Generative AI for Morphologies of Living Systems

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Living systems produce richly structured spatiotemporal data: cells move, change shape, divide, and coordinate with their neighbors over time. Modeling these dynamics would address important questions regarding developmental biology and cancer research, but doing so requires methods that can capture the stochastic and versatile nature of cellular movement. This project investigates the use of autoregressive diffusion models, particularly those employed for video generation, to learn the distribution over multi-cell trajectories. This frames the problem of cell dynamics as a video generation task: Given a dataset where each "video" is a sequence of "frames" describing the positional and morphological features of all cells in a population over time, the model learns to generate plausible trajectories conditioned on the observed portion. Training proceeds by iteratively adding Gaussian noise to trajectories with a forward process and learning a denoising network that reverses the process. Synthetic trajectory data will first be generated by simulating the "swarmalator" model, a system of coupled oscillators that produce collective movement patterns, providing clean data with known dynamics for validating the model. Later, the model will be tested on semi-synthetic data of cellular trajectories obtained through *waxMorph,* an internal model capable of generating biophysically consistent deformation trajectories. Finally, the model will be applied to real biological datasets to assess how well the approach generalizes across contexts involving cell morphology and movement. The outcome of this project will answer whether video generation diffusion models can be modified for cellular trajectory data. In the ideal case, the outcome will be a well-validated model that can analyze cellular trajectories.