Temporal Graph Neural Networks with Time-Continuous Latent States

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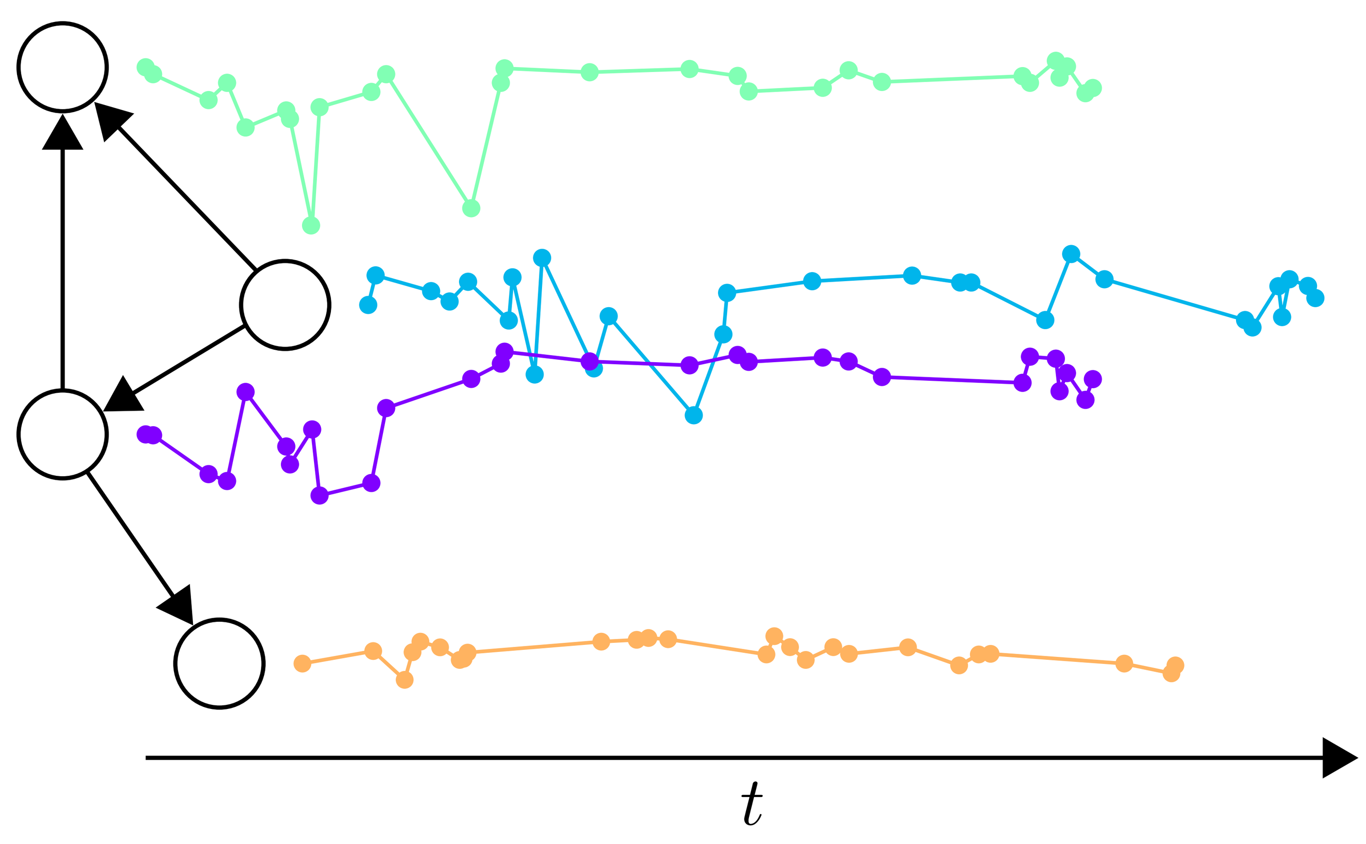
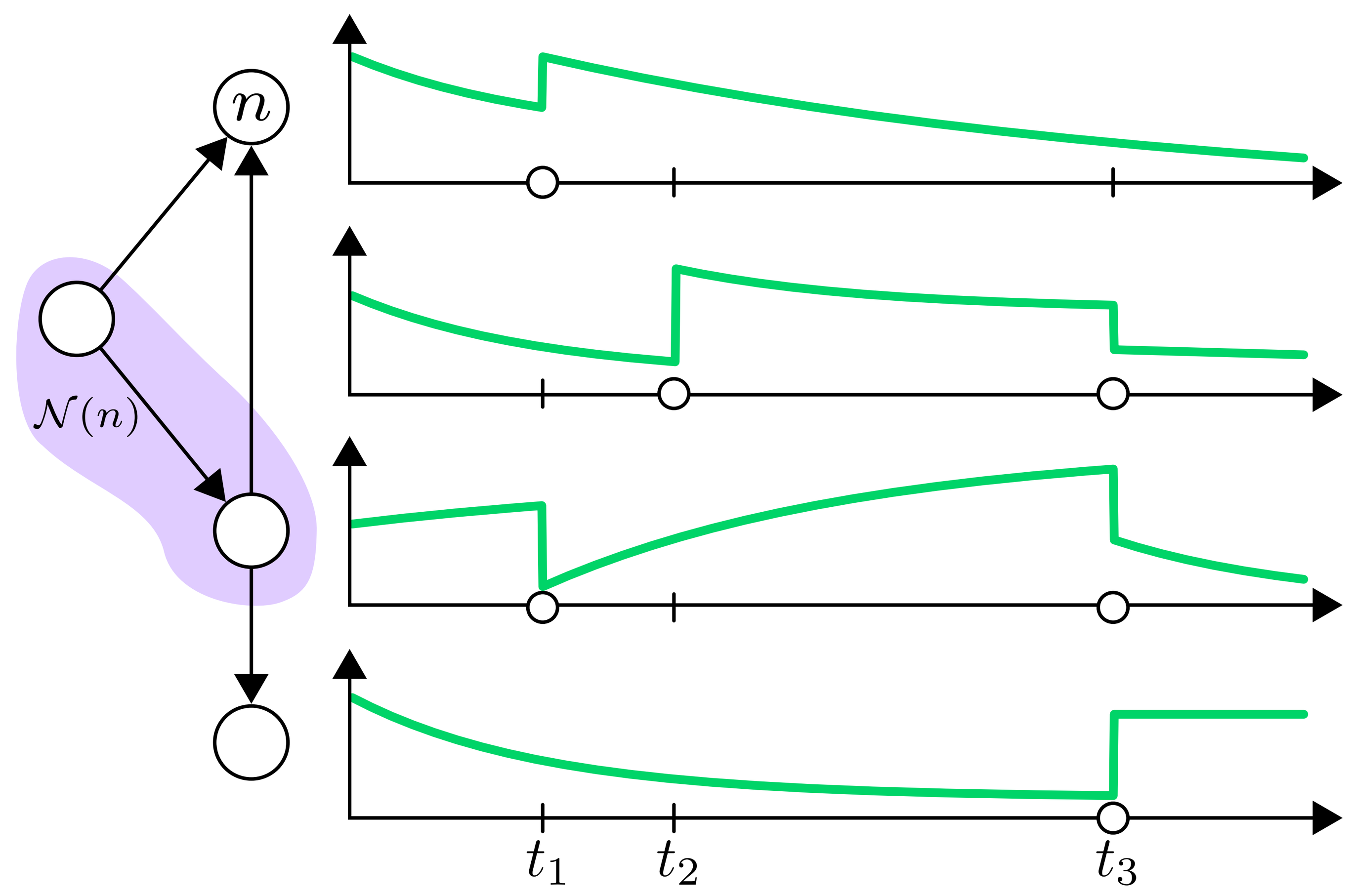
Introduction: Irregularly Observed Graphs



