The 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 determining 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...
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].

Wu 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 the contrite version of TFT that normally copies the other player’s previous choice but does not 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 puts 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.

Consider 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

<table>
<thead>
<tr>
<th></th>
<th>Player I</th>
<th>Player II</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C )</td>
<td>3, 3</td>
<td>0, 5</td>
</tr>
<tr>
<td>( D )</td>
<td>5, 0</td>
<td>1, 1</td>
</tr>
</tbody>
</table>

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

Research into the complexity of cooperation is still in its infancy, 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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