Biography of Robert Axelrod

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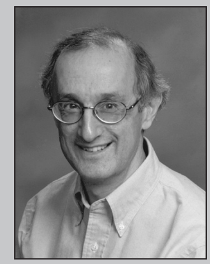
APSA President (2006)

Robert Axelrod

Arthur W. Bromage Distinguished University Professor of Political Science and Public Policy
University of Michigan

Ph.D.
Yale University, 1969



It is a great honor for the American Political Science Association to have Robert Axelrod as our current president. Axelrod combines a devotion to rigorous science as well as a deep concern with policy issues, particularly those of international peace and the threat of nuclear war. His fascination and distress about threats to peace is a major source of the fantastic energy he has brought to his work. Simultaneously, his insistence on rigorous exploration on the processes that enhance cooperation in complex settings has ensured that his theoretical breakthroughs have been widely recognized across the social sciences as well as in biology and computer sciences.

Axelrod received his Ph.D. with distinction from Yale University in 1969 and taught at the University of California, Berkeley, from 1968 to 1974. He moved to the Institute of Public Policy Studies at the University of Michigan in 1974, and has graced that campus since then other than several research leaves. He is now the Arthur W. Bromage Distinguished University Professor of Political Science and Public Policy at the University of Michigan. Axelrod was a fellow at the Center for Advanced Study in the Behavioral Sciences during 1976–1977 and 1981–1982. With William Hamilton, he received the Newcomb Cleveland Prize from the American Association for the Advancement of Science for the most outstanding paper published in *Science* during 1980–1981. He was elected to membership in the American Academy of Arts and Sciences (1985), the National Academy of Sciences (1986), and the American Philosophical Society (2004). Axelrod won the very prestigious MacArthur Prize and was a MacArthur Fellow from 1987 to 1992. The University of Michigan recognized him with their Distinguished Faculty Achievement Award in 1990, with the Russel Lectureship (their highest award to a senior faculty member) in 1992, and the College of Literature Science and the Arts' Excellence in Research Award in 1999.

Axelrod has been an activist concerned about the terrible toll of war since he was a graduate student. He has marshaled those deeply felt concerns as an inner strength, leading him to address the important question of how one avoids destructive conflict. Those of us who read chapter 4, "The Live-and-Let-Live System in Trench Warfare in World War I," in *The Evolution of Cooperation,* will never forget the application of his insights coming from his Prisoner's Dilemma (PD) tournament to the conduct of war on the ground. For his entire career, Axelrod has been concerned with the crucially important issues of our times and how to do the rigorous science and analysis needed to overcome some of these problems.

Few scholars have been able to integrate participation in antiwar protests, computer chess tournaments, working on a campaign staff for a presidential contender, biological evolution, agent-based modeling, and building rigorous methods of policy analysis. Robert Axelrod has a strong interest in all of the above. More important, he has made major contributions to all of them including: (1) the development of a general theory of the emergence of sustainability of cooperation relevant for many repeated settings (Axelrod 1981; 1984; 1997), (2) further analyses relevant to biological evolution (including the evolution of sex) (Axelrod and Hamilton 1981; Hamilton, Axelrod, and Tanese 1990; Axelrod, Hammond, and Grafen 2004; Axelrod, Axelrod, and Pienta 2006), (3) serious applications for the study of international relations (Axelrod 1979; Axelrod and Keohane 1985), (4) the effective development and use of simulation and agent-based modeling (Axtell et al. 1996; Axelrod 1997; 2006), and (5) the development of more rigorous foundations for public policy analysis (Axelrod and Cohen 2000).

