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Toward Swarm Manufacturing: Developing a Multi-Robot Cooperative Framework for Complex Manufacturing Tasks

CIE 2023 Graduate Research Poster

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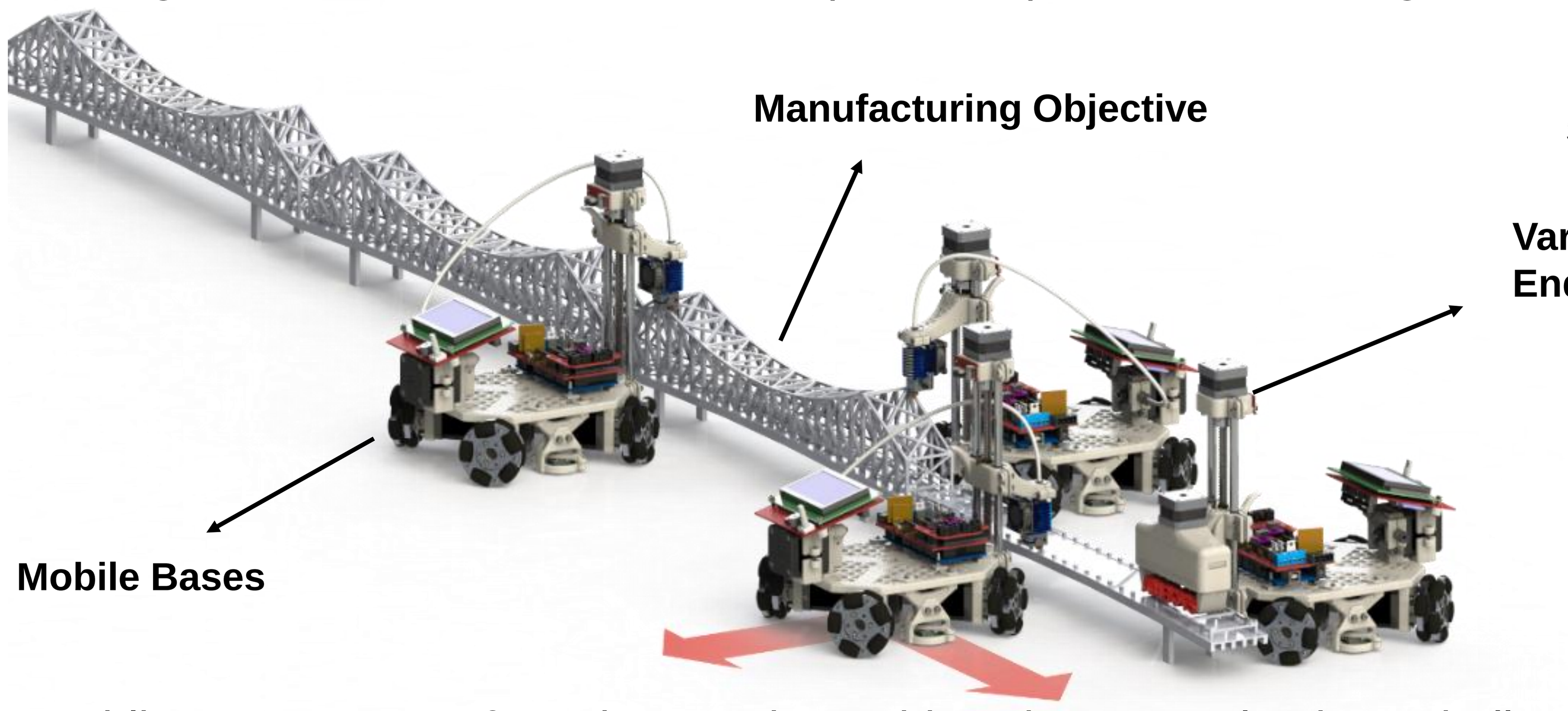
Abstract

- Swarm manufacturing is a novel manufacturing paradigm that uses multiple heterogeneous mobile robots to accomplish complex manufacturing tasks.

