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

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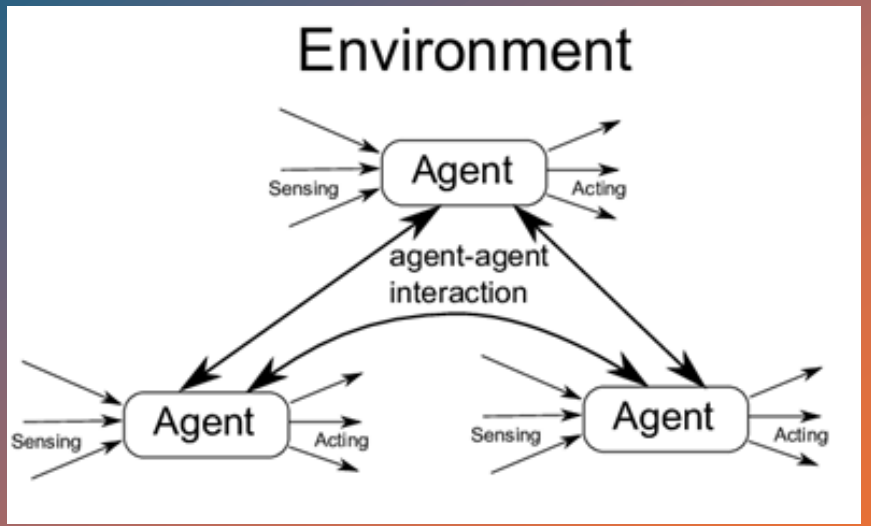
Introduction

Autonomous vehicles (AVs), also known as self-driving cars, are vehicles capable of operating with minimal or no human input. They rely on a complex system of sensors, cameras, radar, and artificial intelligence (AI) to perceive their surroundings, make decisions, and control the vehicle.



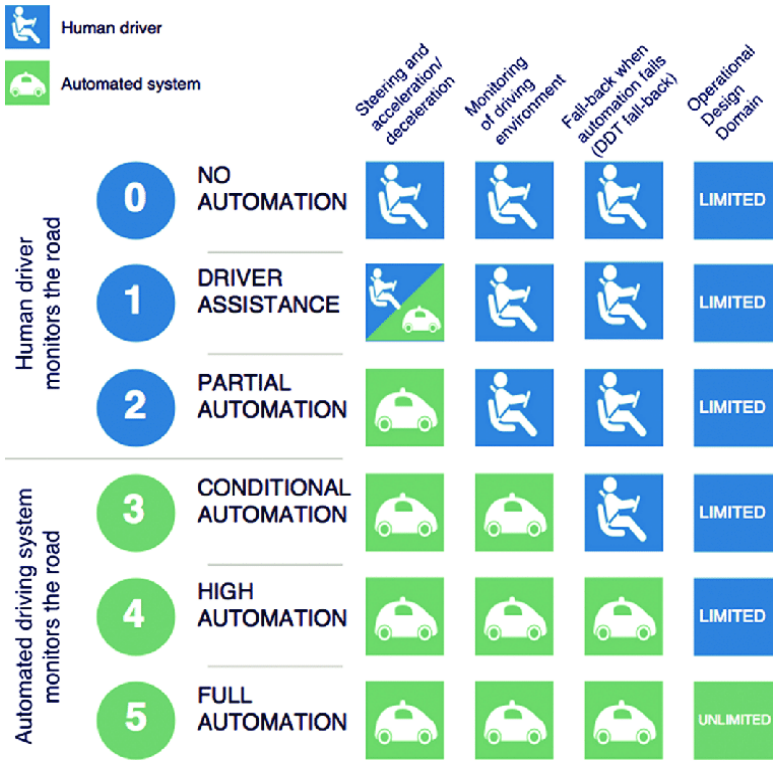
Multi agent system A Multi-Agent System (MAS) refers to a system in which multiple autonomous agents interact with each other to achieve individual or collective goals.

