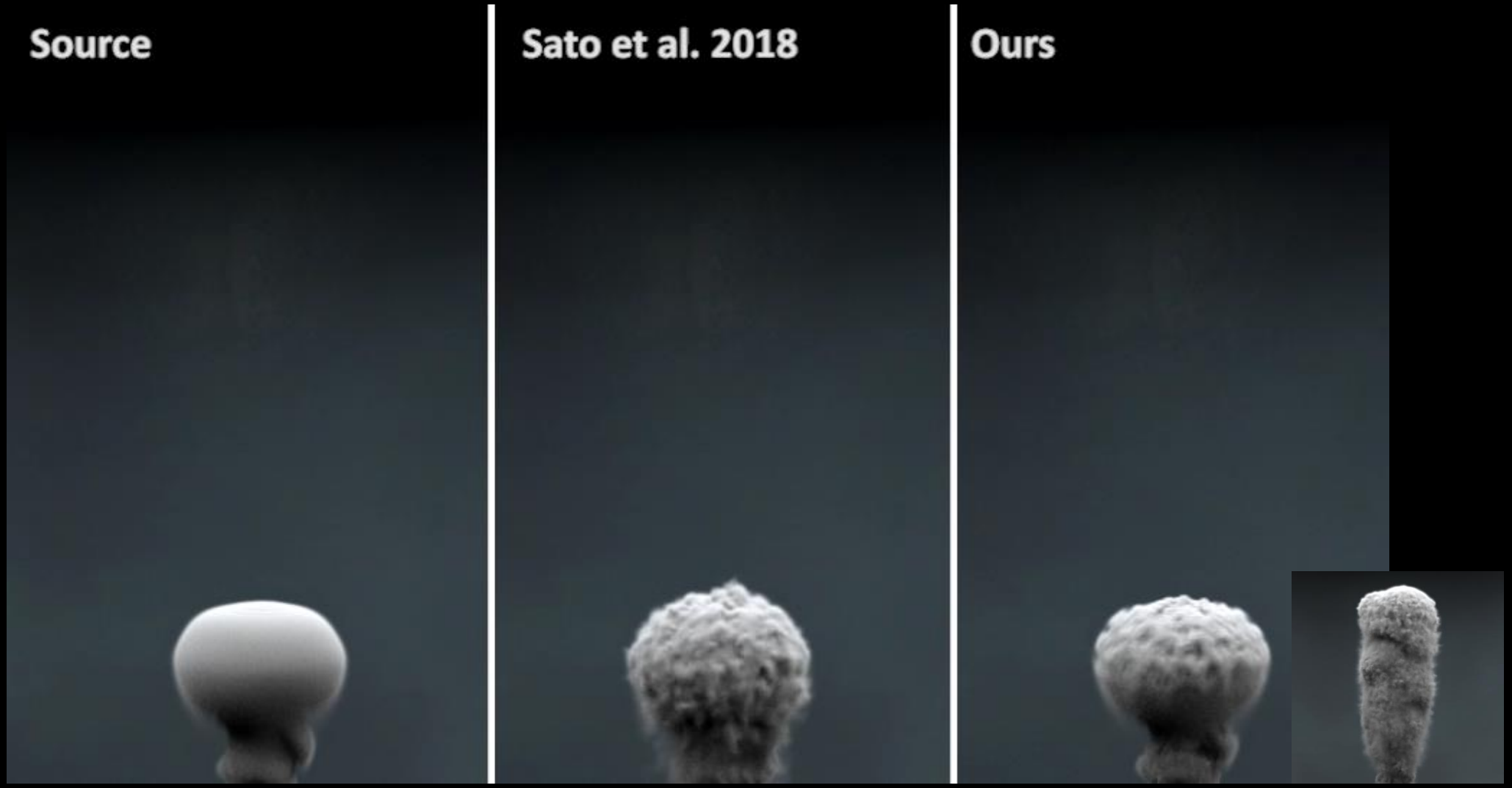
Source

Stylized

Comparison

- Example-based Turbulence Style Transfer [Sato et al. 2018]
  - Minimize divergence, while ours is divergence-free by definition
  - Requires an extra high-res simulation as a reference
  - Instead, we use a single reference image

Comparison



Limitation / Future Work

- Performance & Memory Limitation
  - Up to 200x300x200 with a 8GB GPU
  - Takes around 10 minutes per frame
    - Pre-trained network for instant stylization [Johnson et al. 2016]
    - Analytic differentiation [Liu et al. 2016]

- Other Applications
  - Reconstruct 3D Smoke Volumes from Images [Eckert et al. 2018]
  - Colorized Stylization [Jamriška et al. 2015]

Thank you!

Transport-Based Neural Style Transfer for Smoke Simulations

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Markus Gross Barbara Solenthaler

ETH zürich cgl computer graphics laboratory

- Code / Contact
  - gitlab.ethz.ch/cglsim/neural-flow-style
  - kimby@inf.ethz.ch / www.byungsoo.me