Swarm Manufacturing Demo

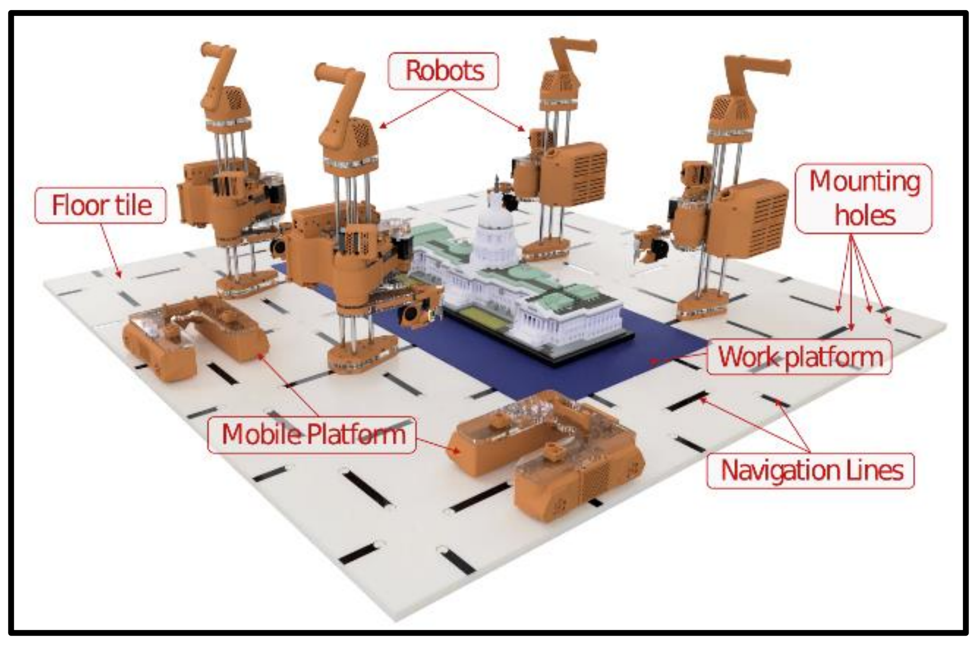


- Enabling swarm manufacturing requires addressing several unique challenges that are not present in traditional manufacturing scenarios.
- This research focuses on developing cooperation techniques for swarm manufacturing while using cooperative 3D printing (C3DP) as a case study.

Background & Motivation

- Traditional factories are generally configured to operate under a specific set of parameters (dimensions, material, etc.) for mass production.
- If these parameters change, the production line, or part of it, will need to undergo a costly reconfiguration and recalibration process, which is undesirable.

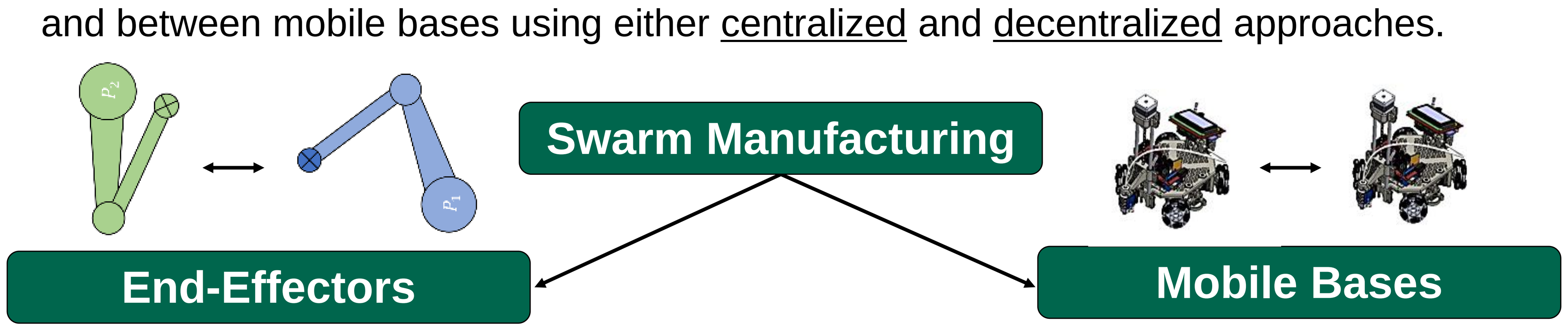
Swarm → Behavior



- Swarm robots can manufacture arbitrarily large parts, calibrate themselves, and acquire new manufacturing capabilities by switching their end-effectors.