Introduction

- **Large Language Models (LLMs)** are AI models with billions or even trillions of parameters, trained on extensive text datasets.
- LLMs can comprehend and interpret human language in a way that is similar to how humans understand each other.
- LLMs can mimic human reasoning to a certain extent by following logical steps and providing explanations for their suggestions.

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.

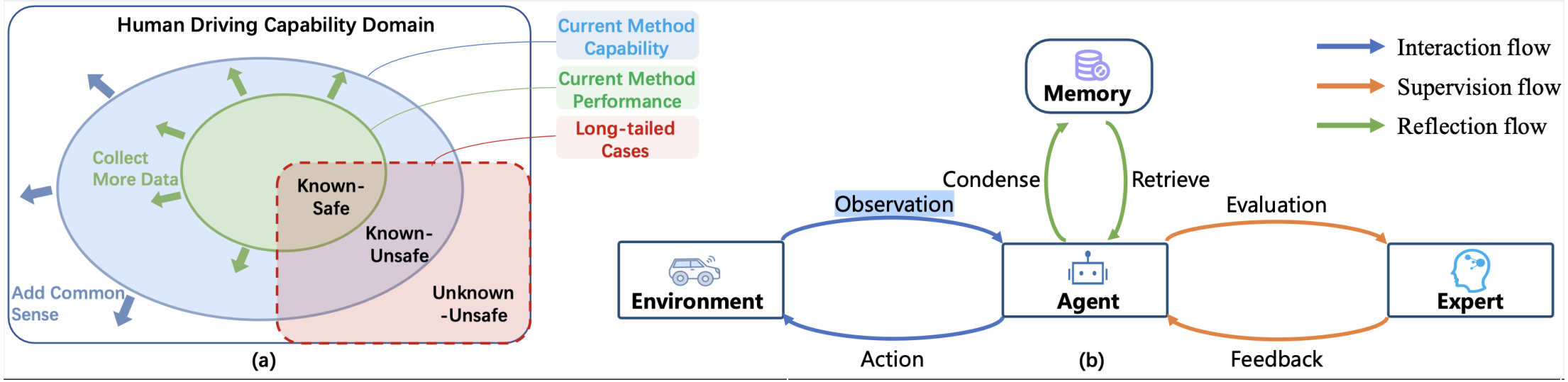
2018

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*.

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).

Introduction

- False Positive: A false positive occurs when a system incorrectly identifies something as positive or present when it is actually negative or absent.

  - The system incorrectly identified the shadow as a potential obstacle.

- False Negative: A false negative occurs when a system fails to identify something as positive or present when it actually is.

  - An autonomous vehicle failing to detect a small animal on the road is a false negative.

Research Motivation:

- 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

Related Study

- 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 study

- 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).

Research Objective

- To explore the use of open-source **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, corner cases

  -False positive and False negative scenarios.

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.

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.

