a. Paired Training Data

Control Profile
$x_c \in R^G$

Perturbed Profile
$y \in R^G$

Cell type, $c \in c$

Model
$p(y \mid x_c, c)$

b. Conditional Flow Field Network

Original gene expression state, x^c

Interpolated gene expression state, x^t

Categorical Cell type, $c \in C$

Latent space $d_c = 16$

Continuous time variable, $t \in [0,1]$

Latent space $d_t = 16$

Concatenation layer

d = 256
Fully Connected layer + ReLU

d = 256
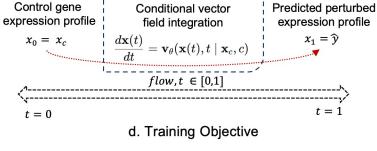Fully Connected layer + ReLU

d = N_G
Output Vector

c. Conditional Flow Matching

Control gene expression profile
$x_0 = x_c$

ODE Block
Conditional vector field integration
$$\frac{d\mathbf{x}(t)}{dt} = \mathbf{v}_\theta(\mathbf{x}(t), t \mid \mathbf{x}_c, c)$$

Predicted perturbed expression profile
$x_1 = \hat{y}$

$flow, t \in [0,1]$

$t = 0$ $t = 1$

d. Training Objective

Timer field

Vector field

Vector field

Vector field

Interpolated
$\mu_t = (1-t)x^c + ty$

Vector field
y

Minimize MSE

Target
$y - x_c$

target

e. Inference: Integrating ODE

Control
$\bar{x}^G$

Cell type c^*

$dx(t)$

$t = 1$

$= \frac{v_g(xt, t)}{x_c^*}, c^*$

Perturbed profile