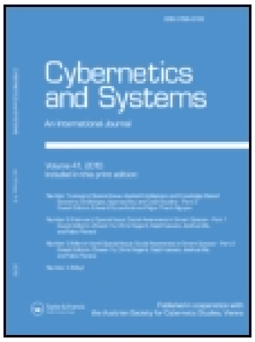

Cybernetics & Systems

ISSN: 0196-9722 (Print) 1087-6553 (Online) Journal homepage: https://www.tandfonline.com/loi/ucbs20

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To cite this article: Stuart A. Umpleby, Eric B. Dent (1999) THE ORIGINS AND PURPOSES OF SEVERAL TRADITIONS IN SYSTEMS THEORY AND CYBERNETICS, Cybernetics & Systems, 30:2, 79-103, DOI: 10.1080/019697299125299

To link to this article: https://doi.org/10.1080/019697299125299

Published online: 15 Dec 2010.

THE ORIGINS AND PURPOSES OF SEVERAL TRADITIONS IN SYSTEMS THEORY AND CYBERNETICS

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The story of systems theory and cybernetics is a story of several research traditions all of which originated in the mid 20th century. Systems ideas emerged in a variety of locations and for different reasons. As a result the ideas were developed in relative isolation and emerged with different emphases. This paper discusses the books and people, conferences and institutes, and politics and technology that have influenced the systems movement. The schools of thought presented are general systems theory, the systems approach, operations research, system dynamics, learning organizations, total quality management, and cybernetics. Three points-of-view within cybernetics are discussed. Total quality management is a new addition to the list, but we feel it is appropriate because of its extensive use of systems ideas. This paper does not address artificial intelligence, complexity theory, family therapy, or other traditions which might have been included.

Helpful comments on an earlier draft were made by Russell Ackoff, Chris Argyris, Jay Forrester, Dennis Meadows, and Anatol Rapoport. Any errors, however, are the responsibility solely of the authors.

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Cybernetics and Systems: An International Journal, 30:79-103, 1999

0196-9722/99 $12.00 + .00

Systems science is generally said to have emerged during and after World War II, although there were precursors to the basic ideas. The people who created each school of thought were working largely independently, although many of them knew each other. They came from different disciplines, were working on different problems, formulated different variations of the principles of systems and cybernetics, and often chose to affiliate with different academic societies.

The authors find that students today tend to speak of systems theory and cybernetics as one field. However, in our experience, it is important to distinguish the different traditions. Scientific ideas are invented to solve particular problems. In this sense, they are answers to questions. Understanding an answer requires understanding the question which generated it. In our experience, students learn concepts much more quickly and easily when the original problem which led to the creation of the idea is described. Another reason for distinguishing the different research traditions in the history of systems science is that people familiar with different traditions may have quite different understandings of the field. An awareness of the different traditions may help to promote communication and eventual integration of the field.

To some people, the term "systems thinking and cybernetics" means the work of Talcott Parsons (1951); to others, Katz and Kahn (1966) or Cleland and King (1968, 1972); and, to still others, Ashby (1956), McCulloch (1965), and von Foerster (1981). Presently, the systems theory and cybernetics literature is highly differentiated. Perhaps the next generation of researchers will produce an integration and synthesis.

GENERAL SYSTEMS THEORY

A key location for the development of general systems theory was the University of Michigan's Mental Health Research Institute (MHRI) where *General Systems*, the yearbook of the Society for General Systems Research (SGSR), was based for many years. A mental health research institute may seem a peculiar place to find systems theory. However, in the 1950s, there was money available for mental health research, and the justification given to funding agencies was that if people could learn to think comprehensively about their interaction with each other and the environment, then their mental health would improve. The director of the Institute, James G. Miller (1978), a psychologist and medical doctor, wrote a large book, *Living Systems*, which is a discussion of matter, energy, and information processes. Miller saw systems as having 19 critical subsystems at each level: cell, organ, organism, group, corporation, nation, and supranational organization. One distinguishing feature of Miller's work is his treatment of information. Information is described as something that goes in, is processed, and then goes out. The notion is similar to a train pulling into a station, the cars being shifted around, and then another train leaving the station. Miller's theory is particularly useful for formulating cross-level hypotheses. For several years the articles in the journal *Behavioral Science* indicated where the article fit within Miller's scheme.

Anatol Rapoport[1] of MHRI was the editor of the yearbook *General Systems*. He is a well-known game theorist who published *Fights, Games, and Debates* in 1960 and *General System Theory* in 1986. Also at MHRI was Kenneth Boulding, a well-known economist and widely-read author. Boulding used an ecological model for understanding corporations and individuals as actors within a social system. His 1956 book, *The Image*, is an early discussion of mental models. His 1978 book, *Ecodynamics: A New Theory of Societal Evolution*, summarizes much of his earlier work.

