GNP: Goal-Based Neural Physics for Vehicle Trajectory Prediction

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HIGHLIGHTS

- ***Goal-based Neural Physics (GNP) Vehicle Trajectory Prediction Model*** integrates **deep learning models** with **physical social force models** to achieve both high prediction accuracy and interpretability.
- Predicting multiple **potential goals** in the future to investigate possible **driving intentions**
- Designed a **neural differentiable equation** to forecast the complete trajectory by calculating key parameters in Social Force
- Experiments conducted show that GNP achieves **high prediction accuracy, strong interpretability** and generalizes to **unseen trajectory data**.

INTRODUCTION

Goal-based Trajectory Prediction – 2 phases

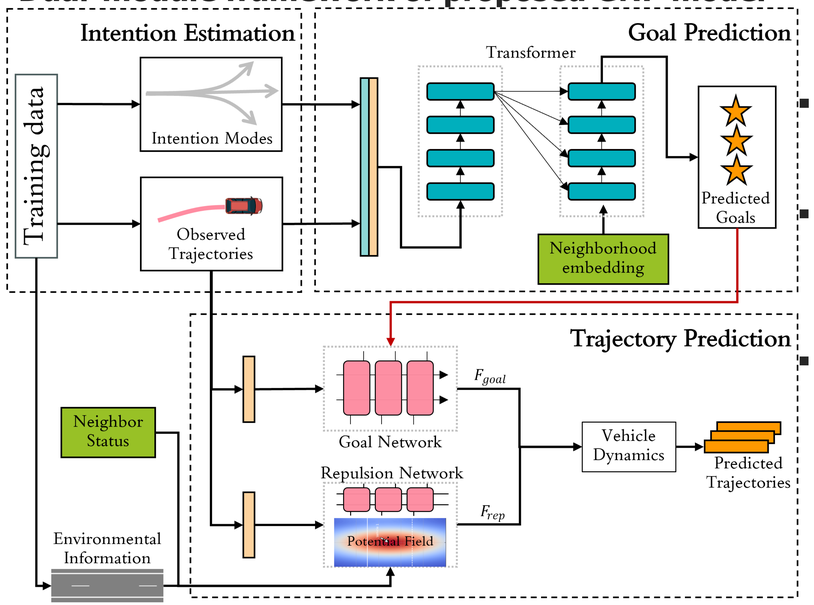
- **Phase 1**: first estimate near future destinations or anchors (***Goals***) to model the ***uncertainty*** of driving intentions;
- **Phase 2**: then fulfill **indeterminate path** based on the predicted goals.

Neural Physics Model

- A trade-off between interpretability and data-fitting accuracy.
- A novel and solid physics-informed neural networks (**PINNs**) framework, where neural networks are deployed to optimize key **parameters** in deterministic physical model.

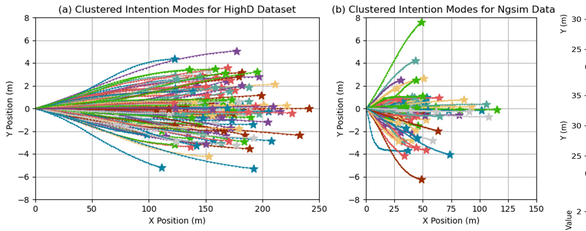
METHODS

Dual-module framework of proposed GNP model



Goal Prediction Module

- **Intention modes** are the general intentions by performing a clustering on normalized trajectories. (Right)
- **Transformer-based** architecture considering **intention** and **neighbor interaction**



Trajectory Prediction Module

- **Social force** model hypothesize vehicle as a particle and follows Newton's second law of motion.

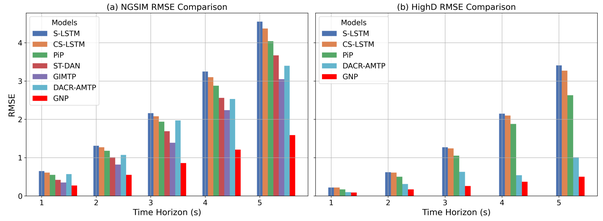
$$q(t+\Delta t) \approx q(t) + \dot{q}(t)\Delta t = \begin{pmatrix} p(t) \\ \dot{p}(t) \end{pmatrix} + \Delta t \begin{pmatrix} \dot{p}(t) \\ \ddot{p}(t) \end{pmatrix}$$

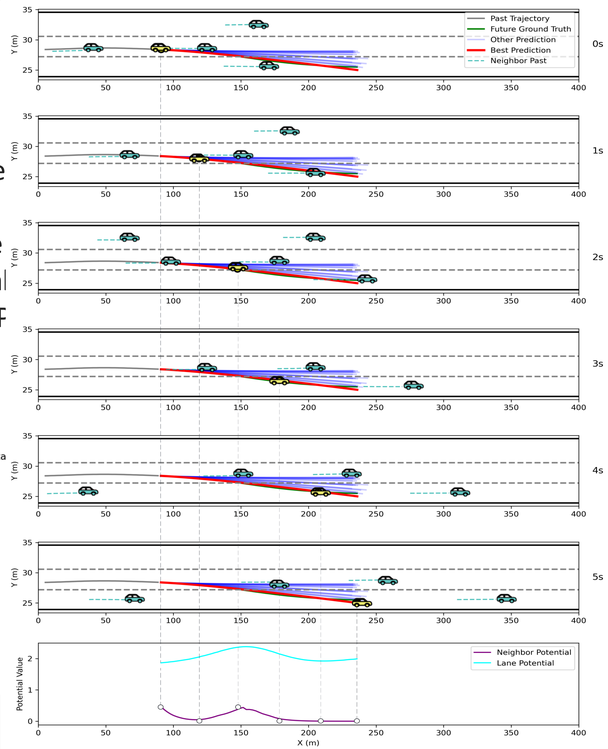
- The **Attraction force** from goals and **Repulsive forces** based on **neighbor and lane marking potential field** are calculated to determine the **acceleration** at each time step.

$$\ddot{p}(t) = F_{\text{goal}}(t, q^T, q^t) + F_{\text{rep}}(t, q^t, \Omega^t)$$

RESULTS

- **Data**: Highway dataset **NGSIM** and **HighD** are employed;
- **Accuracy**: Our GNP model **outperform** all the baseline on both dataset;
- **Generalization:** GNP display smallest increase and achieves highest accuracy on **unseen scenarios**;
- **Interpretability (Right)**: predicted trajectories of the target vehicle over next 5 s and dynamic changes in the **neighbor and lane potential field values** reflect how GNP response to real-time risk.





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For full paper and more information