Neural 3D Strokes: Creating Stylized 3D Scenes with Vectorized 3D Strokes

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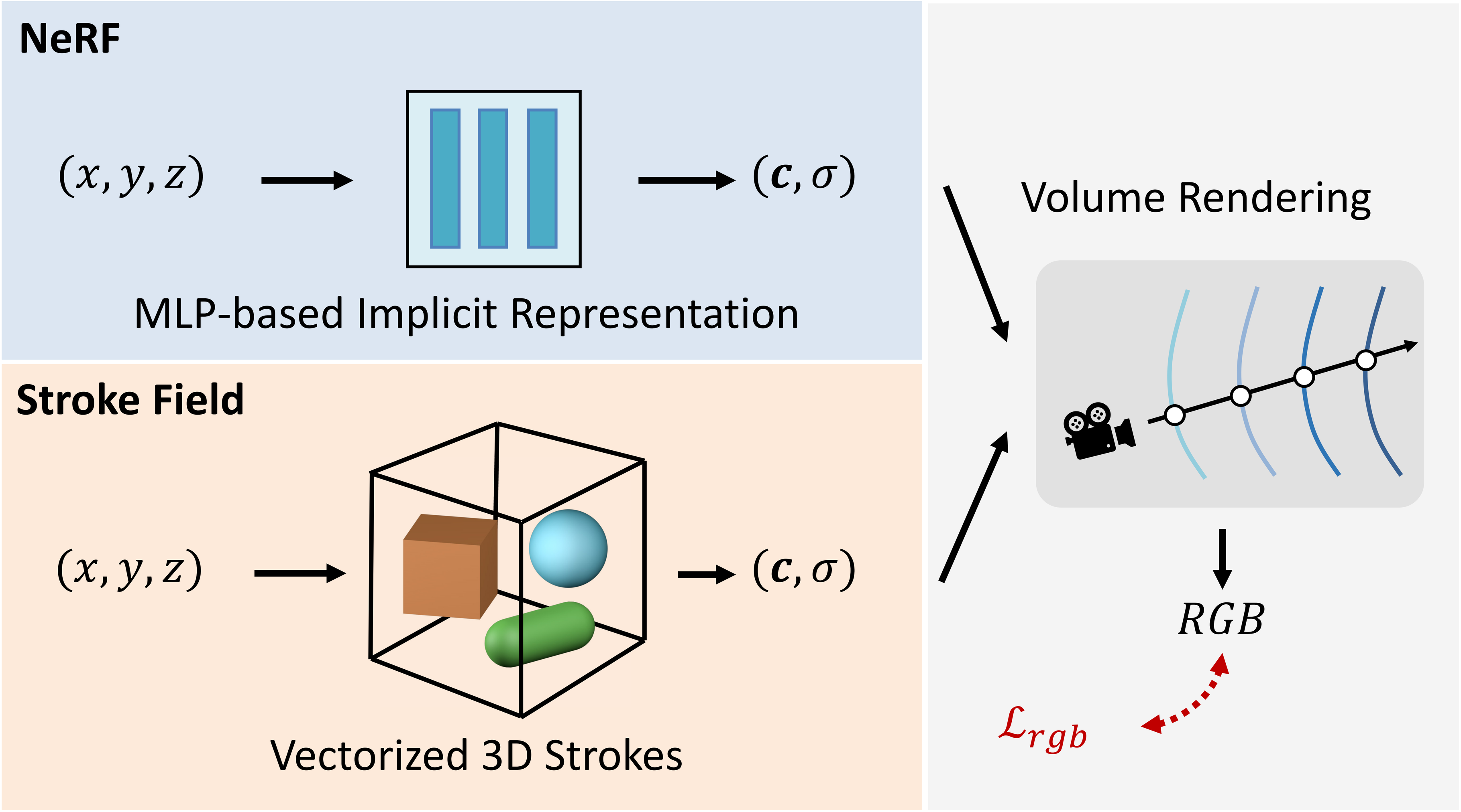
Motivation

- We propose a framework for learning 3D scenes with **vectorized representation** instead of continuous neural field.



- We optimize simple geometry primitives (we call them ***3D strokes***) to reconstruct each part of the whole 3D scene, a procedure similar to "painting in 3D space".

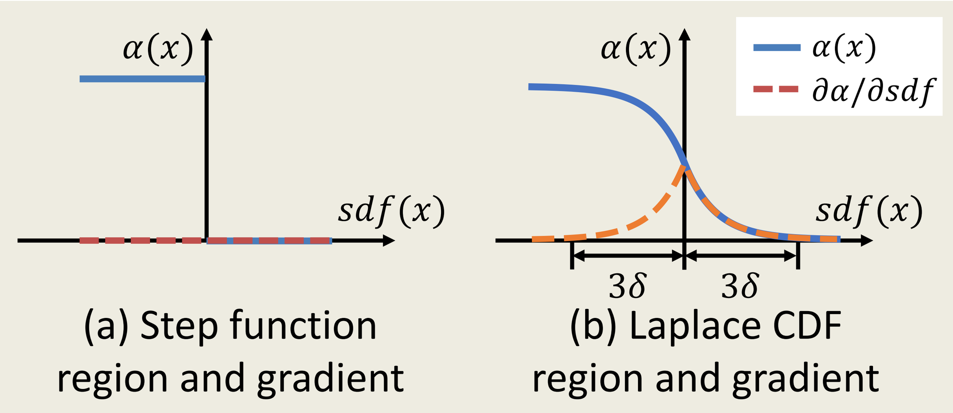
- Under a limited number of strokes, our reconstructed scenes exhibit vastly different geometric styles based on the properties of strokes.

