The Dynamics of Cooperation versus Competition

Extended Abstract

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KEYWORDS

Cooperation, Competition, Evolutionary Agent-Based Models

ACM Reference Format:
Olaf Witkowski and Geoff Nitschke. 2018. The Dynamics of Cooperation versus Competition: Extended Abstract. In *GECCO '18 Companion: Genetic and Evolutionary Computation Conference Companion, July 15–19, 2018, Kyoto, Japan.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3205651.3205688

1 INTRODUCTION

The emergence and inter-play of cooperation versus competition in groups of individuals has been widely studied, for example using game-theoretic models of eusocial insects [11], [1] experimental evolution in bacterium [5], and agent-based models of societal institutions [8]. Game theory models have been demonstrated as indispensable analytical tools to complement our understanding of the emergence and social mechanics of natural phenomena such as cooperation and competition. For example, game theory models have supported the supposition that cooperation between individuals and competition between groups are critical factors in cultural evolution in human societies [2]. However, such game theory models are ultimately limited by their own abstractions and lack consideration for the role of complex phenomena such as evolutionary and environmental change in shaping emergent social phenomena.

Agent-Based Models (ABMs) are well established as complementary bottom-up computational tools [15] for studying the impact of specific environmental and evolutionary conditions on emergent social phenomena such as cooperation and competition [3], as well as for generating empirical data to support game theory model predictions [13]. This study uses an ABM to support or refute predictions elicited by game theoretic models on the interplay of genetic relatedness, cooperation and competition *within* and *between* groups of individuals (agents) [11], [1]. Specifically, we empirically test the *tug-of-war* game theory hypothesis that cooperation in eusocial insect colonies is driven by the dynamics of *within-group* cooperation and *between-group* competition [16] rather than genetic relatedness [4]. That is, increased *between-group* competition leads to more *within-group* cooperation and increased group fitness, regardless of genetic relatedness. This study uses an ABM implementation of previous *tug-of-war* game-theoretic models [11], [1], though experimental parameters (table 1) tested differ compared to those in counterpart analytical models [11], [1]. We evolve *cooperative* versus *competitive* behavior (resources shared versus not shared) in resource gathering agents that move about a 2D toroidal environment. We test the impact of three resource distributions on evolving cooperative behavior and agent genetic relatedness.

2 METHODS

Each simulation initialized 1000 agents in random positions with *patchy* or *uniform* resource distributions (100 or 1000 patches, respectively). Resource density was highest at a patch's center and the total resource amount was 10000 units for each resource distribution. Resources were gathered by agents occupying the same coordinates and replenished at 1.0 unit per simulation iteration. Each agent was initialized with random genotypes encoding a feed-forward *Artificial Neural Network* (ANN) controller. Genetic relatedness thus changed as a function of evolving agent genotypes. All agents were initialized with a maximum energy (fitness) of 100 units (table 1). Agents consumed energy via moving and reproducing and increased energy via consuming gathered resources.

Agents moved in the environment using *Brownian motion*, at 10 units each iteration for a lifetime of 100 iterations. As resources were gathered, an agent's cooperative versus competitive behavior was determined by its ANN output: $[0.0, 1.0]$. An output of 0.0 indicated no cooperation and 1.0 indicates maximal cooperation. Each simulation was an evolutionary run of 100000 iterations. Each iteration, all agents concurrently moved, gathered resources at their environment coordinates, output cooperative versus competitive behavior, and reproduced if possible. Selection, recombination and mutation operators were applied per iteration for any two agents were in a *sharing radius* (5 units) and *genetic similarity distance* (0.1). Gathered resources were replenished at 1.0 unit per iteration (table 1). Offspring agents were initialized at random locations.

