Exploring cooperation and competition using agent-based modeling

Euel Elliott and L. Douglas Kiel*

School of Social Sciences, University of Texas at Dallas, Richardson, TX 75083-0688

Agent-based modeling enhances our capacity to model competitive and cooperative behaviors at both the individual and group levels of analysis. Models presented in these proceedings produce consistent results regarding the relative fragility of cooperative regimes among agents operating under diverse rules. These studies also show how competition and cooperation may generate change at both the group and societal level. Agent-based simulation of competitive and cooperative behaviors may reveal the greatest payoff to social science research of all agent-based modeling efforts because of the need to better understand the dynamics of these behaviors in an increasingly interconnected world.

Both cooperative and competitive behaviors occupy a critically important place in the research into individual as well as both group and societal behavior. Scholarship in this area of study reaches from Hobbes’ *Leviathan* (1) to Mancur Olson’s *Logic of Collective Action* (2), game theoretic models of behavior including the (in)famous Prisoner’s Dilemma, and Robert Axelrod’s (3) pathbreaking work on strategies of cooperation.

Agent-based modeling, the topic of this colloquium, provides an extremely important and flexible computational tool for modeling competitive and cooperative behaviors. The papers included in the section *Cooperation and Competition as Factors in Emergent Human Organization* explain a range of both micro- and macro-level phenomena. Peter Danielson’s contribution, *Competition Among Cooperators: Altruism and Reciprocity* (3), builds on critical earlier contributions by Axelrod (4), Sethi and Samanathan (5), and Danielson (6), among others. Danielson demonstrates the somewhat counterintuitive insight that, although reciprocity is necessary to engender cooperative behavior, it is not sufficient for optimal cooperation. Indeed, he notes that “when we implement reciprocal mechanisms, cooperators can be exploited by those with whom they have coordinated on reciprocity. Reciprocity, although stable, need not be optimal and can be opaque in its complexity.” Moreover, providing the agents with a rationality mechanism that allows agents to base their own behavior on the predicted behavior of others also generates suboptimal outcomes. In short, evidence suggests that cooperation is indeed complex, and extraordinarily sensitive to relatively modest modifications of agent behavior. Reciprocity, or the “tit-for-tat” strategy formulated by Axelrod, simply does not appear to be a sufficient decision rule to achieve a stable equilibrium.

The paper by Macy and Flache, *Learning Dynamics in Social Dilemmas* (7), also explores the issue of cooperation among agents. Macy and Flache expanded on earlier research by Fudenberg and Levine (8); however, their modeling exercise diverges from Danielson’s approach. Whereas Danielson’s agents are modeled using an evolutionary game theoretic framework, Macy and Flache use a learning theoretic approach for exploring the problem of cooperation in mixed-motive games. Their approach is based on principles of reinforcement learning, and serves to “reframe” rather than solve the issue of suboptimal outcomes. These suboptimal outcomes can be avoided through “stochastic collusion” involving a random walk from a noncooperative to cooperative equilibrium, but the real insight here is that there are only a narrow range of preferences that support such outcomes. Just as with Danielson’s results, Macy and Flache find that cooperation is a highly complex, variegated, and fragile phenomenon.

Joshua Epstein’s Modeling Civil Violence: An Agent-Based Computational Approach (9) illustrates macro-level dynamics by using agent-based modeling. Epstein convincingly demonstrates the utility of agent-based approaches in modeling societal breakdown. When using a relatively simple learning model of heterogeneous behavior, agent behavior produces results that are amazingly plausible and consistent with real-world phenomena. Several emergent properties of the model emerge that were not expected in any a priori sense. Among them was a sophisticated display of deceptive behavior. Privately aggrieved agents turn Blue (as if they were nonrebellious) when “cops” are near, but then turn Red (actively rebellious) when “cops” move away. They are reminiscent, Epstein notes, of Chairman Mao’s directive that revolutionaries should “swim like fish in the sea” making themselves indistinguishable from the surrounding population. Importantly, many of the more interesting dynamics would not have been uncovered without the spatial visualization provided by agent-based modeling. Aggregated time series of these societal processes would have obscured rich individual-level dynamics. This reiterates a point that has often been made about agent-based computational approaches; that is, the behavior of particular systems that the agents are representing may be so complex that visualization becomes a critical feature of the methodology, and suggests an important limitation of more orthodox analytical approaches.

