CPS: TTP Option: Synergy: Collaborative Research: Dependable Multi-Robot Cooperative Tasking in Uncertain and Dynamic Environments

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Project Overview

Driven by both civilian and military applications, such as coordinated surveillance, search and rescue, underwater or space exploration, manipulation in hazardous environments, and rapid emergency response, cooperative actions by teams of robots has emerged as an important research area. This project focuses on fundamental theory studies so to enable a scalable, correct-by-construction formal design of multi-robot systems that can guarantee the accomplishment of high-level team missions through automatic synthesis of local coordination mechanisms and control laws. Furthermore, results from the research can be extended to the design of more general cyber-physical systems (CPSs) consisting of distributed and coordinated subsystems, such as the national power grid, ground/air traffic networks, and manufacturing systems. These CPSs are critical components of the national civil infrastructure that must operate reliably to ensure public safety. The multidisciplinary approach taken will help broaden participation of underrepresented groups in research and positively impact engineering education.

Project Objectives and Approach

Goal: Focusing on multi-robot teams, the goal of the research is to build foundations for a provably correct formal design theory for CPSs. This design theory will guarantee a given global performance of multi-robot teams through designing local coordination rules and control laws.

Hence our research tasks include:

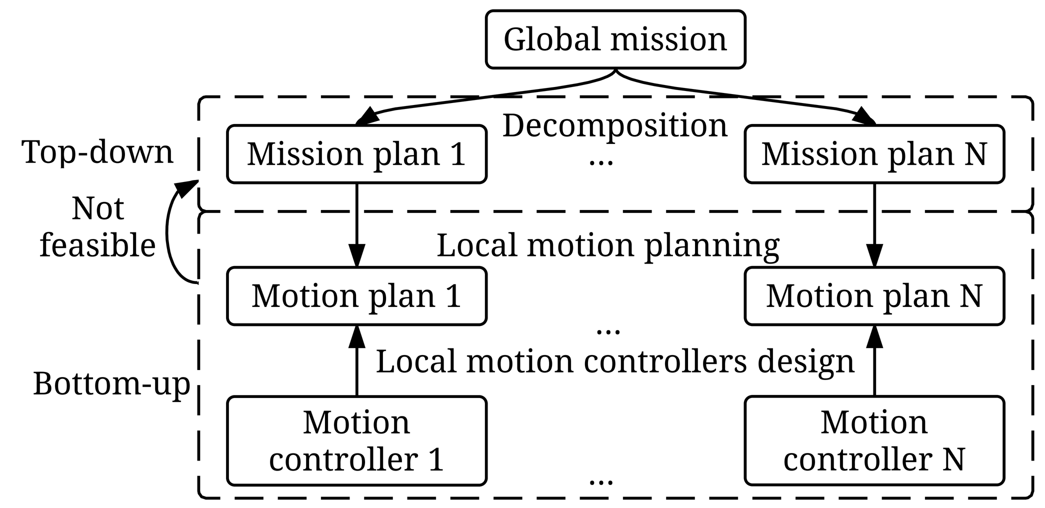
Objective 1. Automatically synthesize supervisors for uncertain discrete-event plants.

Objective 2. Automatically derive subtasks for individual robots from a given team mission.

Objective 3. Implement and demonstrate the top-down design approaches on real robotic systems.

Multidisciplinary approaches combining hybrid systems, supervisory control, regular inference and model checking will be utilized to achieve this goal.

Top-down and Bottom-up Design

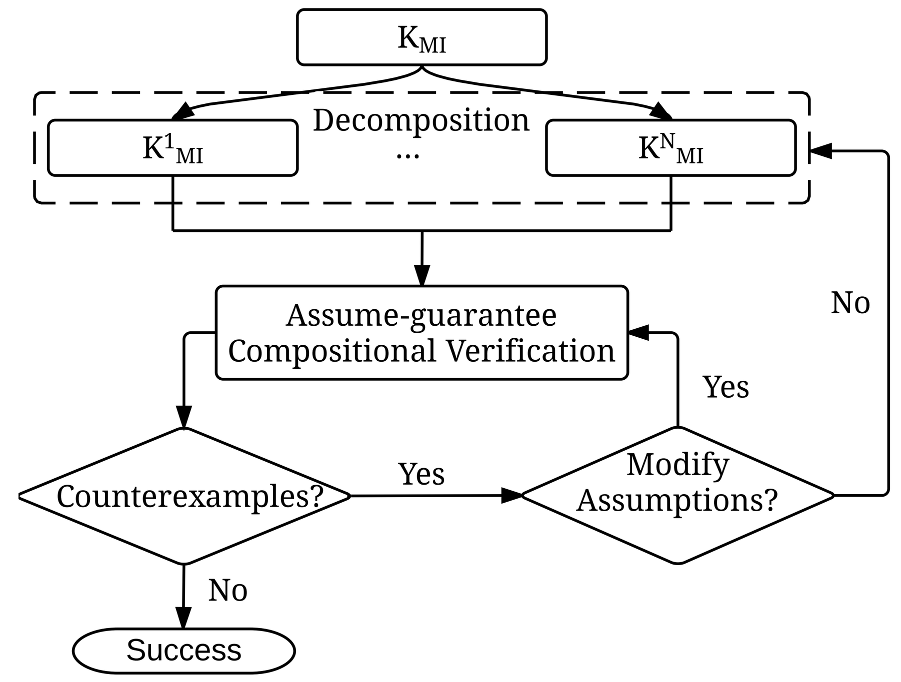


Different from the majority of existing work, such as swarming robotics, behavior based robotics, multi-agent system etc., we are interested in developing a formal correct-by-design method for distributed coordination and control of multi-robot systems consisting of heterogeneous robots in uncertain environments.

