Cybernetics

Knowledge domains in Engineering systems (fall, 2000)

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1. Introduction

Cybernetics is the study of human/machine interaction guided by the principle that numerous different types of systems can be studied according to principles of feedback, control, and communications. The field has a quantitative component, inherited from feedback control and information theory, but is primary a qualitative, analytical tool – one might even say a philosophy of technology. Cybernetics is characterized by a tendency to universalize the notion of feedback, seeing it as the underlying principle of the technological world. Closely related variants include: information theory, human factors engineering, control theory, systems theory. Norbert Wiener founded the field with his in his 1948 book Cybernetics: or Control and Communication in the Animal and the Machine which articulated the marriage of communication and control for a generation of engineers, systems theorists, and technical enthusiasts of varied stripes. Since then cybernetics has had a significant intellectual impact on a wide variety of disciplines across the globe, although as a discipline itself it remains unclear and fragmented, and has essentially faded from prominence in the United States, although it remains more influential in Europe. Still, it had great influence on numerous other of the systems sciences, including some of the most prominent today, and it helped initiate a discourse and a worldview that is deeply embedded in today's technological culture.

2. History and Origins

At the beginning of World War II, when Vannevar Bush initiated the National Defense Research Committee (NDRC) in 1940, he organized it into separate divisions, one of which was devoted to "fire control." This was the problem of tracking targets (optically and then with radar), predicting their future positions, calculating ballistics, and directing guns to fire to destroy the targets. The most pressing and important form of the problem was for antiaircraft, and numerous companies and laboratories had worked on it, with little success, for the previous ten years. The NDRC let contracts to university-based researchers to study the problem, one of which went to Norbert Wiener. Wiener, a brilliant but eccentric MIT mathematician, already had a successful career in which he made numerous contributions to mathematics particularly to fields like harmonic (Fourier) analysis and stochastic processes (Wiener had also served as a mathematical mentor to Bush in his early days as an engineering professor). For the NDRC, Wiener attacked the problem of predicting the flight paths of aircraft taking evasive action, which he reformulated as predicting the future value of a pseudo-random function based on its statistical history (its autocorrelation). Wiener’s work proved to have little application to wartime problems (it generated ponderous, complex solutions) but it did lead him to produce an important paper (“Interpolation, Extrapolation, and Smoothing of Stationary Time Series”) that paved the way for the modern theories of optimal estimation and signal processing. In this paper, Wiener built on his own work in harmonic analysis and operational calculus, while constructing a general theory of smoothing and predicting “time series” — any problem (including economic and policy questions) expressed as a discrete series of data. This generalization, from a specific human/machine problem to any aspect of the world that can be expressed as time-series data, presented an early glimpse of the strategies that would define cybernetics.

Despite its intellectual importance, Wiener’s time series work had little immediate application to the war effort. Frustrated by this lack of immediate practical utility, Wiener began (indeed he was forced) to look outside military matters. Wiener had a long time interest in physiology, and he and collaborators physician Arturo Rosenblueth and neurologist Walter Cannon began addressing physiological and neurological feedback. In the spring of 1942 Wiener’s papers first mention the idea of the human operator as a feedback element, as an integral part of the system (an idea that control engineers were already exploring in their own work). Wiener placed his understanding of the servomechanical nature of the mechanisms of control and communication in both humans and machines at the core of cybernetics, and his program sought to extend that understanding to biological, physiological, and social systems.

In doing so, Wiener elevated his thinking on control and communication from the specific level of muscles and nerves to a universal level, creating nothing less than a moral philosophy of technology, and one that enjoyed enthusiastic response from scientists and the public. Wiener's efforts to bring his model to broad communities of physiologists, physicians, and social scientists, are well documented. Under his direction, an informal group called the "Teleological Society," began meeting in the 1940s, and it was later formalized in a series of conferences supported by the Macy Foundation (known as the “Macy Conferences”). Here a group of theorists and thinkers explored the implications of Wiener's ideas well beyond statistical control theory. Biology, physiology, anthropology, even philosophy and psychology, they was argued, could all be understood according to the basic principles of systems, feedback, and the transmission of information. The new technology of digital computing also created a great deal of excitement, and the conferences addressed analogies of those machines with human minds. Attendees included mathematicians like John von Neumann and Claude Shannon, nuerologist Warren MuCulloch, engineer Heinz von Foerster, and anthropologists Gregory Bateson and Margaret Mead.