Political scientists tend to study tough problems. Many of the situations we study are collective-action problems where individuals are caught in social dilemmas. The outcomes for a group depend on the cooperative input of most participants, while at the same time strong temptations exist to slack off and defect in order to free ride on the efforts of others. Efforts to organize parties to win elections, to build effective teams within the administration of any government, to find solutions to overharvesting of local as well as global resources, to mount an effective but peaceful protest march—all of these are examples of social dilemmas. Game theorists had tackled the analysis of these general problems, and the PD became the generally accepted way of formalizing a two-person social dilemma. Formal theorists repeatedly demonstrated that mutual defection was the predicted outcome of a finitely repeated PD game.

Before Axelrod's 1981 publication of the "Emergence of Cooperation among Egoists" in *APSR,* and his *Science* article with William Hamilton on "The Evolution of Cooperation," there appeared to be no other solution to this depressing theoretical conclusion. After all, this was consistent with the classic description of life in a "state of nature" posited by Thomas Hobbes. Without a Leviathan imposed from the outside—life is nasty, brutish, and short. Whether political scientists followed game-theoretical analysis or Hobbes, they strongly recommended

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that a centralized order was needed to help citizens avoid a war of each against the other and to achieve peaceful productivity. In regard to problems of the environment, Garrett Hardin (1968) eloquently captured the general sense that humans were trapped in an endless "Tragedy of the Commons," unless governments imposed solutions on them. Everyday citizens could not extract themselves from these tragedies without external imposed solutions. Policymakers somewhat naturally believed that they were the essential link to solving all collective-action problems.

In an ingenious effort to use a computer tournament to tackle this question head on, Axelrod asked a set of international experts from economics, mathematics, political science, psychology, and sociology to submit a program that would select cooperation or defection in each of 200 rounds against another program and in light of information about the previous history of play. Fourteen programmed strategies were submitted and a tournament held between each and all of these plus one strategy that was pre-programmed to choose cooperation or defection randomly. The surprisingly simple winner—submitted by the psychologist, Anatol Rapoport—was TIT FOR TAT. TIT FOR TAT starts out with a cooperative move and then simply copies the move that the other player used on the previous round. Axelrod then invited others to contribute to a second tournament in which 62 entries competed. TIT FOR TAT was again the winner of the tournament.

After the second tournament, Axelrod analyzed the core characteristics of Rapoport's winning strategy and of the other programs that achieved high returns. The properties of successful rules included niceness, provocability, and forgiveness. A nice strategy is one that does not choose defection first. Provocability is a response of defection after a defection by the other, and forgiveness is switching back to cooperation after the other stops defecting.

The initial findings from these two tournaments led Axelrod to conduct an ecological analysis and then an evolutionary analysis. In the ecological analysis, he examined the dynamics of an ecology composed of the strategies submitted for the second tournament. Starting with all strategies having an equal proportion of the "population" of agents, Axelrod calculated the weighted average of the scores of each of the rules in the contests with others and created a second generation of agents based on these scores. After some initial rounds, the lowest-scoring programs drop out of the set and the more successful ones "proliferate." TIT FOR TAT again did very well—never losing its slight lead obtained in the initial tournaments. "By the 1000th generation, it was 14.5% of the whole population . . . and was still growing at .05% per generation which was a faster rate than any other rule" (Axelrod 1980, 401).

Then, taking an evolutionary approach, Axelrod asked if an entire population of agents used TIT FOR TAT, whether a single "mutant" agent could do better than the average of all of the others. Basically, he asked three questions concerning an iterated PD setting:

1. Under what conditions is TIT FOR TAT collectively stable?
2. What are the necessary and sufficient conditions for any strategy to be collectively stable?
3. If virtually everyone is following a strategy of unconditional defection, when can cooperation emerge from a small cluster of newcomers who introduce cooperation based on reciprocity? (Axelrod 1981, 311)

In his formal analysis of these questions, Axelrod established the importance of the time horizon of agents and of their clustering in interaction space. If all agents in a population are cooperating as a result of TIT FOR TAT reciprocity, an agent using a different strategy cannot be successful unless the agent's discount rate is relatively low. In other words, reciprocity survives when agents expect to be interacting with one another over a sufficiently long time horizon and collapses if the expectation of future rounds is small. Further, even in a Hobbesian world of everyone defecting, a small cluster of reciprocating mutants, who initially interact more with one another than with others, can successfully survive and invade a population of uncooperative agents. The significance of these findings is repeatedly illustrated by coalitions of politicians, national leaders, and business firms that are successful in sustaining cooperation for some time—but, disintegrate rapidly when the time horizon is shortened. As mentioned above, this pathbreaking work has been broadly applied in the political world as well as to important biological processes.