Another MHRI colleague was John Platt, a physicist who wrote a number of essays on science policy including "What Is To Be Done" (1969). He developed the concept of the "step to man," an idea based on the envelope curve of technologies, a technique used in technological forecasting. A characteristic curve exists for many activities, such as transportation, communication, and explosive power. These curves depict increasing capabilities which reach a physical limit. Platt (1966) claimed that these curves and thresholds can be thought of as the "step to man," a dramatic increase in human capabilities. Another researcher at MHRI was the chemist Richard L. Meier who wrote *Science and Economic Development* (1956) and *A Communication Theory of Urban Growth* (1962). He developed the idea of "wealth-producing cities." He was doing studies of the "Asian tiger" nations when they first received that name.

[1]Rapoport was later the Director of the Institute for Advanced Studies in Vienna, Austria. For a discussion of Rapoport's tit-for-tat strategy, see Robert Axelrod's *The Evolution of Cooperation* (1994).

One person who is widely associated with general systems theory but who was not at MHRI was Ludwig Von Bertalanffy, whose most important book in the field was entitled *General System Theory*. Margaret Mead was also involved with these scientists and Richard Ericson identified primarily with this group. The work of Walter Cannon was yet another influence at MHRI. Skip Porter, Len Troncale, and Terry Oliva represent the next generation of system theorists who were strongly influenced by the work at MHRI.

THE SYSTEMS APPROACH

A group that was somewhat connected with general systems theory is usually associated with the term, the systems approach. They were located originally at the University of Pennsylvania. They later went to Case Western Reserve University and then back to the University of Pennsylvania. Their founding philosopher was E. A. Singer, Jr. One of Singer's students was C. West Churchman, and Churchman's first student was Russell Ackoff. Churchman remained primarily a philosopher, but Ackoff clearly moved in the direction of management and organizations. Churchman and Ackoff helped establish the field of operations research in the United States. Churchman, Ackoff, and Arnoff (1957) wrote the first textbook in the field, *Introduction to Operations Research*, but they use the term "operations research" differently than the group discussed below. For Churchman and Ackoff operations research was an effort to make organizations more effective. Most of the people who went into the field of operations research practiced it as applied mathematics, but Churchman and Ackoff retained an orientation toward management and organizations.

Singer suggested that a producer-product relationship exists when X is necessary, but not sufficient to cause Y. Consider the example of an acorn and an oak tree. An acorn is necessary for an oak tree, but if it is not placed in a suitable environment with soil, water, and sunlight, the acorn will not grow into an oak. In producer-product relationships, the producer alone cannot be the cause of the product. There are always other necessary conditions. From the view of producer-product relationships, the environment becomes central to understanding and to explanation.

Ackoff (1981) notes that "the use of the producer-product relationship requires the environment to explain everything, whereas use of cause-effect requires the environment to explain nothing. Science based on the producer-product relationship is environment-*full*, not environment-*free*" (p. 21). Consequently, by definition, any principle offered about producer-product relationships must stipulate the conditions under which the principle applies. If the principle were to apply in all conditions, then the environmental conditions are not co-producers of the effect.

Churchman and Ackoff started off as philosophers, but they found that philosophers were less interested in their work than practicing managers. Ackoff, in particular, developed a variety of methods for use in organizations. From building mathematical models he moved toward the design of conversations, particularly how one can hold a conversation among a group of people on the present and future direction of an organization. He refers to his method for doing so as "interactive planning," which is described in Ackoff's 1981 and 1984 books, *Creating the Corporate Future* and *A Guide to Controlling Your Corporation's Future*.

Ackoff also developed the circular organization concept. This structure is a democratic hierarchy with three essential characteristics:

> (1) the absence of an ultimate authority, the circularity of power; (2) the ability of each member to participate directly or through representation in all decisions that affect him or her directly; and (3) the ability of members, individually or collectively, to make and implement decisions that affect no one other than the decision maker or decision makers. (Ackoff, 1994, p. 117)

The structure is circular because anyone who has authority over others is subject to the collective authority of the others. Ackoff implements the circular organization by having each manager have a "board." This board consists of, at least, the manager's manager, the manager, and all of the manager's immediate subordinates. Each member of the board has a vote, so one can easily see that the subordinates hold a majority of the votes.

