

# Reviews

## *book & software*

### Game Theory, Agent-Based Modeling, And The Evolution Of Social Behavior

**T**he latest volume in the series of Princeton Studies in Complexity is Robert Axelrod's sequel to his influential book, *The Evolution of Cooperation* [1]. The earlier book was an extended commentary on his pioneering computer simulations of cooperation and competition in the iterated Prisoner's Dilemma game, originally reported in 1980 and discussed in a prize-winning journal article [2].

The new book consists of an introduction and seven chapters extending and developing the earlier research in various directions as well as appendices containing useful technical information for researchers in the fields of complexity and agent-based modeling. The chapters are all reprints of previously published material, but they originally appeared in such widely scattered journals and edited volumes that few readers will have seen all of them before. For this volume, Axelrod has included brief introductory comments to each of them, describing the circumstances in which they were written and reactions to them.

Some chapters are only indirectly related to Axelrod's well-known agent-based models of cooperation. In particular, there are two chapters devoted to his more recent landscape theory—according to which, in a group of decision makers who are myopic in their assessments of their own payoffs, the

coalitions that are likely to form are those that minimize strain between the multiple elements of the interacting system. A chapter by Axelrod and D. Scott Bennett shows that landscape theory successfully predicts the alignment of 17 European nations in World War II. A separate chapter by Axelrod, Bennett, and three others shows how the theory predicts the alignment that occurred among nine major computer companies promoting two different UNIX operating system standards in 1988.

**A** major problem with these contributions is that the coalitions predicted by landscape theory turn out to be nothing more than the Nash equilibria of conventional game theory—outcomes in which none of the actors can gain an individual advantage by defecting unilaterally to a different coalition. Nash equilibria provide necessary but insufficient criteria for determinate solutions to games, and game theorists have developed theories of coalition formation that are far more sophisticated and subtle and that go far

beyond mere Nash equilibria [3].

The most interesting chapters are the ones in which Axelrod is on home territory, developing his earlier agent-

based simulation models of the evolution of cooperation. Starting in 1978-79, he had organized two round-robin computer tournaments based on the Prisoner's Dilemma game (Figure 1) to determine empirically which strategies performed best.

The entries were to be submitted as computer programs for making strategic moves, and the winner was to be the program that amassed the most points after each program had been pitted against each other in an iterated sequence of plays. The winner of both tournaments was Tit for Tat (TFT), a simple program that cooperates on the first move and then, on every subsequent move  $k$ , simply copies the other player's choice on move  $k - 1$ .

In his new book, Axelrod gives pride of place to a chapter describing an interesting evolutionary model in which new strategies are repeatedly generated by random mutation of their component elements (each element being a prob-

#### THE COMPLEXITY OF COOPERATION: AGENT-BASED MODELS OF COMPETITION AND COLLABORATION

By Robert Axelrod,  
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ability of cooperating given one of the 64 possible sequences of outcomes over the previous three moves) and by sex (swapping of elements between parent strategies to produce offspring that are different from either parent).

Starting with a population of purely random strategies and repeatedly adding copies of each strategy to the population according to how many points it amasses, Axelrod reports that evolution occurred rapidly toward strategies that “resemble” TFT and that “mirrored what [TFT] would do in similar circumstances” (p. 20).

But resemblance to TFT is surely a subjective and conjectural matter, and there are many strategies that could be said to resemble it behaviorally. Furthermore, it is striking that several of the programs that evolved were evolutionarily fitter than TFT, at least in the environment of the other competing strategies in the population. But the introduction of mutation and sex into the model was both ingenious and illuminating, and this potentially fruitful line of inquiry deserves to be followed up by other researchers.

Axelrod makes no secret of his protective attitude toward TFT. This emerges clearly in a chapter by Jianzhong Wu and Axelrod describing a stochastic evolutionary model in which moves are occasionally perturbed by random errors, as real players' hands occasionally tremble and cause them to make errors in implementing their moves. Martin Nowak and Karl Sigmund had shown that stochastic models behave quite differently from deterministic ones [4,5].

**W**u and Axelrod ran a stochastic evolutionary simulation over 2,000 generations, incorporating the 63 strategies from the second of Axelrod's earlier deterministic tournaments as well as four new ones. The clear evolutionary winner was a contrite version of TFT that normally copies the other player's previous choice but does not do so when the other player is responding to an unintended defection (a random error). Although (standard) TFT

was the clear evolutionary winner in the earlier deterministic model, Wu and Axelrod do not reveal how it performed in the stochastic model. There are reasons, however, to believe it performed comparatively poorly.

In fact, both TFT and contrite TFT suffer from a fatal flaw not explained in this book—namely that neither of them is an evolutionarily stable strategy [6]. It is easy to see that in a population of TFT or contrite TFT players, an unconditionally cooperative mutant would do at least as well as the resident majority players. In a deterministic model, an unconditionally cooperative player would be behaviorally indistinguishable from a TFT or a contrite TFT player and could therefore spread through the population by genetic drift.

The introduction of random noise only makes things worse for TFT, because in a game against another TFT player, a random erroneous defection would have the consequence of a complete breakdown of cooperation, with both players alternating between cooperation and defection from that point on, or until another random accident put things right. However, this problem does not occur with unconditional cooperators, who ignore such errors and therefore outperform TFT players in the evolutionary struggle.

