Research Statement

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I study topics in Game Theory broadly, with much of my current work centered around the development and use of computational models. Such models can serve as powerful tools to bridge gaps between theory and the real-world by allowing for the relaxation of many tractability assumptions which are required in conventional mathematical models. Computational models can be used both as theory-generating devices (by exploring the implications of relaxing particular assumptions) and as structural models of phenomena for direct estimation on data. Much of my current work either utilizes computational models I've developed of learning, non-trivially interacting agents (both for the advancement of theory and for estimation) or aims to solve a number of practical problems when bringing computational models to data for applied work.

In my Job Market Paper, **Evolving Sustainable Institutions in Agent-Based Simulations with Learning** (with Andreas Pape, Todd Guilfoos, and Peter DiCola), we explore the role in which learning and institutional constraints affect the shape of emergent sanctioning policies used to govern common-pool resources. Ostrom (1990) observed across hundreds of case studies of communities who had successfully sustained common-pool resources for long periods of time the widespread use of graduated sanctioning. While graduated sanctioning favors an initially shallow but increasing punishments in the size of over-exploitation of the resource, one can imagine other strategies such as draconian sanctioning, which maximally punishes any deviation from socially optimal behavior. Game theoretic models with rational agents either conclude that the shape of such policies is irrelevant or that non-graduated policy should be used, both of which directly contradict what Ostrom observed. Drawing insights from Ostrom's writings, we hypothesized that the shape of policy should be relevant for learning agents as it plays an important role in providing lessons for agents, with the goal of graduated sanctioning being to gently steward those in the commons to socially optimal behavior. To explore this avenue, we first extend the aforementioned repeated common-pool resource game with a simple computational model in which we replace rational agents with learning ones, and demonstrate these learning agents are capable of fairly rational behavior if given enough time to learn. Next, the agents play the repeated game facing either 'top-down' policy chosen by an algorithmically optimizing, benevolent social planner or 'bottom-up' policy via 'democracy', modeled as an endogenous self-governance process. We find that graduated sanctions emerge top-down via a social planner who utilizes a fine-based policy without redistribution, but only when agents utilize similarity in their decision-making process. Next, we find that, when policy makers are able to redistribute fines, draconian-style sanctions can emerge. We also demonstrate that implementing the theoretical solution for rational agents who fully understand the game can forgo substantial potential gains in social welfare. Finally, we observe that, when agents participate in democracy, they are able to solve the commons problem fairly well, though we do not observe graduated sanctions emerge in this context.

This first paper from this project, now in revise & resubmit status at JEBO, has generated interest from fairly broad audience, having been presented to Economists[1], Computational Social Scientists[2] and academics in Sustainability research.[3] This is one of the first papers to show the important role that individual learning can play in the emergence of one of Ostrom's principles, graduated sanctions. More broadly, this paper demonstrates the important role computational models can play in extending theoretical insights by extending existing models with relaxed assumptions (in this case, rationality). Looking forward, this project has immense scope for promising future extensions. A number of close extensions, some of which have been suggested by our reviewers, include exploring heterogeneous agents (e.g. in altruism level or learning parameters), imperfect monitoring scenarios, and non-stationary variations of

[1]Presented at the Eastern Economic Association 2024 NYC Computational Economics & Complexity Workshop, S2024

[2]Presented and developed at the Graduate Workshop in Computational Social Science, Santa Fe Institute (with John Miller and Scott Page), Su2023 & Su2024

[3]Presented at the Commons, Commoning, and Social Change Workshop, School for Environment and Sustainability at the University of Michigan, F2023

the common-pool resource game. More generally, there is still a great deal of work to be done exploring the emergence or co-emergence of Ostrom's other principles (e.g. monitoring, multi-level governance) in a similar frameworks. Pursuing these avenues could be very fruitful and would certainly keep me busy for years to come.

Discussing my more applied work, **A Guide and General Method for Estimating Parameters and their Confidence Intervals in Agent-Based Simulations with Stochasticity** (with Nency Dhameja, Yixin Ren, and Andreas Pape) aims to establish best practices for estimating computational models - something which at present is fairly non-standardized. We provide a practical and accessible guide for bringing virtually any computational model to panel data in a manner akin to structural regression estimation in Economics, including block-bootstrapping confidence intervals and using Monte Carlo simulation to explore if the model parameters are reasonably identifiable to begin with. We also introduce a novel test utilizing Monte Carlo methods to decompose typical sources of estimation imprecision from additional sources introduced by features of the search and aggregation processes required in such contexts. This test can help users identify if estimate imprecision is predominately a result of utilizing an ill-suited method for searching the parameter space in question.

This project is in a late manuscript stage and, after receiving some great feedback from some computational economists [4], we feel we are nearly ready to send it out, aiming for either a top computational economics journal or a top computational modeling journal(e.g. Computational Economics or JASSS). One possible future extension of this project includes the development of a python library where many of these tools and tests can be made easily accessible to other analysts as out of the box functions.