Ackoff's (1994) most recent book is entitled, *The Democratic Corporation: A Radical Prescription for Recreating Corporate America and Rediscovering Success*. The titles of these books offer clear evidence of Ackoff's orientation toward organizations. Together with Fred Emery, Ackoff (1972) wrote *On Purposeful Systems*. Churchman also wrote widely-known books—*The Systems Approach* (1968) and *The Design of Inquiring Systems* (1971). Recent contributors to this strand of systems thinking include Ian Mitroff, Peter Checkland, Robert Flood, Michael Jackson, and Ali Geranmayeh.

OPERATIONS RESEARCH OR SYSTEMS ANALYSIS

The British introduced the Americans to operations research during World War II. For 100 years or more, the British had been operating a global empire. They had learned how to move people and material all over the world. To manage a global empire they had to have the right number of soldiers and administrators, guns, tents, food, and ammunition in each of their various colonies. Hence, they had developed a variety of methods to optimize the allocation of resources and to improve logistics. They also developed methods which we now call covert operations, which are ways of creating divisions within the opposing group. If two tribes are "encouraged" to fight among themselves, they won't produce a united front. Consequently, the British had developed ways of making their own systems work while making sure that the opponent's systems did not work. In World War II, the Americans learned both operations research and covert operations from the British.

During World War II, one of the most famous problems in operations research was the design of the optimal size of a convoy to cross the North Atlantic (Machol et al., 1965). A very large convoy meant that a small number of destroyers could protect a large number of freighters. However, the convoy would be moving only as fast as the slowest ship. Furthermore, if the convoy were divided into smaller parts, they might be better able to elude the German submarines. The appropriate size of a convoy was a problem of optimization. After World War II, the people who were doing this kind of work began to apply these methods inside business organizations. For example, the "whiz kids," including Robert McNamara, took over the management of Ford Motor Corporation in the 1950s. In the 1960s, President Kennedy brought many systems analysts into the United States government (Dickson, 1971).

During the Cold War, the military relied heavily upon a number of think tanks such as the RAND Corporation (for the Air Force) and Research Analysis Corporation or RAC (for the Army). These organizations had a number of successes. One of the famous studies that RAND did was on the location of strategic bases. The geopolitical doctrine during the Eisenhower administration was to contain the Soviet Union. The Air Force intended to ring the Soviet Union with air bases. If the Soviets stepped across their border, the policy dictated "massive retaliation" by aircraft from all of these bases against the Soviet Union. The Air Force asked RAND for advice about where to put the bases. RAND recommended against putting aircraft near the Soviet Union. If the Soviet Union decided to attack, the Soviets would not have far to go to reach American targets. By having many bases near the Soviet Union, the United States was increasing the possibility of another Pearl Harbor fiasco. RAND instead recommended keeping the airplanes in the United States, refueling the planes in midair, and setting up a distant early warning (DEW) line across Canada so that if the Soviet Union attacked, the Americans would know that they were coming in time to get the airplanes in the air. Operations research is now a well-established field in schools of engineering and management.

SYSTEM DYNAMICS

Another tradition in systems theory, known as system dynamics,[2] originated at Massachusetts Institute of Technology. The founder of this tradition was Jay Forrester, a creative engineer who invented the magnetic core memory for computers and who built the Whirlwind computer, which is now in the Smithsonian Institution. The Whirlwind computer had a remarkable string of "firsts." It had the first magnetic core memory, the first keyboard entry, the first light pen entry (somewhat similar to a mouse), and the first multitasking (for example, the computer could both print and calculate at the same time).

Forrester's first applications of system dynamics, which used the DYNAMO simulation language developed in his group, were published under the title *Industrial Dynamics* (1961). He was interested in explaining production fluctuations in a firm and the origin of business cycles. Business cycles can greatly disrupt organizational functioning. The fluctuation in inventory levels and the number of employees needed is a difficult management problem. Forrester showed that a random perturbation such as the Christmas buying season can set off cycles and

[2] The method was originally called "industrial dynamics." The term system dynamics first appeared in *The Limits to Growth* and stuck thereafter (Meadows, 1998).

fluctuationw simply due to the lag in information that occurs as the orders go back from the retail stores to the wholesalers to the manufacturing plants. This chain reaction can generate a business cycle. Armed with this knowledge, a business can do a better job of smoothing out manufacturing and inventory systems.

