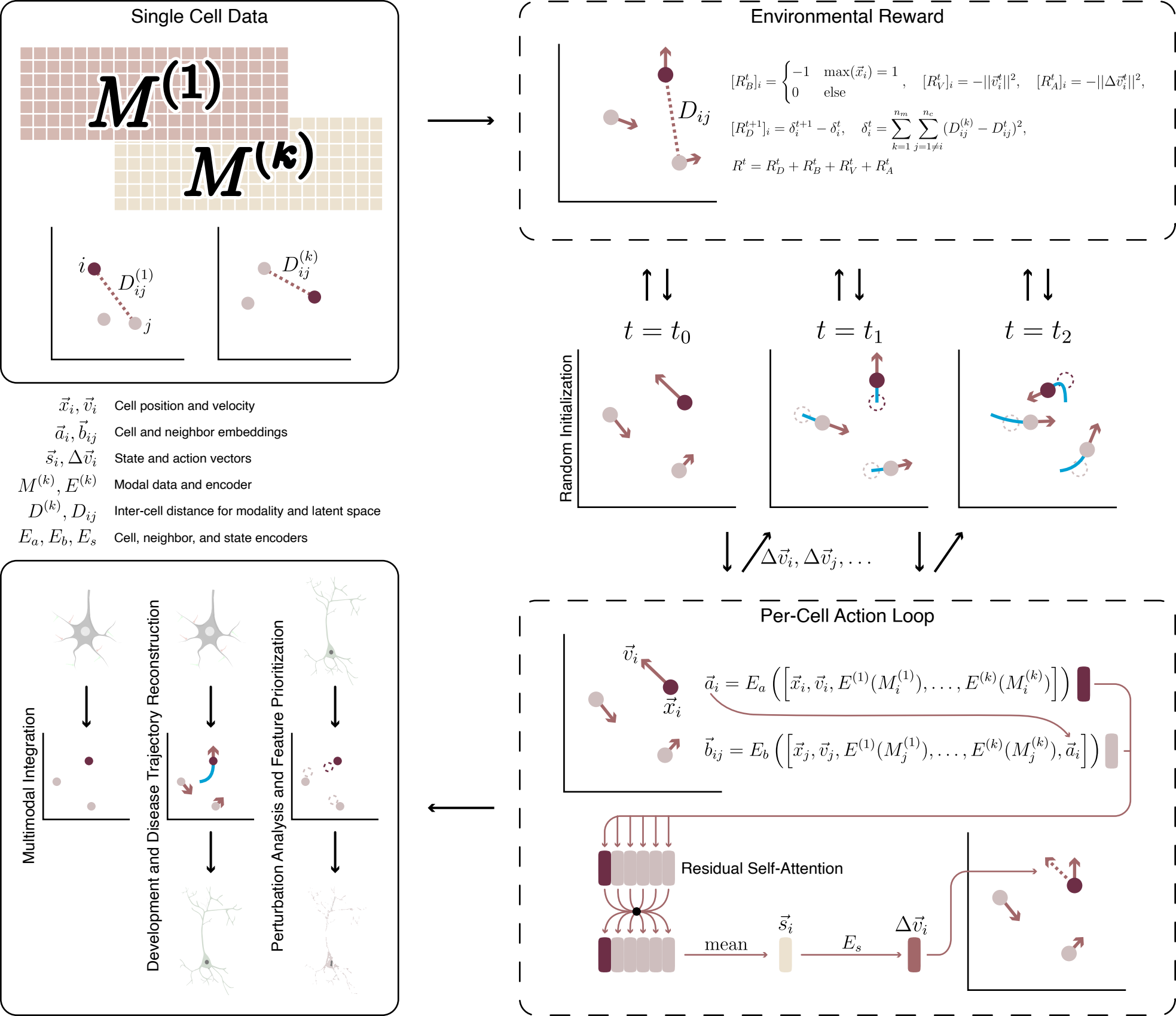
Single Cell Data
$M^{(1)}$
$M^{(k)}$
i
$D_{ij}^{(1)}$
j
$D_{ij}^{(k)}$
Environmental Reward
D_{ij}
$[R_B^t]_i = \begin{cases} -1 & \max(\vec{x}_i) = 1 \\ 0 & \text{else} \end{cases}$, $[R_V^t]_i = -||\vec{v}_i^t||^2$, $[R_A^t]_i = -||\Delta\vec{v}_i^t||^2$,
$[R_D^{t+1}]_i = \delta_i^{t+1} - \delta_i^t$, $\delta_i^t = \sum_{k=1}^{n_m} \sum_{j=1 \neq i}^{n_c} (D_{ij}^{(k)} - D_{ij}^t)^2$,
$R^t = R_D^t + R_B^t + R_V^t + R_A^t$
$\vec{x}_i, \vec{v}_i$ Cell position and velocity
$\vec{a}_i, \vec{b}_{ij}$ Cell and neighbor embeddings
$\vec{s}_i, \Delta\vec{v}_i$ State and action vectors
$M^{(k)}, E^{(k)}$ Modal data and encoder
$D^{(k)}, D_{ij}$ Inter-cell distance for modality and latent space
E_a, E_b, E_s Cell, neighbor, and state encoders
$t = t_0$
$t = t_1$
$t = t_2$
Random Initialization
$\Delta\vec{v}_i, \Delta\vec{v}_j, \ldots$
Per-Cell Action Loop
$\vec{v}_i$
$\vec{x}_i$
$\vec{a}_i = E_a\left(\left[\vec{x}_i, \vec{v}_i, E^{(1)}(M_i^{(1)}), \ldots, E^{(k)}(M_i^{(k)})\right]\right)$
$\vec{b}_{ij} = E_b\left(\left[\vec{x}_j, \vec{v}_j, E^{(1)}(M_j^{(1)}), \ldots, E^{(k)}(M_j^{(k)}), \vec{a}_i\right]\right)$
Residual Self-Attention
mean
$\vec{s}_i$
E_s
$\Delta\vec{v}_i$
Multimodal Integration
Development and Disease Trajectory Reconstruction
Perturbation Analysis and Feature Prioritization