Patterns of Weapon Development

Innovation and the Arms Race. How the United States and the Soviet Union Develop New Military Technologies. MATTHEW EVANGELISTA. Cornell University Press, Ithaca, NY, 1988. xvi, 300 pp. $32.95. Cornell Studies in Security Affairs.

This book is about a puzzle: if each weapons innovation by one superpower provokes countermeasures and imitations by the other, so that no great advantage is gained by the innovator, what deeper sociopolitical dynamic sustains this apparently fruitless technological arms race? Answers offered by analysts in the past have fallen broadly into two clusters—those that emphasize external provocations, such as action-reaction cycles or the incessant demands of balance-of-power politics, and those that emphasize internal factors, such as the self-serving interests of military and scientific bureaucracies. Evangelista argues that past answers are not wrong so much as they are partial, illuminating only a segment of the puzzle at best. The proper approach is to understand that weapons innovation proceeds by stages, each shaped by a different set of actors and their institutional settings. Moreover, because the political, social, and economic settings of the superpowers are radically different, their innovation processes proceed by different stages. Hence, any comprehensive answer to the puzzle "Why do they innovate?" must be baroque indeed if it is to account for the welter of weapons innovations adopted by both superpowers during four postwar decades.

Understandably, Evangelista sets out a more limited ambition for his book: to examine only a small set of innovations that "entailed major restructuring of military organizations, significant changes in strategy, or both"—a dozen new weapons ranging from the jet interceptor through Star Wars. One can quibble about the list, but no matter. For although brief but useful comments are made about most weapons on the list, the book is really an intensive case study of only one—tactical nuclear weapons—with a focus on what might best be called the politics of technology exploitation. (The actual technical achievements that made small nuclear warheads feasible, and their origins, are mentioned only in passing.) Obviously there is only so much one can say about the weapons innovation process in general on the basis of one case study drawn from the 1950s, and only so much one can say at all about the internal politics of Soviet weapons decisions. Nevertheless, Evangelista offers a provocative study and a fine scholarly history of one episode in the nuclear age.

Drawing on the literature of organizational theory, Evangelista highlights five structural characteristics that affect innovativeness: innovation is encouraged by the professional complexity, or diversity, of organizations, by their interconnectedness through interpersonal networks, and by the degree of organizational slack that makes uncommitted resources available for new projects; innovation is inhibited by the centralization of power in organizations and by formalization, which imposes stifling rules and procedures for members to follow. The United States, with its individualistic society, its free market, entrepreneurial economy, and democratic political system, is highly innovative. In contrast, the centralization and rigidity of the Soviet political and economic systems impede innovation, although they may enhance implementation of change once central decisions have been made.

Given these differences, the stages of innovation also diverge. New ideas bubble up from the bottom in the United States, and each stage entails the building of larger constituencies and consensus behind an innovation, until at last high-level endorsement from top leaders is secured. Because the process begins at the bottom, the question of why the United States develops new weapons is best answered by analysis of domestic rather than international factors. Only at the latter stages of constituency-building do external threats play a prominent role. In the U.S.S.R., initiative at the bottom is stifled and subordinated to "the plan," so the impetus for change must come from the top leadership, characteristically in response to an external threat. Consequently, Soviet weapons innovation is generally provoked by international events, such as a weapons innovation or change of strategy by the United States, not by domestic factors.

Evangelista then applies his concept of stages to a long case study of tactical nuclear weapons. His account of the U.S. decision to adopt small nuclear weapons is rich in the sort of detail that access to previously classified archives now makes possible. As Evangelista tells it, the close personal ties among nuclear scientists and military officers fostered by the Manhattan experience, the overlapping membership among ostensibly separate nuclear and weapons organizations and laboratories, and the loose lines of authority among advisory and regulatory panels enabled scientists such as Oppenheimer to prod the Atomic Energy Commission into ordering development of tactical nuclear warheads in 1948–49. The provocation was not a Soviet advancement, since the first Soviet nuclear test had not yet occurred, or a clamor from the military services, which remained largely indifferent to a weapon designed specifically for tactical use until the Korean War. Moral concerns over the strategic use of nuclear weapons—and especially H-bombs—on cities led the small group of advocates to promote the tactical alternative. Only later did the United States study whether definable Soviet threats existed against which tactical nuclear weapons might actually be used.

Evangelista also discerns his expected pattern in the Soviet case, building upon imaginative (though sometimes highly speculative) use of Soviet secondary literature, accounts by emigrés, and declassified U.S. intelligence estimates. Stalin's order that only the select few were even to discuss nuclear weapons exemplifies the stifling character of Soviet conditions at the time. A directive from the Ministry of Defense was required after Stalin's death in 1953 before the students at the General Staff Academy were allowed to study the military implications of nuclear technology. By then, the United States had already deployed tactical nuclear weapons in Europe. Innovation did not vanish in Stalin's system: a series of low-yield nuclear devices were tested in August 1953; the Soviet military had gotten approval to develop an atomic cannon perhaps as early as 1950; development of tactical nuclear ballistic missiles was authorized in 1952. Yet to the end Stalin held a monopoly on all military decisions. Freer discussion and debate became possible after his death. But Evangelista concludes (relying heavily on Khrushchev's accounts) that the grip of top leadership on the most minute aspects of military innovation persists to such a degree that the answer to why the Soviets innovate must still be found in external events that intrude at the top, not in ideas that rise from the bottom of the Soviet system.