In the early 1960s, the former mayor of Boston, John F. Collins, was a visiting scholar at MIT and had an office near Forrester. Collins and Forrester talked about the problems of managing a city, and Collins described the problem of Boston in the following way. If you are a Democratic mayor, as Collins was, then you have an obligation to develop programs for those who are less fortunate. Of course you have to pay for these programs, so you raise taxes. The result is that poor people move into the city to take advantage of the programs, and rich people move out to get away from the high taxes. Before long the central business district becomes impoverished. This phenomenon, which occurred in cities across the country, was described in the book, *Urban Dynamics*, by Forrester (1969). The book's implicit recommendation was that prosperity could be restored by reducing low-cost housing to limit additional inflow of the poor so the urban economy could recover. This idea did not go over well among liberal academics, particularly political scientists and sociologists on college campuses. The book was highly controversial and many books and articles were written in reply to *Urban Dynamics*. But, at least the book presented the problem in a very clear fashion so that it could be discussed and debated.

The next study that Forrester did was entitled *World Dynamics* (1971). This work came about because of contact with an Italian industrialist named Arellio Peccei, who was concerned about the future of humankind. Peccei served on several corporate boards of directors. Peccei tried to convince his fellow board members of the importance of trends in population, natural resources, and pollution. But the other members of the board would say they were concerned with profits in the current quarter. When Peccei would talk to his colleagues in government about population, natural resources, and pollution, they would say that although these things are very important, they were concerned about the next election. When Peccei raised the problem with academics, they would agree, but would explain that they were specialists and were not inclined to work on an interdisciplinary problem.

Peccei (1969) decided that he would have to take his message to the general public. He wanted them to rise up and demand that their leaders pay attention to these global problems. He pondered how to present the message. Peccei called together people from government, business, and academia, including Jay Forrester. On the flight home from the meeting, Forrester wrote the draft of a computer model on world dynamics. It was a path-breaking model because up to that time people had studied population, resources, and pollution, but they had always studied them in isolation. They had made independent projections. No one had put the various trends together in an integrated model to show how they affected each other. Forrester developed a model called World2, which was published in the book *World Dynamics*.

Meanwhile, some of Forrester's colleagues, including Dennis and Donella Meadows, Jorgen Randers, and others received a grant from the Volkswagen Foundation to do a more comprehensive model called World3. In addition to the computer model and documentation, they created a short layperson's overview titled *The Limits to Growth* (Meadows & Meadows, 1972), which was translated into many languages.[3] They presented the results and led a discussion at a day-long event convened by the Smithsonian Institution. Also, Potomac Associates, a policy information firm in Washington, DC, sent free copies to 500 key decision makers. All this activity created quite a stir in 1972. As a result modeling activities sprang up in countries around the world. Every time a group published a new study attempting to refute *The Limits To Growth*, they would present the results at a research institute in Austria, the International Institute for Applied Systems Analysis. In 1982 after 10 years of these meetings, Donella Meadows, John Richardson, and Gerhart Bruckmann published a book called *Groping in the Dark*. The book title is a reference to the well-known joke about the drunk who is looking for his keys under a lamp post even though he dropped them some distance away, where it is dark. Meadows, Richardson, and Bruckmann were goading academics, who have a tendency to study problems that are illuminated by their academic discipline, even though those problems do not reflect the most significant problems in the world around them.

In 1992, 20 years after the publication of *The Limits to Growth*, Meadows, Meadows, and Randers published *Beyond the Limits*. The title is intended to communicate that in 1972 the authors had pointed to

[3] This project also produced *Dynamics of Growth in a Finite World* (Meadows et al., 1974), an extensive scientific description of the model, and *Toward Global Equilibrium*.

limits to growth on a finite planet. By 1992, they claimed that the world had already gone beyond the limits of the carrying capacity of the planet and that a collapse to a sustainable level of population and production would occur. This paper's first author went to the press conference where the authors described their 1992 book. The press and the public paid less attention this second time, perhaps because computer models of policy issues had become more common. Hundreds of teams around the world were modeling global issues such as climate change, ozone depletion, and overfishing of some species.

Forrester, meanwhile, had turned his attention to economic dynamics and did studies of economic long waves. Now the system dynamics group is working on introducing systems thinking at the grade school and high school levels. Software packages have been developed to make this kind of modeling easier and more accessible to a large number of people. Some of the other people working in system dynamics today are John Morecroft, George Richardson, and John Sterman.

ORGANIZATIONAL LEARNING

Another group at MIT and Harvard University developed the notion of "organizational learning." Chris Argyris and Donald Schön (1978) were the key figures in this group. Argyris was a student of Kurt Lewin, who was a participant in the Macy Foundation meetings that were chaired by Warren McCulloch (discussed below). Argyris has referred to Ashby's influence on his notion of double-loop learning (1974, pp. 18–19). Donald Schön was a frequent collaborator with Argyris. Together they wrote *Theory in Practice* (1974) and *Organizational Learning II: Theory, Method, and Practice* (1996). Schön also wrote *Educating the Reflective Practitioner* (1987).

