Research and Teaching Statement

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Research Interests

I am particularly interested in emergent patterns in complex multi-agent systems. I study both how to design effective autonomous decision-making systems as well as the rationale behind decisions of living agents in natural systems. Consequently, my transdisciplinary work connects engineering, computer science, and behavioral ecology. In general, I use theories from optimization, parallel computing, networks, dynamical systems, stochasticity, and formal logic to explain or design emergent system-level phenomena. My past work focused on the interactions of individuals with complex environments [3, 6–9]. In those cases, the study of animal foraging behavior was instructive when designing control strategies for autonomous air and ground vehicles. My more recent work considers systems of many interacting individuals. For engineering, I am interested in decentralized implementations of collective group behavior that rely on little communication or coordination between individuals. For behavioral ecology, I am interested in the individual proximate mechanisms that, when combined with the environment, lead to group synergy.

Task-processing networks: When a number of agents with similar capabilities are connected on a network, each agent may share its own task-processing resources with its neighbors. To generate an adaptive and decentralized cooperation strategy, I implemented a fictitious trading economy that induces individual agents to dynamically adjust cooperation frequency based entirely on locally received incentives [4, 10]. The individual-level utility functions couple the actions of neighboring individuals so that good performance is possible without explicit communication. Moreover, certain motifs present in the network help to guarantee the stability of the decentralized algorithm to solutions that are qualitatively similar to those of a centralized load balancer. Although this approach is focused on flexible manufacturing systems and autonomous-air-vehicle surveillance systems, it is inspired by animal examples of cooperative breeding among unrelated individuals.

Distributed resource allocation under constraints: It is often possible for a team of distributed agents to find optimal solutions in a decentralized fashion so long as solution-space constraints are separable. However, realistic constraints are non-separable and induce tradeoffs between agents; the actions of one agent have to be mirrored in another in order to maintain the constraint. In these latter cases, distributed solution methods are effectively centralized due to necessary communication and coordination. With this problem in mind, I study how to replace explicit communication between agents with anonymous modifications of the shared environment. I have presented results [4, 5] that show how a decentralized bank of lights in a building can achieve multiple illumination constraints using minimum power without any explicit communication between the lights. A similar method could be used for other systems that share access to a physical resource, like distributed power generation systems. I am currently doing empirical work with ants to determine the decentralized rules they use in analogous resource-allocation problems.

Safety verification in mixed-traffic urban environments: In the far future, autonomous urban vehicles may operate within a highway system equipped with a complicated communication infrastructure. On the way to that future, vehicles will have varying levels of autonomy with possibly little-to-no direct communication between them. So I study how collective safety constraints can be satisfied in cases of little coordination. I have combined specifications of the physical environment with software verification methods normally accustomed to guaranteeing safety constraints in discrete-time and discrete-space systems [11, 12]. Because I allow for heterogeneity, solutions that I describe are less conservative than prior work and thus provide more comfortable performance while still ensuring safety.

Stochastic strategies for artificial swarms: My most recent work focuses on swarms of independent agents where each agent must allocate itself to one of a number of tasks. For example, appropriately sized teams of robots on Mars may be required to carry discovered objects to a central area for sophisticated study. Rather than relying on communication between robots, each robot may be viewed as an entity of a gas which attaches and detaches from the object according to certain designed probabilities. My colleagues and I have shown that such models are good fits to the phenomenon of collective food transport observed in ants [2]. For robotic applications, we have introduced enzyme-inspired robot-to-robot interaction rules that ensure equilibrium surface allocations are independent of environmental parameters. The result is a decentralized stochastic algorithm for formation of teams with stable and predictable sizes that do not vary with total number of robots or geometry of the space [13].

Teaching Interests

Facing an audience of millennials, classroom teachers compete for attention with new forms of interactive, highly available content. Staying relevant in this atmosphere is difficult as students see less incentive to physically attend classes that cover content that can be found on-line. Some universities have embraced self-paced e-Learning to appease these students and to free up research time for faculty. However, rather than competing directly with purely on-line schools, institutions can leverage faculty experience to create unique in-person offerings that are complemented by an engaging on-line presence. Along with the opportunity to do research with faculty, instructors can use inquiry-based teaching methods to augment traditional classroom learning with self-paced opportunities that prepare students for future research.

Open-Source Collaborative Course Content: Rather than using textbooks as the primary reference material in the courses I have taught, I have produced hundreds of pages of shorter documents[1] that are not only tailored for each course but provide multiple ways to engage the student. Each print-ready electronic document includes hyperlinks that: assist in navigation throughout the document, link to additional third-party sources of information that I have reviewed on the web, and link to other course documents. These fully searchable versions include professional-quality graphics that can be used by students in their formal reports. Because undergraduate students may have little experience writing technical reports, each document is written to serve as an example. Hence, they simultaneously guide a student through the classroom experience, provide her help finding additional technical resources, and serve as examples of language and format that she should use in her course submissions. Because the students know that these are living documents that I have contributed to, they are more likely to contact me about questions they have about the content. Moreover, I can easily make adjustments to the living documents based upon the responses I receive from the students. Students observe this editorial process directly as the Creative-Commons-licensed document source code is available from a distributed source code repository[2].

Using Laboratory Inquiry to Prove Rules by Exception: To investigate classroom scientific inquiry, I was granted a one-year graduate fellowship developing and implementing inquiry-based scientific instruction curriculum for fourth graders. Since then, my college-level teaching methods have been greatly influenced by the experimental scientific method. I work to strengthen students' understanding and appreciation of the abstract mathematical topics by highlighting how experimental deviations from theory follow from violations in model assumptions. When students assert that observed differences from theory are due to "noise" or "manufacturing variations," I work with them to execute an experiment to make these blunt statements precise. This process typically leads them to re-examine how few assumptions are necessary for many engineering methods and how easy it can be to find which assumptions are violated. By testing different hypotheses for why deviations occur, the students sometimes correct experimental errors and restore the expected results, and they often gain valuable insight into the scientific method itself. When it is not practical to provide a hands-on laboratory experience to every student about every topic, I provide simple first-principle-based simulation models to students that help them with their own out-of-class inquiry[3].

Learning by Creating: Although guided instruction is an important part of post-secondary education, I believe that engineering students greatly benefit from collaborating with their peers to create new solutions to unsolved problems. As described by Freuler et al. [1], I have spent several years on the instructional staff of a program for first-year engineering students that provides a cohesive year-long experience that introduces them to basic mechanical, electrical, and computer engineering tools and then requires teams to design, build, and present autonomous robots to complete novel tasks. This kind of tight organization between classroom instructors throughout the academic year is not practical for older students, and so I also served as a team leader in an extracurricular group that challenged these older students with more advanced design and build problems. In both cases, novel design challenges were valuable examples of real engineering and helped students gain exposure to topics that are not easily covered within the classroom.

[1] Samples can be found on any of the course web page mirrors archived at http://www.tedpavlic.com/teaching/osu/.

[2] Mercurial source code repositories for course material available at http://hg.tedpavlic.com/.

[3] One example is the set of DC–DC boost converter simulation codes and results available at http://www.tedpavlic.com/teaching/osu/ece327/#lab_voltreg. This example was produced at the request of a student.

References

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