What are we to make of all this? As a framework for analysis, Evangelista's stages of innovation may be overly formal and not always discernible even in his single case study, but they embody an important insight missing from competing explanations—that the politics of an issue changes as the issue matures, and our analysis must be equally dynamic. Moreover, it is worth being reminded that just as an army fights like it trains, a society innovates like it lives. If Evangelista is correct, the reactive pattern of Soviet weapons innovation in past decades has little to do with the general backwardness of the Soviet economy, and the Soviets will continue to be technological "followers" as long as they cling to highly centralized and autocratic institutions, regardless of how prosperous the Soviet economy may become. As a policy prescription, Evangelista argues that his study points toward a grand arms-control compromise. Since the U.S. strength is innovation and the Soviet forte is imitation and production in large quantities, the compromise would trade qualitative limits for quantitative reductions. This might well work if Soviet leaders also believe they are destined by their system to be technological laggards forever. That seems to be precisely what Mikhail Gorbachev fears.

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Neural Network Programs

Explorations in Parallel Distributed Processing. A Handbook of Models, Programs, and Exercises. JAMES L. MCCLELLAN and DAVID E. RUMELHART. MIT Press, Cambridge, MA, 1988. xii, 344 pp., illus., + 2 IBM PC-compatible diskettes, in pocket. Spiral bound, $29.95. Computational Models of Cognition and Perception.

This publication, produced by one of the leading neural network groups and illustrating much of their work, is a landmark. The package consists of a book and a collection of computer programs that implement many of the models discussed in the popular two-volume work *Parallel Distributed Processing* produced by the same authors and other members of the "PDP group." [For a review see *Science* **236**, 992 (1987).] The book contains an introduction to the programs, as well as exercises that illustrate important concepts about neural networks. These programs illustrate many of the popular neural network circuits, such as pattern association models, constraint satisfaction, and interactive activation and competition. A variety of learning rules is provided for some of the models, including the delta rule, back-propagation, and Hebbian learning.

For learning about neural network models, there is no substitute for experience running actual programs. The programs in this package are "user friendly" and were tested in classrooms of Carnegie-Mellon University and the University of California at San Diego. Each program contains menu-driven commands that are relatively consistent throughout the various programs. For example, the user can stimulate or inhibit different inputs to the network, as well as manipulate the strength of individual synapses. Each program can be changed in several ways. For example, the association network model includes options for different learning rules such as the delta rule or Hebbian learning, as well as various "activation" functions for determining firing properties of postsynaptic neurons. For the true enthusiasts, the source code in the programming language "C" is provided, allowing the user to make changes in any feature of the model. The inner workings of the programs are documented well enough to make this a realistic option.

The screen displays are not of the lavish quality typically found in commercial software. However, their simplicity has advantages, since the programs remain straightforward for the user to modify.

The book is not easy reading. It is hard to understand a simulation without reading the description of that network in *Parallel Distributed Processing*. The organization of the material is also difficult for readers. For each simulation, the numerous program features are described in detail in the first half of a chapter. In the second half of the chapter, there is a set of exercises that show step by step the capabilities of the network, and detailed thoughtful answers are given. Unfortunately, these exercises assume that the reader has gotten through the first half of the chapter and stored most of the information in memory. A more bite-sized tutorial approach would have been easier for those of us without photographic memories.

Not surprisingly, the book reflects the interests and opinions of its authors. Non-neurophysiologists should be aware that several of the central assumptions of these models could turn out to be dead ends for neural network research. In particular, there is emphasis in these models on the linear addition or subtraction of the "weights" of synaptic inputs that converge onto each neuron. However, we have known for decades that synaptic weights for biological neurons do not summate in the linear fashion one uses when adding resistances "in series." Instead, they summate as conductances connected in parallel. This is formalized in the Goldman equation or the parallel battery equation, well known to neurophysiologists but unfortunately neglected by many computer modelers. Rather than modeling excitation of a neuron as addition and inhibition as subtraction (as is done in the models of the PDP group), one can approximate the Goldman equation using addition to model the sodium-mediated excitation and division to model the shunting chloride-mediated inhibition. Some neural network programs, such as the medical expert system I have developed and the somatosensory models of Gerald Edelman's group, employ such "biological" nonlinearities, and these features confer stability and reasonableness on the performance of the network. Readers should be encouraged to modify the programs in this book to experiment with such nonlinearities. As Marvin Minsky and Seymour Papert demonstrated in their classic book *Perceptrons*, linear circuits are severely limited in their computational power. Computers allow us to explore beyond the territory accessible to linear algebra. It will be ironic if research on parallel processing is slowed down because of the use of serial summation of synaptic weights instead of the more powerful parallel summation.

To a neuroscientist, a second concern about methodology relates to the method of distributing "error signals" to "hidden" layers of neurons, a method known as back-propagation. Neuroscientists, who are able to "peek at the answers" to questions about biological neural networks, find little evidence for the huge network of specific back-connections needed to implement back-propagation as a common method of learning in the nervous system. Another basic problem with back-propagation is that there is no "teacher" signal for most forms of biological learning. Neuroscientists are much more excited about Hebbian learning, particularly since a molecular mechanism for such learning could exist in the voltage- and transmitter-dependence of the NMDA receptor (a ubiquitous type of neurotransmitter receptor sensitive to glutamate). Although back-propagation may be useful for setting synaptic weights in certain computer programs, readers are encouraged to focus on Hebbian learning and experiment with learning rules likely to exist in successful neural networks such as our brains. The neural network programs of Ralph Linsker and of Gerald Edelman's group are good examples of such work with Hebbian learning.

Despite such reservations, this package is extremely valuable because it includes so many different neural network models. Nature took a long time to find its favorite neural networks; one hopes it will take us less time to find successful neural networks for computers. A book like this will help by spreading ideas and source code to thou-