A key contribution of this group is the distinction between what they refer to as Model I and Model II. Each model describes a set of values and theories-in-use by people. Model I is the prevailing theory-in-use and consists of the following values: define goals and try to achieve them, maximize winning and minimize losing, minimize generating or expressing negative feelings, and be rational. Model I behaviors are self-reinforcing and self-sealing because they place people in double binds and because a feature of Model I is making actions that are threatening or potentially embarrassing undiscussable. Argyris and Schön maintain that Model II is a more productive theory for organizations to use because it leads to double-loop learning. Important values in Model II are valid information, free and informed choice, internal commitment to the choice, and constant monitoring of its implementation. Model II action strategies include "design situations where participants can be origins of action and experience high personal causation, [the] task is jointly controlled, protection of self is a joint enterprise and oriented toward growth, and bilateral protection of others" (p. 118).

The most successful of this group in terms of books published is Peter Senge, who was a student of both Argyris and Forrester. His book, *The Fifth Discipline* (1990), has gone through more than 20 printings. *The Fifth Discipline Field Book* (1994) is the follow-up book. This group consists of academics, but they have extensive management consulting experience working with corporations and government agencies. In addition to Senge, the next generation of contributors to organizational learning include Robert Putnam, Diana McLain Smith, and Nancy Dixon.

TOTAL QUALITY MANAGEMENT

A field which did not originate in an academic setting is the field of total quality management or continuous quality improvement. Key figures in this field are W. Edwards Deming, Joseph Juran, and Phillip Crosby. Deming (1960, 1986, 1993), has a very interesting personal history. He was at the Hawthorne Works of the Western Electric Corporation around the same time that Elton Mayo was doing very important studies about human behavior. Mayo reported that no matter what work parameters were changed for a group of people, their performance improved. The effect was attributed to the fact that the researchers were paying attention to them. Mayo also pointed out that workers respond more to their peers than to management. Deming was at Hawthorne at the time, but he did not work on that study. He was collaborating with Walter Shewhart (1939), who was a statistician working on quality control methods. The methods of statistical quality control came out of an industrial setting. Deming also did some work at New York University. When Deming was "discovered" in the 1980s in the United States, he was teaching at George Washington University, not in the School of Management, but in the Continuing Engineering Education Program of the School of Engineering. Since then, Deming's long history of consulting with Japanese organizations has been welldocumented (Walton, 1986). The Japanese named their most prestigious industrial award after Deming.

By 1980, American executives were in a near panic. In several major industries, the Japanese were selling products in the United States for less than American companies could produce them. American manufacturers were building plants in other countries, thereby sending jobs overseas, and quite a number of CEOs believed that competing with the Japanese was the road to bankruptcy. It was at that time that NBC aired a special television report, "If Japan Can, Why Can't We?" The program explored several possible reasons why the Americans were not competitive including: low labor costs in Japan, conflict between government and industry in the United States (i.e., burdensome government regulation), conflict between labor and management in the United States, and the Japanese work ethic. However, whenever the reporter asked the Japanese why they were so productive, they would say that they learned how to produce quality products from the Americans, and they specifically mentioned Edwards Deming. When the people who were working on the television program asked Americans who Edwards Deming was, they did not know. Although he was treated like a god in Japan, he was virtually unknown in the United States.

When the NBC report aired, Deming was teaching short courses for about 15 engineers. However, after the program, he was besieged by calls from corporations across the country asking him to "come and save us." So he began teaching the same classes to groups of 400 to 500 corporate senior managers. American corporations began to listen to Deming, and the United States established a similar prize for corporate excellence called the Malcolm Baldrige Award, named after a former Secretary of Commerce under President Reagan.

The field of continuous improvement is important for the field of systems theory and cybernetics, because it is very easy to describe the principles of total quality management from the point-of-view of systems theory and cybernetics. There is an emphasis on increasing the autonomy of workers, reducing hierarchical relationships, increasing feedback throughout the production process, having good relationships with customers and suppliers, measuring results, and testing innovations on a small scale. These methods have proven to be quite effective and are increasingly adopted in corporations and government agencies. Interestingly, the lag between the creation of the Deming Prize and the Baldrige Award is 35 years, from 1950 to 1985. Current leaders in this field are primarily consultants and authors, not academics. They include Brian Joiner, William Scherkenback, and A. Blanton Godfrey.