We propose to **combine** top-down and bottom-up approaches to com up with a **scalable** formal **correct-by-design** method for distributed coordination and control of multi-robot systems in **uncertain environments**.

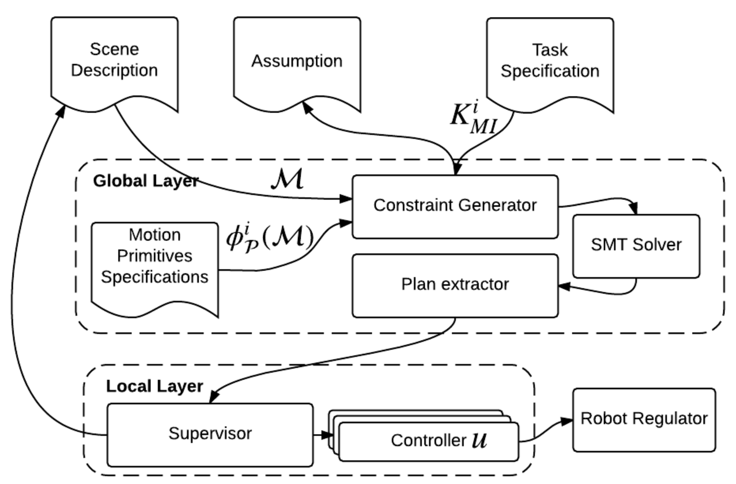
Top-down Task Decomposition

Basic idea is "divide-and-conquer." First, we decompose the team mission into subtasks for individual robots, and then synthesize a local supervisor individually for each robot to fulfill these subtasks.



- Assume the global mission is given as regular languages.
- Need to decompose the global mission into individual robot tasks.