While the PD game has been—and continues to be—an important exemplar for the study of the emergence and sustainability of cooperation in human and nonhuman settings, Axelrod has moved from this relatively simple two-person interaction to examine diverse settings with large numbers of agents interacting in complex systems. In their book, *Harnessing Complexity: Organizational Implications of a Scientific Frontier,* Axelrod and Cohen (2000) ask how humans can actively cope with complex systems rather than their many unsuccessful efforts to try to eliminate complexity. They make a very useful distinction between complicated and complex systems. Complicated systems have many interacting parts. Given various contemporary statistical techniques, it is relatively easy today to achieve reliable predictions of the outcomes produced by a large number of independent components. Complex systems, on the other hand, include nonlinear interactions among components that in turn heavily influence their interactions so that the predictability of system outcomes is extremely difficult. The concept of *emergent properties* applies to complex systems—where system outcomes are not the simple addition of individual actions.

> The conjunction of a few small events can produce a big effect if their impacts multiply rather than add. The overall effect of events can be unforeseeable if their consequences diffuse unevenly via the interaction patterns within the system. In such worlds, current events can dramatically change the probabilities of many future events. A collection of complex systems is therefore a kind of dynamical zoo, a 'wonder cabinet' of processes that change (or resist change) in patterns wildly unlike the smoothly additive changes of their simpler cousins. (Axelrod and Cohen 2000, 14)

Among the examples of complex systems they illustrate are: military personnel systems, Linux software development, combating the AIDS virus, using tags in an iterated PD game, and failures in contemporary information systems.

They focus on the concept of "harnessing" complexity because it is never possible to control a complex adaptive system entirely. Someone in that system is likely to come up with a new strategy that interacts in such a manner that earlier efforts to control are useless, or worse, destructive. They develop a very useful framework that stresses the importance of understanding variations, interactions, and selection. In light of well-developed analysis and the presentation of evocative examples, they make a set of useful recommendations for those interested in harnessing complex systems. These include:

- Arrange organization routines to generate a good balance between exploration and exploitation (p. 156).
- Link processes that generate extreme variation to processes that select with few mistakes in the attribution of credit (p. 156).

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- Build networks of reciprocal interaction that foster trust and cooperation (p. 156).
- Assess strategies in light of how their consequences can spread (p. 157).
- Promote effective neighborhoods (p. 157).
- Do not sow large failures when reaping small efficiencies (p. 157).
- Use social activity to support the growth and spread of valued criteria (p. 157).
- Look for shorter-term, finer-grained measures of success that can usefully stand in for longer-run, broader goals (p. 158).

These eight recommendations differ radically from much of policy analysis that stresses the need for top-down control by leaders who figure out the "best" solution for the long run and impose it on the rest of us. This represents a solid foundation for continued research on complex adaptive systems.

In general, as political scientists, we need to learn from Axelrod's work that political systems—whether we focus at an international, national, regional, or local scale—are complex adaptive systems. Key aspects of the structure of these systems are created by humans as they develop rules, norms, and strategies in trying to do as well as they can over time. While it is possible to evolve mutually productive structures, these are fragile human constructions built on common understanding and shared preferences. Physical constraints can collapse due to external stress, but are relatively robust to changes in knowledge and values. Structures created by shared knowledge and norms can rapidly collapse if some actors develop exploitative strategies and are able to enter and seek their own good without effective and early detection.