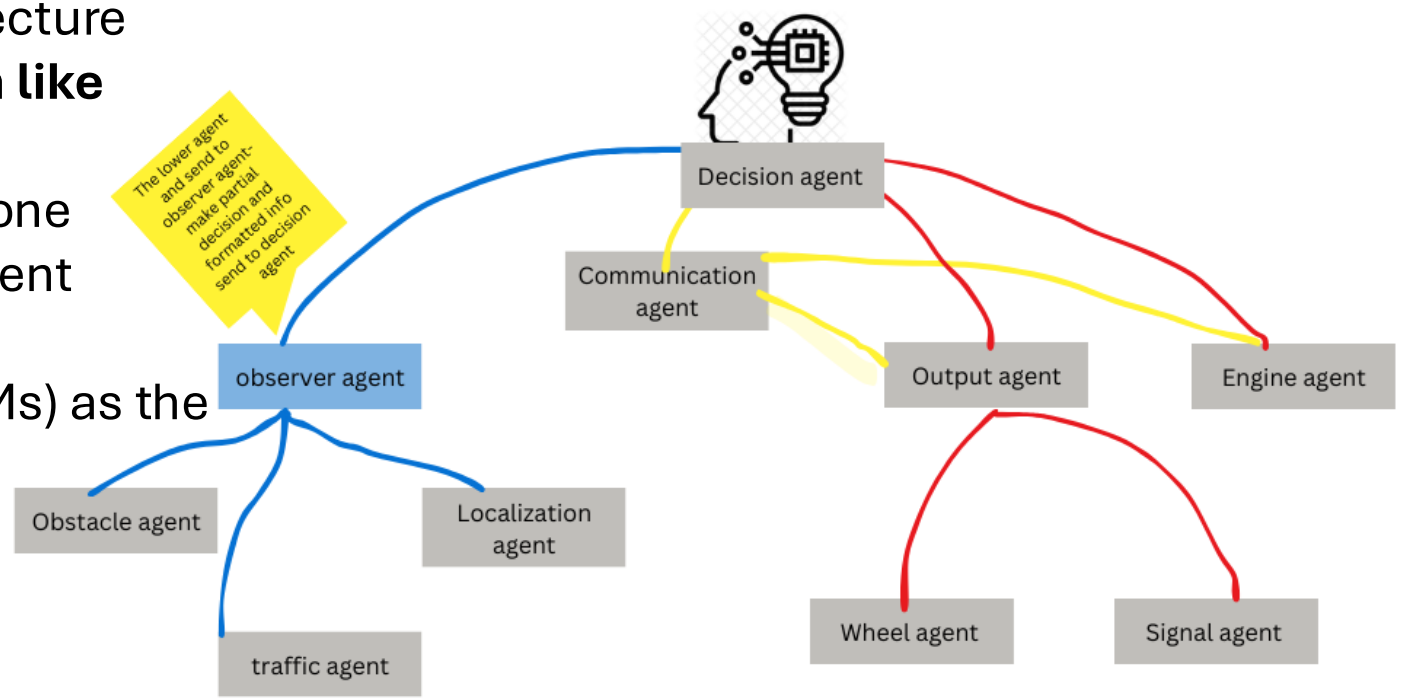
Cui, Y., Huang, S., Zhong, J., Liu, Z., Wang, Y., Sun, C., ... & Khajepour, A. (2023). Drivellm: Charting the path toward full autonomous driving with large language models. *IEEE Transactions on Intelligent Vehicles*.

Thank you

Proposed Approach

We propose a multi-agent system architecture which is **less complex and have Human like Reasoning.**

- Instead of executing several tasks by one process, we split them between different agents.
- Integrate Large Language Models (LLMs) as the main cognitive agent (Decision Agent)
- Why we need proposed approach? Fairness situation?



Related study

- LLMs can interpret natural language commands, adapt to user preferences, and reason about complex driving scenarios [Cui 2023].

  Cui, C., Ma, Y., Cao, X., Ye, W., & Wang, Z. (2024). Receive, reason, and react: Drive as you say, with large language models in autonomous vehicles. *IEEE Intelligent Transportation Systems Magazine*.

- Integrating large language models into autonomous driving systems can improve their ability to handle complex and unexpected driving scenarios [Ananthajothi 2023].

  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.