- Consider forecasting for graph-structured time series
- How can irregular observations be dealt with?
  - Irregularly spaced observation times
  - Only a subset of nodes observed at each time point
- Our solution: A temporal Graph Neural Network (GNN) with latent states defined over continuous time

Time-Continuous Latent States



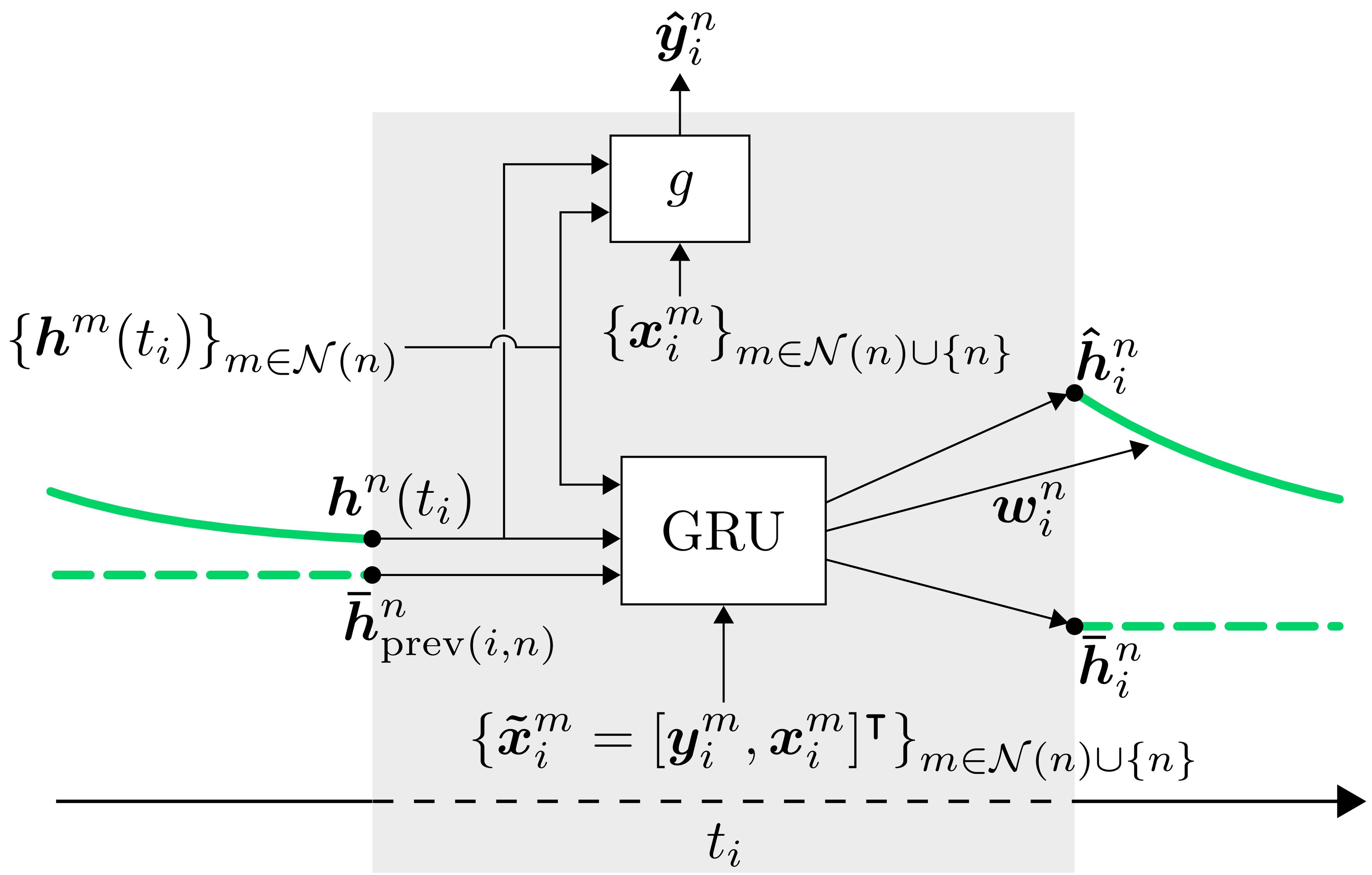
- At each node n a latent state $\boldsymbol{h}^n(t)$ evolves over continuous time
- Between node observations $\boldsymbol{h}^n(t)$ decays exponentially from $\hat{\boldsymbol{h}}_i^n$ towards $\bar{\boldsymbol{h}}_i^n$

$$\boldsymbol{h}^n(t) = \hat{\boldsymbol{h}}_i^n \odot \boldsymbol{\gamma}(t - t_i) + \bar{\boldsymbol{h}}_i^n \odot (\mathbf{1} - \boldsymbol{\gamma}(t - t_i)) \quad (1a)$$
$$\boldsymbol{\gamma}(\Delta_t) = \exp(-\Delta_t \boldsymbol{w}_i^n) \quad (1b)$$

- When node n is observed we perform a GRU-like update

$$\hat{\boldsymbol{h}}_i^n, \bar{\boldsymbol{h}}_i^n, \boldsymbol{w}_i^n = \mathrm{GRU}(\boldsymbol{h}^n(t_i), \boldsymbol{x}_i^n, \boldsymbol{y}_i^n) \quad (2)$$

  - $\boldsymbol{x}_i^n$ are input features and $\boldsymbol{y}_i^n$ the new observation
- By applying a predictive model g to the latent state predictions can be made at arbitrary time points!



