# CAREER: A Compositional Approach to Modular Cyber-Physical Control System Design

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Motivation

- Scalable tools for control design and verification (theory and algorithms) for complex CPS are lagging.
- Synthesis of decentralized controllers/distributed decision makers is a hard problem (i.e., undecidable).
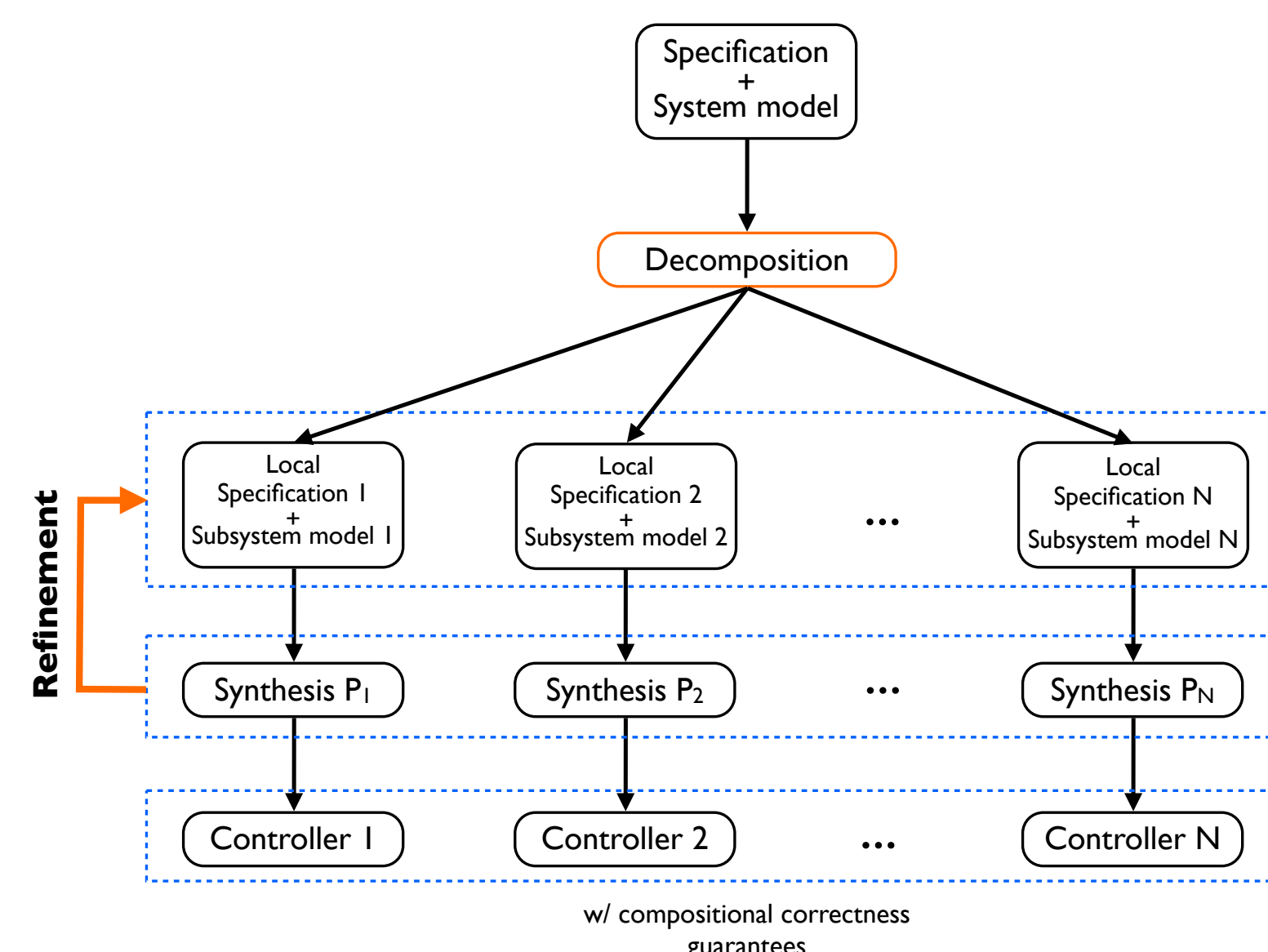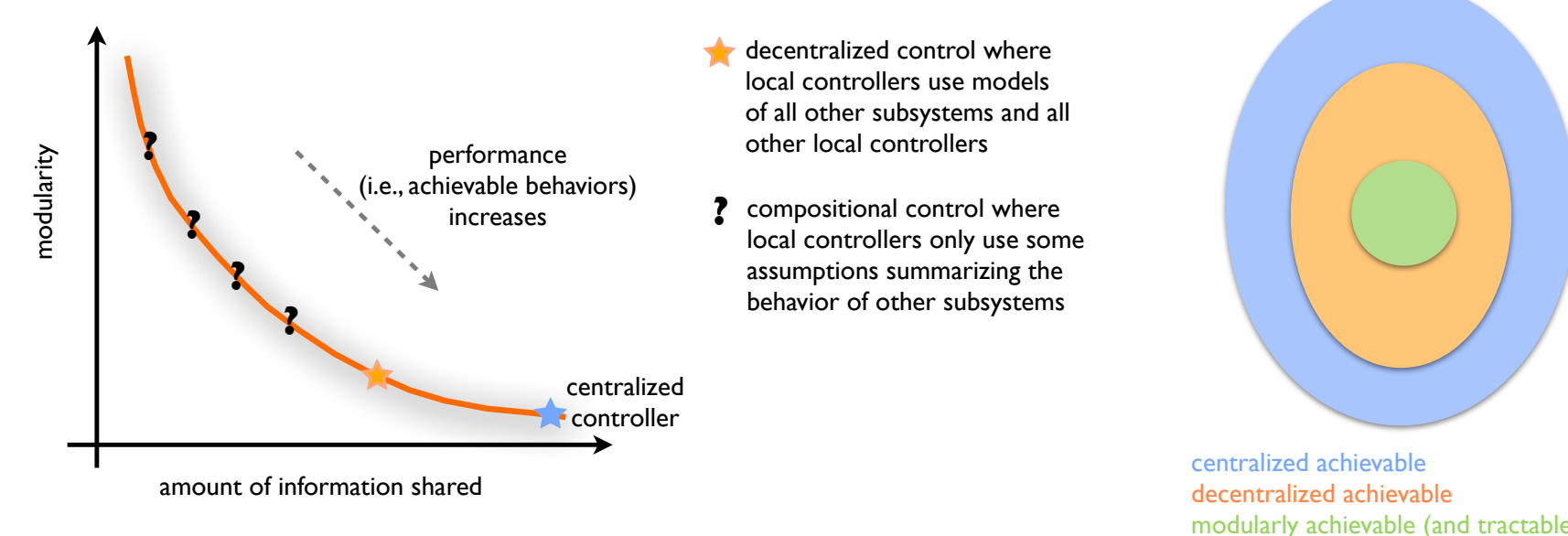
Modularity to manage complexity:

- Composition: Assume/guarantee contracts for designing individual systems and composing them
- Decomposition: Methods for splitting a complex system and specification into local ones
- Handling uncertainty and partial information: New control synthesis methods for subsystems

Scientific Impacts

- Developed theory and algorithms to efficiently synthesize controlled invariant sets for systems with actuation delays (fully mitigating the state-explosion due to delay dynamics)
- Developed theory and algorithms for synthesize correct-by-construction controllers with missing measurements (e.g., package drops, sensor glitches, perception failures etc.)
- A new decentralized multi-agent path execution algorithm with collision and deadlock avoidance guarantees

Broader Impacts

Impact to Society

Methodology applicable to a wide class of CPS

Application focus: 1) Driver assist systems
- Improving driving safety can save lives
- Collaborations with Toyota and Ford
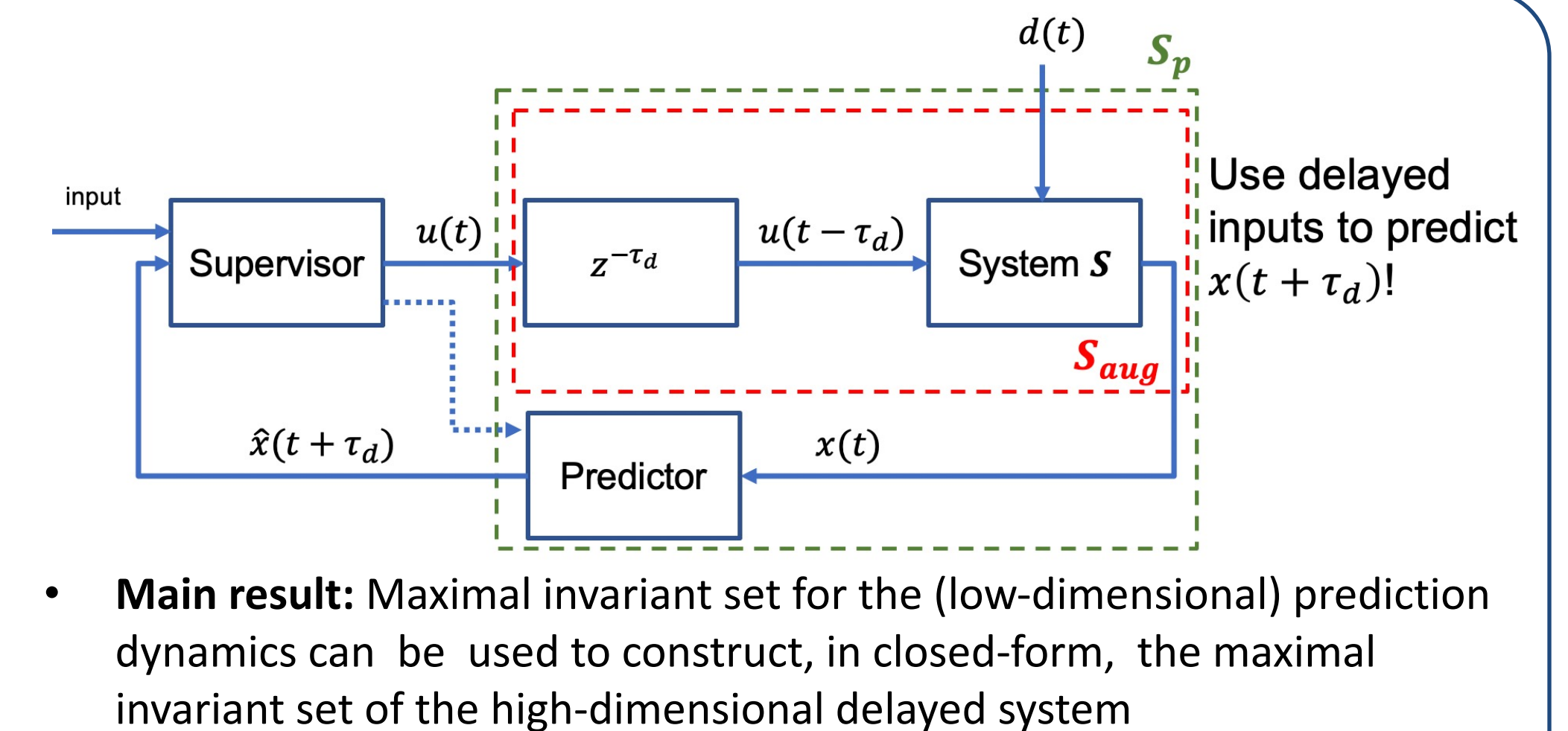
2) Robotics: warehouses, manufacturing

Education and Outreach

- Several graduate student researchers
- Large number of undergraduate research projects: most undergrads end up going to grad school in STEM related fields
- General audience talks, seminars/panels targeted at undergrads
- New course on hybrid systems at Michigan

Methods and Results

Safety control for systems with actuator delays [1]

- Actuation delays are common in many applications (e.g., steering input delay in autonomous driving)
- Delayed systems are equivalent to high (infinite) dimensional systems
- **Main result:** Maximal invariant set for the (low-dimensional) prediction dynamics can be used to construct, in closed-form, the maximal invariant set of the high-dimensional delayed system

Safety control for systems with missing measurements [2]