Method

- Radiance field of strokes is given $(\sigma, \mathbf{c}) = \mathrm{StrokeField}(\mathbf{x}, \mathbf{d}; \theta_s, \theta_c, \theta_\sigma)$, where $\theta_s, \theta_c, \theta_\sigma$ are shape, color, density parameters of 3D strokes.
- We define shape of 3D strokes as Signed Distance Fields (SDFs) $\mathrm{sdf}(\mathbf{x}) \rightarrow s \in \mathbb{R}$ and the density is given as $\sigma(\mathbf{x}) = \theta_\sigma \alpha(\mathbf{x})$. We use Laplace CDF to approximate discrete region function $\alpha(\mathbf{x})$:

$$\alpha(\mathbf{x}) = \begin{cases} 1, & \mathrm{sdf}(\mathbf{x}) \leq 0 \\ 0, & otherwise \end{cases}$$

$$\alpha(\mathbf{x}) = \begin{cases} 1 - \frac{1}{2}\exp(\mathrm{sdf}(\mathbf{x})/\delta), & \mathrm{sdf}(\mathbf{x}) \leq 0 \\ \frac{1}{2}\exp(-\mathrm{sdf}(\mathbf{x})/\delta), & otherwise \end{cases}$$



(a) Step function region and gradient (b) Laplace CDF region and gradient

- We define two types of 3D stroke shapes based on basic primitives and spline curves.

Basic Primitives

1. Define SDF of a unit primitive:

$$\mathrm{sdf}_{\mathrm{unit}}(\mathbf{x}) : (\hat{\mathbf{p}}, \theta_s^{\mathrm{basic}}) \rightarrow s \in \mathbb{R}$$

2. Apply transformation $\mathbf{T} \in \mathbb{R}^{4\times4}$, inc. translation, rotation and scale.

$$\mathrm{sdf}(\mathbf{p}; \theta_s) = \mathrm{sdf}_{\mathrm{unit}}(\mathbf{T}^{-1}\mathbf{p}, \theta_s^{\mathrm{basic}})$$

Primitive	Params	SDF formula
Sphere	None	$\lVert\mathbf{p}\rVert_2 - 1$
Cube	None	$\min(\max(\mathbf{q}_x, \mathbf{q}_y, \mathbf{q}_z), 0) + \lVert\max(\mathbf{q}, \mathbf{0})\rVert_2$, where $\mathbf{q} = \lvert\mathbf{p}\rvert - \mathbf{1}$
Tetrahedron	None	$(\max(\lvert\mathbf{p}_x+\mathbf{p}_y\rvert-\mathbf{p}_z, \lvert\mathbf{p}_x+\mathbf{p}_y\rvert+\mathbf{p}_z)-1)/\sqrt{3}$
Octahedron	None	$(\lVert\mathbf{p}\rVert_1 - 1)/\sqrt{3}$
Round Cube	r	$\min(\max(\mathbf{p}_x, \mathbf{p}_y, \mathbf{p}_z), 0) + \lVert\max(\mathbf{p}, \mathbf{0})\rVert_2 - r$
Triprism	h	$\max(\lvert\mathbf{p}_y\rvert - h, \max(\lvert\mathbf{p}_x\rvert * \sqrt{3}/2 + \mathbf{p}_z/2, -\mathbf{p}_z) - 0.5)$
Capsule Line	h, r_δ	$\lVert\mathbf{p} - [0, \min(\max(\mathbf{p}_y, -h), h), 0]\rVert_2 - r_\delta \min(\max((0.5 * (\mathbf{p}_y + h)/h, 0), 1) - 1$