CYBERNETICS

The final tradition in systems science discussed in this paper is cybernetics. Within cybernetics, we will distinguish three traditions, which will be referred to as "Wiener's Cybernetics," "Turing's Cybernetics," and "McCulloch's Cybernetics." Each of these subdivisions dates to the 1940s. In 1943, Rosenblueth, Wiener, and Bigelow published "Behavior, Purpose and Teleology" and McCulloch and Pitts published "A Logical Calculus of the Ideas Imminent in Nervous Activity." In 1950 Turing published "Computing Machinery and Intelligence." Other important publications in this tradition in the 1940s include Wiener's 1948 *Cybernetics, or Control and Communication in the Animal and the Machine* and Shannon's 1949 *The Mathematical Theory of Communication.*

Cyberneticians refer to predecessors such as Bertrand Russell, Ludwig Wittgenstein, and Ronald Fisher. The generation after the 1940s included the scholars Ross Ashby, Stafford Beer, Humberto Maturana, Gordon Pask, and Heinz von Foerster. The next generation includes Michael Ben-Eli, Barry Clemson, Roger Conant, Fernando Flores, Ranulph Glanville, Klaus Krippendorff, Paul Pangaro, Francisco Varela, and Crayton Walker. The three traditions of cybernetics can be seen in three quite different professional groups. Wiener's early work on control systems (1950) has been carried forward by the Systems, Man, and Cybernetics interest group of the Institute of Electrical and Electronics Engineers. Turing's work on computation and machine intelligence laid the foundation for computer science and artificial intelligence. McCulloch's interest in understanding human cognition and epistemology by studying the nervous system has been pursued by the members of the American Society for Cybernetics.

A series of early conferences was instrumental to all subdivisions of cybernetics. The Josiah Macy Jr. Foundation, created by the Macy Department Store family, funded the Macy Foundation Conferences on Cybernetics, which were chaired by Warren McCulloch. Heinz von Foerster was the recording secretary for the last five of 10 conferences. Because von Foerster did not know English well at the time, Margaret Mead assisted him with the proceedings. The 10 Macy Conferences were held between 1944 and 1954. The conferences were attended by researchers including Ashby, von Neumann, Bateson, Mead, von Foerster, Wiener, McCulloch, and Bigelow (Heims, 1991). Around 1960, there were three conferences on self-organizing systems (von Foerster & Zopf, 1962) sponsored by the Office of Naval Research. The American Society for Cybernetics was founded in 1964 and held its first meeting in 1967.

Wiener's Cybernetics

During World War II, Rosenblueth and Wiener were engaged in designing radar-guided antiaircraft guns. Before there were general purpose electronic computers, Rosenblueth and Wiener set out to design a machine that would sense its environment and act in a fashion suited to a changing environment—a behavior customarily performed by human beings and social organizations. Rosenblueth, a biologist, and Wiener, an applied mathematician, realized that they were dealing with a teleological phenomenon. Teleology is the philosophical study of natural processes that are caused not by events in the immediate past but rather by events in the future. This sort of thinking was inconsistent with a scientific community that was attempting to develop a mechanistic theory of the universe in which events in the present are caused by events in the past. Since Wiener and Rosenblueth succeeded in constructing a mechanism that displayed purposeful behavior, perhaps the distinction between a mechanistic philosophy and teleology was not as great as it had once seemed. Ashby (1960) devoted his life to further developing this idea. He sought to develop a mechanistic (i.e., nonteleological) theory of intelligent behavior.

A key conclusion of this research was that a regulator required a model of the system being regulated (Conant & Ashby, 1970). The model would describe the consequences of various actions. By adding a description of the current state and the desired state, a plan of action for moving from the current state to the desired state could be constructed. Although the goal might be in the future, all of these elements would be in the regulator in the present and could "cause" goal-directed, apparently teleological behavior.

Wiener, in his book *Cybernetics*, proposed the notion of a second industrial revolution. The first industrial revolution occurred when machines began to replace human muscle power and the second industrial revolution occurred when machines began to replace the human capacity to process information and make decisions.

That idea was picked up by Daniel Bell (1973) when he wrote *The Coming of Post Industrial Society*, in which he distinguished the agricultural period and the industrial period and then described a post-industrial period. Later, Alvin Toffler wrote a book called *The Third Wave*, incorporating the same three stages of economic and social development. The control systems tradition in cybernetics has led to a wide range of automatic control devices in homes, factories, and offices.

Turing's Cybernetics

The British Scientist Alan Turing is well-known for having developed the concept of the universal Turing machine and the Turing test. It is less well-known that during World War II he worked on the "ulrasecret," the decoding of messages of the German high command. British intelligence obtained a copy of the German coding machine called Enigma (Winterbotham, 1974). The machine was manufactured in Poland and members of the Polish underground stole a copy piece-by-piece and gave it to British Intelligence. The machine had wheels that could be set for a particular code. Then a message would be typed and Enigma would automatically translate it into a different set of letters. When another person received the message, he would set the machine to the particular code and then out would come a readable message. The Germans had great confidence in Enigma. They felt their communications were very secure. But the messages of the German high command were being read by British Intelligence throughout the war. The ability to know the Germans' war plans in advance led to a relatively quick Allied victory.