3. The Approach

Wiener articulated his new approach in his 1948 book Cybernetics. He created the term from the Greek word for "steersman," to describe the principle governing or directing a technology or system. Wiener claimed to have been the first to unify control theory with communications theory, but that had occurred among engineers several years before during the war. Nevertheless, he did clearly articulate the marriage and explore its implications for philosophy, psychology, and mathematics. In Cybernetics he argued for what we now see as classic "systems approach" – everything can be described as a system, broken down into "black box" components with inputs and outputs, and then understood using the ideas of information flow, noise, feedback, stability, and so on. Wiener brought together this engineering-oriented stance, with what physiologists like Walter Canon had developed in the prior decades under the headings of "homeostasis" and their studies of neuro-muscular behavior. He also made an analogy between the behavior of the new digital computers and that of the human nervous system, and it was such technological/biological analogies that cybernetics would depend. Much of Wiener's own work in cybernetics focused on identifying servomechanism-like behaviors in the nervous systems of animals (suggesting, for example, that nervous systems have a "scanning time" similar to that found in televisions).

Wiener's book generated enthusiastic response, and propelled Wiener to the status of a public intellectual – debating the future of technology and the possibilities of automation, computers, and robotics in a post-war America slightly anxious about their implications. The original Cybernetics was filled with obscure and fairly irrelevant mathematics, which intimidated lay readers, so he followed the book with a popularized account, The Human Use of Human

Beings, which sold well in the United States. In this version, Wiener connected his ideas to concerns about nuclear war and the frightening possibilities of a world dominated by machinery and computers. Hiroshima and Nagasaki had turned Wiener against the military, an ironic turn given that the most concrete expressions of cybernetics appeared in guided missiles and command and control systems. In fact, in American popular culture, cybernetics came to stand for the Cold War mindset that placed computers and automated decision making at the center of military power. Cybernetics also proved so flexible, however, addressing everything from neuron behavior to social systems, from digital computers to analytic philosophy, from visual perception to technological unemployment, that critics began to question what exactly this "new science" was supposed to accomplish. Wiener's work was elaborated and taken up by a number of other thinkers, some of whom did put it on a more rigorous, focused foundation. These included Heinz von Forester, W. Ross Ashby, and Ludwig von Bertalannfy, although these refinements tended to transform cybernetics into other entities, most notably General Systems Theory, which took pains to distinguish themselves from Wiener's original.

Cybernetics was greeted enthusiastically outside the United States as well, although again with varying results. In France, for example, where Wiener's book was originally published, philosophers and scientists greeted quickly began debating Wiener's ideas. Some wondered if, in the development of cybernetics, there were not some "improper associations," "fuzzy meaning" and constitution of "myths." Yet the grand, unifying ambitions of cybernetics had great appeal in post-war France, especially as it carried with it the prestigious (and militarily useful) information theory, computer science, and systems engineering from the United States. In the Soviet Union, cybernetic ideas were at first rejected as "bourgeois science" created to bring all science under capitalist control. After Stalin's death, however, in the late 1950s Soviet scientists also took up the mantle of cybernetics. Russian mathematician A.N.Kolmogorov had independently formulated Wiener's work on time series data, so Russians could claim it as their own. Marxism, after all, was seen as the "scientific" approach to organizing society, and cybernetics promised to bring the physical, engineering, and social sciences all under a similar unifying framework. In contrast to the United States, where cybernetics has had an ambiguous legacy (superceded by later formulations like AI and computer science) cybernetics enjoyed a long career in Europe and especially the Soviet Union, where some universities still maintain departments and professorships in the field. Englishman Stafford Beer applied cybernetic ideas to the management of the Chilean economy in the 1970s, and Chilean's Maturana and Varela built on cybernetics with their notion of "auto-poiesis" in an organism (an idea similar to what we would today call emergence).

