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Agentic Driving Coach: Robustness and Determinism of Agentic AI-Powered Human-in-the-Loop Cyber-Physical Systems

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GitHub Repo: https://github.com/asu-kim/agentic-driving-coach

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KNOWLEDGEABLE & INTERACTIVE MACHINES

Motivation & Challenges in CPS using Foundation Models

- **Safety and determinism of CPS using foundation models**
- **Determinism** is:

  "Given the **initial states and series of inputs (e.g., timestamped events)**, there is **exactly one possible behavior** produced by the model [1]"

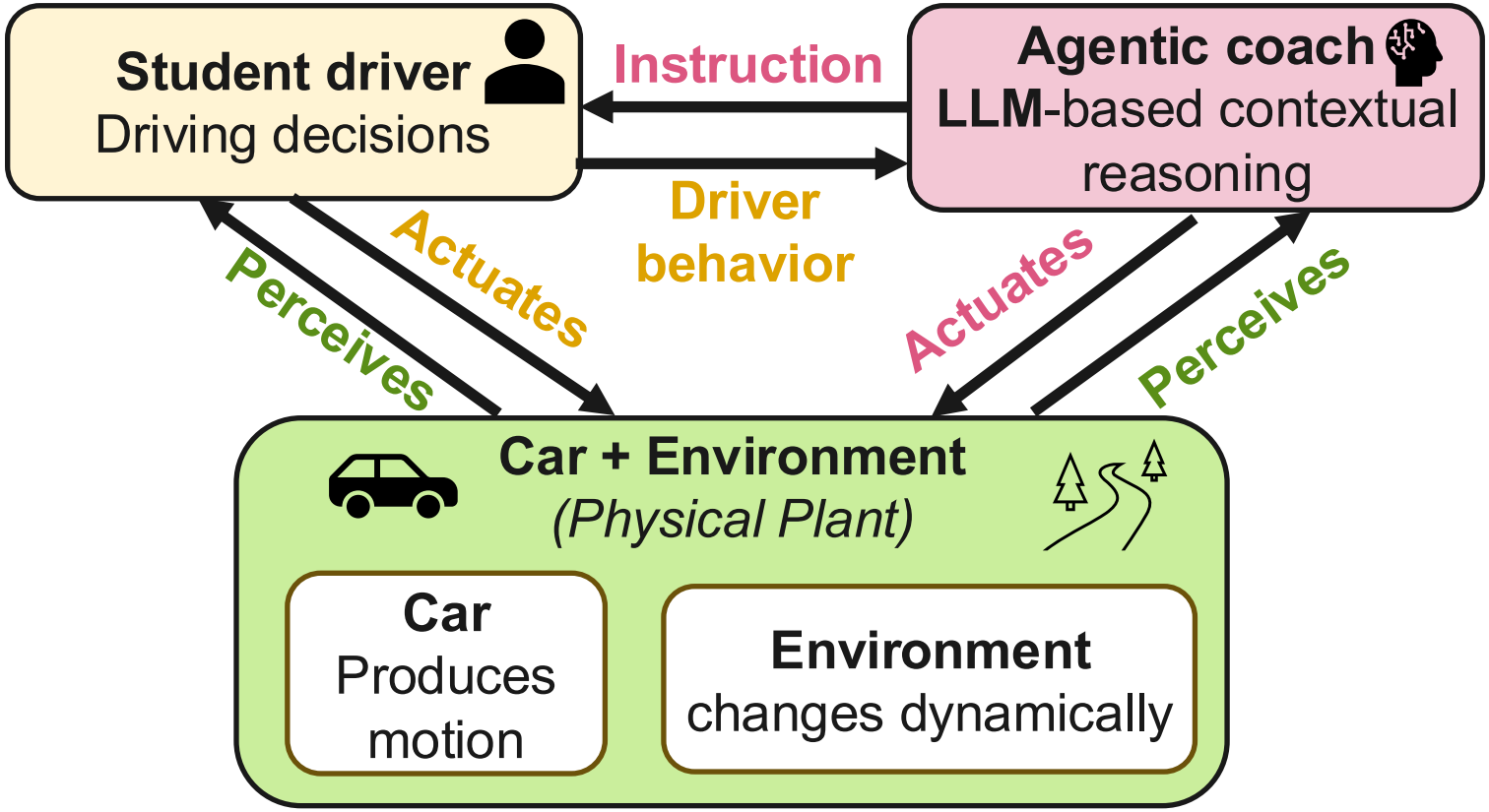
- Determinism is useful for:
  - Repeatable testing
  - Predictable behavior
  - Fault detection (e.g. timing violation)
- Agentic AI-powered human-in-the-loop CPS: exhibits **uncontrollable intrinsic non-determinism** (unpredictable behavior, varying latency, delays)

