Toward a Multi-Agent Approach for Dynamic Traffic Control and Optimization

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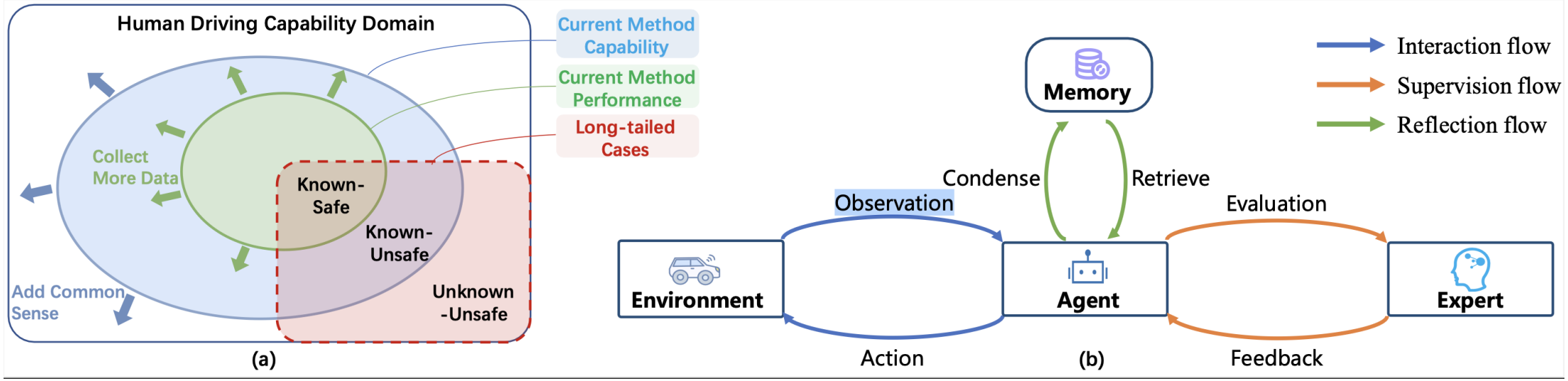
Research Question:

- Can LLMs effectively **enhance decision-making** for AVs in **Unknown-Unsafe domains** within a **multi-agent framework** compared to current mechanisms?

Research Background:

- This appears to be a case of partial road construction or maintenance, that I often I see in Road.
- **What a AV might do in this situation?**
- A typical autonomous vehicle (AV) might see the "STOP" sign and barriers and immediately come to a complete stop. It might interpret this as a full road closure, based on its pre-trained data

Research Background



- The domain (a) is divided into Known-Safe, Known-Unsafe, and Unknown-Unsafe regions.
- Unknown-unsafe cases that humans can often solve with their experience and common sense.

- Current AV System Architecture (b), consists of an Agent that interacts with the Environment, Condenses Observations, Retrieves Evaluations, and receives Feedback from an Expert.
- Without the incorporation of common sense, the model still fails to the long tailed cases. [Fu 2024]

Fu, D., Li, X., Wen, L., Dou, M., Cai, P., Shi, B., & Qiao, Y. (2024). Drive like a human: Rethinking autonomous driving with large language models. In *Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision* (pp. 910-919).

Research Objective

- To explore the use of **Large Language Models(LLMs)** for autonomous driving systems(ADS) as the main decision-making agent within **a multi-agent framework** for evaluating its reasoning abilities in handling long-tail.

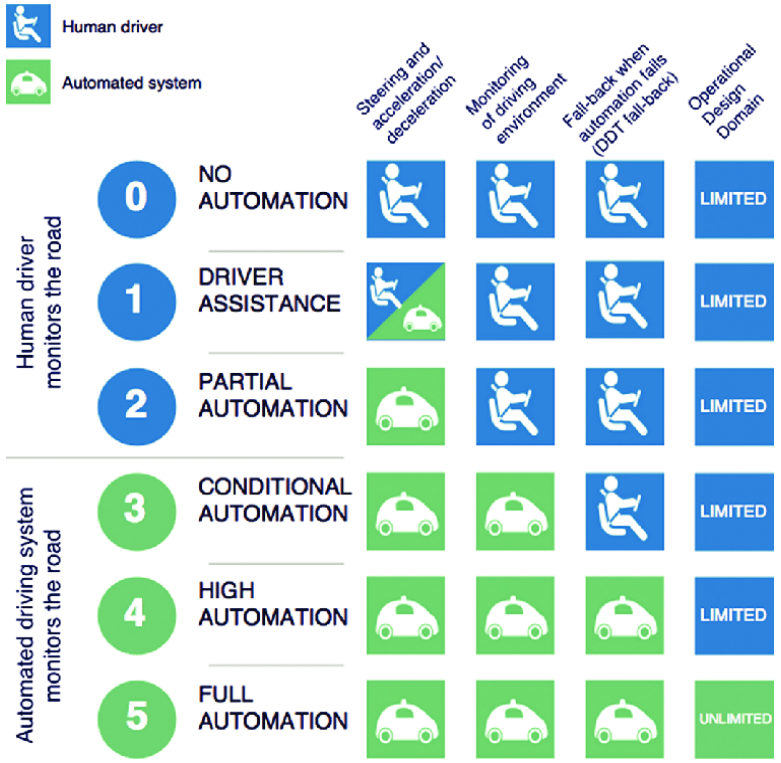
  -False positive and False negative scenarios.