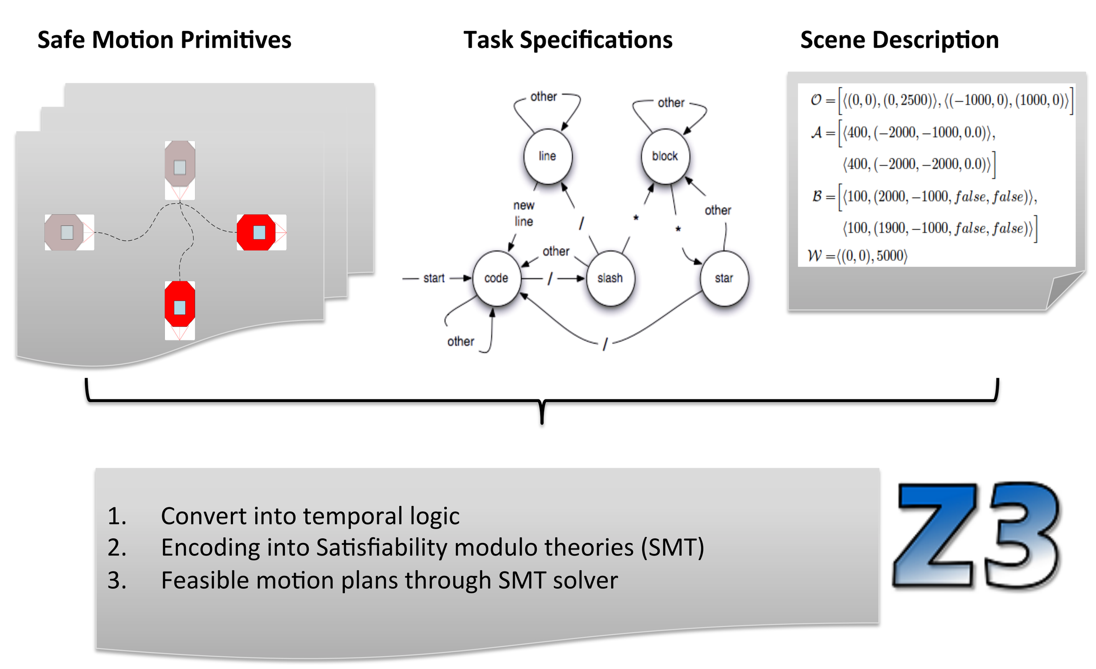
Bottom-up Motion Planning



Inputs:
a. Task specification
b. Scene Description
c. Basic reactive controllers

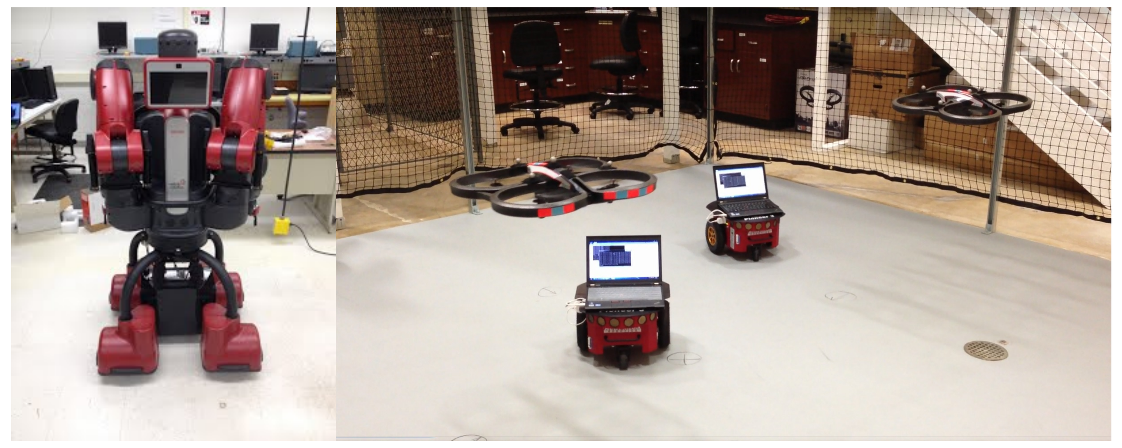
Output:
Safety guaranteed task and motion plans

Composition of Motion Primitives



DISCOVER Lab at Notre Dame

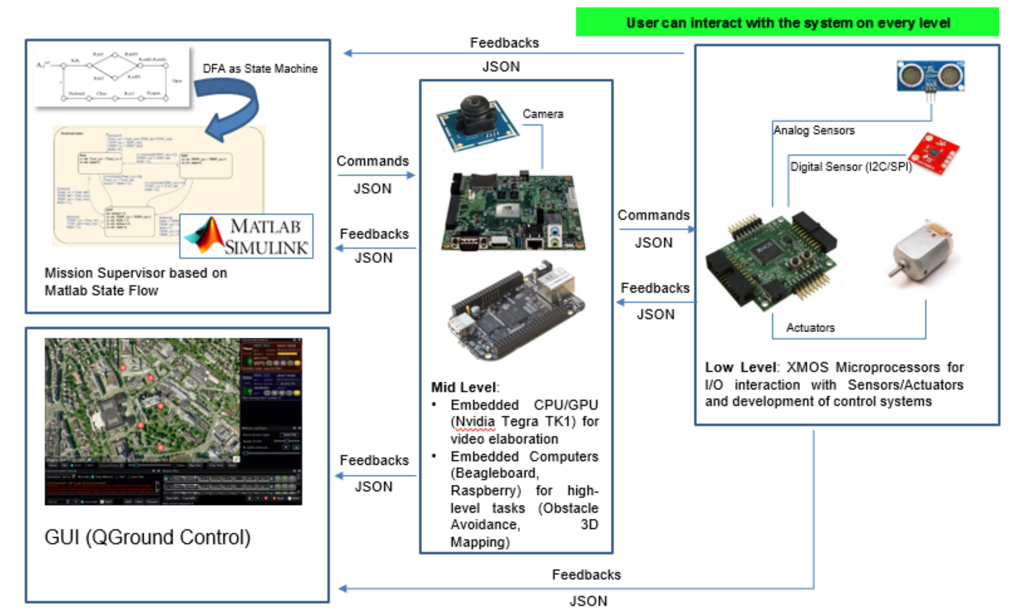
- In Discover Lab (Distributed Cooperative Systems Research Lab) at Notre Dame, we are using multi-robot systems and human-machine collaboration as working examples to study the design principles for engineered complex systems.
- We are interested in developing a scalable formal design theory to guarantee the correctness of cooperative tasking among a group of robots in uncertain environments.



Robot Testbed Development

The DU Unmanned Systems Laboratory (DU2SL) of the School of Engineering and Computer Science (SECS) has a large complement of ground and airborne platforms instrumented with state of the art sensors and custom-made general purpose navigation controllers. The current fleet of available unmanned aircraft includes more than 17 aerial platforms used for experimental proof-of-concept-demonstration, and a swarm of 13 ground robots equipped with hard real-time multicore microcontroller (xMOS). More ground robots are currently under development.

The current efforts focus on upgrading both hardware and software design so to: Enforce strict real-time performance; Each node/agent must be able to interact with a different library/suite of sensors simultaneously (sensor information fusion); The (collaborative robot team) system must be modular and scalable, as well as adaptable even when new agents join or leave the team; The 'supervisory control' system must be event-driven and able to interact with all agents/ nodes using different communication system/protocols. A software library for real-time interaction with sensor has been developed and currently for managing the swarm of robots.



Preliminary results concerning the cooperation between a swarm of ground robots have been published on a joint publication between University of Notre Dame and University of Denver.

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