[1] E. A. Lee, "Determinism," ACM Transactions on Embedded Computing Systems (TECS), vol. 20, no. 5, pp. 1–34, 2021.

Goals: Determinism in Foundation Model-Based CPS

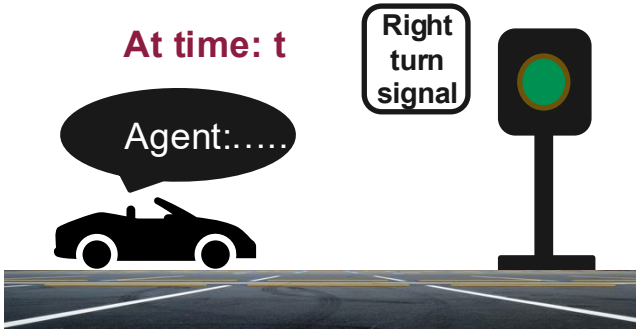
- Surface the **intrinsic non-determinism** in foundation model-based CPS
- **Analyze and embrace** it rather than eliminating it
- Ensure overall **system model is deterministic** despite inherent non-determinism

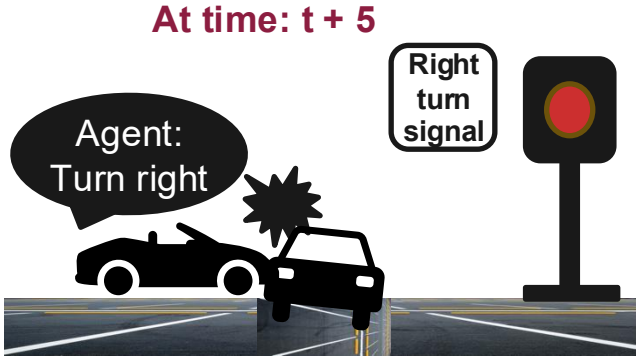
Case Study: Agentic Driving Coach



Challenges in LLMs as Agentic Driving Coach

- **Variable latencies** of LLMs
- **Variable LLM response accuracy/correctness**



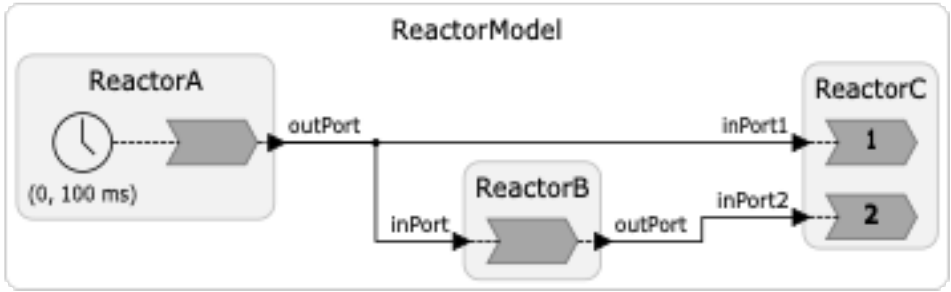


To address these challenges, we use:

Reactor model of computation
via
Lingua Franca

Background: Reactor MoC and Lingua Franca

- Reactor [2] model of computation (MoC):
  - **Deterministic variant** of actor [3] MoC
- Lingua Franca [4]:
  - Open-source **design framework** for deterministic and concurrent runtime coordination of **reactor MoC**
- Lingua Franca provides determinism via:
  - Communication ports
  - Deterministic ordering
  - Deterministic scheduling of reactions



- Provides features to expose and analyze timing behavior (explained later)

[2] M. Lohstroh et al., “Reactors: A deterministic model for composable reactive systems,” in Int'l Workshop on Design, Modeling, & Evaluation of CPS 2019
[3] C. Hewitt. 2010. Actor Model of Computation: Scalable Robust Information Systems. arXiv preprint arXiv:1008.1459
[4] M. Lohstroh et al. "Toward a lingua franca for deterministic concurrent systems." *ACM TECS* vol. 20, no. 4, 2021.

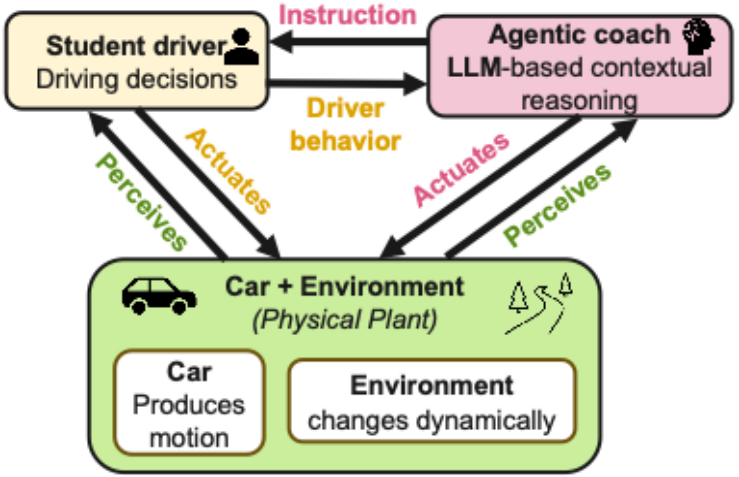
Problem Formulation of Agentic Driving Coach

- System is modeled over n discrete time steps, time $t \in \{1, \dots, n, \dots\}$
- System behavior is defined as:

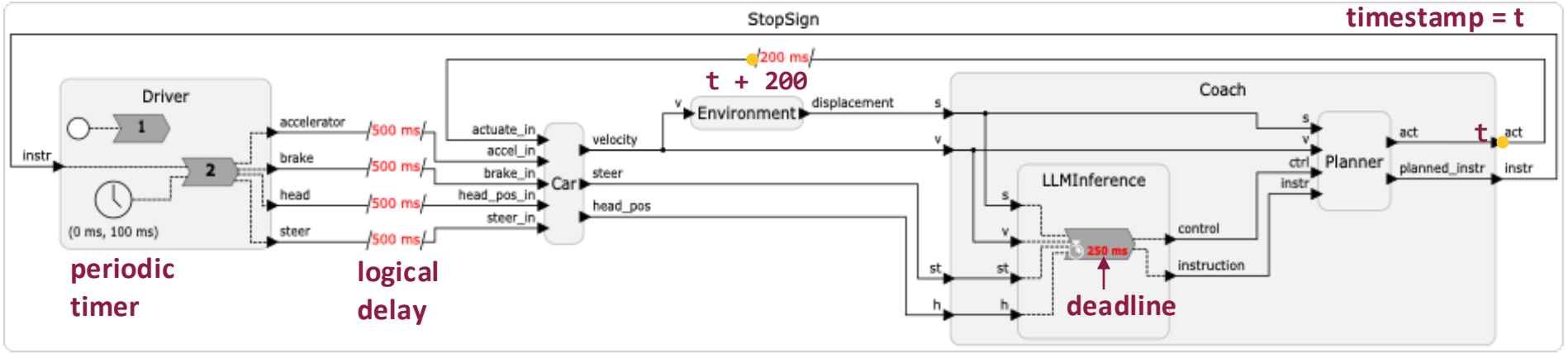
$$y(t) = F(x_i, i_h(t), i_c(t), i_a(t))$$

where,

- $y(t)$: Resulting system behavior
- $F(\cdot)$: System function
- x_i : Initial system state
- Inputs at each time step t:
  - i_h: Driver behavior
  - i_c: Environment and car inputs
  - i_a: Agentic coach input



