Some Notes on the Origins of Cybernetics, Interdisciplinary Models, and Norbert Wiener's Work in the Life Sciences and the Social Sciences

We are but whirlpools in a river of ever-flowing water. We are not stuff that abides, but patterns that perpetuate themselves.…We are swimming upstream against a great torrent of disorganization….In this, our main obligation is to establish arbitrary enclaves of order and system….It is the greatest possible victory to be, to continue to be, and to have been. No defeat can deprive us of the success of having existed for some moment of time in a universe that seems indifferent to us.

This is no defeatism….The declaration of our own nature and the attempt to build up an enclave of organization in the face of nature's overwhelming tendency to disorder is an insolence against the gods and the iron necessity that they impose. Here lies tragedy, but here lies glory too.

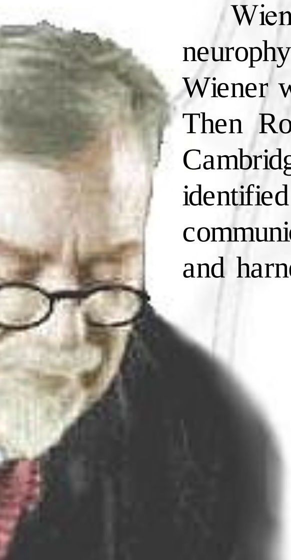
—Norbert Wiener

On the Origins of Cybernetics and its Connections to Wiener's Work in the Life Sciences.

The lockdown of Wiener's war work forced him to seek alternate outlets for his new communication concepts. And find them he did. In fact, only five months after the United States entered the Second World War, Wiener quietly began lobbing a few bombshells of his own into the stately halls of the established sciences, where they caught fire in the minds of some of America's most distinguished scientists and innovative thinkers. That turn marked the start of a postwar scientific revolution that would change the life of the mind and all the world's societies.

The first glimmerings of Wiener's new thinking lit up a conclave of psychologists, physiologists and social scientists who had gathered in the new interdisciplinary spirit to debate some timely issues at the junction between psychology and brain science. They included Warren McCulloch, a neurophysiologist from the University of Illinois and one of the world's foremost authorities on the functions and organization of the brain, neurophysiologist Rafael Lorente de Nó of the Rockefeller Institute in New York, and two celebrated anthropologists, Gregory Bateson and Margaret Mead, renowned for their trailblazing studies of life in remote Pacific Island cultures.

Wiener's contributions that day were in the hands of his colleague Arturo Rosenblueth, the Harvard neurophysiologist. He told his audience about messages, feedback, and the surprising similarities he and Wiener were finding in the actions of electronic devices, automatic machines and human nervous systems. Then Rosenblueth let loose a radical idea he and his colleagues were just beginning to flesh out in Cambridge. In their work on problems of communication and automatic control, Rosenblueth said, they had identified a new realm of orderly processes observable in nature and the human world. These new communication processes were governed by the circuitous feedback loops Wiener and Bigelow had tapped and harnessed in their device for predicting the future positions of fast-flying airplanes. It was a sizeable



Prepared for 21st Century Wiener by Flo Conway & Jim Siegelman,
authors of *Dark Hero of the Information Age: In Search of Norbert Wiener, the Father of Cybernetics*
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leap, from machines that took aim at targets to creatures and machines with aims of their own, and the first formulation in scientific terms of the circular logic of feedback that lay at the root of all intelligent behavior.

Their daring experiments conducted in Wiener's wartime laboratory had uncovered a huge class of living things that carried out purposeful acts along circular paths: light- and heat-seeking movements by plants and primitive creatures; homeostatic processes such as the body's internal mechanisms for regulating appetite and temperature; and virtually every form of higher-order animal behavior. All those purposeful actions were governed by circular communication processes and guided to their goals by error-correcting negative feedback. That fundamental insight raised exciting new possibilities for theory and research in biology, brain science and all the sciences. Wiener's communication principles and statistical methods provided the theoretical foundation and rigorous mathematics needed to ground and verify those complex living processes, and the technical means to reproduce them in working models.

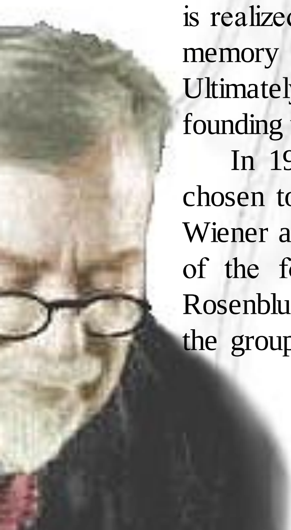
His words set off depth charges among the psychologists. Rafael Lorente de Nó had confirmed the existence of those circular neural networks. Warren McCulloch found the new communication concepts to be ideally suited for application to his own laboratory research, and the logical theory of brain function he was developing in Chicago with his young colleague Walter Pitts. McCulloch had been watching developments in the field of electronic computing and pondering the parallels to neurological processes he had observed in the laboratory. For McCulloch, the new communication perspective and research program raised exciting prospects for novel interdisciplinary projects that could shine new light on age-old questions of brain and mind.