Research Questions

- Swarm manufacturing contains different levels of cooperation. We want to understand the performance and scalability of swarm behavior in the cooperation between end-effectors and between mobile bases using either centralized and decentralized approaches.



- Specifically, we are interested in the following questions:
  - a. How to achieve collision-free end-effector cooperation given a set of manufacturing constraints (robot kinematics, number of robots, type of process, etc.)?
  - b. How to achieve collision-free, time-optimal cooperation between the mobile bases while accurately representing their geometries and considering orientation.

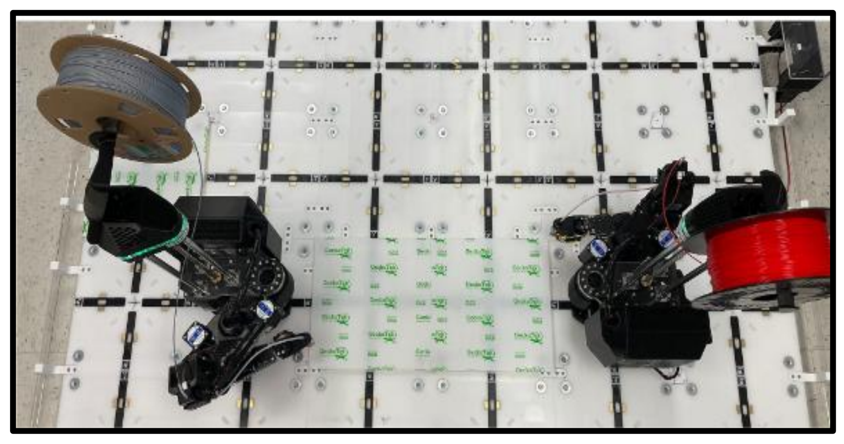
Related Publications

- Poudel, L., Elagandula, S., Zhou, W., and Sha, Z. (October 10, 2022). "Decentralized and Centralized Planning for Multi-Robot Additive Manufacturing." ASME. *J. Mech. Des*. January 2023;.
- Poudel, L., Marques, L. G., Williams, R. A., Hyden, Z., Guerra, P., Fowler, O. L., Sha, Z., and Zhou, W. (February 16, 2022) "Toward Swarm Manufacturing: Architecting a Cooperative 3D Printing System." ASME. *J. Manuf. Sci. Eng*. August 2022;
- Elagandula, S, Poudel, L, Zhou, W, & Sha, Z. "Enabling Multi-Robot Cooperative Additive Manufacturing: Centralized vs. Decentralized Approaches." *Proceedings of the ASME 2021 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*.

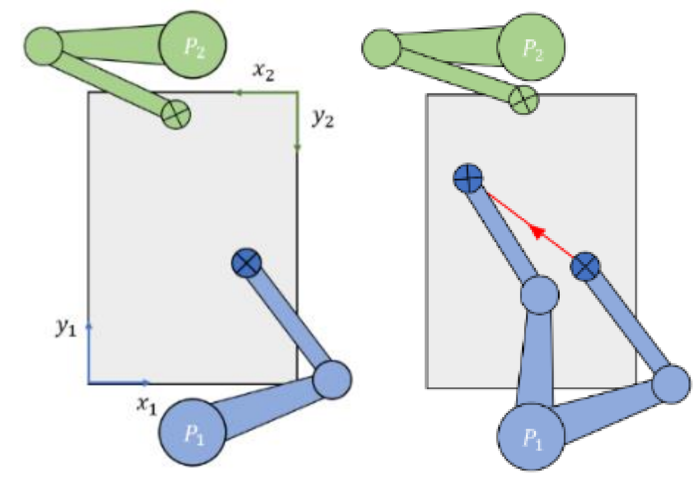
Part 1. End-Effector Cooperation

- The goal is to develop a cooperative framework between the end-effectors of the heterogeneous robots that are operating in a shared workspace.

