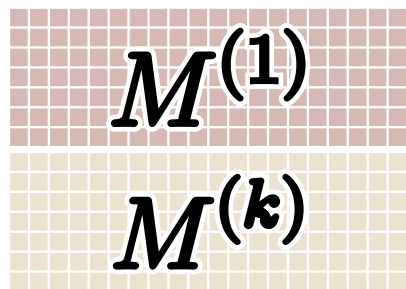
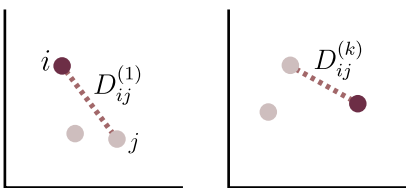


## Multimodal Single Cell Data



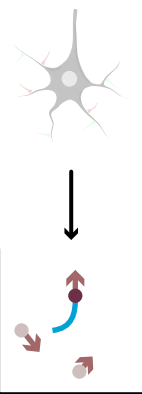
$M^{(k)}, E^{(k)}$  Modal data and encoder

## Inter-Cell Distances

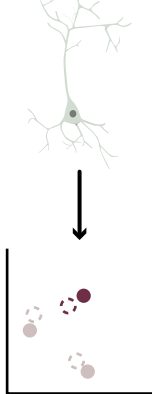


$D^{(k)}, D_{ij}$  Distance for modality and latent space

## Development and Disease Trajectory Reconstruction

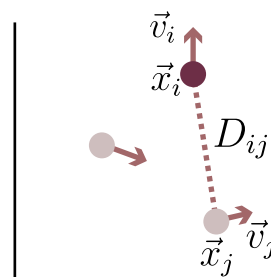


## Perturbation Analysis and Feature Prioritization



$\pi$  Trained policy

## Environmental Reward



$$[R_B^t]_i = \begin{cases} -1 & \max(\vec{x}_i) = 1 \\ 0 & \text{else} \end{cases}, \quad [R_V^t]_i = -\|\vec{v}_i^t\|^2, \quad [R_A^t]_i = -\|\Delta \vec{v}_i^t\|^2,$$

$$[R_D^{t+1}]_i = \delta_i^{t+1} - \delta_i^t, \quad \delta_i^t = \sum_{k=1}^{n_m} \sum_{j=1 \neq i}^{n_c} (D_{ij}^{(k)} - D_{ij}^t)^2,$$

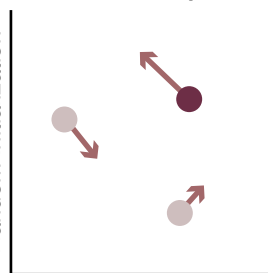
$$R^t = R_D^t + R_B^t + R_V^t + R_A^t$$

$\vec{x}_i, \vec{v}_i$  Cell position and velocity

$\vec{X}^{t_0}, \vec{V}^{t_0} \uparrow \downarrow R^{t_0}$

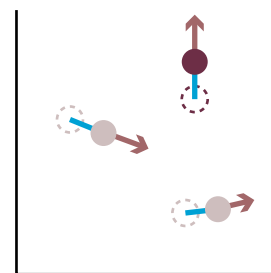
$t = t_0$

Random Initialization



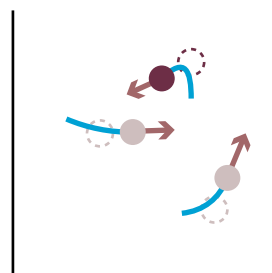
$\uparrow \downarrow$

$t = t_1$



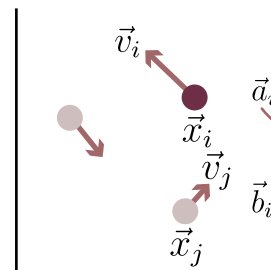
$\uparrow \downarrow$

$t = t_2$



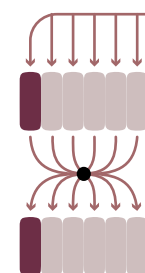
$\vec{X}^{t_0}, \vec{V}^{t_0} \downarrow \nearrow \Delta \vec{V}^{t_0}$

## Per-Cell Action Loop



$$\vec{a}_i = E_a \left( \left[ \vec{x}_i, \vec{v}_i, E^{(1)}(M_i^{(1)}), \dots, E^{(k)}(M_i^{(k)}) \right] \right)$$

$$\vec{b}_{ij} = E_b \left( \left[ \vec{x}_j, \vec{v}_j, E^{(1)}(M_j^{(1)}), \dots, E^{(k)}(M_j^{(k)}), \vec{a}_i \right] \right)$$



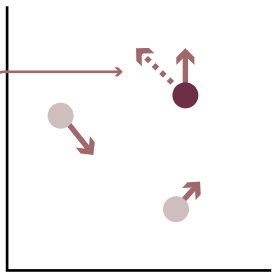
Residual Self-Attention

mean

$\vec{s}_i$

$E_s$

$\Delta \vec{v}_i$



$\vec{a}_i, \vec{b}_{ij}$  Cell and neighbor embeddings  
 $\vec{s}_i, \Delta \vec{v}_i$  State and action vectors

$E_a, E_b, E_s$  Cell, neighbor, and state encoders