Gregory Bateson was especially enthusiastic. He quickly grasped the human implications of a science of communication and saw in its logically sound, mathematically precise, processes and principles practical tools to help sort out the hodgepodge of human relationships that shape the lives of individuals and societies.

Margaret Mead was thunderstruck by what she heard. Years later, she wrote in a memoir, "I did not notice that I had broken one of my teeth until the Conference was over." They were the advance guard of a new counterforce in scientific thought that would become known as "the cybernetics group," and Wiener would soon take his place in their front ranks. (*DHIA*, CHAP. 7)

On Wiener's Interdisciplinary "Cybernetics Group" and its Pioneering Work on Cybernetics of the Brain and Nervous System, the Heart, and Larger Social and Environmental Systems.

Jerome Lettvin, a professor emeritus of electrical engineering and biomedical engineering at MIT was among the first to learn about the brain research getting under way in McCulloch's laboratory and, soon after, introduced McCulloch to the young mathematics genius Walter Pitts. In a matter of weeks, McCulloch and Pitts had parsed the flow of signals through the brain's branching pathways and explained how simple sensory experiences could be "computed" logically in the brain. They drew the first schematic model of a logical "net of neurons" and made the case for their radical proposition "that every idea and every sensation is realized by activity within that net." They even showed how higher mental processes such as learning and memory could be computed and lead to the formation of new synaptic connections between neurons. Ultimately their paper would be cited as a breakthrough in the evolution of digital computing and as the founding work in the field of artificial intelligence.



In 1944, a third outpost was established when Rosenblueth returned to Mexico, where he had been chosen to head the physiology laboratory at the new Instituto Nacional de Cardiología in Mexico City, and Wiener and his new teammates began shuttling north and south of the border. Oliver Selfridge, the grandson of the founder of London's fashionable Selfridges department store, began work with Wiener and Rosenblueth while he was still an undergraduate engineering student at MIT. Prominent new figures joined the group: Heinrich Klüver, a German émigré and Gestalt psychologist at the University of Chicago; MIT social psychologist Kurt Lewin, Columbia University sociologist Paul Lazarsfeld, and British ecologist G. E. Hutchinson, a trailblazer in the study of environmental systems. It was clear that Wiener and the neurophysiologists were offering a versatile new scientific framework for understanding the mind's cognitive powers, the body's organic control processes, and the new arena of communication processes common to humans and machines.

Wiener began a new phase of his work with Rosenblueth on "the study of the nervous system as a communication apparatus." He and Rosenblueth applied Wiener's statistical communication theories to the study of signal transmission in long nerve fibers and to the flow of electrical signals through the tight nets and circles of nervous tissue that governed the rhythmic beating of the heart. Wiener described how physical systems generally run downhill from states of higher organization to the state of maximum randomness and disorganization known as entropy. Then he explained how all living things defied that fundamental directive of nature, in the act of life itself, by means of purposeful, circular processes that enabled them to beat the law of entropy, progress to higher states of organization, and maintain those exceptional states throughout their lifetimes.

Others in the group built on the themes in Wiener's work. Bateson laid out an ambitious program for applying the new communication framework across the social sciences including timely social phenomena that were driven by circular feedback processes, "business cycles, armaments races, systems of checks and balances in government." Hutchinson, the ecologist, provided global examples of feedback processes at work in the environment: the cycle of photosynthesis that plays out between green plants and the earth's atmosphere; changes in the balance of oxygen and carbon dioxide in the air caused, in part, by "the modern industrial combustion of fuel"; cycles of commodity production, consumption, and "long-term privation owing to an excessive rate of depletion of natural resources" in human populations. (*DHIA*, CHAPS. 7-8)

From Biology to Society.

From the outset, Wiener ascribed the start of cybernetics not to technology but to biology and the dream he and Rosenblueth had pursued jointly of blazing those "boundary regions" and "blank spaces on the map of science." The synthesis of cybernetics had emerged from their growing awareness of "the essential unity of the set of problems centering about communication and control...whether in the machine or in living tissue."

