Research Statement

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I design provably correct, real-time control strategies for resource-constrained multi-agent systems operating in dynamic and uncertain environments. A key challenge in this domain is enabling robots with limited sensing, computation, and memory to make decisions with minimal information while still ensuring safety and task completion. My work addresses this by developing generalizable internal agent architectures that offer these guarantees, and when that's not possible, allow for quantifiable tradeoffs between performance and resource limitations. My broader goal is to create autonomous systems that are deployable in the wild and are capable of functioning under real-time constraints.

At the core of my approach is a shift in perspective: instead of reconstructing the world, agents should act based on how they *feel* about it. This insight is formalized through internal state variables (continuous opinions) that evolve over time to reflect an agent's urgency, confidence, or intent, and drive its decisions accordingly. These opinions evolve dynamically in response to local interactions, modulating both fast-timescale motion planning and longer-horizon decision making. Their structure is engineered to foster coordination and robustness without shared maps, global planning, or explicit communication. This stands in contrast with end-to-end learning approaches that train large models to directly map observations to actions. While such models can perform impressively in structured environments, they often fail under distribution shifts or resource degradation. My work offers a complementary path: decentralized architectures with built-in guarantees for generalizability, transparency, and graceful degradation.

This philosophy threads through several domains. Consider how humans navigate crowded spaces: we do not exchange messages or follow scripts, yet somehow avoid collisions and resolve deadlocks. Inspired by this, I develop navigation controllers where each robot maintains a continuously evolving opinion about how urgently it should proceed. This internal variable, influenced by local geometry, goal urgency, and nearby motion, modulates both steering and forward speed. The result is proactive deadlock resolution without a global plan or centralized arbitration while still maintaining formal safety and convergence guarantees. A similar architecture extends to decentralized task allocation and resource monitoring. In dynamic environments where tasks appear and disappear unpredictably, minimalist robots maintain local memory and update latent utility estimates to decide which roles to assume. The nonlinear opinion dynamics model provides a decentralized coordination mechanism enabling agents to self-organize, adapt roles, and maintain persistent coverage, all with limited communication and sensing. Even in minimal setups such as robots without GPS, memory, or inter-agent communication, I have shown in my doctoral work that coordinated behavior like dynamic target encapsulation emerges from local interactions alone. I have also established bounds between agent count, sensor load, and task feasibility.

These efforts illustrate a broader research vision: structured decentralization with guarantees. Rather than learning high-dimensional global policies or optimizing from scratch in every new scenario, I build systems where desired behaviors emerge from constrained local interactions and evolving internal states. This design pattern generalizes from physical navigation to task assignment to distributed decision making because it abstracts away from the specifics of perception and instead encodes coordination logic directly into agent dynamics.

Looking ahead, I aim to formalize internal-state-driven decision making by coupling nonlinear opinion dynamics with ideas from cognitive science, where latent variables such as confidence and intent shape behavior under uncertainty. I am particularly interested in layering structured game-theoretic learning and lightweight optimization atop interpretable dynamics as adaptive tools rather than as replacements for reasoning. I also plan to study how collectives switch behaviors and how uncertainty and resource constraints shape decision making. These directions underpin my goal of building autonomous systems that are inherently safe, adaptive, and resource aware.

My work lies at the intersection of robotics, control, and collective intelligence, and aligns with the MSE Rising Stars mission to develop resilient, intelligent systems. As a first-generation student, I'm committed to making STEM more inclusive. At Cornell, I led a hands-on "Expanding Your Horizons" workshop where middle-school girls explored geometry and elasticity through building soft robots with everyday materials. I also co-organize an annual computing workshop in my hometown in India, introducing rural girls to core ideas in engineering and computing. These grassroots efforts reflect my belief that inclusion and technical excellence must go hand in hand and I am committed to fostering a research culture where both thrive.