Reactor Model Design of Agentic Driving Coach



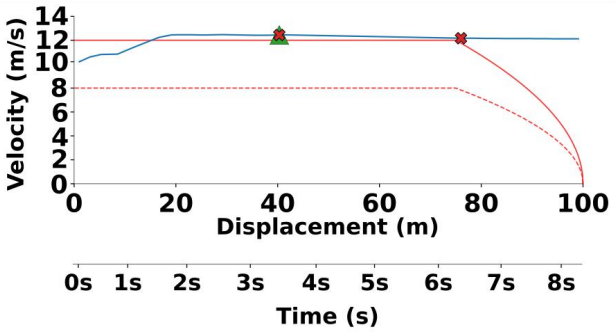
- Human perception to physical response is modeled as *logical delay of 500ms* [5]
- LLM inference delays handled via deadline mechanism
- Coach to actuation response is modeled as *logical delay of 200ms* [5]

[5] H. Han et al., “Driver’s avoidance characteristics to hazardous situations: A driving simulator study,” Transportation research part F: traffic psychology and behaviour, vol. 81, pp. 522–539, 2021.

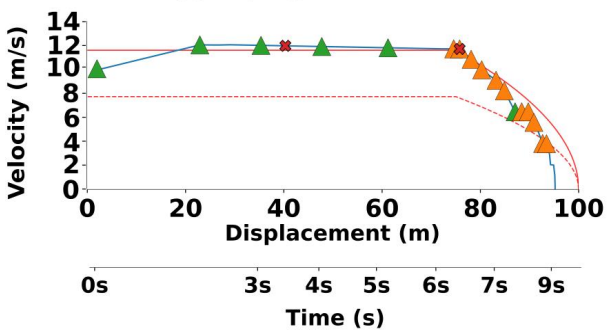
Repeatable Testing of Agentic Driving Coach

- Evaluation setup of our system:
  - **Simulation-based** with Agentic driving coach running on a GPU
  - Predefined driver inputs with timestamps
- Using **deterministic behavior**, we evaluate different driver tasks:
  - ***Stop sign, Speed change, Lane Change***

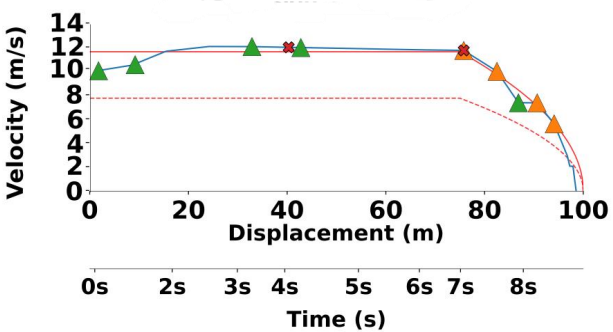
Results: Stop Sign Driving Task with Llama 3 Models



1) Stop Sign, Llama 1B



2) Stop Sign, Llama 8B



3) Stop Sign, Llama 70B

Car velocity (m/s)
Upper bound (m/s)
Lower bound (m/s)
Deadline miss
Instruction
Actuation command

Conclusion and Future Work

- Agentic AI-powered human-in-the-loop CPS can be modeled with the consideration of determinism

Future work:

- Hardware Integration
- Incorporation of human driver inputs
- Reducing inference latency using techniques such as RAG and LoRA

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ASU KIM Lab Page: https://labs.engineering.asu.edu/kim/

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