Wiener laid out the new terms and concepts of cybernetics in a grand tour of the new terrain as he had mapped it. His "fundamental notion of the message" was enlarged to incorporate messages "transmitted by electrical, mechanical, or nervous means." He made the all-important distinction between physical and biological systems, their different modes of organization, and the different forms of information that could be found in each realm of nature, and he proved mathematically that the engineering principle of feedback was equivalent to the physiological process of homeostasis. He proclaimed the essential unity of information processes and showed how the new technical methods of "control by informative feedback" were, in their essence, the same universal processes that nature long ago selected as its basic operating system for human beings and all living things.

Wiener also explored the social and cultural dimensions of cybernetics. Drawing on the ideas of Bateson, Mead, and other social scientists in the Cybernetics Group, Wiener described the stabilizing "homeostatic processes" found in primitive and developed societies alike, and the myriad forces that may strengthen or undermine those essential processes. He saw a dearth of healthful homeostatic processes in large developed societies, due to the modern glut of information and its counterpart, the "constriction of the means of communication" by vested social and political interests. He assailed the simplistic theories of free-market ideologists, and he reserved a special antipathy for modern day "hucksters," media barons, captains of industry, and politicians who sought power over large populations through manipulation of the mass media. "Any organism is held together…by the possession of means for the acquisition, use, retention, and transmission of information," wrote Wiener, especially the mass society, which is "too large for the direct contact of its members." He finished with a warning to his readers: "Of all of these anti-homeostatic factors in society, the control of the means of communication is the most effective and most important." (*DHIA*, CHAP. 9)

On the Rapid Diffusion of Cybernetics into Neuroscience, the Life Sciences, and the Social Sciences.

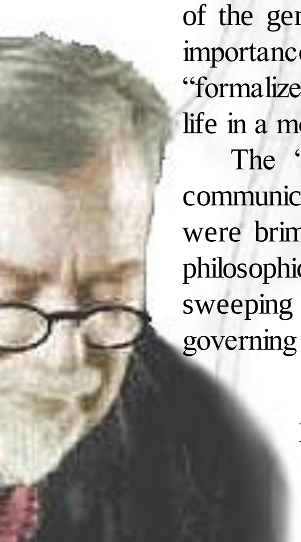
Work at MIT's new neurophysiology lab went forward. Wiener's disciples Lettvin, Pitts, and other keen young MIT minds conceived the bold theories and hypotheses that defined the new field of "neuroscience" and devised ingenious laboratory experiments to study the living information-processing activities transpiring in the brains and nervous systems of animals and humans. Said Lettvin, "Neurons are curious devices. The messages are digital but the processing is analog." Wiener had been thinking about the brain's analog communication channels. In *Cybernetics*, he described the brain's alternate system of communication that operated, not by all-or-nothing mechanisms and yes-no logical decisions, but by a more subtle and random chemical signaling system made up of analog "messages which go out generally into the nervous system" transmitted by versatile chemical messengers which scientists would soon recognize as a broad class of specialized "neurotransmitters."

Wiener's new science wandered through psychology and the social sciences, where Bateson led a revolution of his own to put the new communication tools into the hands of clinicians and people directly. Other social scientists in the 1950s applied cybernetic models and methods to the study of communication in small groups and large organizations. With help from Bateson and European psychologists who came to America after the war, the new "humanistic" psychologists, Carl Rogers, Abraham Maslow and Rollo May developed effective new communication-based methods of individual and group therapy that would transform the field of mental health and influence the whole of American culture. Political scientists, beginning with Wiener's colleague Karl Deutsch at MIT, applied cybernetic principles to the art and science of government. University of Michigan economist Kenneth E. Boulding asked Wiener personally to aid in his "missionary" effort to buck up the dismal science with fresh ideas from cybernetics, which Boulding went on to promote as essential tools for solving complex problems of modern technological societies.

In Canada, in the summer of 1950, Wiener's ideas stimulated Marshall McLuhan's thinking. A decade later, he would use Wiener's ideas liberally, but without attribution, in his own watershed work, *Understanding Media*.The book's subtitle, *The Extensions of Man*, and its oracular pronouncements that "the medium is the message" and that electronic media had turned the world into a "global village," echoed Wiener's words in *The Human Use of Human Beings* that "the transportation of messages serves to forward an extension of man's senses…from one end of the world to another," and that "society can only be understood through a study of the messages and the communication facilities which belong to it."

Cybernetics was rapidly establishing itself as an international scientific movement. In Great Britain, two young biologists reinvented biology in the light of cybernetics. James D. Watson and Francis H. C. Crick enlisted the new tools of cybernetics and information theory in their quest to discover the molecular structure of the genetic material DNA. In the journal *Nature* in 1953, Watson gave a hint of "the possible future importance of cybernetics at the bacterial level." Weeks later, Watson and Crick cracked the genetic code, "formalized information as a fundamental property of biological systems," and spelled out the new facts of life in a model that was "remarkably similar to that of Norbert Wiener's a decade earlier."