The successful experience of World War II shaped the popular imagination of American capabilities during the post-war period. But Americans did not know why their country performed so successfully during that war. In 1975, when the documents from the war were declassified, a British historian named Anthony Cave Brown (1975), who had written a history of World War II, realized that the history of the war had to be rewritten. His reinterpretation of the war is the book *Bodyguard of Lies*. The title comes from Churchill's words, "In wartime, truth is so precious that she should always be attended by a bodyguard of lies." The extraordinary contribution made by the ultrasecret to success in World War II led to large-scale funding of the National Security Agency during the period of the Cold War.

During the Vietnam War research on college campuses, supported by the Department of Defense, became controversial. One result of the controversy was the Mansfield Amendment, which required researchers funded by the Defense Department to explain the relevance of the research to the military mission. Researchers in artificial intelligence created the idea of battles fought using electronic sensors or robots as a way of justifying continued Defense Department funding of their research. Hence, during the Vietnam War, the computer science tradition in cybernetics contributed the idea of an "electronic battlefield."

McCulloch's Cybernetics

McCulloch's cybernetics was quite different from Wiener's and Turing's cybernetics. McCulloch was interested in experimental epistemology, understanding knowledge by understanding the brain. The 1943 article by McCulloch and Pitts, "A Logical Calculus of the Ideas Imminent in Nervous Activity," describes how the operation of a nerve network results in an idea. The paper makes an initial attempt at a formal theory of that activity. McCulloch, a philosopher and neuroanatomist, and Pitts, a mathematician, had similar interests. They reasoned as follows: The brain is a network of neurons. As each neuron fires, it stimulates or inhibits the firing of other neurons. The result of this activity is something we experience as ideas. This phenomenon occurs in nature. Scientists, or natural philosophers, seek to explain natural phenomena. The preferred type of explanation is a formal theory. Hence, the title of their article was "A formal theory of how the activity of a network of neurons results in ideas." The McCulloch and Pitts article seemed to a number of observers, such as John von Neumann, to be the key that they were looking for. Research in "neuro-philosophy" was continued primarily by Humberto Maturana and Heinz von Foerster. This research has influenced the fields of management (Zeleny, 1981) and family therapy (Watzlawick, 1984).

The McCulloch tradition in cybernetics led to the development of "second-order cybernetics," beginning in the mid 1970s. For a description of this movement see Umpleby (1990, 1991, 1997). A key idea is that the observer should be included within the domain of science.

Previously, scientists assumed that two observers looking in the same direction at the same phenomenon would see the same thing. Similarly, conflicts between scientists could be resolved by performing an experiment. Nature, an unbiased judge, would render a verdict.

Cyberneticians point out, however, that the results of experiments are interpreted by observers. As Thomas Kuhn (1970) wrote:

> In a sense that I am unable to explicate further, the proponents of competing paradigms practice their trades in different worlds. One contains constrained bodies that fall slowly, the other pendulums that repeat their motion again and again. In one, solutions are compounds, in the other mixtures. One is embedded in a flat, the other in a curved matrix of space. Practicing in different worlds, the two groups of scientists see different things when they look from the same point in the same direction. Again, that is not to say that they can see anything they please. Both are looking at the world, and what they look at has not changed. But in some areas they see different things, and they see them in different relations one to the other. That is why a law that cannot even be demonstrated to one group of scientists may occasionally seem intuitively obvious to another (p. 150).

The second-order cyberneticians have created a philosophy of constructivism, which is contrasted with realism. Whereas realism holds that the world is primary and theories are imperfect descriptions of a "real world," constructivism holds that observers have more immediate access to thoughts than to the world of experience.

Through experiences each observer "constructs" an image of his or her world. An implication of this point-of-view is that doubt is inherent in human existence. We can never be certain that our views are an accurate description of the world. Our descriptions simply "fit" our experience. And it is reasonable to assume that others will construct descriptions of their experiences, which will necessarily be different in some respects. This view of the nature of knowledge supports democracy and an ethic of tolerance. Second-order cybernetics, by adding the dimension of attention to the observer, is a fundamental contribution to the philosophy of science (Umpleby, 1997).