Experimental Setup



Theoretical Abstraction



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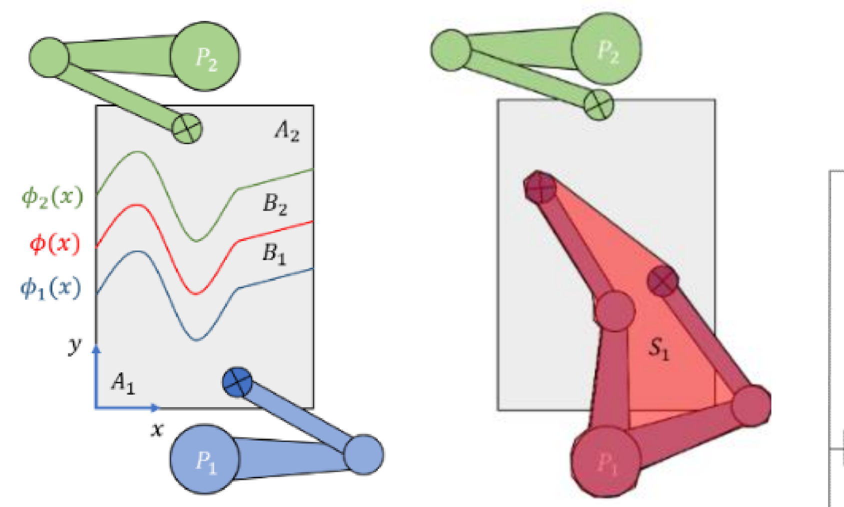
Framework Demo

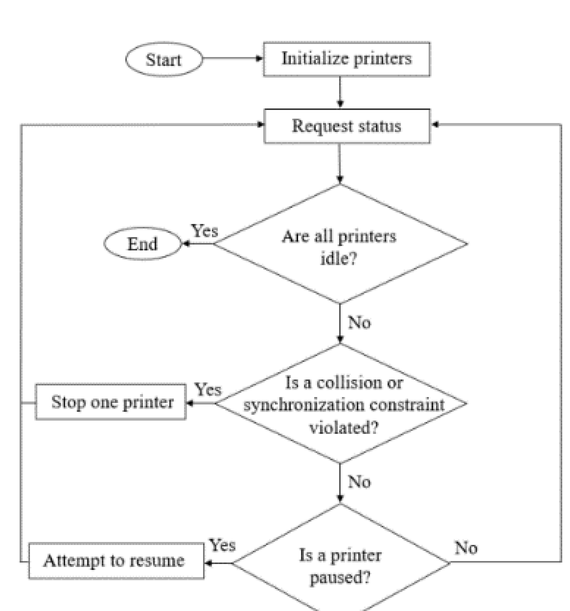
i. Safe Zone **ii. Minimum Distance**



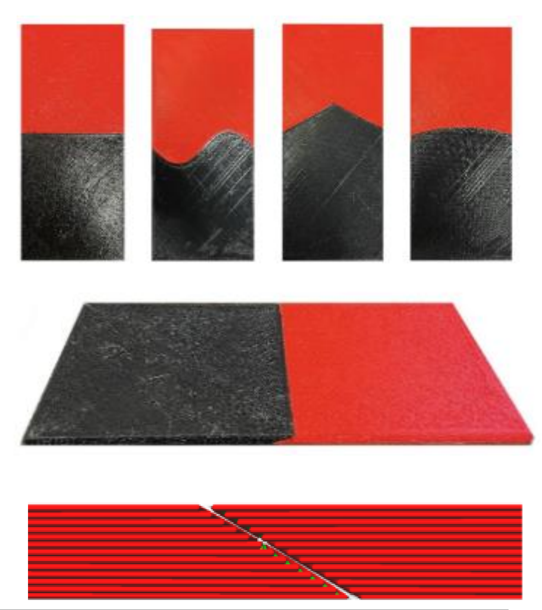
i. $\vec{\xi}_i(t) \in I \wedge \vec{\xi}_j(t) \notin I,\ \forall i,j \le N,\ i \ne j$