The "cybernetic groundswell" rippled through genetics and molecular biology in a wave of new communication models. Soon physiology, immunology, endocrinology, embryology, and evolutionary biology were brimming with ideas from cybernetics and information theory. At the Pasteur Institute in Paris, the philosophically minded cell biologists Jacques Monod and François Jacob embodied Wiener's principles in a sweeping *Cybernétique Enzymatique* that redefined the organism and life itself as "a cybernetic system governing and controlling the chemical activity at numerous points."



During that period, cybernetics helped to lay the foundations for the expanded inter-disciplinary venture that became known as "cognitive science." Cognitive science was born in 1956 at a symposium at MIT, where psychologists, brain scientists and computer theorists formed a new alliance to cross-fertilize their fast-evolving fields. Harvard psychologist George Miller made intriguing discoveries about the physical limits of human information-processing capacities and with neurophysiologist Karl Pribram and psychologist-mathematician Eugene Galanter built on Wiener's work with Rosenblueth. The three theorists took a new "cybernetic approach to behavior in terms of…feedback loops, and readjustments of action in the light of feedback" using the new communication concepts and emerging tools of computer analysis and modeling to shape a more sophisticated scientific understanding of the mind's subjective processes.

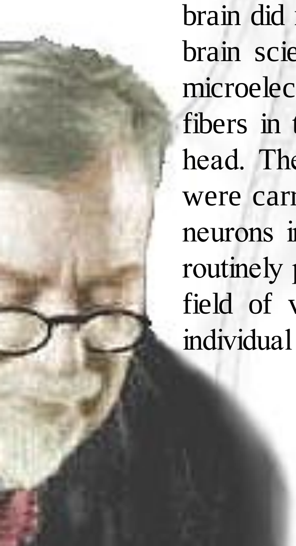
The new subdiscipline of artificial intelligence was another natural outgrowth of cybernetics. Wiener's former student Oliver Selfridge was a pivotal figure in the evolution of AI. At MIT in the mid-fifties, he unveiled one of the first artificial intelligence programs, a pattern recognition program to identify letters and geometric shapes, a sophisticated software version of McCulloch and Pitts' neural network scheme. More impressive was the program's ability to learn from its successes, weed out its weaknesses, and evolve as an ever more accurate pattern recognizer.

Wiener scrupulously avoided any involvement in MIT's military-industrial ventures, but he continued to inspire innovative research in both the technical and biological domains of cybernetics. Among the projects Wiener fired up in the fifties were studies by MIT's Sensory Communication Group, and one he oversaw personally in the Communications Biophysics Laboratory to study biological communication processes "with the aid of…electronics and Wienerian analytical techniques" and another to "find the Rosetta Stone for the script of brain waves." He explained for the first time how the brain's billions of separate neural firings self-organize spontaneously into coherent electromagnetic currents detectable across the whole of the brain's surface. Wiener considered the application of his statistical methods to brain-wave research to be the "most significant" work "of all the things I have done in physiology" and the consummation of the research he and Arturo Rosenblueth had begun a decade earlier. (*DHIA*, CHAPS. 9, 14)

On the Split Between Digital and Analog Processes in Computing and Neuroscience.

In the late 1950s medical science was at last beginning to decode the myriad neurochemicals that affect the brain in all its states, and their intimate interplay with human emotions and the mind's higher cognitive powers. The new discoveries confirmed some of Wiener's earliest speculations about the diverse hormones that flow through the bloodstream into the brain, and the brain's own *neuro*hormones and chemical neurotransmitters—which he first wrote about in *Cybernetics* as likely causes of psychopathology.

Around that time, another breakthrough in brain science defied the digital computer models that were then becoming the rage in cognitive science, artificial intelligence and many other fields. The discovery, based on a whole new approach to neuroscience theory and laboratory research, confirmed that the human brain did not process information in the manner of a digital machine. This time it was Jerry Lettvin who took brain science in a new direction. With expert support from MIT technicians, Lettvin developed probing microelectrodes that could pick up the weak signals generated by the faintest firings of the smallest cells and fibers in the brain and nervous system. Lettvin and his crew turned half a century of neuroscience on its head. Their study of vision in frogs revealed that the brain's most basic information-processing operations were carried out by analog means to an extent never before considered possible. They discovered that the neurons in a lowly frog's eye were capable of sophisticated activities of image detection and analysis, and routinely performed complex tasks, such as determining the size, shape, and motion of objects in the frog's field of view, through analog processes innate in the structure and communication operations of each individual neural cell. Their paper, published in November 1959 with the tantalizing title, "What the Frog's



Eye Tells the Frog's Brain," forced a sudden rethinking of everything that was known and assumed about sensory perception and the brain's cognitive operations.