Table 1. Chronological Listing of a Sampling of Important Historical Contributions to Cybernetics and Systems Thinking

Year	General Systems Theory	The Systems Approach	Operations Research	System Dynamics	Organizational Learning	Total Quality Management	Cybernetics
1939–1949			von Neumann, *Theory of Games*			Shewhart *Statistical Method*	McCulloch, "A Logical Calculus"
						Juran *Bureaucracy*	Wiener *Cybernetics*
						Juran *Management of Inspection*	Shannon *Mathematical Theory*
1950–1959	Boulding *The Image*	Churchman, *Operations Research*	Luce, *Games and Decisions*		Simon *Models of Man*	Juran *Case Studies*	Wiener *Human Use of Human Beings*
			Brown *Statistical Forecasting for Inventory Control*			Feigenbaum "The Challenge of TQ Control"	Turing "Computing Machinery"
							Ashby *Design for a Brain*
1960–1969	Rapoport *Fights, Games and Debates*	Churchman *Prediction and Optimal Decision*	Saaty *Elements of Queueing Theory*	Forrester *Industrial Dynamics*	Schön *Technology and Change*	Deming *Sample Design in Business Research*	Ashby *Introduction to Cybernetics*
	Deutsch *Nerves of Government*	Churchman *Systems Approach*	Ackoff, *Manager's Guide to OR*	Forrester *Urban Dynamics*		Juran *Managerial Breakthrough*	von Foerster, *Principles of Self-Organization*
	Buckley, *Modern Systems Research*		Dantzig *Linear Programming*				McCulloch, *Embodiments of Mind*

			Machol, *System Engineering Hdbk.*				
	Von Bertalanffy *General System Theory*		Boguslaw *The New Utopians*				Beer *Decision and Control*
	Klir *Approach to GST*		Raiffa *Decision Analysis*				Brown *Laws of Form*
1970–1981	Howard *Paradoxes of Rationality*	Churchman *Design of Inquiring Systems*	Box, *Time Series Analysis*	Forrester *World Dynamics*	Allison *Essence of Decision*	Juran, *Quality Planning & Analysis*	Bateson *Steps to an Ecology of Mind*
	Jantsch *Design for Evolution*	Ackoff, *On Purposeful Systems*	Quade, "History of Cost-Effectiveness Analysis"	Meadows, *The Limits to Growth*	Argyris, *Theory in Practice*	Ishikawa *Guide to Quality Control*	Beer *Brain of the Firm*
	Weinberg *General Systems Thinking*	Checkland *Systems Thinking*	Christofides "Optimum Traversal of a Graph"	Meadows, *Dynamics of Growth*	Argyris "Single-Loop and Double-Loop Models"	Crosby *Quality is Free*	Beer *Platform for Change*
	Odum, *Energy Basis for Man and Nature*	Ackoff *Creating the Corporate Future*	Waddington *OR in WWII*	Mesarovic, *Mankind at the Turning Point*	Argyris, *Organizational Learning*	Schlesinger *Quality of Work Life and the Supervisor*	Conant, *Mechanisms of Intelligence*
			Kleinrock *Queueing Systems*	Goodman *Study Notes in System Dynamics*	Schön "Organizational Learning"		von Foerster *Observing Systems*
	Miller *Living Systems*		Shafer *Mathematical Theory of Evidence*				
	Boulding *Ecodynamics*				Revans *Action Learning*		

Note: An author's name followed by a comma indicates that there are co-authors. See the reference section for complete citation.

CONCLUSION

The development of these various traditions between 1940 and 1980 is indicated in Table 1 through a partial list of some of the key books and articles published during this time. Each of these traditions had a different set of concerns. The general system theorists were interested in evolution and hierarchy. They treated information as if it were a physical entity to be manipulated. The cyberneticians who followed in the footsteps of McCulloch were interested in cognition, adaptation, and understanding—issues that most other systems scientists were not so concerned with. For example, the system dynamicists focus on modeling some observed system. They deal with the issue of knowledge acquisition, but only in terms of how one understands what is happening in the referent system. For them, the process of understanding is encompassed by the methodology of modeling. They do not assume that the philosophy of knowledge needs to be reconsidered. They are concerned with verifying their models using historical data and helping decision makers improve their understanding of a referent system. They are not concerned with cognition as a problem in itself.

Interest in human cognition is what distinguishes cyberneticians in the "McCulloch" tradition from the other fields, although the other fields are beginning to adopt a more constructivist epistemology. Now there are people like the Learning Organization group and the Total Quality Management group which are developing ideas that are compatible with constructivist cybernetics, but they tend not to emphasize epistemology or philosophy because they are concerned with the practical problems of making organizations work more effectively. They are interested in effective communication, but they still tend to assume a realist epistemology. However, their interest in effective communication is moving them in the direction of subjectivist epistemologies.

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