- Cannot always access the state measurements: package drops in communication, sensor glitches, perception failures, occlusion
- Partial information problems require subset construction (not scalable)
- **Main result:** Reduction to a simple full-information problem using an automaton capturing the missing data patterns and causality requirements on the controller
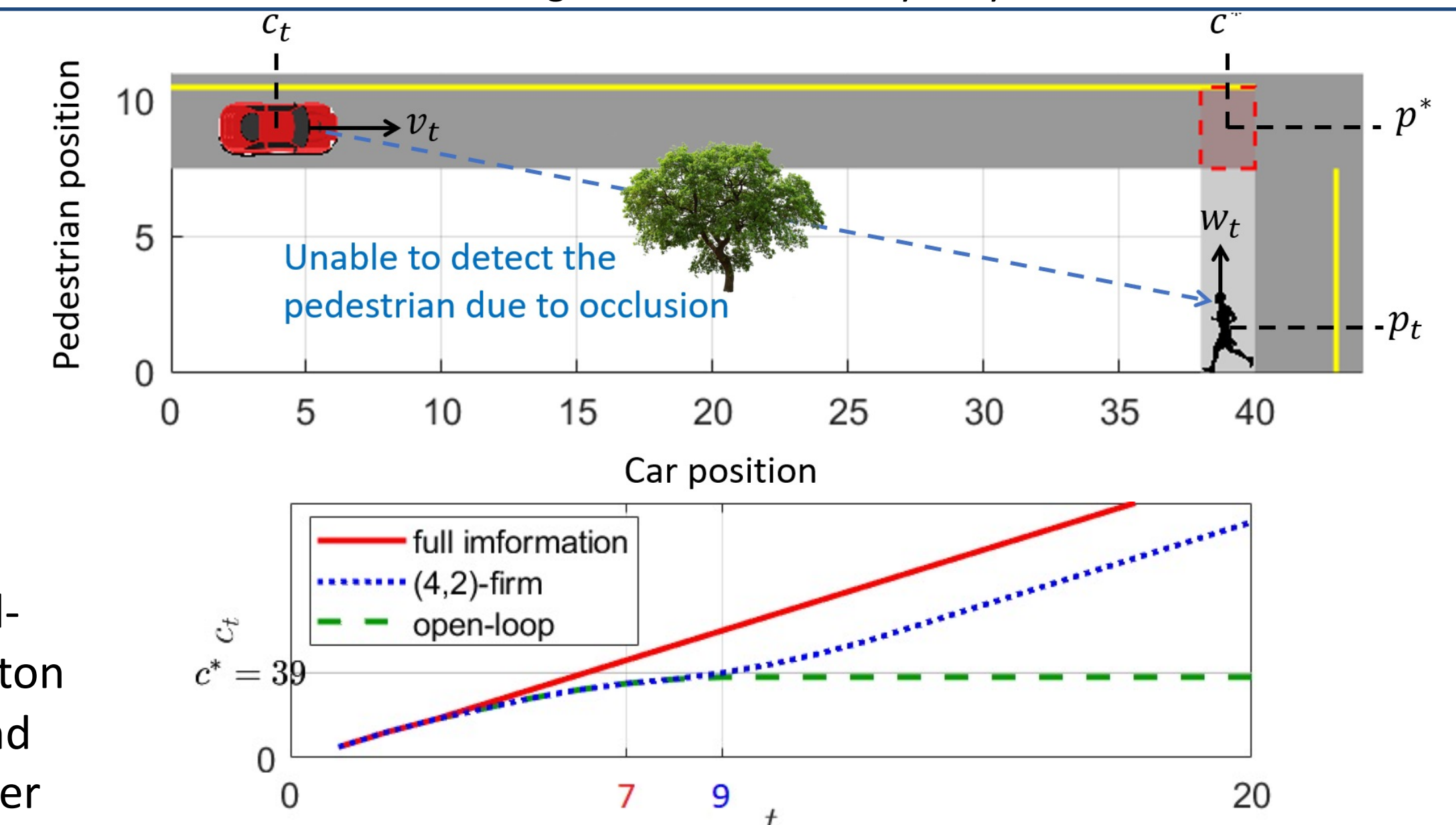
Distributed policies for asynchronous multi-agent path execution [3]