Axelrod has also been an inspiration and a genuine colleague to many scholars within our discipline and across many others. He believes in being "nice" in the sense of extending his own efforts to cooperate without holding back, but he also expects reciprocity in the joint development of rigorous science.

One of his major collaborative efforts relates to the famous "BACH" group that has met frequently at the University of Michigan since the late 1970s. The initial members of this group were Arthur Burks, a colleague of von Neumann in the initial development of computers and the thesis advisor for John Holland, Bob Axelrod, Michael Cohen, who—besides his work with Axelrod—is known to political scientists by his work on the "garbage can" theory of organization, and John Holland, whose pioneering work on complex adaptive systems was influential in Axelrod's approach to modeling. Over the years, BACH has included other major Michigan scholars with a core interest in adaptation in complex adaptive systems including William Hamilton, Scott Page, Rick Riolo, and Carl Simon. They were joined for shorter time periods by Stephanie Forrest, Douglas Hofstadter, Melanie Mitchell, Michael Savageau, and Rieiko Tanese. BACH met every other week, and participants have told me that everyone took the discussions and "homework assignments" of substantial readings between meetings very seriously.[1] Scholars at other universities interested in interdisciplinary work should take note of this important method for serious engagement.

Colleagues from many disciplines have written to me about their deeply felt views about Axelrod as a collaborator and friend. A few of the comments I have received from others include:

> From Rick Riolo: "One thing that is clear throughout Bob's work is the drive for very simple models, carefully explored but also well thought out, both with respect to the models workings but also with respect to how the model is related to and representative of the *fundamental* aspects of the system/problem he was interested in. KISS (keep it simple, stupid) is a constant refrain from Bob. But he also worked very hard to not throw out the baby with the bathwater, i.e., to have the simple models capture the essence of the problem he was interested in exploring at any given time."

> From Leigh Tesfatsion: "I first encountered Bob Axelrod's research on the evolution of cooperation in computer tournaments through one of Douglas Hofstadter's "Metamagical Themas" columns in *Scientific American* (May 1983), and it was a career-changing event for me. It struck me then, as now, that this was a totally new way to practice social science, a way permitting agents represented in social science models to breathe and live within their computationally constructed worlds as real people do in theirs. Bob's work, and the work of Thomas C. Schelling, led to the birth of agent-based computational social science."

> From Michael Cohen: "Working with Bob is the most sustained collaboration of my career, and it has been fantastically rewarding. In every collaboration, he stimulated deep new insights and in every project, he pushed my work to a higher standard. He has an uncanny ability to grasp and formalize the inner logic of a social process. The research I have done without him bears his influence almost as much as the dozen or so pieces we have co-authored. Bob is an exceedingly forthright research partner. When an idea or a draft won't stand up, he says so calmly, but firmly—and he always has solid reasons. If you can muster even more compelling arguments in response, he will readily accept them. But he won't concede until you and he have converged on an air-tight analysis."

> From Robert Keohane: "In my recollection, what really stands out about Bob Axelrod stylistically as a co-author is the series of sharp insights that he came up with—the ability to get to the essence of an issue in only a few words. Substantively, at least in the case of our article, these insights derived, I think, from his orientation as an experimental scientist—largely in the computer laboratory—as well as theorist and conceptualizer. He was therefore able to adapt the insights of game theory to behavioral science and to examine strategies as 'experimental, trial-and-error efforts to improve the current situation based upon recent experience' rather than as 'examples of forward-looking rationality' (our article, p. 251). Bob combines three attributes not usually combined: (1) a fine logical mind with appropriate mathematical abilities; (2) creativity and sophistication as an experimental scientist; and (3) interest in knowledge about historical events and processes. The insights that have emerged from this combination of attributes are truly impressive, and have made an immense impact on our understanding of cooperation and discord."

