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SIXTY YEARS OF CYBERNETICS
From Youthful to Useful

George J. Klir

This year coincides with the 60-year anniversary of the publication of Norbert Wiener's seminal book [1], in which he introduced, under the name "cybernetics", a host of radically new ideas and views regarding science, engineering, and other areas of human affairs that emerged shortly after World War II. It is thus appropriate for a journal whose title is *Kybernetika*, the Czech name for cybernetics, to use this anniversary for reflecting on the evolution of cybernetics during the last 60 years. In this essay, which I was invited to write for *Kybernetika* on this occasion, I intend to express my personal opinion about what I consider the most important ideas of cybernetics from among those suggested and discussed by Wiener in his book. In addition, I intend to trace the evolution of these principal ideas, especially in the United States, since the publication of Wiener's book.

The few years immediately following the end of World War II were extraordinary for science and engineering. It was the time when scientists, engineers, mathematicians, and other professionals who had been involved during the war in the high-intensity research related to war efforts were finally able to reflect on the many innovative ideas that had emerged from this research. Wiener, a brilliant mathematician, was one of them. He had acquired firsthand experience from his participation in this massive research. However, in addition to this unique experience, which he shared with many other researches, Wiener had an extraordinary talent to recognize the essence of the many new ideas emerging from this research and to describe them in a coherent, understandable, and interesting way. It is also significant that he examined these ideas as a whole and coined for this emerging whole a new English name, *cybernetics* (inspired, as is well known, by the Greek word *kybernetes*).

My principal aim in this essay is twofold. First, I would like to describe three groups of ideas subsumed under cybernetics (as characterized in Wiener's book) that I consider the most profound. Second, I would like to express my opinion about the influence of each of these groups of ideas on science, engineering, and other areas. These influences have either modified established paradigms in classical areas or have led to the emergence of new areas during this period. While cybernetics has somewhat lost its identity and youthful vigor over the years, its legacy is now firmly embedded in these new paradigms and the emerging new areas of research.

The first of the three principal groups of ideas put forward under cybernetics is the recognition and claim that many important concepts in science are genuinely crossdisciplinary. That is, they are not specific to any particular area of science, but are applicable to all of them. Some of these concepts, those particularly emphasized by Wiener, are associated with communication and control. They are exemplified by the concepts of information, noise, uncertainty, stability, observability, controllability, feedback, memory, and the like. Among other crossdisciplinary concepts, perhaps the most important is the concept of a system and the many associated concepts, such as behavior, structure, constraint, complexity, modeling, learning, adaptation, anticipation, self-organization, self-reproduction, self-preservation, autopoiesis, and many others.

The second group of principal ideas emerging from cybernetics is based on the recognition that significant problems cannot be adequately dealt with within the confines of any single discipline. Wiener paid a lot of attention in his book to explain the importance of multidisciplinary research. The arguments he presented for multidisciplinary research, which were based on his own experience, are quite convincing [1, pp. 8–9]:

> It is the boundary regions of science which offer the richest opportunity to the qualified investigator. ... If the difficulty of a physiological problem is mathematical in essence, ten physiologists ignorant of mathematics will get precisely as far as one physiologist ignorant of mathematics. If a physiologist, who knows no mathematics, works together with a mathematician who knows no physiology, the one will be unable to state his problem in terms that the other can manipulate, and the second will be unable to put the answers in any form that the first can understand. ... The mathematician need not have the skill to conduct a physiological experiment, but he must have the skill to understand one, to criticize one, and to suggest one. The physiologist need not be able to prove a certain mathematical theorem, but he must be able to grasp its physiological significance and to tell the mathematician for what he should look.

Although multidisciplinary research is now fairly common, it is important to realize how radically new the idea described in this quote was in 1948.