Dwight Read’s contribution, *A Multi-trajectory, Competition Model of Emergent Complexity in Human Social Organization* (10), is an excellent illustration of the uses of agent modeling for explaining broad features of social change. Read’s study in some respects offers important parallels to Axtell et al.‘s paper later in the volume, *Population Growth and Collapse in a Multi-agent Model of the Kayenta Anasazi in Long House Valley* (11). Axtell et al. examine the evolution of a prehistoric Indian culture and the changing fortunes of the Anasazi as various environmental parameters are varied. Read, however, is interested in explaining not so much how exogenous factors contribute to societal change, but how culturally imbedded patterns of cooperation and competition promote societal change, and how such patterns of

*To whom reprint requests should be addressed. E-mail: dkiel@utdallas.edu.

This paper results from the Arthur M. Sackler Colloquium of the National Academy of Sciences, “Adaptive Agents, Intelligence, and Emergent Human Organization: Capturing Complexity through Agent-Based Modeling,” held October 4–6, 2001, at the Arnold and Mabel Beckman Center of the National Academies of Science and Engineering in Irvine, CA.
behavior emerge at different levels of organizational and societal sophistication. Critically, patterns of competition interact with a range of variables including decision strategies, demographics, and the nature of social units to produce outcomes that may either facilitate or hinder the development of more sophisticated forms of societal organization.

The contributions in this section of PNAS help to illustrate both the promise and the problems of agent-based research. Clearly the papers demonstrate the ability of agent simulations to explore the dynamics of cooperative and competitive behavior at dramatically differing levels of analysis. Relatedly, the papers illustrate the flexibility of agent simulations with regard to the nature of agent learning or the kinds of evolutionary processes built into the models. Agent-based modeling may in many respects be ideally suited to research into the dynamics of cooperation and competition. It allows for us to more realistically model heterogeneous agent populations with, in principle, an enormous range of motives and incentives. In particular, such simulation approaches allow for, as Conte notes in this volume, making certain assumptions about “social intelligence,” both at the individual and supra-individual level.

Clearly, however, much still needs to be done. Agents clearly need to be imbued with greater realism in terms of the range of behaviors. Although acknowledging this may be easier said than done without adding a crippling degree of complications to the simulations, such efforts could be well regarded. For instance, Macy and Flache acknowledge the incomplete nature of their study, because the analysis is limited to symmetrical two-person social dilemma games. They themselves suggest one important future innovation, with a much greater focus on cognitive dynamics at the level of the individual. Elements of Danielson’s analysis use only two agents and so could hopefully be extended to n-agent simulations. Ideally, efforts should be made to develop simulations that mimic real-world phenomena as closely as possible. In that sense, the Ana-sazi simulation exercises could be held up as an ideal type.

Finally, a greater understanding of “social intelligence” as it is mediated by both competition and cooperation may be the most salient of all of the potential payoffs of agent-based modeling. In an increasingly globalized and interconnected world, increased knowledge of the relative, and likely dynamic, value of both competition and cooperation is essential. Current public debate on these issues presents very disparate models of the value of competition and cooperation. These models range from ideologues arguing that competition represented by market dynamics will solve the problems of societal under-development to opposing ideologues arguing that increased cooperation is necessary for humanity to avoid an eventual ecological cataclysm. Agent-based modeling thus may help to shed light on what are likely the intimate connections between competition and cooperation and when each of these “social intelligences” can produce beneficial results under varying circumstances.