ii. $S_i(t) \cap S_j(t) = \emptyset,\ \forall i,j \le N,\ i \ne j$

Framework



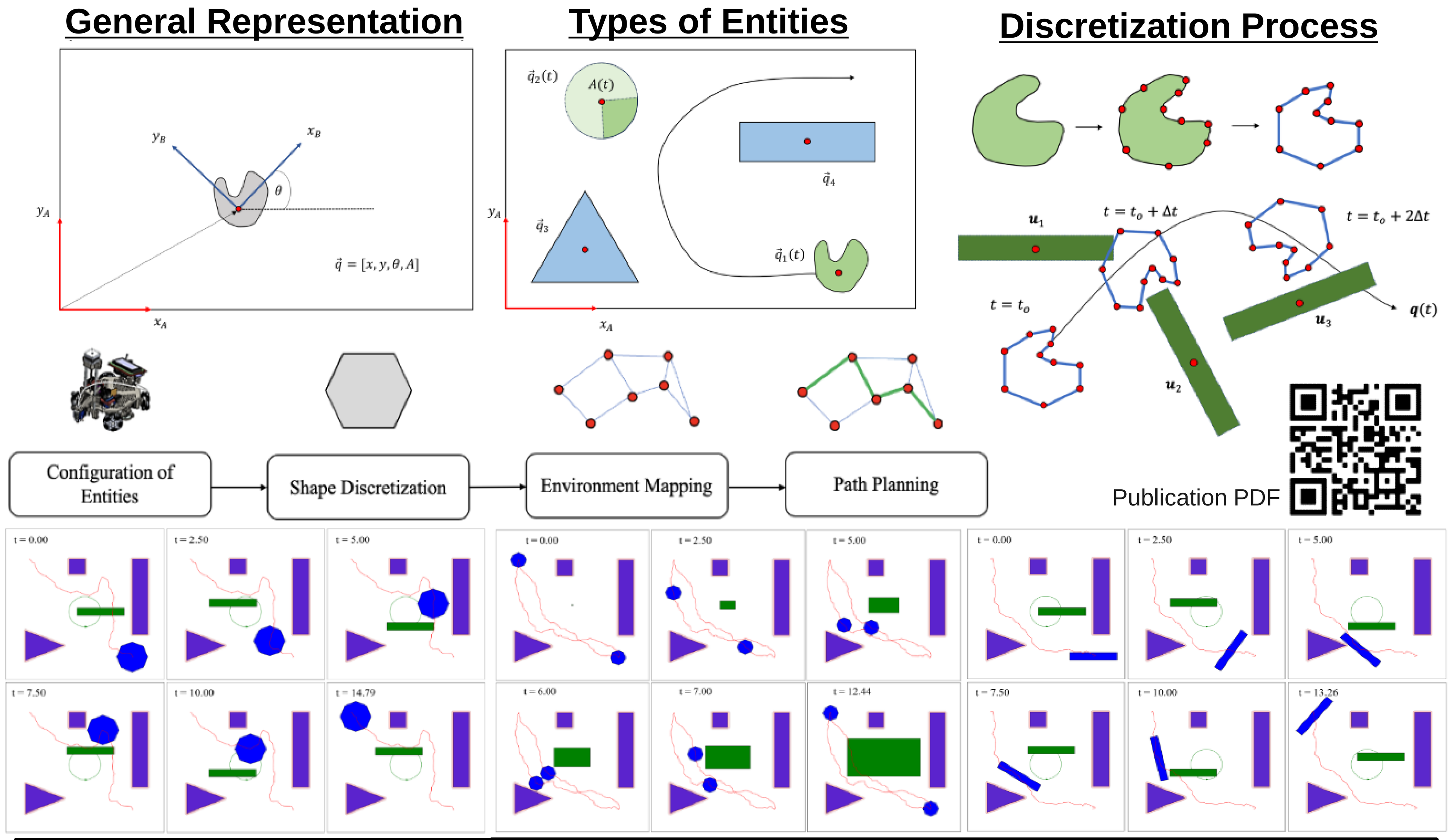
Test Cases



Part 2. Mobile Base Cooperation

- The goal is to develop a scalable, collision-free, time-optimal, multi-agent path planning framework for heterogeneous robots that can deal with arbitrary geometries.

General Representation **Types of Entities** **Discretization Process**



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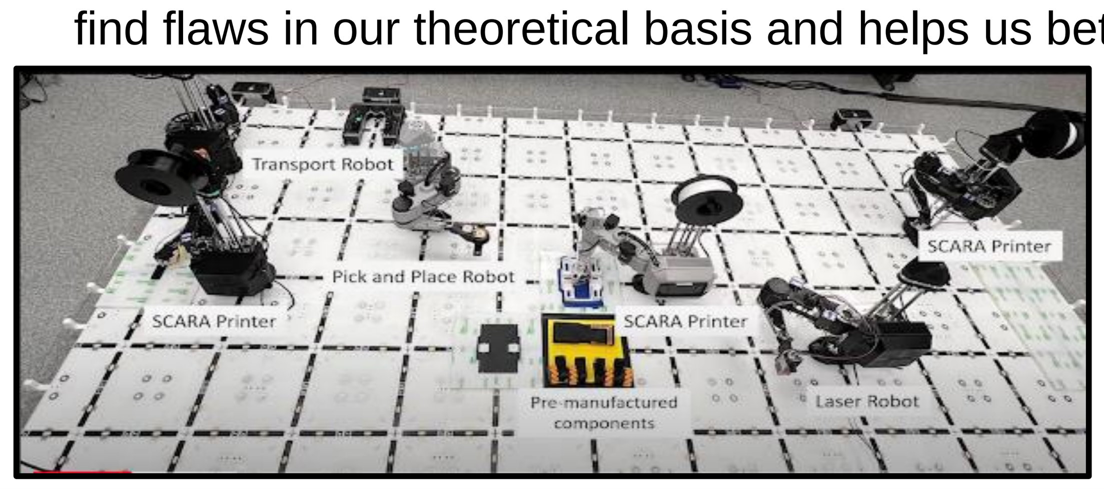
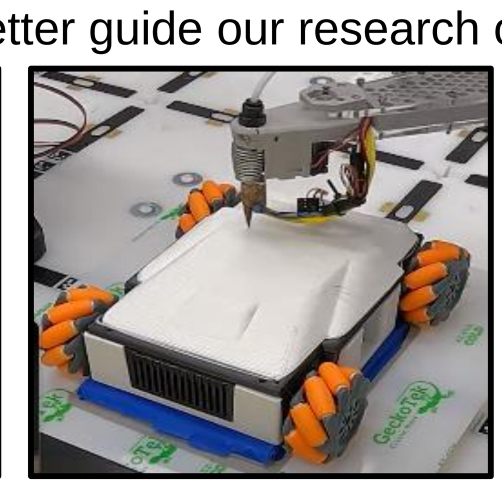
Future Work & Lessons Learned

- Combine the cooperative strategies developed in Parts 1 & 2 into a unified framework.
- Include different manufacturing techniques (laser-cutting, multi-material, assembly, etc.).
- Learned the importance of always physically validating our research, as it allows us to find flaws in our theoretical basis and helps us better guide our research objectives.





Future Work Demo

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