Robert Axelrod represents one of the truly innovative, rigorous, and collegial social scientists in our midst during the fascinating era of major change occurring around us, both in regard to peace and war and related to environmental processes. We can all learn from his excellent scholarship and collegiality. I eagerly look forward to his continuing contributions to political science and almost all other disciplines.

Notes

* I wish to thank Michael Cohen, Robert Keohane, Rick Riolo, Robert Putnam, Carl Simon, and Leigh Tesfatsion for their input and comments on this biographical essay and Nicole Todd and Patty Lezotte for their help in preparing this essay.

1. The importance of the group to the development of Axelrod's, as well as his colleagues', thinking is illustrated by the dedication of *Harnessing Complexity* by Axelrod and Cohen to the BACH group.

Selected Publications

Axelrod, Robert. 1972. *Framework for a General Theory of Cognition and Choice.* Berkeley: University of California Press.

———. 1967. "The Structure of Public Opinion on Policy Issues." *Public Opinion Quarterly* 31 (spring): 51–60.

———. 1972. "Where the Votes Come From: An Analysis of Electoral Coalitions, 1952–1968." *American Political Science Review* 66 (March): 11–20.

———. 1973. "Schema Theory: An Information Processing Model of Perception and Cognition." *American Political Science Review* 67 (December): 1248–66.

———. 1977. "Argumentation in Foreign Policy Settings: Britain in 1918, Munich in 1938 and Japan in 1970." *Journal of Conflict Resolution* 21 (December): 727–56.

———. 1979. "The Rational Timing of Surprise." *World Politics* 31 (January): 228–46.

———. 1980. "More Effective Choice in the Prisoner's Dilemma." *Journal of Conflict Resolution* 24 (September): 379–403.

———. 1981. "The Emergence of Cooperation among Egoists." *American Political Science Review* 75 (June): 306–18.

———. 1984. *The Evolution of Cooperation.* New York: Basic Books.

———. 1986. "An Evolutionary Approach to Norms." *American Political Science Review* 80 (December): 1095–111.

———. 1987. "The Evolution of Strategies in the Iterated Prisoner's Dilemma." In *Genetic Algorithms and Simulated Annealing,* ed. Lawrence Davis. London: Pitman, and Los Altos, CA: Morgan Kaufman, 32–41.

———, ed. 1989. *Perspectives on Deterrence.* New York: Oxford.

———. 1995. "A Model of the Emergence of New Political Actors." In *Artificial Societies: The Computer Simulation of Social Life,* ed. Nigel Gilbert and Rosaria Conte. London: University College Press, 19–39.

———. 1997. "Advancing the Art of Simulation in the Social Sciences." In *Simulating Social Phenomena,* ed. Rosaria Conte, Rainer Hegselmann, and Pietro Terna. Berlin: Springer, 21–40.

———. 2006. "Agent-Based Modeling as a Bridge between Disciplines." In *Handbook of Computational Economics, Vol. 2: Agent-Based Computational Economics,* ed. Leigh Tesfatsion and Kenneth Judd. New York: North-Holland, 1565–84.

Axelrod, Robert, David E. Axelrod, and Kenneth J. Pienta. 2006. "Evolution of Cooperation among Tumor Cells." *Proceedings of the National Academy of Sciences* 103 (36): 13474–9.

Axelrod, Robert, and Michael D. Cohen. 2000. *Harnessing Complexity: Organizational Implications of a Scientific Frontier.* New York: Free Press.

Axelrod, Robert, and Douglas Dion. 1988. "The Further Evolution of Cooperation." *Science* 242 (December 9): 1385–90.

Axelrod, Robert, and William Hamilton. 1981. "The Evolution of Cooperation." *Science* 211 (March 27): 1390–6.

Axelrod, Robert, Ross A. Hammond, and Alan Grafen. 2004. "Altruism via Kin-Selection Strategies That Rely on Arbitrary Tabs with Which They Coevolve." *Evolution* 58: 1833–8.