4. Evaluation and Legacy

Cybernetics, the book as well as the movement, articulated a vision of changing human/machine analogies which resonated with a broad audience. Its ramifications in the United States and abroad were significant, if as much for the overarching vision as for any concrete results. The very malleability, however, of the human-machine analogy and its underlying mathematics, would both undermine cybernetics and be a source of its power. Today, some see cybernetics as the progenitor of fields like Artificial Intelligence, Systems Theory, and Computer Science. This is true to some degree, although each of those fields also had other roots as well. Ultimately, cybernetics represented more of a philosophy of technology than a discipline: it was more a way of seeing and approaching communications, systems, control, and human-machine interaction than a specific set of technical principles and practices that engineers could use to analyze or design systems or machines. In that, it also always competed with approaches like Systems Dynamics, Systems Engineering, and Systems Analysis, each of which had a more narrow scope and hence more concrete practices and results. To this day, the IEEE's "Systems, Man and Cybernetics" society lumps a number of these approaches together under a professional heading and a journal of the same name. Today, neither MIT nor hardly any American universities have cybernetics departments, nor is "cybernetician" seen as a professional occupation.

Still, cybernetics certainly influenced generations of engineers, who embraced its ideas and spent the 50s and 60s embodying cybernetic ideas in computing, the space program, and medicine (one observer called the moon landings "the ultimate cybernetic experience"). We can also see its effects in fields like general systems theory, systems engineering. In the 1960s and 70s, cybernetics-inspired systems approaches invaded social sciences from economics to archaeology (not to mention molecular biology). Cybernetic thinking is often accompanied by a quasi-religious fervor, and both were present in the holistic rhetoric that surrounded ecology in the 1960s and 70s, as well as the Gaia hypothesis that the entire earth is a living organism with interdependent systems.

Cybernetics also survives in subtle ways throughout the computer age. Among its most traceable and significant legacies came through the person of J.C.R. Licklider, an MIT psychologist who attended the Macy Conferences. In 1960, he wrote a seminal paper, "Man-Computer Symbiosis" that employed cybernetic ideas to lay a roadmap for the future development of interactive computing. Licklider went on to become the founding director of DARPA's Information Processing Techniques Office. Licklider's research program, his cybernetic vision, and his disciples played direct, critical roles in forming the fields of AI, computer graphics, among others, and then built the Arpanet, progenitor of the Internet. As we hear about cybersex, cybercash, and cyberwar, the legacies of Norbert Wiener (who died in 1964) and cybernetics are with us still.

Must Reads (assigned reading):

"Introduction" from N. Wiener, Cybernetics: or Control and Communication in the Animal and the Machine

J.C.R. Licklider, "Man-Computer-Symbiosis" from *IRE Transactions on Human Factors and Electronics* (March, 1960) 4-11.

Others of interest:

Paul Edwards, The Closed World: Computers and the Politics of Discourse in Cold War America (Cambridge: MIT Press, 1996).

Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21 (Autumn, 1994), 228-66.

Steve J. Heims, Constructing a Social Science for Postwar America: The Cybernetics Group: 1946-1953 (Cambridge: MIT Press, 1993).

Steve Joshua Heims, John von Neumann and Norbert Wiener: From Mathematics to the Technologies of Life and Death (Cambridge: MIT Press, 1980).

Pesi Masani ed., Norbert Wiener: Collected Works with Commentaries (Cambridge: MIT Press, 1985), Volume 4.

Norbert Wiener, The Extrapolation, Interpolation, and Smoothing of Stationary Time Series (Cambridge, MIT Press, 1949).

Norbert Wiener, The Human Use of Human Beings (Cambridge: MIT Press, 1950).