Preliminary results partially supported tug-of-war game theory since intensity of *within-group cooperation* (resources shared) and *between-group competition* (resources not shared) increases over evolutionary time. Specifically, we observed a bifurcation of the agent population and cooperative behavior over evolutionary time in the *patchy* environment, but not in the *uniform* environment (table 1). Within the first group there was a high degree of cooperation and within the second group there was a high degree of competition (figure 1, left). These groups were defined by agent spatiality, with respect to resource distribution and richness, and intense competition between the two groups. We hypothesize that increased competition, the given spatial distribution and varying

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GECCO '18 Companion, July 15–19, 2018, Kyoto, Japan

ACM ISBN 978-1-4503-5764-7/18/07…$15.00
https://doi.org/10.1145/3205651.3205688

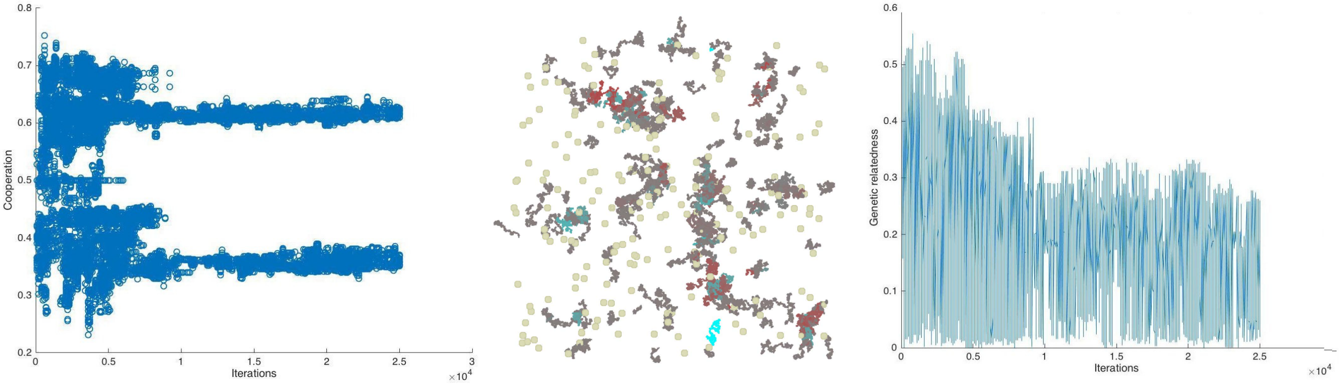

Figure 1: ***Left:*** **Distribution of (normalized) agent outputs (cooperation vs competition) for the patchy environment.** ***Center:*** **Distribution of agent groups on resource patches at iteration 1000 of a typical run. Blue indicates more competitive and red indicates more cooperative. Grey indicates approximately equal cooperation versus competition.** ***Right:*** **Normalized population genetic relatedness over all iterations.**

Parameter	Value
Agent movement / distance / initial (maximum) energy	Brownian motion / 10 units / 1000
Agent movement / Reproduction energy cost	0.1 / 0.1
Agent initial (maximum) energy / Population	100 / 1000
Agent controller / Connection weight range	Feed-forward ANN / [0.0, 1.0]
Environment size / Sharing radius / Genetic similarity distance	1000 x 1000 units / 5 units / 0.1
Simulation iterations / Agent lifetime	100000 / 100
Total resources / Re-grow rate	10000 units / 1.0 per iteration
Resource distributions / Patches	[Patchy, Uniform] / [$Patchy$: 100, $Uniform$: 1000]

Table 1: Agent-Based Model Evolution and Simulation Parameters.

resource density, drove the two emergent competing groups. The first group converged on rich resource patches and were largely cooperative, whereas the second converged on relatively low richness resource patches and were largely competitive (figure 1, center).

Figure 1 presents results for the *patchy* resource distribution (100 patches), where the evolving population splits into cooperative (average ANN output = 0.62) versus a relatively competitive group (average ANN output = 0.35). However, in support of the tug-of-war hypothesis [11], [1], average genetic relatedness did not increase as cooperation increased (figure 1, right). Though, as predicted by previous work [11], [1], average population fitness (energy) increased over evolutionary time (not presented in figure 1).

These results are supported by related *tug-of-war* game theory [14] work in ethology [12], sociology [7] and economics [6], that similarly demonstrate the cooperation versus competition dynamics can drive the evolution of cooperation. That is, such studies predicted resource competition between groups greatly varies with cooperation *within* and *between* groups, where cooperation makes individuals more competitive for resources with other groups [10], thus increasing overall group fitness. This study does not necessarily preclude the role of genetic relatedness in evolving cooperative versus competitive behavior, but rather notes that it as a supposed complementary mechanism given specific environmental and evolutionary conditions [9]. However, the exact relationship between cooperation versus competition and evolutionary and environmental conditions remains the topic of ongoing research.

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