Research Statement

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I am a computer science researcher who is eager to 1) devise new algorithmic and mathematical techniques and 2) design novel AI and robotic systems with interesting properties, with the hope that these techniques and properties are enablers of novel applications that could make a great impact on society. Therefore, one way to look at my work is from a **system perspective** and focus on the properties of the AI and robotic systems my students and I developed:

1. **High Throughput:**
   (a) A set of mobile conveyors can form a **dynamic robot chain** that can achieve a much higher throughput when transferring many objects simultaneously. We studied how to deploy dynamic robot chain networks in foraging tasks in which robots search for resources and bring them back to a collection zone [28, 43, 45]
   (b) We designed a new robotic system called **mobile workstation robots** in which a mobile robot can perform some operations on the objects it carries on the move. The key to unlocking the power of these robots is a better scheduling algorithm for overlapping production time and delivery time [29, 37].
   (c) Autonomous intersection management (AIM) is an intersection control protocol for autonomous vehicles that can achieve a near-zero traffic delay at intersections. I extended AIM to **autonomous traffic management** for more than one intersection and studied how to maximize its throughput [17, 18, 20, 23, 24, 25, 27].
2. **High Responsiveness:**
   (a) There are many practical planning situations in which planners acquire information from external sources during the planning process, but the information may change or expire during the planning process. We presented a reactive planning framework for handling **volatile external information** [3, 7, 12].
   (b) In drone light shows, a group of drones displays a sequence of light patterns in the sky. We consider using drone light shows for **drone-swarm-based games** and devise planning algorithms that provide a real-time guarantee for displaying pixels in animations and a fast response to user inputs [47, 49, 50].
3. **High Safety Guarantee:**
   (a) Autonomous intersection management cannot tolerate mechanical failures that cause vehicles to deviate from their trajectories. We proposed a preemptive approach that pre-computes **evasion plans** for several common mechanical failures before vehicles enter an intersection [15, 21].
   (b) A robotic system is fail-safe if the robot can steer the system to a safe state when an error occurs. We proposed a neural network model that can be used to speed up the generation of **backup paths** for robots in emergency situations in

cooperative transportation tasks [35].

4. **High Degree of Cooperation:**
   In multiagent systems, self-interested agents need to resolve conflicts before they can cooperate with each other. Existing strategies, such as Tit-For-Tat for Iterated Prisoner's Dilemma, perform poorly in the presence of noise. We proposed a **noise detection technique** that is very effective in many non-zero-sum games [6, 8, 10, 11].
5. **High Density:**
   High-density parking increases the capacity of parking lots by allowing vehicles to block each other but making way for departing vehicles by driving autonomously upon request. We proposed **autonomous parking lots**, which employ different parking strategies to increase the car density of parking lots [41, 46].
6. **High Accuracy:**
   A fast algorithm for checking whether a vehicle can arrive at a position at a given **arrival time and velocity** is the key to autonomous intersection management. We presented a complete set of closed-form equations that fully describe the set of all reachable arrival configurations in **longitudinal motion planning** [22, 34, 39].
7. **High Agility:**
   (a) In autonomous parking lots, a group of vehicles can be asked to move to another location when they block other vehicles. I described a dynamic programming algorithm for **formation planning** that minimizes the makespan of moving multiple vehicles from one location to another [46]. Likewise, we proposed a reservation grid solution to the formation planning problem in multi-drone systems under the influence of wind [50].
   (b) We built and programed fully autonomous drones for **autonomous drone racing**. These drones can fly in cluttered environments as fast as possible while delivering an object to a target location [38].
8. **High Availability:**
   Drones have a fairly short range due to their limited battery life. We propose an adaptive exploration technique to **extend the range of delivery drones** by taking advantage of physical structures such as tall buildings and trees in urban environments [33, 40].
9. **High Security:**
   Goal recognition design (GRD) is the task of modifying environments to aid observers in recognizing the objectives of agents during online observations. We presented a new GRD framework called **extended goal recognition design** for goal recognition that involves multiple goals [44, 48].

Most of my work fits very well into multiagent systems, specifically multirobot systems [32]. My work spans across many application domains: intelligent transportation systems [17, 19, 42], logistics systems [45], security systems [44], drone-swarm-based entertainment systems [47], drone delivery systems [40], disaster management systems [36], smart warehouses [31], smart factories [30], mixed reality systems [16], and web applications [4]. I am most interested in studying the mathematical properties of these systems (e.g., [17] and [39]) and devising new algorithms to provide these properties (e.g., [11] and [46]). The techniques that I often use are planning techniques such as motion planning [26] and domain-independent planning [2, 5, 14]. I particularly like to use search algorithms [44] and dynamic programming [9, 46] for combinatorial optimization. I like to put multiagent systems in game theoretical settings [8] and study the best strategies for the agents [13]. Sometimes, I use logic [9, 44] and case-based reasoning [1] to specify the properties of a system. I have already added deep learning and reinforecement learning to my arsenal of machine-learning tools for investigating the systems I studied previously.

There are still plenty of fundamental problems in multirobot systems that have not been widely studied. For example, 1) I used the term *high-throughput robotic systems* to refer to robotic systems that optimize for the number of tasks robots can handle instead of the speed of handling one task [17, 28, 45]. 2) *Contingency formation planning* for a team of mobile robots aims to provide certain performance guarantees in response to environmental changes [21, 35, 46] or user inputs [47, 49]. 3) *Environment design* focuses on modifying environments for optimizing the performance of robots or agents in the environments [41, 44]. Environment design offers a new way to achieve high throughput in the aforementioned robotic systems. These topics are relevant to some real world applications and they are fertile grounds for many interesting results.

The discovery of the incredible learning capabilities of artificial neural networks triggered a renaissance in artificial intelligence a decade ago. An artificial neural network is a complex system that exhibits an *emergent property* of learning by having many neurons interacting with each other. Similarly, other multiagent systems could possess emergent properties with highly desirable effects as well. For example, in my PhD work on cooperative games, I discovered that agents in cooperative environments often exhibit clarity in behaviors, and we can exploit this property to fend off noise in noisy environments such that agents can maintain cooperation in the Noisy Iterated Prisoner's Dilemma. Since then, one of my long-term goals has been to discover all kinds of interesting properties in multiagent systems and unleash the full potential of these properties. I have kept this goal in mind when I chose my research topics in the past, and I will keep working toward this goal in the future.

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