The third group of important ideas associated with cybernetics consists of those concerning the relationship between living organisms, in particular human beings, and machines. These ideas are closely connected with the emergence of general-purpose digital computers at the very end of World War II. Although the prospective scope of capabilities of these computers was not fully understood at the time Wiener's book was published, it was clearly recognized that these were machines of a radically new kind. Contrary to the classical machines, designed primarily for performing physical work, these new machines were designed primarily for performing mental work. This opened a forum for discussing their potential capabilities and limitations, and comparing them with the capabilities of human brain and mind. Moreover, some similarities were observed between the logical structure of these machines and the structure of interconnected neurons in human and animal nervous systems, as understood in the 1940s.

I would like to examine now how each of the three principal groups of ideas subsumed under the name *cybernetics* has evolved over the last 60 years and what is its current status. My overall observation is that these groups of ideas have evolved independently of each other and in this process the identity of cybernetics has been gradually eroded. That is, the original groups of ideas continue to play important roles in contemporary science and other areas of human affairs, but they have become more sophisticated over the years and are now embodied under new names in various new research areas. The historical connection of these new areas to cybernetics is unmistakable, but it is mostly unrecognized by researchers in these areas. Anniversaries like this provide thus good opportunities for reflecting on the historical background of our current research work.

The recognition that many concepts employed in science, engineering, and other areas are genuinely crossdisciplinary emerged not only from cybernetics, but also from an area that became known as *general systems research*. While in cybernetics, as characterized in Wiener's book, the focus was on concepts pertaining to communication and control, the focus in general systems research was on the broad crossdisciplinary concept of a *system* and the various related concepts, such as the concepts of a relation, complexity, holism, isomorphism, modeling, goal-orientation, adaptation, self-organization, and the like. However, except for different foci, the classes of concepts recognized as crossdisciplinary in cybernetics and in general systems research, respectively, are not substantially different. A good support for this conlusion can be found in another classic book on cybernetics, one written by W. Ross Ashby [2].

Ashby was perhaps the most important researcher who was interested and actively involved in both cybernetics and general systems research. In some sense, he integrated them into a larger whole, which eventually became known as *systems science*. One of his contributions was that he paid a lot of attention to the broad crosdisciplinary concept of a system and made it clear, highly general, and practical. Moreover, he made a clear distinction between an object, loosely understood as a part of the world in which someone is interested, and a system defined on the object. He wrote [2]:

> At this point we must be clear about how a "system" is to be defined. Our first impulse is to point at the pendulum and to say "the system is that thing there". This method, however, has a fundamental disadvantage: every material object contains no less than an infinity of variables and therefore of possible systems. The real pendulum, for instance, has not only length and position; it has also mass, temperature, electric conductivity, crystalline structure, chemical impurities, some radio-activity, velocity, reflecting power, tensile strength, a surface film of moisture, bacterial contamination, and optical absorption, elasticity, shape, specific gravity, and so on and on. Any suggestion that we should study "all" the facts is unrealistic and actually the attempt is never made. What is necessary is that we should pick out and study the facts that are relevant to some main interest that is already given ... The system now means, not a thing, but a list of variables.

In addition to recognizing this clear and very simple characterization of every system, Ashby also recognized that there are many distict types of systems subsumed under this overall characterization of systems. This inspired research, conducted primarily in the 1960s and 1970s, into the development of a meaningful taxonomy of systems within this overall conception. This research resulted eventually in the recognition of some basic categories of systems, each useful in some specific application domain [3, 4]. My own research in this area, for example, resulted in the formulation of an epistemological hierarchy (a semilattice) of well-defined systems categories. In this hierarchy, which is described elsewhere [5, 6],categories of systems are actually categories in the strong sense of mathematical category theory.