Spline Curves

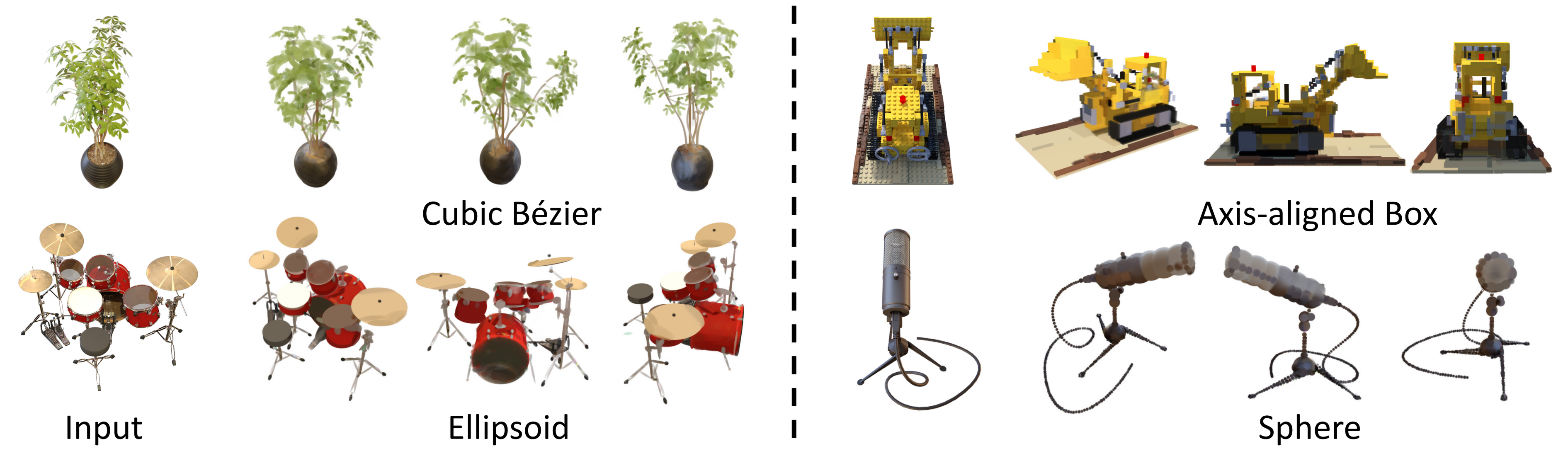
1. Define curves by parametric 3D spline $\mathrm{C} : (\mathrm{t}, \theta_s^{\mathrm{curve}}) \rightarrow \boldsymbol{x} \in \mathbb{R}^3, t \in [0,1]$.
2. Radius of 3D curve is interpolated as $r(\mathrm{t}; r_a, r_b) = r_a(1 - \mathrm{t}) + r_b \mathrm{t}$.
3. SDF of 3D curves is computed as approximation of K line segments. With the nearest point on the line segment to query position p as t*,

$$\mathrm{sdf}(\mathbf{p}; \theta_s) = \lVert\mathbf{p} - \mathrm{C}(\mathrm{t}^*, \theta_s^{curve})\rVert_2 - r(\mathrm{t}^*; r_a, r_b)$$

- Color field is simply treated as constant color $\mathbf{c}(\mathbf{x}, \mathbf{d}) = \theta_c \in \mathbb{R}^3$.
- Combine multiple 3D strokes with "overlay" or "softmax" composition.
- Training Strategy:
  - Use an *error field* to guide the placement of new 3D strokes.
  - Reset parameters of 3D strokes with near-zero density.

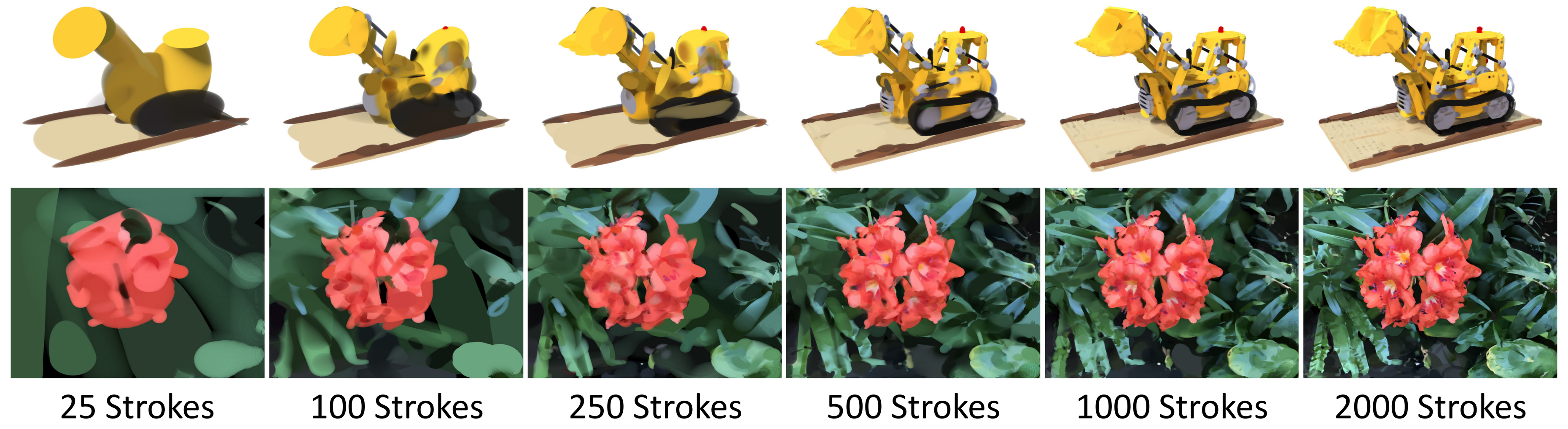
Results

- Result of various 3D strokes on synthetic scenes.



- Result of various 3D strokes on face-forwarding scenes.

- Result of different stroke numbers.



- Color Transfer & Text-driven 3D drawings with 3D strokes.

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