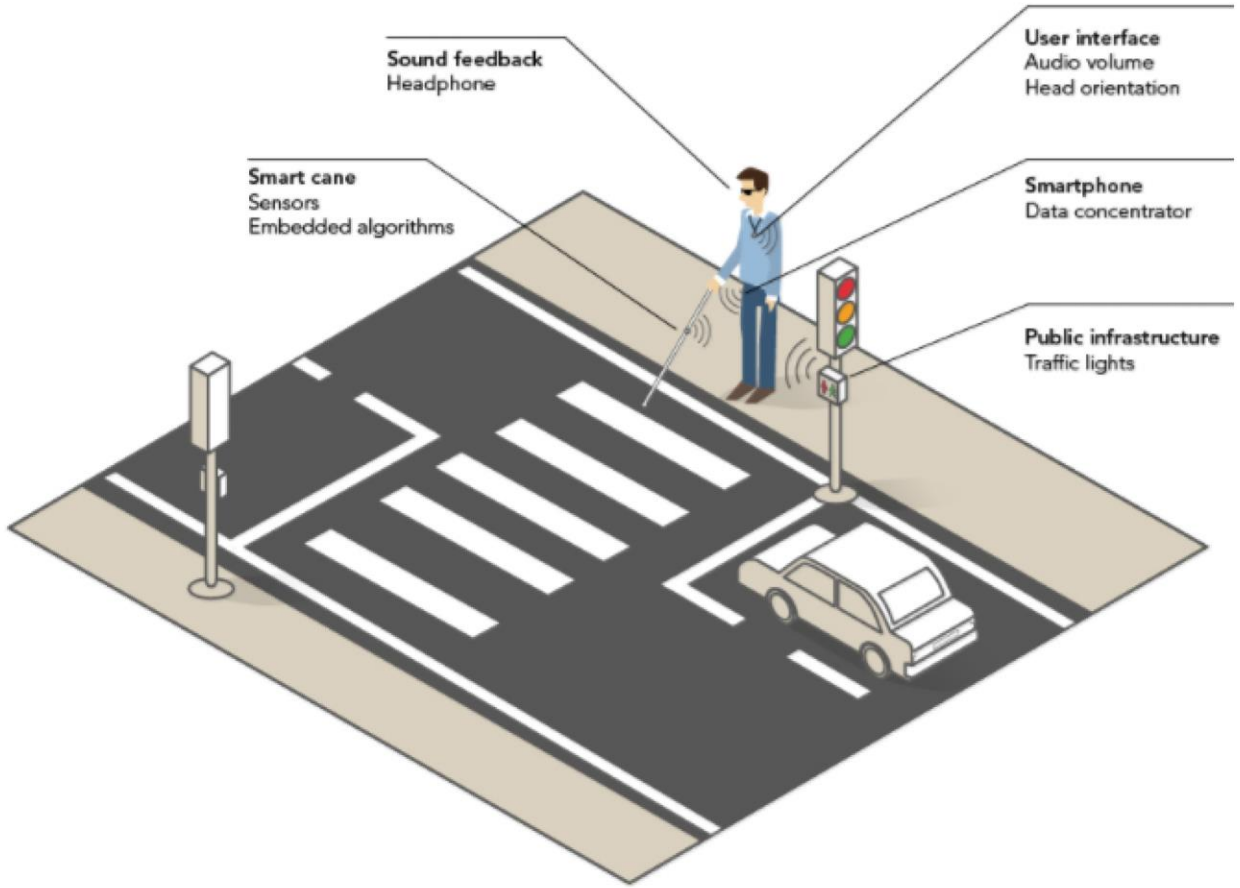
- Incorporating language-based reasoning enables accountable and transparent decision-making for self-driving cars, making LLM a potential solution for autonomous driving [Fangyuan 2024]

Research Background

Autonomous Vehicles: Human-level driving is an ultimate goal of autonomous driving. Yet their systems do not capitalize on the inherent reasoning ability and experiential knowledge of humans.

Advanced Driver Assistance Systems (ADAS):

RESEARCH OBJECTIVE



[1] 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.

Mao, Jiageng, et al. "A language agent for autonomous driving." arXiv preprint arXiv:2311.10813 (2023).

- What a human would do? - A human driver would use their common sense , follow the open roads.---
- The situation is an example of false positive.
- **Positive term then what we gonna do**
- Current autonomous vehicles (AVs) lack human-like reasoning and common sense.
- **Rely heavily on pre-trained data and rigid rules.--dynamic optimization**
- **Struggle with scenarios not covered in their training data.--- human like reasoning is possible someothers working that? Missing?**