Warehouse layout and robots

- Path planning usually assumes synchronous behavior, which is hard to achieve in decentralized systems
- Timing uncertainty can lead to collisions and deadlocks
- **Main results:** 1) Reduction to a distributed resource allocation problem. 2) A modified (utilizing problem structure) drinking philosophers algorithm that leads to state-of-the art performance with safety and liveness guarantees.
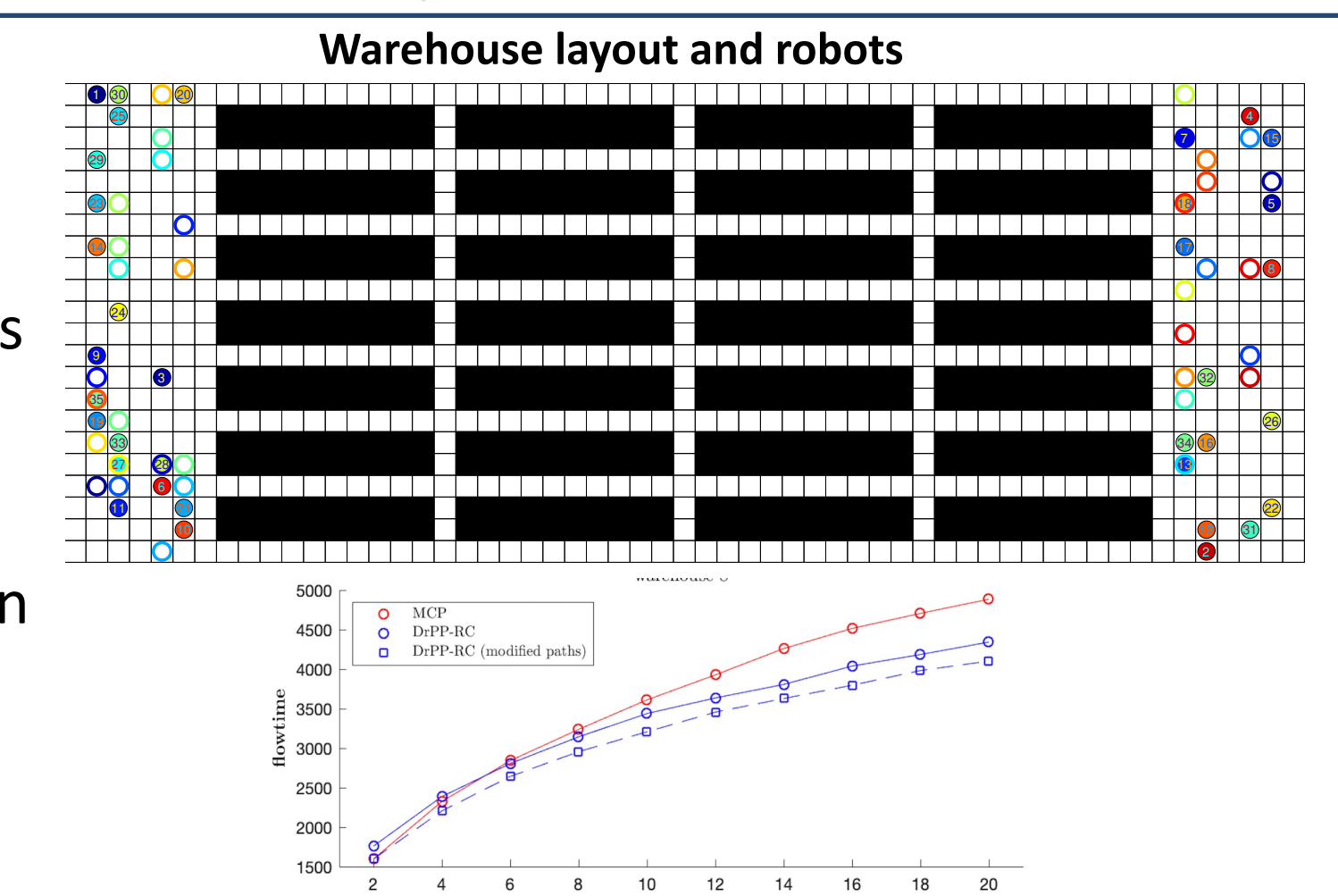
Selected Publications

[1] Z. Liu , L. Yang, and N. Ozay, "Scalable Computation of Controlled Invariant Sets for Discrete-Time Linear Systems with Input Delays", ACC 2020.

[2] L. Yang and N. Ozay, "Safety control synthesis for systems with missing measurements", ADHS 2021.

[3] Y. Sahin and N. Ozay, "From Drinking Philosophers to Wandering Robots", arXiv:2001.00440.