For Wiener, the "Frog's Eye" paper upheld the analog mode of information processing he had always favored. It provided indisputable evidence of that action at bedrock levels of the brain and nervous system. It strengthened the biological foundations of cybernetics, and unveiled a new order of living information processes in the brain, at a time when those analog processes, and organic aspects of cybernetics generally, were being stripped from the field's technical applications.
(*DHIA*, CHAPS. 14)

Wiener's Role in the Development of the First Cybernetic Prosthesis

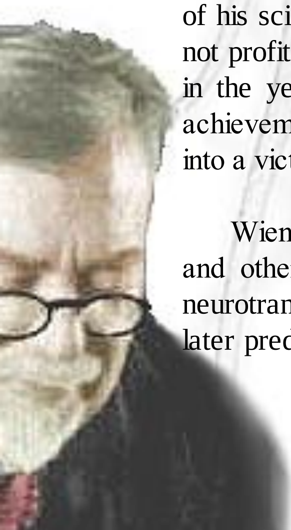
In September 1961, while wending his way through MIT's Building 7, Wiener took a tumble down a flight of stairs and landed across the river, at Mass General, with a broken hip. The hospital's best orthopedists had recently returned from Moscow, where they had witnessed the unveiling of the first triumph of Soviet biocybernetics: a prosthetic hand powered by electronics and precisely controlled by sensors, servomotors, and other cybernetic mechanisms. The Soviets told them, "Look, you people must know all about this, because we got all the ideas from Wiener." The team came back determined to track down Wiener and pick his brain for their own prosthetic project, when they happened upon him in the VIP wing of their hospital. "They all converged on him. 'What about all this stuff?' And he said it was basically what he had told them ten years before."

Indeed, in the early 1950s, Wiener had given a speech at Harvard Medical School about the future of electronics in medicine. He said there was no longer any need for primitive biomedical devices like mechanical limbs and iron lungs that worked passively on people. He explained that live electrical signals could be picked up from a limb or a lung, even if the nerve endings had been severed, and harnessed to control intelligent electronic machines. "At the time, the speech was ignored as a crazy scheme by some wild-eyed mathematician," Wiener's last doctoral student, the future audio innovator Amar Bose recalled. But a decade later, after viewing the Soviets' prosthetic hand, some of those same doctors asked Wiener to steer them through their own project to build not just a prosthetic hand, but a prosthetic arm to ease the lives of "high" amputees.

With their new teammates assembled at his bedside, Wiener laid out a detailed design for the first cybernetic arm that would be attached to the wearer with straps and electrical sensors, and the controlling signals would be relayed through nerve endings at the end of the amputee's lost limb. The mechanics and electronics would be controlled bionically—by the patient's thoughts alone—and refined progressively by feedback training. After two years of research and development, the team made their first successful test. "We…found an amputee with a high amputation," Bose recalled. "We attached the arm, the man was sitting down and the arm came up, and the man jumped. But in ten minutes time he was able to wear it beautifully."

Wiener's design of the Boston Arm was a coup for cybernetics, and a vivid demonstration of the power of his science to foster man-machine interactions with tangible benefits for people's daily lives. Wiener did not profit in any way from the device, or from the lucrative industry in electronic prostheses that blossomed in the years that followed, but he held to his own ethical standards and took pride in his serendipitous achievement. "I have seldom seen Wiener so happy as when he told how he turned the mishap of his fall into a victory for the handicapped," a colleague recalled.

Wiener's predictions for biology and brain science were prescient. His hunches about neurohormones and other "to-whom-it-may-concern messages" were confirmed by the discovery of hundreds of new neurotransmitter molecules that travel irregular paths through the brain and bloodstream. And many of his later predictions about future applications of cybernetics to medicine, which were viewed at the time as pure



fantasy, also came to pass. Two months before he died, Wiener forecast new methods of medical cybernetics that would detect illness "by sensing devices within the body." He predicted that "living materials would, by 1984, be used as part of computers" and that "complex nucleic acids that carry genetic information in living cells would be used in machines." He was only off by a decade: in the 1990s, medical researchers began testing diagnostic cameras the size of a pill that patients could swallow, and marketing hybrid silicon "biochips" that used DNA snippets to detect genetic defects and an array of other "bioinformatics" markers.
(*DHIA*, CHAP. 16)

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