In the win-stay/lose-change strategy, a player's choice on move  $k$  depends on the outcome of move  $k - 1$  in a simple way—a player repeats a choice following a good payoff (either 5 or 3 in Figure 1) and switches to the other option following a bad payoff (1 or 0). In Nowak and Sigmund's stochastic simulation [4], which was much larger and longer than Wu and Axelrod's, the win-stay/lose-change strategy clearly outperformed TFT and many other strategies in terms of evolutionary growth over 10 million generations.

However, the win-stay/lose-change strategy is also not evolutionarily stable, whether moves

are deterministic or stochastic, because in a population of players who used it, an unconditionally defecting (or competitive) mutant would obtain higher payoffs and would reproduce faster than the resident population.

It is doubtful that the Prisoner's Dilemma game can bear the burden of modeling cooperation in all its manifestations. Axelrod's new book includes a few alternative models, but notably absent from all research in this field has been any examination of pure coordination games, which are arguably the most fundamental form of cooperation and are extremely common in everyday life.

**C**onsider the game of Rendezvous, for example, in which two people are accidentally separated while out shopping and face the problem of choosing where to go in the hope of being reunited. It does not matter which location they choose provided they select the same one. However, if they go to different places, they will fail to meet up. Assuming without loss of generality that there are only three reasonable candidate locations, they must play the game shown in Figure 2. In this game, in contrast to the Prisoner's Dilemma, each possible outcome is either good or bad for both players.

People solve pure coordination games with astonishing facility in practice [7,8], and the phenomenon of strategic coordination merits more

FIGURE 1

|          |   | Player II |      |
|----------|---|-----------|------|
|          |   | C         | D    |
| Player I | C | 3, 3      | 0, 5 |
|          | D | 5, 0      | 1, 1 |

Prisoner's Dilemma game. Player I chooses between row C (cooperate) and row D (defect). Simultaneously, Player II chooses between column C and column D. The numbers in the cell corresponding to any pair of choices are the payoffs to Player I and Player II, respectively.

**FIGURE 2**

|          |   | Player II |      |      |
|----------|---|-----------|------|------|
|          |   | A         | B    | C    |
| Player I | A | 1, 1      | 0, 0 | 0, 0 |
|          | B | 0, 0      | 1, 1 | 0, 0 |
|          | C | 0, 0      | 0, 0 | 1, 1 |

A pure coordination game. Each player chooses between locations A, B, and C, hoping that the other player has chosen correspondingly. Their payoffs are positive if they succeed in coordinating, and zero otherwise.

attention than it has received from researchers interested in the evolution of cooperation.

Research into the complexity of co-

*Reviewed by Andrew M. Colman,  
Department of Psychology, University of  
Leicester, Leicester LE1 7RH, UK, e-mail  
amc@leicester.ac.uk.*

operation is still in its infancy, or at most its early childhood, and it is to be hoped that it will mature to include a wider range of models. Axelrod's new book is full of extraordinarily stimulating ideas, and it should be read by anyone interested in complex adaptive systems in general or the evolution of social behavior in particular.

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## The Gazelle, the Wolf and the Peacock's Tail

**W**hy does a gazelle jump in the air, bark, and thump the ground with its forefeet when threatened by a wolf, revealing itself to the predator and wasting time and energy? Why do peacocks have such enormous tails, "fans of glistening feathers, adorned with blue and green 'eyes,'" which seem to be more burdensome than functional?

According to Amotz and Avishag Zahavi, the gazelle's display shows the wolf that it is in good shape and would be likely to escape in a chase that would be costly for both the predator and its prey, and the peacock's tail shows peacocks that he would be quite a good mate choice. The implication of the huge tail is that the peacock is able to find food and avoid predators despite his burden. Only the best gazelles can afford to expend energy before a possible chase and only the best peacocks can afford the

burden of a large tail.

This idea has become known as (Amotz) Zahavi's Handicap Principle [1-3]: Only the best can afford costly handicaps. A cost or handicap is what makes signaling reliable, or honest: If the signal is costly, it may be just too costly for inferior individuals to produce, or, in the context of offspring signaling need to their parents, only for those offspring who really need food is it worth emitting a costly begging signal. An important corollary of this principle is that signals are correlated with the information they convey: For example, the jumping gazelle's signal indicates unambiguously that it is in good shape, and the peacock's tail is a direct indication of the weight the animal can afford to carry.

The animal behavior community was very reluctant to accept that this principle could apply to organisms when, more than 20 years ago, the idea was first

## THE HANDICAP PRINCIPLE

*by Amotz and Avishag Zahavi,  
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proposed. It has now become an accepted argument in animal behavior studies. This popularity may be due in part to Alan Grafen's efforts to formalize the principle [4,5]. Grafen, in one of his articles [4], admits that he did not believe in this idea until he proved formally that it could work. The Zahavis themselves steer clear of formal models, preferring a nonquantitative treatment, except when discussing their (interesting) work on babblers, group-living songbirds of Southern Israel.

They also rely heavily on "anthropo-