Implicit Neural Surface Deformation with Explicit Velocity Fields

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Task description:

- given **source** and **target** point clouds
- Reconstruct the **intermediate continuous shape space**
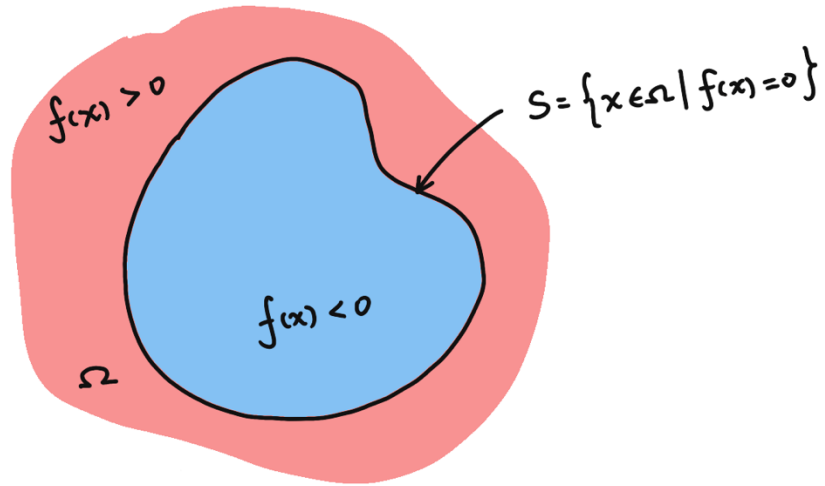

Source Point cloud   intermediate shape deformation   Target Point cloud
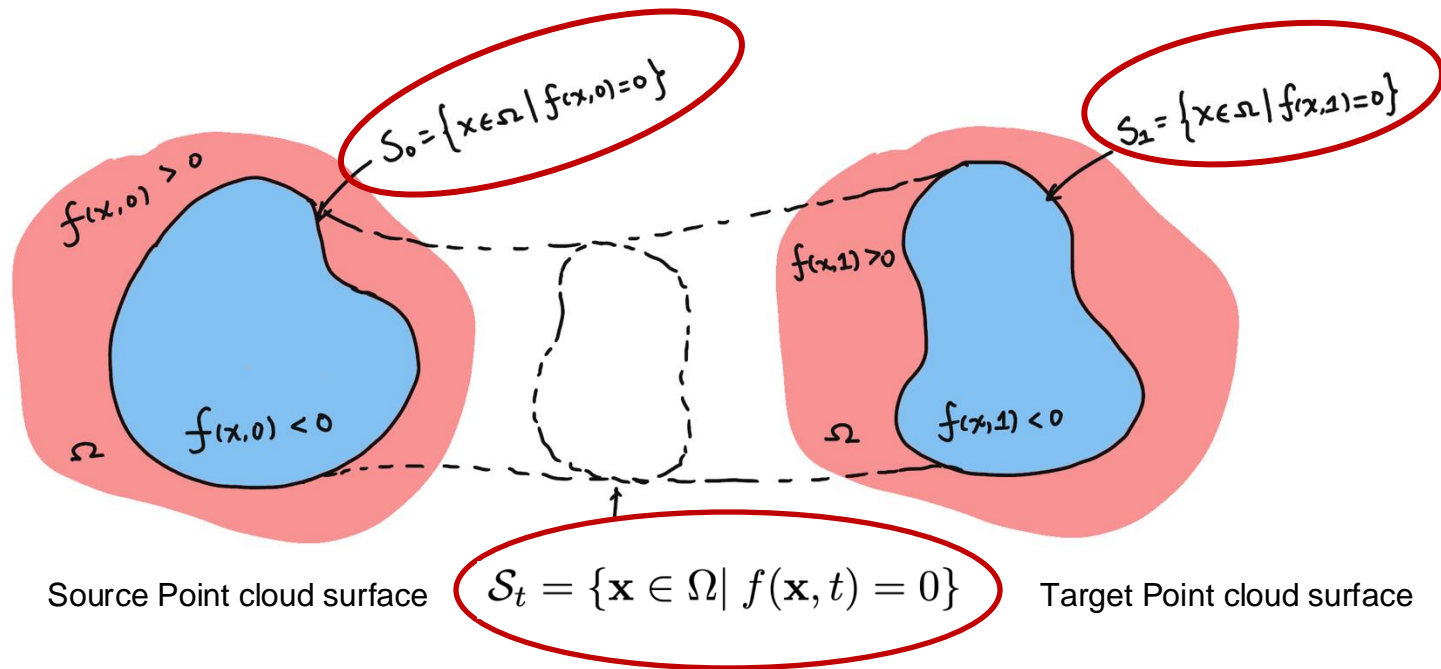
Method:

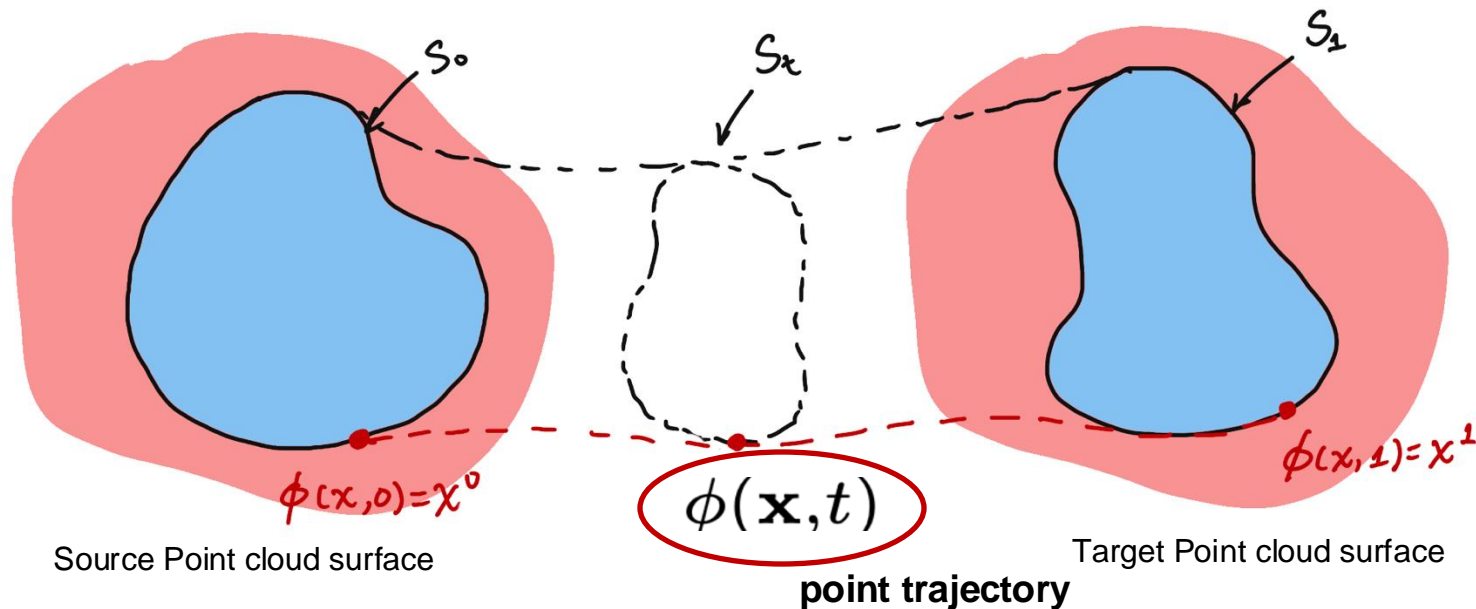Geometry representation: **implicit neural representation**

$$S = \{x \in \Omega \mid f(x) = 0\}$$

with regions labelled $f(x) > 0$, $f(x) < 0$, and Ω.

Method:

Geometry representation: **time-varying** implicit neural representation

Source Point cloud surface $\mathcal{S}_t = \{\mathbf{x} \in \Omega |\ f(\mathbf{x}, t) = 0\}$ Target Point cloud surface

Method:

Deformation representation: **velocity field**

Source Point cloud surface

$\phi(\mathbf{x}, t)$

point trajectory

Target Point cloud surface

Method:

Deformation representation: **velocity field**

$$\begin{cases} \mathcal{V}(\mathbf{x}) = \frac{\mathrm{d}\phi(\mathbf{x},t)}{\mathrm{d}t}, & \text{for } t \in \mathcal{I}, \\ \phi(\mathbf{x}, 0) = \mathbf{x}^0. \end{cases}$$

point trajectory

$$\phi(\mathbf{x}, t) = \mathbf{x}^0 + \int_0^t \mathcal{V}(\phi(\mathbf{x}, t))\mathrm{d}\tau$$
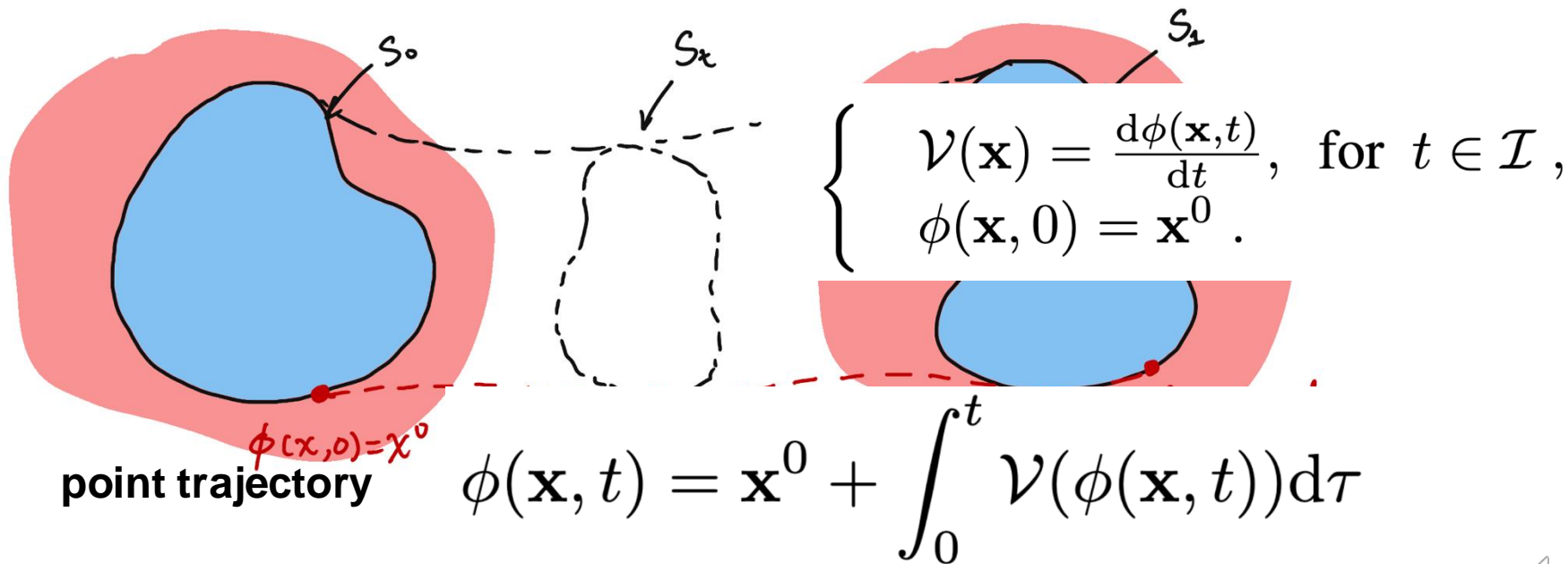
Method:

Combine two representations: **level-set equation**
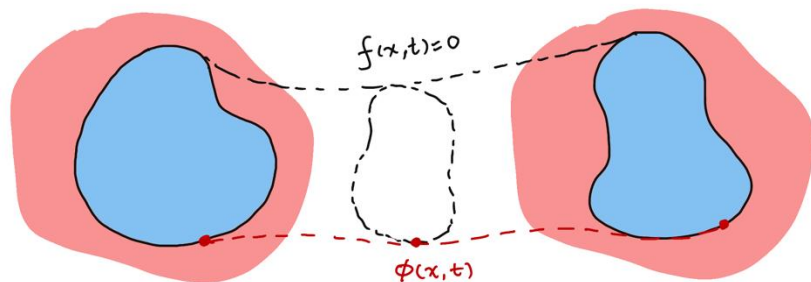
for points on the deformed surface:

$$f(\phi(\mathbf{x}, t)) = 0$$

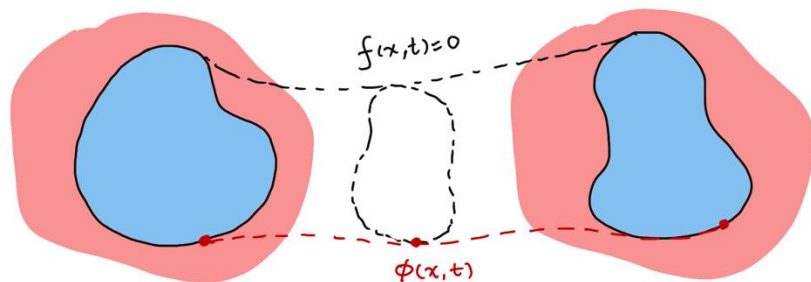$$\frac{\mathrm{d}f(\phi(\mathbf{x}, t))}{\mathrm{d}t} = \partial f_t + \boxed{\partial f_{\mathbf{x}}}\boxed{\partial \phi_t} = 0$$

$$\nabla f \quad \mathcal{V}$$

Method:

Combine two representations: **<u>level-set equation</u>**

for points on the deformed surface:

$$f(\phi(\mathbf{x}, t)) = 0$$

velocity field

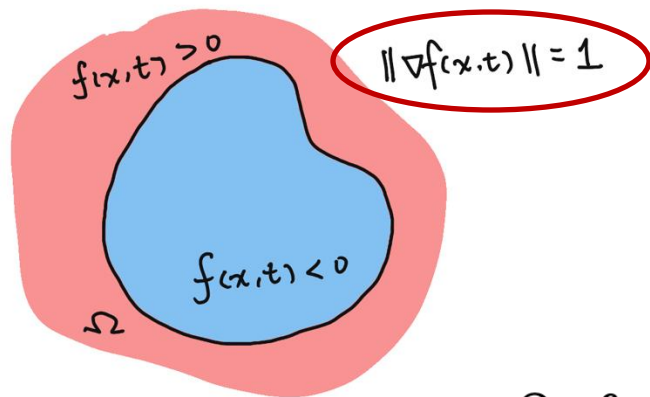level-set equation: $\partial_t f + \mathcal{V} \cdot \nabla f = 0$

implicit neural surface

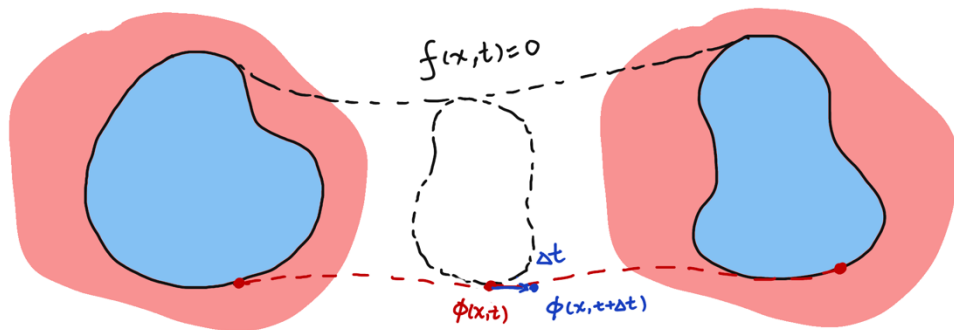# Method:

Combine two representations:

level-set equation

$$\|\nabla f(x,t)\| = 1$$

$$\partial_t f + \mathcal{V} \cdot \nabla f = 0$$

$$\frac{\mathrm{d}}{\mathrm{d}t} \|\nabla f(\mathbf{x}, t)\| = 0$$

$$\partial_t f + \mathcal{V} \cdot \nabla f = -\lambda_l f \mathcal{R}(\mathbf{x}, t)$$

aviod reinitialization step!

Method:

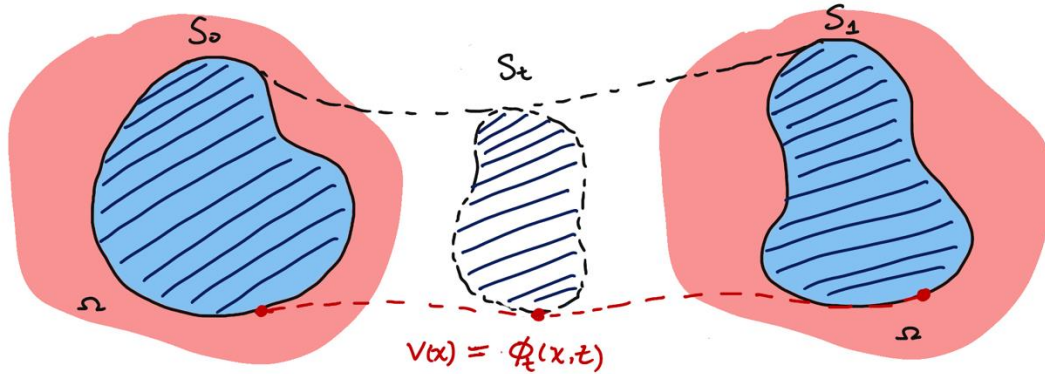Physical realistic velocity field: **spatial smoothness**

