Deep Learning-Based Decentralized Traffic Signal Control and Dynamic Perimeter Adjustment for Traffic Optimization

This internship will be supervised by:

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Context

To avoid traffic conflicts at intersections, traffic signal control allocates green times to various vehicle movements at signalized intersections. However, when poorly optimized, these strategies can lead to severe congestion, increased energy consumption, and higher pollution levels. Optimizing traffic signal strategies across a network is particularly challenging in dense urban areas, where it is crucial to address disruptions caused by congestion, accidents, or equipment failures.

In such urban grid networks, local traffic signal control strategies often result in gridlocks under oversaturated conditions. Perimeter Control (PC) has been proposed as a solution to protect a specific region (the Protected Network) and mitigate the spread of congestion within this region (Li et al., 2021). While existing approaches typically assume a fixed perimeter for the protected region, the real challenge lies in dynamically identifying and adjusting this perimeter in real time as traffic conditions evolve, ensuring a well-fitted and effective traffic flow management. The objective is to avoid over-reacting to gridlock and applying well-suited network protection, when necessary.

Recent advancements have explored the potential of data-driven methods, particularly Deep Reinforcement Learning (DRL) algorithms, for decentralized traffic control systems, demonstrating strong scalability and adaptability (Yu et al., 2023).

In this context, this internship will focus on leveraging Deep Reinforcement Learning (DRL) with Graph Neural Networks (GNN) to integrate the local road network configuration and interaction in the state description of the agent dedicated to optimising the traffic crossing at one intersection. The goal is to develop a strategy where traffic control systems consider the interactions and impacts of traffic flows over time and across space. The integration of attention mechanisms within the graph modeling, coupled with reinforcement learning, will be explored to assess conditions both at individual intersections and across neighboring areas (Munikoti et al., 2023), creating a more adaptive approach. Moreover, this strategy will be tested as a key element for dynamically determine when a protected zone is required and define its boundaries.

Objectives and Activities

The primary goal of this internship is to address the joint problem of traffic signal control and dynamic cordon adjustment for perimeter control, with an emphasis on scalability and resilience. A data-driven, deep learning framework will be considered.

The main steps are:

- **Literature Review** Familiarize with traffic signal control and perimeter control strategies, with a specific focus on applying Reinforcement Learning (RL) and Graph Neural Networks (GNN) to address these challenges.
- **DRL and GNN Integration** Develop a DRL-based algorithm that integrates GNN to model traffic flow and interactions across intersections. Key tasks include: designing the graph model to capture spatial dependencies between intersections, incorporating attention mechanisms to prioritize critical traffic features and intersection conditions, and developing a graph-based reinforcement learning framework to optimize traffic signal control in urban areas.
- **Network Protection Mechanism** Define criteria and develop a strategy to dynamically determine when and where Network Protection is necessary, based on the analysis of intersection observations within the developed framework.
- **Performance Evaluation** Create or adapt a traffic simulation environment to test the model in urban grid networks. Compare the performance of the developed model with conventional approaches from the literature. Assess its scalability by applying it to progressively larger and more complex urban networks, and test its resilience in handling disruptions such as accidents, equipment failures, and sudden surges in traffic.
- **Valorization** The results from the testing and evaluation stage will be documented, with a focus on exploring opportunities for publication in relevant academic journals or conferences.

Materials

- The microscopic traffic simulator **SUMO** can be used to create synthetic traffic environments for testing the proposed strategies.
- The **TraCI** interface in Python is necessary to update the state of SUMO's objects dynamically.
- Python and libraries such as **PyTorch**.

Candidate Profile

The ideal candidate should preferably have:

- Experience with Deep Learning and familiarity with concepts like reinforcement learning, Graph neural networks and attention mechanism.
- Proficiency in Python programming and experience with deep learning libraries such as PyTorch.
- Interest in urban mobility and traffic control systems.

Internship location

ENTPE (Graduate School of Civil, Environmental and Urban Engineering), Vaulx-en-Velin, France

Application Process

To apply, please send your ZIP folder named `[MobilityTransferability_NameSurname]` to `rim.slamasalmi@entpe.fr` and `pierre-antoine.laharotte@univ-eiffel.fr`.

This folder should contain your **CV**, **motivation letter**, **academic transcripts** from high school (post-baccalaureate) to the most recent year of your master's program, and any **certifications in deep learning** if you have any.

References

Li, Y., Mohajerpoor, R., & Ramezani, M. (2021). Perimeter control with real-time location-varying cordon. *Transportation Research Part B: Methodological*, *150*, 101–120.

Munikoti, S., Agarwal, D., Das, L., Halappanavar, M., & Natarajan, B. (2023). Challenges and opportunities in deep reinforcement learning with graph neural networks: A comprehensive review of algorithms and applications. *IEEE transactions on neural networks and learning systems*.

Yu, J., Laharotte, P.-A., Han, Y., & Leclercq, L. (2023). Decentralized signal control for multi-modal traffic network: A deep reinforcement learning approach. *Transportation Research Part C: Emerging Technologies*, *154*, 104281.