Each of these categories of systems represents a concept that is genuinely crossdisciplinary and has been given a suggestive name, such as a data system, generative system, structure system, metasystem, and the like. These categories of systems and their hierarchical ordering formed a broad conceptual framework from which other, more refined crossdisciplinary concepts have naturally emerged, including those recognized in cybernetics and general systems research. Each of the established categories of systems consists of abstract structures of a certain type that can be used for representing knowledge. Meaningful research questions or hypotheses regarding properties of these abstract structures in each particular category can obviously be formed. Some of them can be addressed theoretically, others by experimentation. Although the objects of investigation in this case are abstractions and not phenomena of the real world, they can be simulated on computers and in this sense made real for experimentation. The possibility of answering questions or verifying hypotheses regarding systems experimentally, which was for the first time demonstrated by Gardner and Ashby in the late 1960s [7], is now well established and heavily utilized.

The taxonomy of system and the recognition that systems of the various types can be investigated scientifically, employing theoretical as well as experimental methods, resulted eventually in the notion of *systems science*. The term "science" is justified in this case since there exists a domain (consisting of all systems), taxonomy of the domain (the established categories of systems), and it is known that objects of the domain (i. e. systems) can be investigated by scientific methods (theoretical as well as experimental) through which desirable knowledge regarding the domain is obtained. However, the meaning of the term "knowledge" in systems science is different from its usual meaning in classical science. It is not knowledge regarding various types of phenomena of the real world, but rather knowledge regarding various types of systems. Recognizing that systems are structures in which knowledge of classical science is organized, knowledge in systems science may be characterized as *knowledge concerning knowledge structures*. This knowledge is of course applicable to every discipline of classical science. That is, it is crossdisciplinary knowledge. This means that systems science is not a new discipline of classical science, but rather a new dimension of science. From the standpoint of disciplinary classification of classical science, the domain of systems science is fully crossdisciplinary.

Due to its scientific character, well-defined domain, and utility, systems science is now generally recognized as a legitimate academic area of science that is complementary to classical science. Although cybernetics is now rarely mentioned in the context of systems science, its legacy to systems science is unmistakable.

Let me turn now to multidisciplinary cooperation in science whose importance was for the first time recognized and seriously discussed in Wiener's book. As described so eloquently by Wiener, a group cooperation of several researchers educated in different disciplines is never easy. It can be successful only if each of them acquires enough knowledge of the other disciplines for effective communication within the group. This is almost impossible to achieve without breaking the rigid disciplinary organization of education and stimulating multidisciplinary work by appropriate incentives. Although the successful cooperation of Norbert Wiener with Arturo Rosenblueth, a mathematician and a physiologist, developed quite naturally, it was a very rare event at that time.

It is unfortunate that Wiener's appeal for a coordinated effort to stimulate multidisciplinary research, which he made under the banner of cybernetics, had been largely ignored for many years. Only recently, during the last decade or so, the need for multidisciplinary research has been increasingly recognized. We can see now a broad support for multidisciplinary research by academic and professional communities as well as some efforts to stimulate it. In the United States, for example, the government has lately initiated a fair number of new research programs supporting various forms of multidisciplinary research, as well as new educational programs for preparing graduate students for the challenges of working on multidisciplinary teams. It is unfortunate that cybernetics is almost never mentioned in the context of these important new developments, but, again, its legacy to all these developments is unequivocal.

In the rest of this essay, I would like to examine the evolution of the various ideas and open questions regarding the relationship between living organisms (primarily human beings) and machines (primarily computers) that emerged from cybernetics. First, let me mention that discussions of this relationship in the literature on cybernetics inspired some science-fiction writers, who invented for their stories names such as cyberspace (an attractive synonym for internet), cybermall (for shopping on the internet), and many others. Under this influence, cybernetics has often been understood as the study of any phenomena associated with computers. This is of course a highly superficial understanding. The focus of cybernetics in this domain has been on studying the potential of computers to acquire the various mental capabilies of human beings.