Smooth regularization

$$\|(-\alpha\Delta + \gamma\mathbf{I})\mathcal{V}(\mathbf{x})\| = 0$$

$$\phi(\mathbf{x}, t + \delta t) = \phi(\mathbf{x}, t) + \mathcal{V}(\phi(\mathbf{x}, t))\delta t$$
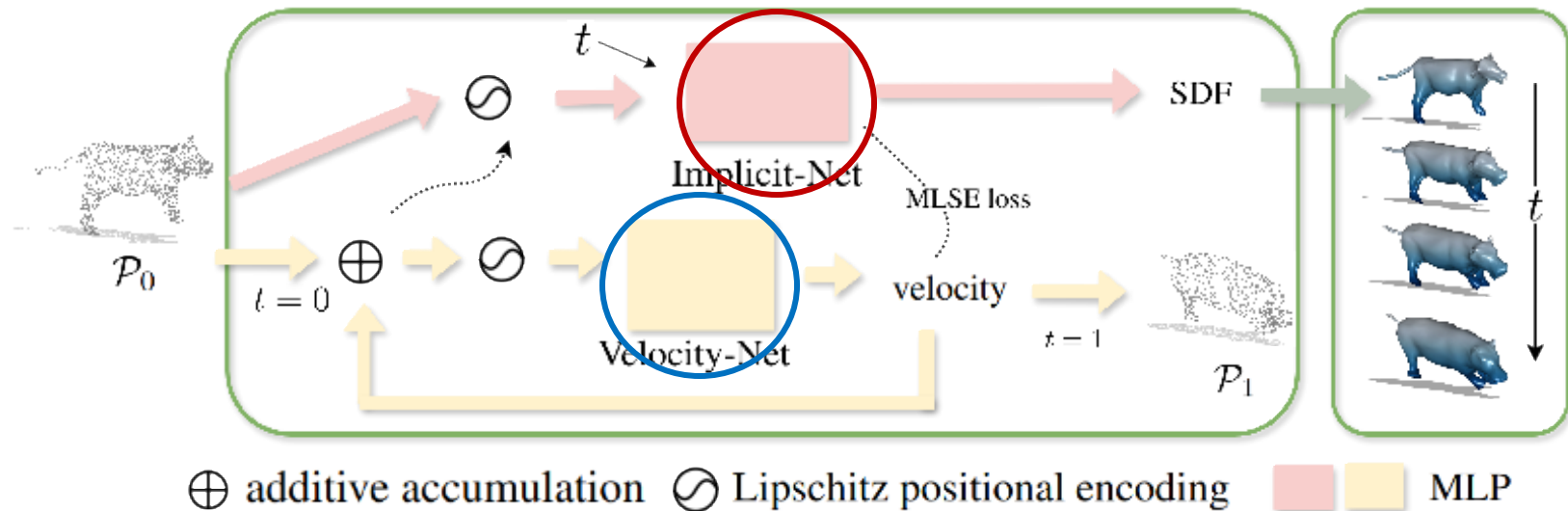
Method:

Physical realistic velocity field: **volume preserving**

Divergence-free velocity field

$$\nabla \cdot \mathcal{V}(\mathbf{x}) = 0.$$

Pipeline

$\oplus$ additive accumulation $\oslash$ Lipschitz positional encoding   MLP

smooth + volume-preserving

$$L = \lambda_f \boxed{L_f} + \lambda_v \boxed{L_v} + \lambda_m \boxed{L_m}$$

level-set equation   correspondences matching

Results
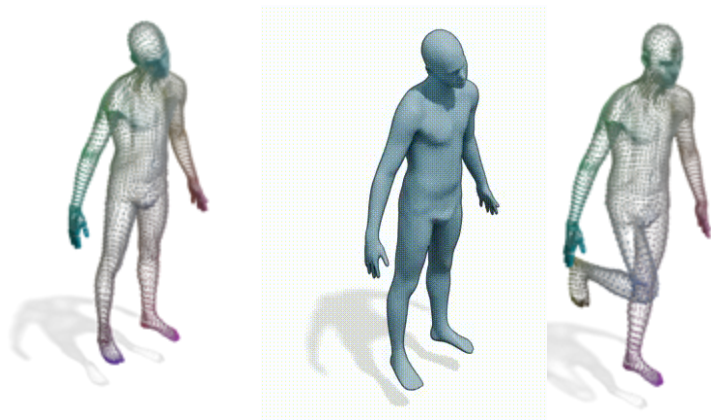
Extrinsic (Pose) Deformation

Ours Output

Ours Output

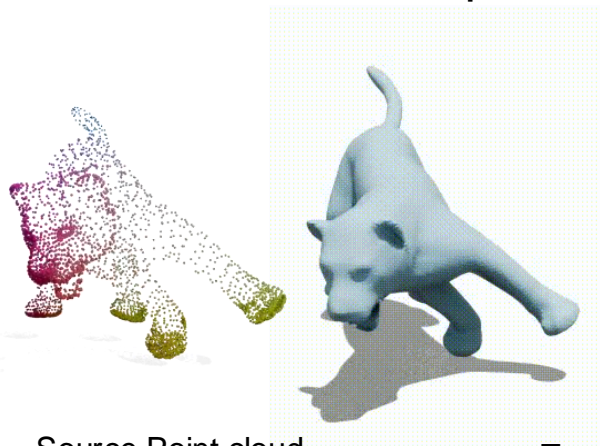Source Point cloud

Target Point cloud

Source Point cloud

Target Point cloud

Results

Intrinsic (non-rigid) Deformation

Ours Output

Source Point cloud

Target Point cloud

Ours Output
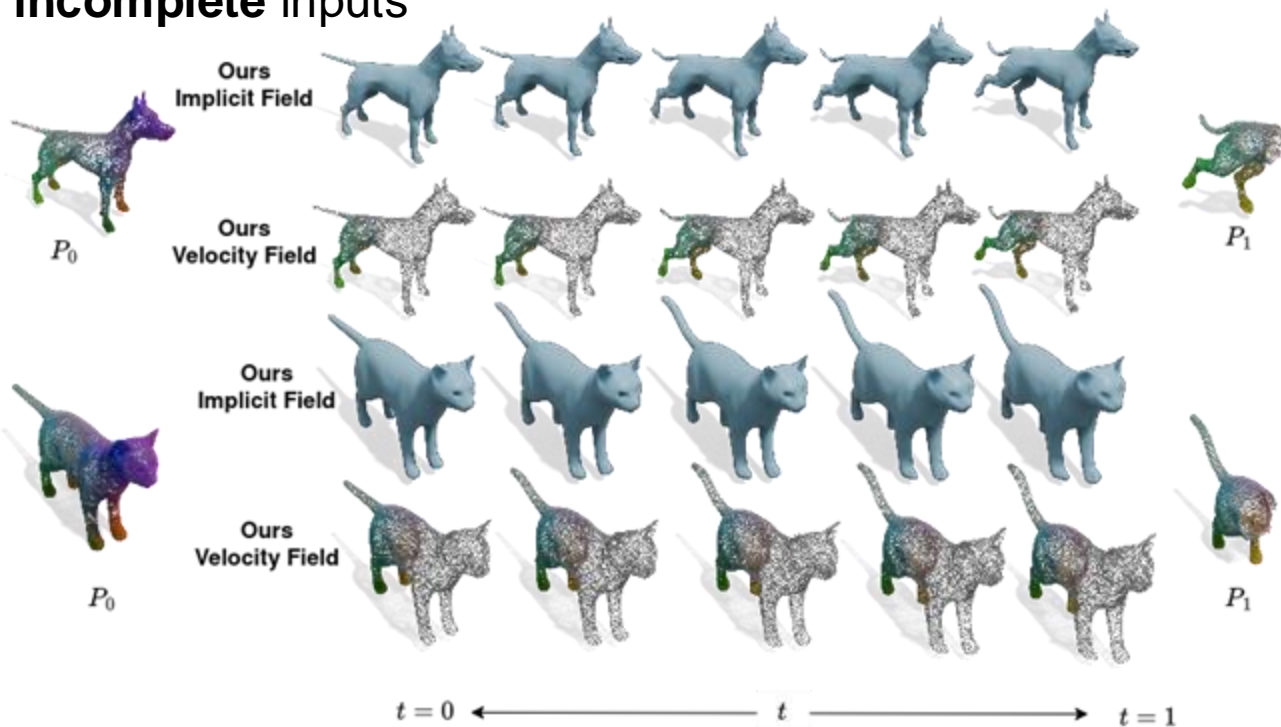
Source Point cloud

Target Point cloud

Results

Deal with **incomplete** inputs

P_0

P_1

P_0

P_1

Results

Deal with **incomplete** inputs

More details please check our paper and code

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with Explicit Velocity Fields