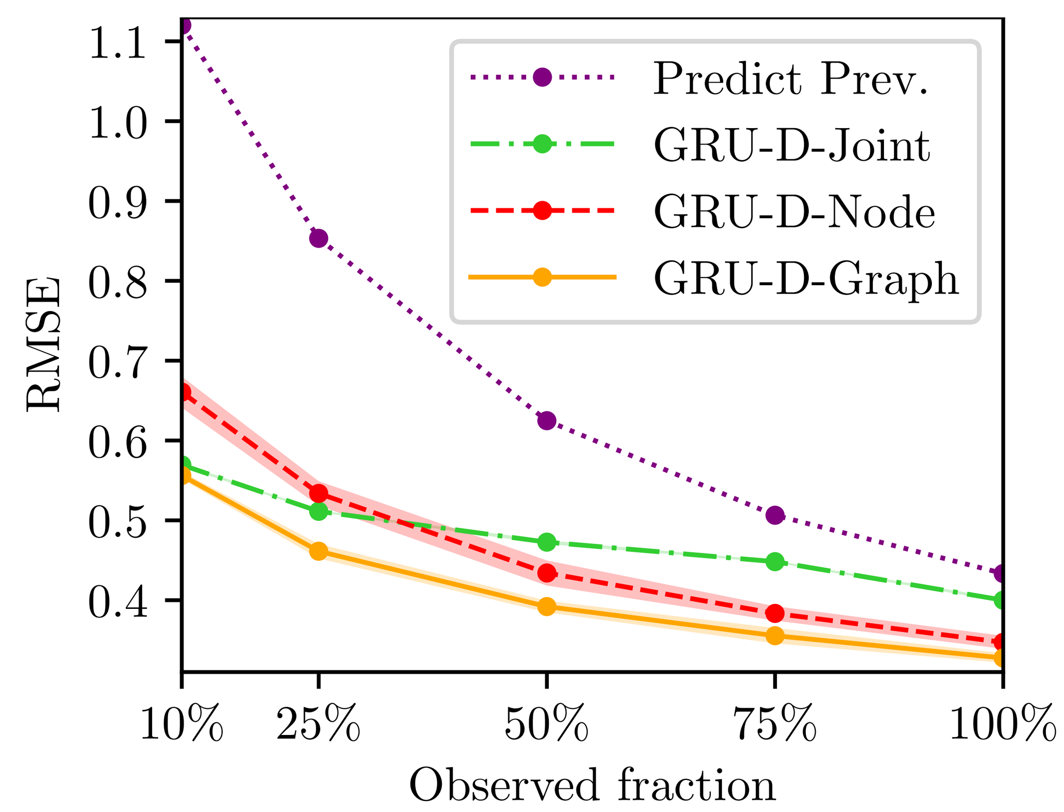
Graph Neural Network Components

- Graph-based node interactions are captured by incorporating GNN components
  - GRU-update depends also on node neighborhood $\mathcal{N}(n)$
  - GNN used as predictive model g

$$\hat{\boldsymbol{y}}_j^n = g\left([\boldsymbol{h}^n(t_j), \boldsymbol{x}_j^n], \{[\boldsymbol{h}^m(t_j), \boldsymbol{x}_j^m]\}_{m \in \mathcal{N}(n)}\right) \quad (3)$$

Experiments on Traffic Data

- The PEMS-BAY dataset contains traffic speed measurements from the highway network
- We create an irregular version by subsampling and keeping different % of node observations
- Goal: Predict next observed value at each node
- Our full model (**GRU-D-Graph**) is compared to simpler versions that do not use graph structure



More Information

Code, link to paper:
github.com/joeloskarsson/continuous-temporal-gnn

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