When general-purpose digital computers emerged at the end of World War II, they were initially viewed as powerful number-crunching machines, superior to human beings in this domain, but completely controlled by the latter. This was a simplistic view, which has been revised in numerous ways over the years, and cybernetics has been quite instrumental in this process. It was soon realized that these machines are capable of processing not only numbers, but any other symbols as well. This implied, for example, that they are able to deal with mathematical problems analytically, as humans do, and not only numerically. This also implied, more importantly, that they are able to manipulate instructions of programs they are supposed to execute. That is, they are able to change their programs. This opened, in turn, a great new possibility: machines can learn from experience. Although a method of learning has to be included in the program, the consequences of the learning are virtually unpredictable.

Numerous other capabilities of computing machines have been established by now, primarily by research in computer science, and in more and more of them machines turn out to be superior to humans. However, in spite of all this progress, it is easy to recognize that machines are still not able to match some human capabilities. Humans are known to perform routinely certain tasks, such as driving in a city, finding a suitable parking space, and parking the car, which cannot be currently performed by machines. The problem of how to bridge this gap between human and machine capabilities has lately been studied under the name "intelligent systems".

Intelligent systems are viewed in this context as human-made systems that are capable of achieving highly complex tasks in a human-like, intelligent way. The qualifier "human-like" in this view of man-made intelligent systems is essential for distinguishing it from other views within the broader area of artificial intelligence. In this area of intelligent systems, the human mind is viewed as a role model and the aim is to understand its various capabilities and emulate them in machines.

It has been increasingly recognized that two of the most examplary capabilities of the human mind, which have not been achieved by machines as yet, are the capability of using perceptions in purposeful ways to perform complex tasks and the capability of describing perceptions by statements in natural language. Understanding these capabilities and emulating them by machines is the essence of current research efforts in the area of intelligent systems. A long-range research program for developing perception-based machines was recently proposed by Zadeh [8]. This reserach program is extremely challenging, but it is formulated in a feasible way. The crux of the program is to approximate perceptions by statements in natural language, to approximate these statements by propositions in fuzzy logic, and to use these propositions as needed.

The legacy of cybernetics to the area of intelligent systems is clearly recognizable, but it is virtually never mentioned in the current literature. This is another example of reemergence of cybernetic ideas in a new context and under a new name.

Let me summarize now the primary point of this essay. It is undeniable that science, engineering, and other areas of human affairs have been profoundly affected by the great ideas for which Norbert Wiener coined the name cybernetics sixty years ago. Most of these ideas have been further developed in various ways over the last sixty years. They have gradually become more and more sophisticated and useful. However, they are now recognizable, by and large, under various new identities. This is illustrated in this essay by three important groups of cybernetic ideas. While cybernetics has lost some of its youthful vigor and identity in this evolutionary process, its ideas have become considerably more mature and useful. We have thus very good reasons this year to remind ourselves that many ideas and views we take now for granted evolved from those recognized sixty years ago under the name of cybernetics.

REFERENCES

[1] N. Wiener: Cybernetics. Wiley, New York 1948.
[2] W. R. Ashby: An Introduction to Cybernetics. Wiley, New York 1957.
[3] M. D. Mesarovic and Y. Takahara: General Systems Theory: Mathematical Foundations. Academic Press, New York 1975.
[4] M. D. Mesarovic and Y. Takahara: Abstract Systems Theory. Springer-Verlag, New York 1988.
[5] G. J. Klir: Architecture of Systems Problem Solving. Plenum Press, New York 1985.
[6] G. J. Klir: Facets of Systems Science. Plenum Press, New York 1991.
[7] M. R. Gardner and W. R. Ashby: Connectance of large dynamic (cybernetic) systems: Critical values of stability. Nature *228* (1970), 784.
[8] L. A. Zadeh: From computing with numbers to computing with words – from manipulation of measurements to manipulation of perceptions. IEEE Trans. Circuits and Systems *45* (1999), 105–119.

George J. Klir, Department of Systems Science and Industrial Engineering, Binghamton University (SUNY), Binghamton, New York 13902. U. S. A.
e-mail: gklir@binghamton.edu