Research Contribution :

- The main contribution of this research includes,
  - Investigating the **LLMs** as the main decision agent in ADS
  - Evaluating LLMs reasoning abilities in handling Unknown-Unsafe domain
  - A Multi agent framework for ADS

Research Background

- AVs can eliminate human error and distracted driving that is responsible for 94% of the accidents[Kukkala 2018].
- AVs are categorized into six levels (0-5) based on the extent of supported automation, as defined by the SAE J3016 standard. [Balasubramaniam 2022]



Tesla was the first company to commercialize AVs with their Autopilot system in 2014 that offered level 2 autonomy

2014

2017

In 2017, Volvo launched their Drive Me feature with level 2 autonomy.

Waymo has launched their driverless taxi service with level 4 autonomy in 2018 in the metro Phoenix area in USA with 1000 – 2000 riders per week, among which 5 – 10% of the rides were fully autonomous.

2018

2021

Cruise Automation started testing a fleet of 30 vehicles in San Francisco with level 4 autonomy in 2017 and launched their selfdriving Robotaxi service in 2021.

Kukkala, V. K., Tunnell, J., Pasricha, S., & Bradley, T. (2018). Advanced driver-assistance systems: A path toward autonomous vehicles. *IEEE Consumer Electronics Magazine*, *7*(5), 18-25.
Balasubramaniam, A., & Pasricha, S. Object Detection in Autonomous Vehicles: Status and Open Challenges. arXiv 2022. *arXiv preprint arXiv:2201.07706*.

Why LLM as Decision Agent:

- This paper[Cui 2023] introduces DriveLLM, a decision-making framework that combines large language models (LLMs) with autonomous driving systems to enhance commonsense reasoning in complex driving scenarios. It includes a cyber-physical feedback system that enables continuous learning and improvement from mistakes. The framework demonstrates superior performance compared to traditional decision-making methods, particularly in challenging real-world autonomous driving situations.

Cui, Y., Huang, S., Zhong, J., Liu, Z., Wang, Y., Sun, C., ... & Khajepour, A. (2023). Drivellm: Charting the path toward full autonomous driving with large language models. *IEEE Transactions on Intelligent Vehicles*.

- Human like Reasoning.

Why Multiagent Approach:

First single agent AV stop seeing the stop sign. But the following AV can see the sign they won't be stop.
1. Single-Agent: Each AV decides when to cross without communication.
Risks: Confusion, potential collisions due to lack of coordination.

- **Multi-Agent:** AVs communicate to determine crossing order. **Benefits:** Smooth traffic flow, reduced collision risk.

- In Multi agent approach We can do something in hybrid scenarios like where 90% vehicles are AV and 10% are manual driving.

Why Multiagent Approach:

- This paper [Ayache 2017] presents an autonomous vehicular system based on multi-agents to reduces the complexity of the autonomous system by splitting tasks between different agents, which in turn reduces execution time and allows for quicker intervention in complex scenarios. The proposed MAS can be applied to all vehicle brands, unlike existing systems that are dedicated to specific brands.

Ayache, N., Yahyaouy, A., & Abdelouahed, S. M. (2017, April). An autonomous vehicular system based on muli-agents control: Architecture and behavior simulation. In *2017 Intelligent Systems and Computer Vision (ISCV)* (pp. 1-7). IEEE.

Our approach would be different from this work,

- Vehicles can cooperate with each other in real-time.
- Vehicles can coordinate each other actions.
- Faster and more efficient responses to unexpected events.
- Significantly reduces the likelihood of accidents.

Related Work

- The objective of this research [Fu 2024] is to explore the potential of using large language models(LLM) to develop autonomous driving systems that can drive like a human, with the ability to reason, interpret, and memorize driving scenarios. Introducing a memorization mechanism to enable the language model-based system to continuously learn and accumulate driving experience, similar to human drivers.

Fu, D., Li, X., Wen, L., Dou, M., Cai, P., Shi, B., & Qiao, Y. (2024). Drive like a human: Rethinking autonomous driving with large language models. In *Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision* (pp. 910-919).

- This study [Ananthajothi 2023] looks to explore the ability of integrating LLMs into Autonomous driving (AD) structures to emulate human-like behavior . LLMs can use their memory to apply past experiences to future decision-making, improving adaptability and decision-making in AD systems. It can enhance reliability and safety by enabling human-like reasoning and adaptability.

Ananthajothi, K., GS, S. S., & Saran, J. U. (2023, December). LLM's for Autonomous Driving: A New Way to Teach Machines to Drive. In *2023 3rd International Conference on Mobile Networks and Wireless Communications (ICMNWC)* (pp. 1-6). IEEE.

Related Work

- This paper [Hook 2021] presents experiments on learning decision-making policies in multi-agent environments for autonomous systems like connected autonomous vehicles. Agents were able to learn to navigate their environment and avoid collisions even in a partially observable setting with obstacles and other moving agents. However, Learning decision-making policies is challenging due to the non-stationary nature of the environment.

Hook, J., El-Sedky, S., De Silva, V., & Kondoz, A. (2021). Learning data-driven decision-making policies in multi-agent environments for autonomous systems. *Cognitive Systems Research*, *65*, 40-49.

- This paper [Händler 2023] proposes a taxonomy to analyze how autonomous LLM-powered multi-agent systems balance autonomy and alignment across various architectural aspects. These systems can significantly enhance AI capabilities. However, the central challenge lies in achieving the right balance between autonomy and alignment.

Händler, T. (2023). A Taxonomy for Autonomous LLM-Powered Multi-Agent Architectures. In *KMIS* (pp. 85-98).

Thank you