In another collaborative project, **On the Preservation of Input/Output Directed Graph Informativeness under Crossover** (with Andreas Pape, J. David Schaffer, and Hiroki Sayama), we propose a partial solution to the problem encountered when trying to optimize the topology of a fairly broad class of computational models - Input Output Directed Graphs (IOD Graphs) - with a popular and fairly robust evolutionary algorithm - the Genetic Algorithm (GA). We define an IOD Graph as a graph with a set of nodes N and directed edges E, where N contains a set of ”input nodes” I and a set of ”output nodes” O. These networks need not be feed-forward and can represent a wide array of systems such as supply chains, chemical transformation networks, electrical circuits, municipal water systems, and neural networks. If an analyst's aim is to search the space of network topologies using the GA with the goal of finding some high-performing solutions, then crossover (a key part of the GA's search process which mixes two existing high performing candidate solutions with the aim of producing a better one) between two IOD Graphs must be well defined. We define a crossover operation on IOD Graphs in which we find sub-graphs from each candidate with matching sets of forward and backward directed links to ”swap.” With this operation, IOD Graphs can be subject to evolutionary computation methods. We also define informativeness, which characterizes the degree to which there exist directed paths from the input nodes to the output nodes, and investigate the extent to which the informativeness of parent graphs is preserved in the child graph(s) resulting from this operation. We show that fully informative parents may yield a non-informative child. We also show that under conditions of contiguousness and the no dangling nodes condition, crossover compatible, partially informative parents yield partially informative children, and very informative input parents with partially informative output parents yield very informative children. However, even under these conditions, full informativeness may not be retained.

This project generated a great deal of interest when presented at NERCCS 2024[5] to an interdisciplinary audience interested in Network Science and Complex Systems. After a rejection but some positive feedback from a top field journal in evolutionary computational methods, Evolutionary Computation, we are making some small revisions and discussing what other journals this manuscript would be well suited for. We've already begun discussions on some promising avenues for future extension of this work. One obvious avenue is to develop a python library to lower the cost of utilizing our methodology. We're also in returning to our original idea which inspired this project, in which we aim to evolve one Spiking Neural Networks (SNNs) capable of solving all of the the canonical categorical learning problems introduced in Shepard, Hovland and Jenkins (1961), which we could then compare to the wealth of experimental results of subjects solving the same problems. Do SNNs struggle in the same way humans do to solve these problems? What can this tell us about how well SNNs can serve as models of decision making? Do we observe any interesting substructures emerge in any of the high performing solutions? Are these substructures common across many of the high performing candidate solutions? There are a wealth of potential insights from this future direction which could have major implications on the viability of using trained SNNs as computational models of human decision making.

[4] Presented at the Eastern Economic Association 2024 NYC Computational Economics & Complexity Workshop, S2024

[5] The Seventh Northeast Regional Conference in Complex Systems, S2024

I also have some in-progress work titled **The Problem with Empty-Headedness: Generalizing K-Level Beliefs as Self-Play to Simulate Priors in Models of Learning and Boundedly Rational Response** in which I introduce the idea of simulated 'self-play' as a way to address the issue of 'empty-headedness' which is derived from the common assumption made in learning models that agents have no information to go on before the first round of play. To highlight why this is problematic, note that a direct implication of this assumption is that we should expect first round play in all games to be precisely the same regardless of the payoffs of the game and whether or not the players even know the rules of the game to begin with. To address this problem, I introduce a method of simulated self-play to generate priors using the features of the game themselves which can be applied to nearly any model of learning. Much like how k-level reasoning encodes players performing mental rounds of best response against themselves to achieve some level of rationality between fully rational and fully random, simulated self play is an analogous process for learning agents where the agents develop priors by learning from simulated mental rounds play against themselves. I demonstrate that, from a theoretical perspective, k-level reasoning exists as a very specific case of this process which utilizes a rational "best response" function and batched updating. Next I develop a computational model in which agents utilize either one of two common learning models (with and without simulated priors) or K-level reasoning. I then test the empirical performance (out of sample prediction) of these computational models, utilizing lab data of players playing different versions of the Beauty Contest Game. I have some preliminary results which seem to indicate that allowing learning agents to use simulated self play improves overall out of sample performance, particularly by improving predictability of early rounds of play.

I am currently in the early process of preparing a manuscript for this project, but I will be present preliminary results this winter at a computational methods workshop with the hopes of getting some useful feedback.[6]

I see computational modeling as a powerful tool and a great addition to any analysts' toolkit. With such methods, analysts can have a free hand to bring well understood game-theoretic models one step closer to reality, whether that's by relaxing assumptions made about decision making or about how agents are able to interact in the system. All of the work I've shared either showcases applications of computational modeling or advances the underlying methodology required for their application. With a wealth of exciting directions for future research at my disposal, I intend to continue advancing and promoting these methods, all while aiming to reduce the barrier of entry for other curious researchers.

[6]Accepted to present at the Eastern Economic Association 2025 NYC Computational Economics & Complexity Workshop, S2025

References

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