Axelrod, Robert, and Robert O. Keohane. 1985. "Achieving Cooperation under Anarchy: Strategies and Institutions." *World Politics* 38 (October): 226–54.

Axelrod, Robert, and Leigh Tesfatsion. 2006. "Guide for Newcomers to Agent-Based Modeling in the Social Sciences." In *Handbook of Computational Economics, Vol. 2: Agent-Based Computational Economics,* ed. Leigh Tesfatsion and Kenneth Judd. New York: North-Holland, 1647–59.

Axtell, Robert, Robert Axelrod, Joshua Epstein, and Michael D. Cohen. 1996. "Aligning Simulation Models: A Case Study and Results." *Computational and Mathematical Organization Theory* 1: 123–41.

Cohen, Michael D., and Robert Axelrod. 1984. "Coping with Complexity: The Adaptive Value of Changing Utility." *American Economic Review* 74 (March): 30–42.

———. 1998. "Complexity and Adaptation in Community Information Systems: Implications for Design." In *Community Computing and Support Systems,* ed. Toru Ishida. Berlin: Springer Verlag, 16–42.

Cohen, Michael D., Rick L. Riolo, and Robert Axelrod. 2001. "The Role of Social Structure in the Maintenance of Cooperative Regimes." *Rationality and Society* 13: 5–32.

Hamilton, William, Robert Axelrod, and Reiko Tanese. 1990. "Sexual Reproduction as an Adaptation to Resist Parasites." *Proceedings of the National Academy of Sciences* 87 (May): 3566–73.

Hardin, Garrett. 1968. "The Tragedy of the Commons." *Science* 162: 1243–8.

Riolo, Rick L., Robert Axelrod, and Michael D. Cohen. 2005. "Tags, Interaction Patterns and the Evolution of Cooperation." In *Perspectives on Adaptation in Natural and Artificial Systems,* ed. Lashon Booker, Stephanie Forrest, Melanie Mitchell, and Rick Riolo. New York: Oxford University Press, 239–52.

Riolo, Rick L., Michael D. Cohen, and Robert Axelrod. 2001. "Evolution of Cooperation without Reciprocity." *Nature* 414 (November 22): 441–3.

Zimmerman, William, and Robert Axelrod. 1981. "The 'Lessons' of Vietnam and Soviet Foreign Policy." *World Politics* 34 (October): 1–24.

New APSA Council Members Elected

Eight new members of the APSA Council have been elected in APSA's fourth contested election in recent years. The new Council members are: Lisa Baldez, Dartmouth College; Susan R. Burgess, Ohio University; Dennis Chong, Northwestern University; Michael W. Doyle, Columbia University; Kerry L. Haynie, Duke University; Arthur Lupia, University of Michigan; Anna Sampaio, University of Colorado, Denver; and Melissa S. Williams, University of Toronto. André Blais, Université de Montréal, was not elected. Under APSA election rules, the APSA Nominating Committee proposes one name per open seat and additional nominations, sponsored by at least 10 members, may be made from the membership. This year, Susan Burgess, Ohio University, was nominated from the membership and was elected. The election was conducted by electronic ballot, with a 31% turnout—similar to other recent APSA elections. Detailed results can be found at http://apsanet.org/section_710.cfm.

The new council members take office immediately. These Council members' terms have correspondingly wrapped up: Lisa Anderson, Columbia University; Andrew L. Aoki, Augsburg College; Neta C. Crawford, Boston University; James L Gibson, Washington University, St. Louis; Pei-te Lien, University of Utah; Harvey C. Mansfield, Jr., Harvard University; Rogers M. Smith, University of Pennsylvania; David Vogel, University of California, Berkeley; and Aili Mari Tripp, University of Wisconsin, Madison. APSA thanks them for their commitment and service to the discipline. The full APSA officer roster can be found on page iv of this and every issue of *PS*.

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