# Hybrid Markov Chain + Neural ODE for Irregular Time Series

Hybrid Modeling for Regime-Switching Dynamics

# Motivation

- Many real-world time series are irregular
  - Markov Chains : discrete state transition
  - Neural ODE : handles continuous irregular dynamics
  - Hybrid combines strengths of both

# Neural ODE Overview

- Defines $dy/dt = f(t, y) \rightarrow y(t)$
  - Uses neural network $f$
  - Integrated using numerical solvers

# Training Neural ODE

- Backpropagation store activations
- Neural ODE Solver may take many step
- Memory Expensive
- Adjoint Method ( backward ODE )
- O(N) → O(1)
- Less memory more computation

# Limitations of Neural ODE

- Assume single continuous function ($dy/dt = f(t, y)$)
- Struggle with sudden Regime change
- Rest → exercise

average of rest + stress + exercise

# Why Hybrid Model

- Markov handles discrete jumps (Regime)
- Neural ODE handles smooth flow (Regime Specific Dynamics)
- Hybrid captures both behaviors
- More realistic for real systems

# Hybrid Strategy : Latent State ODE

Encoder : Handle irregular data and encode it in Latent Space

Soft Regime Inference ( Infer Regime Probability from Latent State)

Regime specific Dynamics

Integrate Weighted mixture of Regime Dynamics

Decode it for prediction

# Architecture Design

1. Input (x_t, t)
2. Encode x_t → z_t ( z_t is the latent state )
3. Infer Regime using Soft Assignment
4. pt = softmax ( W @ z_t )
5. Regime Control Neural ODE
6. Decode z_t → x_t

$$\dot{z} = \sum_k p_t^{(k)} f_k(z, t)$$

# Proposed Dataset

- MIMIC-IV
- eICU Collaborative Research Database ( Irregularly Sampled Data)
- Synthetic Data (Experiment)

# Evaluation Metrics

1) MAE (Mean Absolute Error)

   -easy to interpret

2) MSE/RMSE

   -penalize large mistake

3) Negative Log Likelihood (NLL)

   - common in latent ODE paper

   -measure uncertainty quality

# Baseline Models

- LSTM (widely accepted)
- Transformer (attention)
- Neural ODE (No Markov)

# Expected Benefits

- Handle Irregular Time Naturally
- Separate Noise using Encoder
- Models Different Behaviour ( Regime )

  resting / active / stress

  Each Behaviour have different Dynamics